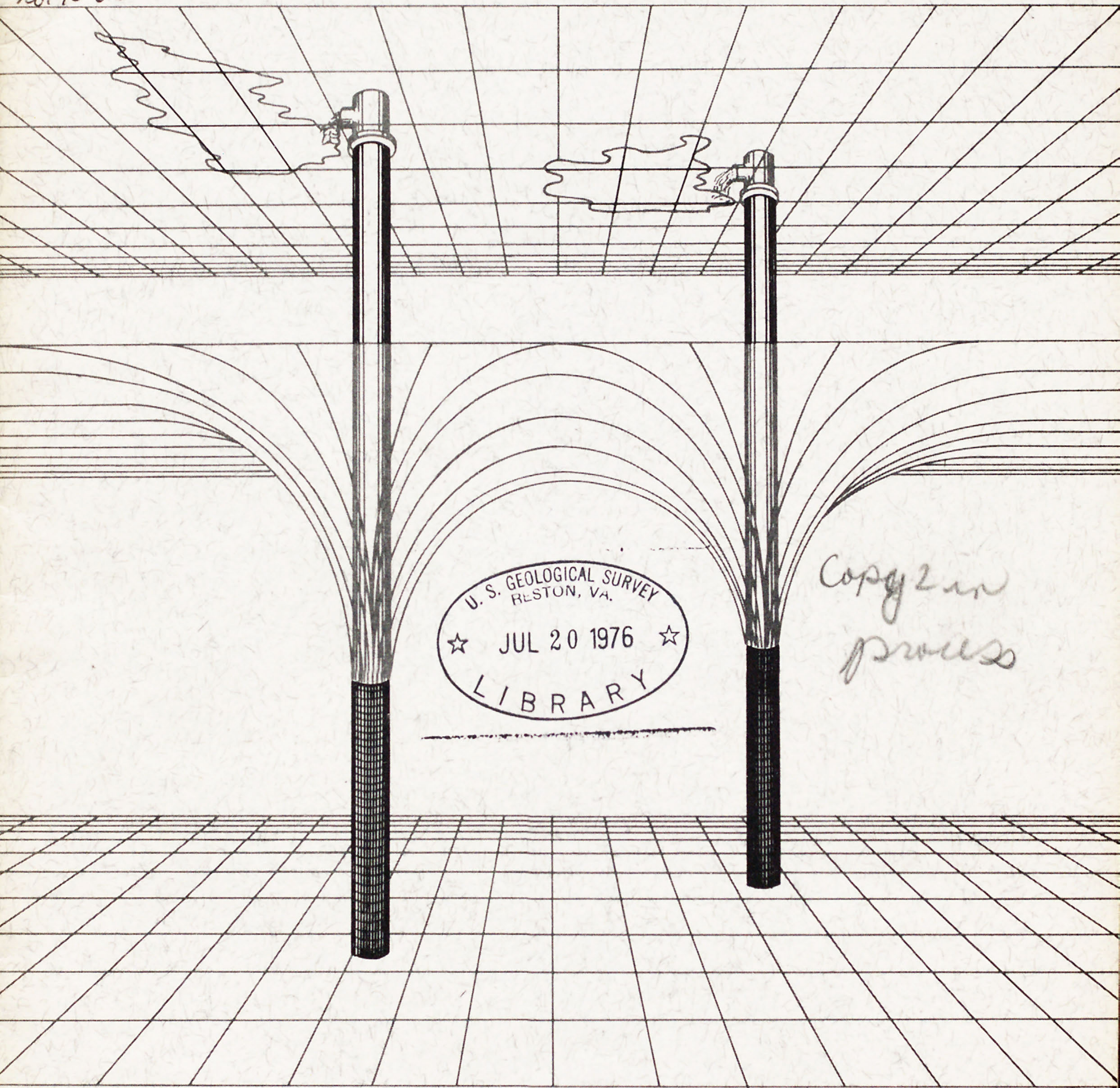
digital-model analysis to predict water levels in a well field near columbus, indiana



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A digital model simulated the effects of two pumping plans on the outwash sand and gravel aquifer in the Columbus well field. In plan 1, a continuous pumping rate of 1,400 gallons per minute (88 litres per second) for 10 years in each of the city's six existing wells was simulated with the model. Model results of plan 1 indicate that the water levels in the area of the well field would be lowered more than 20 feet (6 metres) and that drawdowns in the wells would approach 35 ft (11 m) after 10 years' pumping. In plan 2 stage 1, the model simulated a continuous pumping rate of 1,400 gal/min (88 l/s) for 5 years in each of the city's six existing wells. In stage 2, five planned wells were added to the six existing wells, and all were pumped for five additional years, as in stage 1. Model results of plan 2 indicate that water levels in the area of the well field would be lowered as much as 40 ft (12 m). Drawdown at two of the well sites would approach 60 ft (18 m), leaving less than 15 ft (5 m) of the initial 70 ft (21 m) of saturated thickness at the two wells after 10 years' pumping.

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DIGITAL-MODEL ANALYSIS TO PREDICT WATER LEVELS IN A WELL FIELD NEAR COLUMBUS, INDIANA

By Michael Planert

U.S. GEOLOGICAL SURVEY

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Prepared in cooperation with
the city of Columbus, Indiana,
and Indiana Department of
Natural Resources, Division
of Water

May 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

Thomas S. Kleppe, Secretary

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CONTENTS

ILLUSTRATIONS

TABLE

FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL

SYSTEM (SI) UNITS

English units	Multiplied by	To obtain SI units
	Length	
inches (in)	0.0254	metres (m)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
	Area	
square miles (mi^2)	2.590	square kilometres (km^2)
	Volume	
gallons (gal)	3.785	litres (l)
million gallons (Mgal)	3,785	cubic metres (m^3)
cubic feet (ft^3)	.02832	cubic metres (m^3)
	Flow	
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)
gallons per minute (gal/min)	.06309	litres per second (l/s)
million gallons per day (Mgal/d)	.04381	cubic metres per second (m^3/s)
	Hydraulic Units	
transmissivity: feet squared per day (ft^2/d)	.0929	metres squared per day (m^2/d)
hydraulic conductivity: feet per day (ft/d)	.3048	metres per day (m/d)

DIGITAL-MODEL ANALYSIS TO PREDICT WATER LEVELS IN A WELL FIELD

NEAR COLUMBUS, INDIANA

By Michael Planert

ABSTRACT

Columbus, Indiana, obtains its water supply from six municipally owned wells southwest of the city. The wells are screened in an outwash sand and gravel aquifer that was deposited by glacial melt water in a preglacial bedrock valley. The well field is midway between the East Fork White River and the western edge of the valley.

A digital model was used to determine the effects of two pumping plans on the outwash sand and gravel aquifer. In pumping plan 1, a continuous pumping rate of 1,400 gallons per minute (88 litres per second) for 10 years in each of the city's six existing wells was simulated with the model. Model results of plan 1 indicate that the water levels in the area of the well field would be lowered more than 20 feet (6 metres) and that drawdowns in the wells would approach 35 feet (11 metres) after 10 years' pumping.

Pumping plan 2 had two stages of pumping. In the first, a continuous pumping rate of 1,400 gallons per minute (88 litres per second) for 5 years in each of the city's six existing wells was simulated with the model; the second stage of pumping plan 2 differed from stage 1 only in that five planned wells were added to the six existing wells. Model results of plan 2 indicate that water levels in the area of the well field would be lowered as much as 40 feet (12 metres). Drawdown at two of the well sites would approach 60 feet (18 metres), leaving less than 15 feet (5 metres) of the initial 70 feet (21 metres) of saturated thickness at the two wells after 10 years' pumping.

INTRODUCTION

Problem

Growth of population and industry in Columbus has increased the city's demand for water. In 1966, the U.S. Geological Survey investigated the ground-water resources of the Columbus area and determined the long-range effects of pumping from potential well-field sites (Watkins and Heisel, 1970). On the basis of that study, one site was chosen for an aquifer test, and a 20-in- (0.5-m) diameter well was drilled at the site. The test well yielded 4,200 gal/min (265 l/s). Subsequently, five additional wells were drilled near the site of the test well (fig. 1).

The purpose of this investigation was to use a digital model of the aquifer to estimate drawdowns for two well-field pumping plans. Plan 1 simulated continuous pumping of the city's six existing wells at 1,400 gal/min (88 l/s) each for 10 years. This is equal to 12 Mgal/d (0.5 m^3/s) for six wells. Plan 2 simulated continuous pumping of the city's six existing wells for 5 years (stage 1) and continuous pumping of the six existing wells plus five planned wells for an additional 5 years (stage 2), all at 1,400 gal/min (88 l/s) each. This is equal to 22 Mgal/d (1.0 m^3/s) for 11 wells.

Setting

The wells tap a water-table aquifer in the valley of the East Fork White River about 2 mi (3 km) south of Columbus. The river is in a preglacial bedrock valley that is partly filled with outwash sand and gravel deposited by glacial melt water. The aquifer thins at the outer edges of the valley, where the bedrock rises to form ridges above the flood plain. Except where shale crops out along these ridges, 10 to 40 ft (3 to 12 m) of glacial till covers the bedrock.

The well field is midway between the East Fork White River and the west edge of the valley (fig. 2). The six existing wells are characterized by 17-in (0.4-m) inside diameters, screen lengths ranging from 20 to 30 ft (6.1 to 9.2 m), and gravel-pack thicknesses ranging from 36 to 72 in (0.91 to 1.8 m).

Acknowledgment

The author is indebted to Sieco, Inc., consulting engineers for the city of Columbus, for the aquifer-test data.

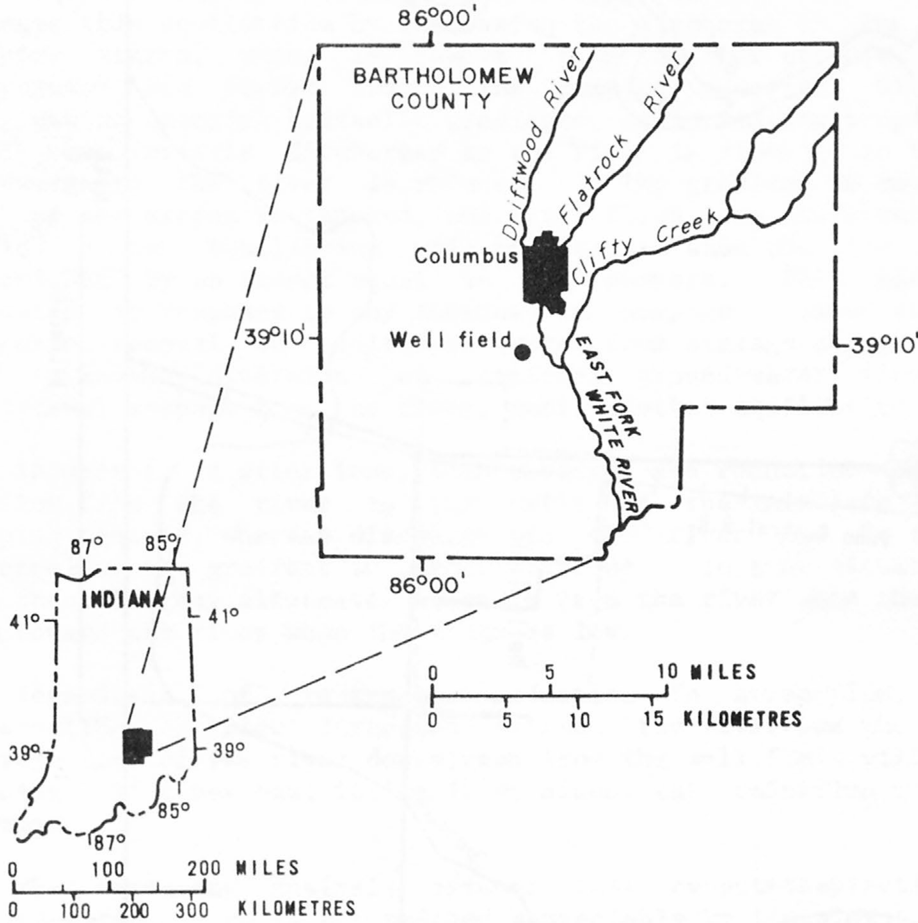


Figure 1 --Location of the well field in Bartholomew County.

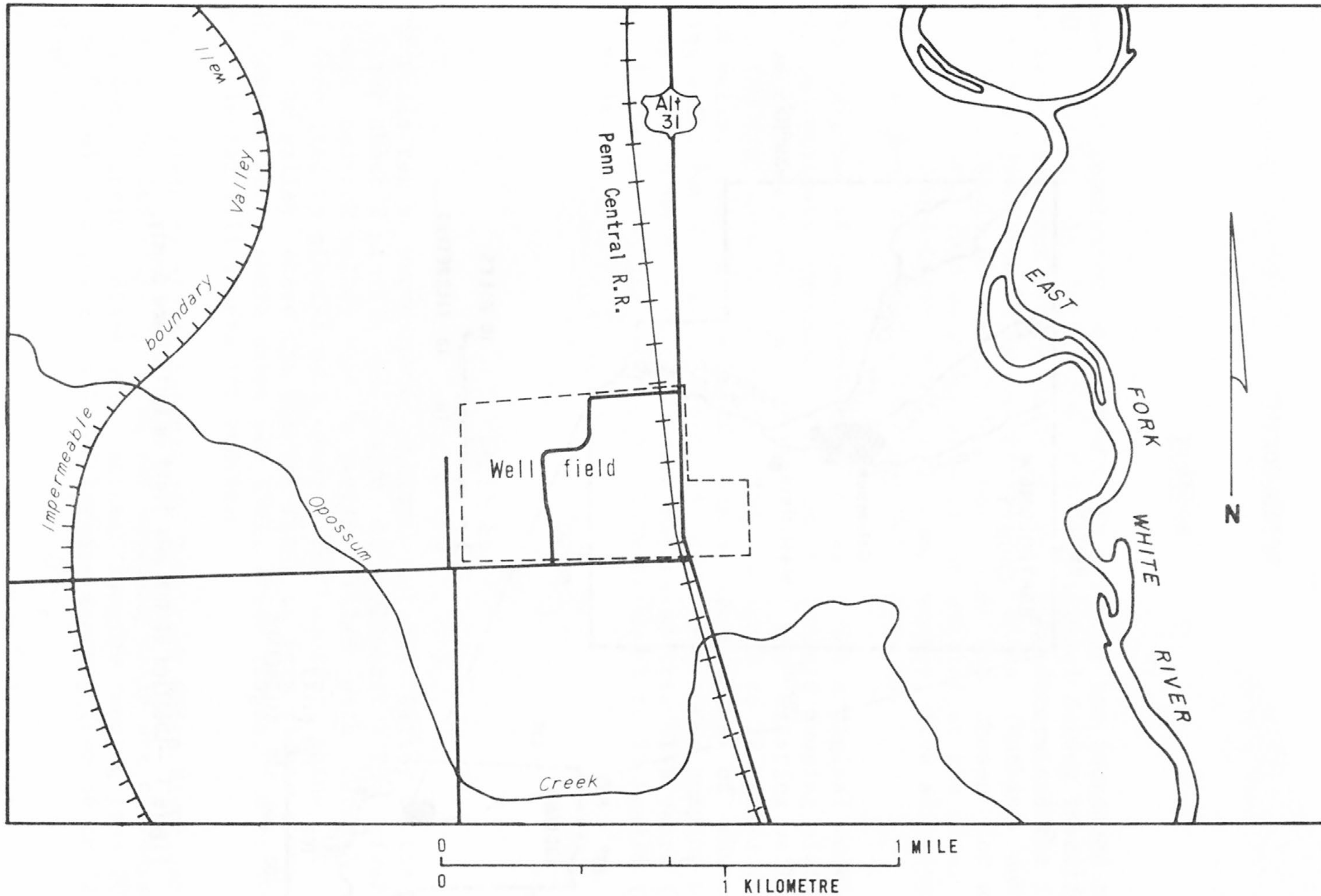


Figure 2.--Location of the well field in the river valley near Columbus, Ind.

EFFECTS OF PUMPING THE GROUND-WATER SYSTEM

In the study area, the ground-water system is discharging water to the streams. Recharge to the aquifer is by infiltration of precipitation. Before pumping, water levels in the aquifer are at equilibrium; recharge to the aquifer equals discharge from the aquifer to the stream. Pumping changes this equilibrium by increasing the discharge of the system. When pumping starts, water is removed from aquifer storage, and cones of depression are formed around the pumping centers. With time and in response to changing hydraulic gradients, an increasing proportion of water that was formerly discharged to the river is diverted to the wells, and discharge to the river is reduced. If the gradient is reversed, seepage out of the stream is induced, and water flows from the stream to the well field. A new equilibrium will be attained when the flow of the river is diminished by an amount equal to the pumpage. This pattern will be repeated in response to any increase in pumpage. Immediately after an increase, removal of additional water from storage changes the gradients and increases diversion of regional ground-water flow, or induces additional seepage from the river, until another equilibrium is attained.

In many field situations, both reversal and reduction occur. There may be flow from the river to the wells in the immediate vicinity of the pumping centers, whereas discharge to the river may be reduced with no reversal of the gradient in other reaches. In some situations, reversal and reduction may alternate. Flow is from the river when the stage is high and toward the river when the stage is low.

Regardless of reversal, reduction in streamflow, and periodic alternation of flow direction between the river and the aquifer, the average flow of the river downstream from the well field will be reduced by pumping. If a new equilibrium is attained, this reduction will equal total pumpage.

The foregoing analysis assumes that evapotranspiration from the ground-water system is not reduced appreciably by lowering the water table. If evapotranspiration would be reduced, an additional source of water would be provided to the aquifer, and the effect of pumping on the flow of the river would be reduced.

SIMULATION

A digital model developed by Trescott (1975) was used to determine the effects of pumping on the aquifer system. In this model, the aquifer was divided into rectangular blocks and finite-difference techniques were used to compute average drawdown for each block.

Uniform values of hydraulic conductivity, 468 ft/d (143 m/d), and of specific yield, 0.2, were used throughout the model. These values, as well as saturated thicknesses plotted in figure 3 and assigned to each block of the model, were based on data from Watkins and Heisel (1970). Distribution of saturated thicknesses used in the model are shown in figure 4.

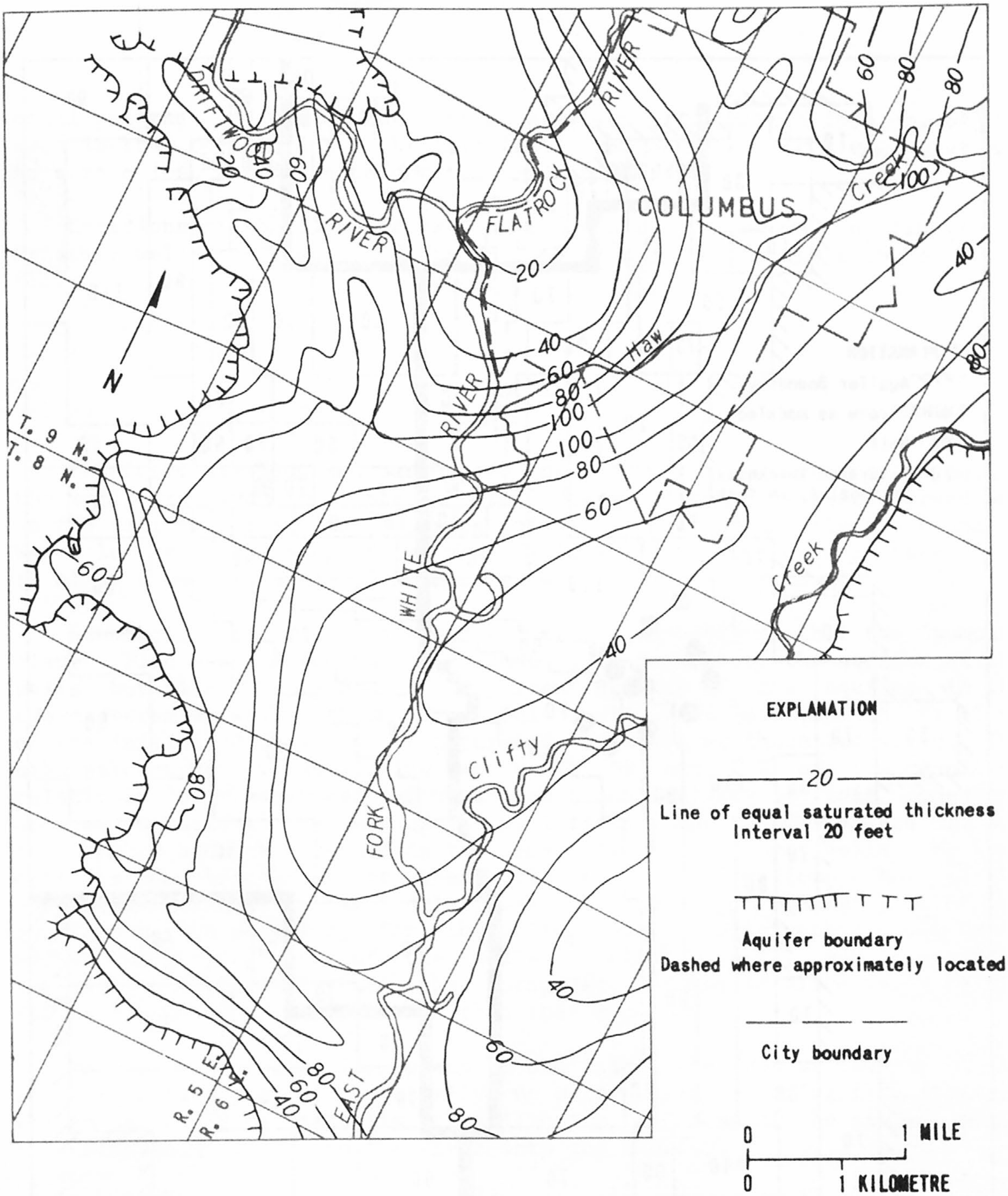
The value of streambed permeability used in the model for the East Fork White River was obtained using a technique described by Law (1965). Data were collected at one point deemed representative of the entire reach of the river for the study area. This technique assumes horizontal flow through a two-permeability system into a stream that fully penetrates the aquifer. The answer obtained is a product of the streambed's permeability and thickness. As thickness is difficult to measure, an arbitrary thickness of 1 ft (0.3 m) was chosen for the solution of the technique and for modeling purposes. The resultant value of streambed permeability was 7 ft/d (2 m/d).

One major assumption not fulfilled in the streambed analysis was that the stream did not fully penetrate the aquifer. This meant a component of vertical flow was present. To determine how accurate a value of streambed permeability was needed for the model, a second set of model runs was made with a streambed permeability of 0.7 ft/d (0.2 m/d). The results obtained with this value did not differ appreciably from the results obtained with a streambed permeability of 7 ft/d (2 m/d), and assured that the accuracy of the streambed permeability used with the model was adequate for the model analysis.

Hydraulic conductivities of shale and till that surround the aquifer are very low in comparison with that of the aquifer. Because the amount of water induced to flow across the aquifer boundaries by pumping should be small in comparison with the amount induced from the river, the sides and the base of the aquifer were modeled as impermeable. Where the aquifer continued either upvalley or downvalley beyond the area of study, the model was extended so that the cone of depression would not be excessively influenced by those boundaries.

Because changes in water level and ground-water flow caused by pumping can be calculated without simulating the initial field conditions, a flat uniform water table, with zero flow, was assumed as the initial conditions for the model. Model results then indicated changes in water level and flow due to pumping. By superposition, these changes can be added algebraically to the water levels and flows in the aquifer prior to pumpage to obtain approximate final water levels and flows. These approximations are reasonably accurate as long as water-level changes do not represent a high percentage of the original saturated thickness.

The finite-difference techniques used in the model compute an average drawdown for the rectangular area of aquifer represented by a given block. The actual drawdown within a pumping well is computed from this average drawdown for the block containing the well in a separate subroutine of the



After Watkins and Heisel, 1970, pl. 1.

Figure 3.-- Saturated thickness of the aquifer in the Columbus, Ind., area, February 16, 1967. Map is oriented to align with the model in figure 4.

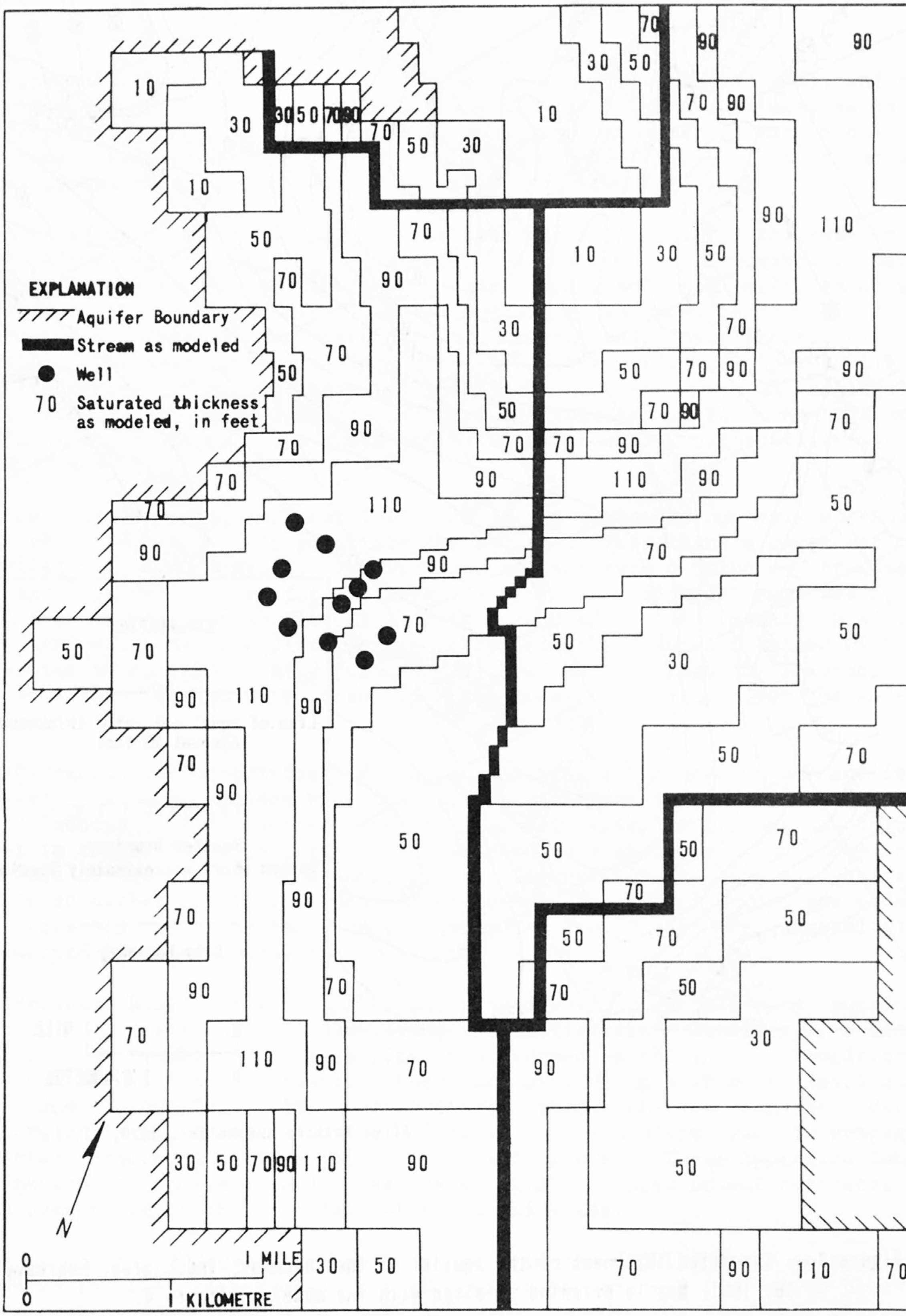


Figure 4. --Distribution of initial saturated thickness of the aquifer as modeled.

model program. A form of the Thiem equation (Trescott, 1975, p. 66) is used in this computation. The calculated drawdown is for a well that has no screen loss and fully penetrates the aquifer.

Locations of the 11 wells used in the model are shown in figure 5. Existing wells are numbered E1 to E6, and planned wells are numbered F7 to F11.

RESULTS

Predicted drawdown and percentage of saturated thickness dewatered for the wells are given in table 1. Areal distribution of predicted drawdowns in the aquifer for the two pumping plans is shown in figures 6 and 7. Water levels in the area of the well field would be lowered more than 20 ft (6 m) by pumping plan 1 and as much as 40 ft (12 m) by pumping plan 2.

Dewatering of the wells would differ considerably in the two pumping plans. Plan 1 would dewater approximately 30 percent of the aquifer at the wells, but plan 2 would dewater 80 percent or more of the aquifer in the two easternmost wells, F9 and F10. This would leave less than 15 ft (5 m) of the initial 70 ft (21 m) of saturated thickness at these two wells. The high percentage of dewatering at wells F9 and F10 are the result of relatively lower saturated thickness and transmissivity in this immediate area as compared to the rest of the well field. These lower values are due to a higher bedrock altitude in the immediate area of these wells. No test drilling has been done at these planned well locations, but if the saturated thickness is as modeled, new locations, in a thicker part of the aquifer, may be necessary for the wells. Another alternative would be to adjust the pumping rates of the wells. Wells E2, F7, and F8 could be pumped at a higher rate than that proposed; this would allow wells F9 and F10 to be pumped at a lower rate than that proposed.

The model results for plans 1 and 2 indicate that at the end of the 10-year pumping period practically no water would be coming from storage. The system would be virtually at equilibrium, and most of the pumpage would be sustained by flow from the river into the aquifer.

The effect of ground-water pumping on the stream would not be severe. The highest pumping rate for the well field (35 ft^3/s or 1.0 m^3/s) is less than 5 percent of the normal flow of the East Fork White River at Columbus (750 ft^3/s or 21 m^3/s) and is about 30 percent of the 7-day, 10-year low flow, 116 ft^3/s or 3.29 m^3/s (Rohne, 1972, p. 222). Decrease in flow of the river would be small because the well field is downstream of the city's wastewater treatment facilities, where most of the water that is pumped would be returned to the river.

The results of this study should be conservative because two possible sources of additional water were not included in the model. First, the base and the sides of the alluvial aquifer were modeled as impermeable.

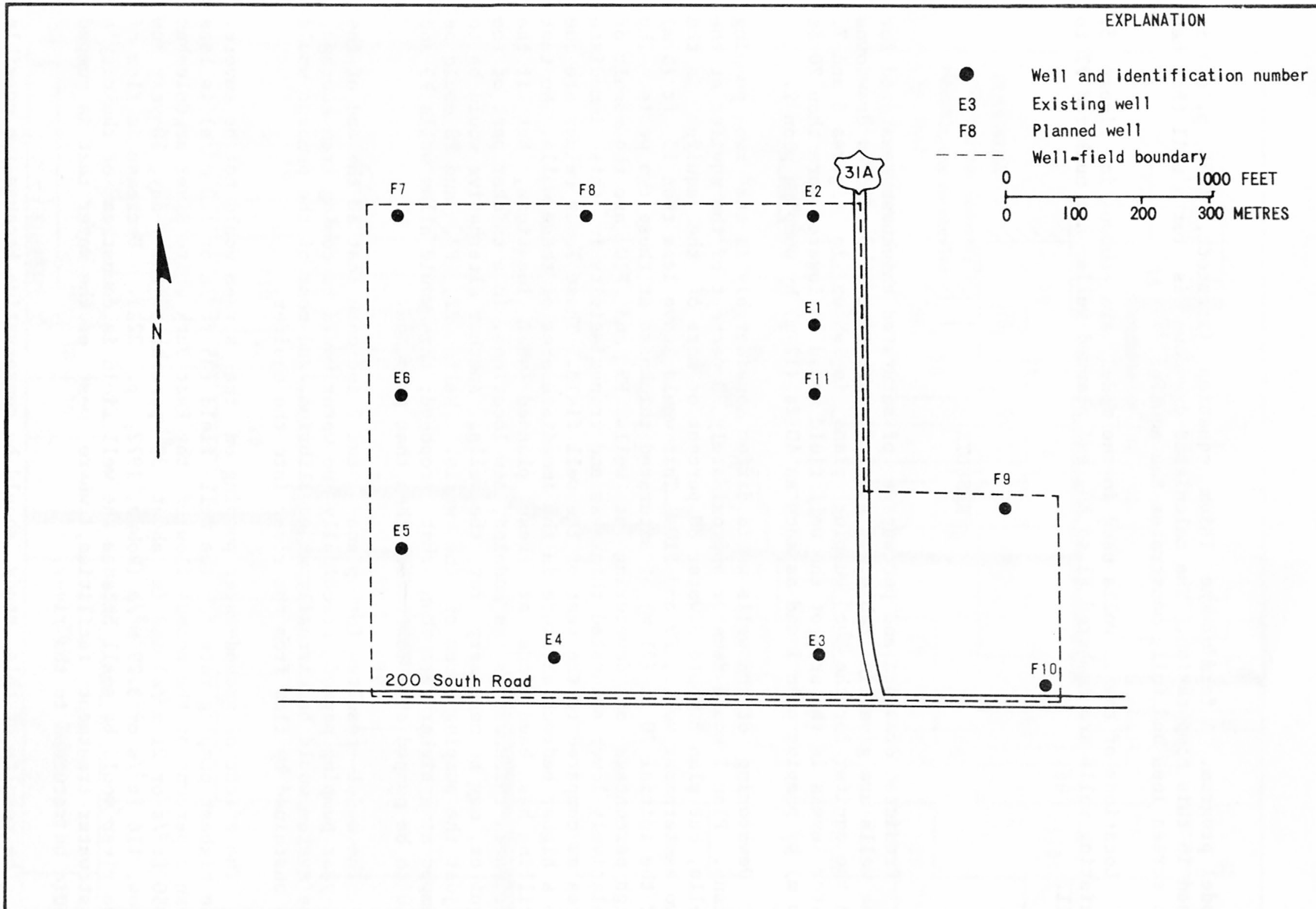


Figure 5.--Location of existing and planned wells.

Table 1.--Predicted drawdown for a well with a radius of 1 foot and percentage of saturated thickness dewatered at each well[1]

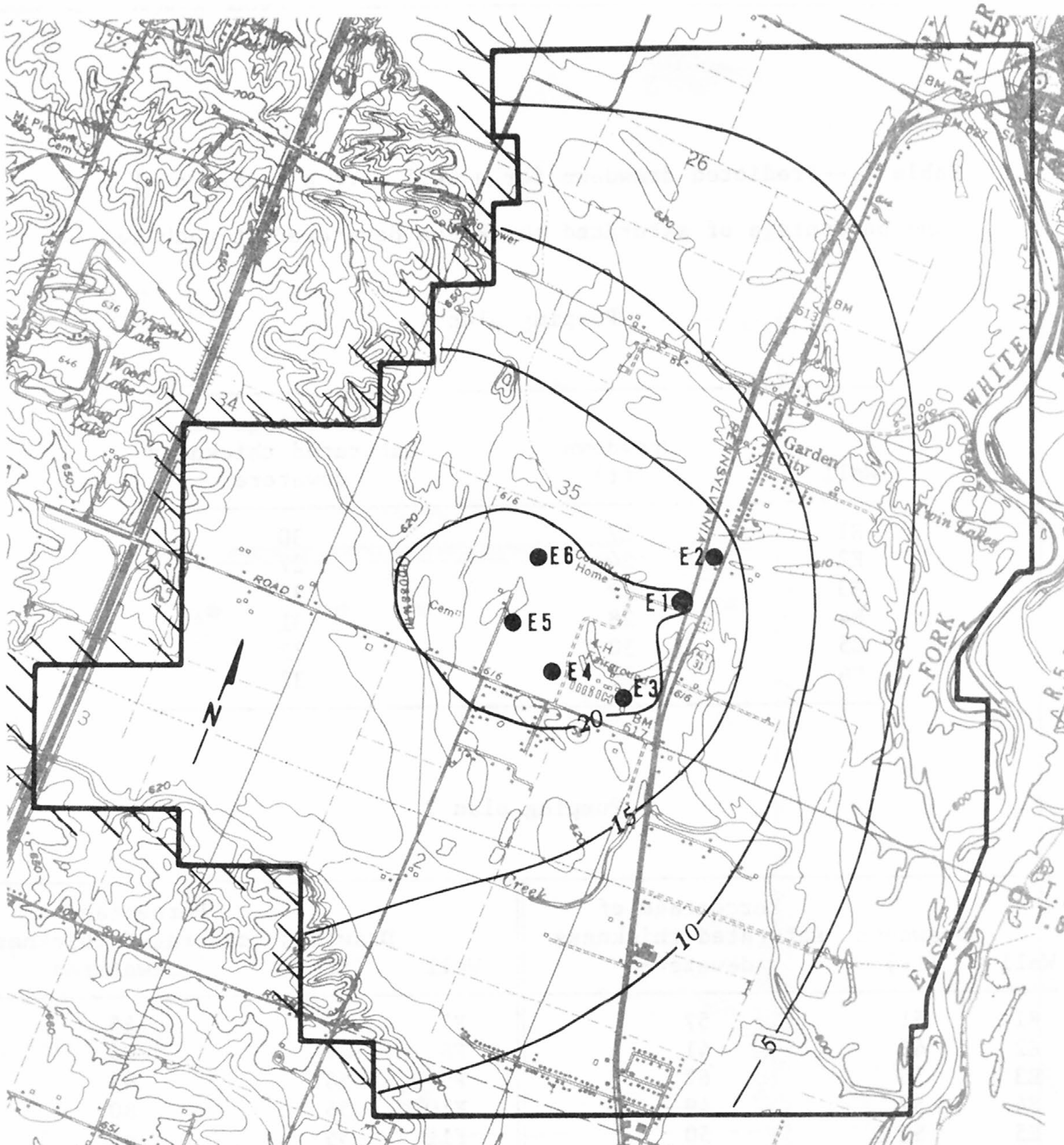
Pumping plan 1

Well	Drawdown (ft)	Percentage of saturated thickness dewatered
E1	27	30
E2	24	27
E3	29	32
E4	28	31
E5	30	33
E6	29	32

Pumping plan 2

Well	Drawdown (ft)	Percentage of saturated thickness dewatered	Well	Drawdown (ft)	Percentage of saturated thickness dewatered
E1	51	57	F7	47	45
E2	43	41	F8	47	45
E3	56	62	F9	58	83
E4	52	49	F10	56	80
E5	53	50	F11	55	61
E6	52	49	--	--	--

[1]Assumes that wells are fully penetrating and that well loss is negligible.



Base from U.S. Geological Survey, 1962

EXPLANATION

● E4 Well and identification number

—*10*— Line of equal drawdown
Interval is 5 feet

——— River, as modeled

Impermeable barrier, as modeled

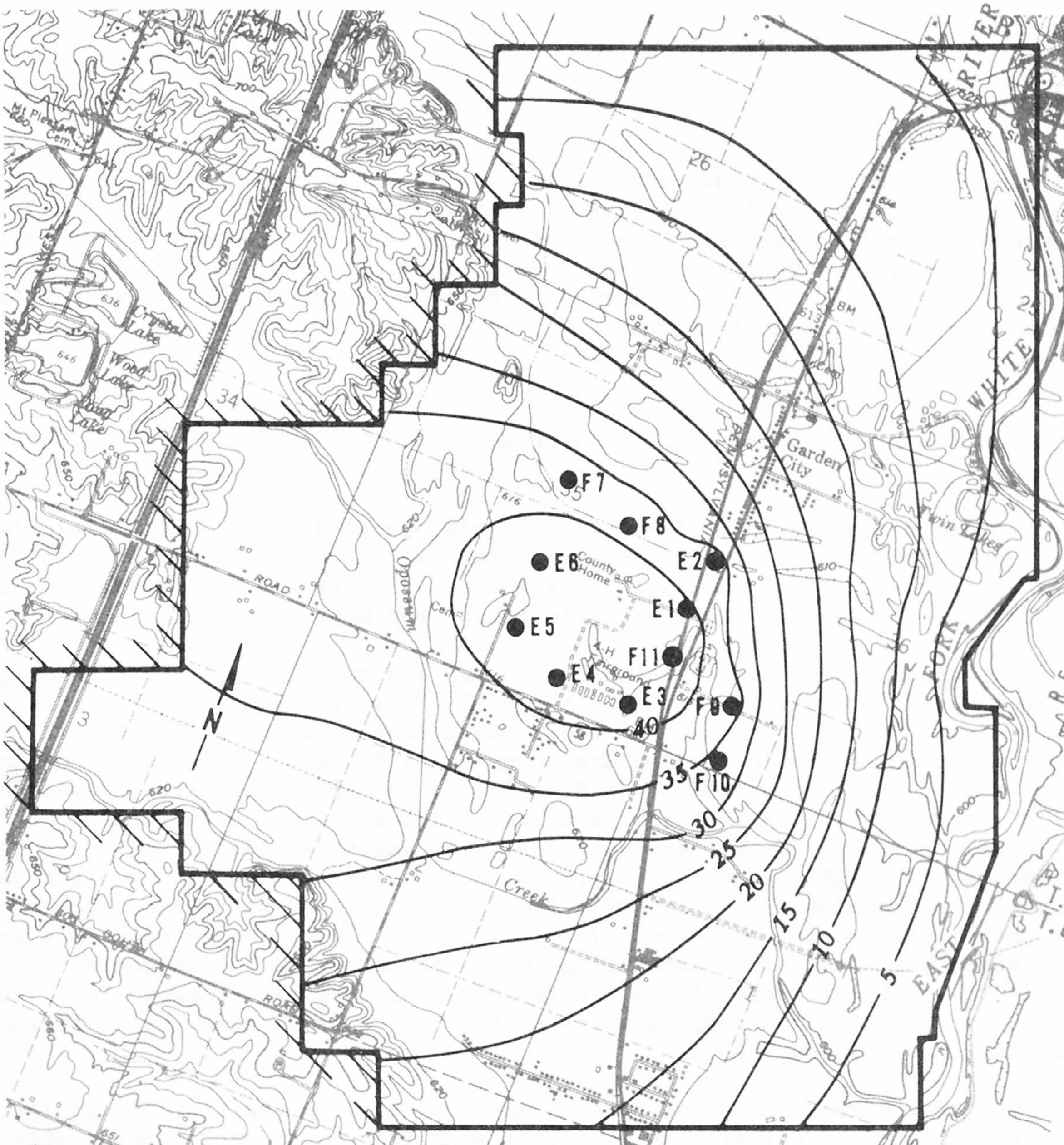
0 — 1 MILE

0 — 1 KILOMETRE

Contour interval 10 feet

Datum is mean sea level

Figure 6.-- Areal distribution of drawdown after 10 years of pumping, plan 1. Map is orientated to align with figure 4.



Base from U.S. Geological Survey, 1962

EXPLANATION

● E4 Well and identification number

—10— Line of equal drawdown. Interval is 5 feet

River, as modeled

Impermeable barrier, as modeled

0 — 1 MILE

0 — 1 KILOMETRE

Contour interval 10 feet
Datum is mean sea level

Figure 7.-- Areal distribution of drawdown after 10 years of pumping, plan 2. Map is orientated to align with figure 4.

Because most materials have some permeability, water would be induced to flow into the aquifer across the aquifer boundaries. Secondly, evapotranspiration salvage was not simulated. If there is direct evapotranspiration from the water table, lowering the water table would reduce evapotranspiration. Both of these effects would decrease the drawdowns predicted in this study.

CONCLUSIONS

According to the digital-model analysis, pumping plan 1 would yield 12 Mgal/d (0.5 m^3/s) and would produce drawdowns in the wells of about 35 ft (11 m) from an initial saturated thickness of 100 ft (30 m). Water levels throughout the area of the well field would drop more than 20 ft (6 m).

A planned addition of five wells to the six existing wells for pumping plan 2 would increase the yield of the well field to 22 Mgal/d (1.0 m^3/s). Water levels throughout the well field would drop more than 40 ft (12 m) for this plan and would produce drawdowns of 41 to 62 ft (12 to 19 m) in the wells. For two of the planned wells, F9 and F10, excessive drawdowns of 80 percent of the initial saturated thickness would drop water levels below the top of 20-ft (6-m) screens. The excessive dewatering would be caused by a higher bedrock altitude in the area of these two wells than that in the remainder of the well field. The initial saturated thickness at these wells would be about 70 ft (21 m). Two possible solutions to alleviate the excessive dewatering would be either to (1) relocate these wells to a thicker part of the aquifer or (2) reduce the drawdown in these wells by adjusting the pumping rates of all the wells to allow wells F9 and F10 to pump at lower rates.

The mass balance computed by the model program showed that the aquifer system would be practically at equilibrium at the end of each pumping plan. The discharge from pumping (35 ft^3/d or 1.0 m^3/s) would be balanced by water diverted from the East Fork White River and the maximum amount of stream depletion would be about 30 percent, using the 7-day, 10-year low flow (116 ft^3/d or 3.29 m^3/s).

REFERENCES CITED

Law, A. G., 1965, The effect of stream perimeter clogging on unsteady ground water flow toward a surface stream: Ph.D dissertation, Wisconsin Univ. (unpub.), 100 p.

Rohne, P. B., 1972, Low-flow characteristics of Indiana streams: U.S. Geol. Survey open-file report, 322 p.

Trescott, P. C., 1975, Iterative digital model for aquifer evaluation: U.S. Geol. Survey open-file report, 88 p.

Watkins, F. A., and Heisel, J. E., 1970, Electric-analog-model study of water resources of the Columbus area, Bartholomew County, Indiana: U.S. Geol. Survey Water-Supply Paper 1981, 22 p.

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