SIMULATED ARTIFICIAL RECHARGE IN THE BIG SIOUX AQUIFER IN MINNEHAHA COUNTY, SOUTH DAKOTA

By Neil C. Koch

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4312

Prepared in cooperation with the

CITY OF SIOUX FALLS, and the

EAST DAKOTA CONSERVANCY SUB-DISTRICT

Huron, South Dakota

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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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 inch-pound units	By	To obtain SI units
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.0630	liter per second (L/s)
mile (mi)	1.609	kilometer

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ABSTRACT

The Big Sioux aquifer in Minnehaha County is a water-table aquifer hydraulically connected to the Big Sioux River. A digital-computer model previously developed by the U.S. Geological Survey was used to simulate potential effects of artificial recharge on the aquifer.

A simulation was made of recharging water at the rate of 870 gallons per minute for four 30-day periods. Total water recharged to the aquifer during the 120 days was 150.3 million gallons. During the 120-day recharge period, 24.4 million gallons of water discharged from the aquifer to the river as a result of the artificial recharge. During the three 30-day recovery periods after the artificial recharge period, about 30 million gallons of water discharged from the aquifer to the river as a result of artificial recharge making a total of 54.4 million gallons that discharged from the aquifer to the river or 36 percent of the 150.3 million gallons that was artificially recharged.

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 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.

A study by the City of Sioux Falls, U.S. Army Corps of Engineers, and the East Dakota Conservancy Sub-District was planned to determine the effect of artificial recharge on the aquifer. A section of a drainage ditch north of the City of Sioux Falls between the Big Sioux River and Silver Creek was selected to conduct an artificial recharge test (fig. 2) but high water-table conditions never allowed for the field test to be conducted. As a result, the City of Sioux Falls and the East Dakota Conservancy Sub-District requested that a digital-computer model previously developed by the U.S. Geological Survey (Koch, 1982) for the Big Sioux aquifer in Minnehaha County be used to simulate the response of the aquifer to artificial recharge at the site selected north of Sioux Falls.

PURPOSE AND APPROACH OF STUDY

The purpose of this study was to evaluate the effects of artificial recharge on the Big Sioux aquifer in Minnehaha County. Using the digital-computer model developed in the previous study (Koch, 1982), a transient simulation was made starting with June 1976 water-level conditions.

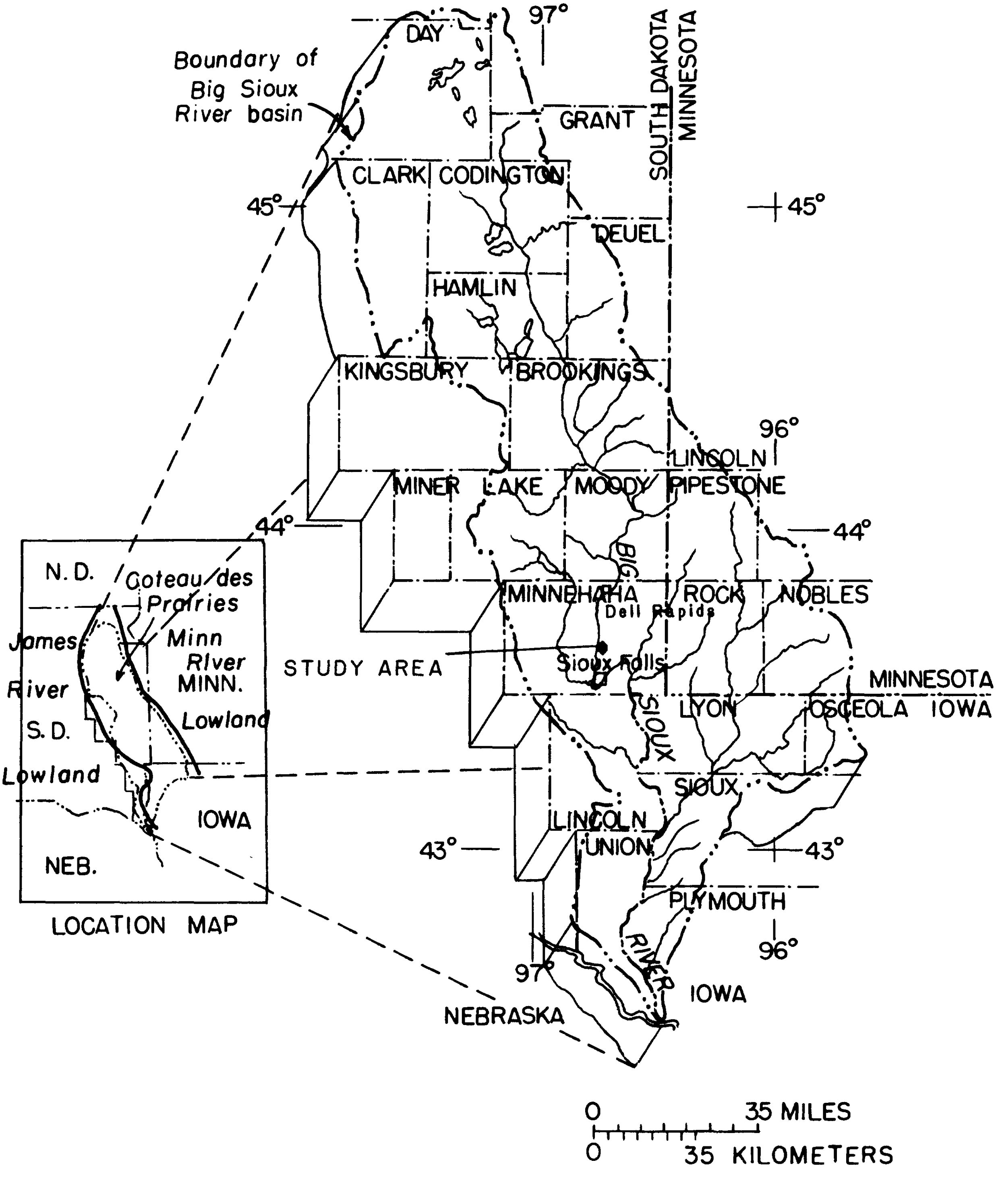


Figure 1.--Location of study area and Big Sioux River basin.

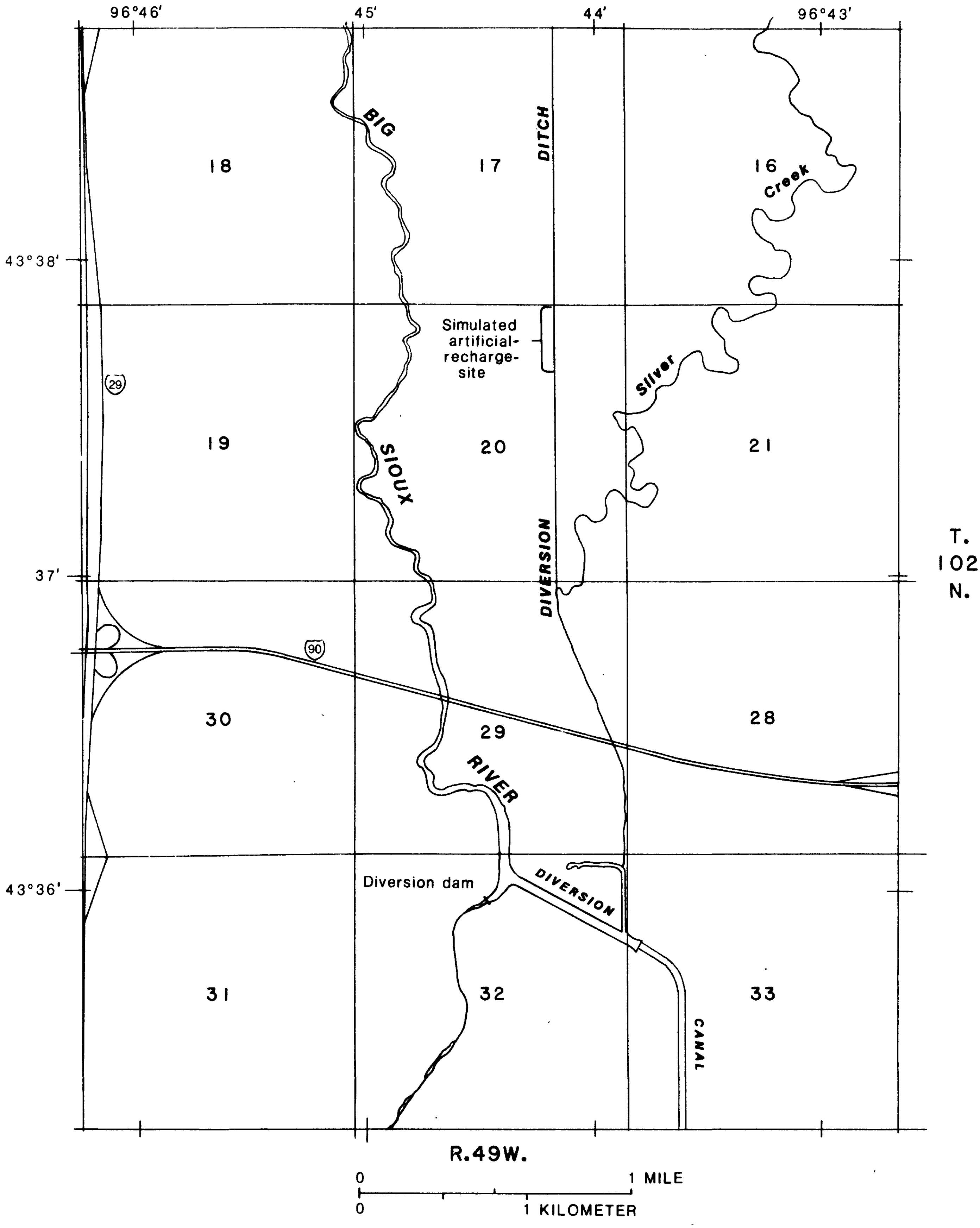


Figure 2.--Location of simulated artificial-recharge site.

MODEL DEVELOPMENT

To develop the digital model for the previous study (Koch, 1982), a map of the project area was prepared showing the aquifer boundary and location of streams. 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. 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 are entered into the computer for each node.

The model was developed based on known hydrologic conditions. A number of simplifying assumptions were used in the model to make it possible to describe the aquifer mathematically. The hydraulic assumptions used in the model of the Big Sioux aquifer were:

(1) The 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.

(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 (12 mi north of the recharge site) and the diversion dam (2 mi south of the recharge site). 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.

RESULTS OF COMPUTER-MODEL SIMULATIONS

To determine the aquifer's response to artificial recharge, a recharge well was simulated in the node at the artificial-recharge site. The aquifer was recharged at a rate of 870 gal/min for 120 days (four 30-day recharge periods). Monthly simulations were made with no other recharge and at the same river stage. The computer-calculated June 1976 (Koch, 1982) water levels were used as the starting hydraulic heads.

To determine hydraulic head and changes in the volume of discharge from the aquifer to the river caused by artificial recharge, the recharge simulations were compared with computer-model simulations that did not have a simulated recharge well. Monthly simulations were continued for 90 days after recharge was discontinued (three 30-day recovery periods).

The volume of water added to the aquifer each month, the volume of water returned to the river, and the volume of recharge water remaining in the aquifer are summarized in table 1.

The river stage was 3.4 ft higher than the water level in the recharge node prior to the start of artificial recharge. After 120 days of recharge the water level in the recharge node was 6.9 ft above the starting water level or 3.5 ft above the river stage. The hydraulic-head change at the end of each 30-day recharge and recovery simulation is shown in figure 3.

Table 1.--Computer-simulated monthly changes in volume of water recharged to and discharged from the aquifer

Days after start of simulation	Cumulative volume of water added to aquifer (million gallons)	Cumulative volume of recharge water returned to the river. Upper number is million gallons; lower number is percentage	Cumulative volume of recharge water remaining in aquifer. Upper number is million gallons; lower number is percentage
		RECHARGE	
30	37.6	1.5 4	36.1 96
60	75.2	6 8	69.2 92
90	112.8	13.9 12	98.9 88
120	150.3	24.4 16	125.9 84
		RECOVERY	
150	150.3	35.7 24	114.6 76
180	150.3	45.8 30	104.5 70
210	150.3	54.4 36	95.9 64

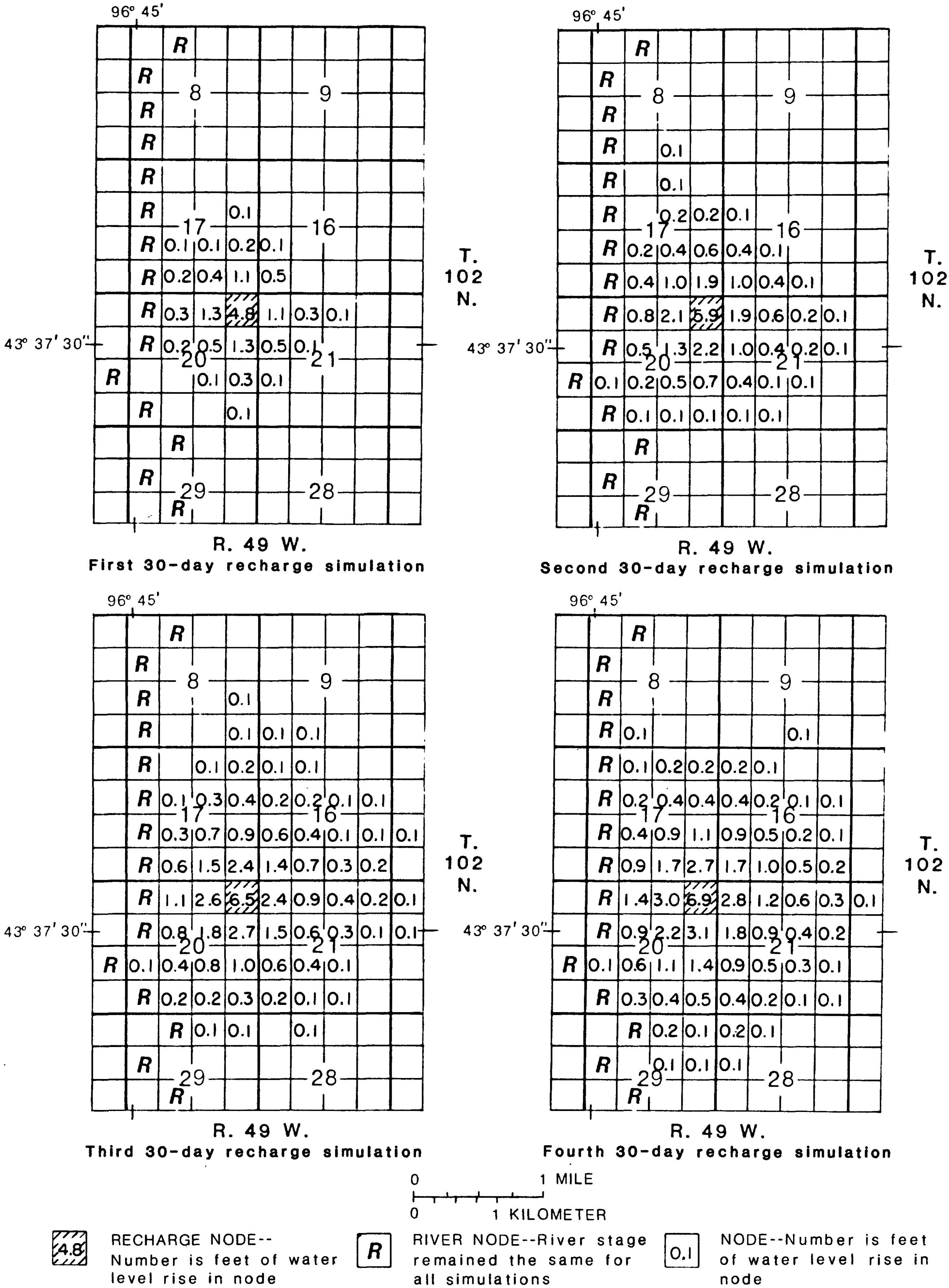
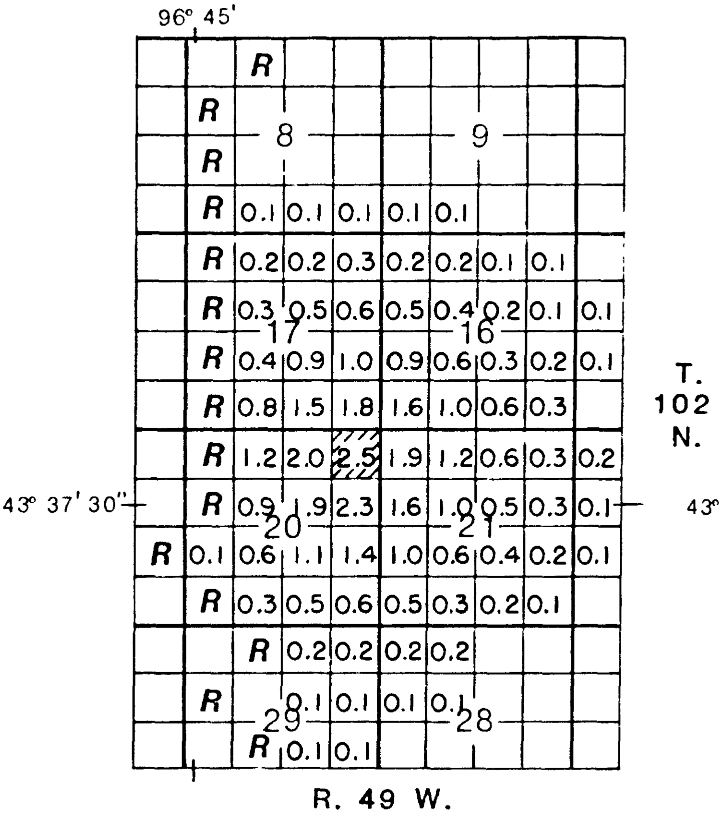
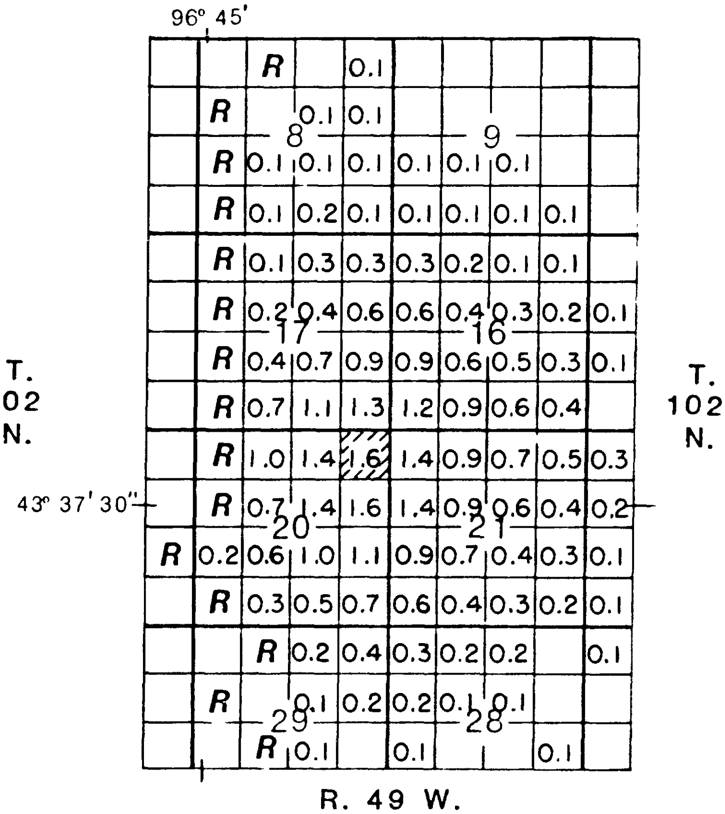


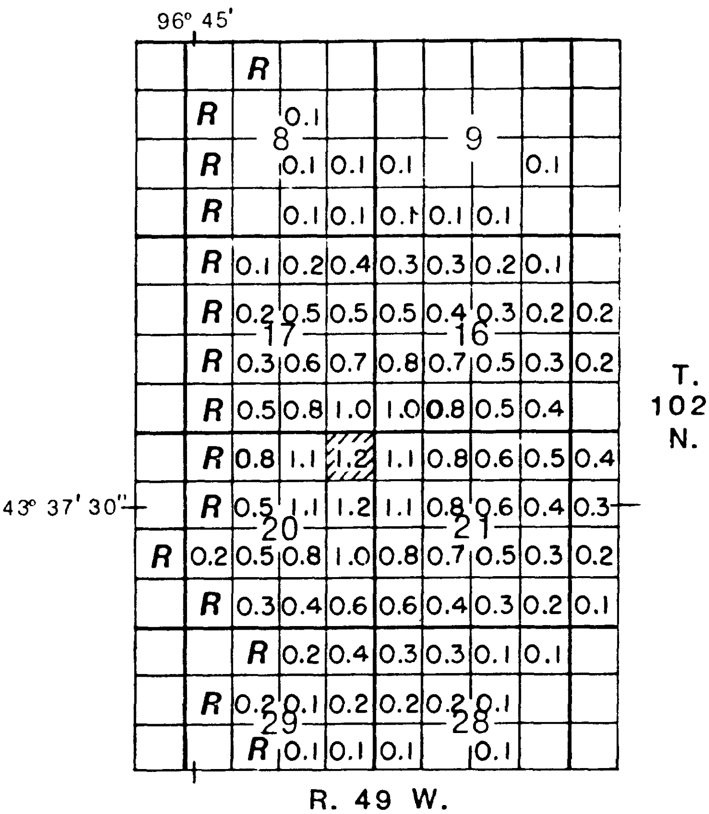
Figure 3.--Head change and recharge mound at the end of each 30-day simulation.



First 30-day recovery simulation



Second 30-day recovery simulation



Third 30-day recovery simulation

Figure 3.—Continued

SUMMARY AND CONCLUSIONS

A digital-computer model previously developed by the U.S. Geological Survey was used to simulate potential effects of artificial recharge on the Big Sioux aquifer.

A simulation was made by recharging at the rate of 870 gallons per minute for four 30-day periods and monitoring recovery for three 30-day periods. During the 120-day recharge period and the 90-day recovery period, 54.4 million gallons of water discharged from the aquifer to the river or 36 percent of the 150.3 million gallons that was artificially recharged to the aquifer.

The river stage prior to the start of artificial recharge was 3.4 ft higher than the water level in the recharge node. After the first 30-day simulation the water level in the recharge node was 1.4 feet higher than the river stage resulting in a reversal in direction of ground-water flow. Prior to recharge river water was recharging the aquifer. At the end of the first 30-day simulation, 1.5 million gallons had discharged from the aquifer to the river.

To effectively recharge an aquifer, the water level in the recharge area needs to remain below the water level in the area of potential discharge. If the water level at the recharge site simulated for this study is below stream stage, the recharge decreases the flow from the river to the recharge area. If the water level at the recharge site is above the stream stage, the flow from the recharge area to the stream is increased. At the recharge site simulated for this study, a developed well field could eventually dewater a significant part of the aquifer which could then be recharged without any appreciable loss by increased discharge to the river.

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.