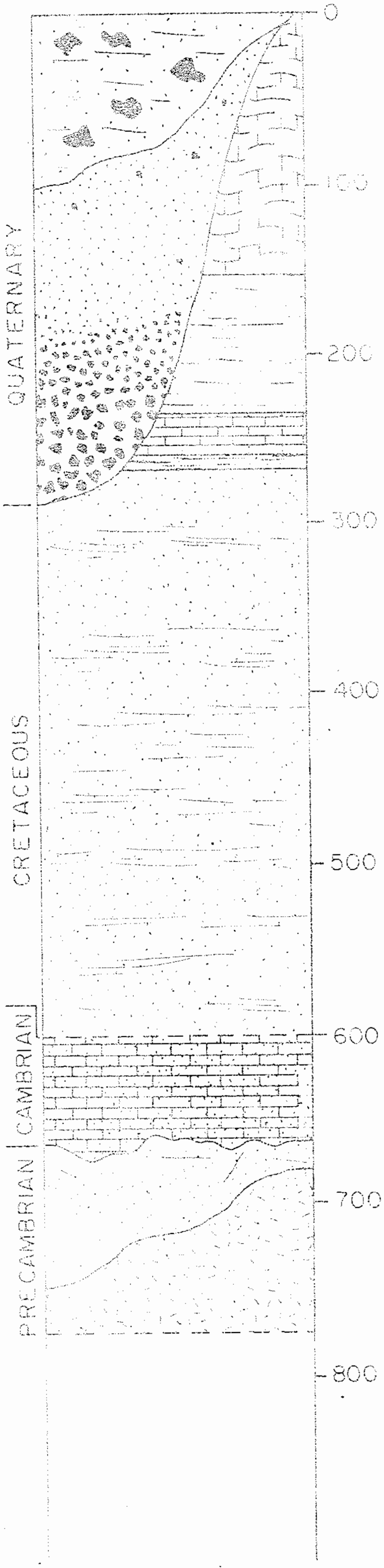
Part II



GEOLOGY AND HYDROLOGY OF CLAY COUNTY SOUTH DAKOTA

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Part II

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GEOLOGY AND WATER RESOURCES OF CLAY COUNTY, SOUTH DAKOTA

PART II, WATER RESOURCES

by
Jerry C. Stephens, U. S. Geological Survey

Prepared in cooperation with the
South Dakota Geological Survey,
and Clay County

Science Center
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GEOLOGY AND WATER RESOURCES OF CLAY COUNTY, SOUTH DAKOTA

PART 2

by Jerry C. Stephens
United States Geological Survey

ABSTRACT

Clay County, near the confluence of the Vermillion and Missouri Rivers in southeastern South Dakota, has an area of 403 square miles. Pleistocene glacial, eolian, and alluvial deposits and Recent alluvium and colluvium overlie the Cretaceous bedrock strata throughout nearly the entire county.

Surface-water resources are little used in Clay County. Discharge of the Vermillion River is due primarily to runoff from precipitation and snow melt, and is very erratic. Discharge of the Missouri River is controlled by upstream dams and is relatively stable.

The Lower Vermillion-Missouri aquifer, composed mostly of outwash, underlies 75 percent of the county, averages 100 feet in thickness, and contains more than five million acre-feet of water in transient storage. This aquifer supplies more than 70 percent of the water used in the county.

Permeability of the aquifer material generally ranges from 1,000 to 2,500 gpd/sq. ft. Water levels range from 0 to 15 feet below land surface under the river floodplains and from 75 to 110 feet where the aquifer is buried. Recharge to the aquifer consists of infiltration of precipitation that falls on the floodplains, influent seepage from surface streams, and subsurface inflow and leakage from adjacent aquifers.

The Wakonda aquifer, which underlies about 70 square miles in northwestern Clay County, consists of the unconsolidated outwash and alluvium and the underlying hydraulically continuous Niobrara Marl. Water in the aquifer is under artesian pressure and locally discharges to flowing wells and springs. Recharge to the aquifer is primarily by subsurface inflow from the northwest.

An aquifer in the Niobrara Marl, underlying about 25 square miles in northeastern Clay County, supplied about 70 acre-feet of water, in 1964. The aquifer, which is probably recharged from overlying outwash aquifers in adjacent counties to the northeast, contains water under artesian pressure and locally yields water to flowing wells.

An aquifer consisting of one or more sandstone beds in the Dakota Group underlies all of Clay County, contains water under artesian pressure, and yields water to flowing wells on the Missouri River floodplain west of the Vermillion River. The altitude of the piezometric surface of water in this aquifer ranges from about 1,280 feet at the northwest corner of the county to about 1,120 feet at the southeast corner.

Most sources of water supply in Clay County yield fresh or slightly saline, hard, calcium-sulfate water that contains undesirable quantities of dissolved iron, manganese, sulfate, and total solids. All aquifers yield water that generally is satisfactory without treatment for livestock and some domestic uses. Most water samples from the Lower Vermillion-Missouri aquifer and the aquifer in the Dakota Group were rated "good to permissible" for irrigation; both aquifers contain water with low-sodium hazard and high-salinity hazard.

INTRODUCTION

A constantly increasing demand for water has created a need for more and better information about South Dakota's water resources. In southeastern South Dakota the expansion of irrigation farming in the past decade has focused attention on the area's ground-water resources. To supply needed information about water--its occurrence, quantity, quality, and availability for irrigation, industrial, livestock, domestic, and municipal uses--the South Dakota Geological Survey and the U. S. Geological Survey are cooperating in a series of water-resources investigations. This report covers the third county-wide investigation in the series.

Clay County, the smallest county in South Dakota, has an area of 403 square miles (257,920 acres) and a population of 10,810 (1960). It is near the southeast corner of the State (see fig. 1) at the confluence of the Missouri and Vermillion Rivers.

The physiographic subdivisions shown on figure 1 correspond to conspicuous topographic features of the county. The dissected uplands north of the Missouri River and west of the Vermillion River are part of the James River highlands, and those north of the Missouri and east of the Vermillion are part of the Coteau des Prairies. The Vermillion River floodplain and the relatively flat uplands along its margins are part of the James River lowland, and the Missouri River floodplain is part of the Missouri River trench. The Missouri and Vermillion floodplains together include about one-third of Clay County.

The gently undulating surface of the Missouri River floodplain in Clay County slopes gradually from an altitude of about 1,160 feet at the Yankton County line to about 1,130 feet at the Union County line. At the margin of the floodplain, the land surface rises abruptly to an altitude of about 1,300 feet along the James River highlands and to slightly over 1,200 feet along the edge of the James River lowland east of Vermillion.

The Vermillion River floodplain, which is bordered by bluffs 50 to 75 feet high, slopes gradually southward from an altitude of about 1,180 feet at the Turner County line to about 1,135 feet at its junction with the Missouri River floodplain near Vermillion. Gradients of the Vermillion and Missouri Rivers in Clay County are 1.5 and 1.1 feet per mile, respectively.

Northward from the "bluff" at the edge of the Missouri trench, the surface of the James River highlands rises steeply but irregularly to an altitude of about 1,475 feet a few miles south of Irene. The James River lowland slopes upward about 70 feet in the nearly 10 miles between the "bluff" and the highland margin to the north. From this margin northward, the Coteau des Prairies rises with a uniform slope to an altitude of about 1,500 feet near the northeast corner of the county.

Pleistocene glacial, alluvial, and eolian deposits and Recent alluvium and colluvium comprise the surficial deposits in Clay County. (See Part I of this bulletin.)

Strata at the bedrock surface include all Cretaceous units from the

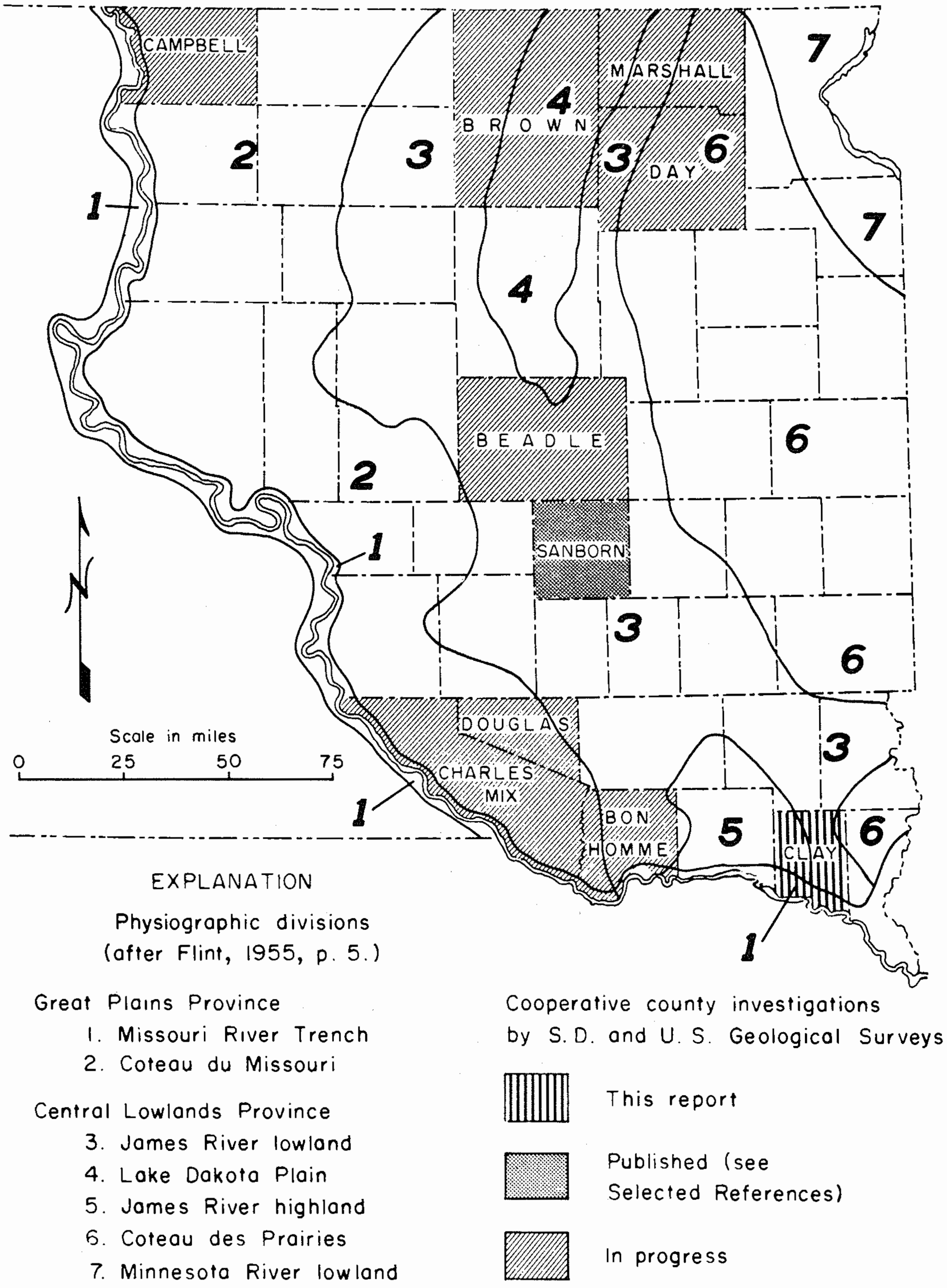

Figure 1. Map of eastern South Dakota showing physiographic divisions and areas of cooperative county investigations.

Niobrara Marl[1] downward through the upper part of the Dakota Group. (See table 1.) The only exposures of bedrock in the county are in T. 93 N., R. 52 W., where small outcrops of Niobrara Marl are present on Spirit Mound in sec. 14 and near the top of the bluff above the Missouri River floodplain in secs. 5 and 8. A small exposure of Carlile Shale occurs near the base of the bluff in sec. 5.

The Cretaceous strata are underlain by strata of Cambrian(?) age (table 1) which in turn are underlain by Precambrian rocks. No pre-Cretaceous rocks are known to yield water to wells in Clay County.

Part I of this report describes the geology of Clay County in detail. Jorgensen (1960) described the geology and shallow ground-water resources of the Missouri River trench. Data used in interpreting the hydrology and geology of the county can be found in the basic data report by Christensen and Stephens (in preparation). Other reports that include information on geology or water resources of all or part of Clay County are listed at the end of this report.

Wells, test holes, and springs referred to in this report are located according to the numbering system shown on figure 2. Each well is assigned a number based on its location according to the Federal land-survey system used in South Dakota. The number consists of the township, range, and section numbers separated by hyphens, a maximum of four lowercase letters that indicate, respectively, the 160, 40, 10, and $2\frac{1}{2}$-acre tract in which the well is located, and a serial number, if necessary, to distinguish between wells in the same tract. Thus, well 93-52-15da (fig. 2) is in the NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 15, T. 93 N., R. 52 W.

The writer gratefully acknowledges the help and cooperation of officials and residents of Clay County. Special thanks are due Mr. Fred Schmer, former Irrigation Engineer, Cooperative Extension Service, South Dakota State University, who collected many of the samples that were used to determine water quality and provided much additional help and information. Mr. Raymond Venard, County Extension Agent, and Dr. Oscar Olson, Dr. John Wiersma, and Mr. Raymond Ward, all of South Dakota State University, provided much valuable assistance and information.

HYDROLOGY

The water resources (usable water to which man has direct access) of an area can be divided into two classes: surface water and subsurface water. Water that falls from the atmosphere may run off or accumulate on the surface as surface water, or infiltrate the soil and become subsurface

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[1] Stratigraphic nomenclature and classification used in this report are those of the South Dakota Geological Survey. They differ somewhat from usage accepted by the U. S. Geological Survey.

1.--Generalized columnar section and water-yielding capability of geologic units in Clay County.

Age	Geologic unit	Thickness (feet)	Description and extent	Water-yielding capability
RECENT	Alluvium	0- 50± Surficial deposits-maximum composite thickness 256(?) ft.	Stratified clay, silt, and sand, locally sandy gravel; usually dark brown or black. Thickest deposits on Missouri and Vermillion River floodplains; thin, discontinuous deposits in minor drainageways.	Although not generally an aquifer except under the Missouri River floodplain, where it forms part of the Lower Vermillion-Missouri aquifer, the thickest, best-sorted deposits yield moderate to large amounts of water.
	Colluvium	0- 15	Poorly stratified clay and silt, usually sandy and gravelly; brown to yellow brown. Occurs locally at and near base of steep slopes.	Aquiclude.
	Loess	0- 15	Massive silt and very fine sand; light yellow-brown to gray. Occurs as a nearly continuous mantle on the James River lowland west of the Vermillion River and in discontinuous patches east of the river.	Aquitard. Locally contains perched ground water, but transmits water too slowly to supply wells.
? PLEISTOCENE	Outwash	0-180±	Stratified silt, sand, and gravel with variable amount of admixed or interlayered clay; brown to gray. Occurs at the surface in small patches on the Vermillion River floodplain in T. 95 N., and overlain by till or alluvium under the Missouri and Vermillion River floodplains and in the buried bedrock valley.	Forms major part of Lower Vermillion-Missouri aquifer. Yields large amounts of water (as much as 2,500 gpm) to wells. Supplies about 70 percent of water used in Clay County.
	Till	0-136	Unstratified silty clay containing sand, gravel, and cobbles; yellow-brown to dark gray. Occurs at the surface or underlying the loess throughout the James River highlands and lowland (except Vermillion River trench) and the Coteau des Prairies.	Aquiclude. Confining layer over parts of deeper aquifers.
	Loess	0- 43	As above. Occurs locally in subsurface on James River highland and Coteau des Prairies.	Aquitard.
	Alluvium(?)	0- 28	Stratified sand and gravel, light-yellow to pink; locally black silt and fine sand. Occurs in discontinuous subsurface deposits on James River highland and Coteau des Prairies.	Forms part of Wakonda aquifer. May yield moderate to large amounts of water where thickest.
CRETACEOUS	Niobrara Marl	0-220(?)	Shale, calcareous, soft; light-gray to black where unweathered, yellow to tan where weathered. Underlies much of James River highland and Coteau des Prairies.	Forms part of Wakonda aquifer. Yields small to moderate amounts of water from and transmits water through fractures. Wells flow in some areas.
	Carlile Shale, including Codell Sandstone Member	0-100(?) 0- 36(?)	Shale, noncalcareous, tough; black. Locally contains a layer of fine-grained light-gray sandstone (Codell Sandstone Member) near top. Present under much of James River highland and Coteau des Prairies.	The shale is an aquiclude. The Codell Sandstone Member yields small to moderate amounts of water to pumped wells.
	Greenhorn Limestone	0-135	Limestone or hard, highly calcareous shale in upper part; soft, calcareous shale in lower part; usually light- to dark-gray. Underlies entire county except bottom of buried bedrock valley east and southeast of Vermillion.	Aquiclude(?). Yields small amounts of water in other areas but is not known to yield water in Clay County.
	Graneros Shale	0- 18(?)	Shale, noncalcareous; black. Probably present only in small area near Vermillion.	Aquiclude.
	Dakota Group	(?)-400(?)	Interbedded siltstone, sandstone, and shale; light-gray to black. Underlies entire county.	Sandstone beds yield small to large amounts of water to pumped wells on uplands and to flowing wells on Missouri River floodplain west of Vermillion. Major aquifer in bedrock.
CAMBRIAN (?)	St. Croixian(?) Series	Unknown	Probably interbedded siltstone, sandstone, and shale. Exact composition and extent unknown.	Not known to yield water in Clay County.
PRECAMBRIAN	Sioux Quartzite	Unknown	Fine to coarse-grained quartzite; may be present in northern part of county.	Not known to yield water in Clay County.
	Granite, other igneous rocks, metamorphic rocks	Unknown	Composition variable. Present under entire county.	Not known to yield water in Clay County.

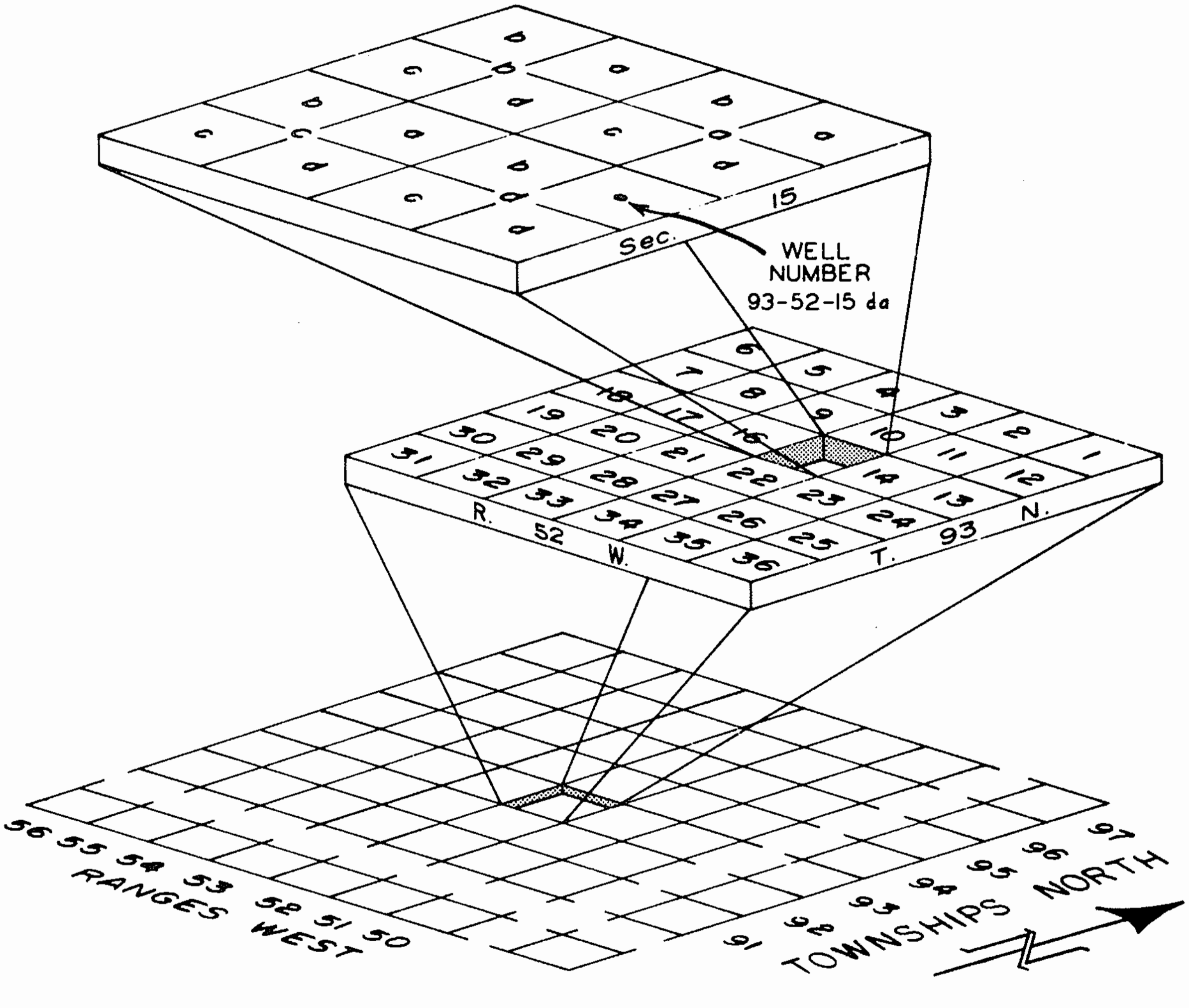


Figure 2. Well-numbering system.

water. Evaporation from surface-water bodies and from soil and shallow ground-water reservoirs, and transpiration of soil moisture and shallow ground water by vegetation, return large amounts of water directly to the atmosphere. Thus, if an entire drainage basin is considered, the quantity of surface and subsurface-water resources is much less than the quantity of precipitation that falls.

Water in Clay County occurs in surface streams and reservoirs and in the intergranular spaces of surficial deposits and bedrock strata. Some of this water comes from precipitation in the county; the remainder flows into the county, either on or below the surface, and is derived from precipitation outside the county.

Normal annual precipitation in Clay County is about 505,000 acre-feet (23.5 inches); annual net runoff probably is no more than 45,000 acre-feet. The remaining 460,000 acre-feet of precipitation evaporates, is transpired, adds to soil moisture, is stored on the surface, or recharges ground-water reservoirs.

Surface Water

Streams

The major streams in Clay County are the Missouri and Vermillion Rivers, which converge a few miles southeast of Vermillion. Neither of these rivers is used as a source of water supply, except for some livestock.

The Missouri River is controlled by dams upstream from Clay County, and discharge is regulated in accordance with flood control, power generation, and navigation requirements. Prior to construction of the dams, discharge of the Missouri River was erratic, and floods occurred frequently during and after spring snow melt. Although an abundant supply of water is available in the river, adjacent land is undeveloped in Clay County, and no use is made of the water.

The average annual discharge of the Vermillion River at gaging station 95-52-2bc in the period 1945-60 was 90,500 acre-feet (U. S. Geol. Survey, 1964, p. 478). Monthly discharge, from 1945 through 1964, is shown on plate 1. Periods of no measurable discharge, ranging in length from less than a day to more than a month, have occurred several times at the gaging station.

The major tributaries of the Vermillion River in Clay County (see fig. 5) are Spring Creek; Clay Creek Ditch, an artificial drainageway on the Missouri River floodplain; Ash Creek; and Baptist Creek. All the tributaries are intermittent.

Runoff and stream discharge from the county, except in the Missouri River, are ordinarily greatest in late March and April as a result of snow melt, and in May and June as a result of precipitation. (See plate 1.) Because of increasing rates of evapotranspiration, runoff generally begins to decrease in late June, even though large amounts of rainfall are received in July and August. Pengra (1959, p. 34, 53) determined that average daily potential evapotranspiration greatly exceeds average daily precipitation at Centerville and Vermillion, from about the middle of June through at least the end of August. Precipitation in amounts equal to or less than the daily average would therefore contribute little to runoff during this period. Runoff from mid-June through August results from abnormally intense precipitation, abnormally large amounts of precipitation, or abnormally low temperatures and high humidity.

Reservoirs

A few small ponds and sloughs in the county contain water perennially, and water is stored intermittently in numerous "potholes" and sloughs, especially on the Missouri and Vermillion River floodplains. There are no large permanent reservoirs in the county.

During and immediately following spring snow melt, or heavy or prolonged rainfalls, many shallow artificial and natural depressions store water on the land surface. Much of the water thus stored evaporates within a few days or weeks, and the remainder infiltrates the soil and becomes subsurface water.

Ground Water

Principles of Occurrence

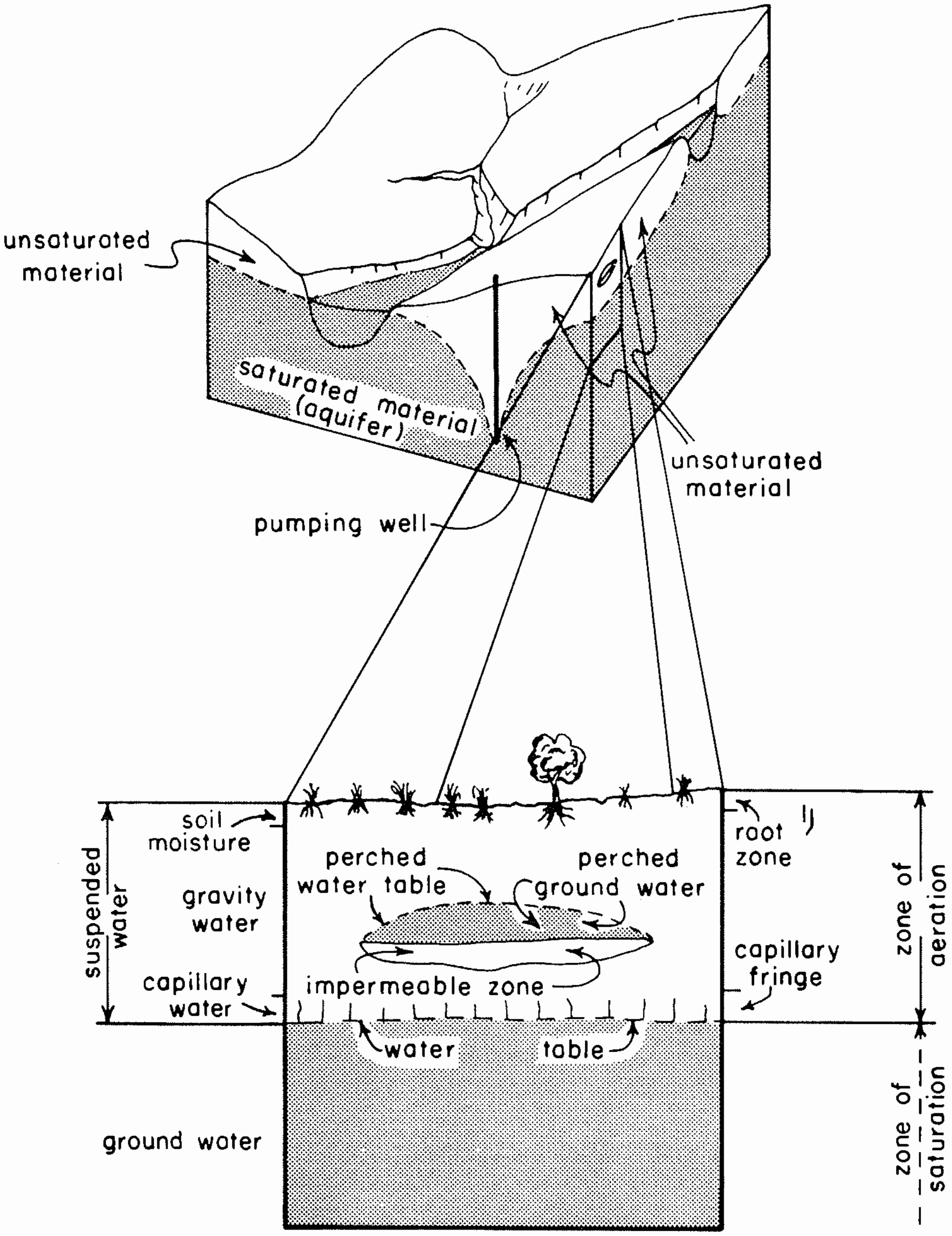
Subsurface water, the most used water resource in Clay County, is divisible into two major categories, suspended water and ground water, according to its location within the subsurface materials. Figure 3 shows these divisions.

Suspended water, which is held against the force of gravity by adhesive forces is unavailable to man. Soil moisture, which is water suspended in the soil zone, is of great significance, however, for it provides the water necessary for plant growth. Infiltrating water must fill the soil to capacity before any water can move downward through the zone of aeration. Water in excess of soil-moisture capacity moves downward because of gravity, and is called vadose, or gravitational. At the bottom of the zone of suspended water which comprises soil water, gravitational water and capillary water, is a zone containing capillary water, or water held in place above the saturated zone by cohesion of the water molecules and adhesion of the water to the solid material.

The surface of the zone of saturation, or ground-water zone, where the saturated material is not confined by an impervious layer, is called the water table. (See fig. 3.) This surface generally is a subdued replica of the land surface, and slopes downward from recharge area to discharge area.

Within the zone of aeration, a relatively impermeable zone may block or retard the downward movement of water and cause the formation of a perched water table. Such a zone is separated from the zone of saturation by unsaturated materials containing gravity water.

Ground water may be free, confined, or fixed. Fixed ground water, which is normally unavailable for man's use, is held in place against normal hydraulic pressures by adhesive forces. Free ground water moves un-



1/ Root zone and capillary fringe may extend completely through zone of aeration

Figure 3. Diagram showing divisions of subsurface water.

der the influence of gravity in the direction of the slope of the water table (fig. 3). Confined (artesian) ground water occurs below an impermeable confining layer and moves under the influence of the difference in head between intake and discharge areas. (See fig. 4.) Free and confined ground water constitute the ground-water resources, or available ground water.

The movement of ground water is controlled in large part by the physical characteristics of the containing material. The amount of water that a given material can contain depends on the porosity (cracks or spaces between grains) of the material. The amount of water that can move through the material depends on the permeability (the ease with which the material can transmit water), and on the effective porosity (the degree to which pores are interconnected by openings large enough to transmit water freely).

Geologic formations are classified according to their water-transmitting ability as follows (DeWiest, 1965, p. 133-134):

> "Aquifer: a geologic formation or stratum containing water in its voids or pores that may be removed economically and used as a source or water supply. Unconsolidated...deposits of sand and gravel, consolidated sandstones are examples...
>
> Aquiclude: a geologic formation so impervious (impermeable) that for all practical purposes it completely obstructs the flow of ground water (although it may be saturated with water itself), and completely confines other strata with which it alternates in deposition. A shale is an example.
>
> Aquitard: a geologic formation of a rather impervious and semi-confining nature which transmits water at a very slow rate compared to the aquifer. Over a large area of contact, however, it may permit the passage of large amounts of water between adjacent aquifers which it separates from each other. Clay layers interbedded with sands, if thin enough, may form aquitards."

The impermeable zone below the perched water table in figure 3 may be an aquiclude or an aquitard. In figure 4, an aquifer and aquicludes are indicated.

Aquifers in Surficial Deposits

More than two-thirds of the wells in Clay County are completed in aquifers in surficial deposits. These deposits shown on figure 5 and in Part I, plate 1, accumulated as a result of action by water, wind, and glacial ice.

Much of the surface of the James River lowland west of the Vermillion River is mantled with loess, a windblown deposit of silt and fine sand. The loess in Clay County (fig. 5) is slightly to moderately permeable but, because it is normally less than 15 feet thick (see Part I, p. 17) and because it is fine grained, it is not an aquifer.

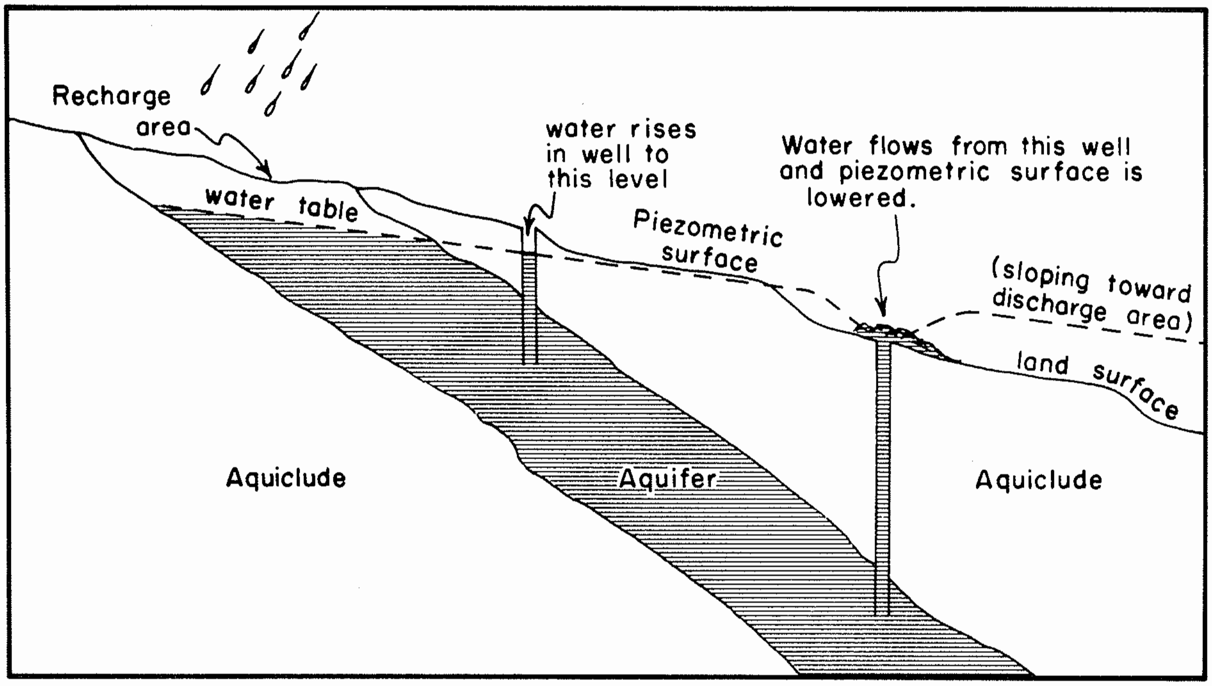
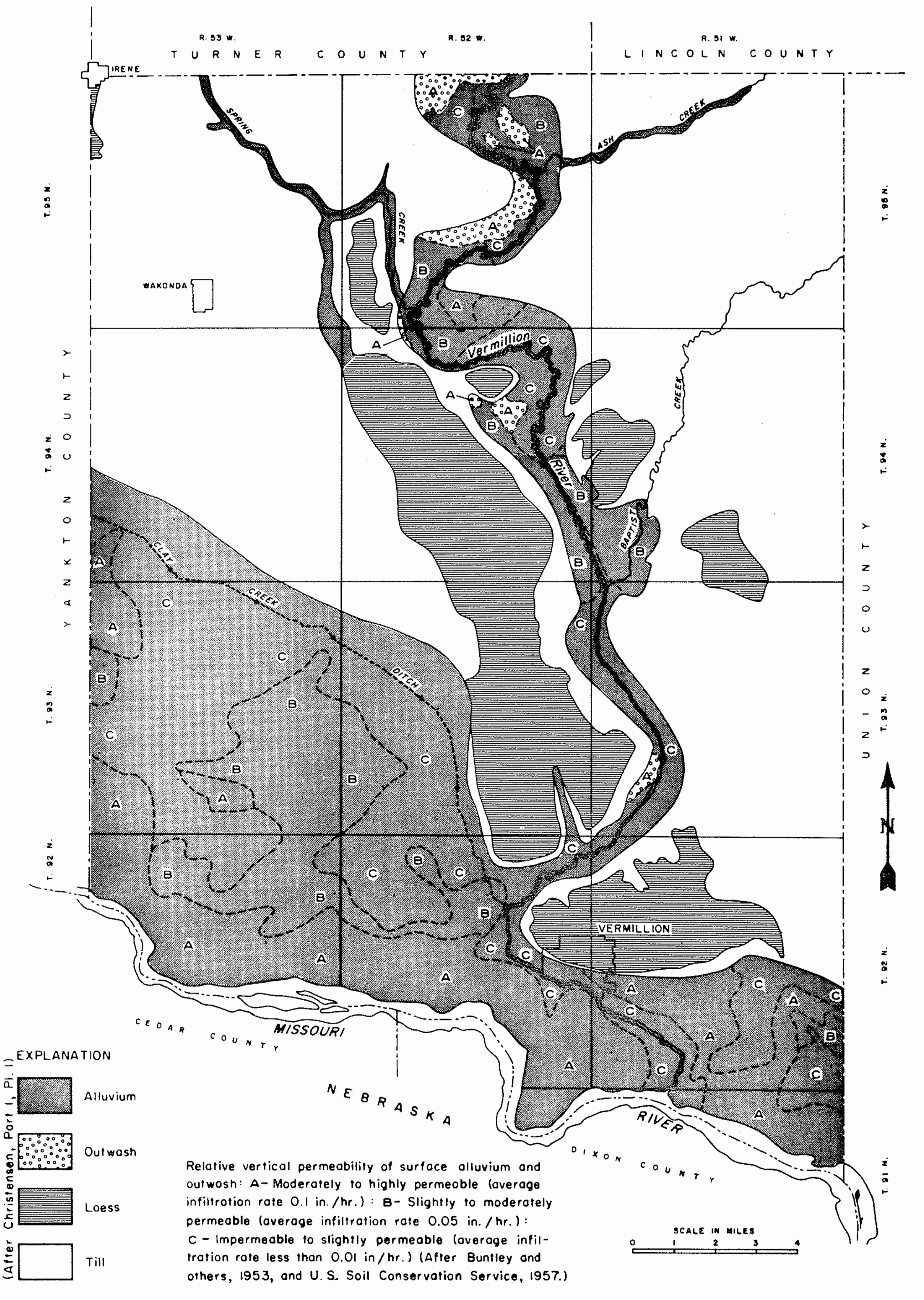


Figure 4. Diagram of confined (artesian) aquifer system.



(After Christensen, Part I, Pl. I)

Relative vertical permeability of surface alluvium and outwash: A- Moderately to highly permeable (average infiltration rate 0.1 in./hr.): B- Slightly to moderately permeable (average infiltration rate 0.05 in./hr.): C - Impermeable to slightly permeable (average infiltration rate less than 0.01 in/hr.) (After Buntley and others, 1953, and U. S. Soil Conservation Service, 1957.)

Figure 5. Generalized geologic map showing relative permeability of flood-plain deposits.

Throughout most of its extent, the loess is immediately underlain by an aquiclude composed of till--unsorted, unstratified material consisting mainly of boulders, gravel, sand, and silt in a matrix of clay, deposited directly from or by glacial ice--and, as a consequence, commonly contains perched ground water. Where loess overlies more permeable material, it may transmit water very slowly into the permeable material.

The extent and thickness of water-saturated aquifer material in surficial deposits in Clay County are shown on plate 2. Figure 6 shows the thickness of surficial deposits, and plate 3 shows the relation of the aquifers to the surface features and to surficial and bedrock formations in the county.

Lower Vermillion-Missouri aquifer

The southern extension of the "Parker-Centerville outwash," described by Tipton (1957), and the glacial outwash deposits underlying the Missouri River floodplain, described by Jorgensen (1960), merge near Vermillion to form a single aquifer which, in Clay County, contains an estimated 5 million acre-feet of water in transient storage. This aquifer, here named Lower Vermillion-Missouri aquifer, underlies about 75 percent of the land area of Clay County (pl. 2) and has an average thickness of about 100 feet.

The Lower Vermillion-Missouri aquifer is composed mainly of glacial outwash--sorted, stratified gravel, sand, silt, and clay deposited by meltwater streams beyond the margin of active glacial ice. Throughout much of the county, the outwash is overlain by a till aquitard.

On the floodplains of the Missouri and Vermillion Rivers (fig. 5) the outwash is overlain by alluvium--gravel, sand, silt, and clay that was transported by the rivers and deposited at places where the velocity of the water was insufficient to maintain the materials in motion. Much of the floodplain alluvium is permeable and forms a single aquifer with the underlying outwash.

The greatest known thickness of the Lower Vermillion-Missouri aquifer is 170 feet at test hole 93-51-15aaaa$_2$. The test hole log, given below, indicates that at this location the aquifer (70 to 240 feet) is composed predominantly of clay-free sand and gravel.

Material	Depth (feet)
Sand and till, brown	0- 25
Till, gray	25- 70
Sand and coarse to medium gravel, gray	70-170
Sand, gray, medium; silty	170-240
Shale, brown and gray; silty	240-260

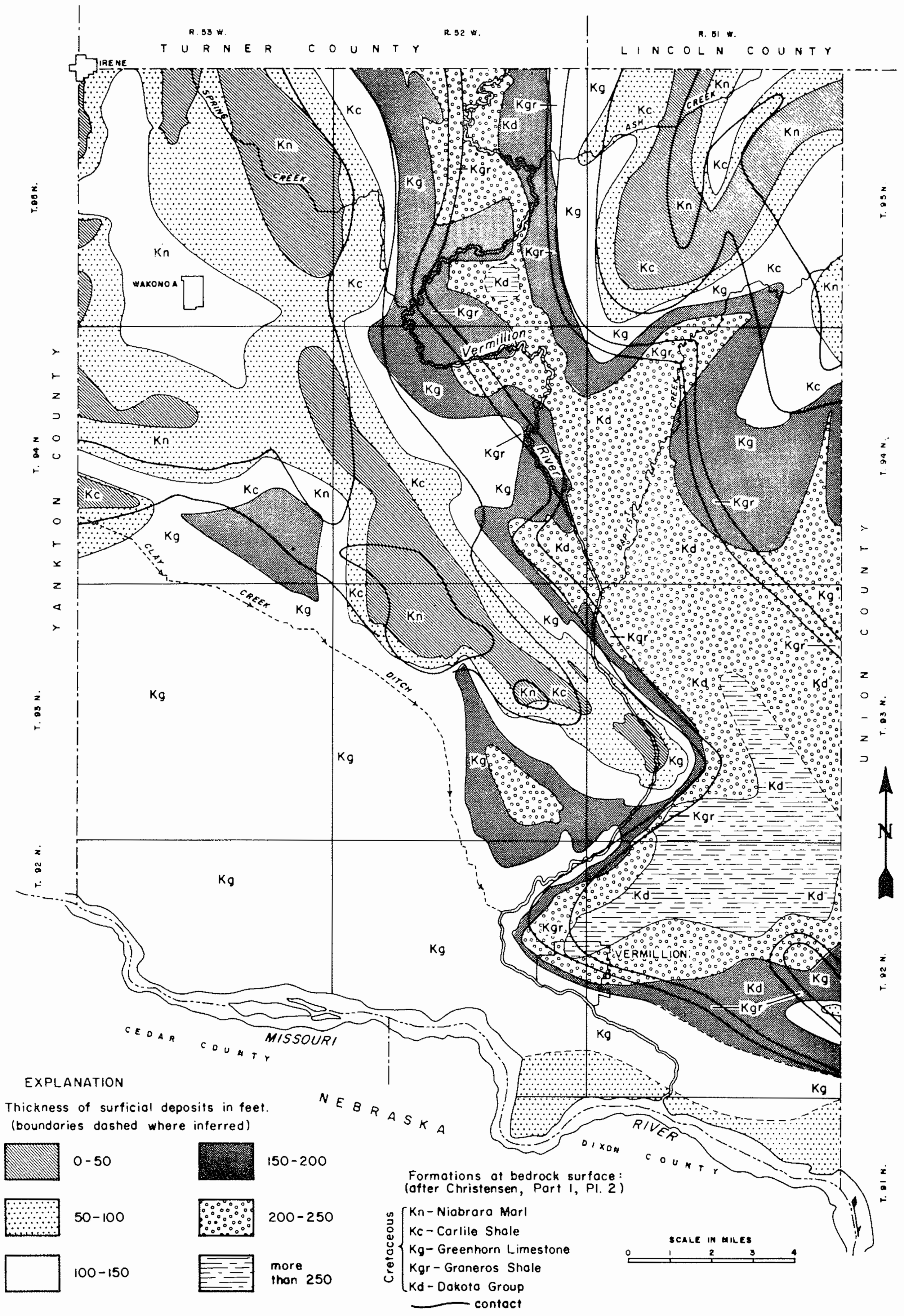


Figure 6. Map showing thickness of surficial deposits and extent of geologic formations at bedrock surface.

Some of the more important physical and hydrologic characteristics of the aquifer materials, as determined indirectly from laboratory analyses and directly from field tests, are given in table 2. Terms used in table 2 are defined as follows:

Specific capacity - the rate of discharge in gallons per minute (gpm) that can be obtained from the well for each foot of drawdown in the well. Specific capacity of 100 indicates that for a pumping rate of 100 gpm the water level in the pumped well lowers 1 foot.

Transmissibility - the average field coefficient of permeability multiplied by the aquifer thickness in feet. This coefficient expresses the rate of flow of water in gallons per day (gpd) at the prevailing water temperature through a vertical strip of the aquifer 1 foot wide extending the full saturated thickness of the aquifer under a hydraulic gradient of 100 percent.

Permeability - a field coefficient expressing the rate of flow of water (gpd) at the prevailing water temperature through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent.

The coefficients of transmissibility and storage listed in table 2 are useful in determining well yields, drawdown, and well spacing. Figure 7 illustrates the relationship between transmissibility and storage coefficients and drawdown for a representative aquifer having characteristics similar to those of the Lower Vermillion-Missouri aquifer. A transmissibility coefficient of 200,000 gallons per day per foot (gpd/ft)--equivalent to an aquifer 100 feet thick with a permeability of 2,000 gallons per day per square foot (gpd/sq ft)--was assumed for the aquifer. The curves show that where transmissibilities are identical, pumping at a given rate causes greater drawdown in an artesian aquifer (assumed storage coefficient 0.0004, fig. 7) than in a water-table aquifer (assumed storage coefficient 0.1, fig. 7).

Drawdown values shown on figure 7 are similar to those that are encountered in the vicinity of wells pumping from the Lower Vermillion-Missouri aquifer--water-table conditions generally prevail on the floodplains and artesian conditions prevail on the uplands in Clay County. Thus, well 92-51-20d, located in an area of water-table conditions, pumping 1,000 gpm continuously for 10 days, would lower the water table about 4.2 feet just outside the well casing, about 1.7 feet at a distance of 100 feet, and about 0.2 feet at a distance of 1,000 feet.

The conditions assumed for computation of the curves in figure 7 are not always encountered in the field--that is, actual aquifers are not completely homogeneous and of infinite extent. Where barriers to the uniform movement of water, such as interbedded layers of clay or impermeable bedrock or till sides of a buried valley, exist within the area influenced by the pumping well, drawdown will be greater than shown by figure 7. Where layers of more permeable material, or hydraulically connected surface-water bodies, come within the area of influence, drawdown will be less than shown by figure 7. In general, however, and particularly for the central part of the Lower Vermillion-Missouri aquifer, drawdown values determined from figure 7 should be about the same as actual values near a well pumping from a 100-foot thickness of aquifer material.

Table 2.--Selected hydrologic characteristics of unconsolidated aquifer material.

Well or sample no.	Location	Specific capacity[1] (gpm/ft drawdown) and Length of test	Transmis-sibility[2] (gpd/ft)	Permeability (gpd/sq ft) From specific capacity[2]	Permeability (gpd/sq ft) From size analysis[3]	Remarks
				CLAY COUNTY		
1	92-51-19	---	---	---	1,450	Average of 2 gravel pit samples.
2	92-51-20d	154 (24 hr)	192,000	2,000	---	Well; aquifer 96 feet thick.
3	92-51-27cad	134 (½ hr)	138,000	1,500	---	Well; aquifer 92 feet thick.
4	92-52-1a	---	---	---	4,800	Gravel pit.
5	92-53-13acaa	124 (24 hr)	155,000	1,550	---	Well; aquifer 100 feet thick.
6	93-51-29aa	---	---	---	6,200	Average of 2 gravel pit samples.
7	93-51-29cd	---	---	---	3,600	Average of 22 gravel pit samples; permeability area A on figure 6 (surface outwash).
8	93-53-31ccaa	173 (½ hr)	185,000	1,850	---	Well; aquifer 100 feet thick.
9	94-52-9b	---	---	---	9,500	Average of 2 gravel pit samples.
10	94-52-10c	---	---	---	2,500	Average of 12 gravel pit samples; permeability area A on figure 6 (surface outwash).
11	94-52-11cb	---	---	---	13,000	Test hole; samples from 20-foot depth; permeability area A on figure 6 (surface outwash).
12	94-52-15aa	---	---	---	2,800	Gravel pit; permeability area A on figure 6 (surface outwash).
13	95-52-3baba	55 (½ hr)	52,000	1,300	---	Well; aquifer 40 feet thick.[4]
14	95-52-5adaa	72 (½ hr)	71,000	1,800	---	Well; aquifer 40 feet thick.[4]
				TURNER COUNTY		
15	96-52-27b	79 (24 hr)	91,000	2,300	---	Well; aquifer 40 feet thick.[4]
16	96-52-33c	66 (½ hr)	62,000	1,500	---	Well; aquifer 41 feet thick.[4]

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[1] Specific capacities of wells 3, 8, 13, 14, and 16 measured by S. W. Black, S. Dak. State Univ. (written communication); others measured by U. S. Geol. Survey.

[2] Transmissibilities estimated from specific capacity by method described by Walton (1962, p. 12-13); permeabilities determined from transmissibility and aquifer thickness.

[3] Samples 1, 4, 6, 7, 9, 10, 11, and 12 collected and analyzed by S. Dak. Dept. of Highways (written communication); permeability calculated from effective grain size, using graph developed by Rose and Smith (1957, fig. 1).

[4] Wells are developed in upper aquifer separated from underlying aquifer material by clay aquitard 10 to 15 feet thick.

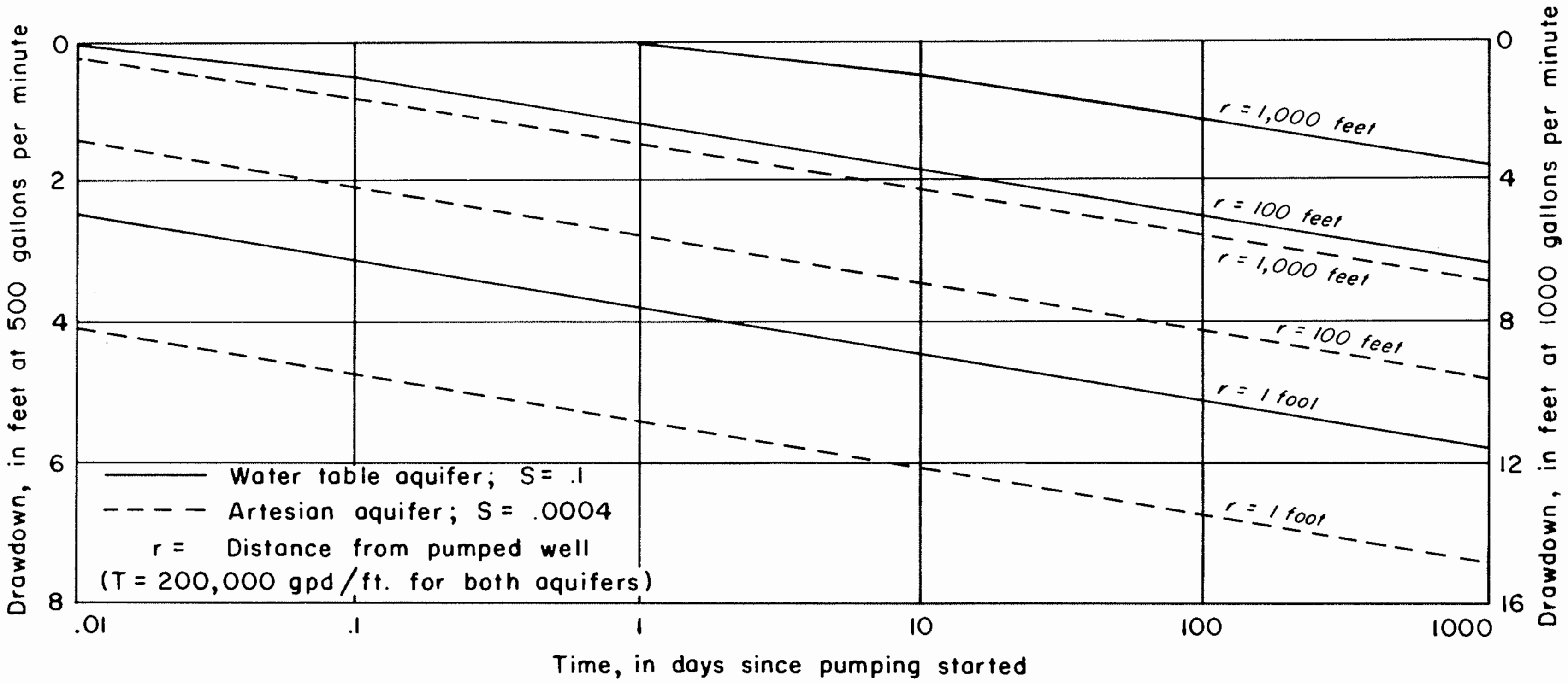

Figure 7. Theoretical drawdown curves for representative water-table and artesian aquifers.

As shown on the cross sections in plate 3 and in test-hole logs (Christensen and Stephens, in preparation), the near-surface portion of the Lower Vermillion-Missouri aquifer under the Missouri and Vermillion River floodplains contains more silt and clay, and consequently is less permeable, than the underlying aquifer material. The near-surface material, which in many places is an aquitard, is predominantly Recent alluvium. Similar silty or clayey aquitard layers occur within the main part of the aquifer.

Recharge.--The Lower Vermillion-Missouri aquifer in Clay County receives recharge from direct penetration of precipitation, influent seepage from streams, and subsurface inflow from adjacent areas. The relative importance, quantitative as well as qualitative, of each type of recharge is unknown. The quantity of recharge from each source varies with time; stream discharge, ground-water discharge, local departures from normal precipitation, and long-term climatic fluctuations all influence the amount of recharge received. Water-quality factors, discussed in a following section, are often directly related to, and useful in determining, the recharge source.

Normal precipitation in Clay County is about 505,000 acre-feet annually. Of this amount, about 45,000 acre-feet or less leaves the county as surface runoff, yet only a small part of the remaining 460,000 acre-feet of precipitation recharges the aquifers. As noted on page 8 , average daily potential evapotranspiration greatly exceeds average daily precipitation in Clay County from about the middle of June to the end of August. During this time, normally distributed rainfall in average amounts would be returned to the atmosphere without adding to ground-water storage.

When rainfall occurs in excess of average amounts, some of the excess may recharge the aquifer. Infiltrating water must bring the soil to its moisture-holding capacity before any recharge can take place. During summer, average daily soil moisture at Vermillion and Centerville ranges from about 40 to 75 percent of capacity (Pengra, 1959, fig. 1).

Alluvial floodplain deposits (shown on fig. 5) along the Missouri and Vermillion Rivers directly overlie the aquifer in about 30 percent of the county. The average moisture-holding capacity of floodplain soils is about 5 inches (estimated from U. S. Soil Conservation Service, 1957, and Buntley and others, 1953). Pengra assumed a soil-moisture capacity of 4 inches for his studies; his values for average daily soil moisture as percent of capacity would therefore be higher than the true values for floodplain soils. The values may, however, be used to estimate the minimum amount of infiltration necessary to fill the soil to capacity.

The average short-term infiltration rate for floodplain soils in Clay County is about 0.5 inch per hour (estimated from U. S. Soil Conservation Service, 1957). Using Pengra's values, a minimum (depending on the initial moisture conditions) of 1.2 to 3.1 inches of water would be required to bring soil moisture to capacity. Thus, after 6 hours or less of infiltration at the average short-term rate, water could begin recharging the aquifer. Normally, the infiltration rate decreases as the soil moisture increases, and the long-term average rate is probably little more than 0.1 inch per hour.

Normal precipitation generally does not provide sufficient water to allow infiltration at the maximum rate for prolonged periods. If sufficient water was present on the surface, and if the infiltration rate remained constant at 0.1 inch per hour, about 640 acre-feet of water per hour could infiltrate the soils on the floodplains of Clay County.

Runoff from the floodplains is slight because of the flat to very slightly undulating topography and the relatively high intake rates of the soils. Light to moderate rains in the spring and summer cause ponding of water on the floodplains in some areas (areas marked C, fig. 5). These small ponds often remain for several days after a rain. In such areas, soil intake rates are much less than 0.1 inch per hour, and little recharge occurs. Most of the ponded water evaporates or is transpired. Over much of the floodplains, ponded water disappears rapidly after a rain (areas marked B, fig. 5), or ponds do not form (areas marked A, fig. 5). In these areas, infiltration rates are such that water is taken rapidly into the soil, and much of the infiltrating water becomes recharge.

Where the Lower Vermillion-Missouri aquifer is overlain by till, little or no direct recharge from precipitation occurs. Intake rates of soils developed on till generally are low (less than 0.01 inch per hour) and the soils have moisture capacities of 1.75 to 2.20 inches per foot of thickness (U. S. Soil Conservation Service, 1957). The till, which averages about 100 feet in thickness where it overlies the aquifer, is an aquiclude in Clay County, as in most of eastern South Dakota.

Influent seepage from the Vermillion River is a source of recharge to the Lower Vermillion-Missouri aquifer in Clay County during a part of each year. Comparison of Vermillion River discharge (pl. 1) and water levels in observation wells on the floodplains (wells V-5, V-6, and SDGS-47, pl. 1) indicates that the ground-water level is generally high during times of greatest stream discharge. During floods, water levels in these observation wells are commonly at or very near the land surface. Much of the water taken into storage in the aquifer when the river level is high is discharged to the river during and after recession of the high water.

An accurate assessment of the river's contribution to recharge of the underlying aquifer in Clay County would require gaging stations at the Turner-Clay County line and at the confluence of the Vermillion and Missouri Rivers, as well as a network of observation wells in the aquifer. From available data it appears that the Vermillion River, at most times, is an effluent stream--that is, the river receives ground-water discharge.

During floods, water may cover the entire floodplain, and infiltration of river water fills the soil to capacity and raises the water table to or above the land surface. Infiltration of flood waters, because of control structures on the Missouri River, is presently limited to the Vermillion River floodplain and areas on the Missouri River floodplain that are inundated by Vermillion River flood waters.

Controlled release of Missouri River water from Gavins Point Dam in Yankton County has resulted in the lowering of the water table under the Missouri River floodplain. The water table is reported to have declined an average of about 4 feet under the floodplain near Yankton following initial closing of the dam, and to have remained at this lower level. Water levels under the floodplain in Clay County probably declined similarly.

The decline in water level under the floodplain caused by controlled release of Missouri River water indicates that the ground-water level is closely related to river level. Precise measurements of river stage and water-table altitude under the floodplain are unavailable, but a few general measurements indicate that ground water probably is discharged into the Missouri River in Clay County during the spring and early summer, and that influent seepage from the river probably recharges the aquifer in late summer and fall.

Because of the hydraulic continuity between the Missouri River and the ground water in the Lower Vermillion-Missouri aquifer adjacent to the river, much of the discharge of the Missouri River is potentially available to recharge the aquifer. Increased ground-water discharge by wells would induce additional recharge from the river.

The Lower Vermillion-Missouri aquifer is recharged by the aquifer in the Dakota Group in the area east and southeast of Vermillion. The aquifers are in contact (pl. 3) and, although the head difference is slight, a large volume of recharge enters the unconsolidated aquifer. Evidence in support of this conclusion is discussed elsewhere in this report.

The Wakonda aquifer recharges the Lower Vermillion-Missouri aquifer where the two are in contact in Tps. 94 and 95 N., R. 52 W. Water-level measurements in this area are scanty, but the few available measurements, plus the supporting chemical and geologic data, indicate that recharge to the Lower Vermillion-Missouri aquifer occurs along the entire area of contact. (See pl. 3.)

Relation of water quality to recharge.--Much of the variation in water quality in the Lower Vermillion-Missouri aquifer is directly related to the source and location of recharge areas. Plate 4, which is based on nearly 650 measurements of specific conductance and hardness, shows that hardness and specific conductance of the water vary systematically within the aquifer, as well as within the adjacent Wakonda aquifer and the aquifer in the Niobrara Marl. Water from the Wakonda aquifer moves down the hydraulic gradient and into the Lower Vermillion-Missouri aquifer where the two are in contact in T. 95 N. and the northern part of T. 94 N. (See pls. 2 and 3.) The more highly mineralized water from the Wakonda aquifer mixes with, and increases the dissolved-mineral content of, water in the Lower Vermillion-Missouri aquifer.

Hardness and specific conductance of water in the Wakonda and Lower Vermillion-Missouri aquifers (pl. 4) decrease regularly eastward from about the middle of T. 95 N., R. 53 W., to near the Vermillion River in T. 95 N., R. 52 W. The lower hardness and specific conductance of water in the Lower Vermillion-Missouri aquifer in the central part of Tps. 94 and 95 N., R. 52 W., under the Vermillion River valley, is due to dilution of the ground water in this area by only slightly mineralized water infiltrating from the surface.

The lowest hardness (less than 500 ppm) and the lowest specific conductance (less than 750 micromhos) of water in the Lower Vermillion-Missouri aquifer occur approximately under areas where outwash forms the floodplain surface (fig. 5) and where infiltration of precipitation and runoff from adjacent areas is most rapid.

The water-level (piezometric) contours on plate 2 indicate that the Vermillion River is receiving ground-water discharge, and the hydrochemical map indicates that the aquifer is receiving recharge under and adjacent to the Vermillion River. This apparent discrepancy is resolved, however, by the fact that most of the water discharged from the aquifer to the river is from infiltration of precipitation and runoff on the adjacent floodplain, and that the aquifer was filled to capacity at the time the water-level measurements on which the contours are based were made.

The "regional" direction of ground-water movement in the Lower Vermillion-Missouri aquifer is southeastward, and the Vermillion River is the overflow channel for water in excess of aquifer capacity. Thus, water is discharged to the river where the channel intersects the water table. Since most of the recharge in this area is from infiltration of precipitation on the floodplain, and the Vermillion River is incised an average of 8 to 12 feet below the floodplain, the water table slopes toward the river. Figure 8 shows the general directions of water movement under the Vermillion River floodplain in Tps. 94 and 95 N.

Discharge.--Natural discharge from the Lower Vermillion-Missouri aquifer is by seepage and flow from springs, by subsurface outflow, and by evaporation and transpiration.

Ground water is discharged into the Vermillion and Missouri Rivers when the water table in the Lower Vermillion-Missouri aquifer slopes downward to the water surface in the rivers. The water-level contours on plate 2 indicate that the Vermillion River was receiving water from the aquifer in September 1965.

The largest volume of ground-water discharge into the Vermillion River takes place during, and immediately following, periods of above-normal recharge to the aquifer. During floods, such as occurred in 1962 (see pl. 1), the water level in the aquifer is at the surface of the floodplain. Following a flood, the water level in the aquifer drops at a much slower rate than the water level in the river. Thus, water is stored in the aquifer during times of high water and released to the river during times of low water.

A similar situation occurs when, as in the summer of 1965, higher than normal quantities of precipitation infiltrate the aquifer. Although the water level in the Vermillion River was high as a result of above-normal precipitation, the water level in the aquifer was higher than the river-water level, and the aquifer discharged water to the river throughout much of the summer and fall.

Subsurface outflow from the Clay County portion of the Lower Vermillion-Missouri aquifer ranges from about 1,600 to 1,700 acre-feet per year, depending on the water level within the aquifer. The following table shows how water-level changes in the aquifer affect the volume of subsurface outflow:

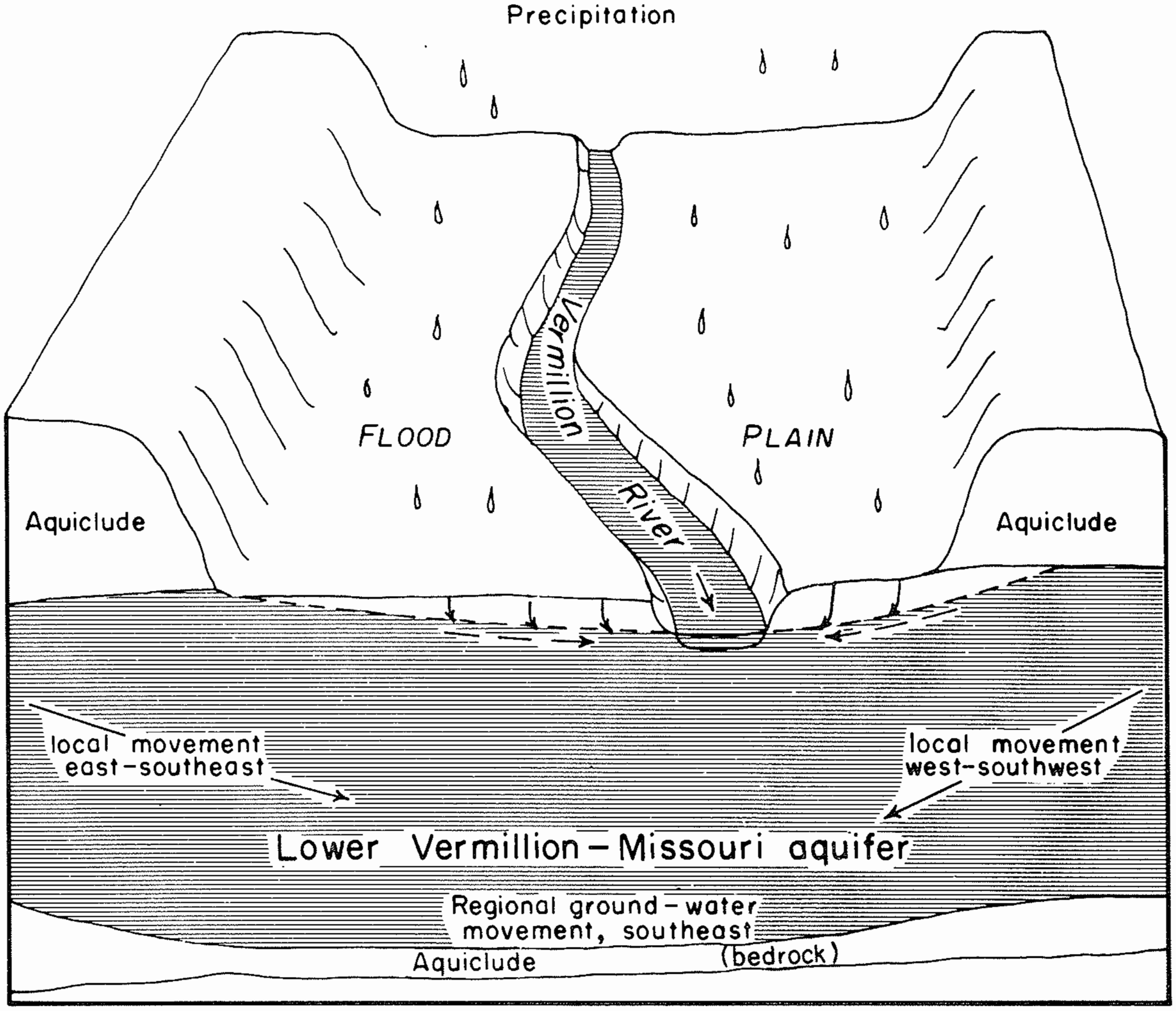

Figure 8. Water movement in relation to Vermillion River and its floodplain and in the lower Vermillion-Missouri aquifer in northern Clay County.

Average altitude of water table in area of outflow (feet)	Cross-sectional area through which flow occurs (sq ft) (A)	Average slope of water table in area of outflow (ft/ft) (I)	Permeability (gpd/sq ft) (P)	Total subsurface outflow (Q)	
				1,000 gpd	acre-feet per year [afy]
1,124	1,674,000	0.0005	1,750	1,465	1,640
1,125	1,690,000	.0005	1,750	1,479	1,655.5
1,126	1,705,000	.0005	1,750	1,492	1,671

The volume of outflow is computed according to Darcy's law, which states the relation between velocity of flow, permeability of material, and slope of water table. (Tolman, 1937, p. 200-201.) In its simplest form, Darcy's law states that Q = PIA,

where Q = discharge
P = permeability
I = water-table slope
A = cross-sectional area

The values of P, I, and A used in calculating outflow were determined from table 2 and plates 2 and 3.

Evapotranspiration removes more water from the Lower Vermillion-Missouri aquifer than is discharged in any other way. Total precipitation, its intensity and distribution throughout the year, temperature, wind velocity, and humidity all affect the amount of evapotranspiration. Direct evaporation of ground water takes place where the water table is at or near the land surface, and the evaporation rate decreases as the depth to the water table increases. Transpiration by plants is limited by the amount of water available in the root zone. Where the root zone extends down to or below the capillary fringe above the water table, transpiration may discharge water directly from the zone of saturation.

Nearly all discharge from the aquifer by evapotranspiration occurs on the river floodplains where the water table is near the surface and vegetation is most abundant. Native trees and shrubs adjacent to the river channels and in the many sloughs transpire large amounts of ground water, as do agricultural crops grown on the cultivated floodplain areas.

Artificial discharge from the Lower Vermillion-Missouri aquifer is primarily through wells. Agricultural practices, river-channel alterations, and the construction of artificial drainageways by man have an effect on discharge from the aquifer, but discharge resulting from these practices cannot be distinguished from natural discharge.

An estimated 2,000 acre-feet of water was discharged from the Lower Vermillion-Missouri aquifer by wells in 1964. The volume of discharge by wells varies greatly from year to year, mostly as a result of climatic variations. In a year of scanty precipitation, water use for irrigation and livestock is much greater than in a year of abundant precipitation. Extremely hot summers result in increased water use for irrigation, livestock, domestic, and municipal purposes.

Water use.--More than 70 percent of the water used in Clay County in 1964 was supplied by the Lower Vermillion-Missouri aquifer. As shown in table 3, this was an estimated 1,730 acre-feet of water. The aquifer furnishes water for about 92 percent of the domestic wells in the county, 39 percent of the stock wells, and 57 percent of the wells used for both domestic and stock supplies.

All irrigation wells in Clay County are completed in the Lower Vermillion-Missouri aquifer. Yields of individual wells range from about 100 to 2,000 gpm, according to well construction and pumping equipment. About 450 acre-feet of water, or nearly one-fifth of the water used in the county for all purposes, was used for irrigation in 1964. Irrigation use varies considerably from year to year. More water is used during hot, dry summers than during cool, wet summers. Irrigation wells in the county were not used in 1965 because of abnormally large amounts of precipitation.

The water supply of the city of Vermillion is obtained from three wells completed in the Lower Vermillion-Missouri aquifer. About 213.5 million gallons of water (656 acre-feet) was supplied by these wells in 1964.

Potential.--The Lower Vermillion-Missouri aquifer has much greater potential for additional development than any other aquifer in Clay County. The aquifer underlies about 75 percent of the county, contains more water in transient storage than all other aquifers combined, and contains water of satisfactory quality for most uses.

Greatly increased use of water from the aquifer would result in lower water levels. Lower water levels would reduce water losses by evapotranspiration on the river floodplains, reduce ground-water discharge to the Vermillion River, increase the amount of recharge from precipitation on the floodplains by making available more space for storage, induce additional recharge from the Missouri River, and reduce ground-water outflow to Union County. Thus, additional use of water from the aquifer would salvage water that is presently being lost and would not permanently deplete the supply of water stored in the aquifer.

More than one-fourth of the water used from the Lower Vermillion-Missouri aquifer in 1964 was for irrigation (table 3). According to Buntley and others (1953, tables 1 and 5), soils on about one-third of the area of Clay County are rated poor to unsuitable for irrigation by either gravity or sprinkler systems. Unfortunately, most of these soils are on the Missouri and Vermillion River floodplains, where irrigation with ground water would be most economical. On the uplands bordering the floodplains, most of the soils are considered fair to excellent for irrigation. Irrigating with ground water on the upland would require pumping lifts of 80 to 100 feet from wells 120 to 200 feet deep. Although well construction and pumping costs would be greater on the uplands, the greatest potential for expansion of irrigation farming is in the upland areas that overlie the Lower Vermillion-Missouri aquifer and have irrigable soils.

Table 3.--Number of wells and springs[1] and water usage by aquifer in 1964.
[F, flowing well or spring; NF, non-flowing well]

Water-bearing unit	Domestic use only				Stock use only				Domestic and stock use				Irrigation				Public supplies				Total			
	Wells		Amount used		Wells		Amount used		Wells		Amount used		Wells		Amount used		Wells		Amount used		Wells		Amounts used	
	F	NF	1,000 gpd	afy	F	NF	1,000 gpd	afy	F	NF	1,000 gpd	afy	F	NF	1,000 gpd	afy	F	NF	1,000 gpd	afy	F	NF	1,000 gpd	afy
Lower Vermillion-Missouri aquifer	0	70	77	86.3	0	210	205	229.7	0	125	270	302.5	0	20	402	450	0	6	590	661.1	0	431	1,544	1,729.6
Minor outwash lenses	0	2	1	1.1	0	11	10	11.2	0	5	8	9.0	0	0	0	0	0	1	[2]	[2]	0	19	19	21.3
Wakonda aquifer	1	0	0.5	.6	12	110	140	156.9	0	30	70	78.4	0	0	0	0	0	0[3]	0		15[4]	140	210.5	235.9
Niobrara Marl	0	0	0	0	8	40	50	56.0	0	5	10	11.2	0	0	0	0	0	0	0	0	8	45	60	67.2
Codell Sandstone Member of Carlile Shale	0	0	0	0	0	10	10	11.2	0	1	2	2.2	0	0	0	0	0	2	30	33.6	0	13	42	47
Dakota Group	2	1	1.5	1.6	75	50	130	145.7	30	25	120	134.6	0	0	0	0	0	0	0	0	120[5]	76	251.5	281.9
Undetermined	0	0	0	0	0	6	5	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0	6	5	5.6
Total	3	73	80	89.6	95	437	550	616.3	30	191	480	537.9	0	20	402	450	0	9	620	694.7	143	730	2,132	2,388.5

[1] Based on well inventory covering 80 percent of county.

[2] Public school well used only during school term. Total discharge insignificant.

[3] Town of Irene obtains water from this aquifer; the wells are in Turner County and supply an estimated 30,000 gpd (33.6 afy).

[4] Includes 3 unused flowing wells.

[5] Includes 13 unused flowing wells.

Wells yielding as much as 2,500 gpm probably can be constructed throughout much of the central part of the Lower Vermillion-Missouri aquifer. Existing irrigation wells in some parts of the aquifer yield as much as 750 gpm from less than 40 feet of aquifer material. Larger yields are obtainable where the aquifer is thicker.

Water in the Lower Vermillion-Missouri aquifer is too highly mineralized for most industrial uses. The large available supply, however, and the ease with which it can be obtained throughout much of the county, might offset the costs of treatment in order to obtain supplies of satisfactory quality for certain industries.

Minor aquifers

Alluvium.--Alluvium on the Missouri River floodplain supplies at least part of the livestock and domestic water for most farms. Elsewhere in the county, surface alluvium is absent or is too thin, too impermeable, or not sufficiently extensive to be used for water supplies. Because the floodplain alluvium commonly overlies and forms a single aquifer with the much thicker and more extensive outwash deposits, the alluvium is considered a part of the Lower Vermillion-Missouri aquifer.

The Wakonda aquifer, discussed in a following section, and the minor aquifers in T. 95 N., R. 51 W. (see pl. 2) may be in part composed of ancient alluvium. Christensen (Part I, p. 19) discusses the origin of the deposits that make up these aquifers and concludes that some of the sand and gravel was probably deposited prior to the establishment of the Missouri and Vermillion Rivers in their present courses by through-flowing streams originating in western South Dakota. Outwash deposited at a later date may overlie the alluvium and, in some areas, may compose the entire aquifer.

Outwash lenses.--Numerous small outwash lenses enclosed by till supply water to wells in Clay County. Such lenses are common sources of water in T. 95 N., R. 51 W., although many of the small, water-yielding deposits in this township may be "ancient" alluvium (see Part I, p. 20).

Some of the permeable deposits near the northeast corner of the county may be hydraulically connected to, or physical extensions of, the "lower buried outwash" in Lincoln and Union Counties, near Beresford, described by Baker (1963, p. 7, 13). Plates 2 and 3 indicate that some of the aquifer lenses in T. 95 N., R. 51 W., extend eastward and northward across the county line.

The greatest known thickness of outwash in T. 95 N., R. 51 W., is 81 feet at test hole 95-51-16aaaa. The following log of the test hole indicates that, at this location, the aquifer (50 to 131 feet) probably is not very permeable because of the mixture of grain sizes present.

Material	Depth (feet)
Road fill	0- 4
Till, yellow-brown; contains small pebbles	4- 35
Till, brown-gray; contains few pebbles; water-saturated below 41 feet	35- 50
Sand, gray, fine to very fine, and clay (about 50 percent each)	50- 70
Sand, gray, with about 25 percent clay	70- 95
Sand, gray, very fine, with about 10 percent clay	95-131
Shale	131-135

Subsurface inflow from the north or east may recharge the minor outwash lenses. Because of the overlying till aquiclude, which averages 60 feet in thickness (see pl. 3), little or no local recharge from precipitation takes place.

Because of their relatively low permeability and small extent, the minor aquifer lenses probably cannot supply much more water than at present. Wells yielding as much as 50 gpm might be developed in these lenses, but throughout most of the area, they probably will not supply more than 8 to 10 gpm to the ordinary domestic or stock well.

Isolated aquifer lenses, because they are enclosed in till and have no surface expression, are difficult to locate. These lenses may be discovered during the drilling of wells intended to tap deeper aquifers, but few wells are drilled specifically to tap a small, isolated aquifer.

Aquifers in Surficial Deposits and Bedrock

Wakonda aquifer

An extensive aquifer complex in northwestern Clay County, here named the Wakonda aquifer (see pl. 2), underlies about 70 square miles of the James River highlands, and is made up of alluvial and outwash sand and gravel and the underlying Niobrara Marl. The permeable surficial deposits are in contact with the Niobrara at many places in the area; although hydraulic continuity is not complete, it is sufficient to allow permeable surficial and bedrock units to function as a single aquifer throughout most of the area.

Cross sections A-A' and E-E', plate 3, show the relationship between some of the unconsolidated surficial deposits and the Niobrara Marl under the James River highlands. Variations in the quality of water from wells completed in the unconsolidated deposits and in the Niobrara indicate that mixing of water from the two sources is not always complete. Certain wells yield water characteristic of the aquifer in the Niobrara Marl (locally called "chalk") while others yield water characteristic of that in the unconsolidated deposits. Although some wells in the area can be assigned to one part of the aquifer only, most wells yield water that apparently is a mixture from both parts of the aquifer, and the aquifer is therefore considered a single, although complex, system.

Isolated lenses of permeable outwash in the drift contain ground water in many places on the James River highlands in Clay County. These isolated lenses supply some water used for livestock, but more than 90 percent of the wells in T. 95 N. and the north half of T. 94 N. withdraw water from the Wakonda aquifer.

The unconsolidated part of the Wakonda aquifer underlies about 20 square miles in Tps. 94 and 95 N., R. 53 W. (pl. 2) and extends westward into Yankton County and northward into Turner County. The average thickness of aquifer material in the surficial deposits is about 55 feet; the greatest known thickness is 115 feet at test hole 95-53-32aaaa. The log of this test hole, given below, indicates that much of the unconsolidated aquifer material (19 to 140 feet) is fine grained and rather poorly sorted.

Material	Depth (feet)
Road fill	0- 4
Till, yellow-brown; contains pebbles	4- 9
Till, yellow-brown, with interbedded yellow sand; water saturated below 15 feet	9- 19
Sand, yellow-brown, very fine	19- 24
Sand, yellow-brown, very fine, and brown-yellow clay	24- 30
Gravel	30- 34
Sand, yellow to yellow-brown, fine	34- 39
Clay, yellow-brown to brown-gray, with about 35 percent fine sand	39- 44
Sand, gray-brown, fine, with about 30 percent clay	44- 64
Sand, gray-brown, very fine	64-140

Water in the aquifer is under artesian pressure except where the aquifer is unsaturated or at the land surface. In some stream valleys, water-table conditions prevail and water levels are at or near the land surface. A layer of till as much as 50 feet thick overlies the aquifer on the uplands (see pl. 3.) The till is a confining layer except where the aquifer is unsaturated.

Artesian springs issue from the Wakonda aquifer in T. 93 N., R. 52 W., T. 94 N., R. 53 W., and T. 95 N., Rs. 52 and 53 W. These springs are located where the aquifer crops out or where the drift overlying the aquifer is very thin and permeable. Wells completed in the aquifer may flow where the land surface altitude is less than about 1,275 feet.

Recharge to the Wakonda aquifer is derived primarily from precipitation within Clay County and from subsurface inflow from Turner County. The valleys of westward-flowing tributaries of Turkey Ridge Creek in Yankton County may be recharge areas, but water-level data are too scanty to establish definitely the direction of water movement in the aquifer. The northern part of the James River highland (fig. 1), an area known locally as Turkey Ridge, probably is a major recharge area for the Wakonda aquifer; recharge is by infiltration of precipitation and by inflow from adjacent aquifers.

The Wakonda aquifer discharged an estimated 245 acre-feet of water to wells and springs in Clay County in 1964. Of this amount, about 25 acre-feet was discharged to flowing wells and springs. Very little water is lost from the aquifer by evapotranspiration because of the overlying till cover.

Subsurface outflow from the Wakonda aquifer recharges the Lower Vermillion-Missouri aquifer where the two are in contact in Tps. 94 and 95 N. The volume of such outflow cannot be determined from available data but is probably several times the volume discharged from the aquifer by all other means.

More than 95 percent of the water discharged by wells and springs from the Wakonda aquifer is beneficially used, primarily for livestock supplies. (See table 3.) Flowing wells generally have low pressure and yield: the two unused, uncontrolled flowing wells disclosed by well inventory have a combined annual yield of only about 9 acre-feet.

The Wakonda aquifer could yield much more water than at present. Increased use of water from the aquifer would lower the water level, and might reduce the yields of springs and flowing wells if large additional withdrawals were made. Subsurface outflow from the aquifer would be reduced at the same time, thus improving, to some extent, the quality of water in the Lower Vermillion-Missouri aquifer.

Because of its generally poor chemical quality, water from the Wakonda aquifer is not well suited for irrigation and industrial use. Additional withdrawals from the unconsolidated parts of the aquifer, which locally contain water of good quality, might eventually induce more water movement from the bedrock part of the aquifer, causing further local deterioration in water quality.

Aquifers in Bedrock

Aquifers are present in the Cretaceous Niobrara Marl, Codell Sandstone Member of the Carlile Shale, and Dakota Group in Clay County. The combined yield of the aquifers in the bedrock is less than the yield of the Lower Vermillion-Missouri aquifer, but bedrock aquifers are important sources of water supply in parts of the county.

Niobrara Marl

The uppermost bedrock formation in Clay County, the Niobrara Marl, contains an aquifer that is extensively used for water supplies in about 25 square miles of the northeastern part of the county (pl. 2). The extent of the Niobrara subcrop is shown on figure 6, and plate 3 shows the relationship of the Niobrara to the surficial deposits. The Niobrara Marl in northwestern Clay County is part of the Wakonda aquifer discussed in the preceding section.

The Niobrara Marl (see table 1) consists of light-gray to black soft, calcareous shale. Where the formation is exposed at the surface, in sections 5, 8, and 14, T. 93 N., R. 52 W., it weathers to a light-tan to yellow, soft clay. The Niobrara was exposed in Clay County by erosion prior to glaciation (see Part I, p. 15), but is now overlain in most of the county by younger deposits.

Water moves through the Niobrara in fractures and solution cavities. The material, even where highly weathered, normally is very dense and transmits little water. Where interconnected fractures and solution cavities exist, and where recharge is available, the Niobrara may yield large quantities of water to wells and springs.

Water in the aquifer in the Niobrara Marl commonly is under artesian pressure. Throughout most of its extent, the aquifer is confined beneath relatively impermeable clay till. (See pl. 3.) Pressure on the water in the aquifer is sufficient to cause wells to flow in parts of Tps. 94 and 95 N., R. 51 W., where the surface altitude is below about 1,350 feet.

Recharge to the aquifer in the Niobrara Marl in northeastern Clay County is primarily by subsurface inflow from the northeast. Test holes drilled near Beresford in Lincoln and Union Counties (Baker, 1963, app. B) indicate that the Niobrara in that area is immediately overlain by permeable outwash as much as 100 feet thick. Water in the outwash is similar in quality to that in the Niobrara (Baker, 1963, table 1). Where the aquifers are in contact, water moves into the aquifer in the Niobrara because the water in the outwash has greater artesian head. The piezometric surface of the ground water in the Niobrara in northeastern Clay County probably slopes toward the southwest, although water-level measurements are too few to determine its exact configuration.

Although the Niobrara is covered by only a few feet of surficial material at some locations in northeastern Clay County, little recharge by direct infiltration takes place. Runoff in the area is rapid and the surface materials are relatively impermeable.

Isolated lenses of permeable outwash or alluvium may be in contact with, and exchange water with, the aquifer in the Niobrara. Because these permeable deposits are small in extent and receive little or no recharge through the enclosing till, they contribute little water to the Niobrara.

Discharge from the aquifer in the Niobrara Marl is almost entirely by wells and subsurface outflow. Locally, small amounts of water may be discharged by evapotranspiration, but throughout most of its area the aquifer is overlain by relatively impermeable till.

Wells completed in the aquifer in the Niobrara discharged about 70 acre-feet of water in 1964. Flowing wells completed in the aquifer yielded about 10 acre-feet of the total discharge, and the remainder came from pumped wells.

Subsurface outflow discharges some water from the aquifer in the Niobrara, especially along the southwestern margin of the aquifer where it is in contact with the Lower Vermillion-Missouri aquifer. Plate 4 shows little gradation in water quality between the two aquifers, however, indicating that water probably does not move from the aquifer in the Niobrara into the Lower Vermillion-Missouri aquifer in significant quantities.

Nearly all the estimated 67 acre-feet of water used in 1964 from wells completed in the aquifer in the Niobrara (table 3) was for livestock supplies. Because of its generally poor quality, very little of the water is used for domestic purposes.

The aquifer in the Niobrara Marl could undoubtedly supply more water than at present. Properly constructed wells could probably supply 75 to 100 gpm at some locations in the area. The generally poor quality of the water limits present use as well as the potential for additional development of water supplies from the aquifer.

Codell Sandstone Member of Carlile Shale

The Carlile Shale, which underlies the Niobrara Marl throughout South Dakota, usually contains, at or near the top, a layer of fine white to gray, poorly- to well-indurated sandstone, called the Codell Sandstone Member. (See table 1.) The Codell is missing from most of Clay County because of erosion and nondeposition. Little subsurface information concerning this unit is available, but an electric log of a test well at Irene, in Turner County, shows that about 36 feet of Codell(?) is present from 217 to 253 feet below the surface (see Christensen and Stephens, in preparation).

The Codell is a widely used aquifer in southeastern South Dakota because, although it seldom supplies large quantities of water, the water is usually softer than that from shallower aquifers. In some parts of eastern South Dakota (Steece and Howells, 1965, p. 68; Howells and Stephens, 1966) the Codell and the Niobrara Marl are hydraulically continuous and the entire unit supplies soft, saline water.

On the basis of water quality and reported depths, at least 13 wells in Clay County are believed to yield water from the aquifer in the Codell. Knowledge of the Codell in Clay County is so slight that no estimate can be made of its potential for development. Additional low-yield wells might be developed in the aquifer, but because of its small area the Codell is not likely to yield much more water than at present.

Dakota Group

The only aquifer underlying all of Clay County is the aquifer in the Dakota Group. The Dakota is composed of interbedded siltstone, sandstone, and shale (see table 1); the aquifer consists of one or more of the sandstone beds. Subsurface information about the Dakota is scanty in Clay County, and much of the stratigraphic and lithologic interpretation is based on information from adjacent areas.

The Dakota Group contains one of the most famous artesian aquifer systems in the United States. Darton (1896, 1897, 1909), Todd (1903, 1908), and others studied the Dakota in the Clay County area and throughout the State before 1900. Later studies, such as those by Barkley (1952), Davis and others (1961), and Dyer and Goehring (1965), have added considerably to knowledge of the Dakota in southeastern South Dakota.

The Greenhorn Limestone and the Graneros Shale (see table 1, fig. 6, and pl. 3) confine the water in the sandstone beds of the Dakota Group throughout most of the county. The Greenhorn and Graneros overlie the Dakota west of Vermillion, but east and north of Vermillion they have been eroded away and the Dakota is overlain by the permeable outwash of the Lower Vermillion-Missouri aquifer. Although the altitude of the Missouri River floodplain is lower east of Vermillion than it is toward the west, and the Dakota is relatively flat lying and occurs at nearly the same depth under the entire floodplain, artesian flows cannot be obtained from the Dakota southeast of Vermillion because the Lower Vermillion-Missouri aquifer is in contact with, receives water from, and dissipates the pressure in the Dakota.

The altitude of the piezometric surface of water in the aquifer in the Dakota Group (fig. 9) is at a maximum of about 1,280 feet in the northwest corner of Clay County and declines to an altitude of about 1,120 feet in the southeast corner. The configuration of the piezometric surface, as a result of aquifer development and of subsurface geologic conditions, is a subdued representation of the surface topography in southeastern South Dakota. In Clay County, the highest pressure on water in the Dakota exists under the James River highlands and the Coteau des Prairies, and a "pressure trough" occurs under the Vermillion and Missouri River floodplains. The water levels in the Dakota and in the Lower Vermillion-Missouri aquifer merge southeast of Vermillion where the two aquifers are in contact.

Long-term records of wells completed in the aquifer in the Dakota indicate that, after initial development, artesian head dropped fairly rapidly. According to Dyer and Goehring (1965, p. 26), the net decrease in head in the Missouri Trench between Yankton and Elk Point has been less than 100 feet since initial development, although the head has decreased by nearly 400 feet in the Fort Thompson and Chamberlain areas about 150 miles northwest of Clay County.

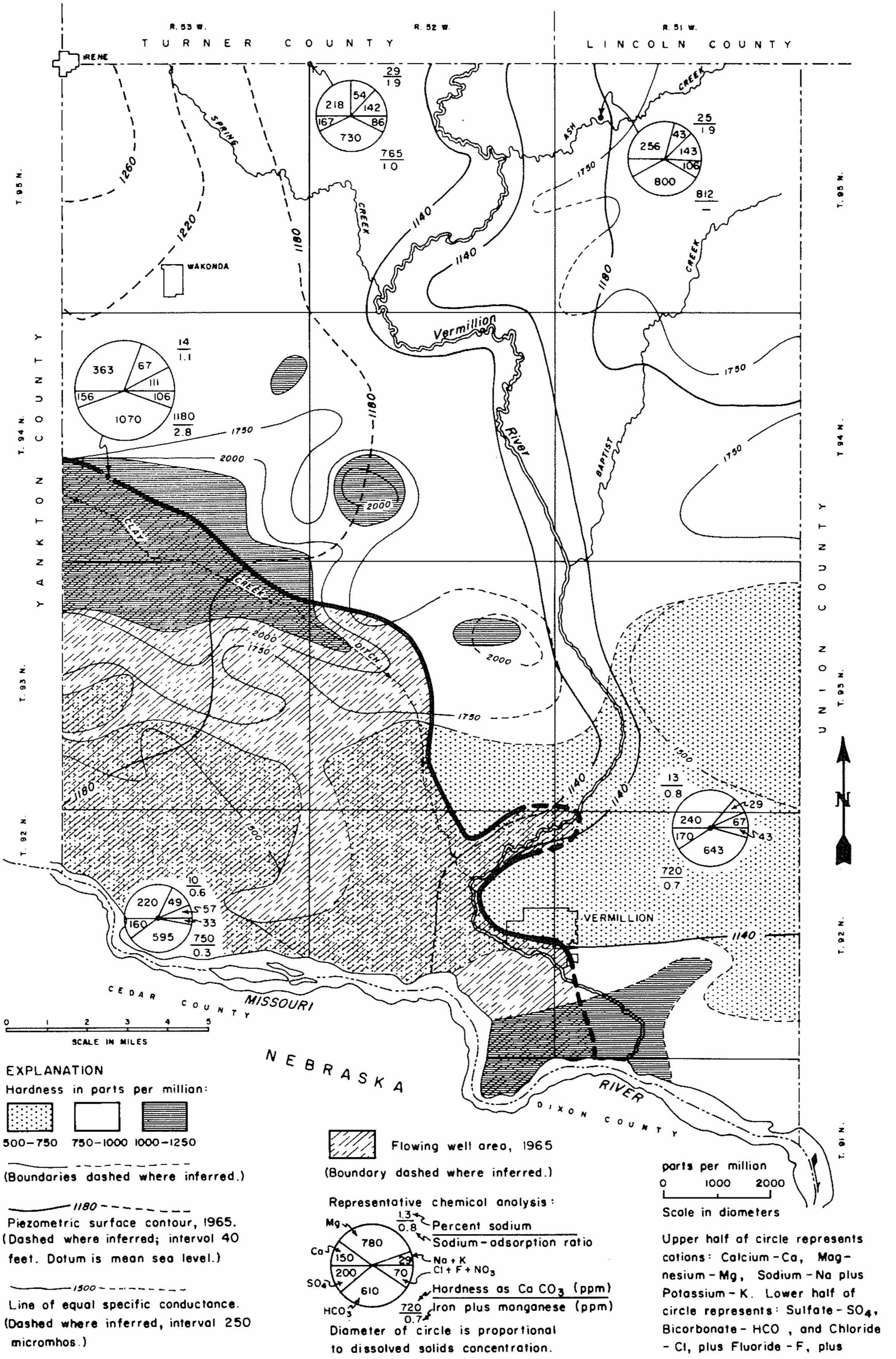

Figure 9. Hydrochemical and piezometric map of aquifer in Dakota Group.

Although the overall trend is a general decline in head, slight increases have been recorded in recent years in some areas near the Missouri River in southeastern South Dakota. A network of observation wells maintained by the U. S. Geological Survey in cooperation with the South Dakota Water Resources Commission has been established to provide information on artesian aquifers in the State. Records from observation wells completed in the Dakota Group in and near Clay County reveal the following short-term water-level changes, through 1965:

Location	Length of record (years)	Net change (feet of rise)	Average net change (feet of rise/year)
92-52-7cbc	5	1.73	0.34
93-52-28aad	4	0.00	.00
95-51-7ada	4	.32	.08
96-53-36dd	4	1.15	.29

The rise of water levels in these wells may be, in part, the result of increased pressure on the aquifer due to filling of the reservoir behind Gavin's Point Dam.

The first wells tapping the Dakota in Clay County were constructed in 1885. At that time, artesian pressure in the aquifer was sufficient to cause wells to flow on the Missouri River floodplain west of Burbank, and on the Vermillion River floodplain as far north as the Turner County line. In answer to a questionnaire from the U. S. Geological Survey, a Clay County resident wrote, in 1895, with reference to a flowing artesian well developed in the Dakota in sec. 33, T. 92 N., R. 51 W.:

> This well is situated in the Missouri Valley near the SE corner of Clay Co., S. D. It is on the East line of the artesian basin, there being only 2 wells farther east, the farthest only 3/4 of a mile E in section 34 and that flows only on very low ground.

By 1964, wells completed in the Dakota would flow only in the area south of the southern boundary of T. 92 N., R. 52 W., on the Vermillion floodplain, and in the area west of a line about 2 miles east of Vermillion on the Missouri floodplain. (See fig. 9.) The decrease in area of flow of the Dakota in Clay County since 1908 is given by the following calculation:

Area of flow, 1908 (after Darton, 1909)	210 square miles
Area of flow, 1965 (from fig. 13)	110 square miles
Decrease	100 square miles
Percent decrease	48

Recharge.--Recharge to the aquifer in the Dakota Group in Clay County is by subsurface inflow. Pressure on water in the Dakota is greater than pressure on water in the Lower Vermillion-Missouri aquifer, the only other aquifer with which it is in contact. Where the outwash is not in contact with the Dakota, one or more shale aquicludes overlie the aquifer and prevent recharge by infiltration of precipitation. Thus the aquifer in the Dakota is not recharged by other aquifers or by precipitation in Clay County.

The source and mechanism of recharge to the aquifer in the Dakota are unknown. Darton (1896, p. 611, fig. 50) pictures the Dakota as a continuous unit that received water in the outcrop area in the Black Hills, transmitted it downward under the plains in western South Dakota, and upward again toward the outcrop area in southeastern South Dakota. Later work shows that the sandstones of the Dakota that crop out in the Black Hills probably are not the primary source of recharge to the aquifer in the Dakota in eastern South Dakota.

A major source of recharge to the Dakota in eastern South Dakota may be the aquifers that underlie, and are in contact with, the formation in central and western South Dakota. Another possible source may be from dewatering of the confining and contained shales by compaction (Steece and Howells, 1965, p. 69). The aquifer in the Dakota may receive some water from overlying, unconsolidated aquifers in Union County, but the pressure differential in that area is probably similar to that in Clay County, and the net movement is probably from, rather than into, the Dakota.

Discharge.--Natural discharge from the aquifer in the Dakota occurs in southeastern Clay County where the Lower Vermillion-Missouri aquifer is in contact with the Dakota. The pressure differential between the two aquifers is very slight and fluctuates, but the volume of water that moves from the Dakota to the Lower Vermillion-Missouri aquifer is large.

Water from the Lower Vermillion-Missouri aquifer is generally similar in chemical quality to water from the Dakota (see table 4 and fig. 11) throughout Clay County, and particularly east and southeast of Vermillion (compare pl. 4 and fig. 9). Where the two aquifers are in contact, water quality is very nearly identical. The similarity in quality is due to a gradual change toward the southeast in the chemical composition of water from the outwash. Alteration of the quality of water in the Lower Vermillion-Missouri aquifer to the extent that it becomes chemically indistinguishable from that in the Dakota requires the admixture of large quantities of water from the aquifer in the Dakota Group. Although the quantity of water discharged to the Lower Vermillion-Missouri aquifer by the aquifer in the Dakota cannot be measured, it must amount to several thousands of acre-feet annually.

In 1964, the Dakota yielded an estimated 1,180 acre-feet of water to wells in Clay County; 80 percent of this total was discharged to flowing wells.

Water use.--Less than 10 percent of the water used in Clay County comes from the aquifer in the Dakota Group. (See table 3.) However, nearly one-fourth of the wells in use in the county are completed in the aquifer.

Uncontrolled, unused flowing wells, and wells with flow in excess of amounts used, accounted for more than three-fourths of the approximately

1,180 acre-feet of water discharged from the aquifer in the Dakota in Clay County in 1964. The inventory of wells disclosed 13 unused flowing wells that alone discharge nearly 900 acre-feet of water annually.

The primary use of water from the Dakota in Clay County is for livestock. Only about 60 wells in the county furnish domestic supplies. Wells completed in the Dakota formerly supplied some water for municipal use at Wakonda, but at present (1965) no municipal supplies come from this source.

Potential.--The aquifer in the Dakota Group could supply considerably more water than at present. Artesian pressure, which has declined constantly since initial development of the aquifer, may now have reached approximate equilibrium. Because much of the pressure decline is attributable to uncontrolled flow to waste, the decline could be at least partially controlled by limiting flow to amounts used and by shutting off unused flowing wells. If this were done, about four times the present amount of water could be used from the aquifer in the Dakota in Clay County and the total discharge would remain the same.

WATER QUALITY

The suitability of water from a given supply is determined not only by its chemical and physical properties, but also by the use made of the water. In water for irrigation, for example, hardness is a desirable property, but in water for domestic use, hardness is generally undesirable. The discussion of water quality in this report is concerned mostly with water for domestic, livestock, and irrigation uses.

How good water may be for a specific use is dependent, of course, on its chemical and physical properties. These properties, most of which can be measured in the laboratory, are influenced both by natural factors such as climate, geology, and topography and by man's activities such as irrigation, drainage, and waste disposal. The influence of these factors differs with location and may vary with time.

The greatest demands for water in Clay County are for domestic, livestock, and irrigation supplies. Some of the factors most significant in determining the suitability of water for these and other uses are listed in table 4, together with statistical parameters relating to the quality of water from the major aquifers in the county, Kerr and Bakken discussed bacterial pollution of water and its prevention. A pamphlet by Swenson and Baldwin (1965) contains a concise, nontechnical discussion of water quality and its significance. Hem (1959) gives a detailed, technical discussion of water quality. The following discussion of some of the more important quality factors in water is derived primarily from the latter two publications.

Chemical Constituents and Physical Properties

pH

The relative abundance of acids and bases in water, indicated by the

Table 4 - Summary of chemical analyses of ground water from Clay County.

Constituent or Property	Recommended Maximum for Public Supply [1]	Concentration or value (ppm except as indicated)																													
		Lower Vermillion-Missouri aquifer						Wakonda aquifer						Aquifer in Niobrara Marl						Aquifer in Codell Sandstone Member of Carlile Shale						Aquifer in Dakota Group					
		Number of analyses	Minimum	Maximum	Average	Median [2]	80% Range [3]	Number of analyses	Minimum	Maximum	Average	Median [2]	80% Range [3]	Number of analyses	Minimum	Maximum	Average	Median [2]	80% Range [3]	Number of analyses	Minimum	Maximum	Average	Median [2]	80% Range [3]	Number of analyses	Minimum	Maximum	Average	Median [2]	80% Range [3]
Iron (Fe)	0.3	59	0.04	[4]	4.3	2.4	0.4-9.7	14	0.08	[4]	6.2	3.3	0.74-14	4	0.02	[4]	11	---	---	6	1.1	[4]	8.3	---	---	17	0.31	[4]	3.4	2.5	0.40-11
Manganese (Mn)	.05	54	0.1	5.7	1.7	1.5	0.8-3.1	14	0.0	2.0	0.4	0.2	0.1-1.0	3	<.1	0.4	0.2	---	---	5	0.0	0.2	0.1	---	---	16	<.1	0.3	0.1	0.2	<0.1-0.2
Calcium (Ca)		64	71	441	202	202	89-317	14	258	537	409	412	280-533	4	397	441	414	---	---	6	76	368	241	---	---	17	218	363	261	256	220-347
Magnesium (Mg)		64	7.3	173	61	55	29-109	14	40	165	101	115	50-126	4	112	234	158	---	---	6	22	100	62	---	---	17	26	100	49	42	29-72
Sodium (Na)		65	8	189	65	62	19-106	14	18	110	54	52	41-77	4	47	176	97	---	---	4	40	180	82	---	---	17	39	127	72	51	40-121
Potassium (K)		55	4.0	19	11	10	5-16	14	8.0	24	18	18	12-22	4	10	24	18	---	---	4	3	24	14	---	---	17	15	26	19	19	15-24
Bicarbonate (HCO_3)		57	166	662	316	268	190-510	14	159	510	366	395	178-480	4	430	633	511	---	---	6	310	490	409	---	---	17	150	193	164	160	151-180
Sulfate (SO_4)	250 (500)	65	72	1360	578	567	161-970	14	440	1790	1160	1210	800-1570	4	1030	1620	1340	---	---	6	325	900	647	---	---	17	595	1110	766	689	600-1070
Chloride (Cl)	250	65	0.0	122	32	23	5-73	14	3.0	20	8.0	5.0	4.0-20	4	5.0	90	26	---	---	6	5	30	11	---	---	17	30	116	70	70	40-107
Fluoride (F)	1.0 [5]	18	0.2	2.5	0.7	0.4	0.2-1.4	11	0.2	1.2	0.8	0.7	0.4-1.1	4	0.5	1.2	0.9	---	---	5	0.4	1.2	0.8	---	---	17	0.1	3.5	2.3	2.4	1.7-3.4
Nitrate (NO_3)	45	30	0.0	6.0	0.6	0.1	0.0-1.0	0	---	---	---	---	---	0	---	---	---	---	---	6	0.0	1.0	0.2	---	---	10	0.0	1.5	0.5	0.3	0.0-1.0
Boron (B)		5	0.13	0.24	0.18	---	---	0	---	---	---	---	---	0	---	---	---	---	---	0	---	---	---	---	---	8	.17	1.4	0.41	0.18	---
Dissolved solids	500(1,000)	54	386	2630	1330	1340	750-2130	10	1590	3260	2260	2360	1590-2820	3	2320	3640	2900	---	---	5	1260	1990	1600	---	---	14	1190	2260	1490	1420	1200-1810
Hardness as $CaCO_3$ [6]		21L 270F	278 86	1470 1710	778 797	687 753	519-1300 428-1150	11L 130F	860 445	1700 2400	1360 1540	1500 1540	995-1690 1100-2070	4L 46F	1450 1350	2000 3460	1690 2010	--- 2040	--- 1590-2280	6L 9F	280 325	1330 1220	862 841	--- ---	--- ---	17L 134F	720 428	1230 1400	868 832	809 813	731-1180 668-1060
Specific conductance (micromhos) [6] per cm. at 25°C		50L 270F	610 250	2800 3820	1600 1790	1600 1510	940-2230 890-2130	12L 130F	1550 1340	2920 3600	2760 2380	2430 2400	1900-2900 1910-2880	4L 46F	2200 2450	3500 5090	2830 3040	--- 2970	--- 2740-3330	4L 9F	1250 1070	2000 1820	1560 1490	--- ---	--- ---	16L 135F	1400 1090	2200 2690	1720 1700	1610 1660	1500-2180 1470-2020
Percent of Sodium		52	5.7	38	16	14	8.8-27	12	4.3	12	7.5	6.9	5.5-10	4	6.5	20	11	---	---	4	6	58	22	---	---	16	10	26	15	12	10-25
Sodium-adsorption ratio (SAR)		46	0.2	3.2	1.1	1.0	0.4-1.9	14	0.3	1.2	0.6	0.6	0.5-0.9	4	0.5	2.0	1.1	---	---	5	0.5	4.7	1.7	---	---	16	0.6	1.9	1.1	0.8	0.6-1.9

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[1] U. S. Public Health Service (1962). Figures in parentheses are recommended maximum concentrations of the South Dakota Department of Health (written communication, 1961).

[2] Fifty percent of samples contained more than this concentration, or had a higher value, and 50 percent contained less or had a lower value. Median not calculated if fewer than 10 analyses available.

[3] Ten percent of samples had content or value equal to or less than lower limit of range, and 10 percent had content or value equal to or greater than upper limit. Eighty percent range not calculated if fewer than 10 analyses available.

[4] Maximum iron concentrations probably reflect the presence of iron compounds in suspension at time of sampling and are not an accurate measure of dissolved iron content.

[5] Optimum concentration for Clay County. Recommend lower limit is 0.8 ppm, recommend upper limit is 1.3 ppm, and mandatory upper limit is 2.0 ppm (U. S. Public Health Service, 1962, p. 7 and 8).

[6] L = Laboratory analyses. F = Field analyses.

pH, is an important property of the water. Water containing equivalent amounts of acids and bases is neutral, and by definition is said to have a pH of 7.0. A solution containing more acid than base has a pH less than 7.0, and one containing less acid than base has a pH greater than 7.0. The pH of most natural waters is between 6 and 8, and it is therefore only slightly acidic or basic.

A combination of carbon dioxide and a carbonate or bicarbonate occurs in most natural waters. This combination is the principal control of the pH of the water. The carbon dioxide-bicarbonate system is unstable in an environment where carbon dioxide can escape from solution. The decrease in confining pressure that occurs when ground water is brought to the land surface allows carbon dioxide to escape; the pH of the water changes accordingly and calcium carbonate or other compounds may be precipitated.

The pH of water from the Lower Vermillion-Missouri aquifer ranges from about 7 to 8, when measured in the laboratory in samples collected from one to several days previously. In a study of water samples from this aquifer, Mr. Raymond Ward, South Dakota State University Soils Laboratory (written communication), found that of 13 samples the pH measured 1 day after the samples were received ranged from 7.1 to 7.7 and averaged 7.4, and the pH measured 2 weeks after the samples were received ranged from 7.7 to 8.2 and averaged 8.1. The change in pH was related primarily to the precipitation of iron compounds.

On the basis of Ward's work it seems likely that the pH of water from the aquifer changes rapidly when the water is aerated upon collection, and that measurements made even a short time after sampling indicate a higher pH than that of water in the aquifer. Thus, water in the aquifer may be at least slightly acidic (pH less than 7). Because of the difficulty of determining pH accurately, no pH values are given in table 4. The acid-base relationship discussed above does, however, have an important bearing on the concentrations of dissolved iron and manganese in water from Clay County.

Iron and Manganese

Iron and manganese in ground water are derived primarily from the soils and sediments through which the water passes. Water with a pH of less than 7 commonly contains more dissolved iron and manganese than does water with a pH of more than 7. In most natural waters, the amount of manganese is less than 0.20 ppm and commonly ranges from 0.05 to 0.22 ppm (Hem, 1959, p. 68). Concentrations exceeding 1.0 ppm are not common except where mining or industrial wastes contribute manganese. Iron concentrations of more than 50 ppm may occur in water with a pH of 5 to 8, and concentrations up to 10 ppm are common in water in this pH range (Hem, 1959, p. 65).

Both iron and manganese are dissolved more readily by water where reducing conditions (lack of oxygen) occur. Reducing conditions resulting from decaying vegetation are present in much of the floodplain alluvium along both the Missouri and Vermillion Rivers. Such conditions also prevail in places in the buried "ancient" alluvium in the vicinities of Wakonda, Irene, and Beresford. In these areas, methane gas, a product of organic decomposition, is often present in the alluvium, and the alluvial material commonly includes large amounts of organic matter and has a distinctively "swampy" odor. The reducing conditions prevalent in many places in the Lower Vermillion-Missouri aquifer probably account for the unusually high manganese concentrations found in water from the aquifer (table 4).

Iron in concentrations as low as 1.8 ppm, and manganese in even lower concentrations, may impart a noticeable taste to water (U. S. Public Health Service, 1962, p. 43, 46). Both iron and manganese in water may cause stains on laundry and porcelain plumbing fixtures. The limits recommended by the U. S. Public Health Service for iron and manganese concentrations in public water supplies (see table 4) were set so as to eliminate taste and staining problems.

Calcium and Magnesium

Calcium and magnesium are found in varying concentrations in almost all natural waters. These constituents cause hardness in water and combine with other constituents to form boiler scale and deposits in water heaters and pipes and in water systems. Calcium is the dominant cation in most ground water from Clay County.

Magnesium in water may have a laxative effect, especially when the water contains much sulfate. These two ions are the ingredients of Epsom salt, a well-known laxative. As little as 200 ppm of magnesium in water may have a laxative effect on sensitive persons not accustomed to the water, and 500 to 1,000 ppm will have a laxative effect on most people. Only one of the samples of water from aquifers in Clay County contained more than 200 ppm of magnesium.

Hardness

Hardness is caused almost entirely by compounds of calcium and magnesium--hard water contains significant amounts of these compounds and soft water does not. The U. S. Geological Survey classifies water for hardness in terms of the amount of calcium carbonate or its equivalent that would be formed if the water were evaporated, according to the following table:

Grains per gallon (approximate)	Parts per million	Classification
0- 3.5	0- 60	Soft
3.6- 7.0	61-120	Moderately hard
7.1-10.5	121-180	Hard
More than 10.5	More than 180	Very hard

Soft water is suitable without treatment for most uses other than irrigation. Moderately hard water may require softening for some industrial uses, but is satisfactory without treatment for most other uses. Hard water is acceptable for many domestic uses, but usually must be softened for laundering and for industrial use. Very hard water requires softening for most purposes.

The hardness classification given above is arbitrary; hardness is more frequently judged with respect to use and by comparison with other local water supplies. In Clay County, nearly all water samples tested were hard or very hard. Differences in water hardness in aquifers can be seen by comparison of the summaries in table 4. Area variations in hardness of water from the Lower Vermillion-Missouri and Wakonda aquifers and the aquifer in the Niobrara Marl are shown on plate 4, and variations in hardness of water from the aquifer in the Dakota Group are shown on figure 9.

Sodium and Potassium

Sodium and potassium are found in all natural water. Moderate quantities of these constituents have little effect on the usefulness of the water for other than industrial purposes. High concentrations of sodium salts may be detrimental in irrigation waters.

Sodium salts are a major cause of alkali soils. Water moving through a soil may take up calcium and magnesium in exchange for sodium, and the soil may, as a result of this exchange, be impaired in tilth and permeability. Calcium and magnesium tend to flocculate soil particles, and sodium tends to cause deflocculation of the particles--flocculated soils are generally loose and permeable, and deflocculated soils are tight and impermeable. Two measurements commonly used in determining the quality of water for irrigation are percent sodium (%Na) and sodium-adsorption ratio (SAR).

Percent sodium

The extent to which an irrigation water can enter into sodium-calcium-magnesium ion exchange with a soil can be approximately predicted by determining the sodium percentage (percent of total cations represented by sodium) and the total concentration of dissolved solids (Hem, 1959, p. 148). Adverse effects on soil do not usually occur unless the sodium percentage of irrigation water is greater than 50. Sodium is a minor constituent of most ground water in Clay County; the greatest sodium percentage determined for water from the county is 58 (see table 4).

Sodium-adsorption ratio

More significant than sodium percentage for determining potential effects on soil of irrigation water is the sodium-adsorption ratio (SAR). The effect on soil of sodium concentration in irrigation water is termed "sodium hazard." The SAR is an index to the sodium hazard of the water.

The SAR is determined by the following equation, where ion concentrations are expressed in equivalents per million (Hem, 1959, p. 148-149):

$$SAR = \frac{Na+}{\sqrt{\frac{Ca++ + Mg++}{2}}}$$

Figure 10 shows the classification for irrigation use of water from the major aquifers in Clay County on the basis of SAR and specific conductance. Table 4 lists SAR values for water from the major aquifers.

Figure 10 is interpreted as follows (U. S. Salinity Laboratory Staff, 1954):

Salinity Hazard

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

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

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

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

Sodium Hazard

The 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, however, may suffer injury as a result of sodium accumulation in plant tissues even when exchangeable sodium values are lower than those causing deterioration of the physical condition of the soil.

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

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having 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 with good permeability.

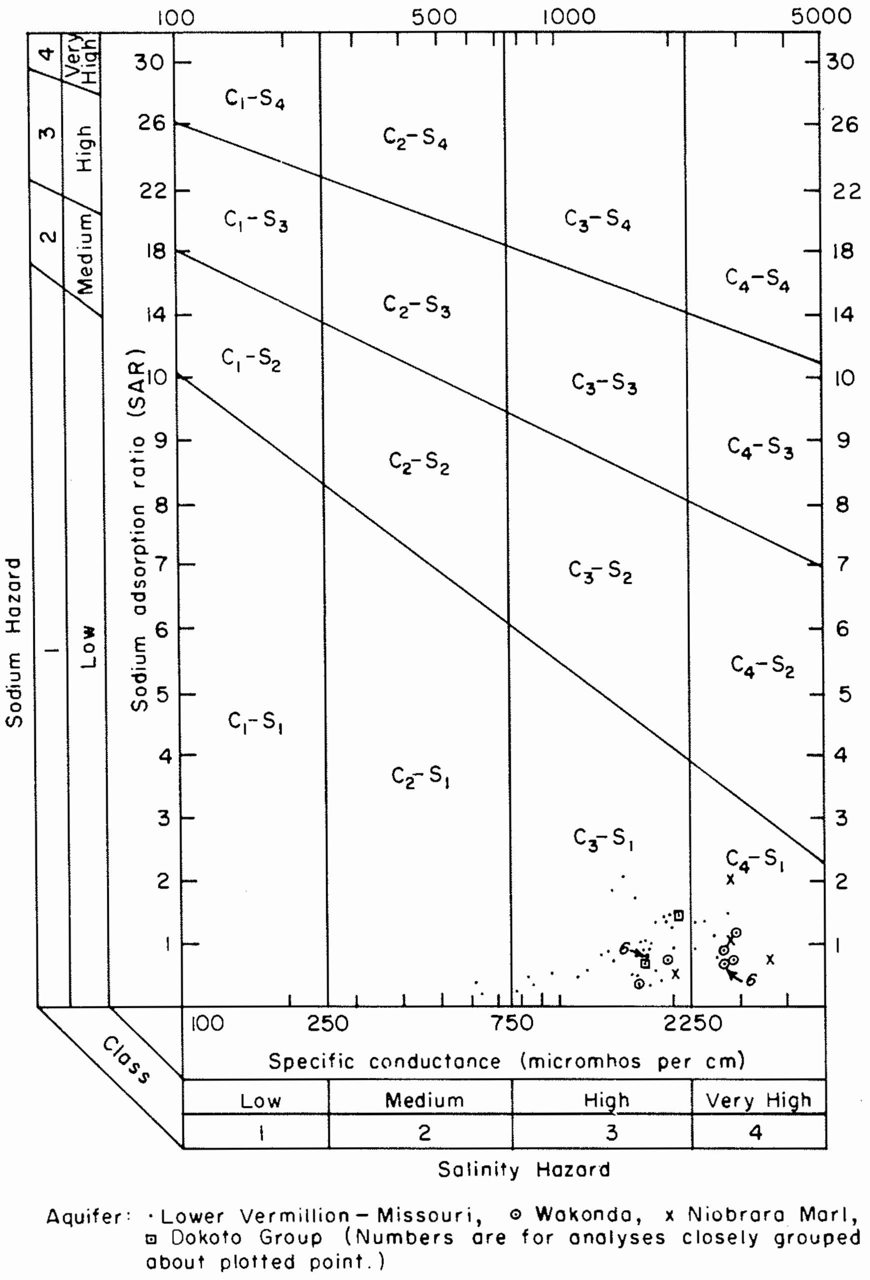


Figure 10. Classification for irrigation use of ground water from Clay County. (classification by U. S. Salinity Laboratory staff, 1954.)

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

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

Bicarbonate

Bicarbonate is a common anion in nearly all natural waters. Water exposed to carbonate rocks, such as limestone and chalk, may contain as much as 500 ppm of bicarbonate (Swenson and Baldwin, 1965, p. 15). Bicarbonate concentration in water is a measure of the alkalinity of the water. Water from the aquifer in the Niobrara Marl (locally known as "chalk") generally contains more bicarbonate than is in water from the other aquifers. (See table 4.) Locally, water from the Wakonda aquifer, where obtained from the "chalk," may be relatively high in bicarbonate.

Sulfate

Sulfate commonly occurs in relatively high concentration in water associated with, or derived from, black shale, as is the water in Clay County. Much of the water-bearing material in the county contains abundant particles of, or is interbedded with, black shale. Water dissolves sulfate from the shale and associated pyrite (an iron sulfide mineral); as a result, sulfate is the predominant anion in nearly all water samples from aquifers in Clay County.

Sulfate, in combination with high concentrations of calcium and magnesium, contributes to the formation of boiler scale and may increase the cost of water softening (Swenson and Baldwin, 1965, p. 15). Sulfate concentrations in excess of 250 ppm may impart an undesirable taste to water, and concentrations in excess of 750 ppm may have a laxative effect (U.S. Public Health Service, 1962, p. 32-34). As shown in table 4, sulfate concentrations in excess of 750 ppm were found in all samples of water from the aquifer in the Niobrara and in more than 90 percent of the samples from the Wakonda aquifer. Less than one-third of the samples from the Lower Vermillion-Missouri aquifer contained sulfate in excess of 750 ppm.

Chloride

Chloride is present in most natural waters, and is a minor constituent in water from aquifers in Clay County. Chloride and sodium are the ingredients of common table salt. Chloride, when present in concentrations of more than about 400 to 500 ppm, may impart a salty taste to water and may noticeably affect the taste of coffee made with the water (U. S. Public Health Service, 1962, p. 34). The lower limit of chloride concentration at which taste becomes objectionable depends, in large part, on the kinds and concentrations of other ions present in the water. Chloride content is less than 100 ppm in all but three of the water samples available from aquifers in the county. The three samples containing 100 ppm or more of chloride were all from the aquifer in the Dakota Group. (See table 4.)

Fluoride

Fluoride occurs in low concentrations in most water in the county. According to public health authorities (U. S. Public Health Service, 1962, p. 41), "Fluoride in drinking water will prevent dental caries. When the concentration is optimum, no ill effects will result and caries rates will be 60-65 percent below the rates in communities using water supplies with little or no fluoride." Excessive fluoride content, however, is undesirable in drinking water and may cause fluorosis, or mottling, of the teeth. The fluoride concentrations recommended by the U. S. Public Health Service (1962, p. 7, 8) are based on climatic factors--for Clay County the recommended lower limit is 0.8 ppm, and the recommended upper limit is 1.3 ppm. The mandatory upper limit for public water supplies is 2.0 ppm. The optimum fluoride concentration for water in Clay County, according to the Public Health Service standards, is 1.0 ppm. The average fluoride content found in samples of water from Clay County is about 0.75 ppm. There is little difference in fluoride content between aquifers above the Dakota Group, and only three samples from these aquifers contained more than the recommended upper limit. (See table 4.)

The aquifer in the Dakota Group contains water with a higher fluoride content than the other aquifers in the county. Twelve of 17 samples analyzed contained fluoride in excess of the mandatory upper limit of 2.0 ppm, and all but one sample contained more than the recommended upper limit of 1.3 ppm.

Nitrate

Nitrate in water results from the oxidation of nitrogen-containing matter. High nitrate concentrations often indicate organic pollution (sewage, "barnyard" wastes, or the presence of organic fertilizers in recharge areas) of the water supply. The U. S. Public Health Service (1962, p. 47) states that "serious and occasionally fatal poisonings in infants have occurred following ingestion of well waters shown to contain nitrate." Because of the lack of precise data, and the frequent occurrence of interfering factors in analysis procedures for nitrate, the U. S. Public Health Service (1962, p. 7) has recommended an upper limit of 45 ppm of nitrate in public water supplies.

All samples of water from Clay County that were analyzed for nitrate contained much less than the recommended limit. However, the nitrate content of water, especially from improperly located, improperly constructed, or badly deteriorated shallow wells, may change rapidly and by large amounts. Local recharge from polluted surface runoff or from septic tanks may raise the nitrate content of ground water for short periods of time, yet an analysis of water collected at another time may show no nitrate. Proper location and construction of wells (see Kerr and Bakken, no date) will normally insure against any potential hazard from nitrate.

Boron

Boron concentrations in water from aquifers in Clay County normally are very small. Boron does not affect the use of water for purposes other than irrigation, but in irrigation water even small amounts of boron may be detrimental. Thirteen analyses of water from Clay County revealed 3 samples, all from the aquifer in the Dakota Group, that contained more than 0.33 ppm of boron. Hem (1959, p. 245) lists 0.33 ppm of boron as the tolerance limit of the crops most sensitive to boron. Field crops and most garden vegetables grown in Clay County are classed as semitolerant or tolerant to boron and can withstand concentrations greater than 0.67 ppm (Hem, 1959, p. 245 and table 23).

Dissolved Solids

The total amount of dissolved mineral constituents, or dissolved solids, in water is often an indication of the suitability of a water supply. Water containing less than 1,000 ppm dissolved solids is considered fresh, and water containing more than 1,000 ppm is considered saline. Most water with less than 500 ppm dissolved solids is satisfactory for domestic and for some industrial uses. Water with less than about 2,000 ppm of dissolved solids is usually satisfactory for irrigation, although other factors are usually more significant in determining the suitability of water for irrigation. Water supplies may contain as much as 7,000 ppm of dissolved solids without apparent harm to livestock (South Dakota Agricultural Experiment Station, 1959, p. 10). The publication cited (p. 12) gives the following classification of water for livestock use:

Dissolved-solids content	Quality
0- 999	Excellent
1,000-3,999	Good
4,000-6,999	Satisfactory
7,000-and over	Unsatisfactory

Specific conductance

The concentration of dissolved solids in a water sample can be determined indirectly by measuring "specific conductance," a property based on the ability of natural water to conduct a current of electricity and controlled by the concentration of ions (electrically charged particles) in the water.

High concentrations of dissolved solids in irrigation water may cause an increase in the amount of salts in the soil, especially in poorly drained soils. Plant growth may be adversely affected if the salt concentration in the soil reaches a high level. The tendency of irrigation water to cause accumulation of salts in soil is termed "salinity hazard." Specific conductance is an index to salinity hazard, as shown on figure 10.

The relationship between specific conductance and dissolved-solids content depends upon the concentrations of specific ions. The content of dissolved solids in water from the major aquifers in Clay County can be approximately determined by multiplying the specific conductance value by an appropriate factor, as follows:

Aquifer	Conversion factor
Lower Vermillion-Missouri aquifer	0.8
Wakonda aquifer	1.0
Aquifer in the Niobrara Marl	1.1
Aquifer in the Dakota Group	.9

Specific conductance of water samples is relatively uniform within each of the major aquifers, as shown on figure 11. The samples near either end of the range shown on the graph account for most of the areal variation in conductance shown on plate 4 and figure 9.

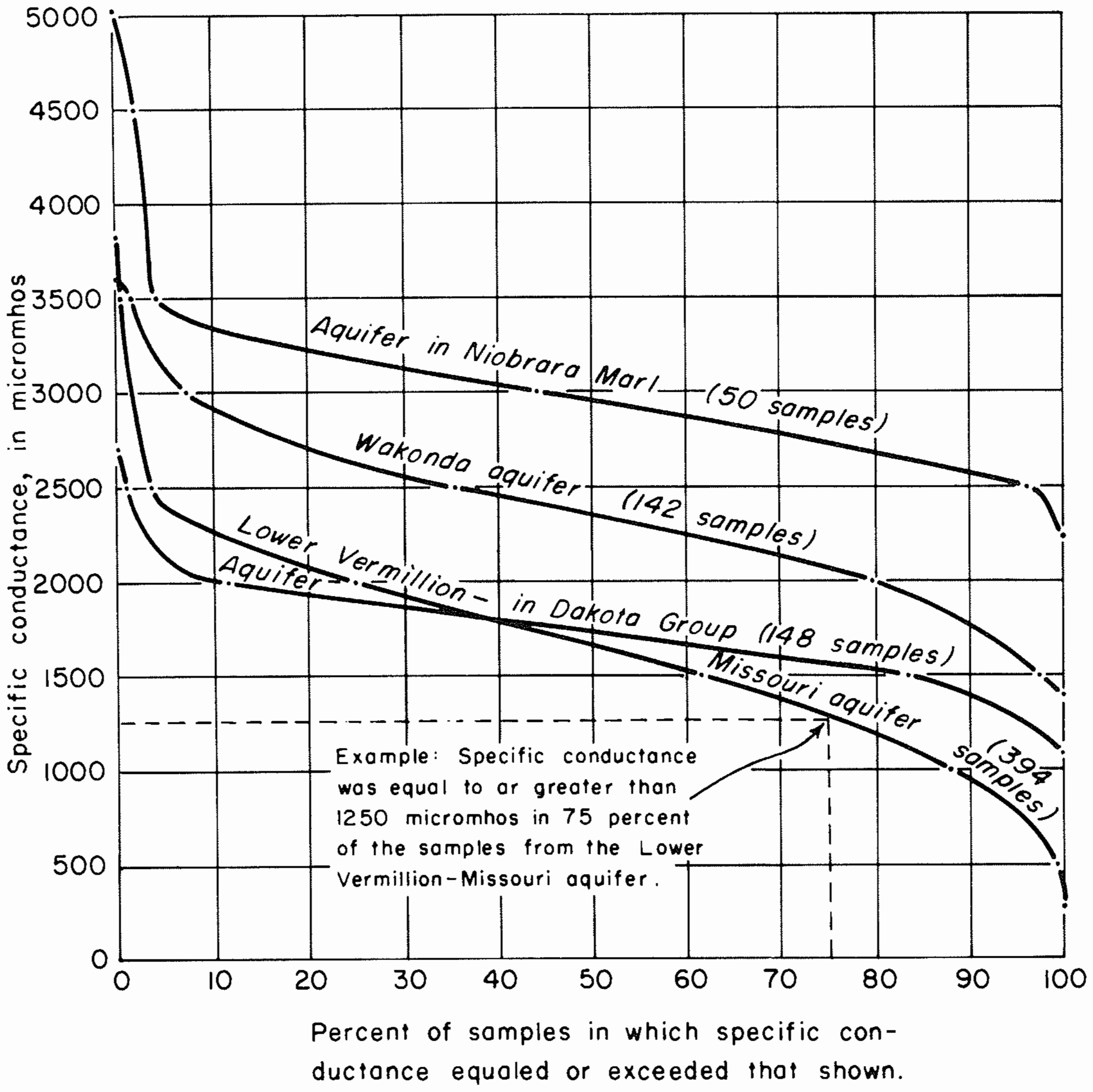
The curves on figure 11 are useful in determining the source and movement of water in the major aquifers in Clay County. The separation of the conductance curves of water from the three shallow aquifers (Niobrara Marl, Wakonda, and Lower Vermillion-Missouri) indicates the absence of significant lateral intermixing of the water in the aquifers. The position of the curve for the Wakonda aquifer, intermediate between the curves for the other two shallow aquifers, may support the conclusion that the Wakonda aquifer contains water from both the Niobrara Marl and unconsolidated outwash similar to that making up the Lower Vermillion-Missouri aquifer.

Specific conductance curves for water from the aquifer in the Dakota Group and from the Lower Vermillion-Missouri aquifer are very similar, indicating similar dissolved-solids concentrations. The conductance of water from the Dakota is extremely uniform, indicating a lack of significant mixing with, or recharge by, water from the other aquifers. This uniformity, together with the similarity of conductance ranges, and the much greater variation in conductance of water from the Lower Vermillion-Missouri aquifer, support the conclusion that water from the Dakota recharges, and dilutes the water in, the Lower Vermillion-Missouri aquifer.

Relation of Water Quality to Source of Supply

Surface Water

The quality of water from the rivers in Clay County varies with stream discharge. Table 5 lists analyses of water from the Vermillion and Mis-



Example: Specific conductance was equal to or greater than 1250 micromhos in 75 percent of the samples from the Lower Vermillion-Missouri aquifer.

Figure 11. Frequency distribution of specific conductance values of water samples from major aquifers.

Table 5.--Representative chemical analyses of water from Vermillion and Missouri Rivers.

Constituent or property (ppm except as indicated)	Vermillion River near Wakonda, S. Dak. (SW¼NW¼ sec. 2, T. 94 N., R. 52 W.)			Missouri River at Yankton, S. Dak. (between sec. 18, T. 93 N., R. 55 W., and sec. 13, T. 93 N., R. 56 W.)[2]		
Date	5/31/60	10/10/60	3/17/61	3/1-25/58	9/1-30/58	10/1/57-9/30/58[4]
Discharge (cfs)	218[1]	24[1]	699[1]	8,206[3]	28,910[3]	19,720[3]
Iron (Fe)	0.02	.03	.07	.01	.00	.01
Manganese (Mn)	0.10	.66	.67	--	--	--
Calcium (Ca)	149	181	79	56	58	57
Magnesium (Mg)	62	54	20	16	19	18
Sodium (Na)	35	34	11	55	63	60
Potassium (K)	8.6	8.2	12	4.6	5.2	5.1
Bicarbonate (HCO_3)	280	324	174	174	187	177
Sulfate (SO_4)	439	467	155	168	201	184
Chloride (Cl)	5.6	6.2	.0	9.0	10	9.6
Fluoride (F)	0.2	.3	.2	.5	.5	.5
Nitrate (NO_3)	3.1	1.8	9.6	1.2	.4	.7
Boron (B)	0.13	.20	.08	.13	.15	.14
Dissolved solids	931	965	412	414	470	443
Hardness as $CaCO_3$)	627	674	279	207	224	216
Percent sodium	11	10	8	36	37	37
Sodium adsorption ratio (SAR)	0.6	.6	.3	1.7	1.8	1.8
Specific conductance (micromhos per cm. at 25° C)	1,180	1,240	593	627	699	671

[1] At time of sampling.

[2] From U. S. Geological Survey, 1962, p. 192. Daily samples for chemical analysis composited by discharge.

[3] Average for period.

[4] Represents 100 percent of runoff for water year October 1957 through September 1958.

souri Rivers together with discharge at the time of sampling, and illustrates the variation in concentration of certain constituents and properties.

Water from the Vermillion River usually is fresh, very hard, and of calcium sulfate type. Compared to U. S. Public Health Service (1962) recommended limits for public water supplies, Vermillion River water contains excess manganese, and excess sulfate and dissolved solids except during the spring runoff period, and is deficient in fluoride. The water has a high salinity hazard and low sodium hazard.

As indicated in table 5, water quality of the Vermillion River varies with discharge. A sample obtained on March 17, 1961, during a time of high flow had only about half the dissolved-solids content of the samples collected during times of lower flow. Water entering the river after storm periods and during spring snow melt has little contact with soluble materials in the drainage area and, consequently, is low in dissolved solids. Water entering the river during periods of low flow (for example, the sample taken October 10, 1960) is mostly ground-water discharge and, as such, has a much higher concentration of materials dissolved from the soil and the aquifer through which it moved.

Water from the Missouri River is fresh, very hard, and a calcium sulfate or sodium bicarbonate type. Usually all constituents except fluoride are within the U. S. Public Health Service (1962) limits; fluoride is present in amounts less than the recommended lower limit. The water has medium salinity hazard and low sodium hazard.

Significant differences in concentrations of many of the constituents shown on table 5 are evident between the waters of the Vermillion and the Missouri Rivers. Dissolved-solids concentrations in Missouri River water are nearly constant and only about one-half as great as concentrations in Vermillion River water at low and moderate flow. Water in the Missouri River in southeastern South Dakota is derived mostly from runoff from unglaciated areas upstream. The difference in source of the water is the primary cause of the difference in water quality between the Vermillion and Missouri Rivers. In addition, the Missouri is controlled by several upstream dams, and mixing of the water while in reservoir storage tends to make the water downstream from the dams relatively uniform in quality.

It should also be noted that the analyses of Missouri River water are of composite samples covering periods of several weeks. Thus, daily or even weekly changes in quality are not apparent. However, because of the effects of storage by the dams, changes in water quality for that reach of the Missouri River adjacent to this report area are small and take place gradually. Changes from day to day are seldom significant.

Ground Water

The quality of water from aquifers in Clay County varies with location, quantity and source of recharge, and, in some cases, depth. Figures 9, and 11, and plate 4 illustrate some of the quality variations. Table 4 summarizes the quality of water from the major aquifers.

Lower Vermillion-Missouri aquifer

The Lower Vermillion-Missouri aquifer contains water that is similar in most respects to water from the Vermillion and Missouri Rivers. Water from this aquifer is variable in quality, as indicated above and illustrated in plate 4. Normally, the water is slightly saline, very hard, and a calcium sulfate type. Compared to the U. S. Public Health Service (1962) standards, more than 90 percent of the water samples from the aquifer contained excessive amounts of iron and manganese, and more than 50 percent of the samples contained excess sulfate and dissolved solids. More than two-thirds of the samples analyzed contained less than the recommended lower limit of fluoride.

Water from the Lower Vermillion-Missouri aquifer normally is satisfactory for all livestock uses and for many domestic uses. The hardness of the water makes it undesirable for some household purposes unless a water softener is used, and the high iron and manganese contents make the untreated water undesirable for laundering, and may cause staining of porcelain plumbing fixtures.

Most water from the aquifer has a high salinity hazard and a low sodium hazard. (See fig. 10.) An investigation of floodplain soils along the Missouri River, currently being conducted by the U. S. Bureau of Reclamation, indicates that the low sodium and high calcium content of this water makes it particularly well suited for irrigation on those portions of the floodplain that can be irrigated. Bureau of Reclamation personnel (oral communications, 1965) have determined that intake rates of the alluvial soils are governed primarily by soil structures; the fine-grained material, because of its chemical composition, forms aggregates. Infiltrating water moves into the soil through the openings between the aggregates rather than through interconnected pore spaces within the aggregates. Water that is low in sodium and high in calcium is adsorbed by the soil aggregate and tends to maintain the aggregate structure, whereas water with a high sodium content tends to cause aggregate breakdown and reduce intake rates. (See discussion on page 41.)

Minor aquifers in surficial deposits

The small lenses of water-bearing outwash and alluvium that supply water to a few wells on the James River highlands and the Coteau des Prairies in Clay County normally contain very hard, slightly saline water containing iron, manganese, sulfate, and dissolved solids in excess of the U. S. Public Health Service (1962) standards. The water is generally similar to, though more highly mineralized than, water from the Lower Vermillion-Missouri aquifer.

Wakonda aquifer

Water from the Wakonda aquifer is very hard and slightly saline. Most of the water contains iron, manganese, and sulfate in excess of U. S.

Public Health Service (1962) standards, and all samples analyzed exceeded the standards for dissolved solids. Most of the analyses show a fluoride content slightly below the recommended minimum.

Untreated water from the Wakonda aquifer normally is satisfactory for all livestock uses; some treatment (softening, iron and manganese removal) is desirable for most household uses. The relatively high dissolved-solids content of the water creates a high to very high salinity hazard. (See fig. 10.)

Some wells completed in the Wakonda aquifer, as delineated on plate 4, yield water similar in quality to that from the aquifer in the Niobrara Marl, whereas other wells yield much less mineralized water, similar to that from the Lower Vermillion-Missouri aquifer. The former wells yield water from the Niobrara where unconsolidated surficial materials are missing, whereas the latter wells yield water from unconsolidated surficial materials where hydraulic continuity with the Niobrara is incomplete. Most wells tapping the Wakonda aquifer, however, yield water that is intermediate in quality between that from the Lower Vermillion-Missouri aquifer and that from the aquifer in the Niobrara Marl. As indicated on page 47, the specific conductance of water from a well in the Wakonda aquifer is a good indicator of the material from which the water is being withdrawn.

Aquifer in Niobrara Marl

Water from the aquifer in the Niobrara Marl is very hard, slightly to moderately saline, and a calcium sulfate type. On the basis of the few chemical analyses available from Clay County, much of the water probably contains excessive iron, manganese, sulfate, and dissolved solids in comparison to the U. S. Public Health Service (1962) standards. All other constituents for which analyses are available are within the recommended limits.

Untreated water from the aquifer normally should be satisfactory for all livestock uses; water for household uses may require softening and iron removal. Water from this aquifer has a very high salinity hazard. (See fig. 10.)

Aquifer in Codell Sandstone Member of Carlile Shale

The aquifer in the Codell Sandstone Member of the Carlile Shale yields water that is very hard, slightly saline, a calcium sulfate or calcium bicarbonate type, and, compared to the U. S. Public Health Service (1962) recommended standards, contains excessive amounts of iron, manganese, sulfate, and total dissolved solids. The water normally is satisfactory for livestock use, but may require softening and iron removal for some domestic uses; it has a low sodium hazard and a high salinity hazard (fig. 10.)

Aquifer in Dakota Group

The aquifer in the Dakota Group yields water of uniform quality throughout Clay County. The water is very hard, slightly saline, of the calcium sulfate type, and in comparison to U. S. Public Health Service (1962) recommended limits, contains excessive concentrations of iron, manganese, sulfate, fluoride, and total dissolved solids.

Water from the aquifer in the Dakota usually is satisfactory for all livestock uses, but may require treatment for some domestic uses. The fluoride content of water from some wells may make the water undesirable for drinking. On the basis of the 80 percent ranges of specific conductance, percent sodium, and SAR (table 4), most water from the Dakota in Clay County is rated "good to permissible" for irrigation; the water has a low sodium hazard and a high salinity hazard.

The aquifer in the Dakota Group east and southeast of Vermillion contains water nearly identical in quality to that in the Lower Vermillion-Missouri aquifer, which immediately overlies the Dakota. (See page 21.) Because Dakota wells do not flow in this area, nearly all wells are completed in the Lower Vermillion-Missouri aquifer.

SUMMARY AND CONCLUSIONS

Ground water is the most important water resource in Clay County. The quantity of surface water available from streams and reservoirs undergoes considerable seasonal variation and, as a result, surface-water resources have been little exploited. In contrast, the quantity of available ground water is large and relatively constant. Water is available from one or more aquifers everywhere in the county; it furnishes all the water used for domestic, irrigation, municipal, and industrial purposes, and nearly all the livestock supplies in the county.

The Lower Vermillion-Missouri aquifer is composed mainly of outwash sand and gravel and underlies about 75 percent of Clay County. The aquifer averages about 100 feet in thickness, contains an estimated 5 million acre-feet of water in transient storage, and supplies about 70 percent of the water used in the county.

Recharge to the Lower Vermillion-Missouri aquifer in Clay County is by local infiltration of precipitation and runoff, especially on the river floodplains, and by subsurface inflow from adjacent counties. In the fall of 1965, the aquifer was practically in a condition of equilibrium--filled to capacity--between recharge and discharge.

Discharge by evapotranspiration and by subsurface outflow accounts for most of the water leaving the Lower Vermillion-Missouri aquifer in Clay County. About 1,730 acre-feet of water from the aquifer was used in 1964, more than one-fourth of which was for irrigation.

The quality of water from the Lower Vermillion-Missouri aquifer is fairly uniform at any given location, but varies systematically from one location to another. The lowest hardness and dissolved-solids concentrations occur in water from the aquifer under the Vermillion and Missouri

River floodplains. Water from the aquifer is very hard and contains undesirable quantities of iron and manganese; it normally is satisfactory without treatment for livestock and irrigation and for some domestic uses, and with treatment, particularly iron and manganese removal and softening, can be made satisfactory for all domestic and some industrial uses.

The Lower Vermillion-Missouri aquifer has greater potential for additional development than any other aquifer in the county. Increased use, resulting in lower water levels, might salvage much of the water now lost from the aquifer by evapotranspiration and surface and subsurface outflow, and might induce additional recharge from precipitation and surface-water bodies.

The Wakonda aquifer, made up of unconsolidated alluvium and outwash and the underlying Niobrara Marl, is present under most of the James River highland in northwestern Clay County. This aquifer is recharged primarily by subsurface inflow from the northwest, and discharges water primarily to wells and, in the subsurface, to the Lower Vermillion-Missouri aquifer. About 236 acre-feet of water was used from the aquifer in 1964.

Water in the Wakonda aquifer is variable in quality and is generally poorer than water from the Lower Vermillion-Missouri aquifer. The chemical composition of water from a given well depends in part on the degree of hydraulic connection between the surficial and bedrock parts of the aquifer in the immediately surrounding area. Except for its generally unsatisfactory quality for irrigation and industrial uses, the water can be used in the same manner as water from the Lower Vermillion-Missouri aquifer.

An aquifer in the Niobrara Marl underlies most of the Coteau des Prairies in northeastern Clay County. This aquifer transmits water through, and yields water from, fractures rather than intergranular openings. Recharge to the aquifer is primarily by subsurface inflow from the northeast, and discharge is almost entirely to wells and subsurface outflow to the Lower Vermillion-Missouri aquifer.

Water from the aquifer in the Niobrara is harder and contains more dissolved solids than water from the other aquifers in the county. The greatest use of water from the aquifer is for livestock--in 1964, more than 90 percent of the water discharged to wells from the aquifer was for this purpose. The poor quality of the water limits its use for domestic purposes, and it is generally unsuitable for irrigation or industrial use.

The Codell Sandstone Member of the Carlile Shale supplies water to a few wells on the James River highlands and Coteau des Prairies. The extent and hydrologic characteristics of this aquifer are unknown, but its potential for additional development in the county probably is very slight. Water from the Codell is similar in quality to water from the aquifer in the Dakota Group.

The most widely used aquifer in the bedrock, and the only aquifer underlying all of Clay County, consists of permeable sandstone strata in the Dakota Group. The aquifer contains water under artesian pressure. It discharges to flowing wells on the Missouri River floodplain west of Vermillion and to pumped wells elsewhere in the county. The altitude of the piezometric surface of water in the aquifer ranges from about 1,280 feet at the northwest corner of the county to about 1,120 feet in the southeast corner. Long-term records indicate that, until recently, artesian pressure in the Dakota has declined since initial development of the aquifer in 1885. Recent measurements in Clay County reveal that the pressure decline has stopped, and that there is a slight trend toward increasing pressure.

The source and mechanism of recharge to the aquifer in the Dakota are unknown. Recharge to the aquifer in Clay County is by subsurface inflow from adjacent areas. Water is discharged from the aquifer by flowing and pumped wells and by subsurface outflow. The Dakota also discharges large quantities of water to the Lower Vermillion-Missouri aquifer where the two are in contact southeast of Vermillion.

Slightly more than 280 acre-feet of water was used from the aquifer in the Dakota in Clay County in 1964. More than three times this amount was wasted by flow from uncontrolled and unused wells during the same year.

Water in the aquifer in the Dakota Group is similar in quality to water from the Lower Vermillion-Missouri aquifer, although the former generally is harder and contains more dissolved solids. From a quality standpoint, the water is usable without treatment for livestock and domestic supplies, and might be satisfactory for irrigation in some areas. A few analyses of the water revealed fluoride concentrations in excess of the U. S. Public Health Service (1962) standards for drinking water. Therefore, it may be desirable to test for fluoride in individual water supplies where excessive amounts might be detrimental.

Clay County contains abundant ground-water resources. Present ground-water use is only a small fraction of the potentially available water in the two most important aquifers in the county--the Lower Vermillion-Missouri aquifer and the aquifer in the Dakota Group. Increased water use and control of wells presently flowing or being pumped to waste could make still more water available for beneficial uses. At present, there is no indication that any aquifer in the county is discharging water in excess of recharge.

GLOSSARY AND ABBREVIATIONS

Acre-foot.--A unit for measuring the volume of water; the quantity of water required to cover 1 acre to a depth of 1 foot; equal to 43,560 cubic feet or 325,851 gallons.

Afy.--Abbreviation of acre-feet per year.

Alluvium.--Sand, gravel, and other material that has been transported by streams and deposited at places where the velocity of flow was not sufficient to maintain the materials in motion.

Anion.--An ion that moves, or that would move, toward an anode; hence nearly always synonymous with negative ion. Common anions in water are bicarbonate (HCO_3^-), sulfate ($SO_4^{=}$), chloride (Cl^-), nitrate (NO_3^-), and fluoride (F^-).

Aquiclude.--A geologic formation so impervious [impermeable] that for all practical purposes it completely obstructs the flow of ground water (although it may be saturated with water itself), and completely confines underlying strata. A shale is an example.

Aquifer.--A geologic formation or group of formations containing water in its voids or pores that may be removed economically and used as a source of water supply. Unconsolidated deposits of sand and gravel and consolidated sandstones are examples.

Aquitard.--A geologic formation of a rather impervious and semi-confining nature which transmits water at a very slow rate as compared to an aquifer. Over a large area of contact, however, it may permit the passage of large amounts of water to and from aquifers that it separates. Clay layers interbedded with sands, if thin enough, may form aquitards.

Artesian.--Refers to ground water under sufficient head to rise in a well above the top of the aquifer in which it is contained. Artesian conditions occur where an aquifer is confined by overlying, relatively impermeable strata.

Bedrock.--Any consolidated rock extending to an indefinite depth and not known to be underlain by unconsolidated rocks.

Cation.--An ion that moves, or that would move, toward a cathode; hence nearly always synonymous with positive ion. Common cations in water are calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), and potassium (K^{+}).

Coefficient of permeability.--The rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60 degrees Fahrenheit. In field practice the adjustment to the standard temperature is commonly ignored and permeability is then understood to be a field coefficient at the prevailing water temperature.

Coefficient of storage.--The volume of water released from or taken into storage in an aquifer per unit surface area of the aquifer per unit change in the component of head normal to that surface. For an artesian aquifer the water released from or taken into storage, in response to a change in head, is attributed solely to compressibility of the aquifer material and of the water; although rigid limits cannot be established, storage coefficients of artesian aquifers range from about 0.00001 to 0.001. For a water-table aquifer, the water released from or taken into storage, in response to a change in head, is attributed partly to gravity drainage or refilling of the zone through which the water table moves, and partly to compressibility of the water and of the aquifer material in the saturated zone; storage coefficients of water-table aquifers range from about 0.05 to 0.30.

Coefficient of transmissibility.--The average field coefficient of permeability multiplied by the aquifer thickness in feet; expressed as the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent.

Colluvium.--Unconsolidated, unsorted material deposited by gravity at the base of steep slopes.

Confined ground water.--See artesian.

Contour.--Line joining points of equal value, such as surface altitude, water hardness, or aquifer thickness.

Drawdown.--Lowering of the water table or piezometric surface by pumping or by artesian flow.

Drift.--Unconsolidated rock material, such as boulders, till, gravel, sand, or clay, transported by a glacier and deposited by or from the ice or by or in water derived from the melting of the ice.

Eolian deposits.--Material deposited by wind. Loess and sand dunes are examples.

Epm.--Abbreviation of equivalents per million.

Equivalents per million.--Relates to the chemical equivalency of ions in solution; equal to the product of the ionic concentration in parts per million times the reciprocal of the combining (atomic) weight of the ion. In an analysis expressed in equivalents per million, unit concentrations of all ions are chemically equivalent.

Evapotranspiration.--Water returned to the atmosphere by evaporation from water surfaces and moist soil, and by plant transpiration.

Fixed ground water.--Water in the zone of saturation that is held in place against normal hydraulic pressures by forces of adhesion; occurs as a thin film on grains and in minute pores.

Floodplain.--The part of the floor of a river valley, adjacent to the river channel, that is underlain by sediments deposited during the present regimen of the stream and is covered with water when the river overflows its banks at flood stage.

Free ground water.--Water in the zone of saturation that moves under the influence of gravity in the direction of slope of the water table.

Fresh water.--Water containing less than 1,000 parts per million of dissolved solids.

Gpd.--Abbreviation of gallons per day.

Gpd/sq. ft.--Abbreviation of gallons per day per square foot (see coefficient of permeability).

Gpm.--Abbreviation of gallons per minute.

Gravity water.--Water in the zone of aeration that is moving downward under the influence of gravity; vadose water.

Ground water.--Water in the ground that is in the zone of saturation, from which wells, springs, and ground-water runoff are supplied.

Hardness of water.--A property of water generally related to its soap-consuming power; caused by the presence in the water of cations (usually calcium and magnesium) that form insoluble compounds with soap. Hardness commonly is reported in terms of an equivalent quantity of calcium carbonate ($CaCO_3$). Hardness is caused almost entirely by compounds of calcium and magnesium--hard water contains significant amounts of these compounds and soft water does not. The U. S. Geological Survey classifies water for hardness in terms of the amount of calcium carbonate or its equivalent that would be formed if the water were evaporated.

Hydrochemical.--Of, or pertaining to, the chemistry of water.

Hydrograph.--A graph showing stage, flow, velocity, or other property of water with respect to time.

Infiltration.--The flow of a fluid into a substance through pores or small openings. Rate of infiltration is expressed in inches of water per hour under a hydraulic gradient of 100 percent; an infiltration rate of 1 in./hr. equals a permeability coefficient of 14.96 gpd/sq. ft.

Intermittent stream.--A stream that flows only at certain times of the year when it receives water from springs and seeps or from some surface source.

Ion.--An atom or group of atoms with an electric charge.

Lithology.--Physical character of a rock, generally as determined by visual examination without magnification of the sample.

Loess.--A sediment, commonly nonstratified and unconsolidated, composed dominantly of silt-size particles ordinarily with minor amounts of clay and fine sand, deposited primarily by wind.

Outwash.--Stratified, sorted material deposited from meltwater streams beyond the margin of active glacial ice.

Parts per million.--A unit for expressing the concentration by weight of a chemical constituent, usually as milligrams of constituent per kilogram of solution or as grams of constituent per million grams of solution.

Perched ground water.--Water in a saturated zone within the zone of aeration, held above the general water table by a relatively impermeable layer, and underlain by unsaturated material containing gravity water.

Permeability.--The capacity of a material for transmitting a fluid; depends upon size and shape of pores and size, shape, and extent of pore connections. (See coefficient of permeability.)

pH.--A unit for measuring the acidity or alkalinity of a solution; the negative logarithm of the hydrogen ion concentration. A pH of 7 indicates neutrality, a pH of less than 7 indicates an acid solution, and a pH greater than 7 indicates an alkaline solution.

Physiography.--Description of the physical features of the earth's surface and the processes by which they are formed.

Piezometric surface.--An imaginary surface that everywhere coincides with the static level of the water in the aquifer. It is the surface to which the water from the aquifer will rise under its full head.

Potential evapotranspiration.--Water loss that will occur if there is never a deficiency of water in the soil for use of vegetation.

Ppm.--Abbreviation of parts per million.

Recharge.--The processes by which water is absorbed and added to the zone of saturation; also, the quantity of water that is so added.

Regimen of a stream.--The system or order characteristic of a stream; in other words, its habits with respect to velocity and volume, form of and changes in channel, capacity to transport sediment, and amount of material supplied to it for transportation.

Saline water.--Water containing more than 1,000 ppm dissolved solids. Sea water has about 35,000 ppm dissolved solids.

Salinity hazard.--The injury-causing potential (to soil or crops) of the total dissolved solids in water. The four classes of salinity are based upon the specific conductance of water.

SAR.--Abbreviation of sodium-adsorption-ratio.

Sodium-adsorption-ratio.--Related to the adsorption of sodium from water by the soil to which the water is added; determined by the following relation where sodium (Na), calcium (Ca), and magnesium (Mg) ion concentrations are expressed in equivalents per million:

$$\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\dfrac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}}$$

Sodium hazard.--The injury-causing potential (to soil or crops) of the sodium ions dissolved in water. The four classes of hazard are based upon the sodium-adsorption-ratio (SAR).

Soil-moisture capacity.--The amount of moisture that a soil can hold in the plant-root zone against gravity; moisture available for plant use.

Specific capacity.--The discharge of a well expressed as rate of yield per unit of drawdown, generally gallons per minute per foot of drawdown.

Specific conductance.--A measure of the ability of one cubic centimeter of water, or a water solution of mineral matter, to conduct electricity. Because conductance is the reciprocal of resistance, specific conductance is reported in terms of reciprocal ohms (units of electric resistance) or "mhos." To avoid the use of inconvenient decimals, specific conductance values are reported in millionths of mhos, or micromhos. Because specific conductance varies with temperature, all values are referred to a temperature standard of 25 degrees Centigrade.

Stratigraphy.--The part of the descriptive geology of an area that pertains to the discrimination, character, thickness, sequence, age, and correlation of stratified rocks.

Subsurface water.--All water below the surface of the earth; includes suspended water and ground water.

Suspended water.--Water in the zone of aeration that is held in place against gravity by adhesive and cohesive forces (soil moisture, capillary water) or is moving downward under the influence of gravity in unsaturated material (gravity water).

Surficial deposits.--Unconsolidated residual, alluvial, or glacial deposits lying on the bedrock.

Till.--Unstratified, unsorted material deposited directly from or by glacial ice. In Clay County, till is a heterogeneous mixture of silt, sand, gravel, and boulders in a matrix of clay.

Transient storage.--Refers to gravity ground water contained in an aquifer at any given time; such water is moving from a recharge area to a discharge area.

Vadose water.--See gravity water.

Water table.--The upper surface of the zone of saturation except where that surface is formed by an impermeable barrier.

Water-table conditions.--Conditions under which the water in an aquifer is not confined by overlying, relatively impermeable strata. Under these conditions, water can be obtained from storage in the aquifer by gravity drainage--that is, by lowering the water level, as in a pumped well.

Water year.--The 12-month period beginning October 1 and ending September 30; designated by calendar year in which it ends and which includes 9 of the 12 months.

Zone of aeration.--The zone, above the zone of saturation, in which the rocks are not saturated with water.

Zone of saturation.--The zone in which the rocks are saturated with water under hydrostatic pressure.

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