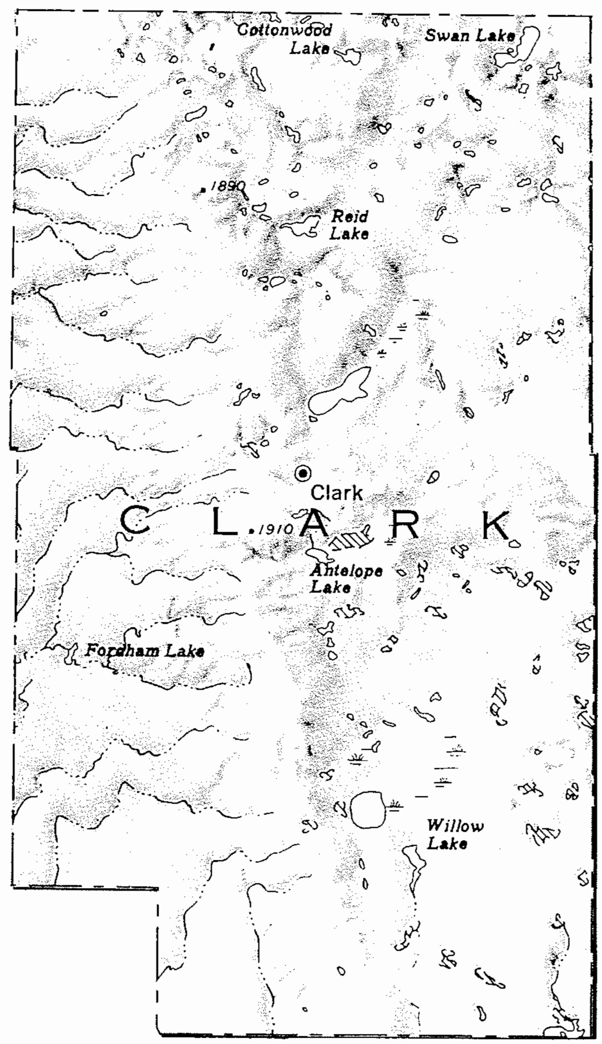
BULLETIN 29

GEOLOGY AND WATER RESOURCES OF CLARK COUNTY, SOUTH DAKOTA

PART II: WATER RESOURCES

by Louis J. Hamilton
United States Department of the Interior, U.S. Geological Survey



Prepared in cooperation with the South Dakota Geological Survey,
Clark County, and the Oahe Conservancy Sub-District

DEPARTMENT OF WATER AND NATURAL RESOURCES – GEOLOGICAL SURVEY 1986

STATE OF SOUTH DAKOTA
William J. Janklow, Governor

DEPARTMENT OF WATER AND NATURAL RESOURCES
Warren R. Neufeld, Secretary

GEOLOGICAL SURVEY
Merlin J. Tipton, State Geologist

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Science Center
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Vermillion, South Dakota
1986

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DEFINITIONS OF TERMS

AQUIFER - A geologic formation, group of formations, or part of a formation that will yield significant quantities of water to wells and springs. In this report, a major aquifer is defined as one that will yield 18 or more gallons per minute to individual wells.

ARTESIAN WATER - Ground water confined under hydrostatic pressure sufficient to raise water levels in wells above the top of the aquifer.

BEDROCK AQUIFER - A water-yielding geologic formation consisting of consolidated rock such as sandstone.

DISCHARGE, GROUND WATER - The flow of water from an aquifer by subsurface outflow and vertical leakage. Also, the removal of water from the zone of saturation by wells, springs, seeps, and evapotranspiration.

DRAWDOWN - The amount of lowering of the water table or potentiometric surface caused by pumping or artesian flow.

ELECTRIC LOG - An electrical recording obtained by lowering electrodes in a borehole and measuring various electrical properties of the geological formations traversed.

EVAPOTRANSPIRATION - Loss of water from a land area by evaporation from the water or soil surface and by plant transpiration.

GLACIAL AQUIFER - A water-yielding geologic formation consisting of materials transported and deposited by glacial action such as unconsolidated sand and gravel deposited as outwash by meltwater from a glacier.

GROUND-WATER DIVIDE - A mound or ridge in the water table or potentiometric surface from which the ground water moves.

HARDNESS - Hardness of water is a physical-chemical characteristic attributable to the presence of alkaline earths (principally calcium and magnesium) and is expressed as equivalents of calcium carbonate ($CaCO_3$). Hardness has been classified in some reports of the U.S. Geological Survey (Durfor and Becker, 1964, p. 27) as follows:

	Milligrams per liter	Grains per gallon
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

HEAD (STATIC) - The hydrostatic pressure expressed as the elevation of the top of a column of water that can be supported by the pressure.

HYDRAULIC CONDUCTIVITY - As commonly defined is the rate of flow of water, in gallons per day, through a square foot of aquifer under a unit hydraulic gradient.

HYDROSTATIC PRESSURE - As used here, the pressure exerted by the water at any given point in an aquifer. The hydrostatic pressure of ground water most commonly is due to the weight of water at higher levels.

LARGE-CAPACITY WELL - Defined by South Dakota law as a well capable of yielding at least 18 gallons per minute on a sustained basis.

MICROGRAMS PER LITER (UG/L) - A unit expressing the concentration of chemical constituents dissolved in water as mass (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter are equal to 1 milligram per liter.

MILLIGRAMS PER LITER (MG/L) - A unit for expressing the concentration of chemical constituents in solution. Milligrams per liter represent the mass of solute per unit volume (liter) of water.

NATIONAL GEODETIC VERTICAL DATUM - A geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada. It was formerly called "mean sea level." Although the datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts, it does not necessarily represent local mean sea level at any particular place.

OUTWASH - A stratified deposit of sand and gravel that has been washed, sorted, and deposited by meltwater from a glacier.

PERMEABILITY - The property of a material to transmit water under a potential gradient (same as hydraulic conductivity).

POTENTIOMETRIC SURFACE - An imaginary surface that coincides with the head of an aquifer as represented by the level to which water will rise in tightly-cased, non-pumping wells open only to the aquifer.

PROPERLY-CONSTRUCTED WELL - A well constructed to transmit the maximum amount of water from an aquifer without excessive drawdown of water level at the well. This usually involves installing a well screen or perforating the casing opposite the aquifer. It also involves developing the well in such a manner as to remove drilling mud and other fine-grained material from the aquifer adjacent to the well.

RECHARGE - Addition of water to the zone of saturation by infiltration of precipitation, seepage from streams or other bodies of surface water, or by subsurface inflow.

RUNOFF - That part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

SALINE WATER - As used in this report it is water containing more than 1,000 milligrams per liter of dissolved solids.

SPECIFIC CAPACITY - The rate of discharge of water from a well divided by the drawdown of the water level, normally expressed as gallons per minute per foot of drawdown.

SPECIFIC CONDUCTANCE - The ability of water to conduct an electrical current, expressed in micromhos per centimeter at 25 degrees Celsius. Because the specific conductance is related to the number and specific chemical types of ions in solution, it can be used for approximating the dissolved-solids concentration in the water. The following general relation is applicable in the area of study:

> Specific conductance, in micromhos per centimeter x 0.65 = dissolved solids, in milligrams per liter.

SPECIFIC YIELD - The storage coefficient for an unconfined aquifer.

STORAGE COEFFICIENT - The volume of water an aquifer releases from or takes into storage in a vertical column of 1 square foot when the head decreases or increases 1 foot, expressed as a ratio of the volume to the volume of the aquifer column.

TILL - An unsorted, unstratified mixture of clay, silt, sand, gravel, and boulders deposited by a glacier.

TRANSMISSIVITY - The rate of flow of water, in gallons per day, through each vertical strip of aquifer 1 foot wide having a height equal to the saturated thickness of the aquifer and under a hydraulic gradient of 1 foot per foot.

WATER TABLE - The surface of 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. In wells which penetrate to greater depths, the water level will stand above or below the water table, respectively, if an upward or downward component of ground-water flow exists.

INCH-POUND AND METRIC UNITS

For those readers interested in converting inch-pound units to metric units, the following factors are used:

Multiply inch-pound unit	By	To obtain metric unit
acre	0.4047	hectare
acre-foot	1,233	cubic meter
acre-foot	1.233×10^{-6}	hectometer
acre-foot per square mile	476.1	cubic meter per square kilometer
cubic foot per second	2.832×10^{-2}	cubic meter per second
cubic foot per second per square mile	1.093×10^{-2}	cubic meter per second per square kilometer
foot	0.3048	meter
foot per day	0.3048	meter per day
foot per mile	0.1894	meter per kilometer
gallon	3.785	liter
gallon	3.785×10^{-3}	cubic meter
gallon per minute	6.309×10^{-2}	liter per second
gallon per day per square foot	0.0407	meter per day
gallon per day per foot	1.242×10^{-2}	square meter per day
inch	25.40	millimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

ABSTRACT

Glaciers have deposited as much as 600 feet of clayey glacial till and outwash sand and gravel on shale bedrock in Clark County, a hilly area of 979 square miles on the west side of the 400-foot high Coteau des Prairies in northeastern South Dakota. Outwash sand and gravel 20 to 30 feet thick constitute six major glacial aquifers that underlie 70 percent of the county. Three of these, Prairie Coteau aquifers 1, 2, and 3, are penetrated at depths of from a few feet to 300 feet.

Beneath these are the three Altamont aquifers, also numbered 1, 2, and 3, penetrated at depths to nearly 600 feet on the Coteau des Prairies. The Altamont aquifers extend westward into the James Basin where depths to the aquifers are as shallow as 10 feet. Glacial aquifers can yield as much as 2,000 gallons per minute of slightly-saline, very hard water to individual wells.

A major bedrock aquifer, the Dakota Formation of Cretaceous age, consists of as much as 200 feet of fine-grained, silty sandstone and sandy shale that is penetrated at depths of from 900 to 1,400 feet beneath 800 feet of relatively impermeable shale. The aquifer can yield as much as 50 gallons per minute of soft, slightly-saline water to a well.

Annual withdrawals of ground water in Clark County during 1976 totaled 5,000 acre-feet, 70 percent of which was for irrigation. Water-level declines around irrigation wells in the glacial aquifers generally were less than 50 feet. Water levels recovered nearly to pre-pumping levels following the irrigation season. Recharge to the glacial aquifers is estimated to range from 5,000 to 54,000 acre-feet annually.

Surface-water resources include approximately 1,000 lakes, ponds, and marshes that dot the Coteau des Prairies. Most are very shallow and dry up during summer. Streamflow off the coteau averages 27,000 acre-feet annually but is ephemeral, occurring mostly during the spring in wet years.

INTRODUCTION

The Clark County Board of Commissioners requested a study of the geology and water resources of the county to determine the available water supply and provide information for planning efficient use of the supply. The study is part of a cooperative program of the South Dakota Geological Survey and the U.S. Geological Survey. It was financed by State, Oahe Conservancy Sub-District, and county funds matched by Federal funds.

The cooperation of well owners in allowing access to their property and of well drillers in providing well logs and well-construction data is greatly appreciated.

This report is published in two parts. The geology is described in Part I (Christensen, in preparation). This report, Part II, is a general appraisal of the water resources. It is not intended as a substitute for detailed hydrologic studies that may include test drilling and aquifer tests required to evaluate the potential of an aquifer for intensive water development.

Purpose and Scope

The purpose of the water-resources part of the study was to determine the availability of surface and ground-water supplies, assess the water quality, and estimate the effects of development on the supply. The glacial aquifers are described in greatest detail because they are a potential source of large amounts of water. Prior to this study little was known of their extent, composition, and thickness. Movement of water was studied to estimate recharge and discharge of aquifers.

Method of Investigation

Geohydrologic data from 400 test holes and 600 wells were obtained and analyzed to determine the composition, depth to the top, and areal and vertical extent of the aquifers as well as the altitude of water levels. Water samples from 400 wells and 10 lakes were collected and analyzed for several chemical constituents and physical properties to determine general water quality. Additional water samples, collected from 60 wells and 4 lakes, were analyzed for major ions, nutrients, and selected trace elements. The water level was measured bimonthly in 40 wells and semiannually in 10 lakes to determine water-level fluctuations and trends. Aquifer tests were made at three sites to determine aquifer characteristics. Landsat photographs were used in the evaluation of surface-water resources and the areal extent of the 80-square mile Prairie Coteau aquifer 1. This aquifer includes near-surface deposits in topographic lows where the water table was shallow and soil moisture was high relative to adjacent areas during the drought of 1973-76. Hence, these moist areas appeared as dark tones of gray on the Landsat imagery of band 7 on October 17, 1974.

Site-Numbering System

Wells, test holes, and surface-water sampling sites are identified by a numbering and lettering system based on the Federal land-survey system used in South Dakota (fig. 1). The location includes a township number followed by the letter N for north, range number followed by the letter W for west, and section number. This is followed by a maximum of four letters that indicate, respectively, the 160-, 40-, 10-, and 2 1/2-acre tract in which the well is located. These letters, A, B, C, and D, are assigned in a counterclockwise direction beginning with "A" in

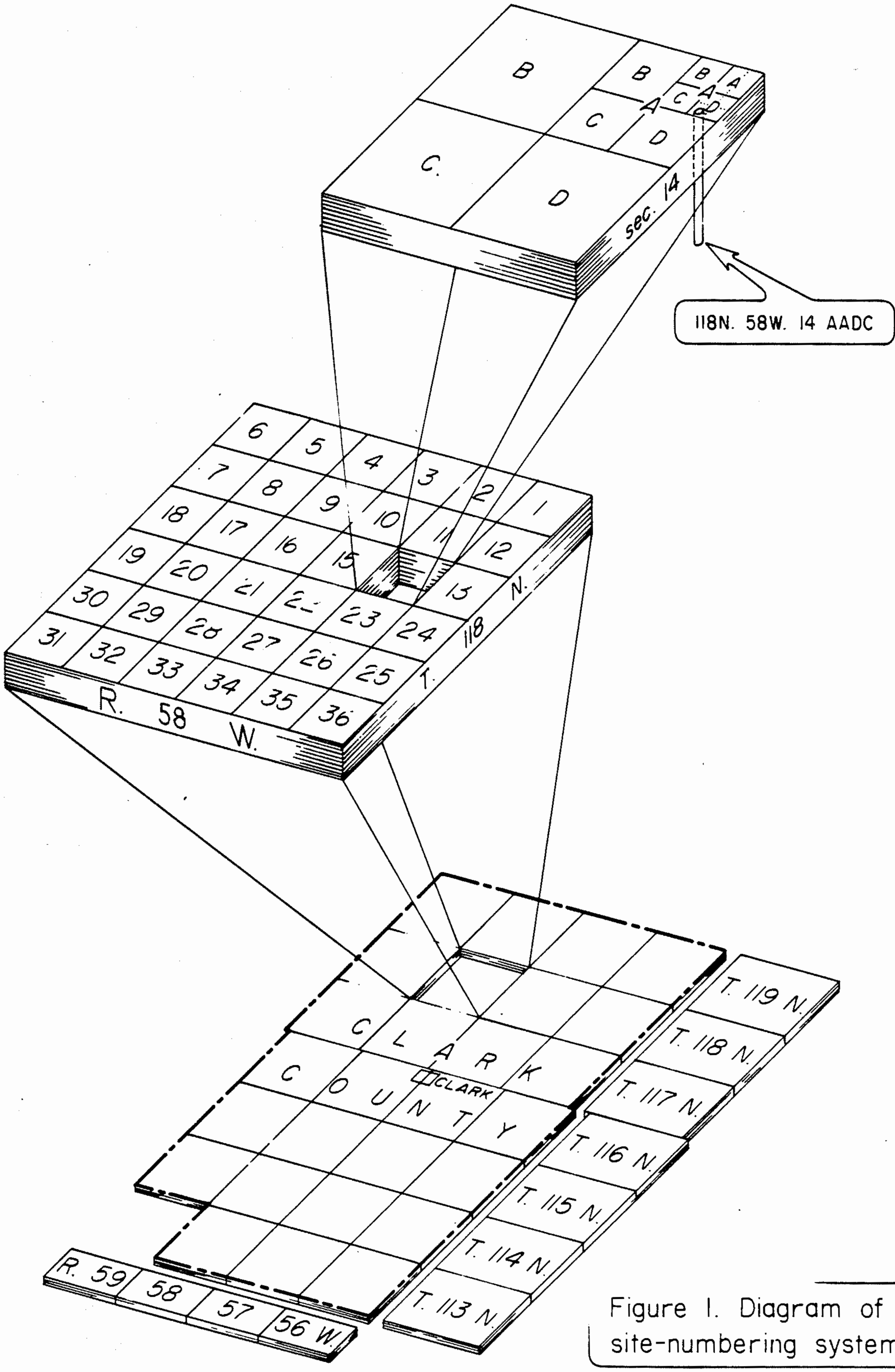


Figure 1. Diagram of site-numbering system.

the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same 2 1/2-acre tract. Thus, well 118N58W14AADC is in the SW 1/4 SE 1/4 NE 1/4 NE 1/4 sec. 14, T. 118 N., R. 58 W.

Geography and Climate

Clark County comprises 979 square miles of till plains and hills along the boundary between the James Basin and the Coteau des Prairies in the Central Lowland physiographic province (fig. 2). The hummocky, glaciated surface of the Coteau des Prairies ranges in altitude from 1,700 feet in the south to 1,900 feet in the north and is about 400 feet above the James Basin to the west. The Coteau des Prairies is characterized by numerous small lakes, ponds, and marshes in poorly-drained swales. Vertical relief in a square mile can exceed 50 feet. Along the border between the Coteau des Prairies and the James Basin, slopes are steep and stream gradients in places exceed 100 feet per mile. The slopes decrease to about 20 feet per mile along the western side of the county.

The county has a population of about 5,500 and an economy based on agriculture. More than 90 percent of the land is range and field crops (U.S. Department of Agriculture, 1970). Agriculture has been adapted to a semiarid, continental climate characterized by cool wet springs, hot dry summers, and long cold winters. The mean-annual temperature is about 7 degrees C (44 degrees F) but mean monthly-temperatures average less than 0 degree C (32 degrees F) for 5 months of each year. Average annual precipitation is only 21.7 inches, and is more than 3 inches below average 30 percent of the time. More than three-fourths of the precipitation occurs during the growing season.

SURFACE-WATER RESOURCES

The surface-water resources of the county are comprised of streams, lakes, ponds, and marshes. The location and extent of streams and larger lakes and marshes on May 31, 1973, are shown in figure 3. The area of steeply-sloping terrane west of the Coteau des Prairies is mostly pasture land and appears on the photograph as a northward-trending gray band 2 to 3 miles wide.

Streams

Most streamflow occurs in 14 short, ephemeral streams that flow from the Coteau des Prairies into the James Basin. Stream gradients range from 20 to more than 100 feet per mile. Most of the annual streamflow occurs during late winter and early spring from snowmelt and rainfall runoff. Although none of the streams were gaged, the mean-annual discharge of six streams was estimated using a regression analysis (Larimer, 1970). Estimated

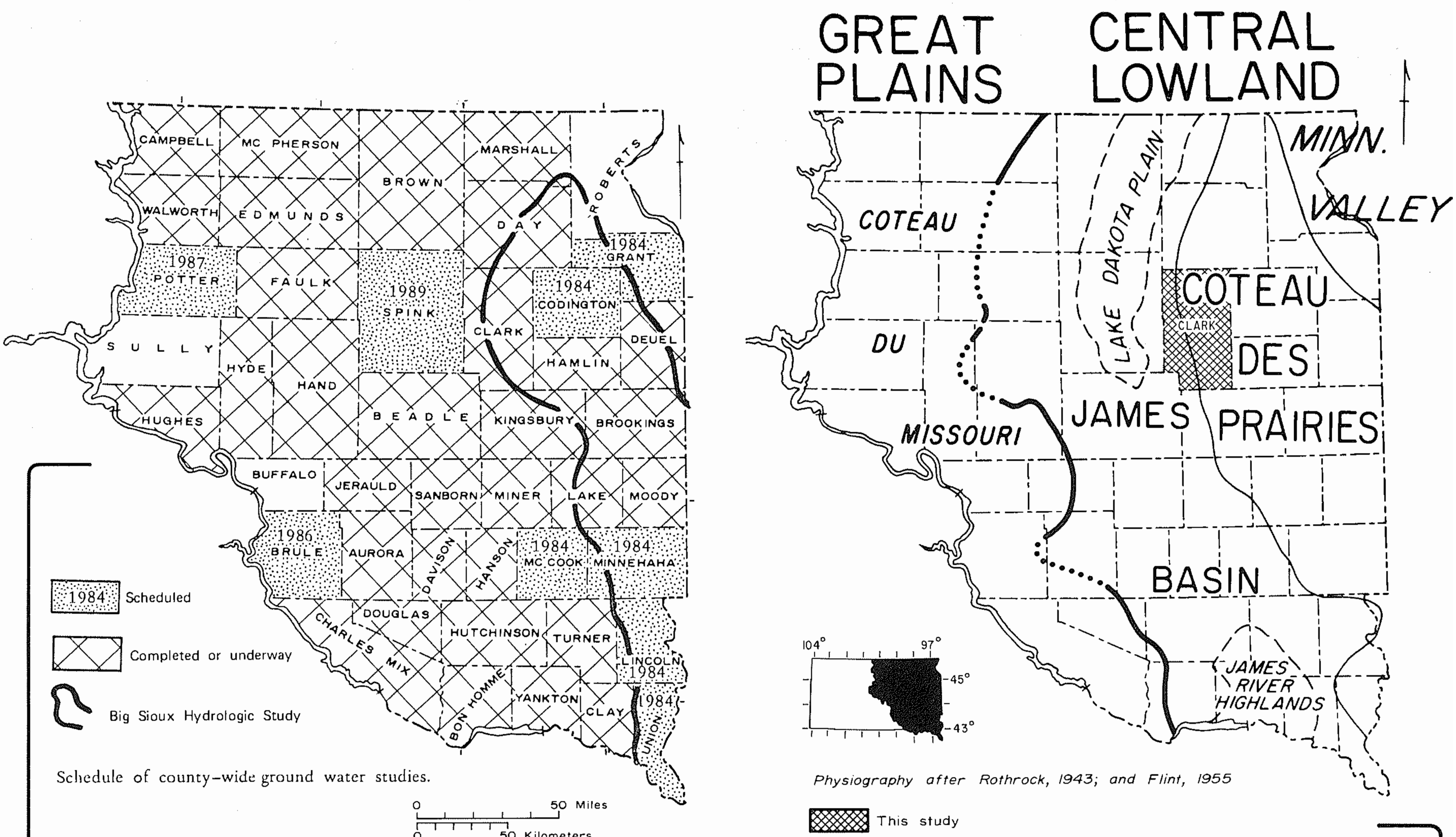
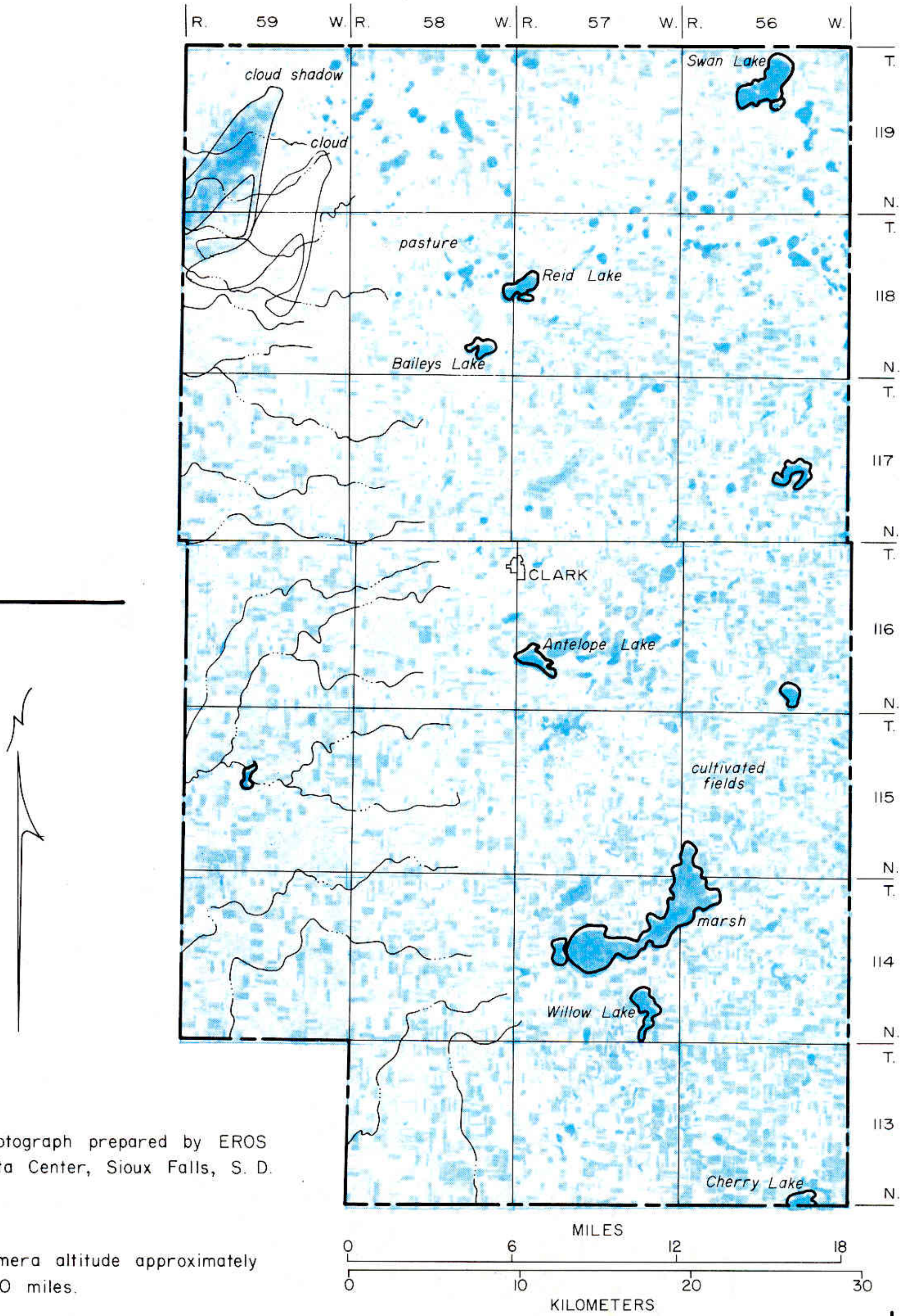


Figure 2. Index maps of eastern South Dakota showing area of this study, status of county investigations, and major physiographic divisions.



Photograph prepared by EROS Data Center, Sioux Falls, S. D.

Camera altitude approximately 570 miles.

Figure 3. Landsat photograph showing streams, lakes, and large marshes, May 31, 1973.

discharge ranges from 0.3 cubic feet per second for streams with drainage areas of 2 or 3 square miles, to 3 cubic feet per second for streams with drainage areas of about 30 square miles. These estimates indicate that runoff averages about 0.1 (cubic feet per second) per square mile. Using this estimate and a drainage area of 400 square miles, the average annual streamflow from the county is about 40 cubic feet per second or 27,000 acre-feet.

Lakes, Ponds, and Marshes

There are about 1,000 lakes, ponds, and marshes in Clark County. Nearly all of them were dry at some time during the drought of 1973-76. Landsat imagery (fig. 3) shows the lakes and marshes on May 31, 1973. The size and number of lakes are different on the landsat photograph than on other base maps in the report because the lakes are shallow, are not supplied by large springs, and change in size with changes in precipitation. Data from land and water inventories (U.S. Department of Agriculture, 1970) indicate that 14,520 acres or 2.3 percent of the county are covered by water in most years. Most of this water is on the Coteau des Prairies, where approximately 4 percent of the land is covered by lakes, ponds, or marshes.

Water-level changes for five lakes and a marsh during 1973-76 are shown in figure 4. By the end of 1976, after 3 years of drought, nearly all of the lakes, ponds, and marshes were dry.

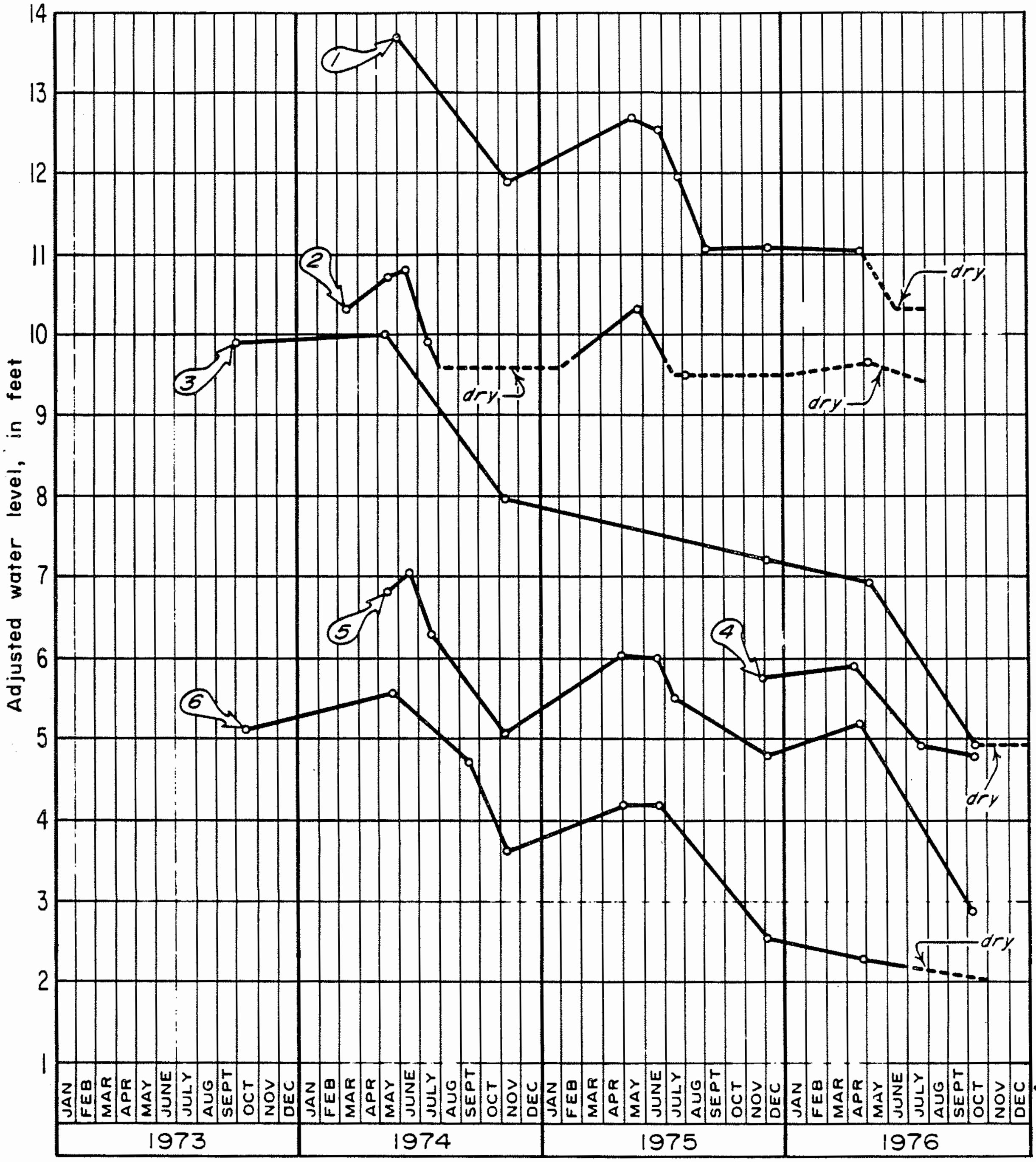
The water level of Willow Lake (site 3, fig. 4) declined the most (5 feet) during the drought because the lake receives little ground-water inflow. Willow Lake probably was deeper than many other lakes in the county at the start of the drought because it had received runoff from a surface drainage area of more than 100 square miles, about three times more than the area for other lakes in the county.

The water level in Antelope Lake (site 4, fig. 4) declined only about 1 foot during 1976 because of spring discharge into the lake. Although Baileys Lake also receives ground-water inflow, its water level declined about 4 feet during 1976 because of a decrease in ground-water inflow, an increase in the watering of livestock, and seepage loss.

It should be noted that the hydrographs in figure 4 are drawn so as not to overlap. Thus, the positions of the hydrographs do not indicate relative lake altitudes. Also, the adjusted water levels are arbitrary.

GROUND-WATER RESOURCES

Well-water supplies adequate for domestic and livestock needs are available within 600 feet of the land surface in most of Clark County. Yields of as much as 2,000 gallons per minute can



Name	Location
1. Cherry Lake	113N56W35CBCC
2. Marsh	114N57W8BCBB
3. Willow Lake	114N57W26ABCB

Name	Location
4. Antelope Lake	116N57W30BBCC
5. Baileys Lake	118N58W26DCDB
6. Swan Lake	119N56W3DAAC

Figure 4. Hydrographs showing water-level changes in five lakes and a marsh, 1973-76.

be obtained from individual wells completed in glacial aquifers and yields of as much as 50 gallons per minute can be obtained from wells completed 900 feet or deeper in the bedrock aquifer. Most water is obtained from artesian aquifers confined by less permeable till or shale.

Glacial Aquifers

The glacial aquifers consist principally of unconsolidated sand and gravel deposited as glacial outwash. Locally, the aquifers consist of clayey, sandy silt or gravelly, clayey silt. The names of glacial aquifers were chosen by the author to correspond with those used in a study of the same aquifers in adjacent counties (Kume, 1976). A discussion of the origin and composition of the outwash and other deposits can be found in Part I of this Bulletin (Christensen, in preparation).

Selected physical and hydrological characteristics of the six major glacial aquifers in Clark County are summarized in table 1. Three of the higher-altitude, Prairie Coteau aquifers occur only on the Coteau des Prairies. Three others, at lower altitudes, are the Altamont aquifers. Aquifers in each set are numbered consecutively in order of increasing depth. Altitudes of aquifer tops range from 1,260 feet for Altamont aquifer 3 (the deepest) to 1,790 feet for Prairie Coteau aquifer 1 (the shallowest).

Depths to the tops of the aquifers range from 0 to 585 feet below land surface. Depths of the Altamont aquifers increase from west to east with the upward slope of the land surface onto the Coteau des Prairies, being greater than 300 feet on the coteau.

The areal extent of the aquifers ranges from 50 square miles for Prairie Coteau aquifer 3 to 630 square miles for Altamont aquifer 2. In about one-fourth of the county, two or more aquifers overlap. Altamont aquifers 2 and 3 are hydraulically connected near the west side, beneath an area of about 50 square miles. Elsewhere the aquifers are separated by 30 to 150 feet of less permeable till that slows the movement of water between aquifers.

The aquifers range from 20 to 40 feet in average thickness. The maximum known thickness of permeable sand and gravel is 121 feet in test hole 118N56W8AAAA, which penetrates Altamont aquifer 2 between the depths of 314 and 435 feet.

Static water levels in wells range from less than 10 feet below land surface for most of the aquifers in the western part of the county to 326 feet below land surface on the coteau near the center of the county. Flowing wells have been completed locally along the western edges of Altamont aquifers 1 and 2.

Estimated water in storage ranges from 130,000 acre-feet for Prairie Coteau aquifer 3 to 3,230,000 acre-feet for Altamont

TABLE 1 SELECTED PHYSICAL AND HYDROLOGICAL CHARACTERISTICS OF MAJOR GLACIAL AQUIFERS.

Aquifer Name	Range in Altitude of Top (Feet Above National Geodetic Vertical Datum of 1929)	Range in Depth to Top (Feet)	Areal Extent (Square Miles)	Average Thickness (Feet)	Range in Water Level (Feet + Indicates Above Land Surface)	Storage (Acre-Feet)	Average Annual Recharge			Maximum Well Yield (Gallons per Minute)
							(Acre-Feet)	(Acre-Feet per Square Mile)	(Inches)	
Prairie Coteau aquifers										
1	1,760-1,790	0-40	80	20	6-40	200,000	16,000	200	3.8	800
2	1,650-1,770	50-170	110	20	1-100	280,000	11,000	100	1.9	800
3	1,520-1,590	200-330	50	20	140-180	130,000	5,000	100	1.9	200
Altamont aquifers										
1	1,450-1,500	70-380	180	30	+25-260	690,000	9,000	50	.9	800
2	1,360-1,500	10-480	630	40	+25-326	3,230,000	54,000*	80	1.5	2,000
3	1,260-1,360	70-590	210	30	8-260	810,000				300

* Includes recharge to Altamont aquifer 3.

aquifer 2. These estimates are based on an estimated specific yield of 20 percent.

Average annual recharge to the glacial aquifers from precipitation ranges from 5,000 acre-feet for Prairie Coteau aquifer 3 to 54,000 acre-feet for Altamont aquifer 2 (table 1). Much of the recharge to the upper aquifers also infiltrates to recharge Altamont aquifer 2. The rate of annual recharge is estimated to range from 50 to 200 acre-feet per square mile. Recharge from vertical infiltration of precipitation is estimated as the product of the assumed vertical hydraulic conductivity of the glacial till, 0.001 feet per day, and the average vertical hydraulic gradient, about 0.3. This product is 0.1 feet per year or 64 acre-feet per square mile per year. This can be expected to vary as much as 50 percent in different localities due to the natural large variations in hydrologic conditions.

Because Prairie Coteau aquifer 1 is not covered by till in many areas, the average annual rise in water level was used to estimate recharge in one well in an area of no till. The average rise in water level in well 113N57W4ADAA (fig. 9) during 1969-78 was 3.7 feet. Converting this to inches and multiplying by a specific yield of 10 percent provides a recharge estimate of 4.4 inches annually. This value was adjusted to 3.8 inches or 200 acre-feet per square mile, annually to account for the aquifer area where recharge is reduced by a cover of till. The use of a value of specific yield one-half of that for other glacial aquifers makes the recharge estimate conservative.

Maximum well yields range from 200 gallons per minute for Prairie Coteau aquifer 3 to 2,000 gallons per minute for Altamont aquifer 2. Such yields may be attained without excessive drawdown where the aquifers contain a near-maximum thickness of sand and gravel and are not severely affected by less permeable boundaries. Theoretical estimates of drawdown for the Altamont aquifers at various distances from a pumping well (figs. 18, 24, and 28) are based on the following aquifer tests:

Location of pumped well ----------	115N58W7DDAA and 115N58W8CCAA
Aquifer ---------------------------	Altamont 1
Aquifer depth (feet) -------------	105
Aquifer thickness (feet) ---------	32
Well depth (feet) ----------------	139 (7DDAA) and 141 (8CCAA)
Average pumping rate (gallons per minute) -----------	*870
Pumping time (days) --------------	32
Drawdown in pumped well (feet) --------------------------	91 (7DDAA) and 32 (8CCAA)
Specific capacity (gallons per minute per foot) -----------	9 (7DDAA) and 25 (8CCAA)
Transmissivity (gallons per day per foot) -------------	15,000

Coefficient of storage ----------	0.0001
Remarks --------------------------	Recovery test for two pumped wells.

* Average of total for two wells pumping intermittently.

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Location of pumped well ---------	116N59W34CACC
Aquifer -------------------------	Altamont 2
Aquifer depth (feet) ------------	95
Aquifer thickness (feet) --------	35
Well depth (feet) ---------------	115
Average pumping rate (gallons per minute) ----------	500
Pumping time (days) -------------	35
Drawdown in pumped well (feet) ------------------------	41
Specific capacity (gallons per minute per foot) ----------	21
Transmissivity (gallons per day per foot) -------------	28,000
Coefficient of storage ----------	.0001
Remarks -------------------------	Recovery test.

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Location of pumped well ---------	116N57W6DCAD
Aquifer -------------------------	Altamont 3
Aquifer depth (feet) ------------	474
Aquifer thickness (feet) --------	30
Well depth (feet) ---------------	506
Average pumping rate (gallons per minute) ----------	100
Pumping time (days) -------------	125
Drawdown in pumped well (feet) ------------------------	67
Specific capacity (gallons per minute per foot) ----------	2
Transmissivity (gallons per day per foot) -------------	2,000
Coefficient of storage ----------	.0001
Remarks -------------------------	Drawdown test.

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Prairie Coteau Aquifer 1

EXTENT AND COMPOSITION

The Prairie Coteau aquifer 1 (fig. 5) extends northward through the middle of the county in a 1.5 to 5-mile-wide band and has an area of about 80 square miles. It is the shallowest

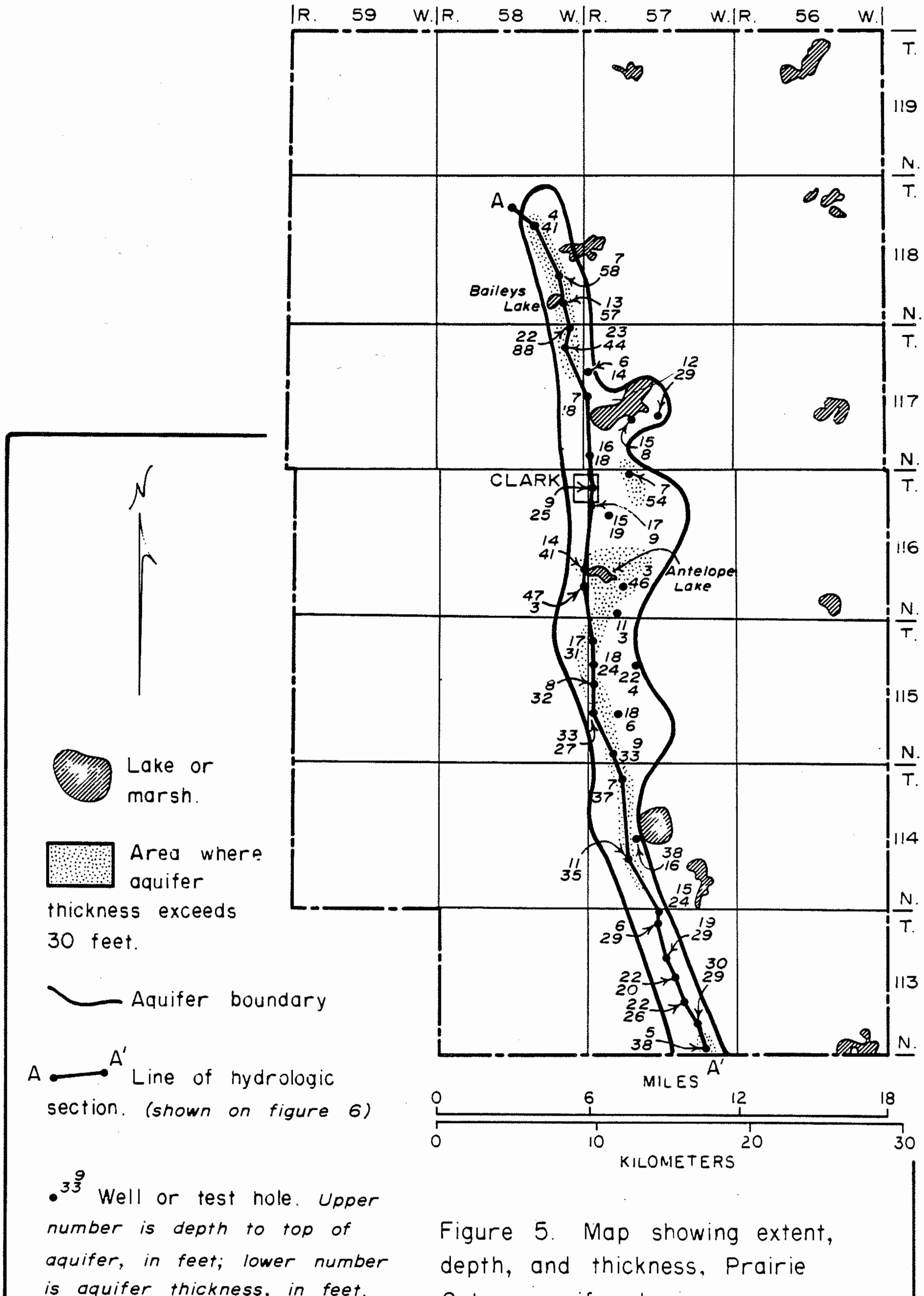


Figure 5. Map showing extent, depth, and thickness, Prairie Coteau aquifer I.

aquifer in the county, occurring within 30 feet of the land surface at most places. The aquifer is composed of glacial outwash consisting of fine to coarse sand and gravel that was deposited in a broad valley cut into stagnant ice and till by meltwaters which flowed southward from an ice-front located in the northern part of the county (Christensen, in preparation). The meltwater streams shifted frequently as their channels became blocked locally by outwash deposits. Consequently, although there are large areas where the thickness of the aquifer exceeds 30 feet, the outwash is distributed irregularly across the valley and is absent locally. The maximum thickness is 88 feet in well 117N58W1BAAA, but the aquifer there is composed mostly of fine, silty, clayey sand that will not yield water as readily as does clean sand and gravel.

Irregularities in thickness are partly the result of deposition of outwash on the irregular erosional surface of the underlying till. The hydrologic section is drawn through areas where the thickness of the aquifer generally is greater than average (fig. 6). At the time the test holes were drilled, the aquifer was partly unsaturated. Clay layers and the unsaturated material are not included in the thickness data in figure 5.

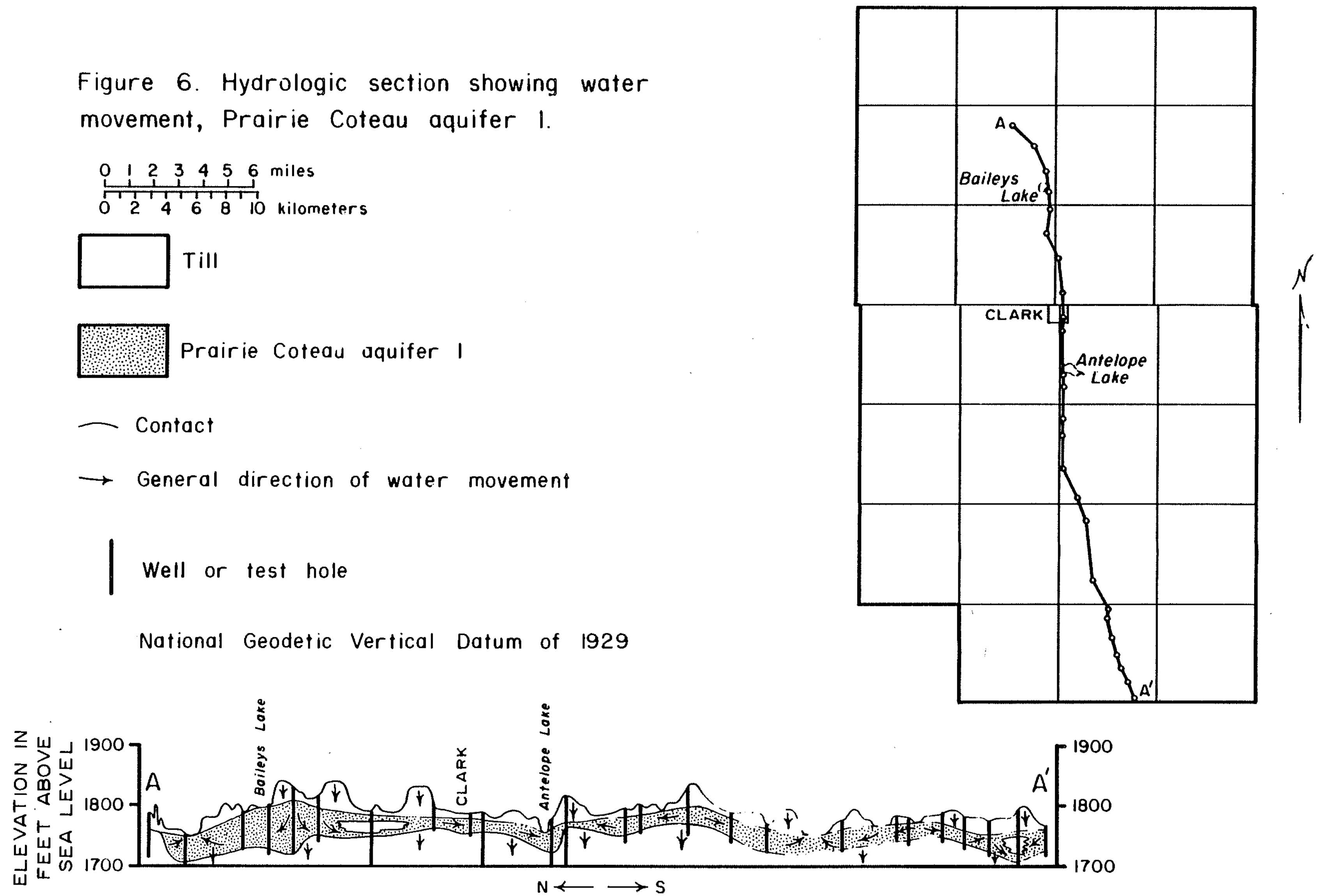
WATER MOVEMENT

Ground-water movement (fig. 6) is from recharge areas beneath hills to where the water discharges in marshes and lakes. There also is leakage downward from the aquifer into underlying till. The direction of movement is determined from water-level altitudes in 33 wells and test holes spaced at intervals of as much as 3 miles along the section. Some lakes, such as Baileys Lake, are recharge sources. Other lakes, such as Antelope Lake, are points of discharge from the ground-water system.

Horizontal components of ground-water movement can be shown on a potentiometric map (fig. 7). Ground water moves horizontally through Prairie Coteau aquifer 1, either eastward or westward, and discharges into till, marshes, and lakes. Water near the western edge of the aquifer moves west through till and discharges at seeps along the slope of the Coteau des Prairies. Locally, movement of water is more complex than is shown by the arrows in figure 7.

Recharge to the aquifer, from infiltration of precipitation and inflow from till adjacent to the aquifer, is estimated to be 16,000 acre-feet per year (table 1). This is equivalent to an average annual rate of 200 acre-feet per square mile, or about 3.8 inches, which is 18 percent of the average annual precipitation. Recharge is estimated to be at least double that of the other aquifers because in many areas the Prairie Coteau aquifer 1 is not covered by till and is quickly recharged by snowmelt and rain during the spring.

Figure 6. Hydrologic section showing water movement, Prairie Coteau aquifer I.



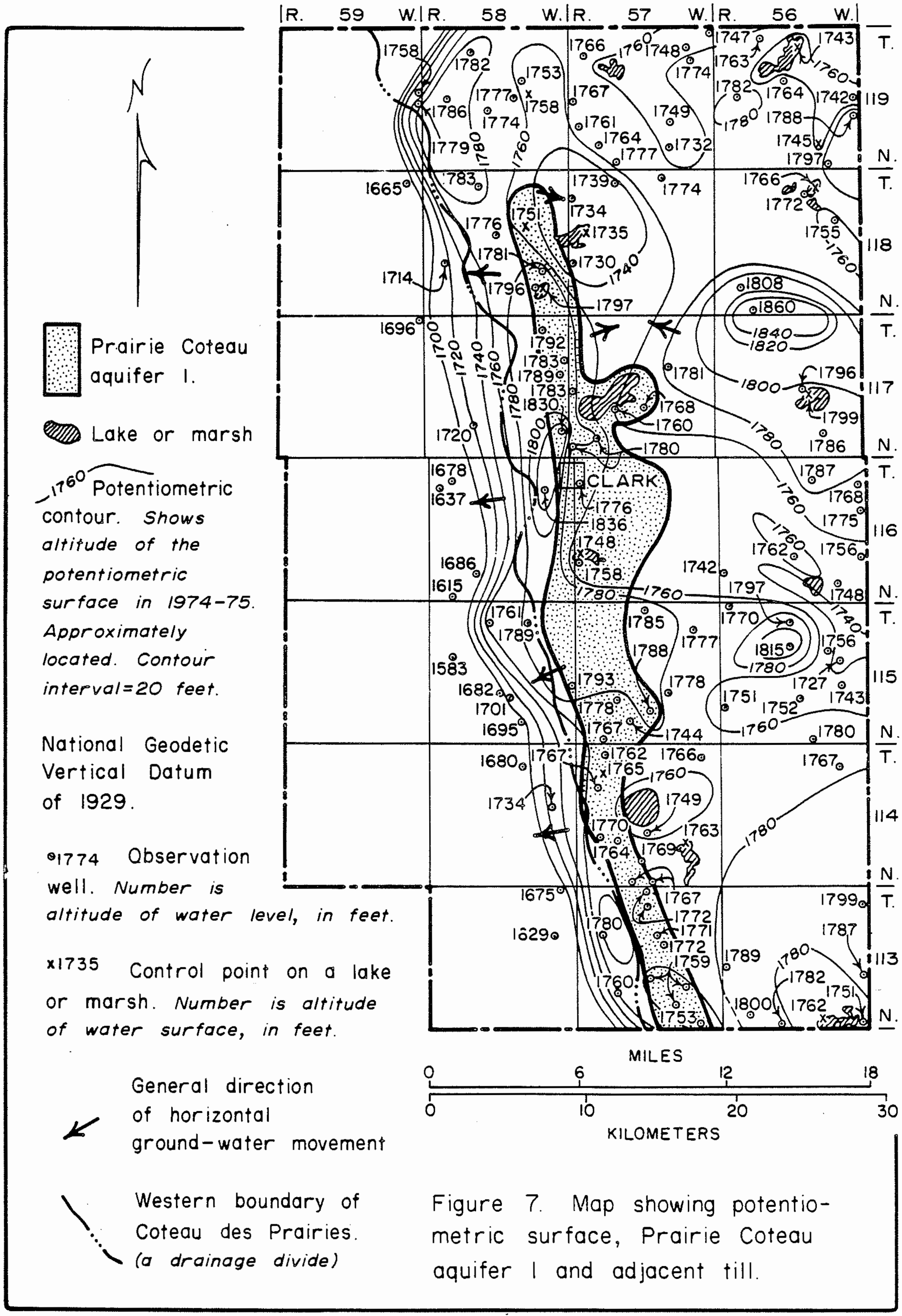


Figure 7. Map showing potentiometric surface, Prairie Coteau aquifer I and adjacent till.

WATER-LEVEL CHANGES

A large decline of the water level in a pumping well results in decreased yield and increased pumping cost. Such a decline may be caused by a decrease in recharge, increased pumping, interference between adjacent wells, or by deterioration of the well through clogging of the well screen by bacterial growth or mineral deposits.

The temporary decline of water levels in Prairie Coteau aquifer 1 during 1976 (fig. 8) was caused by decreased recharge and also by increased pumping by wells. Discharge from 14 large-capacity irrigation wells totaled an estimated 2,480 acre-feet during 1976. Water levels declined 5 to 10 feet during 1976 in areas totaling 6 square miles around these wells. Water levels began recovering after the wells stopped pumping.

Hydrographs of observation wells show both seasonal and long-term fluctuations in water levels (fig. 9). Seasonal fluctuations are caused by differences in recharge and discharge. Water levels rise in winter and spring, when pumpage decreases and recharge from subsurface inflow and infiltration of snowmelt and precipitation is greater than discharge. Water levels generally decline in the summer and fall when recharge decreases and discharge by evapotranspiration, pumpage, and subsurface outflow exceeds recharge.

The water-level decline of 10 feet at observation well 113N57W4ADAA during 1976 was caused by increased pumpage from 3 large-capacity wells, one a municipal well, located within 0.5 mile of the observation well. The water levels rapidly recovered 5.5 feet during the fall after pumping was stopped at the two irrigation wells. The decline in water level in another well, 116N56W3DDBD, was mainly the result of evapotranspiration and increased pumpage during the summer.

Long-term changes for observation well 113N57W4ADAA included a decline in the annual low water level from 11.5 feet during 1973 to 25.0 feet during 1976. This 13.5-foot decline was caused by decreased recharge and increased pumpage during the drought of 1973-76. The trend reversed when precipitation and recharge increased during 1977.

Prairie Coteau Aquifers 2 and 3

EXTENT AND COMPOSITION

Prairie Coteau aquifers 2 and 3 (table 1) occur in 2- to 3-mile-wide irregular bands with a combined area of 160 square miles (fig. 10). The depth to aquifer 2 locally varies greatly but the depth to Prairie Coteau aquifer 3 generally increases from west to east. Depths to aquifer 2 vary from 53 to 168 feet below land surface and those for aquifer 3 from 198 to 327 feet

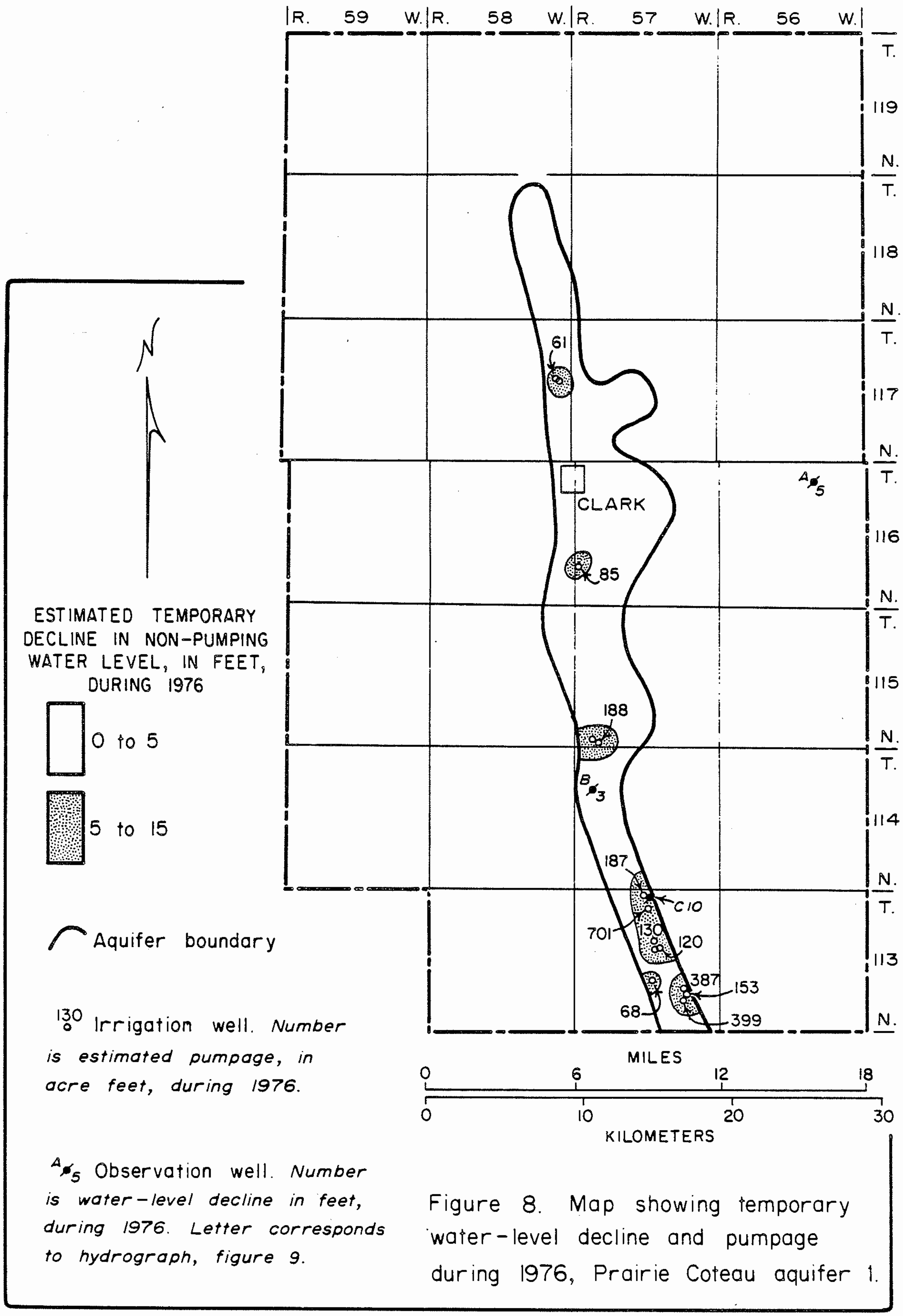


Figure 8. Map showing temporary water-level decline and pumpage during 1976, Prairie Coteau aquifer 1.

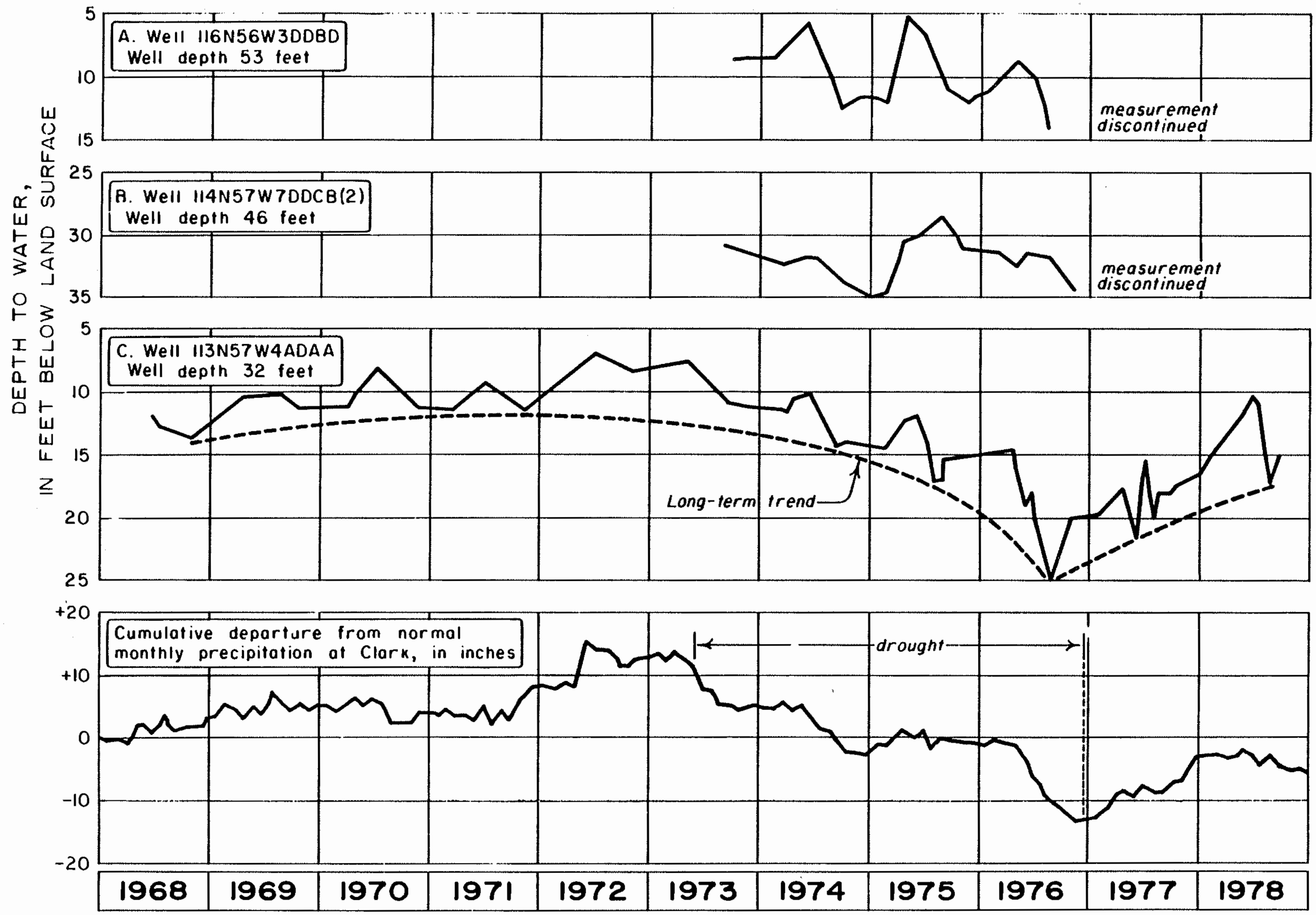


Figure 9. Hydrographs showing water-level changes, Prairie Coteau aquifer I.

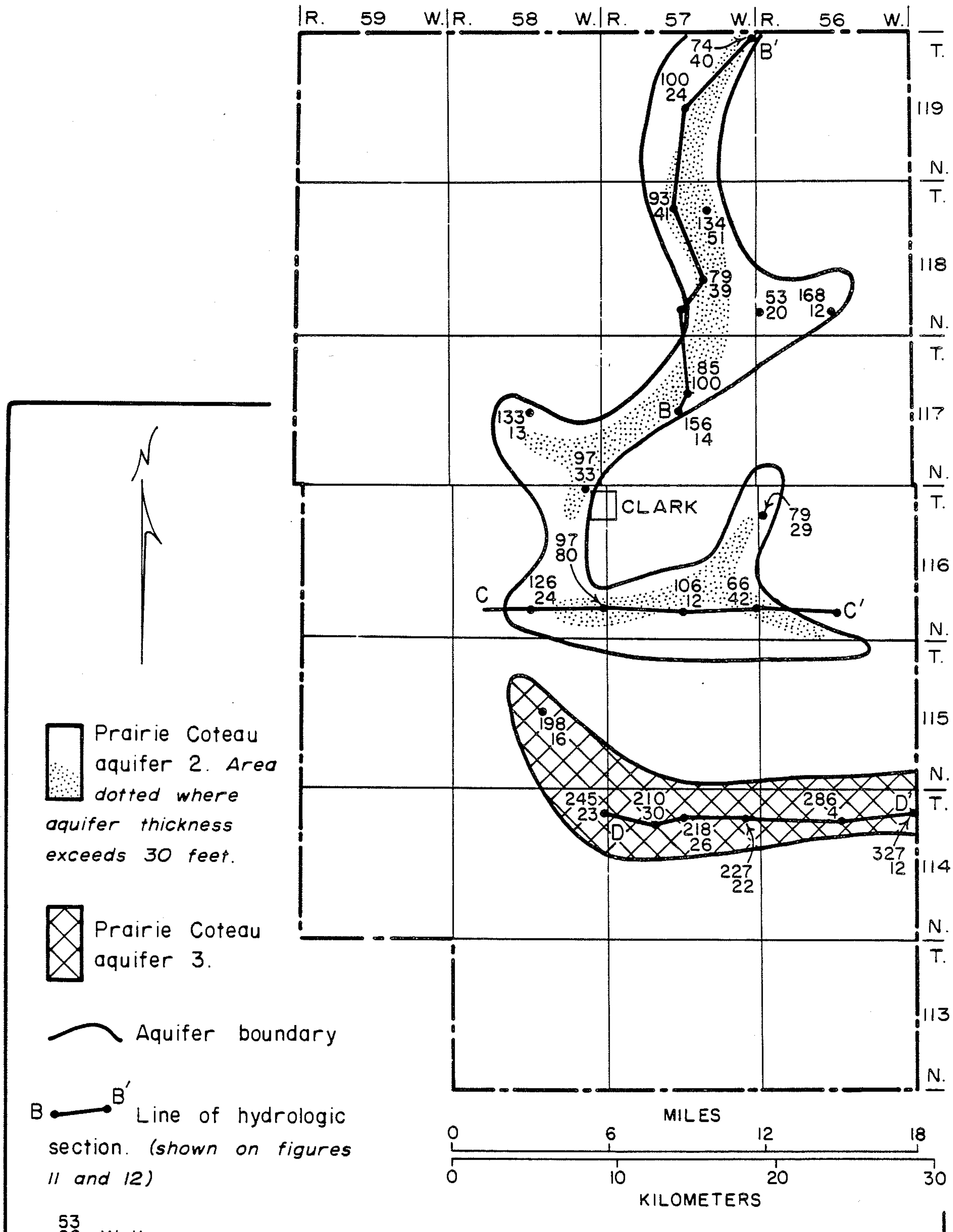


Figure 10. Map showing extent, depth, and thickness, Prairie Coteau aquifers 2 and 3.

below land surface (fig. 10). The aquifers are composed mostly of fine to very coarse, clayey sand and gravel deposited by many different meltwater streams. Prairie Coteau aquifer 3 does not yield as much as the other aquifers (table 1) because it contains much clay and its maximum thickness does not exceed 30 feet.

Prairie Coteau aquifer 2 (fig. 11) is composed of at least three separate units, each of which can have a thickness that exceeds 30 feet locally. Section C-C' shows that aquifer 2 is about 80 feet thick near the middle of the section but thins to less than 20 feet a few miles to the east. The difference in altitude between adjacent units is more than 100 feet in some places.

WATER MOVEMENT

Movement of ground water to Prairie Coteau aquifer 2 is mostly downward (fig. 11), in the direction of decreasing hydraulic head as determined from the altitudes of water levels in 14 wells. Recharge moves downward from the land surface to Prairie Coteau aquifer 3 and continues downward through the aquifer to underlying aquifers (fig. 12). Nearly-horizontal flow occurs where relatively impermeable shale blocks further downward flow. The direction of movement was determined from water-level altitudes in 10 wells.

The dominance of vertical over horizontal flow (figs. 11 and 12) is due to Clark County being a recharge area for a regional ground-water flow system. In such areas, hummocky surface terrane favors greater vertical flow from surface impoundments downward to the permeable basal aquifers (Freeze and Witherspoon, 1967). However, the large vertical exaggeration of the sections in this report mask horizontal flow components that are better shown by potentiometric maps.

Movement of water horizontally in Prairie Coteau aquifer 2 is in several directions but eventually some of the water moves west or south (fig. 13); some also moves down to underlying aquifers. The closed 1,700-foot contour along the west side of the aquifer (T. 117 N., 118 N.) indicates that discharge in that area is into underlying aquifers. At the southwest end of aquifer 2 and in aquifer 3 most of the water also moves downward although there is some horizontal flow westward into till.

Recharge to both aquifers is from infiltrating precipitation and lateral inflow from till. Annual recharge is estimated at 11,000 acre-feet for Prairie Coteau aquifer 2 and 5,000 acre-feet for Prairie Coteau aquifer 3 (table 1).

WATER-LEVEL CHANGES

Seasonal and long-term water-level changes in wells in Prairie Coteau aquifers 2 and 3 are small because there is relatively

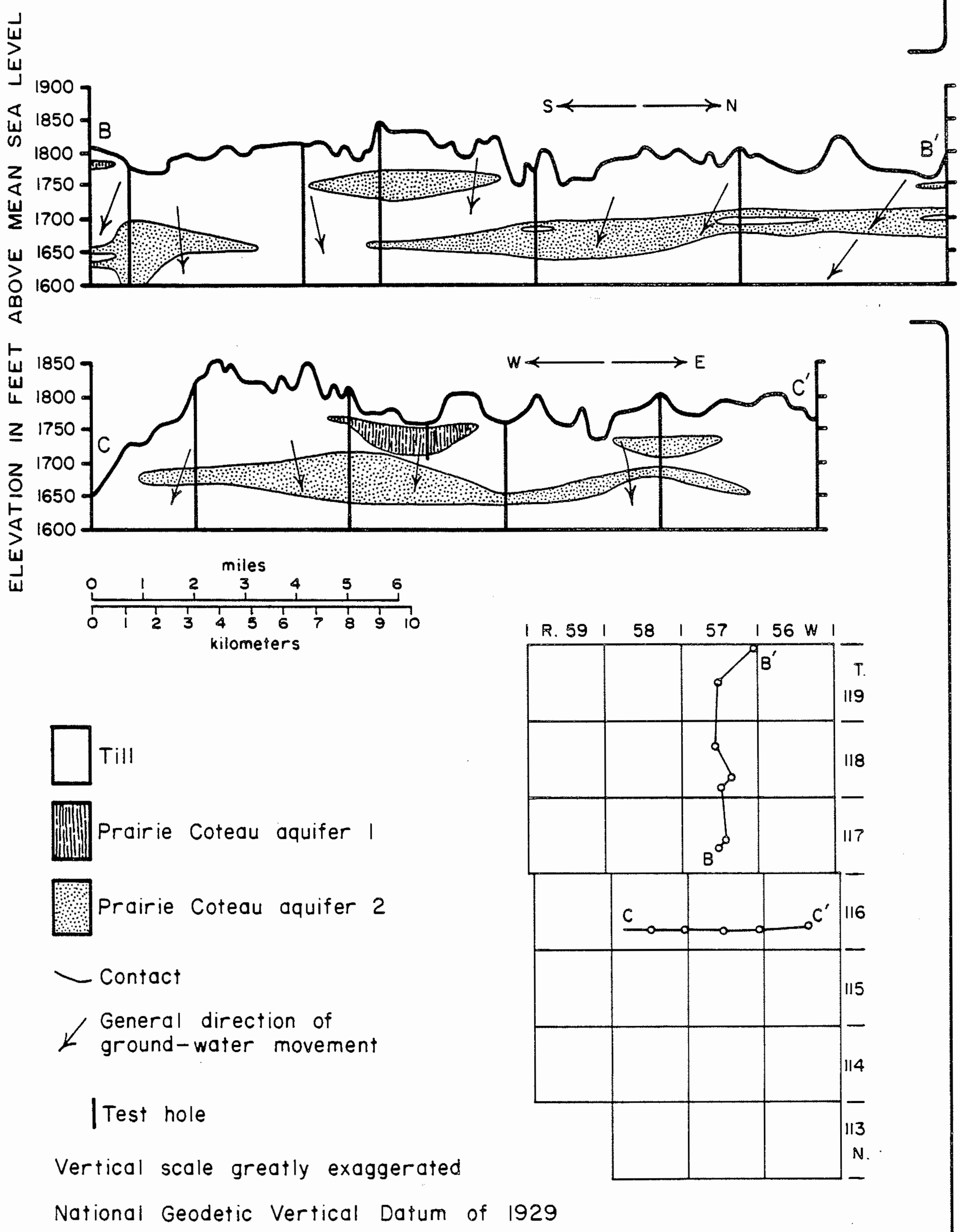


Figure 11. Hydrologic sections showing water movement, Prairie Coteau aquifer 2.

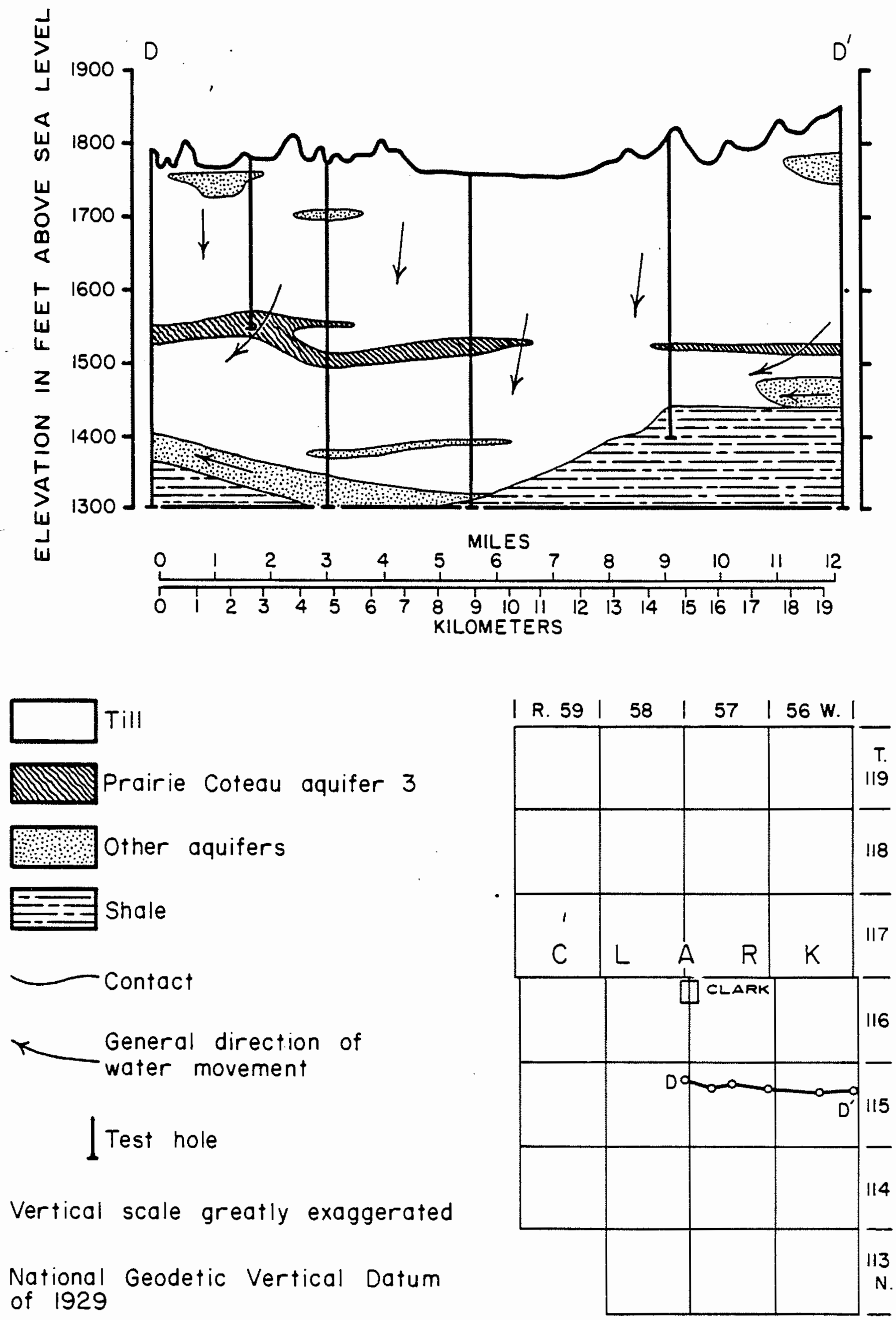
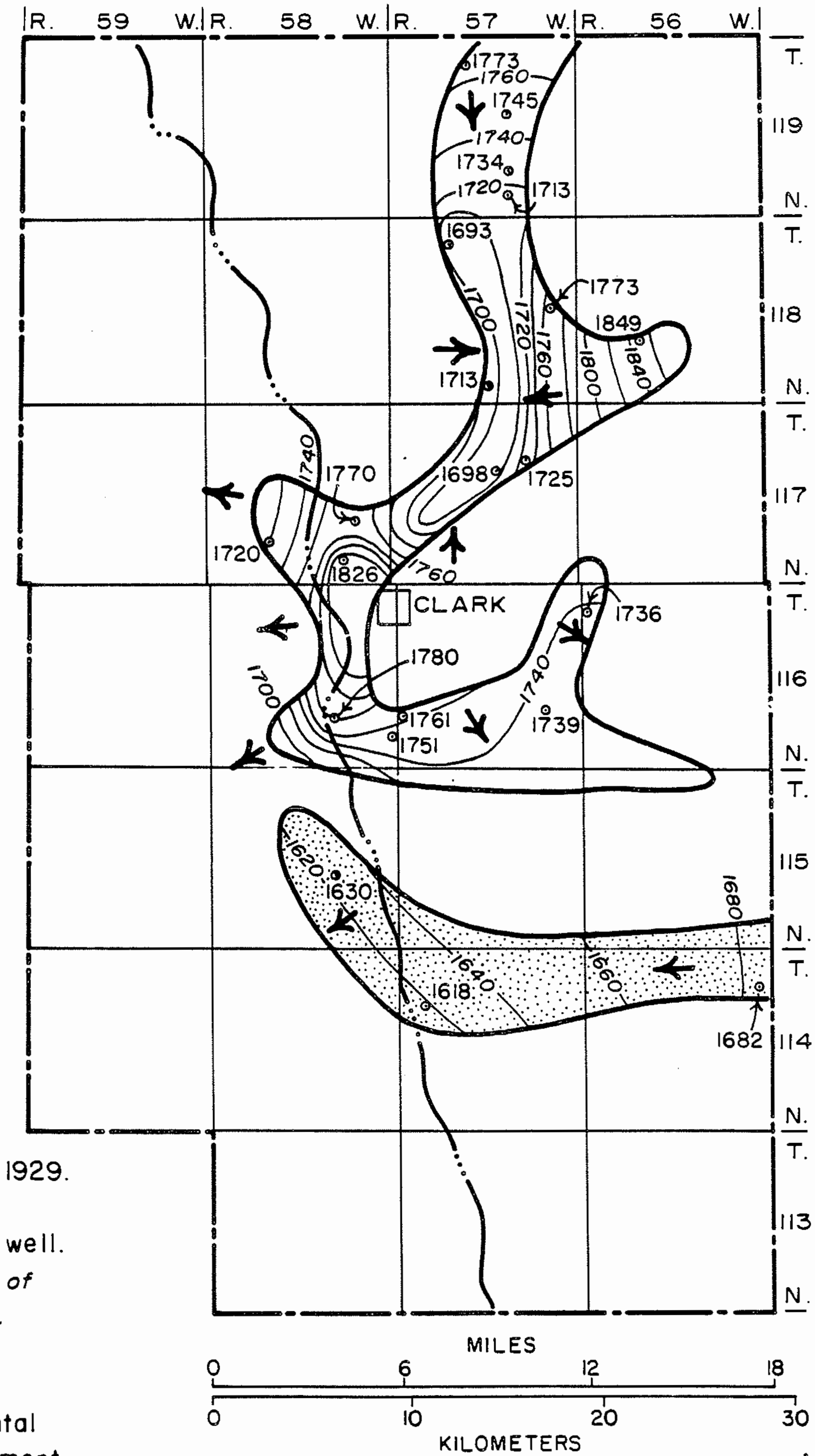


Figure 12. Hydrologic section showing water movement, Prairie Coteau aquifer 3.



Aquifer boundary

Prairie coteau aquifer 2.

Prairie coteau aquifer 3.

1740
1720

Potentiometric contour. *Shows altitude of the potentiometric surface during 1974–1975. Approximately located. Contour interval=20 feet.*

National Geodetic Vertical Datum of 1929.

⊙1773 Observation well. *Number is altitude of water level, in feet.*

General direction of horizontal ground-water movement.

Western boundary of the Coteau des Prairies. *(a drainage divide).*

Figure 13. Map showing potentiometric surfaces, Prairie Coteau aquifers 2 and 3.

little pumpage from either aquifer (fig. 14). Seasonal changes were caused by a temporary increase in the rate of recharge (snowmelt) during the spring. The lower hydrograph shows effects of pumping the well for domestic and stock needs during May and August 1974 and November 1976, but the effects were limited to a small area near the well. Long-term changes in water levels consisted of declines of about 1 foot in annual water-level peaks from 1974 to 1976 during the 3-year drought.

Altamont Aquifer 1

EXTENT AND COMPOSITION

Altamont aquifer 1, underlying 180 square miles, extends 15 to 20 miles east-west and 12 miles north-south (fig. 15). The aquifer is 70 feet below land surface at its western edge and as much as 372 feet deep on the Coteau des Prairies to the east.

The thickness of the aquifer is variable, averaging 30 feet and attaining a maximum of 56 feet at well 116N58W25DDDD.

The relatively thick west-central part of the aquifer is silty, fine to coarse sand whereas the thinner eastern part is medium to very coarse sand and gravel. The aquifer has a nearly level, gently-undulating top, changing in altitude by no more than 20 feet between test holes 3 miles apart.

WATER MOVEMENT

Recharge is by infiltrating precipitation and lateral inflow (fig. 16). Subsequently, water flows westward through the aquifer and discharges through seeps and flowing wells in R. 59 W. Some water moves downward into Altamont aquifer 2, especially in T. 116 N., R. 58 W., where aquifers 1 and 2 are connected. The direction of movement is based on the altitudes of water levels in 16 wells.

The principal horizontal component of water movement in Altamont aquifer 1 is southwestward (fig. 17). The steep gradient near the southern end of the aquifer indicates either that the aquifer is less permeable in the south or that more water is moving through the southern than the northern end. If the latter condition is true, there is much recharge in the central part of the aquifer. Such recharge could come from Antelope Lake and numerous semi-permanent marshes that occur within a 5-mile radius of the lake.

Average annual recharge is estimated at 50 acre-feet per square mile, or about 9,000 acre-feet for the 180-square mile area of the aquifer (table 1). Most discharge is by seepage to underlying aquifers. Pumpage was only about 370 acre-feet during 1976.

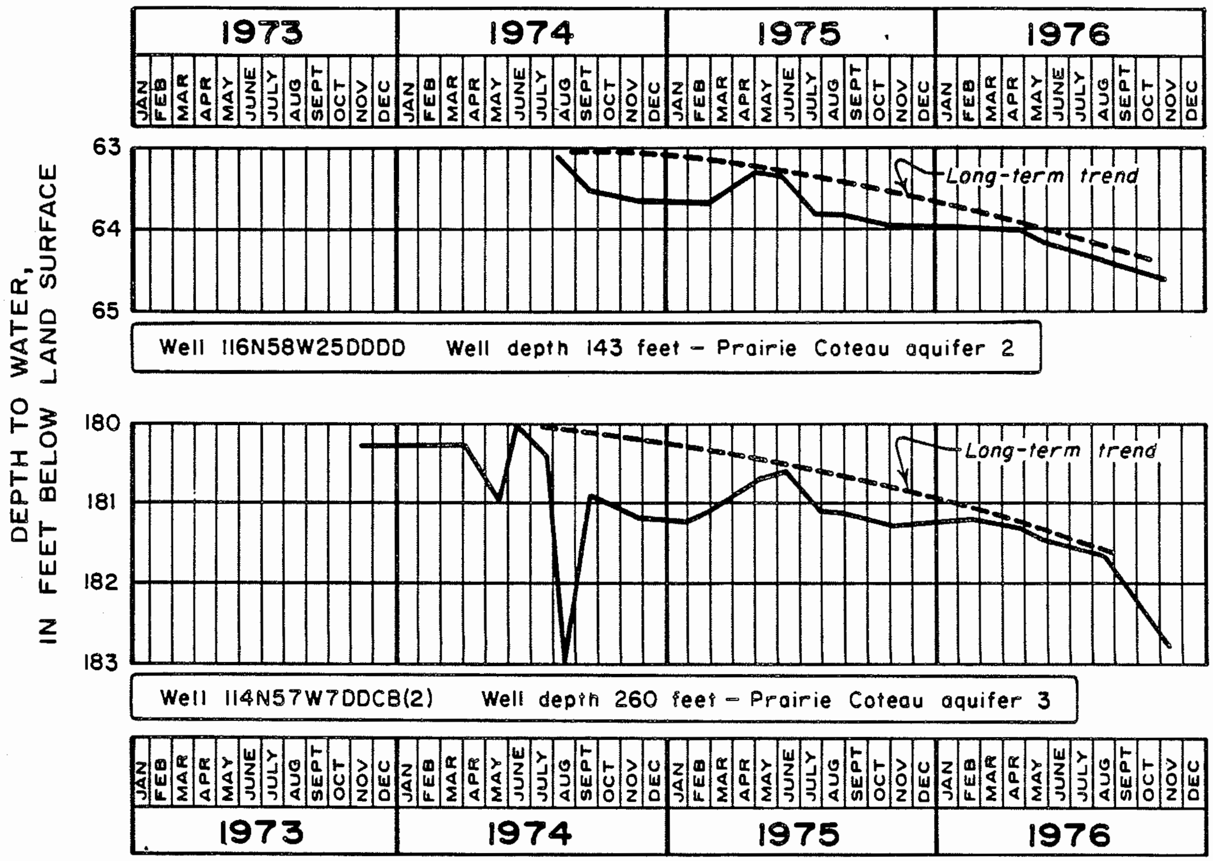
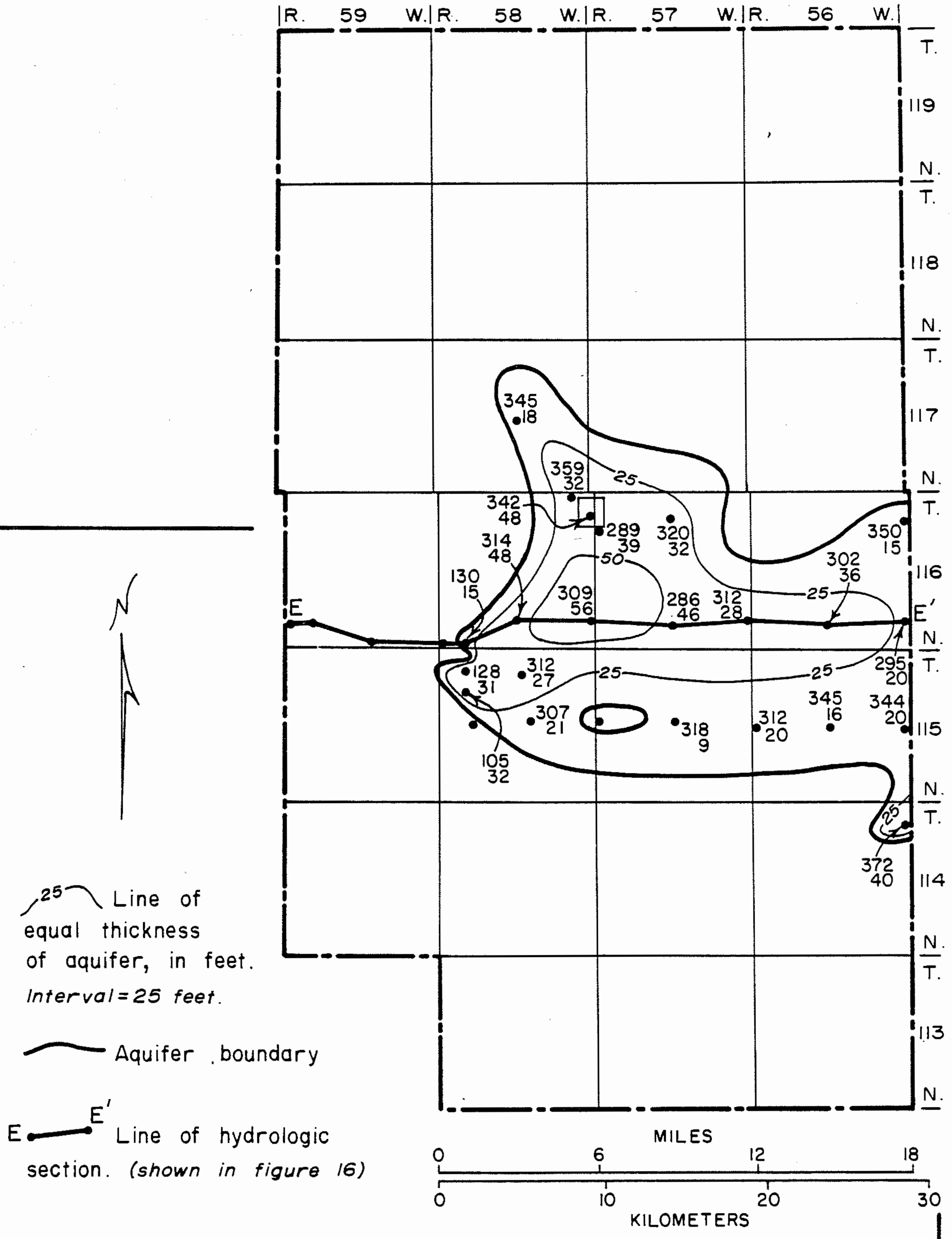


Figure 14. Hydrographs showing water level changes, Prairie Coteau aquifers 2 and 3.



25 Line of equal thickness of aquifer, in feet. *Interval=25 feet.*

Aquifer boundary

E—E' Line of hydrologic section. *(shown in figure 16)*

•289 39 Well or test hole. *Upper number is depth to top of aquifer, in feet; lower number is aquifer thickness, in feet.*

Figure 15. Map showing extent, depth, and thickness, Altamont aquifer I.

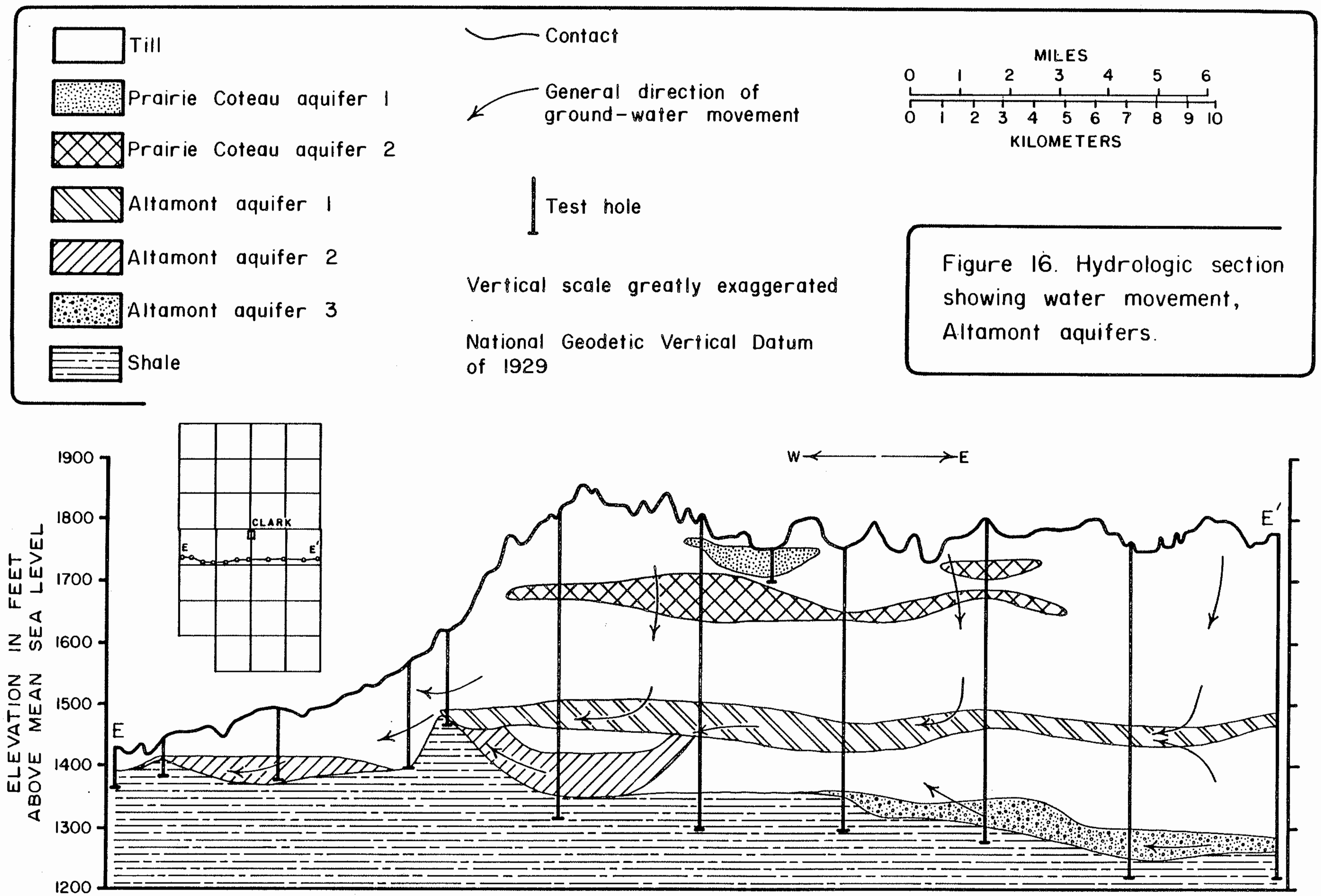


Figure 16. Hydrologic section showing water movement, Altamont aquifers.

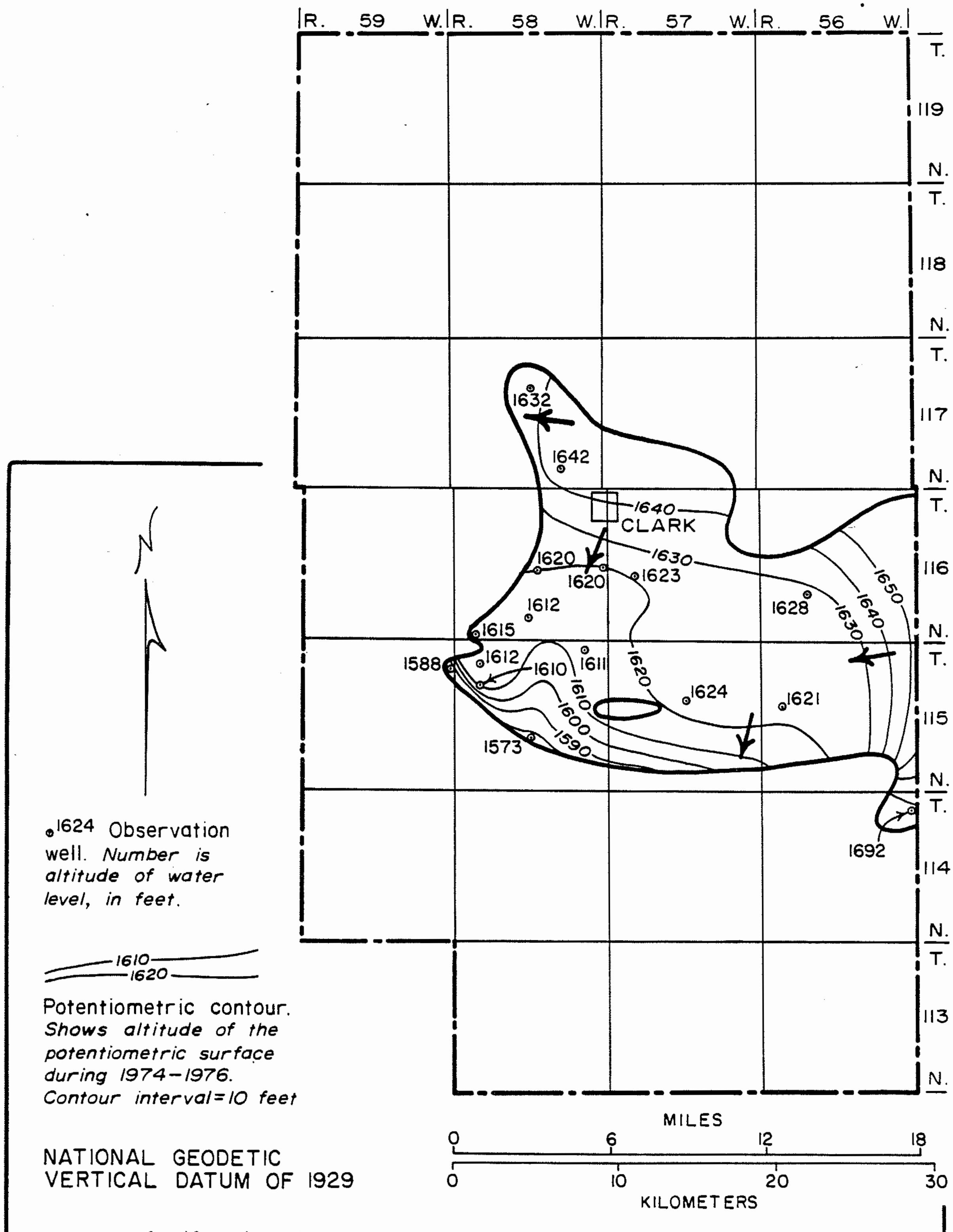


Figure 17. Map showing the potentiometric surface, Altamont aquifer 1.

WATER-LEVEL CHANGES

Water-level declines during 1976 for Altamont aquifer 1 are shown in figure 18. The declines were caused by decreased recharge during the drought but mostly by increased well withdrawals. The map shows that water levels declined more than 10 feet in a 28-square mile area in the southwestern part of the aquifer. This decline was caused by an estimated discharge of 430 acre-feet in 1976 from three irrigation wells and one flowing stock well. A table of theoretical drawdowns also is shown in figure 18. Drawdowns can exceed the aquifer thickness because they are mostly within the height of the non-pumping water level above the top of the aquifer. The data, based on a 6-month recovery test for the irrigation wells, show that drawdowns of 30 feet at a distance of 10,000 feet and 40 feet at a distance of 5,000 feet can be expected from a well pumping 1,000 gallons per minute continuously for 100 days. The map shows that drawdowns were larger than the theoretical values east and north of the pumped wells, even though the total pumping was at an average rate of nearly 1,000 gallons per minute during a 90-day irrigation season.

The difference between observed and theoretical drawdowns probably was due to the relatively impermeable till of the aquifer boundaries, resulting in an increase in drawdown eastward from the pumping wells. Drawdowns will be greatest where new wells are located near aquifer boundaries. However, the drawdown could be smaller than anticipated if recharge increases greatly after the drought.

There is a possibility of partly dewatering an aquifer close to a pumping well. The table of theoretical drawdown (fig. 18) indicates a drawdown of 109 feet at a distance of 100 feet from the pumping well after 1 year of pumping at the rate of 1,000 gallons per minute. However, significant dewatering would not extend more than a few hundred feet from the pumping well, partly because the rate and magnitude of water-level declines decrease greatly as artesian conditions become water-table conditions in large areas of the aquifer.

Seasonal fluctuations of the water level in observation well 115N58W6DDDD (hydrograph A, fig. 19) are characterized by a sharp decline during late spring when irrigation starts, and a rapid recovery of the water level during the fall. During 1976, the water-level decline was about 53 feet in well 115N58W6DDDD, located about 2,000 feet northeast of one irrigation well and 4,000 feet north of two other irrigation wells (fig. 18). The water-level decline in well 115N58W21DDCD, located about 3 miles southeast of the irrigation wells, was only about 3 feet (hydrograph B, fig. 19).

Long-term water-level changes consisted of a gradual decline in the annual highest water-level during 1975-77, totaling about 8 feet in well 115N58W6DDDD. This trend was consistent with the increased pumpage and decreased recharge during the 1973-76

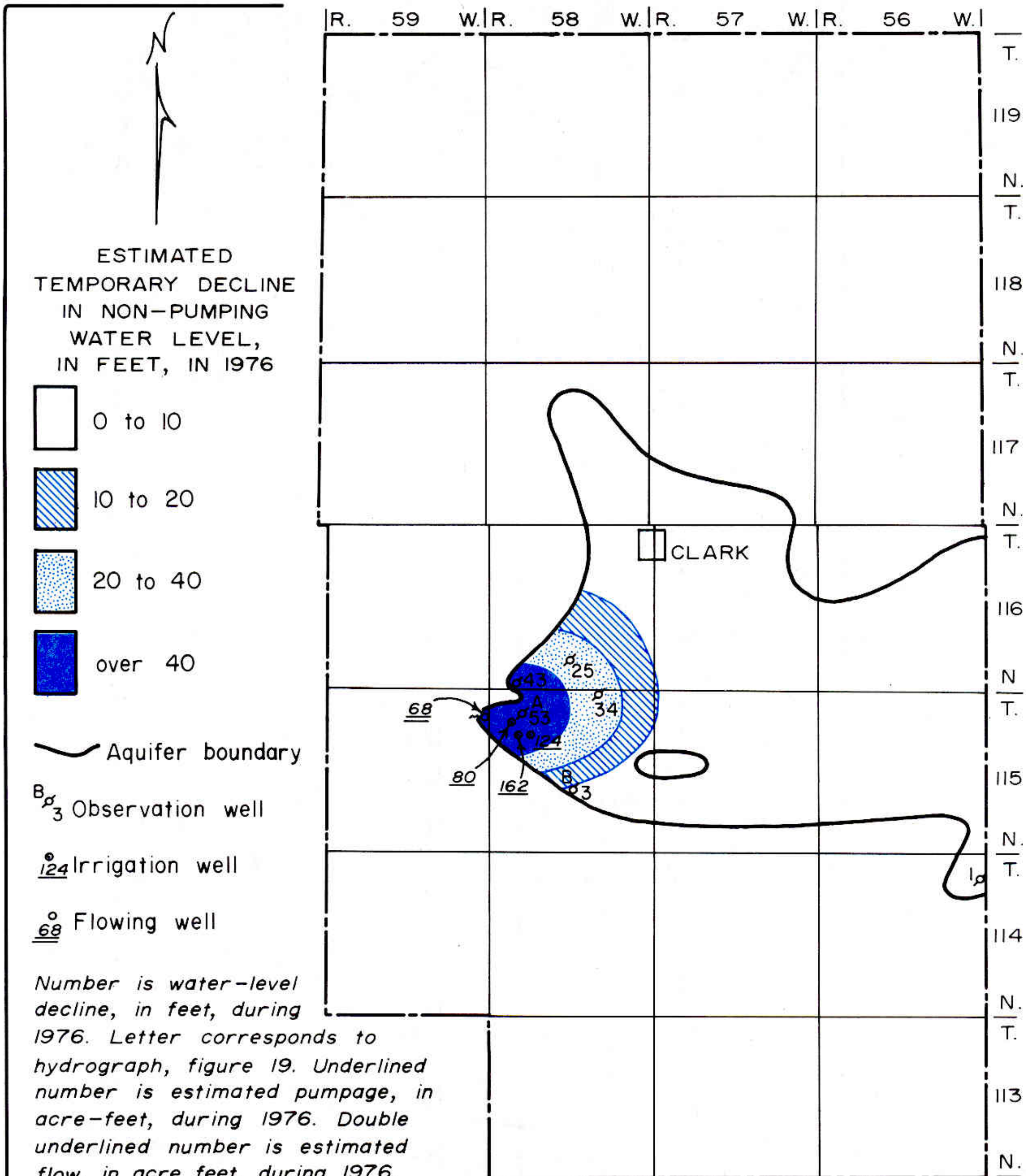


Figure 18. Map and table showing temporary water-level decline and pumpage during 1976, Altamont aquifer 1.

Table-- Theoretical drawdown, in feet, at various distances from a well pumping continuously at 1,000 gallons per minute from Altamont aquifer 1; eight miles southwest of Clark, South Dakota. Transmissivity = 15,000 gallons per day per foot; storage coefficient = 0.0001.

Distance from pumping well, in feet	100	300	500	700	1,000	5,000	10,000
Time since pumping started	Drawdown, in feet						
One day	65	48	40	36	30	7	1
Ten days	82	72	57	52	47	23	13
One hundred days	100	83	75	71	65	40	30
One year	109	92	85	79	74	49	39

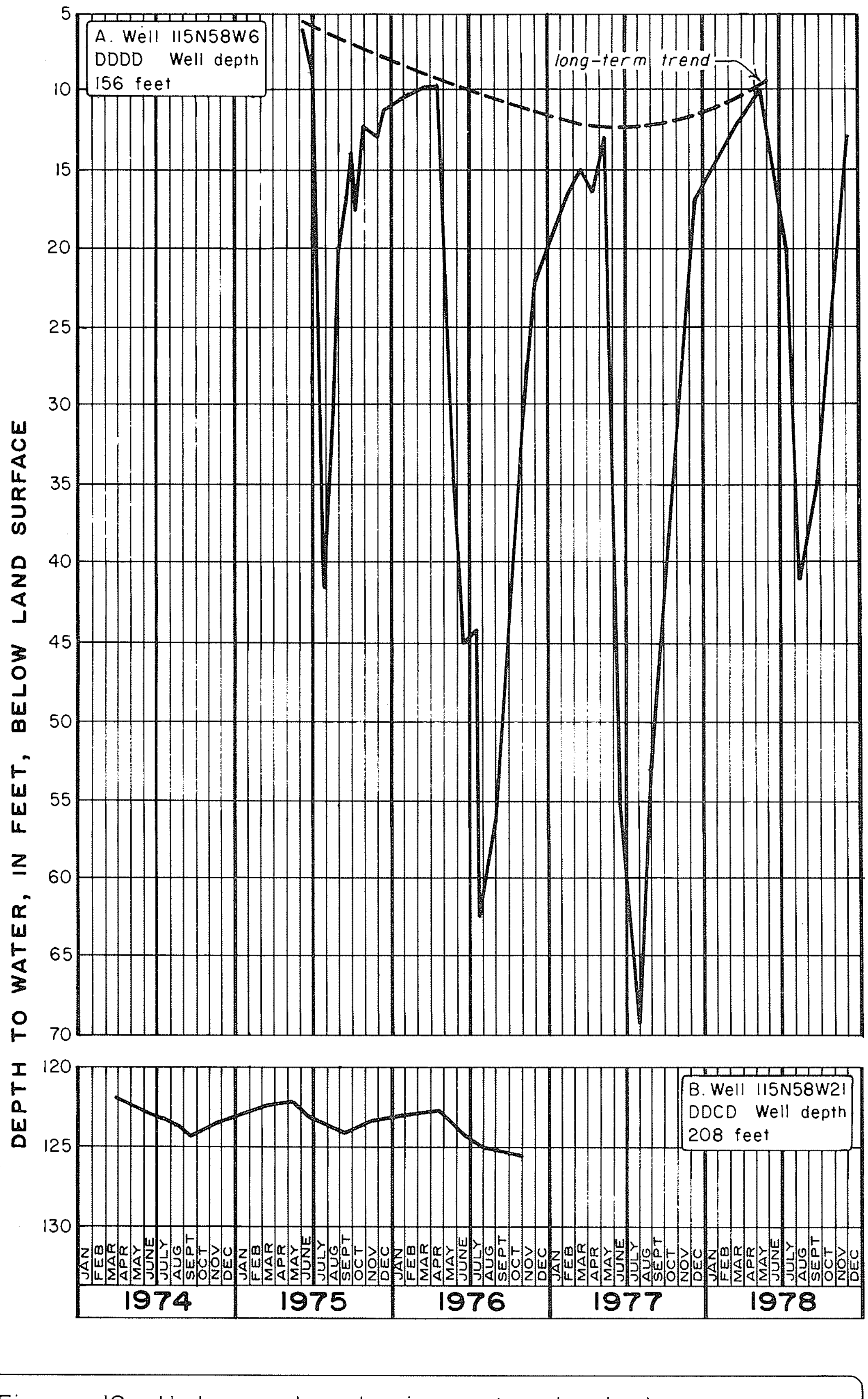


Figure 19. Hydrographs showing water level changes, Altamont aquifer 1.

drought. Apparently a gradual reversal of this trend began during 1978, when precipitation and recharge increased.

Altamont Aquifer 2

EXTENT AND COMPOSITION

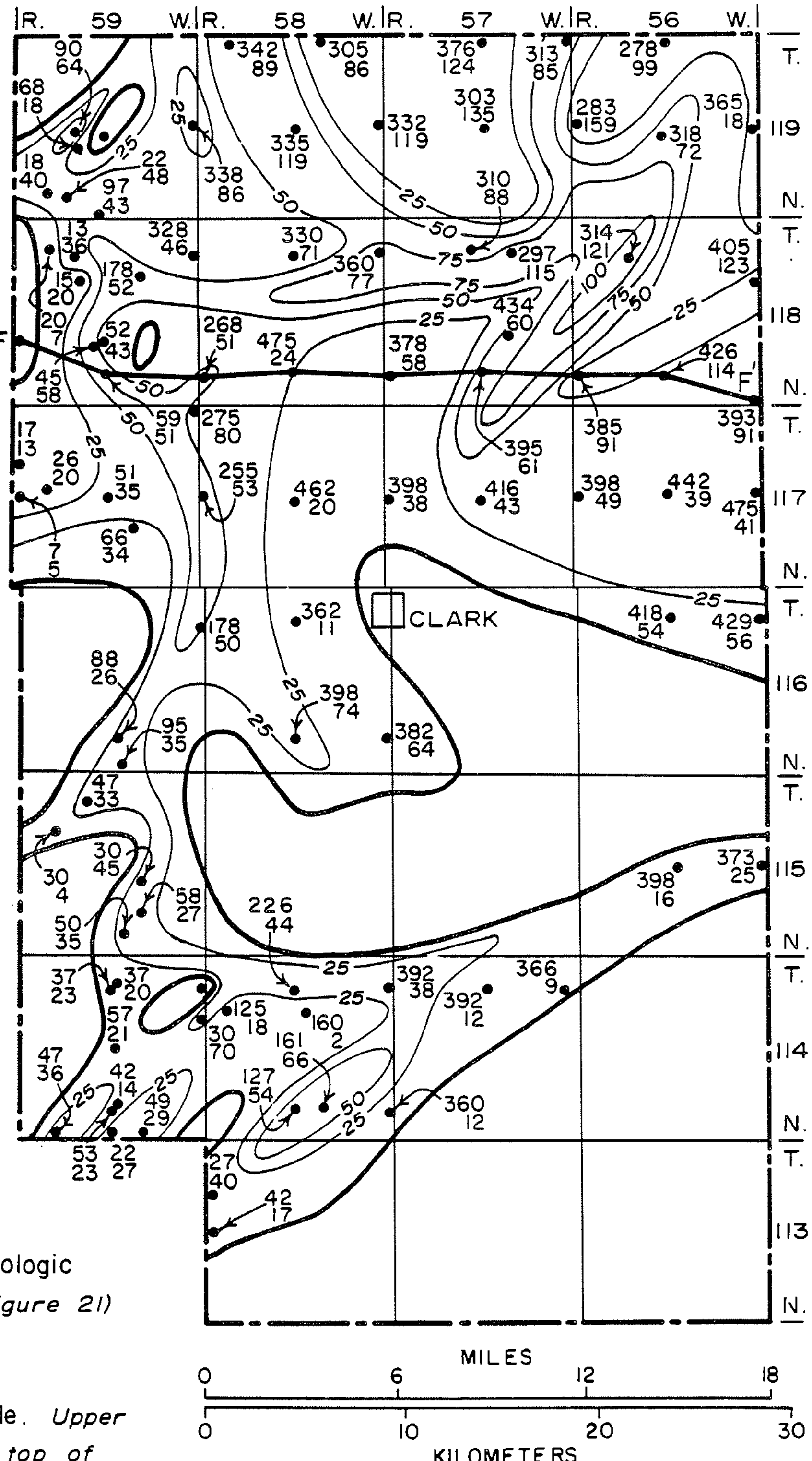
Altamont aquifer 2 underlies 630 square miles and extends through most of the northern one-half of the county (fig. 20). Depths to the aquifer range from about 10 feet in the west to between 300 and 480 feet on the Coteau des Prairies. Structurally, the top of the aquifer is gently-undulating, generally changing in altitude less than 30 feet between test holes 3 miles apart. The aquifer decreases in altitude southward in the northern part of the county. In its central and southernmost parts, the aquifer slopes generally eastward.

Altamont aquifer 2 consists of fine to very coarse sand and gravel and sandy silt. The entire thickness of the aquifer is given by the lower number beside each well or test hole (fig. 20). The sand and gravel part has an average thickness of about 30 feet and a maximum thickness of 121 feet in test hole 118N56W8AAAA. The thickest sand and gravel occurs in outwash channels that may be at least 1 mile wide. The material in channels in T. 118 N., R. 56 W. and T. 118 N., R. 57 W. has been deposited respectively from southwestward- and westward-flowing meltwater streams. The closing of the southwest-trending 50-foot-thickness lines in T. 117 N., R. 57 W. indicates that any outwash deposits of similar thickness to the southwest were removed by glacial scour or meltwater erosion. A similar explanation may account for the termination of the thick channel deposit in the southeast part of T. 114 N., R. 58 W.

In many areas of the northeastern part of the county, outside of the outwash channel deposits, the aquifer is composed primarily of gravelly till or fine, silty sand. The sand, which appears to be outwash (Christensen, in preparation), has an average thickness of about 80 feet. The maximum thickness of the aquifer is 159 feet in well 119N56W18CCCC (fig. 20). The driller's log at this site described the aquifer as a light gray, sandy silt so there probably is no more than 25 feet of sand beds in the entire thickness.

WATER MOVEMENT

Recharge is by infiltration of precipitation and lateral inflow (fig. 21). Subsequent movement of water in the aquifer is nearly horizontal because the underlying shale is relatively impermeable. The movement is determined from water-level altitudes in 17 wells. Large differences of water-level altitudes for several adjacent wells completed in the aquifer indicated that much of the movement is southward from the plane of the



—25— —50— Line of equal thickness of saturated sand and gravel. Interval 25 feet.

Aquifer boundary

F ●—● F' Line of hydrologic section. *(shown in figure 21)*

398 ● 38 Well or test hole. *Upper number is depth to top of aquifer, in feet; lower number is aquifer thickness, in feet. (total thickness includes clay and silt beds that are saturated but yield water slowly).*

Figure 20. Map showing extent, depth, and thickness, Altamont aquifer 2.

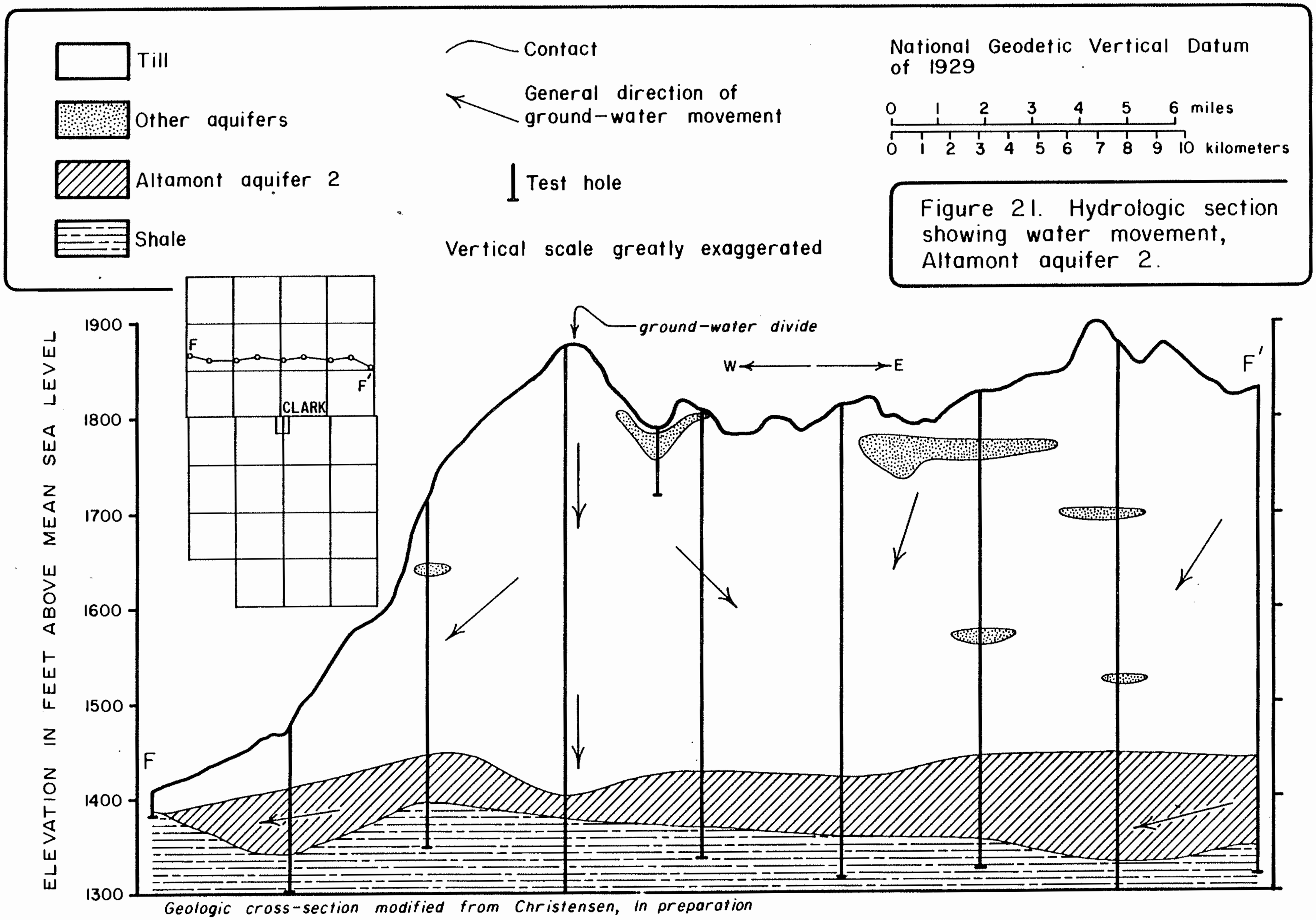


Figure 21. Hydrologic section showing water movement, Altamont aquifer 2.

section. The aquifer is hydraulically connected with Altamont aquifer 1 near the center of the county (fig. 16) and with Altamont aquifer 3 in the western part of the county (fig. 27).

Water moves in several directions in the northeastern part of Altamont aquifer 2 but in general the flow is westward (fig. 22). Some water moves westward into Spink County and some southwestward into Beadle County.

The potentiometric surface, as mapped, has a low point 1,595 feet above the National Geodetic Vertical datum (mean sea level) at well 118N57W35BBAA, which is 414 feet deep. The water level in the well is about 200 feet below land surface as reported both by the owner and the well driller. This low point occurs within an inferred deep, narrow trough in the potentiometric surface that coincides with a 50-foot thick, very permeable channel of outwash deposits (fig. 20). The inferred trough has not been completely mapped because the water-level data are inadequate.

Recharge is estimated to be about 80 acre-feet per square mile, totaling about 54,000 acre-feet annually for the 630-square mile area of aquifer 2 (table 1) and the additional 40 square miles underlain only by aquifer 3.

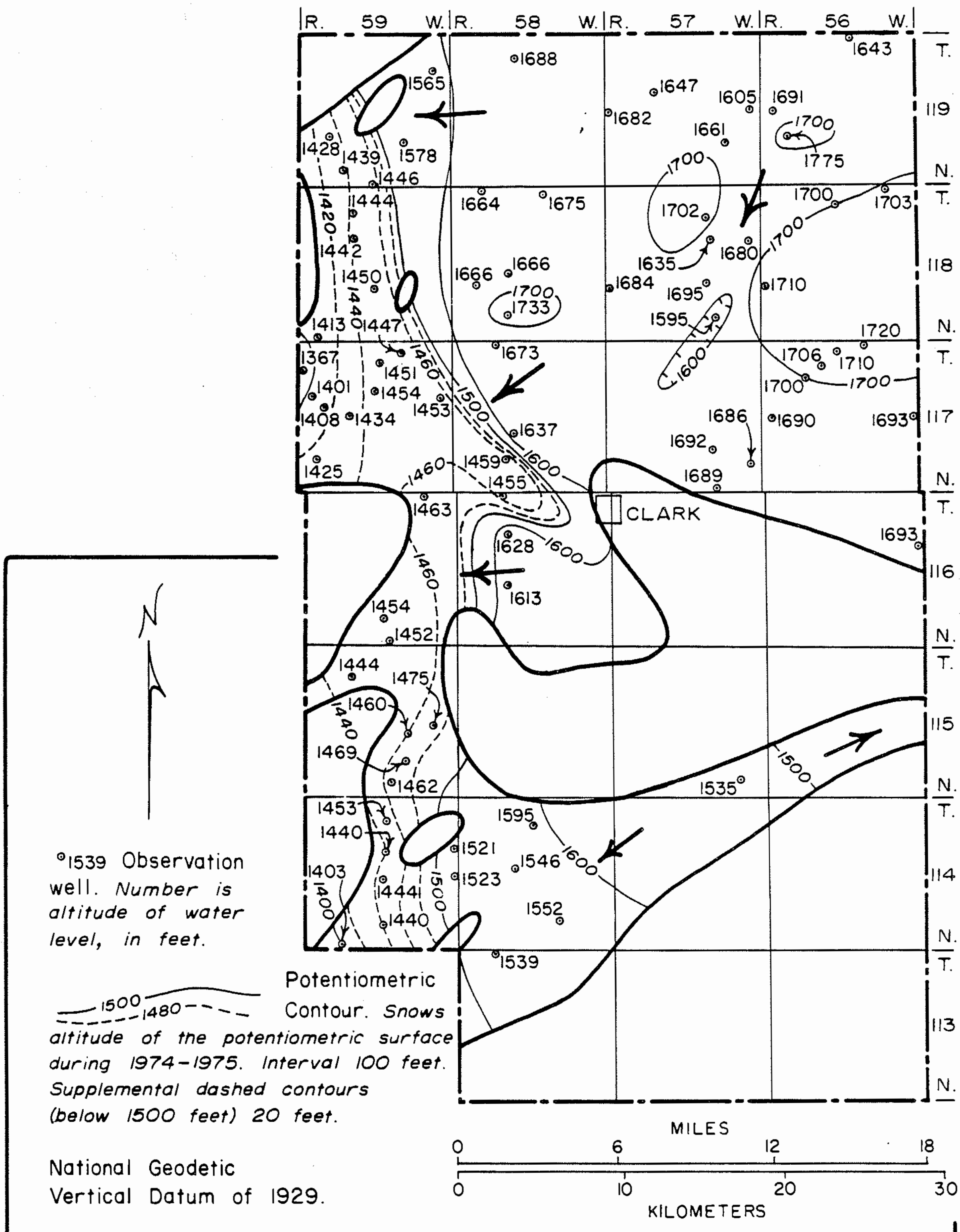
Discharge is by pumpage and by underflow out of the county. Pumpage from irrigation wells was estimated to total 1,230 acre-feet during 1976, about 2 percent of the total discharge. About 53,000 acre-feet probably moves westward annually from the county where it discharges by evapotranspiration and streamflow in large areas of Spink County.

TRANSMISSIVITY AND WELL YIELDS

Although potential well yields may be estimated directly from the thickness of saturated sand and gravel in an aquifer, it is difficult to estimate the amount of drawdown that will occur near a pumping well or the area that the well will affect without knowing the transmissivity of the aquifer.

The estimated transmissivity of Altamont aquifer 2 is 50,000 (gallons per day) per foot or more in about 200 square miles of Clark County (fig. 23). In these areas, the thickness of sand and gravel exceeds 25 feet and a well having a potential yield of 500 gallons per minute can be constructed.

The map showing the estimated transmissivity of the aquifer was constructed by multiplying the thickness of various aquifer units by an estimated value of hydraulic conductivity for the aquifer material. Values assigned are in agreement with those obtained in laboratory tests. (See Wenzel, 1942, p. 13.) For example the computations for test hole 119N59W32ABDC, penetrating Altamont aquifers 2 and 3, are as follows:



Aquifer boundary.

General direction of ground–water movement.

Figure 22. Map showing potentiometric surface, Altamont aquifer 2.

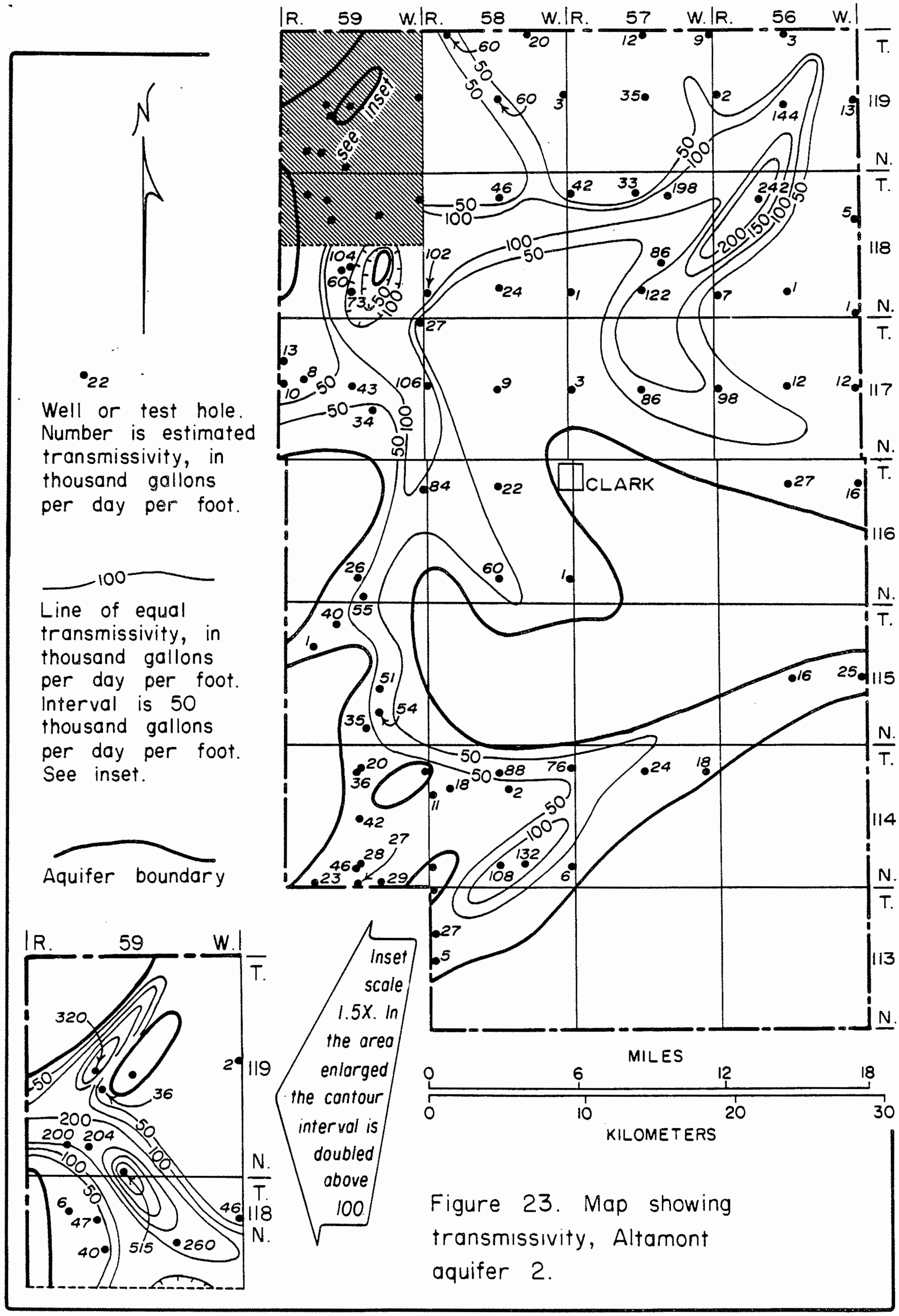


Figure 23. Map showing transmissivity, Altamont aquifer 2.

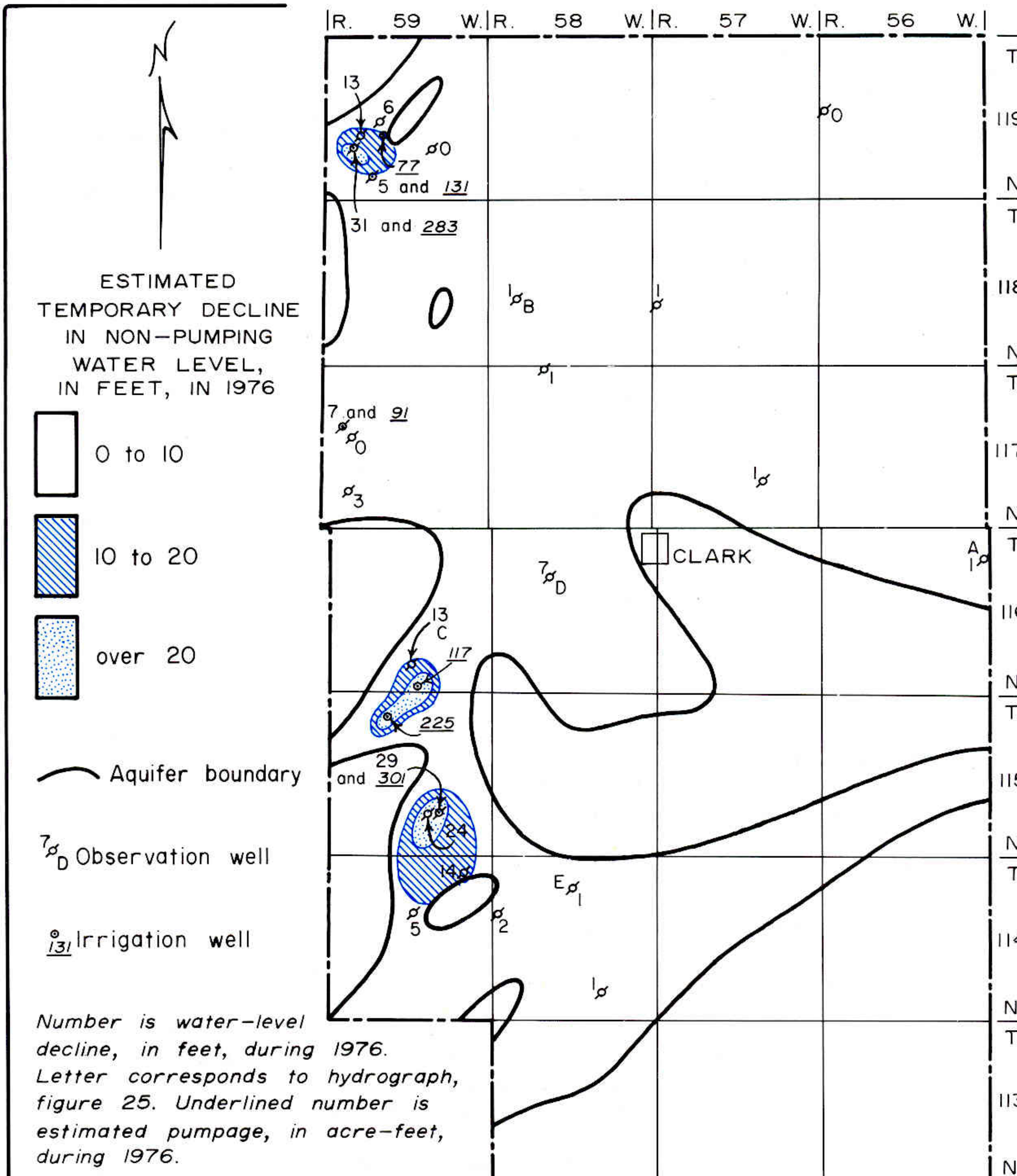
Rock Unit	Estimated hydraulic conductivity (gallon per day per square foot)	Thickness (foot)	Estimated transmissivity (gallon per day per foot)
Sand, fine	100	8	800
Sand, fine, and gravel	300	10	3,000
Sand, coarse, and gravel	5,000	30	150,000
Sand, coarse to medium, and gravel	2,000	10	20,000
Sand, coarse to medium	1,000	30	30,000
TOTAL		88	203,800

The estimated transmissivity of about 204,000 (gallons per day) per foot agrees closely with the transmissivity calculated from the drawdown of water level near the irrigation well at this site.

WATER-LEVEL CHANGES

Water levels for Altamont aquifer 2 declined more than 10 feet during 1976 at three locations with a total area of 18 square miles (fig. 24). These temporary water-level declines were partly caused by decreasing recharge during the drought but mostly by increased irrigation pumpage. Pumpage from six irrigation wells totaled an estimated 1,130 acre-feet during 1976.

A table of theoretical drawdowns (fig. 24), based on a 6-month recovery test for an irrigation well, shows that drawdowns of 19 feet at a distance of 10,000 feet and 24 feet at a distance of 5,000 feet can be expected from a well pumping 1,000 gallons per minute continuously for 100 days. Generally, drawdowns are within the height that the non-pumping water level is above the aquifer. The map shows that drawdowns were much smaller than predicted by the table, possibly because of increased recharge induced by the pumping. Also, in many areas the transmissivity, which is inversely proportional to drawdown, is much larger than 28,000 (gallons per day) per foot.



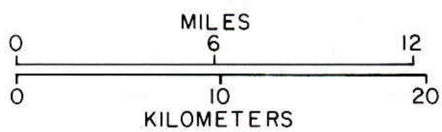


Figure 24. Map and table showing temporary water-level decline and pumpage during 1976, Altamont aquifer 2.

Table--Theoretical drawdown, in feet, at various distances from a well pumping continuously at 1,000 gallons per minute from Altamont aquifer 2; ten miles southwest of Clark, South Dakota. Transmissivity = 28,000 gallons per day per foot; storage coefficient = 0.0001.

Distance from pumping well, in feet	100	300	500	700	1,000	5,000	10,000
Time since pumping started	Drawdown, in feet						
One day	37	28	24	22	19	6	2
Ten days	46	37	33	30	27	15	9
One hundred days	56	47	43	40	37	24	19
One year	61	52	48	45	42	29	23

There is a possibility of partly dewatering an aquifer close to a pumping well. The drawdown table indicates a drawdown of as much as 61 feet at a distance of 100 feet from the pumping well after 1 year of pumping at the rate of 1,000 gallons per minute. However, significant dewatering would not extend more than a few hundred feet from the pumping well, especially where the aquifer can be expected to change from artesian to water-table conditions.

The maximum seasonal water-level fluctuation for five observation wells completed in Altamont aquifer 2 was 27 feet during 1977 in well 116N59W27CCCC (hydrograph C, fig. 25), located within 1 mile of an irrigation well. Drawdown in the observation well was larger during 1977 than in the previous 2 years because of increased pumping during the drought. Water levels in wells 116N58W8DAAD and 114N58W9AAAA (hydrographs D and E, fig. 25) also declined during the summer of 1976, probably due to increased pumpage from irrigation wells. The seasonal decline was 7 feet in well 116N58W8DAAD and 1.5 feet in well 114N58W9AAAA even though both wells were about 6 miles from the nearest irrigation well. Part of the difference in the amount of decline probably was due to increased pumping from the former well for domestic and livestock water. The 1-foot seasonal drawdown for well 116N56W13AAAD (hydrograph A, fig. 25) probably was due to increased pumping of the well during the summer for domestic needs and to increased pumping of the municipal wells at Henry, 1.5 miles away.

Long-term water-level changes consisted of a gradual decline in the annual peaks during 1974-79 because of reduced recharge and increased pumpage during the drought. The greatest long-term decline was about 7 feet in well 116N58W8DAAD, but the trend appears to have been reversed during 1978-79 as precipitation and recharge increased while use of the well probably decreased. The fact that the downward trend in wells 116N59W27CCCC and 114N58W9AAAA continued during 1978-79 indicates that irrigation pumpage continued to increase.

Altamont Aquifer 3

EXTENT AND COMPOSITION

Altamont aquifer 3 underlies 210 square miles within a broad, branching valley, 1 to 6 miles wide (fig. 26), eroded into shale bedrock by preglacial and glacial streams. The aquifer consists of outwash sand and gravel deposited in channels a few hundred feet to as much as 1 mile wide. The widest channels occur in the western part of the county. Gravelly till and alluvial deposits of fine, clayey, sand and silt comprise much of the aquifer in the eastern one-half of the county.

The top of the aquifer is an undulating surface that can change as much as 111 feet in altitude within 1 mile. The top of the aquifer beneath the city of Clark ranges in depth from 474 to

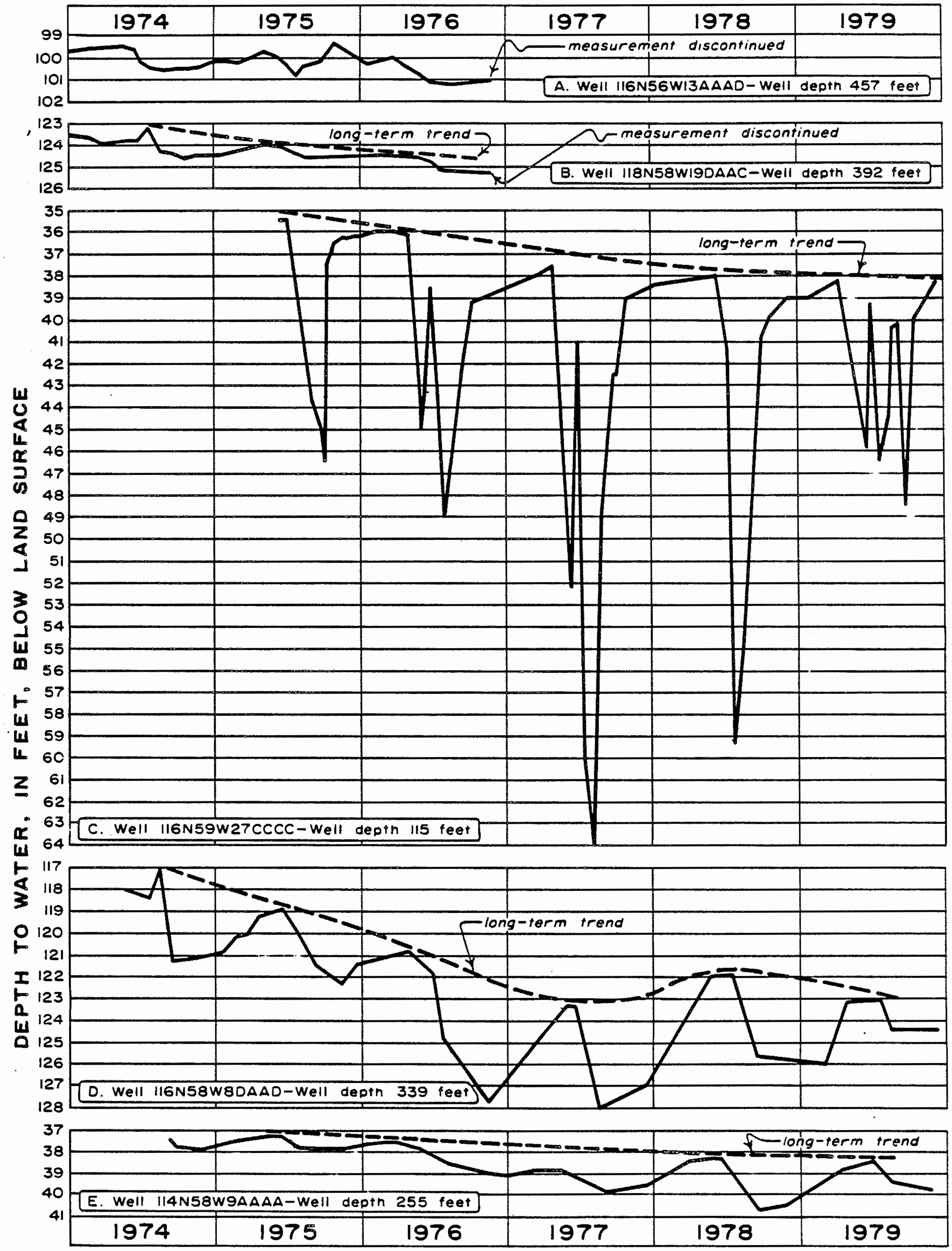
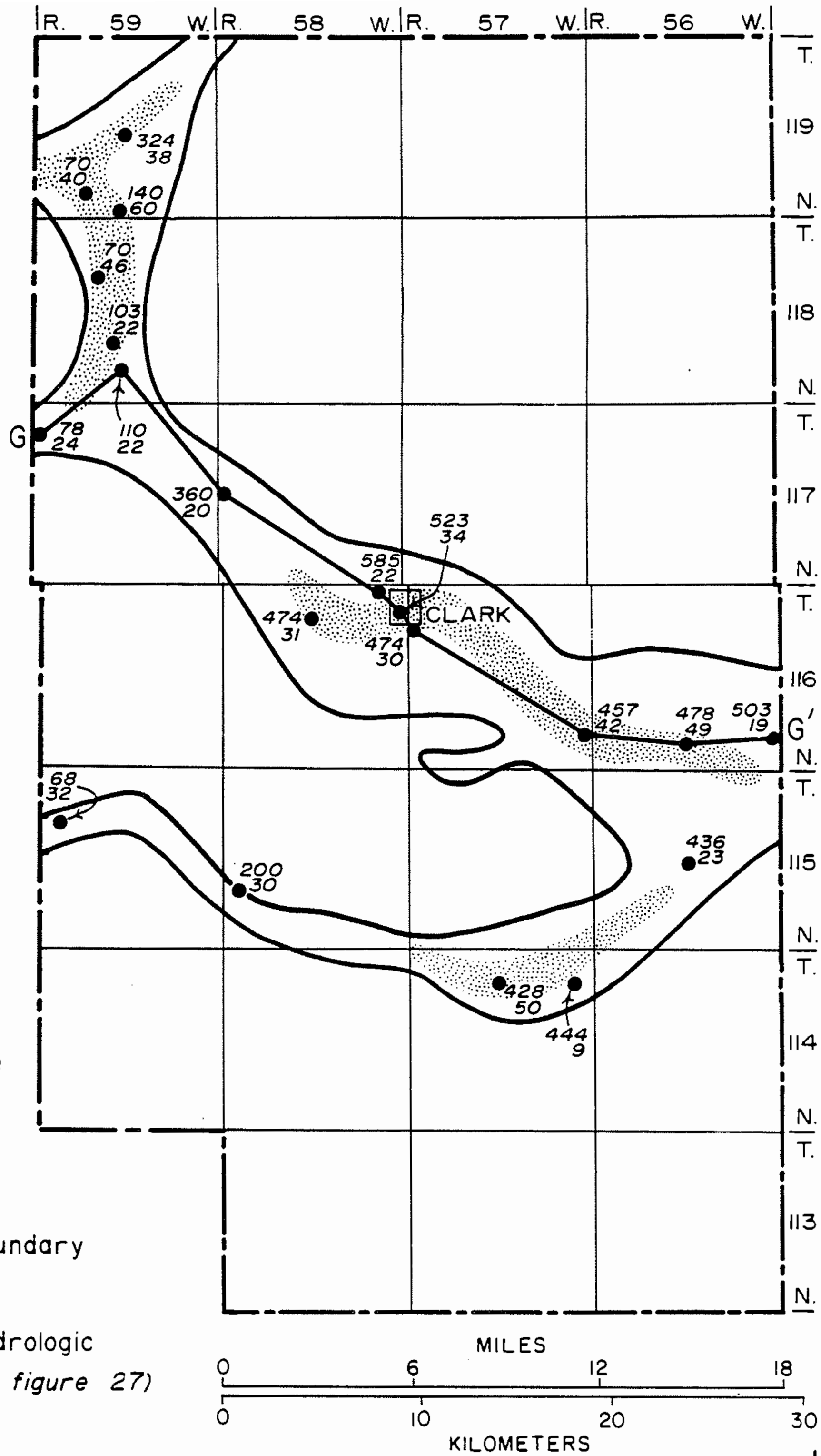


Figure 25. Hydrographs showing water-level changes, Altamont aquifer 2.



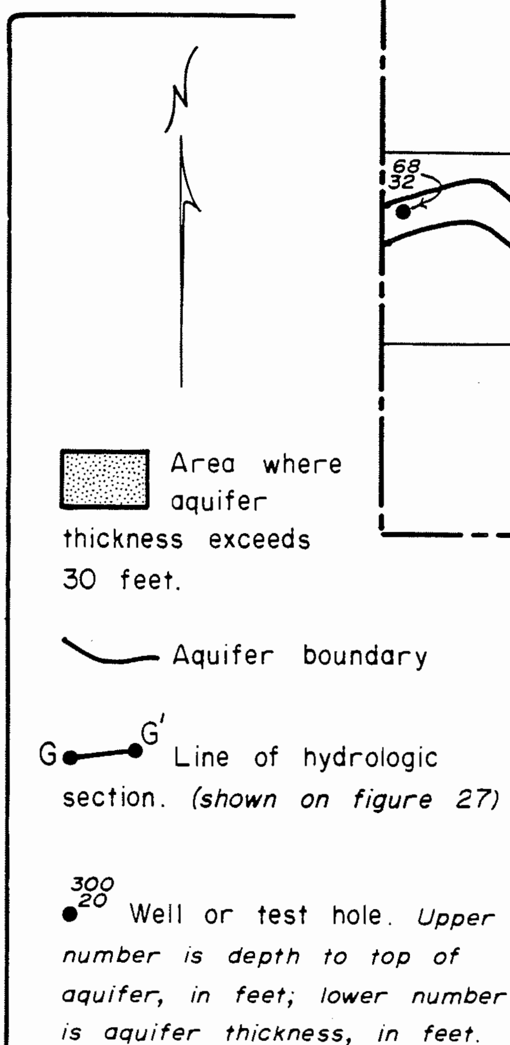


Figure 26. Map showing extent, depth, and thickness, Altamont aquifer 3.

585 feet below land surface. The depth decreases rapidly westward to a minumum of about 70 feet in R. 59 W. because of the decreasing altitude of the land surface.

The average thickness of aquifer 3 is 30 feet and the maximum thickness is 60 feet in well 119N59W33DCAA, where there is about 40 feet of sand and gravel of Altamont aquifer 2 overlying aquifer 3.

WATER MOVEMENT

Recharge is by infiltrating precipitation and lateral inflow (fig. 27). The direction of water movement is determined from water-level altitudes in 25 wells. Water moves westward nearly horizontally through aquifer 3 to where the aquifer contacts aquifer 2 and discharges some water upward into aquifer 2. A potentiometric map was not drawn for this aquifer because water-level data are sparse. The potentiometric surface in the western one-half of the aquifer is nearly the same as that for Altamont aquifer 2.

Recharge is included with that for aquifer 2 (table 1). Discharge generally equals recharge and is mostly by underflow westward from the county.

WATER-LEVEL CHANGES

Water-level declines during 1976 for Altamont aquifer 3 (fig. 28) were caused by decreased recharge during the drought and increased pumpage from large-capacity wells. The map shows that water levels declined more than 10 feet at three locations totaling 16 square miles. The decline at the northern location was caused by pumpage from the overlying Altamont aquifer 2. The decline at the other locations was caused by pumpage of 146 acre-feet from an irrigation well in T. 115 N., R. 59 W. and 100 acre-feet from an industrial well at Clark during 1976. The large decline of 69 feet at the irrigation well (115N59W7DCAA) indicates that the aquifer did not receive much recharge, probably because overlying and adjacent till deposits are clayey and relatively impermeable. Although the aquifer was not dewatered at this site, the large drawdown resulted in a large reduction in the yield of the well. A table of theoretical drawdowns in figure 28, based on a 9-month drawdown test at Clark, shows that drawdowns of 17 feet at a distance of 10,000 feet and 25 feet at a distance of 5,000 feet can be expected from a well pumping 100 gallons per minute continuously for 1 year. Drawdowns can exceed the aquifer thickness because they are mostly confined within the height of the non-pumping water level above the top of the aquifer.

Drawdown is proportional to the rate of pumping, hence, each drawdown value in the table would be 10 times larger if the

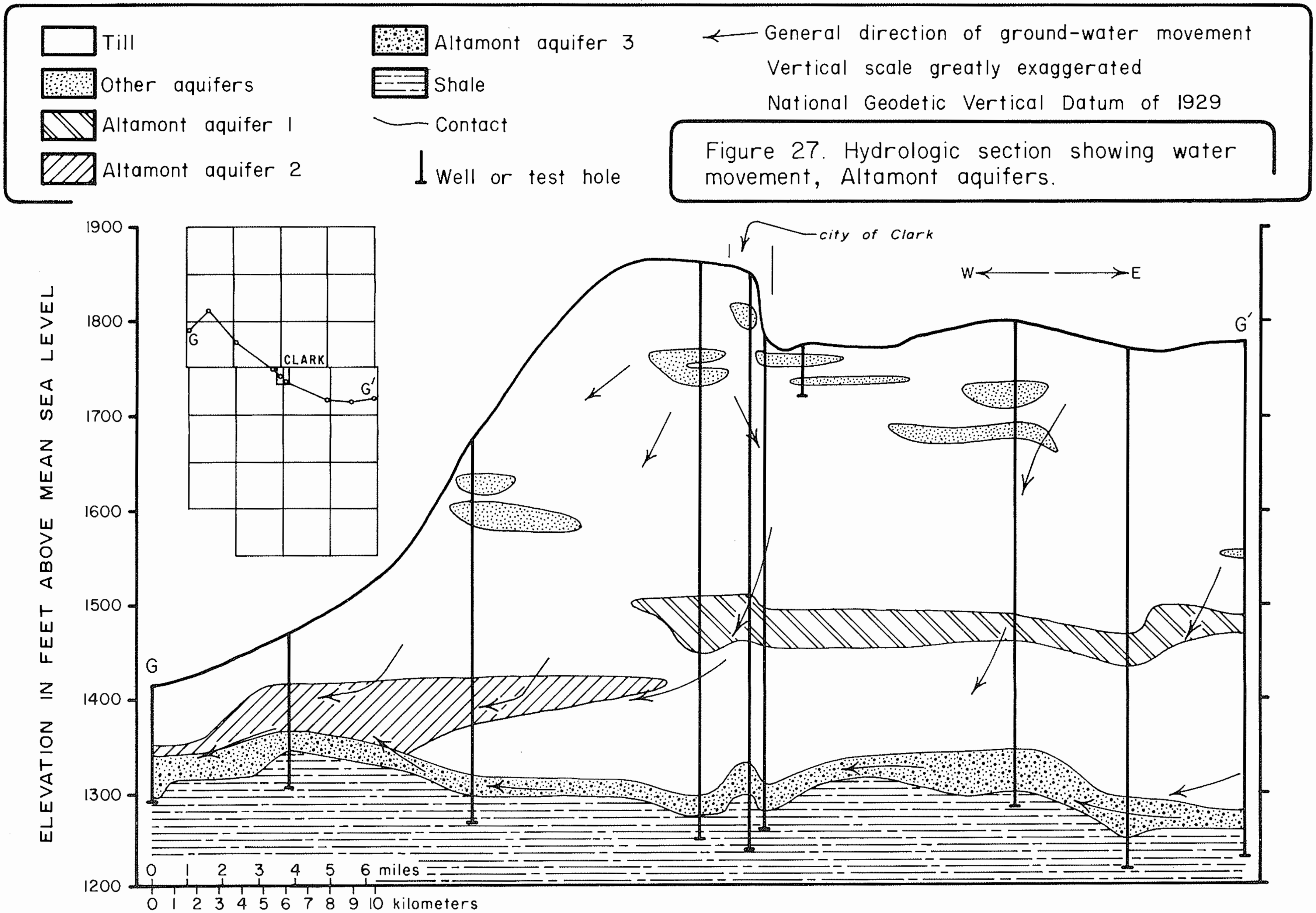


Figure 27. Hydrologic section showing water movement, Altamont aquifers.

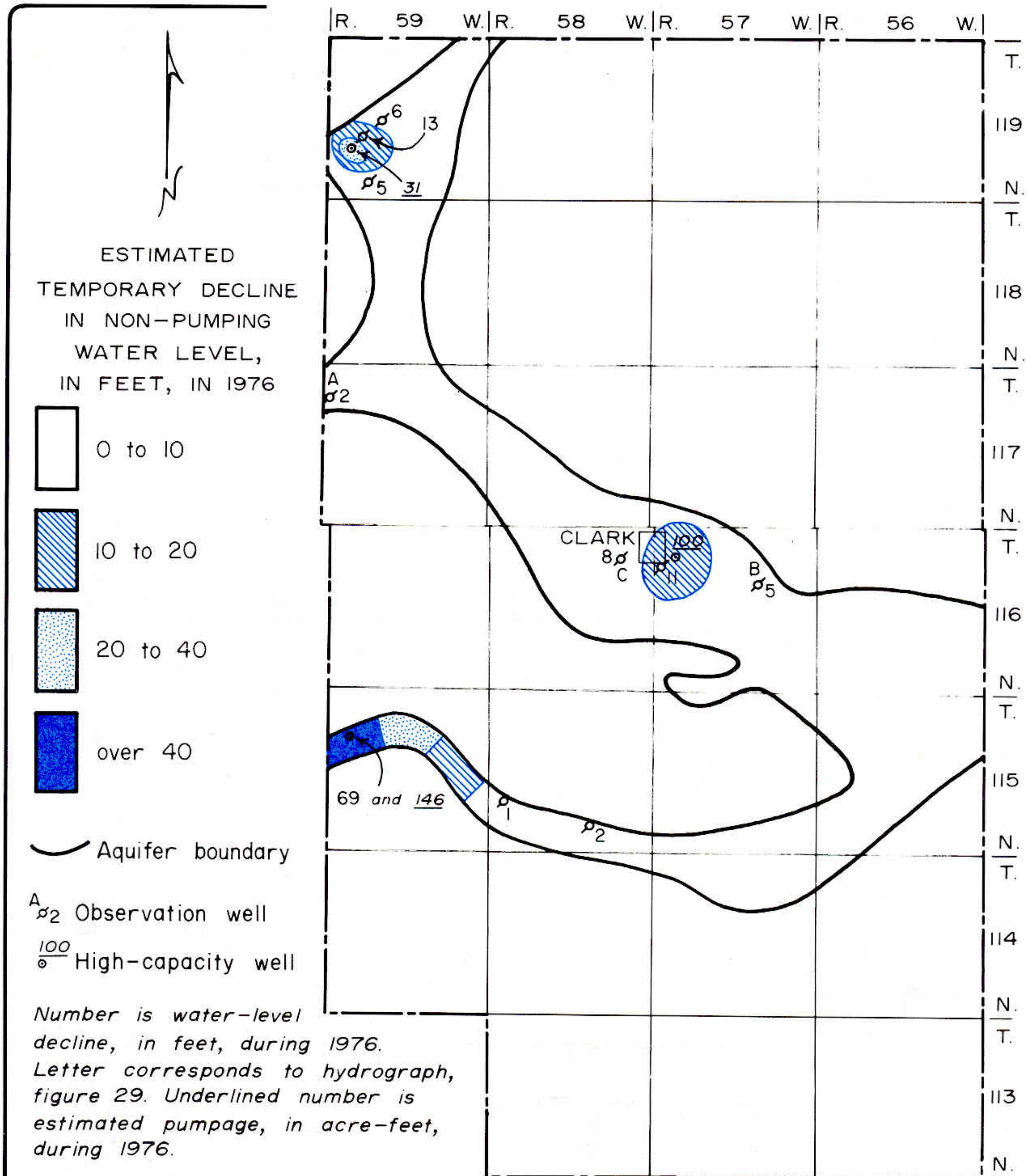


Figure 28. Map and table showing temporary water-level decline and pumpage during 1976, Altamont aquifer 3.

Table--Theoretical drawdown, in feet, at various distances from a well pumping continuously at 100 gallons per minute from Altamont aquifer 3; at Clark, South Dakota (116N57W6DCDD). Transmissivity = 2,000 gallons per day per foot; storage coefficient = 0.0001.

Distance from pumping well, in feet	10	100	300	500	700	1,000	5,000	10,000
Time since pumping started	Drawdown, in feet							
One day	63	37	25	19	15	11	0	0
Ten days	76	50	37	31	27	24	7	1
One hundred days	90	64	51	45	41	37	19	11
One year	97	70	57	52	48	44	25	17

pumping rate were 1,000 instead of 100 gallons per minute.

The map shows that actual drawdowns were much smaller than those shown at corresponding distances in the table because the well at Clark was pumped intermittently only for 5 months during 1976. Drawdowns in other areas were much smaller than those indicated by the table even though discharge was much larger. This is because the transmissivity of the aquifer at those sites is much larger than at Clark.

Seasonal changes in water levels for two deep observation wells completed in Altamont aquifer 3 (hydrographs B and C, fig. 29) consisted of a steady decline of 7 to 16 feet during the fall, winter, and spring due to pumping of the industrial well at Clark. This was followed by recovery during the summer when pumpage was reduced greatly. The long-term trend at well 116N58W11AADB2 shows a 33-foot decline in the annual highest water level during 1974-79, because of increased pumpage. The downward trend probably will continue as long as pumpage in the Clark area increases.

Seasonal changes of water levels in well 117N59W7BBCC shown by hydrograph A (fig. 29) for 1960-79 generally consisted of a sharp decline in water level during the summer as a result of decreased recharge and increased pumpage from irrigation wells. During the spring there was a sharp rise in water level due to increased recharge in more than one-half of the 17 years of record. There was only a small spring-time rise of 1 foot or less during the other years when recharge was less than normal. The decline of about 6 feet during the summer of 1977 was the largest of record because of new irrigation wells completed within 3 miles of the well.

The long-term trend of water levels in well 117N59W7BBCC includes a gradual decline in the annual high water level during 1972-77. This was due to a temporary decrease in recharge and an increase in pumpage for irrigation during the drought. This trend probably will continue as long as pumpage increases.

Bedrock Aquifer

Extent and Composition

The Dakota Formation of Cretaceous age is the only known bedrock aquifer in Clark County. It is buried beneath glacial deposits and about 800 feet of relatively impermeable shale of Cretaceous age and overlies nearly impermeable granite or other crystalline "basement" rock of Precambrian age. The aquifer underlies the entire county except possibly at a few locations where wells have reportedly penetrated only hard, dense rock. This rock may be either cemented sandstone or basement rock, both of which probably are nearly impermeable in this area.

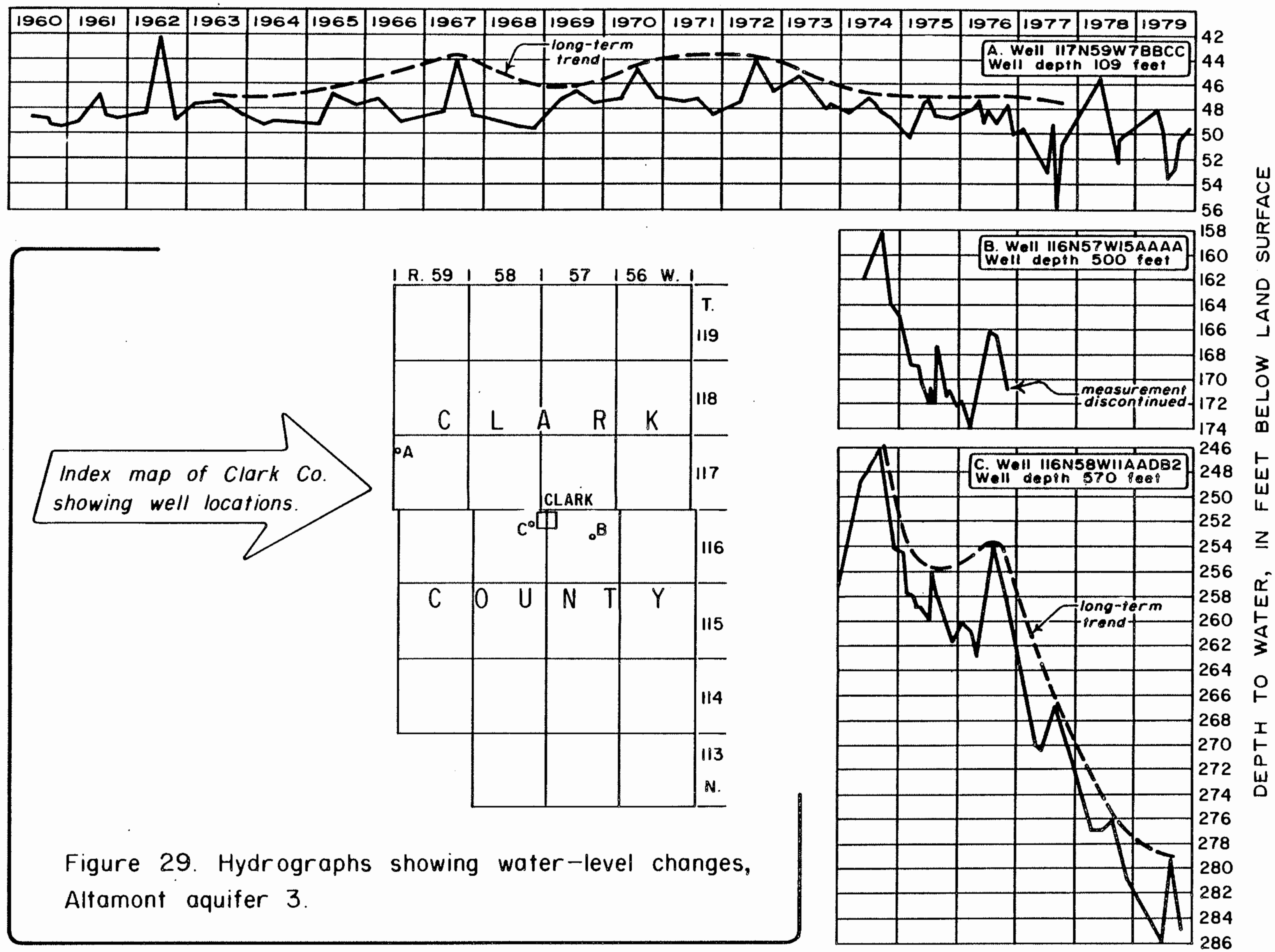


Figure 29. Hydrographs showing water-level changes, Altamont aquifer 3.

Depths to the top of the formation near the western edge of the county range from 900 feet in the south to 1,100 feet in the north. To the east, on the Coteau des Prairies, depths to the top of the formation range from 1,200 feet in the south to 1,400 feet in the north.

The formation ranges in thickness from 0 to 200 feet and is composed of fine-grained, silty, sandstone and sandy shale. A yield of as much as 50 gallons per minute can be obtained from a properly-constructed well. Storage of water in the aquifer probably exceeds 3 million acre-feet in Clark County.

Water Movement

Ground water moves westward through the Dakota Formation in most of the county and southwestward in the southern part of the county (fig. 30). The trend of the 1,500 and 1,550-foot contours to the southeast away from the 1,450-foot contour is probably the result of large local withdrawals of water. It appears that a water-level decline of about 50 feet has been caused by withdrawals through several dozen stock wells located in T. 113 N., R. 57 and 58 W., and in townships just south of the county line.

Water moving through the formation in Clark County is estimated to total 7,000 acre-feet per year, based on an estimated transmissivity of 5,000 (gallons per day) per foot and the gradients indicated by the contours in figure 30. Formation recharge is by subsurface inflow from the east; discharge is by subsurface outflow to the west and southwest and through wells. Discharge from the formation by about 50 wells in Clark County is estimated to average about 55 acre-feet per year.

Water-Level Changes

The potentiometric surface for the Dakota Formation was at an altitude of about 1,650 feet in Clark County during 1909 (Schoon, 1971, fig. 15) and has decreased in altitude by about 150 feet since then. This was caused mainly by large withdrawals from the formation by thousands of flowing wells in the James Basin to the west of the study area (Hopkins and Petri, 1963, p. T29). The rate of decline of artesian pressure has decreased greatly in recent decades because the flow of most wells in the basin has decreased greatly (Koch and Bradford, 1976, p. 36). None of the wells completed in the formation in Clark County are flowing.

The water level in well 119N59W9CCCA (fig. 31) completed in the Dakota Formation declined 14 feet during 1960-78, a rate of about 0.8 foot per year. The water level in well 114N59W17DDCC declined about 5 feet during 1960-68 but has subsequently fluctuated as much as 44 feet. These fluctuations are not representative of water-level changes in the formation but probably are caused by well-casing deterioration, which allows leakage into

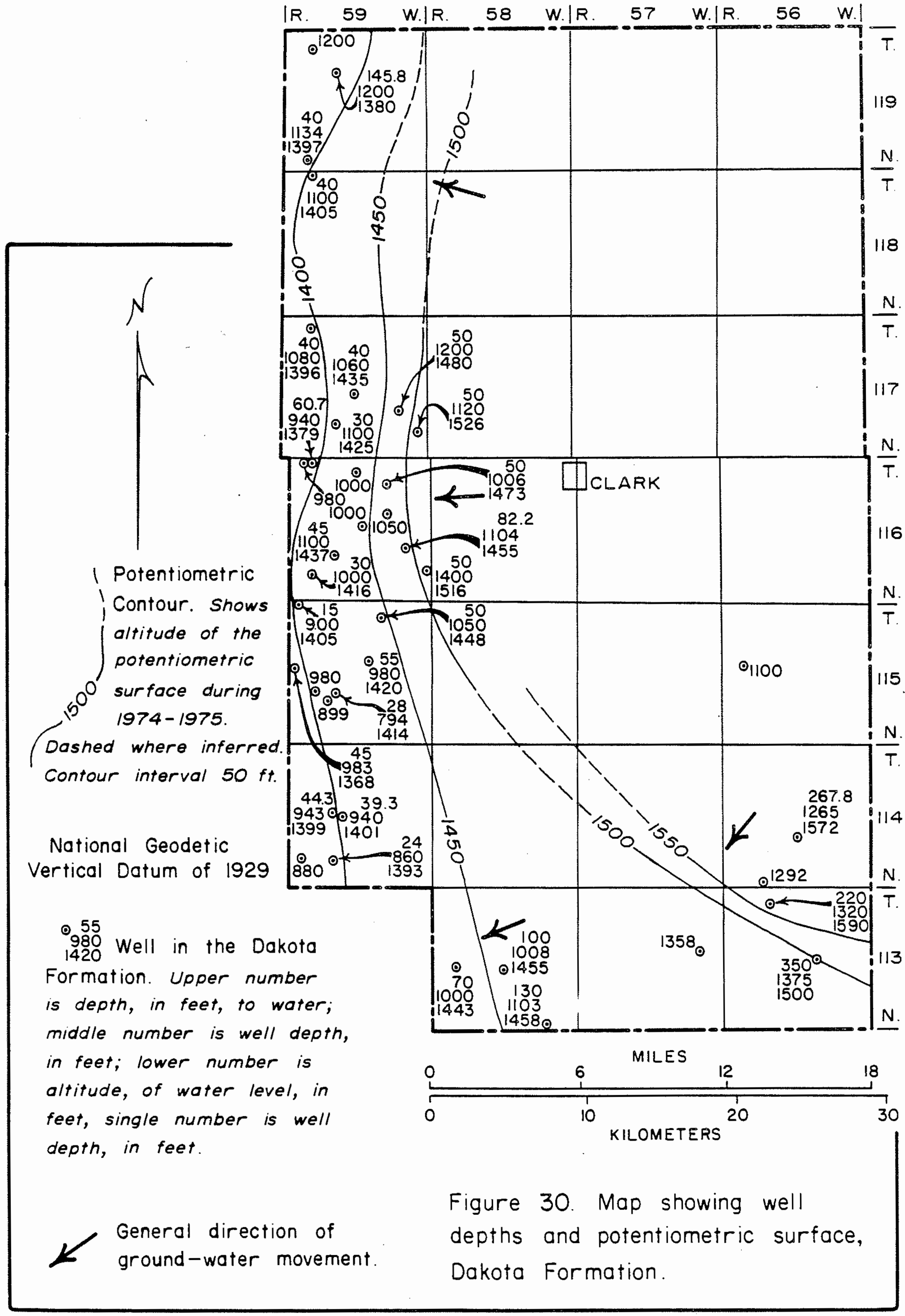


Figure 30. Map showing well depths and potentiometric surface, Dakota Formation.

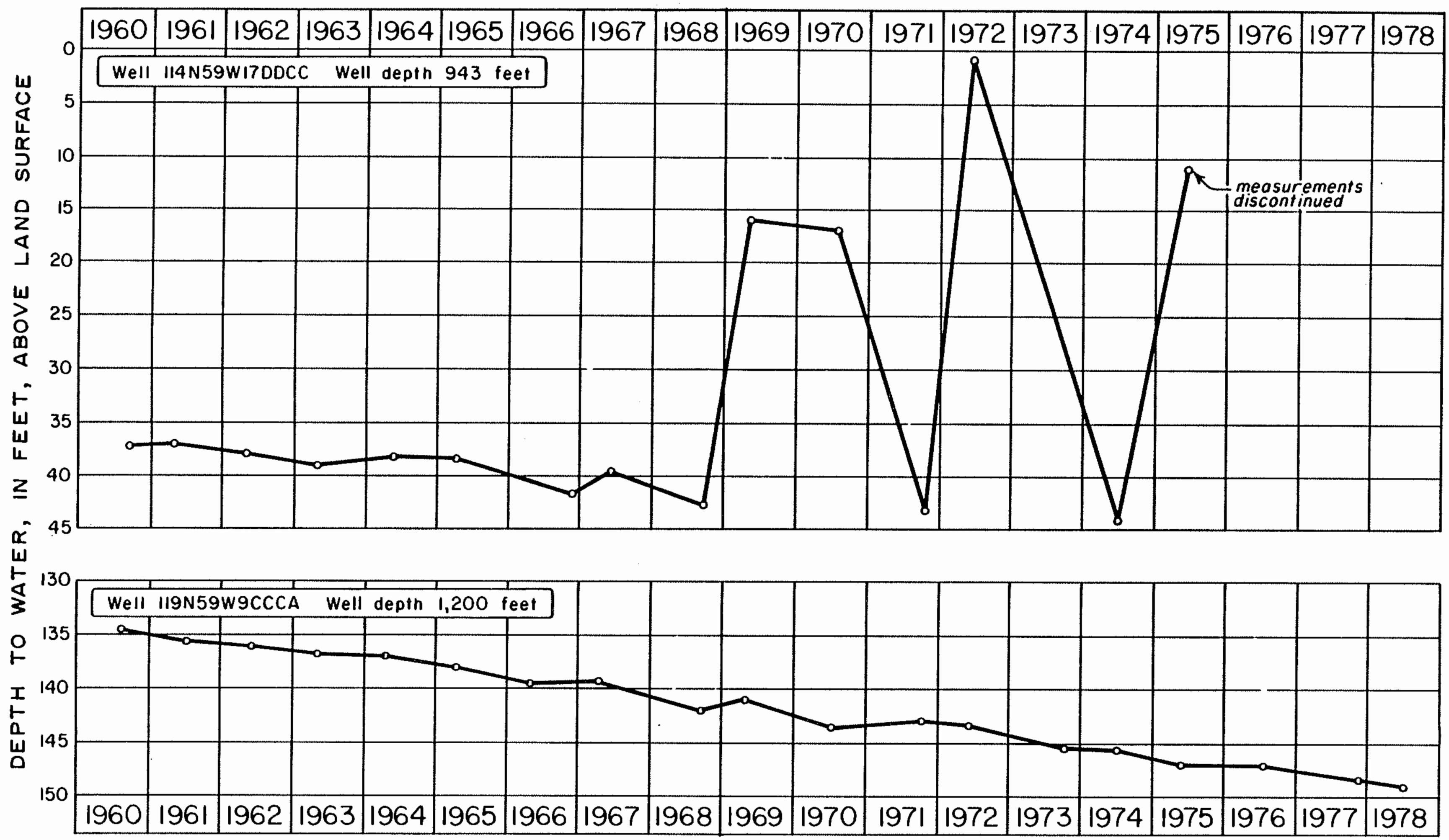


Figure 31. Hydrographs showing water level changes, Dakota Formation.

the well from formations containing water under greater pressure. Initiation of leakage can raise the water level in the well; it is believed, however, that subsequent slumping of muddy shale may seal off breaks in the casing and thus permit the water level to decline to its normal level.

Based on the record for well 119N59W9CCCA, it appears that water levels for the Dakota Formation will continue to decline slowly, thereby increasing the gradient of the potentiometric surface until increasing recharge balances discharge.

WATER QUALITY

Major Chemical Constituents

Most of the surface water and ground water in Clark County contains more than 1,000 milligrams per liter of dissolved solids. Calcium, magnesium, sodium, bicarbonate, and sulfate constitute 80 to 90 percent by weight of the dissolved constituents. Common constituents and properties of water from lakes and major aquifers in the county are listed in table 2.

Lakes

Analyses 1 and 2 in table 2 are of samples from two fresh-water lakes in the southern part of the county, and analyses 3 and 4 are of samples from two saline-water lakes in the northern part of the county. Saline-water lakes contain water having dissolved-solids concentrations exceeding 1,000 milligrams per liter. These lakes are in basins deeper than 15 feet and seldom overflow into an adjacent basin. Consequently, the inflow of dissolved solids from surface- and ground-water discharge is concentrated by evaporation.

The fresh-water lakes are in shallow basins, and dissolved solids are partly flushed out at infrequent intervals when the lakes overflow into adjacent basins.

The predominant chemical constituents in water from the fresh-water lakes are calcium, magnesium, sodium, and bicarbonate. Predominant constituents for saline lakes are magnesium, sodium, and sulfate. Dissolved-solids concentration and total (calcium-magnesium) hardness was about 10 times greater in samples from saline lakes than in samples from fresh-water lakes. The unusually large dissolved-iron concentration of 1,400 micrograms per liter for Cherry Lake indicates local ground-water inflow and probably is not typical of iron concentrations in other lakes. Other tabulations of lake-water quality (State Lakes Preservation Committee, 1977, p. 188) indicate that some lakes in the county have dissolved-solids concentrations that are intermediate between the extremes shown by analyses for the four lakes listed in table 2.

TABLE 2 REPRESENTATIVE CHEMICAL ANALYSIS OF SURFACE AND GROUND 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 + Nitrite (N, mg/L)	Dissolved Solids (mg/L) Calculated	Dissolved Solids (mg/L) Residue on evaporation at 180 C	Hardness as $CaCo_3$ (mg/L) Total (Calcium Magnesium)	Hardness as $CaCo_3$ (mg/L) Noncarbonate	Sodium-Adsorption-Ratio (SAR)	Specific Conductance (Micromhos at 25 C)	Alkalinity as $CaCO_3$ (mg/L)	Percentage Sodium	Boron (B, ug/L)	Dissolved Phosphorus (P, mg/L)	Dissolved Ortho Phosphorus (P, mg/L)	Temperature (C)	PH, Field (Units)
LAKES																											
1. Cherry Lake 113N56W35CBCC	11-07-74	36	1,400	0	60	30	29	38	324	0	80	21	0.1	0.15	457	—	270	8	0.8	750	266	16	160	0.12	0.09	6.0	8.0
2. Willow Lake 114N57W26ABCC	11-07-74	23	60	70	42	66	61	38	319	68	120	30	.2	.01	608	—	380	2	1.4	1,000	375	24	180	.57	.49	6.0	9.3
3. Reid Lake 118N57W18DABB	11-07-74	13	70	60	160	950	990	160	655	50	6,600	280	.0	.01	9,530	—	4,300	3,700	6.6	8,500	620	32	210	.11	.06	—	8.8
4. Swan Lake 119N56W 3DABA	11-07-74	15	70	20	150	530	480	110	459	13	3,000	130	.0	.01	4,660	—	2,600	2,200	4.1	6,250	398	28	1,100	.22	.16	10.0	8.4
GROUND WATER - PRAIRIE COTEAU AQUIFERS																											
AQUIFER 1																											
5. 38-foot well 113N57W26CADD	04-14-76	–	—	—	110	52	12	8.0	322	0	52	4.0	—	—	399	—	490	230	0.2	980	264	5	—	—	—	—	7.1
6. 19-foot well 114N57W34CCCC	05-31-74	29	350	430	84	32	8.8	4.6	305	–	100	6.7	0.0	1.3	423	427	340	92	.2	665	250	5	40	—	0.03	10.0	7.6
7. 31-foot well 116N57W 6CCDC	06-12-74	29	2,300	920	190	66	49	7.6	523	–	370	48	.6	.07	1,020	1,050	750	320	.8	1,460	429	12	240	—	.16	11.0	7.0
8. 50-foot well 116N57W30BCCB2	08-11-76	28	1,600	390	110	37	12	4.8	367	0	130	8.0	.2	.21	514	—	430	130	.3	850	301	6	70	0.02	—	9.5	7.6
9. 56-foot well 117N58W13DBBB	04-28-76	–	—	—	180	60	24	12	439	–	310	5.0	—	—	808	—	700	340	.3	1,150	360	6	—	—	—	—	7.3
AQUIFER 2																											
10. 150-foot well 116N58W27ADAD	08-10-76	30	6,300	1,100	200	60	260	15	437	0	890	9.3	0.3	0.00	1,690	—	750	390	4.1	2,700	358	43	1,100	0.20	—	9.5	7.5
11. 170-foot well 117N57W15BACD	07-22-76	27	550	1,700	200	41	110	9.4	325	0	600	8.0	.4	.01	1,160	—	670	400	1.9	1,750	267	26	1,100	.01	—	9.5	7.8
12. 110-foot well 119N57W27ADDA	11-17-76	29	110	2,600	280	81	57	11	385	0	830	14	.3	.84	1,500	—	1,000	720	.8	1,730	316	11	440	.00	—	9.0	7.2
AQUIFER 3																											
13. 260-foot well 114N57W 7DDCB2	06-10-74	29	200	3,900	220	54	140	13	220	–	810	18	0.2	0.00	1,400	—	770	590	2.2	1,850	180	28	580	0.03	0.04	10.0	7.8
14. 270-foot well 114N57W13DAAB	11-23-76	23	370	4,800	370	99	140	14	301	–	1,300	28	.3	.34	2,130	—	1,300	1,100	1.7	2,350	247	18	820	.00	—	9.0	7.3
GROUND WATER - ALTAMONT AQUIFERS																											
AQUIFER 1																											
15 322-foot well 115N57W15BCBC	10-3C-75	26	0	970	200	120	210	20	330	0	1,100	40	0.2	1.4	1,890	—	1,000	730	2.9	2,820	271	31	800	0.00	—	11.5	7.2
16. 139-foot well 115N58W 7DDAA	07-16-76	28	90	1,800	330	130	210	21	386	0	1,400	31	.3	.63	2,350	—	1,400	1,000	2.5	2,900	317	25	870	.03	—	9.0	7.5
17. 208-foot well 115N58W21DDCD	06-12-74	29	430	4,200	240	61	130	11	278	–	880	11	.3	.01	1,500	—	850	620	1.9	1,910	228	25	470	.07	0.05	11.0	7.2
18. 325-foot well 116N57W20BCCD	06-12-74	30	20,000	2,800	420	140	140	14	456	–	1,500	12	.2	.00	2,500	—	1,600	1,300	1.5	2,860	374	16	810	.03	.03	12.0	7.3
19. 311-foot well 116N58W33AABA	06-18-75	28	690	7,700	270	120	260	19	406	0	1,300	41	.5	.00	2,250	—	1,200	840	3.3	2,950	333	32	1,100	.01	—	—	7.0
AQUIFER 2																											
20. 186-foot well 114N58W26CCCD	05-19-75	32	3,800	1,700	250	93	190	19	377	0	1,100	25	0.3	0.05	1,900	—	1,000	700	2.6	2,550	309	29	1,000	0.00	—	11.0	7.6
21. 115-foot well 116N59W34CACC	07-15-76	27	550	2,400	180	61	170	10	411	0	710	26	.3	.08	1,390	—	700	370	2.8	2,000	337	34	700	.06	—	8.5	7.4
22. 500-foot well 117N56W 8ACDD	05-30-74	32	150	240	130	78	360	10	389	–	1,000	52	.1	.23	1,860	—	650	330	6.2	2,500	319	54	1,400	—	0.06	12.0	7.8
23. 212-foot well 117N59W13BACA	05-22-75	29	4,200	350	200	57	69	9.6	391	0	580	6.1	.4	.01	1,150	1,240	740	420	1.1	1,630	321	17	370	.06	—	11.0	7.3
24. 358-foot well 118N57W10AAAD2	07-16-76	23	8,200	2,300	260	74	52	10	487	0	560	4.3	.2	4.6	1,260	—	960	560	.7	1,860	399	10	400	.07	—	9.5	7.2
25. 108-foot well 119N59W32ABDA	07-15-76	28	1,200	630	93	31	17	4.3	304	0	140	2.7	.2	.13	469	—	360	110	.4	780	249	9	120	.04	—	9.0	7.7
AQUIFER 3																											
26. 550-foot well 116N56W17AADD	06-12-74	34	1,400	210	120	41	620	8.0	430	–	1,300	80	0.2	0.00	2,420	—	470	120	12	3,370	353	74	1,200	0.31	0.15	11.5	7.9
27. 506-foot well 116N57W 6DCAD	11-23-76	26	1,400	150	90	33	760	9.8	644	0	1,100	190	.2	4.7	2,550	2,670	360	0	17	3,300	528	82	1,500	—	.18	11.0	7.6
28. 109-foot well 117N59W 7BBCC	07-10-73	–	460	—	100	26	600	14	366	–	1,400	84	—	—	—	—	370	70	13	3,010	300	77	—	—	—	—	7.5
GROUND WATER - DAKOTA FORMATION																											
29. 960-foot well 114N59W21BBCB	06-10-74	9	200	10	7.7	3.1	860	5.8	436	–	980	370	4.4	0.00	2,460	2,460	32	0	66	3,750	358	98	3,600	—	0.05	14.0	8.9
30. 1,100-foot well 117N59W28CBCA	05-30-74	10	80	30	7.1	2.0	760	8.8	474	2	1,000	220	5.5	.08	2,250	—	26	0	65	3,360	392	98	4,000	—	.06	18.0	8.5

Recommended maximum contaminant level for drinking water (U.S. Environmental Protection Agency, 1977) is: Fluoride - 2.2 mg/L (for annual average maximum daily air temperature of 13 degrees C)
Nitrate - 10 mg/L

mg/L = milligrams per liter
ug/L = micrograms per liter
C = degress Celsius

Prairie Coteau Aquifers

Concentrations of dissolved solids in water from the Prairie Coteau aquifers commonly exceed 1,000 milligrams per liter (table 2). Concentrations of most chemical constituents vary greatly, both between aquifers and locally within an aquifer (table 2). Water from aquifer 1 had the smallest concentration of dissolved solids of any ground water in the county but locally concentrations exceeded 1,000 milligrams per liter, as at Clark (analysis 7, table 2). Concentrations of almost all of the constituents for analysis 7 are larger than for any of the other four analyses from aquifer 1, indicating concentration through evapotranspiration rather than by contamination. Analysis 7 is from a municipal well in a park where the water table is shallow. Salts, which are precipitated in the soil when the well is pumped to irrigate the park, probably are redissolved and returned to the aquifer during spring recharge.

Water from Prairie Coteau aquifers 2 and 3 had much larger concentrations of dissolved solids than water from aquifer 1 because aquifers 2 and 3 are deeper and recharge water has a longer residence time in the system and thus more salts are dissolved from till overlying the aquifers.

The following table summarizes quality-of-water data for the Prairie Coteau aquifers.

Prairie Coteau aquifers	Water type	Concentrations of dissolved solids (milligrams per liter)		Hardness (milligrams per liter)	
		Average	Range	Average	Range
1	Calcium bicarbonate or calcium bicarbonate sulfate	600	270-2,000	500	190-1,400
2	Sodium calcium sulfate	1,300	750-2,200	900	620-1,800
3	Calcium sulfate	1,800	1,400-2,300	1,100	770-1,800

Altamont Aquifers

Most water from the Altamont aquifers had concentrations of dissolved solids exceeding 1,000 milligrams per liter (table 2).

Much of the change in composition of the water, as it flows between the Altamont aquifers, is due to base exchange on clay minerals, sodium replacing calcium and magnesium in solution. The Altamont aquifer 3 appears to contain abundant clay minerals, hence the water tends to have larger concentrations of sodium and less hardness than water from the other Altamont aquifers. Other chemical reactions such as solution of iron, manganese, and boron in rocks appear to vary greatly, both areally and with depth, and cause large differences in their concentrations in the water.

The following table summarizes quality-of-water data for the Altamont aquifers.

Altamont aquifers	Water type	Concentrations of dissolved solids (milligrams per liter) Average	Concentrations of dissolved solids (milligrams per liter) Range	Hardness (milligrams per liter) Average	Hardness (milligrams per liter) Range
1	Calcium sulfate	2,000	1,500-2,500	1,100	850-1,800
2	Sodium sulfate or calcium magnesium sulfate	1,700	780-3,380	800	400-1,600
3	Sodium sulfate or calcium sulfate	1,900	600-2,500	500	250-1,100

Bedrock Aquifer

Water from the Dakota Formation had the largest concentrations of dissolved solids but the hardness was less than one-tenth of that for water from most of the other aquifers (table 2). Base-exchange processes soften the water during the extremely long time the water has been in the formation. The water is of the sodium sulfate type. Considering all available data, concentrations of dissolved solids average 2,500 milligrams per liter and range from 2,200 to 3,300 milligrams per liter; hardness averages 50 milligrams per liter and ranges from 15 to 200 milligrams per liter.

Minor and Trace Constituents

Minor or trace constituents that usually are not included in standard chemical analyses of water samples are listed in table 3. The concentrations listed in the table are all less than the "maximum contaminant level" established by the U.S. Environmental Protection Agency (1977) for drinking water with the exception of fluoride, which was exceeded in water from the Dakota Formation (table 2).

The source of most of these minor and trace constituents probably is shale. Because the glacial outwash contains shale fragments and the Dakota Formation has shale beds, it is to be expected that any of these constituents can be found in any of these aquifers at approximately the concentrations shown in table 3. The absence of these constituents in some samples probably is insignificant.

Changes of Water Quality

There is little evidence to indicate that the quality of water is changing in the aquifers. However, if increased pumpage induces more recharge from adjacent aquifers, till, or shale bedrock, the quality of water in the pumped aquifer could change gradually to that of the recharge sources. Furthermore, if irrigation increases the concentration of salts in soils, eventually these salts could be transported with recharge water and could add to the dissolved-solids concentrations in the underlying aquifers.

Suitability of the Water for Various Uses

The suitability of water for irrigation use is determined by its concentration of dissolved solids, sodium, bicarbonate, and boron. Most water in the Prairie Coteau and Altamont aquifers and in fresh-water lakes has a low sodium hazard but a high to very high salinity hazard if used for irrigation (fig. 32). Use of water with a high salinity hazard for irrigating poorly-drained soils can damage the soil structure. Even with adequate drainage, special management for salinity control may be required. Water from the Dakota Formation has such a high sodium hazard that it cannot be plotted in figure 32.

Boron in trace concentrations is essential to plant growth, but where it is present in irrigation water in concentrations of more than about 1,000 micrograms per liter (table 2) it can be toxic to many types of fruit and vegetable crops.

Although most of the ground water in Clark County is slightly saline it is used for human and livestock consumption. The water may require treatment for many uses in order to reduce excessive concentrations of iron or manganese, and hardness. Concentrations

TABLE 3 MINOR AND TRACE-ELEMENT ANALYSES OF SURFACE AND GROUND WATER

Source Location	Arsenic (As, ug/L)	Barium (Ba, ug/L)	Cadmium (Cd, ug/L)	Chromium (Cr, ug/L)	Cobalt (Co, ug/L)	Copper (Cu, ug/L)	Lead (Pb, ug/L)	Molybdenum (Mo, ug/L)	Nickel (Ni, ug/L)	Silver (Ag, ug/L)	Vanadium (V, ug/L)	Strontium (Sr, ug/L)	Zinc (Zn, ug/L)	Aluminum (Al, ug/L)	Lithium (Li, ug/L)	Selenium (Se, ug/L)	Iodide (I, ug/L)	Bromide (Br, ug/L)
LAKES																		
Cherry Lake 1. 113N56W35CBCC	–	100	--	--	-	-	1	--	--	--	---	260	60	--	60	--	----	---
Willow Lake 2. 114N57W26ABCC	28	-----	<1	--	-	-	7	--	--	--	---	330	20	50	110	--	----	---
Reid Lake 3. 118N57W18DABB	38	----	<1	0	2	2	7	34	--	--	9.6	670	50	40	1,100	--	----	---
Swan Lake 4. 119N56W 3DABA	–	<100	--	--	-	-	3	--	--	--	---	1,100	80	--	850	--	----	---
GROUND WATER - PRAIRIE COTEAU AQUIFERS																		
AQUIFER 1																		
19-foot well 5. 114N57W34CCCC	2	100	1	0	0	0	9	3	2	0	0.0	220	140	0	20	4	0.00	0.1
31-foot well 6. 116N57W 6CCDC	4	100	1	0	3	0	2	2	12	0	.8	480	30	0	60	0	.01	.3
GROUND WATER - ALTAMONT AQUIFERS																		
AQUIFER 2																		
500-foot well 7. 117N56W 8ACDD	0	100	1	0	1	0	5	12	7	0	0.3	1,600	50	0	130	0	0.20	0.4
212-foot well 8. 117N59W13BACA	1	0	0	0	0	0	0	2	0	0	.0	1,500	30	10	120	0	.10	.2
AQUIFER 3																		
506-foot well 9. 116N57W 6DCAD	0	0	0	10	1	1	6	0	5	0	0.9	1,200	0	10	120	0	0.03	1.3
GROUND WATER - DAKOTA FORMATION																		
960-foot well 10. 114N59W21BBCB	0	0	1	0	1	1	5	18	9	0	6.2	340	0	0	20	0	0.14	2.3
1,100-foot well 11. 117N59W28CBCA	0	100	1	0	1	0	3	5	7	0	2.2	270	40	0	120	0	.22	.6
Recommended maximum contaminant level for drinking water by U.S. Environmental Protection Agency (1977)	50	1,000	10	50	-	-	50	--	--	50	---	-----	---	--	-----	10	----	---

ug/L = micrograms per liter

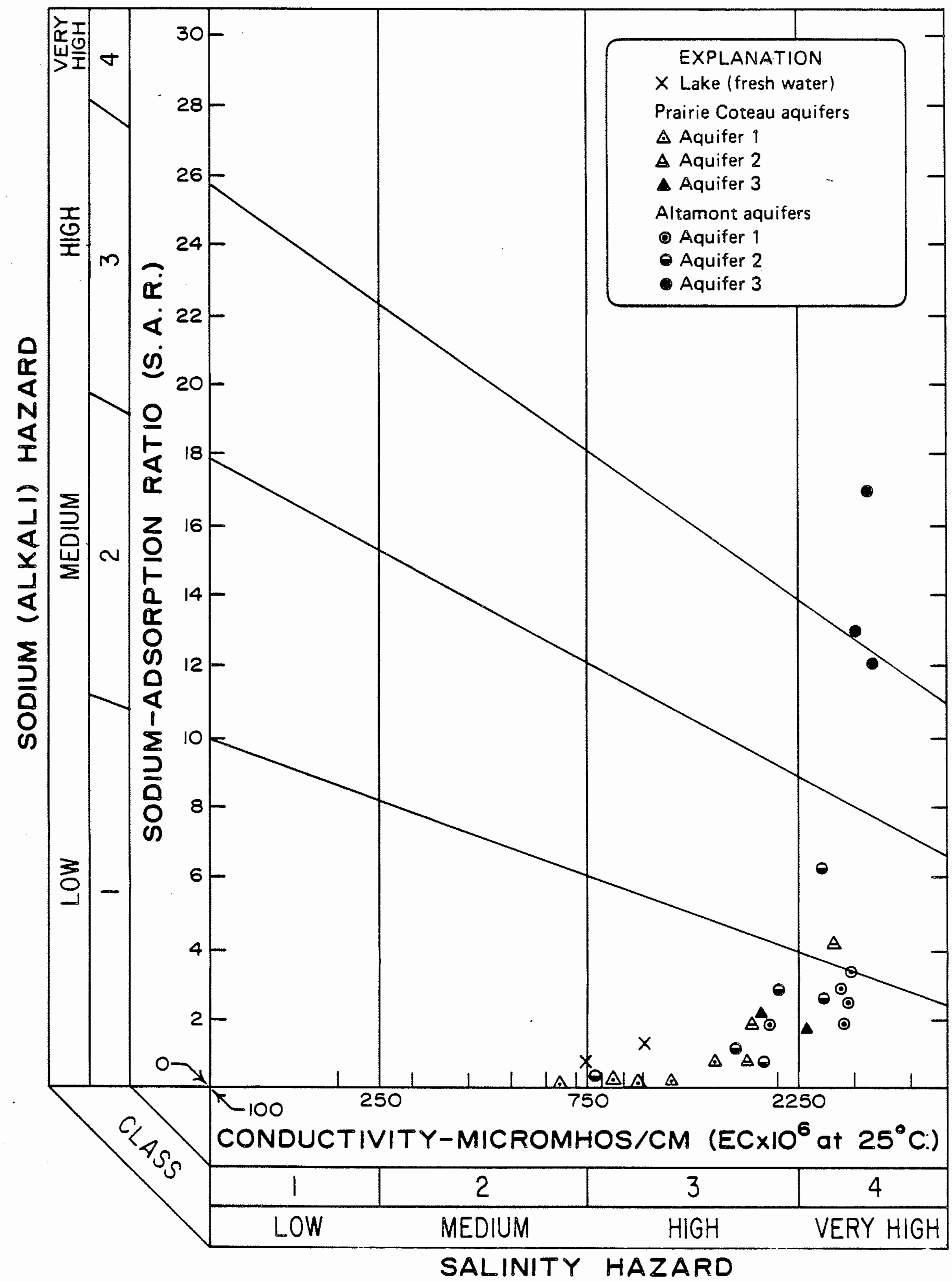


Figure 32. Classification of water for irrigation use, *(classification developed by U. S. Salinity Laboratory Staff, 1954).*

of iron in excess of 300 micrograms per liter and manganese in excess of 50 micrograms per liter (table 2) can cause unsightly turbidity; staining of plumbing fixtures, utensils and laundry; and clogging of well openings with mineral scale. Treatment of water by aeration, filtration, and finally by chemical treatment, if necessary, can make the water acceptable for most uses. Water from the Dakota Formation is suitable for many domestic and industrial uses because the water generally is soft and contains little dissolved iron and manganese. The water contains fluoride in concentrations that exceed the maximum contaminant level (table 2) and may cause mottling of children's teeth.

Surface water is unsuitable for drinking-water supplies because of the need for treatment. Many farms have cisterns to collect rainwater for laundry use.

WATER BUDGET

The balance between the average annual amounts of water coming into and going out of Clark County is the water budget (table 4). Precipitation and evapotranspiration are the dominant budget items.

TABLE 4. Average annual water budget

	Acre-feet	(inches)
Water in -		
Precipitation	1,133,000	(21.7)
Ground-water inflow	7,000	(.1)
TOTAL	1,140,000	(21.8)
Water out -		
Evapotranspiration	1,047,000	(20.0)
Pumpage	5,000	(.1)
Ground-water outflow	61,000	(1.2)
Surface-water outflow	27,000	(.5)
TOTAL	1,140,000	(21.8)

Changes in water storage are not included in the budget because they are assumed to balance out over a long period. All budget items are estimates. Evapotranspiration, calculated as the difference between the other budget items, includes evaporation and livestock watering from lakes and ponds and transpiration by crops and other vegetation. The annual pumpage of 5,000 acre-feet is about 6 percent of the estimated surface- and ground-water outflow. The uses of the pumped water have the following percentages:

Irrigation	70
Livestock	22
Rural-domestic	4
Municipal	2
Industrial	2
TOTAL	100

The only industrial water supply, as of 1976, is at a potato processing plant at Clark.

SUMMARY AND CONCLUSIONS

The principal conclusions of this study are:

1. Although annual streamflow from the county is estimated to average 27,000 acre-feet, it generally occurs only during late winter and early spring as runoff of snowmelt and rainfall. The flow is distributed among 14 short ephemeral streams which flow rapidly, at gradients of from 20 to more than 100 feet per mile, off of the Coteau des Prairies.

2. There are about 1,000 lakes, ponds, and marshes covering about 4 percent of the Coteau des Prairies, but most are shallow and were dry sometime during the drought of 1973-76, when the level of lakes declined as much as 5 feet.

3. Stored ground water includes more than 5 million acre-feet in six major glacial aquifers and 3 million acre-feet in a bedrock aquifer, the Dakota Formation. The glacial aquifers are from 0 to nearly 600 feet below land surface and the Dakota Formation is from 900 to 1,400 feet below land surface.

4. A yield of as much as 2,000 gallons per minute can be obtained from a properly-constructed well in Altamont aquifer 2. The maximum well yields for other glacial aquifers range from 200 to 800 gallons per minute. A well yielding as much as 50 gallons per minute can be developed in the Dakota Formation.

5. Recharge by infiltration of precipitation and lateral inflow is estimated to range from 5,000 to 54,000 acre-feet annually for the six glacial aquifers. Annual recharge to the Dakota Formation by inflow is estimated to average 7,000 acre-feet.

6. A major water development has been the pumping of ground water for irrigation. During the 1973-76 drought, irrigation pumpage increased to nearly 4,300 acre-feet annually and caused a noticeable temporary decline in water levels. Maximum water-level declines in the vicinity of pumping wells were estimated to range from about 10 feet for Prairie Coteau aquifer 1 to 69 feet for Altamont aquifer 3.

7. Water levels recovered between irrigation seasons to within a few feet of the non-pumping high levels of the previous year. Several declining trends in annual high water levels appeared to reverse within a year after the end of the drought because of increased recharge.

8. At Clark, the effect of pumping an industrial well at a rate of about 100 gallons per minute was a decline of 33 feet, comparing the annual water-level peaks during 1974-79. The trend will continue as long as pumping from Altamont aquifer 3 increases in the Clark area.

9. Most of the surface water and ground water in Clark County contains more than 1,000 milligrams per liter of dissolved solids. Concentrations of dissolved solids range from 457 milligrams per liter for a fresh-water lake to 2,550 milligrams per liter for water from a glacial aquifer. Calcium, magnesium, sodium, bicarbonate, and sulfate ions constitute 80 to 90 percent by weight of the dissolved constituents. Although most of the ground water is slightly saline it is used for human and livestock consumption. Some water has a high salinity or sodium hazard which makes it unsuitable for irrigating poorly-drained soils.

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