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HYDROLOGY OF THE SURFICIAL AQUIFER IN THE FLOYD RIVER BASIN, IOWA

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Prepared Cooperatively by the United States Geological Survey and the Iowa Geological Survey

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ACKNOWLEDGEMENTS

Residents in the study area cooperated by supplying information on their wells and allowing measurement of water levels in selected wells. Special thanks are due to those people who permitted test drilling on their property and to Mr. Raymond Anderson who permitted test drilling and allowed his irrigation well to be used for an aquifer test. Drilling contractors who supplied drilling samples to the Iowa Geological Survey provided valuable assistance to this project as well as to geologic and hydrologic studies throughout the State. Information on municipal water supplies and water use in the area was supplied by municipal water superintendents. Water samples collected as a part of the study were analyzed by the University of Iowa, Hygienic Laboratory.

TABLE OF CONTENTS

LIST OF FIGURES

PLATES

LIST OF TABLES

GLOSSARY

Aquifer - A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Conversion factors to convert English (foot-pounds) units to International System (SI) Units:

Multiply English Units	By	To obtain SI Units
acre-feet	1233.00000	cubic meters
cubic feet	0.02832	cubic meters
cubic feet per second	0.02832	cubic meters per second
feet	0.3048	meters
feet per day	0.3048	meters per day
feet per mile	0.1894	meters per kilometer
square feet per day	0.0929	square meters per day
gallon	0.003785	cubic meters
gallon per day per foot	0.0124	square meters per day
gallons per day per square foot	0.04075	meters per day
gallons per minute (gpm)	0.063	liters per second
inch	25.4	millimeter
mile	1.609	kilometer
square foot	0.09290	square meter
square mile	2.59	square kilometer

Cubic foot per second (cfs) - one cubic foot per second is the rate of discharge of a stream having a cross-sectional area of 1 square foot and an average velocity of 1 foot per second; 1 cubic foot per second = 7.48 U.S. gallons per second = 0.646 million U.S. gallons per day.

Hydraulic conductivity - The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Low flow - The part of stream discharge that is derived primarily from ground-water outflow.

Recurrence interval - The average interval in years between occurrences of a flow less than that indicated by the data. A 10-year drought has a probability of 0.10, or a 10 percent chance, of occurring during any given year.

Specific capacity - The rate of discharge of water from a well divided by the drawdown of the water level in the well.

Storage coefficient - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head.

Transmissivity - The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

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."

HYDROLOGY OF THE SURFICIAL AQUIFER IN THE FLOYD RIVER BASIN, IOWA

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ABSTRACT

The Floyd River basin was studied to provide water-resources information for a typical surficial aquifer in northwest Iowa. Data collection included test drilling, water-level measurements, and chemical analyses of surface and ground water.

The Floyd River basin drains 961 square miles of highly dissected to gently rolling topography. Major streams generally are flanked by flood plains underlain by uncemented sand-and-gravel deposits.

Most of the basin is directly underlain by glacial drift of Pleistocene age which is in turn underlain by rocks of Cretaceous age. Sand-and-gravel deposits underlying the major flood plains and in buried bedrock channels within the drift comprise the surficial aquifer.

The surficial aquifer ranges from 10 to 40 feet in thickness and averages about 20 feet thick. Both unconfined and confined conditions occur in the aquifer and water levels range from 2 to 55 feet below land surface.

An aquifer test conducted in the surficial aquifer where it is about 25 feet thick and is confined by an overlying low-permeability bed indicated an average hydraulic conductivity of 383 feet per day and a storage coefficient of 0.0001. The well was pumped at 650 gallons per minute for 43 hours. An observation well about 70 feet from the pumping well had a maximum drawdown of about 10 feet.

Water use in the basin is largely for public supply and rural-domestic or rural-livestock use although irrigation use has been increasing in recent years. The ground water generally is of suitable chemical quality for most uses although it is hard and has excessive concentrations of sulfate in some areas.

INTRODUCTION

The northwestern part of Iowa has the lowest average precipitation in the State. The area generally is the first to be affected when regional drought conditions prevail. During a particularly prolonged drought, 1975-77, the severity of conditions in conjunction with ever increasing water use resulted in an unprecedented number of requests for water data in the area. In response to these requests a water-resource investigation of the area was begun by the Iowa Geological Survey in cooperation with the U.S. Geological Survey. Because of the size of the area, a lack of basic geologic and hydrologic data, and a pressing need for defining supplemental and alternative water supplies, it was decided to begin the study by intensively investigating shallow aquifers in one drainage basin. The Floyd River basin was selected for study because some geologic and hydrologic data were available for that area, it is a basin which is within the major study area, and its geologic setting is typical of many basins in the region. Thus, the data collected and the interpretations made should be typical of northwest Iowa and could be applied to many other basins throughout the area. This report presents the results of the first phase of the northwest Iowa investigation.

Purpose and Scope

The overall purposes of the northwest Iowa study are to describe the geologic setting of the area, evaluate the availability and quality of water resources, estimate water withdrawals, and determine the effect water withdrawals and use will have on the hydrologic system. To provide some immediate information that would be applicable to many parts of the area, the first phase of the project concentrated on the shallow Quaternary aquifer in the Floyd River basin. The primary objective within that basin was to determine the character, extent, and thickness of Quaternary sand-and-gravel aquifers. Other subjects of interest were the chemical quality of the water resources, the nature of underlying bedrock and overlying confining beds, the configuration of the potentiometric surface, water use, and the relationship of surface water and ground water. The long-term effects of water withdrawal and use on the hydrologic system were not intensively investigated.

Streamflow characteristics in the area were analyzed because many of the shallow aquifers are hydraulically connected with major streams. Low-flow and average-flow values for the streams, therefore, are indicative of ground-water discharge and total water availability.

Description of the Area

The Floyd River, draining 961 square miles (Larimer, 1974), is located in northwest Iowa (figure 1). The river and its tributaries drain parts of Cherokee, O'Brien, Osceola, Plymouth, Sioux and Woodbury Counties prior to discharging into the Missouri River at Sioux City.

Major data-collection efforts included test drilling to determine the extent and character of aquifers, water-level measurements in test wells and selected private wells, and collection of water samples from selected wells and streams for chemical analyses. Natural-gamma logs were run in the test wells to provide lithologic detail and to differentiate "clean" sand-and-gravel beds from those containing more clay. In addition, surface-resistivity surveys were made in several areas to obtain additional subsurface information, and an aquifer test using an irrigation well was made to determine aquifer characteristics.

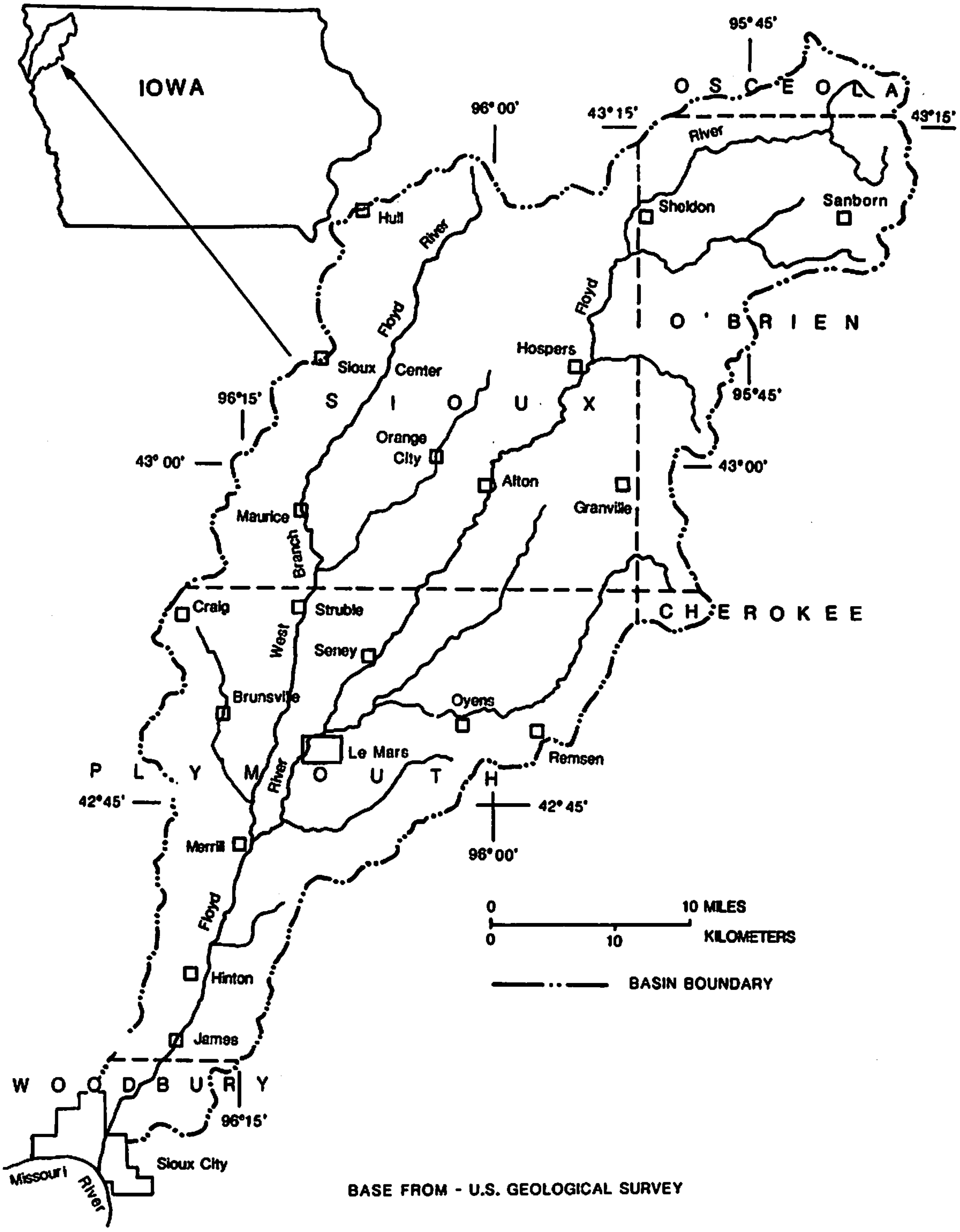
Wells and other data points in this report will be referenced according to the legal location as described by the section subdivision (NW, SW, NE, or SE, ¼ section), the section, the township, and the range in which the well or data point is located.

Climate

The climate of the area is classified as temperate continental warm summer (Trewartha, 1968). The normal annual precipitation ranges from 25.74 inches at Sioux City to 28.07 inches at Sanborn.

Precipitation is variable and the mean annual departure from normal is about 5 inches at Le Mars. Precipitation at Le Mars for 1941-70 is shown in figure 2. The average for this period is 26.53 inches and departures range from 13.5 inches less than normal during 1956 to 16 inches greater than normal during 1951 (figure 2). An analysis of an 82-year record from the weather station at Le Mars is shown in table 1.

Data at other stations in the basin have similar trends. Approximately 82 percent of the annual precipitation at Le Mars falls during the spring and summer from April through September (figure 3). The mean annual air temperature for Le Mars is 47.8 degrees Fahrenheit. The range of mean monthly temperature is from 17.3 degrees Fahrenheit during January to 74.3 degrees Fahrenheit during July (figure 4).



BASE FROM - U.S. GEOLOGICAL SURVEY

Figure 1. Location of Study area.

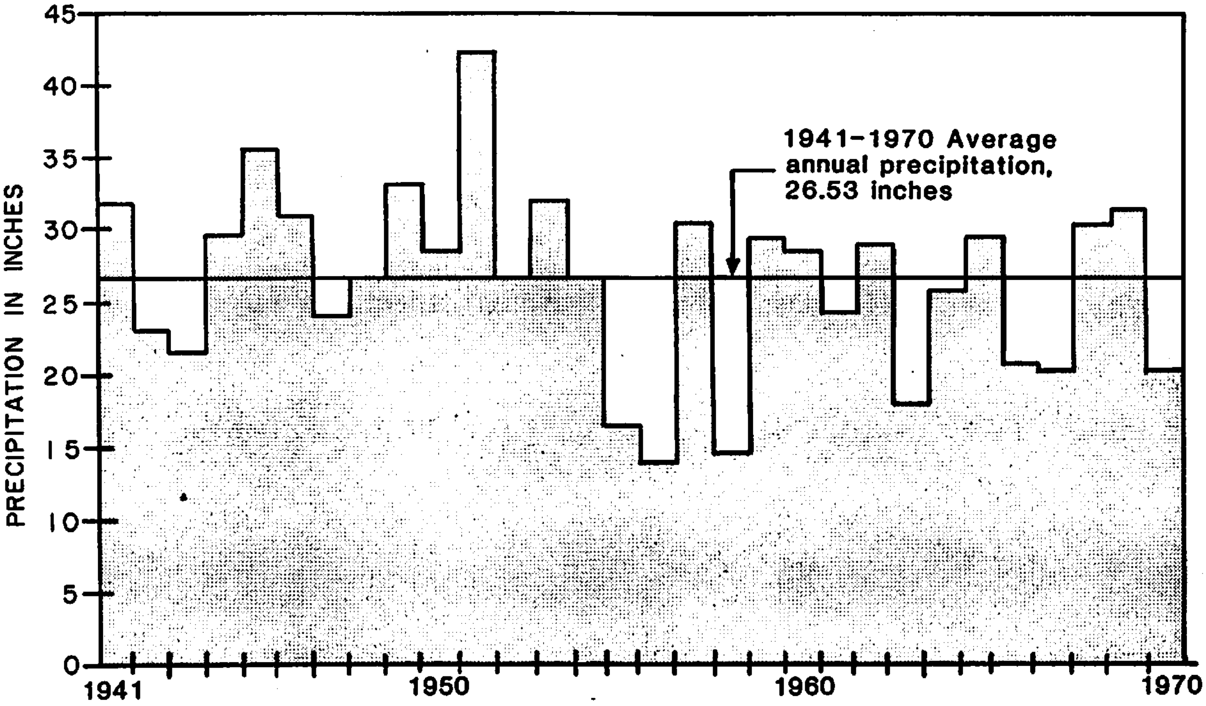


Figure 2. Annual precipitation at Le Mars.

Drainage and Topography

The Floyd River basin is located on the Dissected Till Plains Section of the Central Lowlands Province (Thornbury, 1967). The land surface of the basin can be classified as flood plain, terraces, sideslopes, interfluves, and divides.

Land-surface altitudes range from more than 1,560 feet in the headwaters region in Osceola County to less than 1,100 feet at the confluence of the Floyd and Missouri Rivers; with a maximum relief of approximately 460 feet. The southern part of the basin, in south-central Plymouth County, is extensively dissected with steep sideslopes and has local relief of more than 300 feet. This area, which Prior (1976) calls the Western Loess Hills, is mantled with thick loess deposits.

To the north, the basin is developed in glacial drift with a loess veneer. In this area the greatest relief occurs along major streams; away from streams the landscape becomes gently rolling (Ruhe, 1965 and 1969; Prior, 1976).

Flood plains in the basin generally are flanked by loess-mantled gravel terraces at the toe of the sideslopes. The flood plain generally is less than 1 mile wide although in certain areas such as north of Hinton, in Plymouth County, it is about 1.5 miles wide. The upstream gradient of the flood plain is relatively small; about 20 feet from Sioux City to Hinton, a distance of approximately 11 miles, or an average gradient

Table 1. Departures from average annual precipitation and percentage of occurrence at Le Mars.

Departure from average of 26.53 inches	Percentage of annual departures (1)
+10	5
+ 7	10
+ 5	17
+ 3	34
- 3	32
- 5	23
- 7	10
-10	5

(1) 82 years of record

of 1.8 feet per mile. From that point upstream to the mouth of West Branch, north of Merrill, the gradient is about 30 feet in 7.5 miles; an average of 4 feet per mile. Lara (1973) notes that the gradient for the stream averages 4.38 feet per mile.

Geology

The Floyd River basin is underlain by rocks ranging from Precambrian to Holocene in age (table 2). The older rocks, Precambrian through Devonian, occur in the subsurface and do not crop out in the Floyd River basin. Cretaceous rocks, which overlie the older rocks, are exposed in several small areas in the basin. However, in most of the area, Cretaceous rocks are overlain by uncemented deposits of Pleistocene and Holocene age.

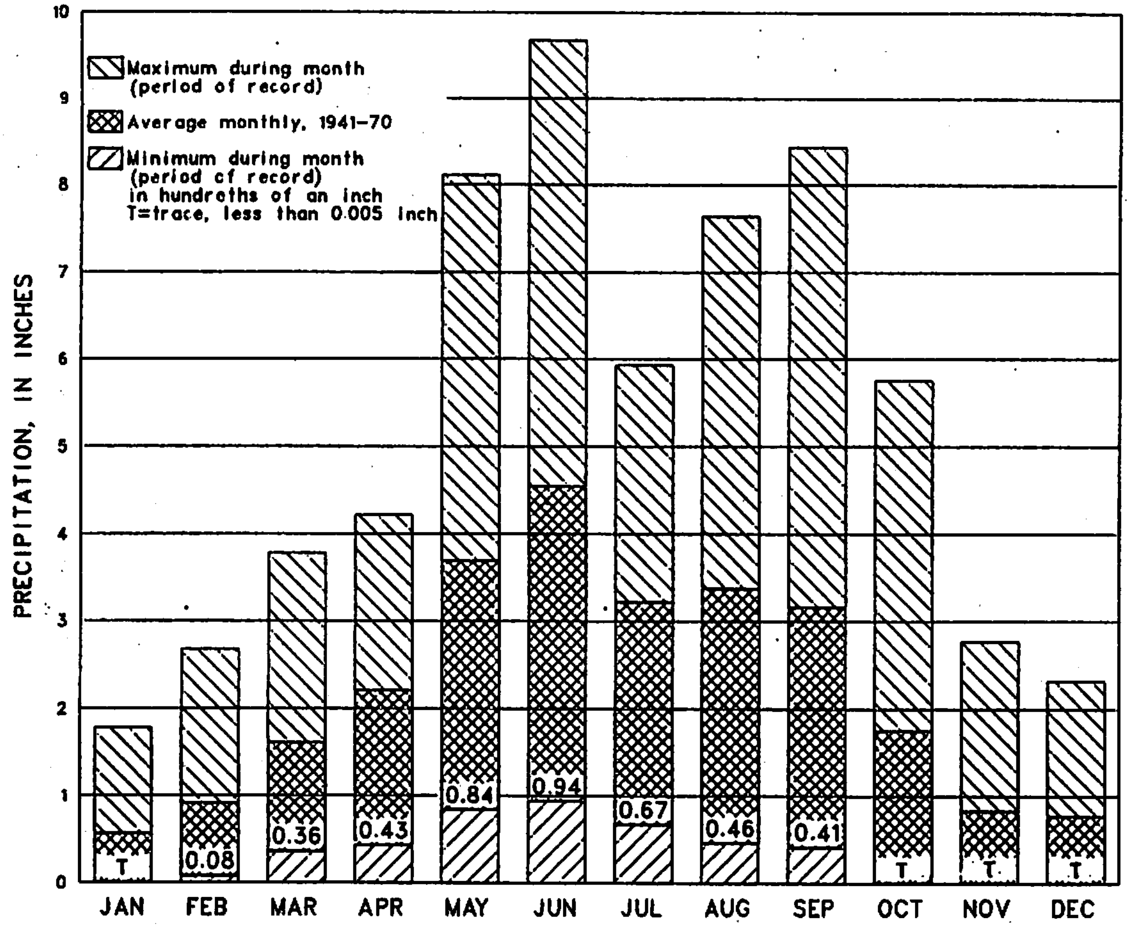


Figure 3. Monthly extremes and average precipitation at Le Mars.

The major part of the Floyd River basin (about 80 percent) is developed in glacial till of Pleistocene age. The age of this surface has been debated for a number of years and until quite recently was considered to be early Wisconsinan. However, Ruhe and others (1968) showed that the basin is cut into Kansan drift and that the post-Kansan paleosols were stripped away during a later erosion cycle of Wisconsinan age.

The deposits of classical Kansan and Nebraskan age have been shown to be much more complex than originally assumed (Hallberg and Boellstorff, 1978). As the details of the stratigraphy of these deposits is determined, they are being assigned rock-stratigraphic status and are now defined as Pre-Illinoian in age (Hallberg, 1980). The complex Pre-Illinoian deposits range in thickness from zero to more than 400 feet in the Floyd River basin.

At least two buried channels, which were eroded into the bedrock 200 to 250 feet, trend from northwest to southeast under the Floyd River

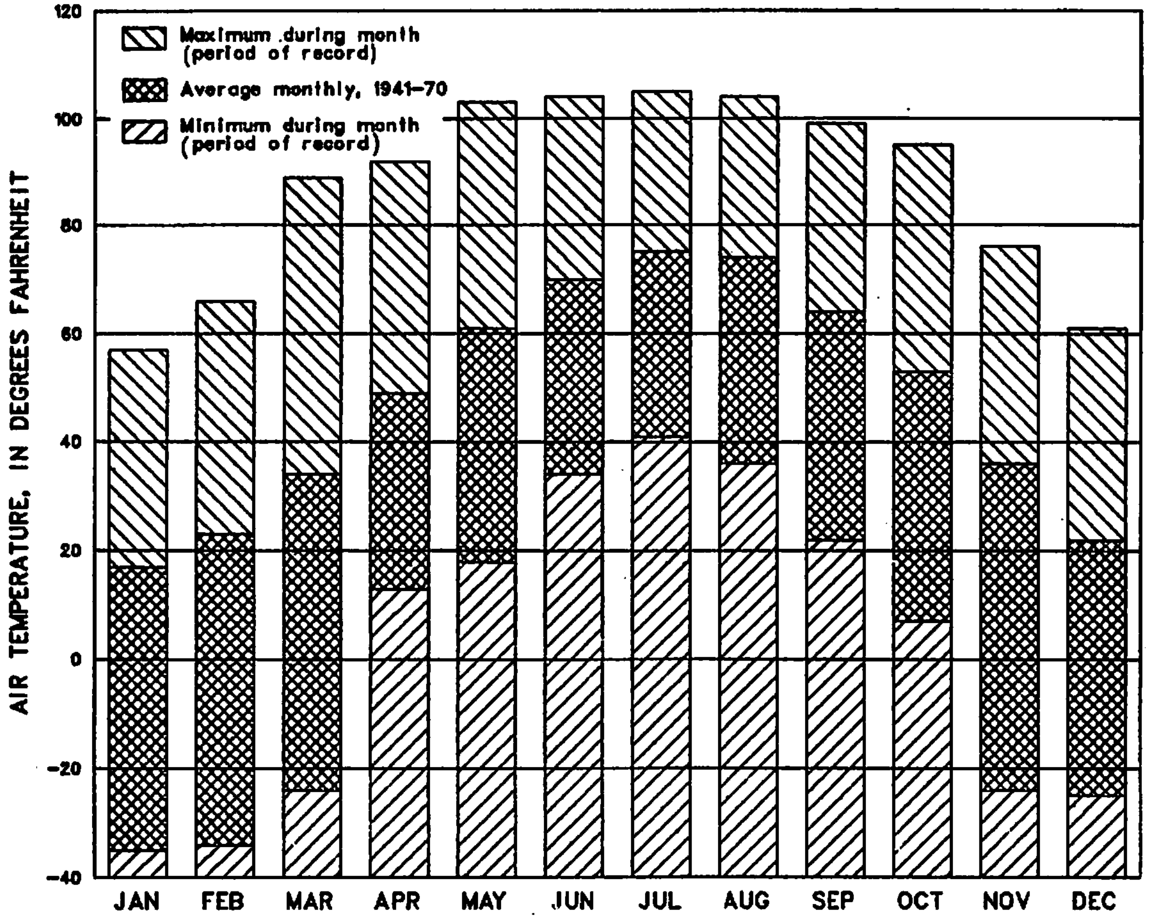


Figure 4. Monthly extremes and average air temperature at Le Mars.

basin (plate 1). These buried channels are filled with uncemented deposits of Pre-Illinoian age. The buried channels are ancient valleys eroded into bedrock by streams before or between transgressions of glacial ice during Pleistocene time. These features have little or no expression on the modern topography. However, the channels are easily recognized on the bedrock topography map (plate 1). Drill holes indicate that at some locations the buried channels contain gravel and sand aquifers and in other areas are essentially filled with glacial till (B. J., Bunker, Iowa Geological Survey, oral communication, 1979, and Meyer, 1978).

Representative lithologic sections of the Floyd River basin are shown in figures 5, 6, and 7. The data used for the sections are from test holes drilled by the Iowa Geological Survey and the U.S. Geological Survey as a part of this study. Section A-A' (figure 5) at Merrill, shows a typical cross-section of the valley. Section B-B' (figure 6) north

Table 2. Stratigraphic column of geologic units*

SYSTEM	SERIES	FORMATION	UNIT &/OR LITHOLOGY
Quaternary	Holocene	Undifferentiated	Alluvium
	Pleistocene	Undifferentiated	Wisconsin deposits Illinoian deposits Pre-Illinoian deposits undifferentiated
Cretaceous		Carlile Shale Greenhorn Limestone Graneros Shale	
		Dakota Formation	Sandstone and shale
Devonian	Devonian Undiff.	Undifferentiated	Dolomite and Limestone
Ordovician	Mohawkian	Galena Formation Decorah Formation Platteville Formation	Dolomite, shale, and limestone
	Chazyan	St. Peter Sandstone	Sandstone and shale
Cambrian	St Croixan	Jordan Sandstone St Lawrence Formation	Sandstone Dolomite
		Undifferentiated	Sandstone, shale and dolomite
Precambrian		Undifferentiated	Granite and rhyolite

*Stratigraphic nomenclature used in this report is that used by the Iowa Geological Survey and does not conform in every detail with nomenclature used by the U.S. Geological Survey.

of Hinton, and section C-C' (figure 7) north of Merrill, show details of the lithology of the aquifer, encountered in the valley.

Ice of the Tazewell stade of Wisconsin Glaciation (about 20,000 years before present, Ruhe, 1969) covered a small part of the northwestern Floyd River basin, north of Sheldon. However, as Ruhe (1969) points out, the river system had already developed in the eolian materials and the underlying pre-Illinoian drift prior to Tazewell times as an

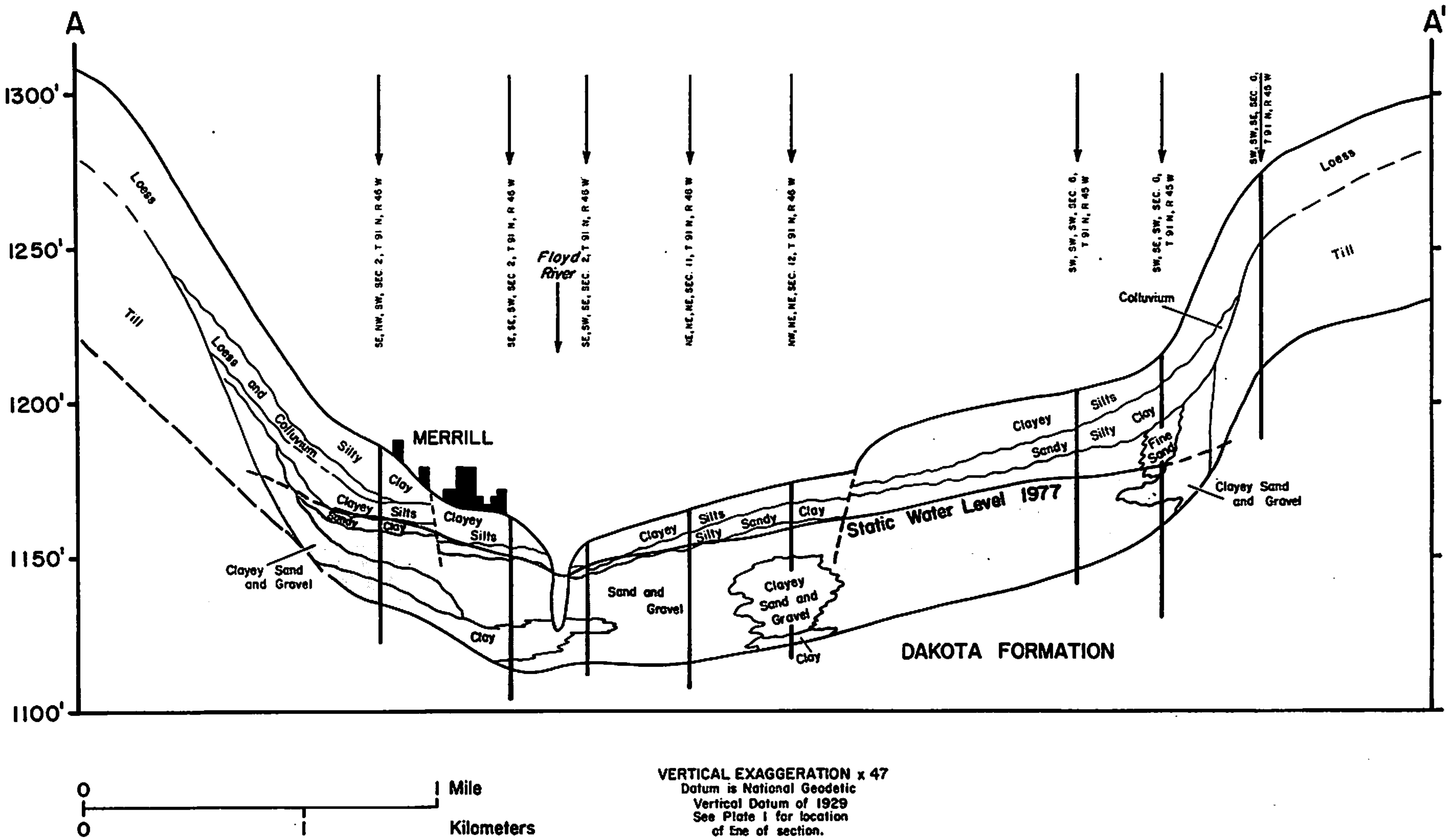


Figure 5. Section across the Floyd River Valley near Merrill.

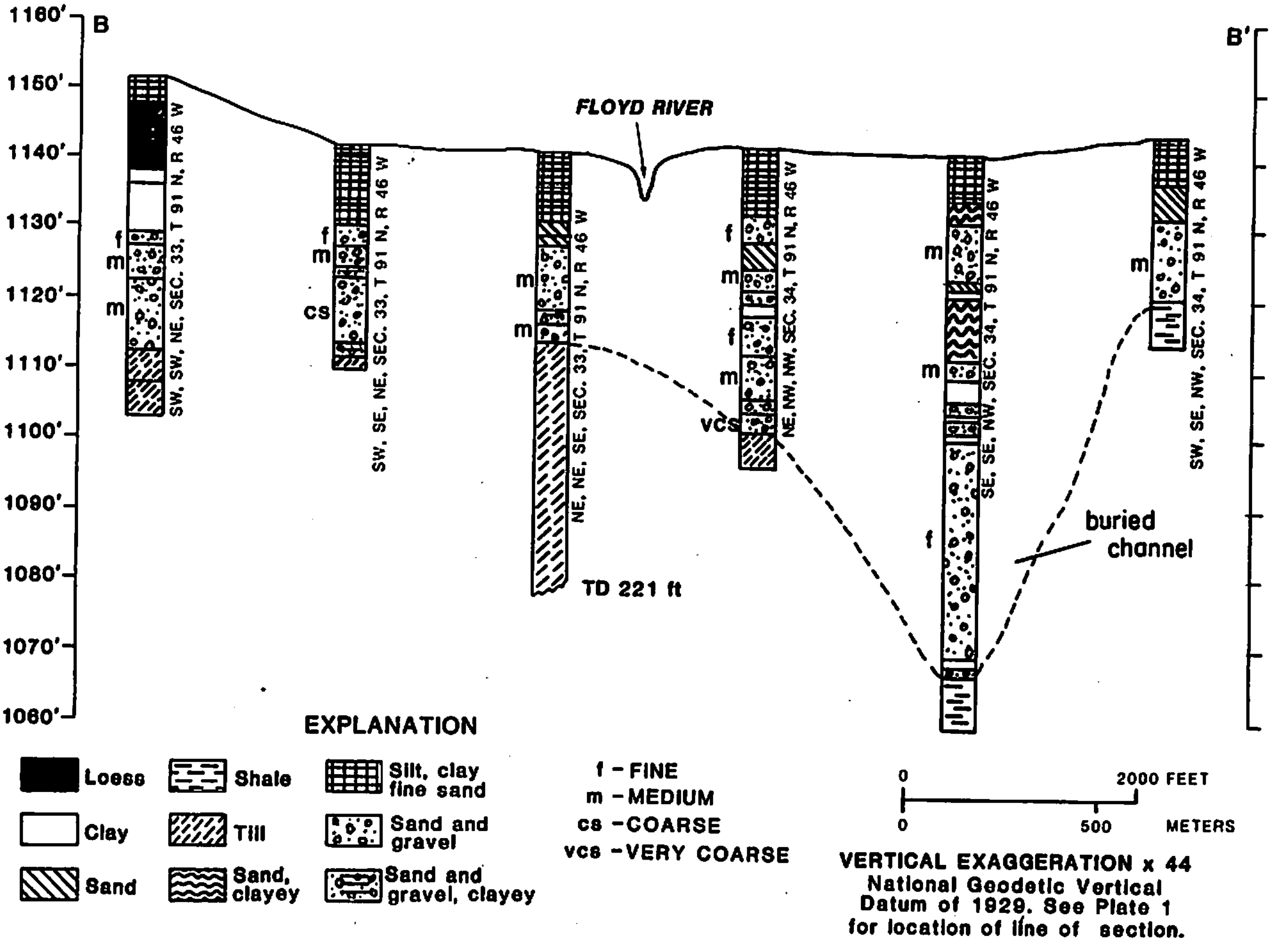


Figure 6. Lithologic section across the Floyd River Valley north of Hinton.

integrated drainage net. Subsequent surface dissection during Tazewell and later periods followed the same drainage network.

The Pre-Illinoian and Tazewell drifts are covered by loess deposits of Illinoian and Wisconsinan age, the deposition of which ended 14,000 years before present (Ruhe, 1969). In the study area the loess has a maximum thickness of about 65 feet in the Western Loess Hills near the Missouri River and is about 50 feet thick on the uplands west of the Floyd River in Plymouth County. The Wisconsinan loess decreases to about 4 feet in thickness to the northeast along the axis of the basin (Ruhe, 1969) and the loess veneer on the Tazewell drift ranges from about 4 to 8 feet in thickness (Ruhe, 1969).

Streams supplied by the melting Tazewell ice deposited outwash in the major channels of the Floyd River valley, forming extensive alluvial deposits. Subsequently, the stream has eroded into these alluvial deposits

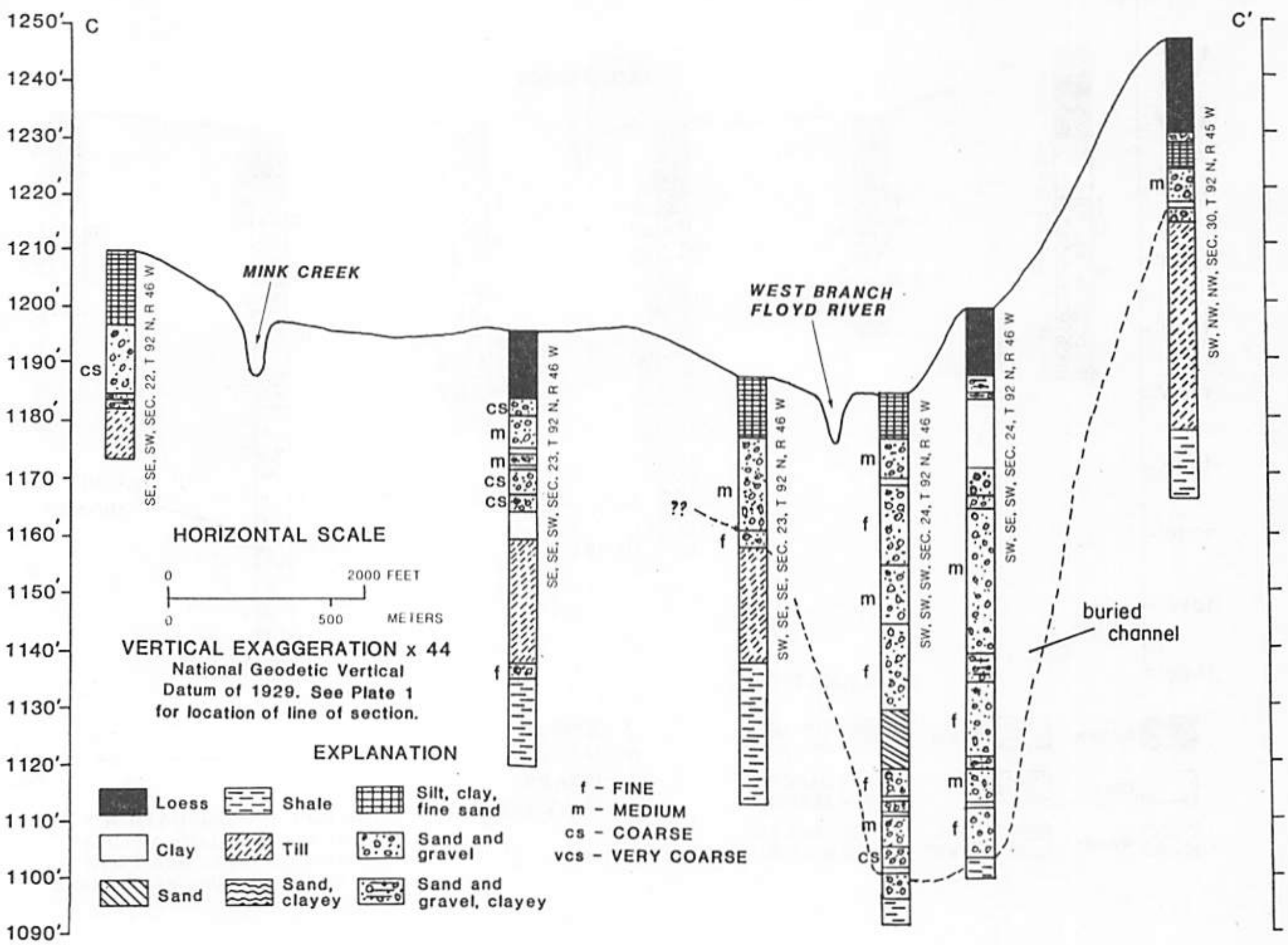


Figure 7. Lithologic section across the Floyd River Valley north of Merrill.

leaving the outwash as terraces. Wisconsinan loess overlies the outwash in these terraces. The outwash materials, which have been slightly modified by Floyd River erosion, underlie the flood plain and terraces and form a major part of the surficial aquifer in the study area.

Flooding by the Floyd River since the end of Wisconsin Glaciation has produced an accumulation of silt deposits on the flood plain averaging about 10 feet in thickness. Erosion of the upland till and loess flankking the valleys has resulted in colluvium being deposited on the flood plain and terraces along the bluffs and on the lower sideslopes.

Table 3. Streamflow-gaging stations in the Floyd River basin.

Station No.	Station name	Drainage area (square miles)	Station type
06600020	Floyd R near Sheldon, IA	64.0	Low-flow partial record
06600030	L Floyd R near Sanborn, IA	8.44	High-flow partial record
06600040	L Floyd R near Sheldon, IA	59.3	Low-flow partial record
06600060	Floyd R below Sheldon, IA	165.0	Low-flow partial record
06600080	Willow C at Hospers, IA	37.9	High-flow partial record
06600100	Floyd R at Alton, IA	265.0	Complete record
06600120	Deep C near Oyens, IA	82.7	Low-flow partial record
06600140	Willow C near Oyens, IA	65.2	Low-flow partial record
06600160	Deep C at Le Mars, IA	156.0	Low-flow partial record
06600180	Floyd R at Le Mars, IA	478.0	Low-flow partial record
06600200	Floyd R near Merrill, IA	489.0	Low-flow partial record
06600250	WB Floyd R near Middleburg, IA	59.7	Low-flow partial record
06600300	WB Floyd R near Struble, IA	181.0	Complete record
06600400	WB Floyd R near Merrill, IA	232.0	Low-flow partial record
06600500	Floyd R at James, IA	882.0	Complete record

SURFACE-WATER RESOURCES

The U.S. Geological Survey has been collecting streamflow data at three types of gaging stations in the Floyd River basin: (1) complete-record stations where continuous records are obtained and daily mean discharge computed, (2) low-flow partial-record stations where periodic low-flow measurements are made, and (3) high-flow partial-record stations (crest-stage stations) where data on flood peaks are collected. The location of these stations is shown in figure 8. A listing of the stations in downstream order, with tributary stations listed between main stem stations, is presented in table 3. Data from these stations were used to analyze such hydrologic characteristics as flow duration, average discharge, low-flow frequencies, and flood frequencies.

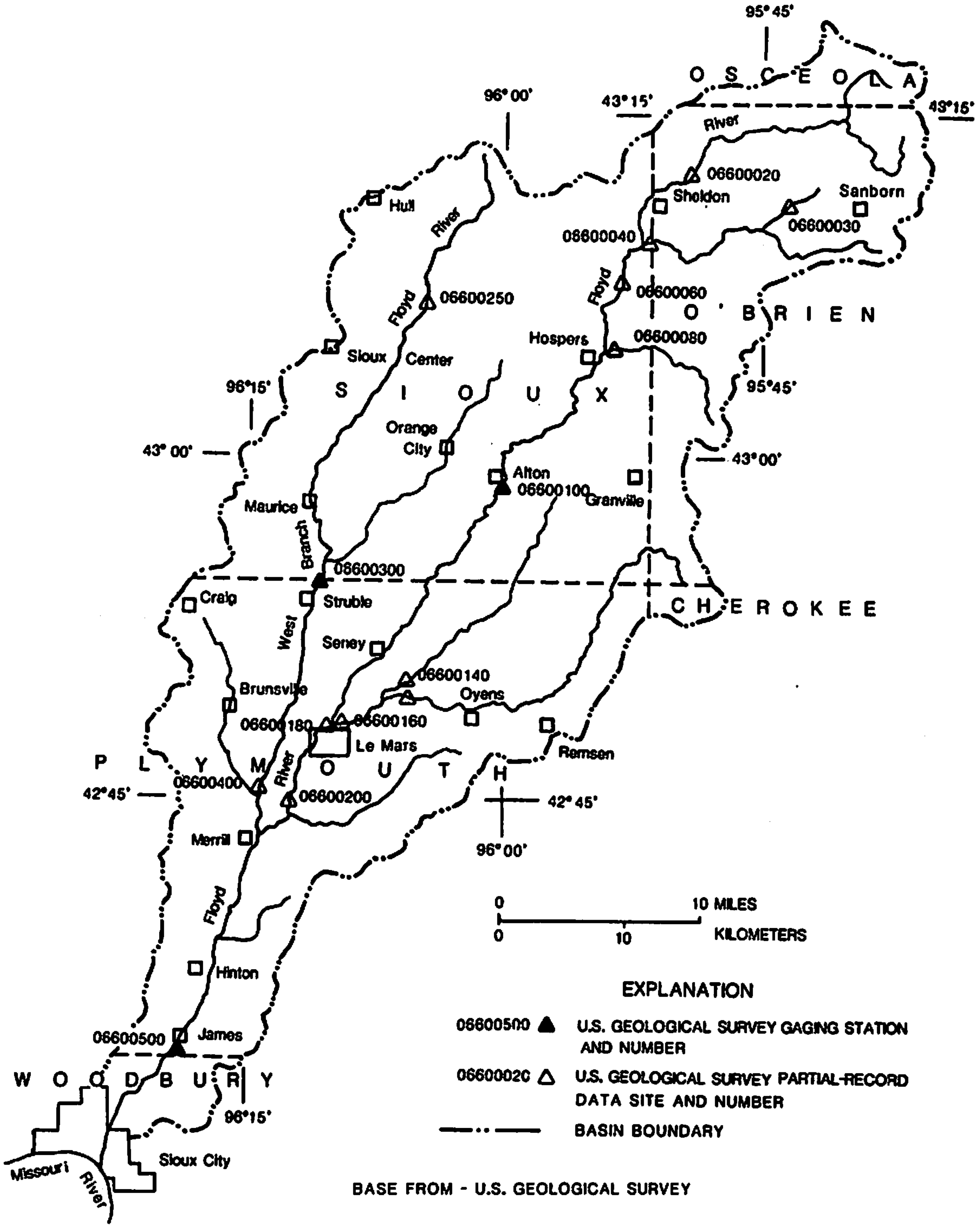


Figure 8. Location of surface-water data sites.

Fluctuations in streamflow are a function of precipitation and snowmelt as well as seasonal variations in land use, vegetation, and temperature. The hydrographs in figure 9 show the variability of streamflow in the Floyd River at James for the 45-year period of record. Water year 1951 had the highest flow of record and water year 1956 had the lowest. During calendar year 1951 precipitation was significantly greater than average throughout Iowa and during calendar year 1955 precipitation was significantly less than average throughout the State.

Although precipitation is the ultimate source of streamflow, the precipitation-streamflow relationship varies seasonally because of changes in evapotranspiration. Average monthly precipitation at Le Mars is plotted with average monthly discharge at James for the period 1941-70 in figure 10. Although there is greater than average precipitaton during this summer and early fall, the greatest runoff occurs in response to less than average precipitation during March and April. This is in part because of snowmelt during the spring months and in part because of increased evapotranspiration during the summer growing season.

The mean discharge of a stream varies from year to year. However, the mean annual discharge is computed from a long period of streamflow record and is a valuable and useful streamflow characteristic. In figure 11, mean annual discharges have been plotted against drainage area at Struble, Alton, and James, and this information is used for the following hydrologic analyses.

Mathematically, the relationship of mean annual discharge to drainage area in the Floyd River is expressed by the equation:

$$Q=0.13\ A^{1.06} \qquad (1)$$

where:

Q = the mean annual discharge, in cubic feet per second
A = the drainage area, in square miles

For comparative purposes, a regional mean annual discharge line was included on figure 11. This line was developed for northwestern Iowa from similar data for a number of streams in the region. The relationship of the variables for that line is represented mathematically by the equation:

$$Q=0.17A^{1.06} \qquad (2)$$

where Q and A are defined as above.

The first curve and equation are applicable only to the Floyd River basin and the second is a general relationship for all of northwestern Iowa. The difference between the two is most likely related to differences in topography, precipitation, and character of the underlying soil and rock.

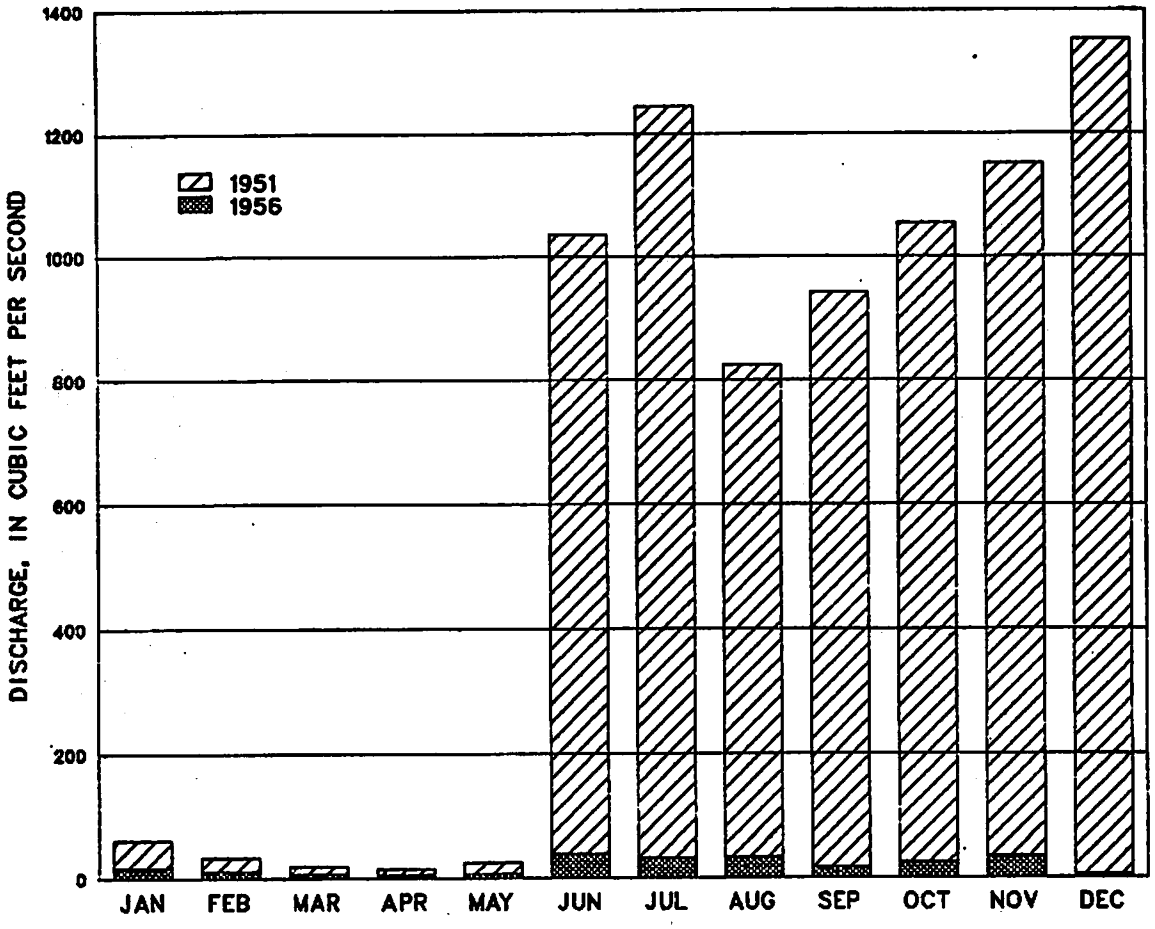


Figure 9. Streamflow in the Floyd River at James during water years 1951 and 1956.

Flow Duration

Flow-duration curves show the percentage of time that specific flows were equaled or exceeded during a given period of record. If this time period is long enough, the curve represents statistically, the stream's flow regime. These data provide information on the availability of water in the basin.

The slope of the duration curve shows the discharge variability of the stream. A steep slope shows a highly variable or "flashy" stream with a large percentage of the flow from surface runoff. A flat slope indicates sustained low flow where streamflow is supplemented by groundwater discharge or surface-water storage during low-flow periods.

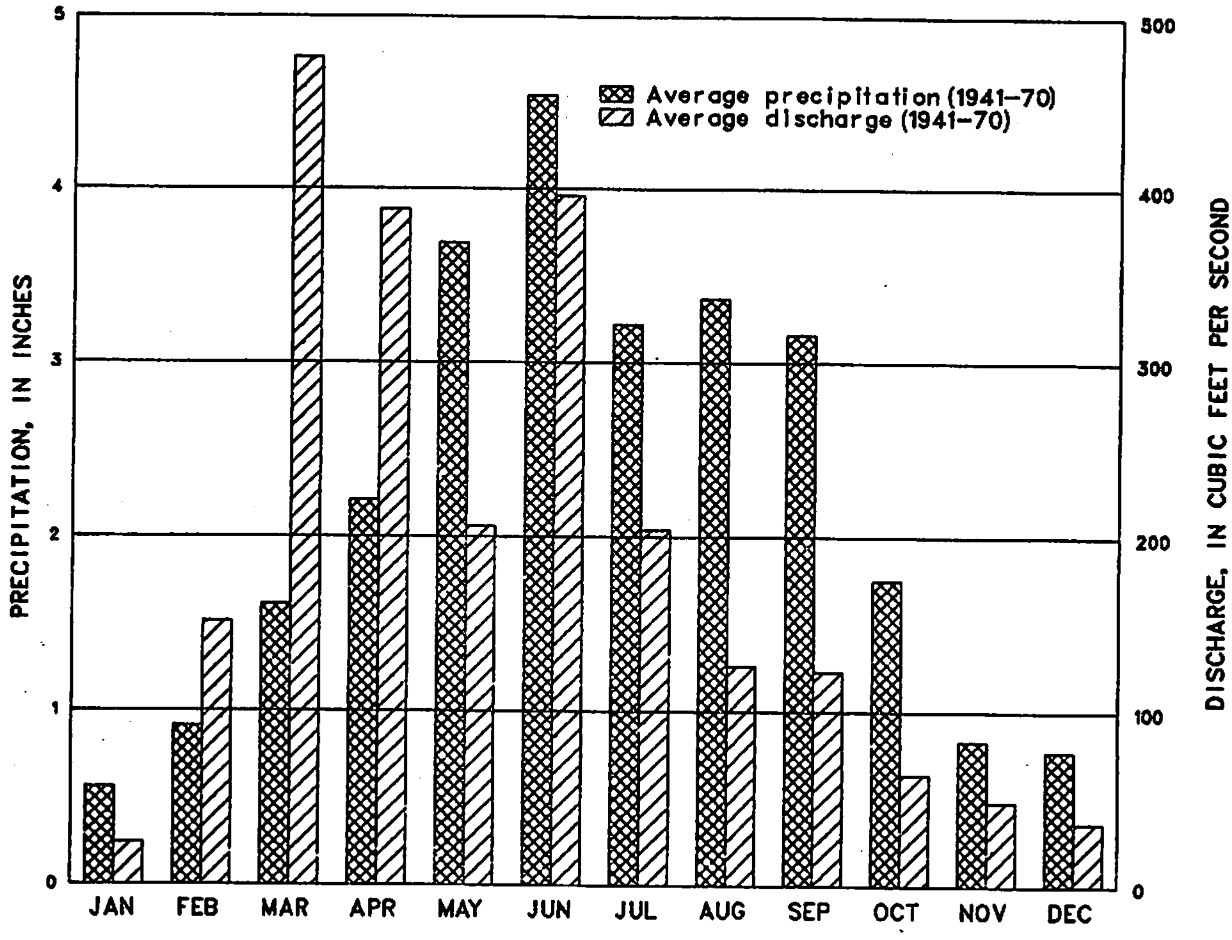


Figure 10. Average monthly precipitation at Le Mars and average monthly discharge for the Floyd River at James.

The three duration curves in figure 12 are for the Floyd River at James for 1937-76. They show flow duration for: (1) The water year, October through September, (2) the entire growing season, April through September and (3) July and August when precipitaton generally is least and evapotranspiration generally is greatest.

The three curves indicate that the flow is quite variable and that the Floyd River is mainly sustained by surface runoff. The change in slope of the curves at the lower end, near the 90 percent duration, shows that there is minor discharge from the ground-water to maintain flows during dry periods.

The 50 percent duration flow for the water year (Oct. 1 - Sept. 30) is about 50 cubic feet per second, which means that 50 percent of the time this flow is equaled or exceeded. The 90 percent duration flow value is about 10 cubic feet per second.

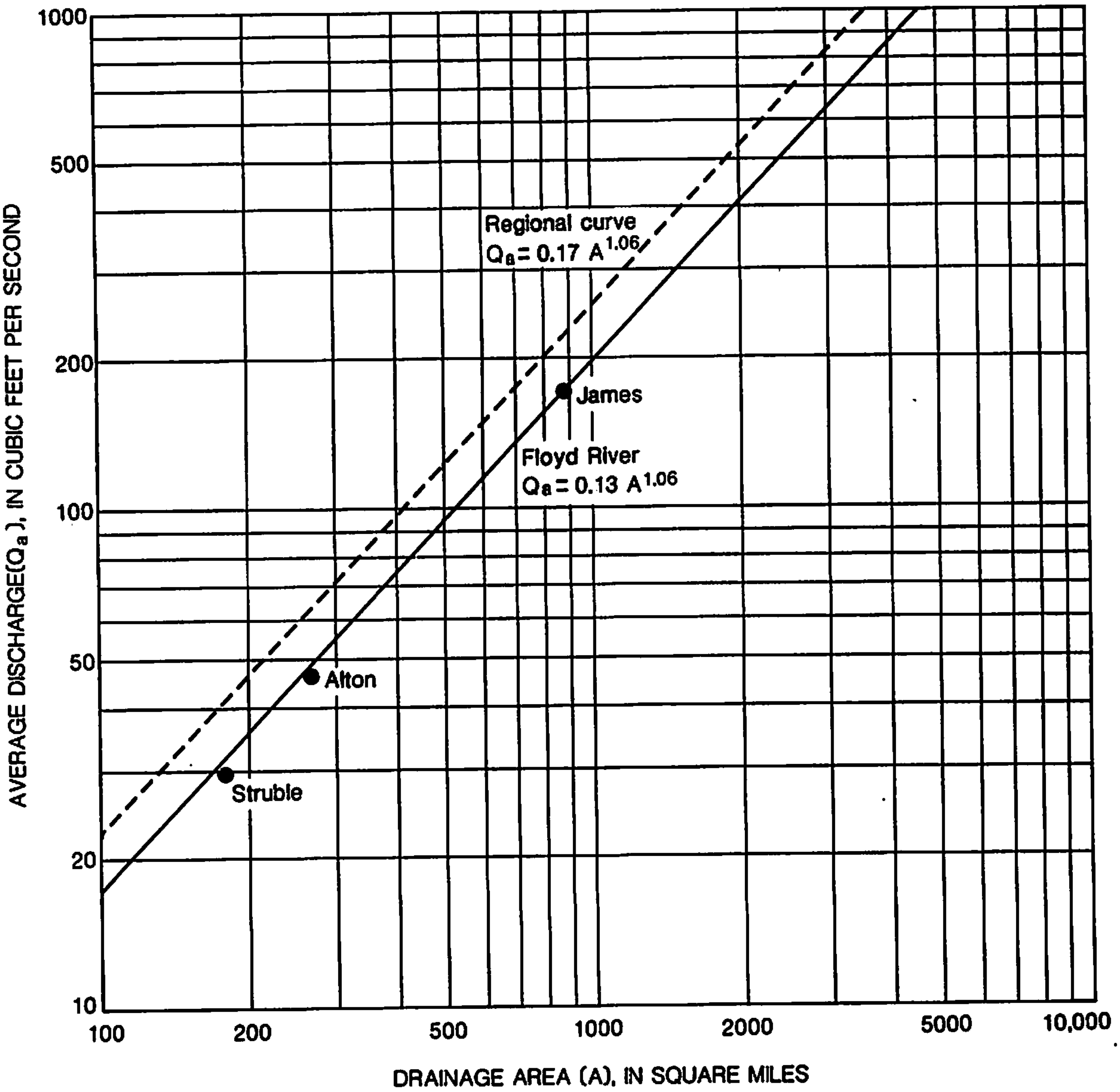


Figure 11. Drainage area in relation to mean annual discharge.

Low-Flow Frequency

Surface water commonly is used as a source of water supply or as a supplement to ground-water sources. Analyses of streamflow data for periods of low flow indicate the amount of water available from streamflow during critical periods of limited precipitation. Heinitz (1970) presented low-flow discharge data for 7-, 30-, 60-, 120- and 183-day periods and frequencies through a 20-year recurrence interval.

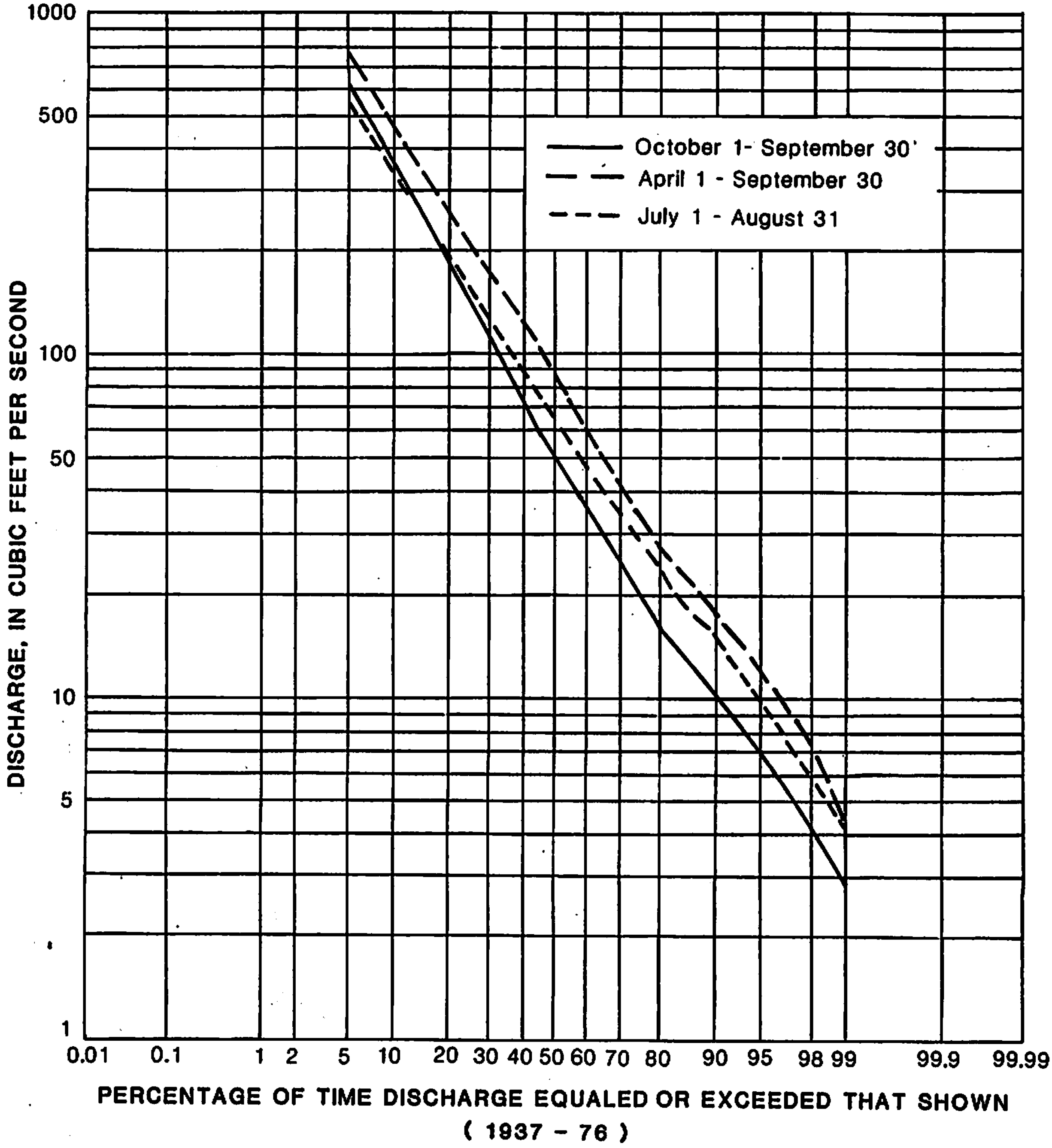


Figure 12. Flow-duration curves for the Floyd River at James.

Low-flow data for the study area were determined from a frequency analysis of annual minimum flows of the Floyd River at James (A. J. Heinitz, U.S. Geological Survey, oral communication, 1979). The smallest average discharge for 7 consecutive days was developed from each year of streamflow record. Two low-flow statistics were determined from the analysis:

(1) 7-day, 2-year low flow and (2) 7-day, 10-year low flow. The 7-day, 2-year low flow and the 7-day 10-year low flow are the smallest average flow for 7 consecutive days that is expected to occur on the average of once every 2 and 10 years. The 7-day 10-year low flow is used by the Iowa Department of Environmental Quality to determine water-quality standards for streams.

The smallest annual average discharge for 7 consecutive days for the Floyd River at James for 1937-76, plus the 7-day, 2-year and 7-day, 10-year low flows are shown in figure 13. Of the 40 annual low-flows, 23 of the flows or 58 percent were equal to or less than the calculated 7-day, 2-year value of 10 cubic feet per second and 4 of the 40 low-flows or 10 percent were less than the computed 7-day, 10-year low flow of 3.2 cubic feet per second.

The 7-day low-flow discharge for the Floyd River at James with recurrence intervals of as much as 20 years for 1937-76 is shown in figure 14. For example, a 7-day low-flow discharge of 4.7 cubic feet per second has a recurrence interval of 5 years. The magnitude and frequency of annual low flows for the Floyd River at James for 1937-76 are presented in table 4; for the Floyd River at Alton in table 5; and for the West Branch Floyd River near Struble in table 6.

Base flow is defined as that streamflow which is entirely derived from the ground-water system. During periods of little or no precipitation during the summer months base flow may sustain streamflow. Thus, information about base flow aids in the understanding of streamflow as it is related to the ground-water supply and also by allowing prediction of effects water withdrawals will have.

Base-flow recession curves define the relationship between base-flow discharge and time. Saboe (1966) developed base-flow data for the three streamflow-gaging stations in the Floyd River basin. The curves in figures 15, 16 and 17 were derived from these data. These curves are applicable only for the summer months, June through September, and provide estimates of minimum streamflow for as much as 20 days in advance, using the assumption that no appreciable precipitation occurs during the intervening period. Saboe (1966) suggests that the reliability of the estimates decrease beyond 20 days. The A curves are for periods of normal evapotranspiration and the B curves are for periods of unusually large evapotranspiration, as in hot, windy weather.

GROUND-WATER RESOURCES

Earth materials that store, transmit, and yield water to wells or springs are called aquifers. In the Floyd River basin, sand-and-gravel beds that occur in Quaternary glacial drift, outwash deposits, and alluvium commonly are aquifers. For the purposes of this report these aquifers will be collectively referred to as the surficial aquifer.

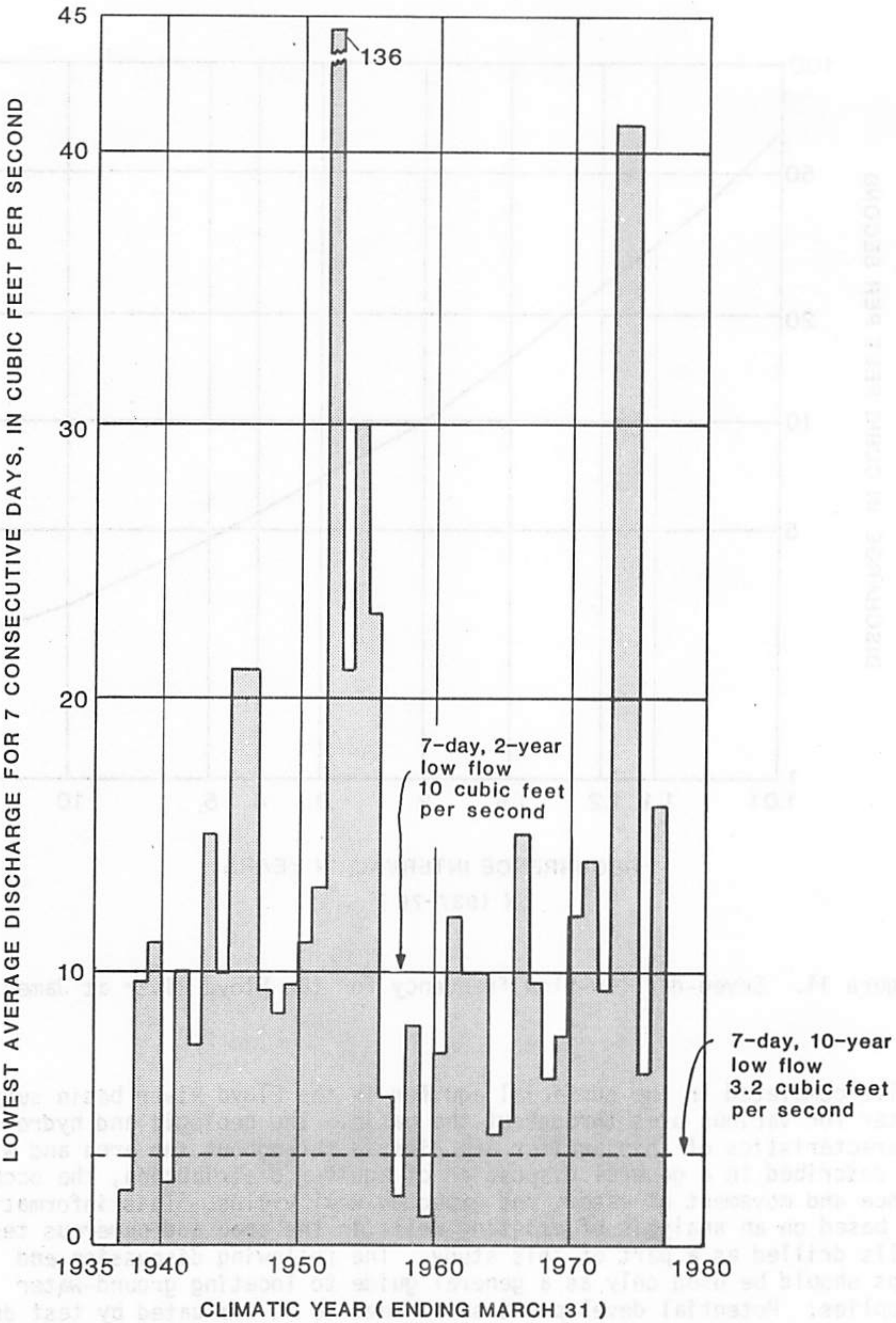


Figure 13. Annual 7-day minimum flow for the Floyd River at James.

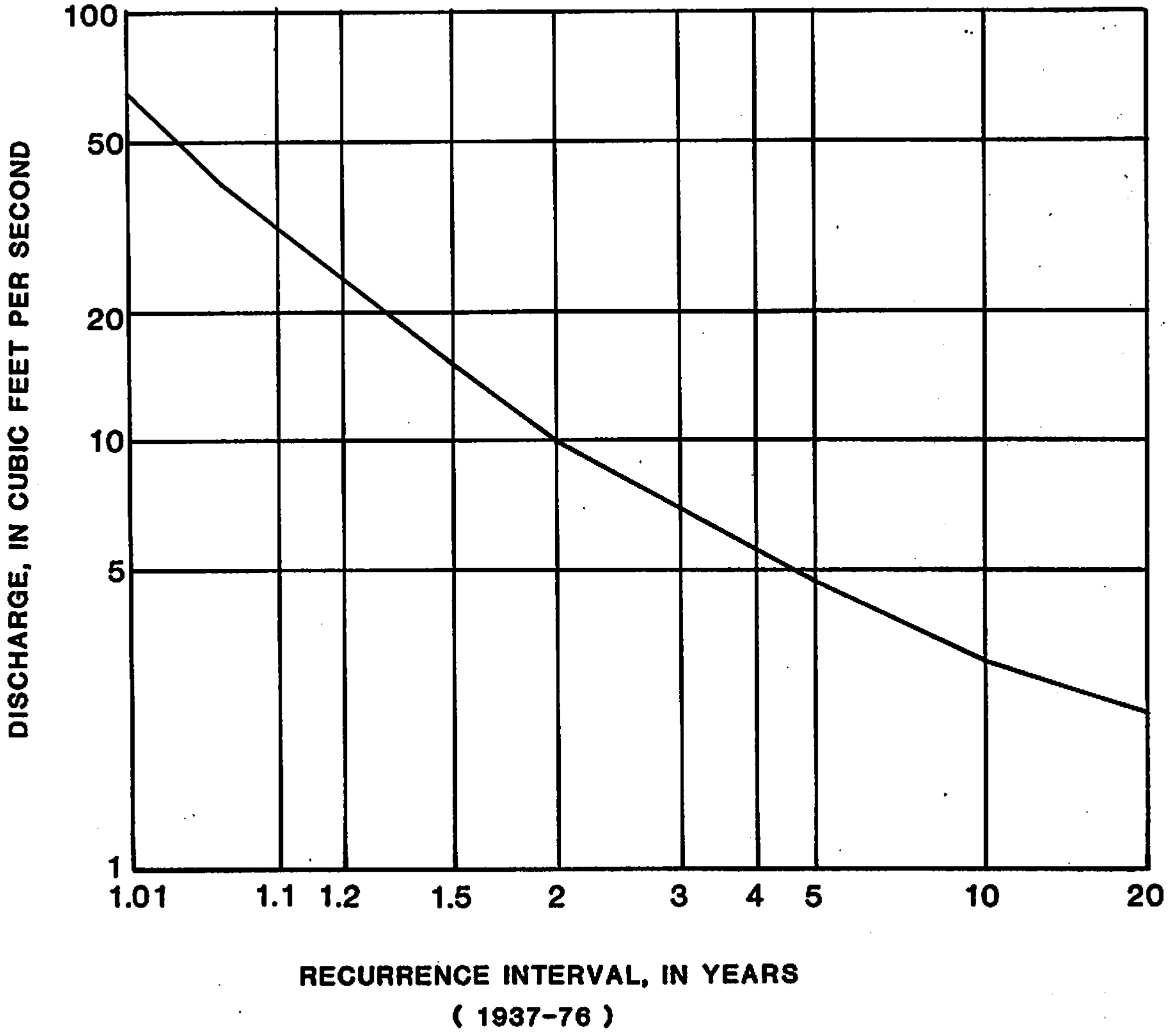


Figure 14. Seven-day low-flow frequency for the Floyd River at James.

Wells completed in the surficial aquifer in the Floyd River basin supply water for various uses throughout the basin. The geologic and hydrologic characteristics of this aquifer are diverse throughout the area and will be described in a general discussion of aquifer distribution, the occurrence and movement of water, and expected well yields. This information is based on an analysis of existing wells in the area and numerous test wells drilled as a part of this study. The following discussion and maps should be used only as a general guide to locating ground-water supplies. Potential development sites need to be evaluated by test drilling and pumping to determine the aquifer characteristics and possible sustained yield at each site.

Table 4. Magnitude and frequency of annual low flows for the Floyd River at James.

Recurrence interval, in years	Lowest average flow, in cubic feet per second, for consecutive days shown below						
	3	7	14	30	60	120	183 days
1.5	14.0	15.0	16.0	19.0	24.0	35.0	55.0
2	9.5	10.0	11.0	13.0	16.0	24.0	37.0
5	4.5	4.7	5.0	5.9	7.6	12.0	16.0
10	3.0	3.2	3.4	3.9	5.1	7.9	10.0
20	2.2	2.3	2.4	2.7	3.6	5.7	7.2

Table 5. Magnitude and frequency of annual low flows for the Floyd River at Alton.

Recurrence interval, in years	Lowest average flow, in cubic feet per second, for consecutive days shown below						
	3	7	14	30	60	120	183 days
1.5	1.30	1.30	1.50	2.10	3.00	7.50	11.00
2	0.45	0.52	0.69	1.10	1.70	4.30	6.20
5	0	0.05	0.11	0.24	0.51	1.30	1.60
10	0	0	0.01	0.03	0.27	0.58	0.68
20	0	0	0	0	0.16	0.30	0.31

Table 6. Magnitude and frequency of annual low flows for the West Branch Floyd River near Struble.

Recurrence interval, in years	Lowest average flow, in cubic feet per second, for consecutive days shown below						
	3	7	14	30	60	120	183 days
1.5	0.38	0.49	0.49	0.83	1.60	3.10	5.80
2	0.06	0.16	0.17	0.37	0.73	1.80	3.40
5	0	0	0	0.01	0.08	0.50	1.10
10	0	0	0	0	0	0.25	0.52
20	0	0	0	0	0	0.13	0.29

Surficial Aquifer

Because of the basic similarity and possible hydraulic interconnection of the individual parts, sand-and-gravel beds in unconsolidated rock units of several distinct ages will be discussed as one surficial aquifer. Part of the surficial aquifer underlies the flood plains and terraces of the Floyd River and its major tributaries as shown on figures 5-7, and is limited laterally by relatively impermeable glacial till. Test drilling has confirmed the lateral extent of this part of the aquifer in several places. However, these relatively shallow beds are underlain by, and are commonly in direct physical and hydrologic contact with sand-and-gravel beds in buried channels (figures 6 and 7).

The most productive parts of the surficial aquifer are the relatively shallow sand-and-gravel units underlying the flood plain and terraces, and the relatively thick sand-and-gravel beds in the buried channels. The deposits underlying the flood plain and terraces are mainly fine- to coarse-grained sand-and-gravel with the coarser materials in the basal part. The sand-and-gravel beds commonly are overlain by silt, clay, and fine grained sands, resulting in an artesian (confined) aquifer in some areas.

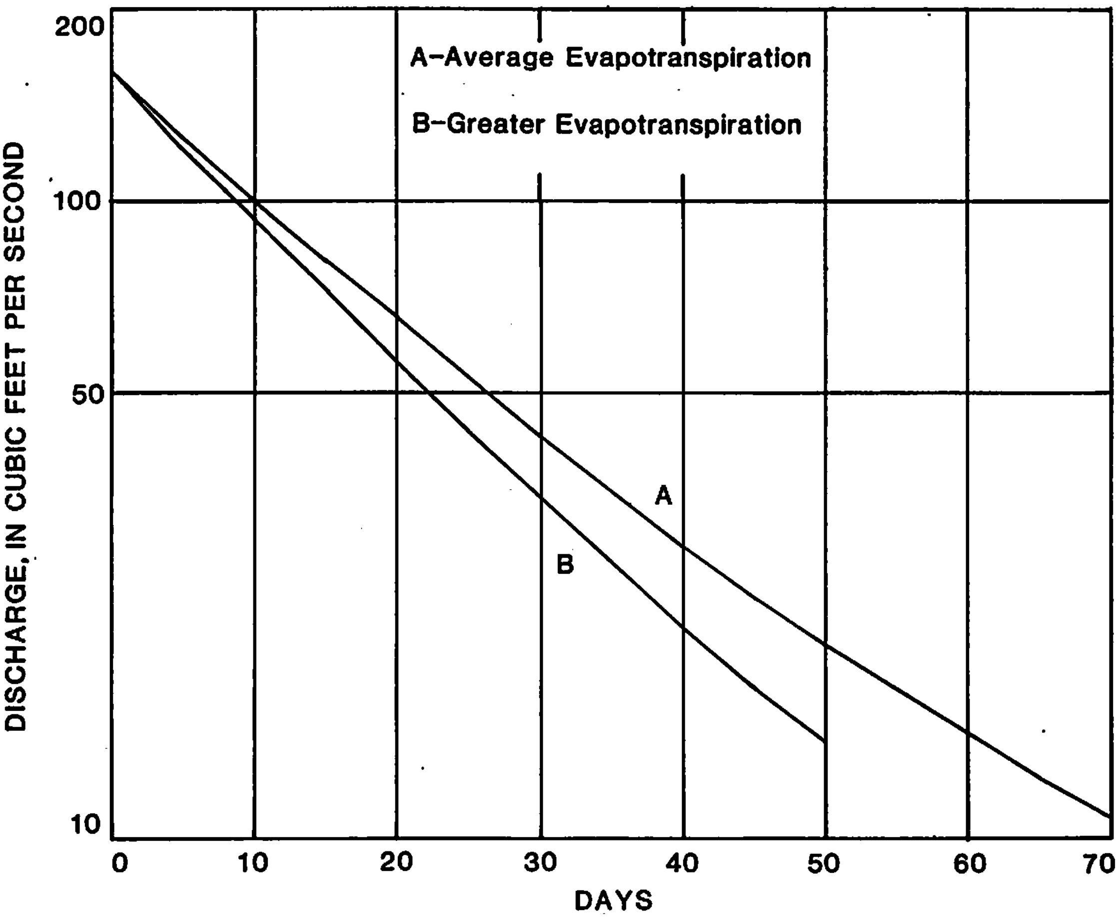


Figure 15. Base-flow recession curves for the Floyd River at James.

The lithology of the shallow-aquifer material is varied and consists mainly of quartz sand and gravel, with pebbles and cobbles of sedimentary, igneous, and metamorphic origin. As grain-size decreases, quartz becomes the dominant mineral present (Meyer, 1978). Test drilling and well records indicate at least two buried-channel systems entering the basin from the southeast (plate 1). The buried channel aquifers are finer grained, better sorted, and contain a greater percentage of quartz than do the overlying aquifers.

The total thickness of the sand-and-gravel ranges from 10 to 40 feet and averages about 20 feet. However, in certain isolated areas, thicknesses of 70 feet have been found (plate 2).

The thickness of sand and gravel shown on plate 2 includes deposits in the glacial till, deposits in the buried channels, and deposits underlying the flood plains and terraces along the Floyd River. In general, the thickness is greater in the buried channels and along the present course of the Floyd River.

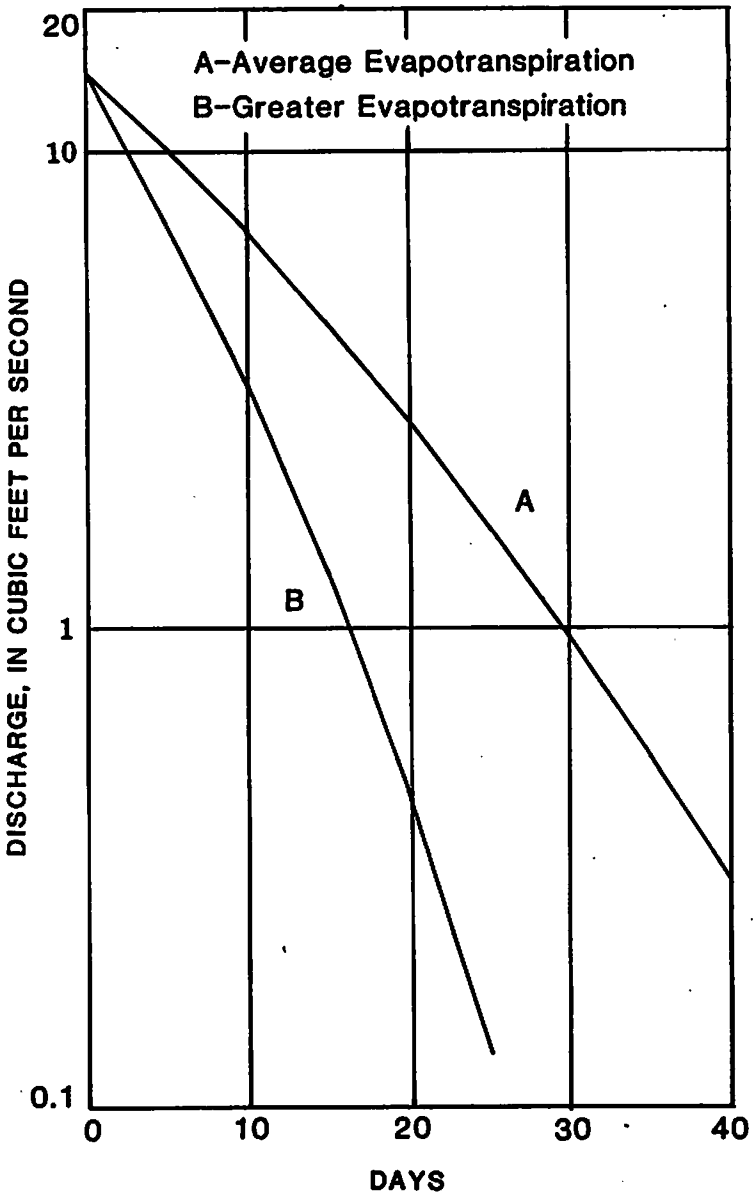


Figure 16. Base-flow recession curves for the Floyd River at Alton.

Water Levels

Water levels in wells indicate the position of the water table or potentiometric surface at the well sites. When plotted on maps, water-level measurements from a number of wells completed in an aquifer represent the water table or potentiometric surface of the aquifer. This water surface generally is shown by altitude contours (plate 3).

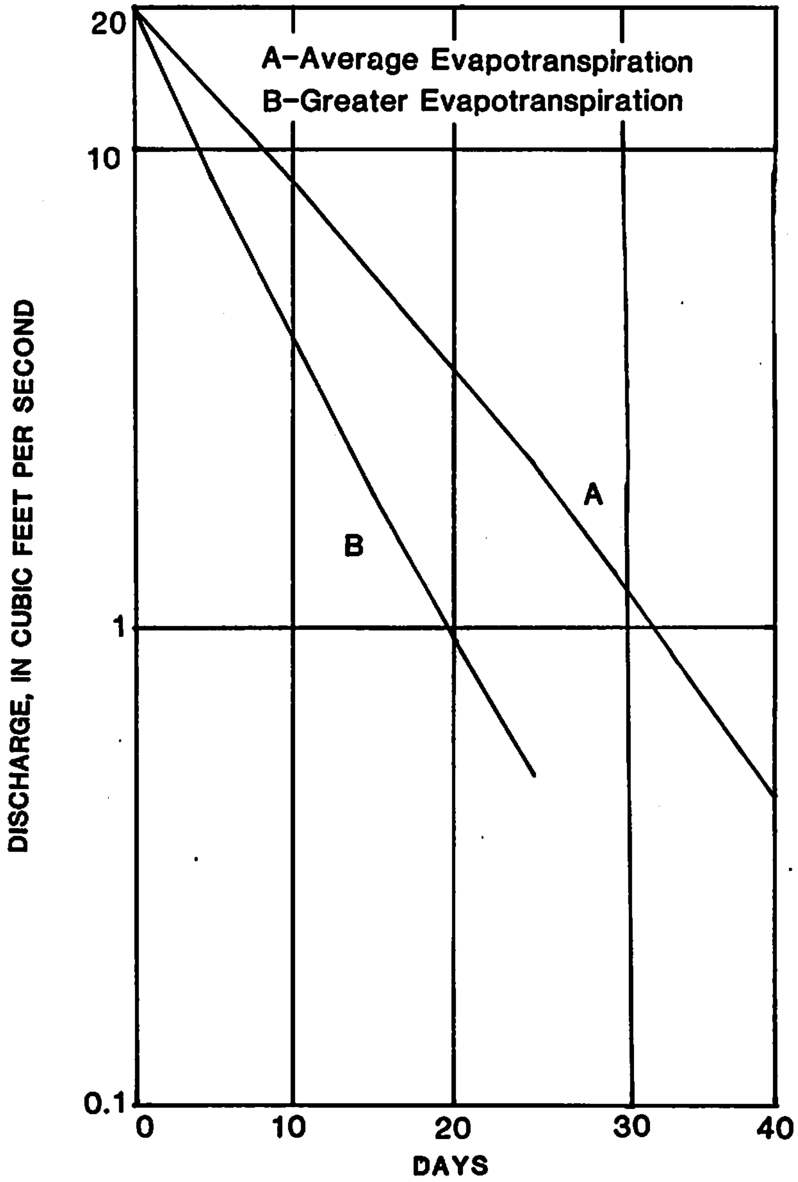


Figure 17. Base-flow recession curves for the West Branch Floyd River near Struble.

Meyer's (1978) data from test wells drilled in the surficial aquifer show water levels ranging from 2 to 55 feet below the land surface. During August of 1978, 46 water-level measurements were made in various test holes in the aquifer (plate 3). At that time, the depth to water ranged from 2.2 to 37.0 feet below the land surface.

In most of the area, the aquifers are unconfined and represent water-table conditions, although, in some locations the clayey or silty deposits which overlie the aquifer act as confining beds; resulting in artesian conditions. Water levels in shallow water-table wells generally respond quickly to precipitation. During periods of deficient rainfall the water table declines because of a decrease in the amount of water in storage. The decrease in storage is the result of negligible recharge and continued discharge to streamflow and evapotranspiration. Conversely, during periods of prolonged rainfall, the water table rises as a result of increased recharge and increased water in storage.

During 1976-77, water-table fluctuations were monitored in the aquifer in Plymouth County using 50 observation wells. Because the effects of ground-water discharge decrease at greater distances from the discharge point, water-level fluctuations decrease with distance from streams, for example, the water level in a well near the Floyd River had greater variations than a well approximately 1 mile from the stream. However, almost all the water levels show similar fluctuation patterns indicating a good hydraulic interconnection throughout the aquifer in Plymouth County (Meyer, 1978).

During the winter of 1976-77, some reaches of the Floyd River were completely frozen preventing normal ground-water discharge into the stream. This caused a rise in the water levels near the stream. A mild February during 1977 also created a rise because of recharge from unusually high river stages. Hydrographs show little recovery from precipitation during March through June of 1977, although a decrease in evapotranspiration at the end of the growing season did result in a slight rise during August and September (figure 18). Greater than average precipitation during September and October, 1977, caused a substantial rise in the water table.

Continued greater than average precipitation during the last part of 1977 resulted in a water-level rise in the aquifer of approximately 2 feet during January 1978. These rains restored soil moisture lost during the earlier drought conditions and also replenished the aquifer (Meyer, 1978).

Meyer (1978) in analyzing the empirical relationships between cumulative departures from normal precipitaton and fluctuations of the water table in Plymouth County, suggests that the water table during 1976 and early 1977 was at its lowest level since records of precipitation began during 1900. This analysis also indicates that the water table would be several feet higher during periods of average precipitation.

Water levels in an aquifer also are affected by pumpage from the aquifer. Pumpage from an unconfined aquifer rapidly lowers the water table at and near the well causing a conical-shaped depression of the water table around the well. This depression is called a cone of depression. A similar situation occurs when a well that is completed in an artesian aquifer is pumped creating a cone of depression in the potentiometric

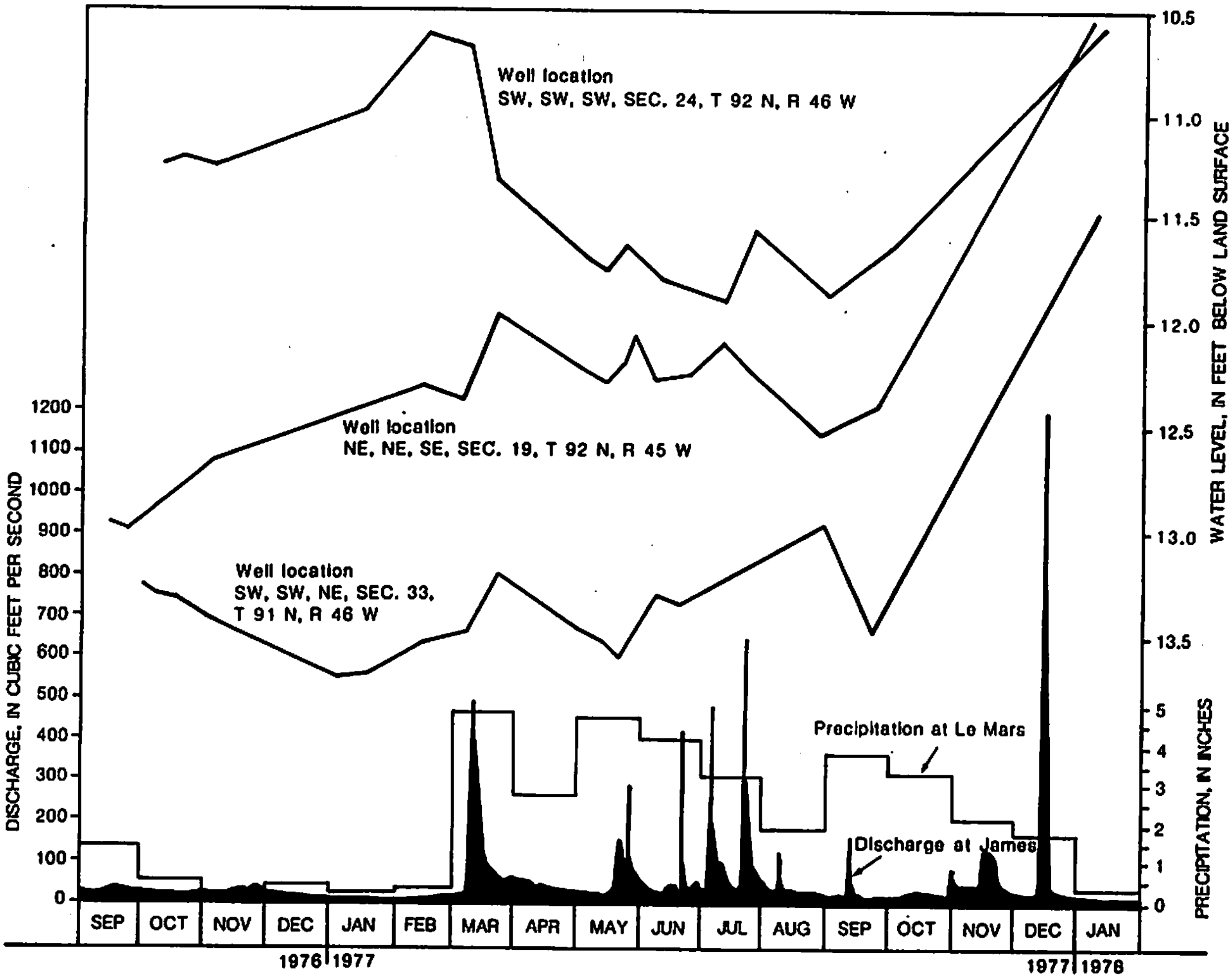


Figure 18. Relationship between river discharge, precipitation, and fluctuations of the water table.

surface. As of 1979 declines in water-level because of pumpage from the surficial aquifer in the Floyd River area are relatively small and noticeable declines usually are limited to an area near the pumping well. Consequently, pumpage was probably not a major factor in the extreme, aquifer-wide water-level decline of 1977.

Recharge and Discharge

The configuration, position, and vertical changes in the position of the water table are the result of the recharge and discharge processes. Almost all recharge to the surficial aquifer comes from local precipitation falling directly on the basin. The most effective recharge occurs during the spring and to a somewhat lesser degree during the fall when precipitation exceeds evapotranspiration rates. During April, May and June, precipitation rates generally are less than evapotranspiration rates and recharge to the aquifer is limited. Infiltration of stream water also contributes recharge water to the aquifer along the Floyd River and its tributaries under certain circumstances. The most notable being when a cone of depression caused by pumpage becomes large enough to induce recharge from the stream.

Recharge is more rapid and more readily noted in the shallow sand-and-gravel aquifers underlying the flood plain and terraces than in the buried-channel deposits. The thicker, less permeable material overlying the buried-channel deposits impede the downward movement of the water and consequently limit the recharge. Overlying and adjacent loess and glacial materials also contribute varying amounts of recharge to the aquifer.

The hilly western part of the basin probably has numerous local aquifers that depend on local recharge and discharge conditions. The more gentle, undulating topography of the eastern Floyd Basin probably has develoepd a more regional flow system and is not so dependent on local recharge-discharge conditions (Meyer, 1978).

Meyer (1978) analyzed recharge to the shallow aquifers using 1976 and 1977 water-table records. The early and middle parts of 1976 were extremely dry, which resulted in unusually low water levels indicating little or no recharge during that time period. However, precipitation during late 1976 and 1977 was sufficient to eliminate soil-moisture deficiency and recharge the aquifer; causing the water table to rise dramatically (figure 18). These data indicate that an average annual water-level fluctuation of several feet is normal, because of seasonal changes in recharge. Using these water-level data, showing a 3-foot rise in the water table, Meyer (1978) assumed a specific yield of 5 percent (0.05) to determine that there was about 1.8 inches of recharge (0.05 x 3 feet of rise = 0.15 foot or 1.8 inches) from the fall rains of 1977.

The data in figure 18 show that the rise in the water table occurred during September, October, and November, 1977. Assuming that recharge from precipitation of less than 0.2 inch was negligible, a total of 8.52 inches of rain contributed to the recharge of the aquifer during these months, indicating that about 21 percent of this precipitation recharged the aquifer (Meyer, 1978).

The major discharge area of the aquifer is the Floyd River and its tributary streams. Another important form of discharge is pumpage by the various water users in the basin. Minor amounts of discharge also occur to underlying aquifers and by evaporation from water in gravel pits and evapotranspiration directly from the aquifer at times and in places where the water table is high; generally within 5 feet of the land surface.

Ground-Water Movement

The configuration of the water table (plate 3) indicates the general direction of ground-water movement. Water in the aquifer moves from areas of high hydraulic head to areas of low hydraulic head and the flow is perpendicular to the contours. The water-level map shows that the water table follows the local topography in the valley with higher altitudes away from the stream and lower altitudes near the Floyd River and its tributaries. This is basically the result of recharge occurring throughout the area and discharge occurring chiefly at the stream channel.

The water-table map shows that the major ground-water movement is toward the streams. However, there is also a downstream or down-basin component of flow in most areas.

Aquifer Characteristics

Storage

Meyer (1978) examined the total volume of ground water in storage in the aquifer under the flood plain and terraces of the Floyd River in Plymouth County. Storage, in gallons, may be calculated using the areal extent of the aquifer, 37 square miles, (1,030 million square feet), a value for the saturated thickness of the aquifer, 20 feet, the average specific yield of the aquifer, 0.15 (Johnson, 1967) and a conversion factor of 7.48 gallons per cubic foot. The saturated thickness value used (20 feet) is conservative because it ranges from 10 to 60 feet (plate 4) and was calculated for a relatively dry period.

Using these numbers the amount of ground water in storage was determined as follows:

Area x average saturated thickness x average specific yield x conversion factor = water in storage

1,030 million sq. ft. x 20 ft. x 0.15 x 7.48 g/cu ft. = 23.1 billion gallons

This estimate does not consider any water in flood plain clay and silt deposits overlying the aquifer. Assuming a conservative average of 3 feet of saturated silts and clays and an average specific yield of 0.05 percent (Johnson, 1967), another 7.7 billion gallons of storage is available for a total of 30.8 billion gallons in Plymouth County. Storage calculations were not made for areas upstream from Plymouth County because the aquifer and the water levels are not as well defined in the headwater areas.

Transmissivity

Meyer (1978) determined the transmissivity of the aquifer beneath the flood plain of the Floyd River 2 miles south of Merrill. An aquifer test was conducted at this site using a large-capacity irrigation well. The geology of the aquifer was determined by drilling six test holes in proximity to the irrigation well. The composition and lithology of the sands and gravel at the site was considered to be typical of the aquifer. Piezometers were installed in all six test holes and they were used as observation wells during the aquifer test.

The aquifer test, which had a 43-hour duration, was conducted during March 1977. The 24-inch diameter irrigation well was 41 feet deep, penetrated the entire thickness of the aquifer, approximately 25 feet, and was pumped at a constant rate of 650 gallons per minute. About 1,000 feet of 10-inch pipe transported the discharge away from the site preventing infiltration near the pumped well.

The pre-pumping water level in the well was approximately 14 feet below land surface, and the maximum pumping level was 37 feet below land surface. Two observation wells about 70 feet east and west of the test well were used in making calculations of aquifer characteristics (Meyer, 1978). The pre-pumping water levels in those wells were 14 feet below land surface and the maximum pumping levels were about 24 feet below land surface.

The values calculated by Meyers from this test were 71,600 gallons per day per foot (9,570 feet squared per day) for transmissivity and 0.0001 for the storage coefficient. These values seem reasonable for the aquifer compared to other pumping tests in the State. Using this transmissivity value and an aquifer thickness of 25 feet gives an average hydraulic conductivity of 2,860 gallons per day per square foot (383 feet per day).

The relatively small storage coefficient determined from this test indicates that the aquifer was under artesian conditions even though near the pumping well the potentiometric surface was lowered below the overlying confining bed. Continued pumping and enlargement of the drawdown cone, however, would show an increase in storage coefficient to values typical of water-table conditions or about 0.15.

Based on the results of this test, Meyer (1978) concluded that the aquifer could produce a sustained yield of 600 gallons per minute. This well, which is located along the southern reaches of the Floyd River, would probably be more productive than some wells located upstream and along tributary streams. However, the aquifer at the test-pumping sites was relatively thin (25 feet) and greater yields are probably available at more favorable sites.

Meyer (1978) related the grain size of the aquifer material to the transmissivity as a check on the value determined from the test. The data also were used in estimating transmissivity in other localities. A table of hydraulic-conductivity values developed by Tyley (1974) was used as a basis for estimating the hydraulic conductivity of various sized material (table 7).

Table 7. Hydraulic conductivities of aquifer materials, in gallons per day per square foot (from Meyer, 1978).

Material	Tyley (1974)	Floyd River basin
Clay	1	0
Silt	2	0
Fine sand	10	10
Medium sand	200	200
Coarse sand	1000	500
Fine gravel	2000	2000
Fine to medium gravel	--	2500
Medium gravel	3000	3000
Medium to coarse gravel	--	3500
Coarse gravel	5000	4000

The hydraulic conductivity value determined from the aquifer test compares closely with Tyley's 3,000 gallons per day per square foot (400 feet per day) for medium gravel. The hydraulic conductivity values for coarse-grained sand and coarse gravel in the aquifer were adjusted because in the study area these beds generally contain an appreciable amount of fine material.

Using the values in table 7, transmissivities were estimated for other test wells by evaluating geologic, drillers, and geophysical logs. Hydraulic conductivity values were estimated for each discrete interval and were totaled to determine transmissivity values. The resulting values were then used to aid in making the transmissivity map, plate 5.

This transmissivity map is intended to serve as a guide to ground-water development in the Floyd River basin. Because the map was extrapolated from the saturated thickness map and from individual data points, sometimes miles to tens of miles apart, all potential developments need to be proven by test drilling and test pumping.

Well Yields

The major factors governing yields from wells are the aquifer's ability to store and transmit water. Generally, the thicker the aquifer, the more water it will yield. Also sand-and-gravel deposits, such as Wisconsinan outwash deposits in the Floyd River basin, will have a larger sustained yield where the deposits are at or near the land surface and can be readily recharged by precipitation, infiltration from streams, or both.

In general, the surficial aquifer along the southern reaches of the Floyd River should have greater yields because the valley is wider resulting in a greater areal extent and saturated thickness of the aquifer (plate 4). Also, the aquifer will have relatively large yields where the Wisconsinan outwash part of the aquifer overlies a gravel-filled buried channel and both are water bearing.

Any attempt to develop a major water supply from these deposits needs to include test drilling and test pumping to determine the water-yielding capability of the aquifer. This is necessary because the water-bearing sand-and-gravel units do not have uniform thickness, areal extent, or aquifer characteristics.

Selected data from the files of the Iowa Geological Survey including depths, yields, static water levels, pumping water levels and pumping time for representative wells completed in the surficial aquifer are presented in table 8.

At Sheldon, on the flood plain of the Floyd River, eight wells 24 to 26 feet deep have a combined yield of 815 gallons per minute. This is apparently the maximum capacity of the well field because it has been noted that this amount does not always meet the needs of the community. Drilling company records show that three test wells along the West Branch Floyd River at Sioux Center should produce 100 to 200 gallons per minute each and four other test wells in the same area should yield 200 to 250 gallons per minute each. Testing during 1974 at Alton indicated that six wells in that area will produce 75 to 100 gallons per minute each from the surficial aquifer.

WATER USE

The term "water use" can have a number of interpretations, each based on the type of use of the water. In navigation on a major river, water is used by passing it through the lock system to raise or lower the river traffic. Although the water has been used, none was lost or consumed, nor was the quality changed.

In some water uses, water is consumed by evaporation, transpiration, or both. Part of the water used for heat transfer in air conditioning

Table 8. Production data for representative wells completed in the surficial aquifer, Floyd River basin.

Location	Test date	Depth (feet)	Yield (gallons per minute)	Static water level (feet)	Pumping water level (feet)	Pumping time (hours)
SEC26T92R46	1959	26	25	15	20	--
Le Mars	1939	109	500	55	70	--
			400	55	65	--
			200	55	58	--
Alton	1937	20	350	10	(1)	(1)
	1939	32	200	--	--	14
Orange City	1970	35	100	5	15	1
	1970	69	240	5.5	12	1
	1968	41	293	5.5	18.8	46
	1970	69	240	5.5	12	1
	1972	79	240	16	22.5	1
	1972	79	200	17	15	2
Remsen	1968	57	110-125	8	20	23.5
	1956	35.3	170-220	20	30	8
Sanborn	1974	80	230	40.5	27.5	0.33
	1974	80	201	41.5	50.5	0.25
	1940	81	245	52.6	59.6	--
	1964	80	400	55	63	--

(1) Pumped dry in 15 minutes

is lost through evaporation and the remainder may be less desirable for other uses because its temperature has been increased. The two water uses where the most water is lost to the atmosphere are steam generation and irrigation. In the former, the steam is ultimately released to the atmosphere and in the latter, water is either transpired by the plants or evaporated from the soil. Consumptive uses of this type deplete the manageable water-resource base. Other types of water uses such as domestic and industrial use are not always significant consumptive uses but they may alter the chemical quality of the water making it less desirable for other uses.

The major categories of water use in the Floyd River basin are public supply, rural-domestic and livestock, self-supplied industrial and commercial, and irrigation. Smaller amounts of water are used in sand-and-gravel operations and in the fossil-fuel electric-generation plants.

Public supply use consists of all the water withdrawn for municipal uses which includes urban-domestic use, and water sold to commercial and industrial operations. Also in this category are transmission losses from the distribution systems and water used for main flushing, street cleaning, and firefighting. Self-supplied commercial and industrial uses consists of water withdrawn from wells or other sources owned by the companies. Rural-domestic water use consists of water used in rural homes. Livestock use is water used in the livestock operations on farms. Both of these categories commonly are supplied by private wells on the individual farmstead. Accurate measurements of water use on each farm is not possible; hence, rural-domestic use was estimated using an average consumption figure of 70 gallons per day per capita (Wahl and others, 1978). Rural-livestock use was estimated by using an average per-capita consumption for each livestock type (Twenter and Coble, 1965, and Todd, 1970).

The amount of water used for irrigation is extremely variable. The need for application of irrigation water is directly related to the amount of precipitation available during the growing season. Also, there are no continuous, long-term data on the amount of water used for irrigation purposes. Meyer (1978) notes that during 1978, irrigation in the Floyd River basin was negligible. However, the drought of 1975-77 stimulated much interest in irrigation.

Historical Water Use

Water use for 1940 in the Floyd River basin was estimated for three categories; rural-domestic, rural-livestock, and public supply (table 9).

Urban and rural population statistics and livestock statistics used for these estimates are from U.S. Department of Commerce (1942a, 1942b). The water use figure for rural-livestock was based on animal population and the consumption data in table 10.

The 1940 water-use figures for rural-domestic and public supply also were based on population figures in the study area. However, there were no accurate data available for per-capital water use during 1940.

Nationally, per-capita water use for public supplies increased by almost 54 percent from 1950 to 1975 (calculated from Murray and Reeves, 1977). The daily per-capita water use in Des Moines increased approximately 56 percent from 1920 to 1968, (calculated from Gieseke, 1970). Hence, it was assumed that per-capita water use during 1940 was 60 percent of use during 1978. It was not possible to estimate use by self-supplied industrial and commercial operations, or irrigation. Water used in the communities of Le Mars, Oyens, Granville, Hull, and Maurice and one-fourth of the water used in Remsen is from wells completed in the Dakota Formation. If those totals are included, estimated total water use during 1940 for public supply is 857.3 million gallons per year and the total water use in the report area 1,643.2 million gallons per year.

Water Use for 1978

Water use for 1978 in the report area was estimated for three classifications; rural-domestic, rural-livestock, and public supply (table 11). The population statistics for rural and urban population and livestock numbers are from U.S. Department of Commerce (1973 and 1977). Rural-domestic water use was estimated on the basis of 70 gallons per day per capita and rural-livestock use on the basis noted in table 10. Municipal water use and sources of information are included in table 12.

Estimates of Future Use

As indicated in table 11, rural-livestock was the major water use category during 1978. The main elements in this classification are cattle and hog watering. The cattle population in the basin during 1974 was approximately 4 times greater and hog production was about 3 1/2 times greater than during 1940. However, since 1969, cattle and hog populations in the basin have been relatively stable, having only minor increases.

The composition of the population in the Floyd River basin has changed significantly. The rural population decreased 20.2 percent from 1940 to 1970 and decreased 10.9 percent between 1960 and 1970. Non-rural population increased 40.4 percent from 1940 to 1970 and for 1960 to 1970, increased 18.5 percent. However, considering these two population components together, there was only a 7.7 percent gain in population from 1940 to 1970 (U.S. Department of Commerce, 1942a, 1952 and 1973).

Total population data for the five counties that have parts of their areas in the basin; Cherokee, O'Brien, Osceola, Plymouth, and Sioux; show a 4.2 percent population decrease from 1940 to 1970 (analysis of data from U.S. Department of Commerce, 1952 and 1973). An analysis of the population projections for these five counties by the Iowa Development Commission (1979) is shown in table 13.

Table 9. Estimated water use, Floyd River basin, 1940.

Use type	Use in million gallons per year		
	Surficial aquifer	Dakota aquifer	Total
Rural-domestic	368.4	--	368.4
Rural-livestock	417.5	--	417.5
Public supply	489.5	367.8	857.3
Total	1,275.4	367.8	1,643.2

Table 10. Water requirements for farm animals.

Animal	Requirements, in gallons per day
Cattle (1)	15
Hogs (1)	3
Sheep (2)	2
Horses (3)	12

(1) From Twenter and Coble (1965)
(2) Adjusted from Twenter and Coble (1965)
(3) From Todd (1970)

Table 11. Estimated water use, Floyd River basin, 1978.

Use type	Use in million gallons per year		
	Surficial aquifer	Dakota aquifer	Total
Rural-domestic	490.0	--	490.0
Rural-livestock (1)	1,426.6	--	1,426.6
Public supply	830.9 (2)	597.9	1,428.8
Total	2,747.5	597.9	3,345.4

(1) 1974 animal population data
(2) Includes some 1977 water-use data

Table 12. Annual municipal water use, Floyd River basin.

Community	Year	Million gallons	Source of data
Alton	1977	38.0	Meyer's field notes
Brunsville	1977	3.5	Meyer (1978)
Craig	----	2.7	Estimated from 1970 population
Granville	1977	8.2 (1)	Meyer's field notes
Hinton	1978	25.5 (2)	Superintendent of Utilities
Hospers	1977	38.0	City Clerk
Hull	1977	44.3 (1)	Iowa Natural Resources Council
Le Mars	1978	504.6 (1)	Iowa Natural Resources Council
Maurice	1977-78	6.1 (1)	City Clerk
Merrill	1977	28.3	Meyer (1978)
Orange City	1978	176.8	Iowa Natural Resources Council
Oyens	----	4.0 (3)	Estimated from 1970 population
Remsen	1978	58.5 (4)	City Clerk
Sanborn	1977	121.4	City Clerk
Sheldon	1978	190.9	Iowa Natural Resources Council
Sioux Center	1978	176.5	Iowa Natural Resources Council
Struble	----	1.6	Estimated from 1970 population
Total		1,428.9	

(1) Dakota Formation water
(2) 75 percent Dakota Formation water
(3) Pleistocene and Dakota Formation water
(4) 20 percent Dakota Formation water

Because the population data in table 13 includes a large area outside of the Floyd River basin; the trends indicated may not be representative of the basin. As noted earlier, the total five-county area had a 4.2 percent decrease in population while the study area had a 7.7 percent increase for the same period. Thus, the percentage of change noted in table 13 may be as much as 12 percent less than anticipated. Using either set of data, however, the rural-domestic population of the area is not expected to increase significantly in the future and water use for public supply probably will increase only moderately in response to population growth.

Table 13. Estimated changes in population for Cherokee, O'Brien, Osceola, Plymouth, and Sioux Counties (Date from Iowa Development Commission, 1979).

Period	Percent change
1970-80	+1.5
1970-2000	+9.6
1970-2020	+15.8

Irrigation use is extremely difficult to predict, but it will no doubt increase in the future. The amount of increase is dependent on both weather and economic conditions in northwest Iowa and in the world.

Self-supplied commercial and industrial water use will, in all probability, remain fairly constant with only moderate increases because the population projections of the Iowa Development Commission (1979) indicate little dynamic growth in the five-county area. However, past population data indicate that the major population and economic growth in the five-county area will probably be in the Floyd River basin because it contains most of the major urban centers.

WATER QUALITY

Surface-Water

The Floyd River is currently (1979) classified by the Iowa Department of Environmental Quality as a Class B warm-water stream from its mouth to State Highway 20 in Sioux County. Thus, the State water-quality standards for wildlife, aquatic life and secondary body contact apply to this river and its tributaries. These standards are summarized in table 14. The prevalent chemical "type" for the Floyd River basin is a calcium magnesium bicarbonate water with occasional large concentrations of sodium and chloride (table 15).

The surface-water quality within the entire Floyd River basin has been considered for many years to be the most degraded in the State, (Iowa State Hygienic Laboratory, 1978). Large concentrations of ammonia nitrogen and BOD (biochemical oxygen demand) and small dissolved oxygen concentrations are reported to be the most serious problems on the Floyd River (Iowa Department of Environmental Quality, 1976).

Table 14. Water-quality standards for streams.

(excerpted from Iowa Administrative Code,
Environmental Quality (400), Chapter 16,
effective August 31, 1977).

Class "B" water. Waters which are designated as class "B" waters are to be protected for wildlife, fish, aquatic and semiaquatic life and secondary contact water uses.

a. Dissolved oxygen.

(1) The dissolved oxygen shall not be less than 5.0 milligrams per liter during at least 16 hours of any 24-hour period and not less than 4.0 milligrams per liter at any time during the 24-hour period.

(2) In areas designated as cold water fisheries the dissolved oxygen shall not be less than 7.0 milligrams per liter during at least 16 hours of any 24-hour period and not less than 5.0 milligrams per liter at any time during the 24-hour period.

b. Chemical constituents. The following concentrations shall not be exceeded at any time the flow equals or exceeds the 7-day, 10-year low flow unless the material is from uncontrollable nonpoint sources:

Constituent	Milligrams per liter
Arsenic	0.1
Barium	1.0
Cadmium in B (W) waters	.01
Cadmium in B (C) waters	.0012
Chromium (total hexavalent)	.05
Copper	.02
Cyanide	.005
Lead	.1
Mercury	.05
Phenol (1)	.05
Selenium	.1
Zinc	1.0

(1) Includes all phenolic compounds

Table 14 Cont.

	Class B	
	warm	cold
	milligrams per liter	
Ammonia Nitrogen (N)		
November 1 to March 31	5	2.5
April 1 to October 31	2	1

c. All substances toxic or detrimental to aquatic life shall be limited to nontoxic or nondetrimental concentrations in the surface water.

d. From April 1 through October 31, the fecal coliform content shall not exceed 2000 organisms per 100 milliliters except when the waters are materially affected by surface runoff.

e. The pH shall be not less than 6.5 nor greater than 9.0. The maximum change permitted as a result of a waste discharge shall not exceed 0.5 pH units.

Fecal coliform bacteria densities ranged from 1,400 to 290,000 colonies per 100 milliliters; ammonia nitrogen concentrations ranged from 0.04 to 5.1 mg/L; and specific conductance ranged from 630 to 1,900 micromhos per centimeter at 25 degrees Celsius for 18 sites in the Floyd River basin during November 1977 (Iowa State Hygienic Laboratory, 1978).

The major cause of the degraded water quality has been attributed to numerous discharges of municipal wastes and runoff from agricutural activities in the basin. Many of the municipalities in the area are modernizing their wastewater-treatment facilities or building new ones in order to improve the quality of wasterwater effluent. Although dissolved oxygen has increased and ammonia concentrations have significantly decreased since the 1950's because of improved waste treatment by municipalities, the water quality of the Floyd River is still adversely affected by wastewater from the cities of Sheldon, Remsen, Le Mars, and Sioux Center. Agricultural runoff is considered to be one of Iowa's most significant pollution sources and considerable work is underway to develop a control

Table 15. Chemical analyses of water from streams in the Floyd River Basin.

(Constituents in milligrams per liter, except as noted.
Analyses by Iowa State Hygienic Laboratory.)

Stream and Location	Date Collected	pH (units)	Temp. (Degrees celcius)	Nitrogen				Phosphate		Arsenic (As)	Barium (Ba)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Mercury (Hg)	Selenium (Se)	Silver (Ag)	Zinc (Zn)	Nickel (Ni)	Strontium (Sr)	Aluminum (Al)
				Organic	Ammonia	Nitrite	Nitrite	Filterable	Total													
Floyd River at James	2/17/77	--	--	2.0	3.4	0.01	0.04	2.1	--	--	0.1	--	--	--	--	--	<0.01	--	0.02	--	0.70	0.10
Floyd River at James	8/30/77	8.3	20.5	1.0	.01	.05	.1	1.4	2.8	0.02	<.1	<0.01	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	.01	<0.1	.42	--
Floyd River near Merrill	8/30/77	8.3	20.0	1.5	.26	.28	1.0	4.5	8.2	--	--	--	--	--	--	--	--	--	--	--	--	--
Floyd River near Le Mars	8/30/77	8.25	21.0	2.0	.02	<.01	<.1	.47	2.0	--	--	--	--	--	--	--	--	--	--	--	--	--
Floyd River at Alton	8/30/77	8.1	23.0	1.9	.50	.14	.3	1.9	4.0	.02	<.1	<.01	<.01	<.01	<.01	<.001	<.01	<.01	.01	<.1	.35	--
Floyd River near Wren	8/30/77	8.2	20.5	.59	.01	.07	.7	1.7	3.2	--	--	--	--	--	--	--	--	--	--	--	--	--
Floyd River near Sheldon	8/30/77	8.3	21.0	.95	.03	.01	.2	.39	.91	<.01	<.1	<.01	<.01	<.01	<.01	<.001	<.01	<.01	<.01	<.1	.29	--
West Branch Floyd River near Le Mars	8/30/77	8.2	20.5	.01	.03	.01	.2	.57	1.1	0.2	<.1	<.01	<.01	<.01	<.01	<.001	<.01	<.01	.01	<.1	.37	--
Willow Creek near Le Mars	8/30/77	8.0	22.5	<.01	.08	.01	.1	.59	.94	--	--	--	--	--	--	--	--	--	--	--	--	--
Deep Creek near Le Mars	8/30/77	8.4	23.0	.08	<.01	.03	.6	.88	1.4	.01	<.1	<.01	<.01	<.01	<.01	.002	<.01	<.01	<.01	<.1	.35	--
Deep Creek near Le Mars	8/30/77	8.0	22.0	.36	.26	.06	.4	.42	.82	--	--	--	--	--	--	--	--	--	--	--	--	--
Little Floyd River near Sheldon	8/30/77	7.9	21.5	.49	.09	.05	.6	4.2	7.0	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 15 con't.

Alkalinity CaCO3	Total Alkalinity	Chloride (Cl)	Soluble Manganese (Mn)	Total Manganese (Mn)	Spec. Cond.	Filterable Residue	Total Residue	Hardness As CaCO3	Fluoride (F)	Nitrate (N)	Sulfate (SO	Silica (SiO2)	Soluble Iron (Fe)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO3)	Carbonate (CO3)
0	434	130	5.4	5.5	1500	991	1010	596	0.5	1.8	170	25	0.25	0.60	160	47	100	13	529	0
0	269	77	.42	.55	930	548	617	379	.35	.4	120	6.0	.12	.40	95	34	53	8.2	328	0
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
0	192	120	.34	.94	910	577	629	297	.4	.1	100	1.8	.17	2.1	64	32	75	10	234	0
0	243	200	.32	.74	1300	745	840	368	.5	1.3	130	1.6	.07	.92	82	39	130	12	296	0
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
0	293	8.5	.19	.37	720	448	521	401	.3	.9	100	18	.08	1.0	97	38	11	4.2	357	0
0	262	12	.45	.56	770	501	563	422	.3	.9	150	11	.10	.76	110	37	15	5.7	320	0
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
0	225	54	.70	.80	820	485	546	360	.35	1.8	120	4.4	.08	.87	87	34	39	8.8	274	0
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
0	360	46	.31	.34	920	561	587	409	.5	2.7	88	18	.05	.25	99	39	52	8.2	439	0

plan. The largest tributary of the Floyd River, the West Branch Floyd River, generally is of better quality than the Floyd River and improves the water quality of the mainstream of the Floyd River by simple dilution.

Ground-Water

Water-quality data for the surficial aquifer (43 water samples collected at 9 testhole piezometers and public supplies at Merrill, Brunsville, and Hinton) are given in table 16 and summarized in table 17.

The prevalent chemical type of water in the aquifer is calcium magnesium bicarbonate sulfate. This chemical type is typical of ground water from glaciated terrane in the upper midwest (Meyer, 1978). Soils in these areas are derived primarily from glacial till or from loess deposits, which are rich in calcium, magnesium, carbonate, and sulfate.

The large concentrations of nitrate, however, are of uncertain origin. Likely sources include feedlots, which are numerous, and fertilizers which are extensively used in the area. Other potential sources are septic tanks, sewage lagoons, and manure kept in uncovered stockpiles.

No areal-distribution patterns or systematic changes with time have been observed in the surficial aquifer for any of the water-quality characteristics analyzed. Chemically the water from the aquifer is suitable for most uses except locally where excessive concentrations of nitrate may occur. Only 1 of 43 samples had a nitrate concentration exceeding the 45 mg/L standard for drinking water.

Table 16. Chemical analyses of water from the surficial aquifer.

(Analyses by Iowa State Hygienic Laboratory. Chemical constituents in milligrams per liter; specific conductance (Cond) in micromhos per centimeter at 25 degrees Celcius)

Sample Source	Depth (feet)	Date	Chemical constituent or Physical property								
			Cond	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (N)	Bicarbonate (HCO_3)
Brunsville-1957	30	08/19/75	890	130	41	2.6	15	228	10	<0.1	326
Brunsville	--	12/14/76	940	150	44	2.3	18	260	8	1.2	334
Hinton	53	07/28/59	1030	158	37	4.1	14	169	20	<1.6	434
Hinton #1	40	08/08/66	1400	184	54	5.5	37	180	85	37	539
Hinton #2	52	08/08/66	1100	160	39	4.5	18	180	26	18	444
Hinton #2	52	09/19/73	1100	160	43	4.3	11	170	17	19	425
Hinton #2	52	04/19/76	1100	160	46	3.7	19	160	37	30	428
Hinton #3	33	01/23/66	730	112	23	3.6	9	98	9	0.7	361
Hinton #3	33	09/19/73	910	140	37	3.6	10	140	24	28	388
Merrill-1959	42	12/07/59	770	108	33	3.9	12	64	9	23	398
Merrill-1960	43	01/03/62	780	109	34	2.8	11	70	10	4.8	395
Merrill #1	42	04/23/74	750	110	37	3.6	12	77	11	16	403
Merrill #2	42.5	02/05/69	790	108	34	5.	12	72	9	21	415
Merrill #2	42.5	04/22/74	810	110	43	4.	14	79	18	28	410
Merrill #3	45	12/18/67	840	116	41	5.6	14	89	14	25	414
Remsen #1	34	11/27/57	980	153	35	2.4	21	267	12	11	334
Remsen #1	34	04/23/62	1040	156	44	2.4	16	313	14	3.5	327
Remsen #1	34	04/29/68	1000	156	37	2.4	16	260	12	1.6	340
Remsen #1	34	10/09/73	880	150	43	2.5	14	200	15	1.1	412
Remsen #1	34	12/03/75	960	140	43	1.8	16	170	18	6.1	399

Table 16 con't.

Remsen #2	37	11/27/57	1010	150	39	2.4	25	282	15	3.5	320
Remsen #2	37	04/23/62	1000	132	46	1.8	22	237	25	0.9	364
Remsen #2	37	04/29/68	1100	168	54	2.2	25	280	33	6.9	396
Remsen #2	37	10/11/73	1100	170	52	2.5	21	260	33	6.9	420
Remsen #2	37	12/03/75	1000	160	51	1.4	22	220	39	6.5	412
Remsen #3	36	11/29/57	990	158	32	2.4	16	244	11	12	325
Remsen #3	36	04/23/62	1060	152	44	1.8	15	277	16	5.7	332
Remsen #3	36	04/29/68	970	144	41	2.2	17	250	13	10	332
Remsen #3	36	10/11/73	1000	160	46	2.9	16	230	23	20	393
Remsen #3	36	12/03/75	1000	150	45	1.9	17	220	23	27	353
Remsen #4	36	08/11/59	1000	160	31	1.6	17	250	21	<.44	351
Remsen #4	36	04/23/62	1090	158	49	1.6	21	290	27	<.1	376
Remsen #5	35	10/11/73	1100	160	48	3.0	16	270	24	9.0	383
NW, NW, SEC. 20, T92N, R45W	30	01/17/77	840	120	40	2.2	13	89	13	65	360
SW, SE, SEC. 23, T92N, R46W	20	07/28/77	810	120	34	3.8	13	140	3.5	21	344
SE, NE, SEC. 30, T92N, R45W	20	07/28/77	1000	160	38	2.3	10	210	46	1.1	329
SW, NW, SEC. 31, T92N, R45W	20	07/29/77	830	110	39	4.0	19	100	8.5	18	398
SW, NW, SEC. 01, T91N, R46W	70	01/18/77	880	140	39	3.7	11	190	1	<.1	362
SE, SE, SEC. 10, T91N, R46W	40	07/29/77	680	96	28	4.2	8.2	71	6	0.9	338
NW, NE, SEC. 22, T91N, R46W	41	01/17/77	990	140	47	5.0	10	40	52	2	536
SW, SE, SEC. 02, T91N, R46W	41	01/17/77	660	100	27	3.4	6.9	78	4	7.8	317
SE, NE, SEC. 33, T91N, R46W	34	01/17/77	860	120	41	4.3	10	71	20	22	433
NE, NE, SEC. 27, T91N, R45W	20	07/28/77	910	130	39	2.3	13	160	3.5	24	376

Table 17. Summary of water-quality analyses from the surficial aquifer.

(Based on a total of 43 samples)

Constituent (milligrams per liter)	Median	Minimum	Maximum
Calcium	150	96	184
Magnesium	41	23	54
Sodium	15	6.9	37
Potassium	2.8	1.4	5.6
Bicarbonate	376	317	539
Sulfate	180	40	313
Chloride	15	1.0	85
Nitrate	7.8	<.1	65
Specific Conductance (micromhos per centimeter at 25 degrees Celsius)	990	660	1400

SUMMARY

A study of the Floyd River basin was conducted to provide water-resource information on a typical northwest Iowa river basin. The major objectives of the study were to determine the availability and quality of shallow ground-water supplies. The major data collection efforts included test drilling to determine the extent and character of the aquifer, the measurement of water-levels, and the collection of water samples for chemical analyses.

The Floyd River basin drains 961 square miles in parts of 6 counties. The normal annual precipitation in the basin ranges from 25.74 to 28.07 inches. The mean annual air temperature is 47.8 degrees Fahrenheit at Le Mars. The land surface altitude ranges from less than 1,100 feet to more than 1,560 feet above sea level. Upland topography of the basin ranges from extensively dissected to gently rolling. Major streams generally are flanked by relatively wide flood plains and terraces both of which are underlain by uncemented sand-and-gravel deposits.

Rocks ranging in age from Precambrian to Holocene underlie the basin. Most of the basin is directly underlain by glacial drift of Pleistocene age with older rocks occurring at greater depths. The glacial drift was deposited on an ancient surface that had several valleys eroded into the bedrock. These buried channels commonly contain sand-and-gravel deposits that are aquifers. Sand-and-gravel deposits underlying the major flood plains, terraces, and in the buried channels comprise the surficial aquifer discussed in this report.

The mean annual streamflow varies from year to year. However, the average discharge computed from a long period of record represents the total water available from that stream during the period. Flow-duration data and low-flow frequencies for the Floyd River basin indicate that the stream flow is highly variable and that the flow in the Floyd River is largely derived from surface runoff. The largest instantaneous-peak discharge recorded was 71,500 cubic feet per second at James on June 8, 1953. This flood resulted from about 9 inches of rainfall over the basin during a 30-hour period.

In the Floyd River basin the surficial aquifer consists of sand-and-gravel beds with Pleistocene glacial drift and sand-and-gravel beds that underlie flood plains and terraces along major streams. The lithology of the surficial aquifer is varied and consists mainly of quartz sand and gravel with pebbles and cobbles of sedimentary, igneous and metamorphic origin.

The total thickness of sand and gravel generally ranges from 10 to 40 feet and averages about 20 feet. In most of the area the surficial aquifer is an unconfined water-table aquifer.

Water levels in wells generally range from 2 to 55 feet below land surface and seasonal fluctuations are on the order of 2 feet. As of 1979, pumpage effects on water levels in the basin are relatively small and limited to areas near pumping wells.

An aquifer test of the surficial aquifer was conducted 2 miles south of Merrill. The well was pumped at a rate of 650 gallons per minute for 43 hours. The resulting drawdown at the pumping well was 23 feet and observation wells about 70 feet from the pumping well had drawdowns of about 10 feet. From this test the transmissivity was calculated to be 9,570 ft^2/day and the storage coefficient was 0.0001. The aquifer at the site was about 25 feet thick indicating a hydraulic conductivity of 383 feet per day.

Almost all recharge to the surficial aquifer comes from local precipitation falling on the basin. Discharge from the aquifer occurs along the Floyd River and its major tributaries. Water-table maps indicate this pattern by showing that the major ground-water movement is toward the streams. The amount of water in storage in the aquifer in Plymouth County was calculated by Meyer to be about 23 billion gallons.

The major factors governing yields from wells in the basin are the aquifer's ability to store and transmit water. In general, the surficial aquifer yields more water in the southern part of the basin where it has a greater areal extent and saturated thickness.

Water use in the Floyd River basin has been estimated for three major categories; rural-domestic, rural-livestock, and public supply for 1940 and 1978. These estimates show a substantial increase in water use during that period of time. Annual water use for irrigation was not estimated because it is highly variable from year to year and has not been significant until recently (1975-77).

Surface water in the Floyd River is a calcium magnesium bicarbonate type of water that occasionally contains large concentrations of sodium chloride. The prevalent chemical type of water in the surficial aquifer is calcium magnesium bicarbonate sulfate. The similarity of the surface and ground water is in part a result of the discharge of water from the aquifer to the stream.

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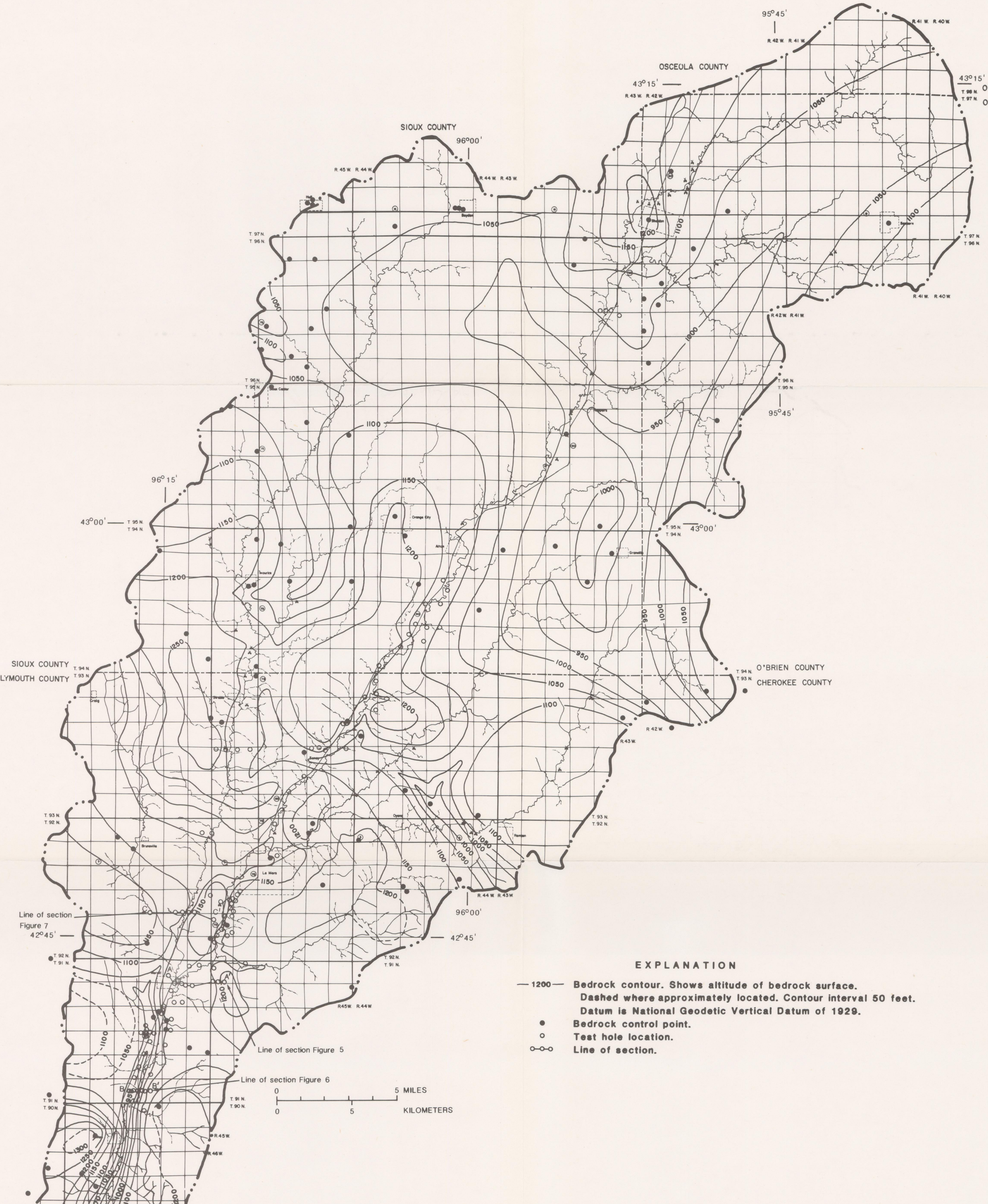
IOWA GEOLOGICAL SURVEY
Donald L. Koch, Director and State Geologist

PREPARED IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

PLATE I



Base from U.S. Geological Survey
1:24,000 and 1:62,500 quadrangles

EXPLANATION

—1200— Bedrock contour. Shows altitude of bedrock surface. Dashed where approximately located. Contour interval 50 feet. Datum is National Geodetic Vertical Datum of 1929.

● Bedrock control point.

○ Test hole location.

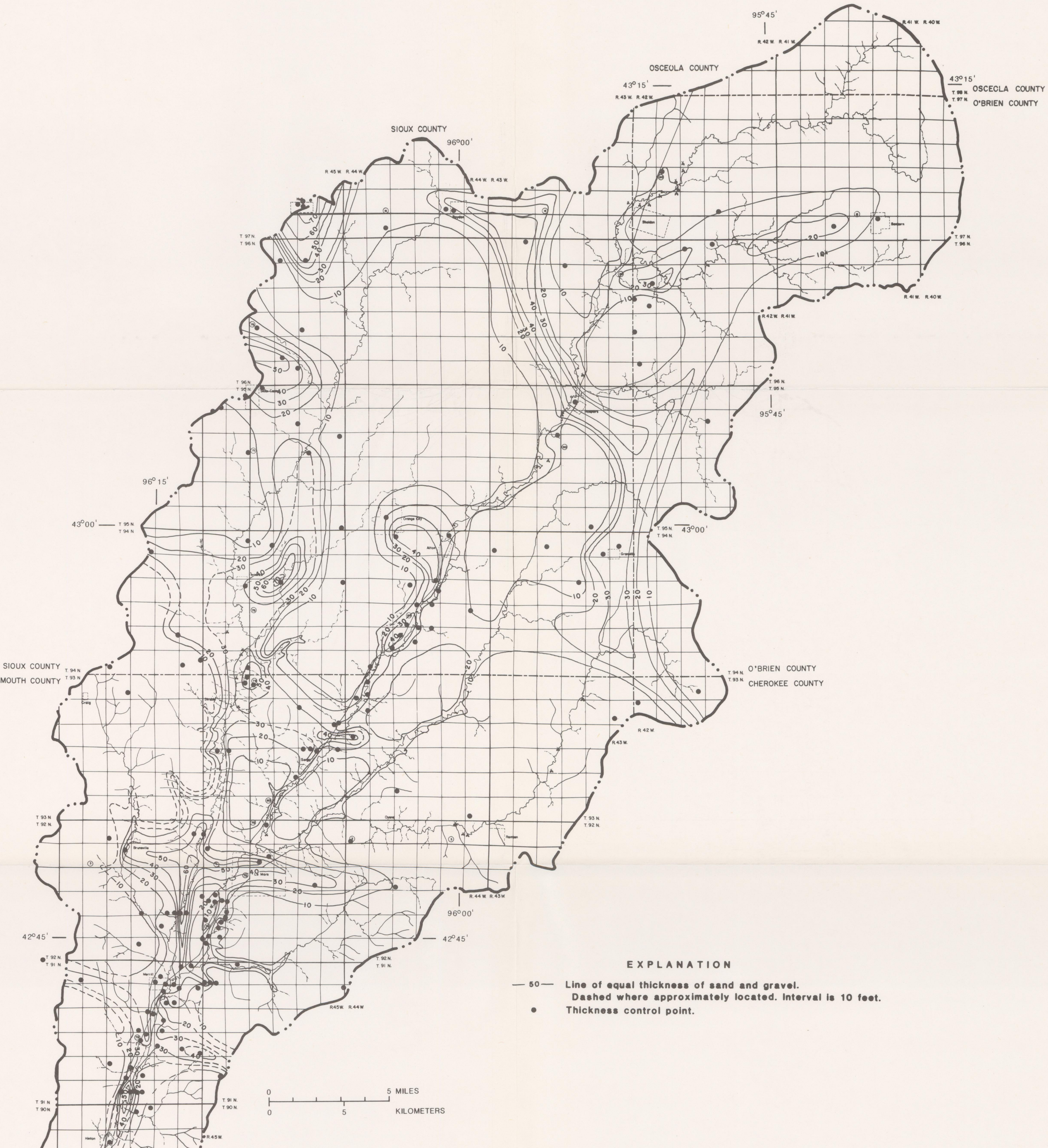
o—o—o Line of section.

Map showing altitude and configuration of the bedrock surface in the Floyd River basin, Iowa.

IOWA GEOLOGICAL SURVEY
Donald L. Koch, Director and State Geologist

PREPARED IN COOPERATION WITH THE
U.S. GEOLOGICAL SURVEY

PLATE 2



Base from U.S. Geological Survey
1:24,000 and 1:62,500 quadrangles

EXPLANATION

— 50 — Line of equal thickness of sand and gravel. Dashed where approximately located. Interval is 10 feet.

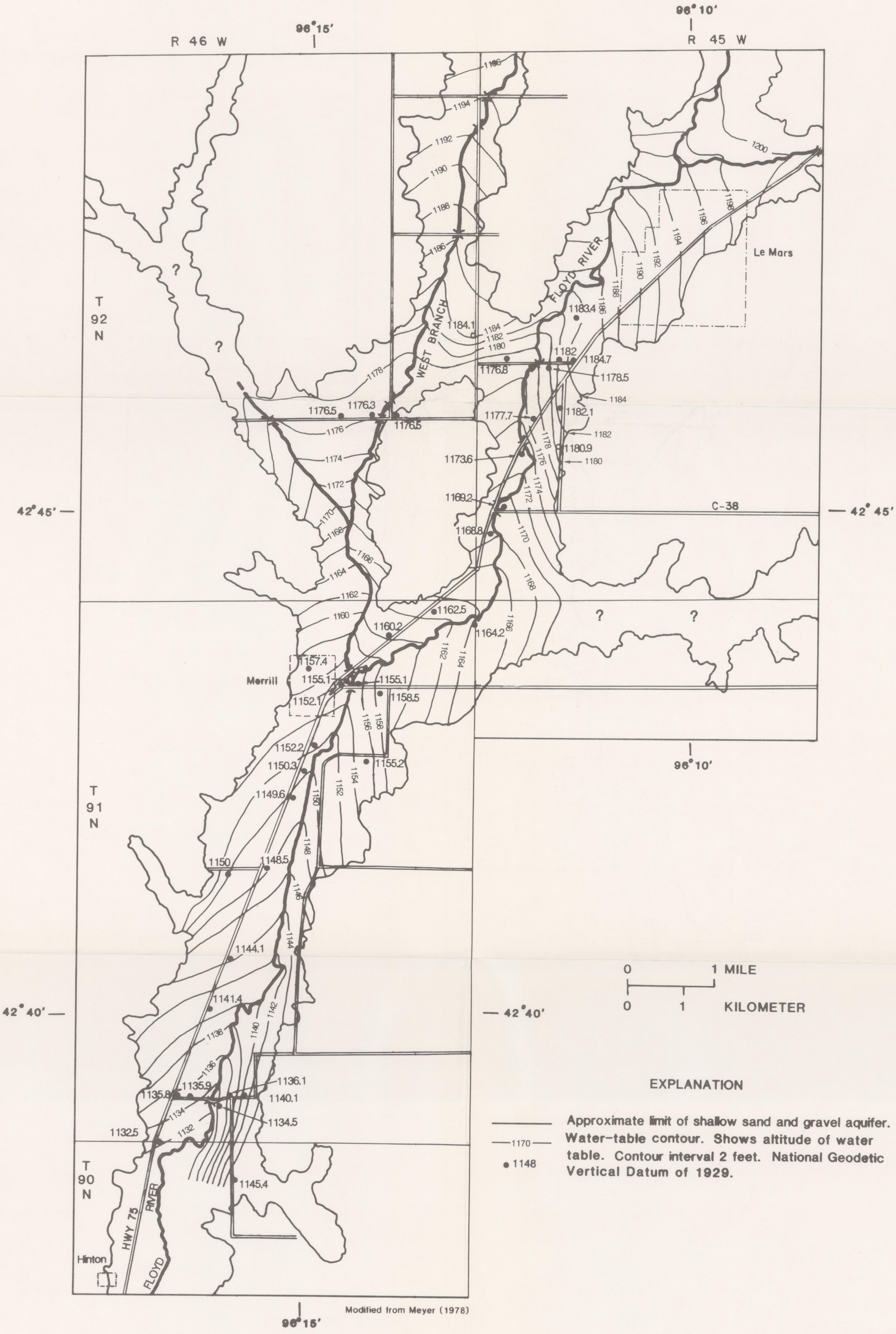
● Thickness control point.

Map showing thickness of sand-and-gravel beds in the surficial deposits of the Floyd River basin, Iowa.

IOWA GEOLOGICAL SURVEY
Donald L. Koch, Director and State Geologist

PREPARED IN COOPERATION WITH
THE U.S. GEOLOGICAL SURVEY

PLATE 3



EXPLANATION

—	Approximate limit of shallow sand and gravel aquifer.
—1170—	Water-table contour. Shows altitude of water table. Contour interval 2 feet. National Geodetic Vertical Datum of 1929.
● 1148	

Modified from Meyer (1978)

Map showing altitude and configuration of the water table in the southern part of the Floyd River basin, Iowa.

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Donald L. Koch, Director and State Geologist

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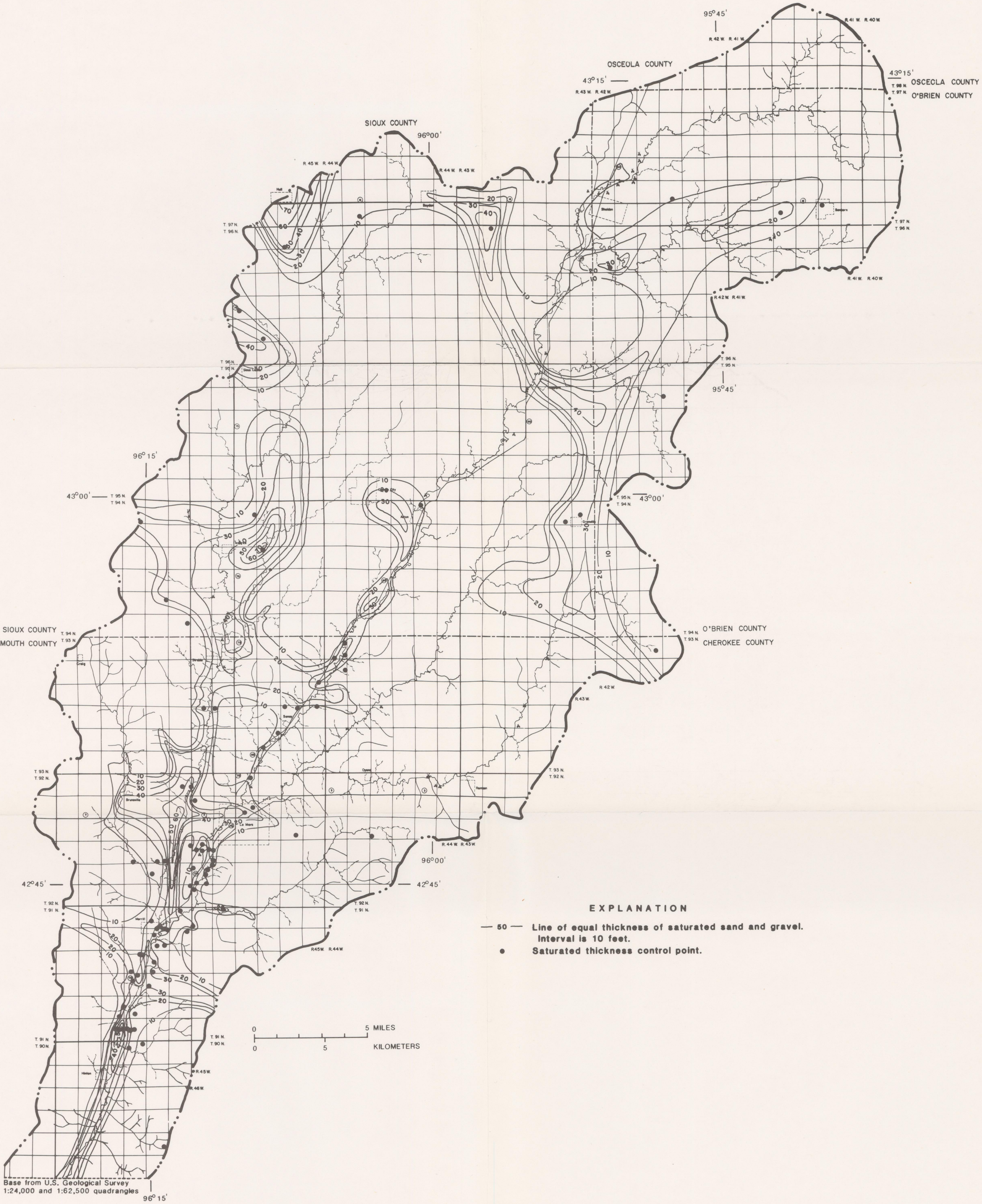
U.S. GEOLOGICAL SURVEY

PLATE 4



Map showing saturated thickness of sand-and-gravel beds in the surficial deposits of the Floyd River basin, Iowa.

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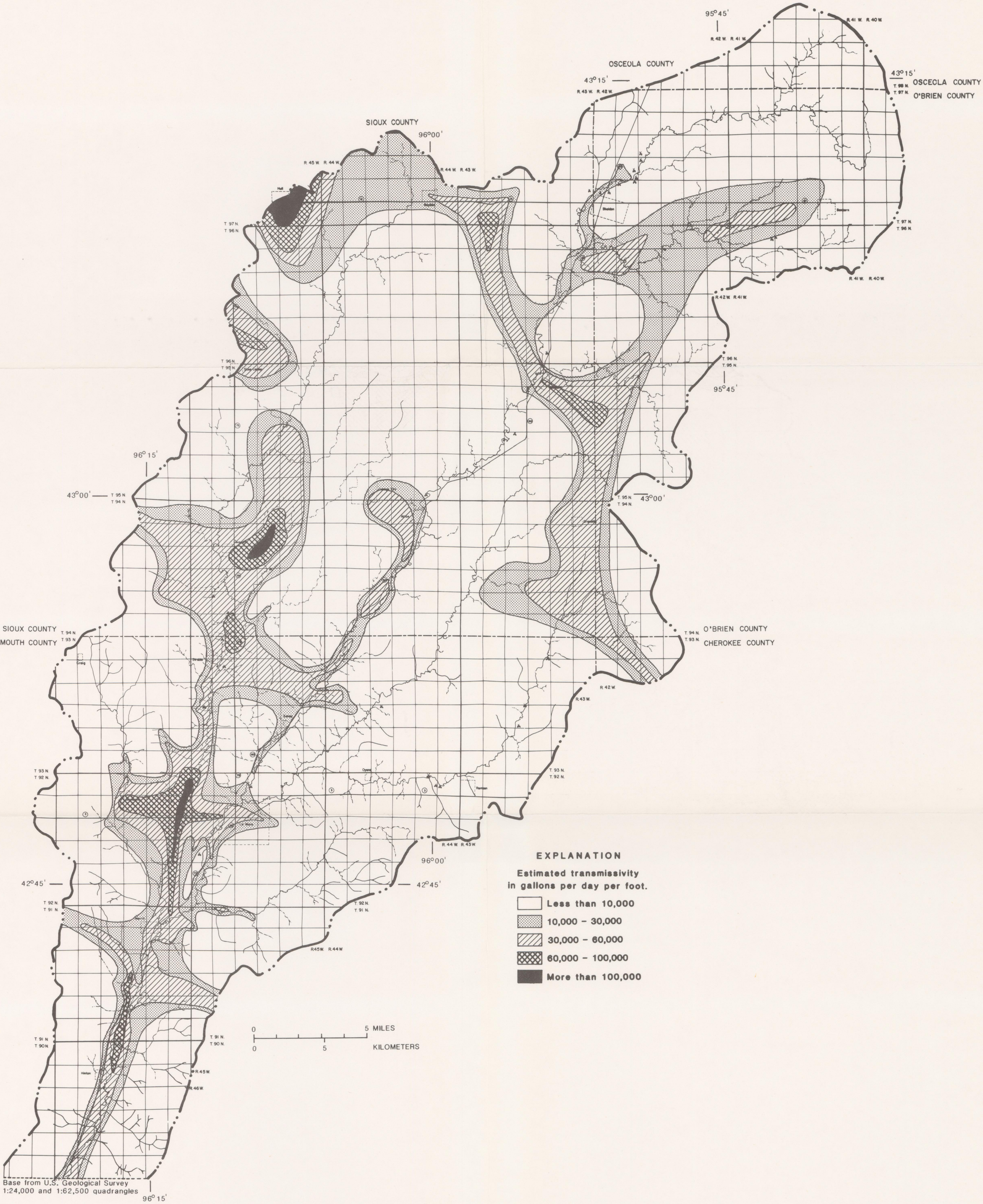
PLATE 5



Base from U.S. Geological Survey
1:24,000 and 1:62,500 quadrangles

Map showing transmissivity of the surficial aquifer in the Floyd River basin, Iowa.