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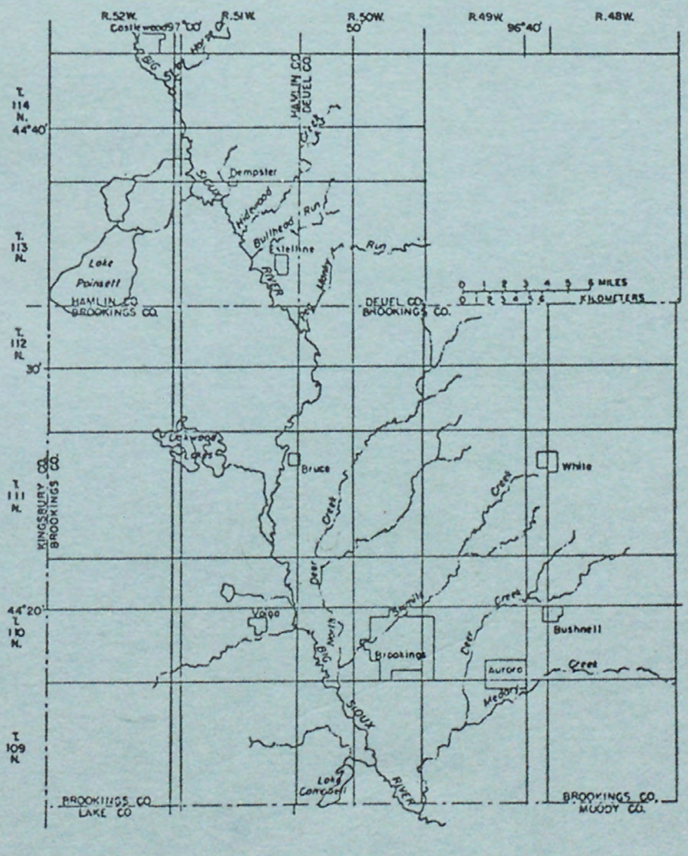
APPRAISAL OF THE WATER RESOURCES OF THE BIG SIOUX AQUIFER, BROOKINGS, DEUEL, AND HAMLIN COUNTIES, SOUTH DAKOTA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 80-100

Prepared in cooperation with the
East Dakota Conservancy Sub-District,
the South Dakota Department of Water
and Natural Resources, and Brookings
and Hamlin Counties



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U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

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16. Abstract (Limit: 200 words)

A finite-difference method digital model was used to simulate steady-state conditions of the Big Sioux aquifer in Brookings and Hamlin Counties. Average annual water levels in the Big Sioux aquifer and average base flow discharge (58 ft^3/s) on the Big Sioux River near Brookings were based on the period 1970 through 1976.

The computer model was used to model transient conditions by simulating monthly periods from April through August 1976. Evapotranspiration and pumpage changes were made for each month. A computer run was made without irrigation pumpage which resulted in an increase in the base flow from 0.66 to 9 ft^3/s for August 1976 on the Big Sioux River at Brookings.

Two transient runs, one under the drought conditions of 1976 and one using all the irrigation permits approved by the State as of February 1979 showed, as a result of pumpage, that there was a decrease in evapotranspiration and a decrease in discharge to streams which amounts to 26 and 31 percent of the total ground water pumped.

Ground water and surface water in the study area are primarily calcium bicarbonate type and are chemically suitable for irrigation with respect to sodium hazard. Specific conductance of ground water ranges from 407 to 1,790 umhos/cm.

17. Document Analysis a. Descriptors

Computer models, Aquifers, Surface water-ground water relationships, Evapotranspiration, Aquifer characteristics, Water quality

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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CONVERSION FACTORS

For readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms in this report are listed below:

Multiply	By	To obtain
acre	.4047	hectare
acre-foot (acre-ft)	.001233	cubic hectometer
foot (ft)	.3048	meter
foot per day (ft/d)	.3048	meter per day
foot per second (ft/s)	.3048	meter per day
foot squared per day	.0929	meter squared per day
foot per year (ft/yr)	.3048	meter per year
cubic foot per second (ft^3/s)	.02832	cubic meter per second
gallon per minute (gal/min)	.06309	liter per second
million gallons per day (Mgal/d)	2.629	cubic meters per minute
inch (in)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

DEFINITIONS

The geologic and hydrologic terms pertinent to this report are defined as follows:

Alluvium.--A material deposited in stream valleys by running water.

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 or springs.

Artesian well.--A well completed in a confined aquifer. Water in the well rises above the top of the confined aquifer, but does not necessarily reach the land surface.

Base flow.--Sustained streamflow consists mainly of ground-water discharge.

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

Glacial drift.--All rock material (clay, silt, sand, gravel, and boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier.

Ground water.--That part of subsurface water that is in the saturated zone.

Hardness.--Dissolved calcium and magnesium salts that reduce the lathering ability of soap and form scale in boilers and pipes. Hardness is reported as calcium carbonate and is classified by the U.S. Geological Survey as follows:

	Milligrams per liter (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

Hydraulic conductivity.--The rate of flow of water transmitted through a porous medium of unit cross-sectional area under a unit hydraulic gradient at the prevailing kinematic viscosity.

Loess.--Generally silt to fine sand believed to be windblown.

Outwash.--Sorted, stratified drift deposited beyond the glacier front by meltwater streams.

Potentiometric surface.--A surface that is defined by the levels to which water will rise in tightly cased wells.

Saturated zone.--Zone in which all voids are ideally filled with water. The water table is the upper limit of this zone, and the water in it is under pressure equal to or greater than atmospheric.

Specific yield.--The ratio of (1) the volume of water which saturated rock or soil will yield by gravity to (2) the volume of the rock or soil.

Steady-state flow.--When at any point in a flow field the magnitude and direction of the flow velocity as well as the potentiometric head are constant with time.

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 potentiometric head. In an unconfined aquifer, it is virtually equal to the specific yield.

Till.--Unsorted, unstratified drift deposited directly by the glacial ice.

Transient flow.--When at any point in a flow field the magnitude or direction of the flow velocity changes with time.

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

Water table.--That surface in an unconfined water body at which the pressure is atmospheric.

APPRAISAL OF THE WATER RESOURCES OF THE BIG SIOUX AQUIFER, BROOKINGS, DEUEL, AND HAMLIN COUNTIES, SOUTH DAKOTA

by Neil C. Koch

ABSTRACT

The Big Sioux aquifer in Brookings, Deuel, and Hamlin Counties, South Dakota, has been extensively developed and in some areas discharge, principally by wells, from the aquifer may be exceeding recharge to the aquifer.

A finite-difference method digital model was used to simulate steady-state conditions of the Big Sioux aquifer. Average annual water levels in the Big Sioux aquifer and base flow discharge of the Big Sioux River near Brookings for 1970 through 1976 were used in the model. The model-computed water levels were within a few feet of the actual annual average water levels and the computed annual average base flow was 66 cubic feet per second compared to the actual base flow of 58 cubic feet per second.

The computer model was used to model transient conditions by simulating water levels and base flow from April through August 1976 and comparing the results with actual data. Evapotranspiration and pumpage changes were made for each month. There was no recharge from precipitation during the test period.

Several different computer simulations were made using different estimates of hydrologic parameters and conditions. Specific yield was increased from 10 to 15 percent which resulted in a much greater base flow for each month. Effective depth of evapotranspiration was changed from 5 to 10 feet which resulted in a very large decrease in base flow. A computer simulation made without irrigation pumpage resulted in an increase in the base flow from 0.66 to 9 cubic feet per second for August 1976 in the Big Sioux River near Brookings. The actual base flow for August 1976 was .01 cubic foot per second.

A water budget showed 22.2 inches of precipitation (average annual), 0.65 inch of surface runoff, 1.06 inches of ground-water outflow (base flow to river, 1970-76), and 20.49 inches of evapotranspiration.

The water from the Big Sioux aquifer is a calcium bicarbonate type and specific conductance ranged from 407 to

1,790 micromhos per centimeter at 25°C. The water is generally very hard, having a mean of 454 milligrams per liter of hardness.

A model simulation using all the pumpage that would be allowed by irrigation permits approved as of February 1979 simulated the withdrawal of 43,900 acre-feet of water for about 4 months during which time there was no recharge from precipitation. If there had been no pumping for that period, evapotranspiration would have been 7,800 acre-feet more than occurred under pumping conditions and discharge to streams would have increased by 3,600 acre-feet.

INTRODUCTION

The Big Sioux River basin has an area of about 9,000 mi^2 in eastern South Dakota, southwestern Minnesota, and northwestern Iowa (fig. 1). The basin is about 210 mi long and 65 mi wide. The Big Sioux aquifer, a major glacial-drift aquifer, extends most of the length of the basin along the Big Sioux River and its tributaries.

The study area extends from near Castlewood on the north, where the aquifer narrows, downstream to the streamflow gaging station on the Big Sioux River 9.5 mi southeast of Brookings (fig. 2). The water resources of this 300 mi^2 aquifer are already extensively developed and in some areas discharge, principally by wells, from the aquifer may be exceeding recharge to the aquifer.

A study of the water resources of the aquifer was requested by the East Dakota Conservancy Sub-District. The Sub-District (a 14-county area in eastern South Dakota, fig. 1) is a governmental organization created under State laws to give local people the authority to plan, develop, and use the water resources within the area organized. The study was conducted by the U.S. Geological Survey in cooperation with the East Dakota Conservancy Sub-District, the South Dakota Department of Water and Natural Resources, and Brookings and Hamlin Counties.

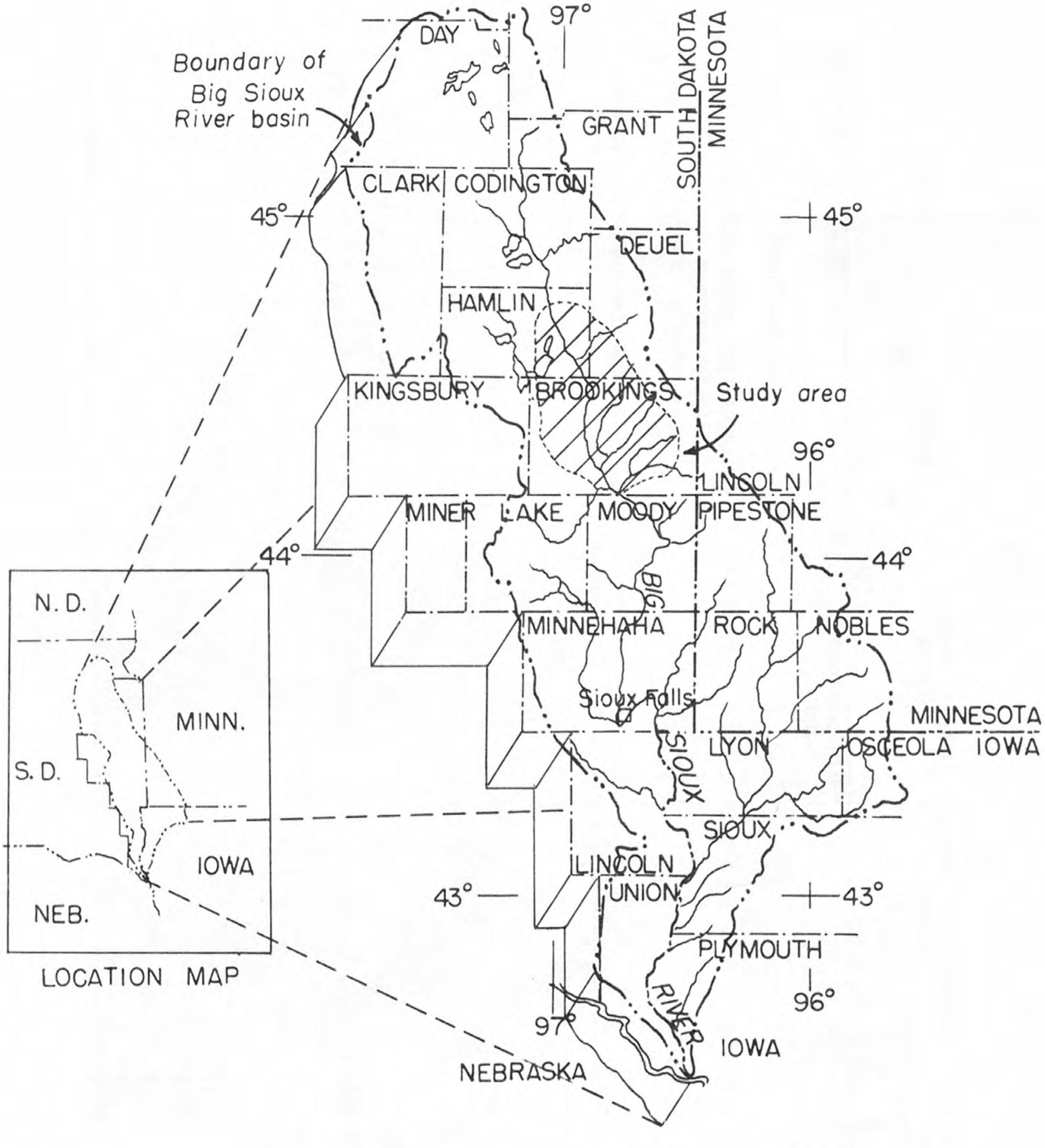
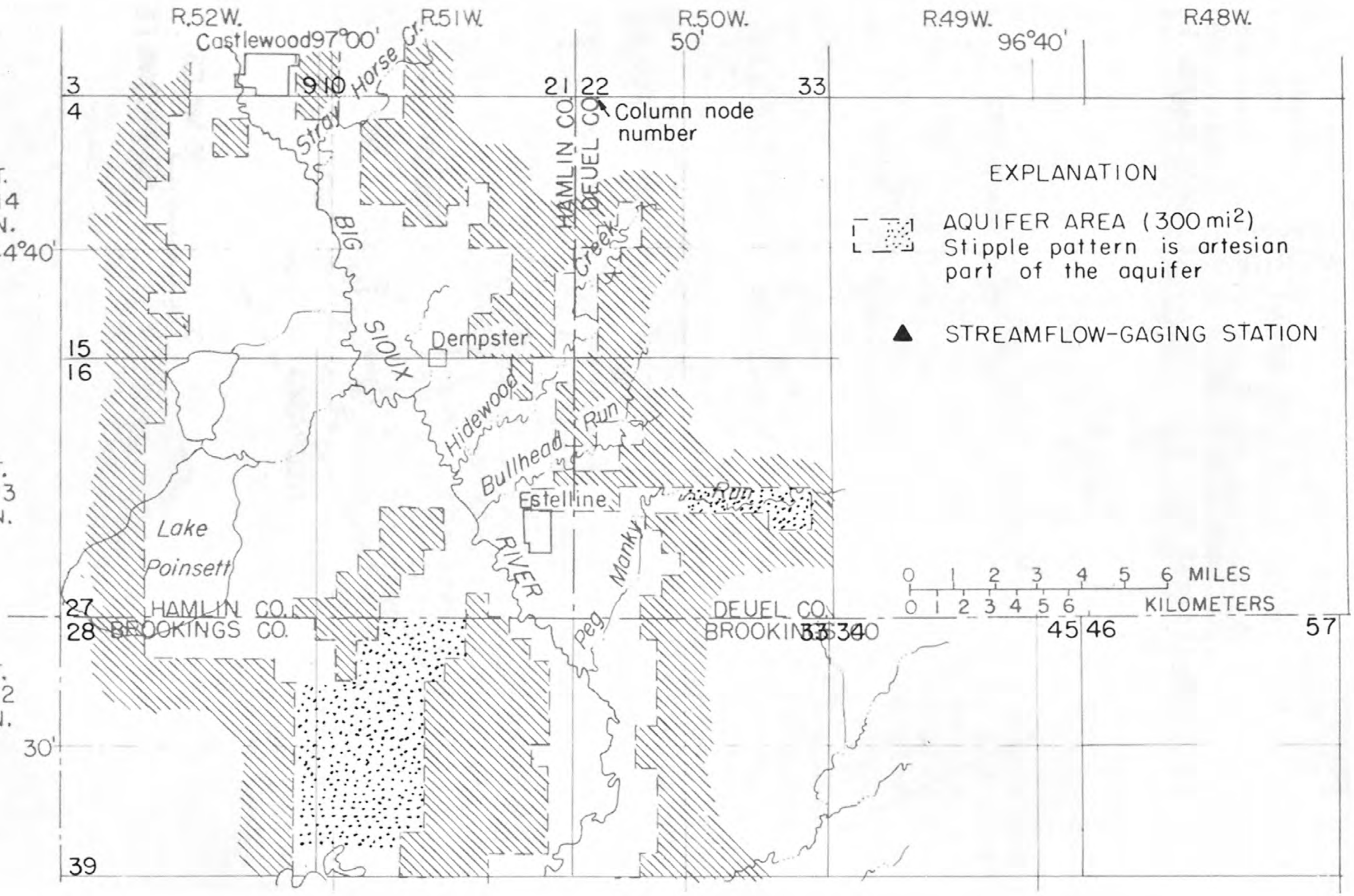


Figure 1. Location of study area and Big Sioux River basin.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T. 112 N.
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3
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45
46
57
Column node number
HAMLIN CO.
DEUEL CO.
BROOKINGS CO.
Stray Horse Cr.
BIG SIOUX RIVER
Creek
Dempster
Hidewood
Run
Bullhead
Run
Estelline
Lake Poinsett
Peg Manky
EXPLANATION
AQUIFER AREA (300 mi²) Stipple pattern is artesian part of the aquifer
▲ STREAMFLOW-GAGING STATION
0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETERS

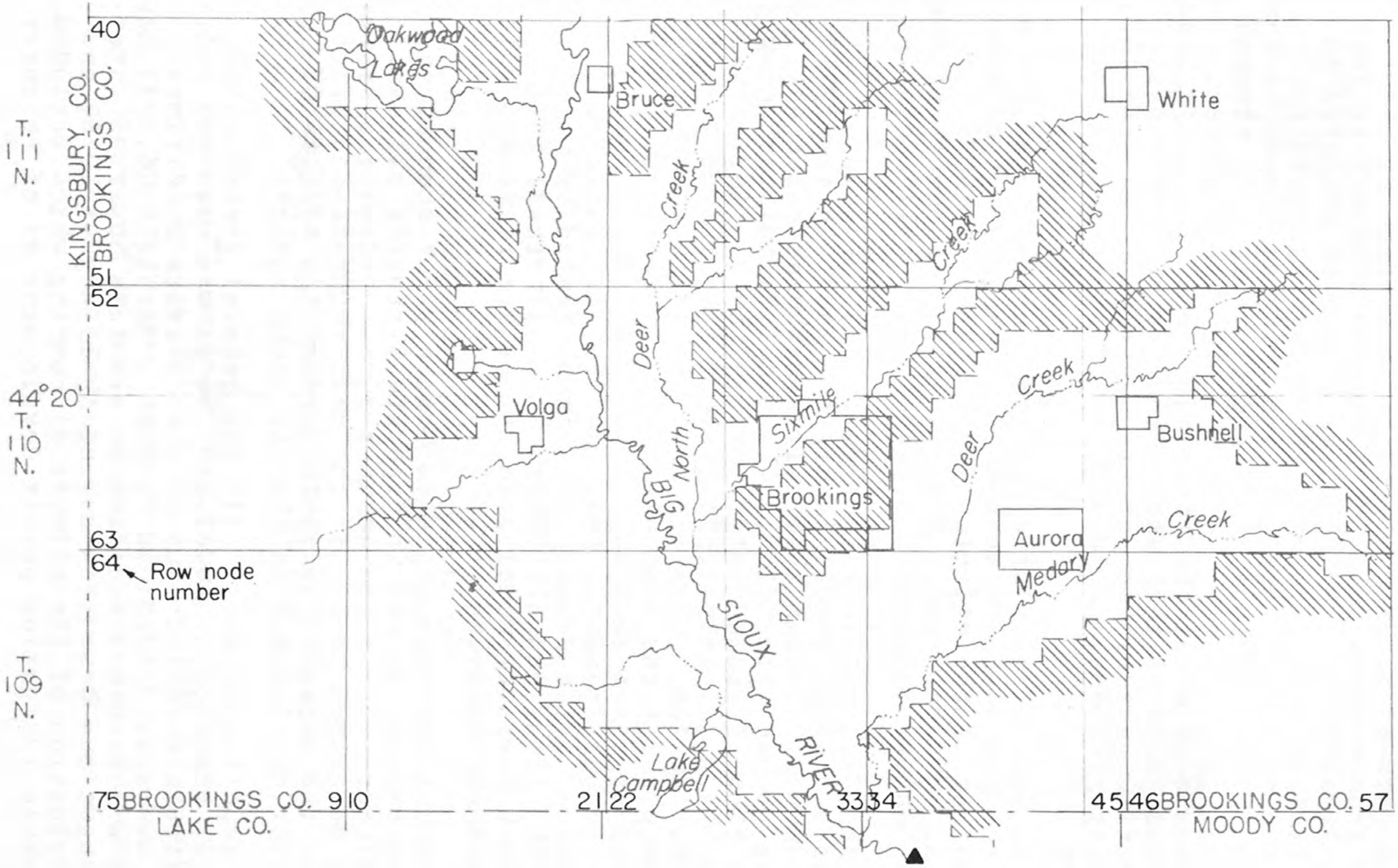


Figure 2. Location of aquifer model area.

Purpose of Study

The water resources of the Big Sioux River basin are being developed at an ever increasing rate. Presently (1978) the city of Sioux Falls pumps an average of about 12 Mgal/d from shallow wells completed in aquifers in the Big Sioux River basin. By 2000, water use is expected to double. Irrigation development is increasing rapidly (fig. 3) and rural water systems are being developed in the study area. The Big Sioux River and its tributary streams are hydraulically connected with the Big Sioux aquifer. Lack of knowledge about the river-aquifer system could lead to overdevelopment of the water resources in some areas. This potential overdevelopment, in addition to causing local water-supply problems, could affect surface-water users downstream.

The purpose of this study was to develop a predictive model of the ground-water system as a management tool for use in evaluating the effects of alternative methods of controlling or developing the ground-water resources of the Big Sioux aquifer in Brookings, Deuel, and Hamlin Counties.

The approach was to gather sufficient hydrologic data to develop a digital model. A digital model is simply, a digital computer program that solves mathematical equations describing ground-water flow. The model "simulates" numerically the flow of ground water through the aquifer. The use of such a model helps to improve the understanding of the physical system. Once the model is calibrated, it can be used to predict the response of the aquifer system to man-induced stresses such as pumping and natural induced stresses such as drought. New plans for irrigation and other forms of water development can be tested by merely changing the rates and distribution of withdrawal in the model. Such computer-model predictions are rapid and relatively inexpensive.

The model approach was used not only for economy and speed, but because it can incorporate virtually all available pertinent information about the real hydrologic system. The model described herein is the most accurate and practical way at the present (1978) to predict the effects of ground-water development on the Big Sioux aquifer.

The report describes: (1) The general ground-water system; (2) the digital model and how it was used and modified to simulate equilibrium or steady-state conditions based on averages determined from data for 1970-76; (3) how the model was used and modified to simulate observed water-level changes and base flow during April-August 1976; and (4) an evaluation of the effects of pumping which included all allowable irrigation permit development as of February 1979.

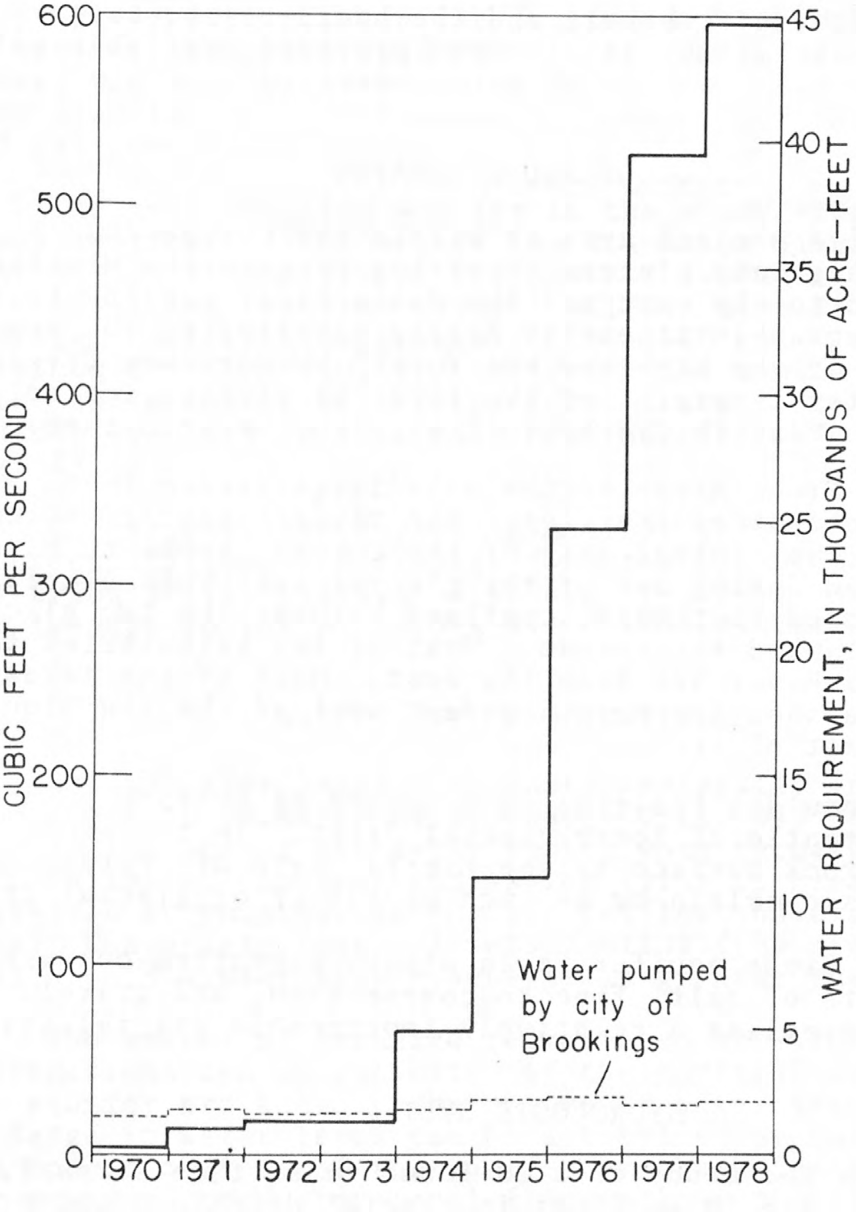


Figure 3. Cumulative annual volume of water that could be used for irrigation, as determined from irrigation permits issued in the study area. Water requirement (acre-feet scale) determined on basis of acres requested multiplied by an annual application of 12 inches of water.

Acknowledgments

Appreciation is expressed to the well drillers, county and municipal officials, and irrigators in the study area for their cooperation, help, and information supplied. Special thanks are extended to Jerry L. Siegel, Manager, Morris Apland, staff member, and the board of the East Dakota Conservancy Sub-District who provided available water data.

GEOLOGY AND GEOGRAPHY

The entire project area is within the Coteau des Prairies, a highland plateau occurring between the Minnesota River lowland to the east and the James River lowland to the west. A topographic linearity nearly parallel to the scarp-like margins of the highland was formed by moraines developed along the lateral margins of two lobes of glacial ice held apart by the wedge-shaped bedrock highland between them.

The Big Sioux River is the only large stream that drains the Coteau des Prairies. The river's course, which approximates the central axis of the coteau, seems to have been developed during one of the glacial ages when glacial meltwater flowed southward, confined between the two glacier lobes that flanked the coteau. Most of the tributaries to the Big Sioux River are from the east. Most of the lakes, ponds, and marshes are more abundant west of the Big Sioux River than east of it.

The Coteau des Prairies is composed of bedrock formations and a mantle of loose glacial drift. In the study area the bedrock surface is the Pierre Shale of Cretaceous age, which is overlain by as much as 500 ft of glacial drift.

The Big Sioux aquifer is an alluvium-mantled outwash which consists of silt, fine to coarse sand, and gravel. The aquifer overlies a relatively impermeable glacial till.

HYDROLOGIC SYSTEM

Water in the study area is found in surface streams, ponds, lakes, and in aquifers in glacial drift and bedrock strata. Surface water, and the ground water in the glacial drift originate as precipitation in or north of the study area. The amount of precipitation, however, is much greater than the amount that runs off from the surface or is added to storage in surface- and ground-water reservoirs. Much of the precipitation is returned to the atmosphere by evaporation and transpiration, which reduces the amount of precipitation available for use in the area.

Normal precipitation in the drainage area upstream from the streamflow gaging station on the Big Sioux River near Brookings is about 22 in (2 million acre-ft) annually. Of this amount, about 110,000 acre-ft (1.2 in) leaves the area as surface runoff. The remaining 1.89 million acre-ft is used by vegetation, evaporated, stored in lakes and sloughs, or replenishes the ground water. By far the largest amount leaves the area by evaporation and transpiration. Evaporation from Lake Poinsett alone is about 21,600 acre-ft (33 in) per year.

The major shallow aquifer in the study area is the Big Sioux aquifer. It underlies the Big Sioux River valley and many of the tributaries. The aquifer averages 25 ft in thickness, and contains about 1 million acre-ft of water in storage. Well yields greater than 1,000 gal/min have been obtained from the aquifer. Water in the aquifer is under water-table conditions except for a small part of the aquifer overlain by till that confines the water (see fig. 2).

Recharge to the Big Sioux aquifer is by infiltration of precipitation, and seepage from the Big Sioux River and its tributaries. Natural discharge is by evapotranspiration and seepage to the Big Sioux River and its tributaries.

WATER-LEVEL FLUCTUATIONS

Ground-water levels fluctuate seasonally in response to changes in recharge or discharge (fig. 4). Water levels rise in the spring and early summer when recharge from percolation of snowmelt and spring rains is greater than discharge by pumping, subsurface outflow and evapotranspiration. Conversely, water levels decline from mid-summer to fall or mid-winter when discharge is greater than recharge.

The amount of recharge represented by water-level fluctuations can be estimated if the physical properties of the aquifer are known. The volume of water associated with a change in water level can be determined by multiplying the specific yield of the aquifer by the water-level change. For example, the water-level fluctuations in well 109N49W18AAAA (fig. 4) show a maximum fluctuation of about 6 ft for the period of record and an average annual fluctuation of about 3 ft. Based on an estimated specific yield of 15 percent, the average annual fluctuation of 3 ft amounts to 5.4 in of water. In the 300 mi^2 aquifer this is a storage change of 86,400 acre-ft. Based on a specific yield of 10 percent this would be a change in storage of 57,600 acre-ft (3.6 in).

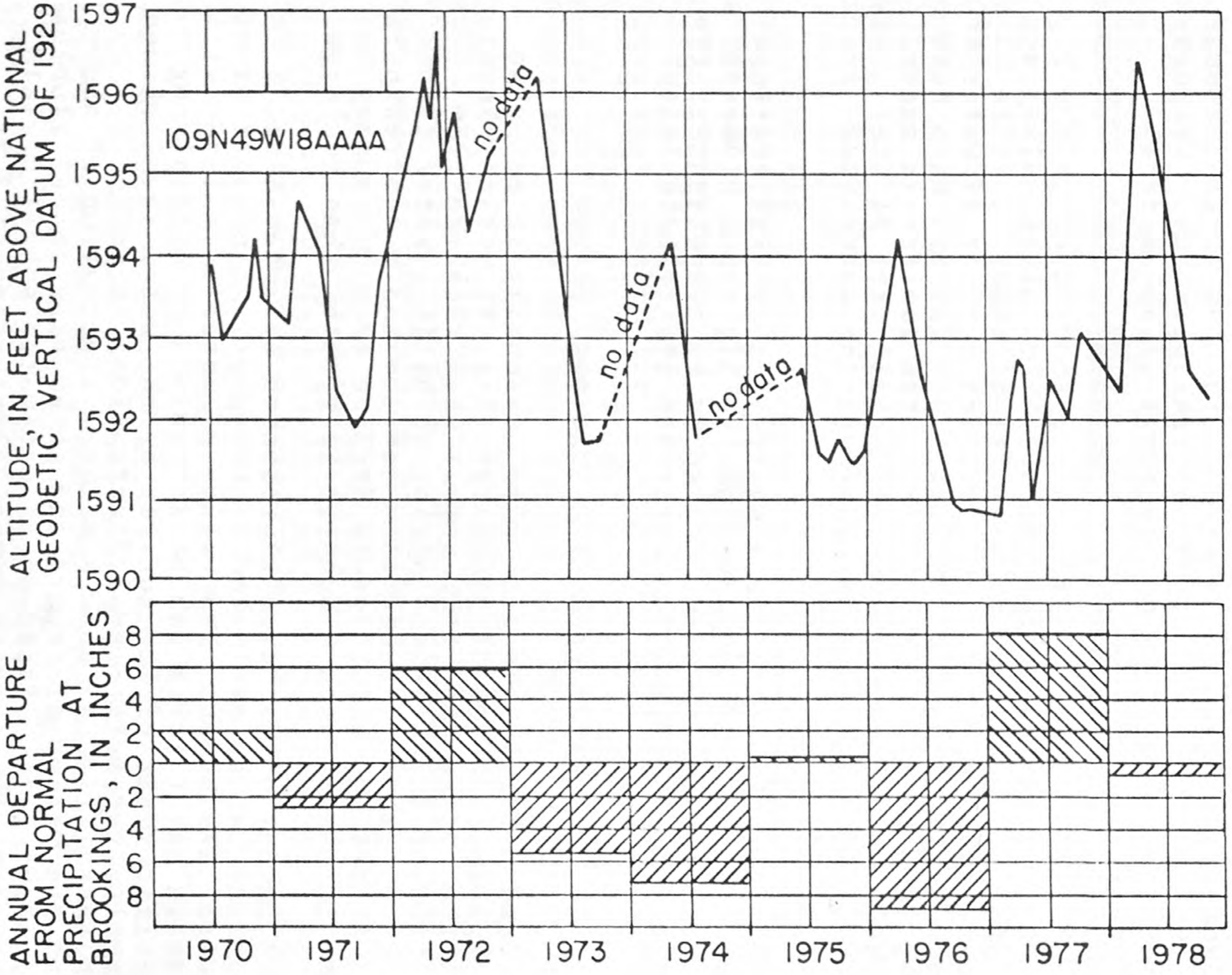


Figure 4. Water-level fluctuations in well 109N49W18AAAA and annual departure from normal precipitation at Brookings.

AQUIFER CHARACTERISTICS

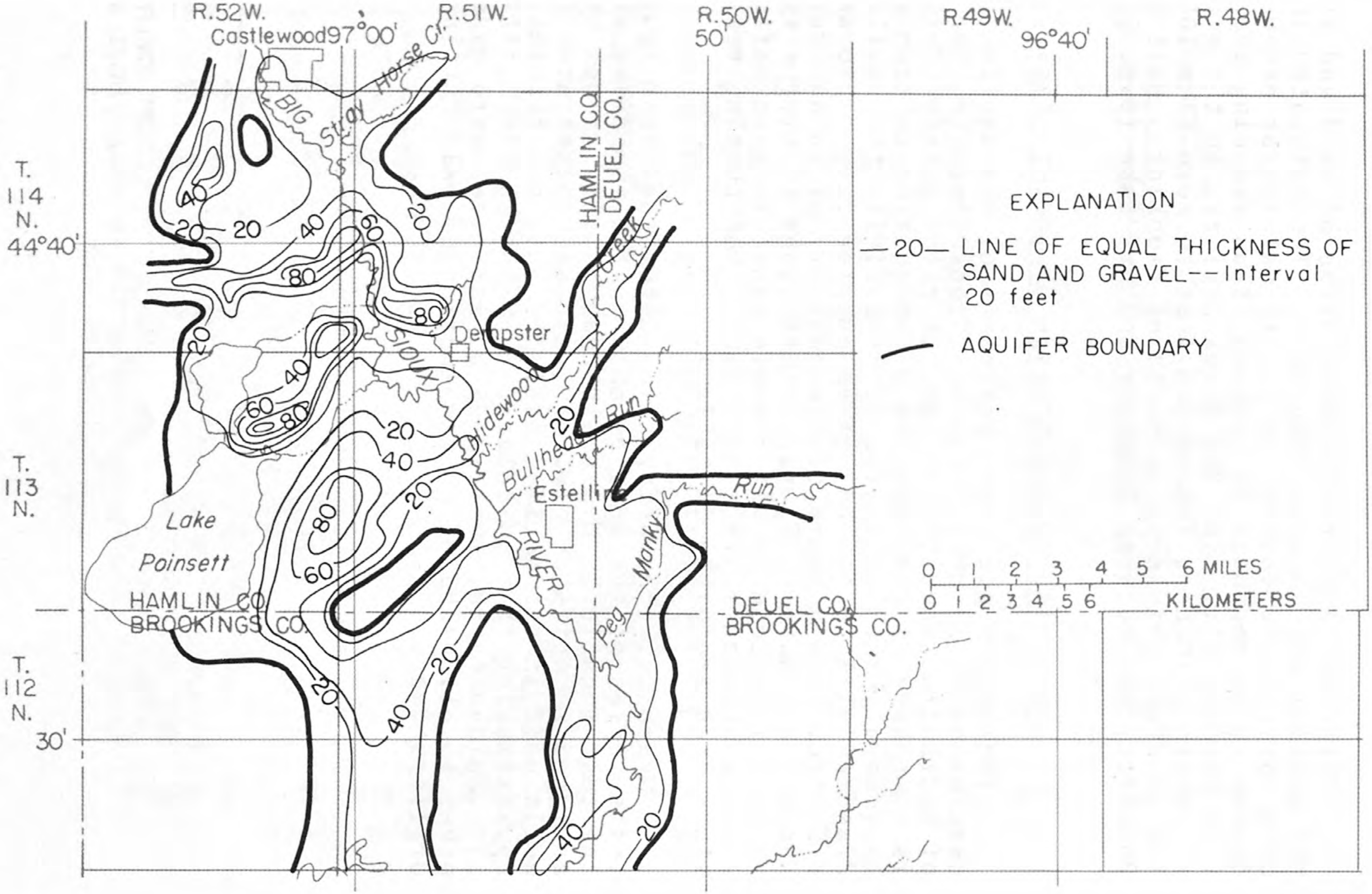
Aquifer Thickness

Thickness and areal distribution of sand and gravel in the aquifer are shown in figure 5. The saturated thickness of a water-table aquifer is a critical factor because it decreases in response to pumping, thus reducing the yield from the aquifer. The Big Sioux aquifer, in the study area, ranges in thickness from a few feet to more than 100 ft. The greatest thickness is south of Brookings, east of Lake Poinsett, and between Dempster and Dry Lake (fig. 5).

Transmissive and Storage Characteristics

The hydrologic characteristics of the aquifer can be determined from pumping tests. Transmissivity, the product of hydraulic conductivity and saturated aquifer thickness, is a measure of the capacity of an aquifer to transmit water. In general, the larger the transmissivity the smaller the drawdown will be for any given pumping rate. Storage coefficient is a measure of the capacity of an aquifer to store and release water. Storage coefficient is virtually equal to specific yield in water-table aquifers (see definitions). Aquifer characteristics determined from pumping tests in the study area are given in table 1.

Hydrologic characteristics determined from aquifer tests represent the aquifer only in the immediate area of the test location. Hydraulic conductivity values were assigned to units of similar grain size penetrated by the wells used in the aquifer tests to obtain a transmissivity approximating that calculated from the aquifer tests (table 2). Guided by the test results, estimates were made for other locations based on examination of well cuttings and drillers logs.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DEUEL CO.
Creek
SIOUX
Dempster
Hidewood
Bullhead Run
Estelline
Run
Lake Poinsett
RIVER
Peg Monky
HAMLIN CO.
BROOKINGS CO.
DEUEL CO.
BROOKINGS CO.
20
40
60
80
EXPLANATION
—20— LINE OF EQUAL THICKNESS OF SAND AND GRAVEL--Interval 20 feet
AQUIFER BOUNDARY
0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETERS

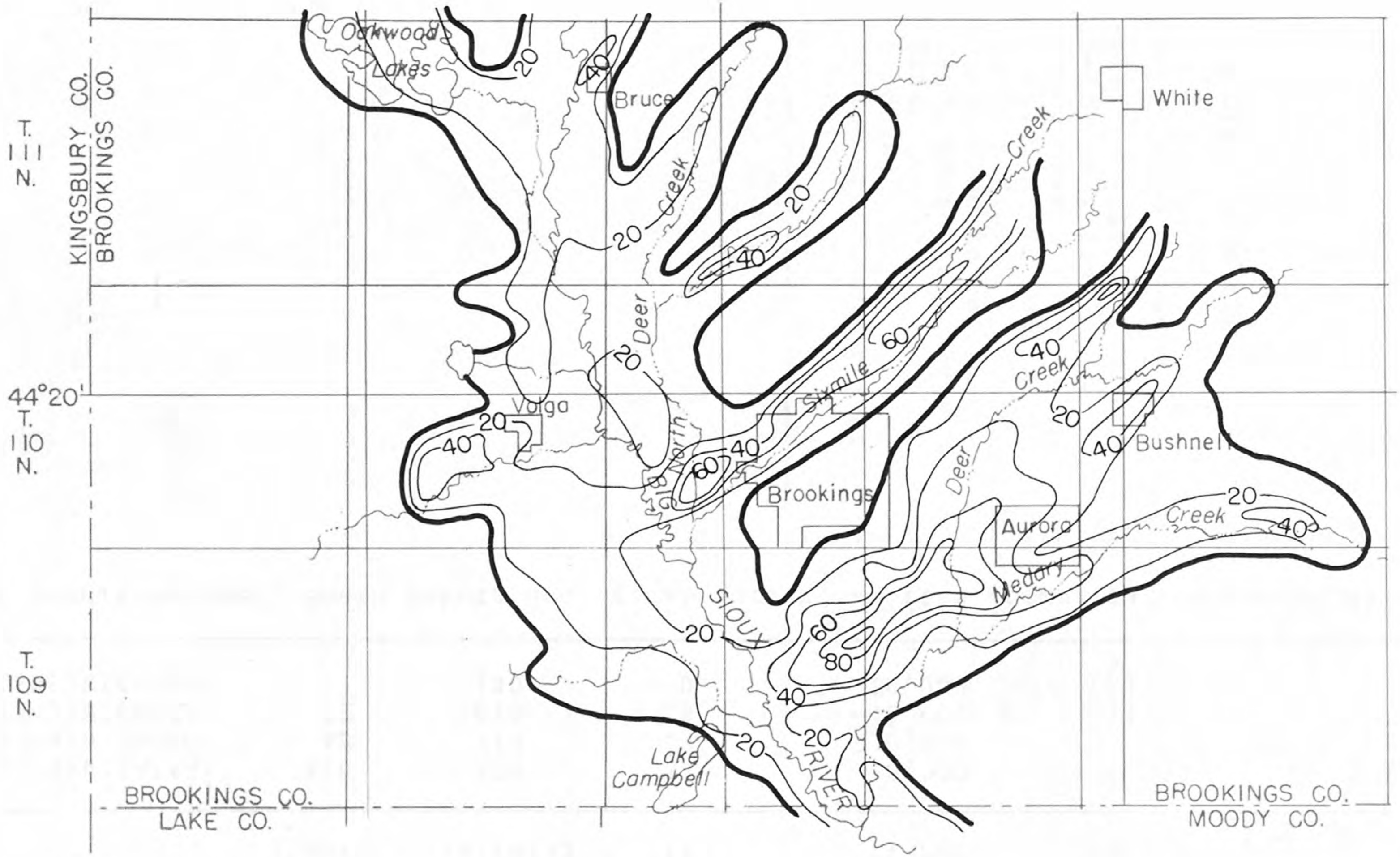


Figure 5. Thickness of sand and gravel in the Big Sioux aquifer.

Table 1.--Results of aquifer tests in the Big Sioux aquifer.

Location	Length of test (hours)	Average pumping rate (gal/min)	Aquifer thickness (ft)	Transmissivity (ft^2/d)	Average hydraulic conductivity (ft/d)	Specific yield
112N51W25AAAA[1]	116	470	34	20,000	600	0.11
113N51W 3DACC	42	710	40	20,000	500	.10
113N51W26ACAA	72	810	28	42,000	1,500	.10
115N52W35CCCC5	7	140	20	20,000	1,000	.17

[1] Dennis Beissel, South Dakota Geological Survey, written communication, April 1976.

Table 2.--Relationship between grain size class and hydraulic conductivity.

Grain size class	Range of hydraulic conductivity in glacial drift (ft/d)	Hydraulic conductivity used in model based on local aquifer tests (ft/d)
Clay or silt	<20	10
Sand, very fine	10-80	40
Sand, fine	70-140	70
Sand, fine to medium	70-400	200
Sand, medium	130-400	270
Sand, fine to coarse	70-600	300
Sand, medium to coarse	130-800	400
Sand, coarse	400-1,000	540
Sand and gravel	400-1,200	600
Sand, coarse, and gravel	400-1,400	670
Gravel	800-2,000	800

GROUND-WATER - SURFACE-WATER RELATIONSHIPS

Ground water is in hydraulic connection with most of the streams and lakes in the study area. Nearly 50 percent of the mid-summer streamflow at the gaging station on the Big Sioux River south of Brookings results from ground-water inflow. Lake Poinsett and Oakwood Lakes are maintained by the aquifer and discharge water by evaporation. Recharge of surface water from the Big Sioux River to the aquifer may occur in short reaches. Recharge to the aquifer from the river during overbank flow occurs occasionally. Water-level declines could induce additional recharge from the streams or divert ground water that, under nonpumping conditions, is discharged to the streams.

Streamflow measurements during base flow were made at 29 locations to determine the quantity of ground-water discharge. Results of measurements made on July 25 and 26, 1978, and on October 10 and 11, 1978, are shown in figure 6. No appreciable amount of precipitation occurred at or shortly before these periods. The total gain to the Big Sioux River in the study area from ground water, discounting tributary stream inflow, was 50.4 ft^3/s for the July measurement and 17.9 ft^3/s for the October measurement. Assuming that flow during July and October in the tributary streams is all ground-water discharge, the total gain in streamflow was 85 ft^3/s for July and 24 ft^3/s for October. The average annual base flow within the study area determined from hydrographs of daily discharge for water years 1970-76 at the streamflow gaging station on the Big Sioux River south of Brookings was 58 ft^3/s. This amounts to an average water-level change of 1.46 ft/yr with a specific yield of 15 percent or 2.19 ft/yr with a specific yield of 10 percent which is a storage change of about 42,000 acre-ft in the 300 mi^2 aquifer. This average annual storage change is offset on the average by an equal amount of recharge each spring.

When measurements were made at several locations on the same stream, most reaches were gaining water and a few reaches were losing water. Of particular interest is a 4-mi reach on Deer Creek west of Bushnell (fig. 6). During July, this 4-mi reach gained almost 1 ft^3/s but during October it lost about 8.5 ft^3/s. In July the aquifer was discharging ground water to Deer Creek but by October the water table had declined sufficiently as a result of nearby pumping so that Deer Creek was recharging the aquifer in the 4-mi reach.

Low-flow characteristics of a stream are important when a well in the aquifer obtains part of the water from the stream. Frequency curves for different periods of sustained low flow during the growing season are shown in figure 7.

WATER QUALITY

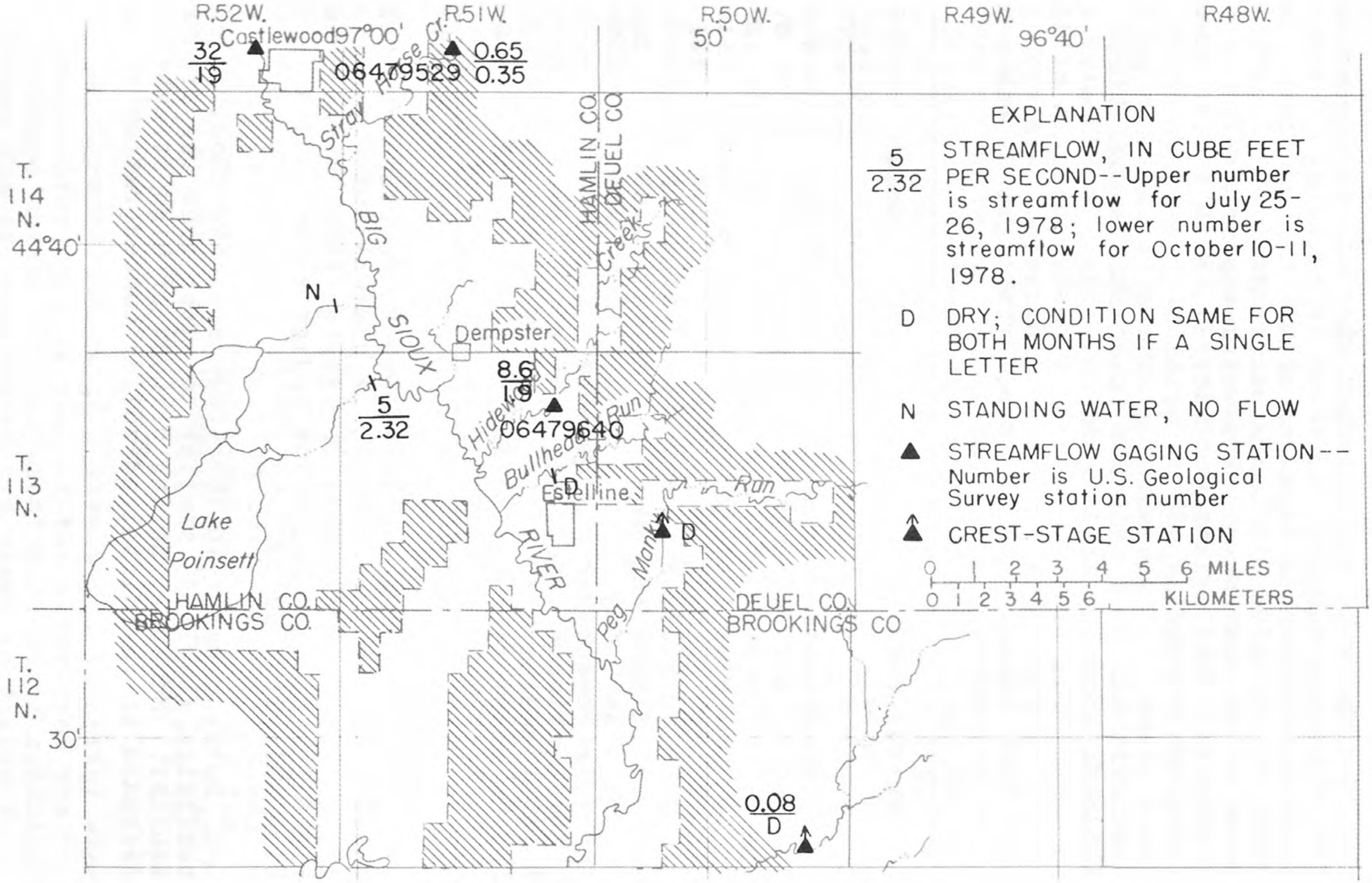
A summary of the chemical characteristics of water from the Big Sioux aquifer are shown in table 3. The water was calcium bicarbonate type and specific conductance ranged from 407 to 1,790 micromhos per centimeter at 25°C with a mean of 802 micromhos. The water was generally very hard [>180 mg/L (milligrams per liter)], with a mean hardness as $CaCO_3$ of 454 mg/L.

Table 3.--Summary of 86 chemical analyses of water from the Big Sioux aquifer. (Constituents in milligrams per liter except as indicated. Analyses by Water Resources Institute, Brookings, S. Dak., and U.S. Geological Survey.)

Constituent	Mean	Range
Calcium, dissolved (Ca)	112	46 - 300
Magnesium, dissolved (Mg)	42	0.5- 110
Sodium, dissolved (Na)	18	3 - 84
Potassium, dissolved (K)	4.8	1 - 24
Bicarbonate (HCO_3)	344	181 - 624
Chloride, dissolved (Cl)	9.3	2 - 84
Sulfate, dissolved (SO_4)	139	24 - 800
Hardness as $CaCO_3$	454	230 -1,100
Specific conductance (micromhos per centimeter at 25°C)	802	407 -1,790
Percent sodium	7.3	2 - 20
Sodium adsorption ratio (SAR)	0.5	0.1- 6

The diagram shown in figure 8, developed by the U.S. Salinity Laboratory (1954), is commonly used to determine the suitability of water for irrigation. Water from the Big Sioux aquifer has a low sodium hazard and a medium to high salinity hazard.

Surface water in the study area has chemical characteristics (table 4) similar to water from the Big Sioux aquifer. However, during periods of high streamflow a decrease in the dissolved-solids concentration is apparent.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44°40'
T. 113 N.
T. 112 N.
30'
Castlewood
32/19
Stray Horse Cr.
06479529
0.65/0.35
HAMLIN CO.
DEUEL CO.
Creek
BIG SIOUX RIVER
N
Dempster
5/2.32
8.6/1.9
06479640
Hidewood
Bullhead Run
D
Estelline
Run
D
Monkey
Peg
Lake Poinsett
HAMLIN CO.
BROOKINGS CO.
DEUEL CO.
BROOKINGS CO
0.08/D
EXPLANATION
5/2.32 STREAMFLOW, IN CUBE FEET PER SECOND--Upper number is streamflow for July 25-26, 1978; lower number is streamflow for October 10-11, 1978.
D DRY; CONDITION SAME FOR BOTH MONTHS IF A SINGLE LETTER
N STANDING WATER, NO FLOW
▲ STREAMFLOW GAGING STATION--Number is U.S. Geological Survey station number
▲ CREST-STAGE STATION
0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETERS

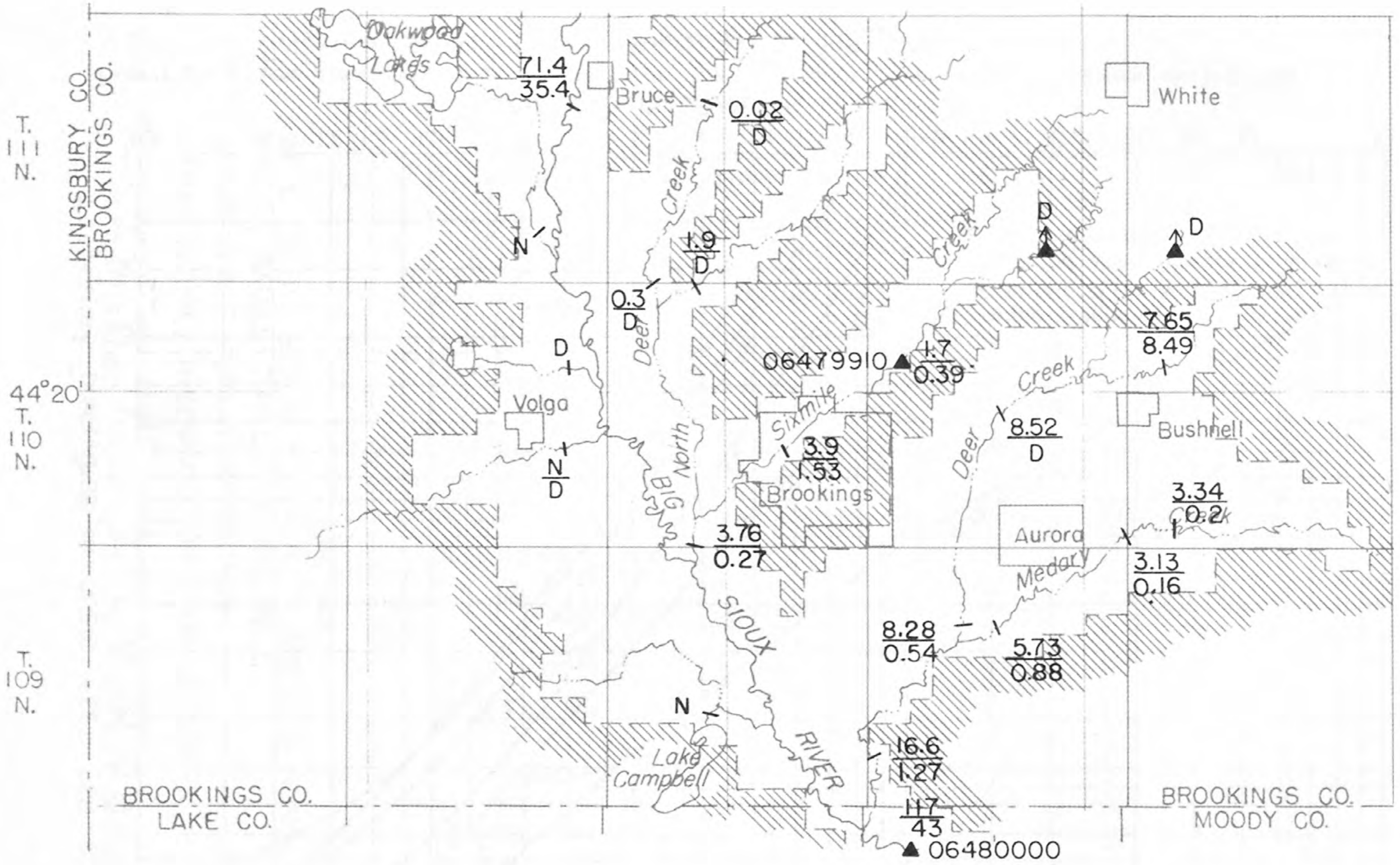


Figure 6. Low-flow measurements for July 25-26 and October 10-11, 1978.

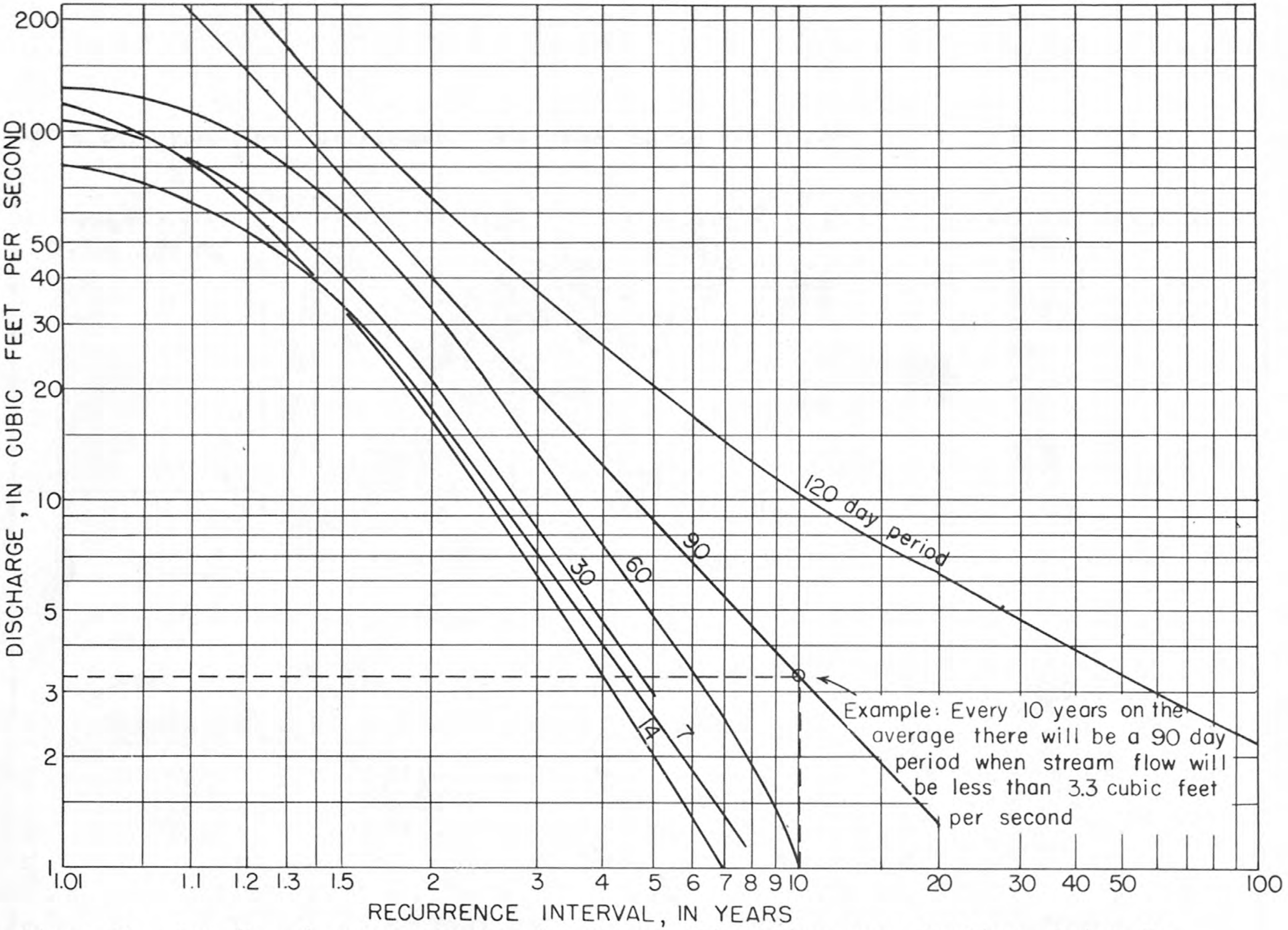
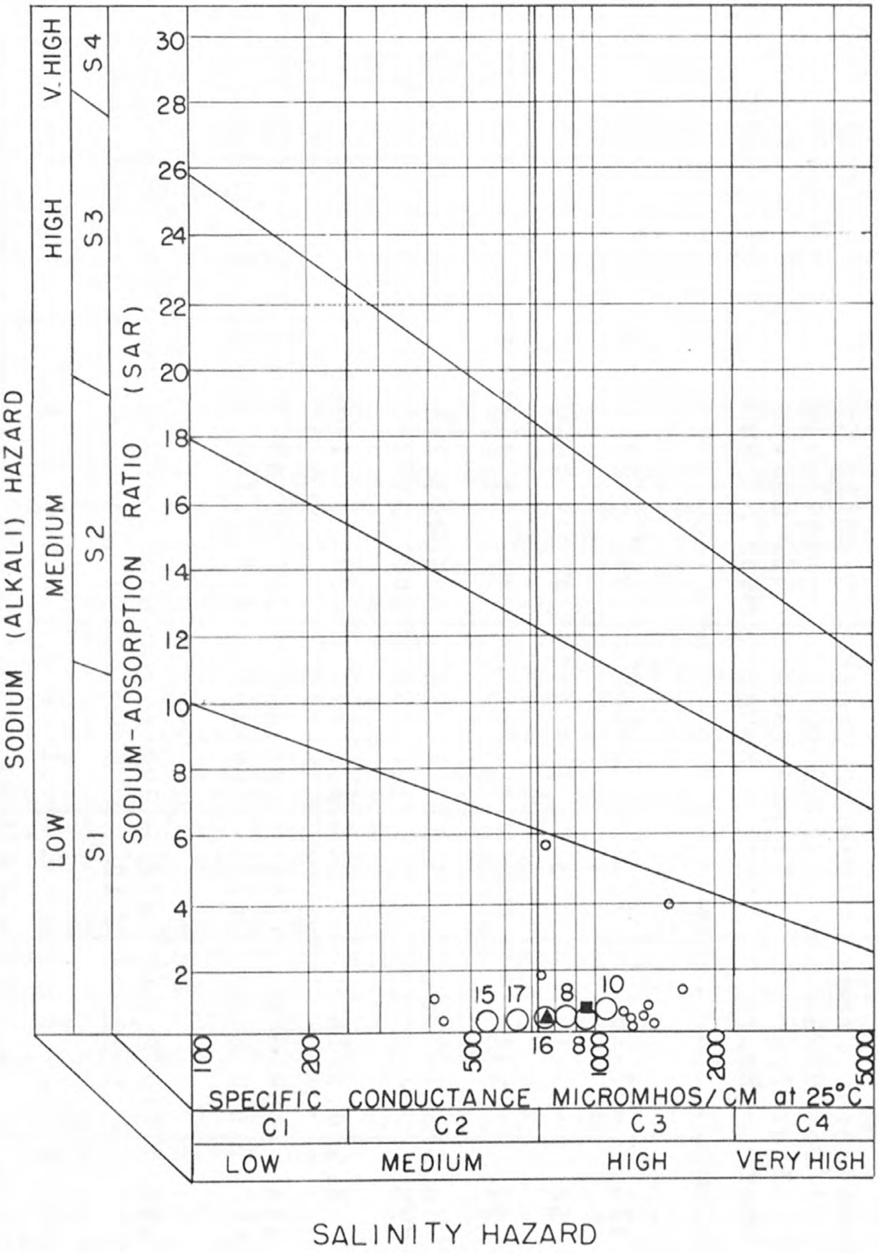


Figure 7. Low-flow frequency curves for the Big Sioux River near Brookings during the irrigation period (May 1 – September 30, 1954-77).



EXPLANATION

15 ○ WELL IN BIG SIOUX AQUIFER; NUMBER IS NUMBER OF WELLS; SMALL CIRCLE IS ONE WELL

▲ BIG SIOUX RIVER AT BROOKINGS

■ STRAY HORSE, HIDEWOOD, OR SIXMILE CREEK

Figure 8. Diagram of classificatition of water for irrigation use. (Classification developed by United States Salinity Laboratory staff, 1954)

Table 4.--Summary of chemical analyses of surface water. (Analyses by U.S. Geological Survey. Constituents in milligrams per liter, except as indicated.)

Constituent	Strayhorse Creek 1/06479529 73 analyses		Hidewood Creek 06479640 73 analyses		Sixmile Creek 06479910 57 analyses		Big Sioux near Brookings 06480000 109 analyses	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Calcium, dissolved (Ca)	115	37-160	103	42-160	104	52-150	81	25-155
Magnesium, dissolved (Mg)	54	12-100	42	14-74	47	18-68	40	12-57
Sodium, dissolved (Na)	22	3.7-50	24	5.8-55	37	7.2-220	26	5.4-45
Potassium, dissolved (K)	6.3	5.1-7.6	5.4	4-7.2	5.4	3.2-14	6.9	3-12
Bicarbonate (HCO_3)	223	94-275	279	128-338	263	109-381	276	81-461
Chloride, dissolved (Cl)	8.5	4.2-13	9.7	4.9-27	29	4.1-280	17	.0-36
Sulfate, dissolved (SO_4)	359	69-670	241	65-500	262	89-410	174	54-283
Hardness as $CaCO_3$	512	140-810	433	160-700	454	200-630	368	110-621
Specific conductance (micromhos per centimeter at 25°C)	987	310-2,000	974	290-1,750	960	450-2,040	777	272-1,130
Percent sodium	7	5-12	10	6-14	12	7-47	13	7-18
Sodium adsorption ratio (SAR)	.4	.1-.8	.4	.2-.9	.7	.2-4.2	.5	.2-.9

1/ U.S. Geological Survey identification number (see fig. 6).

DIGITAL MODEL

A digital model of an aquifer system solves mathematical equations describing ground-water flow. The model developed by Trescott, Pinder, and Larson (1976) used in this study uses a digital computer for numerically solving the partial differential equations. Finite-difference methods are used to calculate approximate solutions to the partial differential equation.

Model Development

A map of the project area was prepared showing the aquifer boundaries, lakes, and stream locations (fig. 2). A 0.5-mi grid network was superimposed on the map. The network has 78 rows and 57 columns, a total of 4,446 cells. Each cell contains a node at its center. These nodes are points at which flow equations are evaluated even though the cell represents a volume of the aquifer through which flow is occurring. At each node the altitude of the top of the aquifer, the altitude of the bottom of the aquifer, the altitude of the land surface, the aquifer or till hydraulic conductivity, and the specific yield are entered into the computer. Boundary conditions, including streams and lakes also are entered at the appropriate nodes.

The model was developed based on existing hydrologic conditions. A number of simplifying assumptions were used in the model to make it possible to describe the aquifer mathematically. The assumptions represent, in concept, the hydrologic process being described.

The basic hydrologic assumptions used in the model of the Big Sioux aquifer are:

(1) The alluvium-mantled outwash aquifer is a single unconfined (water table) aquifer except in the northwestern part of T. 112 N., R. 51 W. and the eastern part of T. 113 N., R. 50 W. where it is a confined (artesian) aquifer.

(2) The aquifer is hydraulically connected to the Big Sioux River and its tributaries and to Lake Poinsett and Oakwood Lakes.

(3) The flow in the aquifer is horizontal and two-dimensional.

(4) On the perimeter of the model there is either a no-flow condition, or a constant potentiometric-head condition corresponding to lakes and streams (fig. 11).

(5) Recharge to the aquifer is from ground-water inflow from till, streamflow and lake recharge, and infiltration of precipitation to the aquifer surface.

(6) Ground water is discharged by pumping from wells, evapotranspiration, and flow to streams and lakes.

(7) The average stream stage remains constant throughout the steady-state simulation but under transient conditions, some constant potentiometric-head stream nodes are removed when the stream becomes dry.

(8) Evapotranspiration is a linear function of depth below land surface. Evapotranspiration is maximum at land surface and decreases linearly to zero at a designated depth below land surface.

(9) Return flow from irrigation is not modeled because most irrigators are under irrigating which holds the irrigation water in the soil zone.

(10) Transmissivity is head dependent except in the artesian area.

Calibration of the Equilibrium Model

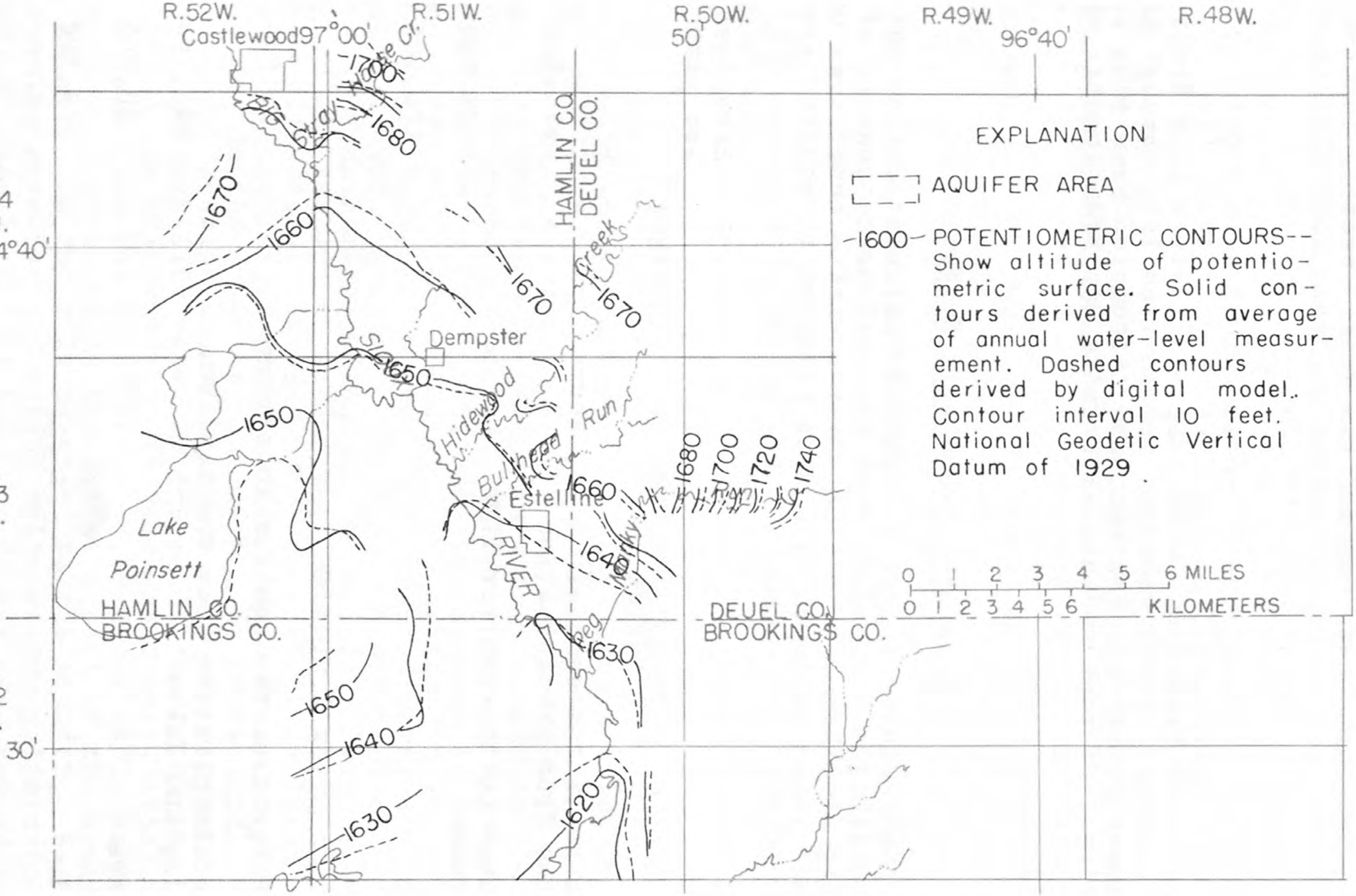
The model was calibrated under equilibrium (steady-state) conditions before it was used to predict the effects of development. Average annual water levels for 1970 through 1976 were used as the potentiometric head in the aquifer. Hydraulic-conductivity values were estimated from about 700 driller's logs using the values shown in table 2. Hydraulic conductivity of the till was assigned a value of 10 ft/d. Altitude of the land surface was determined from topographic maps. Altitudes of the top and bottom of the aquifer were determined using driller's logs. Evapotranspiration was assumed to be maximum (33 in/yr) where ground-water levels were at the land surface, such as in lakes and streams. Evapotranspiration was assumed to decrease linearly to zero for depths to water more than 5 ft below land surface. The average annual recharge rate was estimated by using the permeability rates of the soils overlying the aquifer and the adjacent till (Westin and others, 1959). The recharge rate was 6.57 in/yr to the water table part of the aquifer, 3.29 in/yr to the artesian part of the aquifer, and 0.06 in/yr to the till adjacent to the aquifer. Based on a pumping rate for irrigation wells of 500 gal/min for 45 days, an annual rate of 101 acre-ft was used for 67 irrigation wells. An annual pumping rate of 1,281 acre-ft was used for the Brookings-Sixmile well field and 536 acre-ft for the East well field. Constant potentiometric-head values were placed on stream nodes where the water stage remains above land surface throughout the year. Where a constant potentiometric-head is placed on a stream node the stream is considered to be fully penetrating.

Computed potentiometric-head values were about the same as those determined from the 7 years of record (fig. 9). The measured base flow in the Big Sioux River near Brookings as determined from 7 years of record from 1970 through 1976 was about 58 ft^3/s. The computer calculated base flow was 66 ft^3/s. Of that amount, 48.5 ft^3/s was from the Big Sioux River, 14.3 ft^3/s was from Medary Creek, and 2.9 ft^3/s was from Sixmile Creek.

Simulated Hydrologic Budget

A hydrologic budget of computer calculated flow rates at equilibrium associated with the various components of the Big Sioux aquifer system for the entire model area of 700 mi^2 which includes till area adjacent to aquifer are shown below:

	Acre-feet per year
INFLOW	
Recharge to the aquifer, till, and lakes from precipitation	156,400
Recharge to the aquifer from streams	23,000
Total	179,400
OUTFLOW	
Discharge from the aquifer to streams	65,600
Evapotranspiration from the aquifer, till, and lakes	103,200
Pumpage	10,600
Total	179,400


R.52W.
R.51W.
R.50W.
R.49W.
R.48W.
Castlewood
97°00'
50'
96°40'
T. 114 N.
44°40'
T. 113 N.
T. 112 N.
30'
Big Sioux
Gray Horse Cr.
Hidewood
Bullhead Run
Creek
Peg Munky
Dempster
Estelline
RIVER
Lake Poinsett
HAMLIN CO.
DEUEL CO.
HAMLIN CO.
BROOKINGS CO.
DEUEL CO.
BROOKINGS CO.
1700
1680
1670
1660
1670
1670
1650
1650
1660
1680
1700
1720
1740
1640
1630
1650
1640
1630
1620
EXPLANATION
AQUIFER AREA
1600 POTENTIOMETRIC CONTOURS--Show altitude of potentiometric surface. Solid contours derived from average of annual water-level measurement. Dashed contours derived by digital model. Contour interval 10 feet. National Geodetic Vertical Datum of 1929.
0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETERS

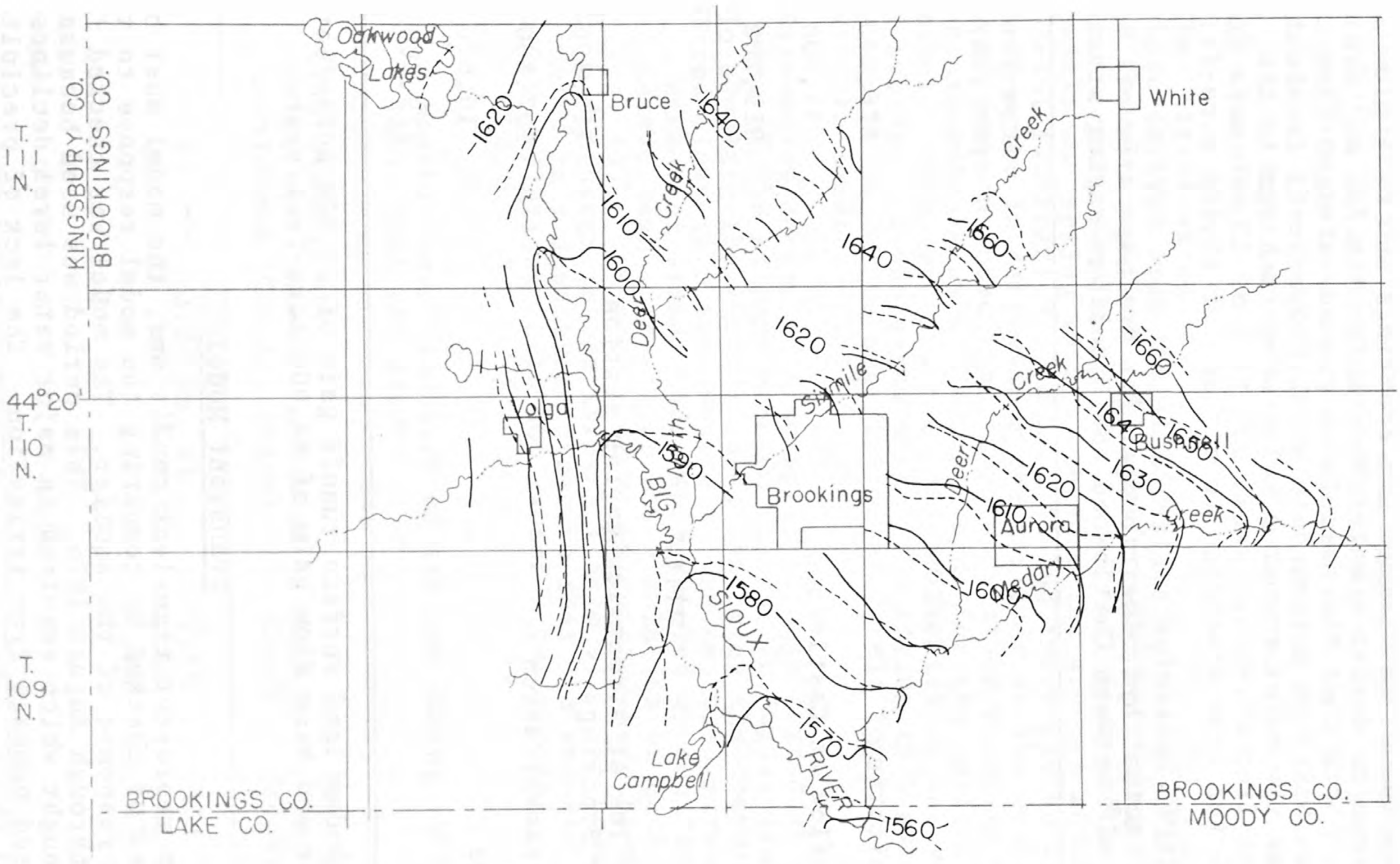


Figure 9. Comparison of measured and model computed potentiometric surfaces in the Big Sioux aquifer.

A hydrologic budget can also be devised by using actual data. The following hydrologic budget uses average streamflow values at Castlewood and Brookings and base flow at Brookings to derive a water budget for the 740 mi^2 drainage basin. Note that the calculated ground-water outflow to streams based on actual data of 42,000 acre-ft is about the same as the model computed value when recharge to the aquifer from streams, lakes, and till of 23,000 acre-ft is subtracted from discharge to streams of 65,600 acre-ft.

Actual hydrologic budget for drainage area of 740 mi^2 between Castlewood and Brookings gaging stations

	Acre-feet per year
INFLOW	
Precipitation	876,200
Streamflow at Castlewood	43,000
Total	919,200
OUTFLOW	
Streamflow at streamflow gaging station near Brookings	110,800 1/
Evapotranspiration	797,800
Pumpage	10,600
Total	919,200

1/ Includes land surface runoff gain of 25,800 acre-feet/year and base flow gain of 42,000 acre-feet/year.

Transient Model

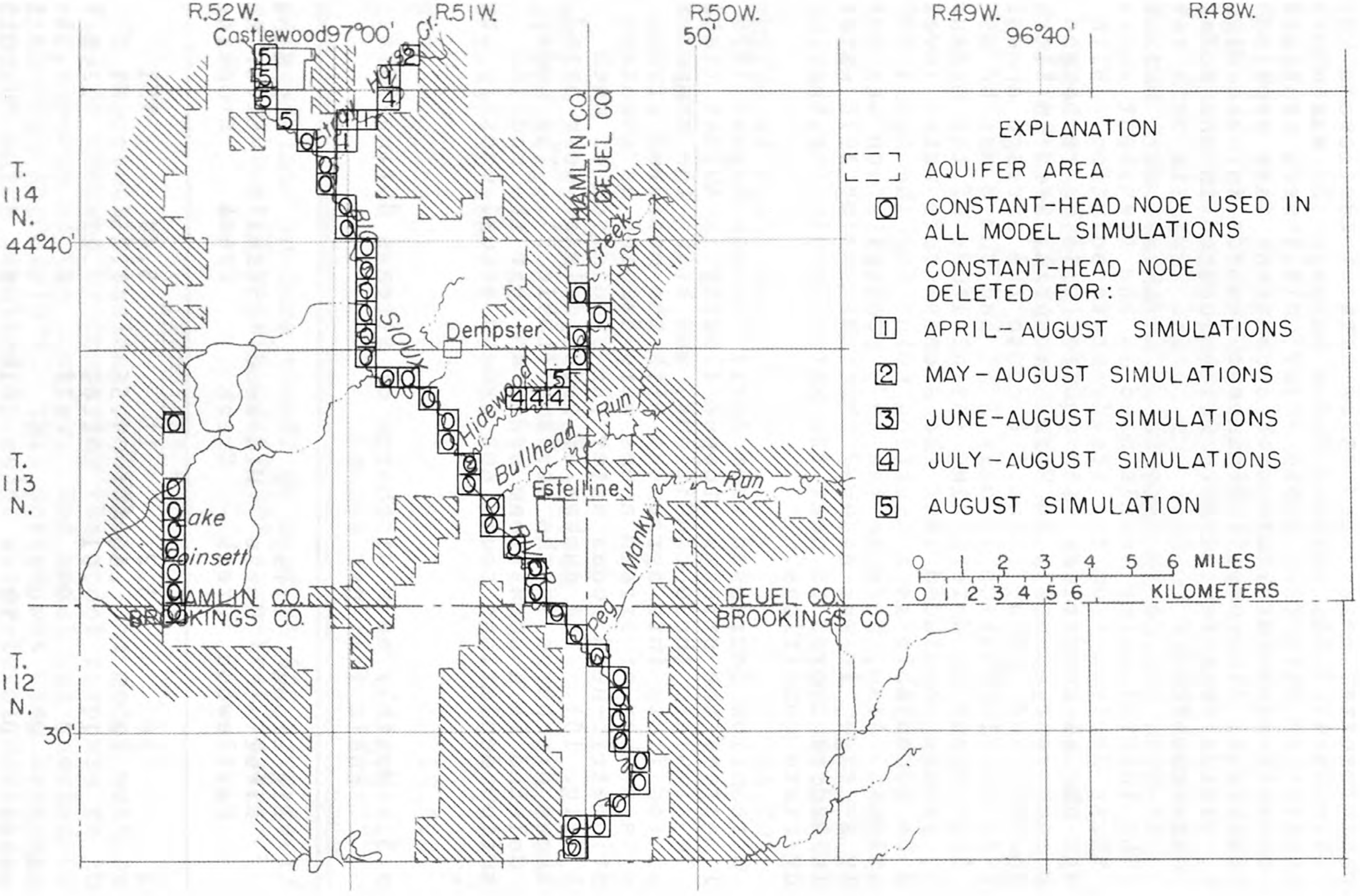
To represent transient conditions, the model must be verified or checked by comparing the model response to the actual response of the aquifer. The model was checked for April through August 1976. This period was used because of the drought which resulted in major water-level declines and increased pumpage from irrigation. The lack of precipitation enabled the transient run to be made without using a recharge factor. Additional water-level data were obtained throughout this period to allow for better comparison of field data with computer results. Also streamflow data at Castlewood was not available until 1976. Ground-water pumpage and maximum evapotranspiration data (see table 7 for units) were separated into monthly time intervals with a constant rate applied for each interval. In compiling pumpage records for the digital model, yields from two or more wells located in one nodal area were combined.

The initial water levels used in the transient analysis were those derived from the steady-state solution. With average annual conditions, the aquifer will be recharged fully each year, usually in March or April, from infiltration of snowmelt and spring rains. Because the average annual water-level fluctuation is only 3 ft and there may be as much as a 3-ft error in determining the altitude of the measuring point, it was concluded that the steady-state water levels would be acceptable as a starting point for the April 1976 conditions. Also, because the 1975 precipitation was very nearly average, it was assumed that the spring 1976 water levels had recovered to near the water levels for the steady-state conditions.

Streamflow decreased from April through August 1976 until most of the streams stopped flowing in August (table 5). To simulate these conditions, and bring the computer calculated flows into agreement with the measured streamflows, a number of stream nodes were deleted as constant potentiometric-head nodes after the simulation of each month (fig. 10). The number of nodes deleted were based on the known discharge in the streams (table 5). The nodes were deleted in a downstream order so that the modeled streamflow depletions could not exceed actual monthly streamflow.

Table 5.--Monthly mean discharge of streams during 1976, in cubic feet per second.

	Big Sioux River at Castlewood	Stray Horse Creek	Hidewood Creek	Sixmile Creek	Big Sioux River near Brookings
April	50	3.2	11	5.44	131
May	20	.46	4.55	1.25	51.7
June	1	.01	1.65	.12	13.5
July	0	0	.27	0	.94
August	0	0	0	0	.016
September	0	0	.016	0	.011


R.52W.
R.51W.
R.50W.
R.49W.
R.48W.
Castlewood
97°00'
50'
96°40'
T. 114 N.
44°40'
T. 113 N.
T. 112 N.
30'
Big Sioux River
Stray Horse Cr.
Hidewood
Bullhead Run
Creek
Peg Manky Run
Lake Poinsett
Dempster
Estelline
HAMLIN CO.
DEUEL CO.
BROOKINGS CO.
EXPLANATION
AQUIFER AREA
0 CONSTANT-HEAD NODE USED IN ALL MODEL SIMULATIONS
CONSTANT-HEAD NODE DELETED FOR:
1 APRIL-AUGUST SIMULATIONS
2 MAY-AUGUST SIMULATIONS
3 JUNE-AUGUST SIMULATIONS
4 JULY-AUGUST SIMULATIONS
5 AUGUST SIMULATION
0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETERS

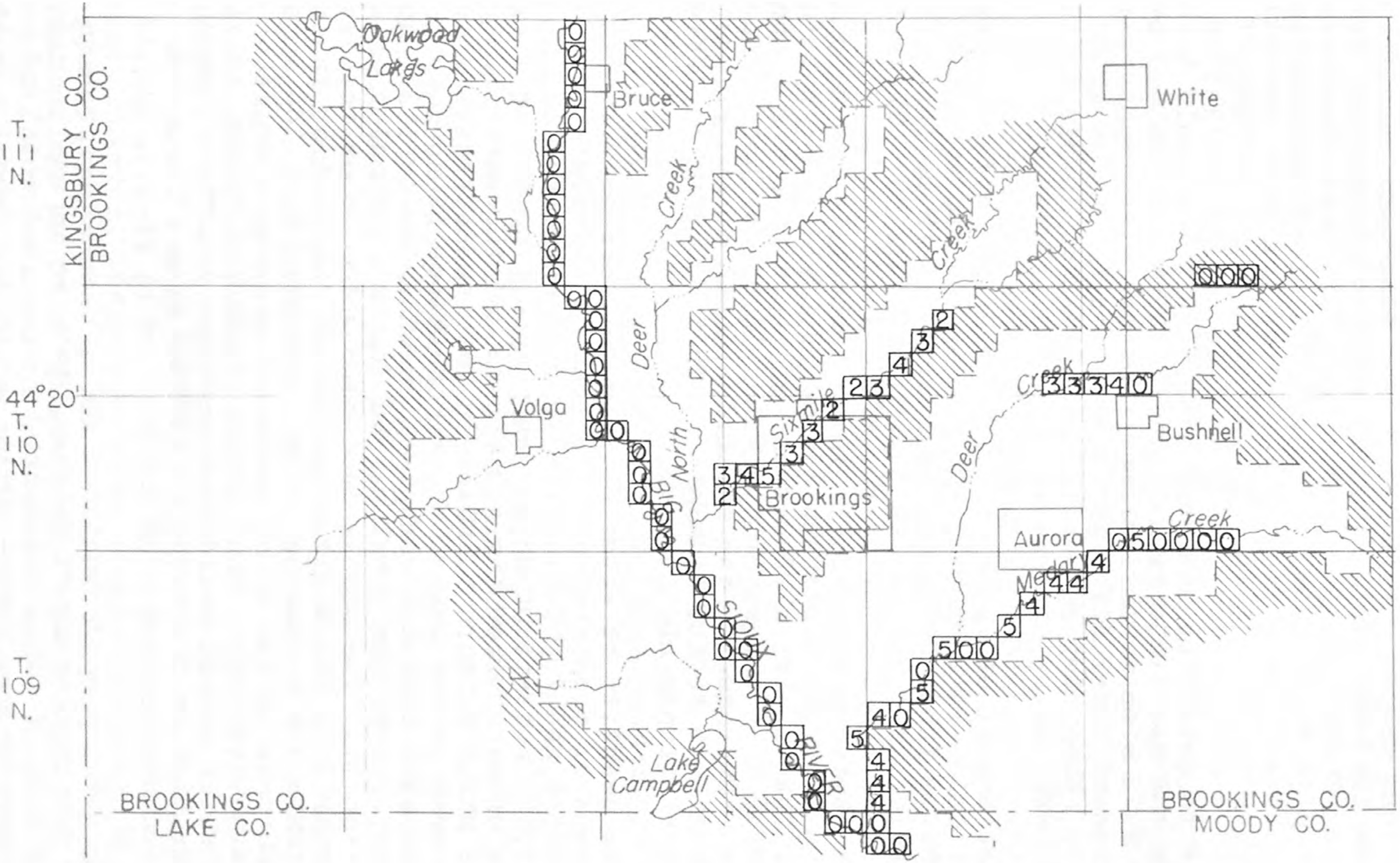


Figure 10. Location of constant potentiometric head nodes used in model.

Several transient simulations were made using evapotranspiration data for 1976. How the different transient simulations compared with calculated base-flow conditions is shown in table 6. A specific yield of 10 percent for the aquifer and till and an effective depth of evapotranspiration of 5 ft (simulation 1) had the best correlation with calculated base-flow data. Water levels in the till were below the effective depth of evapotranspiration of 5 ft. A simulation was made eliminating the irrigation pumpage to determine how much base flow there would have been in the Big Sioux River near Brookings at the end of August 1976 with no irrigation. How the evapotranspiration rate changed under different stress conditions is shown in table 7. When pumpage was increased, water levels declined, further decreasing the evapotranspiration rate.

The amount of water removed from the aquifer by evapotranspiration is controlled mostly by the depth to the water table below land surface. The initial depth to the water table below land surface is shown in figure 11. The water table is within 5 ft of land surface in 33 percent of the aquifer, between 5 and 10 ft in 20 percent, between 10 and 15 ft in 9 percent, between 15 and 20 ft in 5 percent, and greater than 20 ft in 23 percent of the aquifer. In about 10 percent of the aquifer the water level is above land surface. By changing the effective depth of evapotranspiration from 5 to 10 ft, simulated evapotranspiration increased 60 percent (table 6).

The quantity of water diverted by pumpage from discharge to streams or evapotranspiration can be calculated from data in tables 6 and 7. During the irrigation season of 1976, about 9,300 acre-ft of water was pumped from the aquifer. Removal of water from the aquifer caused the water table to decline which in turn resulted in less evapotranspiration as compared to the amount under conditions of no pumpage. This decrease in evapotranspiration amounted to 1,200 acre-ft or 13 percent of the total pumped (table 7, simulation 4 less simulation 1). The stream lost more water to or received less water from the aquifer because of the decline in the water table due to pumpage. This amounted to 1,760 acre-ft or 19 percent of the total pumpage (table 6, simulation 4 minus simulation 1). Thus about 32 percent of the total ground water pumped would have left the aquifer as evapotranspiration or discharge to streams even if no ground water had been pumped from the aquifer.

When the pumpage included all allowable irrigation permit development as of February 1979 at an application rate of 3 in of water per month, a simulated total of 43,900 acre-ft was pumped during a 116-day (about 4 months) period (simulation 5, table 7). During this simulation, there was a decrease of evapotranspiration compared to the amount without pumpage of 7,800 acre-ft or 18 percent of the total pumped. Discharge to streams decreased 3,600 acre-ft or 8 percent of the total pumped. This amount, 26 percent of the total ground water pumped, would have been discharged from the aquifer by evapotranspiration or to the streams even if there had been no ground water pumped from the aquifer.

Analysis of Development

The model was used to study the effects of ground-water withdrawals associated with irrigation development. The scale of the model was chosen to give a regional assessment of system response. Calculated water-level changes represent average changes for each nodal area of 160 acres. Model simulations were made using 30 days of continuous pumping, which does not strictly correspond to realistic practices of short (3-5 day) pumping periods distributed throughout the irrigation season (about 90 days), but the resultant effect on water levels would be similar.

Water withdrawals from the Big Sioux aquifer will change the natural recharge-discharge relationships. Water-level declines from the pre-pumping water-level position will be produced so that water is transmitted to places of withdrawal. As a result of the declines, water will be released from storage within the aquifer, will be diverted from discharge to streams or evapotranspiration, and may be induced as recharge from streams. In addition, flow across system boundaries (underflow) may be changed.

The model simulated response of the Big Sioux aquifer to actual 1976 water use is shown in figure 12. About 9,300 acre-ft of water was pumped from 124 pumping centers from May through August. This resulted in water-level declines which averaged less than 3 ft in a nodal area (160 acres). Computed water-level declines were on the average within 1 to 2 ft of the measured declines.

Modeled responses of the Big Sioux aquifer to allowable irrigation permit development as of February 1979 under conditions of no recharge from precipitation is shown in figure 13. Constant potentiometric-head nodes on streams were deleted similar to the procedure used for 1976 simulations. The model was stressed to simulate withdrawal of about 43,900 acre-ft of water from 197 pumping centers for 116 days. However, pumping stopped after 103 days when a pumping well caused storage to be depleted at a nodal area. The model is set up to terminate calculations when the value representing storage is zero in a nodal area. Simulated pumping at the pumping center in the nodal area of depletion

Table 6.--Comparison between computer calculated and measured base flow for the Big Sioux River near Brookings, in cubic feet per second.

Measured data		1/Computer data (no recharge)				
1976	Average of last 10 days of month	Specific yield at 10 percent	Specific yield at 15 percent	Specific yield at 10 percent. 2/Evapotranspiration changed from effective depth of 5 to 10 feet	Specific yield at 10 percent; no irrigation pumpage	Allowable irrigation permit development as of February 1979 applying 3 inches of water per month at a pumping rate of 191 cubic feet per second from 197 wells
		Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
April	54	40	44	16	40	13
May	24	24	30	1.5	26	2
June	5.4	10	16	.00	16	.00
July	.035	1.22	7.8	.00	13	.00
August	.01	.00	.66	.00	9	.00
Total	83.4	75.22	98.4	17.5	104	15

1/ Computer simulations were made assuming no recharge. Effective depth of evapotranspiration was 5 feet except for Simulation 3 which was at 10 feet.

2/ Evapotranspiration increased by 60 percent when effective depth of evapotranspiration was changed from 5 to 10 feet.

Table 7.--Comparison between computed monthly evapotranspiration rates using different stresses on the aquifer assuming no recharge.[1]

1976	Maximum evapotranspiration at land surface (inches)	Simulated evapotranspiration, acre-feet				
		Specific yield at 10 percent	Specific yield at 15 percent	Specific yield at 10 percent; effective depth of evapotranspiration changed from 5 to 10 feet	Specific yield at 10 percent; no irrigation pumpage	Allowable irrigation permit development as of February 1979 applying 3 inches of water per month at a pumping rate of 191 cubic feet per second from 197 wells
		Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
April	6.30	14,520	15,650	24,220	14,520	13,390
May	9.41	15,770	17,910	26,360	15,830	13,800
June	12.14	14,340	17,610	24,400	14,460	11,900
July	12.79	12,080	14,880	20,590	12,500	9,820
August	11.46	10,350	12,260	17,020	10,950	8,150
Total		67,060	78,310	112,590	68,260	57,060

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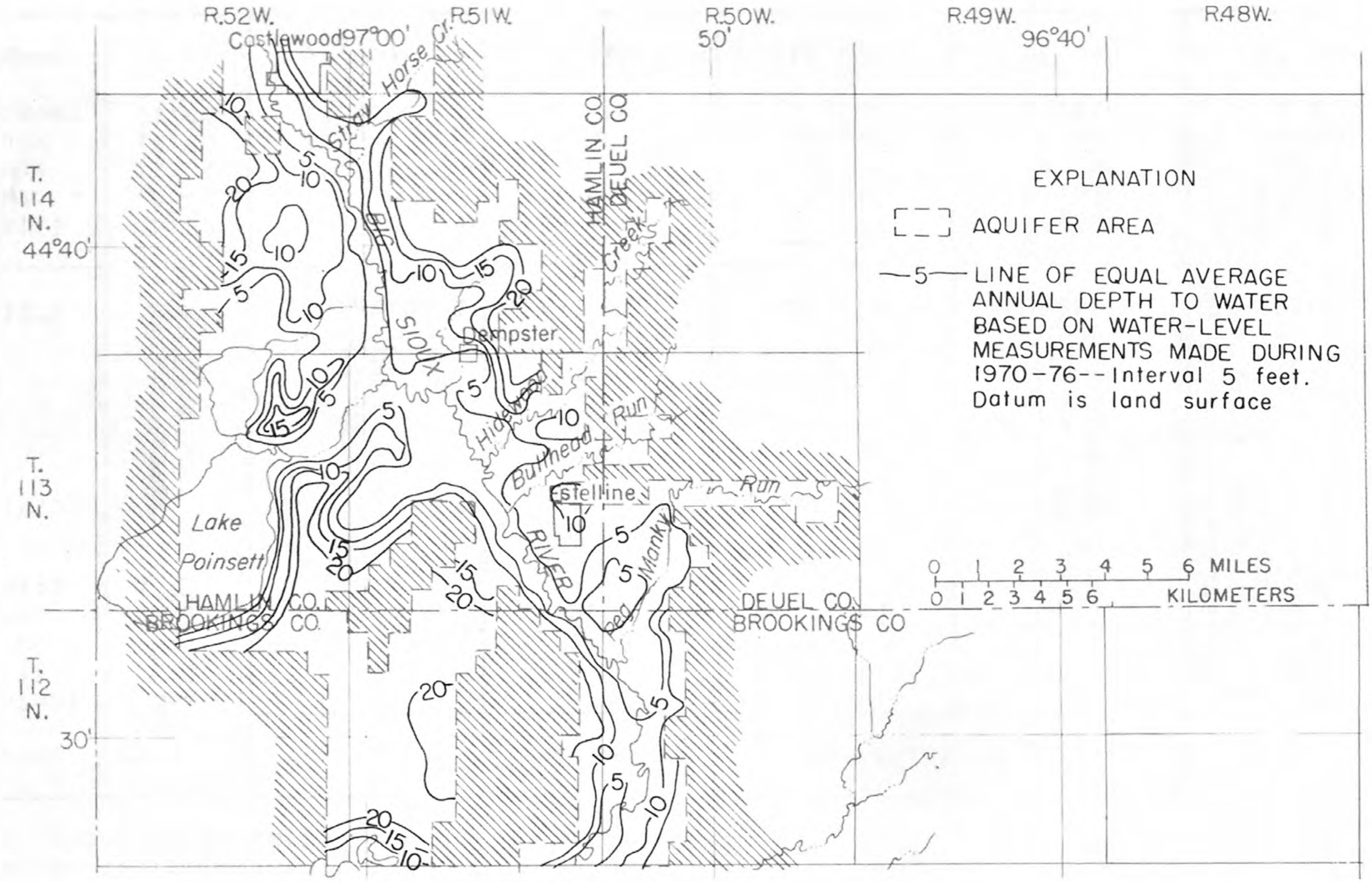
[1] Effective depth of evapotranspiration was 5 feet except for Simulation 3 which was at 10 feet.


R.52W.
R.51W.
R.50W.
R.49W.
R.48W.
Castlewood
97°00'
50'
96°40'
T. 114 N.
44°40'
T. 113 N.
T. 112 N.
30'
Stray Horse Cr.
BIG SIOUX RIVER
HAMLIN CO.
DEUEL CO.
Creek
Dempster
Hidewood
Bullhead Run
Estelline
Run
Lake Poinsett
Peg Monky
HAMLIN CO.
BROOKINGS CO.
DEUEL CO.
BROOKINGS CO
5
10
15
20
EXPLANATION
AQUIFER AREA
—5— LINE OF EQUAL AVERAGE ANNUAL DEPTH TO WATER BASED ON WATER-LEVEL MEASUREMENTS MADE DURING 1970-76--Interval 5 feet. Datum is land surface
0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETERS

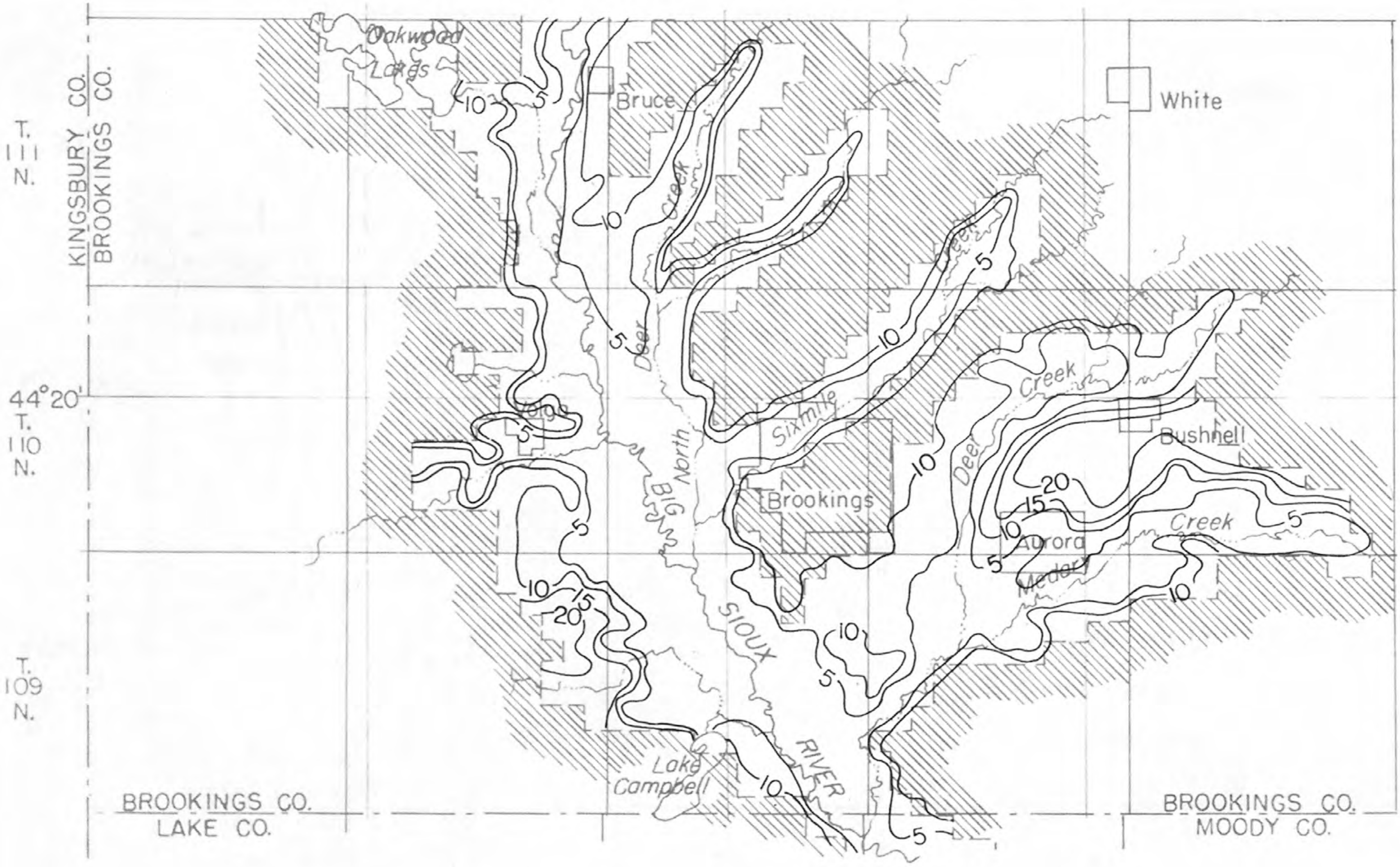
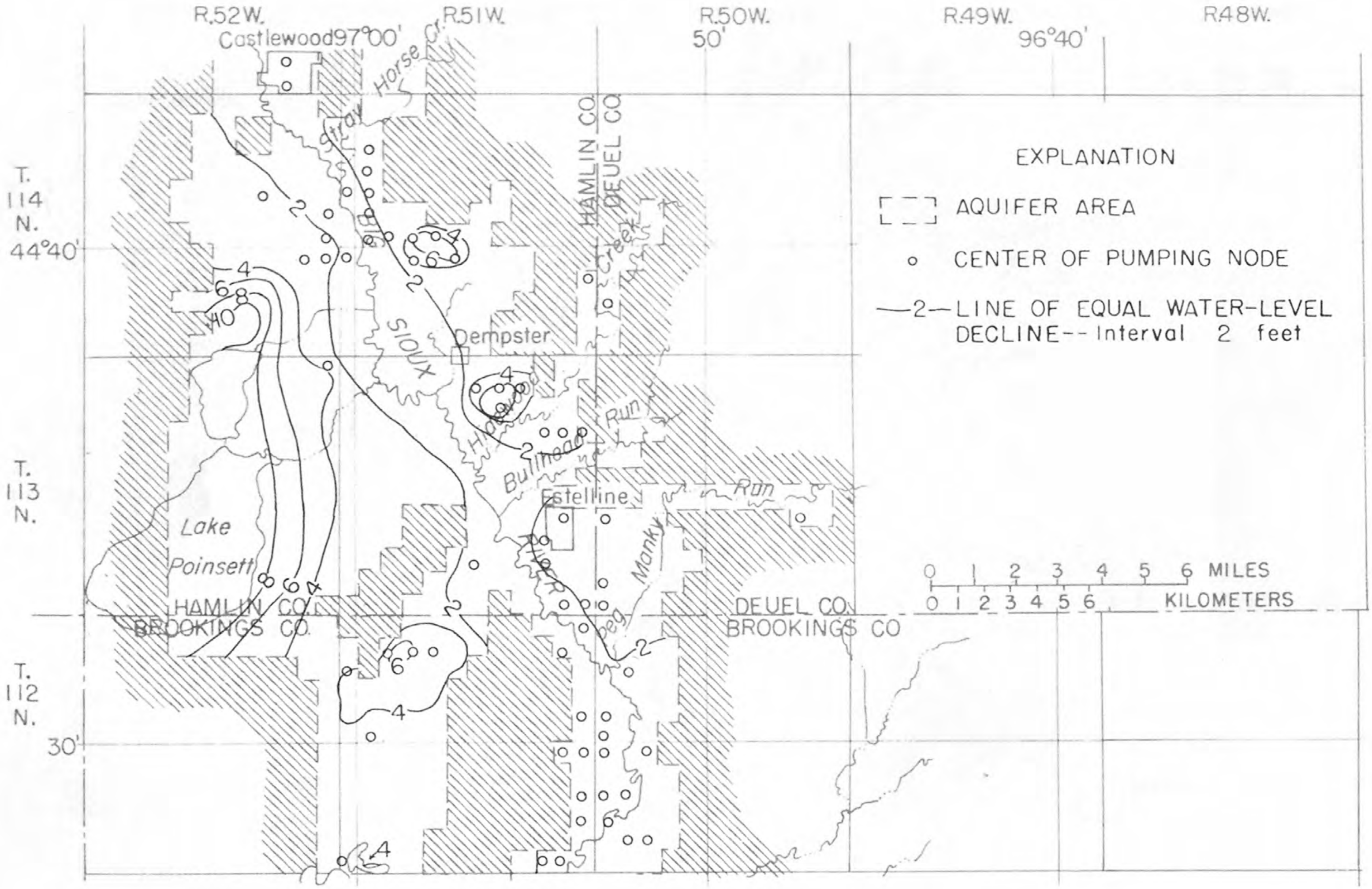


Figure 11. Average annual depth to water.


R.52W.
R.51W.
R.50W.
R.49W.
R.48W.
Castlewood
97°00'
50'
96°40'
T. 114 N.
44°40'
T. 113 N.
T. 112 N.
30'
Stray Horse Cr.
Big Sioux
Dempster
Hidewood
Bullhead Run
Creek
Estelline
Run
Monky
Peg
River
Lake Poinsett
HAMLIN CO.
DEUEL CO.
HAMLIN CO.
BROOKINGS CO.
DEUEL CO.
BROOKINGS CO
2
4
6
8
10
EXPLANATION
AQUIFER AREA
CENTER OF PUMPING NODE
—2— LINE OF EQUAL WATER-LEVEL DECLINE--Interval 2 feet
0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETERS

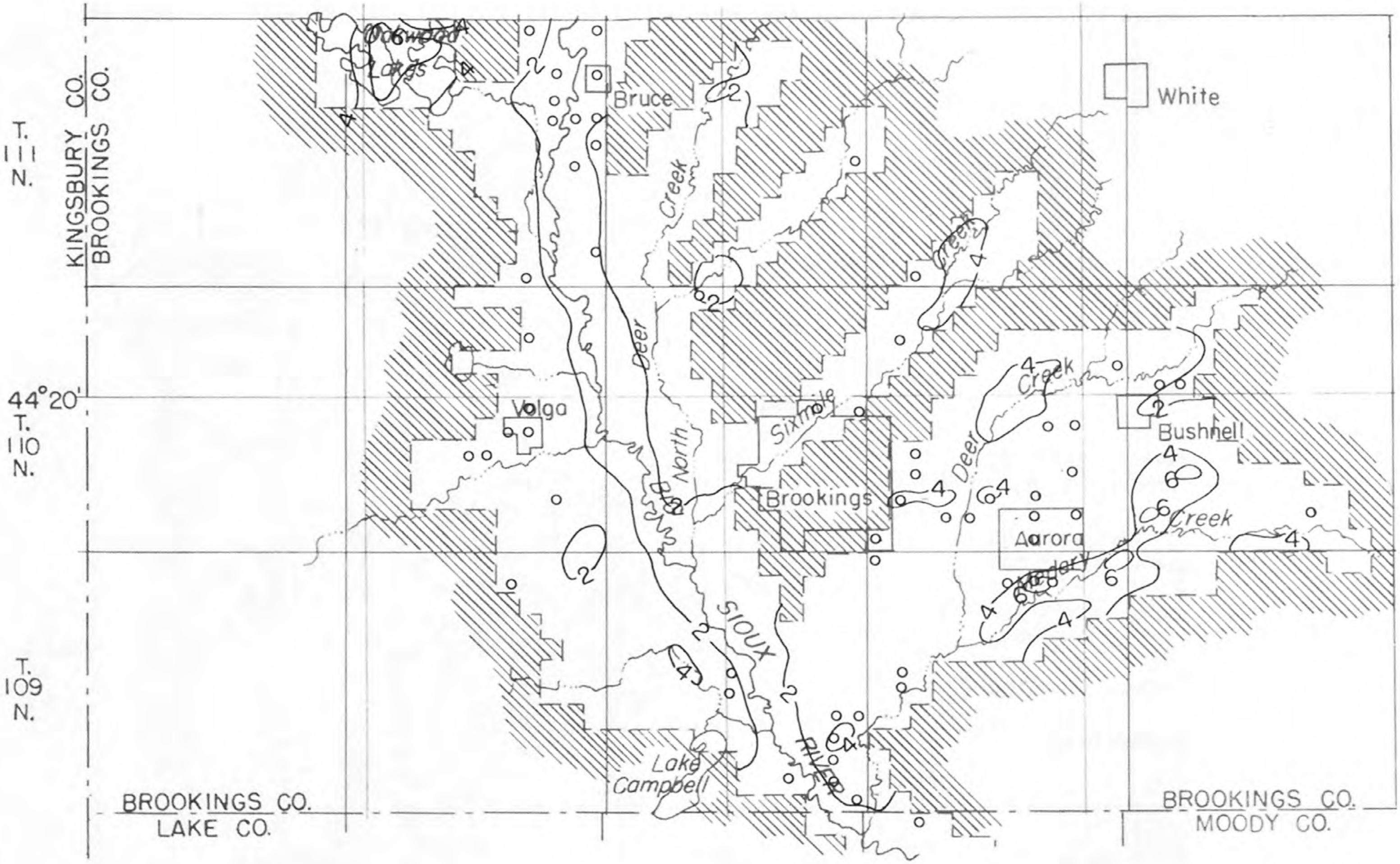
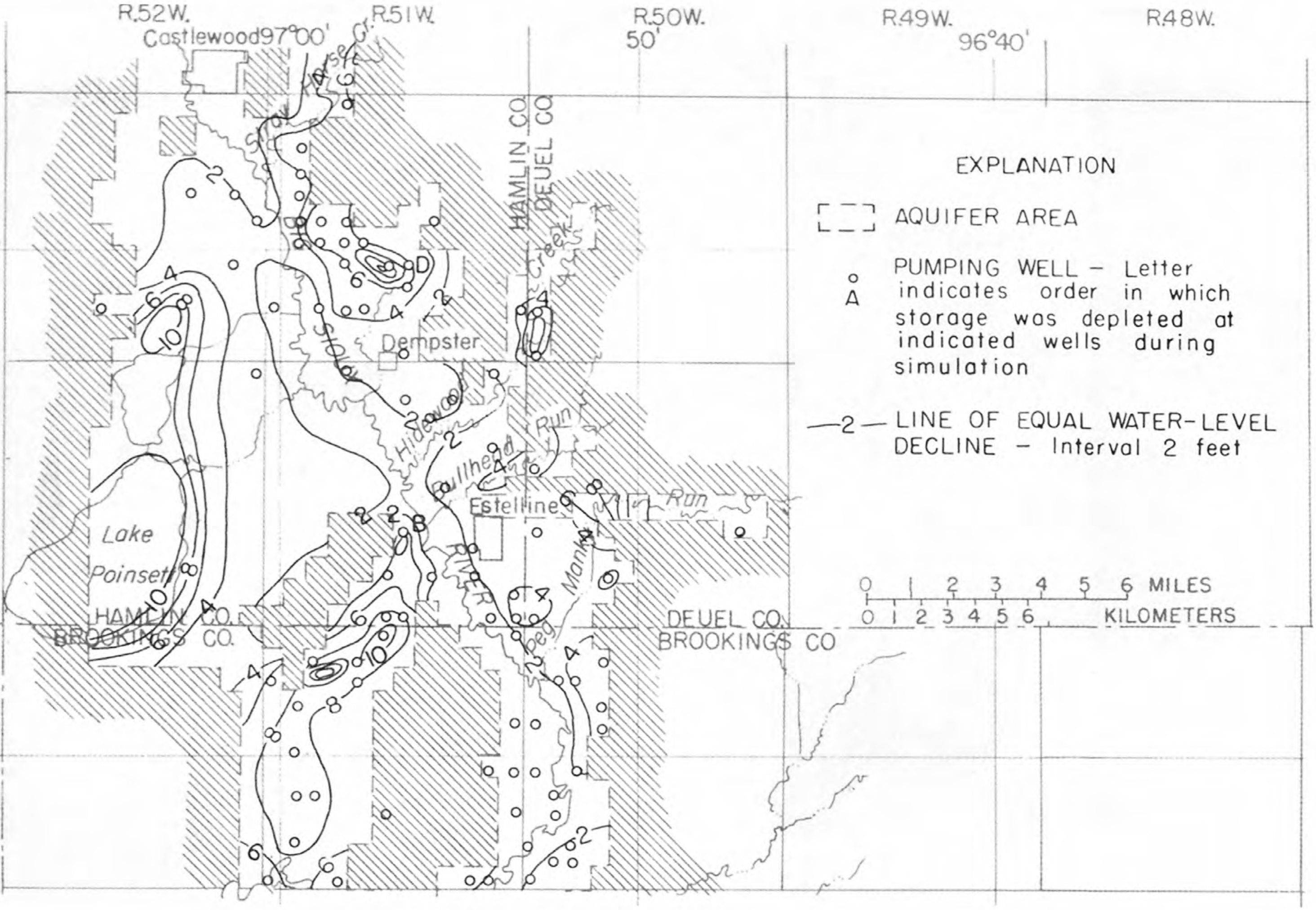


Figure 12. Simulated water-level decline after 9,300 acre-feet of withdrawal in 4 months assuming 1976 irrigation pumpage rate and no recharge from precipitation.


R.52W.
R.51W.
R.50W.
R.49W.
R.48W.
Castlewood
97°00'
50'
96°40'
T. 114 N.
44°40'
T. 113 N.
T. 112 N.
30'
HAMLIN CO.
DEUEL CO.
BROOKINGS CO.
Dempster
Estelline
Lake Poinsett
Stray Horse Cr.
Big Sioux River
Hidewood Creek
Bullhead Run
Peg Munky Run
A
B
D
EXPLANATION
AQUIFER AREA
PUMPING WELL - Letter indicates order in which storage was depleted at indicated wells during simulation
—2— LINE OF EQUAL WATER-LEVEL DECLINE - Interval 2 feet
0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETERS

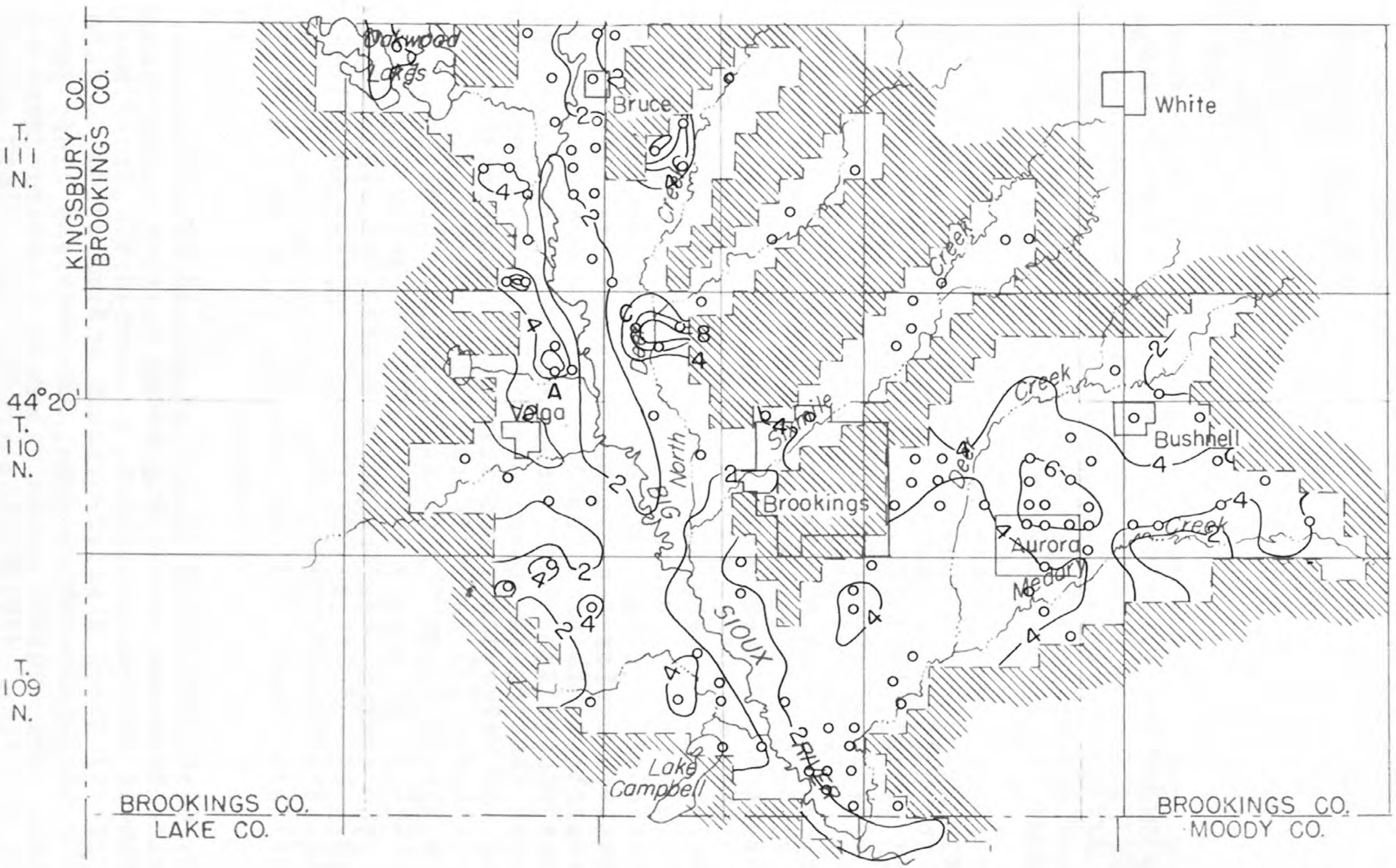


Figure 13. Simulated water-level decline after 39,000 acre-feet of withdrawal in 3½ months assuming 1979 irrigation pumpage rate based on irrigation permits and no recharge from precipitation.

was stopped and pumping continued elsewhere until storage was depleted at a second nodal area after 116 days of pumping. The model was continued beyond the 116-day period to determine other areas where storage would be depleted. Simulated pumping in the node where storage was depleted was stopped and pumping continued until storage was depleted at a third nodal area after 125 days of pumping. Again simulated pumping at this pumping center was stopped and pumping continued until storage was depleted at a fourth nodal area after 145 days of pumping. The first three nodal areas at which storage was depleted were near the Big Sioux River. The river supplies a considerable amount of water to the nearby irrigation wells, and once this source of water is no longer available storage will be rapidly depleted and wells near the river can be expected to go dry.

Seasonal water-level declines are greater than regional long-term declines because most of the water use is seasonal except for pumpage by the city of Brookings. Declines are greatest during the irrigation season. Water levels recover (rise) during the remainder of the year and reach full recovery under normal precipitation conditions before the next irrigation season. The aquifer in the study area is highly stressed but could support considerably greater withdrawals under normal precipitation conditions.

The results of the model study are intended to be a guide in estimating future effects of ground-water development in the study area. The model can be updated and used to evaluate hydrologic and other factors affecting the aquifer system such as: (1) The effects of proposed water-resources projects on the stream-aquifer system; (2) the effects of changes in water use--for example, the effect of lowering the water table to "salvage nonbeneficial evapotranspiration"; (3) the effects of legal, economic, and social constraints on the available water supplies; (4) identification of future water problems such as ground-water mining, conflict of water rights, streamflow depletion, and the effect of changes in upriver developments on surface-water inflows to the model area.

SUMMARY

The most productive source of ground water in Brookings and Hamlin Counties is the Big Sioux aquifer, which ranges in thickness from a few feet to more than 100 ft. The aquifer consists of glacial outwash and alluvium, occurs in about 300 mi^2 in the study area, and averages 25 ft in thickness. The aquifer contains about 1 million acre-ft of water in storage. Well yields greater than 1,000 gal/min have been obtained from the aquifer.

Recharge to the Big Sioux aquifer is by infiltration of precipitation and seepage from the Big Sioux River and tributaries. Natural discharge is by evapotranspiration and seepage to the Big Sioux River and tributaries.

Water in the aquifer is under water-table conditions except where a small part of the aquifer is overlain by till and under artesian conditions.

Water levels are generally within 10 ft of land surface and have an average annual fluctuation of 3 ft. An average of 3.6 inches of water is recharged annually from precipitation. An equal amount on the average is discharge annually, primarily by evapotranspiration, pumpage, and by seepage into the Big Sioux River and tributaries.

The aquifer is in hydraulic connection with most of the streams, Lake Poinsett, and Oakwood Lakes. Usually the lakes do not act as sources of recharge to the aquifer but are points of discharge from the aquifer by evaporation.

Ground water and surface water in the study area are primarily a calcium bicarbonate type and are chemically suitable for irrigation with respect to sodium hazard. Specific conductance of ground water ranged from 407 to 1,790 micromhos.

A finite-difference method digital model was used to simulate steady-state and transient conditions of the Big Sioux aquifer in Brookings, Deuel, and Hamlin Counties. The model may be used as an aid in evaluating and planning for the efficient use of water from the aquifer.

To model steady-state conditions, average annual water levels in the Big Sioux aquifer and base flow in the Big Sioux River near Brookings for 1970 through 1976 were used. The model computed water levels were within a few feet of the measured annual average water levels and the computed base flow was 66 ft^3/s compared to the actual base flow of 58 ft^3/s.

The model was calibrated using data from April through August 1976. Virtually no recharge from precipitation occurred during that time. About 9,300 acre-ft of water was pumped from the aquifer. As a result of the water-table declines, less water was discharged from the aquifer by evapotranspiration or to the streams. This amounted to a 1,200 acre-ft decrease in evapotranspiration loss and a 1,760 acre-ft decrease in discharge to streams.

A transient run using all the pumpage that would be allowed by irrigation permits approved by the State as of February 1979 simulated withdrawal of 43,900 acre-ft of water for about 4 months. There was a decrease in evapotranspiration of 7,800 acre-ft and a decrease in discharge to streams of 3,600 acre-ft. This amounted to 26 percent of the total ground water pumped that would have been discharged to the streams or evapotranspiration if there had been no ground water pumped from the aquifer. This use of ground water that otherwise would have left the aquifer as discharge to streams and evapotranspiration needs to be considered in planning water development.

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