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HYDROLOGY OF CARBONATE AQUIFERS IN SOUTHWESTERN LINN COUNTY AND ADJACENT PARTS OF BENTON, IOWA, AND JOHNSON COUNTIES, IOWA

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Prepared cooperatively
by the U.S. Geological Survey
and the Iowa Geological Survey

IOWA GEOLOGICAL SURVEY

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by Kenneth D. Wahl, U.S. Geological Survey,
and Bill J. Bunker, Iowa Geological Survey

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FOREWORD

This report contains the results of hydrogeological investigations in the Linn County area, principally related to the important Silurian carbonate (dolomite) aquifer system. The work was conducted cooperatively by the U. S. Geological Survey and the Iowa Geological Survey. The information is particularly relevant today, as legislative and media attention continue to focus on the issues of contamination, protection, allocation and conservation of groundwater resources. Indeed, information derived from this study already has been utilized in ongoing analyses of those issues. Because the report represents a significant contribution to our knowledge about the occurrence and movement of groundwater in carbonate (limestone and dolomite) aquifers, it will be a valuable tool for management of groundwater resources not only within the study area, but throughout much of eastern Iowa.

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FACTORS FOR CONVERTING SELECTED INCH-POUND UNITS TO INTERNATIONAL (SI) UNITS

Multiply inch-pound unit	By	To obtain SI (metric) unit
foot	0.3048	meter
gallon	0.003785	cubic meter
gallon per minute	6.090×10^{-5}	cubic meter per second
inch	0.03937	millimeter
mile	1.609	kilometer
square mile	2.590	square kilometer
horsepower		
acre		
million gallons per day (Mgal/d)		
gallon per minute per foot (gal/min)/ft)		

HYDROLOGY OF CARBONATE AQUIFERS IN SOUTHWESTERN LINN COUNTY AND ADJACENT PARTS OF BENTON, IOWA, AND JOHNSON COUNTIES

ABSTRACT

Groundwater is the major source of water in Linn County and the surrounding area. Approximately 90 percent of the groundwater production is from Silurian, Devonian, and Quaternary aquifers.

The Silurian and Devonian aquifers consist of limestone and dolomite with minor shale beds, which have a regional dip to the southwest of approximately 20 feet per mile. The Silurian aquifer in east-central Iowa is confined from below by Upper Ordovician, Maquoketa Formation shales, and from above by the Kenwood Member of the Wapsipinicon Formation and the Otis and Bertram formations. The Quaternary aquifer consists of unconsolidated sand and gravel beds in the glacial drift, and in the alluvium which is associated with modern streams. The alluvium consists of lenticular beds of poorly-to well-sorted silt, sand, and gravel. The sand and gravel beds are interlayered with relatively-impermeable beds of till, silt, and clay.

Water moves through the Silurian aquifer in part due to a complex distribution of porous and dense carbonate facies. Horizons containing skeletal-molds in the Silurian dolomite have porosities as much as 39 percent, and are laterally equivalent to dolomites with porosities as little as less than one percent. Because of subsequent fracturing and solutional enlargement of these porous horizons, hydrologic correlation of the primary water-yielding zones is not always possible. One horizon, however, does occur approximately 70 to 105 feet above the base of the Silurian, and is the most consistently productive water-yielding unit in the area. This horizon is informally referred to as the Farmers Creek aquifer.

The potentiometric surface of the Silurian aquifer has a gradient towards the Cedar River, indicating discharge from the aquifer through the alluvium into the river. By comparison, the potentiometric surface of the overlying Devonian aquifer is equal to that of the Silurian and may range to more than 40 feet higher. Yields to individual wells completed in the Silurian and Devonian carbonate aquifers vary from less than 10 to about 500 gallons per minute. Individual wells completed in the Quaternary aquifer yield as much as 2,000 gallons per minute.

Water analyses from the Devonian and Silurian aquifers indicate that they are of similar chemical quality at most locations in the study area. However, they may commonly contain concentrations of sulfate that exceed 1,000 milligrams per liter. Dissolved-solids concentrations as much as 2,350 milligrams per liter occur in the Silurian aquifer in the western and southwestern part of the study area. Water from the Quaternary aquifer generally is suitable for most uses and dissolved-solids concentrations generally are less than 750 milligrams per liter.

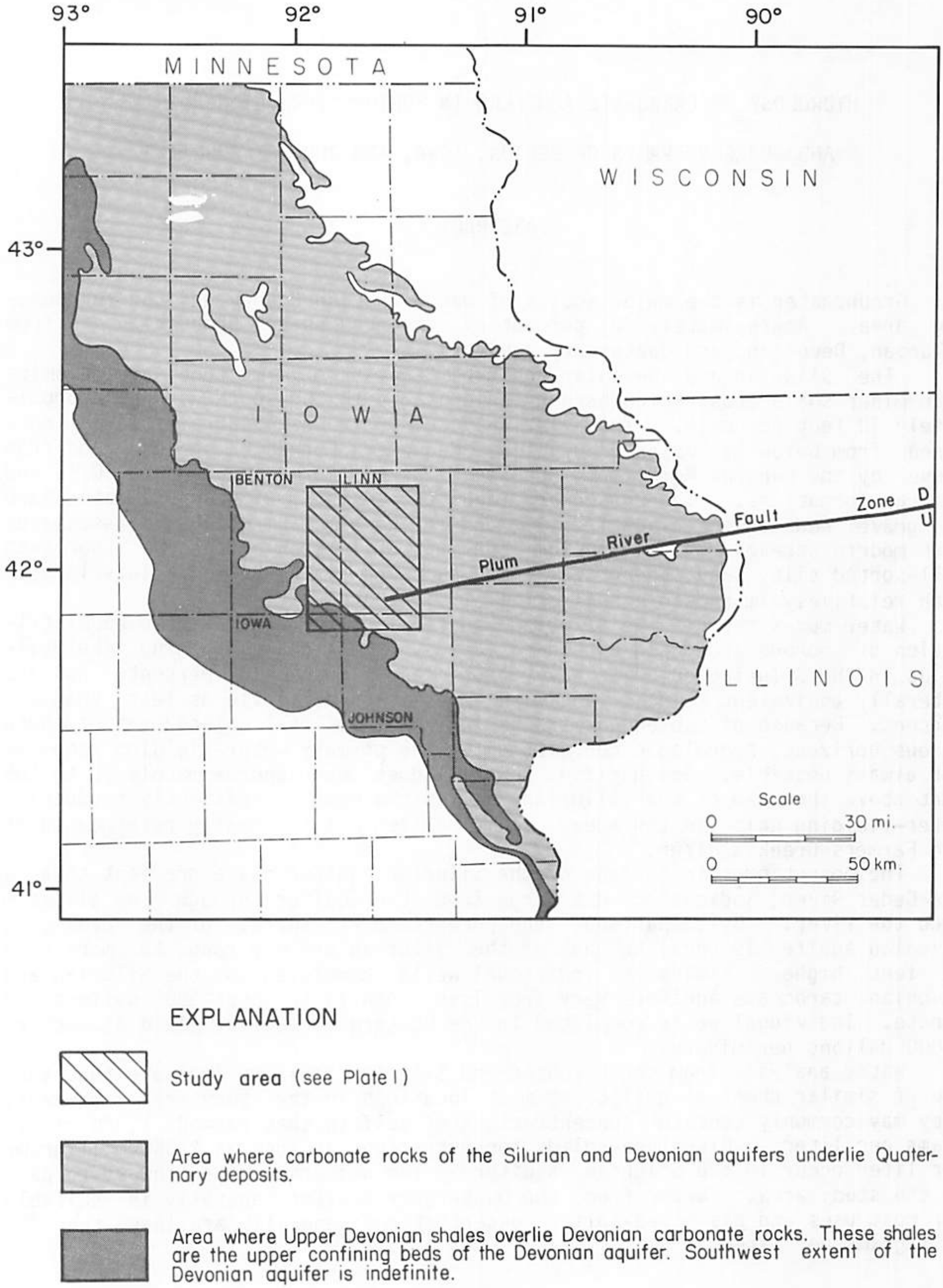


Figure 1. Index map showing location of study area in east-central Iowa.

INTRODUCTION

Purpose and Scope

The purpose of this report is to describe the groundwater occurrence, availability, quality, and flow systems that occur in a glaciated carbonate terrane in east-central Iowa. The overlying Quaternary aquifer is an integral part of the carbonate flow system and has also been included. Similar geologic and hydrologic situations exist throughout eastern, northeastern, and north-central Iowa. An area was selected for study which satisfied a large number of geologic and hydrologic criteria typical of the carbonate area in eastern Iowa. The area selected encompasses about 400 square miles, and includes most of Linn County and adjacent parts of Benton, Iowa, and Johnson counties (Fig. 1; Pl. 1), in east-central Iowa.

It is expected that the information obtained for this project and presented in this report can be extrapolated for use in a 10-county area in the Cedar River basin. Extrapolation into other carbonate areas of the State will be less direct, but principles determined and information collected for this study have aided other projects, and will continue to aid in understanding the hydrology throughout the carbonate area.

Acknowledgments

This project was a cooperative effort by the U.S. Geological Survey and the Iowa Geological Survey. Collection of groundwater data in the project area was aided by the many residents who provided information about their wells and allowed water-level measurements to be made. It was under the direction and organization of Walt Steinhilber, U.S. Geological Survey, and Sam Tuthill, the former State Geologist and Director of the Iowa Geological Survey, that this project was initially developed. It is from this project and methods utilized during the course of its study that applications of these techniques have borne fruit elsewhere in the State of Iowa in the areas of groundwater and geologic research. We also wish to acknowledge and extend our appreciation to Darwin Evans, Research Driller for the Iowa Geological Survey, who drilled the test holes and assisted in the pump-packer tests and collection of water samples. All chemical analyses used in this study were made by personnel of the State Hygienic Laboratory. We also wish to thank Laurie Comstock and Mary Pat Heitman for typing of this manuscript. All maps and illustrations were drafted by Pat Lohmann.

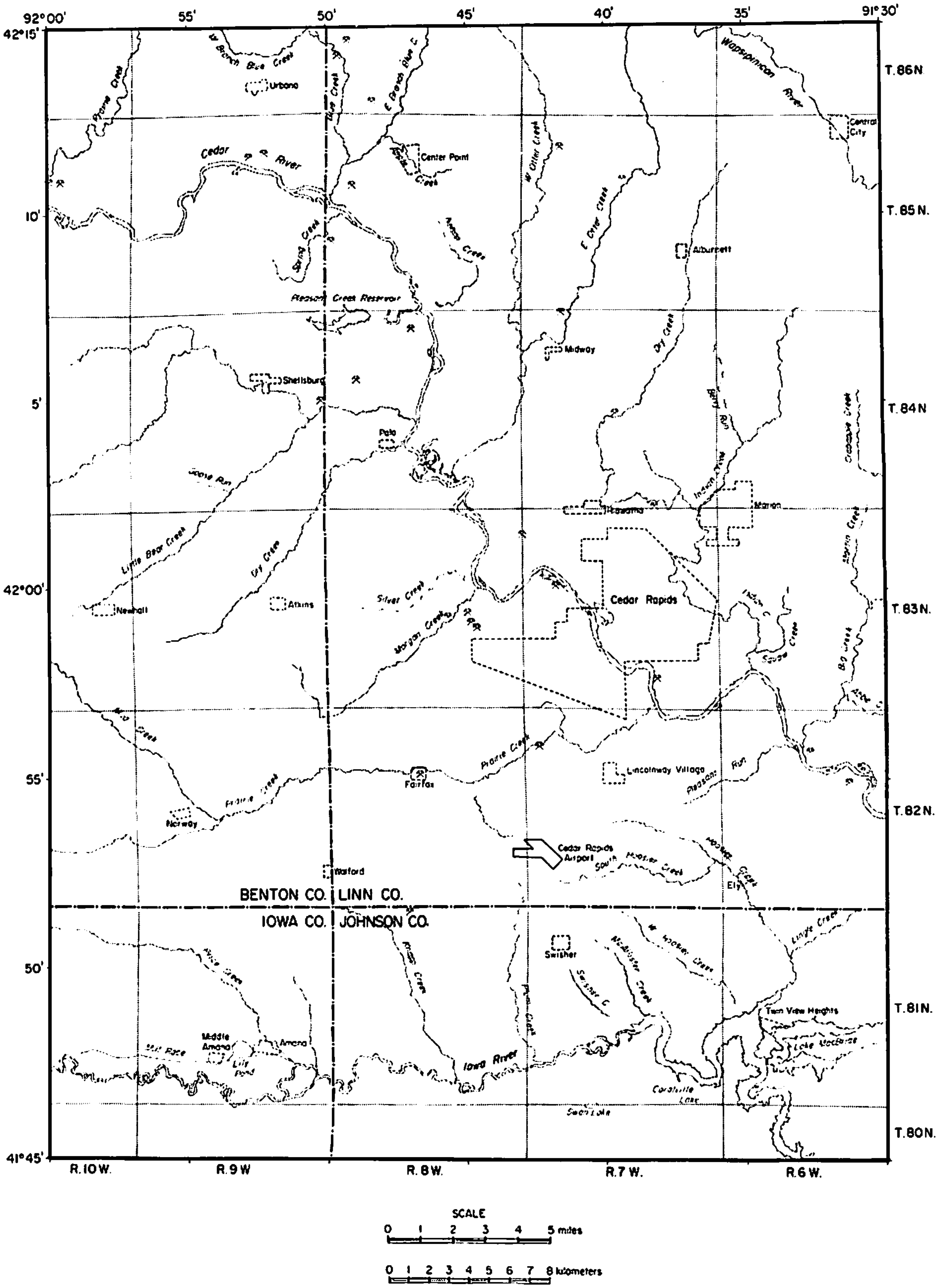
PLATE I

LOCATION OF PROJECT AREA WITH PRINCIPAL GEOGRAPHIC FEATURES NOTED

EXPLANATION

Base map for study area composited from the following U.S. Geological Survey 1:24,000 quadrangles:

Center Point NW	1968
Center Point	1968
Lafayette	1968
Central City	1968
Marion	1968
Cedar Rapids N.	1967
Shellsburg	1968
Center Point SW	1968
Newhall	1968
Fairfax	1968
Cedar Rapids S.	1967
Bertram	1968
Ely	1968
Swisher	1968
Amana	1968
Middle Amana	1968



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T. 80 N.
R. 10 W.
R. 9 W
R. 8 W.
R. 7 W.
R. 6 W.
Urbana
Center Point
Central City
Wapsipinicon River
Cedar River
Alburnett
Pleasant Creek Reservoir
Midway
Shellsburg
Palo
Hiawatha
Marion
Cedar Rapids
Newhall
Atkins
Little Bear Creek
Dry Creek
Silver Creek
Morgan Creek
Prairie Creek
Fairfax
Lincolnway Village
Norway
Walford
Cedar Rapids Airport
Ely
BENTON CO.
LINN CO.
IOWA CO.
JOHNSON CO.
Swisher
Middle Amana
Amana
Iowa River
Twin View Heights
Coralville Lake
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

Methods of Investigation

The techniques and equipment used included test drilling, coring, and borehole-geophysical logging to aid in stratigraphic correlations and to help determine water-yielding zones. The borehole-geophysical logs obtained included: spontaneous potential, rock resistivity, fluid temperature, fluid conductivity, natural gamma, caliper, gamma-gamma, neutron, and borehole flowmeter. The borehole flowmeter generally was used in conjunction with a 5 horsepower submersible pump to determine the depth of major water-producing zones. The submersible pump also was used to pump and collect samples for chemical analysis from specific intervals of the aquifers by installing air-inflated packers above and below the pump. The use of air-inflated packers also allowed hydraulic-head measurements to be obtained from several water-bearing intervals in each well using an airline. Most of the test wells were cased into bedrock with 5- or 6-inch casing and maintained as sites for recording water levels or for periodic water-level measurements.

Well-Numbering System

The well-identification numbers used in this report are based on the U.S. Bureau of Land Management's system of land subdivision. Each well number is composed of three segments. The first segment indicates the township, the second the range, and the third the section in which the well is situated. The letters after the section number are assigned in a counter-clockwise direction (beginning with "A" in the northeast quarter), to represent subdivisions of the section. The first letter denotes the 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. Thus the number 85-08-03 CDBD designates a well in the SE 1/4 of the NW 1/4 of the SE 1/4 of the SW 1/4 section 3, T.85N., R.8W.

Geographic Setting

The study area is drained by three major subparallel streams (Pl. 1): the Wapsipinicon River, flowing diagonally across the extreme northeast part of the area; the Cedar River, crossing the central part of the area from northwest to southeast; and the Iowa River, crossing the southern edge. The river valleys range from sharply entrenched and narrow in the case of the Wapsipinicon and downstream reaches of the Cedar Rivers, to broad flat valleys that are 2 to 3 miles wide along the Iowa River and the upstream reaches of the Cedar River.

The greatest local relief, 150 to 200 feet, occurs adjacent to the major valleys and along the downstream reaches of major tributaries. Away from the major streams, the land surface is gently sloping to undulating, with a well-established drainage system. Some undrained depressions occur and are most notable on upland divide areas between the Wapsipinicon and Cedar rivers.

Prominent elongated northwest trending ridges (pahas), which are composed of windblown silt (loess), occur throughout the area. In some places these ridges are crossed by major streams or tributaries, in other places the streams seem to be deflected by the pahas.

Geologic Framework

Rocks underlying the area of study are subdivided into three major divisions based on the lithology and mode of deposition. The three subdivisions are: (1) Precambrian crystalline rocks or basement complex; (2) sedimentary rocks of Cambrian, Ordovician, Silurian, and Devonian age; and (3) surficial Quaternary material consisting of drift, loess, and alluvium. The altitude and configuration of two key geologic horizons, the top of the Ordovician and the top of the Silurian, are shown on Plates 2 and 3. The bedrock units underlying the area of study have a regional dip of about 20 feet per mile to the southwest. The Plum River Fault Zone is the major structural feature present in the southeastern part of the study area (Bunker et al., 1985).

The surface of the bedrock units was eroded, and an incised drainage system established before deposition of the overlying glacial materials. The glacial drift, which covers the entire area, filled the previously established bedrock valleys with outwash and till deposits and preserved much of the bedrock topography as shown on Plate 4. Further incision of the bedrock surface occurred during interglacial episodes. A detailed description of the Quaternary stratigraphy of the study area is presented in Hallberg, 1970.

Water Use

Groundwater is the major source of water for most uses in eastern Iowa. A previous investigation of Linn County (Hansen, 1970) indicates a total of 24 Mgal/d was pumped from aquifers during 1964. Of this, about 13.3 Mgal/d was for municipal use and pumpage of about 12 Mgal/d was concentrated in the Cedar Rapids-Marion area. Self-supplied commercial-industrial use in 1964 was about 9 Mgal/d, also concentrated in the Cedar Rapids area. Approximately 90 percent of the total pumpage was from the Silurian, Devonian, and Quaternary aquifers.

Since 1964, water use in the area has steadily increased because of increasing population, increasing industrialization, and changes in domestic use. During 1980 total pumpage in Linn County was about 41 Mgal/d of which 27 Mgal/d was for municipal use (Buchmiller and Karsten, 1983). Municipal use in the Cedar Rapids-Marion area was estimated to be about 19 Mgal/d in 1975, and self-supplied commercial-industrial use in that area was estimated at 17.5 Mgal/d. Approximately 80 percent of the total pumpage during 1975 was estimated to be from the Silurian, Devonian, and Quaternary aquifers.

HYDROLOGY

General Concepts

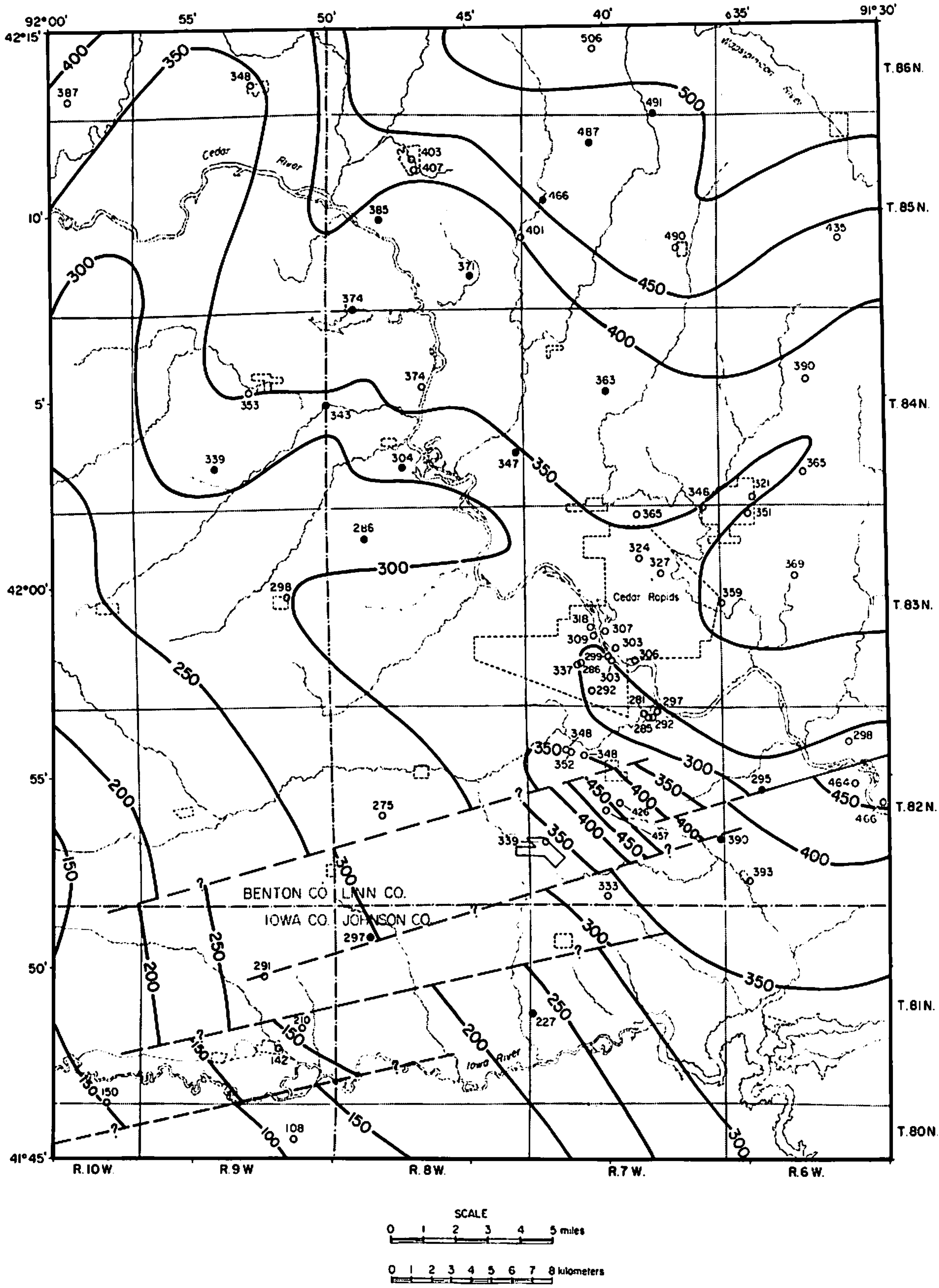
Hydrologically, several distinct aquifers have been identified in the study area (Hansen, 1970). These are: (1) The Cambrian-Ordovician aquifer, consisting of the Jordan Sandstone, the Prairie du Chien Group, and the St. Peter Sandstone; (2) the Silurian aquifer; (3) the Devonian aquifer, principally the Cedar Valley Limestone and the Davenport and Spring Grove members of the Wapsipinicon Formation; and (4) the Quaternary aquifer. This report de-

PLATE 2

STRUCTURAL CONFIGURATION OF THE TOP OF THE ORDOVICIAN

EXPLANATION

350	Structure Contour - Shows altitude of top of Ordovician rocks. Contour interval is 50 feet.
365 o	Control Point - Number is altitude of the top of the Ordovician rocks, in feet above mean sea level.
363 ●	IGS-USGS test site
?	Fault or Structural Zone - Dashed where inferred.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Cedar River
Cedar Rapids
Iowa River
BENTON CO.
LINN CO.
IOWA CO.
JOHNSON CO.
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

PLATE 3

STRUCTURAL CONFIGURATION OF THE TOP OF THE SILURIAN

EXPLANATION

700 — Structure Contour - Shows altitude of top of Silurian rocks. Dashed where projected. Contour interval is 50 feet.

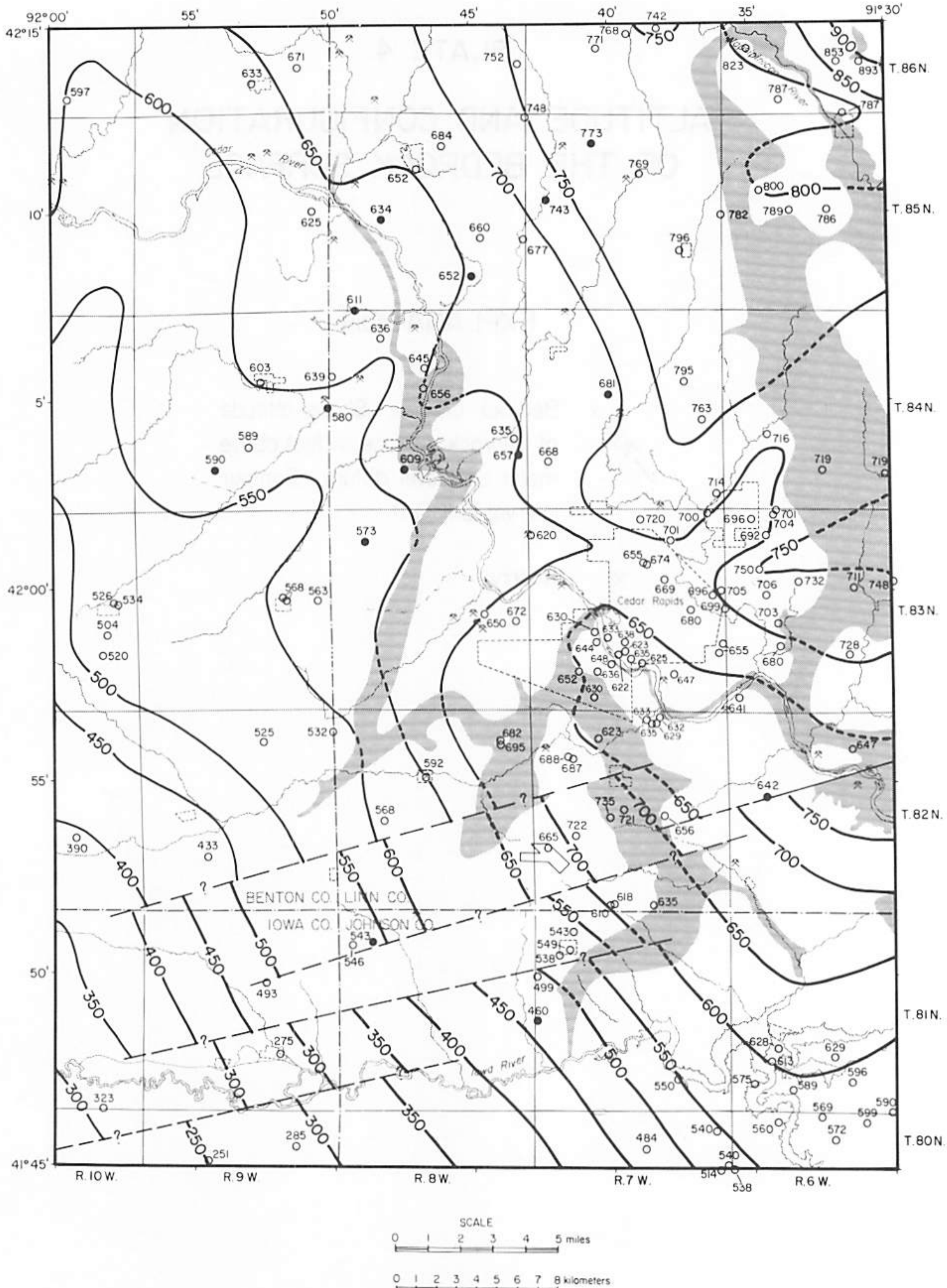
Outcrop area of the Silurian rocks within the study area. Devonian rocks have been removed due to pre-Pleistocene erosion.

596 ○ — Control Point - Number is altitude of the top of the Silurian rocks, in feet above mean sea level.

656 ● — IGS-USGS test site

⚒ — Quarry

? — Fault or Structural Zone - Dashed where inferred.



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Cedar River
Iowa River
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BENTON CO.
LINN CO.
IOWA CO.
JOHNSON CO.
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

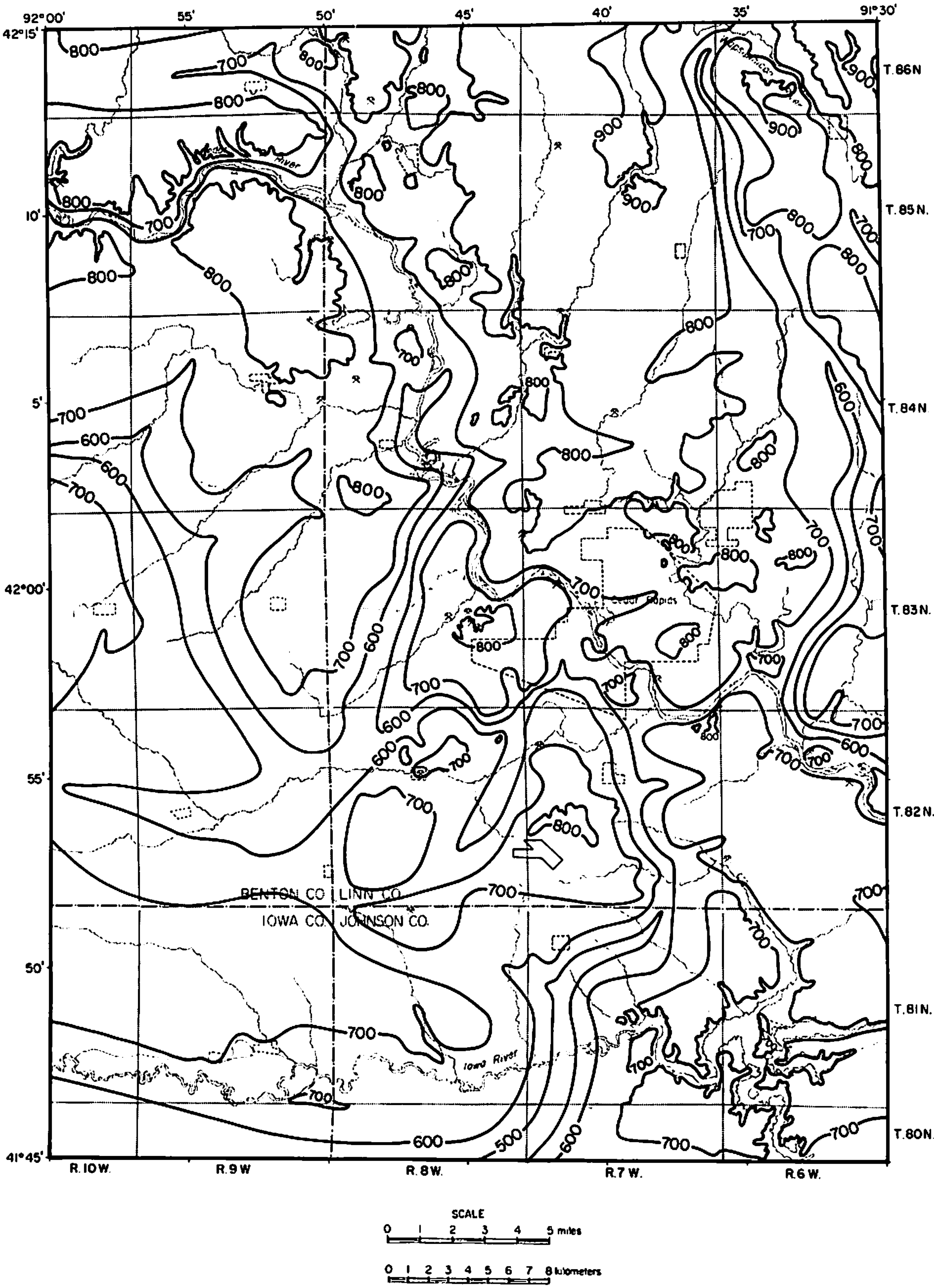
PLATE 4

ALTITUDE AND CONFIGURATION OF THE BEDROCK SURFACE

EXPLANATION

700 — Bedrock Contour - Shows altitude of bedrock surface, in feet above mean sea level datum. Contour interval is 100 ft.

⚒ Quarry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BENTON CO. LINN CO.
IOWA CO. JOHNSON CO.
Iowa River
Cedar Rapids
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

scribes the groundwater system of the Silurian, Devonian, and Quaternary aquifers in the study area.

Individual aquifers commonly are overlain and underlain by shale or dense carbonate rocks. These relatively impermeable units are referred to as confining beds. Although they do not yield significant quantities of water to wells, the confining beds are an important part of the hydrologic system because they restrict the movement of water into or out of aquifers. The major confining beds in the study area are: (1) The Maquoketa Shale of Ordovician age, which directly underlies the Silurian aquifer; (2) the Bertram and Otis formations and the Kenwood Member of the Wapsipinicon Formation which overlie the Silurian aquifer and separate it from the Devonian aquifer; and (3) the Upper Devonian shales found in the southwestern part of the study area. The distribution of the Silurian and Devonian aquifers and confining units occurring beneath the Quaternary-age deposits are shown on Plate 5.

A generalized geohydrologic section showing the three major aquifers and the intervening confining units in the study area is presented in Figure 2. In some areas, an aquifer is not overlain by a confining bed and is a water-table aquifer, in other areas, an aquifer may be confined and is an artesian aquifer. Although the confining beds have little permeability, groundwater moves around or through them as recharge to, or discharge from the aquifers.

Where sinkholes and undrained depressions occur, such as in the Alburnett area (Pl. 1), surfacewater sources recharge to the groundwater system. Surfacewater also receives discharge from the aquifer system where streamflow is augmented by seeps and springs.

Limestone and dolomite aquifers, as found in the Silurian and Devonian rocks, contain openings along joints, fractures, and bedding planes, some of which have been enlarged by solution of the rock. The size, extent, and degree of interconnection between openings determine the water-yielding potential of the individual aquifers. The yield of a well completed in these aquifers is determined by the size and number of openings penetrated by the well.

Weathering and solution of the rock have a distinct effect on the number and size of water-yielding openings present. This is common in the upper part of the bedrock. Where the rocks are more highly weathered, and resulting openings are not filled with clay and silt, the potential yield of these rocks is greater than where the rocks are unaltered.

In general, the overall groundwater flow pattern in carbonate aquifers in the study area is from upland areas toward the major stream valleys. Although the groundwater and surfacewater divides are in similar geographic positions, they do not coincide exactly. The groundwater divides are not fixed and may migrate some distance in response to changes in recharge to, or discharge from the aquifers. Because of this groundwater flow pattern, the hydraulic heads in the underlying aquifers generally decrease with depth in upland areas and increase with depth near and in major stream valleys.

Silurian Aquifer

Silurian rocks in the study area consist chiefly of gray- to buff-colored dolomite containing abundant chert in the lower part and locally abundant chert in the upper part. The rocks are jointed and fractured, and solution openings occur at many horizons. Cores and geophysical logs indicate that in some areas openings are poorly connected or have been filled with clay or silt or both.

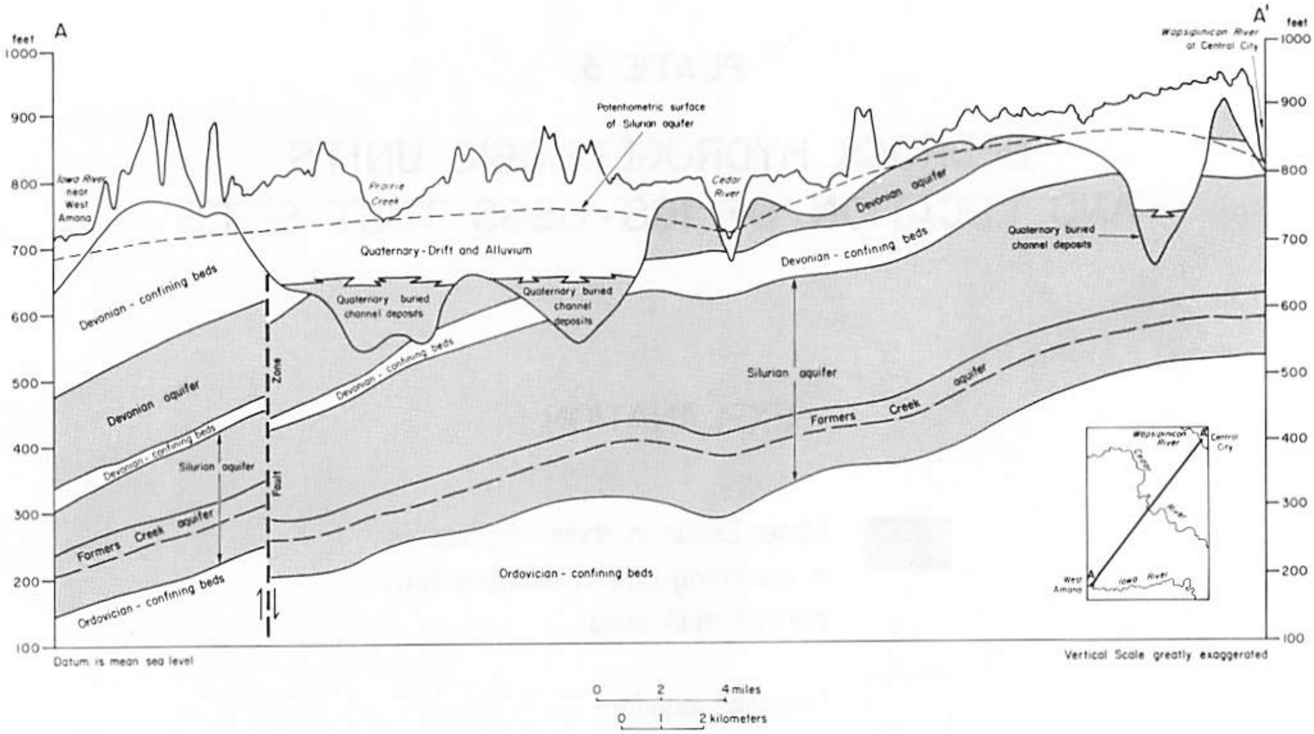


Figure 2. Generalized geohydrologic section across the study area.

The Silurian has been subdivided into six formations (Table 1), which, in ascending order, include: the Mosalem, Tete des Morts, Blanding, Hopkinton, Scotch Grove, and Gower. These subdivisions were established in the outcrop areas of east-central Iowa (Bunker et al., 1985), but generally are difficult to define for the most part in the subsurface of the study area. However, the top of the Blanding Formation can be identified by the predominant abundance of chert near the bottom of the Silurian.

The Silurian aquifer consists primarily of dolomite, although Silurian limestone units are present in central Benton County. Some relatively impermeable beds consisting of shale or relatively dense carbonates occur within the Silurian, but they are not consistent enough to be widely mapped, and the entire sequence is generally considered as one aquifer. As shown on Plate 6, the Silurian aquifer varies in thickness from less than 150 feet to more than 350 feet.

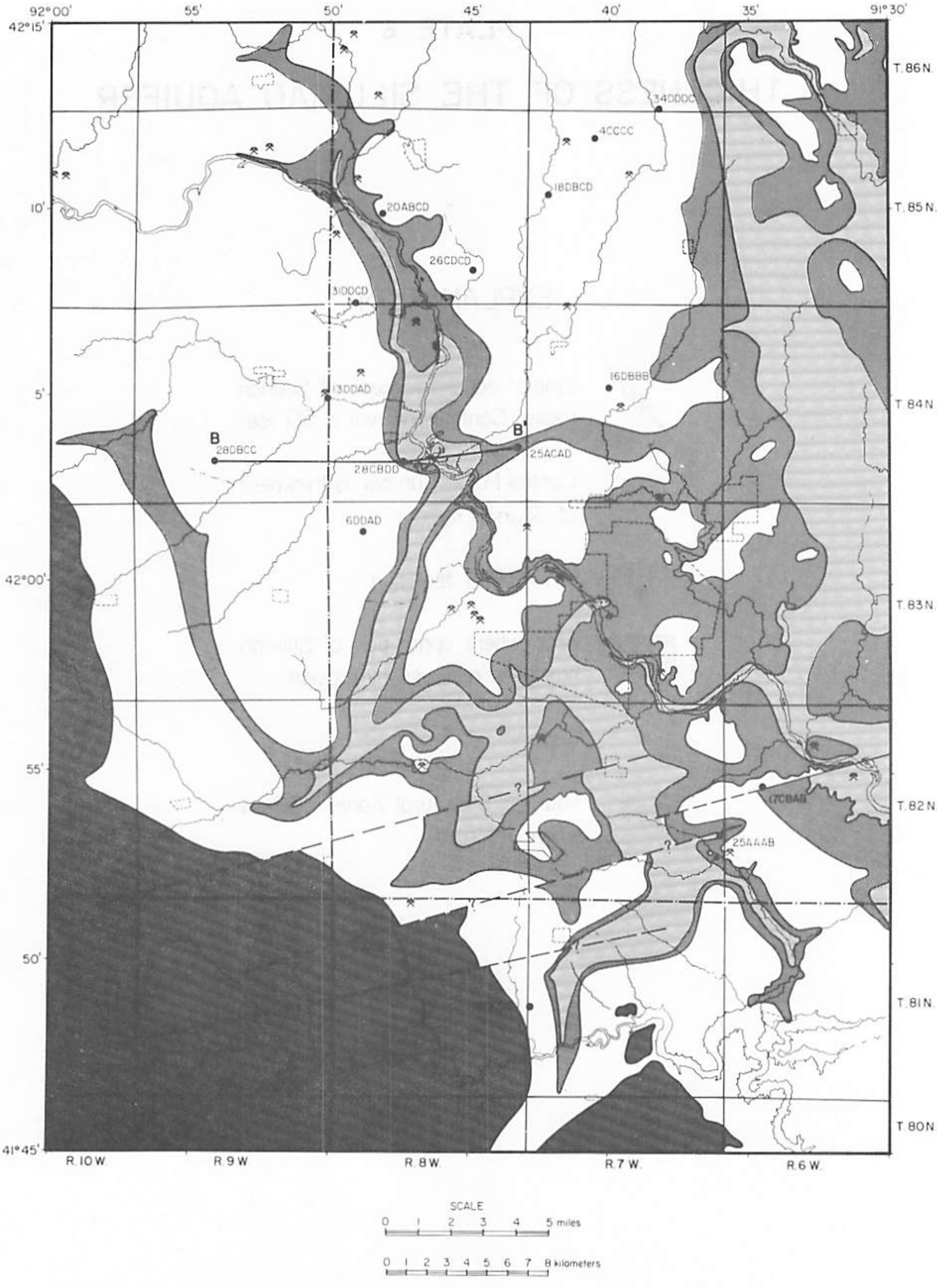
Saturated openings occur throughout the Silurian aquifer and except for one horizon, little correlation or prediction of water-yielding intervals can be made from one area to another. The one horizon that is most consistently productive and predictable is from approximately 70 to 105 feet above the base of the Silurian strata. This horizon yielded water to most of the wells tested, and was the most productive horizon in many of the wells in the study area. This productive horizon occurs in the basal part of the Farmers Creek Member of the Hopkinton Dolomite (Table 1). A map of the approximate altitude of the top of this horizon is shown on Plate 7. Bounk (1983) mapped the outcrop distribution of the Farmers Creek Member (which was informally referred

PLATE 5

BEDROCK HYDROGEOLOGIC UNITS AND LOCATION OF IGS-USGS TEST SITES

EXPLANATION

- Upper Devonian shales - Serves as a confining unit in southwestern part of map area.
- Devonian aquifer
- Devonian confining beds
- Silurian aquifer
- 25AAAB — IGS-USGS test site - Number refers to section - quarter section location as described in text.
- B B' — Trace of section for Figure 7.
- Quarry
- Fault or Structural Zone - Dashed where inferred.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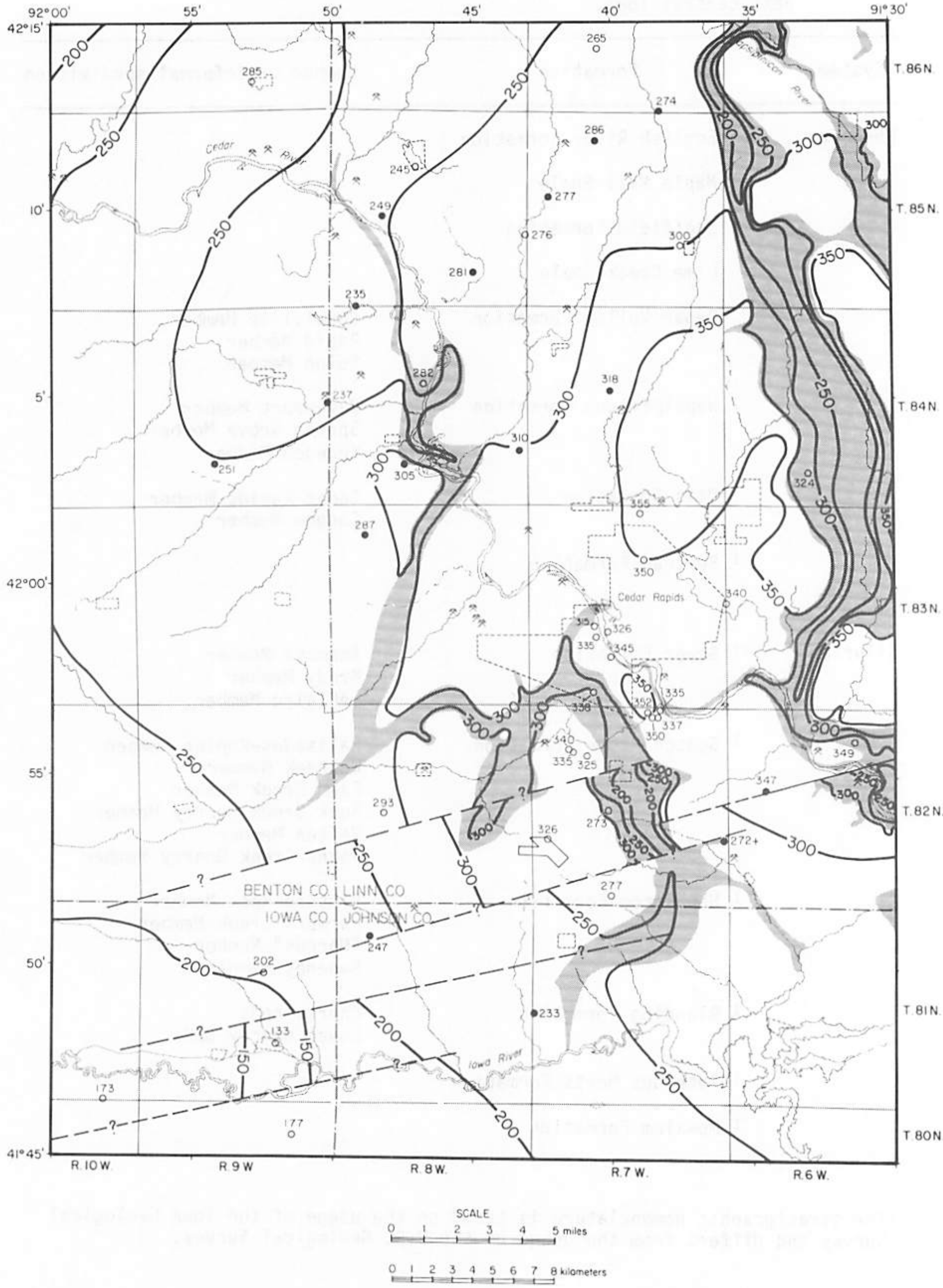
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

PLATE 6

THICKNESS OF THE SILURIAN AQUIFER

EXPLANATION

300	Line of equal thickness of Silurian rocks. Contour interval is 50 feet.
272 ○	Control Point-Number is thickness of Silurian rocks.
326 ●	IGS-USGS test site
(shaded box)	Area where upper part of Silurian has been removed by erosion.
⚒	Quarry
?	Fault or Structural Zone-Dashed where inferred.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SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

Table 1. Stratigraphic subdivisions of the Silurian and Devonian rocks in east-central Iowa.

System	Formation	Member or informal subdivision
Devonian	[1] English River Formation	
	[1] Maple Mill Shale	
	[1] Sheffield Formation	
	Lime Creek Shale	
	Cedar Valley Formation	Coralville Member Rapid Member Solon Member
	[1] Wapsipinicon Formation	Davenport Member Spring Grove Member Kenwood Member
	[1] Otis Formation	Cedar Rapids Member Coggon Member
	[1] Bertram Formation	
Silurian	[1] Gower Formation	Anamosa Member Brady Member LeClaire Member
	[1] Scotch Grove Formation	Palisades-Kepler Member Waubeek Member Fawn Creek Member Buck Creek Quarry Member Welton Member Johns Creek Quarry Member
	[1] Hopkinton Formation	Picture Rock Member Farmers Creek Member "Marcus" Member Sweeney Member
	[1] Blanding Formation	Cherty beds Lower quarry beds
	[1] Tete des Morts Formation	
	[1] Mosalem Formation	

[1]The stratigraphic nomenclature is based on the usage of the Iowa Geological Survey and differs from the usage of the U.S. Geological Survey.

to as the *Cyclocrinites* beds) in extreme east-central Iowa, and determined that it is a major cave-forming horizon in the area. This indicates that the zone is relatively permeable, and that the carbonates in this horizon are very susceptible to solution by groundwater.

Core descriptions from the basal part of the Farmers Creek Member indicate that it consists of porous, vuggy dolomite (Witzke, 1981). In areas where the horizon yields only minor quantities of water, the core descriptions indicate that some of the vugs and pores have been filled with dolomite or shale. The position of this horizon generally can be detected by downhole geophysical-logging techniques. Compared to other carbonate units in the study area, the horizon generally has a smaller natural gamma count, a lesser density as determined by gamma-gamma logging, and a greater water content as determined from neutron logging (Fig. 3). Other water-yielding intervals in the Silurian have similar geophysical characteristics. However, where they contain only one or two widely spaced fractures, these openings may be too thin to show definite indications on borehole-geophysical logs. Where openings are dolomite filled, the density is greater and the water content less; where they are shale filled, the natural gamma and density are both greater.

The estimated yield and estimated specific capacity of major producing intervals were determined by borehole flowmeter, Figure 4, and Table 2. The producing intervals were determined by detecting flow between intervals where natural hydraulic-head differences exist or by pumping the well and determining intervals making detectable contributions.

The intervals tested are listed in Table 2 by both depth below land surface and position above the base of the Silurian rocks, the latter being most useful in correlating producing intervals from well to well. Production from the basal part of the Farmers Creek Member, about 70 to 105 feet above the base of the Silurian rocks, is shown graphically in Figure 4.

Water-yielding horizons in the upper part of the Silurian aquifer are, in part, the result of weathering that enlarged fractures and other porous zones before deposition of the overlying rocks. Water-yielding horizons in the upper part of the Silurian aquifer also relate to the complex distribution of porous and dense carbonate facies (Witzke, 1981). Skeletal molds in the Silurian dolomites have porosities as much as 39 percent and are laterally equivalent to dolomites with porosities as little as less than one percent. Subsequent fracturing and solutional channeling of the porous zones in these upper horizons depend in part on exposure to weathering, either now or in the geologic past, and as such, affect local production, thus making them less predictable than the Farmers Creek aquifer.

Yield characteristics of the Silurian aquifer as determined by short-duration pumping tests are summarized in Table 3. Most of the wells were tested using air-inflated packers which allowed selected intervals to be pumped. Water levels above and below the packers were monitored to determine if the packers were making an effective seal. Those tests which indicated leakage around the packers are footnoted.

Greater yields in the interval 70 to 105 feet above the base of the Silurian rocks (Table 3) are from the basal part of the Farmers Creek Member. A confining bed that overlies this horizon is not consistently hydraulically separated from other parts of the Silurian aquifer. The rocks of the entire Silurian are considered to be one hydrologic unit.

In general, test yields from wells completed in the Silurian aquifer ranged from about 50 to 100 gal/min. The total capacity of the test pump used was 100 gal/min and some of the wells would have yielded more water if a larger pump were used. Yields of 500 gal/min or more were reported by Hansen

PLATE 7

ALTITUDE OF THE TOP OF THE FARMERS CREEK AQUIFER

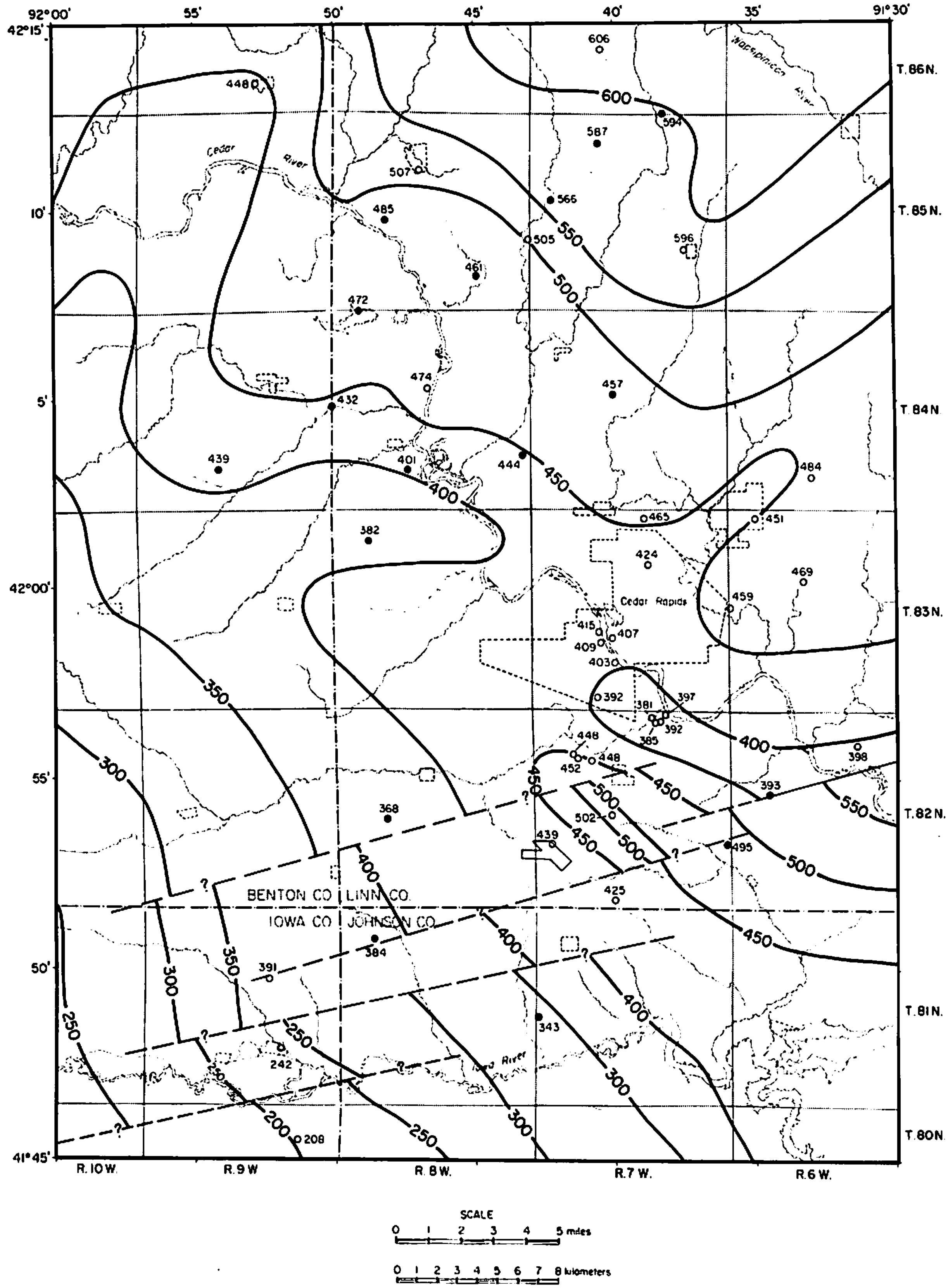
EXPLANATION

500 — Structure Contour - Shows altitude of top of the Farmers Creek aquifer. Contour interval is 50 feet.

495 o — Control Point - Number is altitude of top of the Farmers Creek aquifer, in feet above mean sea level.

364 ● — IGS-USGS test site

?— Fault or Structural Zone - Dashed where inferred.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Wapsipinicon River
Cedar Rapids
Iowa River
BENTON CO.
LINN CO.
IOWA CO.
JOHNSON CO.
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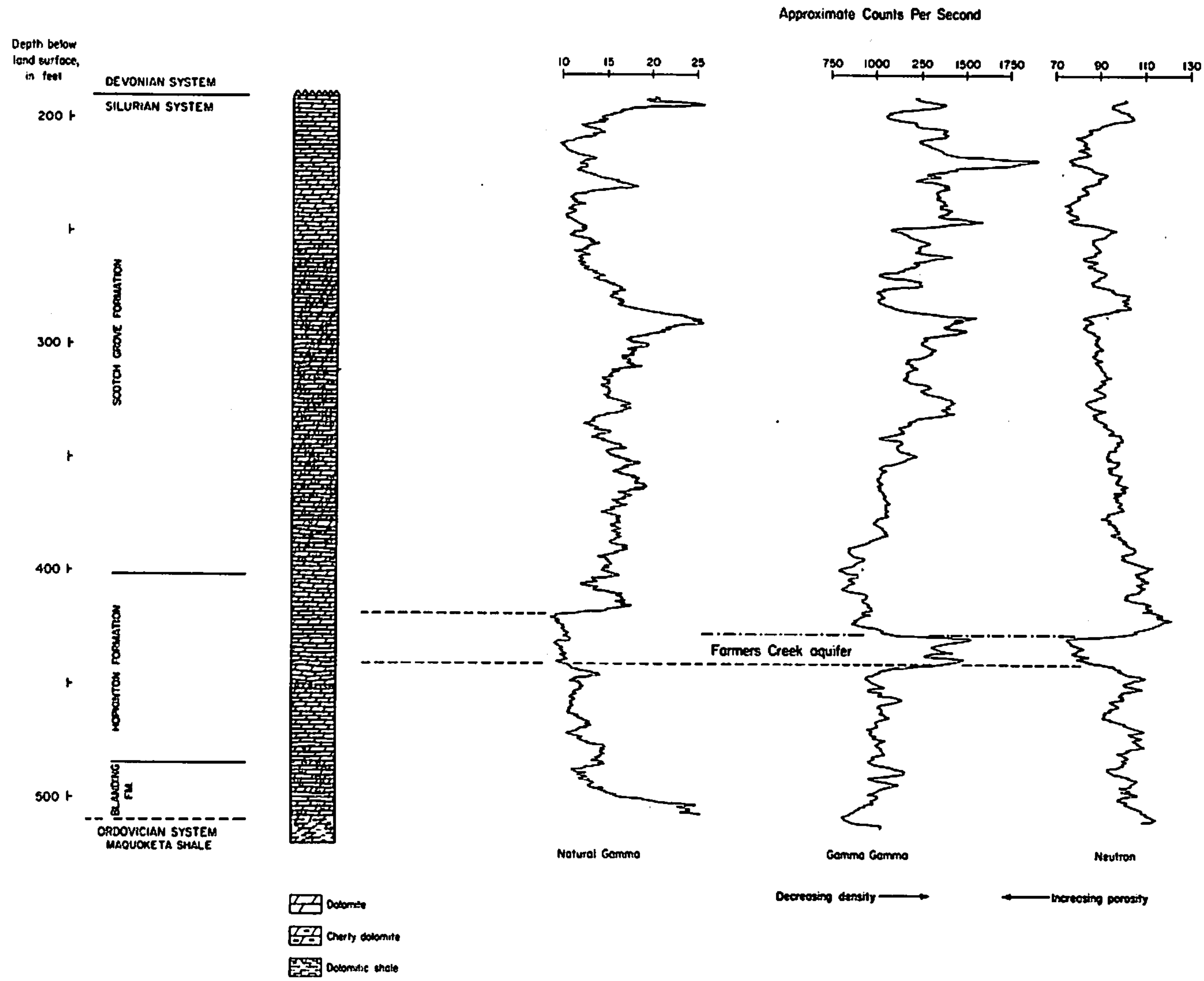


Figure 3. Lithologic log and borehole-geophysical radiation logs of a test well (84-07-16DBBB) in central Linn County.

(1970, p. 63). Test well 85-08-20 ABCD, approximately 2 miles southwest of Center Point, Iowa, was a major exception, in that it produced a maximum quantity of about 10 gal/min. Core samples from that test well indicated dense carbonates and numerous shale-filled vugs and fractures, which may account for the small yield. Several nearby town test wells also produced only minor quantities of water from the Silurian aquifer, indicating an area of negligible yield near and to the southwest of Center Point.

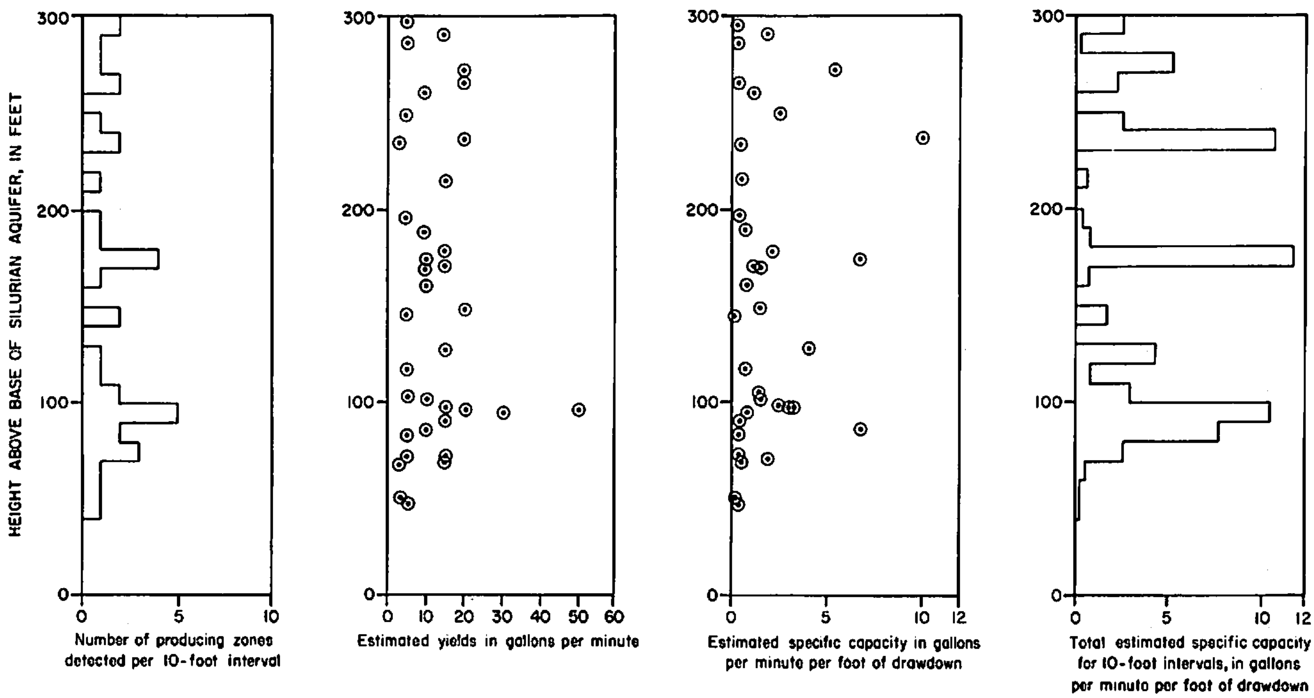


Figure 4. Graph showing production data from 12 wells completed in the Silurian aquifer as determined by a borehole flowmeter.

Water levels measured before pumping of the test wells ranged from about 8 feet above land surface to more than 100 feet below land surface. The water levels also were monitored at different depths by airlines when the air-inflated packers were installed for testing specific zones. However, because of the inaccuracy of the airline readings, it was impossible to determine exact differences in static hydraulic heads. In general, in upland ground-water divide areas the static hydraulic head decreases with depth, and in lowland-valley areas it increases with depth. Hydraulic-head differences within the Silurian aquifer were less than 1 to 5 feet in any individual well. In several wells where the Devonian aquifer also was monitored, that aquifer

Table 2.--Producing zones and estimated yields determined by borehole flowmeter

[gal/min = gallons per minute; (gal/min)ft. dd = gallons per minute per foot of drawdown]

Well location	Pumping rate (gal/min)	Drawdown (feet)	Permeability zone depth (feet)	Position above base of Silurian rocks (feet)	Estimated yield from zone (gal/min)	Estimated specific capacity [(gal/min)ft]
81-07-19 BCBB	0	----	132 Devonian	---	10 [1]	---
	0	----	314	204	10 [2]	---
81-08-05 CCCD	75	13.7	448 Farmers Creek	73	5	0.36
	75	13.7	368	149	20	1.5
	75	13.7	360	161	10	.73
	75	13.7	350	171	15	1.1
	75	13.7	332	189	10	.73
	75	13.7	325	196	5	.36
82-06-17 CBAB	46	23	448 Farmers Creek	84	5	.22
	46	23	316	216	15	.65
	46	23	246	286	5	.22
	46	23	236	296	5	.22
82-07-25 AAAB	88	6.7	285 Farmers Creek	97	20	3.0
	88	6.7	280 Farmers Creek	102	10	1.5
	88	6.7	264	118	5	.75
	88	6.7	212	170	10	1.5
	88	6.7	203	179	15	2.2

Table 2.--Producing zones and estimated yields determined by borehole flowmeter--continued

Well location	Pumping rate (gal/min)	Drawdown (feet)	Permeability zone depth (feet)	Position above base of Silurian rocks (feet)	Estimated yield from zone (gal/min)	Estimated specific capacity [(gal/min)ft]
84-07-16 DBBB	66	8.5	438 Farmers Creek	72	15	1.8
	66	8.5	250	260	10	1.2
	66	8.5	220	290	15	1.8
84-08-25 ACAD	52	57	388 Farmers Creek	70	15	0.26
	52	57	312	146	5	.09
	52	57	192	266	20	.35
84-09-13 DDAD	30	1.5	324 Farmers Creek	86	10	6.7
	30	1.5	236	174	10	6.7
84-09-28 DBCC	0	----	173 Devonian	---	3[1]	--
	0	----	479 Farmers Creek	97	3[2]	--
	68	15	479 Farmers Creek	97	50	3.3
85-07-18 DBCD	26	6	310	69	3	.5
	26	6	280 Farmers Creek	99	15	2.5
	26	6	146	233	3	.5
85-08-20 ABCD	6	44	372	49	5	.1
85-08-26 CDCD	40	2	218	236	20	10.0
	40	2	205	249	5	2.5

Table 2.--Producing zones and estimated yields determined by borehole flowmeter--continued

Well location	Pumping rate (gal/min)	Drawdown (feet)	Permeability zone depth (feet)	Position above base of Silurian rocks (feet)	Estimated yield from zone (gal/min)	Estimated specific capacity [(gal/min)ft]
85-08-31 DDCD	66	34	408	51	3	.09
	66	34	368 Farmers Creek	91	15	.44
	66	34	364 Farmers Creek	95	30	.88
86-07-34 DDDC	105	3.7	313 Farmers Creek	104	5	1.4
	105	3.7	290	127	15	4.1
	105	3.7	145	272	20	5.4
	105	3.7	126 Devonian	---	40	10.8
	0	----	145	272	1)3	---
	0	----	290	127	2)3	---

[1] Nonpumping borehole flow -- producing zone

[2] Nonpumping borehole flow -- receiving zone

Table 3.--Yield characteristics of the Silurian aquifer

[gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot of drawdown]

Well location	Interval tested (feet)	Position above base of Silurian (feet)	Thickness (feet)	Yield (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Average specific capacity per foot of aquifer tested
81-08-05 CCCD	271-323	198-250	52	53	81	0.65	0.012
	316-368	153-205	52	64	14 [1]	4.6	.088
	370-422	99-151	52	18	171	.11	.002
	370-521	0-151	151	25	106	.24	.002
	421-521	0-100	100	16	206	.08	.0008
	133-521	0-388	388 [2]	75	14	5.4	.014
82-06-17 CBAB	176-229	303-356	53 [2]	15	55	.27	.005
	227-280	252-305	53	58	104 [1]	.56	.012
	275-328	204-257	53	57	113 [1]	.50	.009
	327-380	152-205	53	22	238	.09	.002
	377-430	102-155	53	0	--	0	0
	427-480	52-105	53	56	109	.51	.010
	427-532	0-105	105	56	95	.59	.006
82-07-25 AAAB	122-190	192-260	68	15	141	.11	.002
	190-213	169-192	23	90	25 [1]	3.6	.16
	230-253	129-152	23	48	81	.59	.026
	250-273	109-132	23	80	12	6.7	0.29

Table 3.--Yield characteristics of the Silurian aquifer--continued

Well location	Interval tested (feet)	Position above base of Silurian (feet)	Thickness (feet)	Yield (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Average specific capacity per foot of aquifer tested
	275-298	84-107	23	80	12	6.7	.29
	297-320	62-85	23	62	139	.45	.020
	297-382	0-85	85	74	72	1.0	.012
	121-382	0-260	260	88	8	13	.050
83-08-06 DDAD	83-556	0-473	473 [2]	22	13	1.7	.004
	83-556	0-473	473 [2]	43	17	2.5	.005
	83-556	0-473	473 [2]	71	28	2.5	.005
	250-556	0-306	306 [2]	68	32	2.1	.007
84-07-16 DBBB	160-234	276-350	74 [2]	50	25	2.0	.027
	232-306	204-278	74	45	30	1.5	.020
	309-383	127-201	74	0	---	0	0
	382-456	54-128	74	63	28	2.2	.030
	445-510	0-65	65	29	83	.35	.005
84-08-25 ACAD	160-235	223-298	75	24	59	.41	.005
	234-309	149-224	75	4	115	.03	.0004
	308-383	75-150	75	40	162 [1]	.25	.003
	360-435	23-98	75	0	--	0	0
	360-458	0-98	98	48	116	.41	.004
	153-458	0-305	305	75	68	1.1	.004

Table 3.--Yield characteristics of the Silurian aquifer--continued

Well location	Interval tested (feet)	Position above base of Silurian (feet)	Thickness (feet)	Yield (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Average specific capacity per foot of aquifer tested
84-08-28 CBDD	148-200	239-291	52	44	84	.52	.01
	200-254	185-239	54	10	141	.07	.001
	251-306	133-188	55	50	162	.31	.006
	294-348	91-145	54	81	18	4.5	.083
	316-370	69-123	54	81	18 [1]	4.5	.083
	370-439	0-69	69	30	209	.14	.002
84-09-13 DDAD	184-268	142-226	84	70	51	1.4	.017
	220-253	157-190	33	76	58 [1]	1.3	.039
	265-298	112-145	33	39	238 [1]	.16	.005
	278-373	37-132	95	73	66 [1]	1.1	.012
	309-342	68-101	33	71	101 [1]	.70	.021
	184-410	0-226	226	80	35	2.3	.010
84-09-28 DBCC	332-385	191-244	53	.5	141	.004	.00008
	359-412	164-217	53	1.0	113	.009	.0002
	390-422	154-186	32	0	--	0	0
	408-462	114-168	54	9	85	.11	.002
	422-454	122-154	32	6	155	.04	.001
	502-534	42-74	32	18	143	.13	.004
	460-576	0-116	116	53	7 [1]	7.6	.066

Table 3.--Yield characteristics of the Silurian aquifer--continued

Well location	Interval tested (feet)	Position above base of Silurian (feet)	Thickness (feet)	Yield (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Average specific capacity per foot of aquifer tested
	502-576	0-74	74	38	88 [1]	.43	.006
	172-576	0-404	404 [2]	30	7	4.3	.011
85-07-04 CCCC	149-203	228-282	54	32	95	.34	.006
	200-255	176-231	55	0	--	0	0
	254-309	122-177	55	0	--	0	0
	308-363	68-123	55	44	46 [1]	.96	.017
	359-413	18-72	54	0	--	0	0
	359-431	0-72	72	11	127	.09	.001
	41-129; 147-431	0-284; 302-390	372 [2]	94	25	3.8	.010
85-07-18 DBCD	74-88; 110-159	220-269; 291-305	63 [2]	40	60	.67	.011
85-08-20 ABCD	40-148; 177-421	0-244; 273-381	352 [2]	6	44	.14	.0004
	40-148; 177-421	0-244; 273-381	352 [2]	11	59	.19	.0005
	126-148; 177-421	0-244; 273-295	266 [2]	<1	62	<.02	<.00008
85-08-26 CDCD	181-234	220-273	53	72	21	3.4	.064
	232-285	169-222	53	5	140	.04	.0008
	281-334	120-173	53	12	203	.06	.001
	316-369	85-138	53	42	199 [1]	.21	.004
	369-422	32-85	53	43	184 [1]	.23	.004
	369-454	0-85	85	44	171	.26	.003

Table 3.--Yield characteristics of the Silurian aquifer--continued

Well location	Interval tested (feet)	Position above base of Silurian (feet)	Thickness (feet)	Yield (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Average specific capacity per foot of aquifer tested
	61-454	0-393	393 [2]	40	2	20	.051
	61-454	0-393	393 [2]	100	5	20	.051
85-08-31 DDCD	355-379	80-104	24	68	66 [1]	1.0	.042
	400-424	35-59	24	29	192 [1]	.15	.006
	214-459	0-245	245	65	34	1.9	.008
86-07-34 DDCD	155-240	177-262	85	18	127	.14	.002
	210-295	122-207	85	53	8	6.6	.078
	285-370	47-132	85	58	5 [1]	11.6	.14
	295-380	37-122	85	56	39	1.4	.016
	336-417	0-81	81	51	113	.45	.006
	94-417	0-323	323 (2)	100	4	25	0.007

[1] Water levels above or below packed zone declined indicating the packers were leaking or the interval tested was in hydraulic connection with overlying or underlying beds or both.

[2] Interval tested included some overlying Devonian rocks as well as Silurian aquifer.

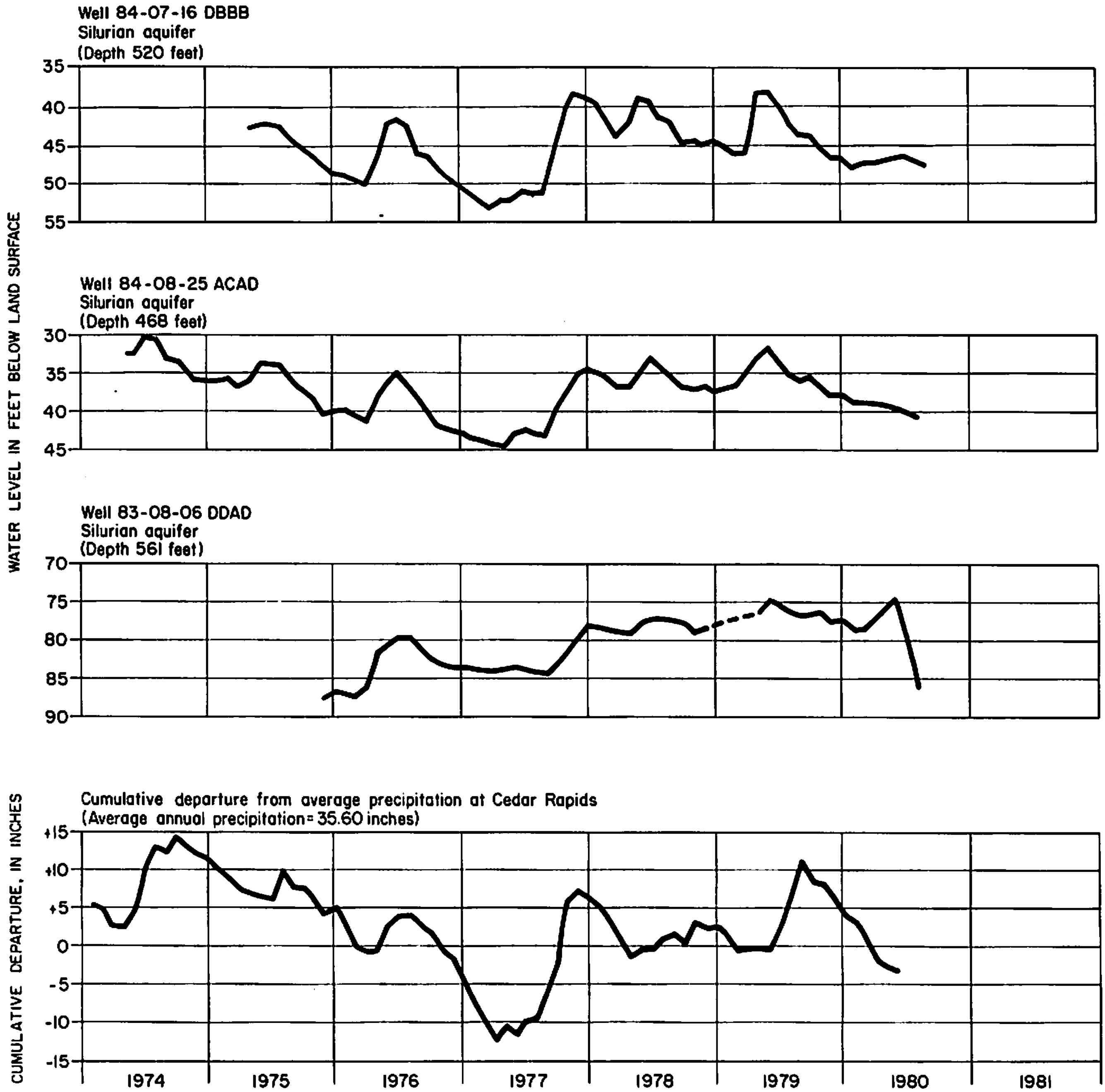


Figure 5. Water levels in selected wells and cumulative departure from average precipitation during period of this study.

had a static hydraulic head 20 to 40 feet higher than the underlying Silurian aquifer. However, in some wells there was no detectable difference between hydraulic heads in the Silurian and Devonian aquifers.

Continuous water-level recorders were maintained on 14 of the test wells completed in the Silurian aquifer at various times during the study. Hydro-

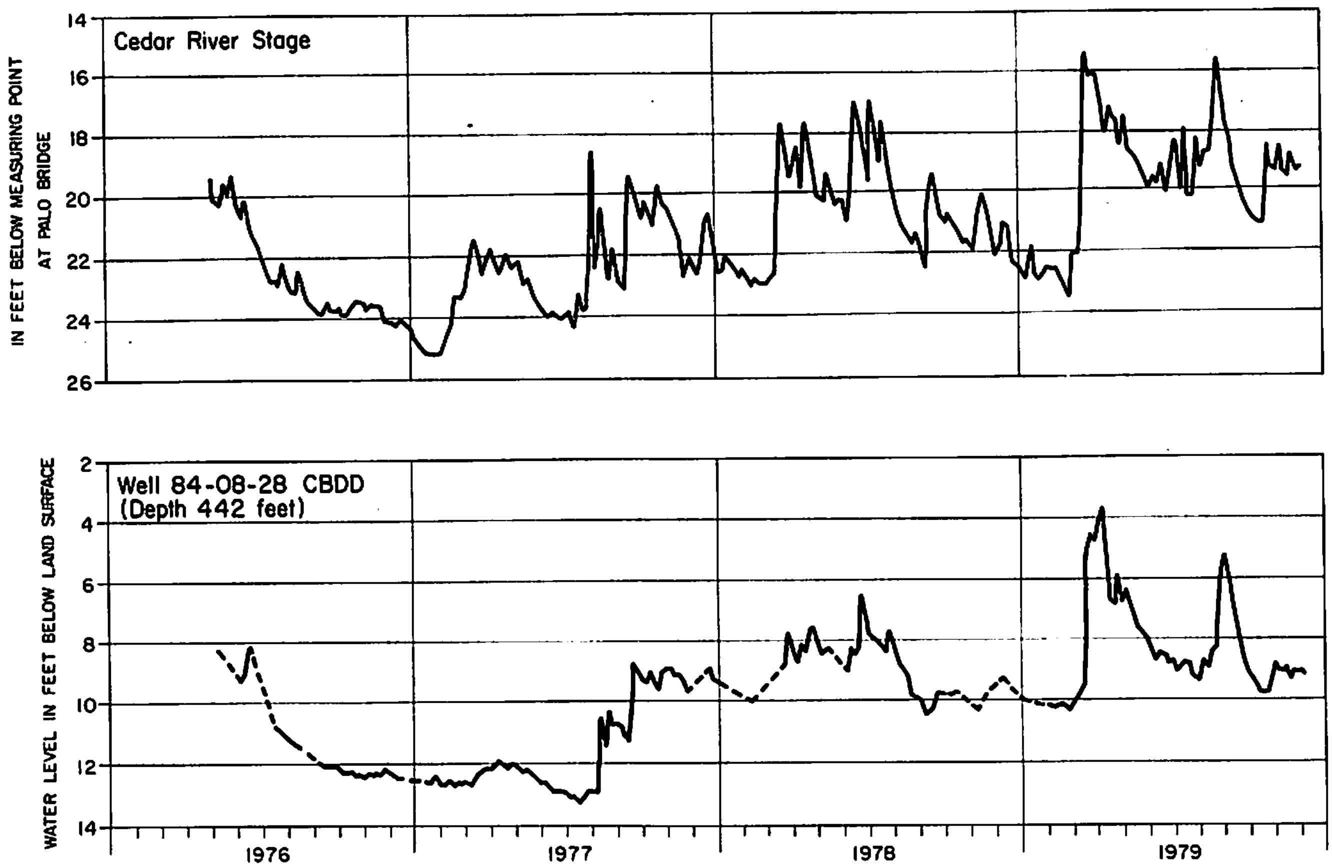


Figure 6. Stage of the Cedar River near Palo and water levels in a nearby test well completed in the Silurian aquifer (1976-1979)

graphs for three representative wells (locations shown on Pl. 5) and the cumulative departure from average precipitation at Cedar Rapids, Iowa, are presented in Figure 5. These hydrographs show a direct response to precipitation, indicating that recharge to the Silurian aquifer occurs both northeast and southwest of the Cedar River. Deficient precipitation from 1974 to August 1977 is indicated on the cumulative-departure curve. The hydrographs show the response of the aquifer to this deficiency. The most noticeable change in the hydrographs is the almost total lack of water-level recovery in the spring of 1977 and the greater than usual recovery in the fall of 1977.

The hydrograph of a well located near the Cedar River at Palo, and the estimated stage of the river at the Palo bridge are shown in Figure 6. The stage of the Cedar River at the Palo bridge was estimated from the flow at Cedar Rapids by relating periodic stage measurements at the bridge to the mean-daily discharge at the U.S. Geological Survey gage at Cedar Rapids. Because of the distance between the sites a 1-day time lag was assumed. This relationship probably could be refined using hourly gage data; however, for the purposes of this report, the mean-daily discharge seems sufficiently accurate. Although some of the sudden rises may be the aquifer's response to rises in stage of the river, the correlation between these two graphs indicates that a hydraulic connection exists between the river and the aquifer. The potentiometric profile in Figure 7 shows a gradient towards the Cedar River, also indicating that there is discharge from the Silurian aquifer through the alluvium into the river.

In the study area the Silurian aquifer is exposed at the land surface in the extreme northeast corner along the Wapsipinicon River and along the Cedar River southeast of Cedar Rapids. Elsewhere, the Silurian aquifer is overlain by Quaternary deposits or by Devonian rocks. The recharge to or discharge Quaternary deposits (Pl. 5). Many of the buried bedrock channels indicated on Plate 4 contain extensive Quaternary sand and gravel beds (Fig. 2), and where these beds are in contact with the Silurian aquifer, there may be significant quantities of recharge or discharge. An example of this can be seen southwest of Central City as illustrated on Plates 4 and 8.

Areas of significant recharge or discharge also may occur where the Silurian aquifer is overlain by less than 50 feet of weathered, fractured, or otherwise disrupted confining beds (Pl. 9). Where the Silurian is overlain by more than 50 feet of confining beds there is relatively small recharge or discharge potential.

Recharge and/or discharge to and from an aquifer depends on the hydraulic-head difference across the recharge or discharge area and the hydraulic conductivities and thickness of confining materials. Detailed hydraulic-conductivity information is not available for the Silurian rocks or the overlying units, and the natural recharge is defined as occurring throughout the upland areas and being most significant in areas where the Devonian confining beds are absent or less than 50 feet thick. Discharge occurs in the major stream valleys, particularly in areas where the Silurian aquifer forms the first bedrock unit directly underlying the Quaternary alluvium (Pl. 5). The potentiometric surface of the Silurian aquifer, Plate 8, also indicates this general pattern of flow.

Recharge from wells for rural, domestic, and stock purposes occurs throughout the area. In addition, several cities use Silurian wells for their municipal supply. The most concentrated pumpage occurs in the Cedar Rapids area, where the aquifer is pumped primarily for industrial and commercial use. There also is evidence that withdrawals from the adjacent surficial aquifer by the city of Cedar Rapids has caused some decline in water levels in the Silurian aquifer (Hansen, 1970, p. 48). This concentration of pumpage from the Silurian in the Cedar Rapids area produced a cone of drawdown prior to 1959 (Hansen, 1970, p. 42). This cone has continued to develop and was approximately 30 feet deeper by 1978 (Pl. 8).

Devonian Aquifer

The Devonian rocks in southeastern Iowa are divided into the Bertram, Otis, Wapsipinicon and Cedar Valley formations, Lime Creek Shale, Sheffield Formation, Maple Mill Shale, and English River Siltstone (Table 1). The Otis, Wapsipinicon, and Cedar Valley formations also have been further subdivided into members as shown in Table 1.

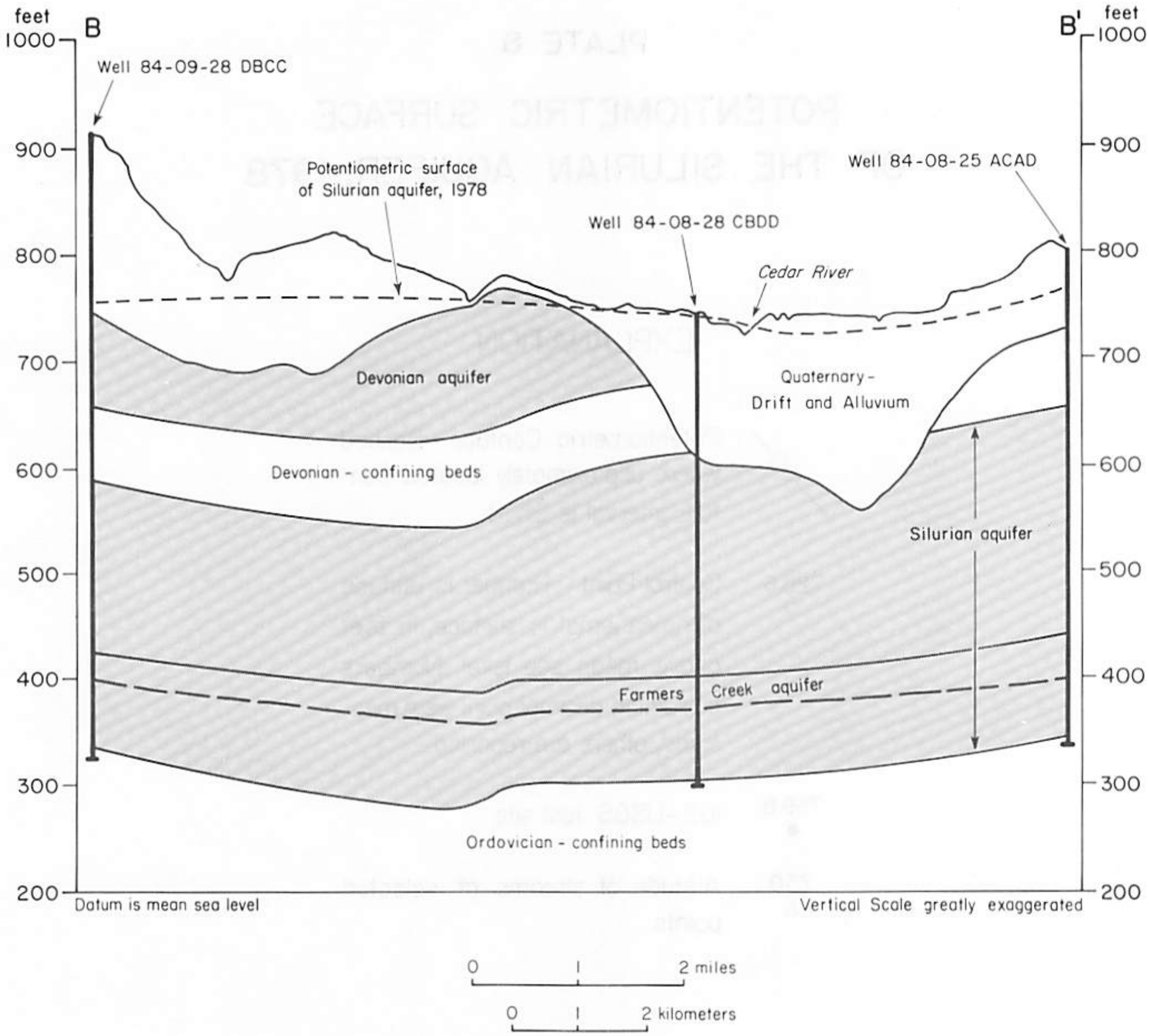


Figure 7. Geohydrologic section across the Cedar River valley near Palo.

The Devonian consists chiefly of white to gray limestone and dolomite with some chert and several beds of gray shale. Some of the carbonate units are argillaceous (shaly) in places and some are extensively brecciated (fractured). Joints, fractures, and vugs are common in the carbonate beds.

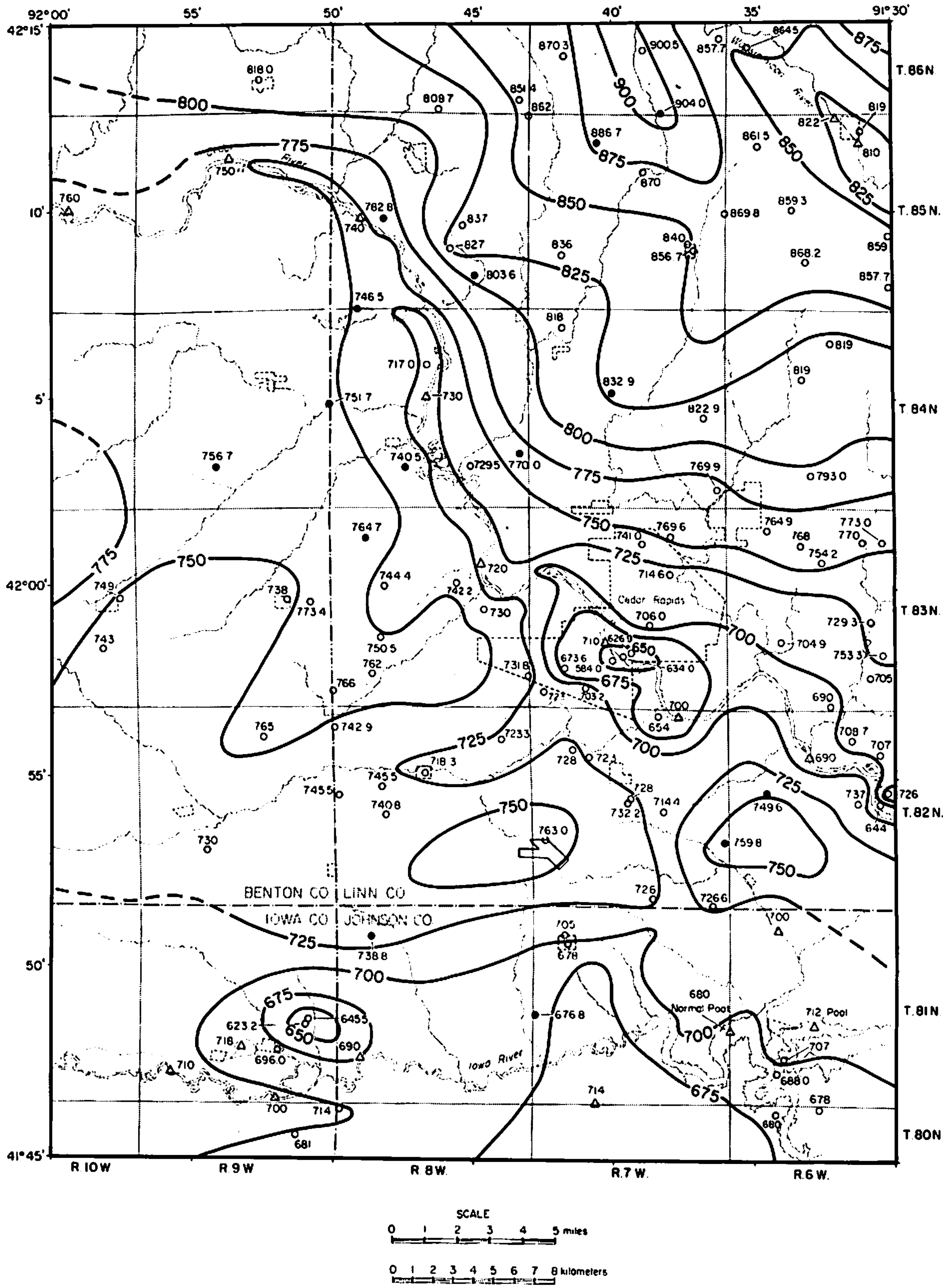
The Bertram and Otis formations, and the Kenwood Member of the Wapsipinicon Formation (Table 1) serve as local confining beds which separate the Devonian aquifer from the Silurian aquifer. The Bertram Formation consists of

PLATE 8

POTENTIOMETRIC SURFACE OF THE SILURIAN AQUIFER, 1978

EXPLANATION

╱700╱	Potentiometric Contour - Dashed where approximately located. Contour interval is 25 ft.
726.6 ○	Control Point - Number is altitude of potentiometric surface, in feet above mean sea level. Numbers containing decimal point were measured, others are reported.
759.8 ●	IGS-USGS test site
730 △	Altitude of streams at selected points.



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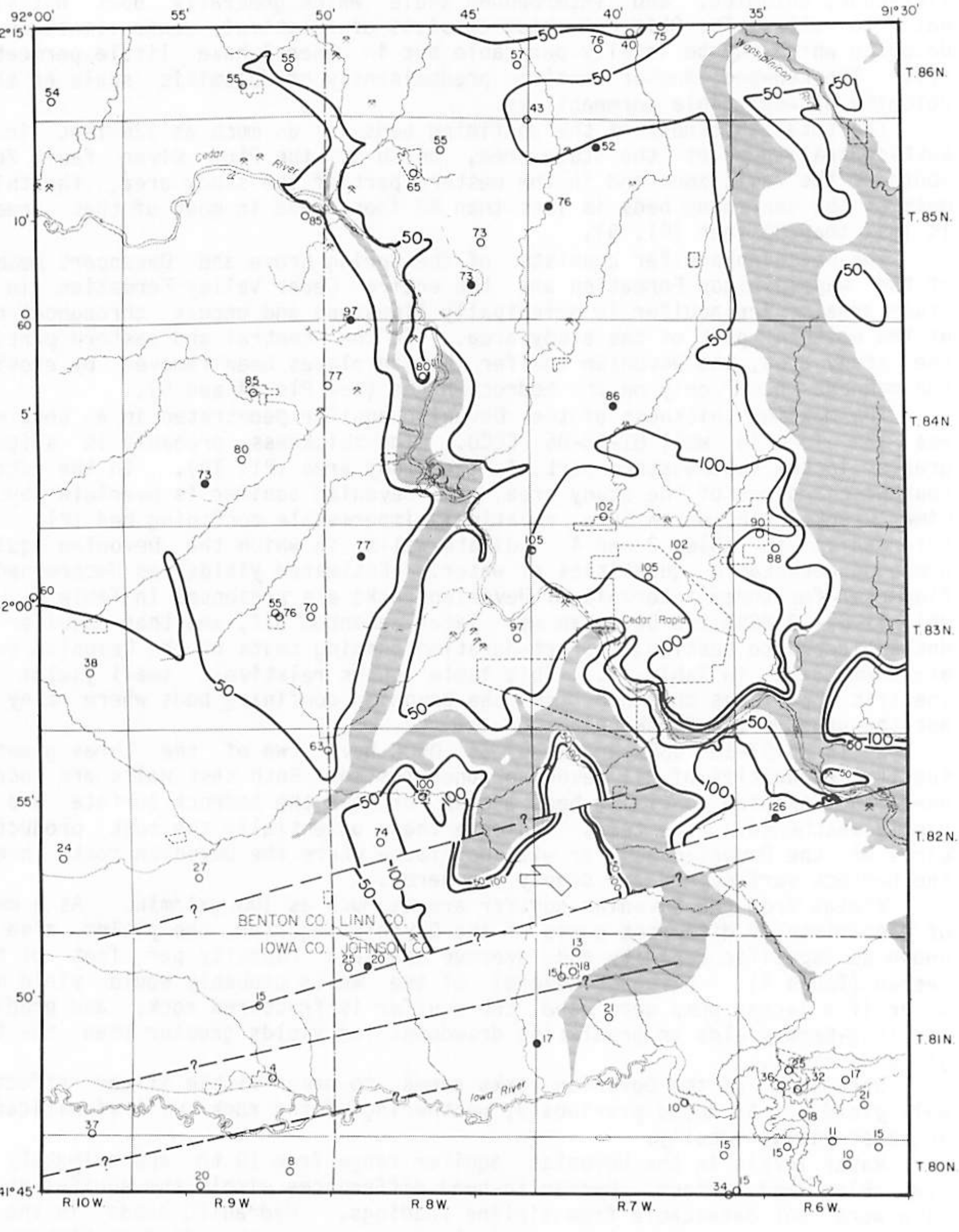
R.9W.
R.8W.
R.7W.
R.6W.
BENTON CO
LINN CO
IOWA CO
JOHNSON CO
Cedar Rapids
Iowa River
Normal Pool
712 Pool
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

PLATE 9

THICKNESS OF THE DEVONIAN CONFINING BEDS

EXPLANATION

50	Line of equal thickness of the Devonian confining beds. Contour interval is 50 feet.
25 o	Control Point - Number is thickness of Devonian confining beds.
20 ●	IGS-USGS test site
?	Fault or Structural Zone - Dashed where inferred.
⚒	Quarry
	Area where Devonian confining beds are missing.



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R.7W.
R.6W.
Cedar River
Wapsipinicon River
Iowa River
Cedar Rapids
BENTON CO.
LINN CO.
IOWA CO.
JOHNSON CO.
50
100
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

limestone, dolomite, and interbedded shale which generally does not yield water to wells. The Otis Formation consists of relatively dense limestone and dolomite which may be locally permeable but in general have little permeability. The Kenwood Member consists predominantly of dolomitic shale or shaly dolomite of negligible permeability.

The total thickness of the confining beds is as much as 126 feet in the east-central part of the study area, north of the Plum River Fault Zone. South of the fault zone and in the western part of the study area, the thickness of the confining beds is less than 40 feet, and in most of that area it is less than 20 feet (Pl. 9).

The Devonian aquifer consists of the Spring Grove and Davenport members of the Wapsipinicon Formation and the entire Cedar Valley Formation in the study area. The aquifer is principally limestone and occurs throughout most of the western part of the study area. In the central and eastern parts of the study area, the Devonian aquifer has in places been removed by erosion, and remnants occur only on the bedrock highs (see Pls. 4 and 5).

The maximum thickness of the Devonian aquifer penetrated in a test well was 124 feet in well 81-08-05 CCCD. The thickness probably is slightly greater in the southwestern part of the study area (Pl. 10). In the extreme southwest corner of the study area, the Devonian aquifer is overlain by the Lime Creek Shale, which is a relatively impermeable confining bed (Pl. 5). Information in Tables 2 and 4 indicate wells in which the Devonian aquifer produced detectable quantities of water. Estimated yields as determined by flowmeter for three intervals of Devonian rocks are presented in Table 2. In well 81-07-19 BCBB the Devonian was later cemented off, and that aquifer was not subjected to testing. Short-duration pumping tests of the Devonian rocks are summarized in Table 4. This table shows relatively small yields and specific capacities obtained from the Devonian confining beds where they are not the uppermost bedrock unit.

Wells 85-07-18 DBCD and 86-07-34 DDDC have two of the three greatest specific capacities of all Devonian zones tested. Both test wells are located where the Devonian confining beds are at or near the bedrock surface and are deeply weathered. The tests indicate that potentially the most productive parts of the Devonian aquifer will be found where the Devonian rocks are at the bedrock surface and are deeply weathered.

Yields from the Devonian aquifer are as much as 100 gal/min. As a means of comparison of different parts of the Devonian aquifer, the yields also are shown as specific capacity and average specific capacity per foot of hole tested (Table 4). Although several of the wells probably would yield more water if a larger pump were used, the aquifer is fractured rock, and predicting long-term yields or predicting drawdowns for yields greater than the test yield is risky.

Structure of the Devonian rocks seems to have little if any effect on well yields. As noted previously, weathering of the rock will significantly increase yields locally.

Water levels in the Devonian aquifer range from 10 to approximately 100 feet below land surface. Hydraulic-head differences within the aquifer at any site were not detectable from airline readings. Hydraulic heads in the Devonian aquifer range from being equivalent to greater than 40 feet higher than those in the underlying Silurian aquifer.

A continuous water-level recorder was maintained on one well completed in the Devonian aquifer near the Pleasant Creek reservoir. Hydrographs of that well, an adjacent well completed in the underlying Silurian aquifer, and cumulative departure from average precipitation are shown in Figure 8. Prior to

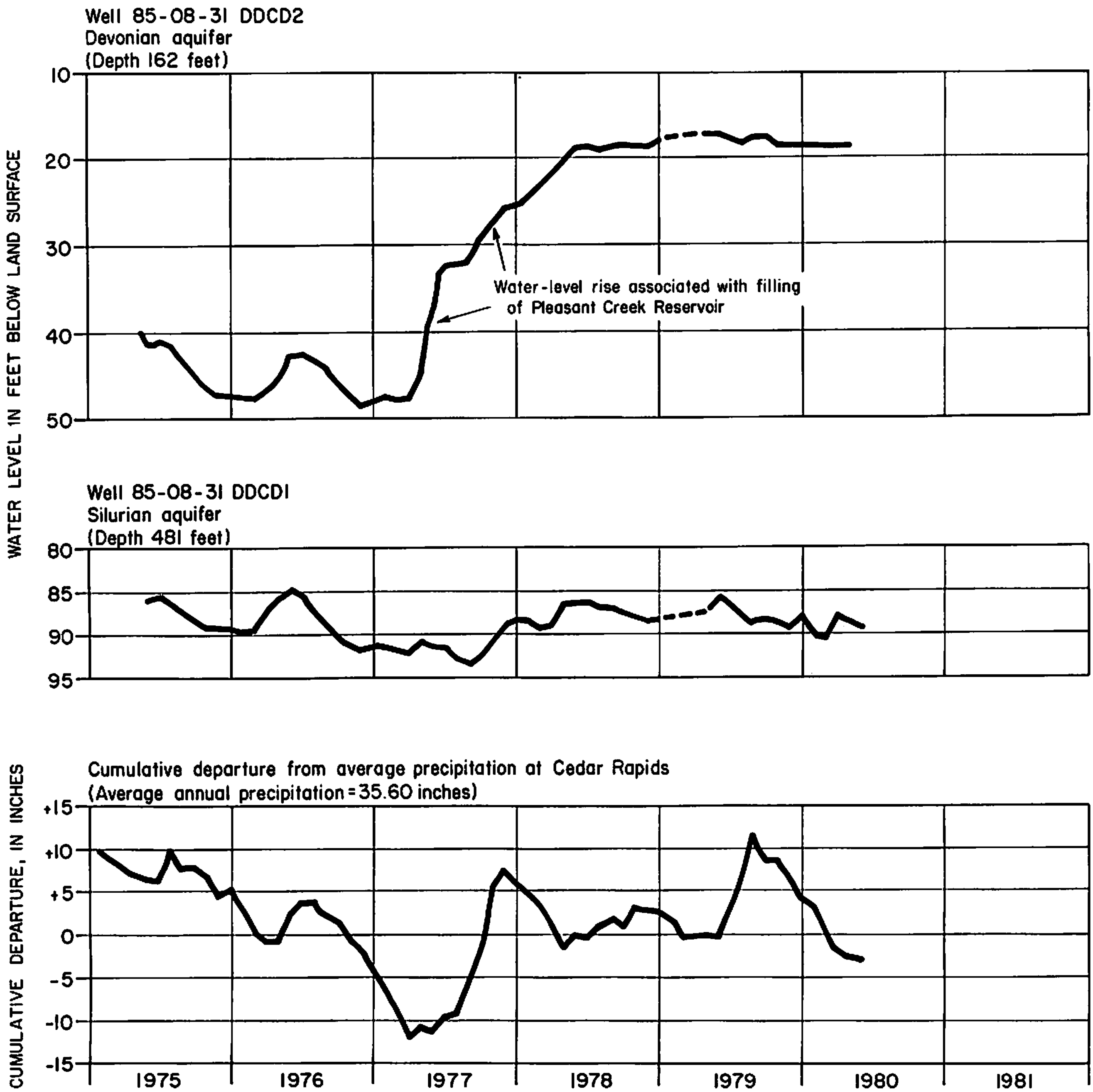


Figure 8. Water levels in two wells near Pleasant Creek Reservoir and cumulative departure from average precipitation (1975-1980)

filling of the reservoir, the water levels in the two wells had fluctuations similar in phase and size, and both were in phase with precipitation trends, although water levels in the Devonian aquifer were about 40 feet above water levels in the Silurian aquifer. Filling of the reservoir by pumping from the Cedar River during the spring of 1977 caused water levels in the Devonian aquifer to rise, but had little, if any short-term effect on the water levels of the underlying Silurian aquifer. The resulting hydraulic-head difference of about 70 feet during the fall of 1978 and the observation that there was no

PLATE 10

THICKNESS OF THE DEVONIAN AQUIFER

EXPLANATION

50 — Line of equal thickness. Contour interval is 50 feet.

62 ○ — Control Point - Number is thickness of Devonian aquifer.

142 ● — IGS - USGS test site

—?— Fault or Structural Zone - Dashed where inferred.

⚒ — Quarry

▭ — Area where rocks that comprise the Devonian aquifer are missing.

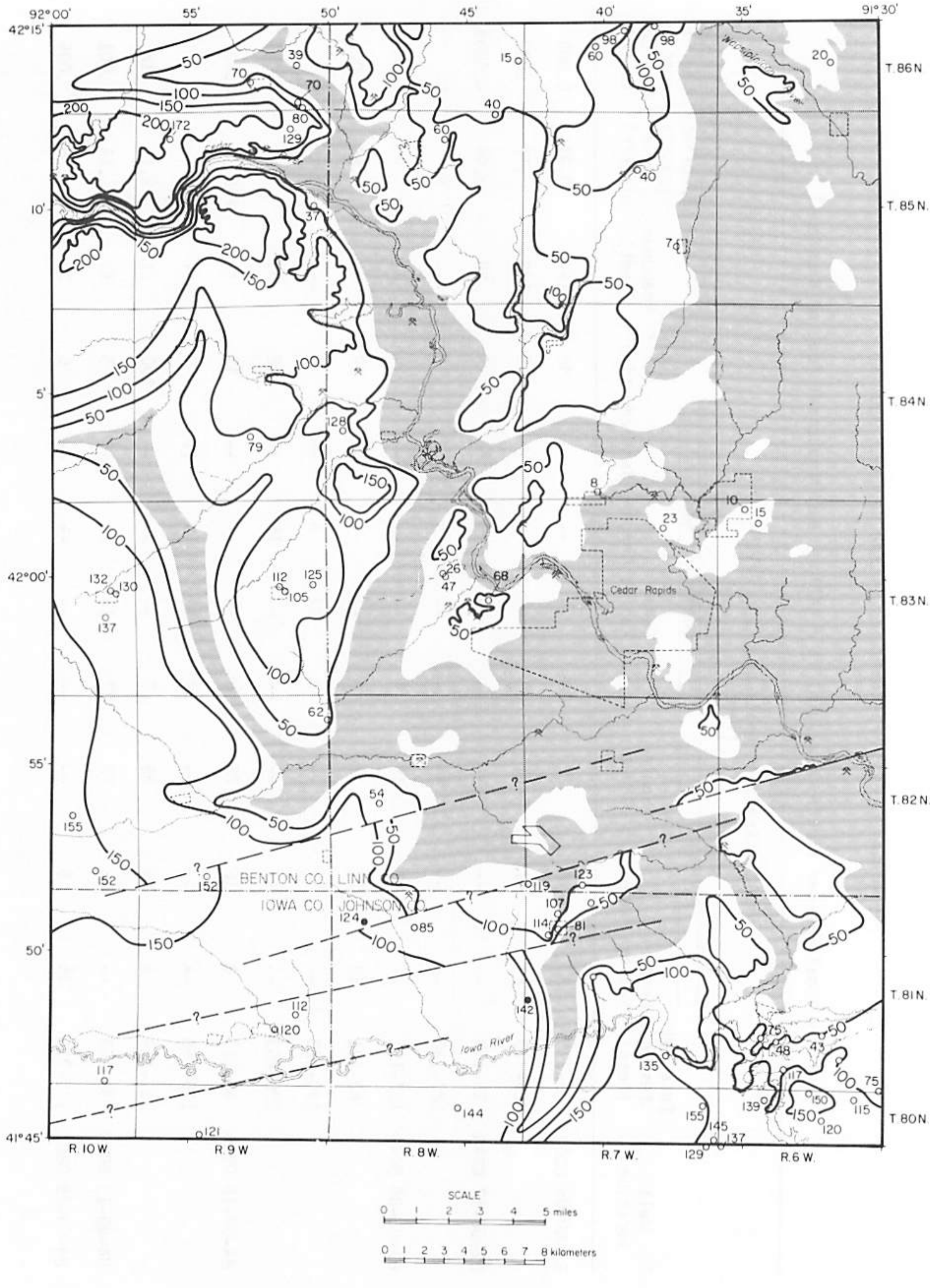

92°00'
55'
50'
45'
40'
35'
91°30'
42°15'
10'
5'
42°00'
55'
50'
41°45'
T. 86 N.
T. 85 N.
T. 84 N.
T. 83 N.
T. 82 N.
T. 81 N.
T. 80 N.
R. 10 W.
R. 9 W.
R. 8 W.
R. 7 W.
R. 6 W.
Cedar Rapids
Iowa River
BENTON CO. | LINN CO.
IOWA CO. | JOHNSON CO.
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

Table 4.--Yield characteristics of the Devonian aquifer

[gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot of drawdown]

		Thickness of units open (to well) (feet)										
		aquifer			confining beds							
Well location	Interval tested (feet)	Cedar Valley	Davenport	Spring Grove	Kenwood	Cedar Rapids	Coggon	Bertram	Yield (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Average specific capacity per foot tested
81-08-05 CCCD	133-275	83	18	21	20	--	--	--	46	124	0.37	0.003
	223-275	--	11	21	20	--	--	--	15	128	.12	.002
82-06-17 CBAB	85-180	--	--	--	--	19	25	51	<5	58	<.09	<.0009
	127-180	--	--	--	--	--	2	51	0	---	0	0
83-08-06 DDAD	158-191	--	6	18	9	--	--	--	14	61	.23	.007
	83-191	59	22	18	9	--	--	--	29	42	.69	.006
	190-223	--	--	--	8	22	3	--	0	---	0	0
	220-253	--	--	--	--	--	16	17	18	83	.22	.007
84-07-16 DBBB	61-117	8	16	26	6	--	--	--	49	<1	>49	>.88
	115-168	--	--	--	19	10	13	11	0	---	0	0
	61-119	8	16	26	8	--	--	--	100	11	9.1	.16
84-09-13 DDAD	35-164	--	28	22	22	16	23	18	5	35	.14	.001
84-09-28 DBCC	172-213	35	6	--	--	--	--	--	6	30	.20	.005

Table 4.--Yield characteristics of the Devonian aquifer--continued

Well location	Interval tested (feet)	Thickness of units open (to well) (foot): aquifer: Cedar Valley	Davenport	Spring Grove	confining beds: Kenwood	Cedar Rapids	Coggon	Bertram	Yield (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Average specific capacity per foot tested
	181-213	26	6	--	--	--	--	--	0	---	0	0
	172-246	35	28	11	--	--	--	--	12	45	.27	.004
	193-246	14	28	11	--	--	--	--	0.6	45	.01	.0002
	277-325	--	--	--	--	20	14	14	4	74	.05	.001
	284-316	--	--	--	--	13	14	5	0	---	0	0
	172-325	35	28	18	22	22	14	14	15	92	.16	.001
85-07-04 CCCC	41-120	--	19	27	18	13	2	--	4	30	.13	.002
85-07-18 DBCD	74-86	--	--	--	--	--	12	--	100	23	4.3	.36
85-08-26 CDCD	70-81	--	11	--	--	--	--	--	0	---	0	0
	81-134	--	5	19	21	8	--	--	75	21	3.6	.067
	128-178	--	--	--	--	21	18	11	0	---	0	0
85-07-34 DDDC	94-143	--	--	--	--	19	22	8	75	5	15	.31

noticeable effect on water levels in the Silurian aquifer, indicates that there is little, if any short-term leakage downward through the Devonian confining beds in this area.

The Devonian rocks are exposed at the land surface or occur at relatively shallow depths in many places in the study area and receive recharge directly from precipitation or from the alluvium and drift. The quantity of recharge depends on the hydraulic conductivity of the confining units and hydraulic-head differences between the recharge source and the Devonian aquifer.

Discharge from the Devonian aquifer occurs locally as seepage to streams, as springs, and as percolation to underlying or overlying units. Several relatively large springs north of Cedar Rapids are reported to discharge from the Devonian aquifer (Hansen, 1970, p. 61). Discharge by pumping is limited to wells for domestic and stock use, usually producing less than 10 gal/min.

Quaternary Aquifer

Till deposited by glacial ice and consisting chiefly of a mixture of sand, silt, and clay with some gravel and boulders constitutes most of the Pleistocene material in the area. The till is poorly sorted and includes material ranging from clay size to boulders more than 5 feet in diameter. Many stratigraphically definable tills occur in the study area (Hallberg, 1980). Outwash deposits from meltwater or postglacial streams characteristically consist of lenticular or sheet-like beds of well-sorted sand, gravel, and finer-grained sediments. Outwash deposits may occur at many stratigraphic horizons within the tills (Hallberg, 1980); however, they are most common and continuous at the base of the till sequence and particularly in bedrock channels. The till and outwash deposits are referred to as glacial drift. In many places the glacial drift is overlain by fine sand or windblown silt deposits called loess.

The glacial drift was deposited on an eroded bedrock surface, which in general must have looked much like the present-day topography. The altitude and configuration of that bedrock surface is shown on Plate 4.

Alluvial deposits underlie the channels, flood plains, and terraces of most major streams in the study area. In general, the deposits consist of lenticular beds of sorted silt, sand, and gravel. This material generally was derived from upstream areas and deposited by streams.

The Quaternary aquifer consists of unconsolidated sand and gravel beds in the glacial drift and in the alluvium associated with modern streams. The sand and gravel beds commonly are interlayered with relatively impermeable beds of till, silt, and clay. Quaternary deposits in the study area are as much as 390 feet thick. The percentage of that thickness that will yield water to wells is variable. In general, the lower part of the Pleistocene, material within buried bedrock channels and alluvial deposits, contains significant thicknesses of sorted sand and gravel beds. Therefore, the Quaternary aquifer system has three important functions: (1) As a connecting conduit for the movement of water between the underlying bedrock aquifers; (2) as a source of recharge to, discharge from, or both of the groundwater system; and (3) as a storage container for potential recharge or discharge water. The aquifer is particularly suited for these functions because it commonly contains sand and gravel in the basal part that is in direct contact with the weathered bedrock aquifers. Hansen (1970, p. 30-39) described the Quaternary aquifers in Linn County in detail.

Alluvium along the Cedar River forms the thickest and most extensive part of the Quaternary aquifer and has the greatest potential yield. In several places, for example near Palo and at Cedar Rapids, the alluvial sands and gravels immediately overlie, and are in hydraulic connection with, underlying buried-channel deposits. The potential yield of the Quaternary aquifer in these two areas is significant because of the thickness and lateral extent of sand and gravel (Fig. 7).

Individual wells producing from the Quaternary aquifer at Cedar Rapids yield as much as 2,000 gal/min, and specific capacities as much as 78 (gal/min)/ft of drawdown (Hansen, 1970). These wells are along the Cedar River and produce from extensive sands and gravels that are hydraulically connected to the river.

Water levels in wells in the Quaternary aquifer vary from above land surface in part of the Prairie Creek valley to more than 140 feet below land surface in the northeast corner of Linn County (Hansen, 1970). Water levels in individual wells may fluctuate 3 feet or more in immediate response to precipitation, and 10 feet or more seasonally (Hansen, 1970).

Recharge to the Quaternary aquifer occurs as infiltration of precipitation, as seepage from adjacent aquifers, and as infiltration from streams where the groundwater level is lower than stream level. Natural discharge from the Quaternary aquifer occurs as seepage to streams, as seepage to other aquifers, and as direct evapotranspiration where the aquifer is unconfined and water levels are near land surface.

QUALITY OF WATER

A review of the historic water-quality information available for the study area indicated that a brief and general description of the water quality could be made without obtaining additional samples from private wells specifically for that purpose. Samples were collected from most of the test wells constructed for the project. These analyses and other representative chemical analyses available are given in Table 5. A detailed discussion of the significance of the various physical and chemical data given in Table 5 and the surfacewater quality in the area can be found in Wahl et al. (1978).

Water from the Devonian and Silurian aquifers is of similar chemical quality, and may occasionally contain objectionable concentrations of sulfate, and almost always contain large concentrations of iron. Water from the Devonian and Silurian aquifers also tend to have small concentrations of nitrate except for several samples from shallow parts of the aquifers where they are in hydraulic connection with the overlying Quaternary aquifer. These samples had concentrations of about 30 mg/L (milligrams per liter) as nitrate (about 7 mg/L of nitrate as nitrogen).

Analyses of samples collected from various depths within the Silurian aquifer indicate that the water is of consistent chemical quality at any given location. Dissolved-solids and sulfate concentrations plotted on Plate 11 show that dissolved-solids concentrations as much as 2,350 mg/L occur in the western and southwestern part of the area. Also there is a small area in Cedar Rapids where the dissolved-solids concentrations exceed 500 mg/L (Pl. 11). In Cedar Rapids the greater values occur in an area of concentrated pumping in the northern part of the resulting drawdown cone. This occurrence of greater dissolved-solids concentrations in the groundwater near Cedar Rapids cannot be explained with information presently available. A study of

Table 5.--Results of chemical analyses of water from selected wells

(micromhos = micromhos per centimeter at 25° Celsius; °C = degrees Celsius; mg/L = milligrams per liter)

Local well identifier	Well depth (feet)	Depth of sample interval (feet)	Date sample collected	Specific conductance (micromhos)	pH (units)	Temperature (°C)	Dissolved solids (mg/L)	Hardness (mg/L as $CaCO_3$)	Sodium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as NO_3)	Fluoride (mg/L)	Iron (mg/L)	Manganese (mg/L)
Quaternary aquifer															
080-10W-01 BBB	72	--	01-17-55	1057	7.5	10.5	741	577	32	2.0	199	<1	0.4	1.4	0.09
081-09W-26 BCDC	33	--	05-20-74	780	6.8	--	418	396	16	37	150	18	.2	1.3	.53
082-09W-38 DCB	35	--	09-09-52	661	7.7	11.1	441	354	16	14	73	4.8	.2	4.4	2.4
081-09W-30 BBAB	40	--	09-29-76	610	7.0	17.0	366	340	8.5	13	27	17	.2	<.01	<.01
083-07W-17 BDBA	67	--	03-21-74	520	7.0	6.0	301	264	8.4	14	48	3.2	.7	1.2	.84
083-07W-17 DAD	68	--	04-27-71	520	6.9	7.0	340	250	13	19	56	10	.2	4.0	.38
084-09W-15 ABA	28	--	11-21-58	587	7.4	15.5	349	336	8.8	10	54	28	1.0	.08	<.05
Devonian aquifer															
080-10W-01 BBBA	780	--	02-23-60	741	7.5	--	451	346	34	1.0	12	1.3	.3	.58	<.05
081-08W-05 CCCD*	533	133-272	05-08-75	890	7.2	12.0	635	410	52	4.0	200	.1	.9	6.5	.26
081-09W-23 DADA	550	--	05-20-74	780	7.3	--	480	316	42	1.0	120	.1	.4	.36	<.01
081-09W-24 BCCC	633	--	03-05-60	724	7.6	12.0	412	320	36	3.0	112	<.4	.4	3.3	.14
081-09W-26 BCDB	555	--	05-20-74	670	7.4	--	445	300	23	3.0	100	.1	.4	.35	<.01
082-09W-17 CCD	120	--	08-10-71	1100	7.0	--	721	520	29	48	200	.4	.3	5.0	.56
084-07W-16 DBBB*	520	60-199	11-19-73	560	7.2	--	355	284	5.5	10	64	30	.2	.03	.01
084-09W-13 DDAD*	421	35-163	08-29-74	560	7.4	11.0	314	312	3.1	2.0	34	.1	.2	.45	.01
084-09W-28 DBCC*	590	276-330	07-24-74	650	7.2	12.0	383	268	46	.5	28	.1	.3	.59	.01
085-07W-18 DBCD*	386	--	08-12-75	400	7.7	11.0	252	244	4.8	3.0	5.0	.1	.3	.05	.01
085-08W-24 DDAD	155	--	11-09-73	390	7.9	13.0	251	272	6.5	8.0	33	.8	.4	.51	.09
Silurian aquifer															
080-09W-02 DCD	765	--	01-27-60	1790	7.7	12.0	1520	847	97	7.0	765	.9	.3	.06	.05
080-09W-03 DDCB	750	--	04-28-75	1800	7.2	--	1630	940	120	7.0	950	.1	.3	.39	.10
081-06W-32 ABCB	517	--	06-14-62	660	7.8	10.5	403	338	14	.5	61	<.1	.2	.24	<.05
081-07W-16 CBCB	391	--	10-06-66	1100	7.3	--	814	575	33	1.0	350	1.7	.3	3.9	.01
081-08W-05 CCCD*	533	269-320	05-08-75	1000	7.3	12.0	735	434	79	4	310	<.1	.8	.35	.06
		316-368	05-12-75	980	7.3	12.0	690	418	70	3	270	<.1	.8	.34	.05
		370-422	05-12-75	1000	7.2	--	716	430	70	3	290	<.1	.8	.40	.04
		421-521	05-12-75	1200	7.3	--	896	480	100	5	420	<.1	.8	.46	.06
081-09W-23 DADD	603	--	11-02-70	760	7.2	--	472	308	46	1.0	150	.1	.5	2.0	.05
081-10W-36 CCCC		--	02-23-60	2570	7.5	13.5	2350	1400	124	11	1340	<.4	.8	1.2	.25
082-06W-17 CBAB	541	176-229	05-03-76	430	7.6	12.5	200	253	2.5	<0.5	6.6	<0.1	0.3	0.01	<0.01
		227-280	05-03-76	410	7.6	11.5	197	239	2.7	<.5	7.1	.2	.3	.03	<.01
		275-328	05-04-76	420	7.5	11.5	201	244	2.8	<.5	5.0	<.1	.3	.02	.02
		327-380	05-05-76	440	7.5	12.5	214	255	2.9	<.5	4.8	.3	.3	.01	.02
		427-580	05-05-76	420	7.5	11.5	211	245	3.1	1.5	12	4.2	.2	<.01	<.01
082-06W-31 ACAA	415	--	05-09-74	480	7.4	12.0	293	262	5.0	2.0	31	.1	.3	.13	.01
082-07W-03 ACBC	432	--	10-11-66	590	7.4	11.5	315	304	14	1.0	18	.1	.3	.52	.05
082-07W-16 DCD	420	--	09-21-51	454	8.0	11.5	257	226	--	1.5	4.5	3.5	.2	2.7	
082-07W-25 AAAB	401	167-190	05-17-76	500	7.4	12.5	259	279	4.2	<.5	5.8	.3	.3	.24	.01
		190-213	05-18-76	470	7.4	11.5	252	266	4.0	<.5	5.8	.3	.3	.71	.04
		230-253	05-18-76	490	7.4	11.5	259	274	4.0	<.5	6.4	.3	.3	.45	<.01
		250-273	05-18-76	490	7.4	11.5	255	274	4.1	<.5	3.9	.3	.3	.47	<.01
		275-298	05-19-76	510	7.3	12.0	264	279	4.1	<.5	4.7	.3	.3	.46	.02
		297-320	05-19-76	520	7.3	12.0	269	289	4.0	<.5	5.8	.4	.3	.06	<.01
		297-401	05-19-76	530	7.3	12.0	299	300	5.3	1.0	9.9	.4	.4	.05	.03
081-08W-05 CCCD**	533	269-320	05-08-75	1000	7.3	12.0	735	434	79	4	310	<.1	.8	.35	.06
		316-368	05-12-75	980	7.3	12.0	690	418	70	3	270	<.1	.8	.34	.05
		370-422	05-12-75	1000	7.2	--	716	430	70	3	290	<.1	.8	.40	.04
		421-521	05-12-75	1200	7.3	--	896	480	100	5	420	<.1	.8	.46	.06
082-07W-30 BAD	672	--	06-28-67	510	7.5	11.5	300	265	8.3	<.5	15	<.1	.3	.56	<.05
082-07W-30 DDAD	520	--	11-27-72	520	7.0	--	310	300	8.0	<.5	28	1.3	.4	5.2	.53
082-08W-16 ABA	410	--	09-23-74	880	7.4	--	530	360	56	2.0	150	<.1	.6	.34	<.01
082-09W-17 CCDD	585	--	09-19-74	1800	7.4	13.5	1470	650	170	7.0	800	<.1	1.7	.25	.01
082-09W-20 DCCD	416	--	11-13-68	850	7.2	--	465	330	62	.5	69	.7	.9	.33	.05

Table 5.--Results of chemical analyses of water from selected well--continued

Local well identifier	Well depth (feet)	Depth of sample interval (feet)	Date sample collected	Specific conduct-ance (micromhos)	pH (units)	Tempera-ture (°C)	Dissolved solids (mg/L)	Hardness (mg/L as $CaCO_3$)	Sodium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as NO_3)	Fluoride (mg/L)	Iron (mg/L)	Manganese (mg/L)
083-06W-20 DCCD	390	--	07-29-70	580	7.2	12.0	340	341	4.7	1.0	26	<.1	.2	1.2	<.05
083-07W-01 BAAA	441	--	07-17-76	570	7.6	11.5	347	310	6.5	20	58	<.1	.2	.38	.01
083-07W-01 BADB	437	--	07-16-75	520	7.5	11.0	305	276	6.1	8.0	38	.5	.1	.25	.01
083-07W-10 DBB	460	--	04-29-41	---	7.3	10.5	238	229	5.3	6.0	16	--	--	.20	---
083-07W-13 DDDA	530	--	11-05-43	---	7.2	11.0	446	451	4.9	70	31	.4	--	.15	---
083-07W-16 CBBB	305	--	08-08-61	551	7.3	11.5	323	284	5.5	1.0	13	.1	.2	.76	.05
083-07W-21 CADD	405	--	08-04-80	870	7.5	16.5	521	360	35	54	81	.2	.3	1.4	.11
083-07W-21 DCC	421	--	01-20-48	---	7.6	13.5	533	421	34	41	94	2.2	.2	--	.07
083-07W-27 BCC	415	--	06-27-45	---	7.4	11.5	520	410	14	19	110	6.6	.1	.10	---
083-07W-27 CCBA	424	--	02-02-62	633	7.8	--	382	334	14	17	69	12	.2	.28	<.05
083-07W-28 AABC	425	--	06-05-40	---	7.3	14.0	675	478	31	58	209	35	1.1	---	---
083-07W-28 ABBA	405	--	08-04-80	840	7.5	15.0	525	390	21	41	100	8.4	.2	<0.01	0.20
083-07W-28 ABBB	415	--	08-04-80	832	7.5	15.5	511	380	23	42	93	4.4	.2	.01	.08
083-07W-28 ACA	423	--	03-16-45	---	7.2	12.0	530	424	21	35	105	27	.1	.10	---
083-07W-28 ADD	430	--	08-06-43	---	7.4	12.0	323	298	16	7.0	32	.9	--	--	---
083-07W-28 DB	450	--	08-06-43	---	7.3	12.0	380	313	6.2	8.0	38	.4	.5	.45	---
083-07W-31 CAB	370	--	11-27-43	---	7.1	--	316	286	16	3.0	29	--	1.5	7.8	---
083-09W-14 DBB	456	--	07-22-75	770	7.4	13.0	435	292	65	5.0	43	<.1	.4	.40	.01
083-09W-14 DBD	485	--	07-22-75	750	7.2	14.0	430	268	63	5.0	30	.1	.4	.05	.01
083-10W-13 CAC	475	--	01-12-76	900	7.4	--	571	379	62	<.5	200	.2	1.3	1.4	.01
083-06W-16 ABB	300	--	08-31-65	521	7.7	11.5	313	252	16	<.5	16	<.1	.2	1.3	<.05
084-07W-16 DBBB**	520	160-234	11-14-75	510	7.5	11.0	335	273	4.0	3.5	23	12	.2	.02	.01
		232-306	11-13-75	480	7.5	11.0	300	266	3.8	1.5	13	7.4	.2	.02	.02
		382-427	11-12-75	480	7.5	11.0	292	255	4.1	2.0	21	9.9	.3	.01	<.01
		445-520	11-13-75	440	7.5	11.5	264	250	5.0	<.5	7.2	8.3	.4	.02	<.01
084-07W-32 DC	285	--	02-13-53	546	7.3	11.0	313	269	2.9	7.0	42	14	--	.22	---
084-08W-25 ACAD	468	158-175	10-27-75	410	7.6	11.0	233	225	6.0	<.5	5.4	.1	.3	.36	<.01
		234-309	10-22-75	450	7.6	13.0	246	252	6.6	<.5	5.2	.1	.3	.27	<.01
		308-383	10-22-75	450	7.6	12.0	258	271	6.2	<.5	8.2	.2	.3	.12	<.01
		360-435	10-23-75	450	7.6	11.5	287	299	6.8	<.5	12	.2	.3	.51	.01
084-08W-28 CBDD	442	148-200	03-10-76	740	7.4	11.0	449	310	42	4.0	120	.1	.4	.46	.03
		200-254	03-10-76	820	7.4	12.0	497	306	63	2.0	160	.2	.4	.12	<.01
		251-306	03-11-76	810	7.4	11.5	494	307	63	2.0	150	.1	.6	.07	.01
		294-348	03-11-76	810	7.4	11.5	488	306	62	2.0	150	<.1	.6	.06	.01
		316-370	03-16-76	820	7.4	11.5	489	309	62	2.0	150	.1	.6	.05	.01
		370-425	01-22-76	820	7.4	12.0	513	318	65	2.5	170	.3	.8	.02	<.01
084-09W-13 DDAD**	420	220-253	03-19-76	570	7.5	11.5	301	345	7.0	.5	6.8	.7	.4	.28	<.01
		265-298	03-18-76	600	7.4	11.5	336	333	10	.5	7.7	.5	.4	.03	<.01
		309-342	03-17-76	530	7.5	11.5	304	334	4.0	.5	9.7	.5	.4	.19	<.01
084-09W-28 DBCC**	590	422-454	04-02-76	710	7.5	11.0	423	299	50	2.0	76	.4	.6	.03	<.01
		459-497	04-06-76	660	7.5	6.5	367	270	45	<.5	29	.5	.3	.67	.01
		502-534	04-07-76	810	7.5	11.0	487	282	64	1.0	160	.4	.8	<.01	<.01
		502-576	04-07-76	790	7.5	11.0	479	288	63	1.0	150	.5	.7	.08	<.01
085-07W-18 DBCD**	386	86-386	08-07-75	460	7.5	11.0	249	244	4.8	4.0	5.0	.1	.4	.05	<.01
085-07W-26 AAD	400	--	10-31-73	520	7.3	11.0	321	268	10	1.0	29	2.4	0.3	0.36	<0.01
085-08W-26 CDCD	465	181-234	03-23-75	480	7.6	11.5	268	257	8.5	.5	11	.3	.4	<.01	<.01
		232-285	08-25-75	480	7.5	13.0	260	253	8.0	1.0	9.5	.1	.4	.03	<.01
		281-334	08-26-75	460	7.5	12.5	253	205	7.5	2.0	9.2	.2	.4	.01	<.01
		316-369	08-27-75	460	7.5	13.0	251	244	6.6	2.0	8.7	.2	.4	.01	<.01
		369-422	08-28-75	440	7.6	12.0	251	244	6.5	1.0	8.7	.7	.4	.04	<.01
		369-465	08-28-75	460	---	12.0	257	244	6.7	.5	9.4	.1	.4	.19	<.01
086-07W-34 DDDC	421	155-240	09-11-75	420	7.6	11.5	240	230	2.7	1.5	3.0	.7	.2	.60	.04
		210-295	09-12-75	490	7.7	11.0	277	268	3.7	8.5	24	14	.2	<.01	<.01
		285-370	09-15-75	470	7.7	11.0	274	263	3.8	8.0	24	16	.2	<.01	<.01
		336-421	09-16-75	420	7.6	11.0	240	235	3.4	2.0	13	1.4	.2	.01	<.01
086-09W-34 ABB	560	--	10-11-76	530	7.5	--	281	233	30	1.5	33	.2	.6	.01	<.01

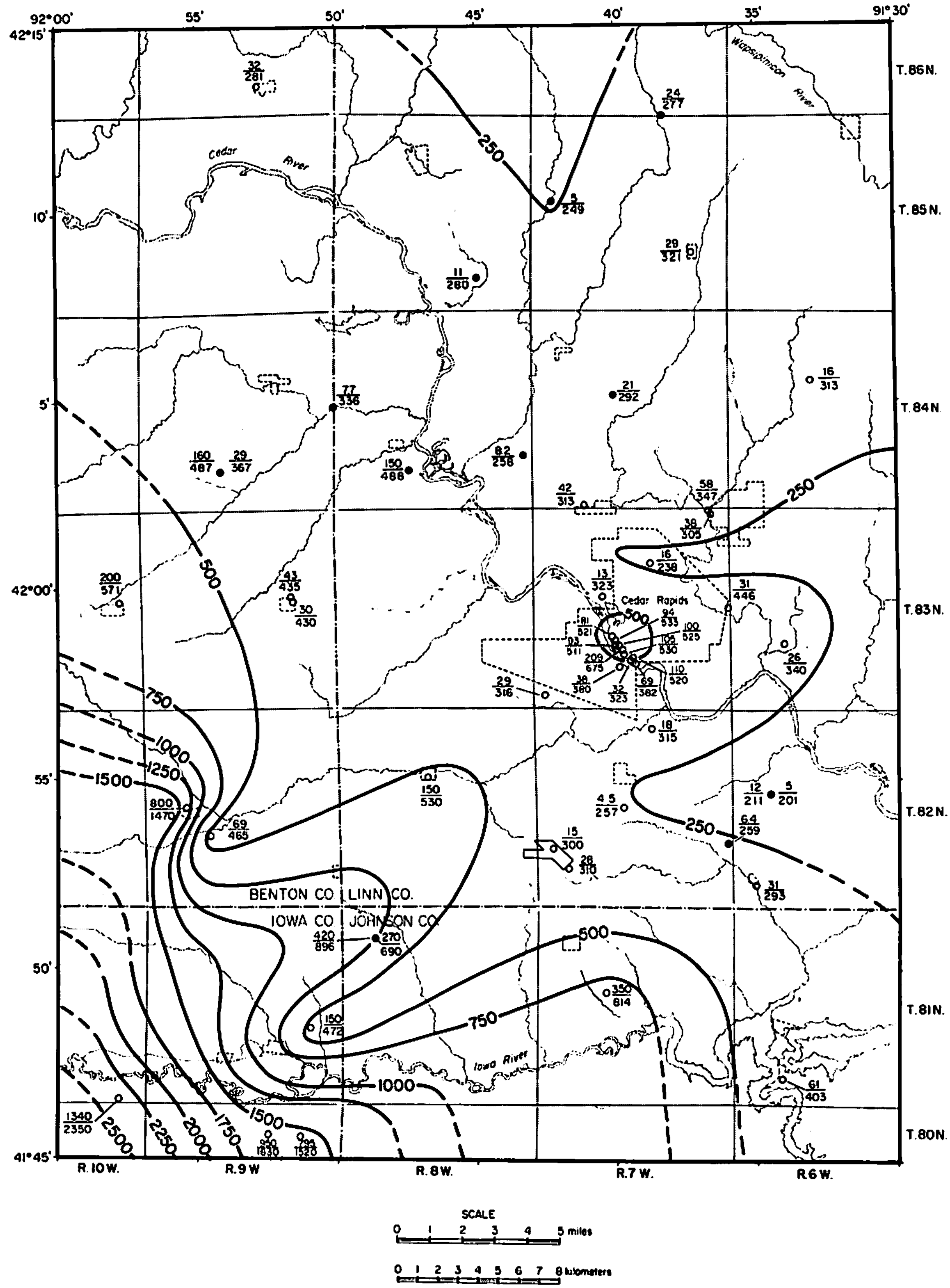
*See Silurian aquifer section of this table for additional analyses at this location
**See Devonian aquifer section of this table for additional analyses at this location

PLATE 11

DISSOLVED - SULFATE AND DISSOLVED- SOLIDS CONTENT OF WATER FROM THE SILURIAN AQUIFER

EXPLANATION

—250—	Line of equal dissolved-solids concentrations. Dashed in areas of poor control. Contour interval is 250 milligrams per liter.
$\frac{31}{293}$ ○	Control Point - Upper number is dissolved - sulfate content and lower number is dissolved solids content. Both values are in milligrams per liter.
$\frac{150}{488}$ ●	IGS-USGS test site



92°00'
55'
50'
45'
40'
35'
91°30'
42°15'
10'
5'
42°00'
55'
50'
41°45'
T.86N.
T.85N.
T.84N
T.83N.
T.82N.
T.81N.
T.80N.
R.10W.
R.9W
R.8W.
R.7W.
R.6W.
Cedar River
Iowa River
Wapsipinicon River
Cedar Rapids
BENTON CO
LINN CO.
IOWA CO
JOHNSON CO.
250
500
750
1000
1250
1500
1750
2000
2250
2500
SCALE
0 1 2 3 4 5 miles
0 1 2 3 4 5 6 7 8 kilometers

historical data on wells and sources of water containing greater than 500 mg/L of dissolved solids may indicate a source for the anomalous water.

Many parts of the Quaternary aquifer in the area are recharged primarily by precipitation that rapidly infiltrates to the water table. As a result, water in the aquifer generally has smaller dissolved-solids concentrations compared to the Silurian and Devonian aquifers. However, rapid recharge also includes agricultural chemicals and fertilizers that are flushed readily through the soil into the aquifer. This occasionally results in nitrate concentrations that exceed the recommended drinking-water standards (National Academy of Sciences--National Academy of Engineering, 1972).

In some areas, such as in the vicinity of Palo, the Quaternary aquifer receives recharge from the underlying bedrock aquifers as well as from precipitation. In these areas the chemical quality of water from the alluvial aquifer is similar to that in the bedrock.

Most water analyses show that water from the Quaternary aquifer has dissolved-solids concentrations of less than 750 mg/L; occasionally concentrations of 1,000 mg/L or more occur. The water is hard, and iron and manganese generally are present in concentrations objectionable for domestic use. Treatment systems are available to remove these constituents.

SUMMARY

Groundwater is the major source of water in this area, with approximately 90 percent of the groundwater production coming from the Silurian, Devonian, and Quaternary aquifers. The Silurian aquifer consists primarily of dolomite, although limestone units are present in the northwestern part of the study area. The Silurian aquifer is underlain by shales in the Upper Ordovician Maquoketa Formation, which are a major confining bed throughout most of Iowa. Water-yielding horizons in the Silurian relate in part to a complex distribution of porous and dense carbonate facies. Skeletal molds in the Silurian dolomite can have porosities as much as 39 percent, and may be laterally equivalent to dolomites with porosities as little as less than 1 percent. Subsequent fracturing and secondary solutional enlargement of these porous horizons makes hydrologic correlation throughout the study area difficult. One horizon in the Silurian, however, does appear to be consistently permeable throughout the study area. This horizon occurs approximately 70 to 105 feet above the base of the Silurian rocks in the Farmers Creek Member of the Hopkinton Formation. Core descriptions from the basal part of the Farmers Creek Member indicate that it consists of porous, vuggy dolomite. In areas where this horizon yields only a minor quantity of water to wells, the core descriptions indicate that some of the vugs and pores have been filled with dolomite or shale. The outcrop distribution of the Farmers Creek Member, which is outside the study area, has shown it to be a major cave-forming horizon in extreme east-central Iowa (Bounk, 1983) indicating that the carbonates present in this interval are very susceptible to groundwater solution.

The Devonian consists chiefly of white to gray limestone and dolomite with some chert and several beds of gray shale. Some of the carbonate units are argillaceous in places and some are extensively brecciated. The Bertram and Otis formations, and the Kenwood Member of the Wapsipinicon Formation locally serve as confining beds between the Devonian and Silurian aquifers. The Devonian aquifer in the study area consists of the Spring Grove and Davenport members of the Wapsipinicon Formation and the entire Cedar Valley Formation. Observation wells near the Pleasant Creek Reservoir in west-central Linn County showed that water levels in the two aquifers had similar fluctuations in phase and size prior to the filling of the reservoir, although water levels in the Devonian aquifer were about 40 feet higher than those in the underlying Silurian aquifer. Filling of the reservoir during the spring of 1977 caused water levels in the Devonian aquifer to rise, but had no effect on water levels in the Silurian aquifer. The resulting hydraulic-head difference of about 70 feet during the fall of 1978 and the observation that there was no noticeable effect on water levels in the Silurian aquifer indicate that there is little, if any, short-term downward leakage through the lower Devonian confining beds in this area.

The Quaternary aquifer consists of unconsolidated sand and gravel beds in the glacial drift and in the alluvium, which is associated with modern streams. The alluvial deposits consist of lenticular beds of poorly- to well-sorted silt, sand, and gravel derived from source areas upstream. The sand and gravel beds are interlayered with relatively impermeable beds of till, silt, and clay. The Quaternary aquifer has three important functions: (1) As a connecting conduit for the movement of water between the underlying bedrock aquifers; (2) as a source of recharge or discharge from, or both, of the groundwater system to the surface; and (3) as a storage container these potential recharge or discharge water. The aquifer is particularly suited for these functions because it contains sand and gravel in the basal part that is in direct contact with the weathered bedrock aquifers.

Yield characteristics of the Silurian and Devonian aquifer, as determined by air-inflated straddle-packer pumping tests of specific intervals, are quite variable, ranging from less than 10 to about 500 gal/min. The average specific capacity per foot of open borehole tested ranged from 0 to greater than 0.88 (gal/min)/ft of drawdown. The Quaternary aquifer also has a range of specific capacities with a reported maximum of more than 2,000 gal/min.

The chemical quality of water from all three aquifers is suitable for most uses although water from the Silurian aquifer has large concentrations of dissolved solids in the Cedar Rapids area and very large concentrations in the extreme southwest part of the study area. There the dissolved solids, and the sulfate concentrations, may be objectionable for domestic use.

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