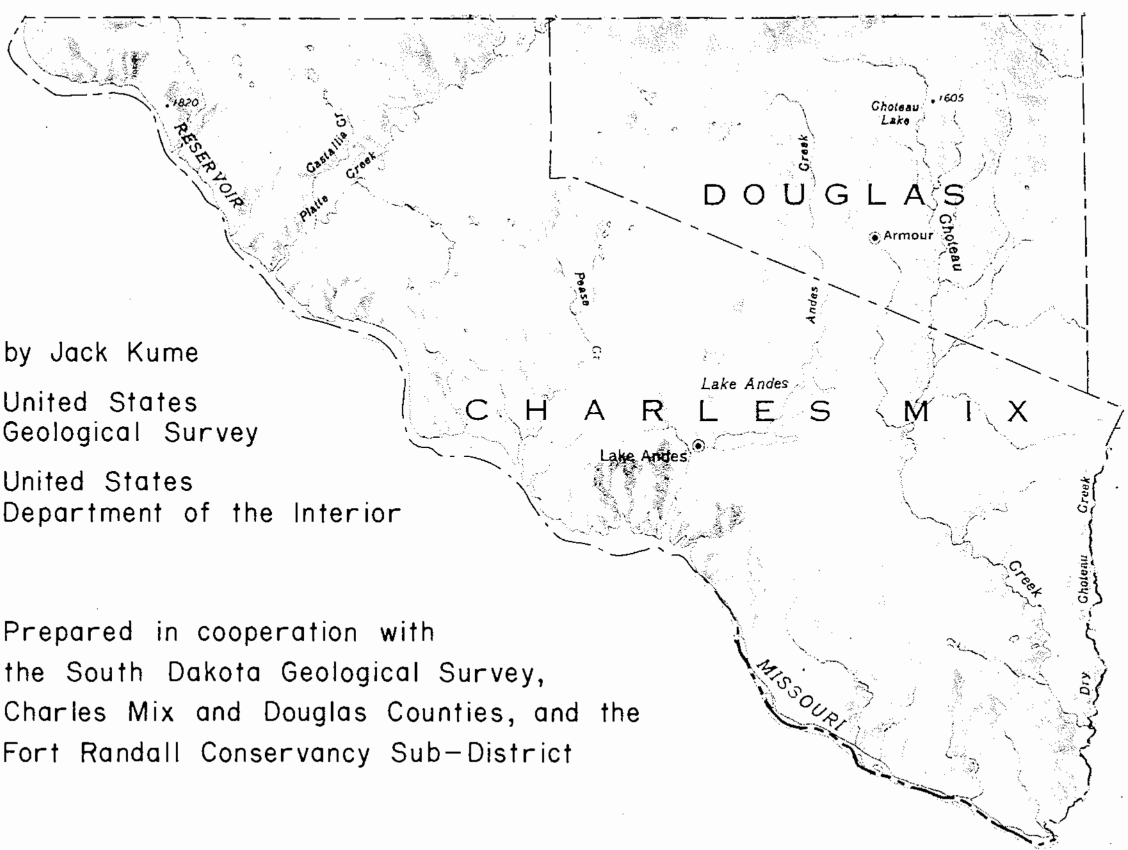
BULLETIN 22

Geology and Water Resources of Charles Mix and Douglas Counties, South Dakota

PART II - WATER RESOURCES



by Jack Kume

United States
Geological Survey

United States
Department of the Interior

Prepared in cooperation with
the South Dakota Geological Survey,
Charles Mix and Douglas Counties, and the
Fort Randall Conservancy Sub-District

Department of Natural Resource Development
South Dakota Geological Survey—Vermillion, South Dakota—1977

STATE OF SOUTH DAKOTA
Richard Kneip, Governor

DEPARTMENT OF NATURAL RESOURCE DEVELOPMENT
Vern W. Butler, Secretary

GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

Bulletin 22

GEOLOGY AND WATER RESOURCES OF CHARLES MIX AND DOUGLAS COUNTIES, SOUTH DAKOTA

Part II: Water Resources

By

Jack Kume
United States Geological Survey
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DEFINITION OF TERMS

Acre-foot (acre-ft).--The quantity of water required to cover 1 acre (4,047 m^2) to a depth of 1 foot (0.3 m); equal to 43,560 cubic feet (1,233 m^3) or 325,851 gallons (1,233,000 l).

Alluvial deposits.--Sand, gravel, and other material known as alluvium that has been transported by post-glacial 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^{-2}), chloride (Cl^-), nitrate (NO_3^-), and fluoride (F^-).

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

Aquifer test.--A means for determining the hydrologic properties of an aquifer. Test made by pumping a well while measuring discharge and drawdown in the pumped well and drawdown in observation wells, then stopping the pump and measuring recovery in all of the wells.

Artesian.--Refers to confined ground water under sufficient pressure to rise above the top of the aquifer in which it is contained. An artesian well is a well deriving its water from an artesian water body. If the water level in an artesian well stands above the land surface the well is a flowing artesian well.

Base flow.--Sustained or fair weather flow is composed largely of ground water discharged into stream channels.

Basement rocks.--A term commonly applied to metamorphic or igneous rocks underlying the sedimentary rock sequence.

Bedrock.--Any consolidated rock exposed at the surface of the earth or overlain by unconsolidated materials.

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^{+2}), magnesium (Mg^{+2}), sodium (Na^+), and potassium (K^+).

Cubic feet per second (ft^3/s).--Flow rate measurement of 1 cubic foot per second, or 448.831 gal/min (28.32 l/s) or 724 acre-ft (892,700 m^3) per year.

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

Drift.--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.

Ephemeral stream.--A stream that flows only in direct response to precipitation. It receives little or no water from springs, and no long-continued supply from melting snow or other sources. Such streams are dry for part of the year.

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

Evapotranspiration.--Water withdrawn from a land area by evaporation from water surfaces and moist soil, and by plant transpiration.

Flood plain.--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.

Fresh water.--Water containing less than 1,000 mg/l dissolved solids.

G.H.--Abbreviation for gage height; stage or water-surface elevation.

gpg.--Abbreviation of grains per gallon.

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 that form insoluble compounds with soap. Hardness commonly is reported in terms of an equivalent quantity of calcium carbonate ($CaCO_3$). Hardness of 1 gpg is equal to 17.12 mg/l.[1]

Head, static.--Height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point.

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

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

Internal drainage.--The condition in which surface

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[1] Description	Milligrams per litre (mg/l)	Grains per gallon (gpg)
Soft	0- 60	0- 3.4
Moderately hard	61-120	3.5- 7.0
Hard	121-180	7.1-10.5
Very hard	More than 180	More than 10.5

runoff accumulates in small depressions that have no outlets to through-flowing streams. When the volume of runoff is exceptionally large, water may overflow the smaller depressions, but under normal climatic conditions, water that flows into the depression remains there until it evaporates, transpires, infiltrates, or is withdrawn by artificial means.

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

Leaching.--Process of removing the soluble material from the soil by passage of water through the soil.

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

lsd.--Abbreviation of land surface datum; surface from which depth is measured.

Milligrams per litre (mg/l).--A common type of concentration unit for reporting water analysis in terms of weights of solute per unit volume of water. By assuming that water weighs 1 kilogram per litre then mg/l and ppm are equivalent.

Outwash.--Stratified, sorted material deposited from or by glacial melt water.

Parts per million (ppm).--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.

Permeability, intrinsic.--A measure of the ease with which a porous medium can transmit a liquid under a potential gradient. It is a property of the medium that is dependent upon the shape and size of the pores and independent of the nature of the liquid and of the force field causing movement. Expressed in square micrometres, 1 $(um)^2$.

Porosity.--The percentage of total volume of rock occupied by pore space.

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

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

Recovery.--Difference between observed water level in a well after pumping has stopped and lowest level reached during pumping.

Saline water.--Water containing more than 1,000 mg/l dissovled solids.

Dissolved Solids
(mg/l)

Slightly saline	1,000 - 3,000
Moderately saline	3,000 - 10,000
Very saline	10,000 - 35,000
Briny	More than 35,000

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.

Saturated zone.--The zone in which the rocks are saturated with water under hydrostatic pressure.

Sodium-adsorption-ratio (SAR).--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^{+2}), and magnesium (Mg^{+2}) ion concentrations are expressed in milliequivalents per litre:

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

Specific retention.--The ratio of the volume of water a saturated rock or soil will retain against the pull of gravity to its own volume.

Specific yield.--The ratio of the volume of water a saturated rock or soil will yield by gravity to its own volume.

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 SAR.

Specific conductance.--The ability of one cubic centimetre of water or a water solution of mineral matter to conduct electricity. Specific conductance values are reported in millionths of mhos or micromhos at a temperature standard of 25 degrees Celsius.

Static head.--The height above the top of a standard datum (aquifer) of the surface of a column of water that can be supported by the static pressure at a given point.

Storage coefficient.--The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Coefficient is numerically small for artesian aquifers indicating that a large pressure change over extensive areas is required to produce substantial water yields.

Stream-environment.--Stream habits with respect to flow velocity and volume, form of and changes in stream channel, capacity to transport sediment, and the amount of material supplied for transportation.

Surface water.--Water on the surface of the earth such as streams, lakes, and ponds.

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

Till.--Unstratified, unsorted material deposited directly from or by glacial ice.

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

ug/l.--Abbreviation of micrograms per litre.

Water table.--Imaginary surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water.

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.

Western origin.--Sediments of a non-glacial fluvial origin derived from the Black Hills and Rocky Mountains.

ABSTRACT

An appraisal of the water resources of Charles Mix and Douglas Counties, an area of 1,540 square miles (3,990 square kilometres) in southeastern South Dakota, shows that these counties are important, but relatively undeveloped, surface- and ground-water resources. Surface-water resources are little developed except for public supplies for Pickstown and Lake Andes, and for irrigation. Surface water is rarely used as a domestic water supply. Ground-water, the most important water resource, is available from one or more aquifers everywhere in these counties. The aquifers furnish water for nearly all of the domestic, stock, public-supply and irrigation needs.

Surface water is available from the Missouri River, Lake Francis Case, Choteau Creek, and several small lakes. The Missouri River with an average discharge of 23,430 cubic feet per second (663 cubic metres per second, 17 million acre-feet per year) and Lake Francis Case with a normal maximum content of 4.8 million acre-feet (6 cubic kilometres) are the major sources of surface water. Choteau Creek with an average discharge of 22 cubic feet per second (0.62 cubic metres per second, 15,900 acre-feet per year) and Lake Andes with a surface area of about 4,400 acres (18 square kilometres) are minor surface-water sources.

The Missouri River and Choteau Creek contain sodium-calcium-sulfate water while the water in Lake Francis Case is a sodium bicarbonate water. All the surface water is fresh except for the base flow of Choteau Creek, the north and south remnants of Lake Andes, and Lake Platte, which are slightly saline.

Lake Francis Case has exceptional potential for recreational development. All the other lakes are used almost exclusively for recreation.

Ground-water resources include aquifers in the surficial deposits and in the bedrock. Ground water is available from aquifers in surficial deposits underlying about 436,000 acres (1,760 square kilometres). Of this area about 50 percent is underlain by aquifers with a saturated thickness greater than 25 feet (8 metres). Total ground-water storage in these aquifers is estimated to be about 3,850,000 acre-feet (4.7 cubic kilometres). The water is generally slightly saline and very hard.

The Dakota, Codell, and Niobrara aquifers are the major bedrock aquifers. Of these, the Dakota is probably the most important aquifer, because it is a potential source of water throughout the area and because it has sufficient static head for artesian wells to flow in the topographically low areas. It contains 44 million acre-feet (5.4 cubic kilometres) of water in storage and furnishes moderate to large supplies of very hard, slightly saline water of the calcium sulfate type to 25 percent of the domestic and stock wells, 11 percent of the public-supply wells, and all of the recreation wells in the area.

The Codell aquifer, which underlies most of the area, is the most desired source for domestic use because its water is soft to moderately hard. It supplies 47 percent of the domestic and stock wells and 70 percent of the public-supply wells. The aquifer furnishes small to moderate supplies of slightly saline water of the sodium-bicarbonate-sulfate type.

The Niobrara aquifer, which underlies nearly all of the study area, yields small supplies of moderately hard, slightly saline water of the sodium-bicarbonate-sulfate type.

The estimated total withdrawal of ground water from surficial deposits and from bedrock aquifers in 1969 was 4,650 acre-feet (0.006 cubic kilometres).

INTRODUCTION

Planning for effective water development and management in Charles Mix and Douglas Counties has been hampered by the lack of reliable and up-to-date information on hydrologic conditions. A rapid increase in the use of wells for irrigation and the demand for more irrigation wells has resulted in a need for more information about the occurrence, quantity, quality, and availability of ground water for irrigation. Additional water information was also needed in order to plan adequately for area growth and economic development.

The primary purpose of this report is to describe and evaluate the various sources of water in Charles Mix and Douglas Counties. The water resources of these counties are appraised in sufficient detail that this report may be used as a guide for future water development. Special emphasis in the study was placed on aquifers that yield or might yield irrigation-water supplies, and on providing data concerning the availability of water for industrial, municipal, domestic, and livestock use.

The study was requested and supported by the County Boards of Commissioners of Charles Mix and Douglas Counties and by the Fort Randall Conservancy Sub-District. It is part of the cooperative county-investigations program (fig. 1) in eastern South Dakota. The U.S. Geological Survey and the South Dakota Department of Natural Resource Development, Division of Geological Survey cooperated in the field investigations. The water resources were evaluated by using standard hydrologic techniques--collecting and studying well data, test drilling, collecting discharge data from streams, inventory and description of lakes, and

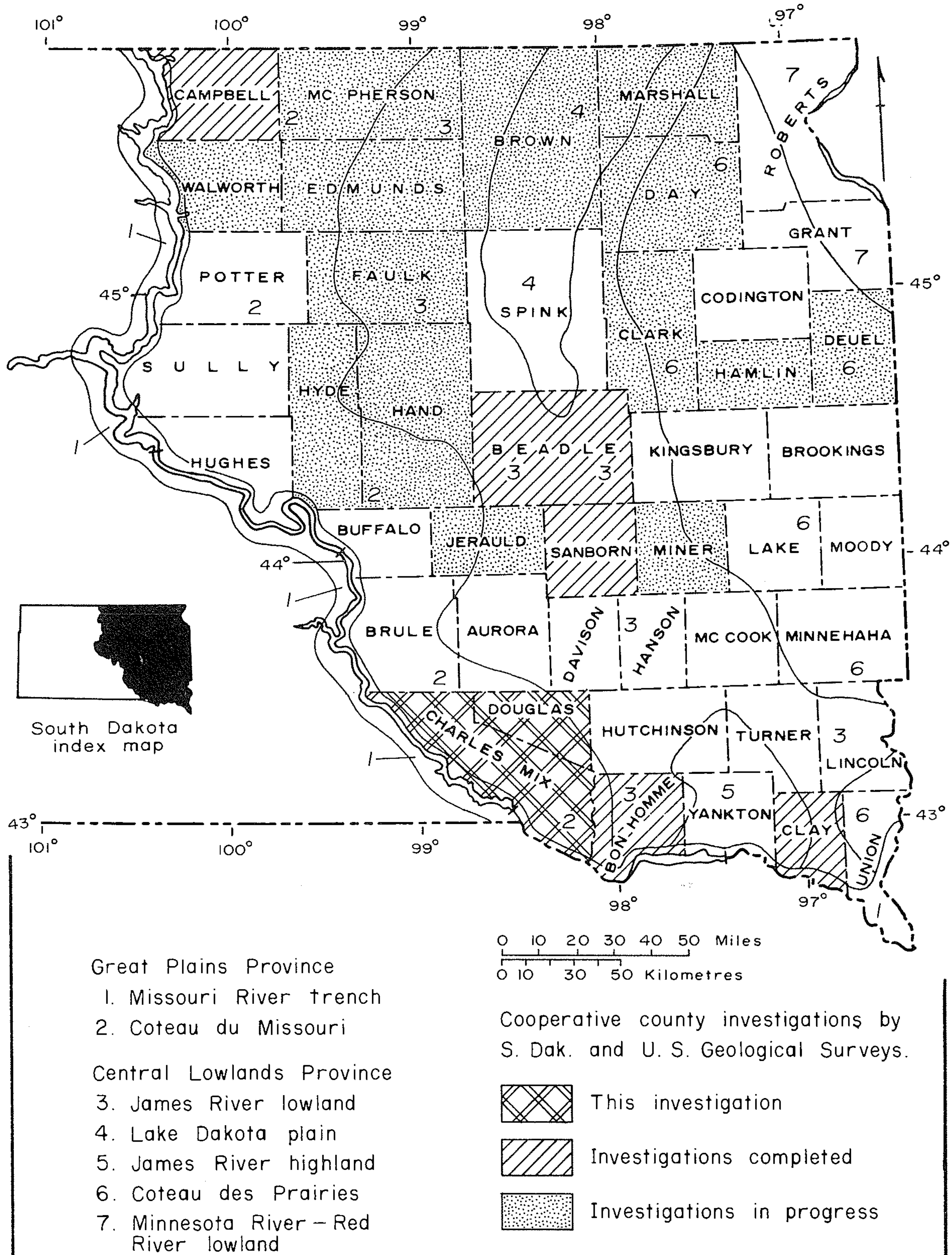

Figure I. Index map of eastern South Dakota showing area of this investigation, status of county investigations, and major physiographic divisions. (*physiographic divisions after Flint*, 1955)

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collecting and analyzing water samples.

This report (Part II, an appraisal of the water resources) is one part of a three-part bulletin which discusses the geology (Part I, Hedges, 1975) and water resources and presents the basic data (Part III, Hedges and Kume, open-file) of Charles Mix and Douglas Counties. The three parts of the bulletin complement each other, and the usefulness of any of them will be greatly enhanced by having all three available for reference.

For those readers interested in using the metric system, metric equivalents of English units are given in parentheses in this report. The English units used were converted to metric units by the following conversion factors:[2]

The numbering system used in this report to describe the location of a particular site such as a well, test hole, spring, or water sampling site is shown by the diagram in figure 2. Each site has been assigned a number based on its location according to the Federal land-survey system in South Dakota. The number consists of the township, range, and section numbers separated by hyphens; four upper case letters that indicate respectively the 160, 40, 10, and 2½ acre tract in which the site is located; and a serial number to distinguish between sites in the same 2½ acre tract, where necessary (95-64-30AABB2).

Appreciation is expressed to the well drillers, county and municipal officials, and residents of Charles Mix and Douglas Counties for their cooperation and help during this study. Thanks are

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[2]

Multiply English units	by	To obtain metric units
	LENGTH	
inches (in)	25.4	millimetres (mm)
	.0254	metres (m)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
	AREA	
acres	4047	square metres (m^2)
	.4047	hectares (ha)
	.004047	square kilometres (km^2)
square miles (mi^2)	2.590	square kilometres (km^2)
	VOLUME	
gallons (gal)	3.785	litre (l)
million gallons (10^6 gal)	3785	cubic metres (m^3)
cubic feet (ft^3)	.02832	cubic metres (m^3)
cubic feet per second per day (ft^3/s)/d	2447	cubic metres (m^3)
acre-feet (acre-ft)	1233	cubic metres (m^3)
	1.233×10^{-3}	cubic hectometres (hm^3)
	FLOW	
cubic feet per second (ft^3/s)	28.32	litres per second (l/s)
	.02832	cubic metres per second (m^3/s)
gallons per minute (gal/min)	.06309	litres per second (l/s)
million gallons per day (mgal/d)	.04381	cubic metres per second (m^3/s)

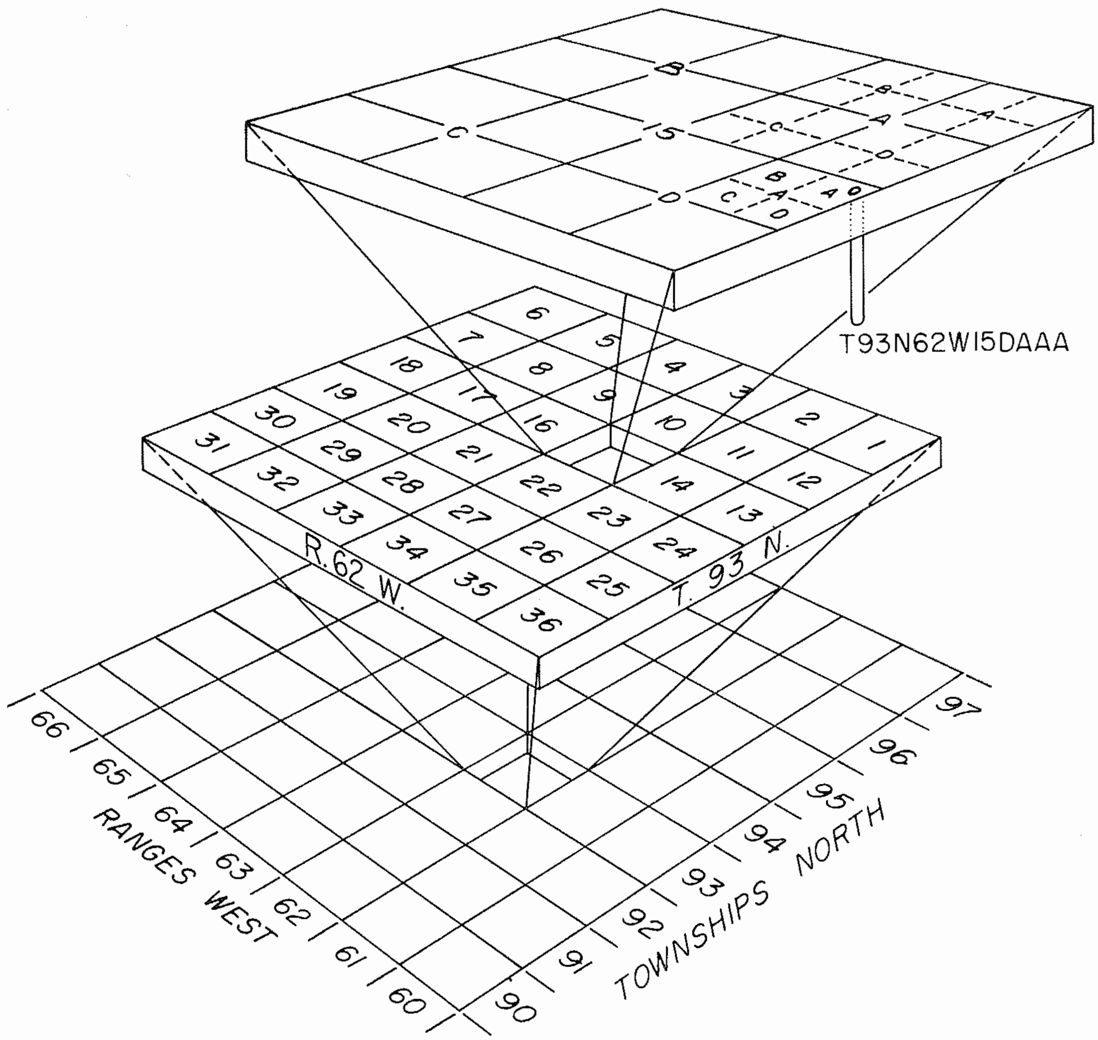


Figure 2. Well numbering system.

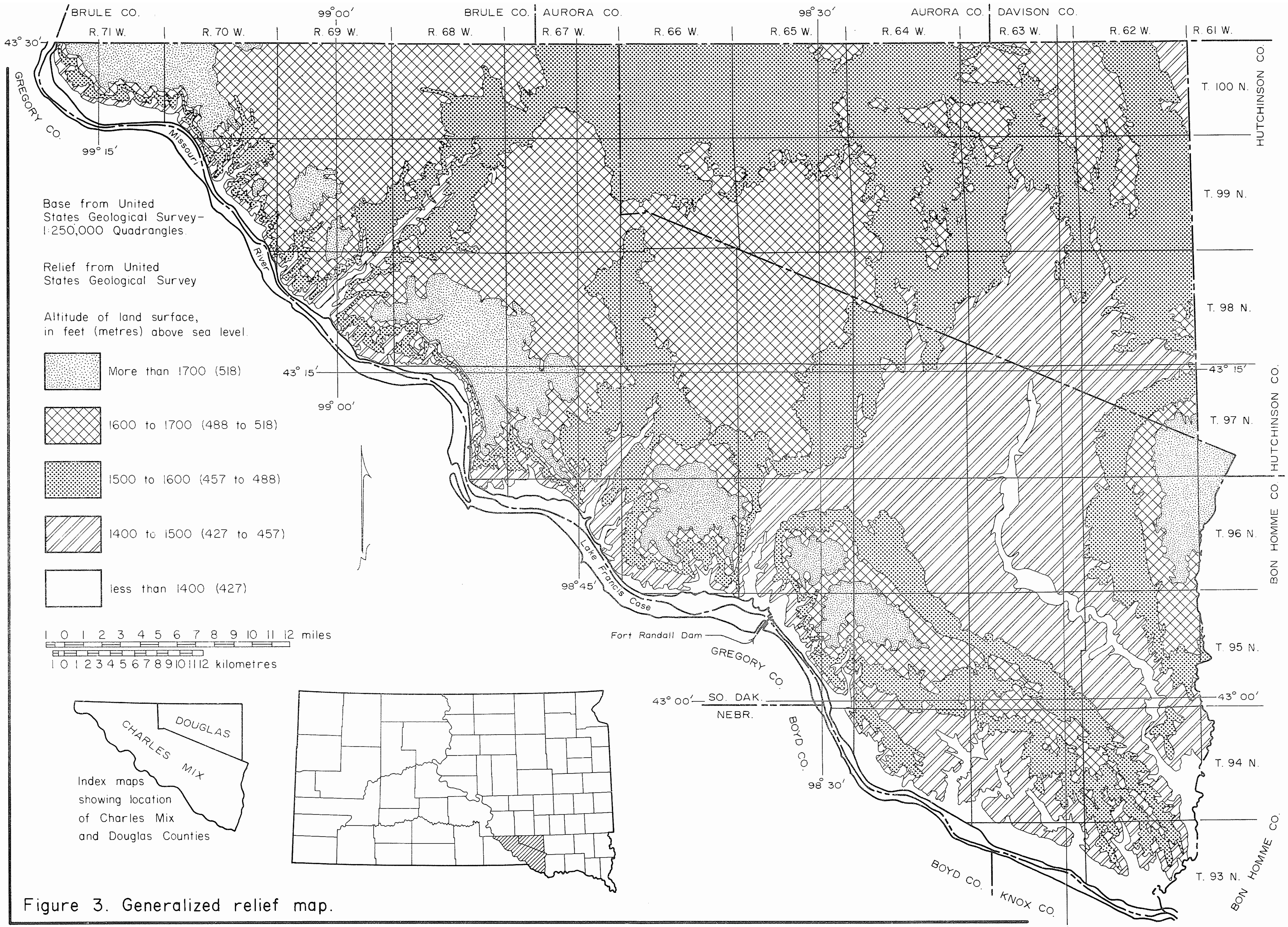


Figure 3. Generalized relief map.

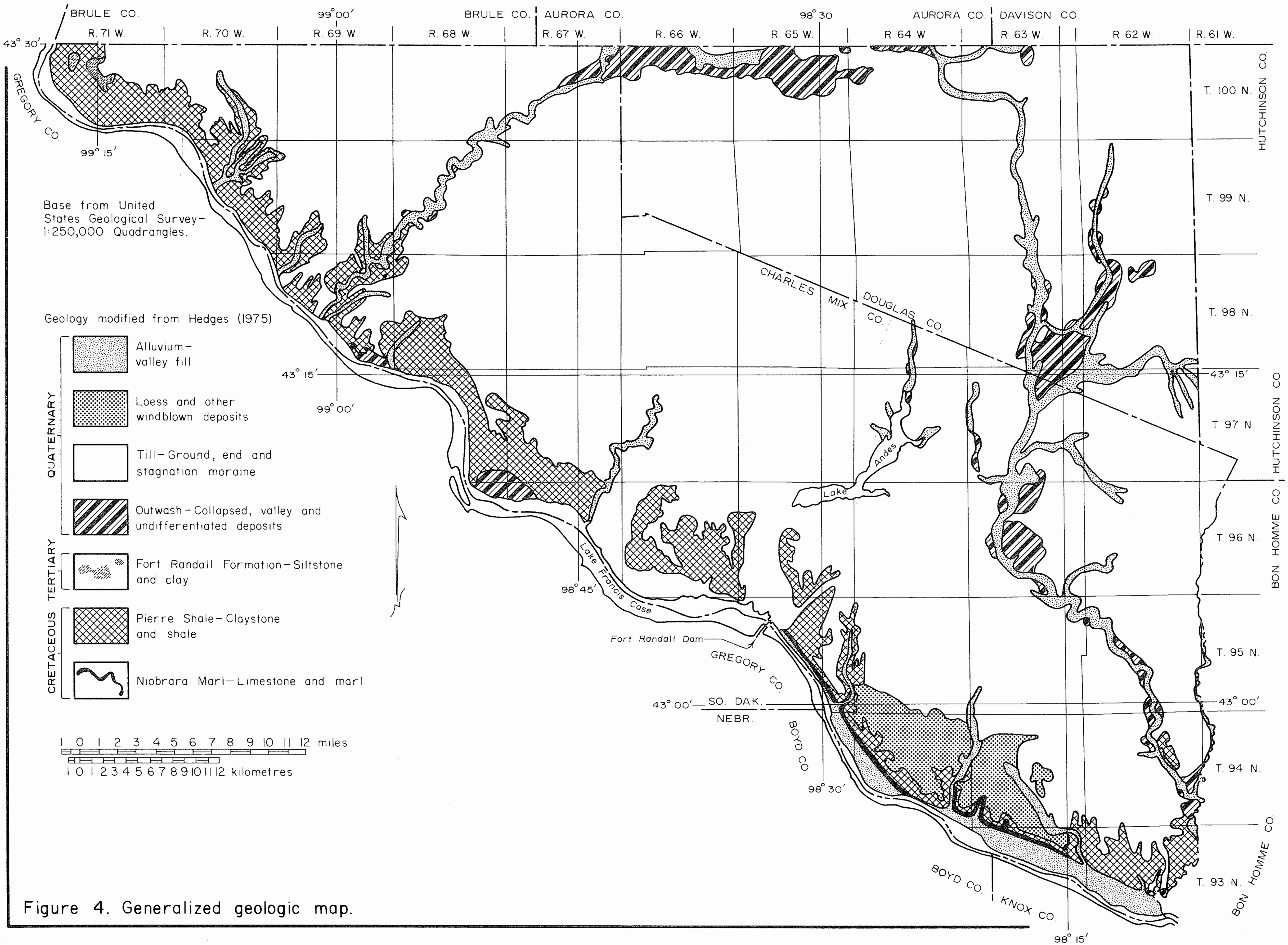


Figure 4. Generalized geologic map.

Table 1. Generalized stratigraphic column listing geologic formations and some of their water-bearing characteristics.

SYSTEM		FORMATION OR DEPOSIT		THICKNESS[1] ft (m)	MATERIAL	REMARKS
QUATERNARY		Alluvium		0-50 (0-15)	Sand, medium, silt, and clay, locally may contain gravel, cobbles, or boulders, generally brown to gray.	Missouri R. sands constitute an important, large source of soft to very hard, fresh water. Alluvium in small stream valleys yields very small to small supplies of very hard, fresh to slightly saline water.
QUATERNARY	Drift	Till and undifferentiated drift	0-450 (0-137)	0-380 (0-116)	Clay and silt, heterogeneous mixture of coase material in a matrix of silt or clay, brown to gray. Undifferentiated drift includes till and relatively fine-grained, poorly sorted, water-laid material.	Relatively impermeable to slightly permeable owing to gravel lenses in the till which yield very small supplies of very hard, fresh to slightly saline water.
QUATERNARY	Drift	Outwash and other fluvioglacial deposits	0-450 (0-137)	0-240 (0-73)	Gravel, sand, silt, and clay, stratified, waterlaid beds, brown to gray. Mostly beds of sandy gravel, clayey or silty sand, and sand and silty clay.	Constitutes the most important source of water in the drift and yields very small to large supplies of soft to very hard, fresh to slightly saline water. Water occurs under both artesian and water-table conditions.
TERTIARY		Ogalalla undifferentiated		0-50 (0-15)	Gravel and sand, stratified beds, brown	Locally it may be a minor aquifer, generally it occurs above the water table.
TERTIARY		Fort Randall Formation		0-120 (0-37)	Clay, sandy, buff, pink to gray. Sand, fine, green, pink to gray.	Locally it may be a minor aquifer, generally it occurs above the water table
CRETACEOUS		Pierre Shale		0-600 (0-183)	Shale, light-gray calcareous to blue-black or black non-calcareous. Commonly contains thin layers of bentonite. Marl, light gray.	Relatively too impermeable to serve as a source of water except that it may yield small quantities of water from fractured or weathered shale.
CRETACEOUS		Niobrara Marl		0-164 (0-50)	Shale, calcareous, medium gray, tan or light-gray, commonly contains abundant microfossils. Marl, light to dark gray, speckled. Limestone, white to orange yellow.	Artesian aquifer which yields very small supplies of moderately hard, slightly saline water. Supplies stock and domestic water—52 wells in Douglas County and 20 wells in Charles Mix County.
CRETACEOUS		Carlile Shale	100-250 (30-76)	0-20 (0-6)	Shale, non-calcareous, dark grayish black.	Relatively too impermeable to serve as a source of water.
CRETACEOUS		Codell Sandstone Member (Carlile Shale)	100-250 (30-76)	0-55 (0-17)	Sandstone, loose to tightly cemented, very fine to coarse, light brownish gray, dark greenish black, and brown. Locally clayey.	Artesian aquifer which yields very small to moderately small supplies of soft to moderately hard, slightly saline water. 2nd most important aquifer in bedrock.
CRETACEOUS		Carlile Shale	100-250 (30-76)		Shale, non-calcareous, light gray and light blue to black, pyrite and marcasite common. Locally contains thin beds or lenses of sandstone below the Codell.	Generally to impermeable to serve as a source of ground water except for those thin beds or lenses of sandstone that are permeable and might yield very small supplies of soft, slightly saline water under artesian pressure.
CRETACEOUS		Greenhorn Limestone		25-60 (8-18)	Shale, fossiliferous, locally may contain beds and lenses of sandstone. Limestone, light and dark gray.	May be a potential, minor aquifer, but is not used in this area as a source of water.
CRETACEOUS		Graneros Shale		50-90 (15-27)	Shale, dark-colored, non-calcareous, pyrite, marcasite and calcareous concretions common. Locally may contain thin beds or lenses of loose to tightly-cemented sandstone.	Generally too impermeable to serve as a source of ground water except for thin beds of permeable sandstone which might yield water.
CRETACEOUS		Dakota Formation		88-450 (27-137)	Sandstone, interbedded tan to white, and shale, dark colored. Sandstone, loose to well-cemented, very fine to coarse, quartz sand, calcium carbonate cement.	Most important aquifer in the bedrock, permeable sandstone beds under artesian head. Aquifer yields moderate to large supplies of very hard, slightly saline water.
CRETACEOUS		Skull Creek Shale		0-50 (0-15)	Shale, gray to varicolored.	Generally too impermeable to serve as a source of ground water.
CRETACEOUS		Fall River Sandstone		0-50 (0-15)	Sandstone, very fine to coarse, tan to white.	An aquifer, but no wells reported, some may be reported as in Dakota aquifer.
PRECAMBRIAN		Sioux Quartzite		+ 3,787 (+ 1,154)	Pipestone, pyrophyllite, hard, dense, purple to red, pink orthoquartzite.	Relatively impermeable, but locally may yield water from fractures or joints.
PRECAMBRIAN		Granite and other crystalline rocks			Biotite and hornblende granite, red to dark-gray, granite, light colored, and mica schist, gray.	Relatively impermeable, but locally may yield water from fractures or joints.

[1] Based on interpretation and projection of data from electric logs, drillers logs, and test holes.

extended to Mr. Emil Grosz, a well driller who provided numerous well logs. The help and cooperation of Mr. Leonard Nelson, Area Extension Agent, is appreciated. Special thanks go to Mr. Lynn S. Hedges, geologist with the South Dakota Geological Survey, for his advice and assistance in the field and later in the preparation of this report. The U.S. Bureau of Reclamation provided drill-hole logs along power transmission lines and information concerning the Wagner, Tower, Greenwood, and Geddes irrigation units. The U.S. Army Corps of Engineers provided drill-hole logs and permitted access to observation wells.

GEOGRAPHIC AND GEOLOGIC SETTING

Geography

Charles Mix and Douglas Counties in southeastern South Dakota (fig. 1) have an area of 1,540 mi^2 (3,989 km^2, 987,000 acres) and a population of 15,835 (1970 census). The area is rural, with all the towns having a population less than 2,500. Charles Mix County, which has an area of 1,097 mi^2 (2,841 km^2) and a population of 11,314, contains about 71 percent of the area and 72 percent of the population.

The physiographic subdivisions shown in figure 1 correspond to the conspicuous topographic features of these counties shown on the generalized relief map (fig. 3). One of the principal features is the Missouri River trench which forms the western boundary of Charles Mix County and comprises the terraces, flood plain, and dissected valley walls of the Missouri River. The Missouri River flood plain ranges in altitude from about 1,230 to 1,250 ft (375 to 381 m) and the tops of the trench walls range from about 1,450 to 1,500 ft (442 to 457 m). Another major feature is the dissected upland called the Coteau du Missouri that stretches from the east margin of the trench to the west drainage divide of the James River in northeastern Douglas County. The Coteau du Missouri, which ranges in altitude from about 1,450 to 2,010 ft (442 to 613 m), is a hummocky upland adjacent to the trench and along the Bon Homme County boundary. The hummocky areas are separated by a broad drainage basin containing Lake Andes and Choteau Creek. The altitude of this drainage basin ranges from about 1,200 to 1,500 ft (366 to 457 m).

Geology

The geology of Charles Mix and Douglas Counties is described in detail in Part I of this bulletin, so only a brief and general discussion of the geology is presented here. A generalized surficial geologic map is shown in figure 4. The Quaternary deposits and formations comprise alluvial valley fill, loess and other windblown deposits, till deposited directly by glaciers as ground, end, and stagnation moraine, and collapsed, undifferentiated, and valley-train outwash deposited by glacial meltwater on stagnant ice and within meltwater channels. Some of the Quaternary sediments, such as the Wagner Formation[3] (Hedges, 1975) were deposited by nonglacial eastward-flowing streams. These sediments are buried by glacial drift and alluvium. The Tertiary and Cretaceous formations that are commonly referred to as bedrock are shown as they are exposed in the study area.

Table 1 is a generalized stratigraphic column that lists and describes the surficial deposits, surface geologic formations, and subsurface geologic formations.

WATER RESOURCES

One of the basic hydrologic principles is the concept of the hydrologic cycle which is the endless circulation of water being transported from the oceans into the atmosphere, dropping upon the land, and eventually returning to the atmosphere or oceans (fig. 5).

Water in Charles Mix and Douglas Counties occurs in surface streams, lakes, ponds, reservoirs, and aquifers in glacial deposits and bedrock strata. Most of the streamflow is derived from snowmelt and spring rains from about 264,000 mi^2 (684,000 km^2) of drainage area. Ground water in surficial deposits originates as precipitation in or near the county. The amount of precipitation, however, is much greater than the amount of water than runs off from the surface or is added to storage in surface- and ground-water reservoirs. About 91 percent of the precipitation is returned to the atmosphere by evaporation and transpiration.

Normal precipitation (21.6 in, 549 mm) in Charles Mix and Douglas Counties provides about 1.8 million acre-ft (2.2 billion m^3) of water annually. Of this amount, about 35,000 acre-ft (43 million m^3) leaves the area as surface runoff, and about 112,000 acre-ft (138 million m^3) falls directly on reservoirs, lakes, and ponds. About 203,000 acre-ft (250 million m^3) is evaporated (average annual lake evaporation 39 in, 991 mm) from reservoirs, streams, lakes, and ponds. Evapotranspiration from vegetation and soil (not including aquifers) accounts for about 1.6 million acre-ft (2.0 billion m^3). About 110,000 acre-ft (1.4 million m^3) is available to recharge aquifers in the surficial deposits, but it is mostly lost through natural discharge from the aquifers by evapotranspiration and subsurface outflow. About 6,000 acre-ft (7.4 million m^3) of the recharge is actually added to aquifer storage to balance the annual consumption of ground water plus the base flow of Choteau Creek.

[3]The stratigraphic nomenclature used in this report is that of the South Dakota Geological Survey and does not necessarily follow the usage of the U.S. Geological Survey.

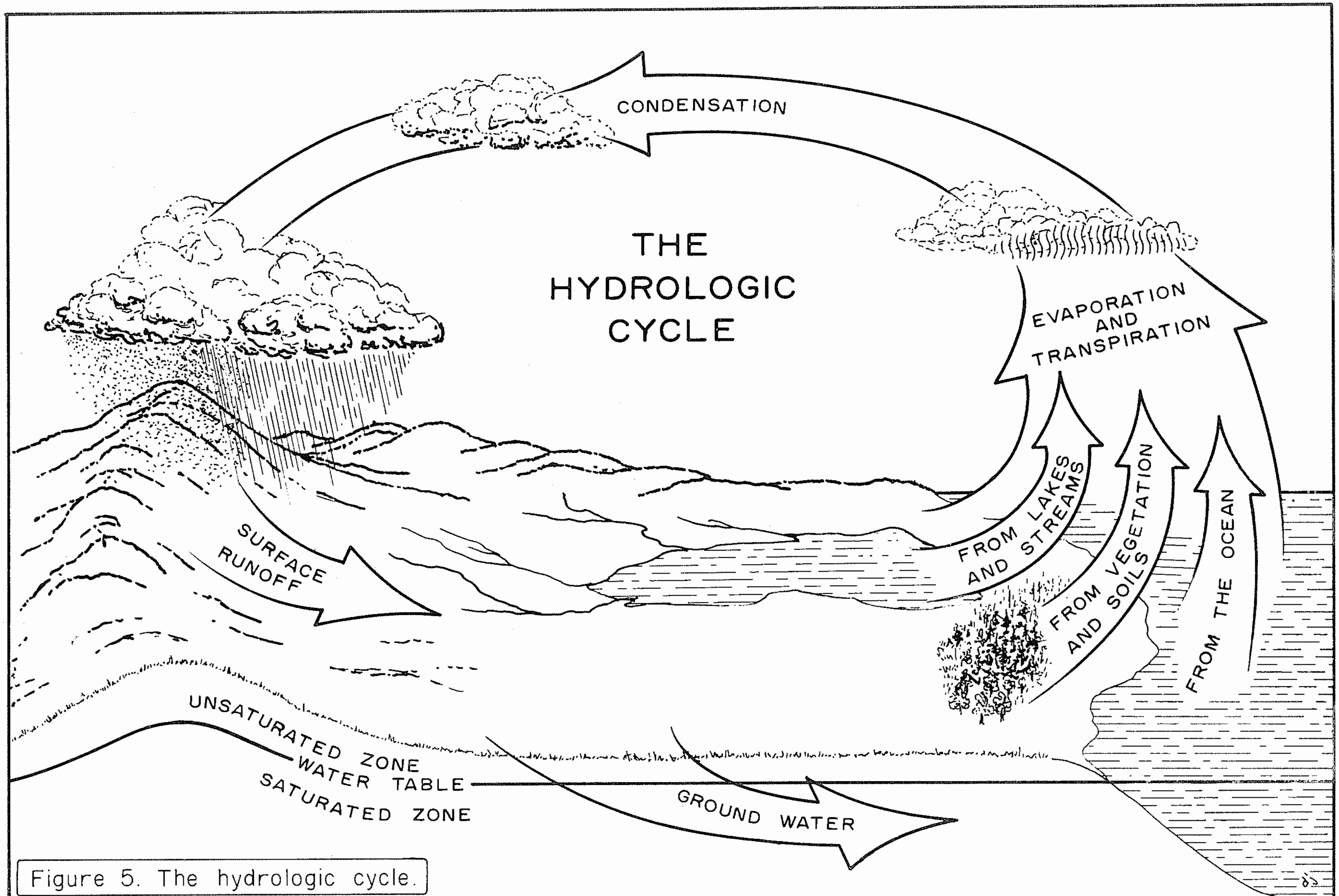


Figure 5. The hydrologic cycle.

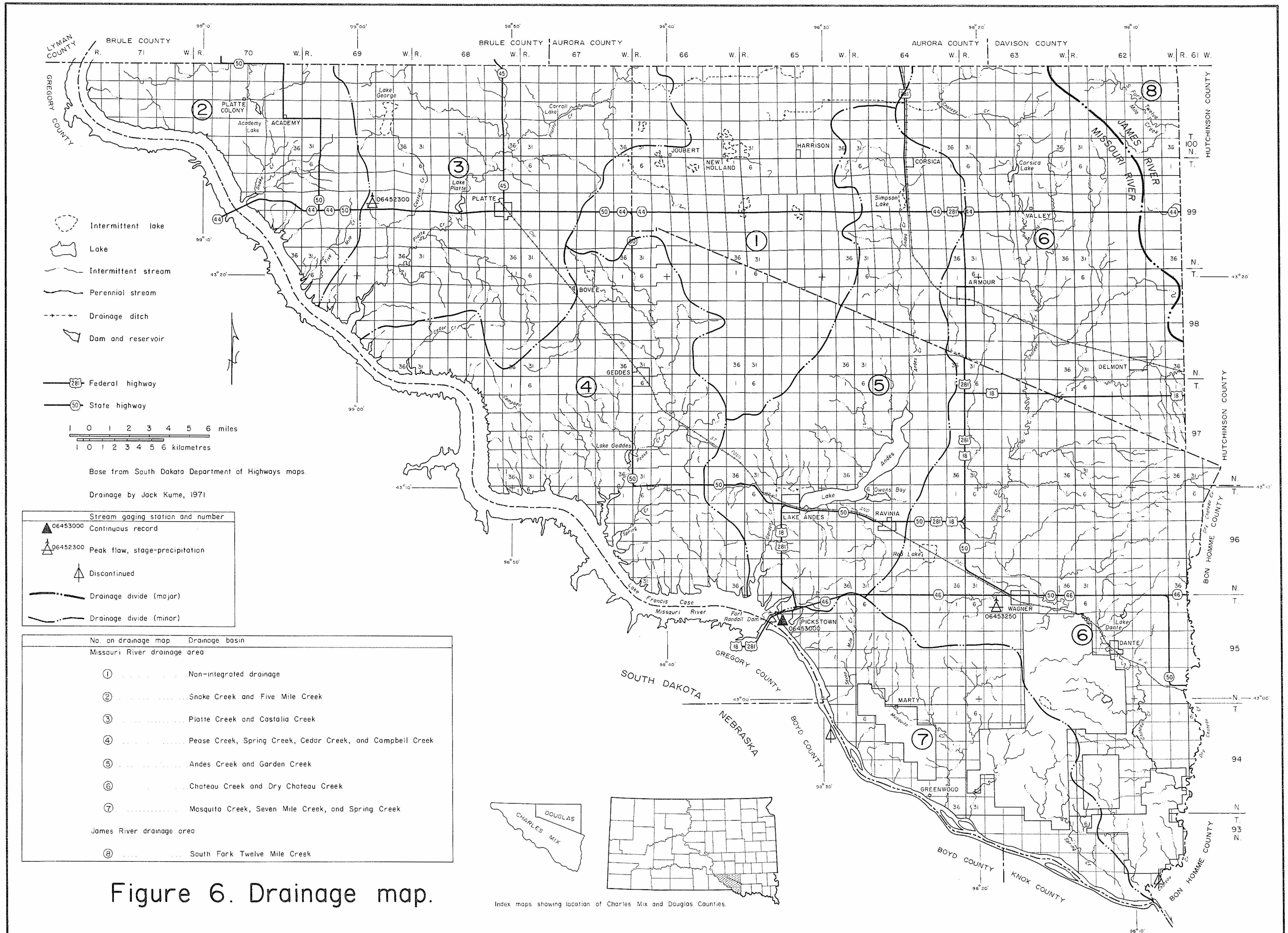


Figure 6. Drainage map.

The surface water leaves the area through the Missouri River and its tributaries. In Charles Mix and Douglas Counties most streamflow and floods occur in the spring and early summer from snowmelt and precipitation. The average annual discharge of the Missouri River at Fort Randall Dam is about 17.7 million acre-ft (21.8 billion m^3).

Ground water in Charles Mix and Douglas Counties is obtained from confined bedrock deposits and from confined and unconfined aquifers in glacial drift. Aquifers in the glacial drift underlie an area of about 436,000 acres (1,764 km^2). The glacial drift contains about 3.8 million acre-ft (4.7 billion m^3) of water in storage. About 50 percent of the total area underlain by aquifers has a thickness greater than 25 ft (8 m). The aquifers are separated or confined by a pebbly clay till. The till deposits are often discontinuous and lenticular. This situation results in varying degrees of permeabilities between the several drift aquifers. The confined Dakota (bedrock) aquifer may contain about 44 million acre-ft (54.2 billion m^3) of water in storage.

Recharge to the aquifers in glacial drift is mainly by infiltration of precipitation. Aquifers in glacial drift adjacent to the bedrock may be recharged with water from the bedrock and vice versa. Natural discharge from the aquifers adjacent to the Missouri River is by subsurface outflow to the river. Natural discharge from the Choteau aquifer is by southeastward flow into Choteau Creek and by upward leakage into the till. Natural discharge from the Delmont aquifer is also into Choteau Creek and by evapotranspiration.

The confined bedrock aquifers are recharged by subsurface inflow (water in the aquifer entering the Counties from an adjacent county) and from underlying bedrock aquifers. Natural discharge is by subsurface outflow (water in the aquifer leaving the Counties) and by leakage into the adjacent drift.

Surface Water

Charles Mix and Douglas Counties are drained by the Missouri River except for a small area of eastern Douglas County which is drained by the James River (fig. 6). Western Douglas and north-central Charles Mix Counties do not have an integrated stream system. It is an area of internal drainage in which the water remains ponded. The largest local drainage basin is that of Choteau and Dry Choteau Creeks. Perennial streams, the ones that flow throughout the year, include the Missouri River and the lower 18 mi (29 km) of Choteau Creek. Most of the other streams (undifferentiated and shown as intermittent in fig. 6) are ephemeral--flowing only in direct response to precipitation, or intermittent--flowing only part of the year. Stream gaging stations, now discontinued, have been located on the Missouri River below Fort Randall Dam and on Choteau Creek in southeastern Charles Mix County.

The slopes of the Missouri River trench and the adjacent dissected uplands are drained by numerous ephermeral and intermittent streams. Spring and Slaughter Creeks flow into the Missouri River, and Andes, Pease, Platte, and Snake Creeks flow into Lake Francis Case.

Two stage-precipitation stations for small drainage basins are located in the study area. Their locations are shown in figure 6. The stations are part of a statewide network to determine the precipitation-runoff relationship of small drainage basins in South Dakota.

The two largest lakes are Lake Francis Case, an impoundment of the Missouri River, and Lake Andes. Smaller lakes include Academy, Platte, Geddes, Dante, and Corsica. These smaller lakes form the reservoirs behind earthfill dams and have an estimated total surface area of about 650 acres (2.6 km^2).

Missouri River

Surface-water records for the Missouri River below Fort Randall Dam (gaging station 06453000) have been published for the period May 1947 to July 1969 (U.S. Geological Survey, 1961-68). The gage was moved July 1969 to the outlet works at Fort Randall Dam (U.S. Geological Survey, 1969-74).

The average discharge based on 23 years of record is 23,430 ft^3/s (663 m^3/s) or 17 million acre-ft per year. The extremes were a maximum discharge of 447,000 ft^3/s (12,700 m^3/s) on April 12, 1952, and a minimum discharge of 100 ft^3/s (2.83 m^3/s) on March 29, 1962. The flow has been regulated by Fort Randall Dam since 1952. The annual mean discharge was 19,360 ft^3/s (548 m^3/s), 23,250 ft^3/s (658 m^3/s), 23,180 ft^3/s (656 m^3/s), 26,590 ft^3/s (753 m^3/s), 26,440 ft^3/s (749 m^3/s), and 29,880 ft^3/s (846 m^3/s) respectively, for 1965-70 water years.

Choteau Creek

The Choteau Creek drainage basin covers an area of 613 mi^2 (1,588 km^2) in parts of six counties. Most of the basin is in eastern Douglas and Charles Mix Counties (fig. 6).

A stream-gaging site was established on Choteau Creek near the downstream end of the basin (NW¼, sec. 23, T. 93 N., R. 62 W.) in May 1966 and was operated continuously until July 1970. The primary purpose of the data collection here was to determine the discharge and base flow of the creek.

Sixty-three discharge measurements were made and the measurements were published in the annual state basic-data releases (U.S. Geological Survey, 1966-70). The equipment at the site consisted of a staff gage and crest-stage gage. The staff gage was read by an observer once a day and daily discharge and base flow values were calculated for the period May 1966 to July 1970.

Base-flow data are useful for estimating the ground-water potential of a basin, and discharge data are useful in determining the relationship of precipitation to runoff. Because the site is located at the downstream end of the basin, the base flow represents most of the ground water output from the basin.

A summary of the monthly precipitation at Wagner and the monthly mean discharge and base flow of Choteau Creek from June 1966 to June 1970 (fig. 7) illustrate the relationship between precipitation and runoff in the area. Annual precipitation at Wagner averaged 23.08 in (586 mm) for the period 1966-69. In 1967 a rainfall of 11.70 in (297 mm) in June resulted in a high mean discharge of 180 ft^3/s (5.2 m^3/s) at the Choteau Creek gage. Snow accumulation in 1969 equivalent to about 8 in (203 mm) of precipitation melted in April to cause a maximum mean discharge of 376 ft^3/s (10.6 m^3/s). In 1970 snowmelt plus a rainfall of 1.89 in (44 mm) during March and 5.97 in (152 mm) during April resulted in a discharge of 56 ft^3/s (1.6 m^3/s). The monthly mean discharge of Choteau Creek ranged from 0.72 to 376 ft^3/s (0.02 to 10.6 m^3/s), and the mean for the entire record interval was 22 ft^3/s (0.62 m^3/s, 15,900 acre-ft per year).

The monthly mean base flow ranged from 0.31 to 2.5 ft^3/s (0.009 to 0.07 m^3/s), and the mean for the entire record interval was 1.7 ft^3/s (0.05 m^3/s, 1,230 acre-ft per year). At various times during the year, the base flow and total streamflow were the same. This was especially true during the winter months of December, January, February, and March when the ground was snow covered and little or no surface runoff entered the stream. The lowest base flow occurred in July, August, and September when withdrawals from the Choteau aquifer, mainly for irrigation, were the greatest.

Eight miscellaneous discharge measurements were made in 1962 on Choteau Creek at a highway bridge (SW¼SW¼, sec. 27, T. 96 N., R. 63 W.) one mi north of Wagner. These measurements were made from March to September, and the discharge ranged from 0.5 ft^3/s (0.014 m^3/s) in September to a peak of 941 ft^3/s (26.6 m^3/s) in July (U.S. Geological Survey, 1962). In March a discharge of 790 ft^3/s (22.4 m^3/s) was measured.

Ground water was found to discharge (base flow) into Choteau Creek channel from the mouth to about 18 mi (29 km) upstream where the channel intercepts the potentiometric surface of Choteau aquifer at an altitude of about 1,375 ft (419 m). Some base flow also comes from the Delmont aquifer. In the upper 7 mi (11 km) of this reach the ground-water discharge is ponded, except during times of heavy runoff. Incipient base flow was observed about 11 mi (18 km) upstream from the mouth, and the discharge increased progressively downstream. Of the total base flow measured at the gaging station, 36 percent was measured at a point 6 mi (10 km) upstream from the mouth. The remaining 64 percent of the streamflow was gained in the next 5 mi (8 km) downstream (Kume, 1970).

Lake Francis Case

Lake Francis Case is an impoundment formed by the Fort Randall Dam on the Missouri River at Pickstown. The initial closure of the earthfill dam was made in July 1952 and storage began in December 1952 (U.S. Geological Survey, 1970). The surface area is estimated to be about 81,000 acres (328 km^2) (U.S. Dept. Agriculture, Soil Conservation Service, 1968, p. 8). Maximum capacity of the reservoir in 1966 was 5,816,000 acre-ft (7.2 km^3) below an altitude of 1,375.0 ft (419 m) (top of spillway gates), but the normal maximum storage was 4,834,000 acre-ft (6 km^3) below an altitude of 1,365.0 ft (416 m). The maximum storage attained from 1952 to 1970 was 5,087,000 acre-ft (5.1 km^3) (altitude 1,364.2 ft, 416 m) on June 20, 1962. Minimum storage since initial filling was 1,450,000 acre-ft (1.8 km^3) (altitude 1,311.5 ft, 400 m) on October 23, 1956 (U.S. Geological Survey, 1970).

Lake Andes

Lake Andes is a natural lake in a bedrock valley that is partly buried by ground moraine--mostly till. Roadway dikes have divided the lake into three remnants--south, north, and far north (Petri and Larson, 1967). The lake is also being referred by others as consisting of the south, middle, and north units. The lake plus Owens Bay covers about 4,400 acres (18 km^2). The altitude of the lake in 1964 was 1,437 ft (438 m). The U.S. Bureau of Sports Fisheries and Wildlife operates the Lake Andes National Refuge here primarily for the protection and production of waterfowl. The refuge including the lake area comprises about 5,400 acres (22 km^2) of which about 900 acres (3.6 km^2) are upland and marsh (U.S. Dept. Agr., 1968).

Andes Creek drains into Lake Andes. The mean annual discharge of Andes Creek above Lake Andes is 6 ft^3/s (0.2 m^3/s) which was determined by a method proposed by Larimer (1970, p. 26).

Lake Andes has a history of widely fluctuating lake levels. During several occasions in the past, the lake has disappeared or nearly disappeared. Low lake

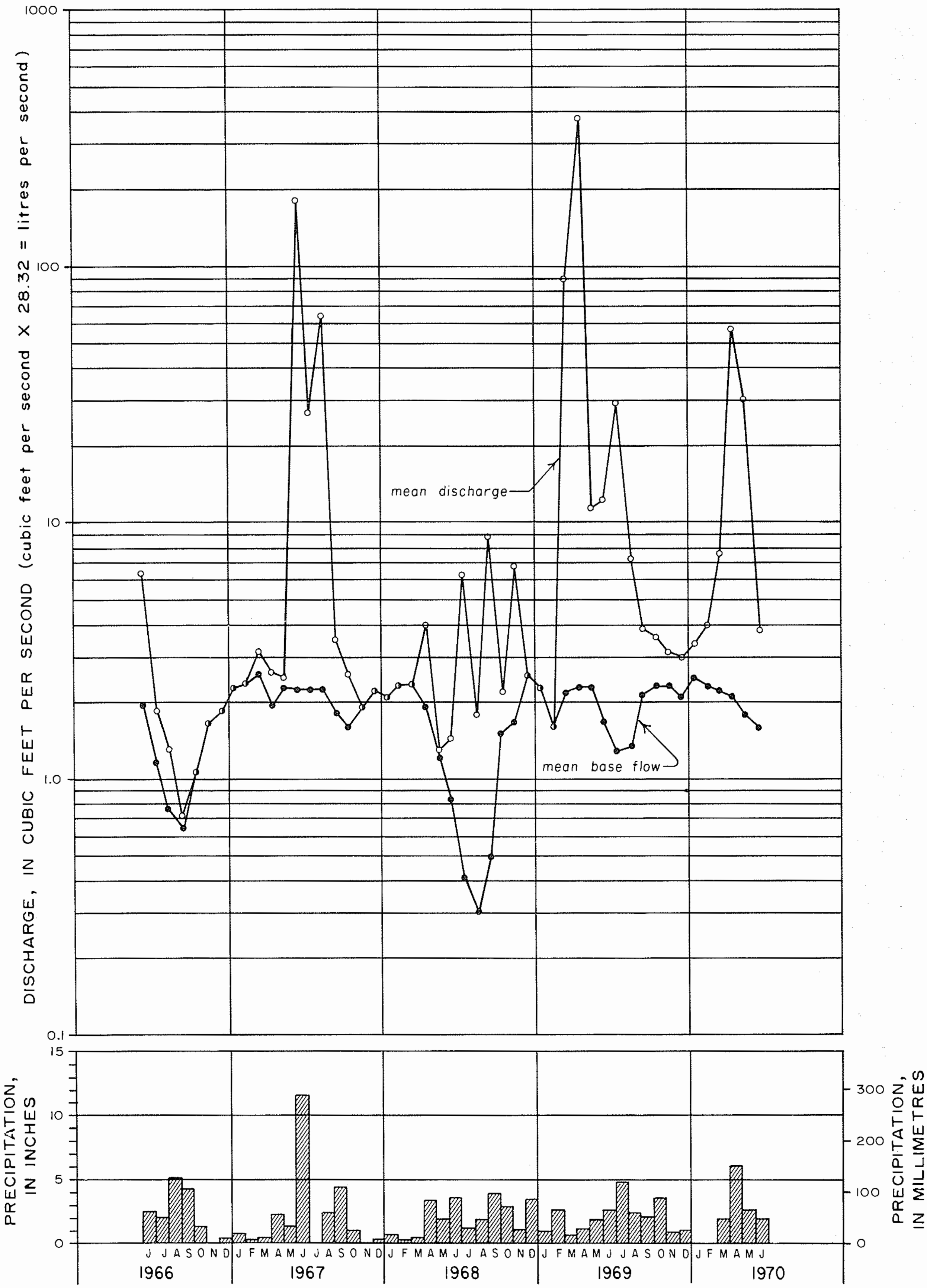


Figure 7. Hydrographs showing monthly mean discharge and base flow of Choteau Creek, and graph of the monthly precipitation at Wagner, S. D.

levels are generally caused by drought conditions (lack of runoff) combined with a high water loss from evaporation. The average annual lake evaporation rate is 39 in (991 mm) according to the U.S. Weather Bureau (1959).

Quality

Chemical Constituents

The chemical constituents of water from eight surface-water sources are indicated by the 19 analyses listed in table 2. The water from the various sources can be grouped into the following water types: Lake Andes and Lake Platte, calcium sulfate; Lake Geddes, calcium bicarbonate; Missouri River and Choteau Creek, sodium and calcium sulfate; Lake Francis Case, sodium-bicarbonate-sulfate; Lake Dante, sodium sulfate; and Corsica Lake, sodium bicarbonate.

Dissolved-solids concentration is probably one of the best single indicators of the general level of chemical quality of water. All of the surface water in the area is fresh except for the base flow of Choteau Creek, the north and south remnants of Lake Andes, and Lake Platte, which are slightly saline. The concentration of dissolved solids in surface water is not constant throughout the year. Seasonal changes in the water from Lake Andes are apparent from table 2. The highest concentrations are in the winter when lake ice is formed. The ice incorporates very little dissolved solids and thereby causes the dissolved solids in the water beneath the ice to become more concentrated. The lowest concentrations occur in the spring when ice melt and spring runoff dilute the lake water. Another factor in the concentration of dissolved solids is the lake level. Petri and Larson (1967) noted that generally as the amount of water in the lake increased and the lake levels rose, the concentrations of dissolved solids decreased; as the lake levels declined the concentrations increased. However, they did not always find this to be true, and the relationship was not clear.

Organisms Affecting Quality

The algal and bacterial content in Lake Andes were determined in October 1964 and again in May 1965 by Petri and Larson (1967, p. 32-39). In October 1964, the north remnant had an algal count ranging from 4,800 to 9,600 per millilitre (ml) with 21 genera present, but in May 1965, the count increased to greater than 38,400 per ml with 42 genera present. In October 1964, the south remnant had an algal count ranging from 9,600 to 19,200 per ml with 19 genera present, but by May 1965, the count increased to greater than 38,400 per ml with 29 genera present. They considered this to be a particularly large number of algae, but could not account for it. Factors that influence algal growth include the presence of nutrients such as nitrate and phosphate, water temperature, pH, turbidity, and sunlight. Heavy algal blooms are detrimental because they may upset the oxygen balance in the lake. The number of bacteria of the coliform and enterococcus group (which are microorganisms of likely fecal origin) changed significantly from zero to low counts in October 1964, to low and high counts in May 1965. Because of these significant changes in bacterial counts, it was concluded that adequate evaluation of this factor would require more frequent sampling (Petri and Larson, 1967).

Utilization

Domestic and Stock

Surface water is rarely used as a domestic water supply in this area because of the need for treatment, the limited availability, and the difficulty of access to sources. Most of the streams have flows which are inadequate for dependable domestic and stock water supplies and most of the lakes are small and have a limited amount of water available for use. Only the Missouri River and Lake Francis Case have an abundant water supply of favorable quality, but access to them is limited. The greatest use of surface water is for livestock watering from stock dams and dugouts. This type of surface water generally is of suitable quality to be used for livestock, but it is not suitable for human consumption.

Public Supply

Pickstown

Surface water for the municipal supply of Pickstown is obtained from the Missouri River at the tailrace below Fort Randall powerhouse. The raw water is treated to reduce the hardness, sulfate, and total solids. The treated water in 1961 (S. Dak. Dept. Health, 1966) was very hard (230 mg/l); however, the total dissolved solids (500 mg/l), chloride, nitrate, and sulfate concentration were all less than the recommended maximum allowable concentrations established by the U.S. Public Health Service (1962) for drinking water. This water analysis indicates that Pickstown has the best-quality public supply in the area.

Estimates of pumpage in acre-ft at Pickstown based on data furnished by the town officials for 1966-70 were 125 (154,100 m^3), 136 (167,700 m^3), 160 (197,300 m^3), 125 (154,100 m^3), and 135 (166,500 m^3), respectively.

Lake Andes

Beginning in September 1971, surface water for the municipal supply of Lake Andes has been obtained from the north shore of Lake Francis Case

Table 2. Chemical analyses of surface water.

Source location	Date of collection (mo.-day-yr.)	Silica (SiO_2, mg/l)	Iron (Fe, ug/l)	Manganese (Mn, ug/l)	Calcium (Ca, mg/l)	Magnesium (Mg, mg/l)	Sodium (Na, mg/l)	Potassium (K, mg/l)	Bicarbonate (HCO_3, mg/l)	Carbonate (CO_3, mg/l)	Sulfate (SO_4, mg/l)	Chloride (Cl, mg/l)	Fluoride (F, mg/l)	Nitrate (NO_3, mg/l)	Dissolved solids (mg/l)		Hardness as $CaCO_3$ (mg/l)		Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25°C)	Alkalinity as $CaCO_3$ (mg/l)	Percentage sodium	Boron (B, ug/l)	Color	Temperature (°C)	Gage Height (G. H.)	pH		Remarks
															Calculated	Residue on evaporation at 180°C	Calcium-Magnesium	Noncarbonate									Time of sampling	Laboratory	
Lake Francis Case																													
99N70W15CBB	9-12-65	—	140	—	58	17	70	5.5	200	—	170	10	—	2.2	513	—	220	—	2.1	—	—	41	—	—	20	—	—	8.23	South Dakota Highway 44 bridge.
Missouri River																													
94N64W28BBAD	9-12-69	—	20	—	57	32	59	4.6	120	—	180	9.9	—	.5	609	—	280	—	1.6	753	130	31	—	—	23	—	—	8.40	Northwest of Greenwood.
95N65W9CDB	2-?-61	—	10	0	70	25	76	5.9	180	—	280	13	.6	1.5	—	589	280	—	—	—	150	—	—	—	1	—	—	8.20	Pickstown (raw) water supply.
Choteau Creek																													
93N62W23BDD	1-15-69	—	0	—	160	53	160	20	160	—	680	37	—	2.5	1,260	—	620	—	2.8	1,810	130	35	—	—	—	1.30	—	8.00	Base flow, G. H. on ice.
Lake Andes																													
96N64W6BAB	10-25-64	37	30	1,200	470	120	180	74	180	0	1,600	170	1.6	2.4	2,770	—	1,700	1,500	1.9	3,220	—	—	370	20	—	6.57	8.0	—	South remnant,(1) G. H. below reference mark.
96N64W6BAB	9-04-65	42	300	4,600	720	120	240	93	230	0	2,400	130	1.0	1.5	3,860	—	2,300	2,100	2.2	4,110	—	—	550	8	—	6.49	7.4	—	South remnant(1).
96N64W6BAB	5-18-65	23	10	930	500	120	190	74	140	0	1,700	190	.9	1.0	2,890	—	1,800	1,600	2.0	3,340	—	—	250	30	—	6.48	8.3	—	South remnant(1).
96N64W6BAB	9-07-65	29	50	1,000	520	140	220	87	96	0	1,900	220	1.9	.4	3,210	—	1,900	1,800	2.2	3,590	—	—	540	25	—	7.38	8.9	—	South remnant(1).
96N64W6BAB	8-26-69	—	860	—	620	300	410	—	75	—	2,600	560	—	15	6,060	—	2,800	—	3.4	6,410	61	23	—	—	28	.60	—	7.20	South remnant, G. H. shore staff.
97N64W16CDC	8-28-69	—	110	—	50	18	20	24	210	—	74	22	—	3.3	401	—	200	—	.6	550	170	16	—	—	24	5.22	—	8.15	Far north remnant, G. H. bridge staff.
97N64W31CDC	10-25-64	36	0	1,400	320	87	110	66	180	0	1,100	99	1.1	.1	1,880	—	1,200	998	1.5	2,350	—	—	300	23	9	6.61	8.0	—	North remnant,(1) G. H. below reference mark.
97N64W31CDC	2-04-65	42	80	7,000	430	110	150	82	240	0	1,400	140	1.3	4.1	2,490	—	1,500	1,300	1.7	2,960	—	—	480	10	—	6.69	7.4	—	North remnant(1).
97N64W31CDC	5-18-65	22	10	1,600	340	89	120	75	150	0	1,200	110	1.2	1.2	2,050	—	1,200	1,100	1.6	2,500	—	—	400	30	—	6.48	8.1	—	North remnant(1).
97N64W31CDC	9-07-65	36	40	950	370	100	150	20	160	4	1,300	130	1.2	.5	2,220	—	1,300	1,200	1.8	2,800	—	—	420	—	—	7.53	8.9	—	North remnant(1).
97N64W31CDC	8-28-69	—	60	—	620	200	170	—	120	—	2,000	340	—	1.6	3,900	—	2,400	—	1.5	4,250	99	13	—	—	27	.60	—	8.26	North remnant, G H bridge staff.
Lake Platte																													
99N68W16DCC	10-01-68	—	430	—	130	53	87	28	130	—	510	83	—	.0	1,080	—	540	—	1.6	1,310	—	25	—	—	20	—	—	7.80	Boat landing.
Lake Geddes																													
97N67W25ACAD	9-11-69	—	10	—	60	31	37	19	210	—	160	19	—	.6	491	—	280	—	.9	631	170	21	—	—	27	—	—	8.30	East shore road.
Lake Corsica																													
99N63W9ADBA	9-12-69	—	110	—	38	16	210	13	260	—	55	170	—	2.3	502	—	—	—	7.2	887	210	72	—	—	23	—	—	8.47	Boat landing.
Lake Dante																													
95N62W9ABBB	9-12-69	—	20	—	58	27	79	9	130	—	160	12	—	.1	452	—	260	—	2.1	650	110	39	—	—	22	—	—	8.35	West shore road.

(1) Analyses from Petri and Larsen, 1967, p. 16-17.

above the Fort Randall Dam. The raw water is pumped through a 5.6 mi (9.0 km), 12-in (300-mm) pipeline to a filtration plant on the south edge of Lake Andes. The pipeline has a capacity of 2,000 gal/min (130 l/s), but the initial withdrawal rate was only about 400 gal/min (25 l/s), sufficient to supply the city's current needs.

Irrigation

Several large surface-water irrigation projects have been proposed by the U.S. Bureau of Reclamation for Charles Mix County. The Wagner, Greenwood, and Tower Units were proposed in 1962 for irrigation development (fig. 8). The Geddes Unit was also being studied at that time.

The proposed Wagner Unit would consist of 19,500 irrigable acres (79 km^2) in the area east from Lake Andes to the West Branch of Choteau Creek and south to Wagner. Water would be pumped from Lake Francis Case into a canal flowing into Lake Andes. From Lake Andes north and south main canals would be used to distribute the water to the irrigable land. Clay or concrete tile would be installed for subsurface drainage to allow for leaching and to prevent water-table encroachment into the root zone.

The proposed Tower and Greenwood Units would be on the "river bottom" land of the flood plain, and the terraces of the Missouri River. The Tower Unit would comprise 1,400 irrigable acres (5.7 km^2) just southeast of Fort Randall Dam and the Greenwood Unit 3,550 irrigable acres (14 km^2) just southeast of Greenwood. Water for these two units would be pumped from the Missouri River into a canal and lateral system for distribution to the various users. Subsurface soil drainage of these units is quite good; however, the water table is shallow--about 10 to 15 ft (3 to 5 m) below land surface.

Surface-water irrigation is currently being practiced as an individual farm operation. Surface water is used mainly to irrigate corn, but a few irrigators also irrigate milo, sorghum, hay, soybeans, wheat, and oats. Pumpage from surface water sources in 1969 was reported to be 3,757 acre-ft (0.0045 km^2). All of the irrigated land is on the Missouri River flood plain and terraces, or on the uplands adjacent to the Missouri River and Lake Francis Case. In southeastern Charles Mix County water is pumped from the Missouri River through a pipeline for about 3.5 mi (5.6 km) northward out of the Missouri River trench and on to the upland. This is the longest irrigation pipeline in the study area.

Recreation

One of the main uses of surface water is for public and private recreational development. Lake Francis Case has exceptional potential for activities such as water sports, fishing, waterfowl production, hunting, and camping. All of the other lakes are small and have only a limited amount of water available for irrigation and public supply so these lakes have been used almost exclusively for recreation. In the proposed Wagner Unit recreational development was an important part of the multipurpose proposal. Lake Andes would have benefited by becoming a storage reservoir for water to be used for irrigation; however, the southern remnant would be used for fishing and boating, and the north and far north remnants were to be used for waterfowl production and limited hunting.

Power Generation

One of the important uses of water impounded by Fort Randall Dam has been the generation of hydroelectric power. The powerhouse contains eight turbine and generator units with a total capacity of 320,000 kilowatts. Water from Lake Francis Case passes through an intake structure and eight tunnels to the turbines in the powerhouse.

Ground Water

Source and Occurrence

Ground water in Charles Mix and Douglas Counties occurs in aquifers that consist of unconsolidated surficial deposits and consolidated bedrock. Unconsolidated surficial deposits include the preglacial stream deposits, the proglacial and glacial deposits which can collectively be called glacial drift, and the postglacial deposits which are called alluvium if waterlain, loess if windblown silt, and colluvium if deposited mainly by gravity (mass wasting). Surficial deposits may be absent in the bedrock outcrop areas along the Missouri River trench but they have a known maximum thickness of 400 ft (122 m) in the drift-buried valleys of eastern Charles Mix and central Douglas Counties (fig. 9). The bedrock formations directly underlying the surficial deposits are shown in figure 10. The bedrock includes the consolidated preglacial formations of sandstone, shale, marl, and limestone.

Aquifers in the Surficial Deposits

The names and areal extent of aquifers in the surficial deposits of Quaternary age in Charles Mix and Douglas Counties are shown in figure 11. The major aquifers, which are informally named in this report for ease of discussion, are composed of outwash or alluvium, or a combination of both. Several minor outwash aquifers are composed of sand and gravel lenses enclosed in till. The lenses are variable in thickness and limited in areal extent. Other minor aquifers consist of undifferentiated outwash, alluvium, and colluvium fill in present-day drainage channels.

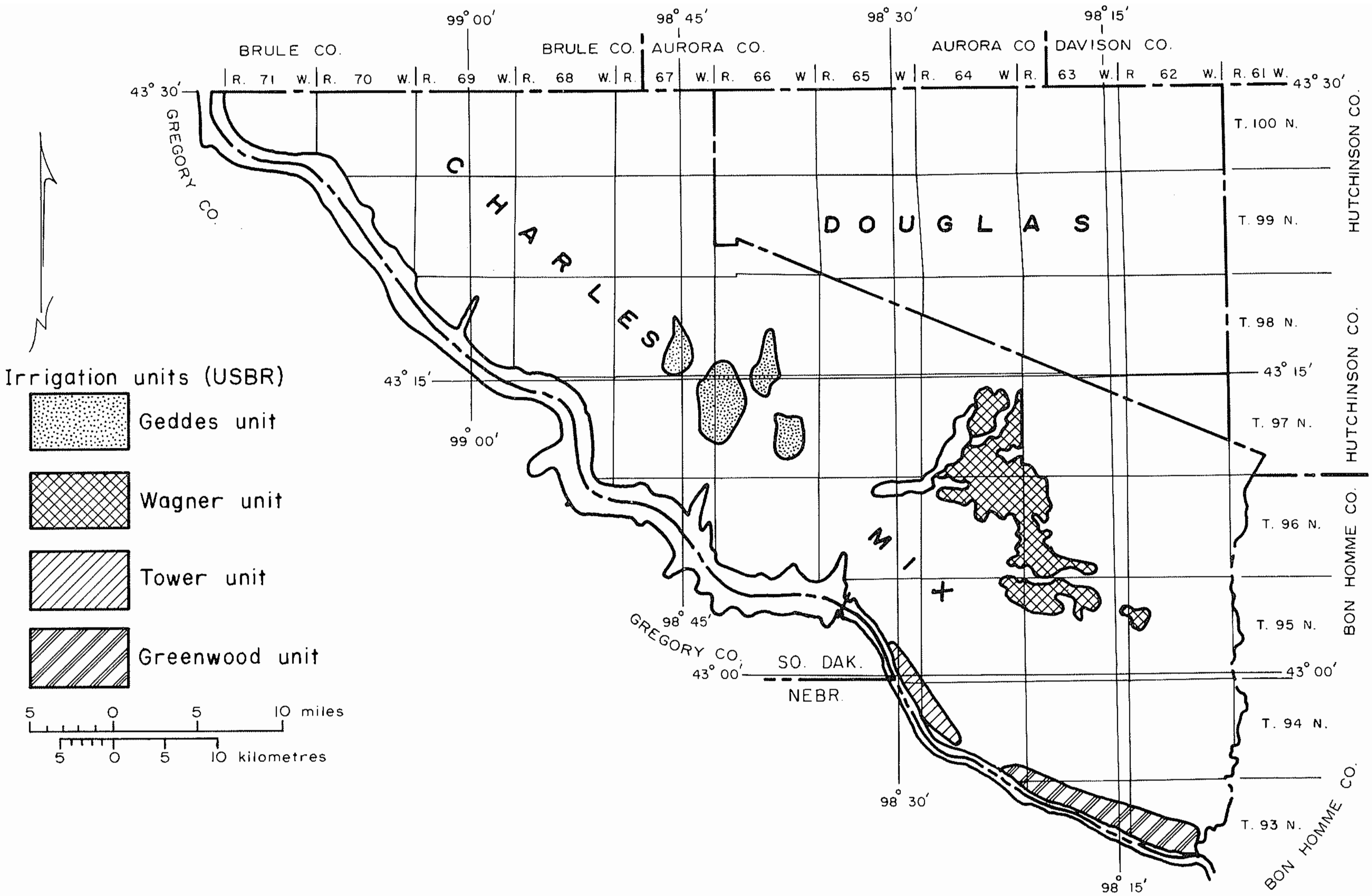


Figure 8. Map showing surface-water irrigation units.

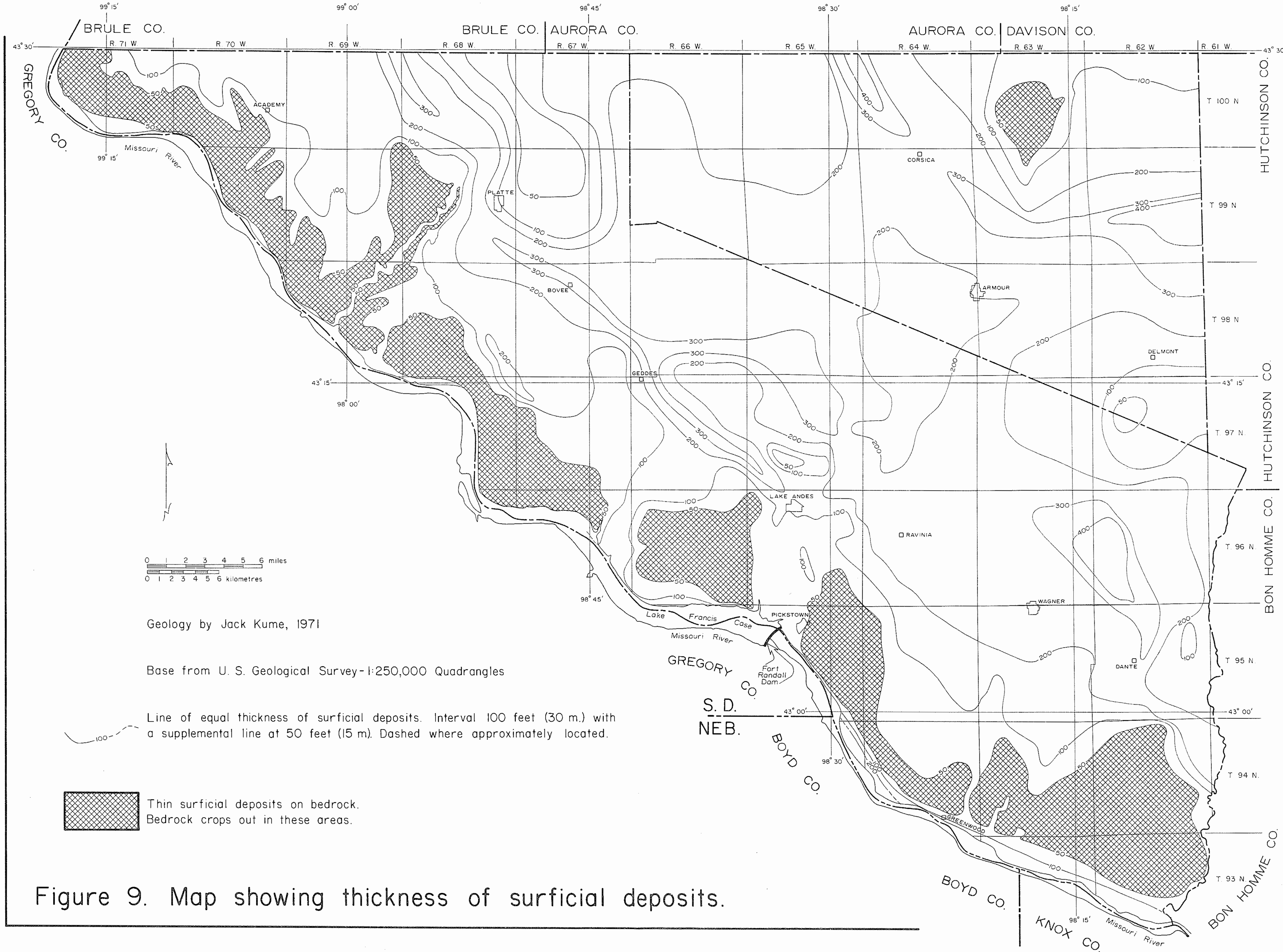


Figure 9. Map showing thickness of surficial deposits.

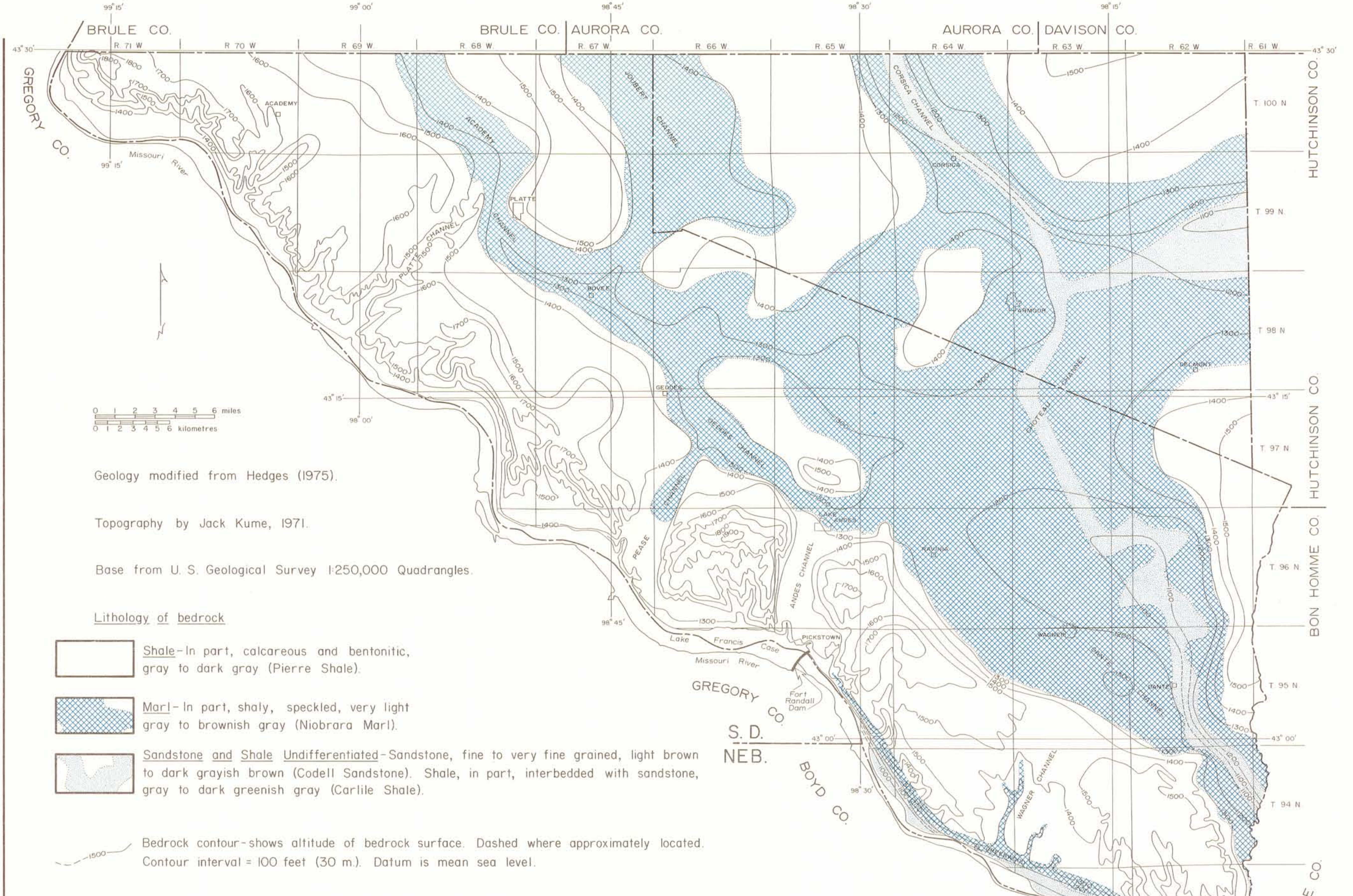


Figure 10. Map showing topography and lithology of bedrock.

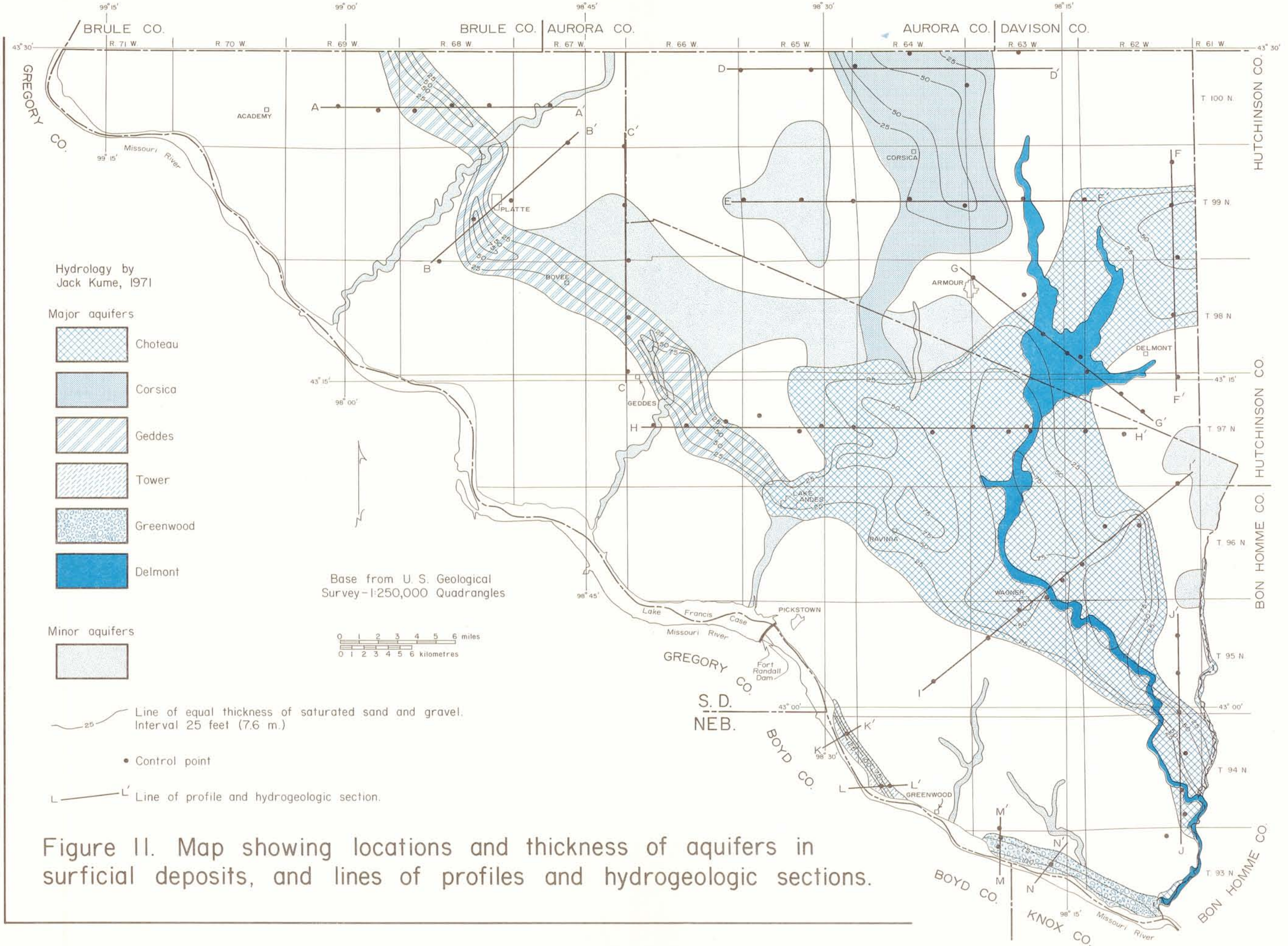


Figure 11. Map showing locations and thickness of aquifers in surficial deposits, and lines of profiles and hydrogeologic sections.

The location of aquifers in the surficial deposits is determined primarily by the underlying bedrock topography (fig. 10). The various channels in the bedrock were probably tributaries of the ancient White and Niobrara Rivers (Flint, 1955, p. 152). Generally, the basal stream sediments found in these bedrock channels were deposited by the tributaries of the ancient White River. These nonglacial stream deposits, generally sands and gravels, are referred to as having a western (Black Hills and Rocky Mountains) origin, as opposed to the outwash sands and gravels which have been transported and deposited by glaciers and have a northern (Canadian Shield) origin. When the Pleistocene glaciers advanced outwash was deposited in these bedrock channels which functioned as melt-water channels. As glaciation continued the channels were buried or partly buried by glacial deposits consisting chiefly of till.

A summary of the characteristics of aquifers in surficial deposits is listed in table 3. Profiles and hydrogeologic sections of surficial deposits and bedrock are shown in figure 12.

Tower and Greenwood Aquifers

Tower and Greenwood aquifers underlie the flood plain and terraces of the Missouri River in the southern part of Charles Mix County (fig. 11). These water-table aquifers consist mostly of sand with some gravel and abundant coal fragments. They are overlain by 3 to 8 ft (0.9 to 3 m) of silty, sandy clay (see table 3). The Tower aquifer is 146 ft (44 m) thick at test hole 94-65-1CDDC where it overlies 83 ft (25 m) of silty to clayey sand and 45 ft (14 m) of silty and sandy clay. This test hole was drilled to a depth of 290 ft (88 m) without reaching bedrock (see fig. 12, sec. K-K'). The thickness and composition of the Greenwood aquifer is shown in sections M-M' and N-N'.

Recharge to both aquifers comes from precipitation, runoff from the slopes adjacent to the Missouri River trench, and from the Missouri River. The aquifers have considerable potential for recharge from the river because any increase in withdrawal from the aquifer will induce recharge from the river to replace the water withdrawn.

The monthly precipitation at Pickstown, the monthly mean discharge of the Missouri River below Fort Randall Dam, and the fluctuation of water levels in wells are shown in figure 13. The water-level fluctuations that occurred during a short period of time appear to be more related to the amount and distribution of precipitation than to the varying discharge and stage of the Missouri River. Precipitation, river discharge, and ground-water levels were low during the winter of 1969-70. However, during the winter of 1968-69 the ground-water levels rose as a result of increased precipitation during a period of low river discharge.

Depth to water on July 9, 1968, was less than 15 ft (5 m) in both aquifers. The water level was at an altitude of about 1,231 ft (375 m) in Tower aquifer and about 1,221 ft (372 m) in Greenwood aquifer. The normal altitude of the river was about 1,230 ft (375 m) adjacent to the Tower aquifer and 1,225 (373 m) adjacent to Greenwood aquifer. These altitudes are nearly the same altitude as the water levels in both aquifers and indicate that the aquifer is in hydraulic contact with the river and that over a prolonged period of time the water table adjusts to the river stage.

An aquifer test in the Greenwood aquifer was made on August 15, 1969, using well 93-62-20ABB. The well was pumped for 5 hours at a rate of 86 gal/min (5.4 l/s). The average transmissivity was 5,750 ft^2/d (feet squared per day, 534 m^3/d), the average storage coefficient 0.014.

The Tower and Greenwood aquifers are relatively undeveloped--they supply only a few domestic and stock wells.

Delmont Aquifer

Delmont aquifer consists of sand and gravel containing abundant coal, chalk, and shale fragments in the Delmont outwash (Stoley, 1956) and the valley fill in the drainage channels of Choteau Creek (see table 3 and fig. 11). The gravel ranges in size from fine to coarse-grained, but it is generally medium-grained and mixed with abundant sand. The sand is generally medium to very-coarse-grained. A profile and hydrogeologic section of the aquifer are shown in figure 12 (section G-G').

The Delmont outwash, with an area of 26 mi^2 (67 km^2), is the largest exposed outwash deposit in the study area; its southern boundary is arbitrarily placed across the channel of Choteau Creek near the middle of sec. 15, T. 97 N., R. 63 W. South of this boundary valley fill outwash occurs in the flood plain and valley floor of Choteau Creek (fig. 14).

The thickness of the sand and gravel in the northern part of the Delmont aquifer is shown in figure 14. A maximum known thickness of 53 ft (16 m) was penetrated in test hole 97-63-10AAAA and thickness of 47 ft (14 m) in test holes 98-62-31CCCC and 98-63-34DDDD. The saturated thickness of the outwash is usually about 5 to 10 ft (2 to 3 m) less than the total thickness of the outwash.

Water in the northern part of the Delmont aquifer is under water-table conditions. Water-level fluctuations in this part of the aquifer generally are related to the amount and distribution of

Table 3. Summary of aquifer characteristics of surficial deposits and of water use.

Aquifer	Saturated thickness [1] Range	Saturated thickness [1] Avg	Material	Area	Transient storage [2]	Use [3]
	ft (ft x 0.3048=m)			acres (acres x $0.004=km^2$)	acre-ft (acre-ft x $0.001=km^3$)	
Tower	51–146	100	Alluvium and outwash, mostly sand, some gravel	2,500	75,000	Few stock and domestic wells.
Greenwood	70–102	80	Alluvium and outwash, mostly sand, some gravel	7,000	168,000	Few stock and domestic wells.
Delmont (northern part)	4–53	15	Outwash, sand and gravel	16,600	77,000	Nine stock and domestic wells.
Delmont (southern part)	8–55	20	Alluvium and outwash, sand and gravel	10,200	61,000	Ten stock and domestic wells.
Corsica	9–73	35	Outwash, sand and gravel	52,500	550,000	Unused
Geddes	10–91	25	Outwash, sand and gravel	48,600	365,000	Eight stock and domestic wells.
Choteau	5–89	35	Outwash, sand and gravel	209,000	2,190,000	Thirteen irrigation, 5 municipal, 203 domestic and stock, and 85 stock wells.
Minor aquifers	1–49	14	Outwash, sand and gravel	90,800	354,000	Few stock and domestic wells.

1) Based on interpretation and projection of data from drillers, logs, and test holes.
2) Based on an assumed average porosity of 30 percent, estimated for 1969.
3) Use based on well inventory based from 1966–69.

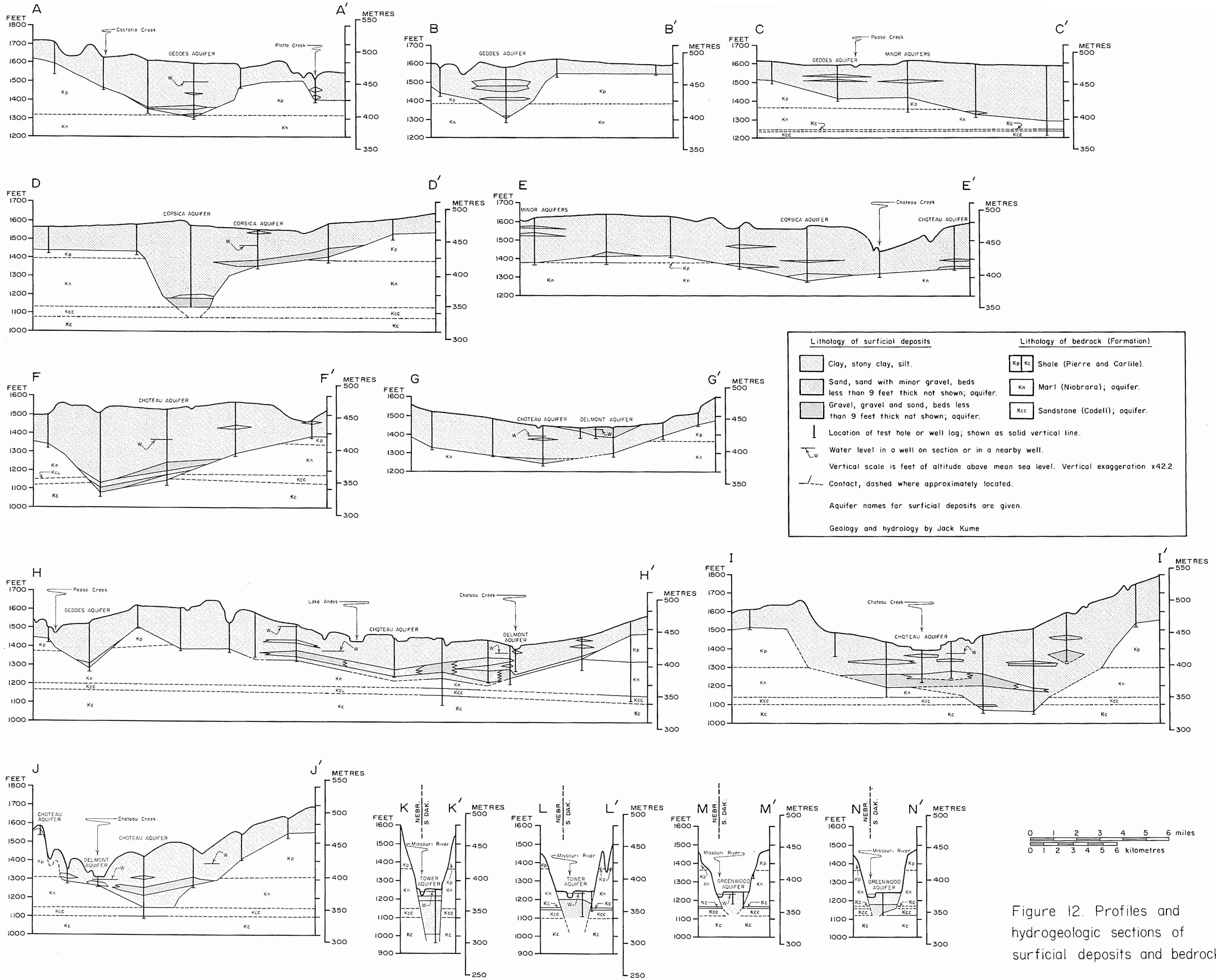


Figure 12. Profiles and hydrogeologic sections of surficial deposits and bedrock.

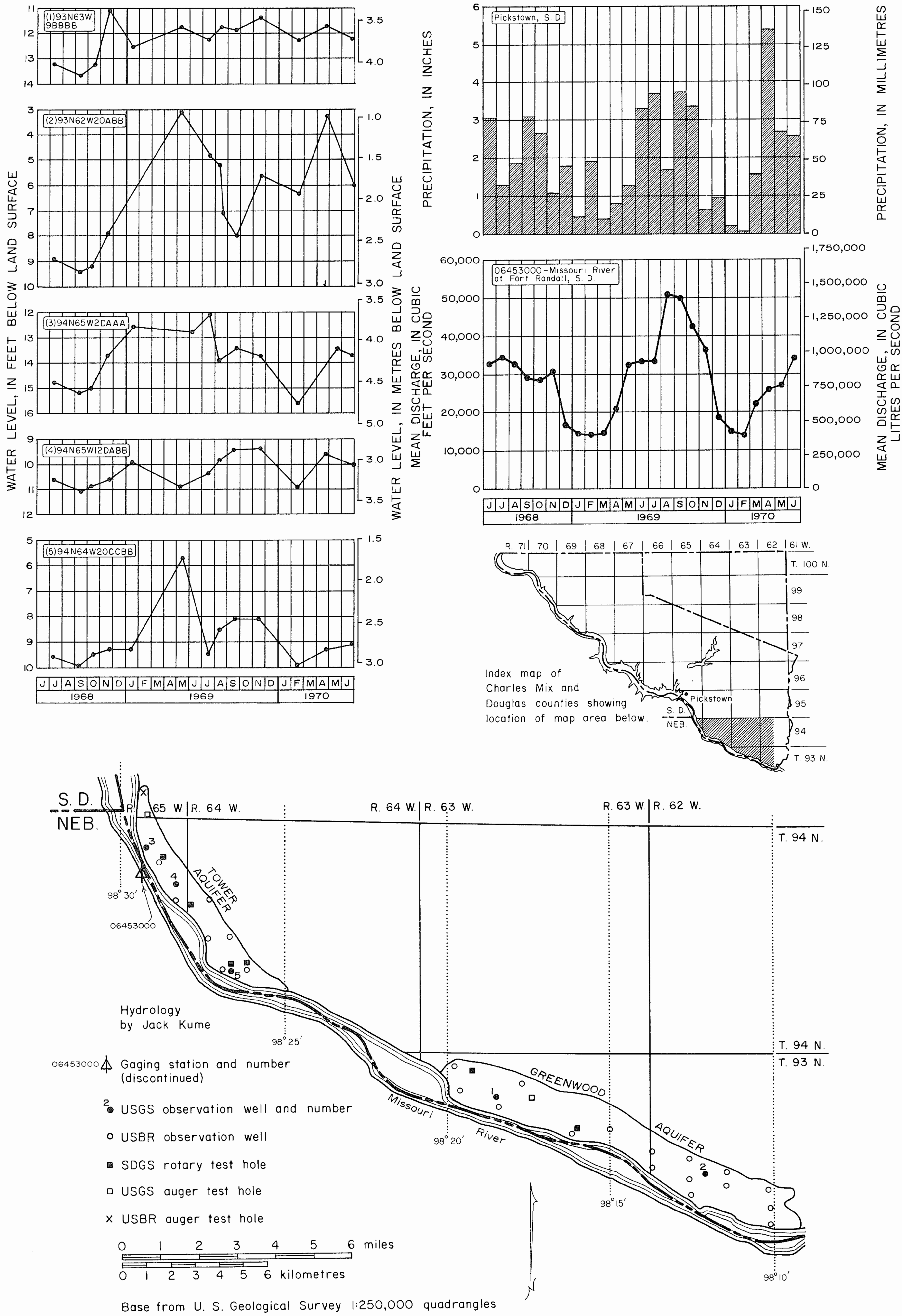


Figure 13. Hydrographs showing discharge of the Missouri River and fluctuations of water levels in wells in Tower and Greenwood aquifers, graph of the monthly precipitation at Pickstown, S. D., and map showing the data points.

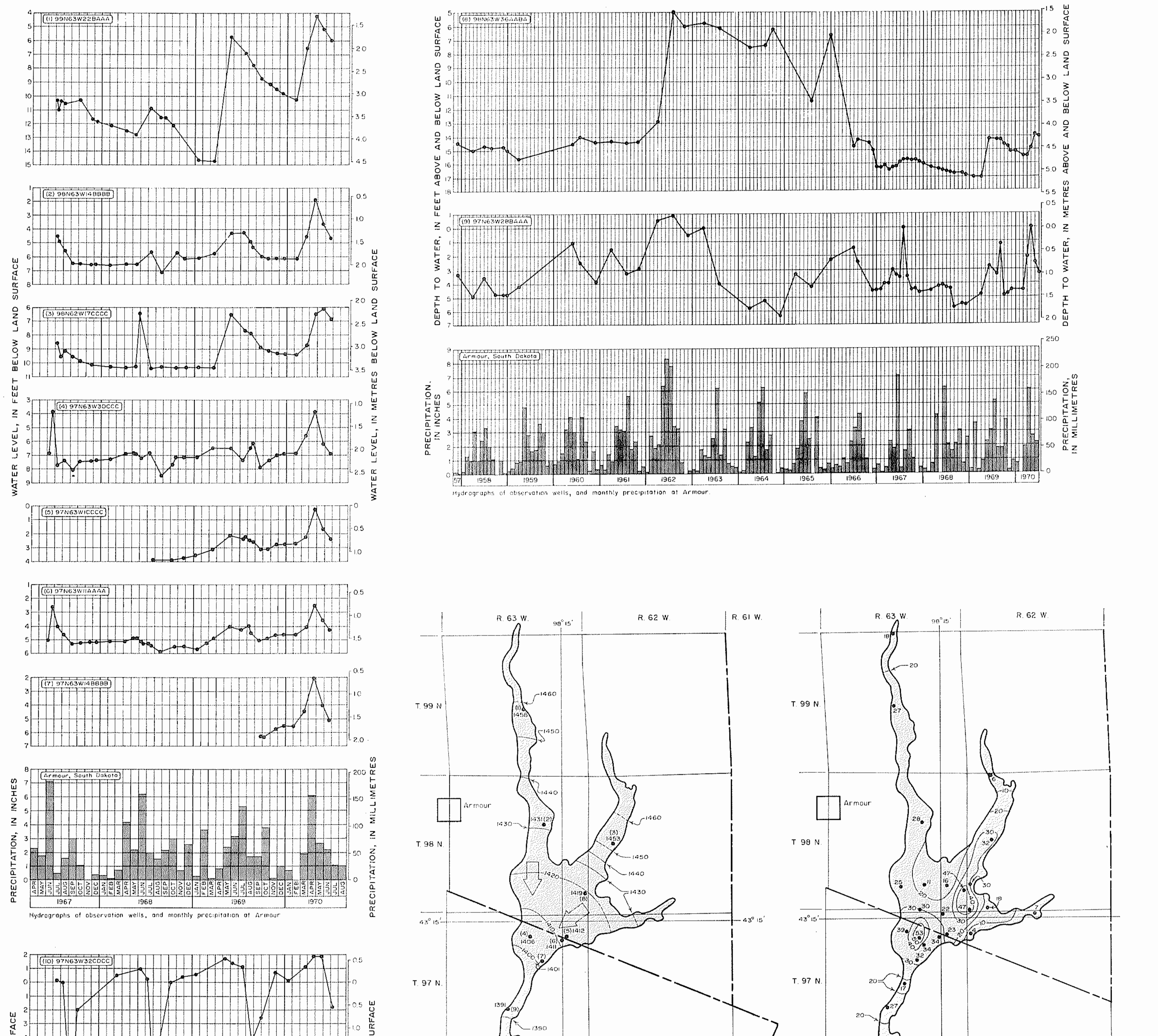


Figure 14. Hydrographs showing fluctuations of water levels in wells in the Delmont aquifer and maps showing altitude of the water table of the Delmont aquifer and thicknesses of Delmont outwash and the outwash in Choteau Creek valley.

precipitation and runoff and not to well pumpage. However, because of varying recharge conditions, the water levels in wells do not fluctuate uniformly in relation to precipitation and runoff. The greatest measured range in water level during the period May 1967 to July 1970 was 10.45 (3.19 m) in well 99-63-22BAAA; however, well 98-63-36AABA, that is more centrally located in the Delmont outwash had a range of only 3.12 ft (0.95 m) for the same period of time.

The direction of ground-water flow and natural discharge from the aquifer is toward the south and downstream below the flood plain and valley floor of Choteau Creek. The altitude of the water table attains a maximum of 1,460 ft (445 m) in the northern branches of the aquifer; the water table slopes toward the south where it has an altitude of 1,400 ft (427 m) near its southern boundary (fig. 14).

An aquifer test was made August 13, 1969, using well 97-63-1CCCC. The well was pumped for 6 hours at a rate of 40 gal/min (2.5 l/s). The average transmissivity was 7,400 ft^2/d (681 m^2/d) and the average storage coefficient 0.006.

The average porosity of sand and gravel in the Delmont outwash is 30.8 percent (Stoley, 1956, p. 16). The porosity was determined for six samples in the laboratory.

The southern part of Delmont aquifer consists of varied thicknesses of alluvium and outwash beneath the flood plain and valley floor of Choteau Creek. The aquifer has a maximum known thickness of 55 ft (17 m) of sand and gravel at test hole 95-62-7BBBA and has thicknesses of 47 (14.3 m) and 45 ft (13.7 m) at test holes 97-63-28BAAA and 96-63-4BAAB, respectively (see table 3). The sand and gravel is generally overlain by alluvium and till. The alluvium is commonly a silty, sandy clay about 8 ft (2 m) thick.

Recharge to the Delmont aquifer is from precipitation, infiltration from Choteau Creek, and movement of water into the aquifer from the adjacent drift. North of Wagner, infiltration from Choteau Creek recharges the aquifer during times of surface runoff. South of Wagner, Choteau Creek gains water by natural ground-water discharge from the Delmont and Choteau aquifers.

Water in most of the southern part of Delmont aquifer is under artesian conditions. Five observation wells in the aquifer were measured monthly (fig. 14); three of them had water levels above the land surface. The hydrographs show that the water-level fluctuations in the southern part of the Delmont aquifer are mostly related to the amount and distribution of precipitation and runoff rather than to well pumpage. Minor well pumpage for stock and domestic use has had no noticeable effect on water levels in the aquifer.

An aquifer test was made October 13, 1967, using well 93-62-20ABB. The well was pumped for 5 hours at a rate of 38 gal/min (2.4 l/s). The average transmissivity was 12,000 ft^2/d (1,100 m^2/d) and the average storage coefficient 0.006.

Corsica Aquifer

Corsica aquifer is a buried outwash which commonly lies directly on the bedrock in Corsica channel (see figs. 10 and 11). The outwash sand has a maximum known thickness of 73 ft (22 m) at test hole 100-64-21DAAA where it consists of very fine-grained sand and medium to coarse sand overlying the Niobrara Marl (see table 3). At test hole 99-64-24AAAA 60 ft (18 m) of gravel and sand occurs as three beds separated by till.

Profiles and hydrogeologic sections of the Corsica aquifer are shown in figure 12 (sections D-D' and E-E'). Section D-D' shows the aquifer as two outwash bodies, one in Corsica valley and one on the valley flank. Section E-E' also shows the aquifer as consisting of several outwash deposits including a basal sand unit and several overlying and adjacent gravel units.

Water in the Corsica aquifer is under artesian conditions. The water level in observation well 100-64-21DAAA was measured monthly during the period July 1968 to June 1970. In this well the top of the aquifer occurs at a depth of 150 ft (46 m), and during the period 1968-70 the depth to water ranged from 98.20 ft (29.93 m) (altitude 1,468 ft, 447 m) to 99.92 ft (30.46 m). The high water level in 1968, 1969, and 1970 occurred in September, August, and April, respectively. The water-level fluctuations were minor as they were not affected by pumpage nor were they immediately responsive to the yearly amount and distribution of precipitation.

Recharge to the aquifer is from the adjacent drift and perhaps from the Niobrara Marl in the areas where the outwash lies directly on the marl and a hydraulic connection exists.

Geddes Aquifer

Geddes aquifer is a buried outwash and basal western-origin stream deposit. The aquifer has a narrow, linear trend (fig. 11), because it is confined to the Academy and Geddes channels (fig. 10).

A sand and gravel thickness map based on 17 test holes in the Geddes aquifer is shown in figure 11. The total thickness is that of one or more sand and gravel beds. The aquifer is thickest 1 mi (1.6 km) southwest of Platte and 2 mi (3.2 km) east of Geddes. A maximum known thickness of 91 ft (28 m) occurs at test hole 99-68-22DDDD, and the aquifer includes an upper gravel bed underlain by three alternating clay and gravel beds. At test holes 98-66-34BBBB and 97-66-4CCCC the aquifer is 80 ft (24 m) thick and consists of four outwash beds each separated by till.

Profiles and hydrogeologic sections of Geddes aquifer are shown in figure 12 (sections A-A', B-B', C-C' and H-H'). The aquifer is mostly a basal western origin sand and gravel. Section B-B' shows three gravel beds with the upper bed being the thickest. Section C-C' shows the aquifer as being two outwash gravel beds of nearly equal thickness.

Water in Geddes aquifer is under artesian conditions as observed in well 100-68-21DDDD which was measured monthly during the period October 1968 to June 1970. The depth to water ranged from 100.84 ft (30.74 m) to 100.17 ft (30.53 m). The water level was not affected by pumping of the few wells in the area, nor was it immediately responsive to the yearly amount and distribution of precipitation.

Recharge to the aquifer is from the adjacent drift, and perhaps from the Niobrara Marl in areas where the aquifer lies directly upon the marl.

Choteau Aquifer

Choteau aquifer consists of buried outwash and western-origin stream deposits (Kume and Ackroyd, 1969). The outwash is composed of sand and gravel that occurs in several layers within the till. The western-origin stream deposits are sand and gravel. Choteau aquifer underlies 326 mi^2 (844 km^2, 209,000 acres) and is the largest aquifer in the study area (fig. 11). It occurs in Choteau bedrock valley (fig. 10) in eastern Charles Mix and Douglas Counties (see table 3).

A previous study of this aquifer was made by Walker (1961) in the Wagner area. Part of the aquifer was mapped and water-level measurements were recorded. Another study of the aquifer was made by Shurr (1966) who worked in the Lake Andes area in an attempt to find a better quality ground water for that city.

A thickness map of Choteau aquifer is shown in figure 11 and is based on well logs of 100 test holes and 44 private wells. The aquifer thickness includes one or more beds of sand and gravel (see table 3).

The aquifer thickness is greater than 75 ft (23 m) north of Dante, northeast of Ravinia, and northeast of Wagner. The maximum known thickness of 89 ft (30 m) occurs at test hole 96-62-30DDDC. Northwest of Delmont it is less than 25 ft (8 m) thick. The aquifer includes an upper sand bed separated by clay from a lower sand and gravel bed.

Profiles and hydrogeologic sections of Choteau aquifer are are shown in figure 12 (sections F-F', G-G', H-H', I-I', and J-J'). Sections F-F' and G-G' show that the aquifer consists of a basal sand and gravel deposit overlain by a thick section of clay. Section H-H' shows the aquifer near its maximum width and the continuity of the aquifer across the Choteau bedrock valley; here, it is mostly a single bed of sand and gravel, but an upper sand tongue interbedded with clay is also shown. Along the eastern valley flank the aquifer directly overlies the bedrock. Section I-I' shows the aquifer as a thick sand and gravel bed which directly overlies the bedrock along the western valley flank and is interbedded with clay on the east. Several smaller, lenticular bodies of outwash overlie the main outwash deposit. Section J-J' shows the narrow southern end of Choteau aquifer at the Bon Homme County line and several adjacent and overlying outwash deposits. The aquifer also extends into Bon Homme County (Jorgensen, 1971).

Water in Choteau aquifer is under artesian conditions. The static head ranges from 49 ft (15 m) at well 96-65-9ADBA to 126 ft (38 m) at well 98-63-22 DDDD and averages about 100 ft (30 m).

Hydrographs showing the water-level changes at 16 observation wells in Choteau aquifer are shown in figure 15. The hydrographs show similar yearly cyclic water-level fluctuations which were caused by withdrawal of water from the aquifer and subsequent recharge. The water levels generally declined sharply in July and August because of large withdrawals of water by irrigation wells. The highest water levels occurred in April, May, or June and reflected the amount of recharge that had taken place since the previous irrigation season.

A preliminary water-level study was made on the Choteau aquifer by Kume and Ackroyd (1969). For this study a teledeltos-paper analog model of the aquifer was constructed and used to determine the configuration of the potentiometric surface for the winter of 1966-67 and the summer of 1967. The winter potentiometric surface when compared to the summer surface was lower in the western and northeastern areas of the aquifer and higher in the southeastern area. The lower surface indicated the areas where withdrawals for irrigation had lowered the water level.

The potentiometric surface in February 1970 (fig. 15) in the northern area of the aquifer has a gradient of about 20 ft/mi (4 m/km). The gradient is steepest here because of reduced permeability in the area shown on the map between the 1,400 to 1,475 ft

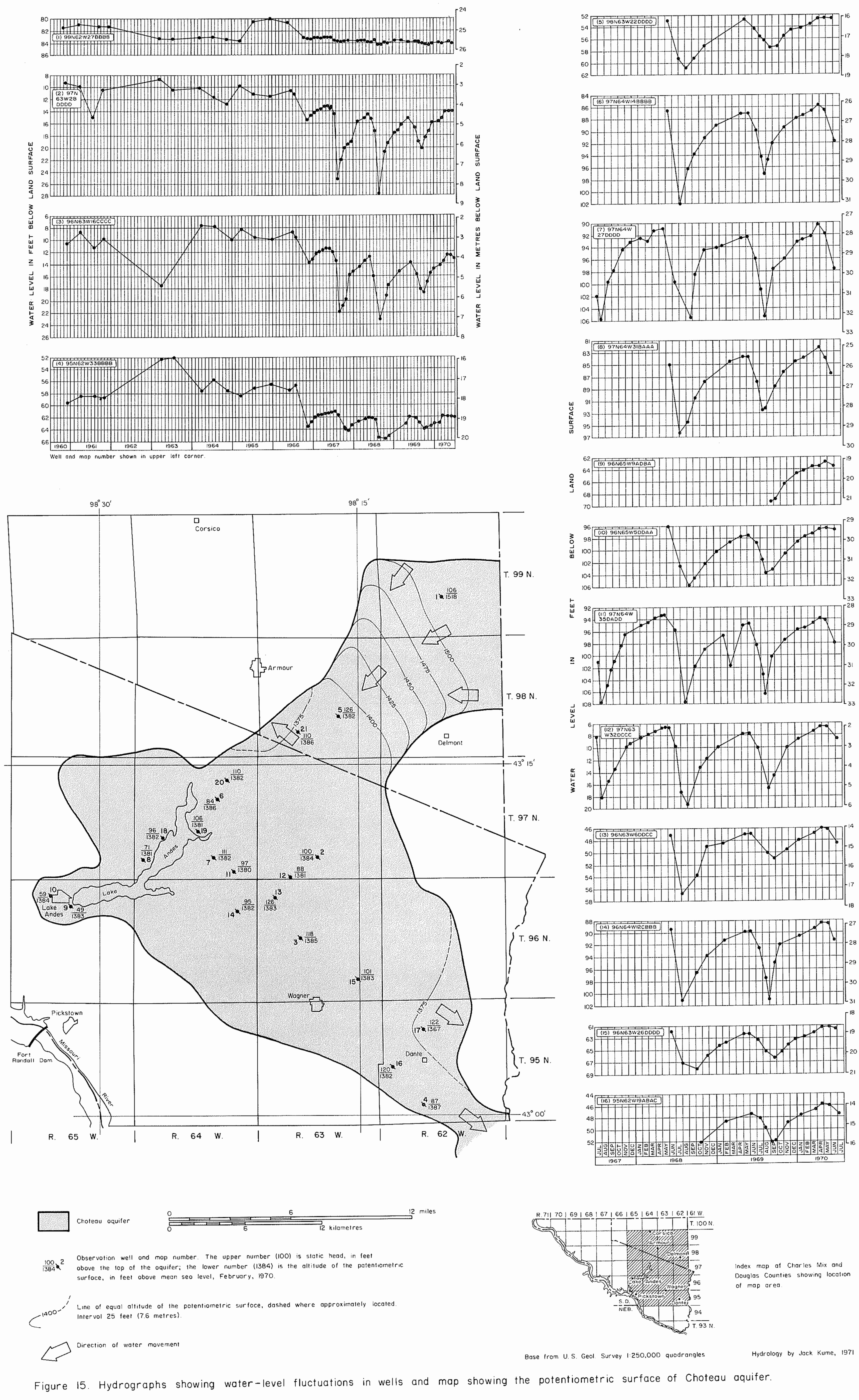


Figure 15. Hydrographs showing water-level fluctuations in wells and map showing the potentiometric surface of Choteau aquifer.

(427 to 450 m) water-level contours. In that area, the aquifer is thinner and more lenticular than elsewhere. The potentiometric surface for the remainder of the aquifer area is almost flat with altitude generally between 1,376 (419 m) and 1,387 ft (423 m).

An aquifer test was made January 15-17, 1970, by a commercial well driller using the municipal well 95-63-4DABB at Wagner in the Choteau aquifer. The well was pumped for 48 hours at a rate of 384 gal/min (24 l/s). The average transmissivity was about 12,700 ft^2/d (1,180 m^2/d). Specific capacities ranged from 23.3 (gal/min)/ft [4.8 (l/s)/m] of drawdown for one hour while pumping at a rate of 443 gal/min (28 l/s) to 79.3 (gal/min)/ft [16 (l/s)/m] of drawdown for one hour while pumping at a rate of 317 gal/min (20 l/s).

Irrigation well 97-64-35BCAA had specific capacities ranging from 63.7 to 72.0 (gal/min)/ft [13.2 to 14.9 (l/s)/m] of drawdown when the well was pumped at rates of 720 to 1,340 gal/min (45 to 85 l/s). Transmissivities ranged from about 17,000 to 19,400 ft^2/d (1,580 to 1,800 m^2/d), and averaged about 18,200 ft^2/d (1,690 m^2/d).

Recharge comes mostly from adjacent till. Water is available in the till and from the numerous saturated lenticular outwash bodies. Perhaps some recharge also comes from the Niobrara Marl where the aquifer lies directly upon the marl.

Discharge is by pumping from wells and by natural losses such as springs and seepage into surrounding drift or bedrock. Springs occur in the southern part of Choteau aquifer. The hydraulic gradient slopes southeastward indicating that the direction of ground-water flow is southward via the valley fill of Choteau Creek to the Missouri River.

The Choteau aquifer is tapped by more wells than any of the other aquifers in surficial deposits (see table 3). Water is used for irrigation, municipal, stock, and domestic supplies.

Minor Aquifers

Minor sand and gravel aquifers in till and in valley fill occur in Charles Mix and Douglas Counties as shown in figure 11. The aquifer boundaries enclose the approximate areas of occurrence of gravel lenses in the till. The lenses are quite variable in thickness, in areal extent, and in depth below land surface. Minor aquifers occur in the valley fill of several creeks such as Platte, Dry Choteau, Pease, Andes, Spring, and Slaughter Creeks. Hubonmix aquifer was a name given to an aquifer in northwestern Bon Homme County by Jorgensen (1971, p. 15). It also occurs as buried outwash lenses in the upland area along the east boundary of Charles Mix County where the aquifer is 10 to 35 ft (3.0 to 9 m) thick and is overlain by as much as 200 ft (61 m) of till. The water level is unknown here; however, in Bon Homme County the potentiometric surface in the period 1966-67 ranged from an altitude of 1,550 to 1,700 ft (472 to 518 m). The aquifer supplies two domestic and stock wells in Douglas County.

The artesian aquifer underlying the valley of Platte Creek is overlain by till and clay which ranges in thickness from 13 to 35 ft (4 to 11 m). The aquifer is very narrow apparently being only as wide as Platte Creek valley which is cut into bedrock (fig. 12, sec. A-A'). Near Lake Platte the Pierre Shale crops out along the valley walls and from Lake Platte to the Missouri River trench, the valley fill is generally less than 50 ft (15 m) thick.

The depth to water during the period 1967-70 in two observation wells, 100-68-35CDCC and 99-68-29BBBB, near Platte Creek ranged from about 2.6 ft (0.79 m) to 8.43 ft (2.59 m). The water levels in these wells reflected the changing stage of the creek.

The water-table aquifer that underlies the valley of Dry Choteau Creek had a depth to water during the period 1967-70 in well 94-61-19CCCC that ranged from 6.49 to 8.95 ft (1.98 to 2.73 m). An aquifer test was made October 26, 1966, on well 94-61-19CCCC. The well was pumped for 12 hours at a rate of 76 gal/min (4.8 l/s). The average transmissivity was 26,700 ft^2/d (2,480 m^2/d) and the storage coefficient 0.20.

The water-table aquifer that underlies the valley of Pease Creek has a maximum known thickness of 49 ft (15 m) in test hole 97-66-4CCC. The depth to water during the period 1967-70 in well 97-66-30BBBC ranged from 2.50 to 7.53 ft (0.76 to 2.30 m).

The artesian aquifer that underlies the valley of Andes Creek has a maximum known thickness of 33 ft (10 m) at test hole 96-65-30AABB. The depth to water during the period 1968-70 in observation well 96-65-8DCBD ranged from 20.38 to 23.07 ft (6.21 to 7.03 m). A hydrograph of the water levels showed a pattern similar to the pumpage-effected water-level fluctuations in Choteau aquifer. As there are no irrigation wells in this aquifer, the similarity of the patterns suggest that these aquifers may be hydraulically connected.

The aquifer that underlies the valley of Spring Creek has a maximum known thickness of 47 ft (14 m) at test hole 94-63-35CCCD. Depth to water at two test holes ranged from 9 to 11 ft (2.7 to 3.4 m).

The aquifer that underlies the valleys of Slaughter and Mosquito Creeks has a maximum known thickness of 28 ft (9 m) at test hole 94-63-6BBBB.

Development Potential

A map showing the estimated potential yield of individual wells in the surficial deposits is shown in figure 16 The yield estimates are based on aquifer thickness and extent, material grain size, and on the reported yields of irrigation and municipal wells. The estimates of yield probably are low in the ranges above 500 gal/min (32 l/s) and high in the ranges below 500 gal/min (32 l/s). Because the map portrays a generalized estimate of potential yield, it should be used with some caution when predicting well yields at a specific site. Test drilling at a proposed well site should always precede the drilling of a large-capacity well such as an irrigation or municipal well.

The Choteau, Tower, and Greenwood aquifers have the highest potential for irrigation and municipal wells of large (more than 500 gal/min, 32 l/s) yield. The Choteau aquifer which has the greatest potential of these aquifers, has had the most development. The Choteau aquifer has supplied irrigation wells since 1957 and continues (1973) to supply 93 percent of the irrigation wells in the area. The cities of Wagner and Lake Andes have municipal-supply wells in the Choteau aquifer. Greenwood and Tower aquifers have not been developed, but they have a good potential for irrigation wells of large yield. Their favorable aquifer characteristics include thickness, a shallow water table, and excellent recharge potential from the Missouri River.

The Geddes and Corsica aquifers probably have a good potential for developing irrigation wells to small to moderate (250-500 gal/min, 16-32 l/s) yield. They have not been developed so no well data are available to use in estimating the potential yield.

The Delmont aquifer also has a good potential for developing irrigation wells of small to moderate yield; however, if irrigation is developed, some form of water management will be needed because of the limited amount of water in the aquifer; the aquifer is thin, underlies only a small area (table 3), and is dependent almost entirely on precipitation for recharge

Minor aquifers in till and the other unnamed aquifers (fig. 11) have a potential for developing domestic and stock wells that would yield 50 to 100 gal/min (3.2 to 6.3 l/s). These aquifers generally underlie small areas (table 3) and contain very limited supplies of water except locally where they are thick.

Aquifers in the Bedrock

The characteristics of bedrock aquifers in Charles Mix and Douglas Counties are listed in table 1 which is a generalized stratigraphic column.

The individual aquifers are referred to by the name of the formation in which they occur. The Niobrara Marl contains the uppermost aquifer of any significance. The Carlile Shale which contains the Codell Sandstone Member underlies the Niobrara Marl. The Codell aquifer is the second most important bedrock aquifer and is used extensively as a source for domestic water supplies, because the water is soft to moderately hard The Dakota Formation probably contains the most important bedrock aquifer which is used primarily as a source of water for livestock, because in many topographically low areas the static head is sufficient to allow a flowing artesian well. The Dakota aquifer is not widely used as a source of domestic water where better water is available, because the water is extremely hard, and is high in sulfates and iron.

Little is known about the water-bearing potential of the other bedrock formations, because they are not being used as a source of water in this area. A few wells have been reported in the Pierre Shale; however, in one instance the water appeared to be contained in the weathered and fractured zone in contact with the glacial drift. No wells have been reported in the Greenhorn Limestone, Graneros Shale, or Fall River Sandstone. However, there is the possibility that some wells supplied by the Fall River Sandstone were mistakenly reported as being supplied by the Dakota aquifer.

Niobrara Aquifer

The Niobrara Marl of Upper Cretaceous age, locally known as the "chalkrock" underlies the entire study area except in the deeper parts of the Corsica, Choteau, Dante, and Missouri bedrock channels where it has been completely eroded (fig. 10). The Niobrara aquifer is directly overlain by glacial drift or by the Pierre Shale. Where the Pierre Shale overlies the Niobrara Marl a complete section of the aquifer is present. However, most of the Niobrara Marl has an erosional upper surface, and consequently, it occurs mostly in an incomplete section. The aquifer is about 200 to 300 ft (61 to 91 m) deep in the Corsica, Choteau, Geddes, and Bovee bedrock channels and about 50 to 500 ft (15 to 152 m) deep in the areas where the Pierre Shale is present.

The Niobrara aquifer consists of medium gray, tan, or light gray, speckled, calcareous shale and marl. It is absent in some areas where it has been completely eroded. It has a maximum known thickness of 164 ft (50 m) at test hole 97-67-25AADC. The minimum complete thickness where not eroded is 112 ft (34 m) at test hole 95-64-11AAAA The average thickness for a complete section is about 140 ft (43 m).

Water probably moves through the aquifer mostly in fractures and solution cavities; where they are interconnected the aquifer may yield small to

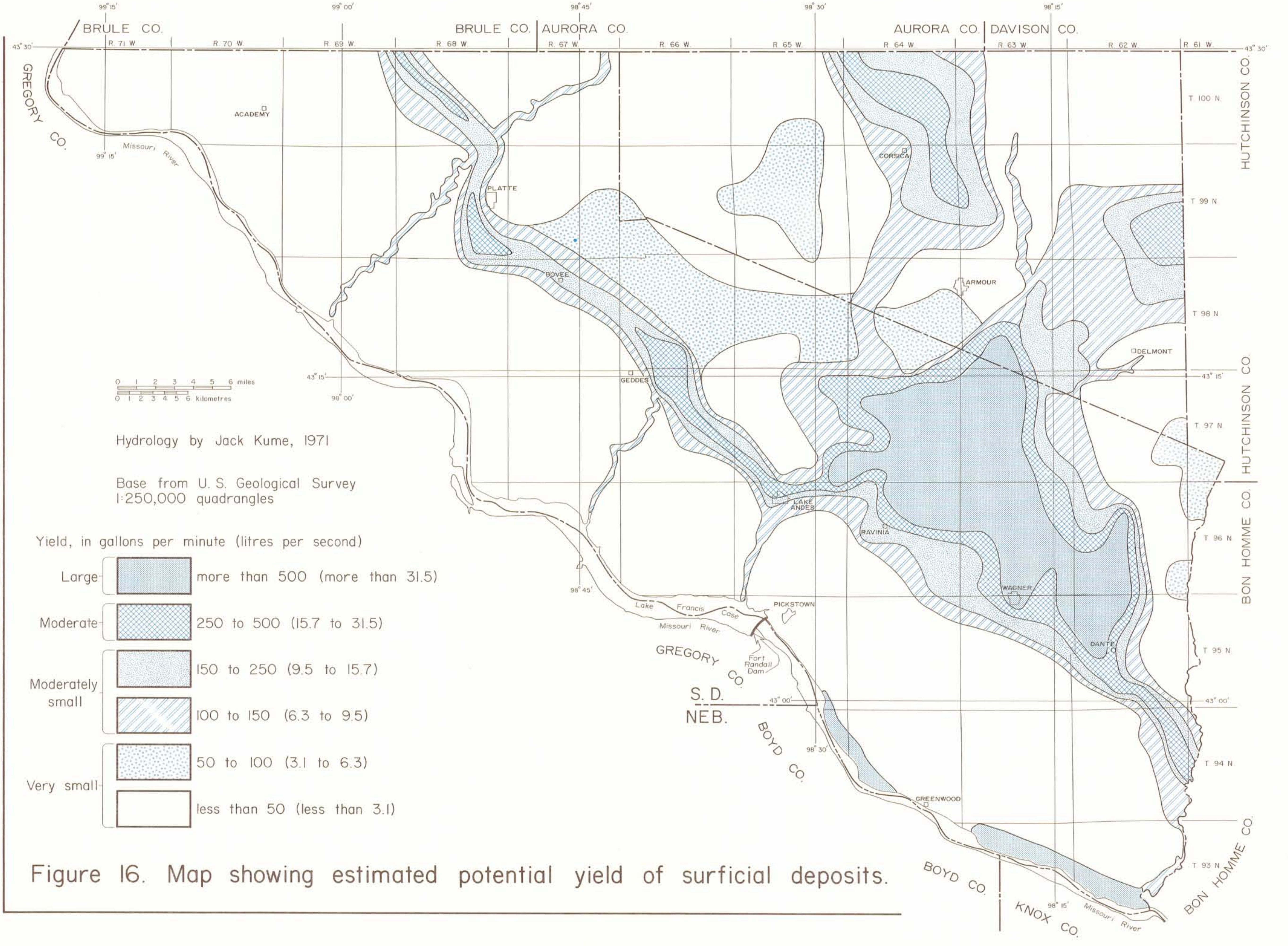


Figure 16. Map showing estimated potential yield of surficial deposits.

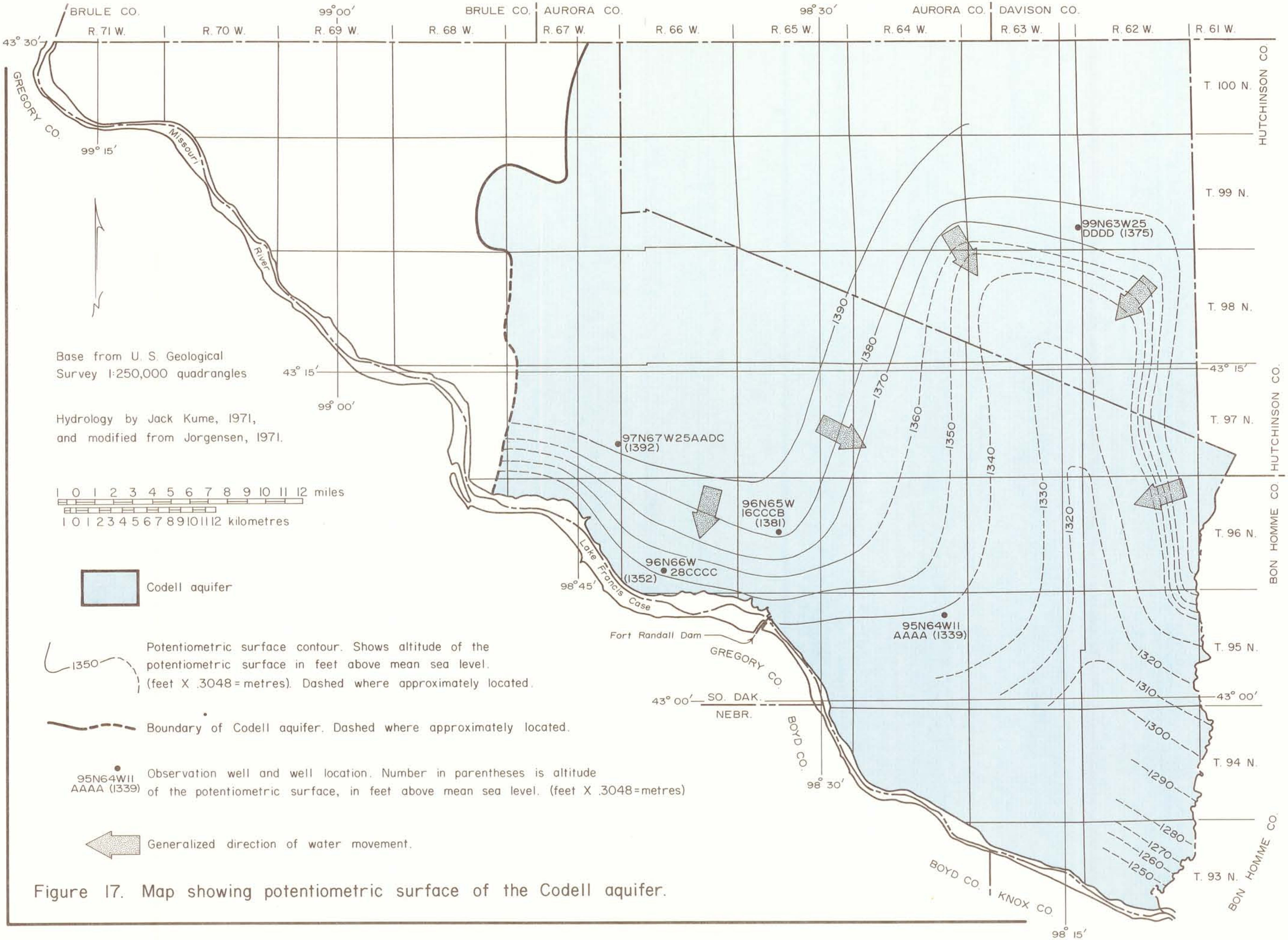


Figure 17. Map showing potentiometric surface of the Codell aquifer.

moderate quantities of either fresh or slightly saline, moderately hard water. During the hydraulic rotary test drilling for this project it was a common occurrence to "lose circulation" of the drilling mud in the marl. This indicates that some parts of the formation are very porous and suggests the presence of fractures and solution cavities.

Water in the Niobrara aquifer is under artesian conditions. The water level in observation well 98-63-19AAAA, where the top of the chalk occurs at a depth of 178 ft (54 m), was measured monthly during the period October 1969 to June 1970. The depth to water ranged from 90.91 ft (28 m) to 94.28 ft (29 m).

Recharge to the Niobrara probably occurs outside the study area, and locally, by infiltration of precipitation, and by inflow from adjacent drift and alluvium. The adjacent drift is probably the source of most of the recharge because of the large area of contact. Also, a hydraulic connection probably exists between the marl and outwash aquifers where the outwash lies directly on the marl. Infiltration of precipitation on the surface outcrop areas of the marl contributes recharge to the aquifer. The Niobrara is in contact with alluvium in the Missouri channel, and is recharged there by water moving downward from the alluvium.

Discharge is by well pumpage, by movement into the adjacent drift, and by seepage to springs in the outcrop area. Well pumpage is a minor discharge factor, because the aquifer supplies water only to stock and domestic wells.

Codell Aquifer

The Codell Sandstone Member of the Carlile Shale of Upper Cretaceous age underlies most of the study area except in the deeper parts of the Corsica, Choteau, and Missouri bedrock channels where it has been eroded and in western Charles Mix where it was thinly deposited and in part not deposited (fig. 10). The well inventory showed there were no wells supplied by the Codell aquifer west of the boundary as shown on figure 17.

The Codell aquifer, locally known as the "sandrock" or the "soft water sand," is overlain by a thin shale of the Carlile Shale and by the marl of the Niobrara Marl except where the shale and marl have been eroded. The depth to the aquifer ranges from about 80 to 125 ft (24 to 38 m) in the Missouri bedrock valley to 300 to 400 ft (91 to 122 m) in the Corsica and Choteau bedrock valleys.

The Codell aquifer consists of a brown, light-brownish gray, and dark-greenish black, friable to indurated, medium to fine-grained sandstone (table 4). The aquifer is absent in some areas, but has a maximum known thickness of 55 ft (18 m) at well 96-65-16CCCB where it occurs at a depth of 317 ft (97 m) below land surface and consists of a brown, dark-greenish black, and black sandstone. It is overlain by 20 ft (6 m) of dark-grayish black Carlile Shale. Other test hole data indicate that the thickness of the sandstone is quite variable, but generally ranges from about 18 to 40 ft (6 to 12 m).

Permeability tests on cores of the Codell Sandstone from a depth of 335 to 353 ft (102 to 108 m) at observation well 96-66-28CCCC were made by the U.S. Geological Survey Hydrologic Laboratory (A. I. Johnson, written commun., 1953). The intrinsic permeability ranged from 3.186 $(um)^2$ to no measurable flow in several intervals. (See test results in table 4.)

Particle-size, specific gravity, specific retention, total porosity, specific yield, and intrinsic permeability were determined for samples of Codell Sandstone at well 96-62-24CCCC (table 4). The samples were collected from a depth of 381 to 412 ft (116 to 126 m).

The configuration of the potentiometric surface of the artesian Codell aquifer in 1968 is shown in figure 17. Hydrographs of water-level records were plotted for five wells, including four U.S. Corps of Engineers observation wells (fig. 18). The hydrographs show that an unusual water-level rise occurred in well 96-66-28CCCC during the period 1952-61 from a depth of 136.25 ft (41.53 m; altitude 1,306 ft or 398 m) in 1952 to 91.31 ft (27.83 m) by 1961. This well is about 1 mile (1.6 km) from Lake Francis Case which has a normal pool elevation of 1,354 ft (413 m). The water-level rise corresponds to the reservoir rise that occurred in about a 10-year period and indicates that there is a hydraulic connection between the sandstone and the alluvium beneath the reservoir. In contrast well 99-63-25DDDD, about 26 mi (42 km) from the lake, had a high water level of 151.43 ft (46.16 m; altitude 1,379 ft or 420 m) and a low water level of 156.29 ft (47.64 m) which indicates fairly stable conditions during the same period.

Most of the recharge to the aquifer probably comes from the north and outside of the study area; however, some minor local recharge probably occurs in the Missouri, Choteau, and Corsica bedrock channels where the sandstone is beneath and in contact with the outwash.

The potentiometric surface is highest in the north-central part of the study area and slopes to the south toward the Missouri River trench (fig. 17) and to the east toward Choteau channel which probably are natural discharge areas for the aquifer.

The Codell aquifer is the principal source of ground water in the areas underlain by Codell

Table 4. Physical properties of Codell Sandstone and Carlile Shale.

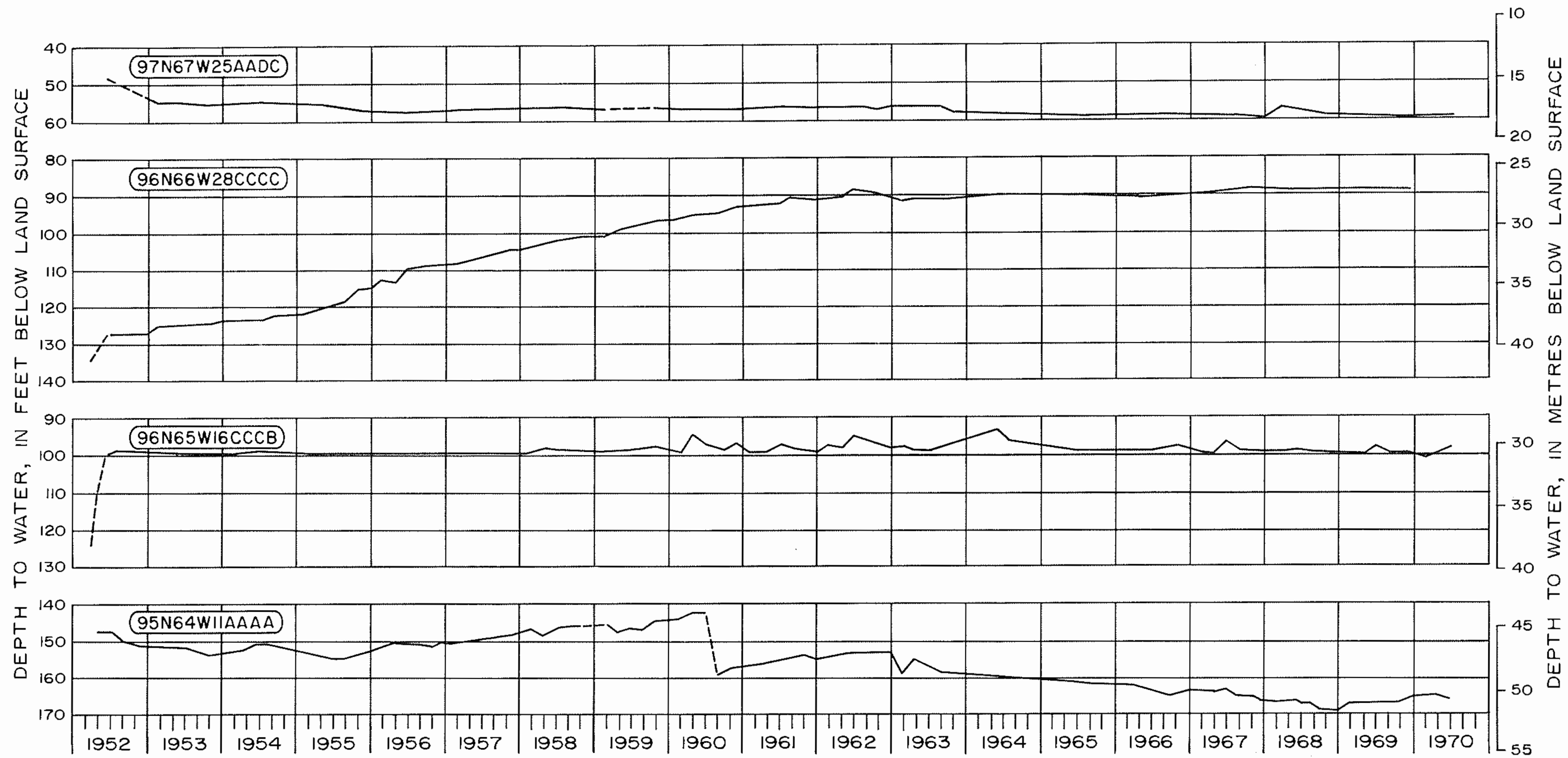
Well 96N66W28CCCC				
Depth ft(m)		Description of Material	Type of Core Sample	Intrinsic Permeability $(um)^2$
From	To			
335.7 (102.3)	335.8 (102.3)	Codell Sandstone	Horizontal	2.430
336.7 (102.6)	336.8 (102.7)	Codell Sandstone	Horizontal	3.186
341.8 (104.2)	341.9 (104.2)	Codell Sandstone	Horizontal	.032
342.3 (104.3)	342.8 (104.5)	Codell Sandstone	Vertical	a
343.0 (104.5)	343.1 (104.6)	Codell Sandstone	Horizontal	a
343.9 (104.8)	344.4 (105.0)	Codell Sandstone	Vertical	a
344.6 (105.0)	344.7 (105.1)	Codell Sandstone	Horizontal	a
346.2 (105.5)	346.3 (105.6)	Codell Sandstone	Horizontal	.016
346.5 (105.6)	347.0 (105.8)	Codell Sandstone	Vertical	.016
348.0 (106.1)	348.1 (106.1)	Codell Sandstone	Horizontal	.216
348.3 (106.2)	348.4 (106.2)	Codell Sandstone	Horizontal	.108
349.5 (106.5)	350.0 (106.8)	Codell Sandstone	Vertical	.054
350.3 (106.7)	350.9 (107.0)	Codell Sandstone	Vertical	.108
351.7 (107.2)	351.8 (107.2)	Codell Sandstone	Horizontal	.486
353.3 (107.7)	353.4 (107.7)	Carlile Shale	Horizontal	.162
354.4 (108.0)	354.9 (108.2)	Carlile Shale	Vertical	.011
355.2 (108.3)	355.3 (108.3)	Carlile Shale	Horizontal	.001

a—No measurable flow

Well 98N62W24BBCC								
Codell Sandstone		Particle size diameter, in millimetres						
Depth ft (m)		Clay sizes	Silt sizes	Sand sizes				
		Less than 0.004	0.004–0.0625	Very fine 0.0625–0.0125	Fine 0.125–0.25	Medium 0.25–0.5	Coarse 0.5–1	Very coarse 1–2
From	To							
381 (116)	389 (119)	6.8		4.7	36.2	44.2	7.5	0.6
389 (119)	412 (126)	1.5		4.5	70.2	23.4	0.4	—
		PERCENT OF SIZE						

Well 98N62W24BBCC						
Codell Sandstone[1]		Specific gravity of solids (grams per cubic centimetre)	Specific retention (percent)	Total porosity (percent)	Specific yield (percent)	Intrinsic permeability $(um)^2$
Depth ft (m)						
From	To					
381 (116)	389 (119)	2.79	9.0	38.7	29.7	12.960
389 (119)	412 (126)	2.64	4.5	36.0	31.5	14.040

[1] Repacked samples



Location of wells shown on Figure 17

Water level dashed where inferred due to uncertain or unusual data point

Figure 18. Hydrographs showing water-level fluctuations in wells in the Codell aquifer.

Sandstone and ranks first in the study area in number of wells supplied. The aquifer supplies 322 wells in Douglas County and 325 wells in Charles Mix County with small to moderate quantities of soft, slightly saline water.

Dakota Aquifer

The Dakota Formation of Upper Cretaceous age underlies the entire study area. The Dakota aquifer, locally known as the "artesian" or the "hard-water sand," consists of several sandstones that are interbedded with shale. The sandstones are tan, gray, and white, very-fine to coarse-grained, and friable to well-cemented, and are overlain by the Graneros Shale. The depth to the aquifer in the Missouri River trench at well 95-65-35ADDA is 465 ft (142 m). Shale occurs between the three sand beds penetrated by this well. In east-central Douglas County the aquifer is about 597 ft (182 m) below land surface at well 98-64-5BCAC where the Dakota Formation has a maximum known thickness of 450 ft (125 m). The minimum known recorded thickness of the formation is 88 ft (27 m) at well 97-67-21AAAA in west-central Charles Mix County.

Water-level records of 6 observation wells in the Dakota aquifer showed that generally, the water levels have been declining. Measurements were made intermittently in some wells and by continuous recorder on others. During the period 1952-63 the U.S. Army Corps of Engineers obtained water-level records from well 96-65-4DAAC by the use of a continuous pressure recorder. (See hydrograph on fig. 19.) Water-level fluctuations in these observation wells are often influenced by local conditions and individual well withdrawals, but they are also influenced by the total withdrawal by all wells and the amount of recharge to the aquifer.

The artesian pressure in the Dakota aquifer is sufficient to obtain flowing artesian wells in topographically low areas. The potentiometric surface is highest in the northwest and lowest in the southeast (fig. 20), and it has a difference of altitude of about 200 ft (61 m). The configuration of the potentiometric contours shows a direct relationship to the topographically low areas such as the drainage basin of Choteau Creek, the valleys of Pease, Platte, Andes, Slaughter, and Spring Creeks, and the trench of the Missouri River. The water level in these areas rises the highest above the land surface, and water discharges are the greatest. Uncontrolled flowing wells in these areas are the main cause for the lowering potentiometric surface.

Recharge to the Dakota aquifer in southeastern South Dakota as proposed by Dyer and Goehring (1965, p. 20-21) is probably derived from water entering the Pahasapa Limestone in the Black Hills and moving eastward through the Madison Group. At the truncated edge of the Madison Group in the central part of the State, the water migrates upward into the Dakota Formation. Other studies of the Dakota aquifer by Swenson (1968, p. 174) and Schoon (1969, p. 210) should be referred to for more detail about the recharge to the Dakota aquifer in this area.

Discharge from the Dakota aquifer has occurred mostly from flowing artesian wells. In Charles Mix County there were 13 uncontrolled or unrestrained wells each flowing 25 to 1,500 gal/min (1.6 to 95 l/s) whose total flow in 1958 was 4,200 gal/min (260 l/s) (Davis, and others, 1961, p. 17). These wells are in the Missouri River trench where the water level above the land surface is the greatest in the area. Well 100-71-26DBBB was described as an example of an unrestrained well with its resultant wasteful flow. The well casing has deteriorated and a crater forming a pond about 80 ft (24 m) in diameter surrounded the well head. The uncontrolled discharge rate was reported to be about 2 mgal/d (million gallons per day, 7,570 m^3/d). The total discharge from the well was estimated to be more than 57 billion gallons (215×10^6 m^3) of water since the well was drilled in 1895. The water is wasted as it flows from the large pond down a gulley to the Missouri River.

The Dakota aquifer is probably the most important source of water because it underlies the entire area, and in the topographically low areas, it still supplies flowing artesian wells. The aquifer ranks second in the number of wells supplied--7 wells in Douglas County and 332 wells in Charles Mix County. It yields moderate to large quantities of very hard and slightly saline water.

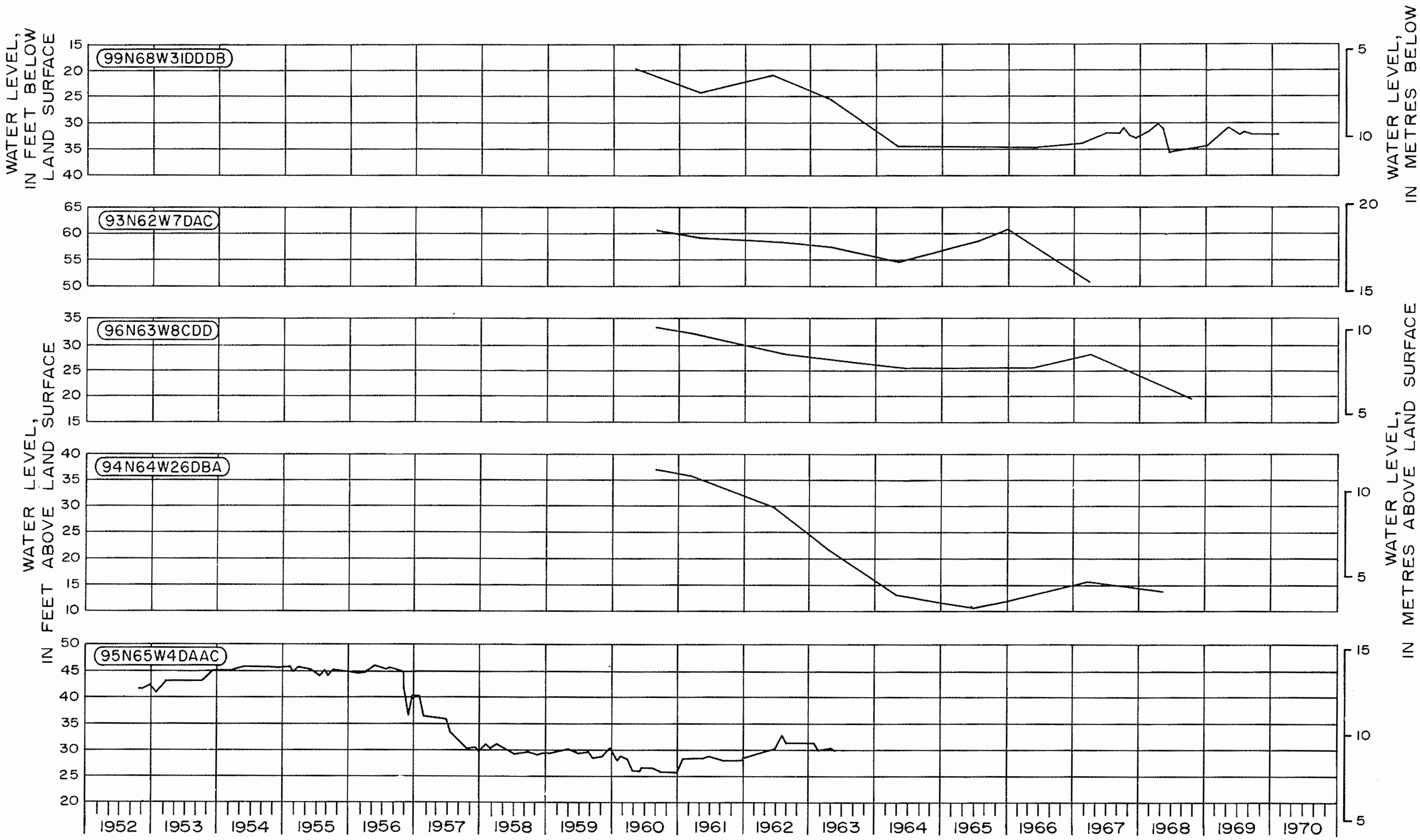
Quality

Chemical Constituents

The chemical constituents and physical properties of the ground water of Charles Mix and Douglas Counties are indicated by 219 standard chemical analyses and 197 partial analyses. These analyses are listed in Part III, basic hydrologic data, of this bulletin. Water samples were collected from 160 wells for the standard analyses. A summary of selected chemical analyses of ground water from Choteau, Niobrara, Codell, and Dakota aquifers is listed in table 5.

The Tower and Greenwood aquifers contain a water in which calcium, sodium, bicarbonate and sulfate are the predominant ions. The water is slightly saline and very hard. The dissolved solids range from 423 to 2,410 mg/l and average 1,198 mg/l; hardness ranges from 340 to 1,200 mg/l and averages 758 mg/l.

The Delmont aquifer contains water in which calcium, magnesium, bicarbonate, and sulfate are the



Location of wells shown on Figure 20.

Figure 19. Hydrographs showing water-level fluctuations in wells in the Dakota aquifer.

Table 5. Summary of selected chemical analyses of ground water.

Constituent or property	Recommended maximum for public supply [1]	CHOTEAU AQUIFER				NIOBRARA AQUIFER				CODELL AQUIFER				DAKOTA AQUIFER			
		No. of analyses	Minimum	Maximum	Average	No of analyses	Minimum	Maximum	Average	No. of analyses	Minimum	Maximum	Average	No. of analyses	Minimum	Maximum	Average
Calcium (Ca, mg/l)		31	44	620	150	4	22	72	40	30	6.1	140	30	27	180	420	300
Magnesium (Mg, mg/l)		31	3.8	210	40	4	4.8	34	14	30	1	35	8.8	27	30	100	59
Sodium (Na, mg/l)		31	250	650	370	4	310	500	400	29	240	640	460	27	47	180	110
Potassium (K, mg/l)		31	17	42	24	4	16	22	18	26	1.5	28	15	25	10	28	20
Bicarbonate (HCO_3, mg/l)		31	160	560	310	4	310	540	410	27	270	610	400	24	68	260	160
Sulfate (SO_4, mg/l)	250 (500)	31	410	1,600	700	4	170	650	430	30	2	980	380	27	300	1,200	920
Chloride (Cl, mg/l)	250	31	7	250	150	4	90	380	190	30	18	590	280	26	26	200	120
Fluoride (F, mg/l)	0.9 – 1.7 [2]	1	.6	.6	.6	0	—	—	—	8	.2	3.1	1.6	9	1.5	5	3
Nitrate (NO_3, mg/l)	45	27	0	12	3	4	0	10	4.5	27	0	11	5.3	24	0	110	6
Iron (Fe, ug/l)	300	26	0	60,000	3,400	4	40	3,300	1,400	28	0	6,800	800	24	0	20,000	3,200
Manganese (Mn, ug/l)	50	1	1,600	1,600	1,600	0	—	—	—	8	0	1,500	200	7	100	300	200
Hardness as calcium carbonate ($CaCO_3$, mg/l)		28	170	1,500	470	3	76	140	100	30	36	490	120	27	680	1,300	990
Specific conductance (micromhos at 25° C.)	500 (1,000)	30	1,300	3,500	2,300	4	2,000	2,400	2,100	20	1,500	3,200	2,200	24	1,600	2,600	2,100
Percent sodium		29	25	85	62	4	66	92	83	22	69	97	90	21	9.1	32	19
Sodium-adsorption-ratio (SAR)		28	1.5	16	8.5	4	7.5	25	16	21	7	44	22	21	.7	2.8	1.5
Residual-sodium-carbonate (Na_2CO_3, RSC, epm)		27	0	2.5	.2	4	4	7	4	18	0	10	5	14	0	0	0
pH		31	6.6	8.6	7.9	4	7.8	8.3	8.1	28	7.1	8.5	7.9	23	6.8	8.4	7.7
Dissolved solids (mg/l)		31	990	3,000	1,700	4	1,400	1,900	1,600	30	410	1,900	1,400	23	1,200	2,300	1,800
Boron (ug/l)		7	200	5,000	2,400	0	—	—	—	1	4,000	4,000	4,000	7	100	2,500	1,000

(1 U. S. Public Health Service (1962); figures in parentheses are South Dakota Department of Health (1962).

(2 For Charles Mix and Douglas Counties.

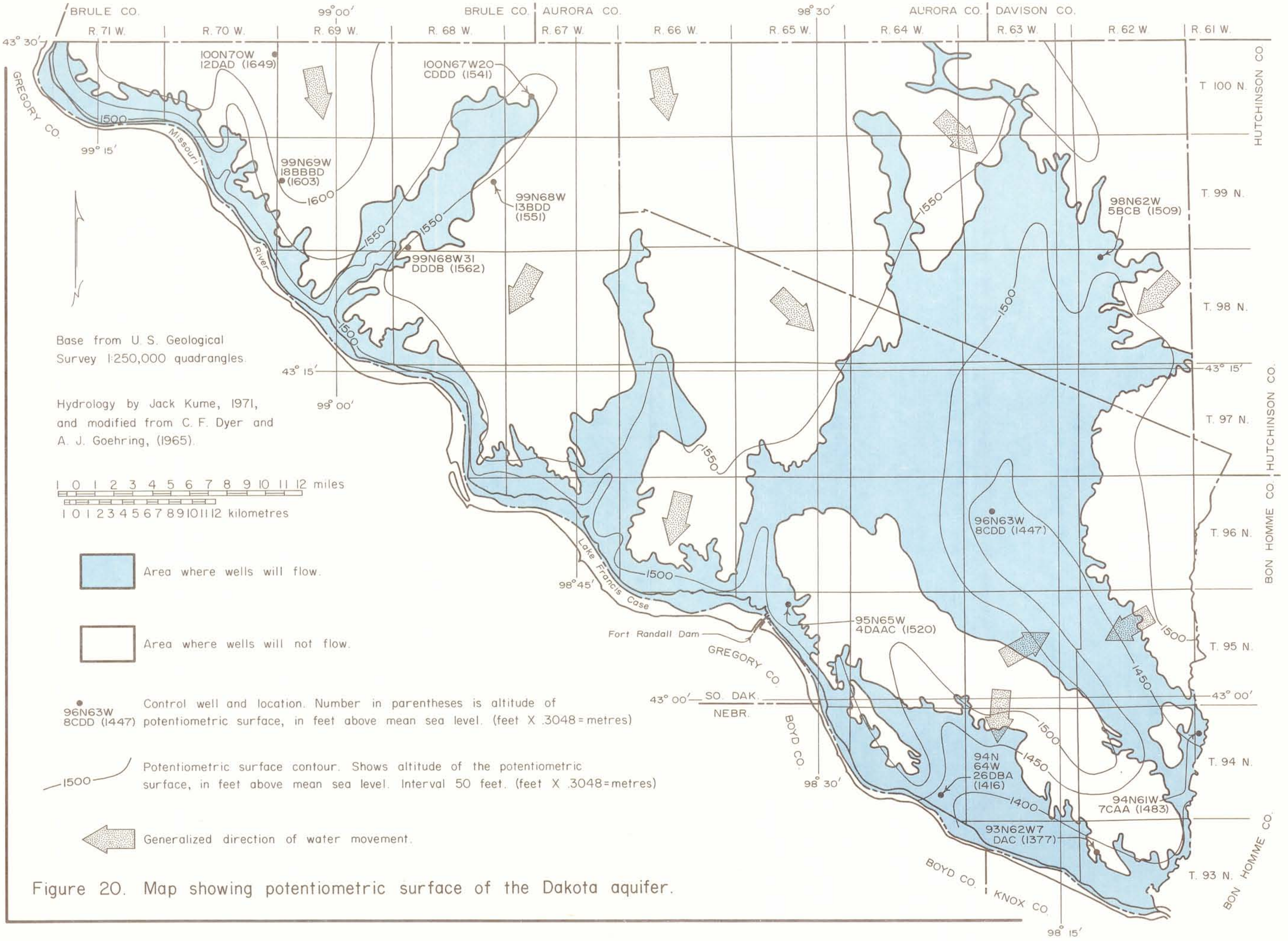


Figure 20. Map showing potentiometric surface of the Dakota aquifer.

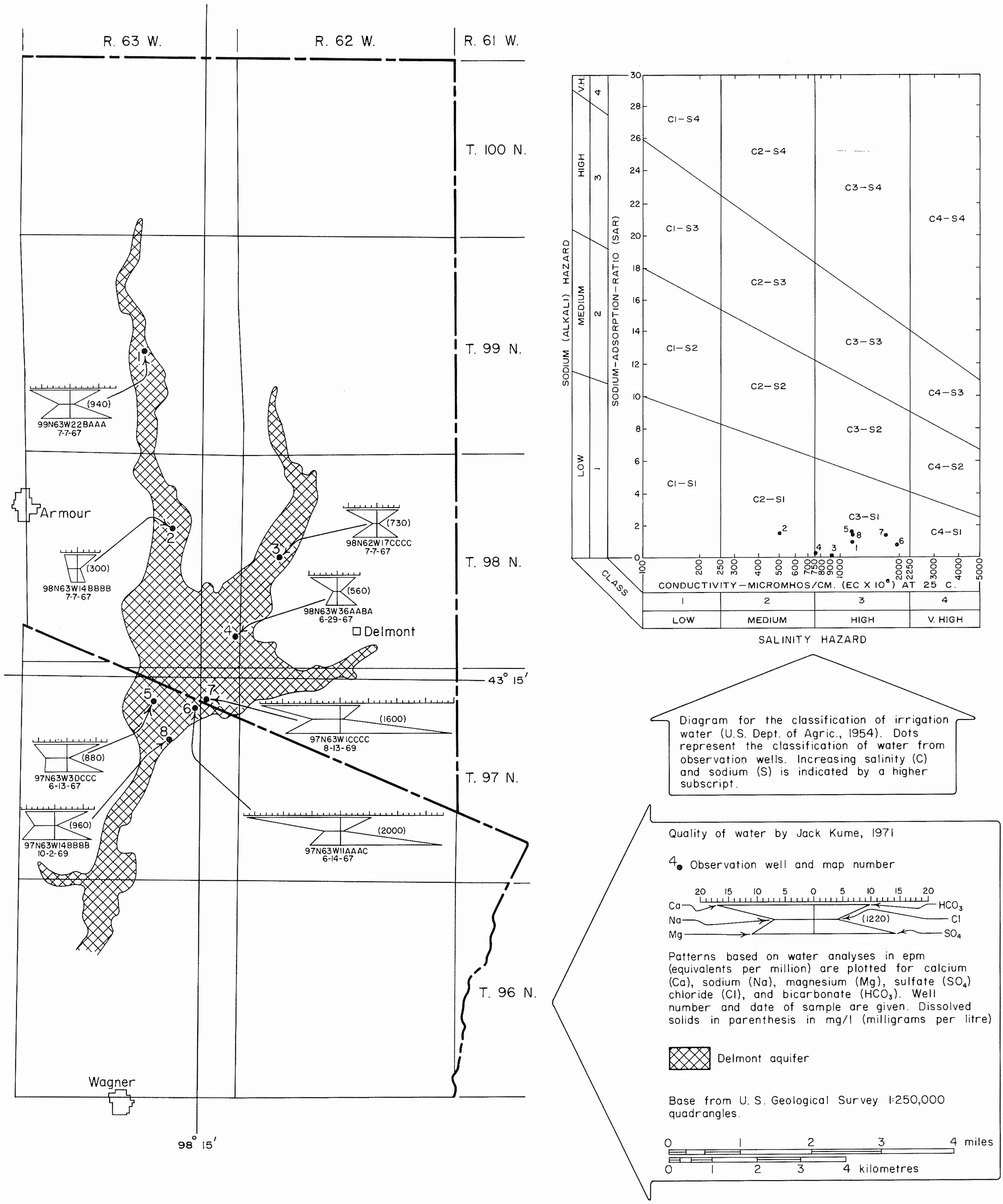
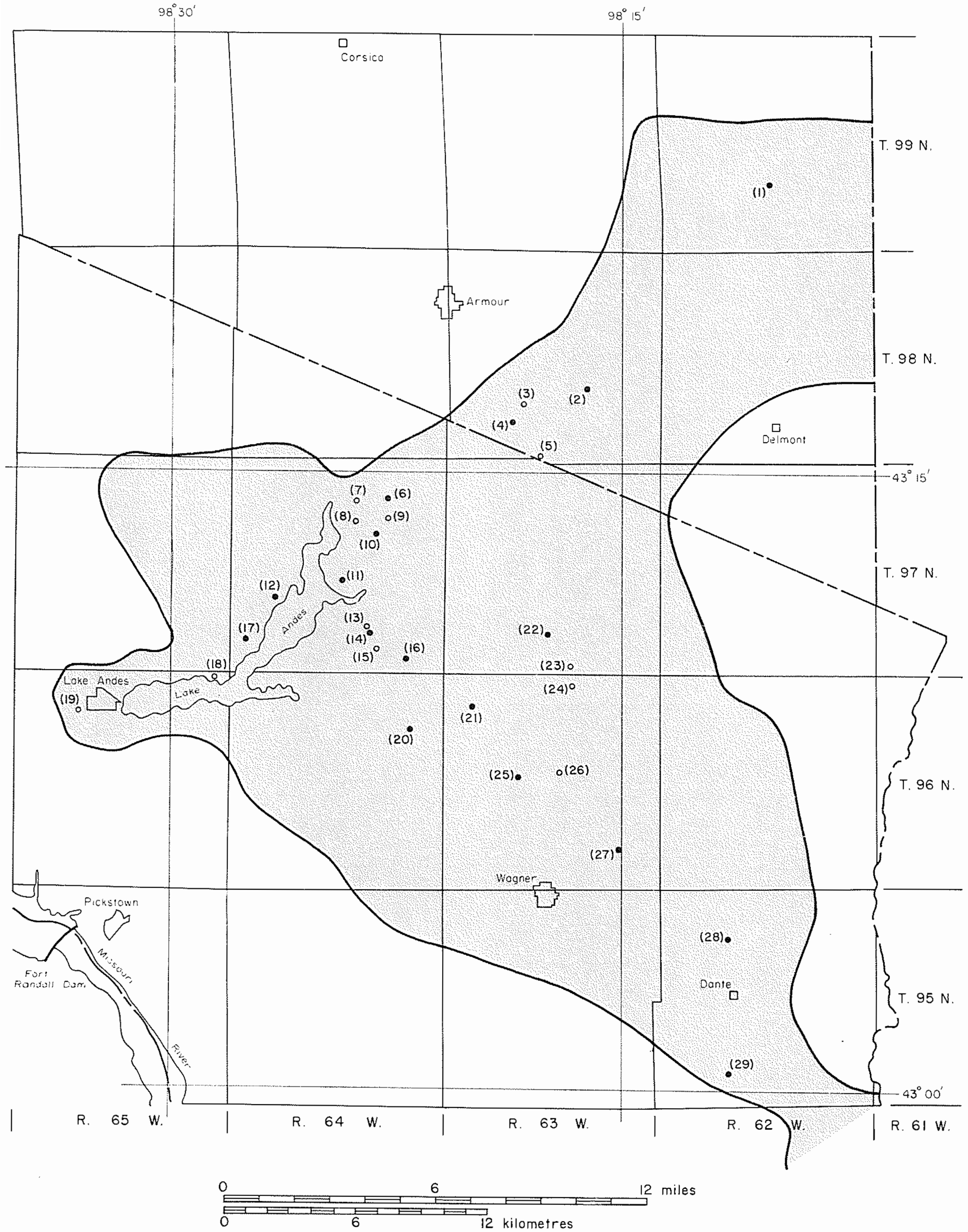
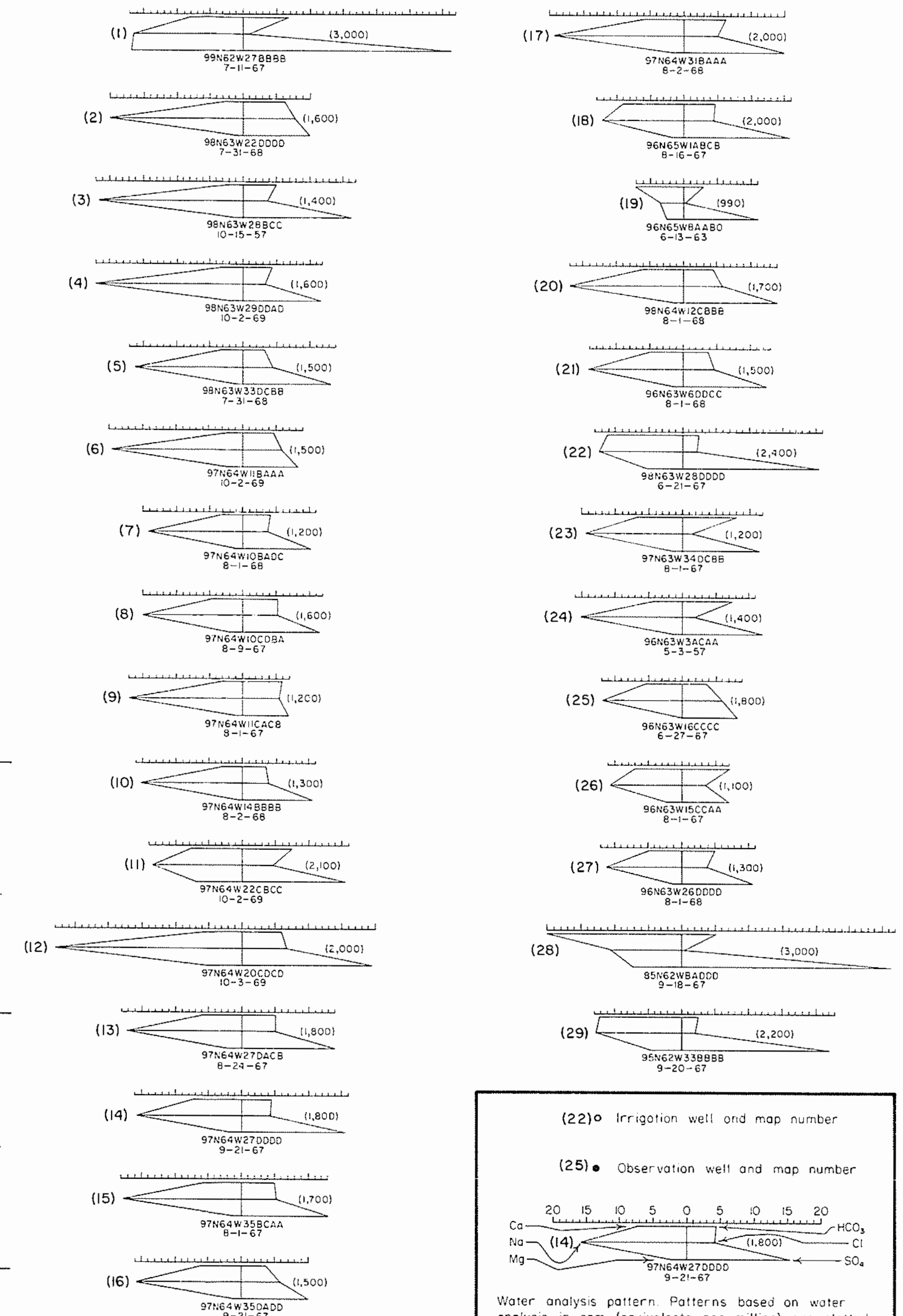


Figure 21. Water analysis patterns of chemical quality and classification of water for irrigation–Delmont aquifer.





Choteau aquifer

(22)○ Irrigation well and map number

(25)● Observation well and map number

Water analysis pattern. Patterns based on water analysis in epm (equivalents per million) are plotted for calcium (Ca), sodium (Na), magnesium (Mg), sulfate (SO_4), chloride (Cl), and bicarbonate (HCO_3). Well location and date of sample are below pattern. Well number (in parentheses) is on the left and dissolved solids (in parentheses) in mg/l (milligrams per litre) is on the right.

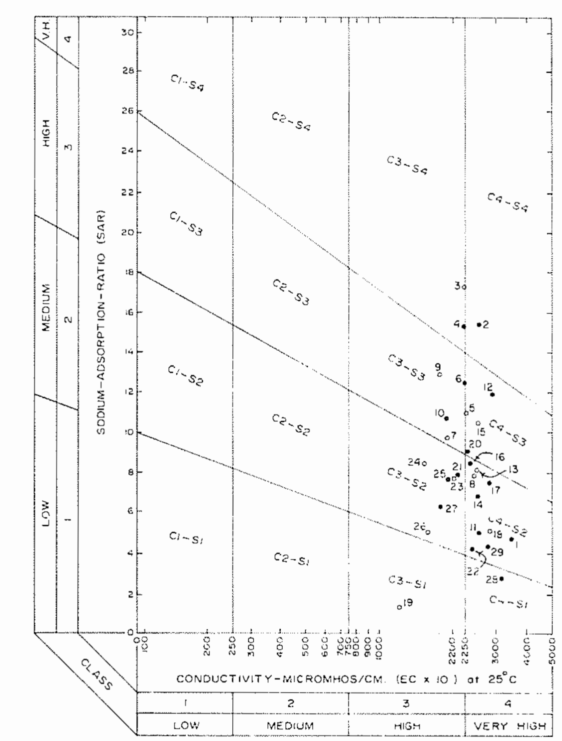
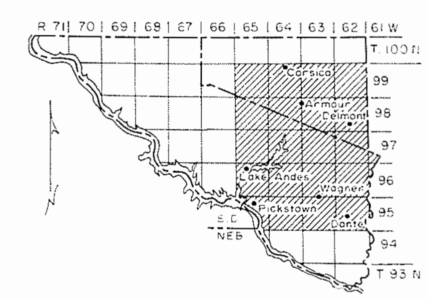


Diagram for the classification of irrigation water (U.S. Dept. Agr., 1954). Dots represent the classification of water from observation wells (•) and irrigation wells (○). Increasing salinity (C) and sodium (S) is indicated by a higher subscript.



Index map of Charles Mix and Douglas Counties showing location of map area

Base from U.S. Geol. Survey 1:250,000 quadrangles
Hydrology by Jack Kume, 1971

Figure 22. Water analysis patterns of chemical quality and classification of water for irrigation--Choteau aquifer.

predominant ions as shown by the water analysis patterns in figure 21. The dissolved solids range from 300 to 2,000 mg/l and average 1,000 mg/l. The water is very hard and has a wide variation in the amount of dissolved solids--six wells produced water that was fresh and two wells produced water that was slightly saline. The variation in the content of dissolved solids was due partly to the amount of fresh water recharge from precipitation, snowmelt, and runoff. The water, as classified for irrigation, generally has a low sodium hazard and a high salinity hazard (fig. 21).

The Choteau aquifer contains sodium sulfate water as shown by the water analysis patterns on figure 22 and the summary of chemical analyses in table 5. The dissolved solids range from 990 to 3,000 mg/l and average about 1,700 mg/l. The water is very hard, slightly saline, and shows a wide variation in the concentration of dissolved solids in the 31 samples. It has a high to very high salinity hazard and a medium to high sodium hazard for irrigation (fig. 22).

Water in the Niobrara aquifer is a sodium-bicarbonate-sulfate type (table 5), slightly saline and moderately hard. The dissolved solids range from 1,400 to 1,900 mg/l and average 1,600 mg/l.

The Codell aquifer also contains sodium-bicarbonate-sulfate water (table 5), but with higher concentrations of sodium and chloride than water from the Niobrara aquifer. The dissolved solids range from 410 to 1,900 mg/l and average 1,400 mg/l. Fresh water was collected from a few of the wells, but most of them produced slightly saline, soft to moderately hard water.

Water in the Dakota aquifer is a calcium sulfate type (table 5), slightly saline, low in sodium, and commonly high in iron. The dissolved solids range from 1,200 to 2,300 mg/l and average 1,800 mg/l; hardness ranges from 680 to 1,300 mg/l and averages 990 mg/l. Most of the water analyzed contained iron in excess of the recommended maximum concentration for drinking water (U.S. Public Health Service, 1962) ranging from 0 to 17,600 ug/l and averaging 3,000 ug/l.

Quality and its Relation to Water Use

The practical significance of the chemical composition of water depends on its intended use. The suitability of water for public supply and domestic use can be judged by standards that have been established by the U.S. Public Health Service (1962) for drinking water (table 6). Although many people in this study area consistently drink water containing concentrations substantially higher than the suggested limits, other persons unaccustomed to drinking such water may suffer ill effects until they become accustomed to the change. The significance of dissolved mineral constituents and physical properties of water are summarized in table 7.

Water for domestic and livestock uses is withdrawn from most of the aquifers. The water is satisfactory for all classes of livestock, but none entirely satisfies the recommended standards for human consumption (U.S. Public Health Service, 1962). Water from the Codell aquifer is the most desirable for domestic supply, because it is soft to moderately hard. It contains less than the recommended maximum concentrations for nitrate and fluoride, but exceeds the allowable concentrations for all of the other chemical constituents. Water from the Niobrara aquifer contains less than the maximum allowable concentrations of chloride and nitrate, but exceeds the allowable concentrations of all of the other chemical constituents. It also may have an undesirable "rotten-egg" odor and black color when first pumped from the well. The black color generally disappears after a short time, but it may leave numerous specks of a black precipitate. This black water is very corrosive to pump rods and pipes. Water from the Choteau aquifer contains less than the maximum allowable concentrations of chloride, fluoride, and nitrate but exceeds the allowable concentrations of other chemical constituents. Water from the Dakota aquifer contains less than the maximum allowable concentration of chloride and nitrate but exceeds those for all of the other constituents. The Dakota water is the least desirable for domestic water because of its extreme hardness, very high sulfate, and excessive iron concentration.

The chemical characteristics of water that are most important in determining its suitability for irrigation are: (1) Total concentration of soluble salts (salinity); (2) relative proportion of sodium to other cations (alkalinity); (3) concentration of boron or other elements that may be toxic; and (4) under some conditions, the bicarbonate concentrations (U.S. Salinity Laboratory Staff, 1954).

Water containing a high concentration of dissolved solids, when used for irrigation, tends to cause the soil to increase in salinity. The tendency of water to do this is called the "salinity hazard" of the water. Increases in soil salinity are undesirable for growing crops. Soil type, drainage, and the amount of water used are also factors determining whether use of a given water for irrigation will cause a buildup in soil salinity, also the salt tolerance of the crops to be grown must be considered.

A high concentration of sodium in irrigation water has an undesirable effect on the soil through the process of base exchange. Sodium in the water is exchanged for calcium and magnesium in the soil. This produces an "alkali soil" in which the soil

Table 6. Standards for drinking water adopted by the U.S. Public Health Service and the South Dakota Dept. of Health.

(Recommended Maximum concentration[1])		
Constituent	United States Public Health Service (1962)	South Dakota Dept. of Health[2]
Chloride (Cl, mg/l)	250	250
Fluoride (F, mg/l)	0.9–1.7[3]	0.9–1.7
Iron (Fe, µg/l)	300	300
Manganese (Mn, µg/l)	50	50
Nitrate (NO_3, mg/l)	45[4]	45
Sulfate (SO_4, mg/l)	250	250
Dissolved solids (mg/l)	500	1,000

(1) Should not be exceeded where other more suitable supplies are or can be made available.

(2) Written communication, February 5, 1972.

(3) For Charles Mix and Douglas Counties; limit (based on temperature) varies for different parts of the United States.

(4) In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

particles have deflocculated and impaired the soil texture. The soil becomes difficult to till and to drain. The tendency of water to deflocculate the soil particles is called the "sodium hazard" of the water. The tendency of irrigation water to produce this condition depends not only on the sodium content, but also on the sodium content in relation to the calcium and magnesium content. This is expressed either as sodium percentage or sodium-adsorption-ratio (SAR). Low SAR values are desirable for irrigation water.

The following table describing the classification of water for irrigation is based on a diagram published by the U.S. Salinity Laboratory Staff (1954, p. 80).

Classification of Water for Irrigation

Low-salinity water (C1) — Water can be used for irrigation with little likelihood that soil salinity will develop.

Medium-salinity water (C2) — Water can be used if a moderate amount of leaching occurs.

High-salinity water (C3) — Water cannot be used on soil with restrictive drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected.

Very high-salinity water (C4) — Water is not suitable for irrigation under ordinary conditions.

Low-sodium water (S1) — Water can be used for irrigation with little danger of development of harmful levels of exchangeable sodium.

Medium-sodium water (S2) — Water will present an appreciable sodium hazard in fine-textured soil having high cation-exchange capacity, unless gypsum is present in the soil. This water can be used on coarse textured or organic soils with good permeability.

High-sodium water (S3) — Water may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic conditions.

Very high-sodium water (S4) — Water is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity.

Water for irrigation is withdrawn from the Choteau and Dakota aquifers. Choteau water sampled in different areas of the aquifer has a wide range in quality. The salinity hazard is high to very high; the sodium hazard generally is medium to high but ranges from low to very high. The amount of sodium ranged from 25 to 85 percent and averaged 62 percent in 31 samples. The Dakota water also has a high to very high salinity hazard but a low sodium hazard. The amount of sodium ranges from 9 to 32 percent and averages 19 percent in 27 samples.

The Delmont aquifer has the best quality ground water for irrigation, but because of the limited supply, it has not been used for that purpose. The water has a low sodium hazard and a medium to high salinity hazard.

Utilization

Domestic and Stock

Ground water is the main source of domestic and stock water supplies. Of the 1,400 domestic and stock wells for which records were obtained 23 percent were supplied by aquifers in surficial deposits and 77 percent by aquifers in bedrock. The Codell, Dakota, and Choteau aquifers furnished water to 47, 25, and 21 percent, respectively, of the total number of wells inventoried.

The estimated withdrawal of water for domestic and stock use in 1969 was 1,500 acre-ft (0.002 km^3, 1,300,000 gal/d).

Public Supply

Ground water is the main source of public water supplies. Of the public-supply wells inventoried, 19 percent were supplied by aquifers in surficial deposits and 81 percent by aquifers in bedrock. The Codell, Choteau, and Dakota aquifers furnished water to 70, 19, and 11 percent, respectively, of the total number of wells.

The Codell aquifer furnishes the entire water supplies of seven towns—Armour, Corsica, Delmont, Ravinia, Geddes, Greenwood, and Joubert (table 8). The Codell and Choteau aquifers have furnished water to the City of Lake Andes. The Choteau aquifer was the main water supply for Lake Andes until 1968 when yield was sharply reduced perhaps because of screen intake problems in the city well. Water from the Choteau aquifer was filtered for iron and treated for odor. The Codell aquifer became the main source of water during the period 1968-71. The Dakota and Codell aquifers furnish water to Platte; however, most of the water is withdrawn from the Dakota aquifer. The yield of the Codell is very small because it is thin, has low permeability and the supply well is near the aquifer boundary.

Estimates of past water use at Wagner based on data furnished by town officials showed that the total pumpage in 1954 was 72 acre-ft (88,780 m^3) or about 42 gal/d per capita. By 1966 the total pumpage had increased to 237 acre-ft (292,200 m^3) or about 131 gal/d per capita.

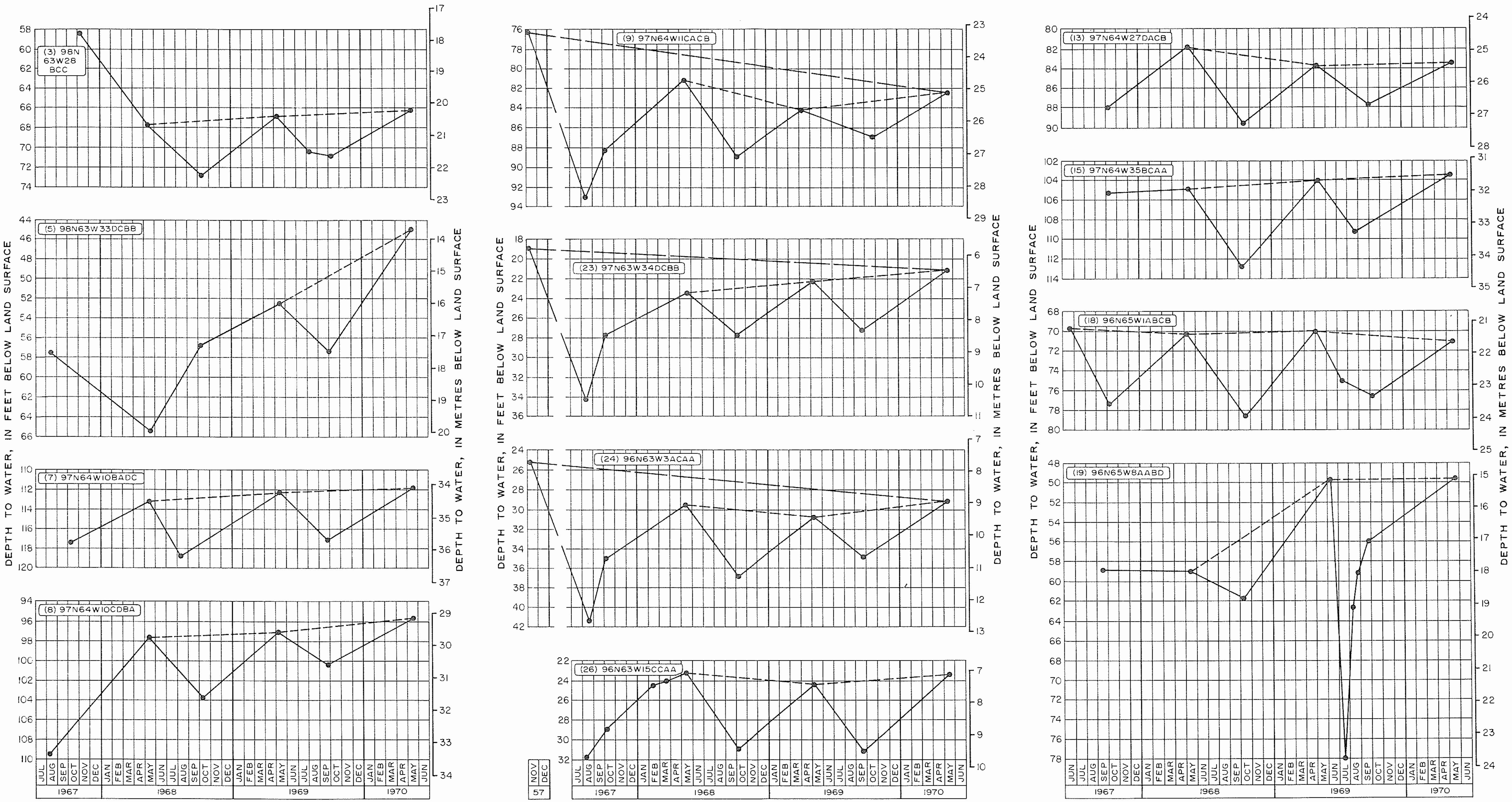
The estimated withdrawal of water in 1969 for public supply in the study area totaled 380 acre-ft (468,500 m^3).

Table 7. Significance of dissolved mineral constituents and physical properties of water.

Constituent or physical property	Significance
Silica (SiO_2)	Forms hard scale in pipes and boilers and may form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Forms rust-colored sediment; (300 ug/l or more) stains laundry, utensils, and fixtures reddish brown. Objectionable for food and beverage processing.
Manganese (Mn)	Causes dark brown or black stains on porcelain, enamel, and fabrics. Can promote growth of certain kinds of bacteria.
Calcium (Ca) and Magnesium (Mg)	Causes most of the hardness and scale-forming properties of water.
Sodium (Na) and Potassium (K)	Large amounts (500 mg/l or more) may limit use of water for irrigation and industrial use of water for irrigation and industrial use and, in combination with chloride, give water a salty taste. Abnormally high concentrations may indicate natural brines, industrial brines, or sewage.
Bicarbonate (HCO_3) and Carbonate (CO_3)	In combination with calcium and magnesium forms carbonate hardness. Produces alkalinity.
Sulfate (SO_4)	Sulfates of calcium and magnesium form hard scale. Large amounts of sulfate have a laxative effect on some people, and in combination with other ions, give water a bitter taste.
Chloride (Cl)	Large amounts increase the corrosiveness of water and, in combination with sodium, give water a salty taste.
Fluoride (F)	Reduces incidence of tooth decay when optimum fluoride content is present in water consumed by children during the period of tooth calcification. Excessive amounts of fluoride may cause mottling of teeth.
Nitrate (NO_3)	Concentrations higher than local average may indicate pollution by sewage or organic fertilizers. Concentrations higher than 45 mg/l may cause methemoglobinemia in infants (blue babies).
Boron (B)	Essential for proper plant growth and nutrition but may be toxic to crops when present in excessive concentrations (3,750 ug/l or more is unsuitable) in irrigation water (Wilcox, 1955).
Specific conductance (Micromhos at 25° C)	A measure of the ability of a unit cube of water to conduct an electric current; varies with temperature. Magnitude depends on concentration, kind, and degree of ionization of dissolved constituents; can be used to determine the approximate concentration of dissolved solids.
Hydrogen-ion concentration (pH)	A measure of the hydrogen-ion concentration; pH of 7.0 indicates a neutral solution, pH values lower than 7.0 indicate acidity, pH values higher than 7.0 indicate alkalinity. Water generally becomes more corrosive with decreasing pH; however, excessively alkaline water may be corrosive.
Percent Sodium (Na)	Ratio of Na to total cations in epm, expressed as a percentage. Important in irrigation waters; the higher the percent Na, the less suitable the water for irrigation (50 percent or more causes some soils to become less permeable).
Sodium-adsorption ratio (SAR)	A ratio used to express the relative activity of sodium ions in exchange reactions with soil. Important in irrigation water; the higher the SAR, the less suitable the water for irrigation.
Temperature (°C)	Affects the usefulness of water for many purposes. Generally, users prefer water of uniformly low temperature.
Residual sodium carbonate (RSC, Na_2CO_3)	A measure of the alkali hazard involved in irrigating with water containing high concentrations of HCO_3 and CO_3. The amount of epm of HCO_3 and CO_3 in excess of Ca and Mg. Less than 1.25 epm, safe for irrigation; 1.25 to 2.5 epm, marginal; more than 2.5 epm, not suited (depending on soil conditions).
Turbidity	Attributable to suspended matter such as clay, silt, fine fragments of organic matter, and similar material. It has a cloudy effect on water.
Color	Color refers to the appearance of water that is freerof suspended matter. Color to table 2 is reported in Hazen units; one unit is equivalent to the color produced by 1 mg/l of platinum.
Dissolved solids	The total of all dissolved mineral constituents. Saline water is unsuitable for many industrial uses. The concentration of dissolved solids may affect the taste of water.
Hardness as calcium carbonate ($CaCO_3$)	Related to the soap consuming power of water; results in formation of scum when soap is added. May cause deposition of scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate in water is called carbonate hardness; hardness in excess of this amount is called noncarbonate hardness.

Table 8. Summary of use of ground water for public supplies.

Town	Aquifer	No. of wells	Average depth of wells in ft (m)	Pump capacity, total in gal /min (l/s)
Armour	Codell	4	415 (126)	400 (25)
Corsica	Codell	3	380 (116)	200 (13)
Delmont	Codell	2	340 (104)	100 (6)
Ravinia	Codell	1	350 (107)	160 (10)
Geddes	Codell	2	475 (145)	90 (6)
Greenwood	Codell	3	170 (52)	—
Joubert	Codell	1	360 (110)	—
Lake Andes	Codell	2	380 (116)	100 (6)
Lake Andes	Choteau	1	200 (61)	230 (15)
Academy	Dakota	1	900 (274)	—
Platte	Dakota	2	948 (289)	375 (24)
Platte	Codell	1	455 (139)	22 (1)
Wagner	Choteau	2	240 (73)	650 (41)
Wagner	Choteau	1	158 (48)	100 (6)



Location of wells shown on Figure 22.
Well and map number shown in upper left corner.

Hydrographs by Jack Kume, 1971

– – – – – Water-level trends indicated by spring high levels.

—— —— Water-level trends indicated by 1957 to 1970 water levels.

Figure 23. Hydrographs showing water-level fluctuations in irrigation wells in the Choteau aquifer.

Irrigation

Irrigation with water from the Choteau aquifer has been practiced on an individual farm basis since 1957 when four irrigation wells were constructed. By 1969, thirteen irrigation wells had been constructed in the area north of Wagner, around Lake Andes, and southeast of Armour. The estimated withdrawal of water from Choteau aquifer for irrigation was 1,250 acre-ft (0.0015 km^3) in 1959; 1,230 acre-ft (0.0015 km^3) in 1967; 1,290 acre-ft (0.0016 km^3) in 1968, and 1,070 acre-ft (0.0013 km^3) in 1969.

Hydrographs showing the water-level fluctuations in 12 irrigation wells during the period 1967-70 and the water-level decline in three wells since 1957 are shown in figure 23. The water levels declined about 2 to 4 ft (0.6 to 1 m) during the period 1957-70 in the area north of Wagner, and about 6 ft (2 m) in the area east of Lake Andes. The decline is mainly the result of irrigation-well pumpage. Each year the irrigation wells were measured in May when the water levels were the highest owing to recharge and again in October when the irrigation withdrawals had been completed and the water levels were about their lowest level. A few water-level measurements were made during the irrigation season, and these low water levels were the result of drawdown in the recently pumped well. Well 96-65-8AABD in 1969 shows an unusual water-level decline and rise which may have been caused by poor well construction and development. The water levels in five wells were highest in 1970 owing to less pumpage in 1969.

Irrigation is being practiced on one farm using water from a flowing artesian well 98-69-26DDAD developed in the Dakota aquifer. The estimated withdrawal of water in 1969 totaled 46 acre-ft (0.28 km^2) which was used to irrigate 30 acres (0.12 km^2) of corn and 70 acres (0.28 km^2) of hay and pasture.

Recreation

Ground water from flowing artesian wells in the Dakota aquifer is being used for recreation at Wagner Park, Armour Park, and Lake Andes National Wildlife Refuge. The well in Wagner Park fills Lake Wagner which is a fishing lake and recreation area. The well in Armour Park fills the fishing lake and the swimming pool. The park is also a picnic area. Water from a well in Lake Andes National Wildlife Refuge flows into Owens Bay which is a production and protection refuge, especially for waterfowl. Water flowing from the well enters the bay at about 22°C (Celsius) which, combined with the movement of waterfowl in the water, had kept about 4 acres (0.02 km^2) of water from freezing throughout the winter. Consequently, many waterfowl have wintered in the open waters of Owens Bay. The estimated withdrawal of water in 1969 from these three wells totaled 1,650 acre-ft (0.002 km^3) per year (1.5 million gal/d).

SUMMARY AND CONCLUSIONS

Charles Mix and Douglas Counties have very important, but relatively undeveloped, surface- and ground-water resources. Surface-water resources have had little development except for the public supplies of Pickstown and Lake Andes, and for irrigation. Surface water is rarely used as a domestic water supply because of its need for treatment, its limited availability, and difficulty of access compared to ground water. Ground water is the most important water resource and is available from one or more aquifers everywhere in these counties. Aquifers furnish water for nearly all of the domestic, stock, public-supply, and irrigation needs. The estimated withdrawal of ground water in 1969 totaled 4,650 acre-ft (0.006 km^3).

Surface water is available from the Missouri River, Lake Francis Case, Choteau Creek, and several small lakes. The Missouri River with an average discharge of 23,430 ft^3/s (663 m^3/s, 17 million acre-ft per year) and Lake Francis Case with a normal maximum content of 4.8 million acre-ft (6 km^3) are the major surface-water sources. Choteau Creek with an average discharge of 22 ft^3/s (0.62 m^3/s, 15,900 acre-ft per year) and Lake Andes with a surface area of about 4,400 acres (18 km^2) are minor surface-water sources.

The Missouri River and Choteau Creek contain sodium-calcium-sulfate water. Lake Francis Case contains sodium bicarbonate water. Lake Andes and Lake Platte contain calcium sulfate water. The sulfate water is fresh except for the base flow of Choteau Creek, the water in the north and south remnants of Lake Andes, and in Lake Platte.

Lake Francis Case has exceptional potential for recreational development such as for water sports, fishing, waterfowl production, hunting, and camping. All of the other lakes have been used almost exclusively for recreation due to their small areas and limited water supplies.

Ground water is generally available from aquifers in surficial deposits. The total area underlain by aquifers in surficial deposits is 436,000 acres (1,764 km^2). Of this, 50 percent is underlain by aquifers with a saturated thickness greater than 25 ft (8 m). Choteau, Tower, Greenwood, Corsica, Geddes, and Delmont aquifers are the six major alluvium and outwash aquifers in the surficial deposits. Minor aquifers underlie an area of 88,800 acres (366 km^2) and contain 350,000 acre-ft (0.43 km^3) of water in storage.

The artesian Choteau sand-and-gravel aquifer is the largest aquifer within the surficial deposits. It underlies 209,000 acres (846 km^2), has an average saturated thickness of 35 ft (11 m), and has

2,190,000 acre-ft (2.7 km^3) of water in storage. It has had the greatest development and has the greatest potential for future development. It furnishes water to 21 percent of the domestic and stock wells, 19 percent of the public-supply wells, and 93 percent of the irrigation wells. The aquifer contains sodium sulfate water which is very hard and slightly saline. Recharge is from the adjacent drift and bedrock.

The Tower and Greenwood are sand-and-gravel, water-table aquifers which underlie an area of 9,500 acres (38 km^2), have an average saturated thickness of 90 ft (27 m), and contain 243,000 acre-ft (0.30 km^3) of water in storage. They have a high potential for future development of large-capacity irrigation wells, but have not been developed. Recharge is from infiltration of water into the aquifer from precipitation, runoff, and the Missouri River.

The Corsica and Geddes sand-and-gravel, artesian aquifers underlie an area of 101,000 acres (409 km^2), have an average saturated thickness of 30 ft (9 m), and contain 915,000 acre-ft (1.1 km^3) of water in storage. The aquifers have a high potential for future development of small to moderate-capacity irrigation and municipal wells, but presently the aquifer has not been developed. The towns of Platte, Geddes, and Corsica have a potential future public water supply in these aquifers. Recharge is from infiltration of water into the aquifer from the adjacent drift and bedrock.

The Delmont sand-and-gravel, water-table aquifer underlies an area of 26,800 acres (108 km^2), has an average saturated thickness of 18 ft (6 m), and contains 138,000 acre-ft (0.17 km^3) of water in storage. The aquifer contains calcium-magnesium-bicarbonate-sulfate water which is fresh to slightly saline, and very hard. It has a high potential for small to moderate-capacity irrigation and municipal well development. Some caution must be exercised with any large withdrawals from the aquifer, because of possible excessive lowering of the water levels. The aquifer occurs in a surface outwash that is recharged by runoff and precipitation, and has an average saturated thickness of only 17 ft (5.2 m). During a period of low precipitation and the resultant water-level decline, pumpage would increase the rate of water-level decline.

Ground water is available from the Dakota, Codell, and Niobrara sandstone and marl bedrock aquifers. These aquifers supply 77 percent of the domestic and stock wells and 81 percent of the public-supply wells in the area.

The Dakota is the most important aquifer in the area, because it is a potential source of water throughout the area and because it has sufficient static head to maintain flowing artesian wells in the topographically low areas. It contains about 44 million acre-ft (54 billion m^3) of water in storage. It furnishes moderate to large supplies of very hard, slightly saline water of the calcium sulfate type to 25 percent of the domestic and stock wells, 11 percent of the public-supply wells, and all of the recreation wells in the area.

The Codell aquifer underlies most of the area and is the most desired source for domestic use because its water is soft to moderately hard. It supplies 47 percent of the domestic and stock wells and 70 percent of the public-supply wells. The aquifer furnishes small to moderate supplies of slightly saline water of the sodium bicarbonate sulfate type.

The Niobrara aquifer underlies nearly all of the study area and yields small supplies of moderately hard, slightly saline water of the sodium-bicarbonate-sulfate type.

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