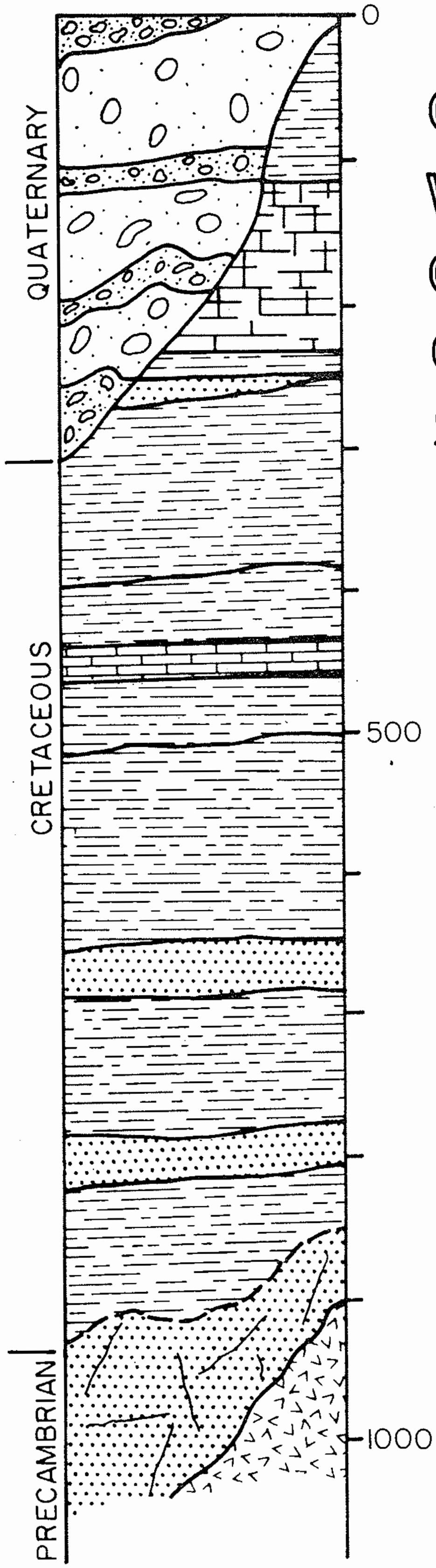

GEOLOGY AND WATER RESOURCES OF BON HOMME COUNTY SOUTH DAKOTA

Part II; Water Resources

by
Donald G. Jorgensen
United States Geological Survey

Prepared in cooperation with the South Dakota Geological Survey, County of Bon Homme, and Fort Randall Conservancy Sub-District.

Bulletin 21
SOUTH DAKOTA GEOLOGICAL SURVEY

1971

Beissel

STATE OF SOUTH DAKOTA
Richard Kneip, Governor

SOUTH DAKOTA GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

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Science Center
University of South Dakota
Vermillion, South Dakota
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Geology and water resources of Bon Homme County, South Dakota
Part II, Water Resources

by
Donald G. Jorgensen

ABSTRACT

Bon Homme County, an agricultural county in southeastern South Dakota, has an area of 570 square miles and a population of 8,707. Sands and sandstones of Tertiary age, sands and gravels, till, and loess of Pleistocene age, and alluvium of Holocene age overlie the Cretaceous bedrock strata throughout nearly the entire county.

Water from Lewis and Clark Lake and the Missouri River has a low sodium hazard and a medium salinity hazard. It is suitable for domestic and stock uses and for irrigation with only moderate leaching of the soil. The water is used by the city of Springfield and also to a limited extent for irrigation.

The quality of water from Emanuel and Choteau Creeks varies with the rate of discharge in the creeks. In general, the water has a high salinity hazard at low flows and should not be used for irrigation on soils with poor drainage. However, the water is suitable for stock use.

In Lake Henry the quality of water varies with both the season of the year and the volume of water in the lake. In particular, the water has a low sodium hazard and a variable high to very-high salinity hazard. The water is not suitable for irrigation under ordinary conditions. However, in general, the water is suitable for domestic and stock uses.

Alluvial and surficial outwash aquifers supply ground water for domestic and stock use. Shallow wells finished in these aquifers produce 3 to 10 gpm (gallons per minute).

Widespread till deposits usually yield water with a low sodium hazard and a very high salinity hazard. This water is not suitable for irrigation under ordinary conditions. At certain locations in the till the water has excessively high sulfate and dissolved solids concentrations and may not be suitable for domestic use. However, the water is suitable and is commonly used for stock watering. Wells finished in the aquifer yield from 1 to 5 gpm.

Three extensive glacial outwash aquifers are present in the county. The 32-square mile Choteau aquifer is adjacent to Choteau Creek. The Tyndall-Scotland aquifer underlies an area of more than 90 square miles and extends from near Springfield to near Scotland. The Hubonmix aquifer in northwestern Bon Homme County has an areal extent of about 36 square miles. Water from these three aquifers usually has a low sodium hazard and a high salinity hazard. Therefore it should be used for irrigation only on land which has good soil drainage. The water, in general, is suitable for domestic and stock uses. At locations where these aquifers contain more than 50 feet of saturated aquifer material, properly constructed wells should produce more than 100 gpm.

The Codell Sandstone Member of the Carlile Shale, a bedrock aquifer that commonly yields "soft" water, is widely used as a source of domestic water. Water from this aquifer usually has a very high sodium hazard and a high salinity hazard. It is unsuitable for irrigation but is usually suitable for domestic and stock uses.

The Niobrara Marl and the sandstone layers of the Dakota Formation are also bedrock aquifers. Water from these aquifers generally has a low sodium hazard and a high salinity hazard; it should be used only on land which has good soil drainage. The water, in general, is suitable for domestic and stock uses. Properly constructed wells at certain locations in the Niobrara aquifer will produce more than 100 gpm, and properly constructed wells in the lower Dakota aquifer may produce as much as 900 gpm.

INTRODUCTION

The increasing use of water and the increasing awareness of the importance of water resources in Bon Homme County and in other South Dakota counties have created the need and desire to evaluate the water resources of the State. The purpose of this investigation is to identify and evaluate the water resources of Bon Homme County. The significant findings and the data obtained will be useful in planning the orderly development of the water resources.

The study was started in 1965 as a part of the program of the U. S. Geological Survey, the South Dakota Geological Survey, Bon Homme County, and the Fort Randall Conservancy Sub-District. This is the fifth in a series of such cooperative county-wide studies. The author is indebted to the residents of the county for their help and especially to Kenneth Karanda, who supplied many valuable well logs.

Method of investigation.–The investigation included the collecting of well data, test drilling, measuring water levels and stream flow, sampling and chemical analyses of waters, and determining altitudes by spirit-level and altimeter surveys. The data were studied to determine the source, movement, quantity, and quality of the ground and surface waters in the county. The accuracy of maps and of other interpretations based on altitude determinations is plus or minus 10 feet. Geological mapping was done by the South Dakota Geological Survey.

Geography.–Bon Homme County is located in southeastern South Dakota. It has an area of approximately 570 sq mi (square miles) and a population of 8,707 (1970 census). Five municipalities, Tyndall, population 1,262; Springfield, population 1,194; Scotland, population 1,077; Avon, population 637; and Tabor, population 378, are located in the county. About 97 percent of the land in the county is in farms. More than half of the farms are primarily engaged in raising livestock, and about one-third are small grain or row crop farms.

Physiography.–The county, as shown on figure 1, is part of two physiographic provinces, the Great Plains and the Central Lowland. The dissected glacial uplands west of Emanuel Creek are part of the glaciated Missouri Plateau section of the Great Plains Province (Fenneman, 1946) and the low-lying land east of Emanuel Creek is part of the James Basin of the Central Lowland Province. The James River Highlands in the southeast corner of the county is a part of the James Basin. The Missouri River flood plain, which is approximately 1 mile wide on the South Dakota side of the Missouri River, has now been submerged by the water in Lewis and Clark Lake, above Gavins Point Dam, except for small areas along the river in the southwest corner of the county. The flood plain is defined by bluffs 200 to 300 feet high in the southeast and southwest corners of the county, and by bluffs 25 to 100 feet high in the south-central part of the county.

Altitudes of land surface in the county range from approximately 1,210 feet on the Missouri River flood plain to approximately 1,950 feet on three hills of the glacial upland in the northwest corner of the county.

Geology.–The surficial deposits, except for the exposed bedrock strata, are glacial drift, alluvium, colluvium, and eolian materials (Christensen, in preparation). Figure 2 is a generalized geologic map of the surficial deposits of Bon Homme County.

Exposed bedrock consists of the Tertiary age Ogallala sands and sandstones[1], and the Pierre Shale and Niobrara Marl of Cretaceous age. The configuration of the upper surface of the Cretaceous age bedrock is shown in figure 3. Unexposed bedrock formations of Cretaceous age include the Carlile Shale, Greenhorn Limestone, Graneros Shale, and Dakota

[1] Stratigraphic nomenclature used in this report follows that of the South Dakota Geological Survey, which differs somewhat from the usage adopted by the U. S. Geological Survey.

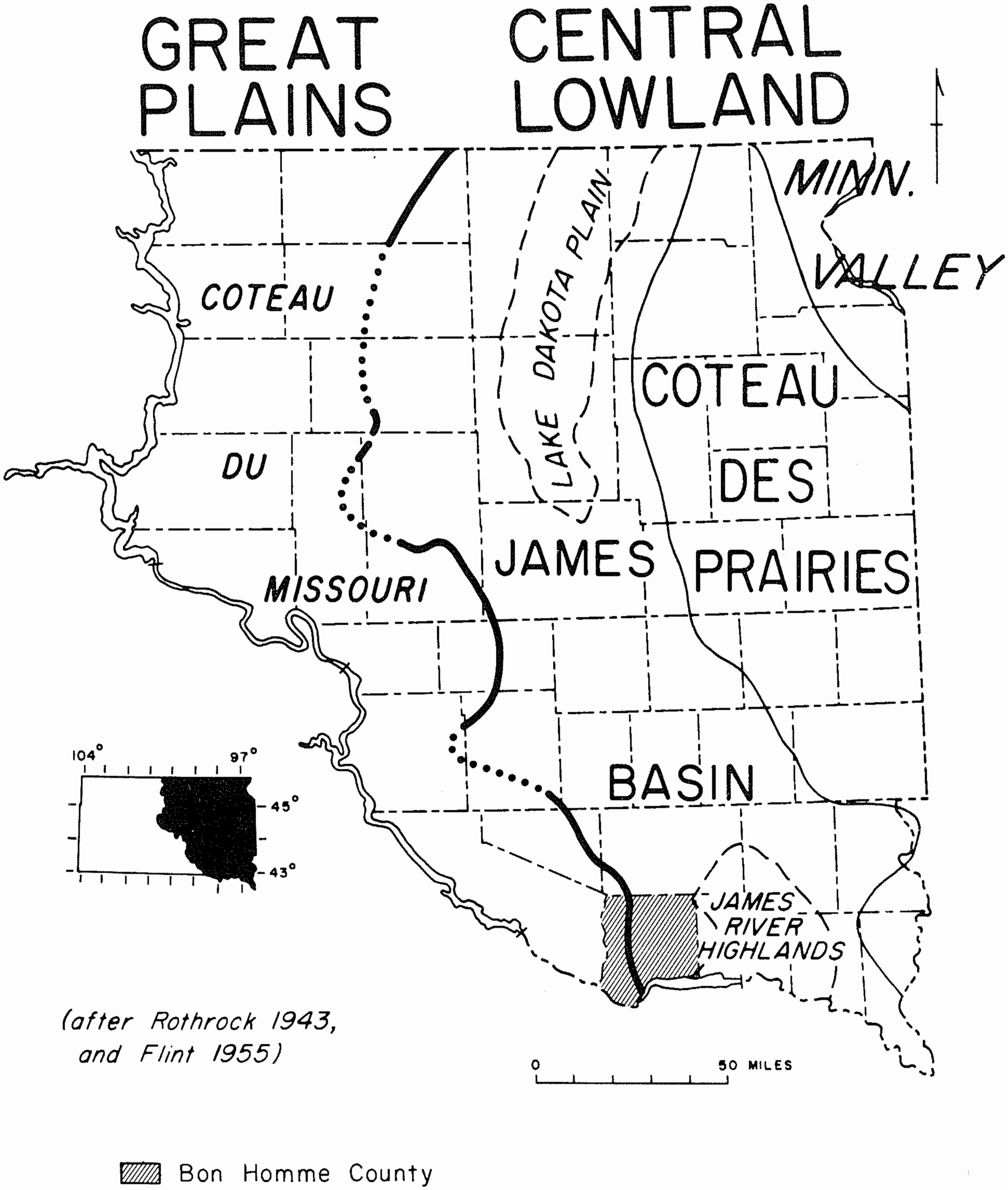


Figure 1. Map showing physiographic divisions of eastern South Dakota and location of Bon Homme County.

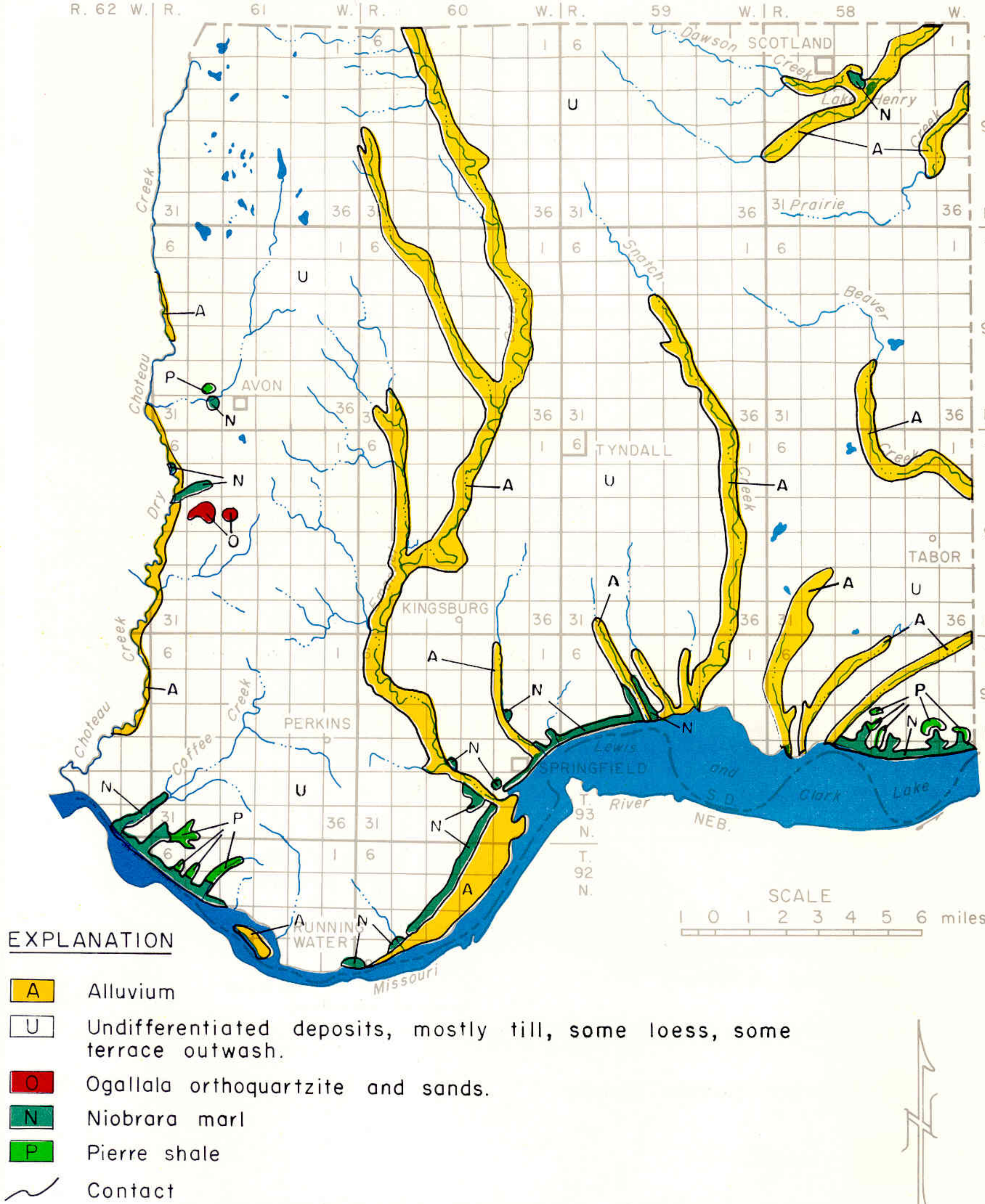


Figure 2. Generalized geologic map.

After Christensen, Part I, (in preparation).

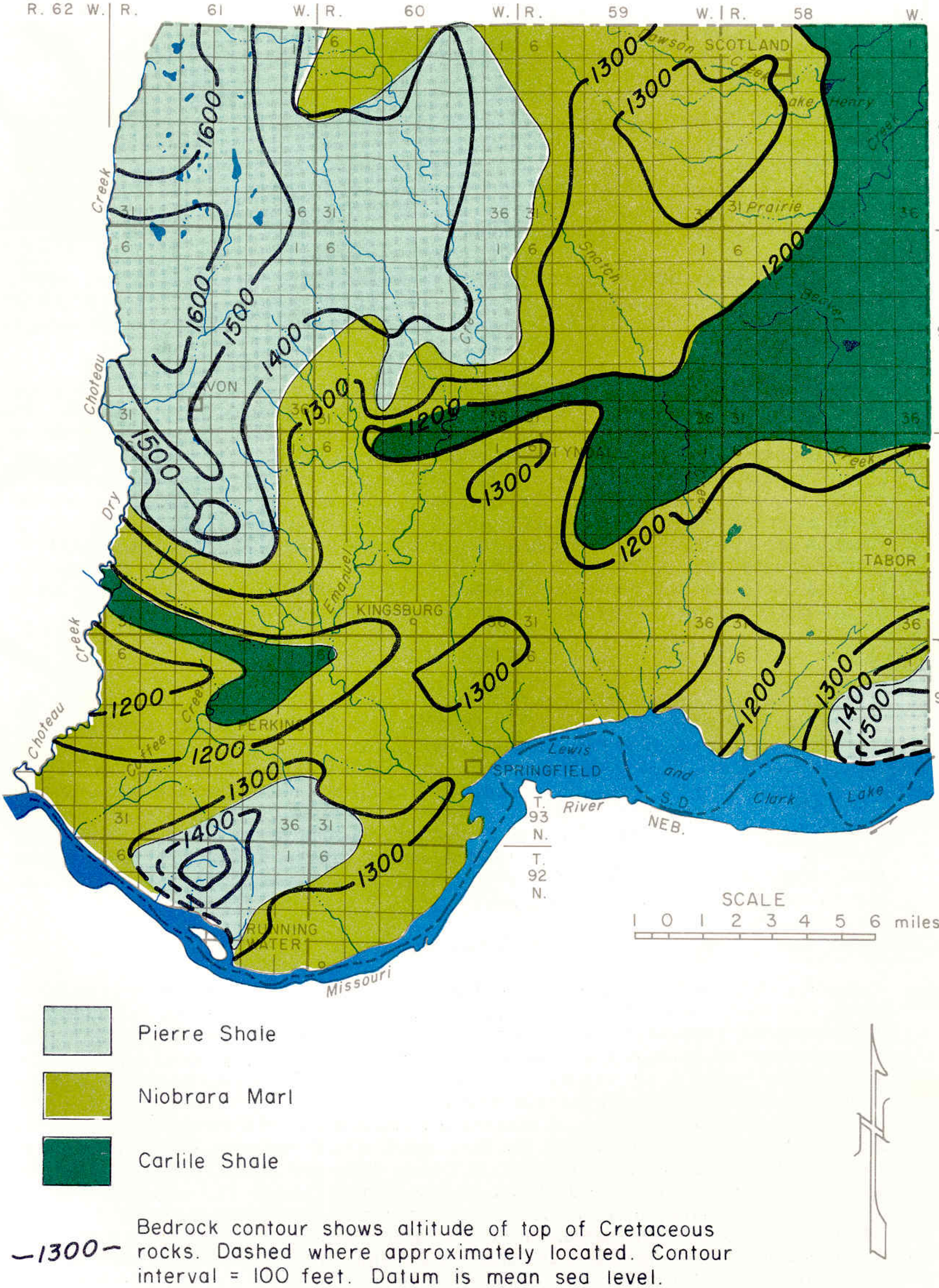


Figure 3. Map showing altitude of the surface of the Cretaceous bedrock.

Formation. The Dakota lies unconformably on the Sioux Quartzite "basement" rock of Precambrian age.

Climate.–U. S. Weather Bureau meteorological records (1967) for Tyndall indicate that the average annual temperature is 9.3° Celsius (48.7°F) and the average annual precipitation is 22.46 inches. The average dates of the last spring and first fall frosts are May 4 and September 30 (Pengra, 1957b). The average dates of the first spring and first fall occurrence of a "killing frost," which is -2°C (28°F) or lower, at Tyndall are April 26 and October 10 (Pengra, 1956a).

Previous investigations.–Previous geologic or hydrologic investigations in the county include water-supply studies for the cities of Tyndall (Bruce, 1962) and Scotland (Christensen, 1963). Simpson (1960) mapped the geology of the Yankton area, including a part of Bon Homme County.

Well-numbering system.–The location of wells, test holes, and other items is described according to the numbering system shown in figure 4. The first segment indicates the township, the second the range, and the third the section in which the well, test hole, or other feature is located. The lowercase letters following the section number indicate the position of the well in the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, the third letter the quarter-quarter-quarter section, the fourth letter the quarter-quarter-quarter-quarter section (2½-acre tract). The subdivisions of a section are lettered a, b, c, and d in a counterclockwise direction, starting in the northeast quarter. If more than one well is listed in a 2½-acre tract, consecutive numbers starting with 1 are added to the well numbers. Thus well 93-58-15babb (fig. 4) is in the NW¼, NW¼, NE¼, NW¼ of section 15, Township 93 North, Range 58 West.

WATER RESOURCES

Water resources include all water that can be used, whether it occurs in the air, on the ground, or in the ground. All water in Bon Homme County is of atmospheric origin. Precipitation or the condensation of water vapor in the form of rain, snow, dew, or frost is the source of both ground water and surface water. Surface water is water that runs over the land or is stored on the land surface. Water which infiltrates into the ground to the zone of saturation is termed ground water. Some water is transpired by plants or evaporates and returns to the atmosphere. The continual cyclic movement of water is termed the hydrologic cycle. Figure 5 is a simplified sketch of the hydrologic cycle showing precipitation returning to clouds (vapor) by means of evapotranspiration from plants, soil, and surface-water bodies (rivers, lakes, etc.).

Surface Water

Surface water is the water on the surface of the earth. It includes the water in lakes, ponds, reservoirs, rivers, creeks, etc. Runoff is that part of the precipitation that appears in surface streams. Amount of runoff is a function of many variables including precipitation, size and slope of drainage area, and soil permeability. The drainage areas and the main surface-water bodies in the county are shown in figure 6. The approximate sizes and the names of the drainage areas are listed in table 1.

Magnitude and the frequency of flooding is a characteristic of a stream that is of special importance to anyone who utilizes the flood plain. Flood-frequency studies are used to predict the occurrence and magnitude of floods. Patterson (1966, p. 3-11) developed regional flood-frequency curves applicable to Bon Homme County. The method is based on two sets of curves and can be used to estimate the magnitude of floods that have recurrence intervals of 1.1 to 50 years. Recurrence interval is the average interval of time within which the given flood will be equaled or exceeded once. A flood having a recurrence interval of 10 years is one that has a 10 percent chance of occurring in any year; likewise a 50-year flood

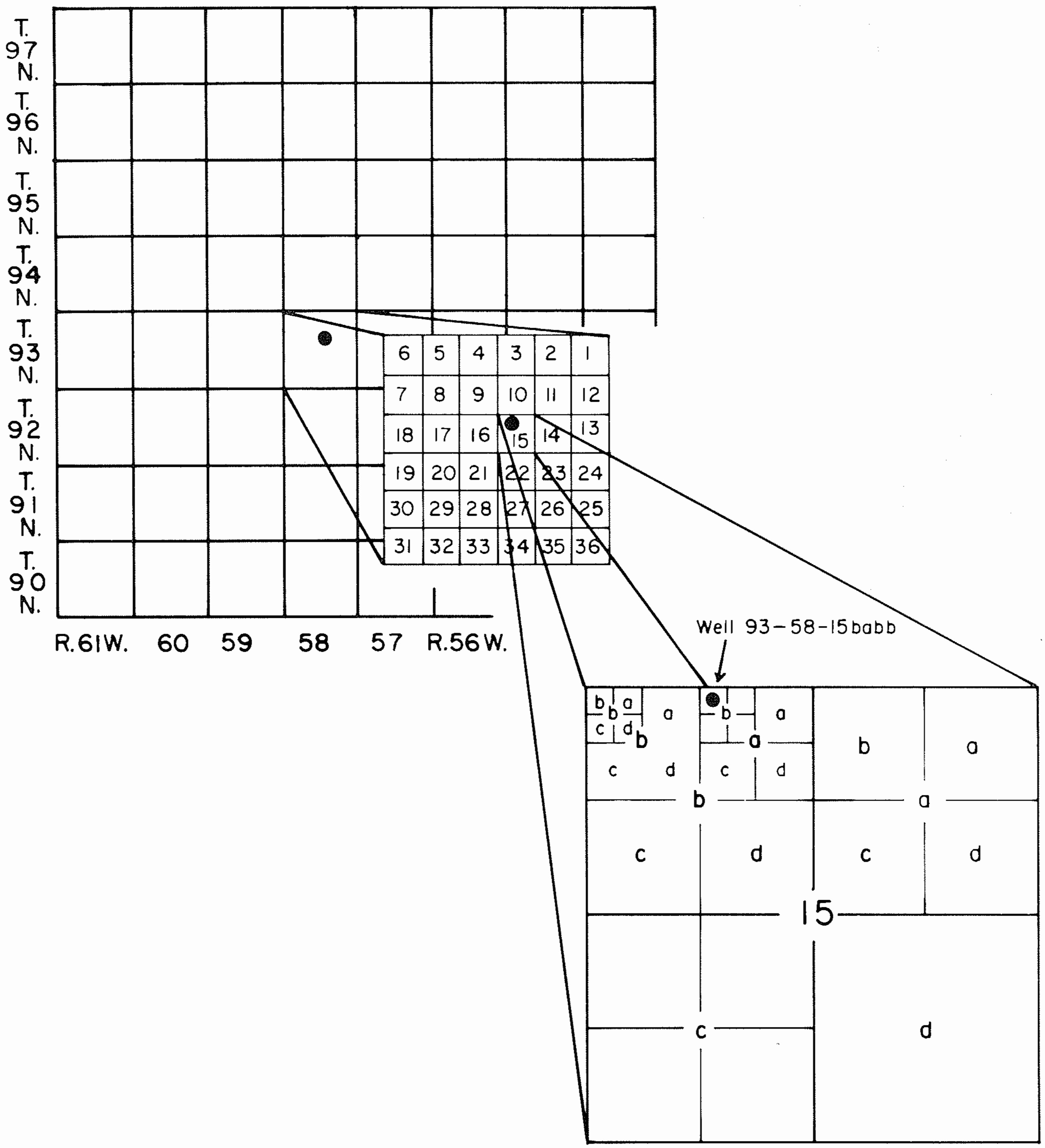


Figure 4. Diagram of well-numbering system.

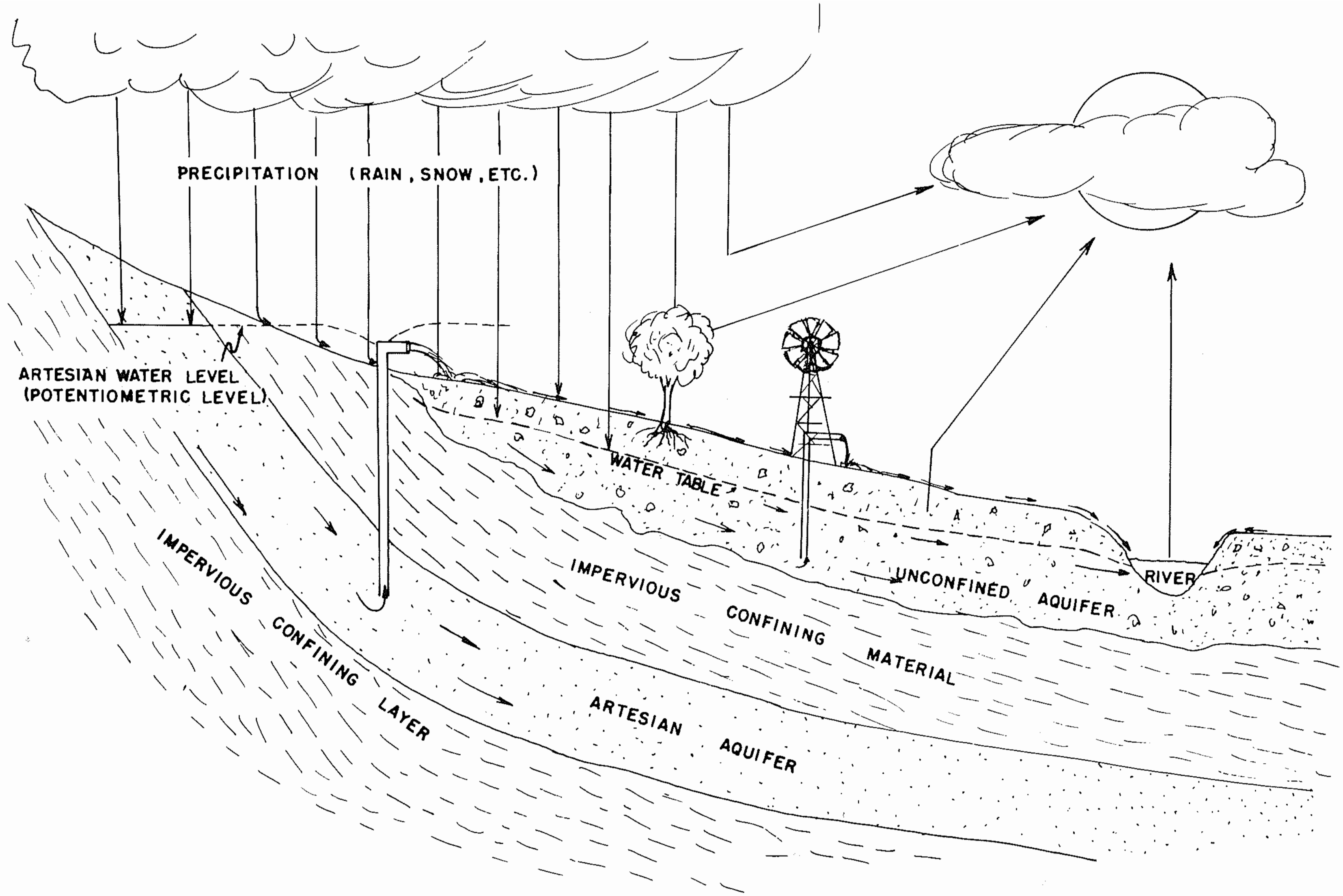


Figure 5-- Simplified diagram of the hydrologic cycle

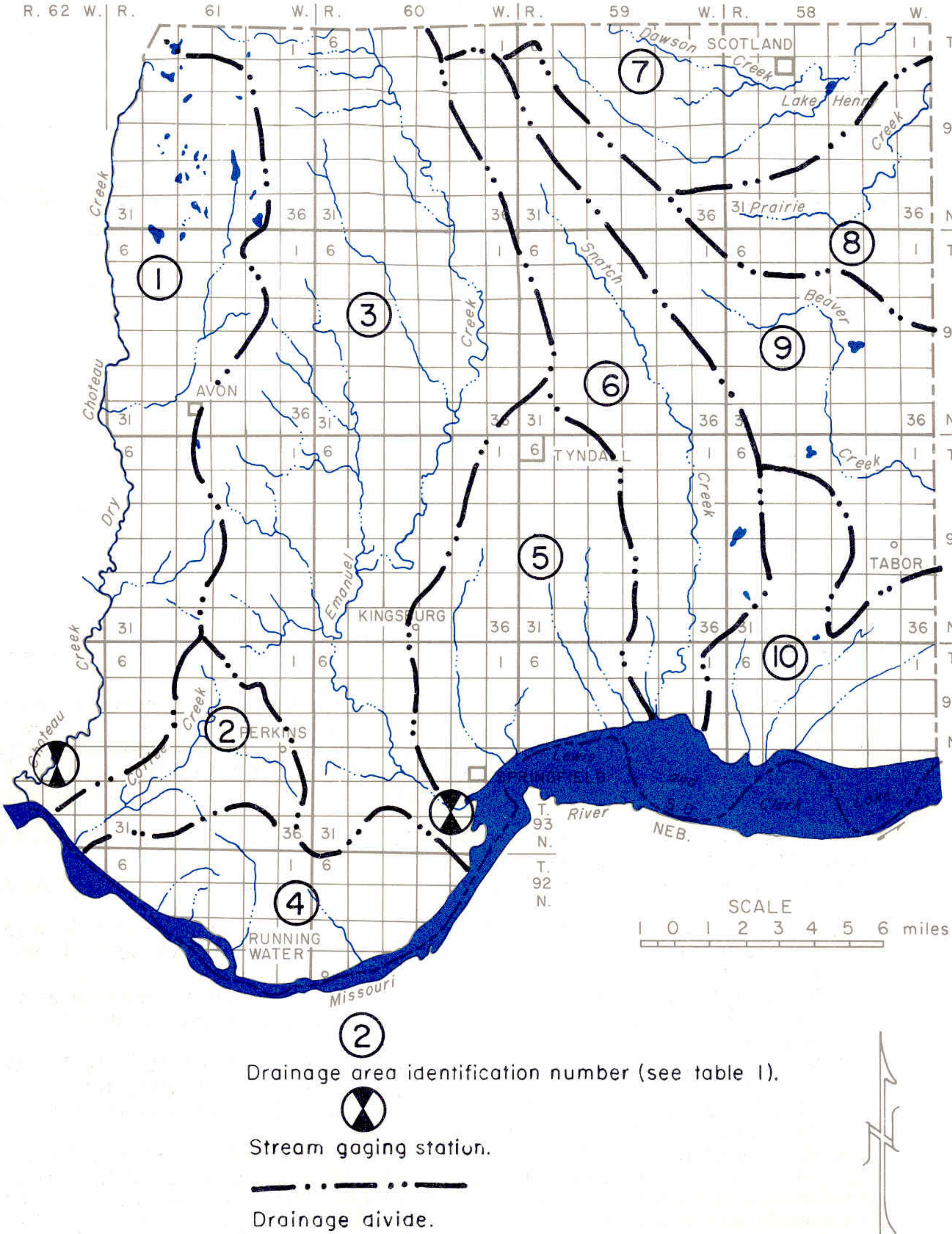


Figure 6. Map of drainage areas

Table 1.–Drainage areas

(See fig. 6)

Number	Name	Drainage area (sq mi) Total	Drainage area (sq mi) Bon Homme County
1	Choteau Creek	613	69½
2	Coffee Creek	19½	19½
3	Emanuel Creek	182	154
4	Unnamed	36	36
5	Unnamed	54	54
6	Snatch Creek	63	63
7	Dawson Creek	76	44½
8	Prairie Creek	39	30
9	Beaver Creek	146	57
10	Unnamed	42½	42½

has a 2 percent chance of occurring in any year. One flood-frequency curve (fig. 7) relates the size of the drainage area to the mean annual flood. Mean annual flood for a gaging station is, by definition, the 2.33-year flood from the graphic-frequency curve defined by points which are referred to the same base-time period. Other flood-frequency curve (fig. 8) shows the relation between the ratio of discharge to mean annual flood and the recurrence interval.

Procedure for using these curves in determining the discharge of a 10-year flood at the mouth of Snatch Creek is as follows:

1. Determine the size of the drainage area. (Snatch Creek has a drainage area of 63 sq mi.)
2. Determine the discharge in cubic feet per second (cfs) of the mean annual flood for this size drainage area from figure 7. (The discharge for the mean annual flood for 63 sq mi is 620 cfs.)
3. Determine the ratio of the flood of the selected recurrence interval to the mean annual flood from figure 8. (The ratio for a flood with a 10-year recurrence interval to the mean annual flood is 2.7.)
4. Multiply the discharge obtained from the mean annual flood curve (fig. 7) by the ratio obtained from the frequency curve (fig. 8) to obtain the discharge of the flood in cubic feet per second. (The discharge of the 10-year flood at the mouth of Snatch Creek is 620 times 2.7, which is 1,670 cfs.)

Another useful runoff characteristic is the total annual runoff in acre-feet that can be expected. An acre-foot is a unit for measuring volume of water, and is equal to the quantity of water required to cover 1 acre to a depth of 1 foot (43,560 cubic feet). The probability that annual runoff in acre-feet per square mile (acre-ft per sq mi) will equal or exceed the stated amount is given below:

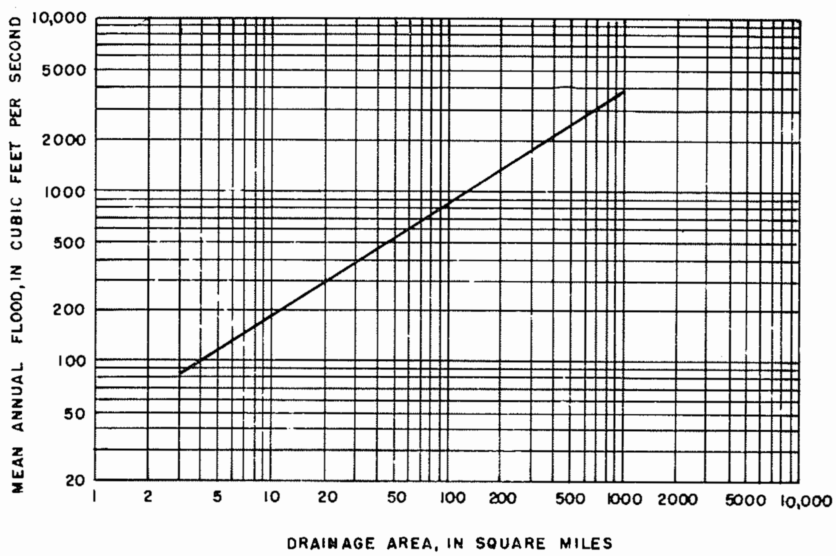


Figure 7. --Variation of mean annual flood with drainage area (after Patterson, 1966)

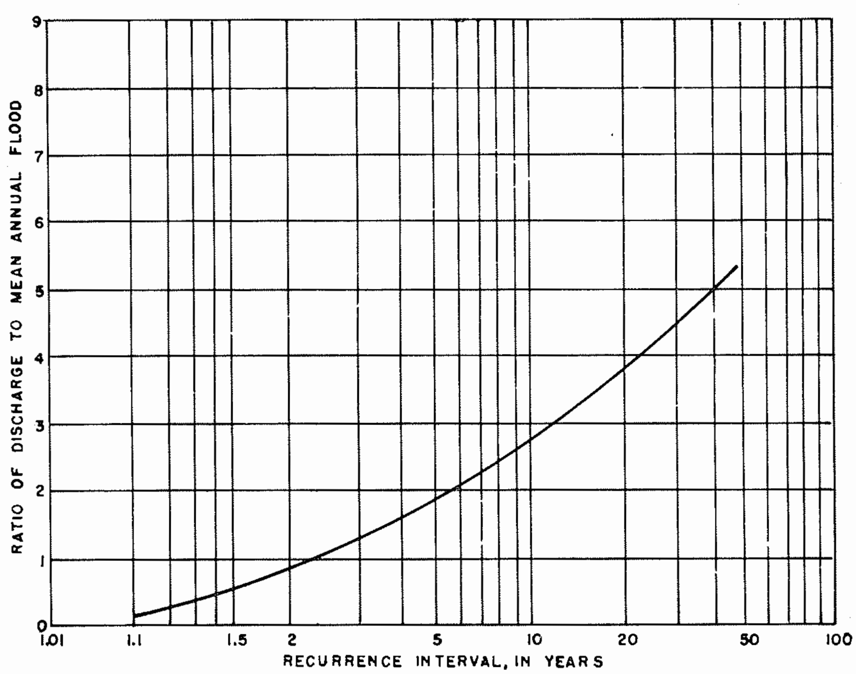


Figure 8.-- Variation of flood discharge with recurrence interval (after Patterson, 1966)

Probability (percent)	Runoff (acre-ft per sq mi)
10	200
25	100
50	60
75	30
90	20

Average runoff is 80 acre-ft per sq mi which is considerably larger than the 50 percent probability of 60 acre-ft per sq mi annual runoff. To determine the annual runoff for any probability, multiply the runoff figure listed above by the drainage area. For example, to determine the annual runoff that will be equaled or exceeded 10 percent of the time for Emanuel Creek, multiply the drainage area of 182 sq mi, as listed in table 1, by 200 acre-ft per sq mi, as listed above, thus obtaining a value of 36,400 acre-ft.

Missouri River

The Missouri River is the largest stream in the area. Discharge of the Missouri River has been measured below Fort Randall Dam since May 1947. Flow had been regulated by Fort Peck Dam in Montana prior to 1952 and by Fort Randall Dam thereafter. Average discharge for the period of record (U. S. Geological Survey, 1968) is 22,890 cfs. Maximum discharge during the period of record was 447,000 cfs on April 12, 1952. Water, other than that from Lewis and Clark Lake, is unused in Bon Homme County.

Choteau Creek

Choteau Creek drains 613 sq mi in Davison, Aurora, Douglas, Charles Mix, and Bon Homme Counties. The 69.5 sq mi part of the drainage area in Bon Homme County consists of dissected till plains and a well-defined flood plain along the lower reaches of Choteau Creek. A gaging station was established for this study at 93-62-23bdd to determine amount of flow in the creek. Monthly mean discharges are listed in table 2. The maximum peak discharge for the period May 16, 1966 to October 31, 1968 was 3,140 cfs (gage height, 9.11 ft) at 1200 hours on June 19, 1967. The minimum discharge for the same period was 0.60 cfs on September 5, 1966. It is believed that the flood on June 19, 1967, has been exceeded only once in the last 20 years. A flood at a gage height of about 11 feet occurred in March 1962. Base flow of Choteau Creek is ground water derived from the Choteau aquifer.

Water is unused except as stock water in a few small dugouts and small stock dams.

Table 2.–Monthly mean discharge of Choteau Creek
(units of discharge are cfs)

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1966									6.44	1.84	1.34	0.72
1967	1.08	1.68	1.84	2.28	2.36	3.14	2.61	2.54	180	27.2	64.5	3.50
1968	2.61	1.87	2.21	2.11	2.35	2.35	4.03	1.31	1.43	6.32	1.76	8.88

Emanuel Creek

Emanuel Creek has a drainage area of 182 sq mi, 154 of which is in Bon Homme County. The creek, which drains an area of till plains, flows into Lewis and Clark Lake. Its lower reaches are characterized by a small but well-defined flood plain. A gaging station was established for this study at 93-60-27dbb. Monthly mean discharges are listed in table 3. Source of base flow is springs that discharge water from the Tyndall-Scotland and Niobrara aquifers.

Maximum discharge for the period May 16, 1966, to October 31, 1967, was 1,590 cfs (gage height, 7.11 ft) on June 19, 1967, at 1445 hours. Minimum discharge for the same period was 1.16 cfs on September 12, 1966. Several floods have been observed by local residents in the last 20 years at crests 2 to 3 feet above the peak recorded on June 19, 1967.

Water is unused except as stockwater in a few small dugouts and stock dams.

Table 3.--Monthly mean discharge of Emanuel Creek
(units of discharge are cfs)

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1966									3.59	1.66	1.97	1.50
1967	2.26	2.72	3.00	3.18	3.32	4.06	3.06	3.01	125	9.13	7.33	2.24

Lewis and Clark Lake

Lewis and Clark Lake is formed by Gavins Point Dam, which is on the Missouri River 7½ miles east of the southeast corner of the county. Storage began in July 1955. Normal maximum capacity below altitude 1,208.0 ft is 477,000 acre-ft. Water is used primarily for downstream navigation, recreation, power, and flood control. Four residents in the county have used the water for irrigation. The city of Springfield used an estimated 207 acre-ft of this water for domestic purposes in 1968.

Lake Henry

Lake Henry is formed by impoundment of water behind a small dam located on Dawson Creek at 96-58-9. The lake is used for recreation.

Other Surface-Water Bodies

There are many small lakes and ponds in the county. Most of the lakes are less than 4 feet deep, and commonly dry up during periods of drought. These lake areas are a habitat for wildlife, but are not otherwise used. The many small dams and dugouts in and along the creeks have little storage and do not hold water permanently.

Ground Water

Definitions

Ground water is that water which occurs beneath the surface of the ground in the saturated zone. The ground is said to be saturated when all the voids are filled with water. A soil or rock material that yields water to wells or springs at a sufficient rate to be used as a water supply is called an aquifer. If ground water is confined it is said to be under artesian conditions. If ground water is only under atmospheric pressure, it is unconfined, or it is said to be under water-table conditions. Artesian and water-table conditions are shown graphically in figure 5.

The level to which water will rise in a well is termed the potentiometric level. The potentiometric level is the water surface at atmospheric pressure. For water-table conditions, this surface (water table) is within the aquifer; whereas, for artesian conditions it is an imaginary surface above the aquifer. The shape of the water table or potentiometric surface is the configuration of water surface slopes resulting from water movement between areas of recharge (water entering the aquifer) and areas of discharge (water leaving the aquifer).

Porosity is the ratio of the volume of voids to the total volume of a rock or rock material. The greater the porosity of an aquifer, the larger the amount of water that can be stored in the aquifer. The amount of water that can be drained from a unit volume of aquifer material by gravity is called its specific yield. However, not all of the water will drain by natural gravitational force because some water adheres to the pore walls; the quantity of water per unit volume retained in this manner is termed its specific retention. Therefore, specific retention plus specific yield is equal to the effective porosity of a saturated material.

Storage coefficient (S) is the volume of water that an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. For an unconfined aquifer, the value of S is the same as its specific yield. Typical storage coefficient values range from 0.1 to 0.3 for unconfined aquifers and from 0.0005 to 0.005 for confined aquifers.

Hydraulic conductivity (K), expressed in terms of feet per day (ft per day), represents the rate at which water will pass through an area of 1 square foot of water-bearing material at unit head. Rate of water movement through a material may also be discussed in terms of permeability (P) expressed in gallons per day per square foot (gpd per ft^2) at unit head. The relation between hydraulic conductivity in feet per day and permeability in gallons per day per square foot is $P=0.134K$.

Transmissivity (T) is an expression of the water transmitting capability of the entire thickness of an aquifer. It is equal to the average hydraulic conductivity times the aquifer thickness. Transmissivity of an aquifer can be expressed in units of square feet per day (ft^2 per day) or in units of volume such as gallons per day per foot (gpd per ft). Transmissivity values in square feet per day are converted to values in gallons per day per foot by multiplying by 7.48.

Well yield is a function of transmissivity; other factors being equal, the larger the transmissivity the larger the yield. If an aquifer has uniform permeability, a well constructed in the portion of the aquifer that has the largest saturated thickness will produce the most water.

To describe an aquifer in any detail it is necessary to determine its size, thickness, amount of water in storage, and hydraulic conductivity. A water-level map or map of the potentiometric surface is important because it describes the altitude of the water surface at a particular time and place. The water-level or potentiometric map, together with hydrographs of the water level in particular wells, are very useful in defining areas and types of recharge and discharge for the aquifer.

Alluvial Aquifers

Stream-deposited sediment (alluvium) is found along stream channels in the county. Most alluvium consists of silty clay, clayey silt, and some sand. Figure 2 shows the location and extent of alluvial deposits in Bon Homme County. Alluvial deposits have low permeabilities and do not yield water rapidly. Thus, small yields of 3 to 10 gpm (gallons per minute) are normally obtained from wells finished in the alluvium. One gpm approximately equals 1/449 cfs.

Recharge to the alluvial aquifers is by infiltration of precipitation, seepage from streams, and subsurface inflow; discharge is by evapotranspiration, seepage to streams, and subsurface outflow. The aquifers are of minor importance to the county as only 5 to 10 stock wells are finished in them.

Till Aquifer

Till is an unstratified heterogeneous deposit of glacial debris consisting of clay and silt with some sand, gravel, and cobbles. It is the predominant surficial deposit in the county (fig. 2) and underlies most of the surficial alluvial and glacial outwash deposits. In Bon Homme County, till has a low permeability and is a poor aquifer because it yields water slowly. Recharge to the till is from precipitation, and discharge is by evapotranspiration, subsurface outflow into more permeable aquifers, and pumping.

Figure 9 shows that water levels in the till have not changed appreciably since 1936. In constructing this graph, water levels measured during the 4th quarter of the calendar year were plotted. Water levels at this time of year are more stable and are the best indication of long-term water-level changes. Most of the long-term changes in water level are the result of long-term weather variations; that is, a greater depth to water is the result of drought conditions; a lesser depth is the result of "wet" conditions.

Figure 10 shows the seasonal water-level fluctuation. The rise of the water level in March 1967 occurred when the ground frost melted and allowed snowmelt and rain to recharge the aquifer. The rise of the water level in July 1967 was the result of infiltration of rainwater to the saturated zone. Declining water levels resulted from the loss of water by evapotranspiration, by drainage to other deposits, and by pumping.

The till aquifer is used extensively as a stock-water source because wells drilled at almost any location will yield from 1 to 5 gpm. In 1968, the 150 wells producing from the till furnished an estimated 180 acre-ft of water.

Shallow Outwash Aquifers

Sand and gravel deposited by glacial melt water is called outwash. Most outwash deposits are porous and permeable and, therefore, are good aquifers if they have sufficient saturated thickness. Shallow outwash deposits are present below the thin alluvial cover along Dawson, Prairie, Snatch, Emanuel, and Dry Choteau Creeks (fig. 2). These aquifers do not have adequate saturated thickness to yield large volumes of water. Even though yields are low, more than 50 shallow wells, which produce 1 to 10 gpm, have been constructed. These wells in 1968 withdrew an estimated 65 acre-ft of water, most of which was used by livestock.

Choteau Aquifer

Those glacial outwash sand and gravel deposits (fig. 11), which underlie the surficial alluvium along Choteau Creek and extend eastward beneath the surficial till layer, are collectively termed the Choteau aquifer. The aquifer has a 32-sq mi area within the county, and a much larger areal extent in adjacent counties. Maximum known thickness is 170 feet at 94-61-19adcc. About 10 sq mi of the aquifer, as shown in figure 11, has a saturated thickness of 50 feet or more.

A 12-hour aquifer test at the site of well 94-16-19cccc indicated a transmissivity of 200,000 gpd per ft and an estimated storage coefficient of 0.2.

Recharge to the aquifer is by subsurface inflow, direct precipitation, seepage from Choteau Creek and Dry Choteau Creek, and percolation through the till cover. Limited water-level observations indicate water movement is from Choteau Creek toward Emanuel Creek. Water-level maps of the Niobrara and Codell aquifers, which are contiguous with the Choteau aquifer, indicate that there is little or no water movement between these aquifers within Bon Homme County.

Figure 12 shows the rise of water level in well 94-61-19cccc due to seepage from Dry Choteau Creek. The abrupt rise of the water table in June and July 1967 is largely the result of water seepage from Dry Choteau Creek. Lowering of the water table during the first half of August mostly results from spreading of the ground-water mound that was built up during the time when the aquifer was being recharged.

Natural discharge from the aquifer is by subsurface outflow, evapotranspiration, and loss to Choteau and Dry Choteau Creek. In 1968 the water stored in the Bon Homme County part of the aquifer was estimated to be 120,000 acre-ft. Only 20 to 30 wells, which in 1968 withdrew an estimated 28 acre-ft of water, are finished in the aquifer. Properly constructed wells in the area with the greatest saturated thickness as shown in figure 11 should produce water at rates exceeding 450 gpm.

Hubonmix Aquifer

The Hubonmix aquifer of silty sand and gravel is located in the northwest corner of the

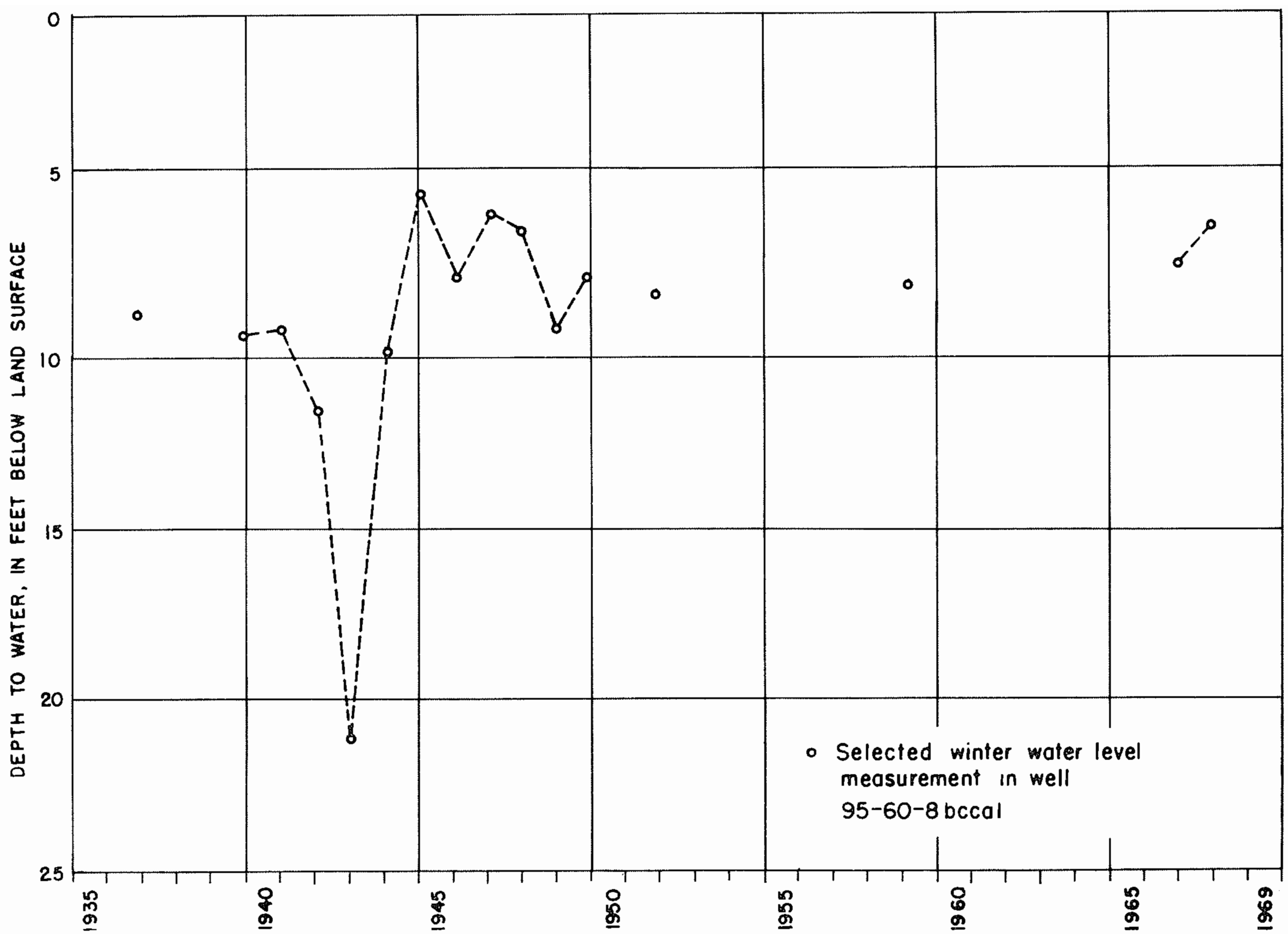


Figure 9.-- Hydrograph showing annual changes of water level in a well tapping the till aquifer.

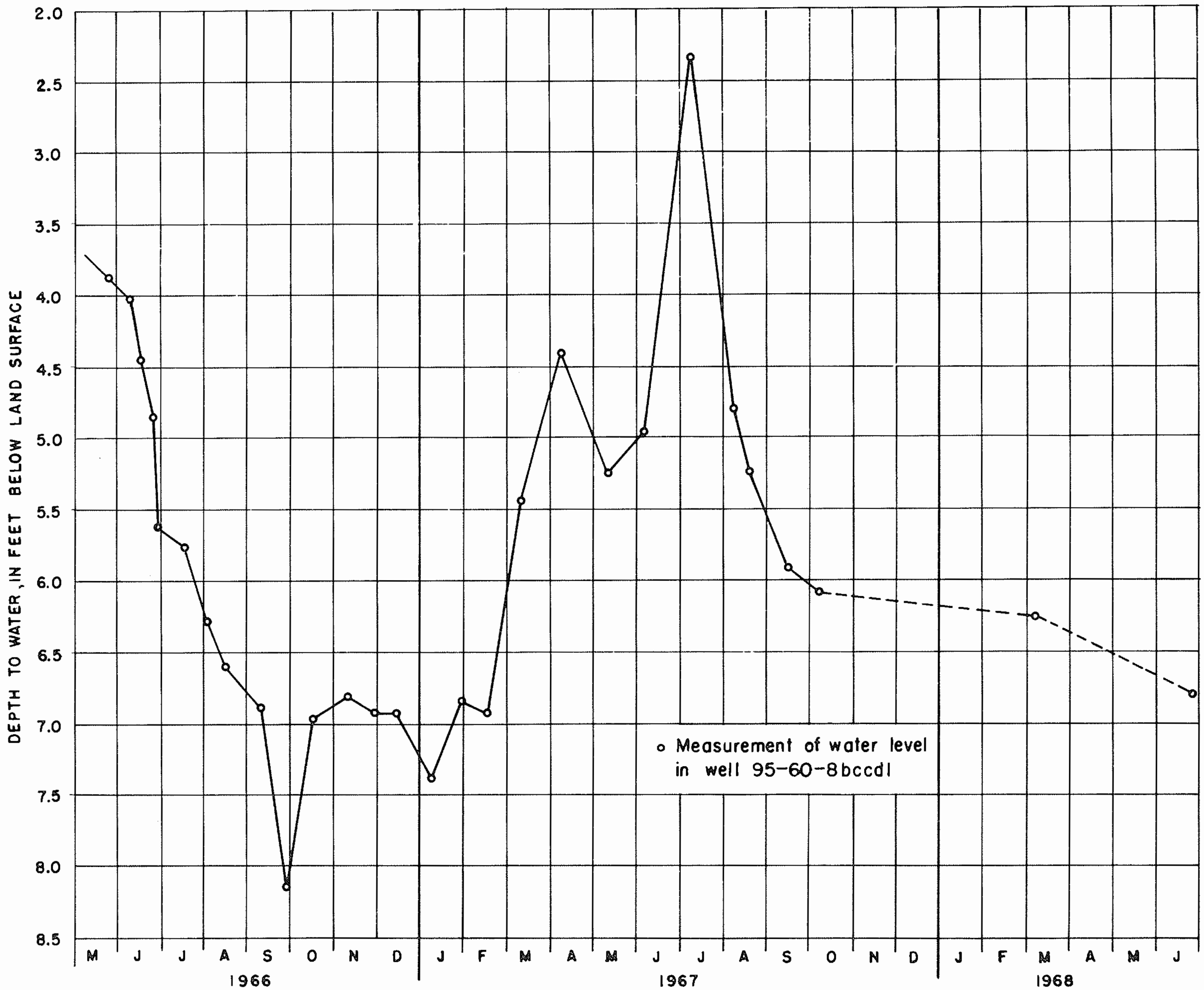
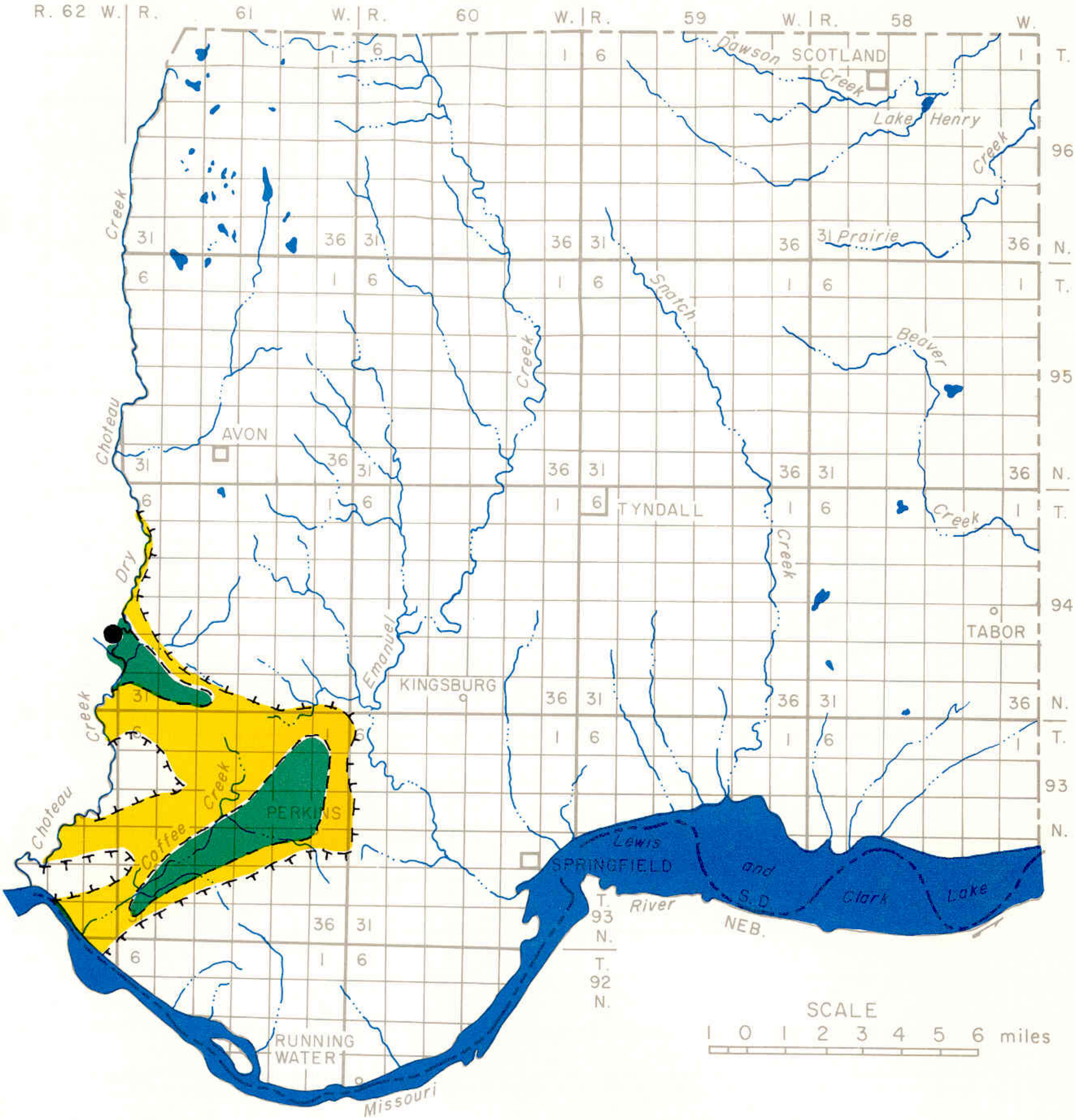


Figure 10. -- Hydrograph showing monthly changes of water level in a well tapping the till aquifer.



EXPLANATION

Approximate aquifer boundary.

Aquifer thickness greater than 50 feet.

Aquifer thickness less than 50 feet.

Location of observation well.

Figure 11. Map showing areal extent and thickness of the Choteau aquifer.

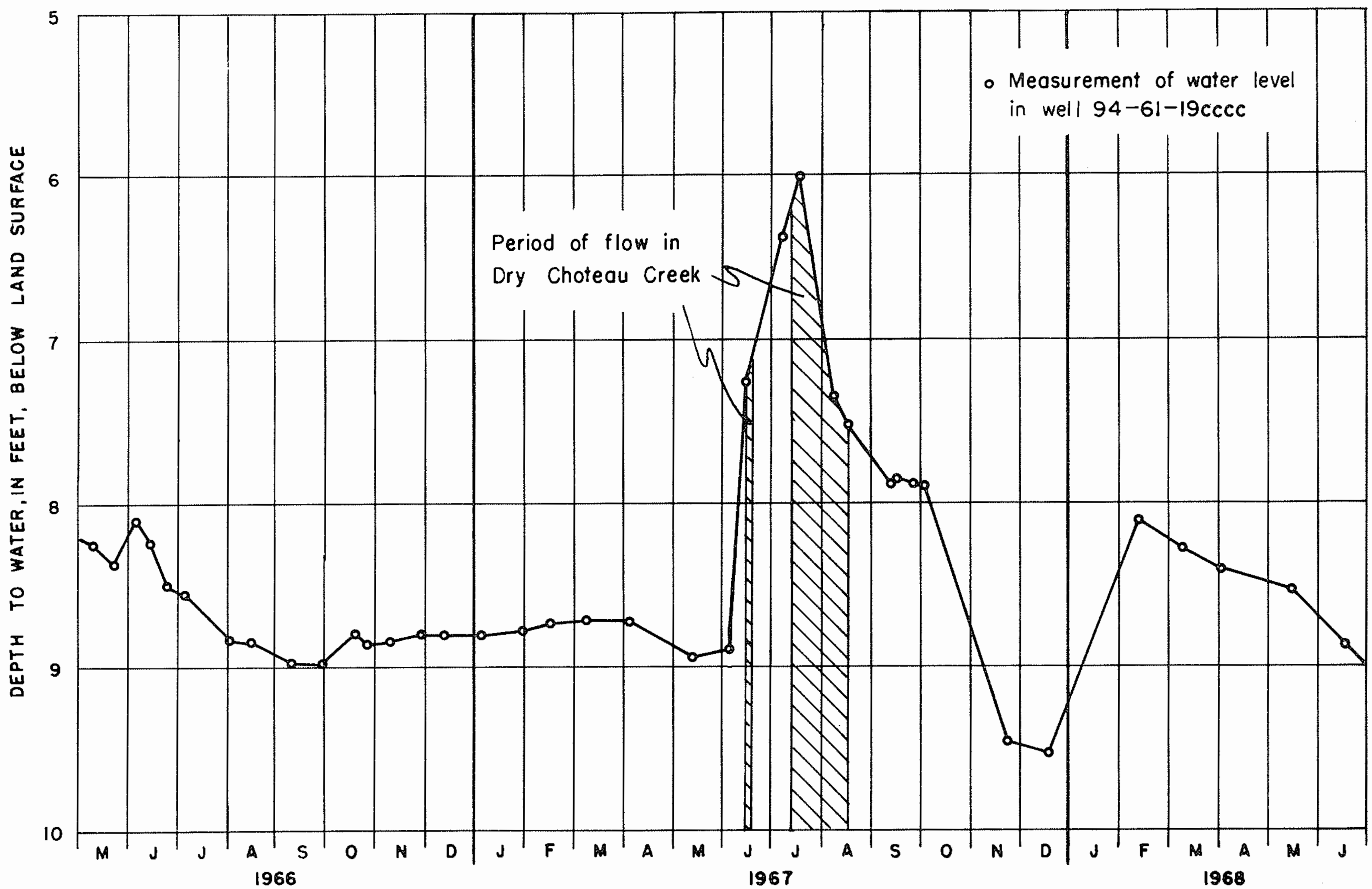


Figure 12.-- Hydrograph of water level in a well tapping the Choteau aquifer.

county. This aquifer has an area of about 36 sq mi; however, its exact extent is poorly defined. The outwash deposit is normally 10 to 30 feet thick and is overlain by as much as 200 feet of till. Maximum known thickness is 53 feet at well 96-60-5bbbc.

Only a few domestic and stock wells are finished in the aquifer; many wells extend through the outwash to the deeper Codell aquifer. Properly constructed wells at locations with more than 50 feet of saturated sand and gravel should produce water at rates in excess of 100 gpm. At certain locations, wells that tap the aquifer flow. Figure 13 shows the known area and the potentiometric surface of the aquifer.

Tyndall-Scotland Aquifer

The Tyndall-Scotland aquifer is an outwash deposit of sand and sands and gravels that partly fills a preglacial valley extending generally northward from about 3 miles northwest of Springfield to west of Tyndall, then eastward and northeastward out of the county east of Scotland (fig. 14). This outwash is the most extensive in the county. The aquifer underlies an area of 90 sq mi within the county and includes an area of 25 sq mi with a saturated thickness greater than 50 feet. (See fig. 14.) The outwash is buried beneath the till, except for a small area where it is overlain by surficial alluvium along Emanuel Creek (fig. 2) where it crops out.

Water in the aquifer is under artesian conditions at most places; however, water-table conditions exist locally. Rise of the water level in well 94-60-21bccc, which is located about 300 feet from Emanuel Creek, indicates that recharge takes place when there is flow in Emanuel Creek. (See fig. 15.) The effect of recharge is so pronounced at this location that it suggests the possibility of artificially recharging the aquifer by water-spreading methods. Most recharge is by percolation of water through the overlying till or alluvium. Possibly some recharge is by underflow from bedrock aquifers at some of the locations where they are in contact with the Tyndall-Scotland aquifer.

The Tyndall municipal well (94-60-21accc) can produce more than 700 gpm and has a specific capacity of 22 gpm per ft of drawdown after 72 hours of continuous pumping. An aquifer test made by pumping this well indicates a transmissivity of 210,000 gpd per ft and a storage coefficient of 0.2. A test hole at the site penetrated 130 feet of saturated material; thus, the average hydraulic conductivity is 216 ft per day (1,600 gpm per ft^2).

A 12-hour aquifer test at well 94-60-20dcbd indicated a transmissivity of 20,500 gpd per ft. Relatively low transmissivity at this site as compared to the transmissivity at well 94-60-21accc is due to a decrease in saturated thickness.

Areas underlain by more than 50 feet of saturated aquifer material are shown in figure 14. These areas offer the most promising sites for properly constructed wells that might produce from 100 to 900 gpm.

Discharge from the aquifer is largely from springs in the outcrop area along the lower reaches of Emanuel Creek as shown in figure 16. This discharge constitutes most of the base flow at the Emanuel Creek gaging station at 93-60-27d. Study of daily discharge records at this site indicates that the ground-water discharge from the outwash was approximately 3 cfs (1,000 gpm). Discharge is also by evapotranspiration, by pumping, and at certain locations by seepage into the contiguous bedrock aquifers. Discharge is also by subsurface flow out of the county near Scotland to the James River trench; such discharge occurs east of a ground-water divide 6 to 10 miles east of Tyndall. Some discharge is to the Niobrara and Codell aquifers; specifically this occurs 2 to 3 miles northeast of Tyndall and probably along a line between 94-60-4 to 95-59-28.

Pumpage in 1968 from the one municipal well and the 80 or more domestic wells in the aquifer was about 244 acre-feet, or only about 0.06 percent of the estimated 440,000 acre-feet of water stored in the aquifer within the county.

Niobrara Aquifer

The Niobrara Marl, locally called the "chalk rock," consists of nearly horizontal layers of calcareous shale, chalk, and chalky limestone. Thickness of the formation ranges from 0, where it has been completely removed by erosion, to about 205 feet in the northwest corner of the county.

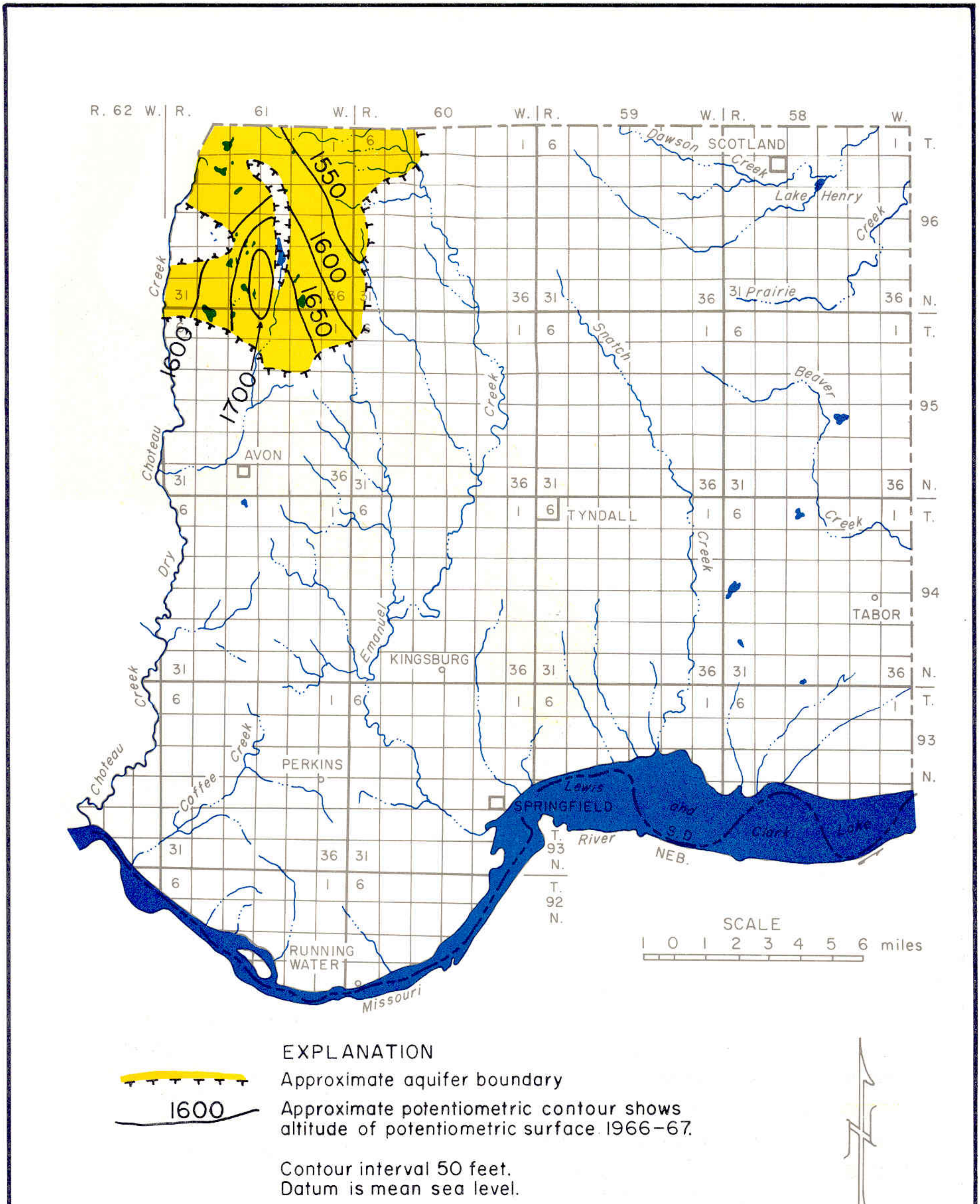
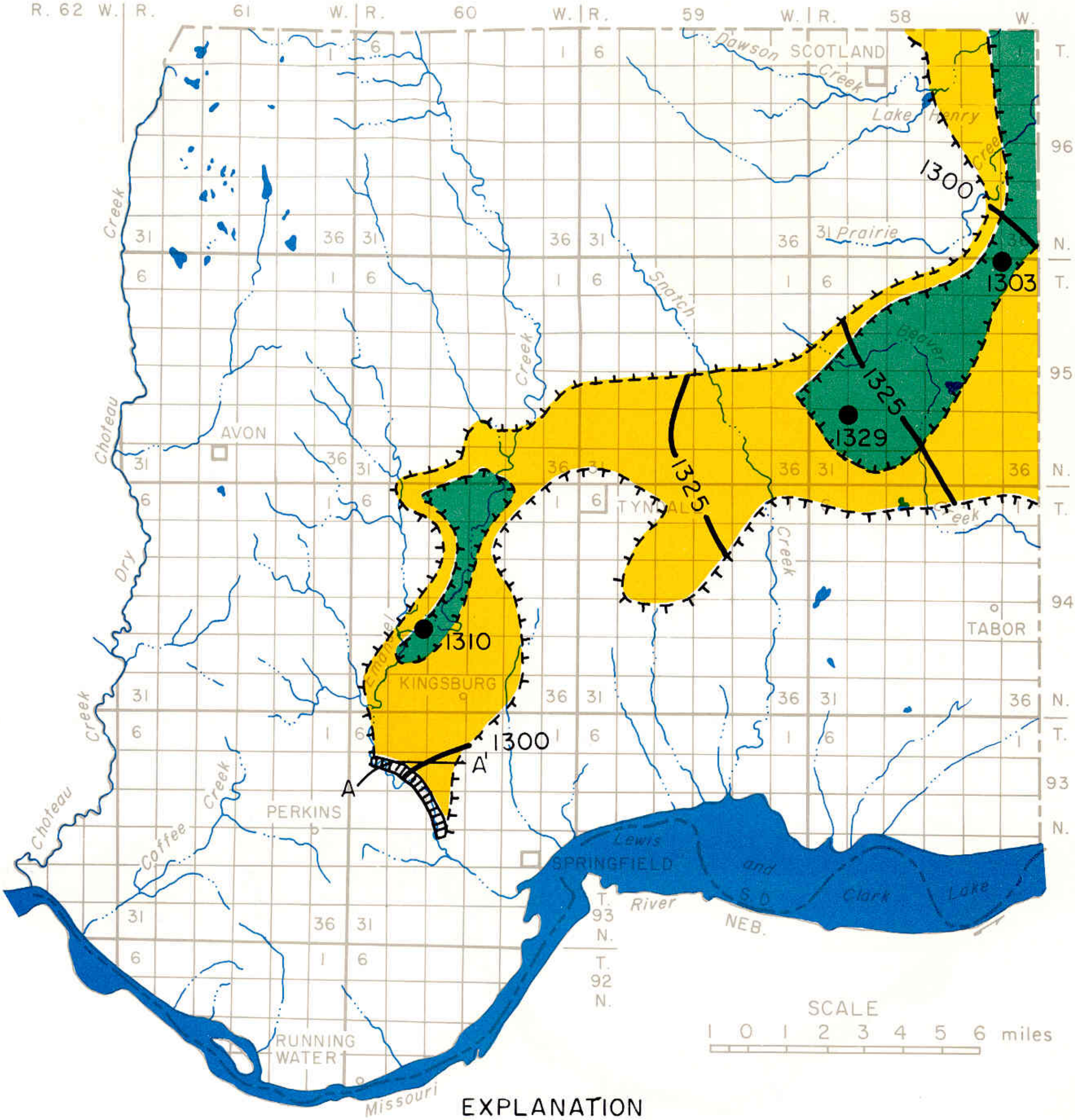


Figure 13. Map showing areal extent and potentiometric contours of the Hubonmix aquifer.



EXPLANATION

Approximate aquifer boundary

Aquifer outcrop

Aquifer thickness less than 50 feet.

Aquifer thickness more than 50 feet.

1310 ● Observation well. Number is altitude of potentiometric surface, 1970.

A—A' Trace of geohydrologic section (fig.16).

—1325— Approximate potentiometric contour, shows altitude of potentiometric surface. Contour interval 25 feet. Datum mean sea level.

Figure 14. Map showing areal extent, thickness, and potentiometric contours of the Tyndall-Scotland aquifer.

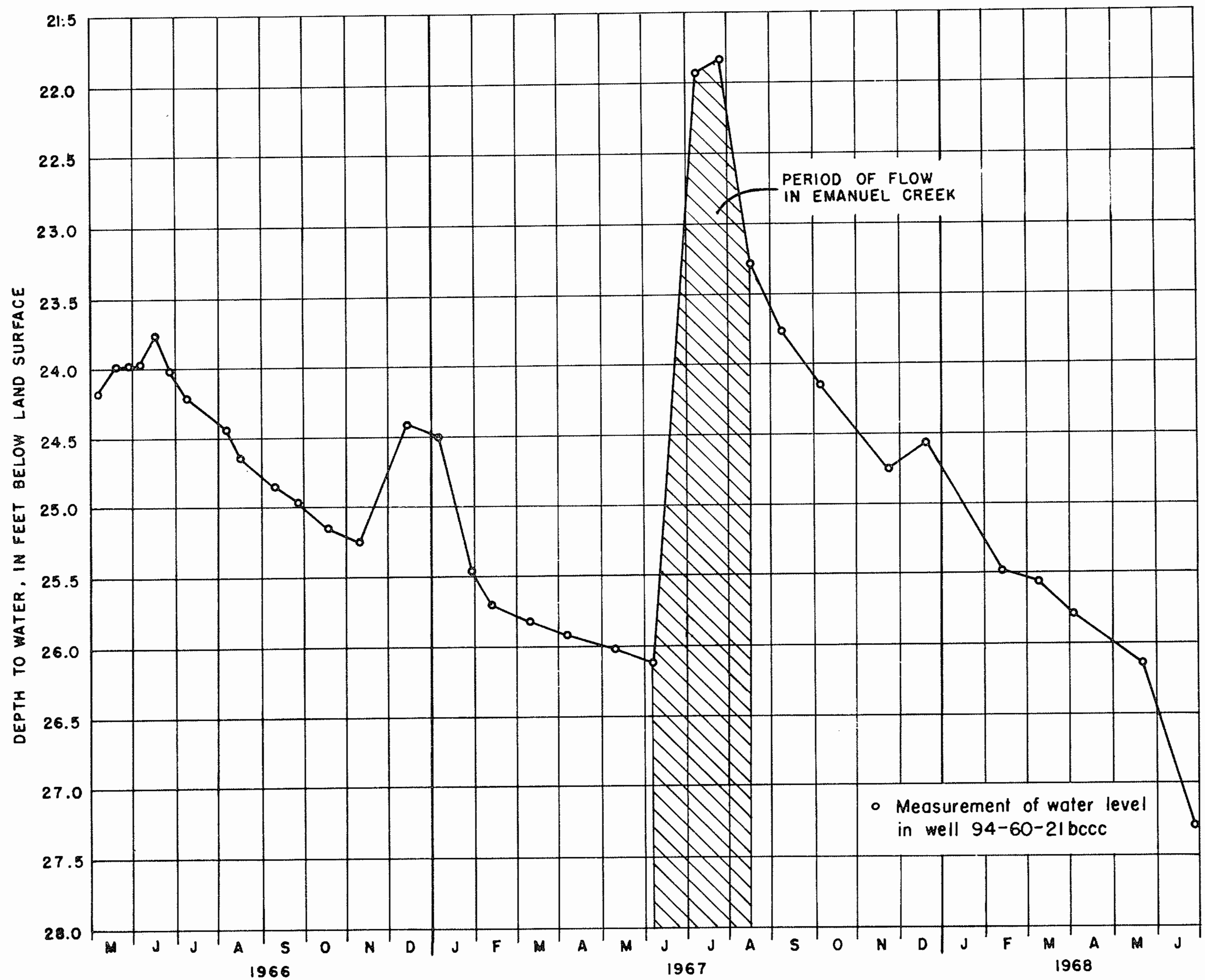


Figure 15. -- Hydrograph of water level in a well tapping the Tyndall-Scotland aquifer

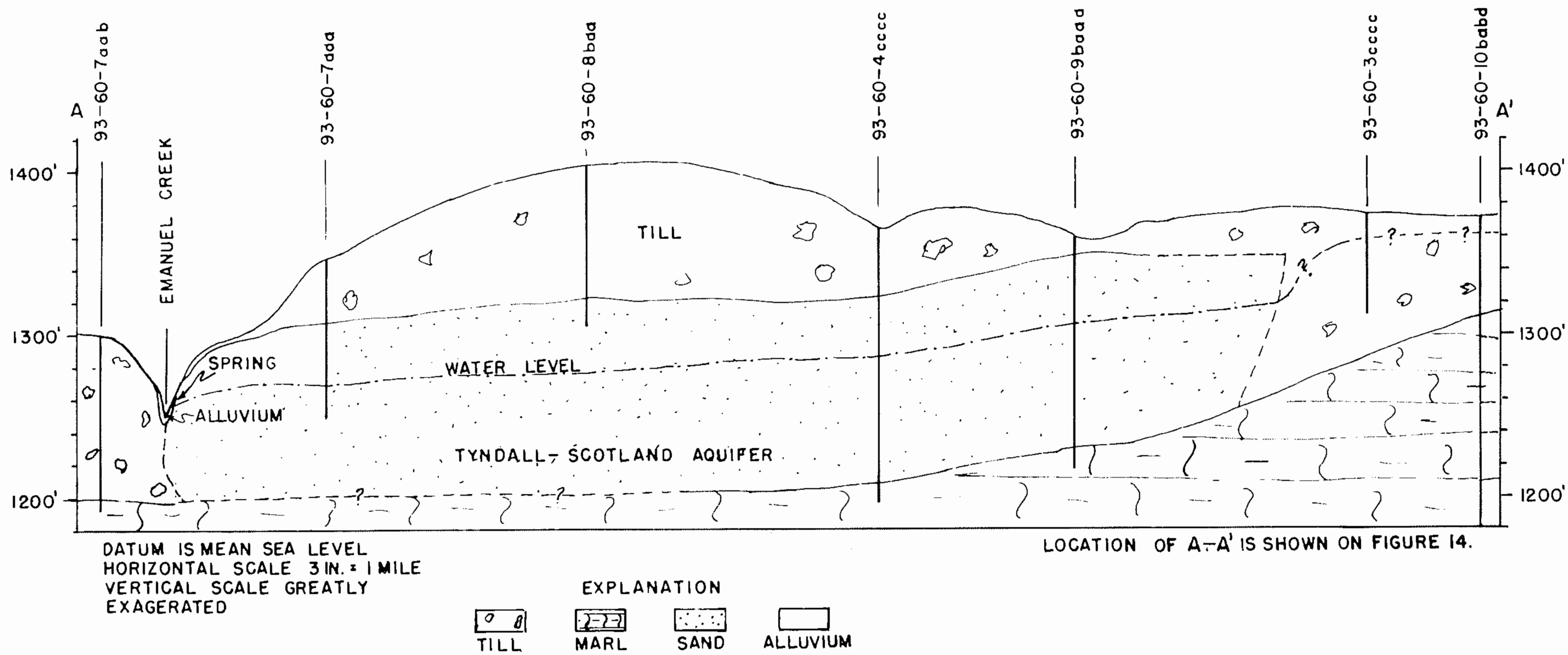


Figure 16.-- Geohydrologic section of the Tyndall-Scotland aquifer.

Figure 17 shows the altitude of the upper surface (top) of the Niobrara Marl. Depth to the top of the formation can be calculated by subtracting the altitude of the top of the formation from the altitude of the ground surface. For example, to determine the depth to the top of the Niobrara Marl at Perkins, subtract 1,200 feet from 1,451 feet (land-surface altitude). Thus at Perkins the top of the "chalk rock" is 251 feet below land surface.

In figure 18 the contours show the depth below ground level to the top of the formation. For example, the depth to the marl at Perkins is more than 200 feet but less than 300 feet. Either figure 17 or figure 18 can be used to estimate the depth to the top of the formation; however, if the altitude of the land surface is known, the calculated depth to the formation using data from figure 17 will probably be more accurate than the depth as shown in figure 18.

Water at some locations in the Niobrara aquifer is under artesian conditions; however, at most locations it is under water-table conditions.

Water levels measured in well 93-61-28cdac, as shown in figure 19, had only minor fluctuations during the period of measurement indicating nearly equal amounts of recharge and discharge.

Shape and altitude of the potentiometric surface and the direction of water flow are shown in figure 20. The figure also shows that the subsurface flow probably discharges from the aquifer near Scotland and that subsurface flow from the Tyndall-Scotland aquifer probably occurs in the area about 2 miles northeast of Tyndall. In addition figure 20 indicates that the Missouri River valley is the major discharge area. Many of the springs are in the bluffs of the Missouri River valley where water in the Niobrara aquifer emerges at the land surface.

Most recharge to the aquifer is by subsurface inflow and by percolation through the overlying till, outwash, or shale deposits.

Pumpage of water from municipal wells at Scotland and Tabor and an estimated 225 domestic and stock wells was about 438 acre-ft in 1968. Well yields range from 2 to 100 gpm. Maximum yield that can be obtained from this aquifer is unknown; however, it probably is in excess of 200 gpm and less than 700 gpm. In other counties, yields larger than 450 gpm have been obtained, but porosity, specific yield, and permeability vary so greatly that local values can be determined only by an aquifer test. However, test drilling indicates that, in general, the most favorable locations for the construction of wells that might produce more than 100 gpm are in areas where the depth from the land surface to the top of the aquifer is less than 100 feet.

Codell Aquifer

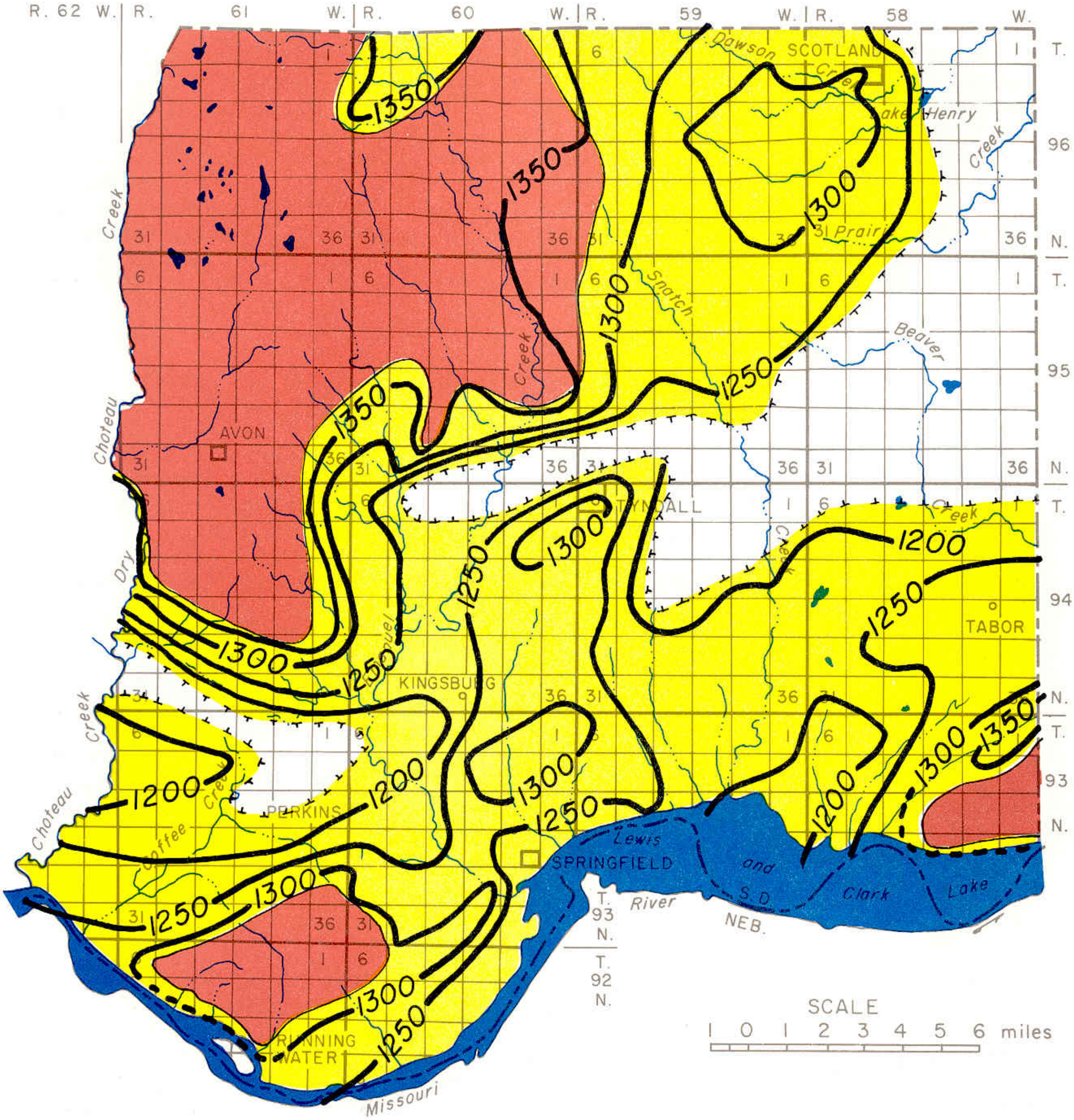
The Codell Sandstone Member of the Carlile Shale in Bon Homme County is siltstone to fine-grained sandstone. This unit is locally called the "soft-water sandstone" because it yields characteristically soft water. The aquifer is present in the subsurface of the entire county except for a part of the Tyndall-Scotland bedrock valley, where it has been removed by erosion (fig. 21). Where present, the sandstone is overlain by 5 to 30 feet of impermeable shale and underlain by 130 to 160 feet of nearly impermeable shale. The sandstone layer ranges in thickness from 0 to 100 feet and is commonly about 25 feet thick.

Depth below land surface to the top of the aquifer ranges from approximately 100 to 900 feet. Figure 22 shows the altitude of the upper surface of the sandstone. Either figure 21 or figure 22 may be used to estimate the depth to the aquifer.

The sandstone is saturated and the water is under artesian conditions. Hydrograph of the water level in well 93-61-15ddbb (fig. 23) shows neither a continuous rising nor a continuous declining trend. Fluctuations were less than 1 foot in magnitude during this period of record, indicating that the rates of recharge and discharge were uniform and nearly equal.

Discharge from the aquifer is largely by well pumpage and by subsurface outflow to the Missouri River trench. Discharge by subsurface outflow to the Tyndall-Scotland aquifer may also occur north of a possible ground-water divide in the Tyndall-Scotland aquifer east of Tyndall.

Recharge is mostly by subsurface inflow from outside the county. Some recharge is from



EXPLANATION

Approximate aquifer boundary.

Formation not eroded.

Formation partly eroded.

1300 Structure contour, shows altitude of top of Niobrara Marl. Dashed where approximately located. Contour interval 50 feet. Datum is mean sea level.

Figure 17. Map showing areal extent and altitude of the upper surface of the Niobrara Marl.

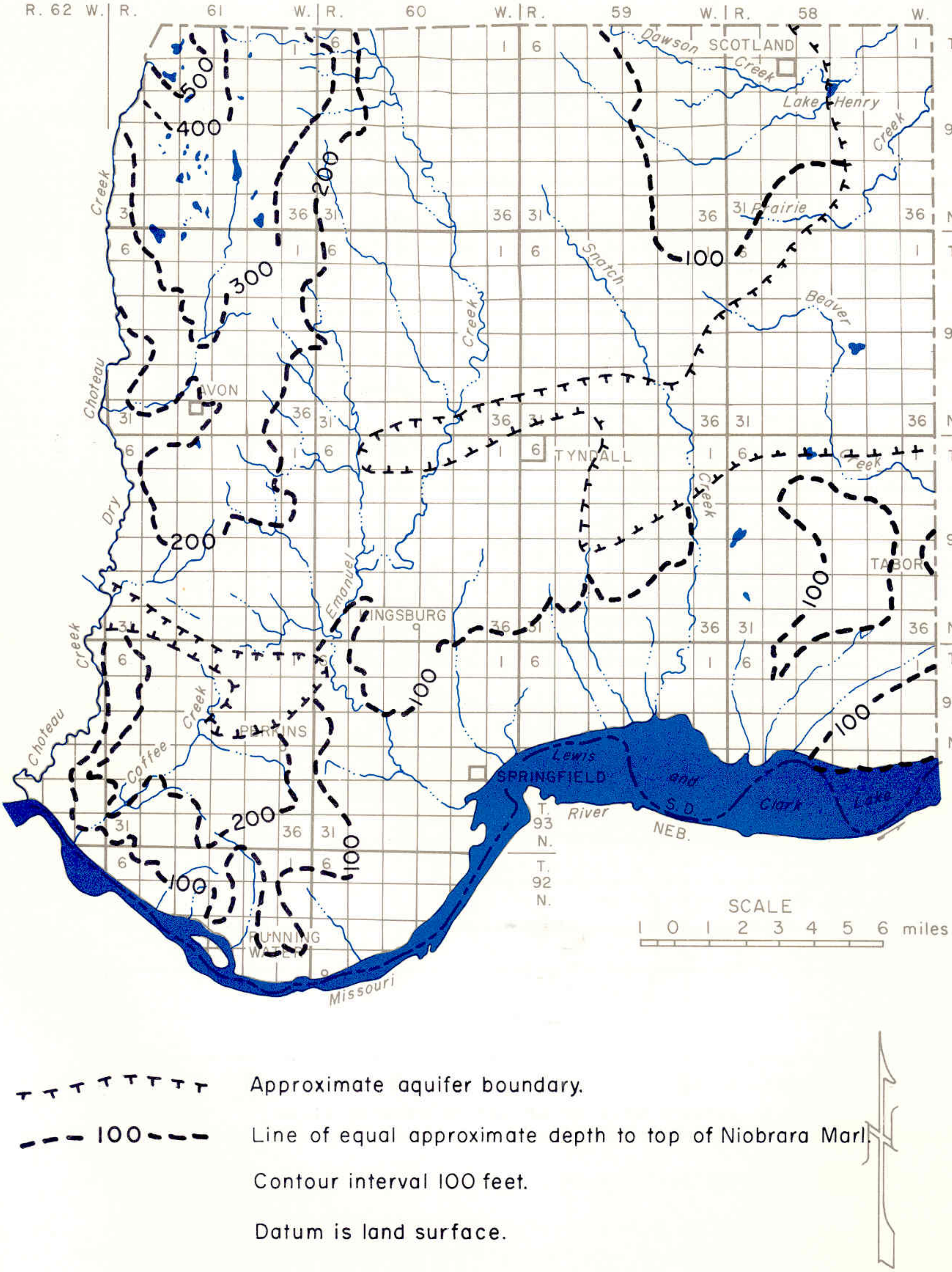


Figure 18. Map showing depth to the Niobrara Marl.

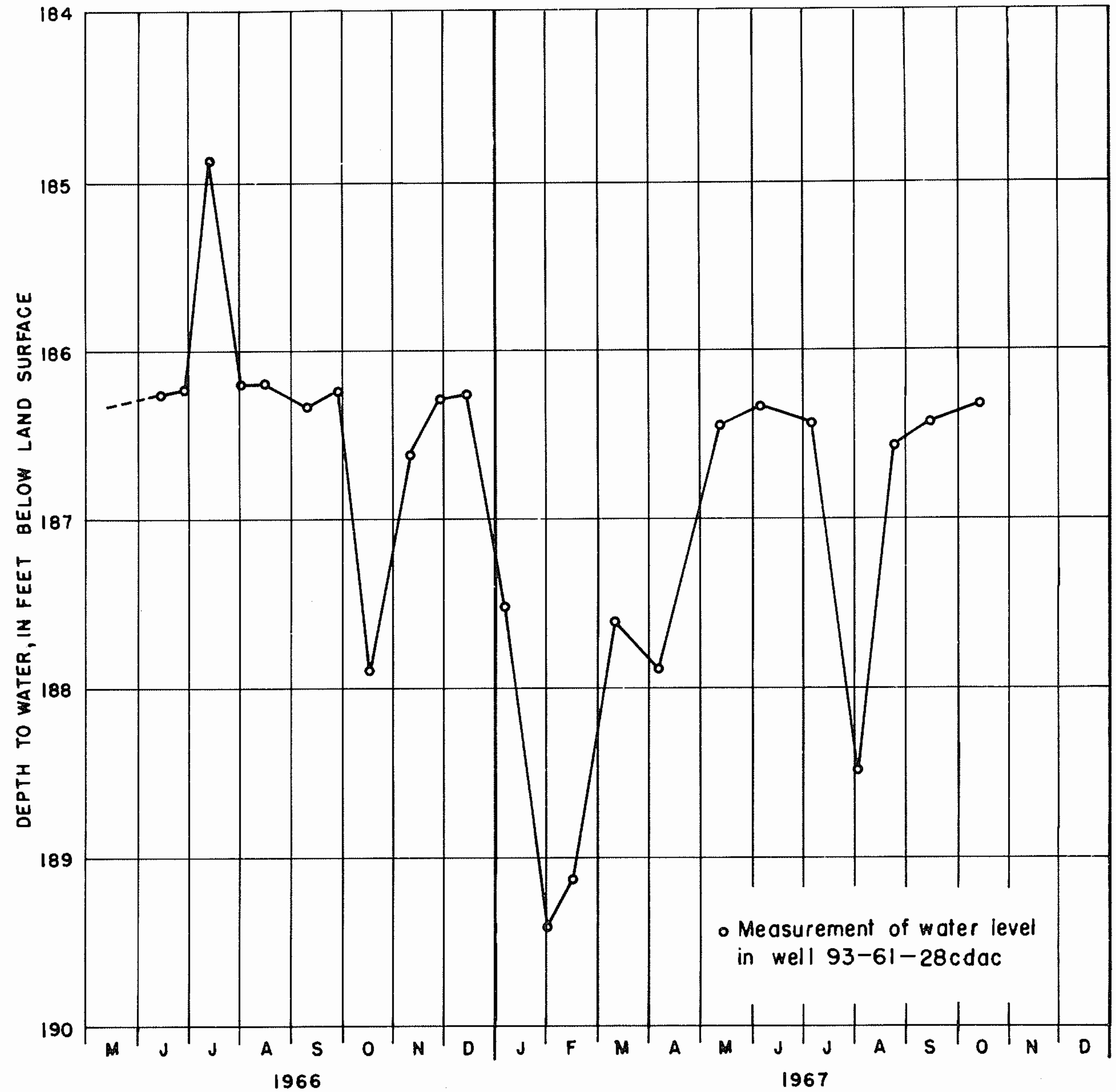
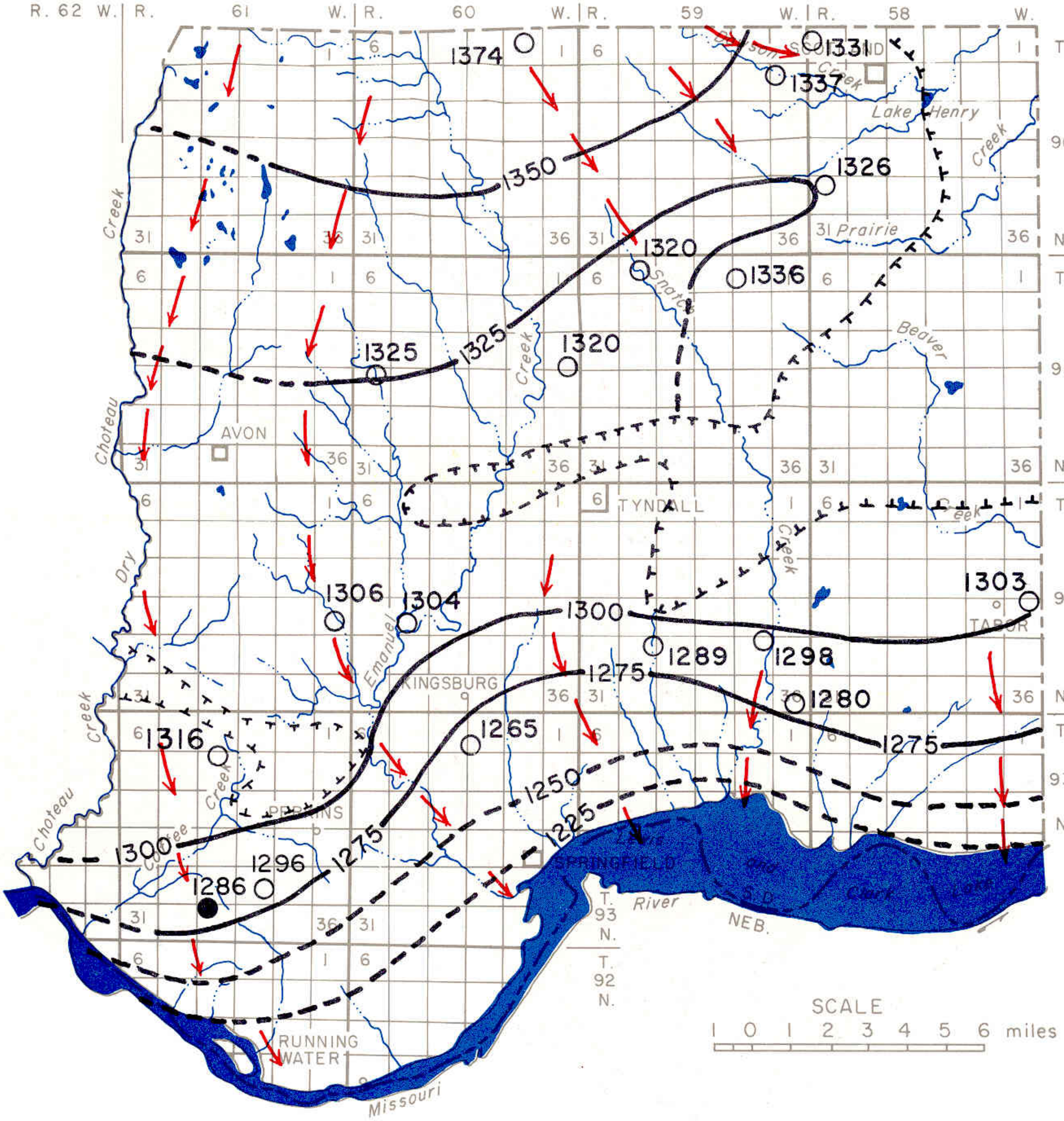


Figure 19 -- Hydrograph of the water level in a well tapping the Niobrara aquifer.



Approximate aquifer boundary

—1325— — Potentiometric contour shows altitude of potentiometric surface. Dashed where approximately located. Contour interval 25 feet. Datum mean sea level.

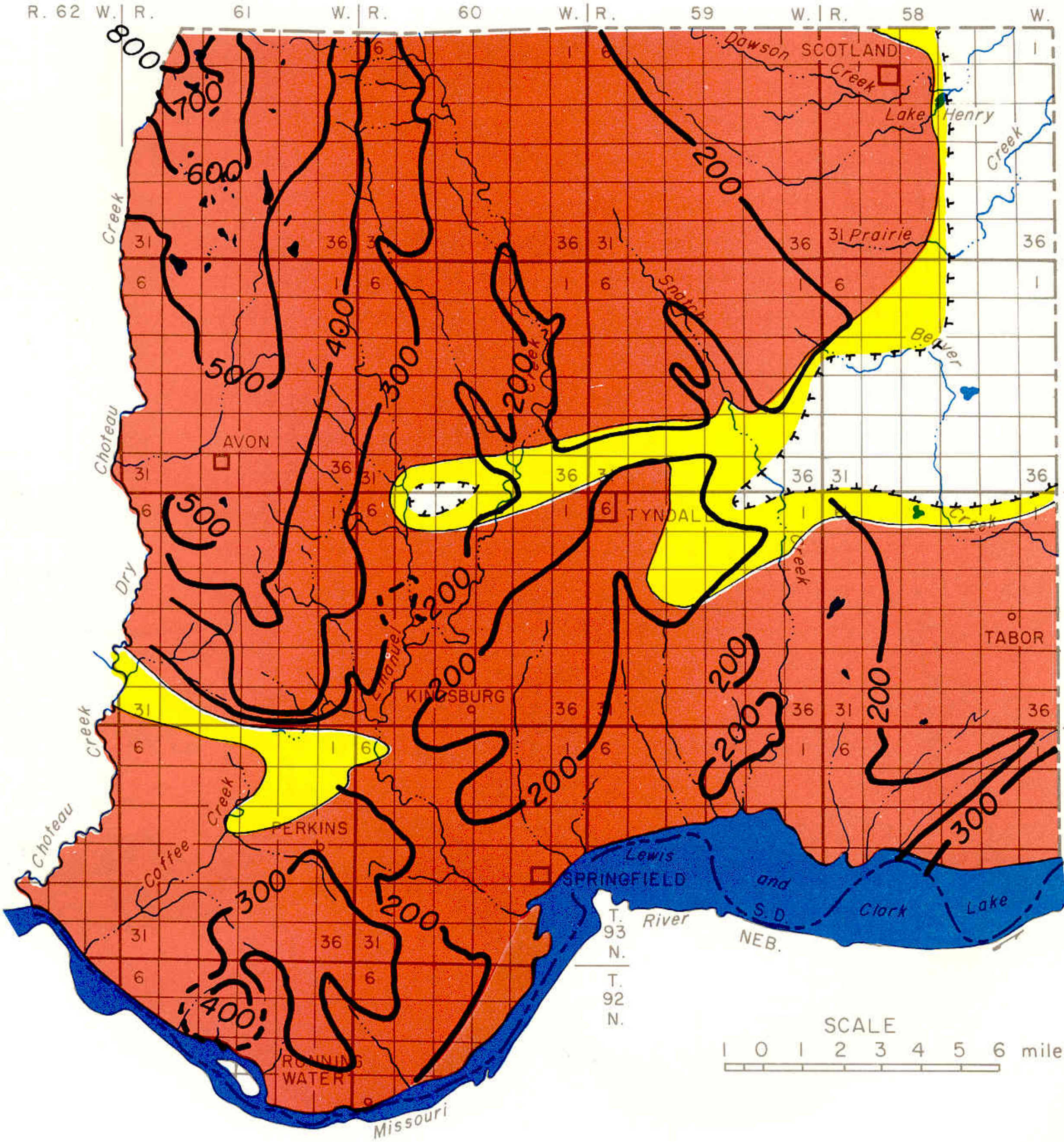
1374 ○ Well

● 1286 Observation well

Number is altitude of potentiometric surface in 1966-67.

→ → → Direction of water movement.

Figure 20. Map showing potentiometric contours of the Niobrara aquifer.



EXPLANATION

Approximate aquifer boundary.

Aquifer partly eroded.

Aquifer not eroded.

300 Line of equal depth to top of Codell aquifer. Dashed where approximately located. Contour interval 100 feet. Datum is mean sea level.

Figure 21. Map showing depth to the Codell aquifer.

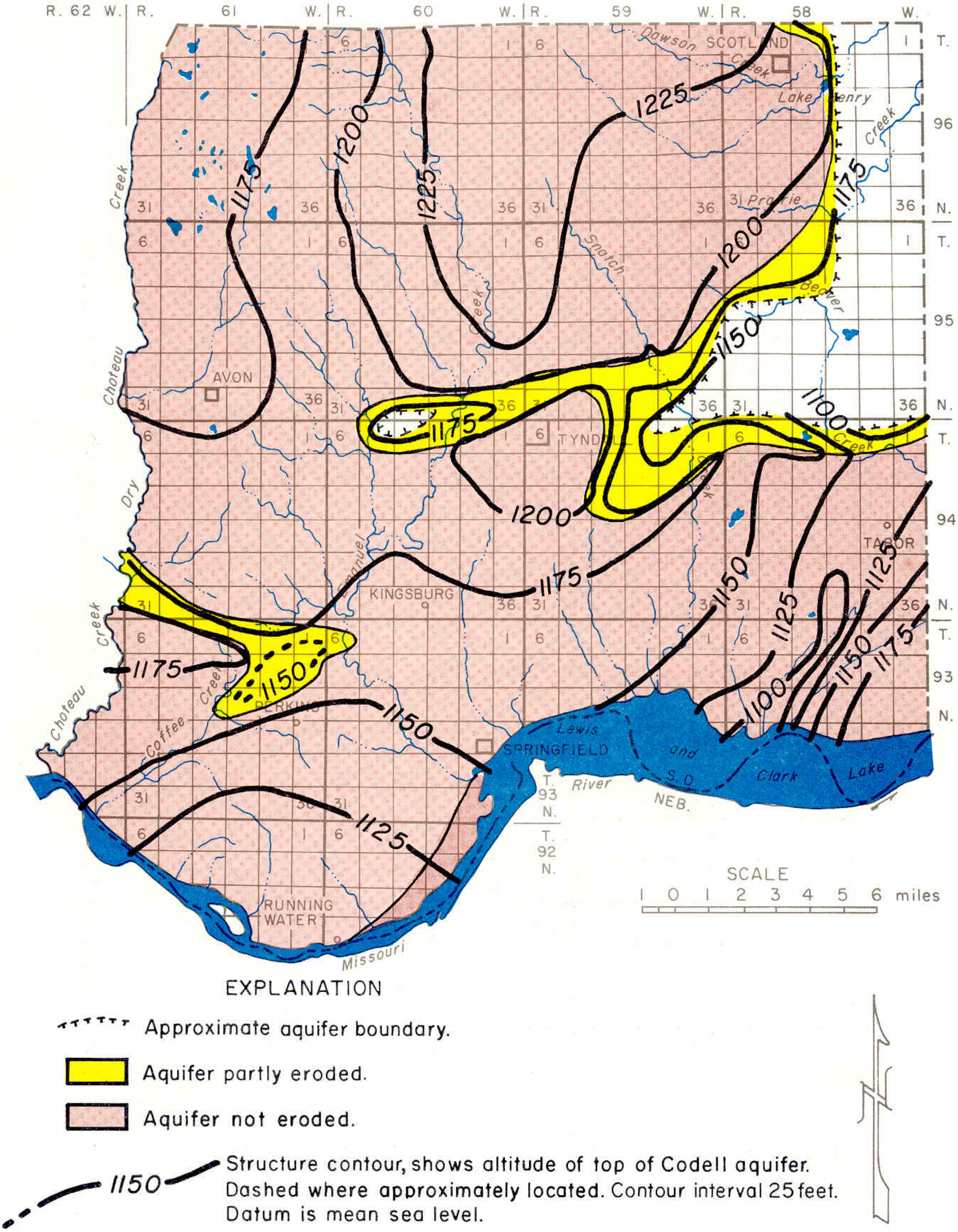


Figure 22. Map showing altitude of the upper surface of the Codell aquifer.

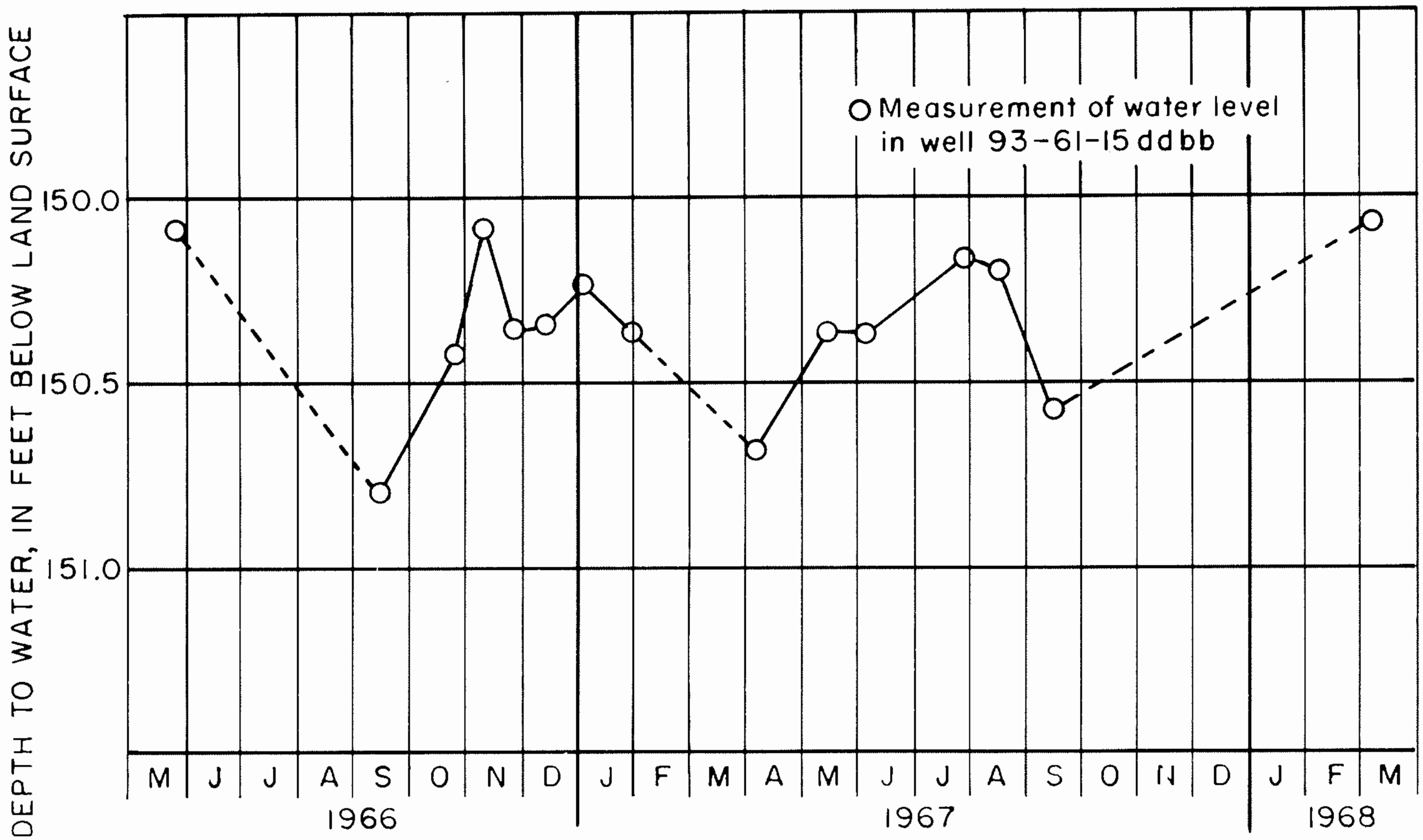


Figure 23. Hydrograph of the water level in a well tapping the Codell aquifer.

the Tyndall-Scotland aquifer and occurs at a location about 3 miles northeast of Tyndall and from a source associated with the anomalous high in the potentiometric surface at 94-61-13. (See fig. 24.) The anomaly may be the result of recharge from the Tyndall-Scotland aquifer at 95-60-32 where the glacial outwash is contiguous with the Codell Sandstone Member. (See fig. 21.) At some locations water from the artesian aquifers of the Dakota Formation leaks through broken casing into the Codell aquifer; however, the amount of water recharging the aquifer in this manner is small.

An 8-hour aquifer test in the Avon municipal well indicated a transmissivity of 400 gpd per ft and an approximate storage coefficient of 0.001.

Yields from domestic and stock wells range from 2 to 5 gpm. The public-supply well at Avon produces 90 gpm, and two public-supply wells at Tripp, 4 miles north of the county, produce 80 and 100 gpm. Total pumpage in 1968 from the estimated 465 wells tapping the aquifer was about 609 acre-ft and was used largely for domestic purposes.

Aquifers in the Dakota Formation

The sandstone layers of the Dakota Formation underlie the entire county and constitute two aquifers. These layers are composed of poorly consolidated, fine- to medium-grained sandstone.

Relation of the Dakota sandstone layers to each other and to the overlying and underlying formations is illustrated in figure 25. Figure 25 also shows a composite electric log; the formations and the sandstone layers are easily identified by their characteristic traces of spontaneous potential and resistivity on the electric log. The upper sandstone layer, which is an aquifer and locally is called the "first flow," is termed the upper Dakota aquifer in this report. The lower sandstone layers also are an aquifer, which locally is called the "second flow," and in this report is termed the lower Dakota aquifer.

The upper sandstone, which is about 20 feet thick, contains water under artesian pressure; however, the water is under less artesian pressure than the water in the lower sandstones. Wells tapping the upper Dakota aquifer yield less water than wells tapping the lower sandstones because the upper Dakota aquifer has a lower transmissivity and has less pressure. Altitude of the top of the upper Dakota aquifer is shown in figure 26 and the depth below land surface to the top of the upper Dakota aquifer is shown in figure 27. The depth to the top of the lower Dakota aquifer can be estimated by adding 90 feet to the depth to the top of the upper Dakota aquifer.

Aggregate thickness of the lower Dakota aquifer is not constant because of the uneven surface of the underlying Sioux Quartzite, and because of possible variations in deposition. At well 93-60-10ddc the total thickness of the aquifer is 217 feet.

Several studies have been made of the artesian conditions in the Dakota Formation. Studies, which include those by Darton (1896 and 1909), Barkley (1952), Davis, Dyer, and Powell (1961), and Dyer and Goehring (1965), document the declining potentiometric surfaces of the aquifers in the Dakota.

Figure 28 shows the decline of pressure (lowering of the potentiometric surface) in the lower Dakota aquifer. The water level in wells finished in the upper Dakota aquifer has decreased more rapidly than the water level in wells finished in the lower Dakota aquifer. Recently, the pressure has stabilized or increased slightly in the lower Dakota aquifer. Large pressure decrease in the past occurred during a time when many wells were allowed to flow uncontrolled. As the pressure decreased the number of flowing wells decreased, thus reducing the volume of discharge and causing a change in the rate of pressure decline.

Figure 29 shows some pressure variations which may indicate a seasonal water-level trend. An increase of pressure occurred in the spring of 1967 and possibly again in the spring of 1968. However, because the accuracy of the measurement is ±½ pound per square inch (1.15 ft) the existence of the seasonal variation cannot be positively ascertained. Abrupt rise of the potentiometric level in August 1966 occurred when the normal free flow of 250 gpm from the well was terminated. Specific capacity of the well is 14.7 gpm per foot of drawdown indicating that if the well was pumped it could produce water at a rate of approximately 900 gpm.

Discharge from the aquifer is by subsurface outflow, flow from wells, and well pumpage;

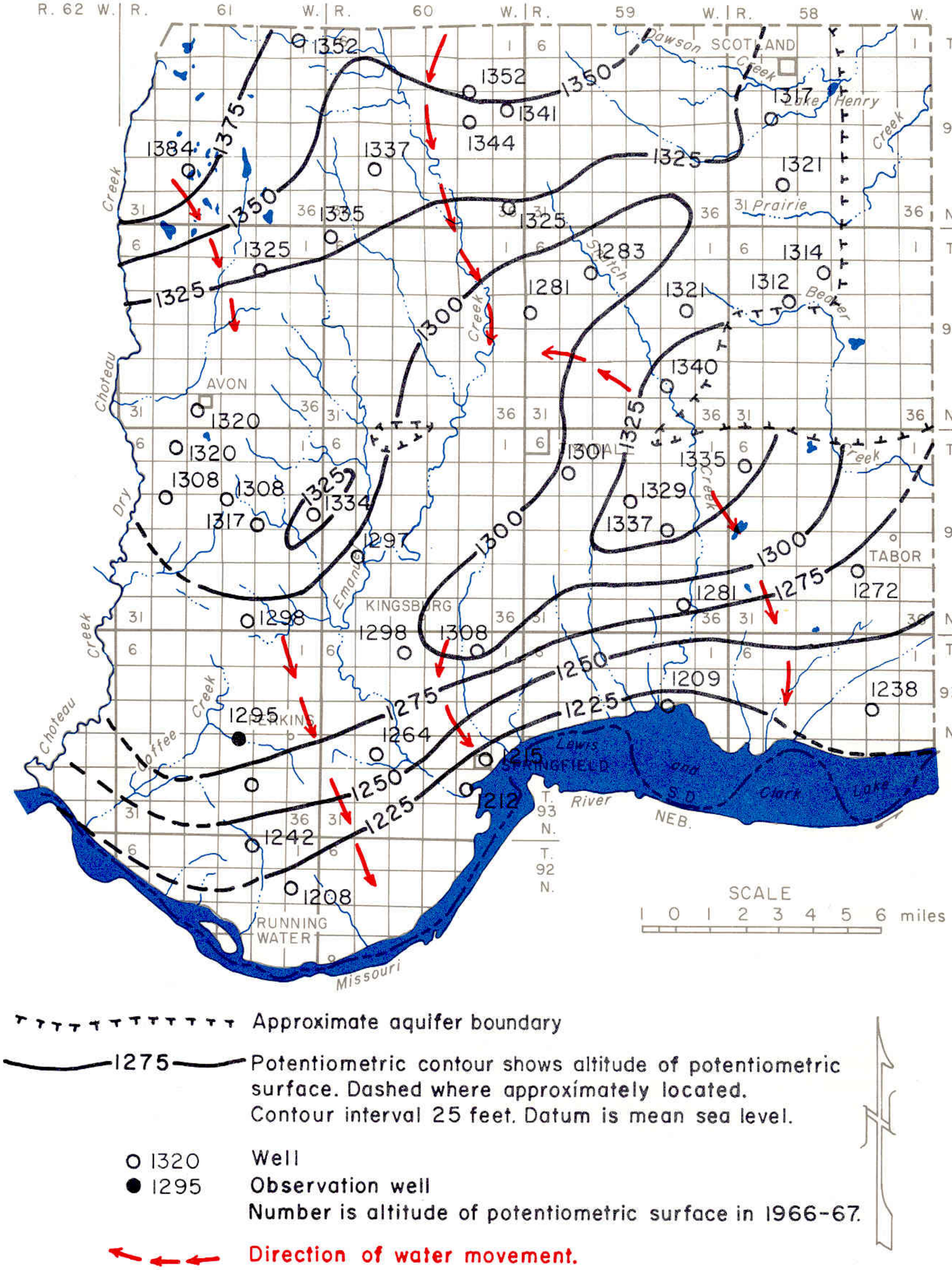


Figure 24. Map showing potentiometric contours of the Codell aquifer.

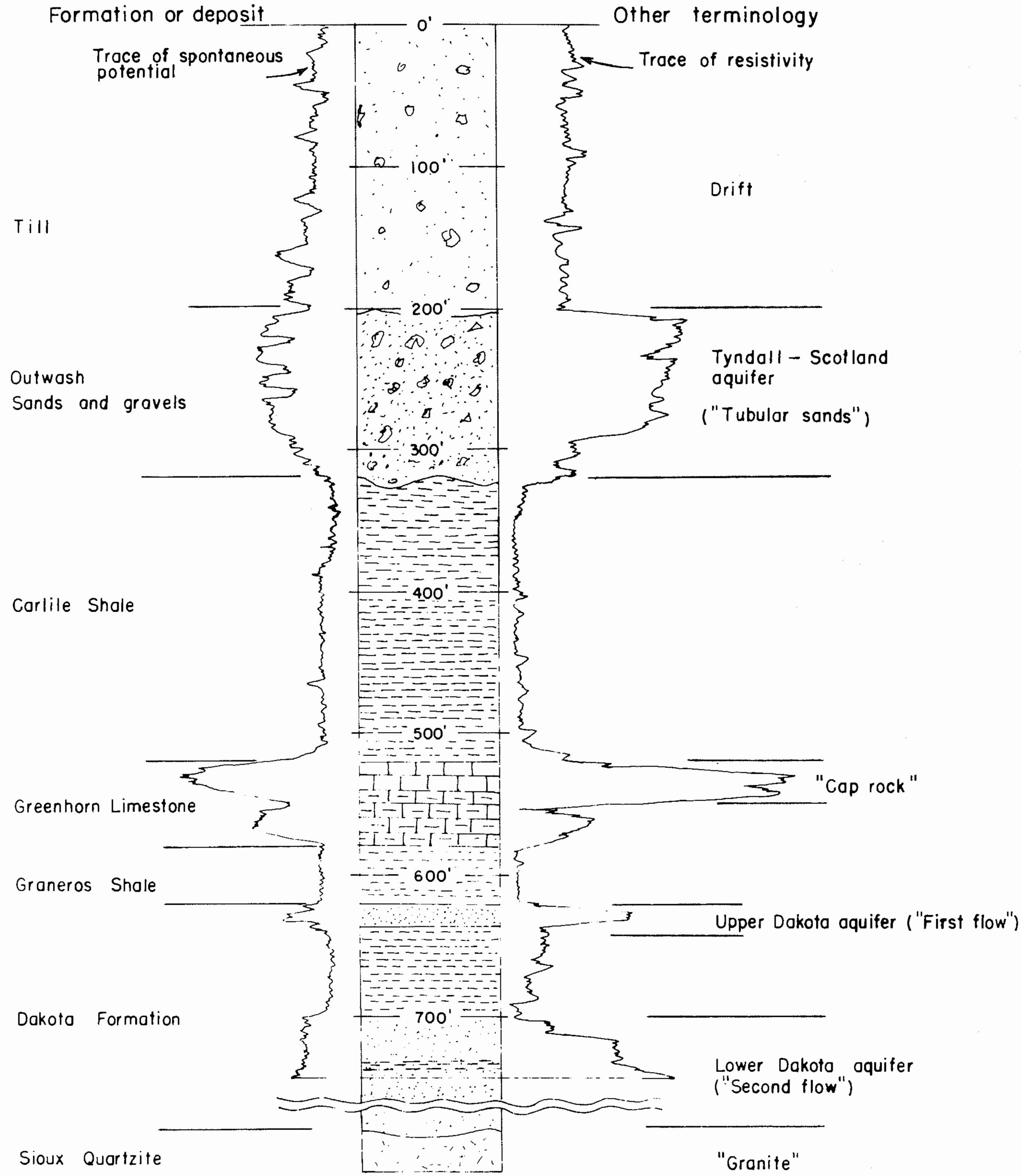
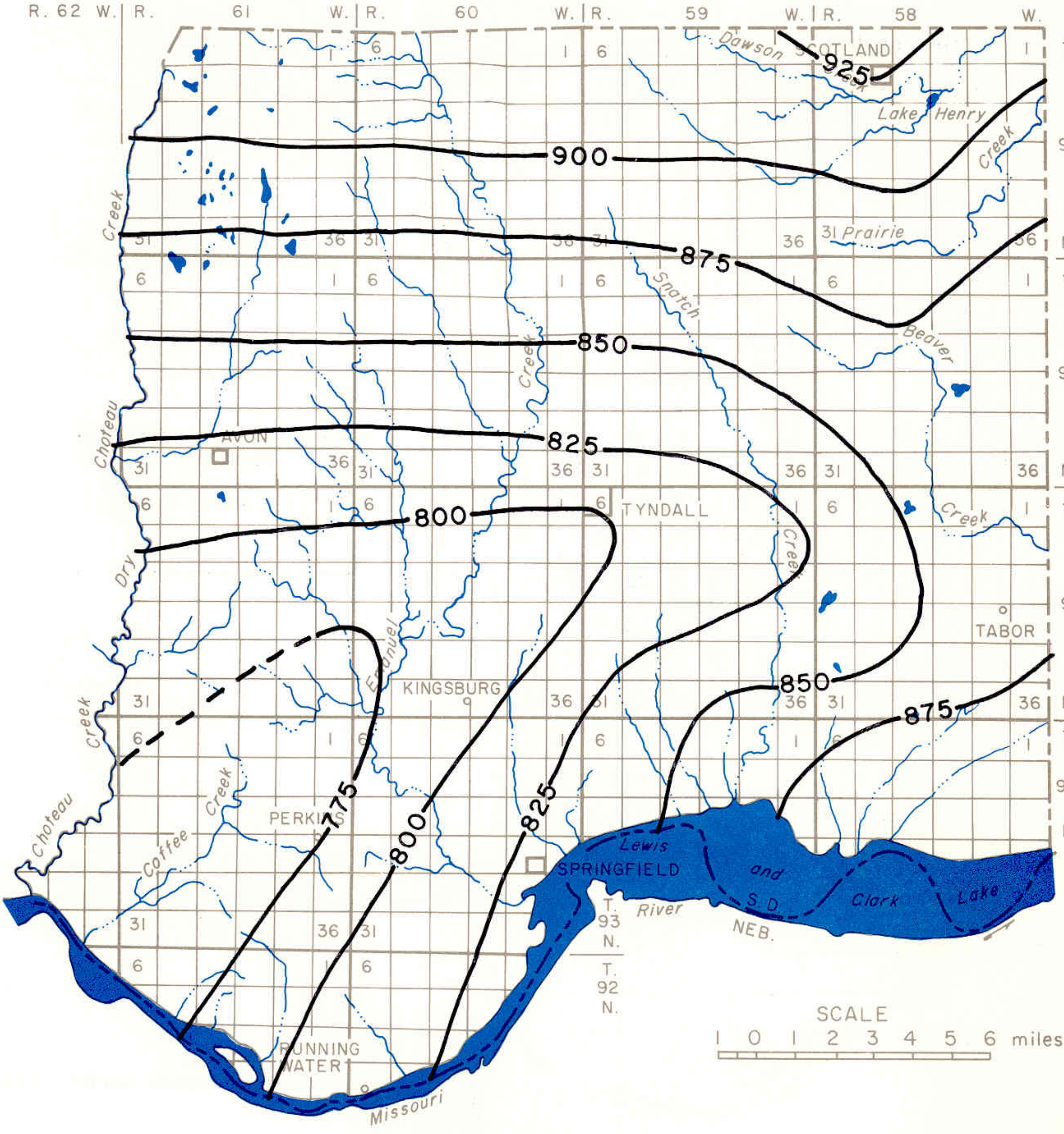


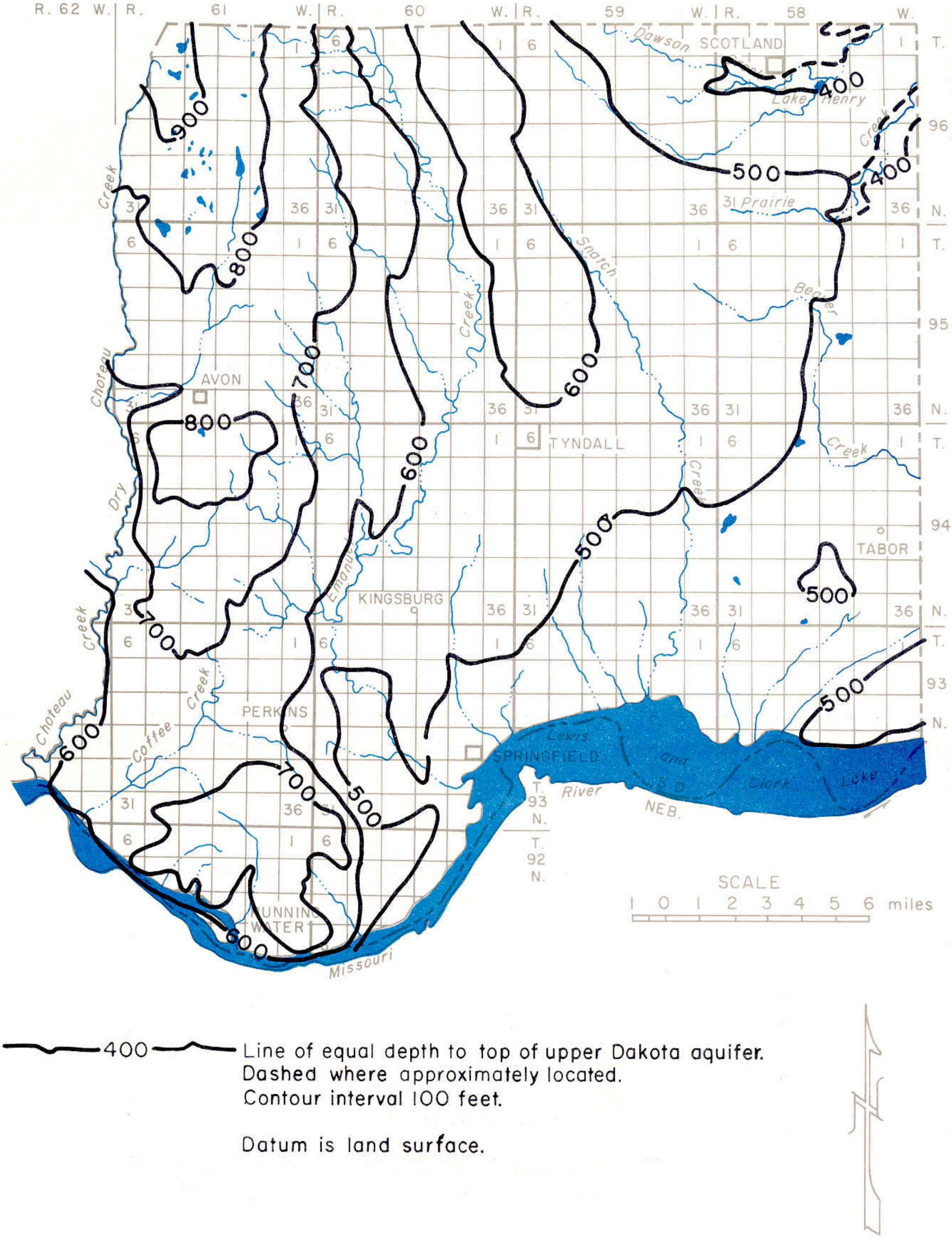
Figure 25.-- Diagram of formations and composite electric log at well 95-60-34ccac



—775— Structure contour shows altitude of top of upper Dakota aquifer. Dashed where approximately located.
Contour interval 25 feet.

Datum is mean sea level.

Figure 26. Map showing altitude of the upper surface of the upper Dakota aquifer.

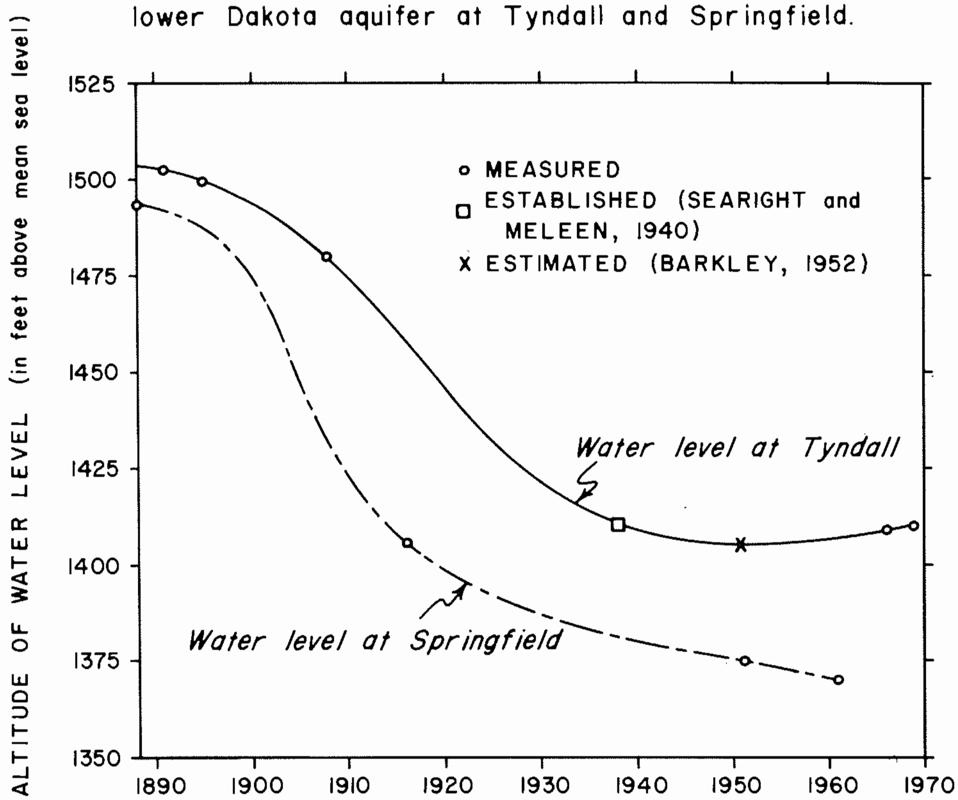


——400—— Line of equal depth to top of upper Dakota aquifer. Dashed where approximately located. Contour interval 100 feet.

Datum is land surface.

Figure 27. Map showing depth to the upper Dakota aquifer.

Figure 28. Hydrograph of the water levels of the lower Dakota aquifer at Tyndall and Springfield.



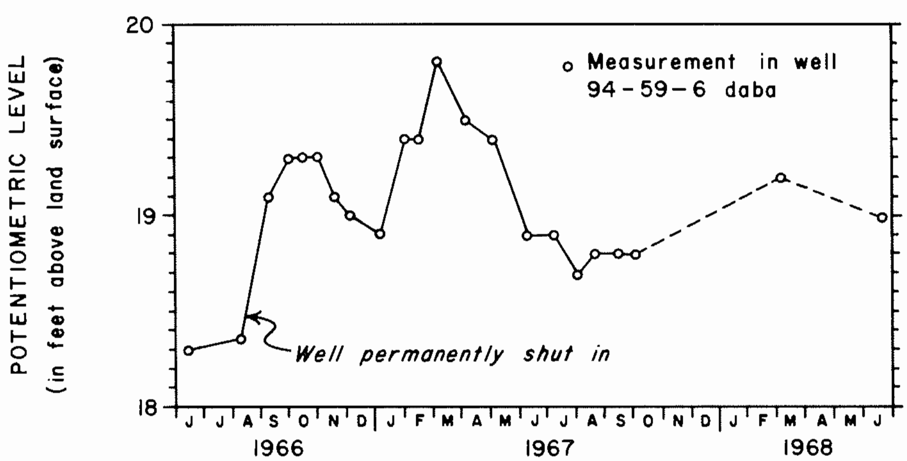


Figure 29. Hydrograph of the potentiometric level in a well tapping the lower Dakota aquifer.

recharge, however, is entirely from subsurface inflow. Because of the variable thickness of the aquifer, and because the storage coefficient is undetermined, the volume of water in storage was not estimated.

Approximately 190 flowing wells which tap the Dakota aquifers in the county discharged an estimated 1,290 acre-ft of water in 1968. Only 269 acre-ft of water was used beneficially; the rest flowed to waste. Figure 30 shows the area where wells will flow, the contours on the potentiometric surface, and the direction of water movement in the lower Dakota aquifer.

Water Quality

Suitability of water for a given use is determined by its chemical and physical properties. Water suitable for one use may not be suitable for another. For example, water suitable for stock may be undesirable for both irrigation and domestic use. Some of the factors that affect the chemical and physical properties of water are climate, geology, topography, and man's activities such as irrigation, drainage, and waste disposal.

This report emphasizes properties associated with inorganic constituents that influence the suitability of water for domestic, livestock, and irrigation uses. All concentrations except pH are reported in milligrams per liter (mg/l). Units of milligrams per liter are very nearly equivalent to parts per million (ppm) and are regarded as equivalent in this report.

Chemical constituents that are often measured to evaluate water for domestic use are listed in table 4. Limits of concentration recommended by U. S. Public Health Service, 1962, for some constituents for domestic use are also included in table 4. These recommended limits are hereinafter referred to as "Federal drinking water standards."

A water-classification system for livestock use is given below (South Dakota Agricultural Experiment Station, 1959, p. 10):

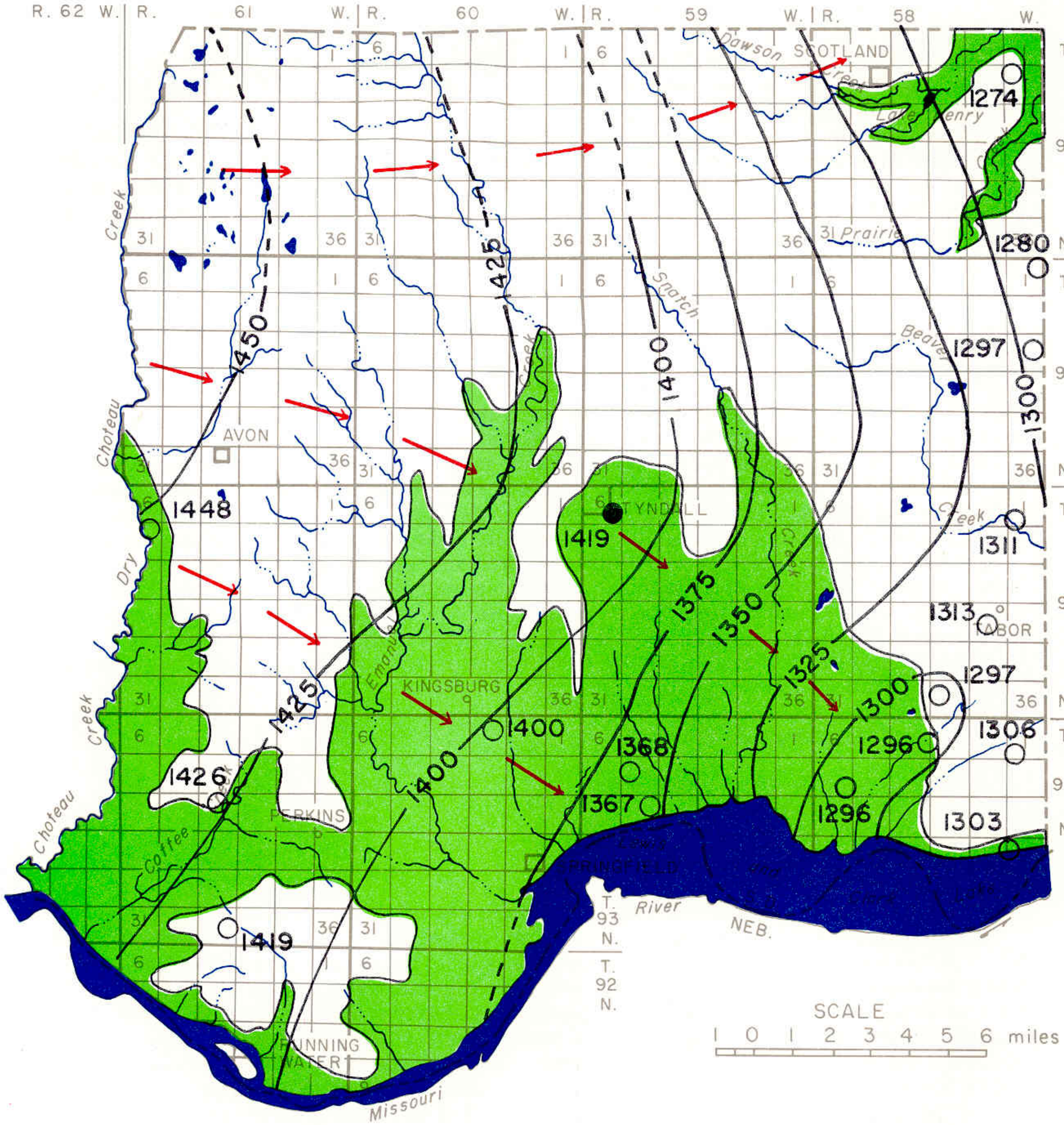
Dissolved solids (mg/l)	Class
0- 999	Excellent
1,000-3,999	Good
4,000-6,999	Satisfactory
7,000 and over	Unsatisfactory

Most livestock can tolerate water of higher mineral content than humans.

Selenium is toxic even in small quantities and when present in some soils can adversely affect livestock health. Certain pea-type plants of the genus *Astragalus,* such as the well-known locoweed, remove selenium from the soil and water and concentrate it within their tissues. Animals grazing on these plants may suffer from the ailment called "blind stagger" (Hem, 1959). In Bon Homme County, Cretaceous-age strata, which are in part aquifers that are known to contain selenium, are the Pierre Shale, the Niobrara Marl, the Carlile Shale, the Greenhorn Limestone, and the Graneros Shale (Koch, 1967, p. 971). The county agent generally is aware of selenium poisoning and should be consulted whenever a new source of water is to be used for irrigating forage crops or pastures.

Several methods of classification of water for irrigation are in use. For these classifications it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of the crop. Large deviations from the average of one or more of these factors may make it unsafe to use water that would be safe under average conditions.

Method of classification most often used is based on the irrigation hazards of salinity and sodium. This method is described fully by Wilcox (1955). A measure of the salinity of the water is its specific conductance. Specific conductance of a water is easily measured with use of a conductance meter which indicates the ease (conductivity) of electrical flow in the water. Units of measurement of EC (specific electrical conductance) are micromhos per centimeter (μm per cm) at 25°C; however, in reports of the U. S. Geological Survey the term "centimeter" is commonly omitted. A measure of sodium hazard is the sodium-adsorption ratio (SAR). The larger the SAR ratio the greater the sodium hazard. The



Area where wells finished in the lower Dakota aquifer will flow.

1375 Potentiometric contour shows altitude of potentiometric surface. Dashed where approximate. Contour interval 25 feet. Datum is mean sea level.

1274 ○ Well

1419 ● Observation well

Number is altitude of potentiometric surface in 1966-67.

→ Direction of water movement.

Figure 30. Map showing potentiometric contours of the Lower Dakota aquifer.

Table 4.--Significance for domestic use of common chemical constituents and physical properties of water.

Constituent or physical property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, usually in amounts less than 25 mg/l. However, waters draining from deposits high in silicate minerals particularly feldspars, often contain as much as 60 mg/l.	Forms hard scale in pipes and boilers. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. Usually less than 1 mg/l in alkaline surface water. Higher amounts occur in acid waters from mine drainage or other sources.	More than about 0.3 mg/l stains laundry and utensils reddish-brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and other processes. Federal drinking water standards state that iron should not exceed 0.3 mg/l.
Manganese (Mn)	Dissolved from some rocks and and soils. Usually less than 1 mg/l in alkaline surface waters. Large concentrations often associated with high iron content and with acid waters.	Same objectionable features as as iron. Causes dark brown or black stains. Federal drinking water standards provide that manganese should not exceed 0.05 mg/l.
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all rocks and soils, but especially from limestone, dolomite, gypsum, and gypsiferous shale.	Causes most of the hardness and and scale-forming properties of water; soap consuming. (See hardness.)
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in sewage, industrial waste, and waste brines.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers.
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks and soil materials such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonate of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts,

Table 4--continued.

Constituent or physical property	Source or cause	Significance
	Usually present in drainage from mines and in some industrial wastes.	sulfate in combination with other ions gives a bitter taste to water and may cause a laxative effect. Federal drinking water standards recommend that sulfate content should not exceed 250 mg/l.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in waste brines and some other industrial wastes.	Chloride in large amounts and in combination with sodium gives salty taste to drinking water and increases the corrosiveness of water. Federal drinking water standards recommend that the chloride content should not exceed 250 mg/l.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Present in salt water from oil wells, and industrial waste from processing of insecticides, disinfectants and preservatives.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. Federal drinking water standards recommend that fluoride content be between 0.8 and 1.3 mg/l for Bon Homme County.
Nitrate (NO_3)	Decaying organic matter, sewage, and nitrates in soil and fertilizer.	Concentrations much greater than the local average may suggest pollution. More than about 45 mg/l nitrate may cause methemoglobinemia in infants, sometimes fatal. Water of high nitrate content should not be used in baby feeding.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter.	Water with large concentrations of dissolved solids often taste. Federal drinking water standards recommend that the dissolved solids should not exceed 500 mg/l unless mineralized supplies are not available.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. Metallic cations	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale

Table 4–continued.

Constituent or physical property	Source or cause	Significance
	except alkali metals also cause hardness.	in boilers, water heaters, and pipes. Waters of hardness up to 60 mg/l are considered soft; 61 to 120 mg/l, moderately hard; 121 to 200 mg/l, hard; more than 200 mg/l, very hard.
Specific conductance	Mineral content of the water.	Specific electrical conductance (EC) is a measure of the ability of the water to conduct an electric current. Varies with temperature, concentration, and degree of ionization of the constituents.
Hydrogen ion concentration(pH)	Acids, acid-generating salts, and dissolved carbon dioxide lower the pH; carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutral solution. Values higher than 7.0 indicate increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions, corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.
Color	Natural color is usually associated with swamp drainage, and is often the result of decomposition products of vegetal material.	Color affects the use of water for dyeing, textiles, food processing, ice making, and is esthetically unpleasant.

sodium-adsorption ratio is calculated by the equation:

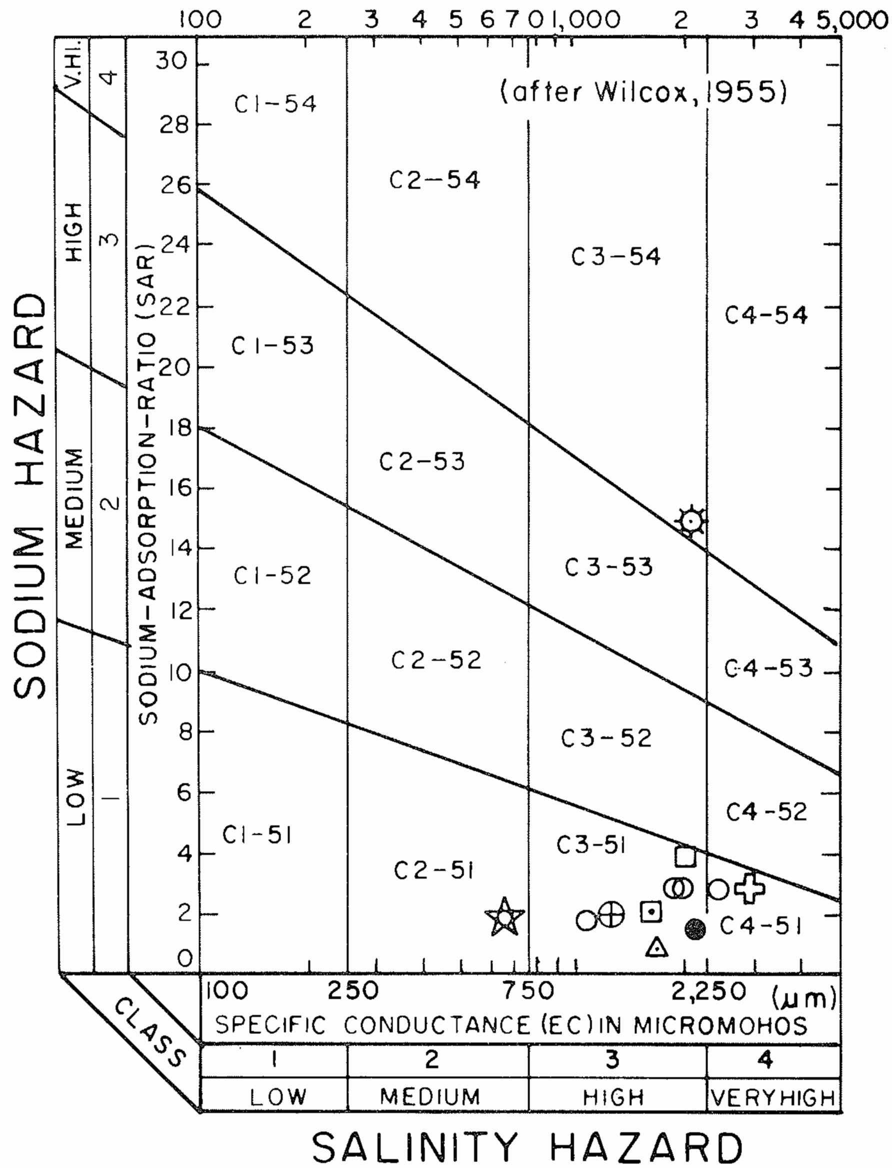
$$SAR = \frac{NA^{+}}{\sqrt{\frac{CA^{++} + Mg^{++}}{2}}}$$

in which the concentrations of sodium (Na^{+}), calcium (Ca^{++}), and magnesium (Mg^{++}) are given in millequivalents per liter (meq/l). Millequivalents per liter may be calculated by dividing the constituents molecular weight by the ionic charge or valence.

The irrigation water classification method based on EC and SAR uses a diagram as is shown by figure 31. For example, the average SAR and EC for the analyses of Codell aquifer water are 15 and 2,030 μm respectively. These values are used as coordinates and define a point in the C3-S4 area of the diagram.

Significance of the classes of water shown on figure 32 is summarized as follows (Wilcox 1955):

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



⊕ Hubonmix-aquifer water

⊡ Average Choteau-aquifer water

△ Average Tyndall-Scotland-aquifer water

✚ Average till-aquifer water

□ Average Niobrara-aquifer water

☼ Average Codell-aquifer water

● Average Dakota-aquifer water

○ Seasonal analysis of water from Lake Henry

☆ Discharge-weighted average of Missouri River water from October 1, 1957–September 30, 1958 at Yankton, South Dakota.

Figure 31. Diagram for classification of irrigation water.

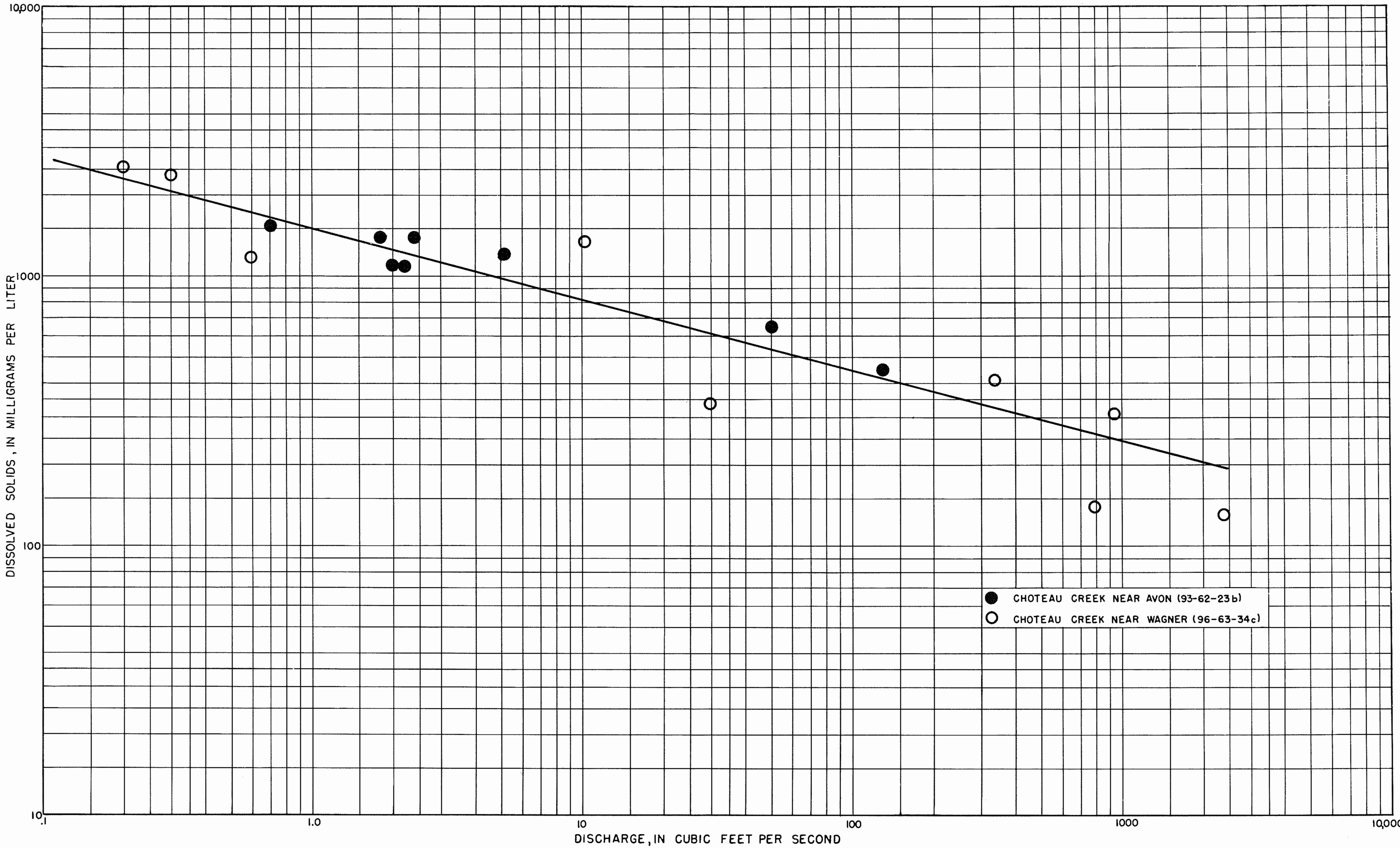


Figure 32. ---- Graph showing relation of dissolved solids to discharge in Choteau Creek

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

High-salinity water (C3) can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerances should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but it may be used occasionally under special circumstances. If this water is used, the soils must be permeable, the drainage must be adequate, the quantity of irrigation water applied must be in excess so as to provide considerable leaching, and very salt-tolerant crops should be grown.

Classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may suffer injury as a result of sodium accumulation in plant tissue when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low-sodium water (S1) can be used for irrigation on most soils with little danger of harm. However, sodium-sensitive crops may be injured by accumulation of sodium concentrations.

Medium-sodium water (S2) presents appreciable sodium hazard in fine-textured soils of high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils that have good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and requires good drainage, high leaching rates, and addition of organic matter. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium.

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

Sometimes the irrigation water may dissolve sufficient calcium from calcareous soils to decrease the sodium hazard appreciably, and this should be taken into account in the use of C1-S3 and C1-S4 waters. For calcareous soils with high pH values or for noncalcareous soils, the sodium status of waters in classes C1-S3, C1-S4, and C2-S4 may be improved by the addition of gypsum to the water. Similarly, it may be beneficial to add gypsum to the soil periodically when C2-S3 and C3-S2 waters are used.

Classification of water for irrigation based on the concentration of boron is also useful. Boron, even in small quantities, is toxic to some types of plants. Some crops, including most deciduous fruit and nut trees and beans are sensitive to boron; most small grains, potatoes, and some vegetables are semitolerant; alfalfa and most root vegetables are tolerant. Permissible boron concentrations are shown in table 5 (Hem, 1959, p. 245).

Surface Water

Quality of surface water varies widely within the same stream and from one stream to another. Variations in quality are due to the type of soil that the water contacts, length of contact time, past use of the water, amount and source of base flow, amount of storm runoff, and many other factors. These variations can be described in terms of maximum and minimum concentrations, frequency of occurrence of specific concentrations, and their duration. A computation of average quality for a year from an analysis of daily samples has limited value; however, a discharge-weighted quality computation is meaningful in anticipating the quality of water in a reservoir.

Quality of water in both Choteau Creek and Emanuel Creek varies inversely with discharge. Low mineral concentrations occur during periods of high discharge when most of the flow is surface runoff. High mineral concentrations occur during periods of low discharge when most of the base flow is ground water. Figure 32 shows the discharge-dissolved solids relation for Choteau Creek, and figure 33 shows this same relation

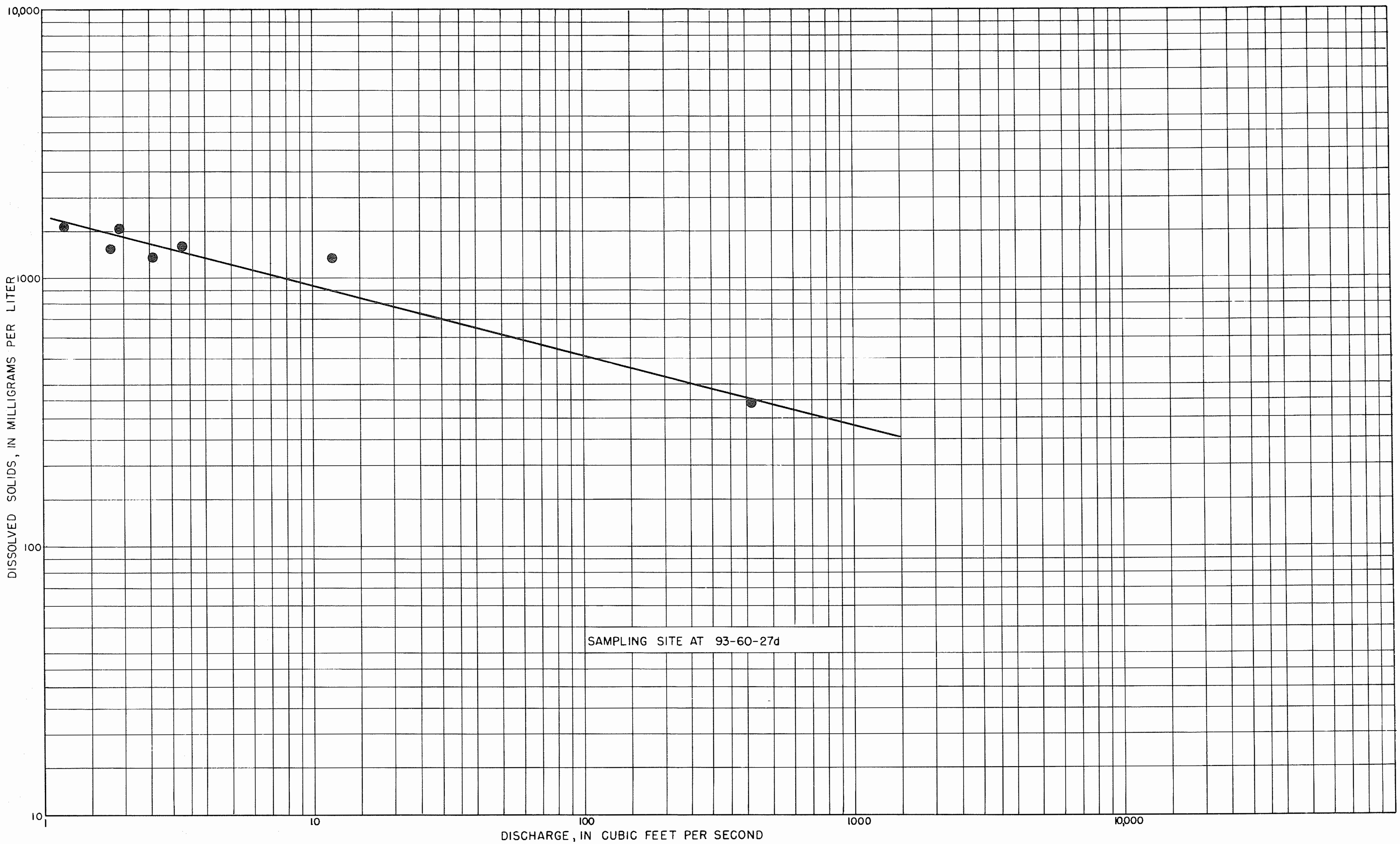


Figure 33 – – – – Graph showing relation of dissolved solids to discharge in Emanuel Creek

Table 5.–Rating of irrigation water for various crops on the basis of boron concentration (after Hem, 1959).

Classes of water				
Rating	Grade	Sensitive crops (mg/l)	Semitolerant crops (mg/l)	Tolerant crops (mg/l)
1	Excellent	<0.33..........	<0.67..........	<1.00..........
2	Good	.33 to .67	.67 to 1.33	1.00 to 2.00
3	Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	Unsuitable	>1.25..........	>2.50..........	>3.75..........

for Emanuel Creek. No relation between season and mineral composition of water was found. Tables 6 and 7 list chemical analyses at various rates of discharge for Choteau and Emanuel Creeks. In general, the water at discharges of less than 8 cfs from either creek is unsatisfactory for irrigation because of its high dissolved solids and salinity. These creeks are not considered as sources of irrigation water because they seldom have flows exceeding 8 cfs. Water in either creek is suitable for stock use and could be used for domestic purposes although the concentrations of dissolved solids, sulfate and iron at commonly occurring discharge rates may exceed those recommended in the Federal drinking water standards.

Quality of the water in Lewis and Clark Lake was monitored from July 1, 1964 to June 30, 1966 at Gavins Point Dam, 9 miles east of Bon Homme County, by a continuous recorder operated by the Bureau of Sport Fisheries (written commun.). The results were:

Constituent or Property	Range
Conductivity	650-840 micromhos
Turbidity	10-675 mg/l
Bicarbonate	144-180 mg/l of HCO_3
Dissolved oxygen	5.4-14.0 mg/l

Quality of water discharged from the lake measured at Yankton, 12 miles east of the southeast corner of Bon Homme County, for the 1958 water year is shown in table 8 (U. S. Geological Survey, 1962).

Although some differences between the quality of water in the Missouri River above Springfield, and in Lewis and Clark Lake below Springfield is observable, the differences are not of such a magnitude to appear significant.

Water from Lewis and Clark Lake and the Missouri River is of good quality for domestic and stock use, and is classified as C2-S1 (low sodium hazard and medium salinity hazard) for irrigation. (See fig. 31.) The water is suitable for most plants and requires only moderate leaching of the soil to prevent sodium build-up.

Quality of water in Lake Henry, a reservoir on Dawson Creek, may be similar to the quality of water that would be expected if a reservoir was constructed on Emanuel or Choteau Creek. The variation of the quality is seasonal and is due to the processes of dilution and distillation. That is, when surface water of low mineral content flows into the lake it dilutes the more mineralized lake water. During the growing season, transpiration removes nearly pure water and leaves a concentrated mineral solution behind; during winter months, freezing at the surface concentrates the minerals in the unfrozen water beneath the ice. Table 9 shows that dissolved-solids content decreased with the rising lake level except for the February 4, 1965 analysis which shows the increased concentration caused by

Table 6.–Selected chemical analyses of water from Choteau Creek.
(All concentrations in mg/l–all samples collected at 93-62-23b)

Date	9-8-66	6-7-67	7-7-67
Discharge (cfs)	0.62	130	50.3
Gage height (ft)	1.00	2.20	1.56
Iron (Fe)	.03	.32	.70
Calcium (Ca)	232	76	123
Magnesium (Mg)	44	14	27
Sodium (Na)	86	17	44
Potassium (K)	17	10	18
Bicarbonate (HCO_3)	259	161	273
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	680	120	104
Chloride (Cl)	38	12	30
Nitrate (NO_3)	.0	.0	2.5
Selenium (Se)			.001
Dissolved solids	1,540	452	664
Ca, Mg hardness as $CaCO_3$	762	249	420
Noncarbonate hardness as $CaCO_3$	550	117	196
SAR	1.4	.5	.9
EC in μm	1,700	560	900
pH	7.6	7.0	7.3
Temperature in °C	20	17	
Remarks	base flow		

Table 7.–Selected chemical analyses of water from Emanual Creek
(All concentrations in mg/l–all samples collected at 93-60-27d)

Date	9-8-66	6-7-67	7-7-67
Discharge (cfs)	1.19	415	11.8
Gage height (ft)	.10	3.86	.80
Iron (Fe)	.00	.60	.00
Calcium (Ca)	244	64	194
Magnesium (Mg)	32	4.8	56
Sodium (Na)	130	6.3	67
Potassium (K)	20	7.7	15
Bicarbonate (HCO_3)	324	151	263
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	730	60	504
Chloride (Cl)	38	4.0	25
Nitrate (NO_3)	2.7	4.0	16
Selenium (Se)			.005
Dissolved solids	1,580	332	1,200
Ca, Mg hardness as $CaCO_3$	745	180	716
Noncarbonate hardness as $CaCO_3$	477	0	500
SAR	2.2	.2	1.1
EC in μ m	1,960	377	1,530
pH	7.5	7.2	
Temperature in °C	24	17	
Remarks	base flow		

Table 8.–Water quality of Missouri River at Yankton, South Dakota

LOCATION.--At gaging station at Meridian Highway Bridge on U. S. Highway 81 in Yankton County, 5.8 miles upstream from James River, and 6.1 miles downstream from Gavins Point Dam.
DRAINAGE AREA.--279,500 square miles, approximately.
RECORDS AVAILABLE.--Chemical analyses: October 1950 to September 1951; October 1956 to September 1958.
Water temperatures: October 1956 to September 1958.
EXTREMES, 1957-58.--Dissolved solids: Maximum, 489 mg/l Oct. 1-31; minimum 377 mg/l May 26 to Apr. 17.
Hardness: Maximum, 236 mg/l Oct. 1-31; minimum, 194 mg/l Mar. 26 to Apr. 17.
Specific conductance: Maximum daily, 772 μm Oct. 1; minimum daily, 537 μm Apr. 6, 7.
Water temperatures: Maximum 27°C (81°F) Aug. 19; minimum 1°C (33°F) on many days during December to February.
EXTREMES, 1956-58.--Dissolved solids: Maximum, 559 mg/l Aug. 29 to Sept. 30, 1957; minimum 327 mg/l Mar. 16-31, 1957.
Hardness: Maximum, 250 mg/l Aug. 29 to Sept. 30, 1957; minimum, 168 mg/l Mar. 16-31, 1957.
Specific conductance: Maximum daily, 839 μm Aug. 24-25, Sept. 5-8, 1957; minimum daily 479 μm Mar. 30, 1957.
Water temperatures: Maximum 27°C (81°F) Aug. 19, 1958; minimum, freezing point on many days during winter months.
REMARKS.--Daily samples for chemical analyses composited by discharge. Records of specific conductance of daily samples available at USGS office, Lincoln, Nebraska.

Chemical analyses, in mg/l, water year October 1957 to September 1958

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue at 180°C): Milligrams per liter	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance EC in μm	pH
Oct. 1-31, 1957	28,120	10	0.04	64	19	71	5.6	191	209	12	0.6	0.4	0.19	489	0.67	37,130	236	79	2.0	748	7.7
Nov. 1-30	11,800	13	.02	63	17	64	5.2	185	190	10	.7	.5	.14	466	.63	14,850	228	76	1.8	698	7.3
Dec. 1-31	8,351	18	.01	59	18	60	4.9	200	180	11	.5	1.2	.07	453	.62	10,210	222	58	1.8	678	7.4
Jan. 1-31, 1958	8,803	13	.01	61	17	58	5.3	182	174	10	.5	1.2	.12	440	.60	10,400	222	73	1.7	661	7.7
Feb. 1-28	6,695	13	.01	60	17	55	5.0	185	167	9.8	.5	.6	.10	442	.60	10,380	221	69	1.6	674	7.7
Mar. 1-25	8,206	13	.01	56	16	55	4.6	174	168	9.0	.5	1.2	.13	414	.56	9,170	207	64	1.7	627	7.6
Mar. 26-Apr. 17	20,820	14	.00	51	16	44	4.7	166	140	7.7	.5	1.4	.08	377	.51	21,190	194	58	1.4	578	7.5
Apr. 18-May 12	24,920	11	.04	56	17	54	4.7	176	164	9.4	.5	1.4	.10	411	.56	27,650	210	66	1.6	637	7.5
May 13-31	26,580	9.5	.04	54	18	55	4.6	172	167	9.2	.5	.8	.11	411	.56	29,500	208	67	1.6	639	7.3
June 1-30	27,950	9.6	.01	53	18	60	4.7	162	184	8.9	.4	.6	.12	425	.58	32,070	206	73	1.8	652	7.6
July 1-31	25,970	7.7	.00	56	17	60	5.2	168	195	8.9	.5	.1	.19	445	.61	31,200	211	73	1.8	675	7.2
Aug. 1-31	28,220	8.5	.00	56	18	61	6.0	174	194	9.0	.5	.8	.16	456	.62	34,740	215	72	1.8	673	7.0
Sept. 1-30	28,910	8.6	.00	58	19	63	5.2	187	201	10	.5	.4	.15	470	.64	36,690	224	71	1.8	699	7.2
Weighted average[a]	19,720	10	0.01	57	18	60	5.1	177	185	9.6	0.5	0.7	0.14	443	0.60	23,590	216	71	1.8	671	...

[a]Represents 100 percent of runoff for water year October 1957 to September 1958.

Table 9.--Selected chemical analyses of water from Lake Henry.
(All concentrations in mg/l--all samples collected at 96-58-9d)

Date	10-24-64	2-4-65	5-17-65	9-6-65
Gage height (ft)	9.86*	9.99*	8.80*	7.97*
Iron (Fe)	.06	.09	.01	.05
Manganese (Mn)	.19	1.4	.29	.09
Calcium (Ca)	128	160	111	88
Magnesium (Mg)	119	156	112	71
Sodium (Na)	185	225	166	98
Potassium (K)	18	21	17	17
Bicarbonate (HCO_3)	168	239	172	178
Carbonate (CO_3)	0	0	0	0
Sulfate (SO_4)	867	1,150	744	432
Chloride (Cl)	107	139	115	71
Fluoride (F)	.4	.4	.3	.3
Nitrate (NO_3)	1.5	4.8	1.5	.3
Phosphorous as PO_4	.56	1.4	0.44	1.2
Phosphate (PO_4)	.36	1.4	.37	1.2
Boron (B)	.68	.69	.58	.37
Dissolved oxygen (DO)	11.8	.3	8.4	8.3
Dissolved solids	1,520**	1,980**	1,350**	936
Ca, Mg hardness as $CaCO_3$	808	1,040	737	511
Noncarbonate hardness as $CaCO_3$	670	844	569	310
SAR	2.8	3.0	2.7	1.09
EC in µm	2,060	2,520	1,920	1,300
pH	8.5	7.8	8.5	8.4
Temperature in °C	10	2	19	19

*Depth below reference mark 1.
**Calculated

freezing. The quality of water of Lake Henry and other selected lakes is discussed fully by Petri and Larson (1968).

Figure 31 indicates that the classification of the water for irrigation has a low sodium hazard and high to very high salinity hazard; therefore, the water should not be used on soils that are not permeable or adequately drained. The water is suitable for stock use. However, it is not recommended for domestic use because it has concentrations of manganese, sulfate, and dissolved solids that exceed the limits specified by Federal drinking water standards.

Ground Water

Summaries of the results of 109 "complete" chemical analyses are shown in tables 10 through 15. The tables list the number of determinations for each constituent, the maximum and minimum values for each constituent, and the average $(\overline{X})$. A measure of dispersion of data from the mean is the standard deviation (s) and is defined as the positive square root of the sum of squares of the deviations of the observations from the arithmetic mean divided by one less than the total number of observations. Values of s and $\overline{X}$ listed in tables 10 through 15 were determined numerically. The curve defined by plotted points on normal probability paper was used to determine the probability of a value being equal or exceeded. That is, the values listed under 25 percent, 50 percent, and 75 percent in table 8 indicate that the probability of the listed value being equaled or exceeded is 25 percent, 50 percent, and 75 percent, respectively. The 50 percent value is the median or middle value of the group. Neither standard deviation nor probability was determined if less than four observations were available.

Ground water from the Choteau, Tyndall-Scotland, Niobrara, Codell, and the upper and lower Dakota aquifers is suitable for domestic use; although, all of the aquifers yield water with one or more undesirable characteristics. As an example, water from the Choteau, Tyndall-Scotland, Codell, and the upper and lower Dakota aquifers can be expected to have excessively high sulfate and dissolved solids concentrations as compared to those recommended in Federal drinking water standards. Water from the till may not be suitable for domestic use because it has concentrations of sulfate and dissolved solids which often greatly exceed Federal drinking water standards.

Water from all aquifers sampled is classified as satisfactory to excellent for livestock.

Figure 31 shows the irrigation classification for the average values of conductivity and sodium-adsorption ratio for waters from each aquifer. Water from the Choteau, Tyndall-Scotland, Niobrara, and Dakota aquifers is classified as C3-S1 (low sodium hazard and high salinity hazard), and thus should not be used for irrigation on soils with restricted drainage, even though sodium build-up would not be a problem. Water from the Codell aquifer is classified as C3-S4 (very-high sodium hazard and high salinity hazard) and is generally unsatisfactory for irrigation because of the likelihood of crop damage by sodium build-up especially on poorly drained soil. Water from the till aquifer is classified as C4-S1 (low sodium hazard and very-high salinity hazard) and is not suitable for irrigation under ordinary conditions.

Chemical analysis of a water sample from well 96-61-29cdca finished in the Hubonmix aquifer is as follows: calcium=128 mg/l; magnesium=20 mg/l; potassium=28 mg/l; bicarbonate=98 mg/l; carbonate=0 mg/l; sulfate=628 mg/l; chloride=17 mg/l; nitrate=8.4 mg/l; boron=1.0 mg/l; EC=1,440 μ m; and SAR=2.2. As only one sample was obtained from this aquifer no confident statement can be made about the chemical quality of the water from the aquifer. All chemical analyses of water samples collected are listed in part III, the basic-data report for this investigation.

Average boron concentration of water samples from the till, Tyndall-Scotland, Niobrara, Codell, and Dakota aquifers did not exceed that recommended for irrigation of semitolerant crops (Hem, 1959). Not enough boron analyses were available for the Choteau aquifer water to permit an evaluation of the boron hazard and no boron determination was made of the water sample from the Hubonmix aquifer.

Mixing of natural waters caused by recharge of water from one aquifer to another occurs at several places within the county. Recharge to both the Niobrara and the Codell aquifers from the Tyndall-Scotland aquifer is indicated by the nearly identical water levels and the

Table 10.--Summary of chemical analyses of water from the till aquifer
(All concentrations in mg/l)

Constituent or property	Number of deter- minations	Maximum	Minimum	Average ($\bar{X}$)	Medium (50%)	Standard deviation (s)	25%	75%
Calcium (Ca)	16	555	154	325	318	117	400	235
Magnesium (mg)	16	662	25	180	.....	.....	235	55
Sodium (Na)	16	486	41	222	220	124	310	130
Potassium (K)	16	40	1.4	18	18	11	25	12
Bicarbonate (HCO_3)	16	735	122	329	305	174	450	160
Carbonate (CO_3)	15	9	0	1	.....	.....	...	.....
Sulfate (SO_4)	16	2,680	450	1,380	1,340	687	1,820	850
Chloride (Cl)	16	386	4.0	85	.....	.....	110	28
Boron (B)	5	1.6	1.2	1.4	1.4	.55	1.5	1.2
Dissolved solids	16	7,220	1,030	3,080	2,880	1,610	3,950	1,800
Mg,Ca hardness as $CaCO_3$	16	4,000	480	1,610	1,480	986	2,000	950
Noncarbonate hardness as $CaCO_3$	16	3,510	296	1,360	1,300	969	1,900	700
EC in μm	16	7,380	1,370	3,270	3,080	1,450	3,850	2,300
SAR	16	6.6	.6	3.0	2.7	1.8	4.0	1.4

Table 11.--Summary of chemical analyses of water from the Choteau aquifer
(All concentrations in mg/l)

Constituent or property	Number of deter- minations	Maximum	Minimum	Average $(\overline{X})$	Median (50%)	Standard deviation (s)	25%	75%
Calcium (Ca)	4	248	128	160	160	51	215	105
Magnesium (Mg)	4	30	19	24	24	3.8	27	21
Sodium (Na)	4	225	38	126	125	66	177	73
Potassium (K)	4	28	9.4	19	19	6.7	19	13
Bicarbonate (HCO_3)	4	372	97	198	197	105	289	107
Carbonate (CO_3)	4	0	0	0	0	0	0	0
Sulfate (SO_4)	4	630	500	568	570	61	623	517
Chloride (Cl)	4	49	10	30	31	17	46	16
Boron (B)	1	.....	.....	1.0	.....	.....	.....	.....
Dissolved solids	3	1,340	1,140	1,220	.....	.....	.....	.....
Mg, Ca hardness as $CaCO_3$	4	718	400	500	503	127	574	432
Noncarbonate hardness as $CaCO_3$	4	492	284	358	368	83.5	433	303
EC in μm	4	1,630	1,440	1,520	1,530	71	1,580	1,470
SAR	4	4.0	.6	2.3	2.3	1.2	3.2	1.3

Table 12.--Summary of chemical analyses of water from the Tyndall-Scotland aquifer
(All concentrations in mg/l)

Constituent or property	Number of deter-minations	Maximum	Minimum	Average ($\overline{X}$)	Median (50%)	Standard deviation (s)	25%	75%
Calcium (Ca)	6	293	108	172	170	62	210	130
Magnesium (Mg)	6	43	20	35	36	7.5	42	30
Sodium (Na)	6	474	18	128	.....	.....	50	20
Potassium (K)	4	22	6.9	14	14	6.7	19	9
Bicarbonate (HCO_3)	4	281	146	186	162	110	176	148
Carbonate (CO_3)	4	13	0	3	.....	.....	.....	.....
Sulfate (SO_4)	6	770	260	520	515	202	650	380
Chloride (Cl)	6	119	8.0	36	27	38	15	39
Boron (B)	3	2.7	.9	1.8	.....	.....	.....	.....
Dissolved solids	6	1,840	684	1,210	1,220	428	1,520	930
Mg, Ca hardness as $CaCO_3$	5	872	450	609	600	151	460	740
Noncarbonate hardness as $CaCO_3$	4	501	330	384	362	71.9	387	337
EC in μm	3	2,080	857	1,590	.....	.....	.....	.....
SAR	5	3.0	.3	1.0	.....	.....	1.2	.5

Table 13.–Summary of chemical analyses of water from the Niobrara aquifer
(All concentrations in mg/l)

Constituent or property	Number of deter-minations	Maximum	Minimum	Average $(\overline{X})$	Median (50%)	Standard deviation (s)	25%	75%
Calcium (Ca)	25	433	80	241	235	93	300	170
Magnesium (Mg)	25	129	19	55	52	33	80	23
Sodium (Na)	22	384	24	209	215	118	310	120
Potassium (K)	22	56	6.2	26	26	9.9	30	21
Bicarbonate (HCO_3)	26	471	112	289	288	115	370	205
Carbonate (CO_3)	26	18	0	1	.....	.....	.....	.....
Sulfate (SO_4)	26	1,435	300	891	900	282	1,110	690
Chloride (Cl)	26	235	6	53	38	61	60	15
Boron (B)	11	2.4	0.93	1.7	1.8	0.46	2.1	1.5
Dissolved solids	26	2,800	759	1,860	1,880	483	2,200	1,550
Mg, Ca hardness as $CaCO_3$	26	1,610	300	827	820	349	1,040	600
Noncarbonate hardness as $CaCO_3$	26	1,230	156	593	600	308	805	395
EC in μm	20	3,020	985	2,160	2,180	515	2,510	1,850
SAR	20	8.6	.5	3.8	3.8	2.4	5.3	2.2

Table 14.–Summary of chemical analyses of water from the Codell aquifer
(All concentrations in mg/l)

Constituent or property	Number of deter-minations	Maximum	Minimum	Average $(\overline{X})$	Median (50%)	Standard deviation (s)	25%	75%
Calcium (Ca)	33	344	10	80	.....	.....	126	18
Magnesium (Mg)	33	67	1.0	18	.....	.....	26	6
Sodium (Na)	30	494	13	356	356	105	416	297
Potassium (K)	33	55	1.4	20	20	11	26	14
Bicarbonate (HCO_3)	33	501	66	329	323	113	403	203
Carbonate (CO_3)	33	67	0	12	.....	.....	19	.....
Sulfate (SO_4)	33	1,550	44	410	.....	.....	650	80
Chloride (Cl)	31	420	3	174	180	142	295	65
Boron (B)	2	2.1	1.1	1.6	.....	.....	.....	.....
Dissolved solids	33	2,360	440	1,360	1,330	472	1,650	1,010
Mg, Ca hardness as $CaCO_3$	33	1,390	37	296	.....	.....	500	64
Noncarbonate hardness as $CaCO_3$	33	1,180	0	175	.....	.....	240	.....
EC in μm	32	3,000	581	2,030	2,090	468	2,550	1,640
SAR	31	30	.4	15	16	9.6	21	10

Table 15.--Summary of chemical analyses of water from the lower Dakota aquifer
(All concentrations in mg/l)

Constituent or property	Number of determinations	Maximum	Minimum	Average ($\overline{X}$)	Median (50%)	Standard deviation (s)	25%	75%
Calcium (Ca)	24	415	206	315	320	73	366	273
Magnesium (Mg)	24	82	19	52	54	18	66	42
Sodium (Na)	23	202	42	101	102	34	122	82
Potassium (K)	22	22	14	19	19	1.8	20	18
Bicarbonate (HCO_3)	23	205	97	147	145	26.3	164	126
Carbonate (CO_3)	23	0	0	0	0	0	0	0
Sulfate (SO_4)	24	1,450	538	890	899	240	1,060	899
Chloride (Cl)	23	160	57	113	118	36.0	144	91
Boron (B)	3	2.8	1.0	1.7	.....	.....	.....	.....
Dissolved solids	23	2,230	1,210	1,780	1,830	364	2,130	1,530
Mg, Ca hardness as $CaCO_3$	24	1,330	620	1,010	1,010	246	1,170	855
Noncarbonate hardness as $CaCO_3$	22	1,200	525	868	880	77.2	1,000	760
EC in μm	19	2,650	1,510	2,040	1,540	378	2,320	1,750
SAR	17	3.3	.4	1.4	1.4	.6	1.7	1.1

similar quality of water from wells that are finished in these aquifers at locations in Township 94 North and Range 60 West.

An apparent chemical anomaly exists at the municipal well in the Codell aquifer at Avon where the hardness of water is considerably greater than the hardness of water in the Codell aquifer from nearby wells (Jorgensen, 1968). Increased hardness of the water at Avon is due to mixing of Dakota and Codell waters. Dakota water, which is under greater artesian pressure than Codell water, flows into the Codell aquifer through a rupture in the casing of an abandoned Dakota well. Many other cases of water mixing as the result of well-casing failures exist in the county, but the quantity of water involved is not as large as at Avon and the effects upon water quality are probably very localized.

SUMMARY

Water from Lewis and Clark Lake and from the Missouri River is suitable to use for irrigation, domestic, and stock purposes. The water has a low sodium hazard and a medium salinity hazard, and thus is suitable for irrigation use in soils with only moderate leaching.

Quality of water in Lake Henry is variable. This variation is seasonal and is due to the processes of evaporation, transpiration, freezing, and dilution. Because the water has a high to very-high salinity hazard, it should not be used on soils that are not permeable or well drained. The water is not recommended for domestic use because at times it is very high in dissolved solids; however, the water is suitable for stock use.

Limited information about the quality and quantity of the water in Choteau and Emanuel Creek indicates that the mineral concentration decreases as the rate of discharge increases. Water in the creeks is, in general, unsatisfactory for irrigation at commonly occurring low flow rates because of its high salinity. The water is suitable for domestic and stock use; however, at commonly occurring discharge rates the concentrations of iron, sulfate, and dissolved solids may exceed Federal drinking water recommendations.

Water from the alluvium and the shallow outwash aquifers is used as stock water. Wells finished in these aquifers yield water at rates of 1 to 10 gpm.

Till-aquifer water has a low sodium and a high salinity hazard; therefore, it is not suitable for irrigation under ordinary conditions. The aquifer yields water to wells at most locations at rates of 1 to 5 gpm. Most of the water is used for livestock.

Available quality-of-water data for the Tyndall-Scotland, Choteau, and Hubonmix aquifers indicates that these waters have a low sodium hazard and a high salinity hazard. Therefore, the waters are suitable for irrigation on soil with good drainage. Water from these aquifers is largely used for domestic and stock purposes. Properly constructed wells tapping these aquifers at locations at which the saturated aquifer thickness is more than 50 feet should yield water at rates in excess of 100 gpm.

The Niobrara aquifer can be expected to yield water with a low sodium hazard and a high salinity hazard which is suitable for irrigation on soils with good drainage. Yields of wells that are finished in the aquifer range from 2 to 100 gpm. Sites at which wells might produce more than 100 gpm can probably be found by drilling and aquifer testing.

The Codell aquifer yields relatively "soft" water which is widely used for domestic purposes. The water has a very high sodium hazard and a high-salinity hazard and is unsuitable for irrigation. Wells finished in the aquifer produce water at rates from 2 to 100 gpm.

The upper and lower Dakota aquifers yield water which has a low-sodium and a high salinity hazard. The water is suitable for irrigation on land with good soil drainage. Properly constructed wells tapping the lower Dakota aquifer could produce up to about 900 gpm.

Water suitable for domestic use can be expected from wells tapping the Choteau, Tyndall-Scotland, Niobrara, Codell, and the upper and lower Dakota aquifers. However, all the aquifers can be expected to supply water that has concentrations of dissolved solids and sulfate in excess of those recommended in the Federal drinking water standards.

Water from all aquifers sampled is classified as satisfactory to excellent for livestock.

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