EVALUATION OF THE RESPONSE OF THE BIG SIOUX AQUIFER TO EXTREME DROUGHT CONDITIONS IN MINNEHAHA COUNTY, SOUTH DAKOTA

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CONTENTS

ILLUSTRATIONS

TABLE

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
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon	0.003785	cubic meter
	3.785	liter
million gallons per day (Mgal/d)	2.629	cubic meter per minute
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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ABSTRACT

The Big Sioux aquifer in the study area is a 36-square mile, water-table aquifer hydraulically connected to the Big Sioux River. There is concern about the capacity of the aquifer to provide sufficient water for the rapidly urbanizing Sioux Falls area if a drought similar to that which occurred in 1976-77 should recur. A digital-computer model previously developed by the U.S. Geological Survey was used to simulate potential effects on the aquifer of ground-water pumpage under worst-drought conditions.

Flow-duration data for the Big Sioux River at the Dell Rapids stream-gaging station showed that the streamflow was less than 23 cubic feet per second for 270 consecutive days from June 1976 to March 1977. This flow probably was the 100-year or greater low-flow in the Big Sioux River at the Dell Rapids stream-gaging station.

A model simulation with no recharge, a dry river, and pumpage from 60 wells of 25 million gallons per day stopped after 248 days when two pumping wells caused storage to be depleted at a model node. A new pumping rate of 24 million gallons per day allowed the model simulation to continue for an additional 31 days. Water-level declines in the Big Sioux aquifer at the end of the model simulation varied from less than 4 to more than 20 feet in the pumped area.

Another model simulation was made under the hydrologic conditions determined by calculating averages based on 1970-79 data with pumpage decreased to 21 million gallons per day by shutting down 12 wells in the city well field. The water-level recovery converted to volume of water added to storage was 531 million gallons after 186 days of pumping at the decreased rate.

INTRODUCTION

The Big Sioux aquifer, a major glacial-drift aquifer hydraulically connected to the Big Sioux River, extends most of the length of the Big Sioux basin in eastern South Dakota (fig. 1). The study area (36 mi^2 of the aquifer) extends from Dell Rapids on the north where the aquifer pinches out on quartzite, downstream to the city of Sioux Falls where again the aquifer pinches out on the quartzite.

The Big Sioux aquifer provides all the water for the city of Sioux Falls. There is concern about the capacity of the aquifer to provide sufficient water for the rapidly urbanizing Sioux Falls area if a drought similar to that which occurred in 1976-77

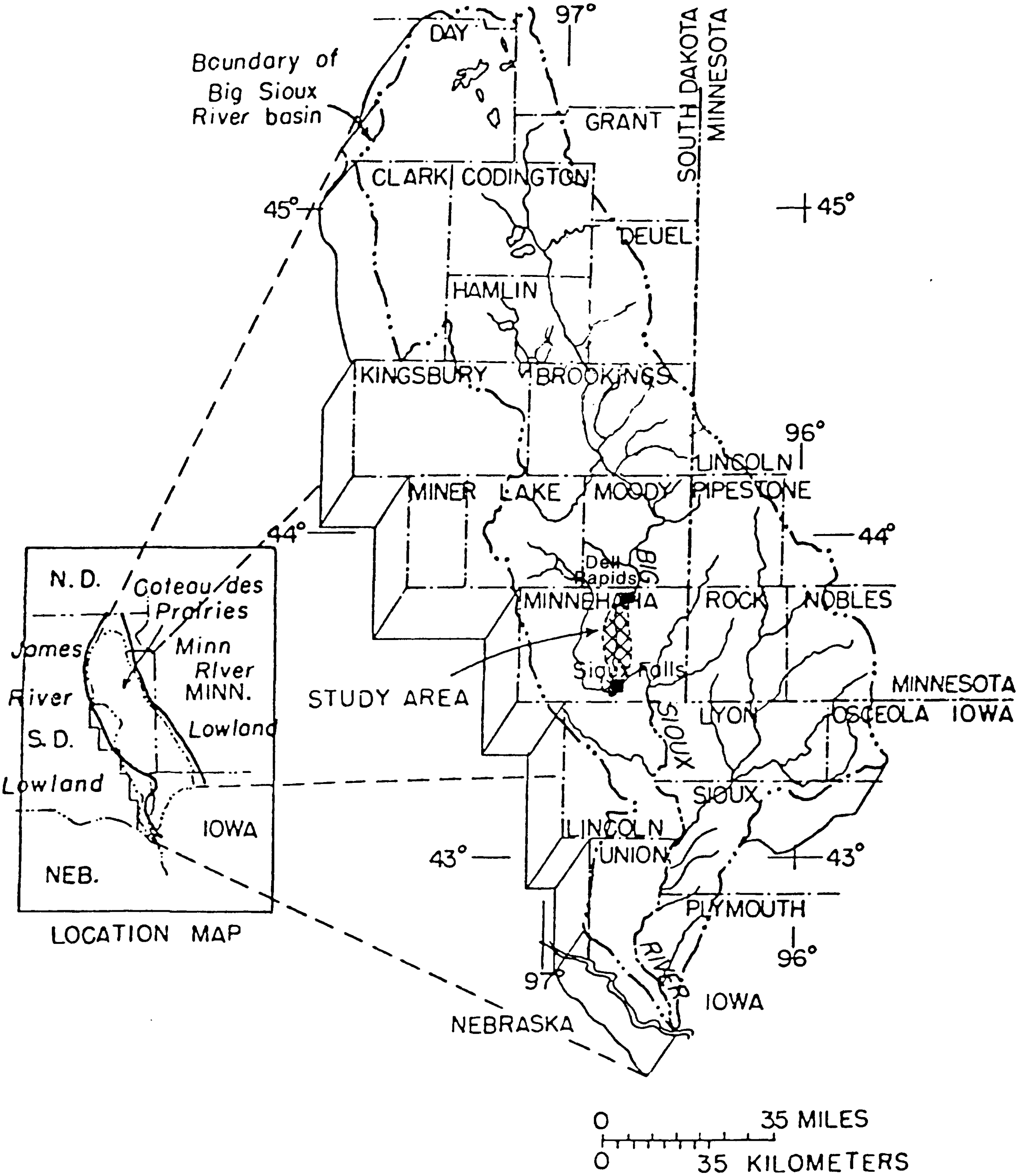

Figure 1.--Location of study area and Big Sioux River basin.

should recur. A digital-computer model previously developed by the U.S. Geological Survey (Koch, 1982) for the Big Sioux aquifer in Minnehaha County was used to simulate effects on the aquifer of ground-water pumpage under worst-drought conditions.

The study of this aquifer for the purpose of developing a predictive model of the hydrologic system was completed in 1982. The report about that study (Koch, 1982) describes the digital model and how it was used and modified to simulate equilibrium and transient conditions.

PURPOSE AND APPROACH OF STUDY

The purpose of this study was to use the digital-computer model developed from the previous study (Koch, 1982) to examine the effects on the aquifer of a pumping rate of 25 Mgal/d under the worst-drought conditions that occurred during 1974-78. A frequency rating was determined for the most severe low-flow condition in the Big Sioux River.

A transient simulation was made under the hydrologic conditions determined by calculating averages based on 1970-79 data (Koch, 1982) with pumpage decreased by shutting down several wells to determine the water-level recovery in the city well field.

MODEL DEVELOPMENT

To develop the digital model for the previous study (Koch, 1982), a map of the project area was prepared showing the aquifer model boundary and stream locations (fig. 2). A 0.25-mi grid network was superimposed on the map. The network has 77 rows and 18 columns, a total of 585 cells representing the aquifer. 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. Data entered into the computer for each node are the altitude of the water table, the altitude of the bottom of the aquifer, the altitude of the land surface, the hydraulic conductivity of the aquifer, and the specific yield of the aquifer.

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 hydrologic assumptions used in the model of the Big Sioux aquifer were:

(1) The alluvium-mantled outwash aquifer is a single unconfined (water-table) aquifer.

(2) The aquifer is hydraulically connected to the Big Sioux River.

(3) The flow in the aquifer is horizontal.

(4) No-flow conditions exist on the perimeter of and beneath the aquifer.

(5) Recharge to the aquifer is from streamflow and infiltration of precipitation on the surface of the aquifer.

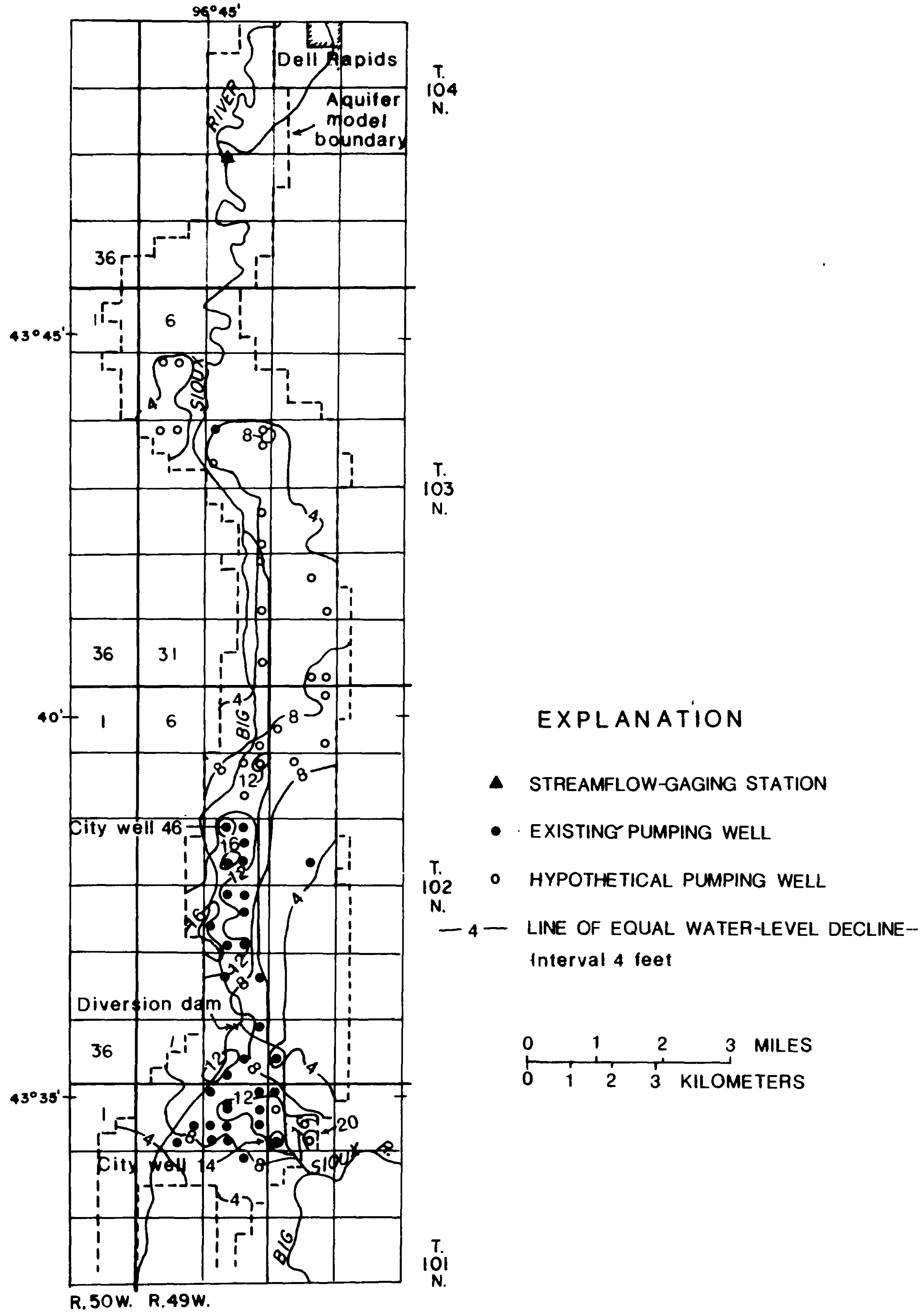

Figure 2--Computer-simulated drawdown in the Big Sioux aquifer after pumping for 279 days.

(6) Ground water is discharged by pumpage from wells, evapotranspiration, and flow to the Big Sioux River.

(7) The average stream stage remains constant throughout the steady-state simulation but under transient conditions, the stream stage is raised or lowered each month based on stream stage at Dell Rapids and the diversion dam. The constant hydraulic-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 5 ft below land surface.

(9) Return flow from irrigation is not modeled because the irrigation water applied is assumed to be entirely consumed by the crops or evaporated.

(10) Transmissivity is hydraulic-head dependent.

FREQUENCY OF DROUGHT

The flow-duration data for the Big Sioux River at the Dell Rapids stream-gaging station showed that during the 35 years of record (1948-82), the longest period of lowest or zero streamflow occurred for 270 consecutive days, from June 1976 to March 1977, when there were 54 consecutive days of zero streamflow, 73 consecutive days of less than 23 ft^3/s streamflow prior to zero flow, and 143 consecutive days of less than 23 ft^3/s streamflow after zero flow. The steady-state simulation under recharge and streamflow conditions, determined by calculating averages based on data for 1970-79 at a pumping rate of 25 Mgal/d showed that 23 ft^3/s (16 Mgal/d) recharged the aquifer from the river. The streamflow-duration data showed that the 1976-77 drought probably was the 100-year or greater low-flow in the Big Sioux River at the Dell Rapids stream-gaging station.

RESULTS OF COMPUTER-MODEL SIMULATIONS

To determine the aquifer's response to increased pumpage, 60 wells were spaced throughout the aquifer and withdrawal rates were established at a total pumping rate of 25 Mgal/d. Monthly simulations were made with no recharge from precipitation and the Big Sioux River dry. The computer-calculated June 1976 (Koch, 1982) water levels were used as the starting hydraulic heads.

The model simulations continued for eight 31-day increments for a total of 248 days at which time pumping stopped after pumping wells (city wells 14 and 46 on figure 2) caused storage to be depleted at a node. The model is set to terminate calculations when the value representing storage is zero at a node. Pumpage was stopped for city well 14 and decreased by one-half for city well 46 and the simulation was continued at a new pumping rate of 24 Mgal/d for an additional 31 days. The total simulation of 279 days exceeded the drought so the model simulation was concluded. Water-level declines in the Big Sioux aquifer at the end of the model simulation varied from less than 4 to more than 20 ft in the pumped area (fig. 2).

Another model simulation was made under the hydrologic conditions determined by calculating averages based on data for 1970-79 (Koch, 1982) with pumpage decreased to 21 Mgal/d by shutting down 12 wells in the city well field (T. 101 N). Six monthly simulations were made and the recovery calculated. The recovery was converted to volume of water by multiplying the average recovery by the specific yield (20 percent) and the area effected by the recovery (table 1).

Table 1.—Water-level recovery and volume of water added to storage in the Sioux Falls well field

Days after pumpage-rate decrease	Average water-level recovery (feet)	Maximum water-level recovery in 0.25-square-mile node (feet)	Area affected by recovery (square miles)	Cumulative volume of water added to storage[1] (million gallons)
31	0.95	3.7	2.9	116
62	1.4	5.4	3.8	223
93	1.6	6.8	4.5	311
124	2.0	7.8	4.8	395
155	2.2	8.8	5.1	467
186	2.3	9.7	5.4	531

1/ Based on average water-level recovery (feet) times area affected by recovery (square miles) times estimated specific yield of 20 percent.

REFERENCE

Koch, N. C., 1982, A digital-computer model of the Big Sioux aquifer in Minnehaha County, South Dakota: U.S. Geological Survey Water-Resources Investigations 82-4064, 49 p.