HYDROLOGY OF THE ALLUVIAL, BURIED CHANNEL, BASAL PLEISTOCENE AND DAKOTA AQUIFERS IN WEST-CENTRAL IOWA

By Donna L. Runkle

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound units	By	To obtain metric units
acre	0.4047	hectare
acre-foot	0.001233	cubic hectometer
	1,233	cubic meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	square meter per day
cubic foot per second	0.02832	cubic meter per second
gallon per day	0.003785	cubic meter per day
gallon per day per square foot	4.720×10^{7}	liter per day per square meter
gallon per minute	0.06308	liter per second
gallon per minute per foot	0.207	liter per second per meter
inch	25.4	millimeter
mile	1.609	kilometer
million gallons	3,785	cubic meter
square mile	2.590	square kilometer

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

HYDROLOGY OF THE ALLUVIAL, BURIED CHANNEL, BASAL PLEISTOCENE, AND DAKOTA AQUIFERS IN WEST-CENTRAL IOWA

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ABSTRACT

A ground-water resources investigation in west-central Iowa indicates that water is available from alluvial, buried channel, basal Pleistocene, and Dakota aquifers. The west-central Iowa area includes Audubon, Carroll, Crawford, Greene, Guthrie, Harrison, Monona, and Shelby Counties.

Nine alluvial aquifers consisting of sand and gravel are in the valleys of the Little Sioux, Maple, Soldier, Boyer, West Nishnabotna, East Nishnabotna, South Raccoon, Middle Raccoon, and North Raccoon Rivers. These aquifers contain about 870,000 acre-feet of water that is potentially available to wells. Potential well yields generally are less than 50 gallons per minute. The water generally is very hard (greater than 180 milligrams per liter hardness as calcium carbonate), is a calcium bicarbonate type, and has an average dissolved-solids concentration of less than 600 milligrams per liter.

Seven buried channel aquifers--Anthon, Denison, Fremont, Hardin Creek, Adaza, Beaver, and Bagley--consisting of sand and gravel, underlie about 594 square miles in west-central Iowa and contain about 65,000 acre-feet of water potentially available to wells. Potential well yields of as much as 1,000 gallons per minute are possible in a few of the deeper and thicker parts of some of the buried channel aquifers, but well yields of 10 to 100 gallons per minute are more common. Water generally is very hard, is a calcium bicarbonate type, and has an average dissolved-solids concentration of 400 to 800 milligrams per liter in the shallow buried channel aquifers in Carroll, Greene, and Guthrie Counties. In the deep buried channel aquifer in Audubon, Crawford, Harrison, Monona, and Shelby counties, the water generally is very hard, is a sodium sulfate or calcium sulfate type, and has an average dissolved-solids concentrations of 3,000 milligrams per liter.

The basal Pleistocene aquifer is at the base of the Pleistocene deposits on many bedrock ridges and consists of sand and gravel. Estimated well yields of as much as 500 gallons per minute can be obtained from the aquifer; however, 5 to 50 gallons per minute are more common. Water from the basal Pleistocene aquifer generally is very hard, is a calcium bicarbonate or calcium sulfate type, and has an average dissolved-solids concentration of 1,000 milligrams per liter.

The Dakota aquifer consists of the saturated sandstone and gravel units in the Dakota Formation. Isolated erosional remnants of the Dakota Formation form the caps of many bedrock ridges. The Dakota Formation is thickest where the bedrock surface is relatively high and flat, forming an ancient, buried, surface-water divide between southwest and southeast trending buried drainages in Audubon, Carroll, and Guthrie Counties. Sandstone thickness of as much as 150 feet exists in Guthrie County, but an average thickness of 30 feet is more

common. Water from wells less than 200 feet deep generally is a calcium bicarbonate type and has an average dissolved-solids concentration of 650 milligrams per liter. Water from wells more than 200 feet deep generally is a calcium sulfate or sodium bicarbonate type and has an average dissolved-solids concentrations of 2,200 milligrams per liter.

INTRODUCTION

West-central Iowa is an agricultural area where individuals, towns, and industries depend on ground water for a variety of uses, and an increasing number of farmers are looking for supplementary water supplies for crop irrigation when rainfall is not sufficient or not available at critical times. The demands for water supplies have prompted a need to better understand the ground-water resources. The west-central Iowa study area includes the following counties: Audubon, Carroll, Crawford, Greene, Guthrie, Harrison, Monona, and Shelby (fig. 1).

The four major ground-water sources in west-central Iowa are the alluvial, buried channel, basal Pleistocene, and Dakota aquifers. Where these aquifers are present, they are the first ground-water sources encountered during well construction. Water from deeper aquifers generally has an undesirable water quality, generally because of a larger dissolved-solids concentration.

The results of this investigation are published in three reports: a bedrock topography map of the study area (Hansen and Runkle, 1984), a data report that is a compilation of geologic and hydrologic data collected during the investigation (Hunt and Runkle, 1984), and this interpretive report that describes the ground-water resources. This project was a cooperative effort between the Geological Survey Bureau, Iowa Department of Natural Resources and the U.S. Geological Survey.

Purpose and Scope

The purpose of the investigation was to determine the availability, quantity, and quality of ground water from the alluvial, buried channel, basal Pleistocene, and Dakota aquifers in west-central Iowa. Specific objectives were to: (1) determine the location, areal extent, and nature of these aquifers; (2) evaluate the occurrence and movement of ground water, including the sources of recharge and discharge and causes of fluctuations of the water levels; (3) estimate the quantity of water stored in the aquifers; (4) estimate the potential yields to wells completed in the aquifers; (5) describe the chemical quality of the ground water; and (6) determine the water withdrawn from these aquifers for municipal purposes.

The Missouri alluvial aquifer is in the extreme western section of the study area labeled Missouri alluvial plain in figure 1. This aquifer was not included in this investigation.

Acknowledgments

The data collection for this project was made possible by the residents of west-central Iowa, municipal water superintendents, and county engineers. The author extends thanks to all well drillers who have voluntarily and faithfully provided sample cuttings and well information over the years to the Geological

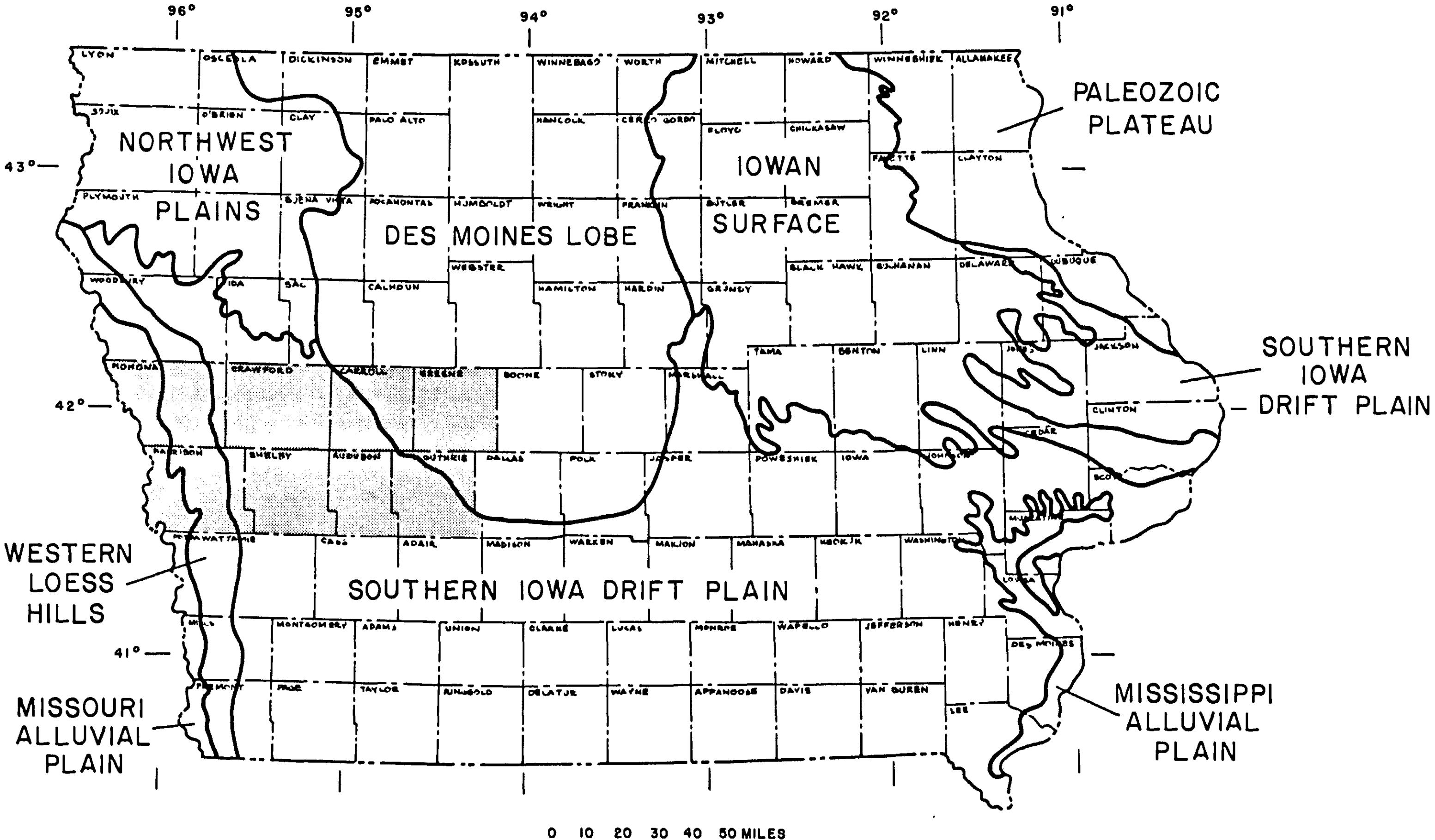

Figure 1.--Study area (shaded) and landform regions of Iowa (modified from Prior, 1976).

Survey Bureau and the U.S. Geological Survey. A special thanks to well drillers Leonard Bresnahan, Junior Hansen, John Iverson, Charles Jacobs, Mark Seitzinger, Russell Tell, and Wayne Tell, who provided the author with valuable information on the buried channel and Dakota aquifers in west-central Iowa. Recognition is due the following Geological Survey Bureau personnel: Darwin Evans and aide, Koby Kielhorn, for providing sample descriptions for the test holes and observation wells, Gregory Ludvigson for contributing to the interpretation of the geology of the study area, and Michael Bounk for analyzing and logging the sample cuttings from 241 test holes. Also thanks to personnel of the University of Iowa Hygienic Laboratory and the U.S. Environmental Protection Agency for analyzing water samples for this report and the Iowa Department of Natural Resources for municipal-water withdrawal information.

Well Location-Numbering System

The well location-numbering system used in this report is based on the system of land survey used by the U.S. Bureau of Land Management and the Iowa District of the U.S. Geological Survey. For example, in the well 84-37-15DABA, the first number indicates the township north of a base line, the second number indicates the range west of the fifth principal meridian, and the third number indicates the section in which the well is located. The letters A, B, C, and D designate the northeast, northwest, southwest, and southeast quarters of a section or quarters of any smaller square area of a section. The letters following the section numbers are in order of decreasing areal size from left to right. The first letter designates the 160-acre quarter, the second designates the 40-acre quarter, the third designates the 10-acre quarter and the fourth designates the 2½-acre quarter. For the example, well 84-37-15DABA is in the NE¼ of the NW¼ of the NE¼ of the SE¼ of section 15, in township 84 north and range 37 west (fig. 2).

General Hydrologic Concepts

The term hydrology encompasses the distribution, movement, and quality of water. The hydrologic cycle (fig. 3) is the circulation of water between the atmosphere, land, and surface-water features such as streams, lakes, and oceans. This cycle has no recognized beginning, but for descriptive purposes, the atmosphere is an adequate starting point. Precipitation enters the hydrologic cycle as rainfall or snow. Once precipitation falls on the land surface, it follows different pathways through the hydrologic cycle. Most of the water will evaporate, some will run off into streams, and the remainder will infiltrate into porous surface soil or rocks. Part of the water entering the ground will evaporate or will be used by plants, which then transpire it back to the atmosphere as water vapor. Any excess soil moisture infiltrates downward because of the force of gravity to the saturated soil or rock. The top of the saturated zone is called the water table. Ground water in the saturated zone moves through fractures and small openings between grains of soil and rock at a rate controlled by: (1) the hydraulic conductivity of the material the ground water is moving through and (2) the hydraulic gradient within or between aquifers. This movement usually is slow and may only be a few feet per year.

Hydraulic conductivity is a physical property used to express the ability of a material to transmit water. It is controlled, in part, by the size and connection of the openings in the material. Gravel, well-sorted sand, poorly

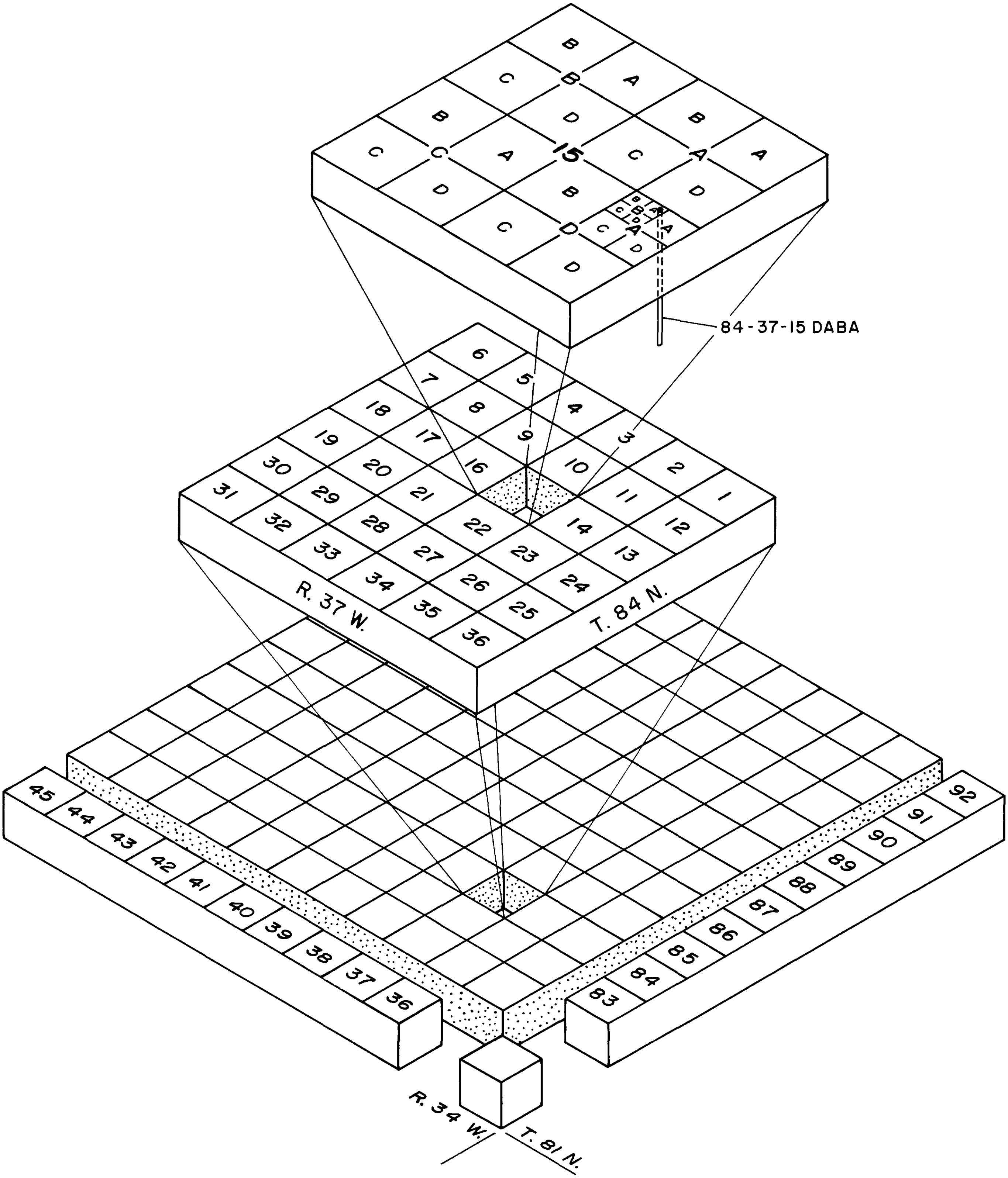

Figure 2.--Well location-numbering system.

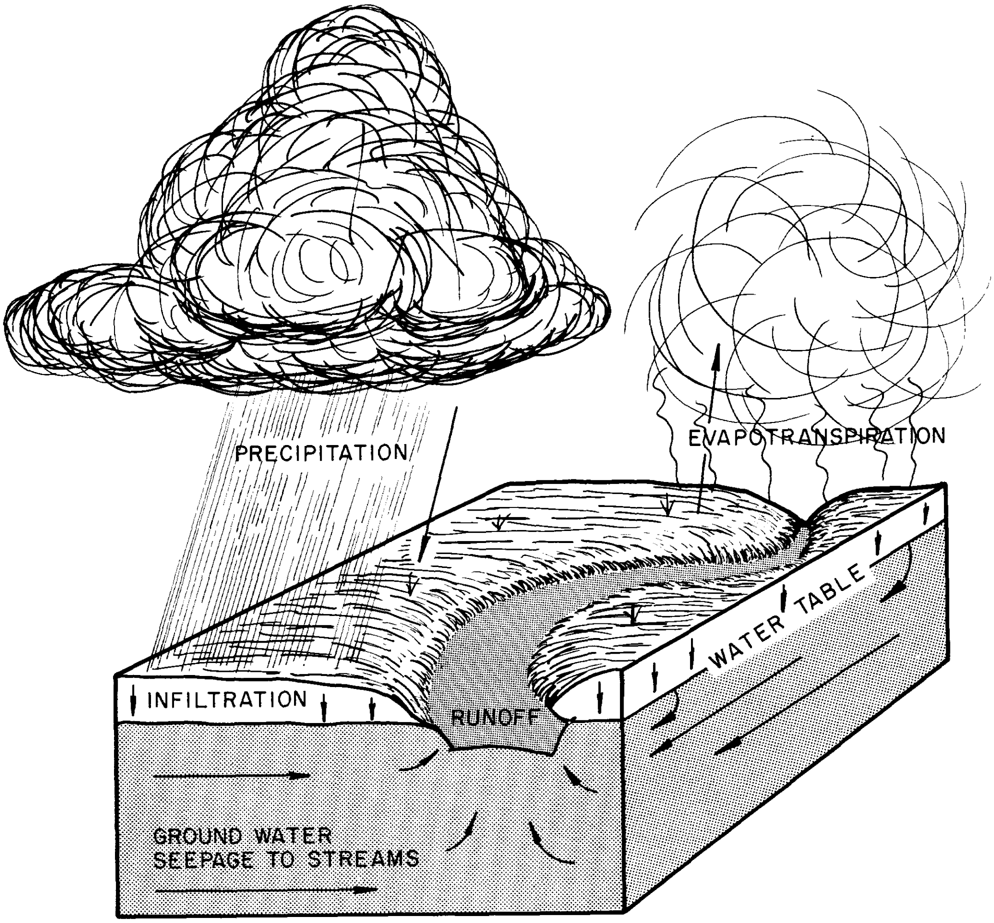

Figure 3.--The hydrologic cycle.

cemented sandstone, and fractured rocks generally have the largest values of hydraulic conductivity. These materials form aquifers. Cemented sandstone and fine-grained materials such as silt, clay, and shale usually have the smallest values of hydraulic conductivity and resist ground-water movement. These materials form confining units. The values of hydraulic conductivity, in ft/d (feet per day), of some typical material present in the study area are summarized in table 1. Transmissivity, a measure of the ability of an aquifer to transmit water through connected openings, is a product of the hydraulic conductivity and the aquifer thickness. Transmissivity is measured in ft^2/d (feet squared per day).

Aquifers overlain by confining units in which the water level in a well usually rises above the top of the aquifer are called artesian aquifers. The fluid pressure in an artesian aquifer when penetrated by a well has the potential to push water above the top of the aquifer. The hydraulic head, or water-level altitude, of an artesian aquifer is called the potentiometric surface. In a water-table aquifer, the water table forms the upper boundary of the aquifer. The water table is in equilibrium with atmospheric pressure. Artesian aquifers generally occur at depth, and the water-table aquifers generally occur near the land surface.

The hydraulic gradient refers to the slope of the water-level surface between two points. The overall movement of ground water is from an area of high hydraulic head to an area of low hydraulic head. The most common method used to evaluate hydraulic gradients is to measure water levels in wells that penetrate the aquifer or aquifers of interest. Then water-level altitudes can be contoured on a map and flow lines drawn to show the direction of ground-water movement. The hydraulic gradient can be calculated by dividing the hydraulic-head difference between two points by the distance between those two points.

The hydraulic gradient may be a steep or almost vertical slope, as between two separate, horizontal aquifers (one aquifer above the other) or a slight or almost horizontal slope, as between two points within the same aquifer. The steeper the gradient, the greater the potential is for flow to the points of lower hydraulic head, assuming uniform hydraulic conductivity.

The water level in an aquifer fluctuates in response to recharge to and discharge from an aquifer, usually indicating a change in the volume of water stored in the aquifer. Water-table aquifers near the land surface are recharged by excess soil moisture. Most recharge to the aquifers in the study area normally occurs in the spring and sometimes in the fall, and usually is sufficient to replace water losses caused by pumping wells or natural ground-water movement. Artesian aquifers generally are recharged by leakage through the overlying or underlying confining material or through a recharge area exposed at the land surface.

The potential yield, as used in this report, is an estimate of the quantity of water that can be pumped from an 100 percent efficient well penetrating the total thickness of the aquifer under ideal conditions. The quantity that can be pumped will vary with the available drawdown in the pumping well. The potential yield in this report was calculated using a graph shown in figure 4 (Meyer, 1963) relating well diameter, specific capacity, storage coefficient or specific

Table 1.--Hydraulic conductivity of selected materials

[modified from Freeze and Cherry, 1979]

Material	Hydraulic conductivity (feet per day)
Glacial till	0.000005 to 1
Silt, loess	.005 to 15
Silty sand	.05 to 800
Clean sand	1 to 8,000
Gravel	675 to 800,000

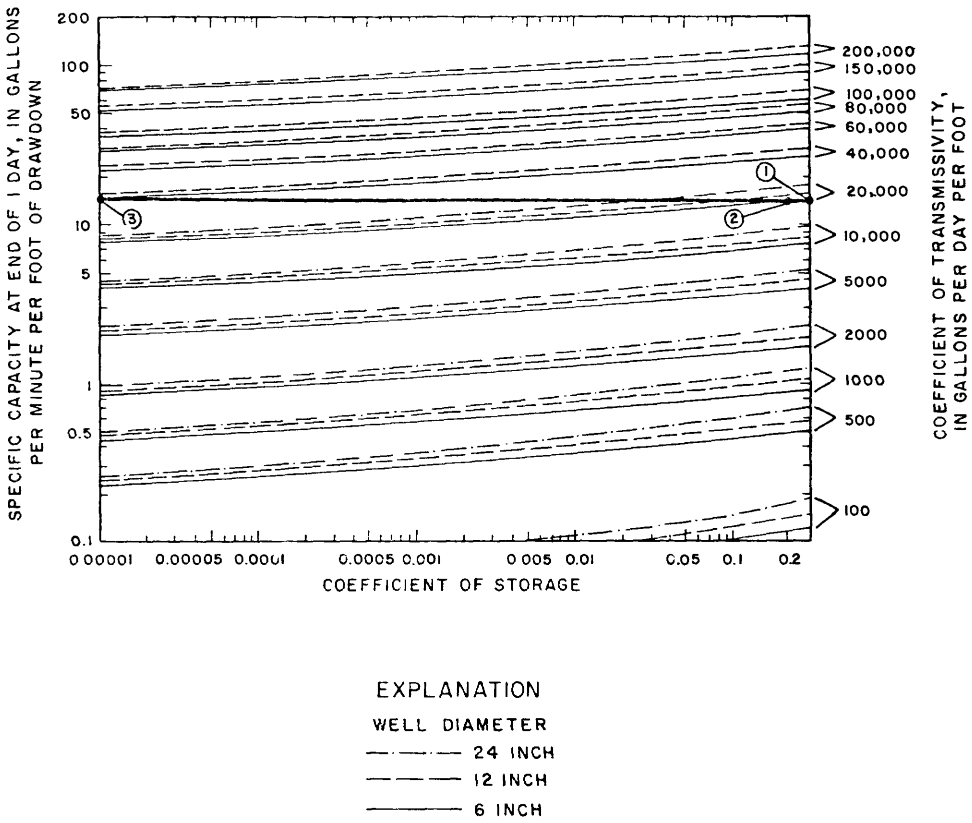

Figure 4.--Relation of well diameter, specific capacity, and coefficients of transmissivity and storage (modified from Meyer, 1963).

yield, and transmissivity. Specific capacity is defined as the pumping rate per unit of water-level drawdown in units of (gal/min)/ft (gallons per minute per foot) of drawdown. A well diameter of 6 inches was used to estimate potential well yield from this graph.

For an artesian aquifer, the storage coefficient is a dimensionless property of an aquifer that reflects the quantity of water that is released from or added to storage per unit surface area of aquifer, per unit hydraulic-head change. In water-table aquifers, the storage coefficient virtually is equivalent to the specific yield. For water-table aquifers, the water level rises or declines with the changes in the volume of water in storage. As the water level declines, water drains from the pore spaces. This release from storage is proportional to the specific yield of the aquifer material. The average specific yields for some materials are summarized in table 2. If transmissivity and storage can be estimated, then the specific capacity can be read off the graph (Meyer, 1963). Once the specific capacity is known, the potential yield of a well can be calculated by multiplying the specific capacity by the drawdown. In this report the estimated potential yield for the alluvial aquifer is equal to the specific capacity because 1 foot of drawdown was used. A drawdown of 20 feet was used to estimate the potential yield from the buried channel and Dakota aquifers.

An example of how to use the graph in figure 4 to obtain the potential well yield is described below. Well 82-40-08BBBB, completed in the Boyer aquifer in Crawford County (plate 1), has a sand and gravel thickness of 27 feet. The potential yield for this well is determined by: (1) multiplying the thickness by 100 ft/d, the average hydraulic conductivity for the Boyer aquifer, to obtain a transmissivity of 2,700 ft^2/d; (2) the graph in figure 4 has transmissivity in (gal/d)/ft (gallons per day per foot) units. To convert the units from ft^2/d to (gal/d)ft, multiply by 7.48 gal/ft^3 (gallons per cubic foot). For the example, multiply the transmissivity of 2,700 ft^2/d by 7.48 gal/ft^3 to get 20,196 (gal/d)/ft; (3) using the graph in figure 4, locate 20,196 (gal/d)/ft on the right side of the graph labeled with a circled 1, and, using the 6-inch-well-diameter curve, follow the curve to where it intersects the coefficient of storage for 0.2 (the specific yield for the Boyer aquifer). This intersection is labeled with a circled 2; (4) then a straight line from the circled 2 to the left side of the graph is drawn to obtain the specific capacity for this well. The specific capacity for this well is about 14 (gal/min)/ft, which is labeled on the graph by a circled 3; and (5) the final step is to multiply the specific capacity by an acceptable drawdown (1 foot of drawdown was used for the Boyer aquifer and other alluvial aquifers) to obtain the potential well yield. The potential yield for this well is 14 gal/min (gallons per minute).

An estimate of the volume of water available from ground-water storage, assuming gravity drainage under water-table conditions, is calculated by multiplying the areal extent, average saturated thickness, and specific yield of the aquifer. An estimate of the volume of water available from an artesian aquifer is calculated by multiplying the areal extent, the average water-level drawdown to the altitude of the top of the aquifer, and storage coefficient of the aquifer.

Throughout the study area, marshes, lakes, ponds, and rivers are hydrologically connected with aquifers. The aquifers may either receive recharge from the surface-water sources or discharge ground water into them, depending on their hydraulic-head relations, which vary with time.

Table 2.--Specific yield of selected materials

[modified from Freeze and Cherry, 1979]

Material	Average specific yield (percent)
Clay	2
Sandy clay	7
Silt	18
Fine sand	21
Medium sand	26
Coarse sand	27
Gravelly sand	25
Fine gravel	25
Medium gravel	23
Coarse gravel	22

Ground water contains varying concentrations of dissolved mineral matter. Water dissolves mineral matter as it infiltrates through the soil and rock. The concentration and kind of dissolved mineral matter in water depends on the kind and proportions of minerals that comprise the soil and rocks. The solubility of the porous media, the pressure and temperature of the water, and the concentration of acids and gases, specifically carbon dioxide, affect proportions of dissolved materials. Ground water that has been in transit or storage a long time or has moved a long distance from a recharge area usually is more mineralized than water that has been in transit for only a short time.

The suitability of water for various uses is determined, in part, by its physical properties, the concentration and kind of dissolved material it contains, and its esthetic characteristics. The physical properties, chemical constituents, and esthetic characteristics most often mentioned are pH, temperature, specific conductance, sodium-absorption-ratio, dissolved solids, sodium, iron, manganese, nitrate, sulfate, hardness, odor, and taste.

Drinking-water standards have been established by the U.S. Environmental Protection Agency. Primary and secondary drinking-water standards (table 3) apply only to public-water supplies. Primary standards pertain to constituents and regulations affecting the health of consumers and are enforceable by the U.S. Environmental Protection Agency or the State that has accepted the primary standards. Secondary standards refer to the esthetic qualities of drinking water intended as a guideline for the State. The chemical analyses of water samples collected from the aquifers in this project can be found in Hunt and Runkle (1984).

The dissolved-solids concentration is a measure of the mineralization of the water. The dissolved-solids concentration is significant because it may limit the use of water for many purposes. In general, the suitability of water for most uses decreases with an increase in dissolved-solids concentration. Water with a dissolved-solid concentration of less than 1,000 mg/L (milligrams per liter) is considered fresh; from 1,000 to 3,000 mg/L is considered slightly saline; and from 3,000 to 10,000 mg/L is moderately saline. Specific conductance can be used as an indirect measure of the salinity or dissolved-solids concentration.

Hardness does not seriously affect the use of water for most purposes, but it does decrease the effectiveness of soap. Hardness removal by a softening process increases the suitability of the water for washing clothes and some industrial purposes. The classification of hardness (Durfor and Becker, 1964) used in this report is listed below:

Calcium and magnesium, as calcium carbonate, (milligrams per liter)	Hardness designation
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Table 3.--Drinking-water standards for community water systems

[mg/L, milligrams per liter; μg/L, micrograms per liter; pCi/L, picocuries per liter; --, no standard determined]

Property or constituent	Maximum contaminant levels in community water supplies	
	Primary regulations[a]	Secondary regulations[b]
pH, in standard units	--	6.5 - 8.5
Dissolved solids	--	500 mg/L
Chloride	--	250 mg/L
Flouride	2.4 mg/L	--
Sulfate	--	250 mg/L
Nitrate as nitrogen	10 mg/L	--
Arsenic	50 μg/L	--
Barium	1,000 μg/L	--
Cadmium	10 μg/L	--
Chromium	50 μg/L	--
Copper	--	1,000 μg/L
Iron	--	300 mg/L
Lead	50 μg/L	--
Manganese	--	50 mg/L
Mercury	2 μg/L	--
Selenium	10 μg/L	--
Silver	50 μg/L	--
Zinc	--	5,000 μg/L
Radium (radium-226 and radium-228 combined)	5 pCi/L	--
Gross-alpha activity (including radium-226 but excluding radon and uranium)	15 pCi/L	--
Gross-beta activity as cesium-137	[c]200 pCi/L	--

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[a] U.S. Environmental Protection Agency, 1983.
[b] U.S. Environmental Protection Agency, 1977.
[c] Annual average concentrations yielding 4 millirem per year for a 2-liter daily intake (U.S. Department of Commerce, 1963).

Large nitrate concentrations are a concern in some shallow ground-water supplies in west-central Iowa. The occurrence of large nitrate concentrations in shallow ground-water aquifers has been attributed to runoff from feedlots, effluent from septic tanks, or leaching of fertilizer from fields where nitrogen compounds have been applied. Large nitrate concentrations are undesirable in drinking water because they can cause methemoglobenemia (blue-baby disease) in infants. Methemoglobenemia is a condition where a large concentration of nitrate can decrease the oxygen capacity of the infant's blood.

In this report references are made to ground-water types such as calcium bicarbonate or sodium sulfate. These types are derived from the dominant cation (calcium, magnesium, or sodium) and anion (bicarbonate, sulfate, or chloride) expressed in milliequivalents per liter. The water type or types for each aquifer for which water-quality information is available are represented by a Piper diagram found in the section describing the aquifer of interest. The Piper diagram is made up of two triangular plots and a diamond plot. One triangle represents the cation content (sodium plus potassium, magnesium, and calcium) in a water sample and the other triangle represents the anion content (bicarbonate plus carbonate, sulfate, and chloride) in a water sample, where the ions are expressed in percentage of total milliequivalents per liter. The percentage of sodium plus potassium, sulfate plus chloride, calcium plus magnesium, and bicarbonate plus carbonate is transferred to the diamond plot. The Piper diagram can be a useful tool in water-analyses interpretation and comparing water types in an aquifer or water types in different aquifers.

Water samples were analyzed to describe the chemical constituents typically detected in the water from each aquifer. When primary or secondary regulations (table 3) were exceeded in a water sample, the excess chemical constituents and concentrations are noted.

Two significant factors used to assess the suitability of water for irrigation are the sodium-adsorption-ratio (SAR) and specific conductance. SAR can be used to approximate the sodium hazard, and specific conductance to approximate the salinity hazard. The hazards increase as the numerical values of the SAR and specific conductance increase. Irrigation-classification diagrams for water in aquifers having large SAR values and a high salinity hazard can be found in the section of this report describing the aquifer of interest. The U.S. Department of Agriculture Salinity Laboratory (U.S. Salinity Staff, 1954) defined SAR of a water as

$$\frac{(\mathrm{Na}^{+})}{[(\mathrm{Ca}^{+2}) + (\mathrm{Mg}^{+2})]/2^{\frac{1}{2}}}$$

where ion concentrations are expressed in milliequivalents per liter.

SAR can be used to predict the degree to which irrigation water is susceptible to cation-exchange reactions in soil. SAR was developed for the neutral and alkaline soils of arid and semiarid areas. Humid areas, like Iowa, generally have acidic soils and contain more clay minerals that have a smaller exchange capacity than soils of arid and semiarid regions (National Academy of Sciences-National Academy of Engineering, 1972). SAR values cannot be applied to humid regions without consideration of the pH and mineralogy of the soil. Large SAR values indicate there is danger of sodium replacing calcium and magnesium, and this replacement can be damaging to soil structure.

Climatic differences between arid and humid regions also affect the criteria for use of irrigation water. The quantity of precipitation determines, in part, the degree to which a given constituent will accumulate in the soil. In humid areas, evapotranspiration generally is less than in arid regions, and plants are not as susceptible to water stress. In general, criteria regarding salinity for irrigation in humid areas can be more flexible than for arid areas. The individual SAR and salinity-hazard irrigation classifications (U.S. Salinity Laboratory Staff, 1954) are described as follows:

SAR classifications:

Low-sodium water (S1) can be used for irrigation on almost all soils with small danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees may accumulate hazardous concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having a large cation-exchange capacity, especially under minimal leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with substantial permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management, such as adequate drainage, adequate leaching, and additions of organic matter. Soils with a large gypsum content may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes, except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Salinity classifications:

Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely minimal permeability.

Medium-salinity water (C2) can be used if a moderate quantity of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with a large salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and extremely salt-tolerant crops should be selected.

Further information regarding sodium and salinity hazards may be found in a report about alkaline soils by the U.S. Salinity Laboratory Staff (1954). Further information regarding the use of the irrigation classification system in humid areas may be found in a report by the National Academy of Sciences-National Academy of Engineering (1972).

AVAILABILITY AND QUALITY OF GROUND WATER

Geohydrologic Setting

The four landform regions in west-central Iowa are the Des Moines Lobe, Southern Iowa Drift Plain, Western Loess Hills, and Missouri Alluvial Plain (fig. 1; Prior, 1976). The Des Moines Lobe is a feature in the northeast corner of the study area that was formed by the last glacial advance into Iowa. This area is characterized by inadequate drainage, knob and kettle terrain, and lack of loess cover. Numerous ponds and marshes are in low areas between knobs and have no drainage outlets. Small streams in the more level areas are shallow and slow-moving and meander without appearing to have any direction. The few large rivers that drain this region have eroded deep valleys and have sand and gravel terraces on the valley sides. The Southern Iowa Drift Plain, in the central part of the study area, is the most common landform region in west-central Iowa. This region is characterized by rolling hills and valleys and well-established drainage patterns. The Western Loess Hills region is a narrow zone in the western part of the study area. This region has unusual wind-carried loess deposits that form sharp-featured hills with narrow ridge crests and steep-sided slopes that stand out in relief against the Southern Iowa Drift Plain to the east and the Missouri Alluvial Plain to the west.

Surficial materials are comprised of unconsolidated deposits of Quaternary age. These deposits can be divided into three types: alluvium, loess, and glacial till. Alluvium consists of permeable sand and gravel interbedded with less permeable clay and silt. Alluvium is water-deposited material in flood plains along streams and rivers. Alluvial aquifers are a frequently used source of ground water in the area. Loess, a wind-deposited material, is comprised of clay, silt, and fine sand that often has a distinctive yellow-brown color. Thick deposits of loess can form a minor aquifer, but more commonly it is a leaky confining material. Till, deposited by glaciers, is a mixture of clay, silt, sand, gravel, and boulders whose total thickness can be as much as 500 feet in west-central Iowa. Glacial till generally is a confining material, although aquifers underlain by till can be recharged slowly by leakage through the till.

Some significant sand and gravel deposits are in buried bedrock channels. The sand and gravel in the buried channels were deposited by ancient streams that flowed before, during, or between glacial advances. These buried channel deposits are overlain by glacial till in the study area. Locally these buried channel deposits are productive aquifers. A basal Pleistocene aquifer consisting of sand or sand and gravel is on many of the buried bedrock ridges between buried channels in parts of west-central Iowa. Water from this aquifer is often used for domestic and livestock purposes in Audubon, Carroll, Crawford, Harrison, Monona, and Shelby Counties.

The Dakota Formation consists of sandstone, shale, and gravel of Cretaceous age. The Dakota is underlain by Pennsylvanian rocks and usually is overlain by Quaternary deposits. Two members of the Dakota Formation have been recognized in Iowa. The Woodbury Member (White, 1870a, 1870b; Munter and others, 1983) consists of interbedded shale and sandstone and locally is an aquifer where the sandstone units are connected, although it usually is a confining unit where the shale beds are the principal rock. The maximum measured thickness of the Woodbury Member in west-central Iowa is 192 feet. The Nishnabotna Member underlies the Woodbury and is a fine- to coarse-grained, poorly cemented sandstone interbedded with gravel and thin shale units. The maximum measured thickness of the Nishnabotna sandstone and gravel in west-central Iowa is 150 feet. The thickest sandstone and gravel units are in Carroll and Guthrie Counties. The Nishnabotna Member is the major aquifer in the Dakota Formation. Many surface exposures of the Dakota Formation are along the South Raccoon River, Middle Raccoon River, and Brushy Creek in Guthrie County (Witzke and Ludvigson, 1982).

The Pennsylvanian rock generally form a regional confining unit and are mostly shale, with some thin interbedded sandstone, limestone, and coal units. However, in eastern Greene and northern Guthrie Counties, a fine-grained sandstone unit reaches a thickness of 115 feet, and some towns in these counties obtain their water from the Pennsylvanian sandstone. Geohydrologic units in west-central Iowa are summarized in table 4.

The configuration of the bedrock surface, which in west-central Iowa consists of the Dakota Formation and undifferentiated Pennsylvanian rocks, is shown in figure 5. This map illustrates the buried bedrock channels and ridges of the ancient drainage systems. When used in conjunction with surface topography maps, the depth to the base of buried channel and basal Pleistocene aquifers and the top of bedrock can be estimated.

Alluvial Aquifers

Alluvial deposits occur beneath and adjacent to most of the present streams and river valleys in the project area. Logs of test holes and municipal and private wells indicate that these deposits consist of clay, silt, sand, gravel, and often combinations of these materials. The thickness of these deposits ranges from 3 to 96 feet in 173 wells and test holes. The typical distribution of material encountered in these river valleys is an average thickness of 18 feet of sand and gravel. Significant alluvial aquifers occur in the Little Sioux, Maple, Soldier, Boyer, West Nishnabotna, East Nishnabotna, South Raccoon, Middle Raccoon, and North Raccoon River valleys (plate 1). For convenience of discussion, identification, and future reference, the aquifers were given the name of the adjacent river, for example, the Little Sioux aquifer.

Geohydrologic sections are included in the discussion of each of the alluvial aquifers that show the aquifer thickness, geometry, location of associated terrace deposits, configuration of the water table, and underlying material for each aquifer (plate 1). Terraces are remnants of earlier alluvial deposits that have been incised by the present river channel. The hydrologic connection between terrace deposits and alluvial aquifer is not always known.

Table 4.--Geohydrologic units in west-central Iowa

[modified from Munter and others, 1983]

Era	System	Stratigraphic Unit		Description
CENOZOIC	QUATERNARY	Alluvial		Water-deposited sand and gravel interbedded with clay and silt in floodplains along streams and rivers. Deposits are up to 96 feet thick.
		Loess		Wind-deposited silt, clay, and fine sand that mantles the uplands and terraces. Can be a minor aquifer but most commonly forms a leaky confining unit. Thickest along the eastern Missouri River bluff.
		PLEISTOCENE	Glacial till	Glacial till comprised of poorly sorted clay, silt, sand, gravel, and boulders. Typically forms a regional confining unit and can be 500 feet thick.
				Sand, sand and gravel, or gravel units beneath glacial till in buried bedrock channels. Known to range from 1 foot to 170 feet thick in test holes and wells.
			-?-?-?-?-?-?- Basal aquifer	Sand, sand and gravel, or gravel units on buried bedrock ridges. Known to range from 1 foot to 104 feet thick in test holes and wells.
MESOZOIC	CRETACEOUS	DAKOTA FORMATION	Woodbury Member	Consists of thin beds of interbedded shale and sandstone that form a minor aquifer when sandstone beds are connected and a confining unit when shales are thick. This unit in test holes and wells is known to be 192 feet thick.
			Nishnabotna Member	Consists of shale and poorly cemented, fine- to coarse-grained sandstone. Occasionally fine- to coarse-gravel beds or iron-cemented conglomerate is at the base. Ranges from 1 foot to more than 146 feet thick with the thickest sandstone units in Carroll and Guthrie Counties. Surface exposures are abundant along the South Raccoon River, the Middle Raccoon River, and Brushy Creek in Guthrie county. Is a major aquifer when present.
PALEOZOIC	PENNSYLVANIAN	Undifferentiated rocks		Generally is a regional confining unit comprised of mostly shale interbedded with fine-grained sandstone, limestone, and coal. In Greene and northern Guthrie Counties, 115-foot-thick sandstone beds have been found.

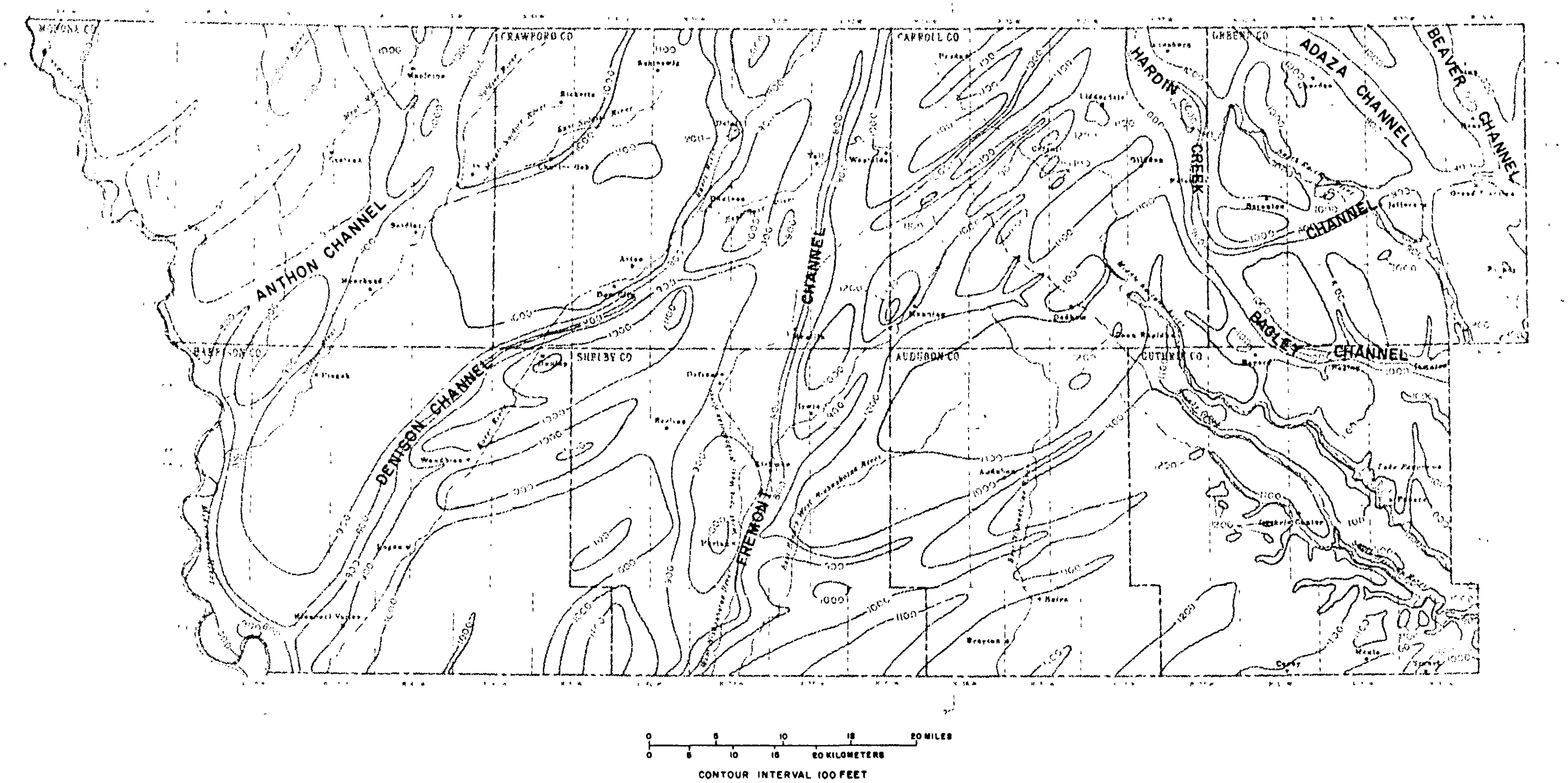


Figure 5.--Bedrock topography map of west-central Iowa.

Recharge to the alluvial aquifer is from infiltration through soils and during periods of high streamflow that usually occur each spring. Water is discharged from the alluvial aquifers to the adjacent river during periods of low streamflow. Recharge and discharge relations may be more complex when other aquifers underlie or are adjacent to the alluvial aquifers. Water-level fluctuations have been plotted for each aquifer. Evaporation, river discharge, and precipitation were graphed where data were available. In general, the quantity of runoff in relation to precipitation usually is largest in the late winter and early spring when the ground often is either saturated or frozen. Water levels in the alluvial aquifers usually rise during the spring because precipitation is recharging the aquifer. Runoff and recharge to alluvial aquifers usually decrease considerably in the summer as evapotranspiration increases. Water levels in the alluvial aquifers usually decline during the summer because of ground-water losses through evapotranspiration and discharge to streams. Water levels contoured on plate 1 were measured August 1, 2, or 3, 1983. Water from alluvial aquifers also is discharged through pumping wells. Many municipal wells and a few irrigation wells are completed in the alluvial aquifers in west-central Iowa.

Where sufficient data are available, an estimate of the quantity of ground water available from storage is given. Estimates, in acre-feet, are products of areal extent, average saturated thickness, and specific yield. These estimates are based on static conditions and do not consider recharge, natural discharge, or ground-water movement.

For this study, estimates of the value of transmissivity of each alluvial aquifer were determined by estimating the hydraulic conductivity of the aquifer from geologic and drillers' logs and multiplying this by the average sand and gravel thickness of the aquifer. The estimates are valid only for the site of the logged hole, but because of the number of data points, an average can be used. The silty clay was not used in the estimates of the transmissivity because the hydraulic conductivity is much smaller than that of the sand and gravel.

The estimated potential yield to properly constructed wells in these aquifers is shown on plate 1. The potential yield was calculated using the graph shown in figure 4. Potential yield in all the alluvial aquifers was determined to be less than 50 gal/min. Larger well yields are possible if more than 1 foot of drawdown is acceptable. The yield can be multiplied by the drawdown to obtain a different potential yield. The largest well yields can be obtained only by developing and screening the thickest section of the aquifer.

Water-quality information is illustrated with Piper diagrams for each aquifer. As described earlier, these diagrams can be used to help compare water from one aquifer with water from another.

Municipal-water withdrawals from the alluvial aquifers during 1980 are shown on plate 1 and in table 5. Data were collected from municipal-water superintendents and the Iowa Department of Water, Air, and Waste Management files (Buchmiller and Karsten, 1983).

Table 5.--Municipal-water withdrawal from alluvial, buried channel, basal Pleistocene, and Dakota aquifers in west-central Iowa, in 1980

Town	Water withdrawn (in millions of gallons per year)	Aquifer
Castana	[a]7.3	Maple aquifer
Mapleton	[a]70.7	Maple aquifer
Charter Oak	28.8	Soldier aquifer
Moorhead	[a]9.1	Soldier aquifer
Ricketts	3.6	Soldier aquifer
Ute	[a]20.0	Soldier aquifer
Pisgah	11.4	About 50 percent from Soldier aquifer and 50 percent from the basal Pliestocene aquifer
Arion	3.5	Boyer aquifer
Deloit	18.0	Boyer aquifer
Denison	479.8	Boyer aquifer
Dow City	24.9	Boyer aquifer
Dunlap	61.9	Boyer aquifer
Logan	80.1	Boyer aquifer
Missouri Valley	161.4	Boyer aquifer
Vail	12.1	Boyer aquifer
Westside	[a]15.3	Boyer aquifer
Defiance	14.1	West Nishnabotna aquifer
Harlan	252.9	West Nishnabotna aquifer
Irwin	17.7	West Nishnabotna aquifer
Kirkman	2.0	West Nishnabotna aquifer
Manilla	38.4	West Nishnabotna aquifer
Manning	68.4	West Nishnabotna aquifer
Audubon	131.3	East Nishnabotna aquifer
Brayton	4.1	East Nishnabotna aquifer
Exira	45.8	East Nishnabotna aquifer
Dedham	[a]12.0	South Raccoon aquifer
Guthrie Center	81.6	About 50 percent from the South Raccoon aquifer and 50 percent from the Dakota aquifer
Carroll	456.4	About 50 percent from the Middle Raccoon aquifer and 50 percent from the Dakota aquifer
Jefferson	208.8	Hardin Creek aquifer
Ralston	5.6	Hardin Creek aquifer
Scranton	36.4	Hardin Creek aquifer

Table 5.--Municipal-water withdrawal from alluvial, buried channel, basal Pleistocene, and Dakota aquifers in west-central Iowa, in 1980--Continued

Town	Water withdrawn (in millions of gallons per year)	Aquifer
Dana	[a]1.4	Beaver aquifer
Bagley	13.1	Bagley aquifer
Churdan	21.6	Basal Pleistocene aquifer
Rippey	10.6	Basal Pleistocene aquifer
Coon Rapids	55.9	About 92 percent from the basal Pleistocene aquifer and 8 percent from the Dakota aquifer
Breda	43.7	Dakota aquifer
Glidden	45.0	Dakota aquifer
Lanesboro	[a]5.7	Dakota aquifer
Lidderdale	3.3	Dakota aquifer
Woodbine	50.5	Dakota aquifer

[a] Indicates that water withdrawn was estimated based on town population because water-use records were not available.

Little Sioux Aquifer

The Little Sioux aquifer within the study area is 1.75 to 2.5 miles wide and has an areal extent of about 17 square miles in northern Monona County (plate 1). Data from four test holes drilled across the valley indicate that the aquifer consists of 26 to 42 feet of silty clay underlain by 9 to 31 feet of sand and gravel (geohydrologic section A-A', fig. 6). The sand and gravel part of the aquifer has an average thickness of about 19 feet. Based on test-hole information, the thickest and probably most productive areas are east of the Little Sioux River channel. Terrace deposits consisting of sand or sand and gravel exist on both sides of the aquifer. The terrace deposits are separated from the Little Sioux aquifer by 10 to 20 feet of glacial till and are not hydraulically connected to the aquifer.

The Little Sioux aquifer is underlain and hydraulically connected to the Dakota aquifer as shown in figure 6. In these areas, wells pumping from one or both aquifers virtually are lowering the water levels in both aquifers. Water levels in Dakota aquifer wells are slightly higher than the water levels in nearby Little Sioux aquifer wells, indicating the Dakota aquifer is discharging into the Little Sioux aquifer. The Little Sioux aquifer also is recharged by infiltration of precipitation. Water flowing in the river during low-flow periods probably is provided by water discharging from the Little Sioux aquifer.

Based on an areal extent of 17 square miles, an average thickness of 19 feet, and a specific yield of 25 percent, about 52,000 acre-feet of ground water are available to wells from storage in the Little Sioux aquifer. Transmissivity is estimated to be about 2,600 ft^2/d using an average aquifer thickness of 19 feet and estimated aquifer hydraulic conductivity of 135 ft/d. Estimated yield to wells, assuming that 1 foot of drawdown is possible, is less than 50 gal/min (plate 1).

Analysis of one water sample from the Little Sioux aquifer from well 85-44-16DCDD indicates that the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 7). Dissolved-solids concentration was 306 mg/L and manganese exceeded the recommended 50 ug/L (micrograms per liter) secondary drinking-water standard with a concentration of 420 ug/L.

Three wells, 85-44-16CDAA, 85-44-17DCAA, and 85-44-22ADAA (fig. 6), are completed in the underlying Dakota aquifer. Analyses of water samples from these wells indicate that water from the Dakota aquifer in this area is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 8). However, in well 85-44-22ADAA, sodium was the significant secondary cation, sulfate the significant secondary anion, and the water has twice the dissolved-solids concentration. The reason for this water-type difference within the Dakota aquifer is that the lower sandstone unit well 85-44-22ADAA is completed in is separated from the upper sandstone unit and the Little Sioux aquifer by at least 25 feet of shale, which hinders mixing of water between the sandstone units (fig. 6). The water levels of the upper and lower sandstone units are virtually the same, indicating they are in equilibrium with one another.

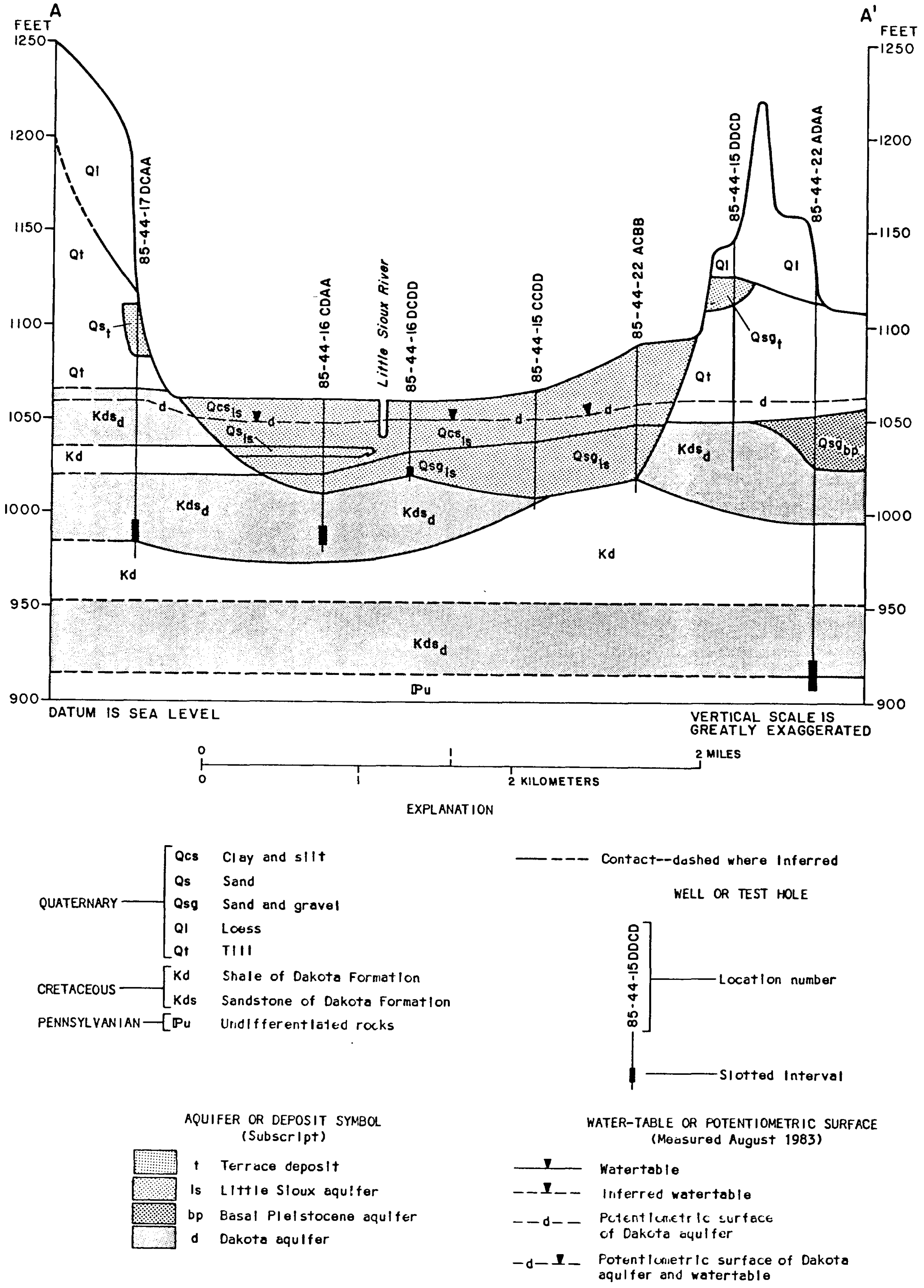
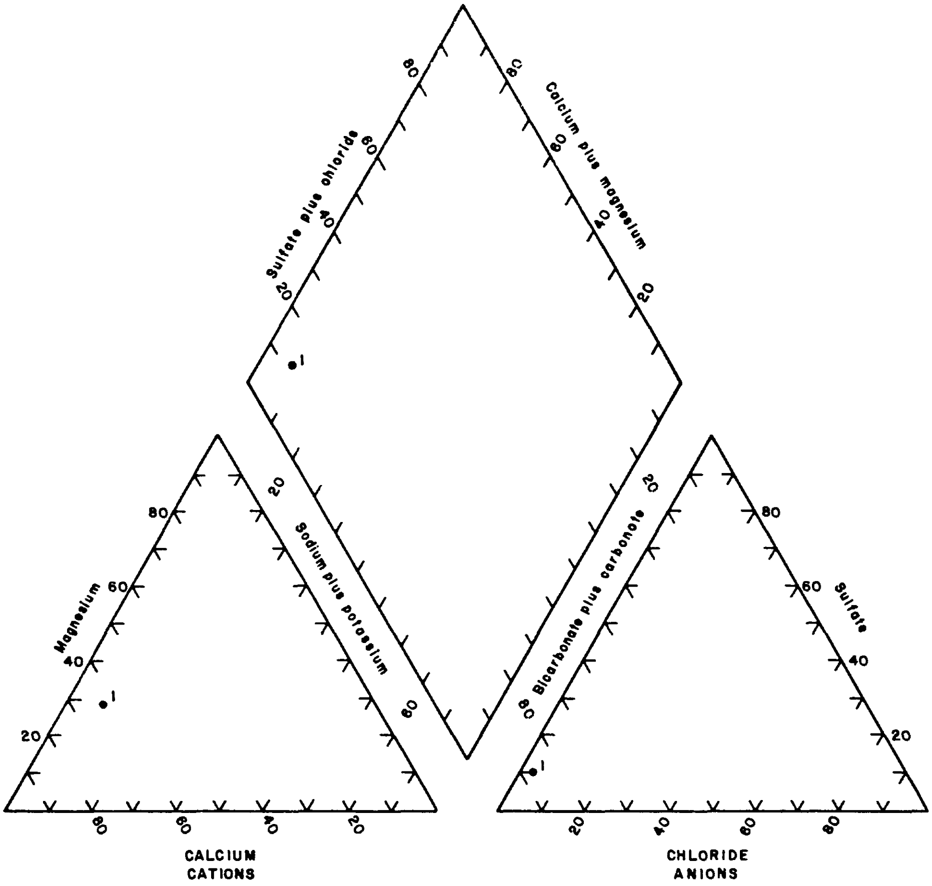


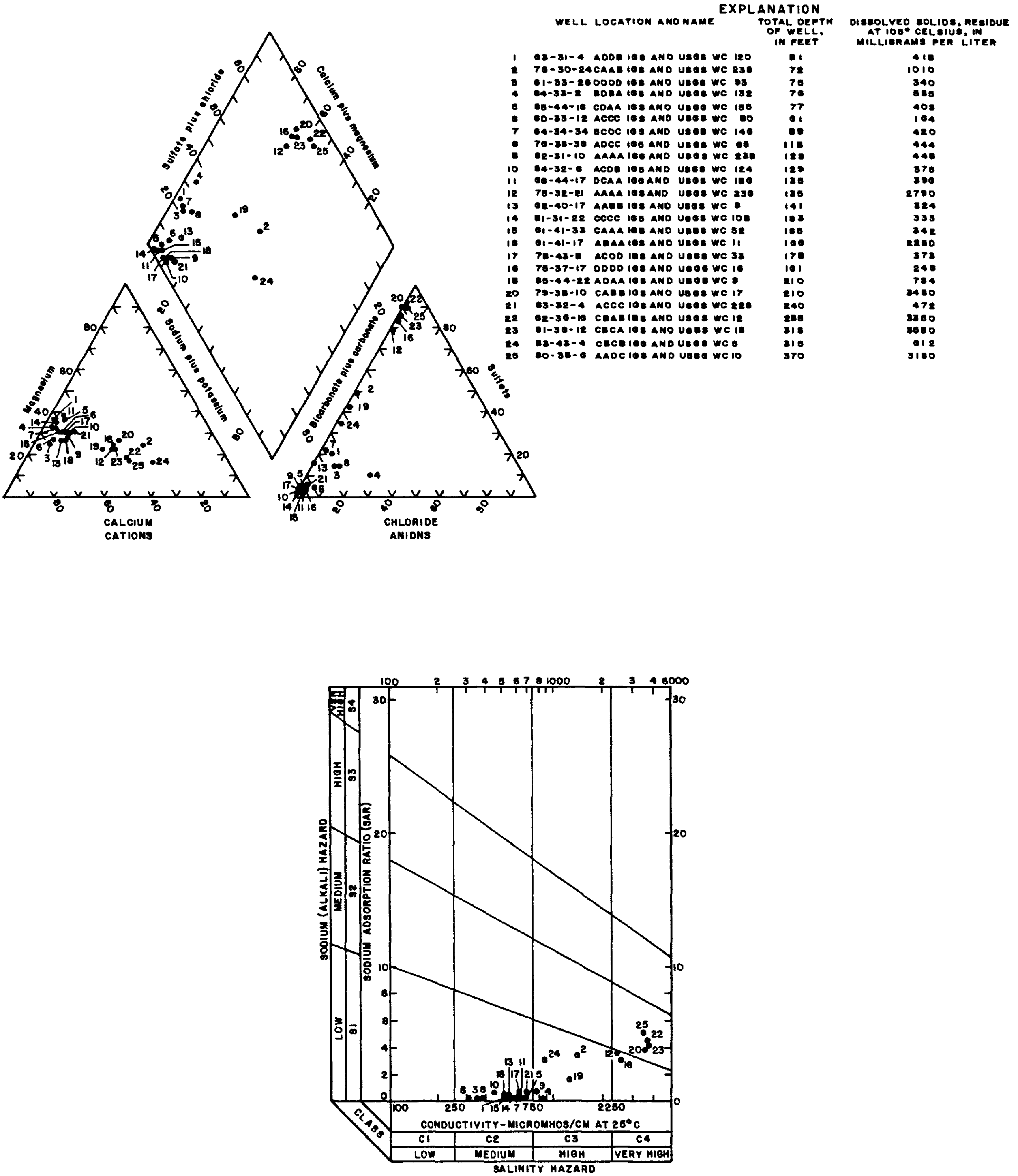
Figure 6.--Geohydrologic section A-A' of the Little Sioux, basal Pleistocene and Dakota aquifers.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	85-44-16 DCDD IGS AND USGS WC 156	40	306

Figure 7.--Piper diagram of water quality in the Little Sioux aquifer.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	83-31-4 ADDB IGS AND USGS WC 120	81	418
2	76-30-24CAAB IGS AND USGS WC 238	72	1010
3	61-33-26DDDD IGS AND USGS WC 93	75	340
4	84-33-2 BDBA IGS AND USGS WC 132	76	585
5	85-44-16 CDAA IGS AND USGS WC 155	77	408
6	80-33-12 ACCC IGS AND USGS WC 80	81	164
7	84-34-34 BCDC IGS AND USGS WC 146	89	420
8	76-38-36 ADCC IGS AND USGS WC 65	118	444
9	82-31-10 AAAA IGS AND USGS WC 238	128	448
10	84-32-6 ACDB IGS AND USGS WC 124	129	375
11	86-44-17 DCAA IGS AND USGS WC 186	135	396
12	75-32-21 AAAA IGS AND USGS WC 236	135	2790
13	82-40-17 AABB IGS AND USGS WC 8	141	324
14	81-31-22 CCCC IGS AND USGS WC 108	183	333
15	81-41-33 CAAA IGS AND USGS WC 52	185	342
16	81-41-17 ABAA IGS AND USGS WC 11	166	2250
17	78-43-8 ACDD IGS AND USGS WC 33	178	373
18	75-37-17 DDDD IGS AND USGS WC 16	161	246
19	85-44-22 ADAA IGS AND USGS WC 8	210	784
20	79-38-10 CABB IGS AND USGS WC 17	210	3480
21	83-32-4 ACCC IGS AND USGS WC 226	240	472
22	82-36-16 CBAB IGS AND USGS WC 12	285	3350
23	81-36-12 CBCA IGS AND USGS WC 18	318	3850
24	83-43-4 CBCB IGS AND USGS WC 5	315	612
25	80-38-6 AADC IGS AND USGS WC 10	370	3180

Figure 8.--Piper diagram and irrigation classification of water in the Dakota aqufier.

When the analyses of water from the Little Sioux aquifer and the upper sandstone unit of the Dakota aquifer are compared, few differences are apparent. The dissolved-solids concentrations (figs. 7 and 8) are slightly larger and the water is a little harder from the Dakota aquifer, but the similarities between the water analyses from the two aquifers imply that the aquifers are hydraulically connected.

Maple Aquifer

The Maple aquifer is the alluvial and terrace deposits associated with the Maple River in Monona County (plate 1). The Maple aquifer within the study area is about 1.5 miles wide and has an areal extent of about 25 square miles. The aquifer at 10 test holes consists of 16 to 28 feet of silty clay underlain by 9 to 48 feet of sand and gravel (geohydrologic section B-B', fig. 9; geohydrologic section C-C', fig. 10). The sand and gravel part of the aquifer has an average thickness of about 31 feet. Terrace deposits consisting of silty clay and sand and gravel exist on one or both sides along some segments of the Maple aquifer. The terrace deposits are adjacent and hydraulically connected to the Maple aquifer. The Maple aquifer is underlain by glacial till but probably is underlain by the Dakota aquifer southwest of Castana (plates 1 and 3).

Pan-evaporation data for the study area, water-table fluctuations in a well completed in the Maple aquifer, the Maple River discharge at Mapleton, and precipitation at Mapleton are shown in figure 11. The hydrograph shows that the water level in well 84-43-04ABAA declined from July to November 1983, reflecting a combination of decreased recharge and increased discharge to evapotranspiration and to the river. The water level increased from December 1983 to March 1984, reflecting an increased recharge from infiltration of precipitation and decreased evapotranspiration. The low water level corresponds to periods of low flow in the Maple River and indicates that the river during these low-flow periods probably is receiving water discharged from the Maple aquifer. The low water level in the observation well corresponds to periods of large evaporation. This indicates that water is discharging from the aquifer and is lost to evapotranspiration during these periods. Pumpage from wells completed in the Maple aquifer also could affect water levels in the aquifer. However, pumpage information for 1983 and 1984 was not available at the time this report was prepared.

Based on an areal extent of 25 square miles, an average thickness of 31 feet, and a specific yield of 25 percent, about 125,000 acre-feet of ground water are available to wells from storage in the Maple aquifer within the study area. Transmissivity is estimated to be about 4,200 ft^2/d using an average aquifer thickness of 31 feet and estimated average hydraulic conductivity of 135 ft/d. Estimated yield to wells is less than 50 gal/min (plate 1).

Analyses of five water samples from the Maple aquifer indicate that the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 12). Water from well 84-43-04ABAA (fig. 9) is very hard, is a sodium sulfate type with calcium as a significant secondary cation, and is significantly different than the water from other wells in the Maple aquifer, as indicated by its location on the Piper diagram. The water from this well has almost twice the dissolved-solids concentration, more than five times the sulfate concentration, and more than six times the sodium concentration as the other wells in the Maple aquifer. The Maple aquifer is underlain by 50 feet of glacial till and the 0 to 25 feet of sand and gravel of the basal Pleistocene aquifer.

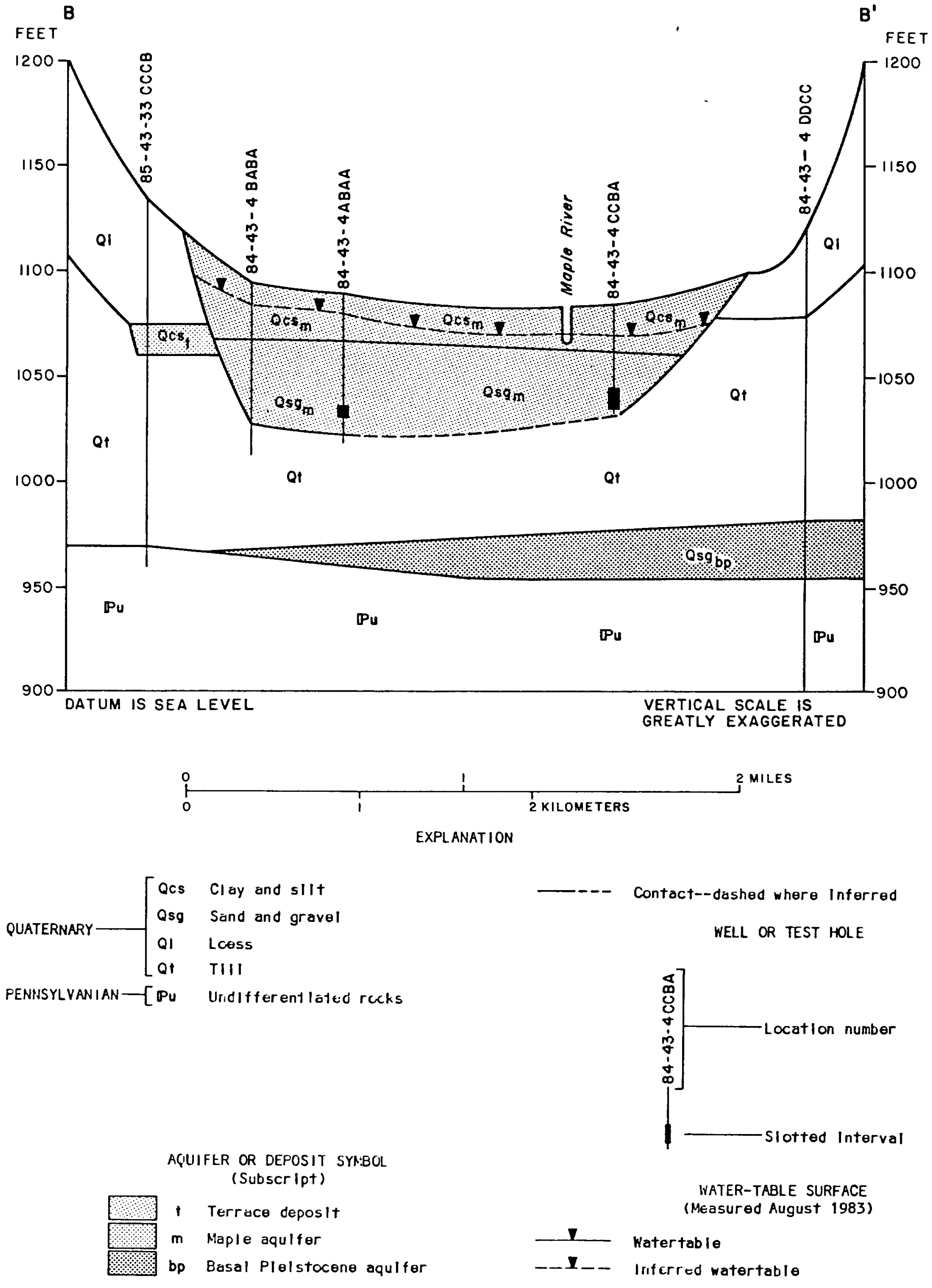


Figure 9.--Geohydrologic section B-B' of the Maple and basal Pleistocene aquifers.

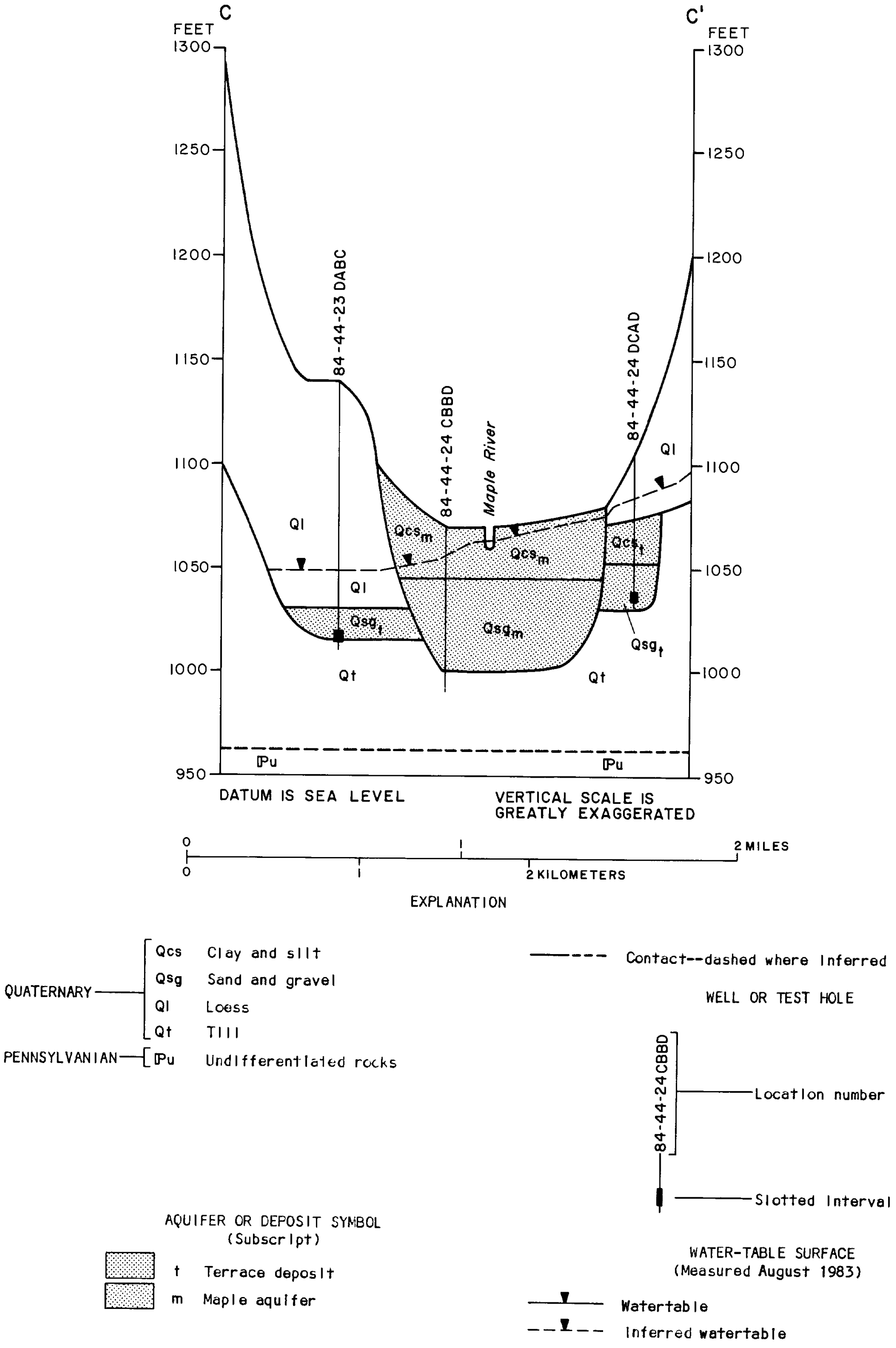


Figure 10.--Geohydrologic section C-C' of the Maple aquifer.

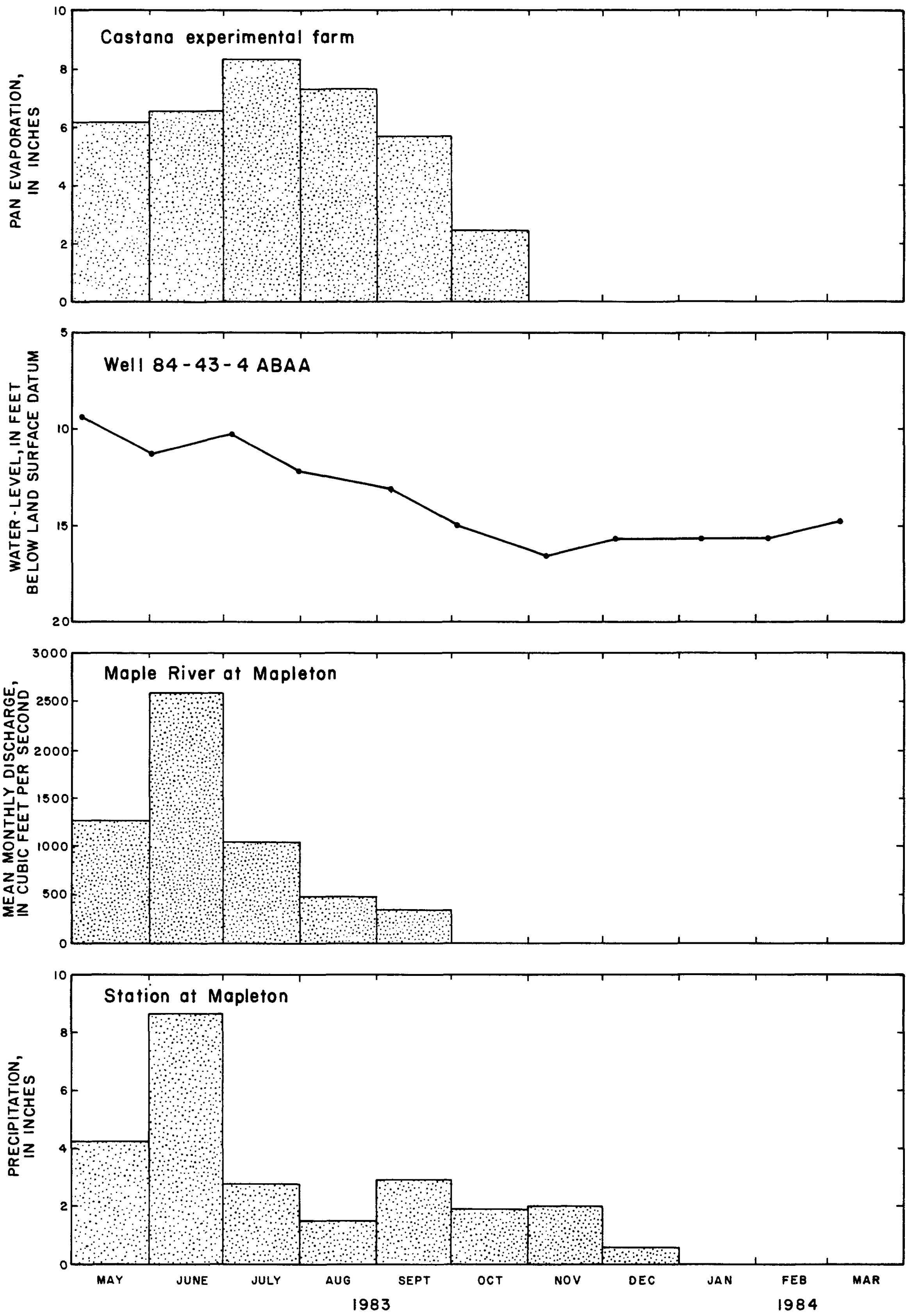
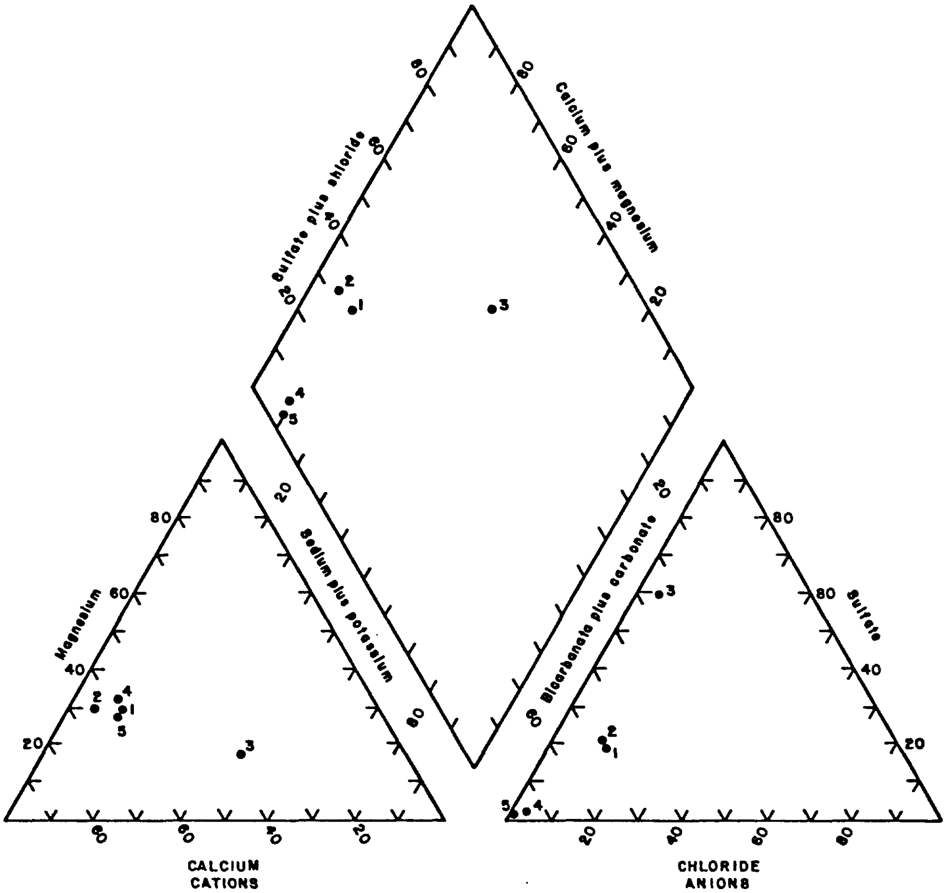


Figure 11.--Pan-evaporation data for the study area, water-table fluctuations in a well completed in the Maple aquifer, the Maple River discharge at Mapleton, and precipitation at Mapleton.



EXPLANATION

	WELL LOCATION AND NAME		TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	85-43-24BAAA	MAPLETON 4 (AIRPORT)	72	516
2	84-44-24CAAC	CASTANA 1 WET WELL	58	588
3	84-43- 4 ABAA	IGS AND USGS WC163	58	964
4	84-43- 4 CCBA	IGS AND USGS WC164	50	533
5	84-44-24DCAD	IGS AND USGS WC 166	71	404

Figure 12.--Piper diagram of water quality in the Maple aquifer.

The water from well 84-44-24DCAD, completed in a terrace of the Maple aquifer (fig. 10), has the smallest dissolved-solids concentration of the five Maple aquifer wells sampled. The water level in the alluvial deposit indicates that ground water is moving from the eastern terrace toward the alluvial deposit. The water quality in the terrace would be expected to be better because the water in the terrace is being recharged by infiltration, and then discharged to the alluvial deposit, thereby reducing the time the water is in the aquifer and the degree of mineralization of the water.

In some water samples the following constituents exceeded secondary drinking-water standards; dissolved-solids concentrations ranged from 404 to 964 mg/L and exceeded the 500 mg/L secondary standard in four samples; iron ranged from less than 50 to 1,100 ug/L and exceeded the 300 ug/L secondary standard in three samples; manganese ranged from less than 2 to 1,800 ug/L and exceeded the 50 ug/L secondary standard in four samples; and sulfate ranged from 8 to 460 mg/L and exceeded the 250 mg/L secondary standard in one of the samples.

Castana and Mapleton used 78 Mgal (million gallons) of water from the Maple aquifer in 1980. Municipal-water withdrawals are shown on plate 1 and in table 5.

Soldier Aquifer

The Soldier aquifer is the alluvial and some terrace deposits associated with the East Soldier, Middle Soldier, and Soldier Rivers located in eastern Monona County, northwestern Crawford County, and northwestern Harrison County (plate 1). The Soldier aquifer in the study area underlies an area of about 52 square miles. The width of the aquifer ranges from less than 0.25 to 1.5 miles. The aquifer at 19 test holes consists of 27 to 54 feet of silty clay underlain by 4 to 48 feet of sand or sand and gravel (geohydrologic sections D-D' and E-E', fig. 13; geohydrologic section F-F', fig. 14; geohydrologic section G-G', fig. 15). The sand and gravel part of the aquifer has an average thickness of about 17 feet. Terrace deposits consisting of silty clay, sand, and sand and gravel exist on both sides along some segments of the Soldier aquifer. The terrace deposits are adjacent and hydraulically connected to the Soldier aquifer.

The Soldier aquifer is underlain by glacial till (figs. 13 and 14). In well 83-42-17ACDD (geohydrologic section E-E', fig. 13) the water level in the basal Pleistocene aquifer is lower than the water level in the wells developed in the Soldier aquifer, indicating that if a hydraulic connection exists, the Soldier aquifer is recharging the basal Pleistocene aquifer in this area.

The Soldier aquifer is underlain by and hydraulically connected to the Dakota aquifer (fig. 15). In this area, wells pumping from one or both aquifers are virtually lowering water levels in both aquifers. No water-level data are available for the Dakota aquifer near this area. Therefore, it is unknown whether the Dakota aquifer is discharging into the Soldier aquifer or if the Soldier aquifer is recharging the Dakota aquifer.

Pan-evaporation data for the study area, water-table fluctuations in a well completed in the Soldier aquifer, the Soldier River discharge at Pisgah, and precipitation at Soldier are shown in figure 16. The hydrograph shows that the water level in well 81-44-09ABAB declined from July to September 1983,

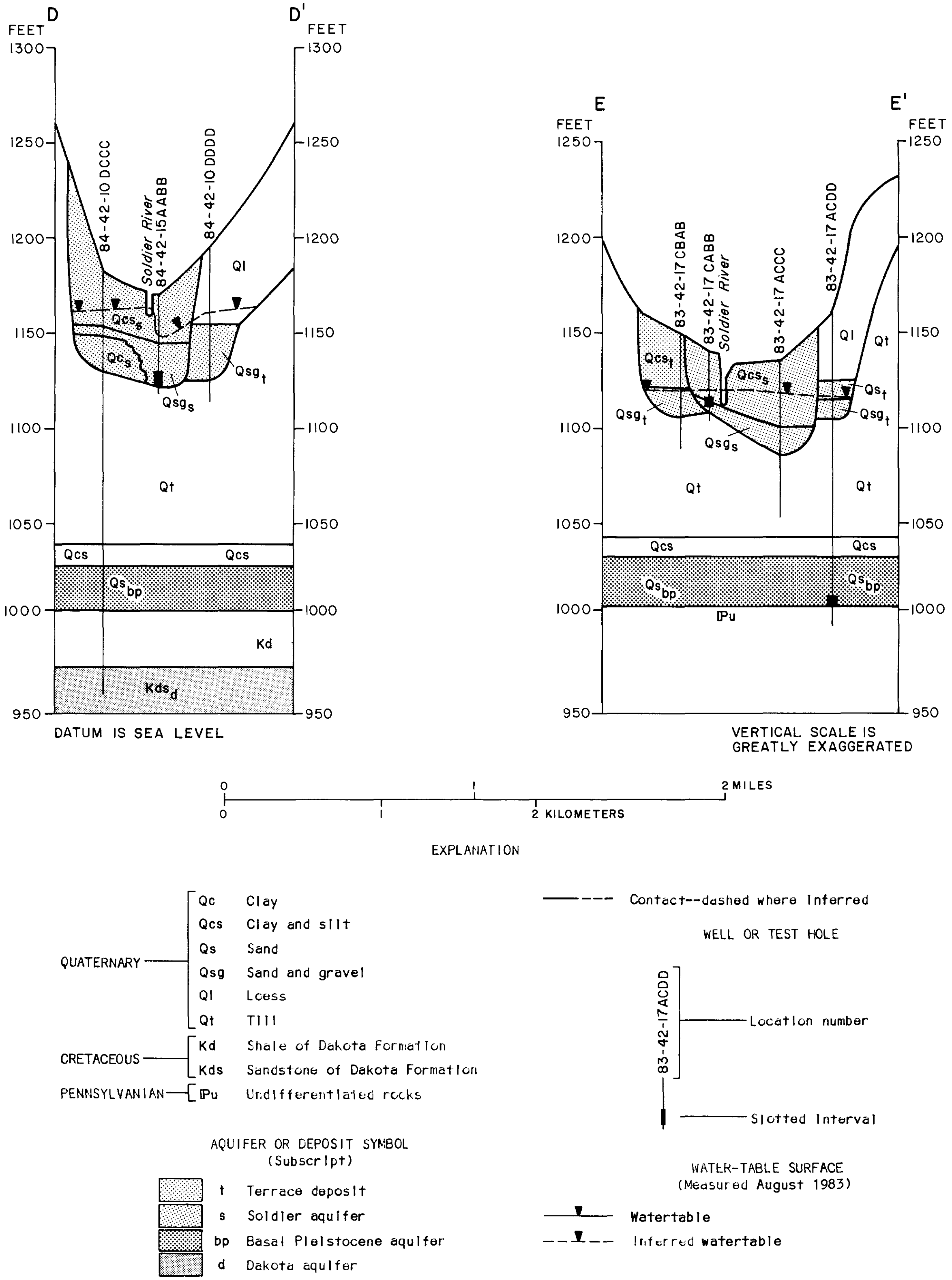


Figure 13.--Geohydrologic sections D-D' and E-E' of the Soldier, basal Pleistocene, and Dakota aquifers.

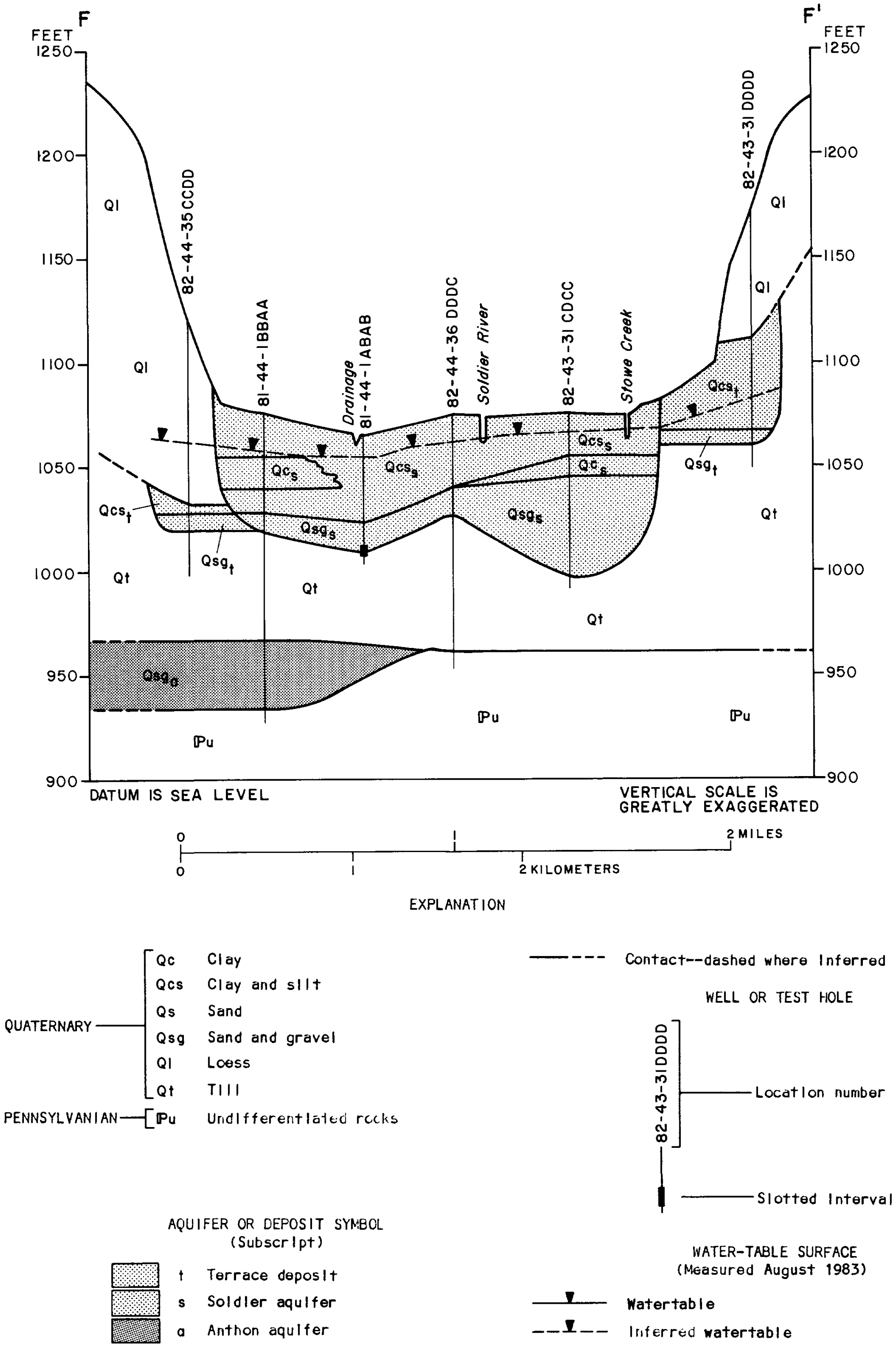


Figure 14.--Geohydrologic section F-F' of the Soldier, Anthon, and Dakota aquifers.

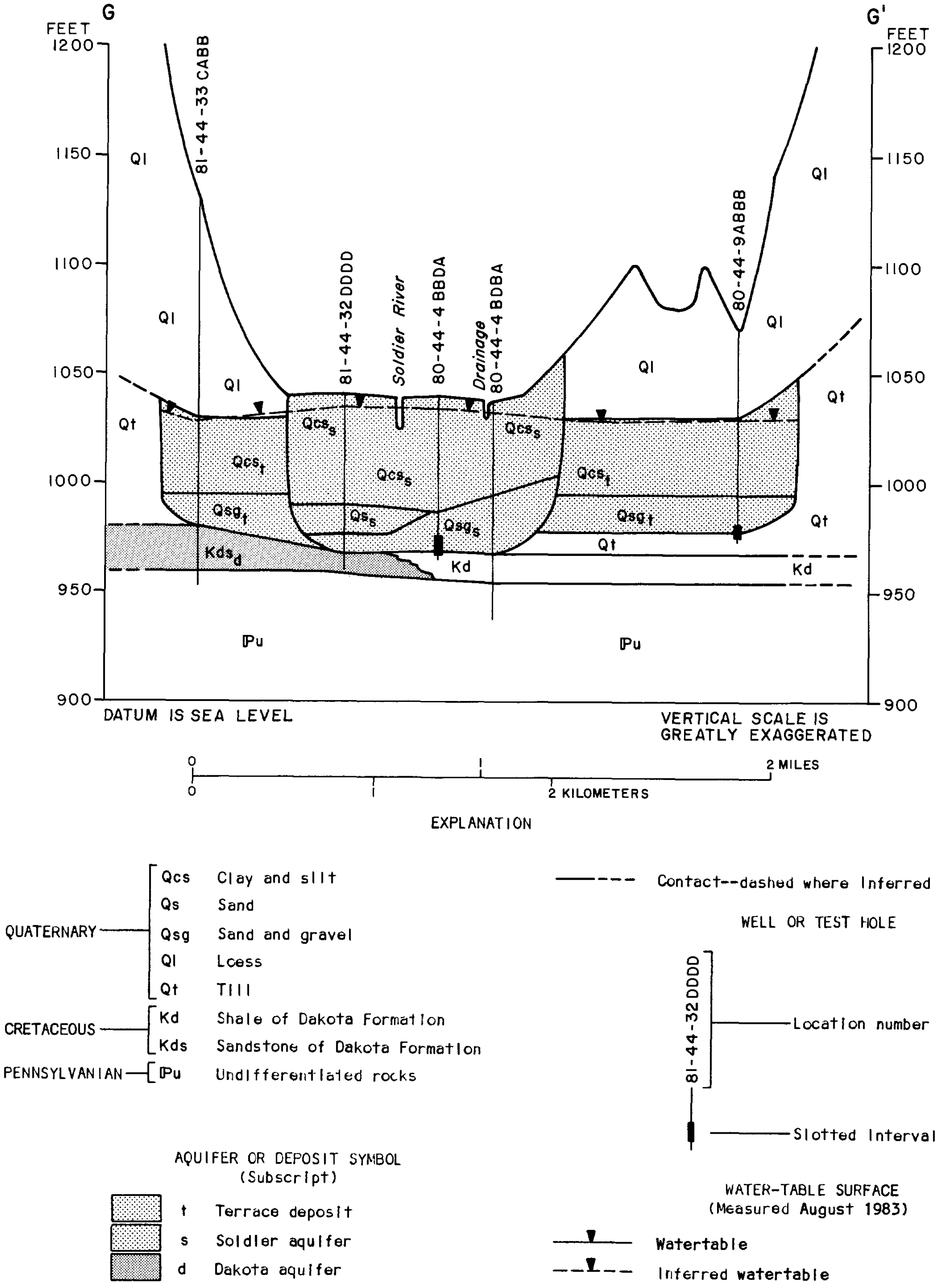


Figure 15.--Geohydrologic section G-G' of the Soldier and Dakota aquifers.

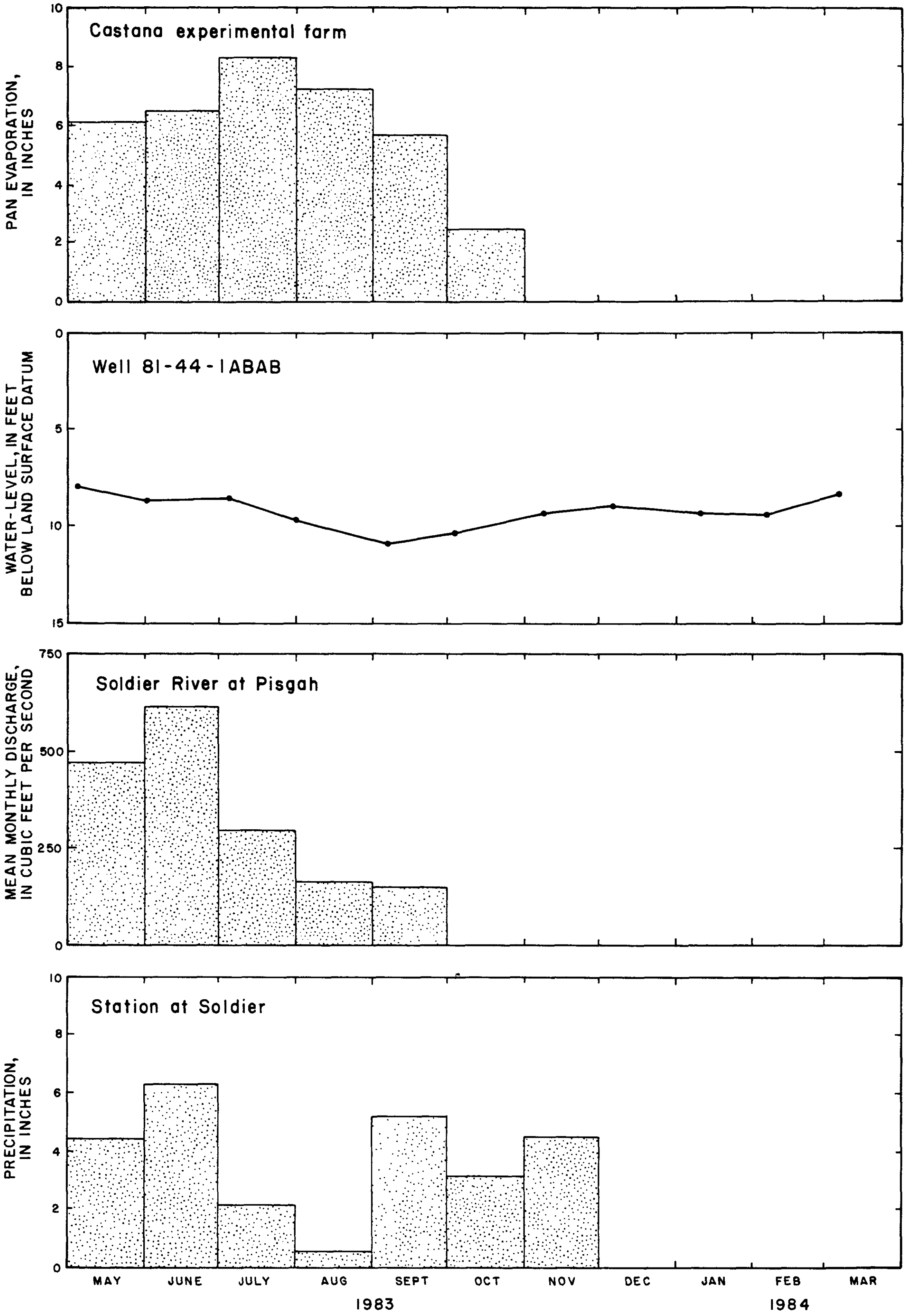


Figure 16.--Pan-evaporation data for the study area, water-table fluctuations in a well completed in the Soldier aquifer, the Soldier River discharge at Pisgah, and precipitation at Soldier.

reflecting a combination of decreased recharge and increased discharge to evapotranspiration and to the river. The water level increased from October 1983 to March 1984, reflecting increased recharge from the infiltration of precipitation and decreased evapotranspiration. The low water level corresponds to periods of smaller discharge in the Soldier River. Water flowing in the river during low-flow periods probably is provided by water discharging from the Soldier aquifer. The low water level in the observation well corresponds to periods of large evaporation. This indicates that water is discharging from the aquifer and is lost to evapotranspiration during these periods. Pumpage from wells completed in the Soldier aquifer also could affect water levels in the aquifer. However, pumpage information for 1983 and 1984 was not available at the time this report was prepared.

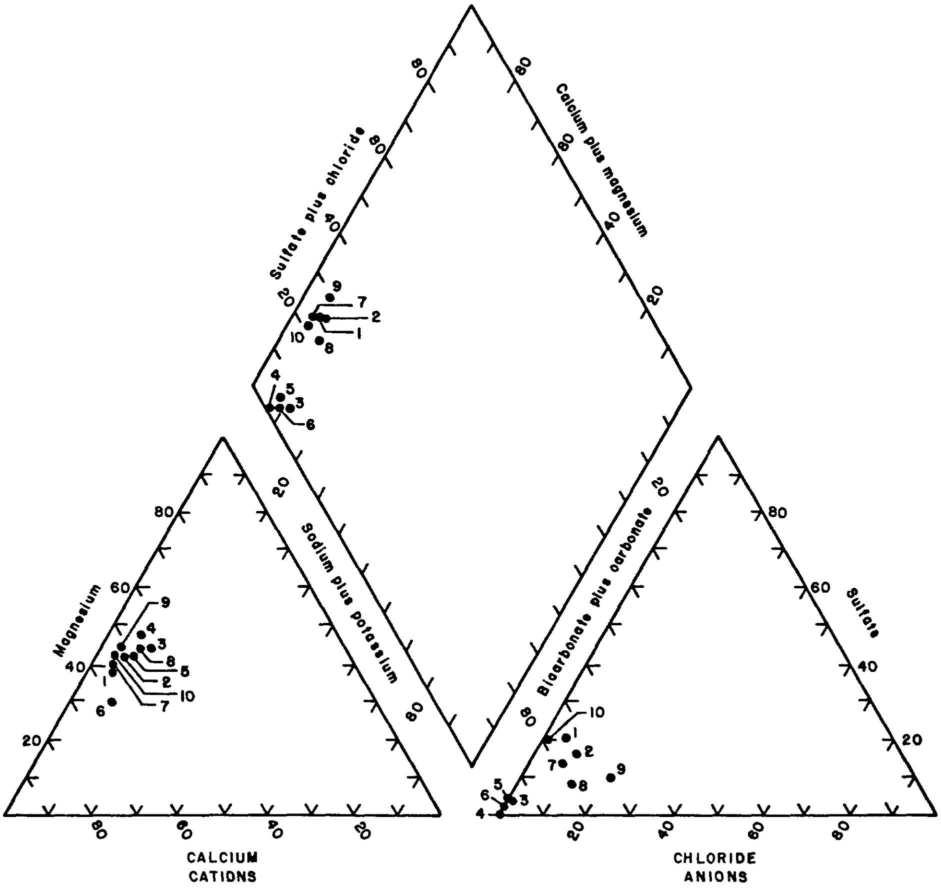
Based on an areal extent of 52 square miles, an average thickness of 17 feet, and a specific yield of 20 percent, about 115,000 acre-feet of ground water are available to wells from storage in the Soldier aquifer. Transmissivity is estimated to be 1,700 ft^2/d using an average aquifer thickness of 17 feet and estimated hydraulic conductivity of 100 ft/d. Estimated yield to properly constructed wells generally is less than 50 gal/min (plate 1).

Analyses of 10 water samples from the Soldier aquifer indicate that the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 17). In a water sample from well 84-42-15AABB (geohydrologic section D-D', fig. 13), nitrate as nitrogen exceeded the 10 mg/L primary drinking-water standard with a concentration of 16 mg/L. In a water sample from well 85-41-36CCBC, the gross-alpha activity was 15 pCi/L (picocuries per liter), the maximum limit permissible by the primary drinking-water standard. In some water samples the following constituents exceeded secondary drinking-water standards: dissolved-solids concentrations ranged from 416 to 652 mg/L and exceeded the 500 mg/L secondary standard in four samples; iron ranged from less than 50 to 10,000 ug/L and exceeded the 300 ug/L secondary standard in seven samples; and manganese ranged from less than 2 to 2,400 ug/L and exceeded the 50 ug/L secondary standard in eight samples.

Charter Oak, Moorhead, Pisgah, Ricketts, and Ute used 67.2 Mgal of water from the Soldier aquifer in 1980. About one-half of water used by Pisgah came from the Soldier aquifer and the other one-half from the basal Pleistocene aquifer. Municipal-water withdrawals are shown on plate 1 and in table 5.

Boyer Aquifer

The Boyer aquifer is the alluvial and some terrace deposits associated with the East Boyer and Boyer Rivers in Crawford and Harrison Counties (plate 1). The Boyer aquifer ranges from less than 0.25 to 2 miles wide and has an areal extent of about 79 square miles. Data from 52 test holes indicate that the aquifer consists of 7 to 51 feet of silty clay underlain by 3 to 57 feet of sand or sand and gravel (geohydrologic sections H-H' and I-I', fig. 18; geohydrologic section J-J', fig. 19; geohydrologic section K-K', fig. 20; geohydrologic section L-L', fig. 21; geohydrologic section M-M', fig. 22). The sand and gravel part of the aquifer has an average thickness of about 20 feet. Based on the test-hole information, the thickest and probably most productive areas generally lie near the Boyer River channel. Terrace deposits consisting of clay, silty clay, sand, and sand and gravel exist on one or both sides along some segments of the Boyer aquifer. The terrace deposits (geohydrologic section I-I', fig. 18; figs. 19 and 20) are adjacent and hydraulically connected to the Boyer aquifer.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	84-41-23CABA CHARTER OAK 5	50	652
2	85-41-36CCBC RICKETTS 2 (MAIN)	30	478
3	81-44-13BBBB PISGAH 1	103	470
4	61-44-1 ABAB IGS AND USGS WC177	58	463
5	60-44-4 BBDA IGS AND USGS WC184	73	416
6	80-44-9 ABBB IGS AND USGS WC183	86	462
7	84-42-35CABB UTE 3	59	616
8	82-43-9 DDCD MOORHEAD 2 WEST WELL	76	532
9	84-42-15AABB IGS AND USGS WC170	47	482
10	83-42-17CABB IGS AND USGS WC173	37	600

Figure 17.--Piper diagram of water quality in the Soldier aquifer.

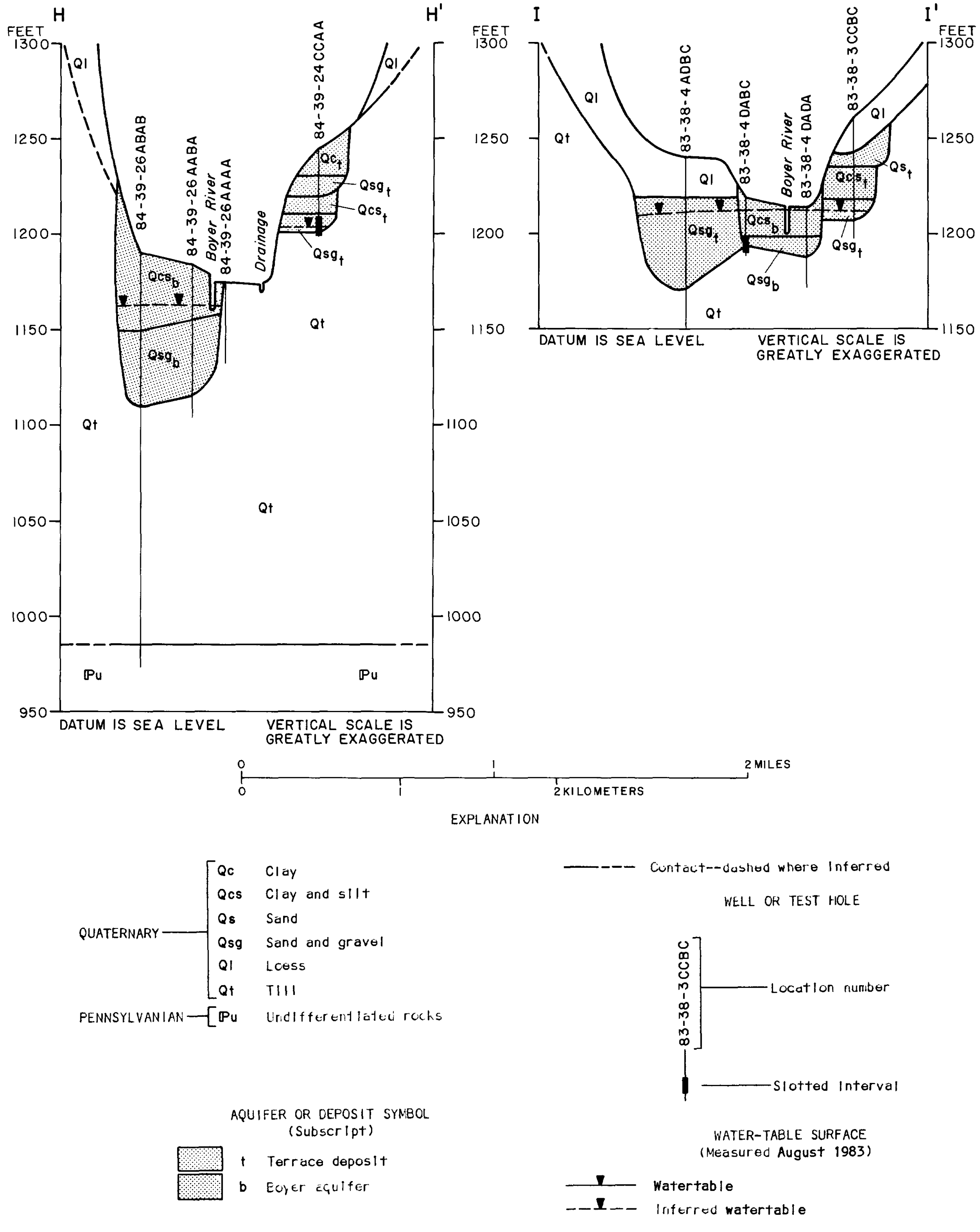


Figure 18.--Geohydrologic sections H-H' and I-I' of the Boyer aquifer.

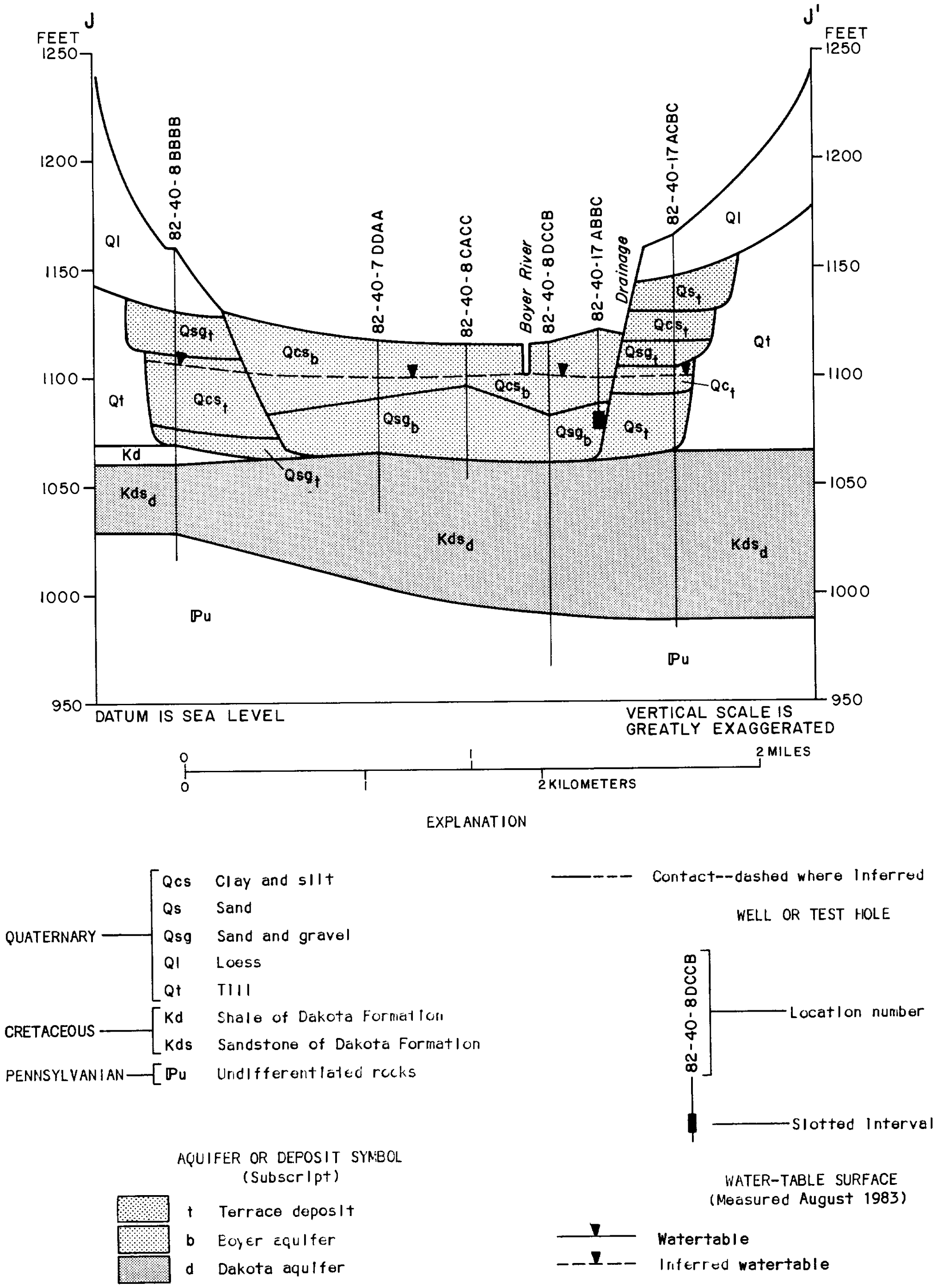


Figure 19.--Geohydrologic section J-J' of the Boyer and Dakota aquifers.

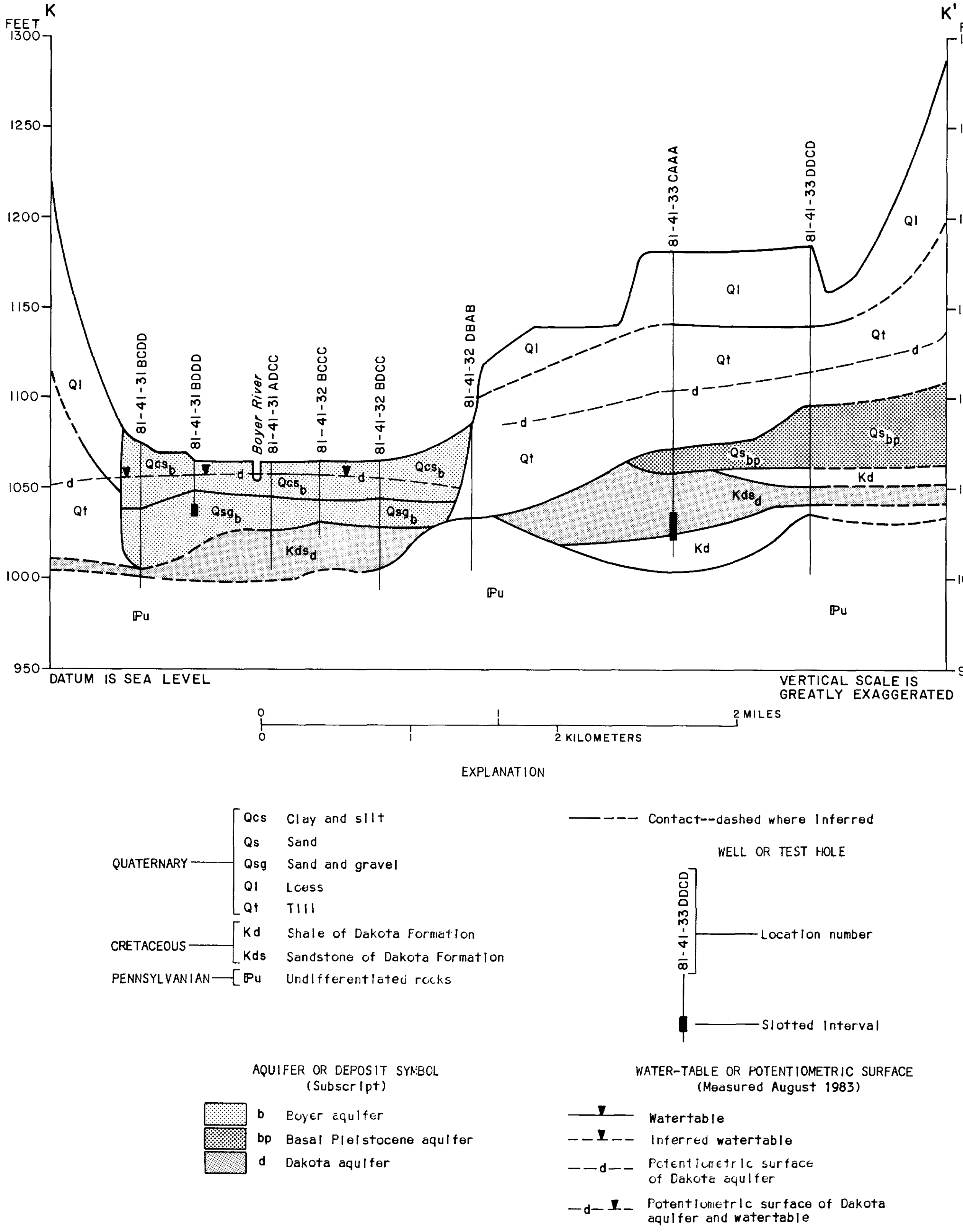


Figure 20.--Geohydrologic section K-K' of the Boyer, basal Pleistocene, and Dakota aquifers.

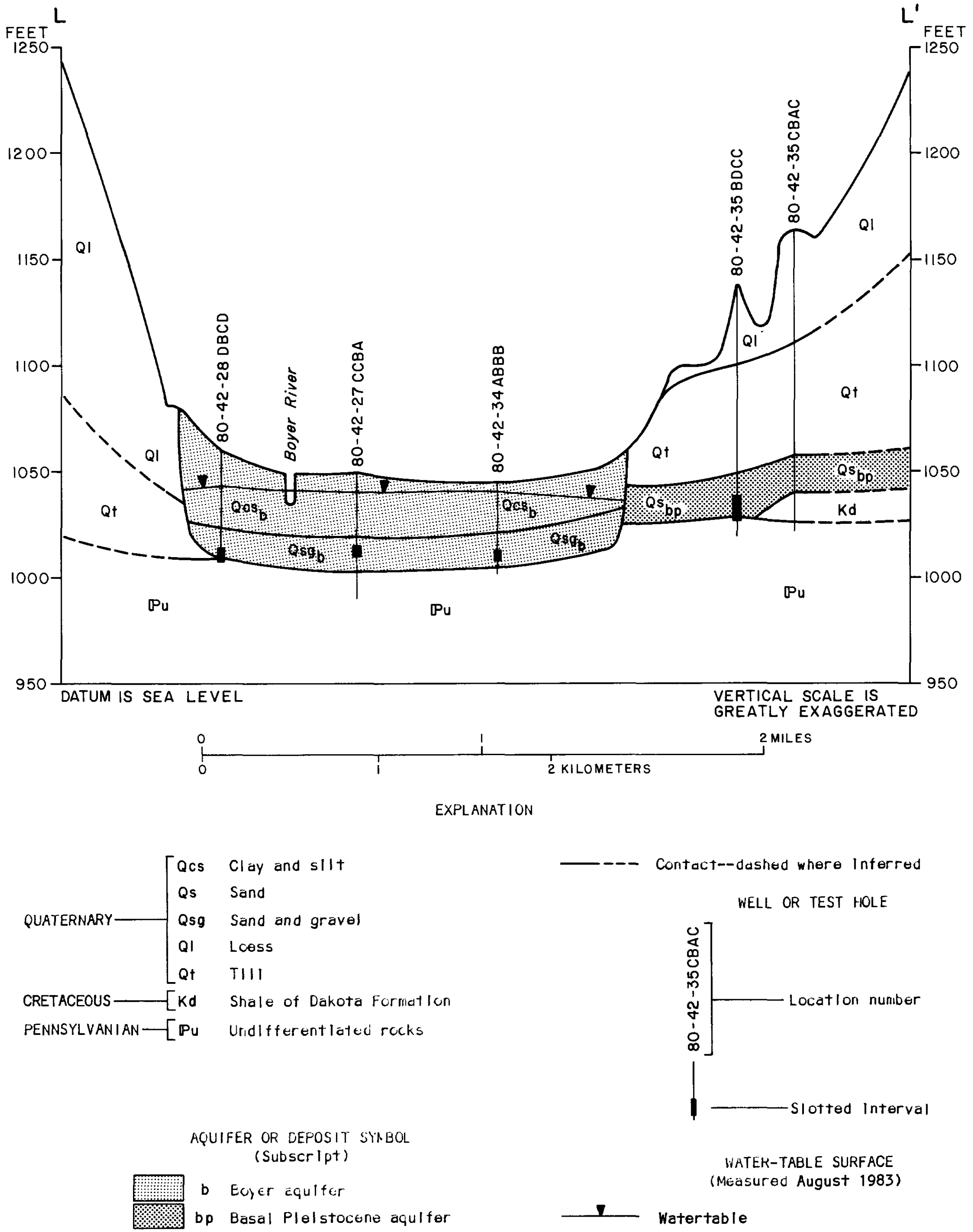


Figure 21.--Geohydrologic section L-L' of the Boyer and basal Pleistocene aquifers.

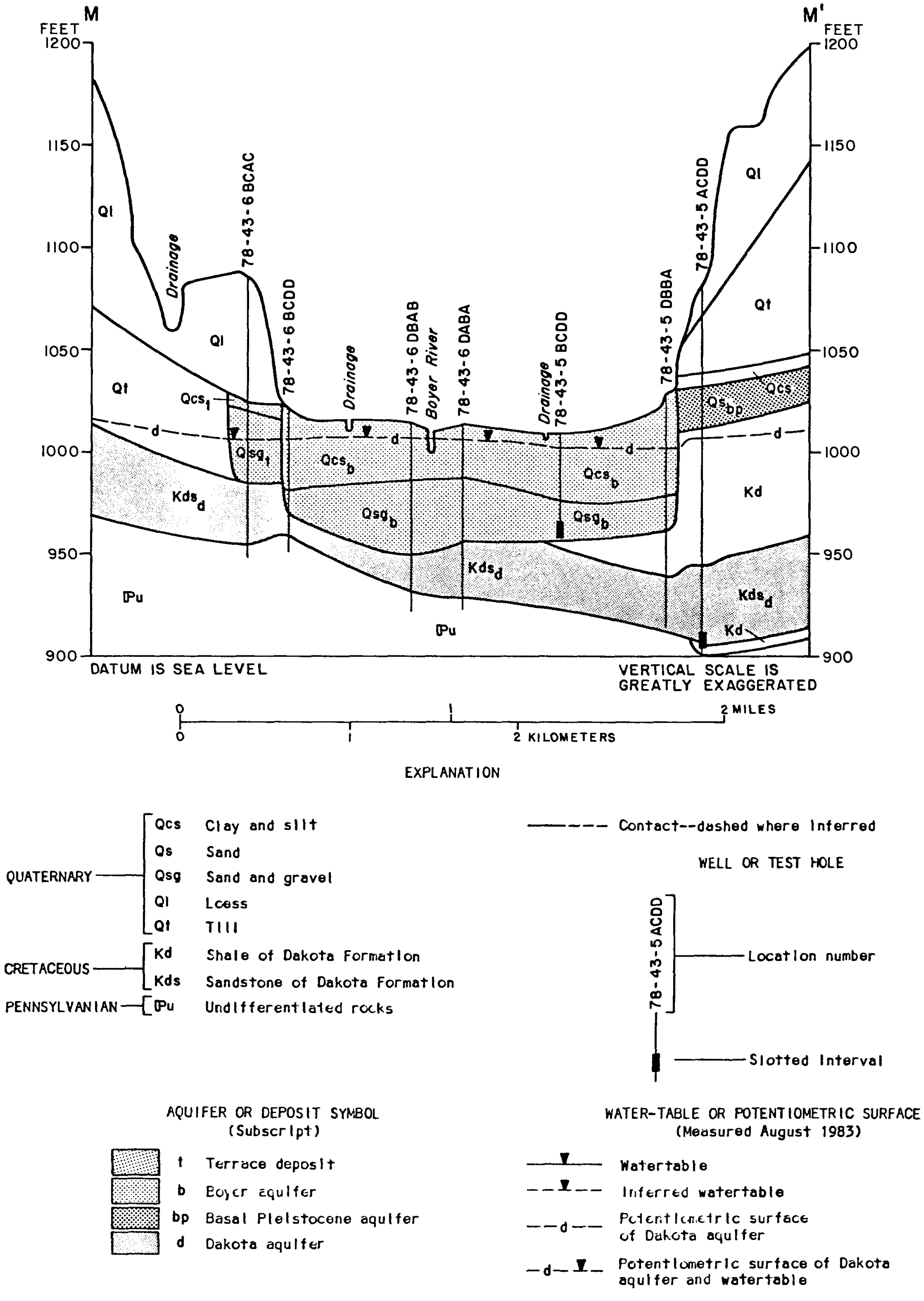


Figure 22.--Geohydrologic section M-M' of the Boyer, basal Pleistocene, and Dakota aquifers.

The Boyer aquifer is underlain by glacial till (fig. 18). Where the Boyer aquifer is underlain by the Dakota aquifer (figs. 19, 20, and 22), the water levels in Dakota aquifer wells are slightly higher than water levels in the Boyer aquifer, indicating that the Dakota aquifer is hydraulically connected to and discharging into the Boyer aquifer. In these areas, wells pumping from one or both aquifers virtually are lowering the water levels in both aquifers. In the central section of Harrison County and near the town of Logan, the Boyer aquifer is underlain by Pennsylvanian rock (plate 1; fig. 21).

Pan-evaporation data for the study area, water-table fluctuations in a well completed in the Boyer aquifer, and the Boyer River discharge at Logan are shown in figure 23. The hydrograph shows that the water level in well 78-4305BCDD declined from June through August 1982 and July through September 1983, reflecting a combination of decreased recharge and increased discharge to evapotranspiration and to the river. The water level increased from September to November 1982; in February, March, and November 1983; and in February 1984. These water-level rises are interpreted to have been caused by recharge from the infiltration of precipitation and decreased evapotranspiration. The lower water levels correspond to periods of smaller discharge in the Boyer River. Water flowing in the river during these low-flow periods probably is provided by water discharging from the Boyer aquifer. The low water level in the observation well corresponds to periods of large evaporation. This indicates that water is discharging from the aquifer and lost to evapotranspiration during these periods. Pumpage from wells completed in the Boyer aquifer also could affect water levels in the aquifer. However, pumpage information for 1982, 1983, and 1984 was not available at the time this report was prepared.

Based on an areal extent of 79 square miles, an average thickness of 20 feet, and a specific yield of 20 percent, about 200,000 acre-feet of ground water are available from storage in the Boyer aquifer. Transmissivity is estimated to be 2,000 ft^2/d using an average aquifer thickness of 20 feet and estimated average hydraulic conductivity of 100 ft/d. Estimated yield to properly constructed wells is less than 50 gal/min (plate 1).

Analyses of 18 water samples from the Boyer aquifer indicate that the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 24). In the following four water samples, nitrate as nitrogen exceeded the 10 mg/L primary drinking-water standard: well 80-42-28DBCD with a concentration of 11 mg/L, wells 11-41-3DBBD and 84-37-24ABDB with 13 mg/L, and well 83-38-4DABC with 54 mg/L. The water sample from well 80-42-28DBCD also exceeded the 15 pCi/L primary drinking-water standard of gross-alpha activity with a concentration of 19 pCi/L. Also in the water sample from well 83-38-4DABC, barium reached the maximum limit of 1,000 ug/L permitted by primary drinking-water standards. In some water samples, the following constituents exceeded secondary drinking-water standards: dissolved-solids concentrations ranged from 350 to 1,000 mg/L and exceeded the 500 mg/L secondary standard in 11 samples; iron ranged from less than 50 to 8,700 ug/L and exceeded the 300 ug/L secondary standard in 10 samples; and manganese ranged from 20 to 2,200 ug/L and exceeded the 50 ug/L secondary standard in 15 samples.

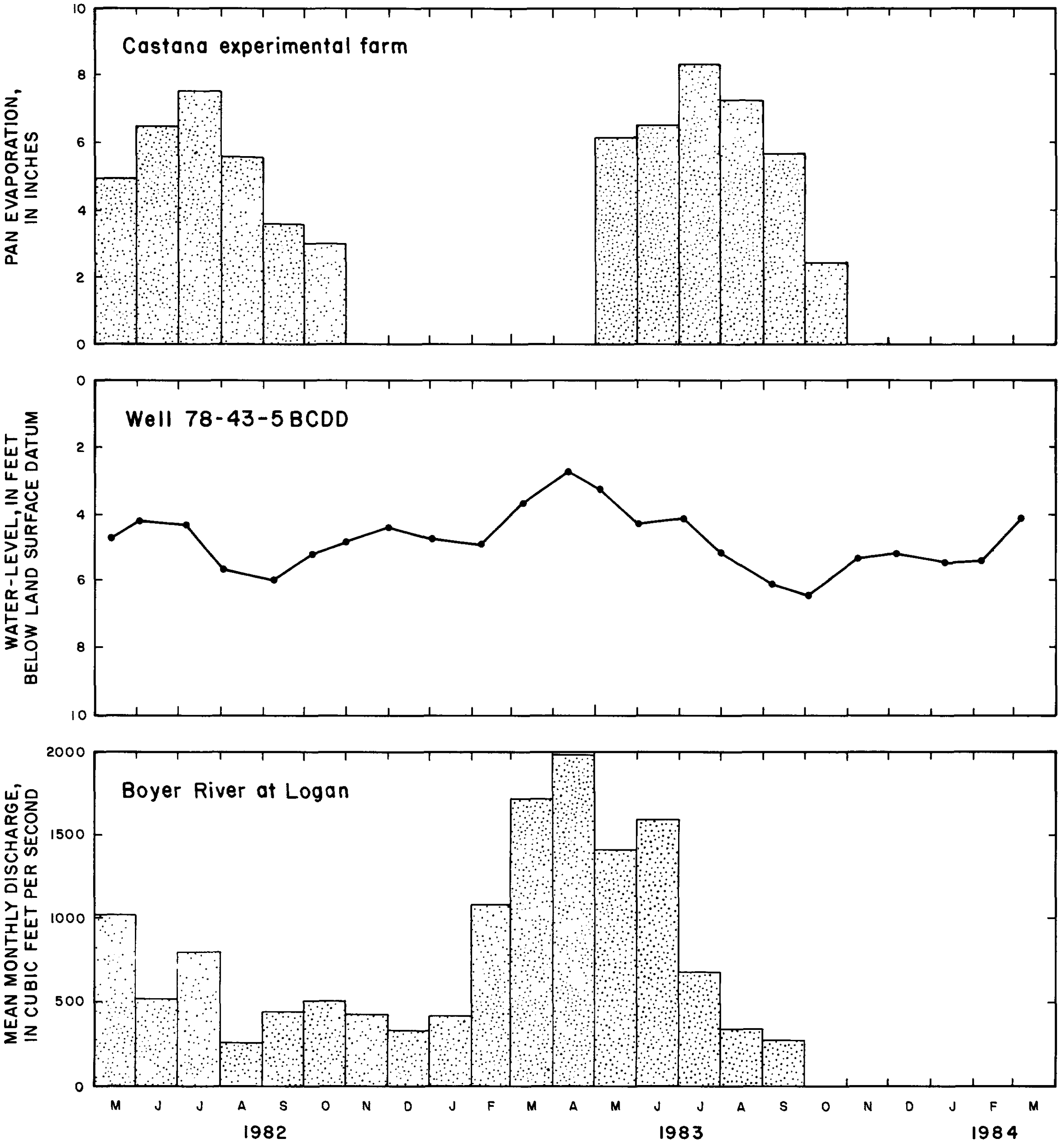
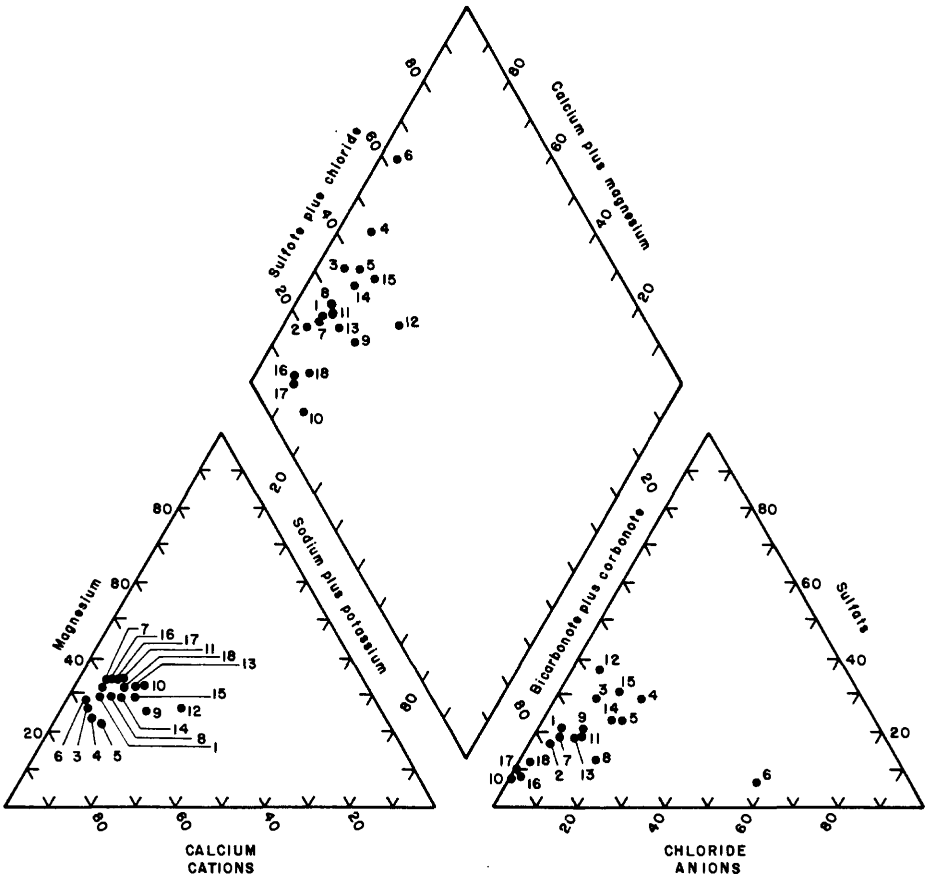


Figure 23.--Pan-evaporation data for the study area, water-table fluctuations in a well completed in the Boyer aquifer, and the Boyer River discharge at Logan.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	82-40-10CBAB DOW CITY 1	81	444
2	84-38-7CADC DELOIT 1	65	424
3	84-37-30CBBB VAIL 2	32	572
4	84-37-24ABDB WESTSIDE 4	45	946
5	83-39-10ADBC DENISON 6	71	740
6	83-38-4DABC IGS AND USGS WC 63	29	1000
7	82-40-17ABBC IGS AND USGS WC 188	46	445
8	81-41-3DBBD DUNLAP 1	85	614
9	79-42-19CBAB LOGAN 7	52	552
10	78-43-5BCDD IGS AND USGS WC 32	51	422
11	80-42-28DBCD IGS AND USGS WC 37	52	619
12	81-41-31BDDD IGS AND USGS WC 53	30	621
13	78-44-15CBAD MISSOURI VALLEY 2	100	890
14	81-41-31ACCC IGS AND USGS WC 189	46	729
15	81-41-3CDBB IGS AND USGS WC 190	40	889
16	80-42-34ABBB IGS AND USGS WC 191	37	389
17	80-42-27CCBA IGS AND USGS WC 192	40	350
18	79-42-19BADC IGS AND USGS WC 196	49	465

Figure 24.--Piper diagram of water quality in the Boyer aquifer.

Water from the Boyer and Dakota aquifer wells (fig. 19) had similar water quality. The Dakota water sample had slightly smaller concentrations of calcium, potassium, magnesium, and sulfate, and a slightly larger concentration of sodium than water from the Boyer aquifer. The water level in a Dakota aquifer well, located close to the area in figure 19, was about 10 feet higher than the water level in Boyer aquifer well 82-40-17ABBC, indicating the Dakota is hydraulically connected to and discharging into the Boyer aquifer. Water from the Boyer and Dakota aquifer wells (fig. 22) also had similar water quality. The water level in the Dakota aquifer well 78-43-05ACDD is slightly higher than the water level in the Boyer aquifer well 78-43-05BCDD, indicating the Dakota is hydraulically connected to and discharging into the Boyer aquifer.

A segment of Dakota aquifer is east of, but not adjacent or hydraulically connected to, the Boyer aquifer or the Dakota aquifer underlying the Boyer aquifer (fig. 20). The water from this segment of the Dakota aquifer has significantly smaller concentrations of dissolved solids and sulfate than water from the Boyer aquifer and the segment of Dakota aquifer underlying the Boyer aquifer. This situation illustrates that where the Dakota and Boyer aquifers are hydraulically connected, the water quality in both aquifers is similar. However, where the aquifers are separated by confining material, such as glacial till, the water quality of each aquifer is markedly different.

The basal Pleistocene aquifer (fig. 21) is adjacent and hydraulically connected to the east side of the Boyer aquifer. The water level in the basal Pleistocene aquifer is at least 40 feet higher than the water level in the Boyer aquifer, indicating the basal Pleistocene aquifer is discharging into the Boyer aquifer. The quality of water from the basal Pleistocene and Boyer aquifers east of the Boyer River is similar, but water from Boyer aquifer well 80-42-28DBCD, west of the Boyer River, has noticeably larger concentrations of dissolved solids, sulfate, and nitrate and is harder than water from other Boyer aquifer wells in the same geohydrologic section. This water-quality difference might be explained by the presence of an isolated nob of Pennsylvanian rock in the flood plain south of well 80-42-28DBCD. This nob could be impeding the movement of ground water and increasing the residence time and mineralization of the water in this area.

Arion, Deloit, Denison, Dow City, Dunlap, Logan, Missouri Valley, Vail, and Westside used 857 Mgal of water from the Boyer aquifer in 1980. Municipal-water withdrawals are shown on plate 1 and in table 5. About 1.3 percent of the water stored in the Boyer aquifer is withdrawn by towns every year.

West Nishnabotna Aquifer

The West Nishnabotna aquifer consists of the alluvial deposits and some terrace deposits associated with the West Fork West Nishnabotna, East Branch West Nishnabotna, and the West Nishnabotna River in Shelby County, northeastern Audubon County, and southwestern Crawford County (plate 1). The West Nishnabotna aquifer ranges from 0.25 to 1.5 miles wide and has an areal extent of about 65 square miles. The aquifer at 29 test holes consists of 12 to 40 feet of silty clay underlain by 5 to 28 feet of sand and gravel (geohydrologic sections N-N' and O-O', fig. 25; geohydrologic section P-P', fig. 26; geohydrologic section Q-Q', fig. 27; geohydrologic section R-R', fig. 28; geohydrologic section S-S', fig. 29). The sand and gravel part of the aquifer

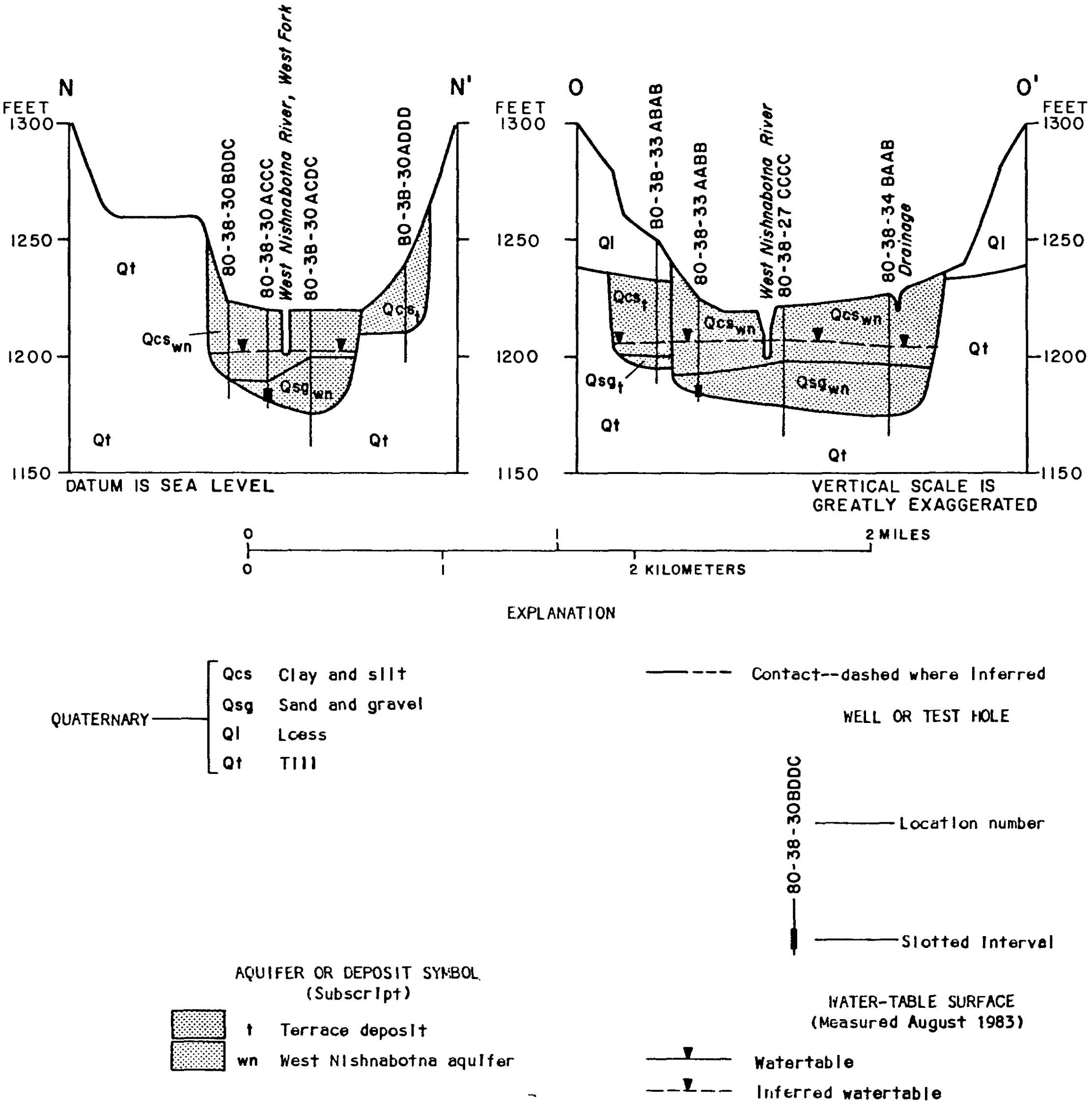


Figure 25.--Geohydrologic sections N-N' and O-O' of the West Nishnabotna aquifer.

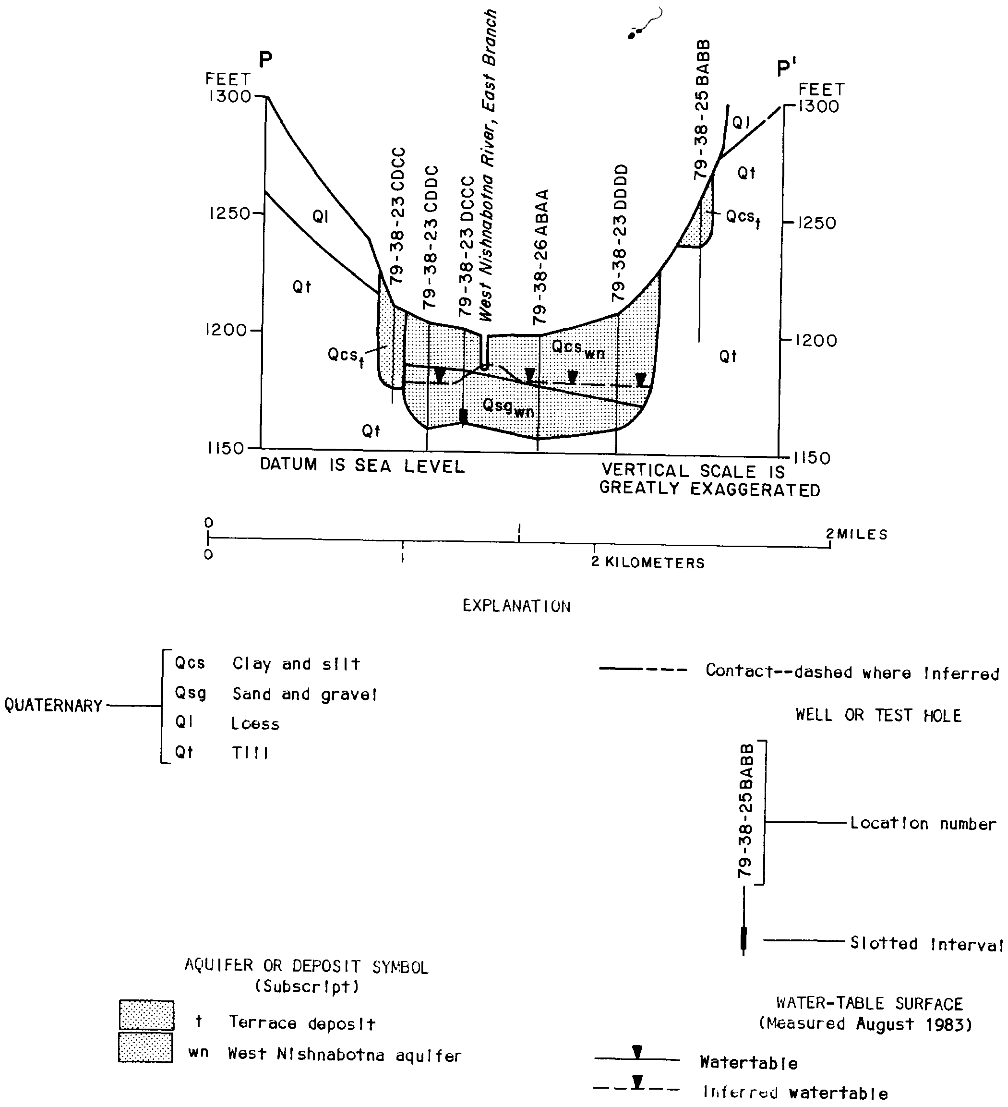


Figure 26.--Geohydrologic section P-P' of the West Nishnabotna aquifer.

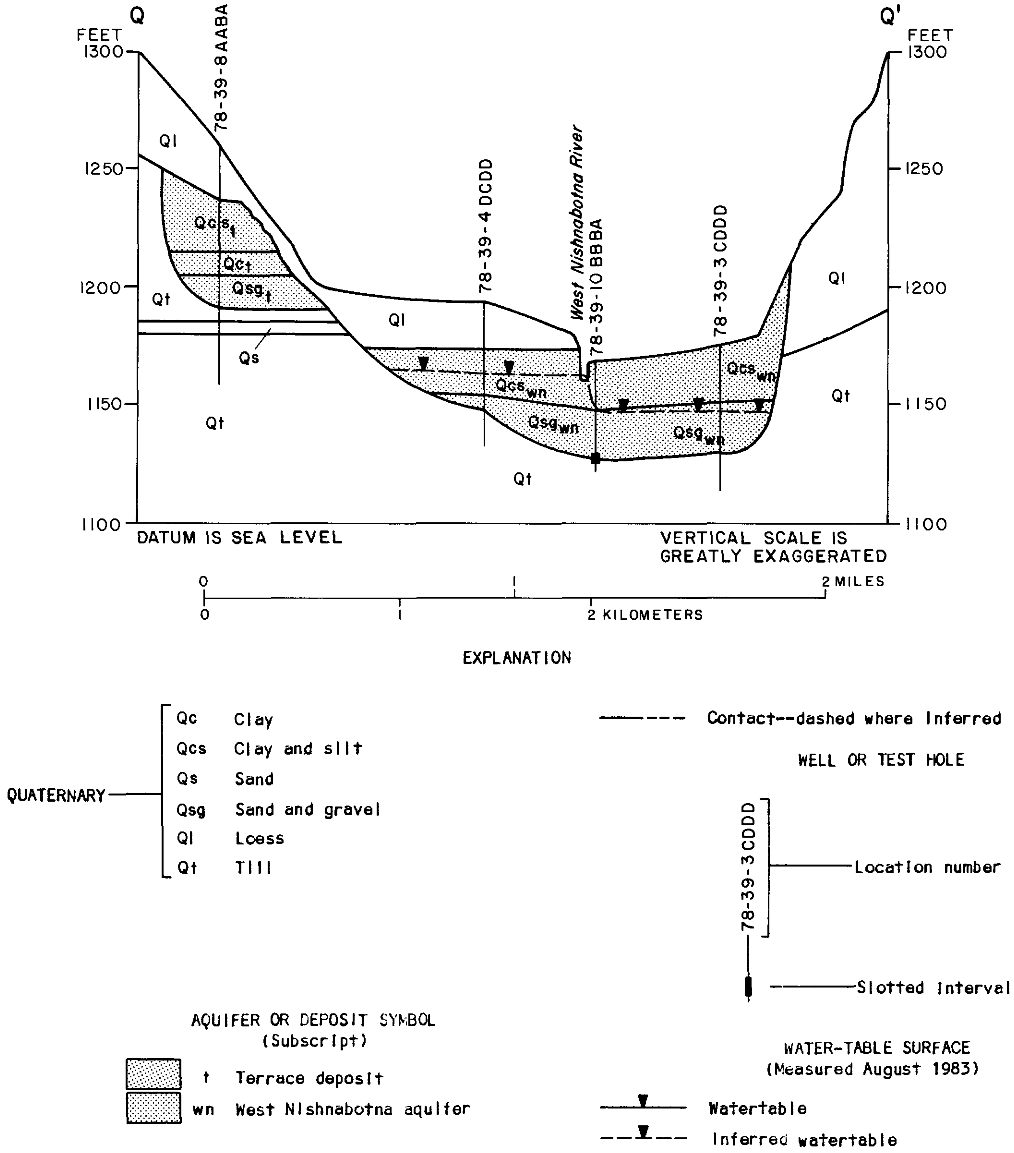


Figure 27.--Geohydrologic section Q-Q' of the West Nishnabotna aquifer.

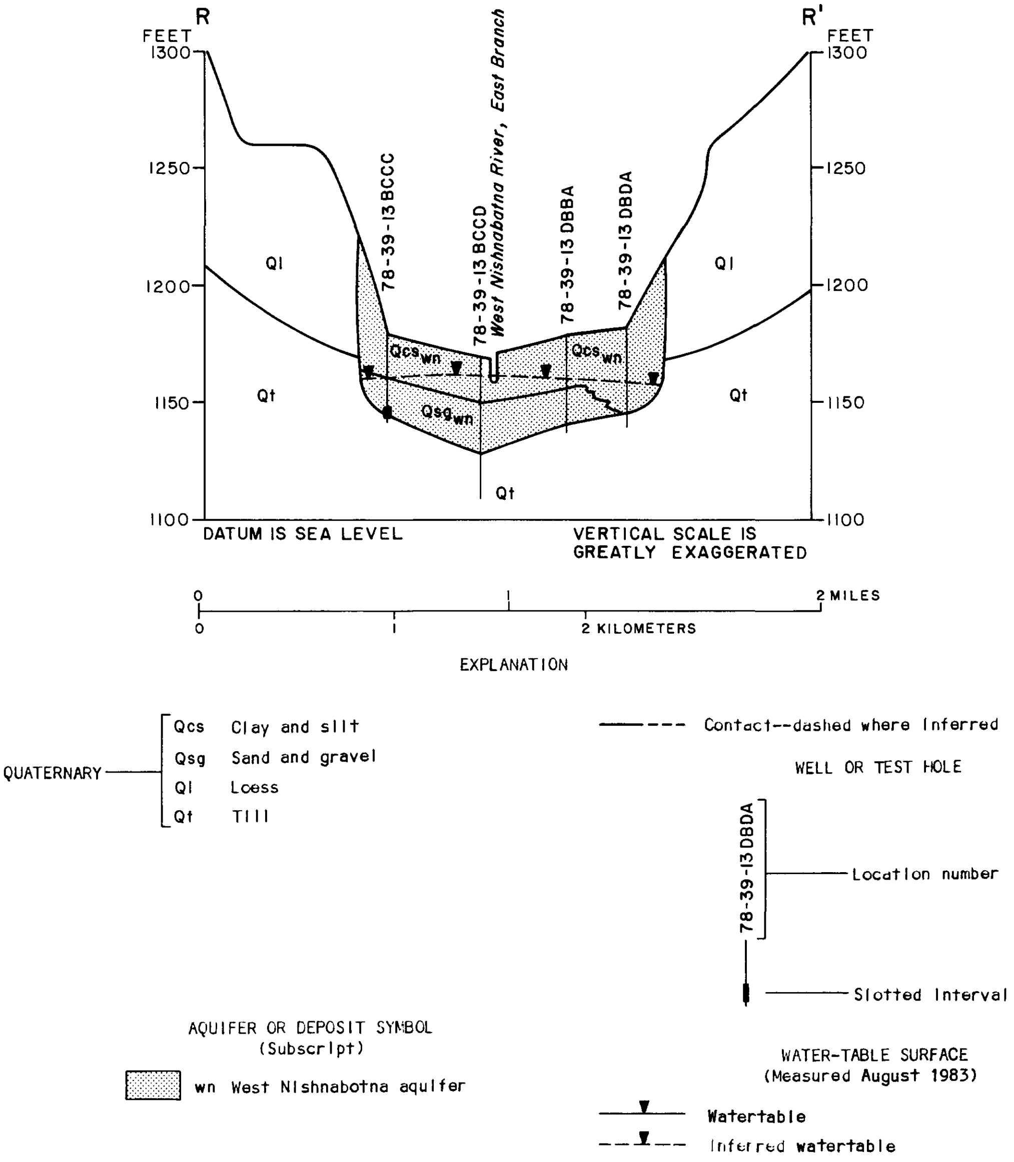


Figure 28.--Geohydrologic section R-R' of the West Nishnabotna aquifer.

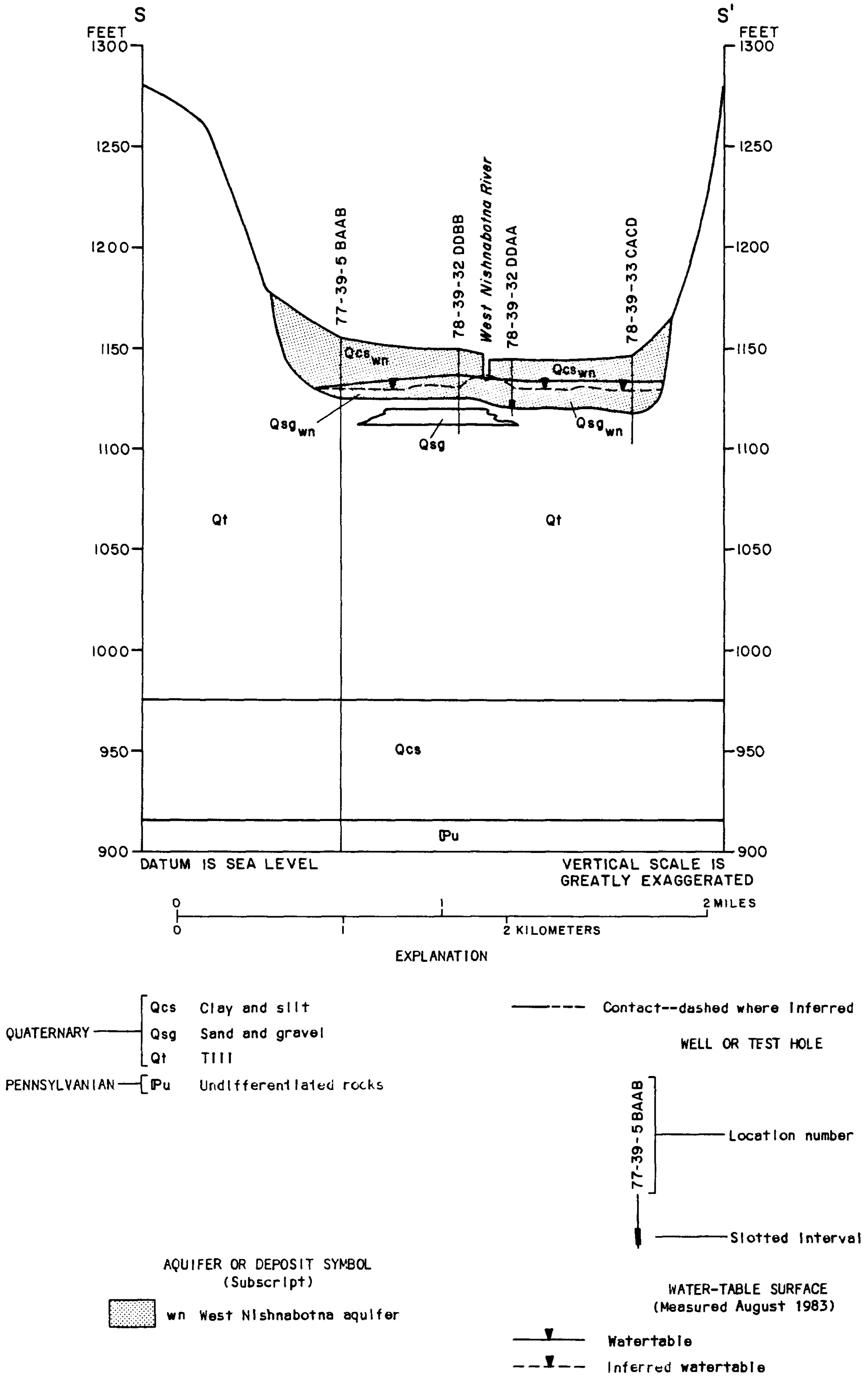


Figure 29.--Geohydrologic section S-S' of the West Nishnabotna aquifer.

has an average thickness of about 15 feet. Terrace deposits consisting of clay, silty clay, and sand and gravel exist on both sides along some segments of the West Nishnabotna aquifer. The terrace deposits in figure 27 are not adjacent or hydraulically connected to the West Nishnabotna aquifer. However, the terrace deposits (figs. 25 and 26) are adjacent and hydraulically connected to the aquifer. The aquifer is underlain by glacial till in all areas.

The West Nishnabotna aquifer and the Fremont aquifer that underlies much of the West Nishnabotna aquifer are separated by up to 400 feet of glacial till near geohydrologic sections Q-Q' and R-R' (figs. 27 and 28). The water levels in the West Nishnabotna and Fremont aquifers are virtually the same, suggesting the possibility of a hydraulic connection. It can be seen that the Fremont aquifer underlies a large part of the West Nishnabotna drainage basin, and in most areas underlies the West Nishnabotna River and alluvial aquifer (plates 1 and 2).

Pan-evaporation data for the study area, water-table fluctuations in the West Nishnabotna aquifer, and precipitation at Harlan are shown in figure 30. The hydrograph shows that the water level in well 78-39-10BBBA peaked in early July 1983, declined and then increased steadily from November 1983 to March 1984. These high water levels are interpreted to be caused by increased recharge to evapotranspiration. The graph also shows that the water level in the well declined from July to September 1983, reflecting the combination of decreased recharge and increased discharge to evapotranspiration and to the West Nishnabotna River. The water level in the observation well began to decline during periods of large evaporation. This indicates that water is discharging from the aquifer and is lost to evapotranspiration during these periods. Pumpage from wells completed in the West Nishnabotna aquifer also could affect water levels in the aquifer. However, pumpage information for 1983 and 1984 was not available at the time this report was prepared.

Based on an areal extent of 65 square miles, an average thickness of 15 feet, and a specific yield of 25 percent, about 156,000 acre-feet of ground water are available from storage in the West Nishnabotna aquifer. Transmissivity is estimated to be 2,000 ft^2/d using an average thickness of 15 feet and an estimated hydraulic conductivity of 135 ft/d. Estimated yield to wells is less than 50 gal/min (plate 1).

Analyses of 11 water samples from the West Nishnabotna aquifer indicate that the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation and sulfate as a significant secondary anion (fig. 31). In some water samples, the following constituents exceeded secondary drinking-water standards: dissolved-solids concentrations ranged from 316 to 668 mg/L and exceeded the 500 mg/L standard in 6 samples; iron ranged from less than 50 to 4,800 ug/L and exceeded the 300 mg/L standard in 8 samples; and manganese ranged from 60 to 1,700 ug/L and exceeded the 50 ug/L standard in 11 samples.

Defiance, Harlan, Irwin, Kirkman, Manilla, and Manning used 393.5 Mgal of water from the West Nishnabotna aquifer in 1980. Municipal-water withdrawals are shown on plate 1 and in table 5.

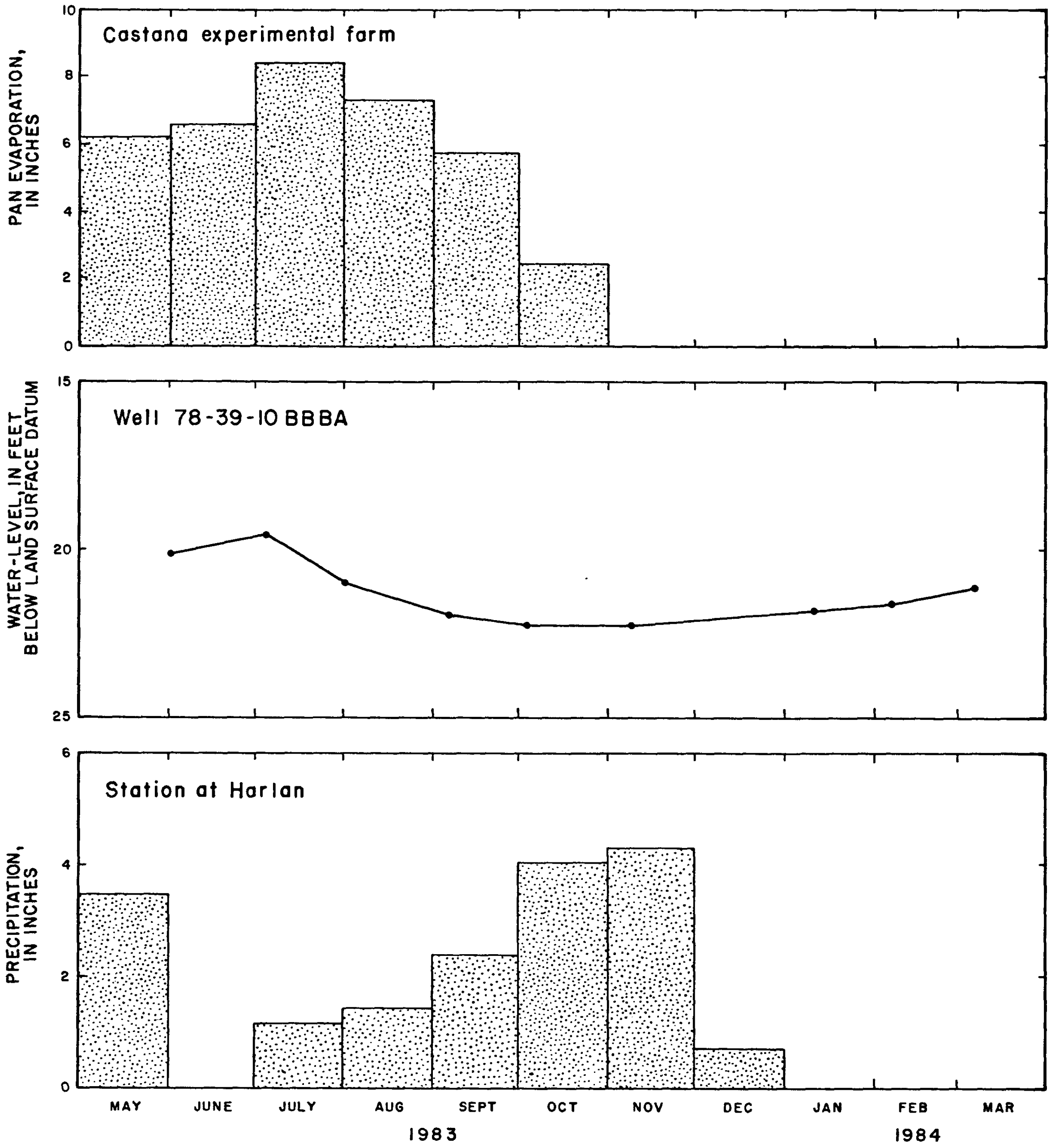
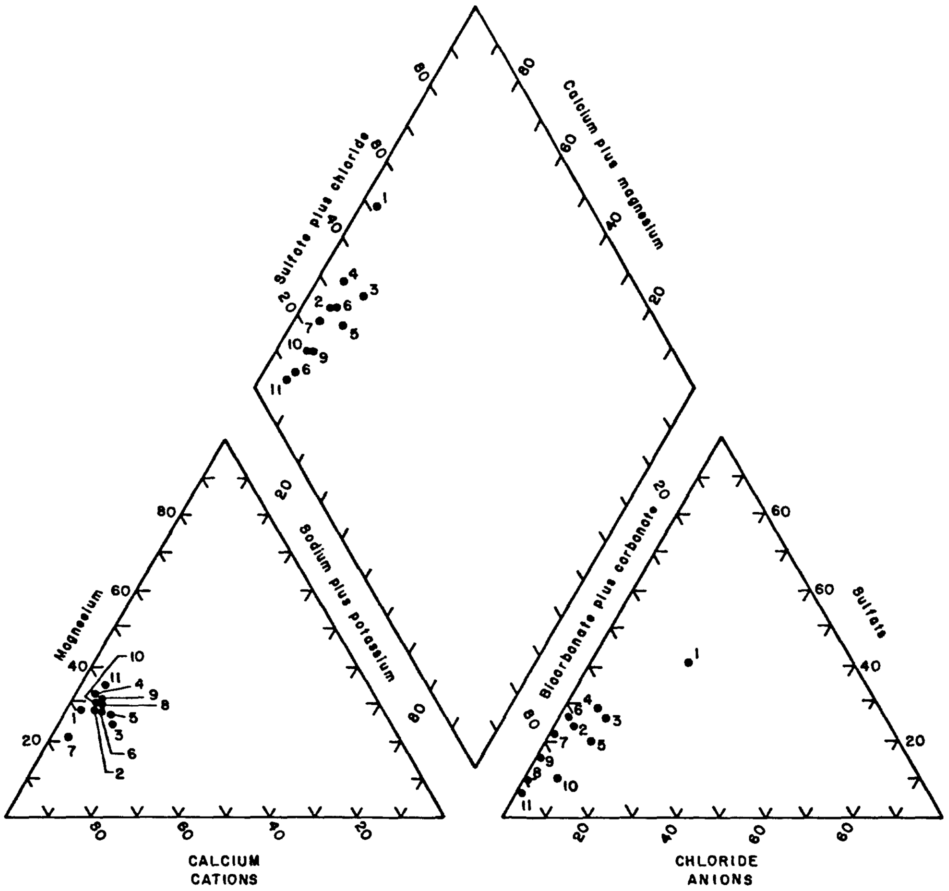


Figure 30.--Pan-evaporation data for the study area, water-table fluctuations in a well completed in the West Nishnabotna aquifer, and precipitation at Harlan.



EXPLANATION

	WELL LOCATION AND NAME		TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	82-36-17 CCAC	MANNING 2	30	654
2	82-38-26 ADDB	MANILLA 1	65	504
3	79-38-19 BDDB	HARLAN 16	35	522
4	81-39-13 CACB	DEFIANCE 2	42	666
5	81-38-36 AAAB	IRWIN 4	41	590
6	78-39-10 BBBA	IGS AND USGS WC 200	44	391
7	76-39-32 DDAA	IGS AND USGS WC 197	24	316
6	78-39-13 BCCC	IGS AND USGS WC 204	36	374
9	79-38-23 DCCC	IGS AND USGS WC 206	39	344
10	80-38-33 AABB	IGS AND USGS WC 216	41	325
11	60-38-30 ACCC	IGS AND USGS WC 221	36	534

Figure 31.--Piper diagram of water quality in the West Nishnabotna aquifer.

East Nishnabotna Aquifer

The East Nishnabotna aquifer generally ranges from less than 0.25 to 1.25 miles wide and has an areal extent of about 18 square miles in Audubon County and southwestern Carroll County (plate 1). The aquifer at 14 test holes consists of 16 to 21 feet of silty clay underlain by 3 to 31 feet of sand or sand and gravel (geohydrologic sections T-T' and U-U', fig. 32; geohydrologic section V-V', fig. 33). The sand and gravel part of the aquifer has an average thickness of 15 feet. Terrace deposits consisting of clay, silty clay, sand, and sand and gravel exist on both sides, along some segments of the East Nishnabotna aquifer. The terrace deposits (geohydrologic section T-T', fig. 32) are not adjacent or hydraulically connected to the East Nishnabotna aquifer. The terrace deposits in geohydrologic section U-U', figure 32 and figure 33, are adjacent and hydraulically connected to the aquifer.

The aquifer is underlain by glacial till (figs. 32 and 33). The aquifer is partially underlain and hydraulically connected to the Dakota aquifer (Fig. 33). In these areas, wells pumping from one or both aquifers are virtually lowering the water levels in both aquifers. Water levels in the nearby Dakota wells are slightly higher than water levels in the East Nishnabotna aquifer, indicating the Dakota aquifer is discharging into the East Nishnabotna aquifer.

Pan-evaporation data for the study area, water-table fluctuations in a well completed in the East Nishnabotna aquifer, and precipitation at Audubon are shown in figure 34. The hydrograph shows that the water level in well 79-35-15DCDD declined from July to October 1982 and May to August 1983, reflecting a combination of decreased recharge and increased discharge to evapotranspiration and to the East Nishnabotna River. The water level increased from November 1982 to January 1983, February to May 1984, and from January to March 1984. The water-level rise is interpreted to have been caused by recharge from infiltration of precipitation and the decreased discharge from evapotranspiration. The low water level in the observation well corresponds to periods of high evaporation. This indicates that water is discharging from the aquifer and is lost to evapotranspiration during these periods. Pumpage from wells completed in the East Nishnabotna aquifer also could affect water levels in the aquifer. However, pumpage information for 1982, 1983, and 1984 was not available at the time this report was prepared.

Based on an areal extent of 18 square miles, an average thickness of 15 feet, and a specific yield of 20 percent, about 35,000 acre-feet of ground water are available from storage in the East Nishnabotna aquifer. Transmissivity is estimated to be 1,500 ft^2/d using an average thickness of 15 feet and an estimated average hydraulic conductivity of 100 ft/d. Estimated yield to properly constructed wells is less than 50 gal/min (plate 1).

Analyses of five water samples from the East Nishnabotna aquifer indicate that the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation and sulfate as a significant secondary anion (fig. 35). In some water samples the following constituents exceeded secondary drinking-water standards: dissolved-solids concentrations ranged from 452 to 706 mg/L and exceeded the 500 mg/L standard in four samples; iron ranged from less than 50 to 8,600 ug/L and exceeded the 300 mg/L standard in three samples; and manganese ranged from 390 to 1,600 ug/L and exceeded the 50 ug/L standard in all five samples.

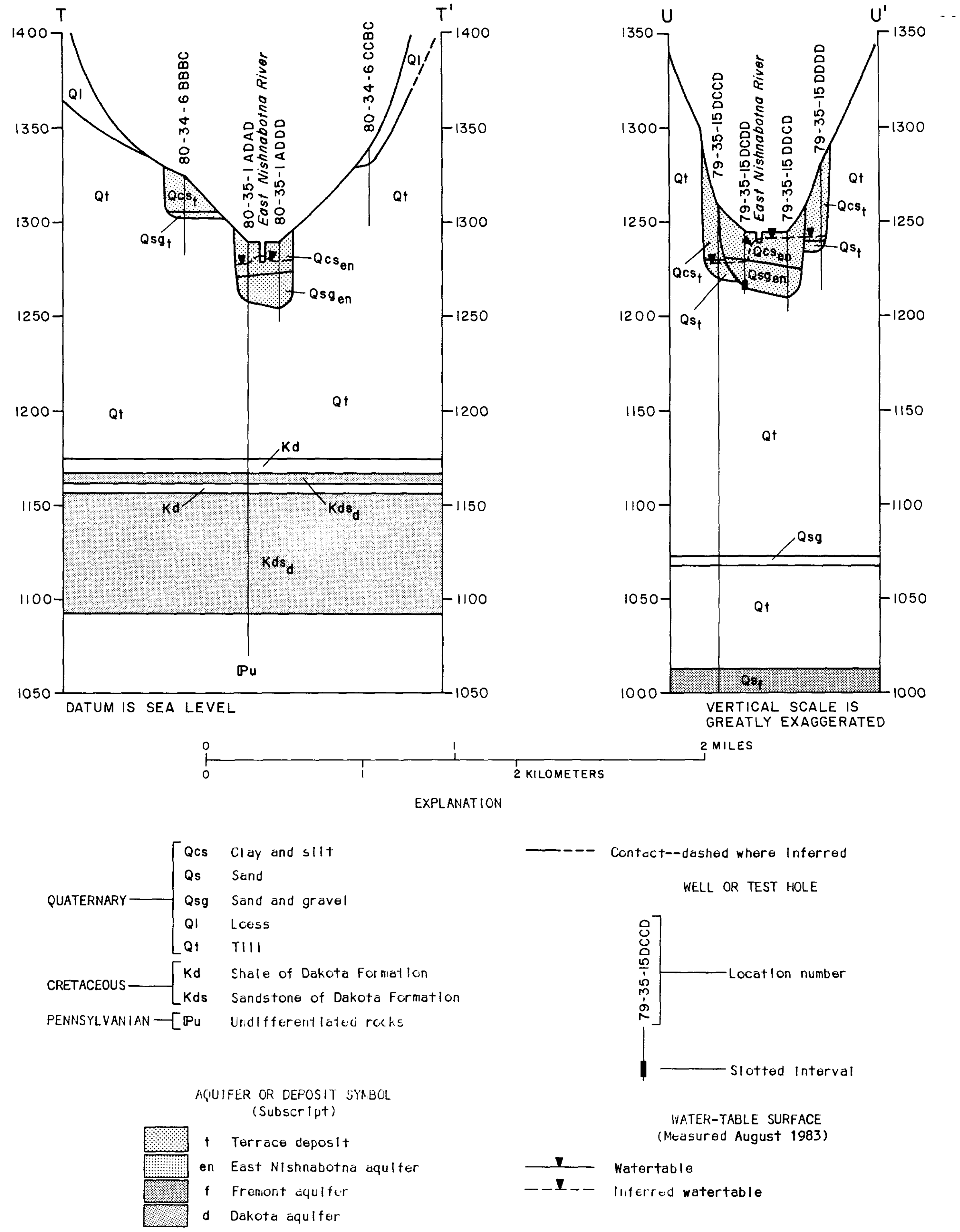


Figure 32.--Geohydrologic sections T-T' and U-U' of the East Nishnabotna, Fremont, and Dakota aquifers.

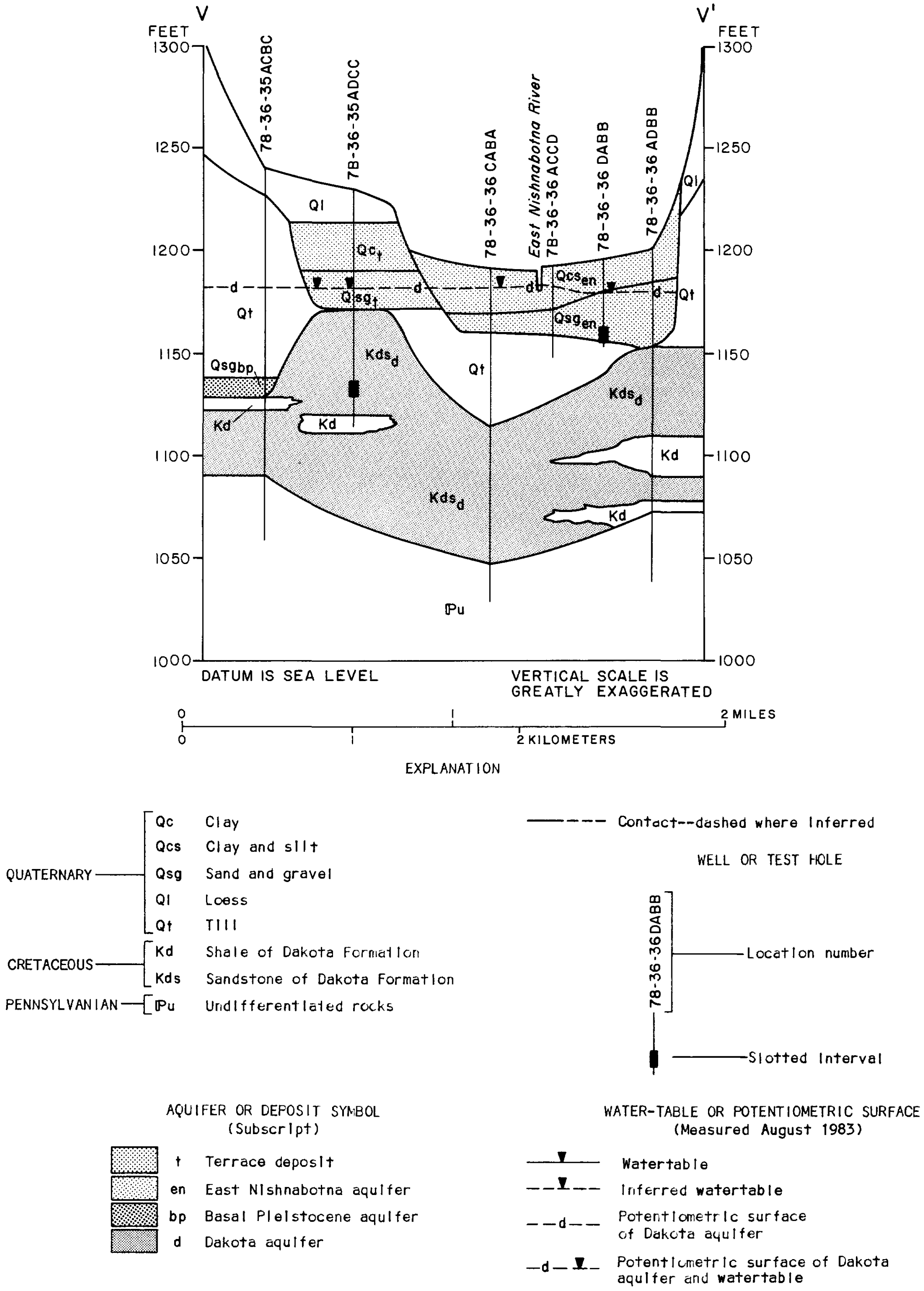


Figure 33.--Geohydrologic section V-V' of the East Nishnabotna, basal Pleistocene, and Dakota aquifers.

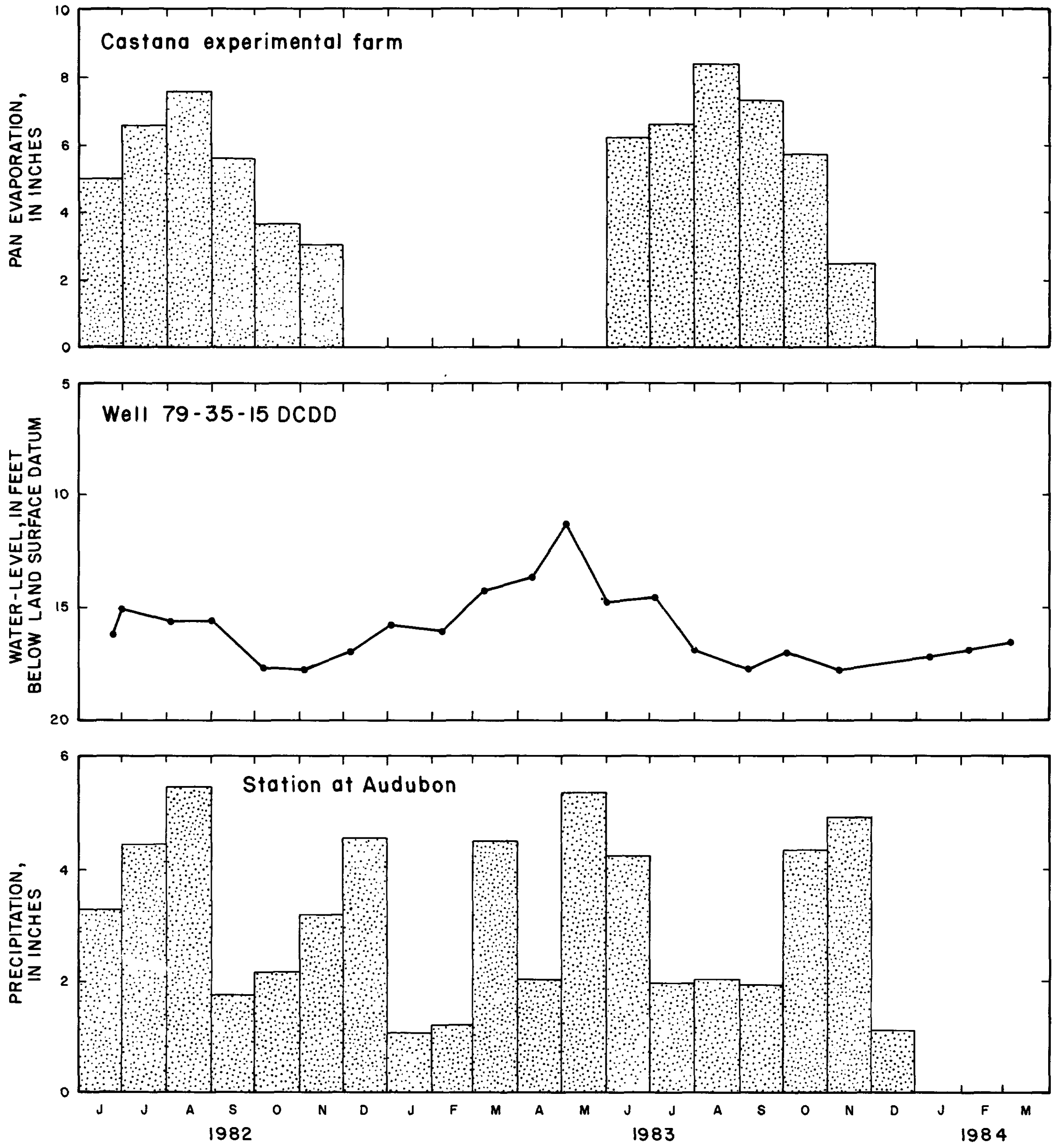
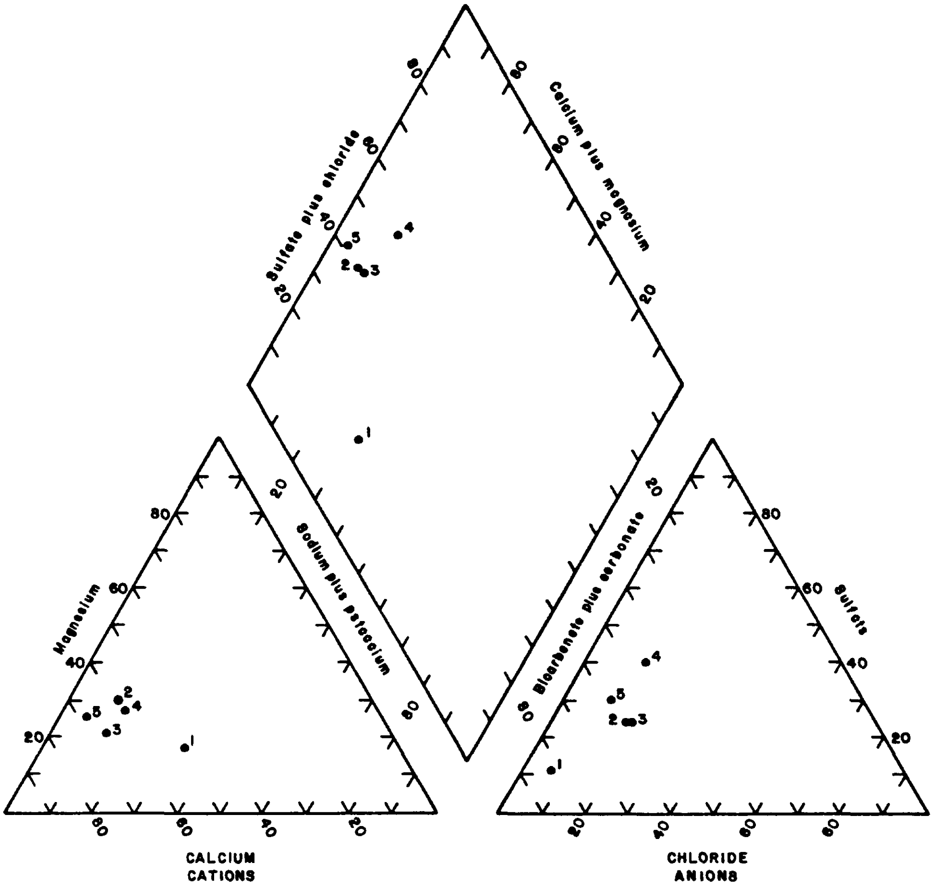


Figure 34.--Pan-evaporation data for the study area, water-table fluctuations in a well completed in the East Nishnabotna aquifer, and precipitation at Audubon.



EXPLANATION

	WELL LOCATION AND NAME		TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 106° CELSIUS, IN MILLIGRAMS PER LITER
1	80-35-26CDDA	AUDUBON TOWN WELL 19	30	452
2	78-35-19BCDB	BRAYTON	40	706
3	78-35- 4BCBD	EXIRA II	60	612
4	78-36-36DABB	IGS AND USGS WC 71	39	512
5	79-35-15DCDD	IGS AND USGS WC 75	30	525

Figure 35.--Piper diagram of water quality in East Nishnabotna aquifer.

The Dakota and East Nishnabotna aquifers (geohydrologic section T-T', fig. 32), probably are hydraulically connected and have similar water types. Water from the Dakota aquifer has slightly smaller concentrations of dissolved solids, sulfate, calcium, sodium, and magnesium and less hardness than water from the East Nishnabotna aquifer. No differences in water quality are apparent between water from the East Nishnabotna aquifer in areas where it is underlain by glacial till or the Dakota aquifer.

Audubon, Brayton, and Exira used 181.2 Mgal of water from the East Nishnabotna aquifer. Municipal-water withdrawals are shown on plate 1 and in table 5. About 2 percent of the water stored in the East Nishnabotna aquifer is withdrawn by towns every year.

South Raccoon Aquifer

The South Raccoon aquifer is the alluvial aquifer associated with the South Raccoon River and Brushy Creek in Guthrie County, Carroll County, and extreme tip of northeastern Audubon County (plate 1). The South Raccoon aquifer is much narrower in width than the other alluvial aquifers in west-central Iowa. It generally is from less than 0.125 to 0.75 mile wide and has an areal extent of about 38 square miles. The South Raccoon River deeply incises the Cretaceous and Pennsylvanian bedrock. It has not developed the broad flood plains and aquifer thickness of the other aquifers, and its gradient is much steeper than the other alluvial aquifers. The aquifer at 15 test holes consists of 2 to 27 feet of silty clay underlain by 1 foot to 17 feet of sand and gravel (geohydrologic sections W-W' and X-X', fig. 36; geohydrologic sections Y-Y' and Z-Z', fig. 37). The sand and gravel part of the aquifer has an average thickness of 10 feet. Terrace deposits consisting of silty clay and sand and gravel exist on one or both sides along some segments of the South Raccoon aquifer (fig. 37). The terrace deposits shown in geohydrologic-section Y-Y' are not adjacent or hydraulically connected to the aquifer; however, the terrace deposit shown in geohydrologic-section Z-Z' is adjacent and hydraulically connected to the aquifer.

Where the South Raccoon aquifer is underlain or adjacent to the Dakota aquifer (geohydrologic section Y-Y', fig. 36; fig. 37), the water levels in Dakota aquifer wells are higher than the water levels in the South Raccoon aquifer, indicating that the Dakota aquifer is discharging into the South Raccoon aquifer. The Dakota aquifer and South Raccoon aquifer are hydraulically connected in areas where the South Raccoon aquifer is underlain by the Dakota aquifer. In these areas, wells pumping from one or both aquifers virtually are lowering the water levels in both aquifers. The aquifer is underlain by Pennsylvanian rock (fig. 37).

Pan-evaporation data for the study area, water-table fluctuations in a well completed in the South Raccoon aquifer, and precipitation at Guthrie Center are shown in figure 38. The hydrograph shows that the water level in well 79-31-23BBBB declined from July to November 1982 and from July to October 1983. Water levels that usually decline during this time reflect a combination of decreased recharge and increased discharge to evapotranspiration and to the South Raccoon River. The water level increased from November to January 1982, from March to April 1983, and from October 1983 to March 1984. The water-level rise is interpreted to have been caused by recharge from the infiltration of precipitation and decreased discharge of evapotranspiration. Water levels that

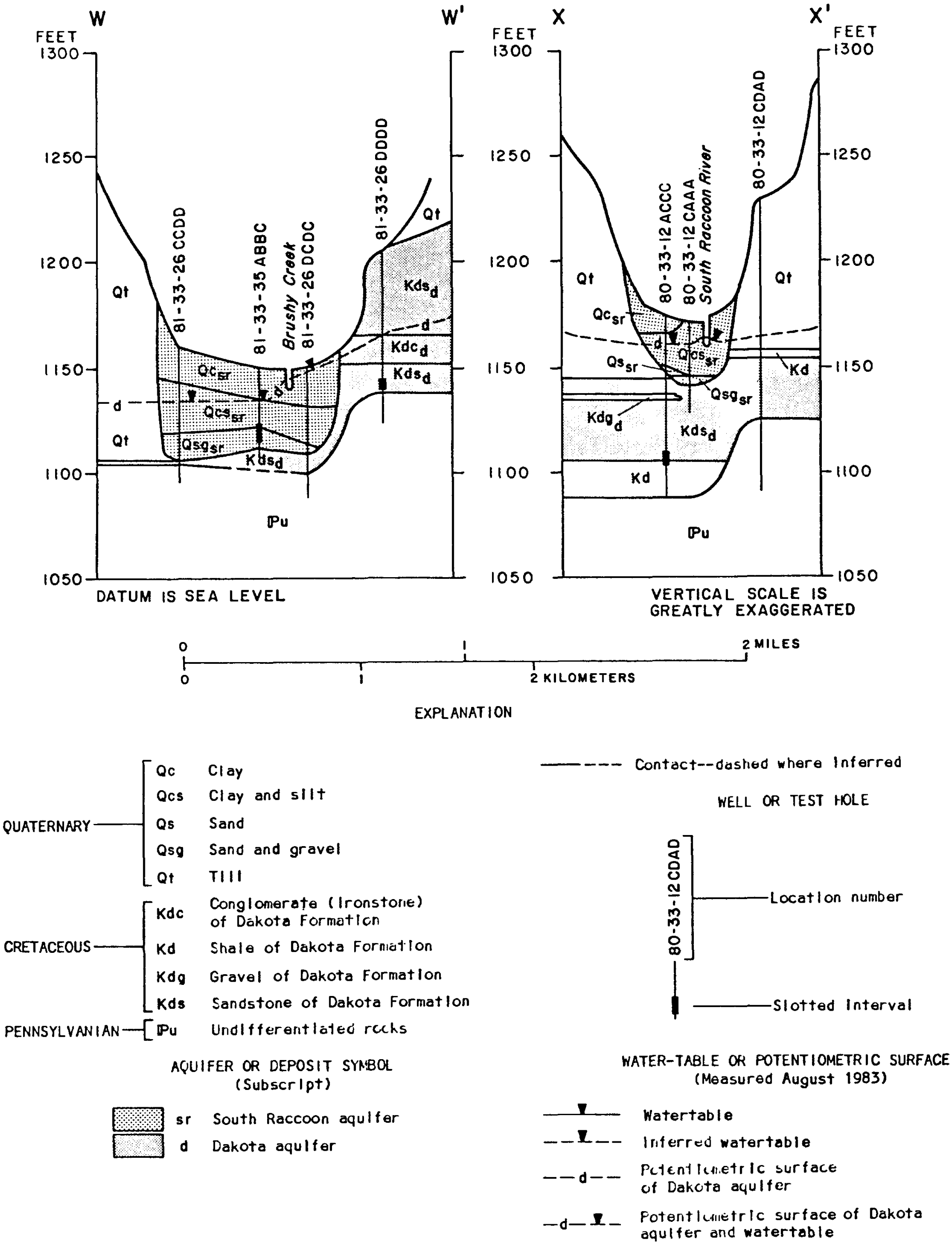
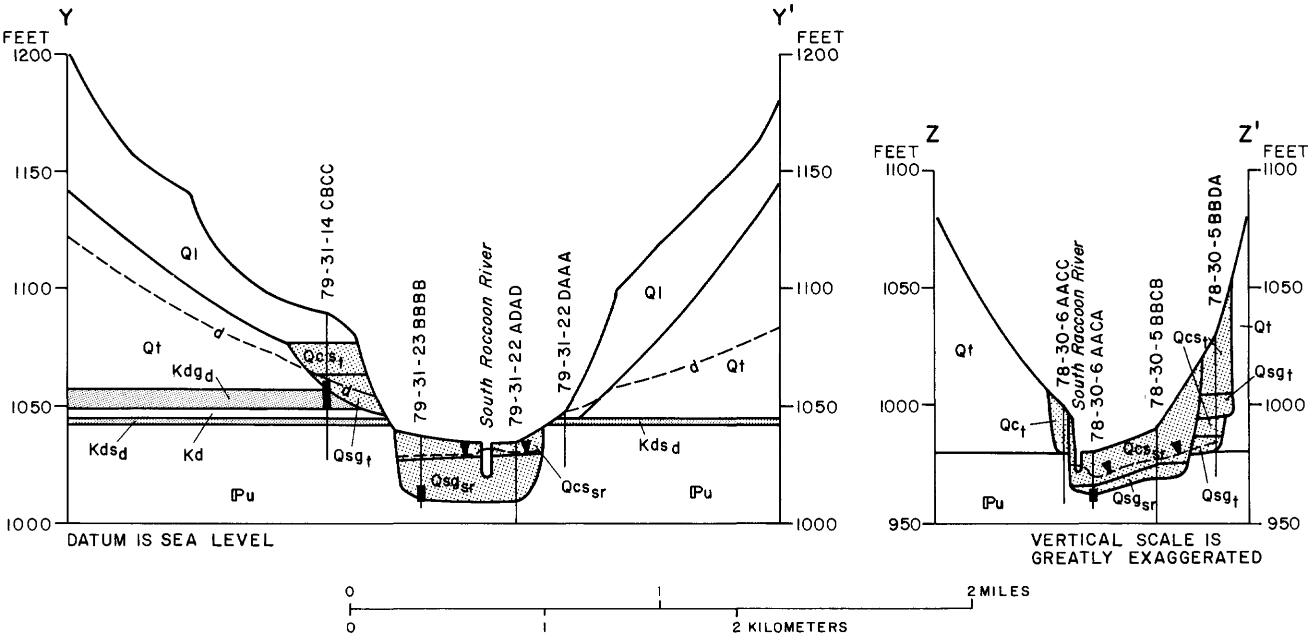


Figure 36.--Geohydrologic sections W-W' and X-X' of the South Raccoon and Dakota aquifers.



EXPLANATION

QUATERNARY	Qc	Clay
	Qcs	Clay and silt
	Qsg	Sand and gravel
	Ql	Loess
	Qt	Till
CRETACEOUS	Kd	Shale of Dakota Formation
	Kdg	Gravel of Dakota Formation
	Kds	Sandstone of Dakota Formation
PENNSYLVANIAN	IPu	Undifferentiated rocks

AQUIFER OR DEPOSIT SYMBOL
(Subscript)

▤	t	Terrace deposit
▤	sr	South Raccoon aquifer
▨	d	Dakota aquifer

——— – – – Contact--dashed where inferred

WELL OR TEST HOLE

79-31-14 CBCC ——— Location number

——— Slotted interval

WATER-TABLE OR POTENTIOMETRIC SURFACE
(Measured August 1983)

—▼— Watertable

– –▼– – Inferred watertable

– –d– – Potentiometric surface of Dakota aquifer

–d—▼– Potentiometric surface of Dakota aquifer and watertable

Figure 37.--Geohydrologic sections Y-Y' and Z-Z' of the South Raccoon and Dakota aquifers.

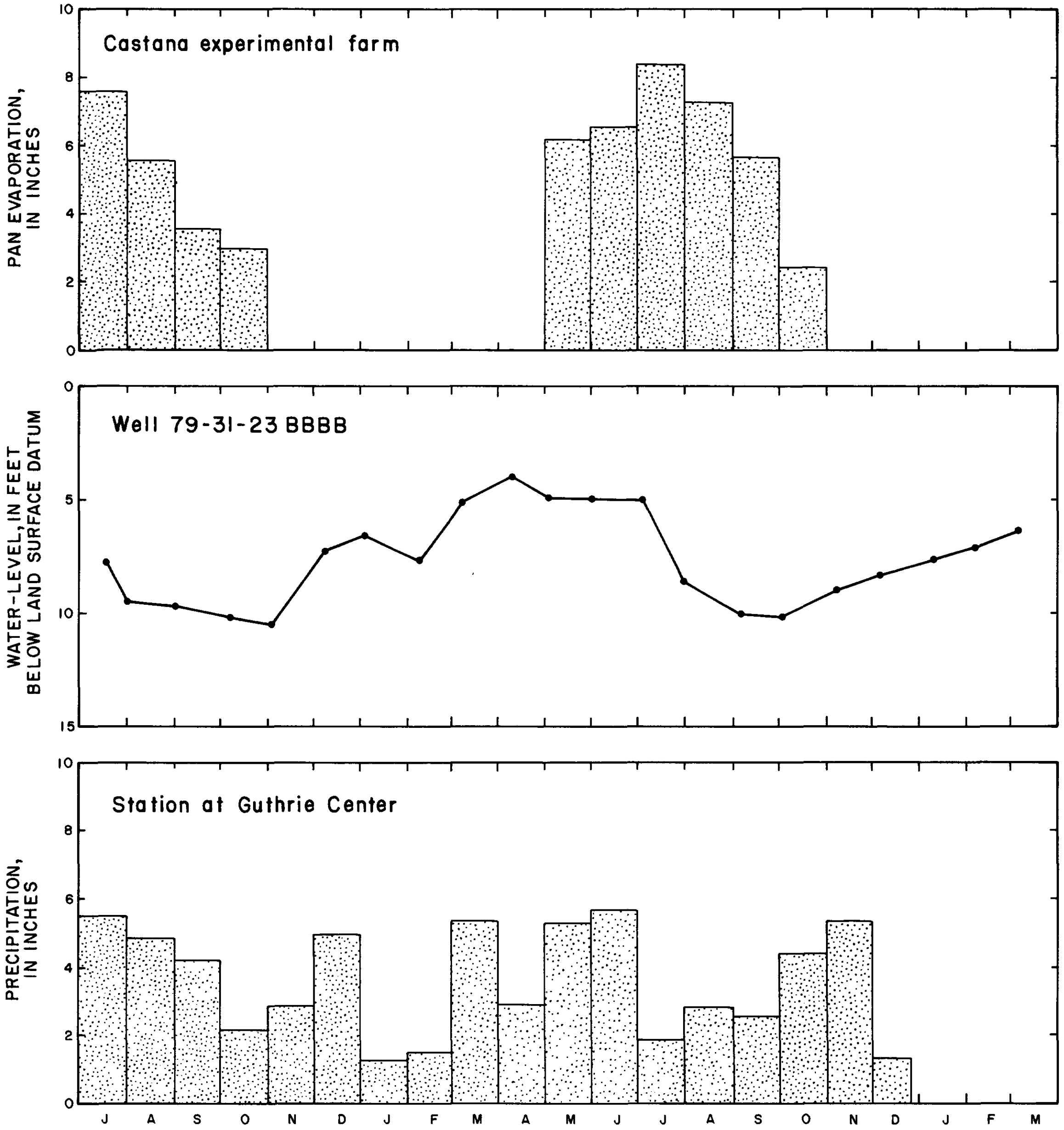


Figure 38.--Pan-evaporation data for the study area, water-table fluctuations in a well completed in the South Raccoon aquifer, and precipitation at Guthrie Center.

usually decline during this time reflect a combination of decreased recharge and increased discharge to evapotranspiration and to the river. The low water level in the observation well corresponds to periods of large evaporation. This indicates that water is discharging from the aquifer and is lost to evapotranspiration during these periods. Pumpage from wells completed in the South Raccoon aquifer also could affect water levels in the aquifer. However, pumpage information for 1982, 1983, and 1984 was not available at the time this report was prepared.

Based on an areal extent of 38 square miles, an average thickness of 10 feet, and a specific yield of 25 percent, about 61,000 acre-feet of ground water are available from storage in the South Raccoon aquifer. Transmissivity is estimated to be 1,350 ft^2/d using an average thickness of 10 feet and an estimated hydraulic conductivity of 135 ft/d. Estimated yield to wells generally would be less than 50 gal/min (plate 1).

Analyses of four water samples from the South Raccoon aquifer indicate that the water is moderately hard to very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 39). Dissolved-solids concentrations ranged from 156 to 390 mg/L with an average of 258 mg/L. In some water samples the following constituents exceeded secondary drinking-water standards: iron ranged from less than 50 to 14,000 ug/L and exceeded the standard in three samples, and manganese ranged from 94 to 1,200 ug/L and exceeded the standard in all four samples.

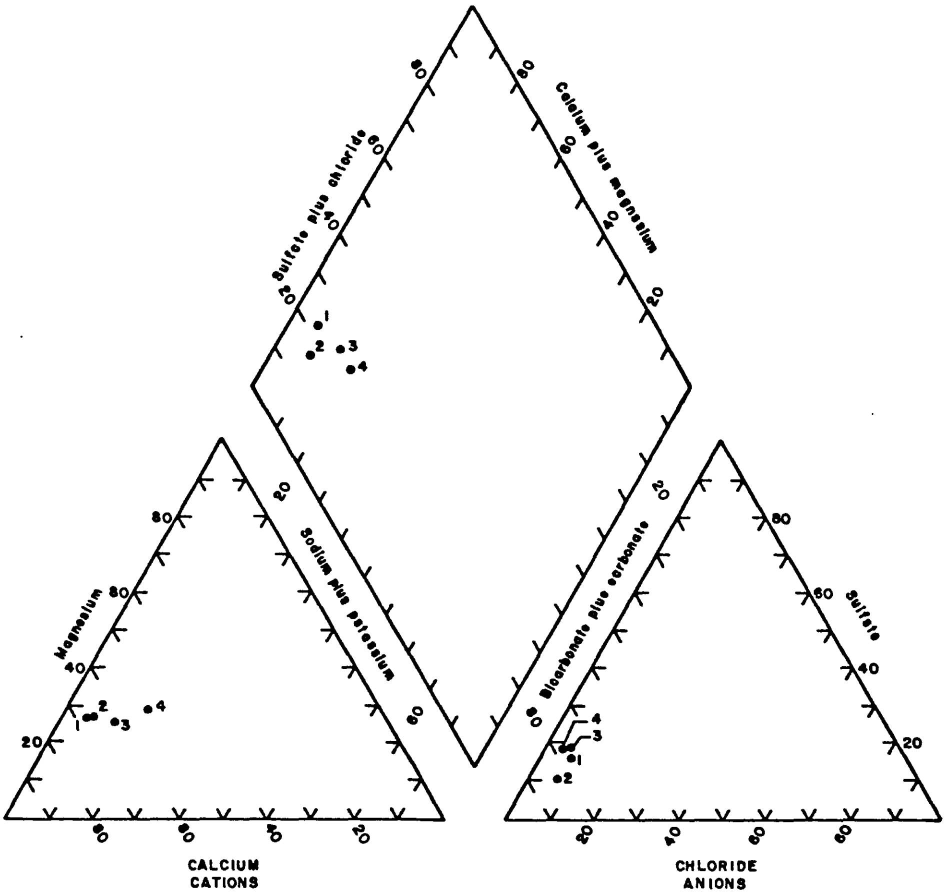
The South Raccoon aquifer has the best water quality of the alluvial aquifers in west-central Iowa. This aquifer has, on the average, one-half the dissolved-solids concentration that the other alluvial aquifers have. This probably is a result of the shorter residence time of the water in the South Raccoon aquifer because the aquifer is thinner, narrower, and has a much steeper gradient than the other alluvial aquifers.

The South Raccoon and Dakota aquifers in geohydrologic section W-W' (fig. 36) are hydraulically connected and have similar water types. The only difference is that water from the Dakota aquifer has a slightly larger dissolved-solids concentration that water from the South Raccoon aquifer.

Dedham and Guthrie Center used 52.8 Mgal of water from the South Raccoon aquifer. Guthrie Center obtains water from both the South Raccoon and the Dakota aquifers. Municipal-water withdrawals are shown on plate 1 and in table 5.

Middle Raccoon Aquifer

The Middle Raccoon aquifer generally ranges from 0.25 to 1.25 miles wide and has an areal extent of about 26 square miles (excluding Lake Panorama) in Guthrie and Carroll Counties (plate 1). The Middle Raccoon River marks the southernmost extent of the last glacial advance in west-central Iowa. The landform region to the northeast is the poorly drained Des Moines Lobe and to the southwest is the well-drained Southern Iowa Drift Plain (fig. 1). The aquifer at 31 test holes consists of 5 to 31 feet of silty clay underlain by 4 to 48 feet of sand or sand and gravel (geohydrologic sections AA-AA' and BB-BB', fig. 40; geohydrologic section CC-CC', fig. 41; geohydrologic section DD-DD',



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	82-34-17DDBA DEDHAM 4	45	390
2	81-33-35ABBC IGS AND USGS WC 94	35	238
3	78-30-8AACA IGS AND USGS WC 88	22	246
4	79-31-23BBBB IGS AND USGS WC 85	27	156

Figure 39.--Piper diagram of water quality in the South Raccoon aquifer.

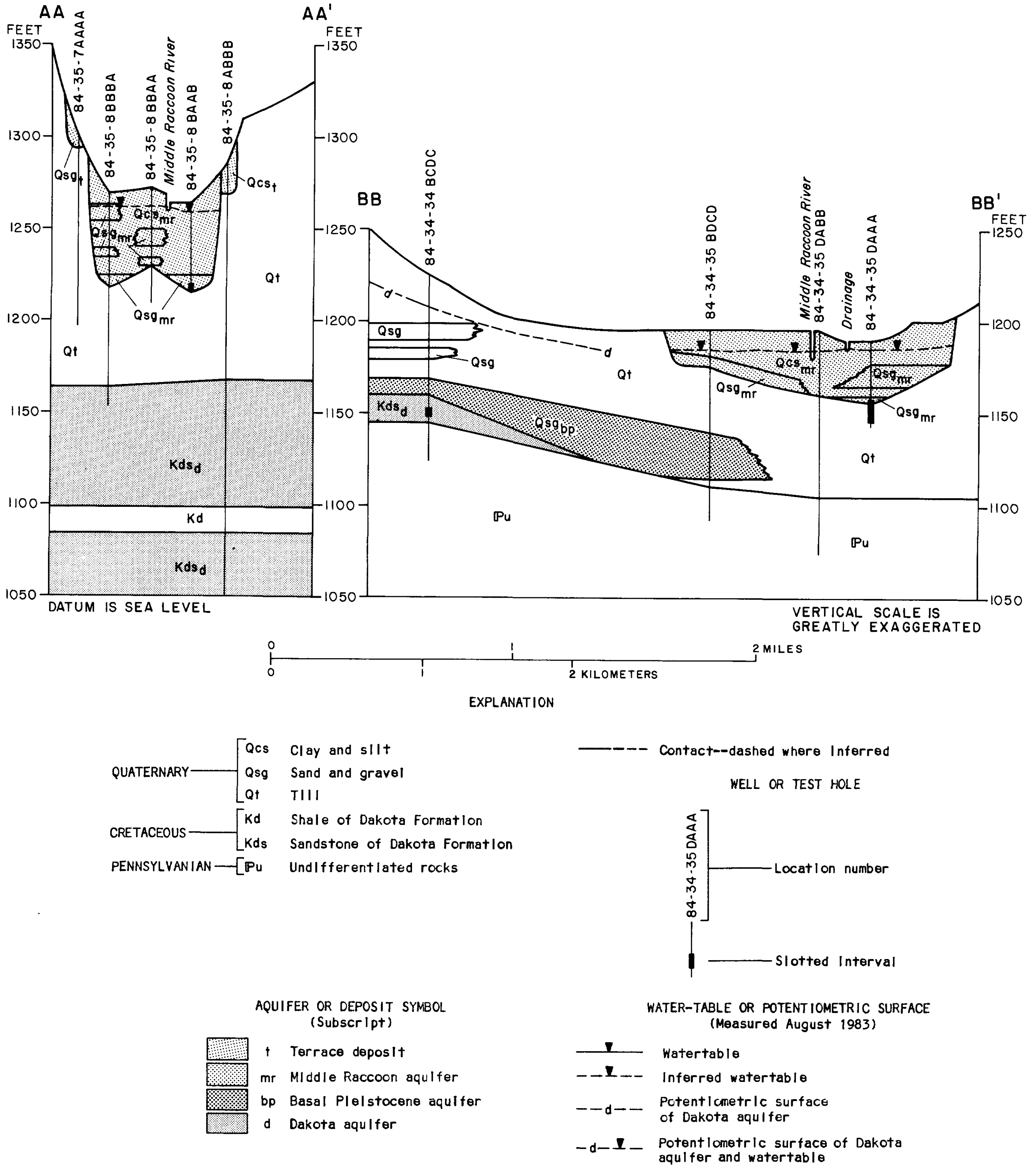


Figure 40.--Geohydrologic sections AA-AA' and BB-BB' of the Middle Raccoon, basal Pleistocene, and Dakota aquifers.

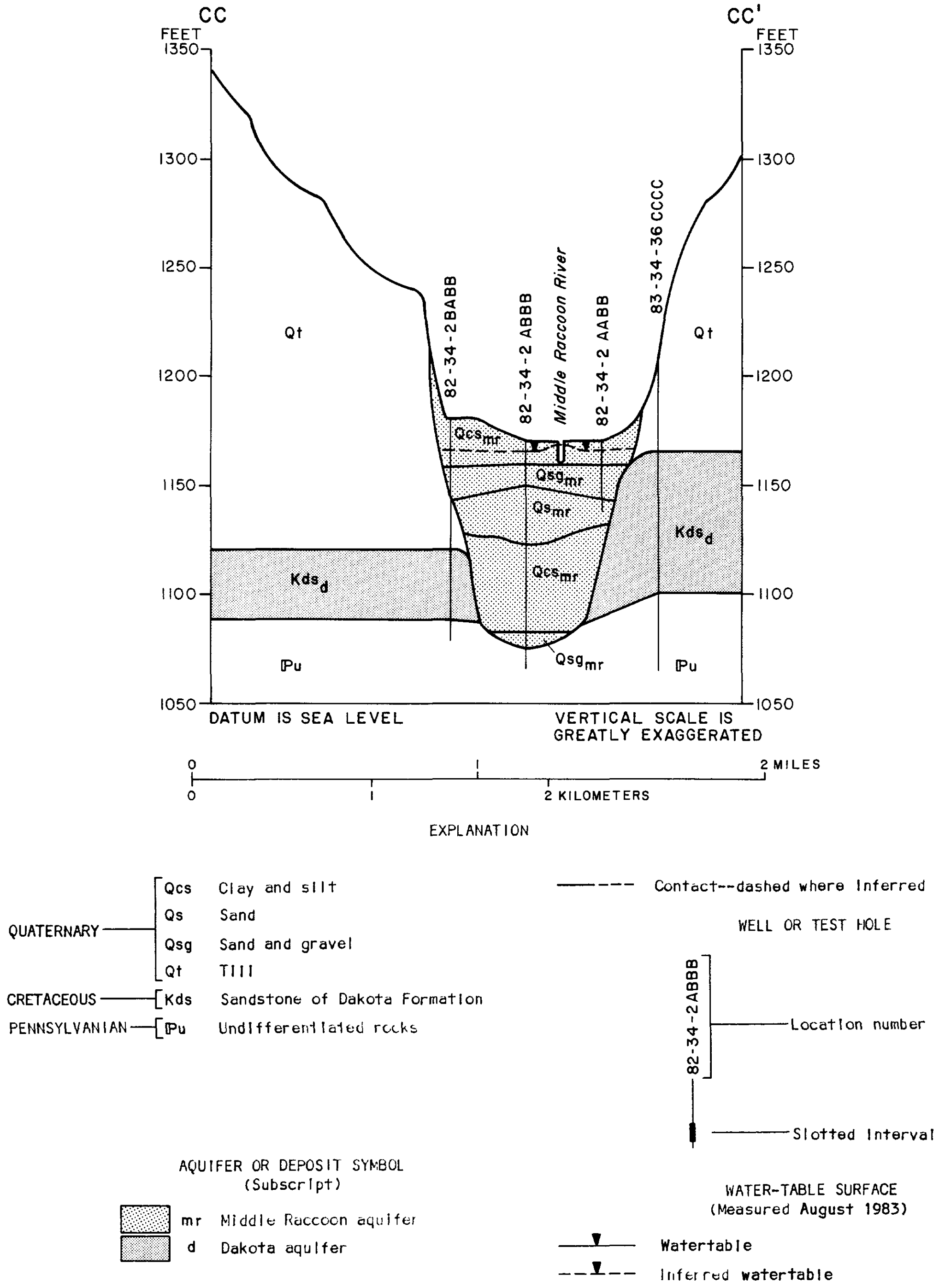


Figure 41.--Geohydrologic section CC-CC' of the Middle Raccoon and Dakota aquifers.

fig. 42; geohydrologic sections EE-EE' and FF-FF', fig. 43). The sand and gravel part of the aquifer has as average thickness of 16 feet. Terrace deposits consisting of silty clay and sand and gravel exist on one or both sides along some segments of the Middle Raccoon aquifer but are not hydraulically connected to the aquifer.

The Middle Raccoon aquifer is underlain by glacial till as shown in figure 40. The aquifer is underlain by Pennsylvanian rock (figs. 41, 42, and 43) and is adjacent and hydraulically connected to the Dakota aquifer in geohydrologic sections CC-CC' and EE-EE'. In these areas, the water levels in Dakota aquifer wells are higher than water levels in the Middle Raccoon aquifer, indicating that the Dakota aquifer is discharging into the Middle Raccoon aquifer. Wells pumping from one or both aquifers virtually are lowering the water levels in both aquifers.

Pan-evaporation data for the study area, water-table fluctuations in a well completed in the Middle Raccoon aquifer, and Middle Raccoon River discharge near Bayard are shown in figure 44. The hydrograph shows that the water level in well 81-31-32CBCC declined from August to October 1982 and from July to September 1983, reflecting a combination of decreased recharge and increased discharge to evapotranspiration and to the river. The water levels increased from October to December 1982, in February and April 1983, from October to December 1983, and February to March 1984. These water-level rises are interpreted to have been caused by recharge from infiltration of precipitation and decreased discharge to evapotranspiration. The low water level corresponds to periods of small discharge in the Middle Raccoon River. Water flowing in the river during these low-flow periods probably is provided by water discharging from the Middle Raccoon aquifer. The low water level in the observation well corresponds to periods of large evaporation. This indicates that water is discharging from the aquifer and is lost to evapotranspiration during these periods. Pumpage from wells completed in the Middle Raccoon aquifer also could affect water levels in the aquifer. However, pumpage information for 1982, 1983, and 1984 was not available at the time this report was prepared.

Based on an areal extent of 26 square miles, an average thickness of 16 feet, and a specific yield of 20 percent, about 54,000 acre-feet of ground water are available from storage in the Middle Raccoon aquifer. Transmissivity is estimated to be 1,600 ft^2/d using an average thickness of 16 feet and an estimated hydraulic conductivity of 100 ft/d. Estimated yield to ideally constructed wells generally would be less than 50 gal/min (plate 1).

Analyses of four water samples from the Middle Raccoon aquifer indicate the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 45). Dissolved-solids concentrations ranged from 283 to 460 mg/L with an average of 388 mg/L. In one water sample from well 82-34-2ABBB, the barium concentration was the same as the primary drinking-water standard of 1,000 ug/L. In some water samples the following constituents exceeded secondary drinking-water standards: iron ranged from 10 to 8,000 ug/L and exceeded the 300 ug/L standard in three samples, and manganese ranged from 10 to 620 ug/L and exceeded the 50 ug/L standard in three samples.

The water in the Middle Raccoon aquifer and underlying Dakota aquifer virtually is the same type. This indicates that the aquifers are hydraulically connected.

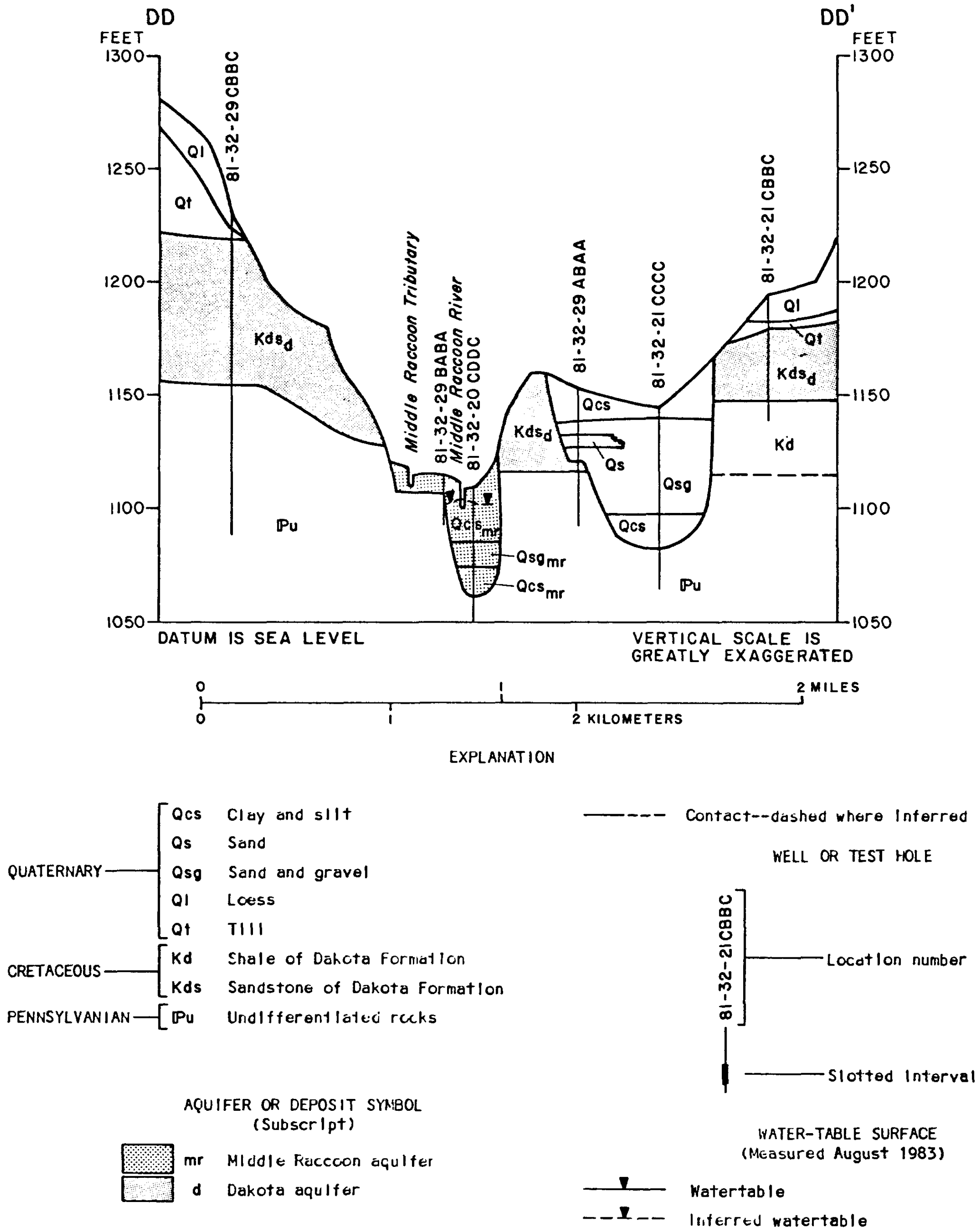


Figure 42.--Geohydrologic section DD-DD' of the Middle Raccoon and Dakota aquifers.

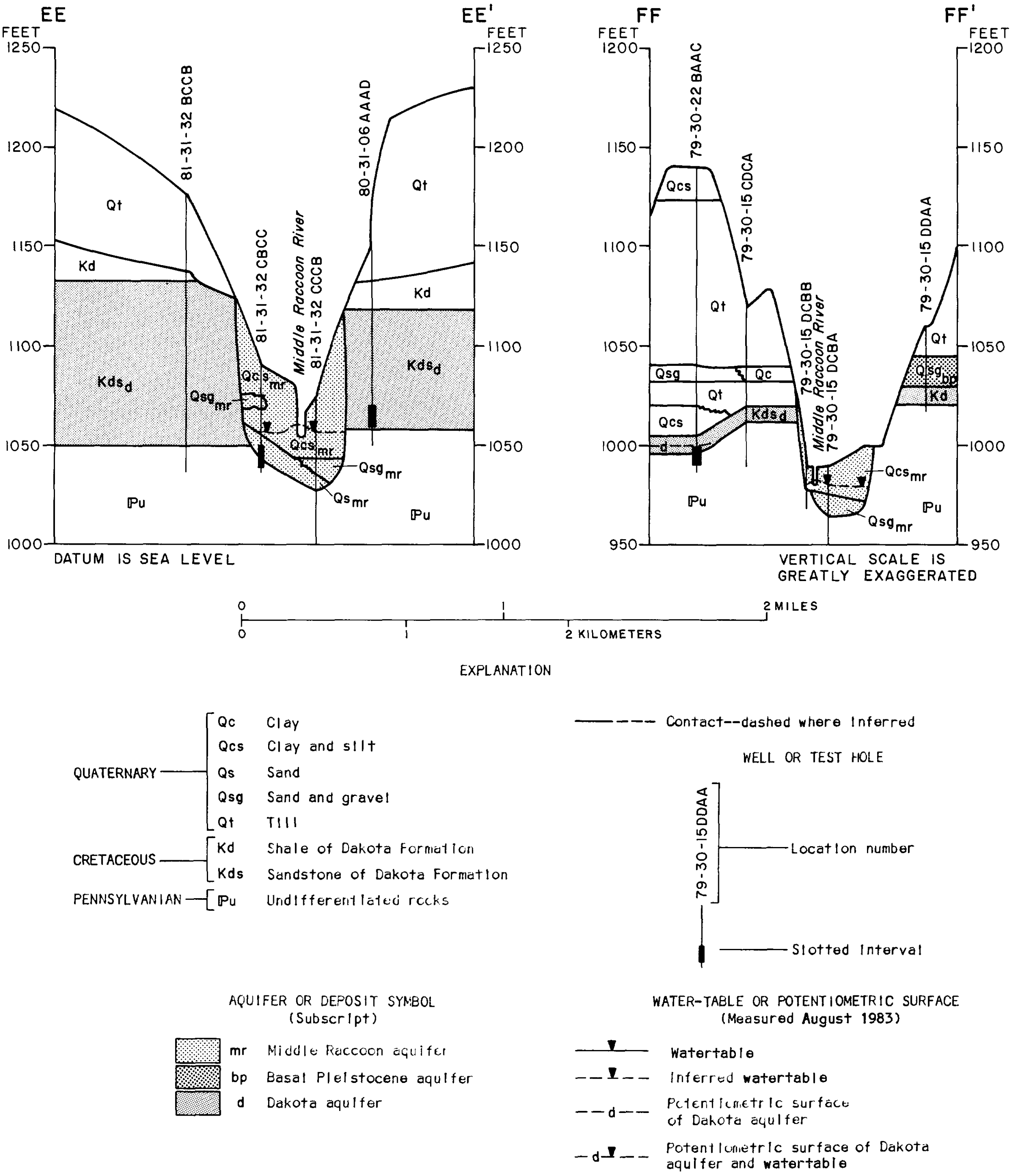


Figure 43.--Geohydrologic sections EE-EE' and FF-FF' of the Middle Raccoon, basal Pleistocene, and Dakota aquifers.

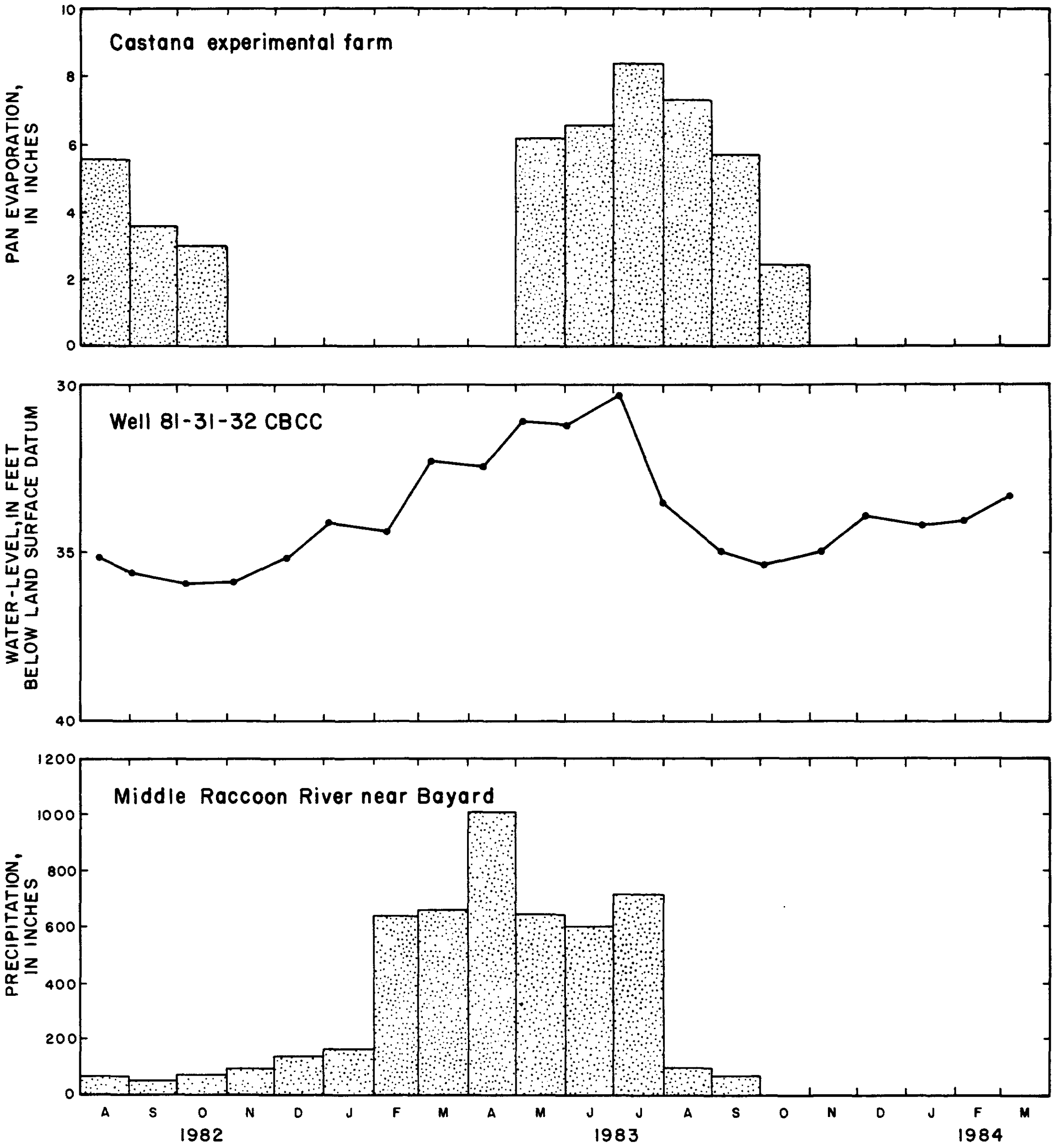
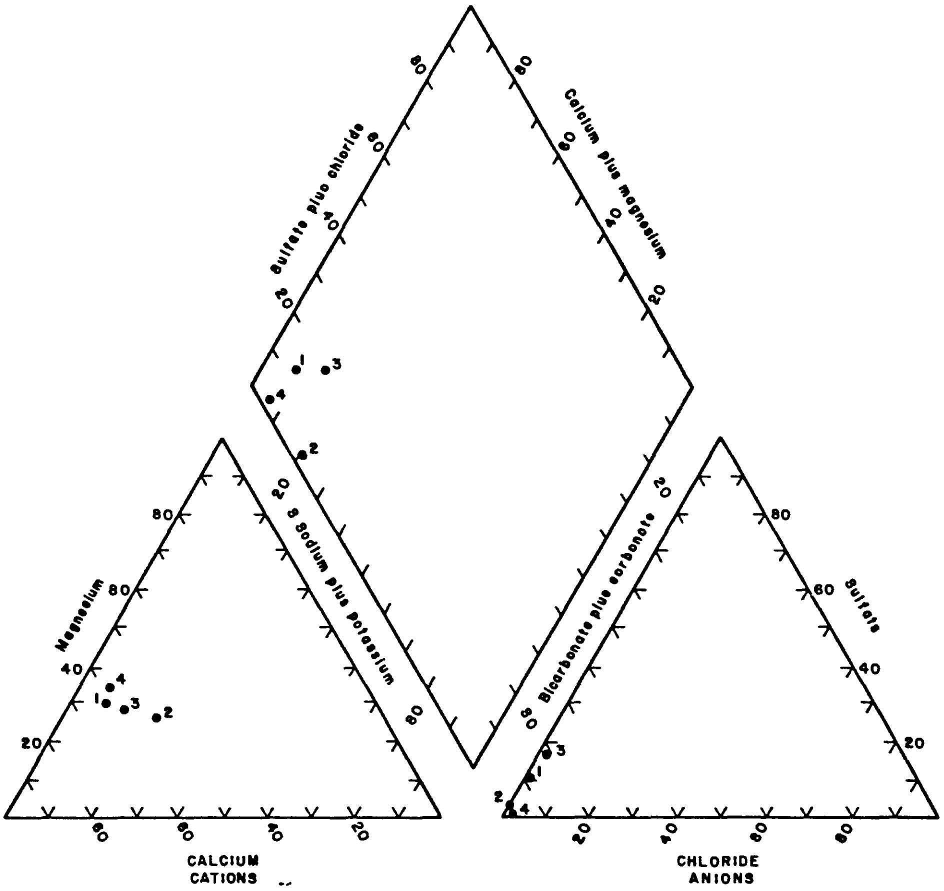


Figure 44.--Pan-evaporation data for the study area, water-table fluctuations in a well completed in the Middle Raccoon aquifer, and the Middle Raccoon River discharge near Bayard.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	84-35-8BAAB IGS AND USGS WC 141	48	361
2	82-34-2ABBB IGS AND USGS WC 149	105	449
3	82-34-2AABB IGS AND USGS WC 152	31	480
4	81-31-32CBCC IGS AND USGS WC 106	51	283

Figure 45.--Piper diagram of water quality in the Middle Raccoon aquifer.

Carroll obtains water from both the Middle Raccoon and the Dakota aquifers. Municipal-water withdrawals are shown on plate 1 and in table 5.

North Raccoon Aquifer

The North Raccoon aquifer generally ranges from 0.5 to 1.25 miles wide and has an areal extent of about 30 square miles in Greene County and northeastern Carroll County (plate 1). The North Raccoon drainage basin is in the poorly drained Des Moines Lobe. The aquifer at 24 test holes consists of 1 foot to 21 feet of silty clay underlain by 3 to 37 feet of sand and gravel (geohydrologic section GG-GG', fig. 46; geohydrologic section HH-HH', fig. 47; geohydrologic sections II-II' and JJ-JJ', fig. 48; geohydrologic section KK-KK', fig. 49). The sand and gravel part of the aquifer has an average thickness of 15 feet. Terrace deposits consisting of sand and sand and gravel exist on one or both sides along some segments of the North Raccoon aquifer but are not adjacent or hydraulically connected to the aquifer.

The North Raccoon aquifer is underlain by glacial till (figs. 46 and 47; geohydrologic section JJ-JJ', fig. 48; fig. 49). In geohydrologic section II-II' the west side of the North Raccoon aquifer is underlain by glacial till and the east side is underlain by the Dakota aquifer, and in geohydrologic section JJ-JJ' the Dakota aquifer is adjacent to the south side of the aquifer (fig. 48). The North Raccoon aquifer and Dakota aquifer are hydraulically connected where the North Raccoon aquifer is underlain by the Dakota aquifer. In these areas, wells pumping from one or both aquifers are lowering the water levels in both aquifers. In geohydrologic section II-II' (fig. 48), the water level in the Dakota aquifer is slightly higher than the water level in the North Raccoon aquifer, indicating that the Dakota aquifer is discharging into the North Raccoon aquifer.

Pan-evaporation data in the study area, water-table fluctuations in a well completed in the North Raccoon aquifer, and the North Raccoon River discharge at Jefferson are shown in figure 50. The hydrograph shows that the water level in well 82-29-18CBAA increased from September through November 1982, from February through March 1983, in June and November 1983, and February 1984. These water-level rises are interpreted to have been caused by recharge from the infiltration of precipitation and decreased discharge to evapotranspiration. The graph also shows that the water level in the well declined from April to May, and from July to October 1983 reflecting a combination of decreased recharge and increased discharge to evapotranspiration and to the river. In general, the low water level in the aquifer corresponds to periods of smaller discharge in the North Raccoon River. Water flowing in the river during low-flow periods probably is provided by water discharging from the North Raccoon aquifer. The low water level in the observation well corresponds to periods of large evaporation. This indicates that water is discharging from the aquifer and is lost to evapotranspiration during these periods. Pumpage from wells completed in the North Raccoon aquifer also could affect water levels in the aquifer. However, pumpage information for 1983 and 1984 was not available at the time this report was prepared.

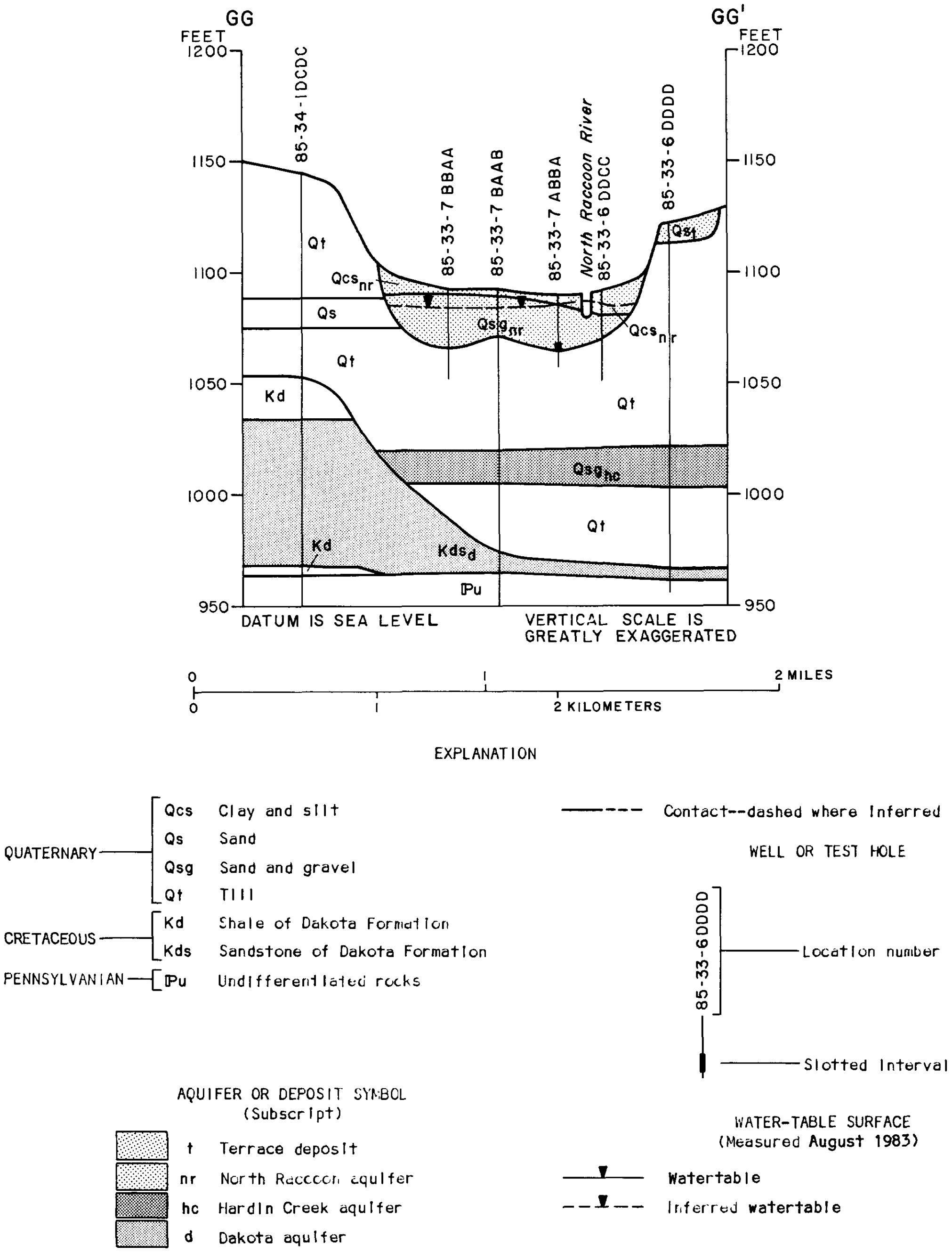


Figure 46.--Geohydrologic section GG-GG' of the North Raccoon, Hardin Creek, and Dakota aquifers.

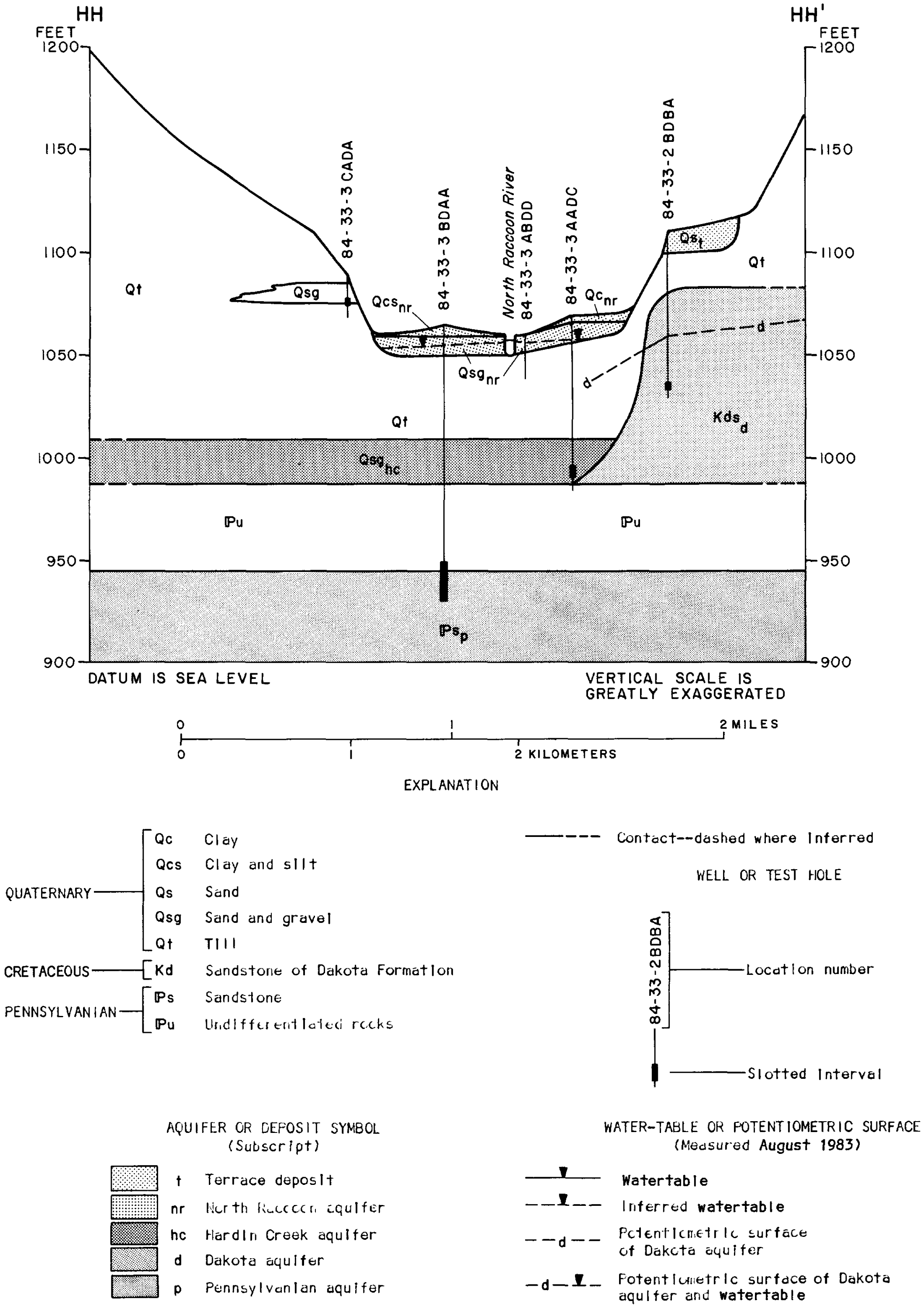


Figure 47.--Geohydrologic section HH-HH' of the North Raccoon, Hardin Creek, and Dakota aquifers.

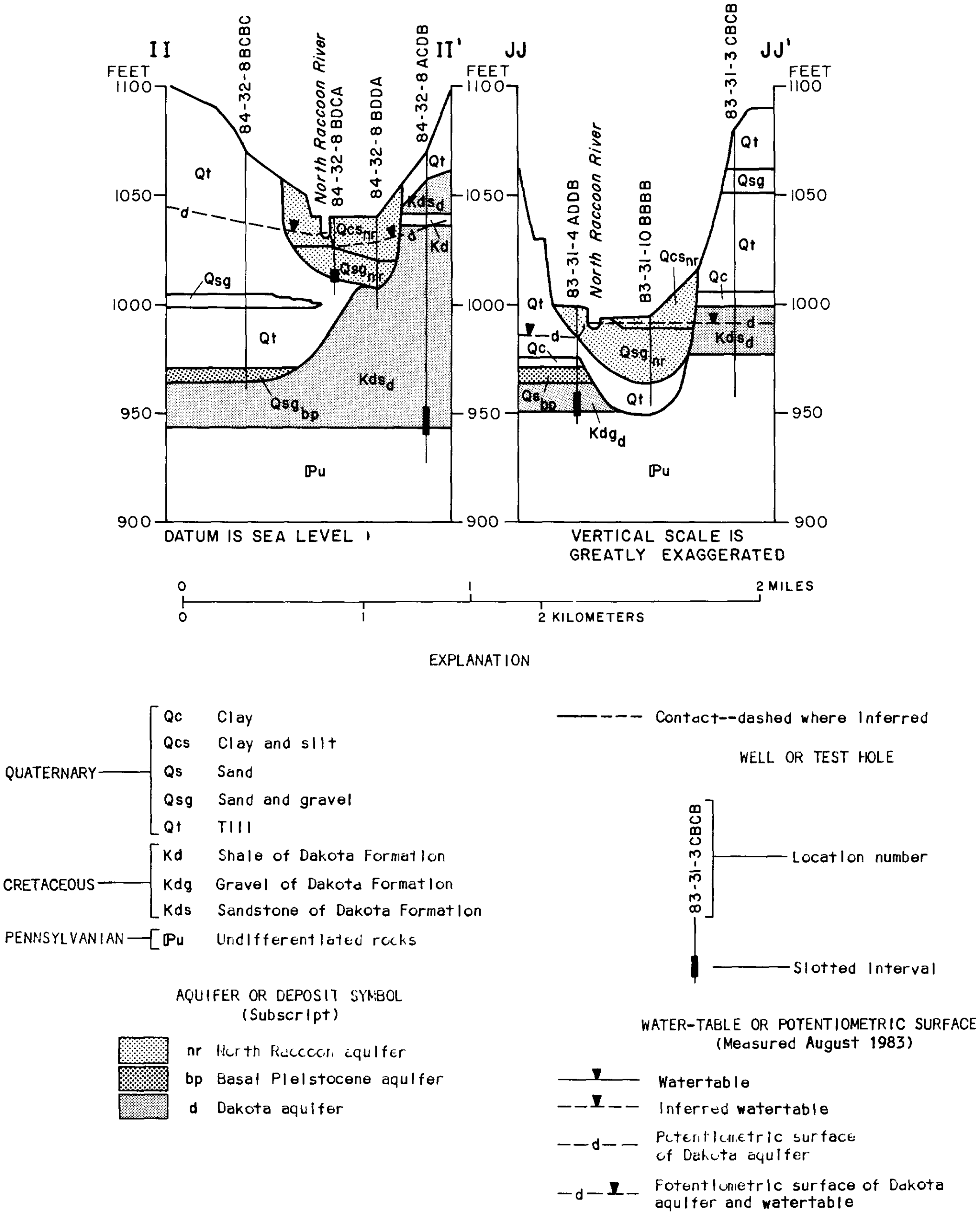


Figure 48.--Geohydrologic sections II-II' and JJ-JJ' of the North Raccoon, basal Pleistocene, and Dakota aquifers.

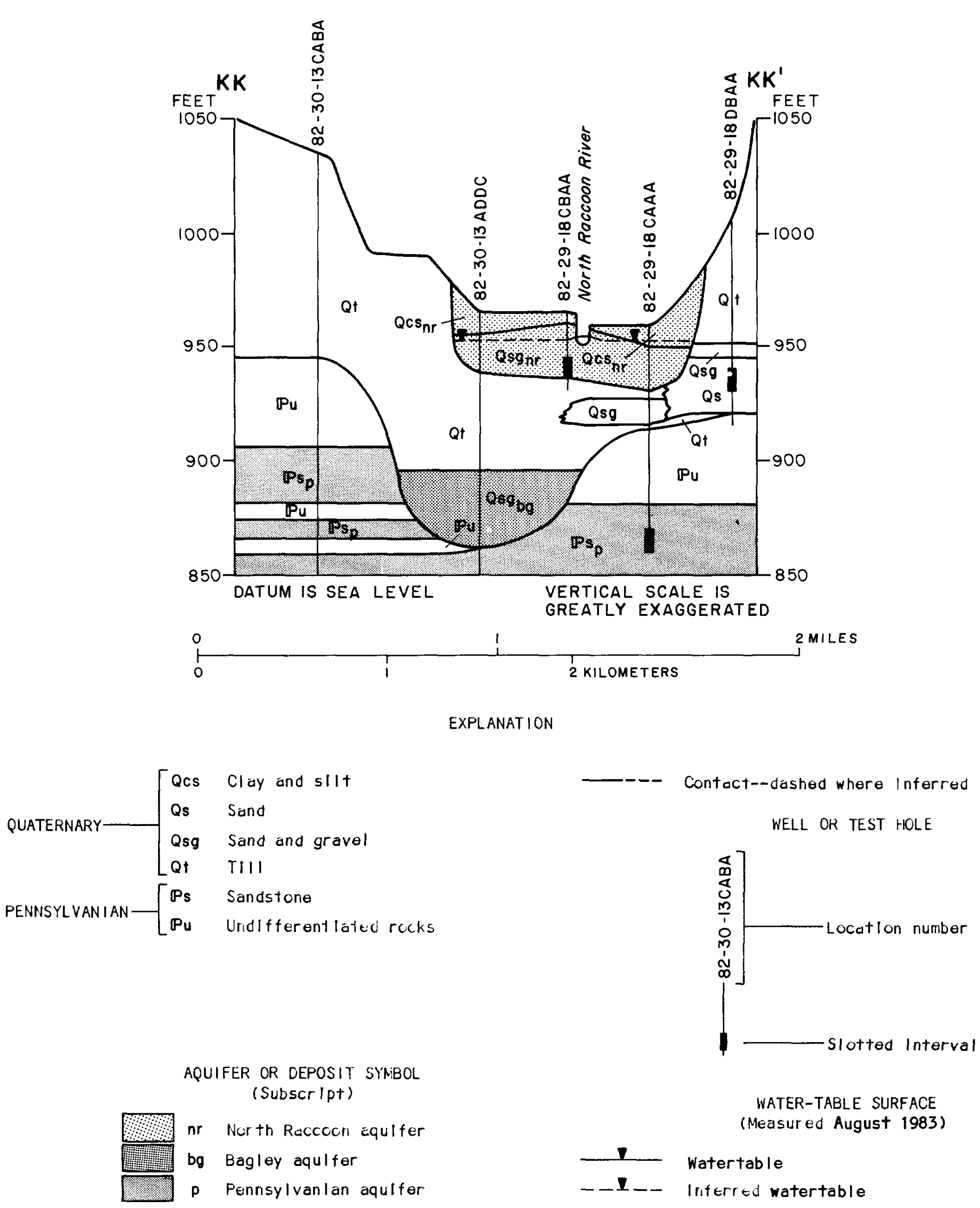


Figure 49.--Geohydrologic section KK-KK' of the North Raccoon and Bagley aquifers.

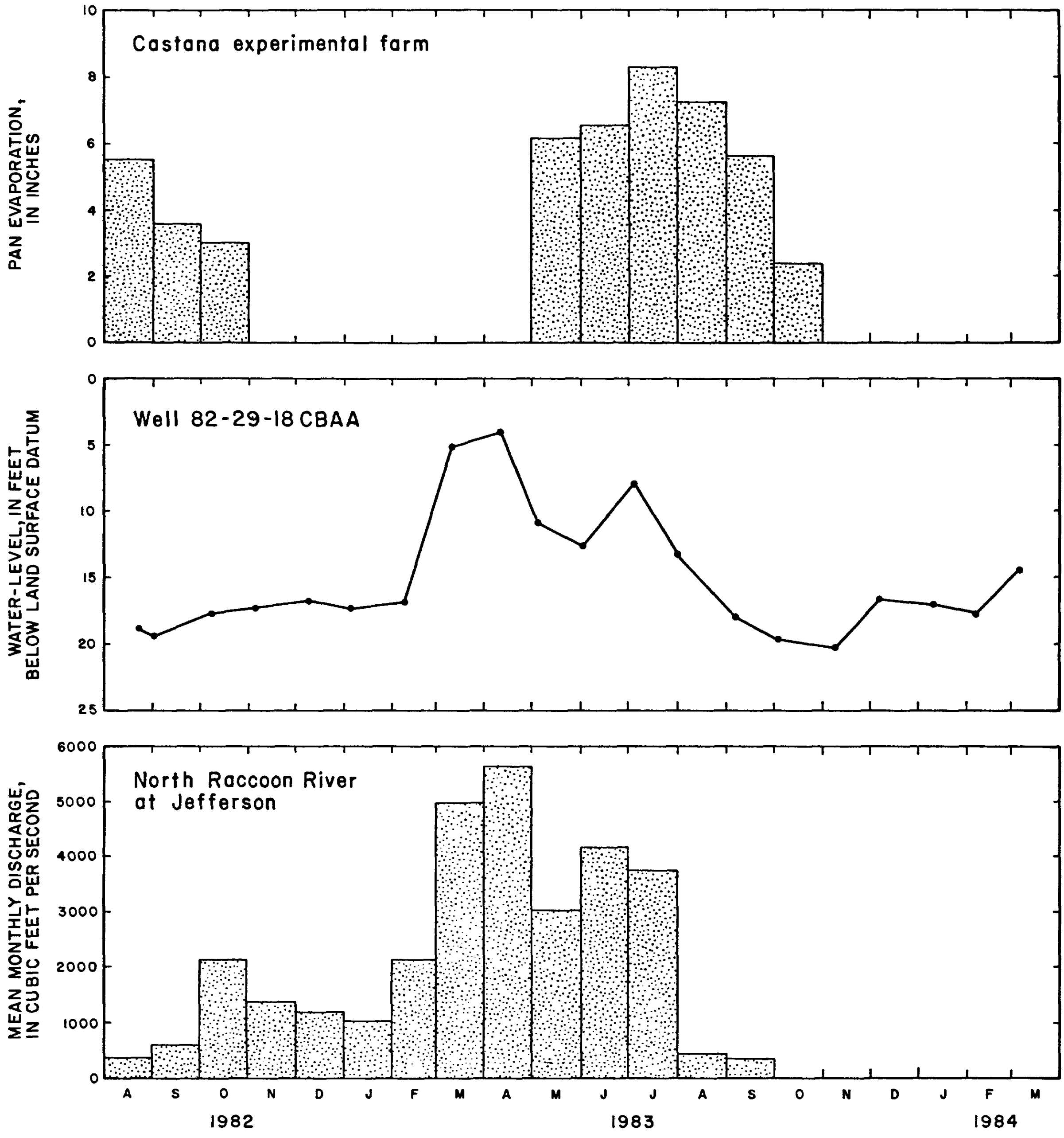


Figure 50.--Pan-evaporation data for the study area, water-table fluctations in a well completed in the North Raccoon aquifer, and the North Raccoon discharge at Jefferson.

Based on an areal extent of 30 square miles, an average thickness of 15 feet, and a specific yield of 25 percent, about 72,000 acre-feet of ground water are available from storage in the North Raccoon aquifer. Transmissivity is estimated to be about 2,000 ft^2/d using an average thickness of 15 feet and hydraulic conductivity of 135 ft/d. Estimated yield to wells generally would be less than 50 gal/min (plate 1).

Analyses of three water samples from the North Raccoon aquifer indicate that the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation and sulfate as a significant secondary anion (fig. 51). In some water samples the following constituents exceeded secondary drinking-water standards: dissolved-solids concentrations ranged from 441 to 720 mg/L and exceeded the 500 mg/L standard in two samples; iron ranged from 30 to 3,300 ug/L and exceeded the 30 ug/L standard in one sample; and manganese ranged from 20 to 2,100 ug/L and exceeded the 50 ug/L standard in two samples.

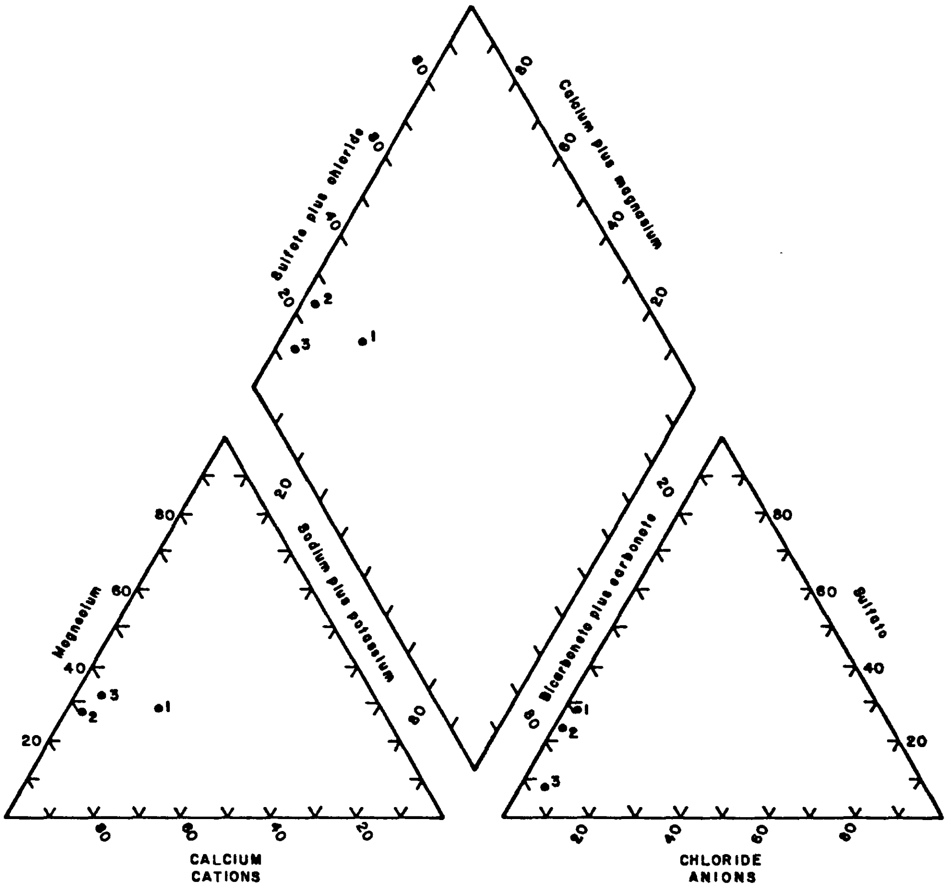
Water from wells completed in the North Raccoon, Hardin Creek, Dakota, and Pennsylvanian sandstone aquifers shown in or near geohydrologic section HH-HH' (fig. 47) is all basically the same water type. Water from wells completed in the basal Pleistocene and North Raccoon aquifers in geohydrologic section KK-KK' also are the same water type (fig. 49). Refer to the Hardin Creek aquifer section of this report for water level and water-quality comparisons of these aquifers.

Buried Channel and Basal Pleistocene Aquifers

The seven major buried channel and basal Pleistocene aquifers in west-central Iowa are underlain by bedrock and usually overlain by glacial till. The buried channels were eroded in bedrock by streams before, during, or between glacial advances. For convenience of discussion, identification, and future reference, aquifer names previously defined for adjacent areas are used. Newly defined aquifers are named after towns, such as the Anthon, Denison, and Adaza aquifers (plates 2 and 4; fig. 5). The basal Pleistocene aquifer is defined in this report as sand, sand and gravel, and gravel deposits found on some buried bedrock ridges in the study area. Data on the basal Pleistocene aquifer from test holes and wells are presented on plate 2. No attempt was made to contour the water-level altitude of this aquifer because of insufficient information.

Geohydrologic sections through the buried channel and basal Pleistocene aquifers are shown on plate 4 and other figures with the alluvial aquifers. The basic data report (Hunt and Runkle, 1984) contains more specific information about aquifer material, water levels, and water-quality analyses. The bedrock topography map (fig. 5) shows the location of the channels in the bedrock. For more detail on the bedrock surface and buried channels refer to the west-central Iowa topographic bedrock map (Hansen and Runkle, 1984).

Historical and observation-well water-level altitudes are plotted on plate 2. Recharge is through overlying glacial till and, where present, from the adjacent Dakota aquifer. Hydrographs of the water levels in observation wells are presented for each aquifer for which water-level data are available.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	85-33- 7ABBA IGS AND USGS WC 133	25	729
2	82-29-18CBAA IGS AND USGS WC 115	30	441
3	84-32- 6 BDCA IGS AND USGS WC 128	28	510

Figure 51.--Piper diagram of water quality in the North Raccoon aquifer.

The ground water available from storage was estimated by multiplying the areal extent by the storage coefficient and drawdown. Values of transmissivity were determined by estimating the hydraulic conductivity from geologic and drillers' logs and multiplying by the average thickness of the aquifer. The estimates are valid only for the site of the logged hole, but the number of data points permit an average value to be determined.

The estimated potential yields to ideally constructed wells from these aquifers are shown on plate 2. The potential yield was calculated using figure 4. An arbitrary drawdown of 20 feet was used to estimate the potential yield. Larger well yields are feasible if more than 20 feet of drawdown is determined to be possible.

For areas near an aquifer boundary, the estimated yield was reduced to account for the effects of the boundary on long-term pumping. The estimated potential well yields shown on plate 2 are total yields available from both the unconfined and confined parts of an aquifer system where the two conditions exist. These estimates do not take into account recharge, natural discharge, or ground-water movement.

Generally, the buried channel aquifers are lens-shaped, and the largest well yields are possible only by screening and developing the thickest sections of the aquifer. The estimated yields shown on plate 2 should be used with the understanding that they are for wells which fully penetrate the aquifer and have been ideally screened and developed. The map is intended as a guide in the location of ground-water resources and not as a map to locate specific production wells. Few, if any, of the aquifers discussed in this report are so uniform in thickness, areal extent, and physical properties that production wells could be constructed in them without additional test drilling.

Water-quality information is illustrated in Piper diagrams and some irrigation classification diagrams for each aquifer for which water-quality data exist. As described earlier, these diagrams can be used to help compare water from one aquifer to water from another.

The water in the shallow buried channels in Carroll, Greene, and Guthrie Counties is generally a calcium bicarbonate type, whereas the water in the deeper buried channels in Audubon, Crawford, Harrison, Monona, and Shelby Counties is a sodium sulfate or calcium sulfate type.

Water from the buried channel aquifers and the basal Pleistocene aquifer predominately is used for domestic or livestock purposes. Municipal-water withdrawals from the basal Pleistocene and buried channel aquifers are shown on plate 2 and in table 5. Data were collected from municipal-water superintendents and the Iowa Department of Water, Air, and Waste Management files (Buchmiller and Karsten, 1983).

Anthon Aquifer

The Anthon aquifer includes a main and three tributary channels in western Harrison, northwestern Crawford, and Monona Counties (plate 2). The aquifer extends from northeastern Monona County southward toward Moorhead. Northwest of Moorhead, the channel has two segments; the deeper western channel bends southwest toward the Missouri River and the shallower, more eastern channel extends south through the northwest corner of Harrison County parallel to the Soldier River, then south parallel to the Missouri River. The Anthon aquifer has three major tributaries that branch northeast off the deeper, main channel. One tributary is northeast of Soldier and extends northeast south of Charter Oak. Another tributary extends northeast parallel to and west of the Soldier River. The third tributary branches from the main channel south of Mapleton and is northeast of Mapleton. The main channel of the Anthon aquifer extends northwest of Mapleton. The Anthon aquifer has an areal extent of about 95 square miles in west-central Iowa. The location of the Anthon aquifer is dashed on plate 2 where information about the aquifer is not available. The bedrock map in figure 5 was used to extrapolate the location and extent of the aquifer by using the channels in the bedrock surface.

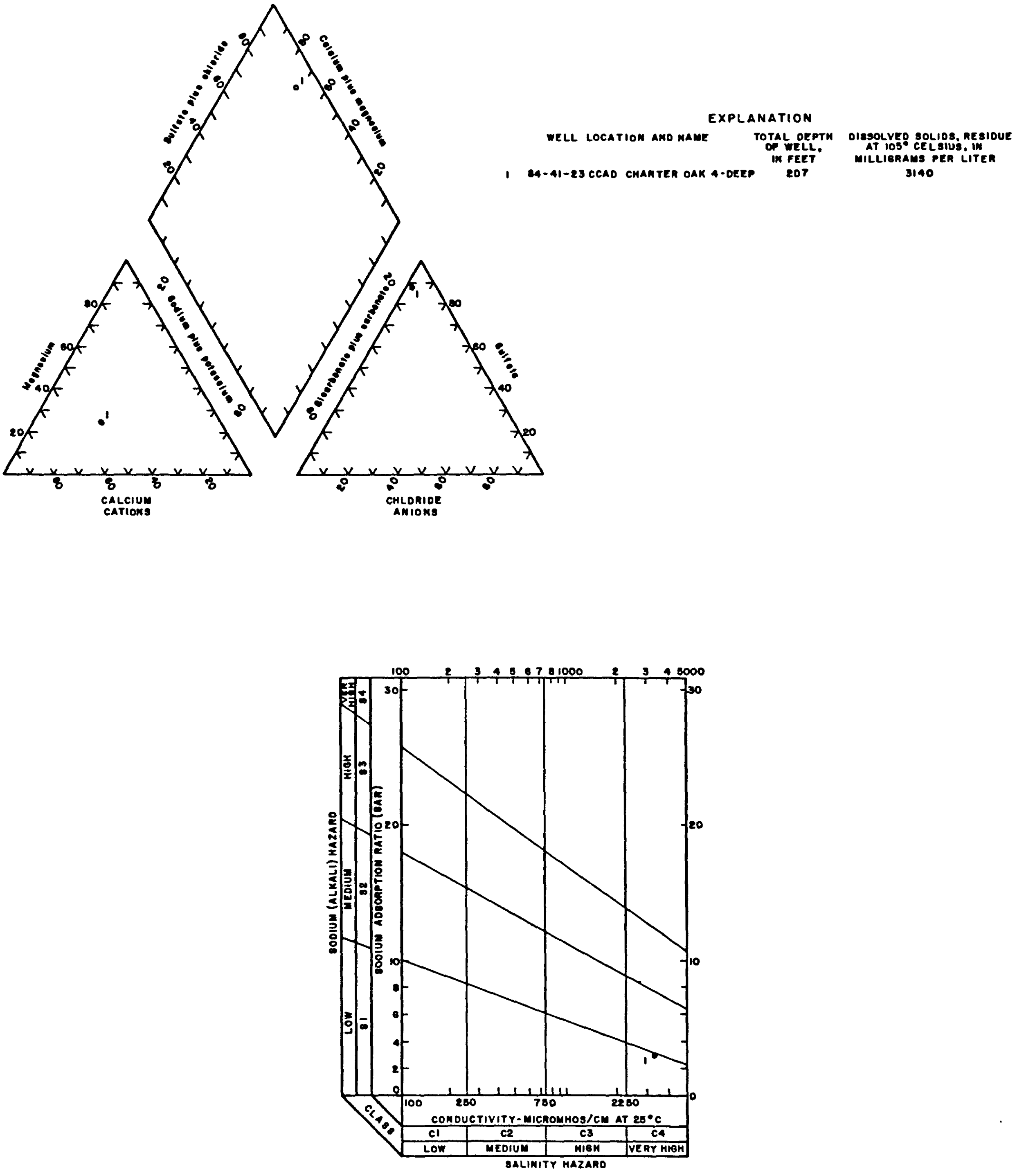
In 14 wells the aquifer consists of sand, sand and gravel, or gravel units that range from about 1 foot to 33 feet thick. The average thickness is about 14 feet. The aquifer is underlain by Pennsylvanian rock and overlain by glacial till in most of the study area. The Dakota aquifer is adjacent to the Anthon aquifer south of Mapleton, southeast of Castana between Ricketts and Schleswig, and southwest of Pisgah. The Dakota aquifer underlies the Anthon aquifer east and northeast of Mapleton. The thickness and lithology of the Anthon aquifer and the surrounding materials are illustrated in figure 14 and geohydrologic section LL-LL', plate 2. Since no water-level data are available for the Anthon aquifer, no statement can be made about hydraulic connection between the Soldier and Anthon aquifers in this area. A segment of the Anthon aquifer northeast of Soldier to Charter Oak is separated from the Soldier aquifer by about 150 feet of glacial till. Water-level data indicate that the Soldier aquifer is discharging into the Anthon aquifer in this area.

The Anthon aquifer in township 85 and ranges 42 and 43 is separated from the Maple aquifer by about 100 feet of glacial till. No water-level data are available for the Anthon aquifer to determine any hydraulic relation. The Anthon aquifer is separated from the Missouri Alluvial Plain (fig. 1) by 100 feet of sand and gravel and 100 feet of glacial till. No water-level data exist for the Anthon aquifer to determine any hydraulic relation.

The potentiometric surface of the Anthon aquifer ranges from 1,078 feet above sea level southwest of Moorhead to 1,125 feet above sea level north of Mapleton. The general direction of ground-water movement is from the northeast to the southwest toward Pottawattamie County, south of Harrison County. Recharge is derived from leakage through overlying glacial till.

Based on an areal extent of 95 square miles, an estimated average hydraulic head of 100 feet above the altitude of the top of the aquifer, and a storage coefficient of 0.001, about 6,000 acre-feet of ground water are available from artesian storage in the Anthon aquifer. The average transmissivity is estimated to be about 1,000 ft^2/d using an average thickness of 14 feet and hydraulic conductivity of 70 ft/d. Estimated yields to wells range from 10 to 200 gal/min (plate 2).

Analysis of one water sample from the Anthon aquifer indicates the water is very hard and is a calcium sulfate type with both magnesium and sodium as significant secondary cations (fig. 52). In this water sample the following



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	84-41-23 CCAD CHARTER OAK 4-DEEP	207	3140

Figure 52.--Piper diagram and irrigation classification of one water sample from the Anthon aquifer.

constituents exceeded secondary drinking-water standards: dissolved-solids concentration was 3,140 mg/L and exceeded the 500 mg/L standard; manganese concentration was 2,000 ug/L and exceeded the 50 ug/L standard; and sulfate concentration was 1,600 mg/L and exceeded the 250 mg/L standard. The irrigation classification of the water sample is C4-S1, meaning the water has a very high salinity hazard and low sodium hazard and would not be suitable for irrigation.

Denison Aquifer

The Denison aquifer includes a main and four tributary channels in Crawford, Harrison, and Shelby Counties (plate 2). The aquifer extends from north central Crawford County southward toward Denison. South of Denison the channel curves to the southwest and joins the Anthon aquifer in the southwest corner of Harrison County. The Denison aquifer has four tributaries that branch east off of the deeper, main channel. Tributaries are located northeast of Logan extending to the northeast toward Earling, south of Woodbine extending to the northeast, east of Dow City, and northeast of Deloit. In Harrison County the aquifer parallels the Boyer River. The Denison aquifer has an areal extent of about 81 square miles in west-central Iowa. The location of the Denison aquifer is dashed on plate 2 where figure 5 was used to extrapolate the location and extent of the aquifer by using the channels in the bedrock surface.

The aquifer at seven wells consists of sand units that range from about 1 foot to about 47 feet thick. The average aquifer thickness is about 22 feet. The Denison aquifer is underlain by Pennsylvanian rock and overlain by glacial till (geohydrologic section LL-LL; plate 4) except near Earling where it is underlain by the Dakota aquifer.

The potentiometric surface of the Denison aquifer is 1,122 feet above sea level north of Deloit. No other water-level data exist, but recharge is probably by leakage through overlying glacial till similar to the other buried channel aquifer. Water probably discharges to the Anthon aquifer in the southwest corner of Harrison County.

The Denison aquifer is separated from the Boyer aquifer by 250 to 300 feet of glacial till north of Dunlap, near Denison, and northeast of Deloit. The water level in the Denison aquifer north of Deloit is lower than the water level in the Boyer aquifer, indicating that water is moving downward from the Boyer aquifer through the glacial till to the Denison aquifer.

Based on an areal extent of 81 square miles, an estimated average hydraulic head of 150 feet above the altitude of the top to the aquifer, and a storage coefficient of 0.001, about 8,000 acre-feet of ground water are available from artesian storage in the Denison aquifer. Transmissivity is estimated to be about 1,200 ft^2/d using an average thickness of 22 feet and hydraulic conductivity of 55 ft/d. Estimated yields to wells range from 10 to 200 gal/min (plate 2).

Fremont Aquifer

The Fremont aquifer is the largest of the buried channel aquifers in west-central Iowa. The Fremont aquifer includes a main and five tributary channels in Audubon, Carroll, Crawford, and Shelby Counties. The aquifer extends from the northeast corner of Crawford County to south-central Shelby

County (plate 2). The Fremont aquifer has several tributaries that branch east off of the main channel. Two large tributaries are located southeast and east of Harlan, and extend south of Audubon. Another large tributary extends northeast of Kirkman toward Manning and Carroll. Two tributaries extend northeast of Manilla. The Fremont aquifer has an areal extent of about 282 square miles. The location of the Fremont aquifer is dashed on plate 2 where information about the aquifer is not available. The bedrock map in figure 5 was used to extrapolate the location and extent of the aquifer by using the channels in the bedrock surface.

The aquifer in 46 test holes and wells consists of sand, sand and gravel, and gravel units that range from about 1 foot to 125 feet thick. The average aquifer thickness is about 39 feet. The aquifer is underlain by Pennsylvanian rock and overlain by glacial till except northeast of Manilla where the Dakota aquifer is adjacent to or underlies the Fremont aquifer. The thickness and lithology of the Fremont aquifer and the surrounding material are illustrated in geohydrologic section U-U, figure 32 and geohydrologic sections LL-LL and MM-MM, plate 4. The thickest units of the coarsest, most permeable material generally are in the deepest part of the aquifer, particularly along the axis of the channel and east of the axis through much of the length of the aquifer. Of all the buried channels in west-central Iowa, this has the largest potential for water withdrawal, yet has the poorest water quality of the aquifers evaluated in this report.

The potentiometric surface of the Fremont aquifer ranges from 1,159 feet above sea level south of Harlan to 1,169 feet above sea level north of Vail. Water levels followed by a star on plate 2 can be used at show that the general movement of ground water is from north to south, with water discharging to Pottawattamie County to the south of Shelby County. The star indicates water levels in observation wells that were measured August 1, 2, or 3, 1983. These measurements are more representative of current conditions than the historical water levels.

The hydrograph in figure 53 shows the water-level fluctuations in an observation well completed in the Fremont aquifer north of Vail near the Boyer River. The hydrograph shows muted seasonal variations similar to those seen in the alluvial aquifers, indicating a hydraulic connection between the Boyer and the Fremont aquifers. In this area the water table in the Boyer aquifer is higher than that in the Fremont aquifer, indicating the Boyer aquifer is discharging into the Fremont aquifer through about 250 feet of glacial till.

The West Nishnabotna aquifer and the Fremont aquifer are separated by up to 400 feet of glacial till near the areas in figures 27 and 28. The water levels in the West Nishnabotna and the Fremont aquifers are virtually the same, suggesting the possibility of a hydraulic connection. From plates 1 and 2 it can be seen that the Fremont aquifer underlies a large percentage of the West Nishnabotna drainage basin and in most areas underlies the West Nishnabotna River and alluvial aquifer.

Recharge is from leakage through overlying glacial till. Where the Fremont aquifer is underlain or adjacent to the Dakota aquifer, water levels in the Dakota aquifer wells are slightly higher than water levels in the Fremont aquifer, indicating that the Dakota aquifer is recharging the Fremont aquifer.

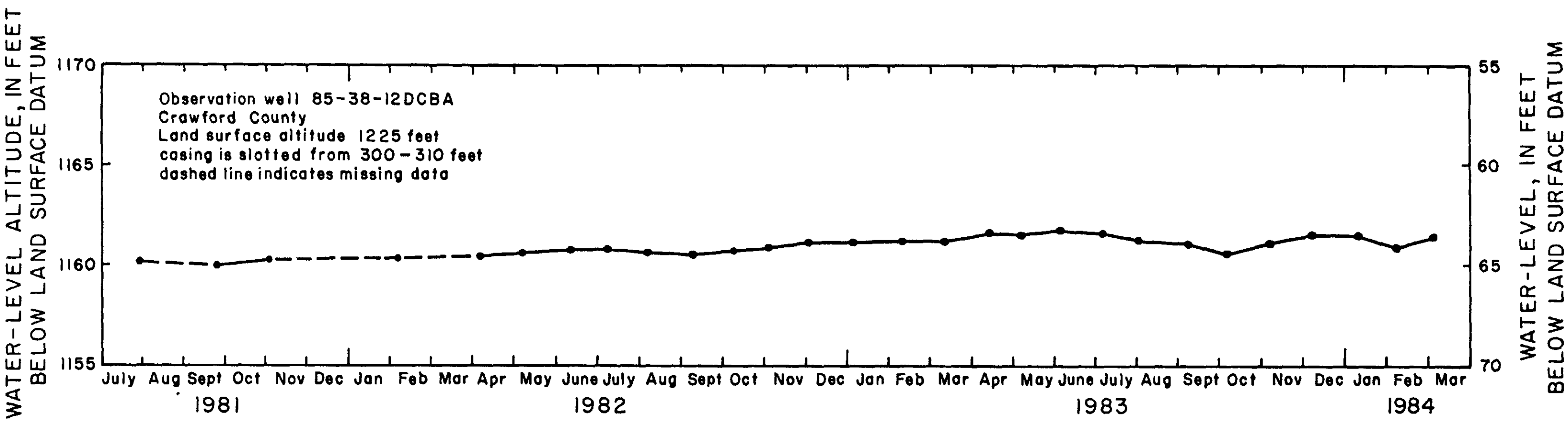


Figure 53.--Water-level fluctuations in the Fremont aquifer.

Based on an areal extent of 282 square miles, an estimated average hydraulic head of 250 feet above the altitude of the top of the aquifer, and a storage coefficient of 0.001, about 45,000 acre-feet of ground water are available from artesian storage in the Fremont aquifer. Transmissivity is estimated to be about 3,900 ft^2/d using an average thickness of 39 feet and hydraulic conductivity of 100 ft/d. Estimated yields to wells range from 10 to 800 gal/min (plate 2).

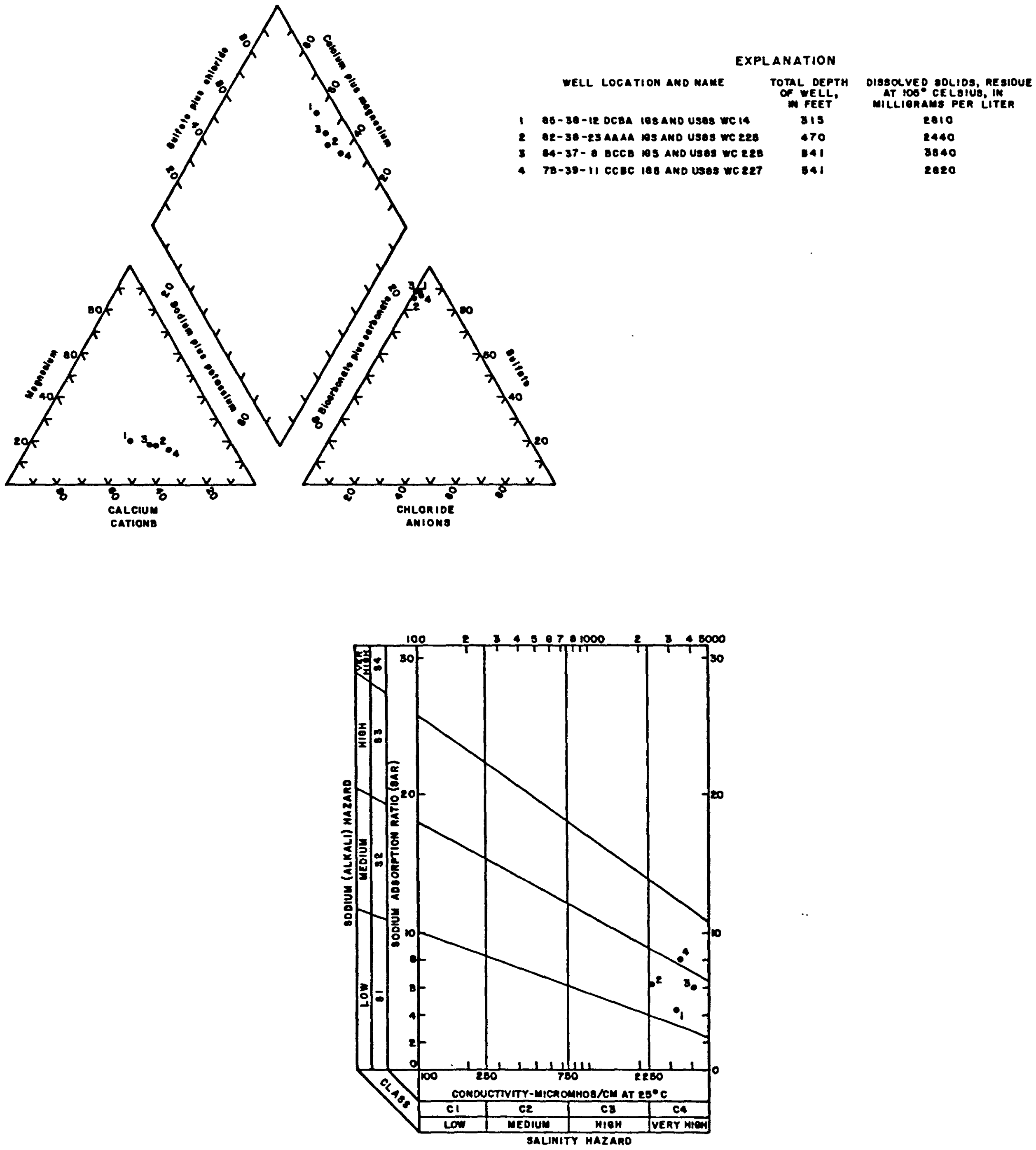
Analyses of four water samples from the Fremont aquifer indicate that the water is very hard and is a sodium sulfate type with calcium as a significant secondary cation (fig. 54). In some water samples the following constituents exceeded secondary drinking-water standards: dissolved-solids concentration ranged from 2,440 to 3,540 mg/L and exceeded the standard in all samples; iron ranged from 50 to 5,900 ug/L and exceeded the standard in three samples; and sulfate ranged from 1,400 to 1,800 mg/L and exceeded the standard in all samples. The irrigation classifications of the water sample are C4-S2 and C4-S3, indicating the water has a high salinity hazard and a medium to high sodium hazard and is unsuitable for irrigation purposes.

Hardin Creek Aquifer

The Hardin Creek aquifer is in Greene and northeastern Carroll Counties (plate 2). The aquifer extends southeast from northeast Carroll County. South of Lanesboro the aquifer consists of two channels which merge north of Ralston. South of Ralston the aquifer again has two channels: the main channel extends south, then east toward Jefferson and the channel south of Scranton merges with the main channel east of Scranton. East of Grand Junction the Hardin Creek aquifer joins the Beaver aquifer. West of Grand Junction the Adaza aquifer merges with the Hardin Creek aquifer. The Hardin Creek aquifer has an areal extent of about 66 square miles.

The aquifer at 22 test holes and wells consists of sand, sand and gravel, or gravel units that range from about 13 to 170 feet thick. The average aquifer thickness is about 37 feet. The aquifer is underlain by Pennsylvanian rocks, except east of Lanesboro where the aquifer is underlain by glacial till or the Dakota aquifer. The Dakota aquifer is adjacent to the Hardin Creek aquifer in eastern Carroll and western Greene Counties (plates 2 and 3). Water levels in the Dakota aquifer wells are slightly higher than water levels in the Hardin Creek aquifer, indicating that the Dakota aquifer is discharging into the Hardin Creek aquifer where the Hardin Creek aquifer is underlain by or adjacent to the Dakota aquifer. The thickness and lithology of the Hardin Creek aquifer and the surrounding material are illustrated in figures 46 and 47, and geohydrologic section MM-MM', plate 4. The thickest units and the coarsest, most permeable material generally are in the deepest part of the aquifer.

The potentiometric surface in the Hardin Creek aquifer ranges from 1,012 feet above sea level east of Jefferson to 1,079 feet above sea level south of Lanesboro. The general movement of ground water is from the northwest to the southeast where water is discharged to the Beaver aquifer east of Grand Junction.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	85-38-12 DCBA IGS AND USGS WC 14	315	2810
2	82-38-23 AAAA IGS AND USGS WC 226	470	2440
3	84-37-8 BCCB IGS AND USGS WC 228	541	3840
4	78-39-11 CCBC IGS AND USGS WC 227	541	2820

Figure 54.--Piper diagram and irrigation classification of water in the Fremont aquifer.

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The hydrograph of an observation well completed in the Hardin Creek aquifer northeast of Glidden, near the North Raccoon River is shown in figure 55. The location of this well, 84-33-3AADC, shown in figure 47, is where the Hardin Creek aquifer and North Raccoon aquifer are separated by about 50 feet of glacial till and the Dakota aquifer is adjacent to the east side of the Hardin Creek aquifer. The water level in the hydrograph shows seasonal variations similar to the alluvial aquifers. The water levels in the Hardin Creek and North Raccoon aquifers are the same, indicating that the aquifers are in equilibrium. The water level in a flowing well, 84-33-3BDAA (fig. 47), completed in a Pennsylvanian sandstone, was at least 10 feet higher than the water level in the North Raccoon, Hardin Creek, and Dakota aquifers, indicating that the Pennsylvanian aquifer is discharging into all of these aquifers in this area. The water quality from the Hardin Creek, Dakota, and Pennsylvanian aquifers is similar in this area. The water from the Pennsylvanian aquifer has a larger concentration of sulfate and sodium than the other aquifers, but the overall quality of water from the aquifers is the same, which is further evidence of the hydraulic connection among the aquifers. The Hardin Creek aquifer is recharged by leakage through overlying glacial till; where present, by the adjacent Dakota aquifer; and some locations by the Pennsylvanian sandstone that underlies the Hardin Creek aquifer.

Based on an areal extent of 66 square miles, an estimated average hydraulic head of 75 feet above the altitude of the top of the aquifer, and a storage coefficient of 0.001, about 3,000 acre-feet of ground water are available from artesian storage in the Hardin Creek aquifer. Transmissivity is estimated to be about 3,700 ft^2/d using an average thickness of 37 feet and estimated hydraulic conductivity of 100 ft/d. Estimated yields to wells range from 50 to 1,000 gal/min (plate 2).

Two aquifer tests were conducted on a shallow segment of the Hardin Creek aquifer in township 84, range 33, section 15 in Carroll County. Here the aquifer ranges from 15 to 54 feet thick and transmissivity, calculated from the aquifer test, ranged from 3,300 to 35,000 (gal/d)/ft (Munter, 1981). Results of the aquifer tests have a large range, which reflects the variation in the aquifer geometry, thickness, and hydrologic properties.

Analyses of five water samples from the Hardin Creek aquifer indicate that the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 56). In the water sample from well 83-30-7DADA, sodium was a significant secondary cation and chloride was a significant secondary anion. In some water samples the following constituents exceeded secondary drinking water standards: dissolved-solids concentrations ranged from 350 to 760 mg/L and exceeded the 500 mg/L standard in two samples; iron ranged from 1,400 to 8,100 ug/L and exceeded the 300 ug/L standard in all samples; and manganese ranged from 110 to 460 ug/L and exceeded the 50 ug/L standard in all samples.

Jefferson, Ralston, and Scranton used 250.8 Mgal of water from the Hardin Creek aquifer in 1980. Municipal-water withdrawals are shown on plate 2. About 24 percent of the water stored in the Hardin Creek aquifer is withdrawn by towns every year. Recharge through confining units appears to be replacing the quantity of water withdrawn from storage for the present. However, in the future, if the water withdrawn from the aquifer exceeds the rate of recharge, the result will be a decline in the water level.

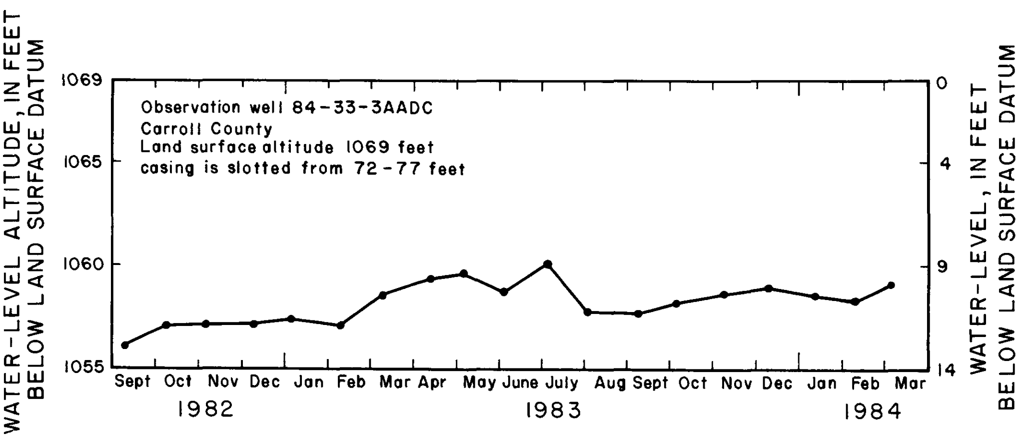
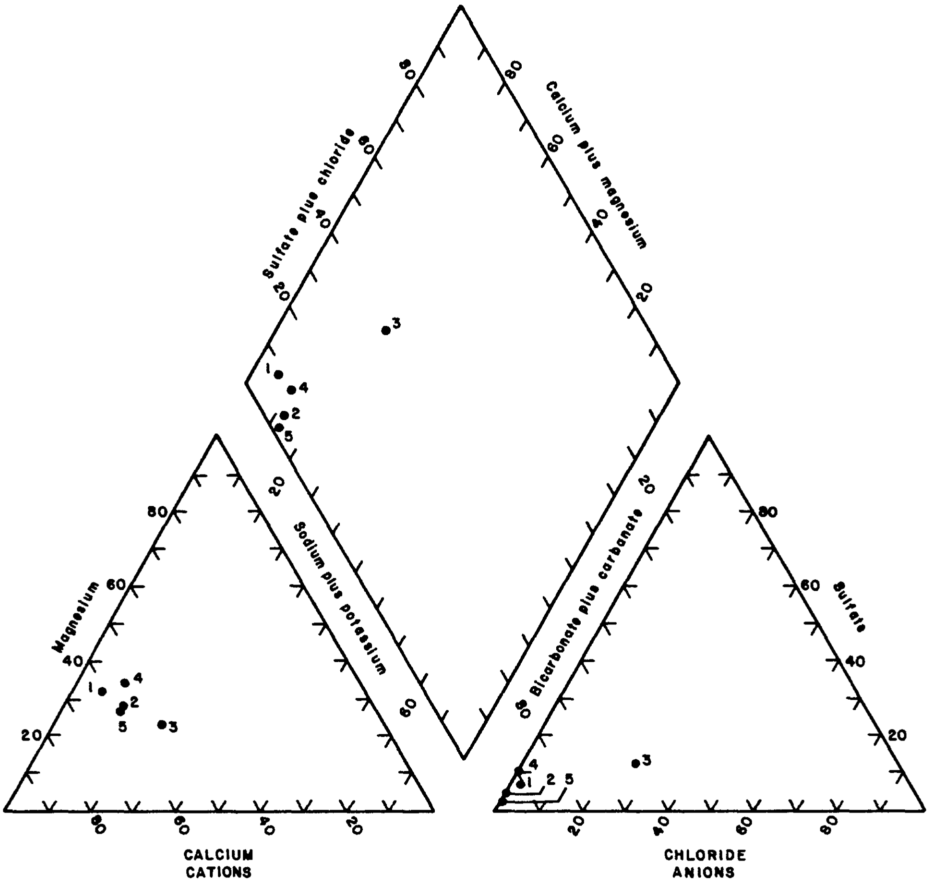


Figure 55.--Water-level fluctuations in the Hardin Creek aquifer.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	64-33-3AADC IGS AND USGS WC 129	77	456
2	84-33-36DBAB RALSTON 1	160	550
3	63-30-7 DADA JEFFERSON TOWN 4	156	740
4	63-32-11BDBC SCRANTON 3	209	426
5	83-32-8 BBBC IGS AND USGS WC 229	161	350

Figure 56.--Piper diagram of water quality in the Hardin Creek aquifer.

Water withdrawn by Jefferson probably stresses the Hardin Creek aquifer more than any other town. The drawdown effects of the Jefferson wells can be seen in nearby farm wells. During dry weather Jefferson has an agreement with local farmers to decrease withdrawal from a particular well that causes the largest drawdown in water levels in farm wells.

Adaza Aquifer

The Adaza aquifer is in north-central Greene County (plate 2). The aquifer extends south from northwestern Greene County toward Churdan and joins the Hardin Creek aquifer east of Jefferson. The Adaza aquifer has an areal extent of about 19 square miles in west-central Iowa.

The aquifer at five wells consists of sand and gravel, or gravel units that range from about 7 to about 42 feet thick. The average aquifer thickness is about 21 feet. The aquifer is underlain by Pennsylvanian rock and overlain by glacial till. The Dakota aquifer is adjacent to the Adaza aquifer north of Jefferson (geohydrologic section MM-MM', plate 4).

The potentiometric surface of the Adaza aquifer ranges from 1,035 feet above sea level north of Jefferson to 1,077 feet above sea level north of Churdan. Recharge is from leakage through overlying glacial till. Discharge is to the Hardin Creek aquifer. The general movement of ground water is from the north to the south.

Based on an areal extent of 19 square miles, an estimated average hydraulic head of 100 feet above the altitude of the top of the aquifer, and a storage coefficient of 0.001, about 1,000 acre-feet of ground water are available from artesian storage in the Adaza aquifer. Transmissivity is estimated to be about 2,800 ft^2/d using an average thickness of 21 feet and estimated hydraulic conductivity of 135 ft/d. Estimated yields to wells range from 50 to 400 gal/min (plate 2).

Beaver Aquifer

The Beaver aquifer extends south from northeastern Greene County east of Paton (plate 2). South of Paton the channel splits into two paths. The deeper, main channel, extends southeast, and the shallow channel extends south. The shallow channel merges with the deeper channel south of Dana. East of Grand Junction, the Hardin Creek aquifer joins the Beaver aquifer. The Beaver aquifer has an areal extent of about 23 square miles in west-central Iowa.

The aquifer at 18 test holes and wells consists of sand and gravel, or gravel units that range from about 4 to about 40 feet thick. The average aquifer thickness is about 18 feet. The aquifer is underlain by Pennsylvanian rock and overlain by glacial till (geohydrologic section MM-MM', plate 4).

The potentiometric surface of the Beaver aquifer ranges from 1,034 feet above sea level north of Grand Junction to 1,063 feet above sea level northwest of Paton. The hydrograph in figure 57 shows the water-level fluctuations in an observation well north of Dana completed in the Beaver aquifer. Although there is less than a year of record, muted seasonal variations of the water level, similar to those in alluvial aquifers, were recorded at this observation well.

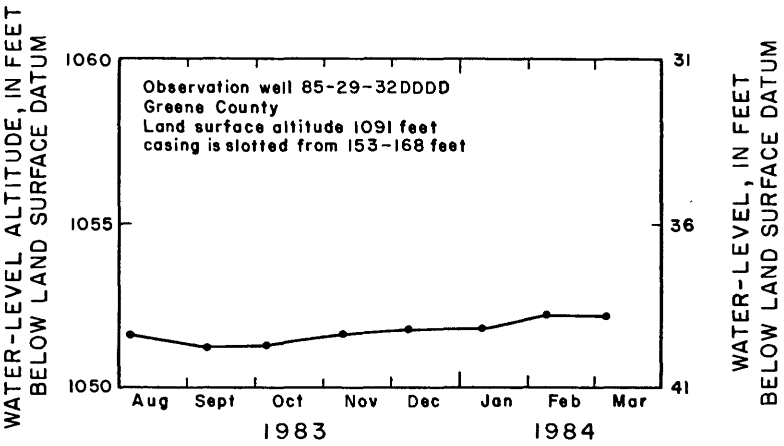


Figure 57.--Water-level fluctuations in the Beaver aquifer.

Water levels declined from August to September 1983 and then increased from October 1983 to February 1984. Recharge is from leakage through overlying glacial till. Discharge is toward Boone County east of Grand Junction. The overall movement of ground water is from north to south.

Based on an areal extent of 23 square miles, an estimated average hydraulic head of 85 feet above the altitude of the top of the aquifer, and a storage coefficient of 0.001, about 1,000 acre-feet of ground water are available from artesian storage in the Beaver aquifer. Transmissivity is estimated to be about 2,400 ft^2/d using an average thickness of 18 feet and estimated hydraulic conductivity of 135 ft/d. Estimated yields to wells range from 50 to 400 gal/min (plate 2).

Analyses of four water samples from the Beaver aquifer indicate the water is very hard and is a calcium bicarbonate type with both sodium and magnesium as significant secondary cations (fig. 58). A water sample from well 84-29-16CBAB is a sodium sulfate type with both calcium and magnesium as significant secondary cations and bicarbonate as a significant secondary anion. In some water samples the following constituents exceeded secondary drinking-water standards: dissolved-solids concentrations ranged from 550 to 1,020 mg/L and exceeded the 500 mg/L standard in all samples; iron ranged from 5,300 to 6,600 ug/L and exceeded the 300 ug/L standard in all samples; and sulfate ranged from 32 to 460 mg/L and exceeded the 250 mg/L standard in one sample.

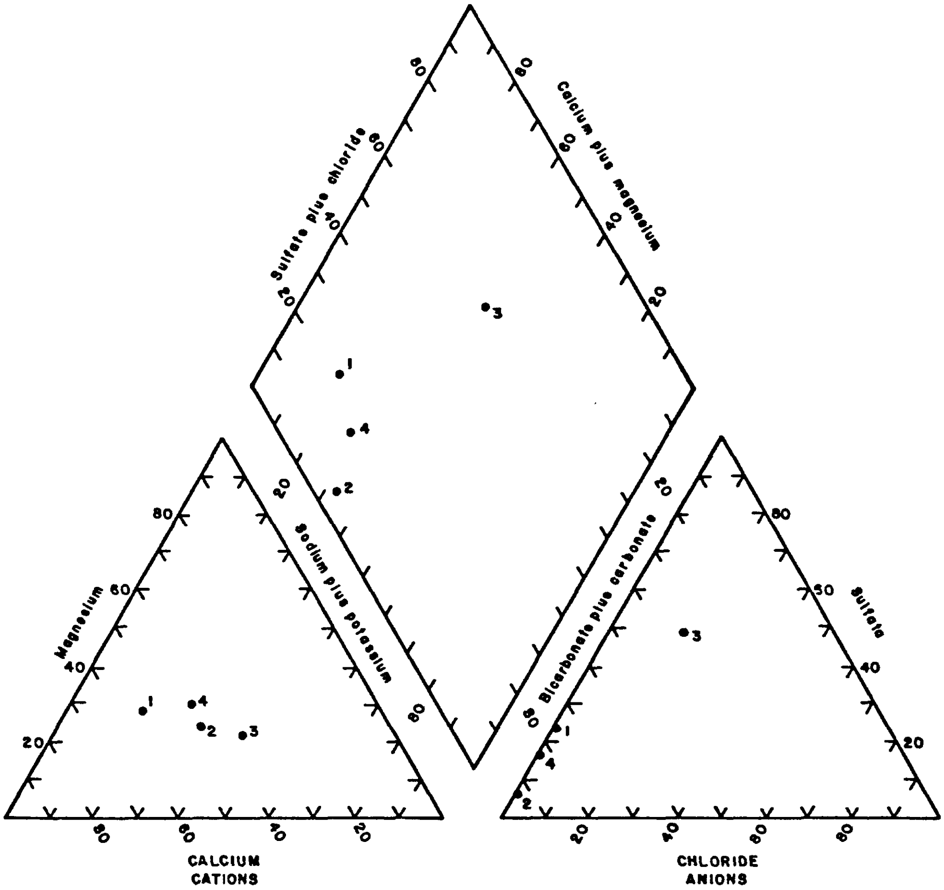
Dana used 1.4 Mgal of water from the Beaver aquifer in 1980. Municipal-water withdrawals are shown on plate 2 and in table 5.

Bagley Aquifer

The Bagley aquifer includes a main and three tributary channels in southern Greene County and northern Guthrie County (plate 2). The Bagley aquifer and Hardin Creek aquifer intersect south of Ralston, where the Bagley aquifer extends southeast, curving to the east toward Bagley. The Bagley aquifer has three tributaries that branch north off of the deeper, main channel. One tributary is north of Bagley and extends northwest toward Scranton. The second tributary is north of Jamaica. The third tributary is northeast of Jamaica and trends toward Jefferson. The Bagley aquifer has an areal extent of about 28 square miles in west-central Iowa. The location of the Bagley aquifer is dashed on plate 2 where information about the aquifer is not available. The bedrock map in figure 5 was used to extrapolate the location and extent of the aquifer by using the channels in the bedrock surface.

The aquifer at nine test holes and wells consists of sand, and gravel, or gravel units that range from about 4 to 35 feet thick. The average aquifer thickness is about 23 feet. The aquifer is underlain by Pennsylvanian rock and overlain by glacial till. The lithology and thickness of the Bagley aquifer and surrounding materials are illustrated in figure 49.

The potentiometric surface of the Bagley aquifer ranges from 977 feet above sea level at Jamaica to 1,110 feet above sea level north of Bayard. Recharge is from leakage through overlying glacial till. The general movement of ground water is from northwest to southeast toward Dallas County, east of Guthrie County.



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	84-29-4CCBB DANA 1	186	550
2	85-29-32DDDD IGS AND USGS WC 232	171	816
3	84-29-16CBAB IGS AND USGS WC 233	181	1020
4	85-29-19BAAA IGS AND USGS WC 231	221	780

Figure 58.--Piper diagram of water quality in the Beaver aquifer.

Based on an areal extent of 28 square miles, an estimated average hydraulic head of 80 feet above the altitude of the top of the aquifer, and a storage coefficient of 0.001, about 1,000 acre-feet of ground water are available from artesian storage in the Bagley aquifer. Transmissivity is estimated to be about 3,100 ft^2/d using an average thickness of 23 feet and an estimated hydraulic conductivity of 135 ft/d. Estimated yields to wells range from 10 to 200 gal/min (plate 2).

Analyses of two water samples from the Bagley aquifer indicate the water is very hard and is a calcium bicarbonate type with magnesium as a significant secondary cation (fig. 59). Dissolved-solids concentrations were 340 and 515 mg/L, and manganese exceeded the secondary drinking-water standard of 50 ug/L with a concentration of 1,300 ug/L.

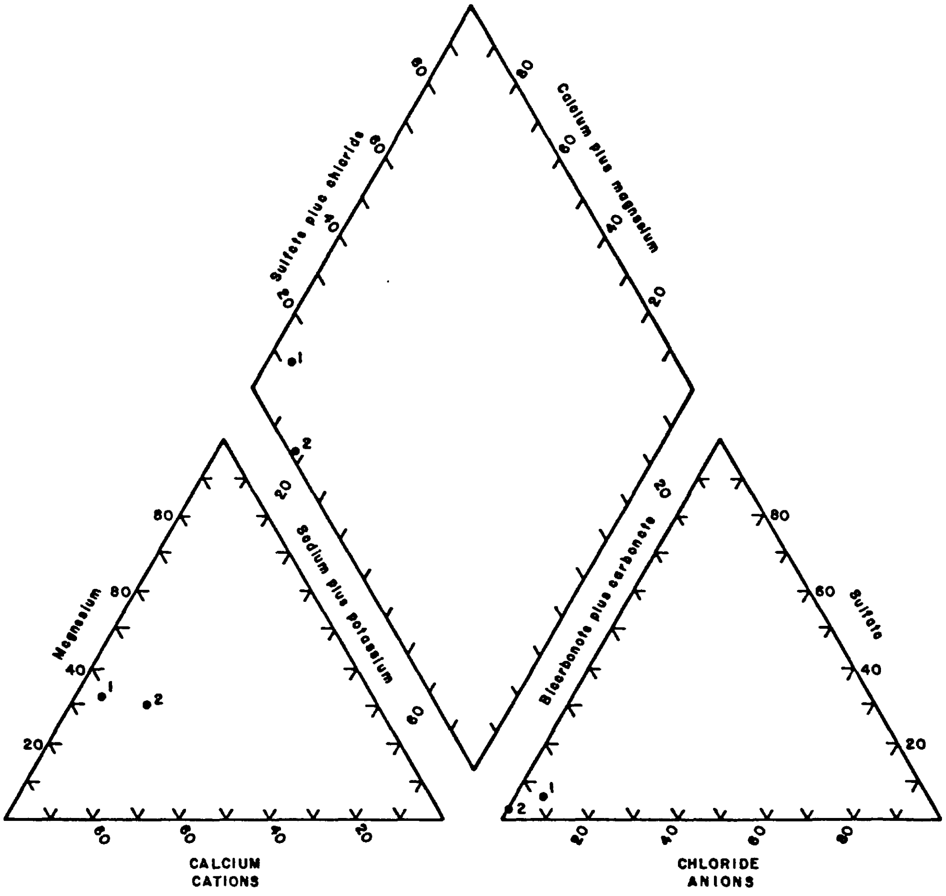
Bagley used 13.1 Mgal of water from the Bagley aquifer in 1980. Municipal-water withdrawals are shown on plate 2 and in table 5.

Basal Pleistocene Aquifer

The basal Pleistocene aquifer is defined in this report as a sand or sand and gravel deposit overlain by glacial till and underlain by bedrock. The aquifer is on many of the buried bedrock ridges between buried channels in parts of west-central Iowa. The aquifer ranges from 1 foot to 104 feet thick, but generally it is less than 30 feet thick. In Audubon, Crawford, Harrison, Monona, Shelby, western Carroll, and western Guthrie Counties, test hole and well information indicate that the aquifer generally is a fine to coarse sand or sand and gravel that ranges from light gray-green to red to yellow-brown and sometimes has dark, mafic minerals mixed with the lighter quartz and feldspathic grains giving a salt and pepper appearance. In some areas, the aquifer material appears to be poorly cemented. The basal Pleistocene aquifer material is similar to the buried channel aquifer material except that the buried channel aquifer material tends to be coarser. In Greene, eastern Guthrie, and eastern Carroll Counties, test-hole and well information indicate that the basal Pleistocene aquifer generally is yellow-brown and consists of coarser material and is not as laterally continuous as it is in the rest of west-central Iowa.

Data on the basal Pleistocene aquifer from test holes and wells are plotted on plate 2. Some water-level altitudes on plates 2 and 3 represent the combined water-levels of the basal Pleistocene and Dakota aquifers. In many places where the Dakota aquifer underlies the basal Pleistocene aquifer, wells are open to both aquifers. It often is difficult to distinguish between the basal Pleistocene and Dakota aquifers in well logs because of brief material descriptions. No attempt was made to contour a regional map of the distribution of the basal Pleistocene aquifer because of the sparse distribution of data points and the discontinuous nature of this deposit. Widely scattered data and the noncontiguous nature of the aquifer made accurate mapping impossible. The relative location and thickness of the basal Pleistocene aquifer at several locations are shown in plate 4 and figures 6, 9, 10, 13, 20, 21, 22, 33, 40, 43, and 48.

The potentiometric surface of the basal Pleistocene aquifer ranges from 1,103 feet above sea level northeast of Panora to 1,373 feet above sea level east of Exira. Hydrographs in figure 60 show the water-level fluctuations in three observation wells in the basal Pleistocene aquifer. Recharge is from



EXPLANATION

	WELL LOCATION AND NAME		TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	81-31-11BDCA	TOWN OF BAGLEY	95	340
2	82-29-18DBAA	IGS AND USGS WC 117	75	515

Figure 59.--Piper diagram of water quality in the Bagley aquifer.

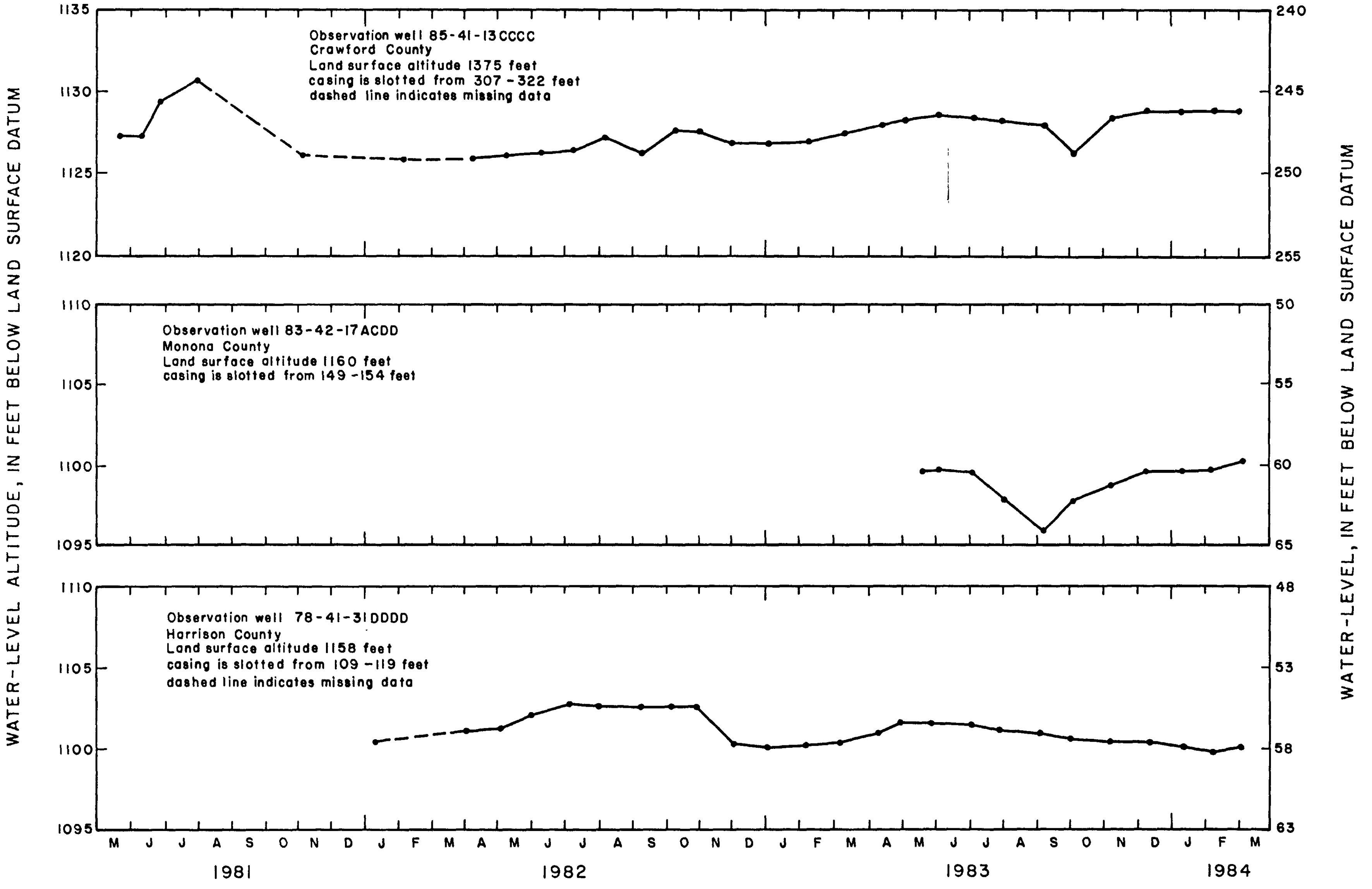


Figure 60.--Water-level fluctuations in the basal Pleistocene aquifer.

leakage through overlying glacial till, and probably some recharge is from the underlying Dakota aquifer, where it is present. It is difficult to establish the recharge relation between the basal Pleistocene and Dakota aquifers because many wells are open to both. Estimated yields to wells range from 5 to 500 gal/min.

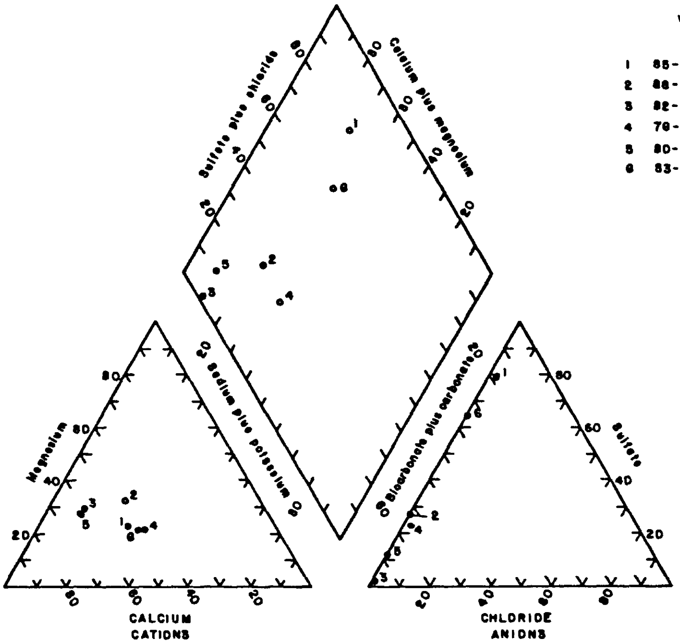
Interrelations between the basal Pleistocene aquifer and other aquifers are described in previous sections on the Maple, Soldier, Boyer, and North Raccoon aquifers.

Analyses of six water samples from the basal Pleistocene aquifer indicate the water is very hard and is either a calcium bicarbonate type with sodium or magnesium as significant secondary cations and sulfate as a significant secondary anion, or a calcium sulfate type with sodium as a significant secondary cation and bicarbonate as a significant secondary anion (fig. 61). In a water sample from well 85-31-2CCAA, arsenic exceeded the primary drinking-water standard of 50 ug/L with a concentration of 54 ug/L. In some water samples the following constituents exceeded secondary drinking-water standards: dissolved-solids concentrations ranged from 388 to 2,170 mg/L and exceeded the 500 mg/L standard in five samples; iron ranged from 20 to 5,400 ug/L and exceeded the 300 ug/L standard in four samples; manganese ranged from 60 to 860 ug/L and exceeded the 50 ug/L standard in all samples; and sulfate ranged from 5.5 to 930 mg/L and exceeded the 250 mg/L standard in two samples. The irrigation classifications of the water samples are C2-S1, C3-S1, and C4-S1, indicating the water has a medium to very high salinity hazard and a low sodium hazard. Water that has a very high salinity hazard would not be suitable for irrigation purposes.

Churdan, Coon Rapids, Pisgah, and Rippey used 89.3 Mgal of water from the basal Pleistocene aquifer. Pisgah obtains one-half of its water from the basal Pleistocene aquifer and Coon Rapids obtains over 90 percent of its water from the basal Pleistocene aquifer. Municipal water withdrawals are shown on plate 2 and in table 5.

Dakota Aquifer

The Dakota aquifer is defined in this report as the saturated sandstone and gravel units in the Dakota Formation (table 4). Where the Dakota Formation is present in the study area it is underlain by Pennsylvanian rock and usually overlain by Quaternary deposits. Isolated erosional remnants of the Dakota Formation form the cap of many buried bedrock ridges (plates 3 and 4; fig. 5). In the study area the Dakota aquifer is thickest along a broad bedrock divide between a southwest and southeast trending buried drainage divide in Audubon, Carroll, and Guthrie Counties. Many exposures of the Dakota Formation are along the Middle Raccoon River, South Raccoon River, and Brushy Creek in Guthrie County. These rivers have deeply incised the Dakota bedrock uplands and, in southeastern Guthrie County, the contact between Pennsylvanian rocks and the Dakota Formation can be seen in some exposures. A few exposures of the Dakota Formation can be found in eastern Carroll and western Greene Counties along the North Raccoon River (Witzke and Ludvigson, 1982).



EXPLANATION

	WELL LOCATION AND NAME	TOTAL DEPTH OF WELL, IN FEET	DISSOLVED SOLIDS, RESIDUE AT 105° CELSIUS, IN MILLIGRAMS PER LITER
1	85-40-13 CCCC SCHLESWIG 4 WEST	348	2170
2	86-31-21 CCAA CHURDAN 1	160	972
3	82-29-11 BDBC RIPPEY 1	138	460
4	78-41-31 DDDD IGS AND USGS WC 27	129	374
5	80-42-35 BDCC IGS AND USGS WC 163	118	368
6	83-42-17 ACDD IGS AND USGS WC 176	161	1200

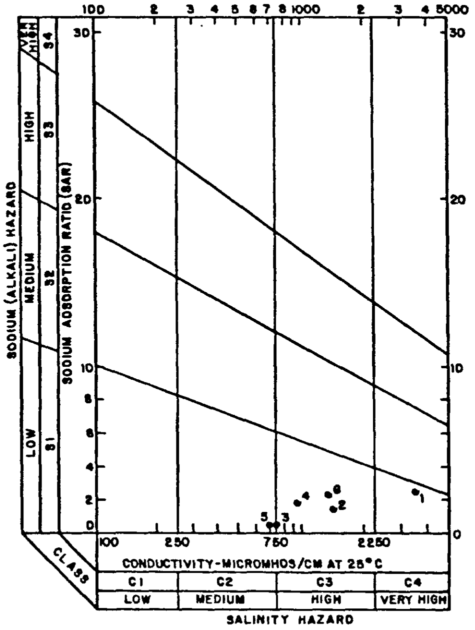


Figure 61.--Piper diagram and irrigation classification of water in the basal Pleistocene aquifer.

The Dakota Formation has two members in west-central Iowa. Where present, the upper one, the Woodbury Member (Munter and others, 1983), consists of interbedded shale and sandstone that comprise a minor aquifer where the sandstone beds are interconnected, or a confining unit when shale is the predominant rock. Data from test holes and wells indicate that the Woodbury Member is 39 feet thick in a well northeast of Missouri Valley, up to 192 feet thick southeast of Pisgah, 36 feet thick west of Dunlap in Harrison County, 115 feet thick northwest of Pisgah, 30 feet thick north of Ute, 15 feet thick northeast of Castana, 17 feet thick northeast of Mapleton in Monona County, and up to 160 feet thick northeast of Carroll in Carroll County. In Carroll County the Woodbury Member was in test holes and wells in a region east of Breda and west of Lanesboro, west of Ralston, and as far south as Coon Rapids.

Data from test holes and wells indicate that the lower member of the Dakota Formation, the Nishnabotna Member (Munter and others, 1983) is a white to brown, fine- to coarse-grained sandstone and conglomerate that is interbedded with thin beds of shale that generally are less than 10 feet thick. The Nishnabotna Member is the most significant part of the Dakota aquifer. The sandstone at many locations is interbedded with iron oxide-cemented conglomerate, mudstone, shale, ironstone, siderite, and pyrite nodules, or lignite. Calcite or iron oxide-cemented sandstone and gravel may be encountered, but more often the Nishnabotna sandstone is poorly cemented and resembles loose sand rather than sandstone. Iron oxide-cemented sandstone, gravel, and conglomerate are characteristic of the basal part of the Nishnabotna member in southern Audubon, southern Guthrie, and southern Harrison Counties. In Guthrie County this basal gravel and conglomerate is quarried along the South Raccoon River valley and used for road aggregate. The Nishnabotna Member is about 95 feet thick in Carroll County and about 150 feet thick in Guthrie County. Data from test holes and wells indicate the Dakota aquifer ranges from 2 to about 150 feet thick. The average thickness is about 30 feet. The Dakota aquifer has an areal extent of about 2,217 square miles in west-central Iowa. The nature and thickness of the Dakota aquifer, the surrounding material, and the potentiometric surface, when known, are shown on plate 4 and in figures 6, 13, 14, 15, 19, 20, 22, 32, 33, 36, 37, 40, 41, 42, 43, 46, 47, and 48.

The potentiometric surface of the Dakota aquifer is contoured on plate 3. Water movement generally is from topographically high areas to topographically low areas. Hydrographs in figure 62 show the water level fluctuations in five observation wells in the Dakota aquifer. From these graphs it can be seen that water levels fluctuate less as the depth to the aquifer increases. This indicates that water levels in the Dakota aquifer respond to variations in seasonal precipitation as do alluvial aquifers when there is a water table situation (wells 83-31-4ADDB and 84-34-34BCDC, fig. 62). As the depth to the Dakota aquifer increases and the aquifer becomes confined, the hydrographs generally are much smoother and show general trends rather than seasonal variations.

Recharge is by leakage through overlying material or directly from precipitation where the Dakota Formation is exposed at the land surface. Discharge is to adjacent or overlying aquifers when the water level in the Dakota is higher than the water level of the adjacent or overlying aquifer and where the Dakota aquifer is exposed along the wall of river valleys. Transmissivity is estimated to be 1,200 ft^2/d using an average thickness of 30

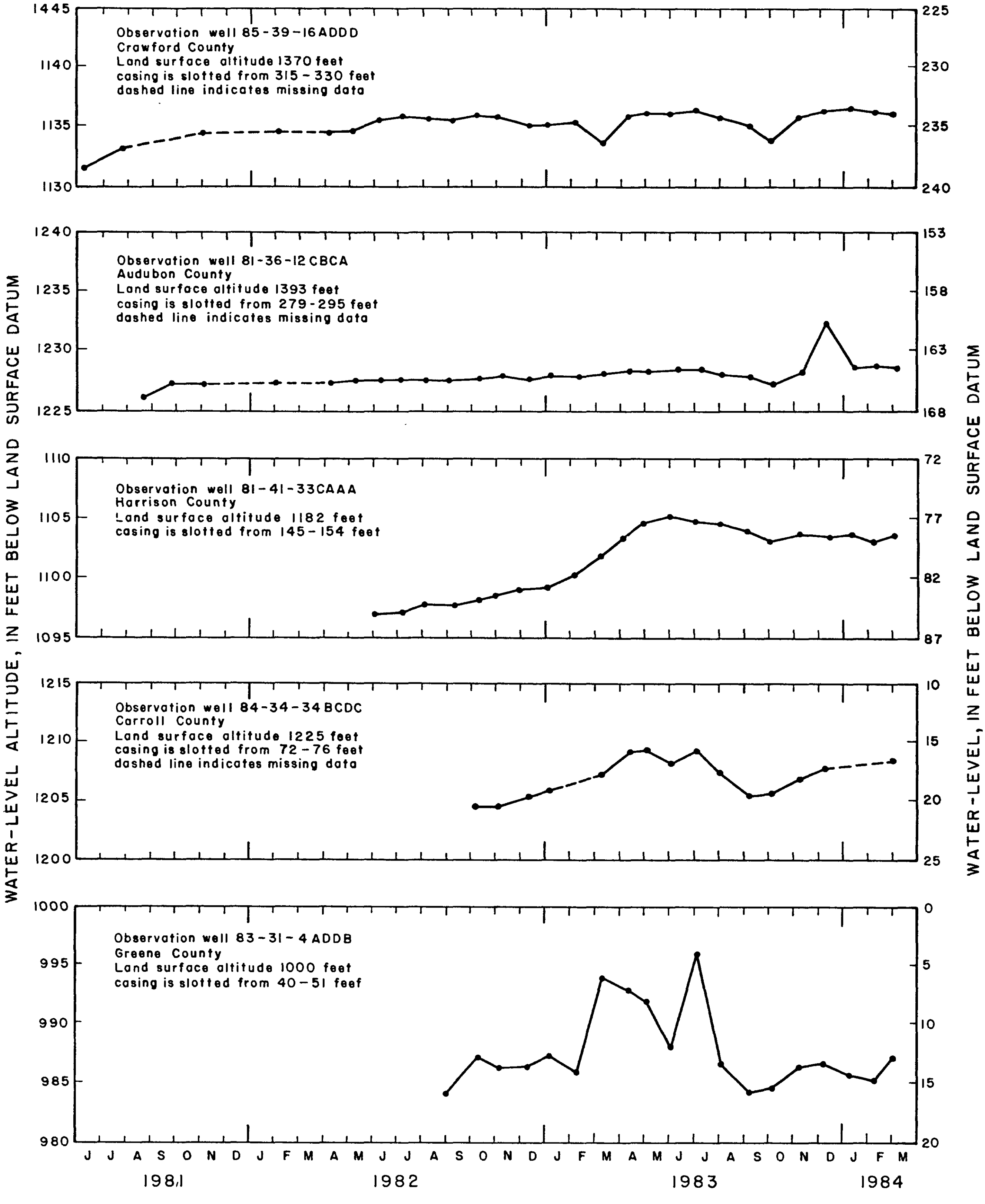


Figure 62.--Water-level fluctuations in the Dakota aquifer.

feet and estimated hydraulic conductivity of 40 ft/d. The aggregate sandstone and gravel thickness plotted on plate 3 varies appreciably throughout west-central Iowa; therefore, the estimates of water available from storage and the average transmissivity must be used with the understanding that these values are generalized estimates for a large region.

The potential yields to wells in the Dakota aquifer are shown on plate 3. The values are based on values of transmissivity, specific capacity, and storage calculated according to methods in the "General hydrologic concepts" section of this report. A drawdown of 20 feet was used to estimate the potential yield. Larger well yields are feasible if more than 20 feet of drawdown is possible. Aquifer boundary conditions affect the yields to wells; therefore, the estimated yields shown on plate 3 are total yields available from both the unconfined and confined parts of an aquifer system where the two conditions exist. Estimated well yields range from 10 to 400 gal/min (plate 3).

Interrelations between the Dakota aquifer and other aquifers have been presented in previous section on the following aquifers: Little Sioux, Soldier, Boyer, East Nishnabotna, South Raccoon, Middle Raccoon, North Raccoon, and Hardin Creek aquifers.

Analyses of 34 water samples from the Dakota aquifer, 25 of which are plotted in figure 8, indicate the water is very hard and is one of the three following water types: a calcium bicarbonate type with magnesium or sodium as significant secondary cations and sulfate as a significant secondary anion; a calcium sulfate type with sodium or magnesium as significant secondary cations and bicarbonate as a significant secondary anion; or a sodium bicarbonate type with calcium as a significant secondary cation and sulfate as a significant anion. In general, water from wells 50 to 200 feet deep was a calcium bicarbonate type and had less than 500 mg/L dissolved-solids concentration. Water from well greater than 200 feet deep generally was a calcium sulfate or sodium sulfate type and had more than 500 mg/L dissolved-solids concentration.

In some water samples the constituents exceeded primary drinking-water standards. Radium 226 and radium 228 had a combined concentration of 5.2 pCi/L in well 83-31-4ADDB and 8.4 pCi/L in well 85-34-35CCCD, exceeding the 5 pCi/L standard. Nitrate, as nitrogen, had a concentration of 22 mg/L in one water sample from well 84-33-2BDBA, exceeding the 10 mg/L standard. Gross-alpha activity had a concentration of 23 pCi/L in a water sample from well 81-36-13CBCA, exceeding the 15 pCi/L standard. Lead had a concentration of 80 ug/L in one water sample from well 79-35-10CABB, exceeding the 50 ug/L standard. In some water samples the following constituents exceeded secondary drinking-water standards: dissolved-solids concentrations ranged from 184 to 3,440 mg/L, and exceeded the 500 mg/L standard in 14 samples; iron ranged from 20 to 10,800 ug/L and exceeded the 300 ug/L standard in 14 samples; manganese ranged from 10 to 3,600 ug/L and exceeded the 50 ug/L standard in 21 samples; and sulfate ranged from 6 to 2,000 mg/L and exceeded the 250 mg/L standard in 8 samples. The irrigation classification of the water samples are C2-S1, C3-S1, C4-S1, and C4-S2, indicating a high to very high salinity hazard and low to medium sodium hazard and would not be suitable for irrigation purposes (fig. 8).

Breda, Carroll, Glidden, Guthrie Center, Lanesboro, Lidderdale, and Woodbine pumped 421.7 Mgal of water from the Dakota aquifer. Carroll uses water from both the Middle Raccoon and Dakota aquifers. Guthrie Center uses water from both the South Raccoon and Dakota aquifers. Coon Rapids uses about 8 percent of its water from the Dakota aquifer. Municipal-water withdrawals are shown on plate 3 and in table 5.

Data from alluvial, buried channel, basal Pleistocene, and Dakota aquifers have been summarized in table 6. Data includes approximate areal extent, estimated quantity of ground water in storage, average dissolved-solids concentration, and potential yield to wells.

SUMMARY AND CONCLUSIONS

The four major ground-water sources for municipal, industrial, domestic, and livestock water supplies in west-central Iowa are alluvial, buried channel, basal Pleistocene, and Dakota aquifers. Alluvial aquifers are in the floodplains of the Little Sioux, Maple, Soldier, Boyer, West Nishnabotna, East Nishnabotna, South Raccoon, Middle Raccoon, and North Raccoon River valleys. Alluvial deposits measured in test holes consist of clay, silt, sand, and gravel that range from 3 to 96 feet thick. Alluvial aquifers are recharged by infiltration of precipitation through surface soils. Water is discharged from the alluvial aquifers to the rivers during periods of low streamflow. Local recharge and discharge relations may be more complex where other aquifers underlie or are adjacent to the alluvial aquifers. Alluvial aquifers contain about 870,000 acre-feet of available ground water in west-central Iowa. Potential well yields generally are less than 50 gallons per minute if drawdowns are limited to 1 foot. Water from alluvial aquifers generally is very hard, is a calcium bicarbonate type, and has an average dissolved-solids concentration of less than 600 mg/L. Most towns in Audubon, Crawford, Harrison, Monona, and Shelby Counties obtain their water supplies from alluvial aquifers.

Seven buried channel aquifers--Anthon, Denison, Fremont, Hardin Creek, Adaza, Beaver and Bagley--underlie about 600 square miles in west-central Iowa. These aquifers consist of sand, sand and gravel, or gravel units that range from 1 foot to 170 feet thick and are underlain by bedrock and usually overlain by glacial till. Buried channel aquifers are recharged by leakage through overlying material and, where present, the adjacent Dakota aquifer. Buried channel aquifers contain about 65,000 acre-feet of available ground water in west-central Iowa. Potential well yields range from 10 to 1,000 gal/min. Water from buried channel aquifers generally is very hard. The water in the shallow buried channel aquifers in Carroll, Greene, and Guthrie Counties is a calcium bicarbonate type and has an average dissolved-solids concentration of 400 to 800 mg/L. In the deeply buried channel aquifers in the six western counties, the water is a sodium sulfate or calcium sulfate type and has an average dissolved-solids concentration of 3,000 mg/L. Towns in Greene and northern Guthrie Counties obtain their water supplies from buried channel aquifers. The principal use of water from buried channel aquifers is for domestic and livestock water supplies.

The basal Pleistocene aquifer occurs on many buried bedrock ridges between buried channels and consists of sand, sand and gravel, or gravel. Measured thickness of this aquifer ranges from 1 foot to 104 feet, but generally is less

Table 6.--Summary of data from alluvial, buried channel, basal Pleistocene, and Dakota aquifers

[mg/L, milligrams per liter; <, less than; --, no data; >, greater than]

Aquifer	Approximate areal extent (square miles)	Estimated quantity of water from storage (acre-feet)	Average dissolved-solids concentration (mg/L)	Potential Yield to wells (gallons per minute)
Little Sioux aquifer	17	52,000	300	<50
Maple aquifer	25	125,000	600	<50
Soldier aquifer	52	115,000	500	<50
Boyer aquifer	79	200,000	600	<50
West Nishnabotna aquifer	65	156,000	500	<50
East Nishnabotna aquifer	18	35,000	600	<50
South Raccoon aquifer	38	61,000	250	<50
Middle Raccoon aquifer	26	54,000	400	<50
North Raccoon aquifer	30	72,000	600	<50
Total	350	870,000		
Anthon aquifer	95	6,000	3,000	10 to 200
Denison aquifer	81	8,000	--	10 to 200
Fremont aquifer	282	45,000	3,000	10 to 800
Hardin Creek aquifer	66	3,000	500	50 to 1,000
Adaza aquifer	19	1,000	--	50 to 400
Beaver aquifer	23	1,000	800	50 to 400
Bagley aquifer	28	1,000	400	10 to 300
Total	594	65,000		
Basal Pleistocene aquifer	--	--	1,000	5 to 500
Dakota aquifer	2,217	--	650 for wells < 200 feet deep 2,200 for wells > 200 feet deep	10 to 400

than 30 feet thick. This aquifer predominantly is in Audubon, Crawford, Harrison, Monona, Shelby, western Carroll, and western Guthrie Counties. The basal Pleistocene aquifer is recharged by leakage through overlying material and probably, where present, the adjacent Dakota aquifer. Sufficient data are not available to map the areal extent and potential well yields or to calculate the estimated quantity of water from storage. Estimated well yields of up to 500 gal/min can be obtained from this aquifer, but yields of 5 to 50 gal/min are more common. Water from the basal Pleistocene aquifer generally is very hard, is a calcium bicarbonate or calcium sulfate type, and has an average dissolved-solids concentration of 1,000 mg/L. Irrigation classifications of water from the basal Pleistocene aquifer range from a medium to very high salinity hazard with a low sodium hazard. Several small towns obtain water from the basal Pleistocene aquifer, although most water withdrawn from this aquifer is used by farms for domestic and livestock water supplies.

The Dakota Formation is present as isolated erosional remnants forming the cap of many buried bedrock ridges in west-central Iowa. The Dakota Formation has two recognized members in Iowa (Munter and others, 1983). The upper member is the Woodbury Member, which consists of interbedded shales and sandstones that usually form a confining unit where present. The measured Woodbury Member is up to 192 feet thick. The lower member is the Nishnabotna Member and is a fine- to coarse-grained, poorly cemented sandstone interbedded with gravel and thin shale units. The measured Nishnabotna sandstone and gravel are up to 150 feet thick, but an average thickness of 30 feet is more common. The thickest sandstone units are in Carroll and Guthrie County. The Nishnabotna Member is the major aquifer unit in the Dakota Formation. The Dakota aquifer is overlain by Quaternary material, although abundant surface exposures of the Dakota Formation exist in Guthrie County along the South Raccoon and Middle Raccoon Rivers, and Brushy Creek.

The Dakota aquifer, as defined in this report, is the saturated sandstone and gravel in the Dakota Formation. The aquifer is recharged by leakage through overlying material and directly from precipitation where the aquifer is exposed at land surface. The Dakota aquifer underlies about 2,200 square miles of west-central Iowa. Potential well yields range from 10 to 400 gal/min. Water from the Dakota aquifer generally is very hard. Water from wells 50 to 200 feet deep generally is a calcium bicarbonate type and has an average dissolved-solids concentration of 2,200 mg/L. Irrigation classifications of water from the Dakota aquifer range from a medium to very high salinity hazard and a low to medium sodium hazard. Towns in Carroll and Guthrie Counties obtain water from the Dakota aquifer for their water supplies. Water from the Dakota aquifer primarily is used for domestic and livestock water supplies.

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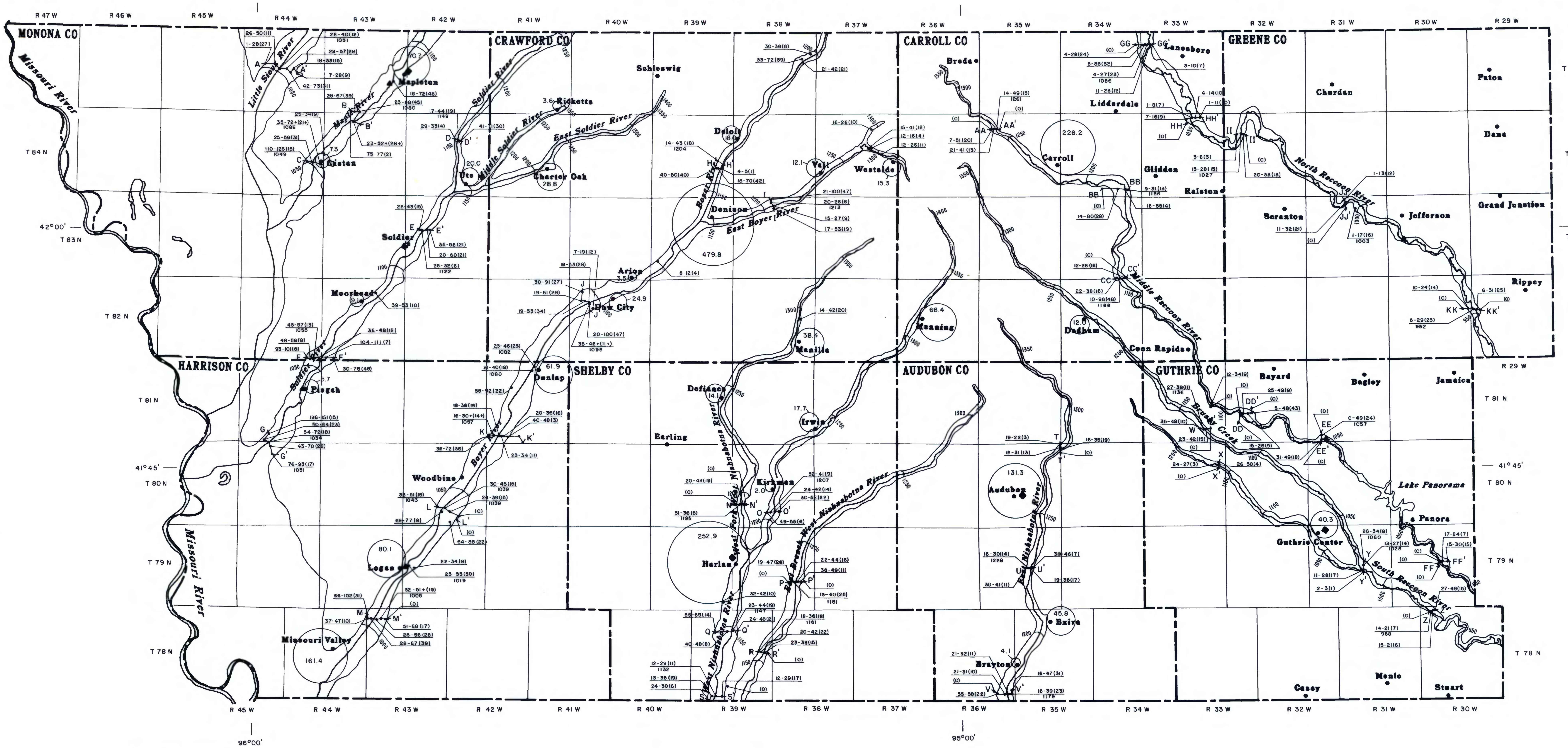
WATER-RESOURCES INVESTIGATIONS REPORT 85-4239
PLATE 1



Base from Geological Survey
State Base Map 1:500,000

Scale 1: 250 000
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS

EXPLANATION

▭ ALLUVIAL AQUIFER--Well yields generally less than 50 gallons per minute

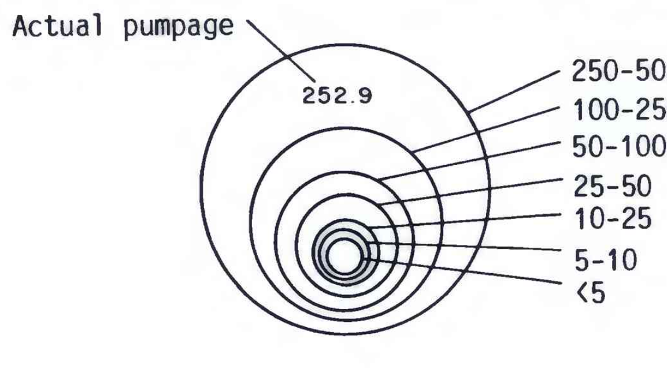
▲ STREAMFLOW-GAGING STATION

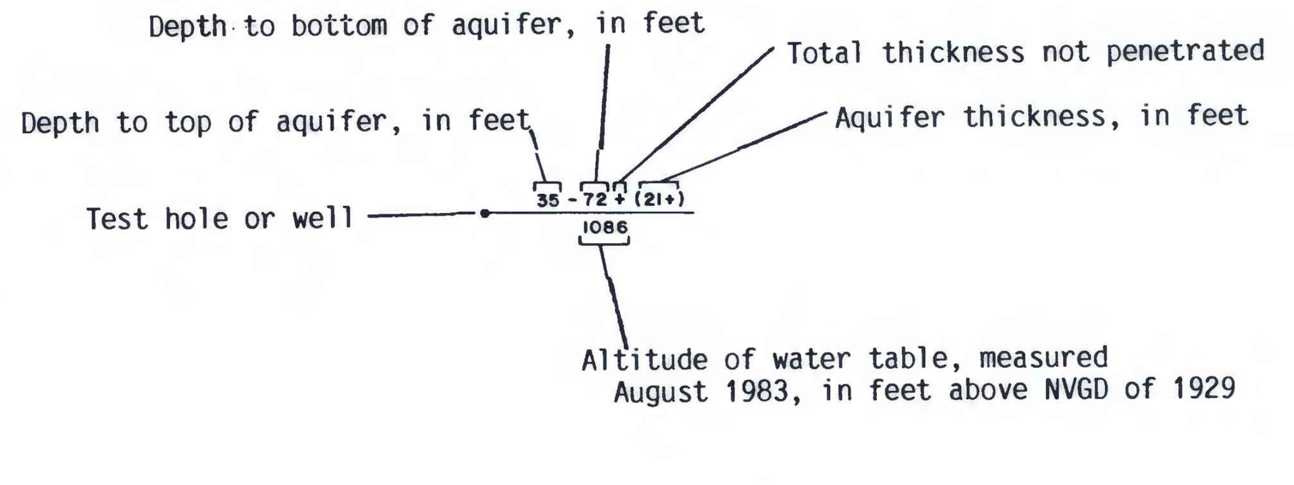
◆ PRECIPITATION STATION

—1200— WATER-TABLE CONTOUR--Shows altitude of water-table surface, August 1983. Contour interval 50 feet. Datum is NGVD of 1929

V V' TRACE OF GEOHYDROLOGIC SECTION

MUNICIPAL PUMPAGE, IN MILLIONS OF GALLONS, FROM THE ALLUVIAL AQUIFERS DURING 1980





MAP SHOWING LOCATION, ESTIMATED WELL YIELDS, AND MUNICIPAL PUMPAGE FROM ALLUVIAL AQUIFERS IN WEST-CENTRAL IOWA

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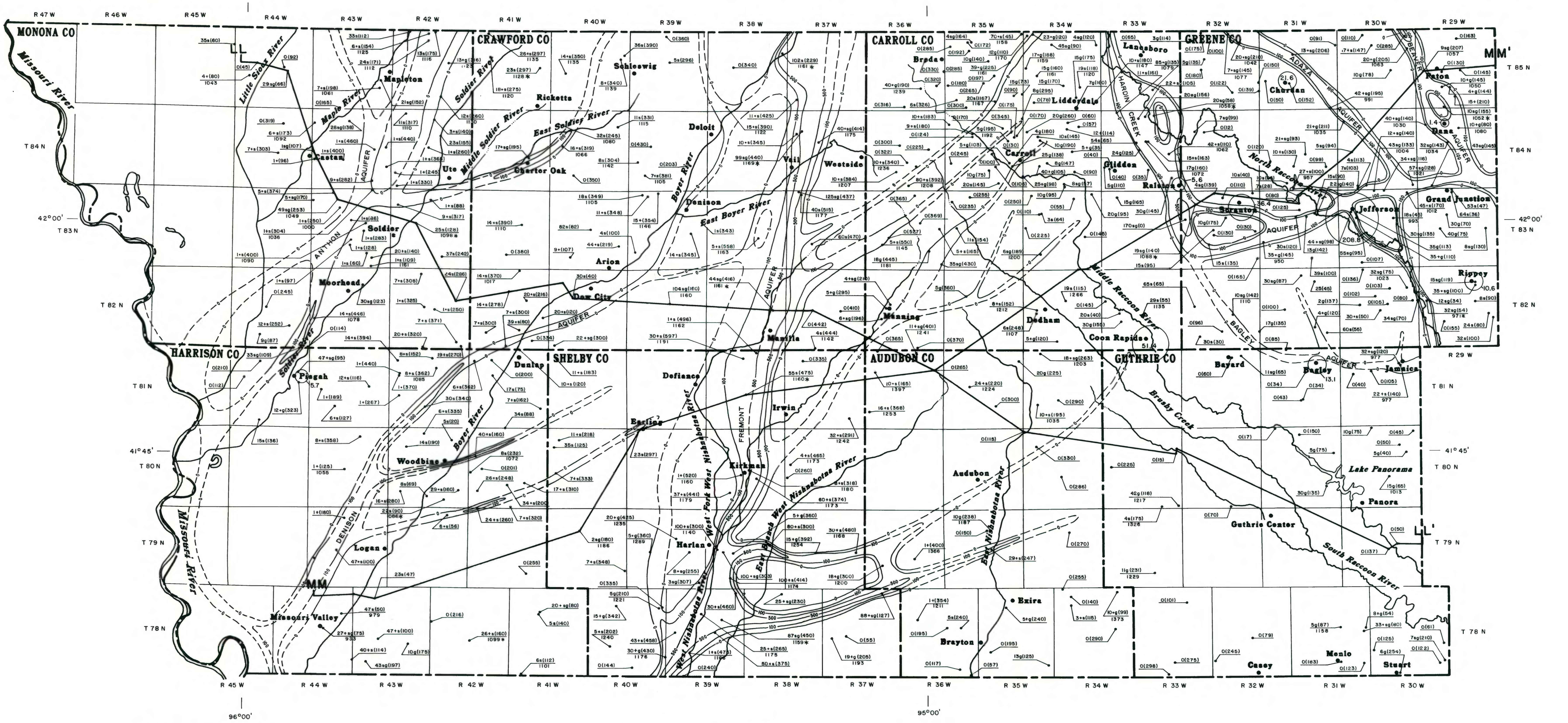
WATER-RESOURCES INVESTIGATIONS REPORT 85-4239
PLATE 2



Base from Geological Survey
State Base Map 1:500,000

Scale 1:250 000
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS

EXPLANATION

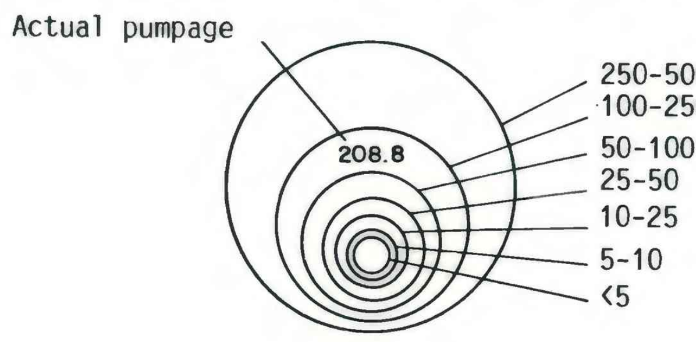
BURIED CHANNEL AQUIFER--Estimated well yields, in gallons perminute

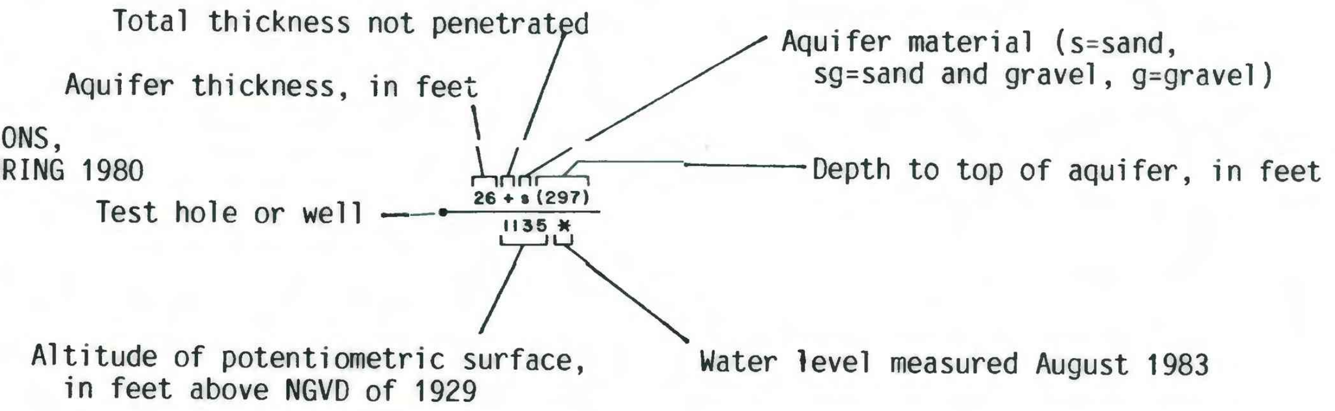
☐ Greater than 500
☐ 100-499
☐ Less than 100
☐ No buried channel aquifer

——100——— LINE OF EQUAL ESTIMATED POTENTIAL YIELD--Dashed where approximately located

LL———LL' TRACE OF GEOHYDROLOGIC SECTION

MUNICIPAL PUMPAGE, IN MILLIONS OF GALLONS, FROM THE BURIED CHANNEL AQUIFERS DURING 1980





MAP SHOWING LOCATION, ESTIMATED WELL YIELDS, AND MUNICIPAL PUMPAGE FROM BURIED CHANNEL AND BASAL PLEISTOCENE AQUIFERS IN WEST-CENTRAL IOWA

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WATER-RESOURCES INVESTIGATIONS REPORT 85-4239
PLATE 3

Base from Geological Survey
State Base Map 1:500,000

Scale 1:250 000
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS

EXPLANATION

DAKOTA AQUIFER--Estimated well yields, in gallons per minute

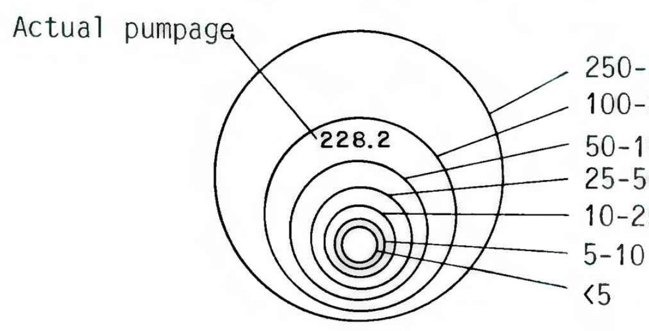
☐ Greater than 500
☐ 100-499
☐ Less than 100
☐ No Dakota aquifer

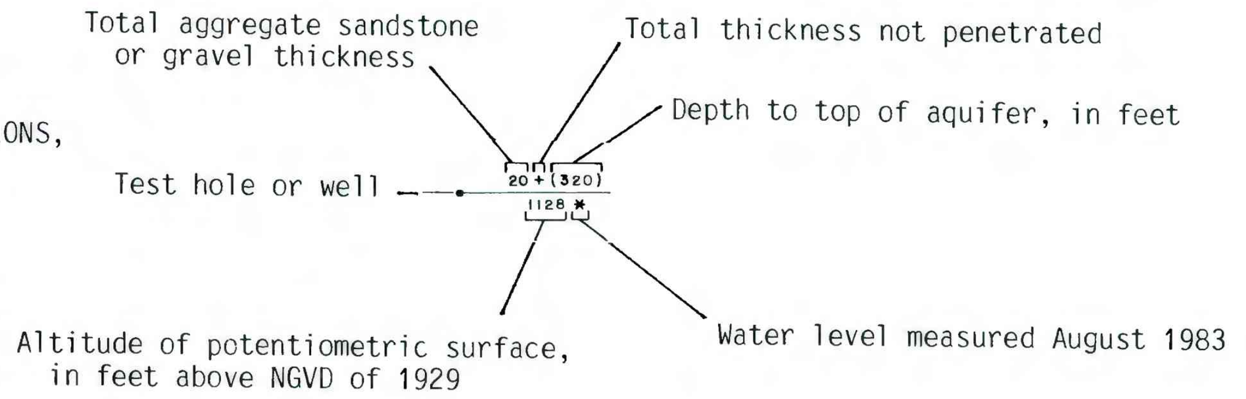
—100— LINE OF EQUAL ESTIMATED POTENTIAL YIELD--Dashed where approximately located

— — 1150— — POTENTIOMETRIC SURFACE CONTOUR--Altitude of the potentiometric surface. Contour interval 50 feet. Datum is NGVD of 1929

A A' TRACE OF GEOHYDROLOGIC SECTION

MUNICIPAL PUMPAGE, IN MILLIONS OF GALLONS, FROM THE DAKOTA AQUIFER DURING 1980



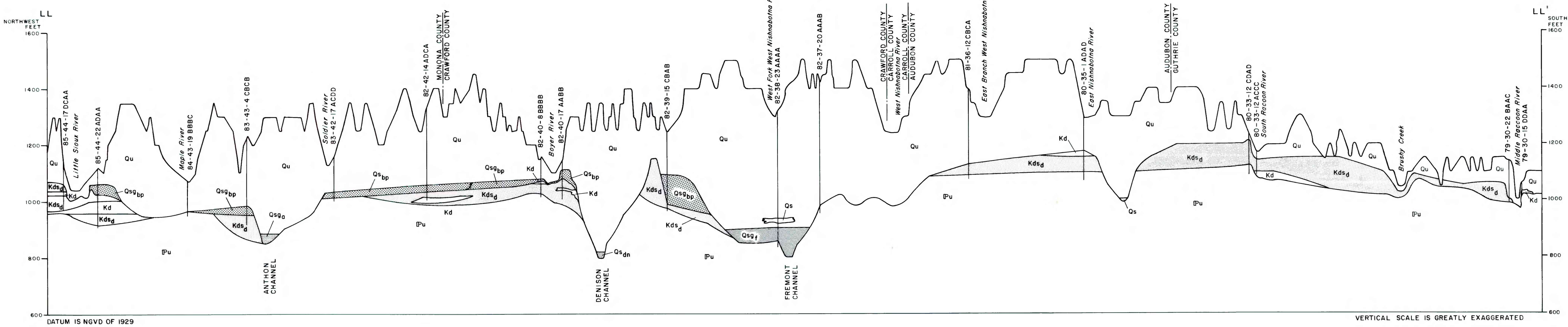


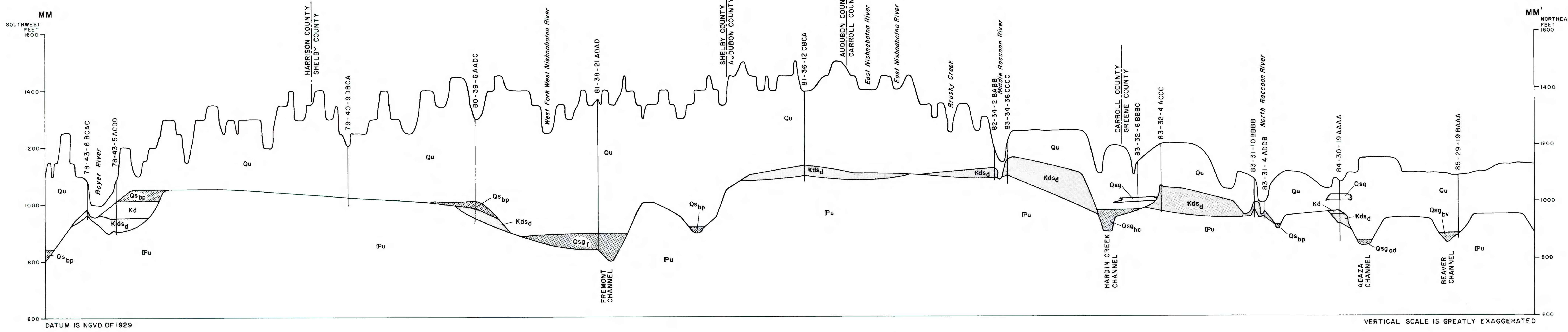
MAP SHOWING LOCATION, ESTIMATED WELL YIELDS, AND MUNCIPAL PUMPAGE FROM THE DAKOTA AQUIFER IN WEST-CENTRAL IOWA

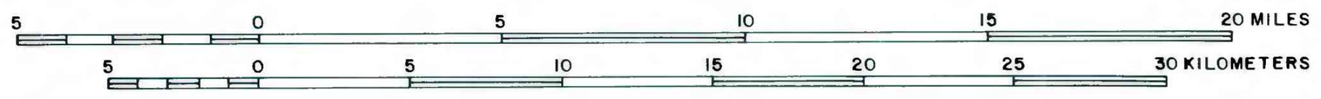
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
GEOLOGICAL SURVEY BUREAU,
IOWA DEPARTMENT OF NATURAL RESOURCES
and
UNIVERSITY OF IOWA HYGIENIC LABORATORY

WATER-RESOURCES INVESTIGATIONS REPORT 85-4239
PLATE 4







EXPLANATION

QUATERNARY
- Qs Sand
- Qsg Sand and gravel
- Qu Undifferentiated material

CRETACEOUS
- Kd Shale of Dakota Formation
- Kds Sandstone of Dakota Formation

PENNSYLVANIAN
- IPu Undifferentiated rocks

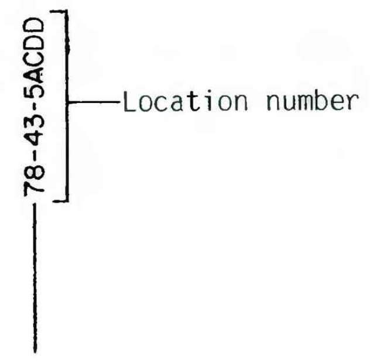
AQUIFER SYMBOL
(Subscript)

▨
- a Anthon aquifer
- ad Adaza aquifer
- bv Beaver aquifer
- dn Denison aquifer
- f Fremont aquifer
- hc Hardin Creek aquifer

▩ bp Basal Pleistocene aquifer

░ d Dakota aquifer

WELL OR TEST HOLE



GEOHYDROLOGIC SECTIONS LL-LL' AND MM-MM' THROUGH THE BURIED CHANNEL, BASAL PLEISTOCENE, AND DAKOTA AQUIFERS IN WEST-CENTRAL IOWA