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EFFECTS OF PUMPING ON GROUND-WATER LEVELS NEAR TAYLORSVILLE, BARTHOLOMEW COUNTY, INDIANA

U.S. GEOLOGICAL SURVEY

WATER RESOURCES INVESTIGATIONS 79-20

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February 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

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METRIC CONVERSION FACTORS

The inch-pound units used in this report can be converted to the metric system of units as follows:

Multiply inch-pound unit	By	To obtain metric unit
inch (in)	25.40	millimeter (mm)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.0631	liter per second (L/sec)
cubic foot per second (ft^3/sec)	0.0283	cubic meter per second (m^3/sec)
foot per day (ft/day)	0.3048	meter per day (m/day)

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By Michael Planert and Patrick Tucci

ABSTRACT

A two-dimensional digital flow model was used to estimate the effects of continuous pumping of a public-supply well field on the ground-water levels near Taylorsville, Indiana. Results of the modeling showed that the water levels would decline from less than 1 to about 4.5 feet within the study area and a maximum of 1 to 2 feet in Taylorsville in response to a pumping rate of 700 gallons per minute. Model results also show that the ground-water system would reach steady state in approximately 5 years after pumping begins. Corrections applied to water-level declines indicated by the model, to account for the effects of partial penetration of the aquifer by wells, showed that these effects, although substantial in the pumping wells, are negligible 200 feet from the wells.

INTRODUCTION

The town of Taylorsville, Ind., in north-central Bartholomew County, is 7 miles northwest of Columbus, Ind. (fig. 1). A preglacial bedrock valley filled with glacial sand and gravel deposited by melt water during Wisconsin Glaciation underlies the town. The water in the deposits represents the major water supply for the homes and towns in the area, including Taylorsville and Columbus.

In April 1966, the U.S. Geological Survey (USGS) in cooperation with the Indiana Department of Natural Resources (IDNR) began a study to determine the availability of water in the sand and gravel in an approximately 100-mi^2 area extending north and south from Columbus to the county line. The study, which included determining water-level declines associated with ground-water development at selected sites, is described by Watkins and Heisel (1970).

Since the recent (1977) installation of a well field by the Eastern Bartholomew Water Corp. (EBWC) in the sand and gravel aquifer near Taylorsville (fig. 2), the townspeople have become concerned that pumping at the well field would adversely affect domestic wells. Because of this concern, the USGS in cooperation with IDNR began a study to evaluate the hydrologic effects of pumping on water levels and streamflow. To accomplish this goal, the geohydrologic data in Watkins and Heisel (1970) were updated with information collected by the USGS and IDNR since 1970, and the combined information was used to construct a digital model of the ground-water flow system

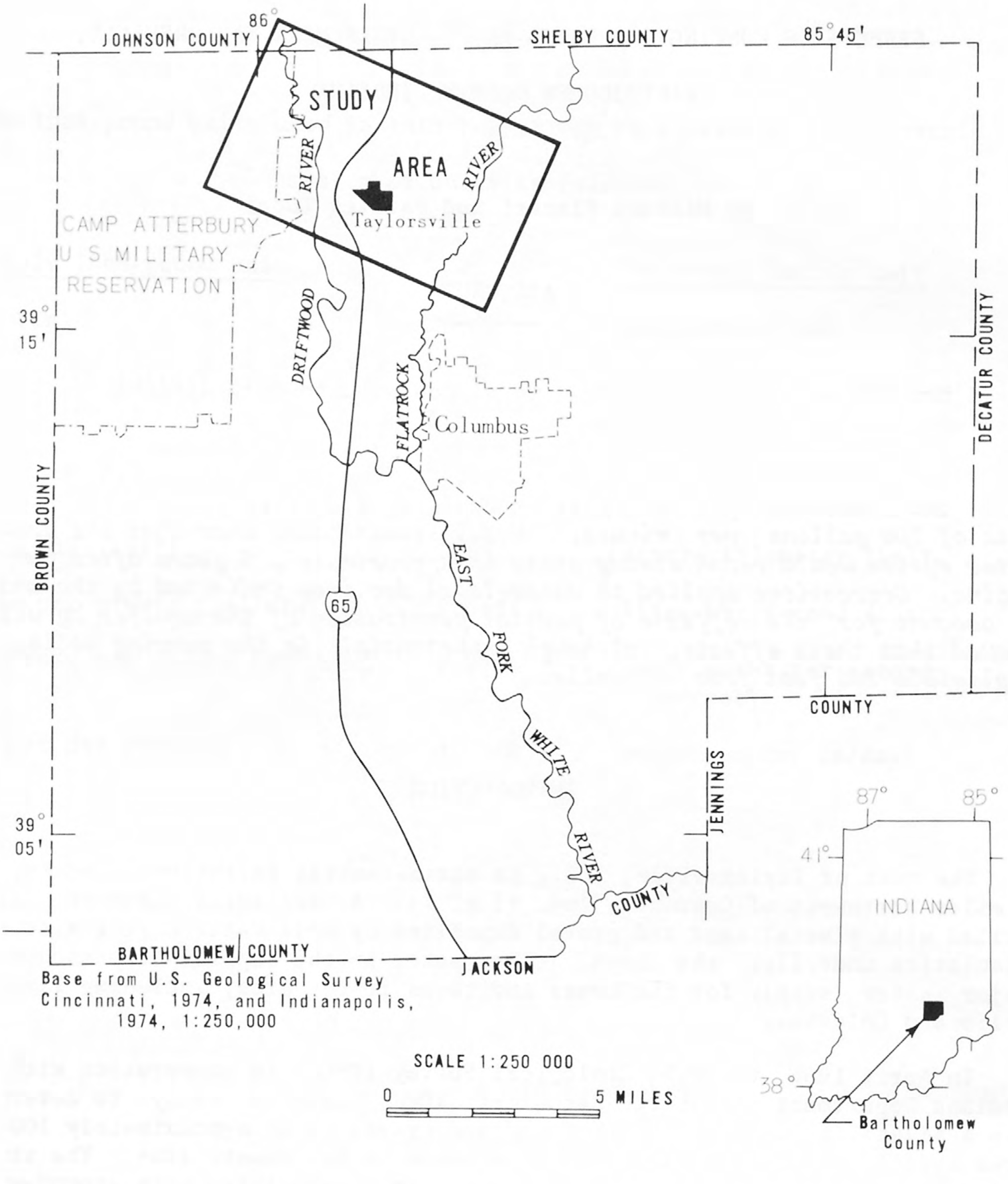


Figure 1.-- Location of the study area near Taylorsville, Bartholomew County, Ind.

in the Taylorsville area. The model was used to evaluate water-level declines associated with pumping from the EBWC well field. This report summarizes the geohydrologic data on which the model was constructed and the results obtained from the model after simulation of pumping at the well field.

GEOHYDROLOGIC SETTING

The glacial outwash in the study area consists of sand and gravel (fig. 3). This sand and gravel constitutes the primary aquifer. The aquifer is bounded on the east and west by sandy till, a mixture of clay, silt, and some gravel, and discontinuous sand and gravel lenses that may be as much as 10 ft thick. The till crops out in a series of hills west, southwest, and northeast of Taylorsville (fig. 4). The saturated thickness of the aquifer ranges from zero at its edges to more than 120 ft in the center of the buried valley (fig. 5). Data from well logs collected since the study by Watkins and Heisel (1970) were used to update the saturated-thickness map presented in their report (fig. 6). The updating caused no major changes in the original map.

Beds of Devonian age limestone, dolomite, and shale constitute the bedrock in the study area (fig. 4). The aquifer is underlain by the Devonian New Albany Shale along the edges of the valley and by limestone and dolomite on the valley floor.

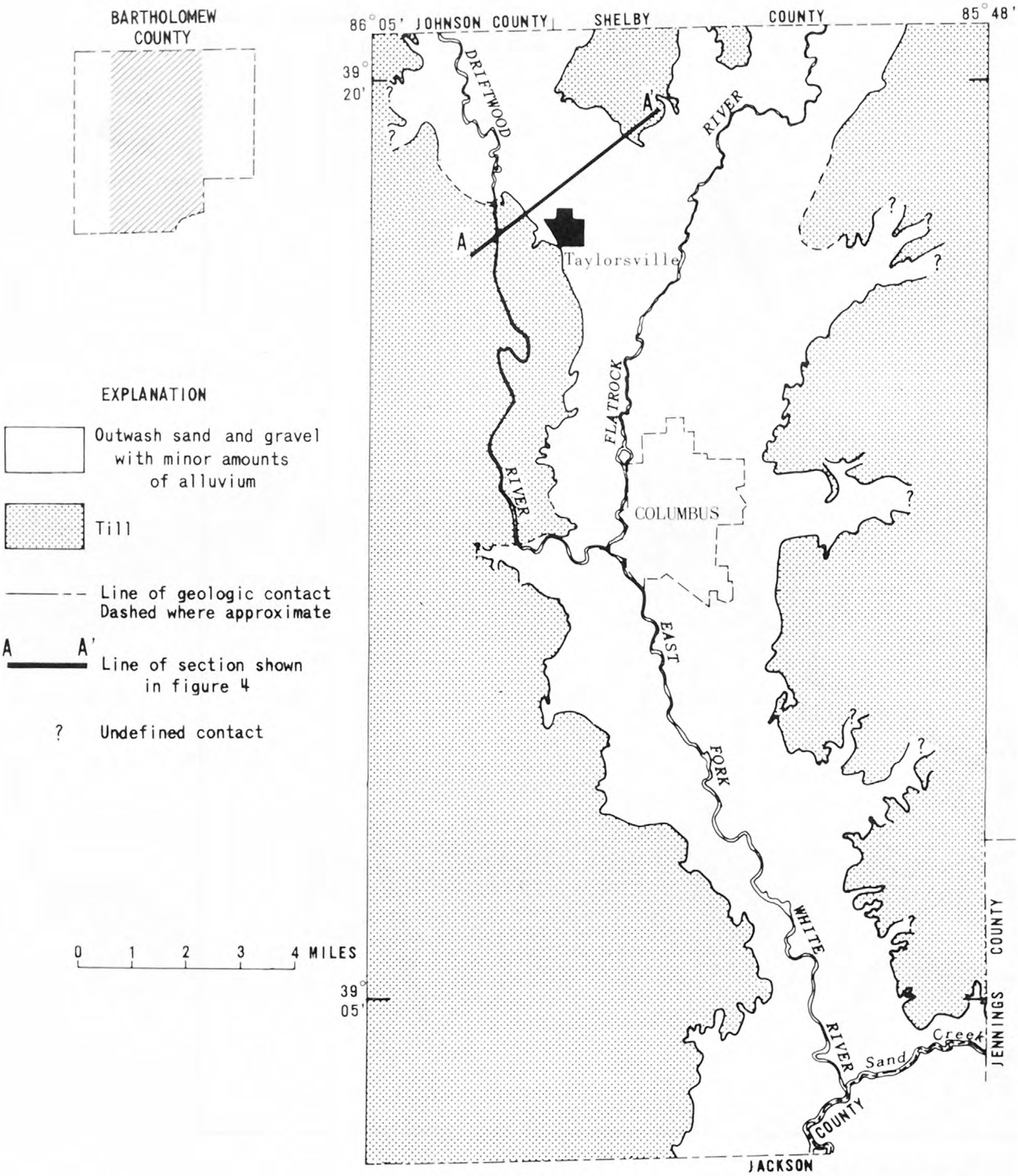
Schneider and Gray (1966) described the geology of the area in more detail as a part of a study of the Upper East Fork White River.

HYDRAULIC CHARACTERISTICS OF THE AQUIFER SYSTEM

The rate at which water can flow through an aquifer to a well is a function of the aquifer transmissivity and hydraulic gradient. Transmissivity of the aquifer was calculated by multiplying its saturated thickness by an average hydraulic conductivity estimated by Watkins and Heisel (1970) from specific-capacity data (well yield, in gallons per minute, divided by drawdown of water level, in feet). They also used four aquifer tests of the outwash to estimate hydraulic conductivity and compared the values obtained with those from the specific-capacity data. The average hydraulic conductivity was calculated to be 468 ft/day.

Specific yield for the aquifer, determined by Watkins and Heisel, was 0.2, an average value obtained by the four previously mentioned aquifer tests. Specific yield determines the amount of water released from storage in the aquifer for a given change in water level. It also governs the length of time needed for the ground-water system to attain a new equilibrium after a new stress, such as pumping, is imposed. Specific yield of

Figure 2.-- Study area near Taylorsville, Bartholomew County, Ind.



Modified from
A. F. Schneider and
H. H. Gray, 1966

Figure 3.-- Generalized surficial geology in central Bartholomew County, Ind.

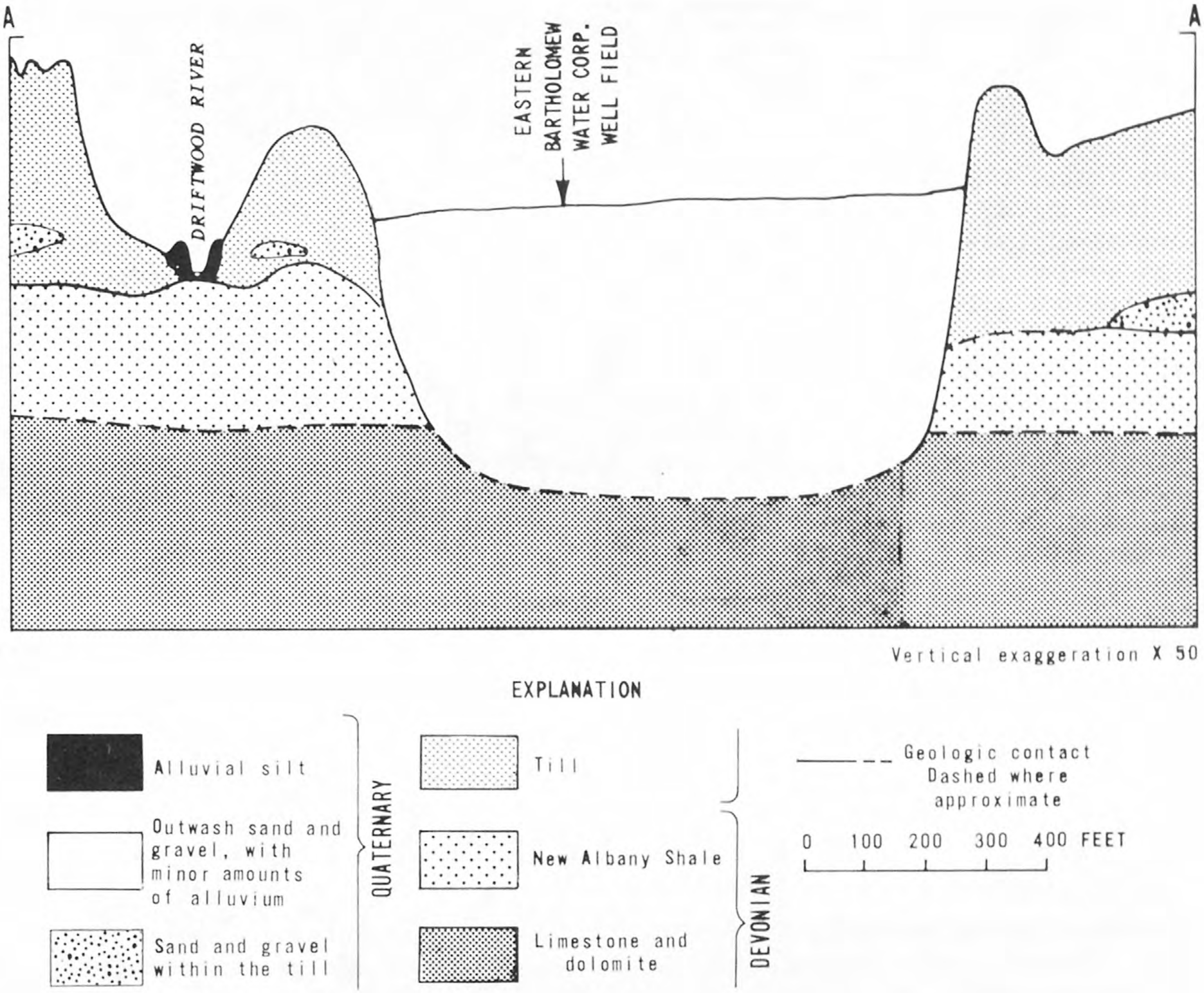


Figure 4.-- Generalized geologic section north of Taylorsville, Ind.

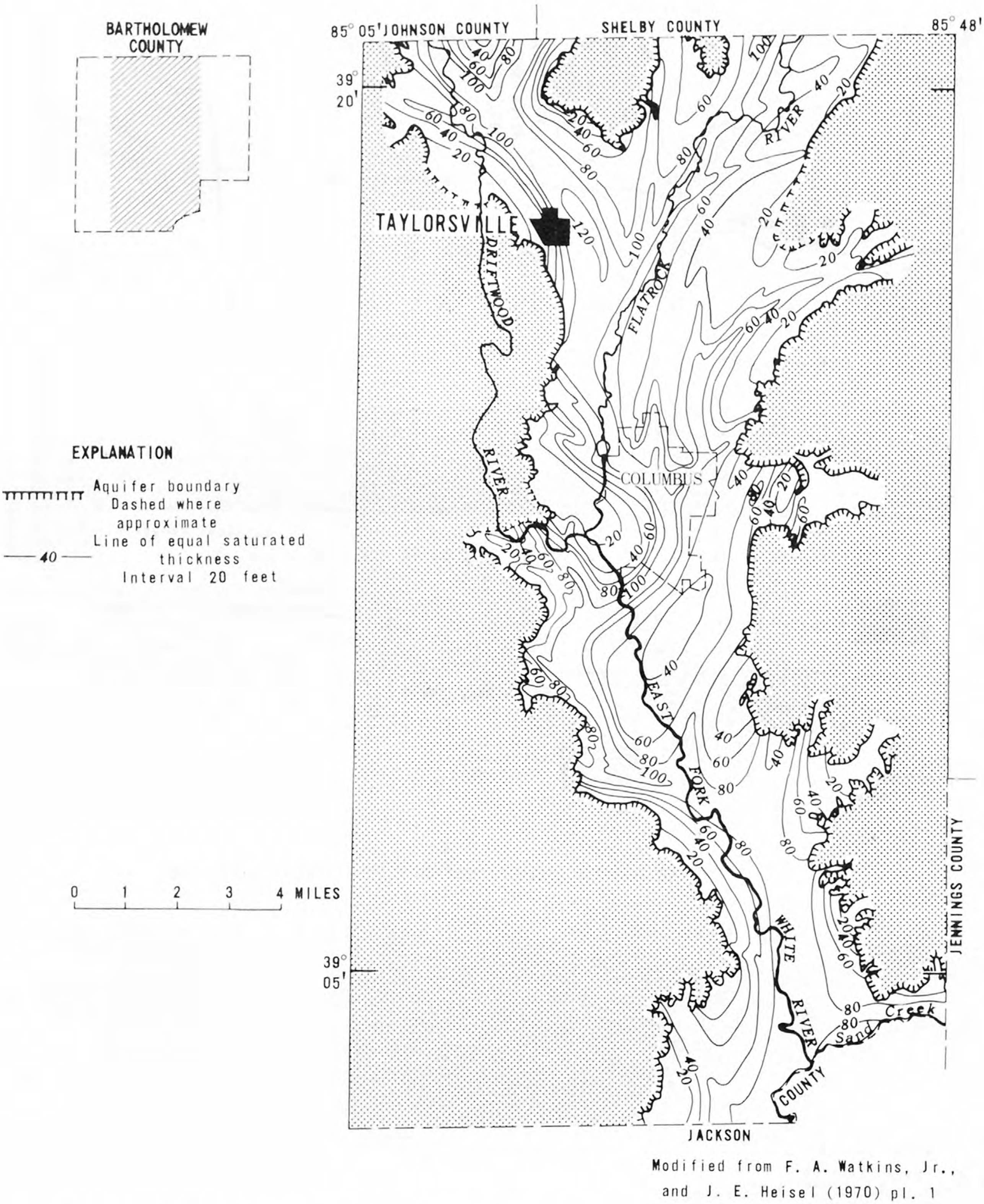


Figure 5.-- Saturated thickness of the glacial-outwash aquifer, Bartholomew County, Ind., February 16, 1967.

most unconfined aquifers ranges from 0.1 to 0.3 (Lohman, 1972). The amount of water available from storage in an aquifer and the length of time for the ground-water system to reach equilibrium in response to a stress increase as the specific yield increases.

The hydraulic connection between a stream and an aquifer determines the amount of water that can be diverted from the stream by a pumping well. Pumping diverts some of the water that otherwise would have been discharged to the streams. If the pumping rate is high enough, some water may be induced directly from the stream into the aquifer. This hydraulic connection also affects the water-level declines in the aquifer for a given rate of pumping. The vertical hydraulic conductivity of the river beds near the study area has been evaluated independently by Planert (1976) and William Meyer (USGS, oral commun., 1978). Both Meyer's evaluation, involving an aquifer test, and the other evaluation, involving the response of the aquifer to a flood pulse in a river, determined a value of 7 ft/day on the basis of a riverbed thickness of 1 ft. Other information needed to describe stream-aquifer connection were the average width and depth of local streams. From inspection at bridges, the average width was estimated to be 200 ft and the average depth 2 ft. This depth approximately corresponds to the 50-percent flow duration of the Driftwood and Flatrock Rivers. Flow duration is the amount of flow that is equaled or exceeded in the river for that percentage of time during the period of record.

GROUND-WATER FLOW

Ground water originates as infiltration of precipitation moving downward through the soil to the water table. In the saturated zone beneath the water table, the water moves under the force of gravity to lower points of discharge. Examples of these points include pumping wells and streams. The water table of the outwash aquifer mapped by Watkins and Heisel (1970) and its relation to the rivers are shown in figure 7. Direction of ground-water flow is generally perpendicular to and downgradient from the lines of equal water level. Ground-water flow is generally from the valley walls to the rivers, although some flow is downvalley. Also, a minor amount of water enters the outwash aquifer from the till and shale that form the valley walls, where the lines of equal water level do not intersect the valley walls at right angles.

Water also moves vertically within the aquifer, although the areal extent of the vertical flow is small. Near the valley edge, the movement is predominantly downward. As the water moves toward the rivers, the flow is mostly lateral. Finally, the movement of water is upward into the river.

The amount of water flowing in the aquifer varies with the amount of recharge it receives from precipitation, which, in turn, varies seasonally and annually. From a total precipitation of approximately 40 in/yr, the average contribution from precipitation to the outwash aquifer was estimated to be 5.8 in/yr (Watkins and Heisel, 1970). From late fall through approximately early spring, recharge to the aquifer exceeds discharge; for the remainder

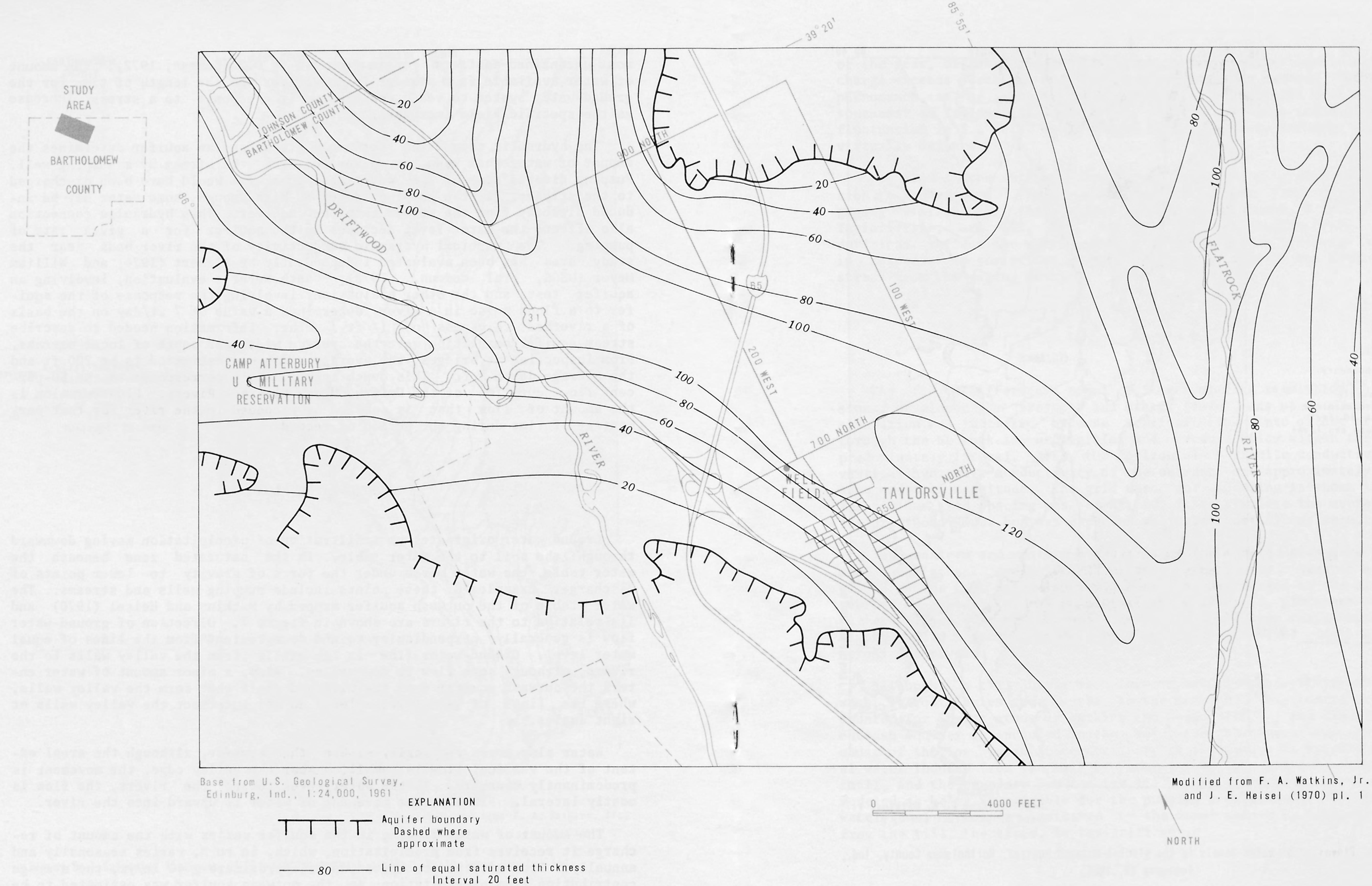


Figure 6.-- Saturated thickness of the glacial-outwash aquifer in the study area, February 16, 1967.

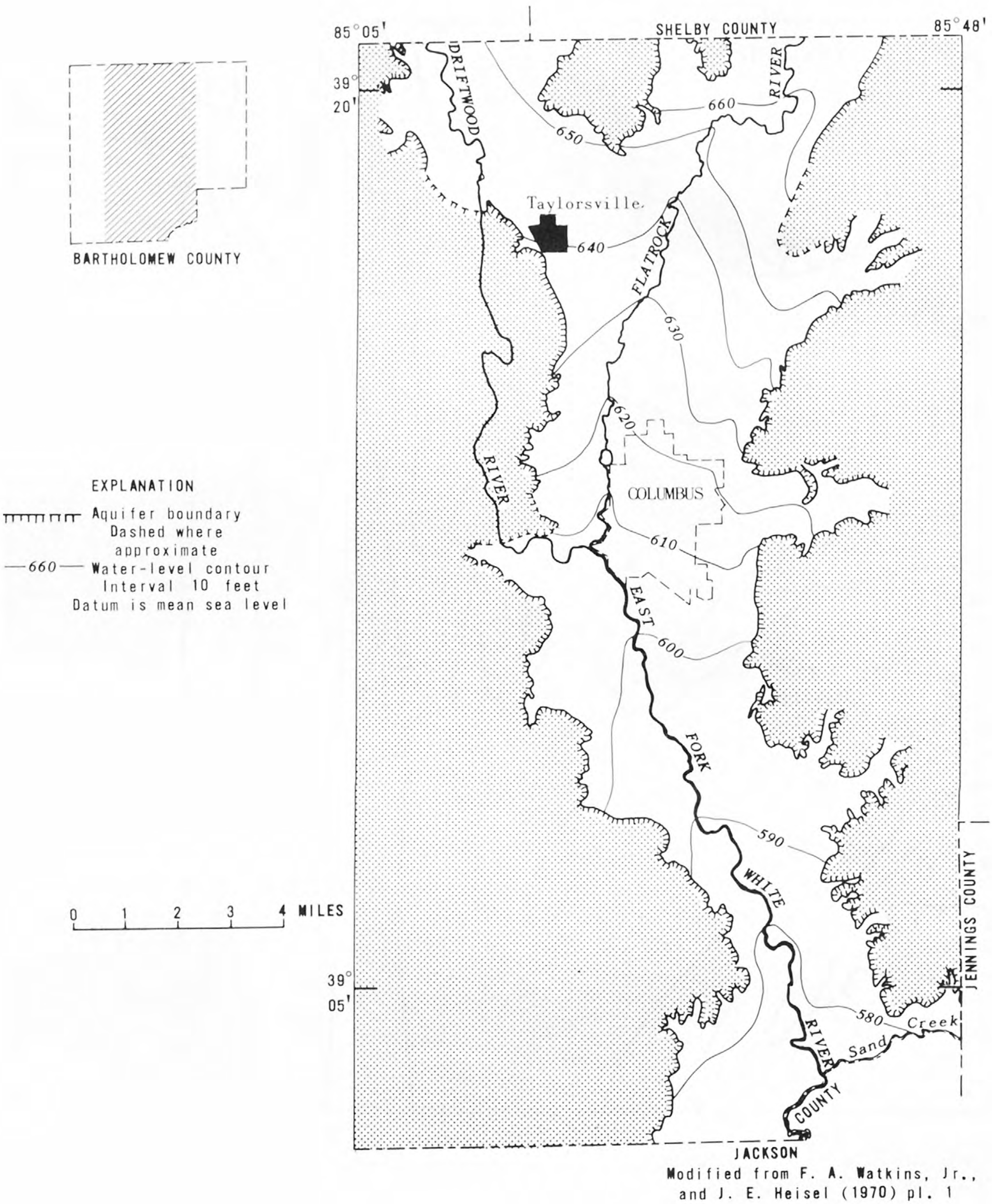


Figure 7.-- Elevation of water-levels in the glacial-outwash aquifer, Bartholomew County, Ind., February 16, 1967.

of the year, discharge exceeds recharge. Ground-water levels rise when recharge exceeds discharge and decline when discharge exceeds recharge. This phenomenon can be seen in the hydrograph of observation well BA-4, 3 miles southeast of Taylorsville (fig. 8), where the average seasonal water-level fluctuation is 3.6 ft. On an annual basis, however, recharge and discharge virtually balance.

Low flow in the streams generally reflects only ground-water contribution to the streams. The 50-, 70-, and 90-percent flow durations at the gaging station for the Driftwood River at Edinburgh, 3 miles north of Taylorsville, are 500, 267, and 147 ft^3/sec, respectively. These flow durations reflect the varying amount of ground-water discharge to the river in response to variations in ground-water recharge to the entire basin upstream from the gaging station.

MODEL CONSTRUCTION

The finite-difference model for aquifer-flow simulation in two dimensions, developed by Trescott and others (1976), was used. Two-dimensional simulation was justified because vertical flow into or out of the system through the bedrock is negligible and because flow within the outwash is predominately lateral. Also, the horizontal hydraulic conductivity and the vertical hydraulic conductivity of the outwash are approximately within the same order of magnitude. The grid used for modeling is shown in figure 9. The minimum grid spacing was set at 200 ft to simulate the average width of the Driftwood River but was expanded where less detail was required.

The eastern and western boundaries of the modeled area were placed beyond the Flatrock and Driftwood Rivers, respectively. Because diversion of ground water that otherwise would have been discharged to the rivers is the source of water for the pumping at the well field, placement of the boundaries at some distance beyond the rivers would keep those boundaries from significantly affecting model results if water-level declines extended across the rivers.

Although the till has a much lower hydraulic conductivity than the outwash, it contributes some water to the outwash. This contribution was accounted for in the study by Watkins and Heisel (1970), and its effect on the outwash aquifer is included in the saturated thickness map (fig. 6). Because of the low hydraulic conductivity of the till, the amount of additional water induced from the till by pumping in the outwash aquifer will be small, and the boundary between the till and the outwash can sensibly be modeled as being impermeable for the pumping simulations. The error in the water-level declines indicated by the model caused by neglecting the flow from the till, therefore, is insignificant.

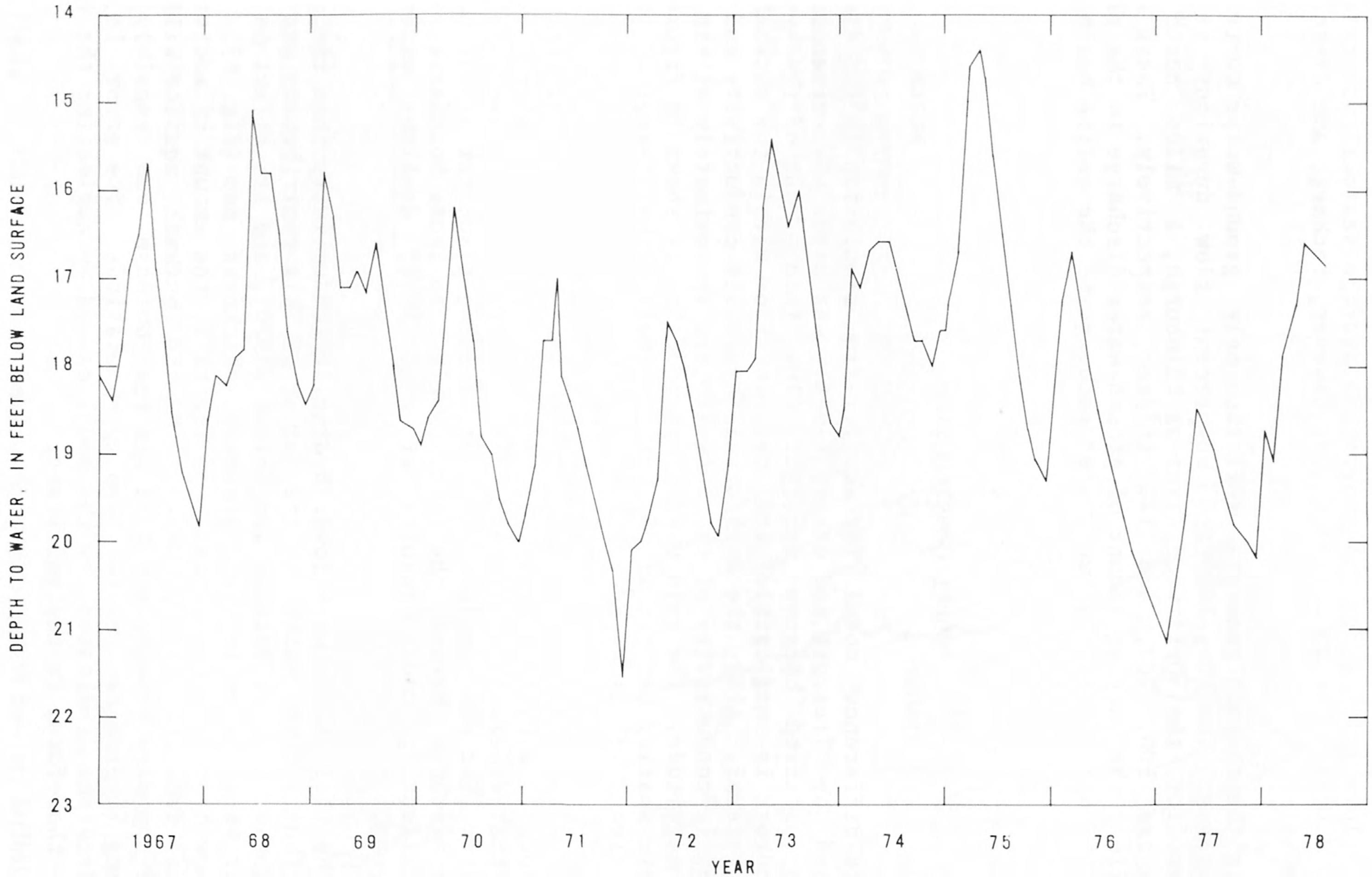


Figure 8.-- Hydrograph of water-levels in observation well BA-4, north of Columbus, Ind.

The bedrock was simulated as being the impermeable base. The other model boundaries, although not hydraulically bounded, were also simulated as being impermeable. However, these boundaries were placed sufficiently far away from the simulated pumping that they did not significantly affect the model results.

Any pumping well simulated in the model is assumed to be screened through the entire saturated thickness of the aquifer (fully penetrating) and to be 100 percent efficient. The wells in the EBWC well field are not fully penetrating, because they are screened only in the bottom 20 ft of the aquifer, and are not 100 percent efficient. The significance of the model assumption concerning well penetration is discussed in the section "Model Results." The model assumption of 100-percent efficient pumping wells does not affect the prediction of water-level declines outside the well bore.

The rivers were simulated as constant water levels (constant heads) separated from the aquifer by the riverbed. The amount of water per unit area of riverbed diverted from the river by pumping depends on the vertical hydraulic conductivity, thickness, and area of the riverbed. The riverbed was assigned a vertical hydraulic conductivity of 7 ft/day and a thickness of 1 ft. The area of the riverbed was assumed to be the same as the area of the grid blocks assigned to the rivers.

Specific yield and lateral hydraulic conductivity of the aquifer, as discussed in the section "Hydraulic Characteristics of the Aquifer" were also simulated as being constant. Variation in saturated thickness of the aquifer was simulated by changing the elevation of aquifer bottom from node to node.

Because the objectives of the current study are concerned only with changes in water levels caused by pumping and the data of Watkins and Heisel (1970) were used without significant change, calibration of the digital model to existing conditions was not necessary. The only water movement simulated in the model was that caused by pumping at the well field. Water-level changes indicated by the model reflect only those changes resulting from this pumping. This analysis assumed that no significant changes in pumping have occurred since the study of Watkins and Heisel (1970). It also assumed that the distribution of effective areal recharge is not affected by pumping at the well field.

Pumping at the EBWC well field was simulated in the model by one well discharging 700 gal/min from the node block that corresponds most closely to the location of the well field. This pumping rate is the maximum capacity of the filter plant at the well field (Burl Carlton, EBWC, oral commun., 1978). Although the well field has two wells, each designed to pump 700 gal/min, only one well is pumped at any one time. The pumping simulation was continued until steady-state conditions were achieved. At steady state, water levels in the aquifer stop declining because the water pumped from the well is obtained by diversion of ground water that otherwise would be discharged to the rivers rather than obtained from aquifer storage.

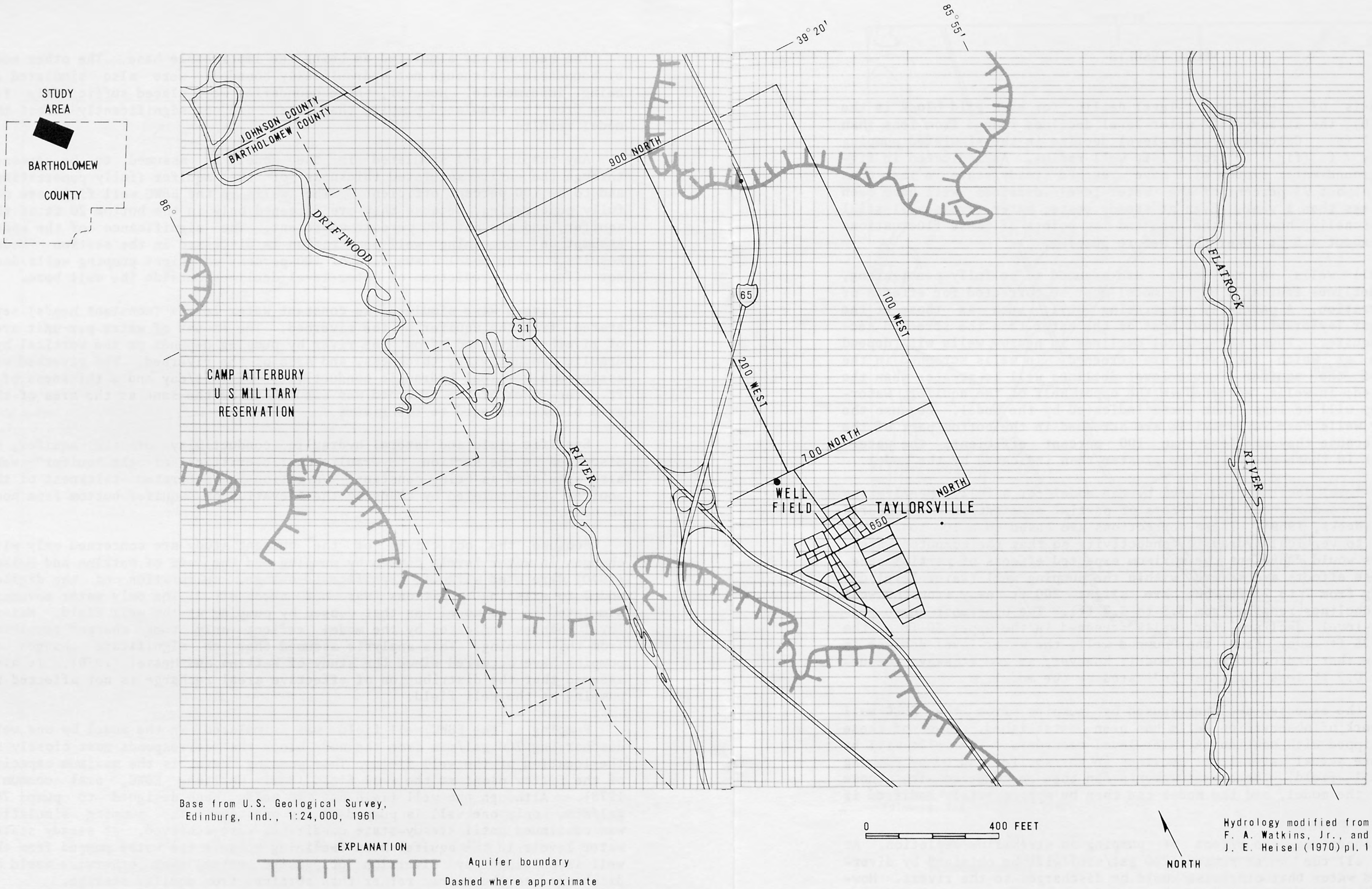


Figure 9.-- Nodal grid used in the model.

MODEL RESULTS

On the basis of average water-level decline for each grid block in the model (fig. 10), the steady-state water-level declines ranged from less than 1 to about 4.5 ft. Calculated water-level decline in the simulated pumping well is nearly 7 ft (fig. 11) for a 1-ft well radius. As indicated in figure 11, the ground-water system will have reached steady state in less than 5 years, and almost 95 percent of the water-level declines will have been attained in less than 1 year. Even at steady state, water levels will still fluctuate seasonally; however, the high and low points of these fluctuations will be 1 to about 4.5 ft lower than before pumping.

Because all wells in the model are assumed to be fully penetrating, water-level declines indicated by the model must be corrected for effects of partial penetration. A partially penetrating well, such as those at the well field near Taylorsville, draws most of the water from the screened section of the aquifer. Thus, water-level declines in nearby wells will depend on the depth at which the wells are screened. In wells screened in the bottom half of the aquifer, water-level declines will be greater than the model indicated; in wells screened in the upper half of the aquifer, water-level declines will be less than those indicated by the model. Because the public-supply wells near Taylorsville are screened in the bottom part of the aquifer and because they are less than 100 percent efficient, the water-level declines in those wells will be greater than indicated by the model.

The water-level declines indicated by the model for a fully penetrating well and declines corrected for effects of partial penetration are compared in figure 12 (Weeks, 1969). These corrections are based on a 10 to 1 ratio of horizontal to vertical hydraulic conductivity so that the computed water-level declines would represent the maximum expected effects of partial penetration. These effects are severe within the pumping well (water-level declines ranging from 7 to 21 ft) but are slight 200 ft away from the well (water-level declines ranging from 3.5 to 3.7 ft). The uppermost curve represents water-level declines for wells screened in the upper 30 ft of the aquifer. At 25 ft away from the pumped well, the water-level decline is 1 ft less than that indicated by the model; however, at 200 ft away, the decline is only 0.2 ft less than that indicated by the model.

To verify the expected declines caused by pumping from the EBWC well field, a network of observation wells has been established. Two of these wells are equipped with continuous water-level recorders. The wells will be used to measure actual water-level declines in the aquifer caused by pumping from the well field. These measurements can then be compared with those calculated by the model, and the model can then be appropriately modified if necessary.

Another concern was the effect of pumping on streamflow depletion. At steady state, all the water pumped (700 gal/min) will be obtained by diversion of ground water that otherwise would be discharged to the rivers. However, this pumping rate is about equal to or less than 1 percent of the current low flows of the Driftwood River.

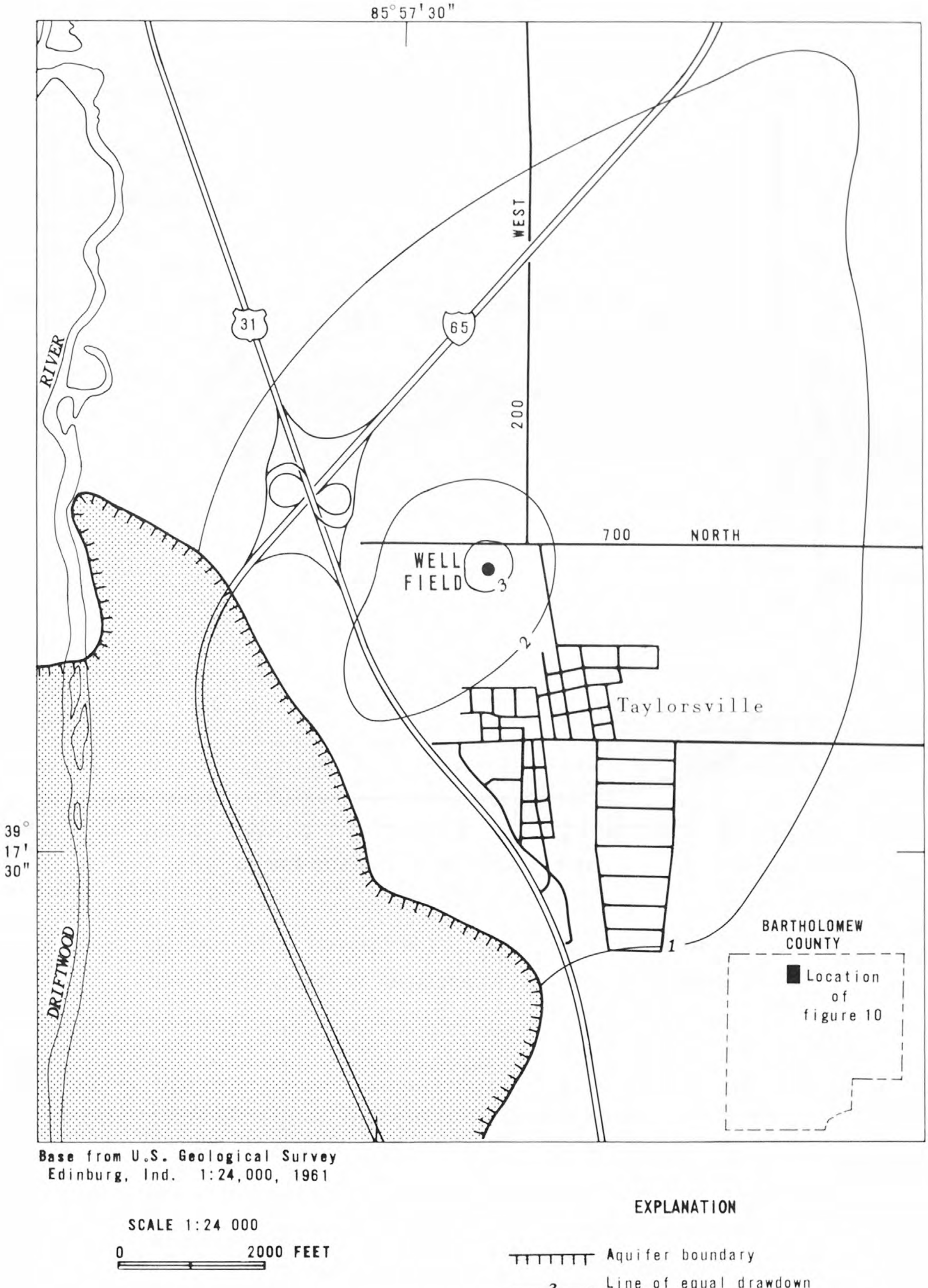


Figure 10.-- Water-level declines indicated by the model after 16 years of simulated continuous pumping, Taylorsville, Ind.

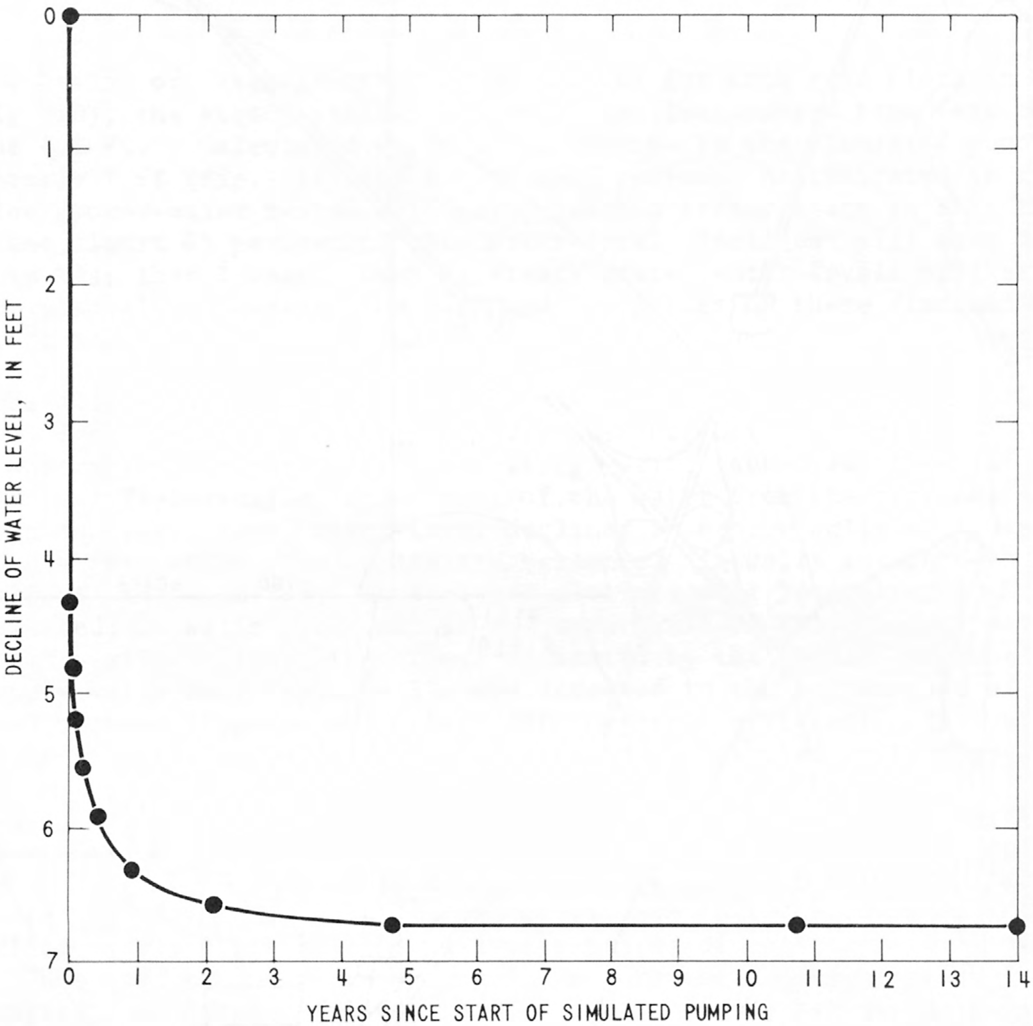


Figure 11.-- Water-level declines indicated by the model in the simulated continuous pumping well since start of pumping at the rate of 700 gal/min.

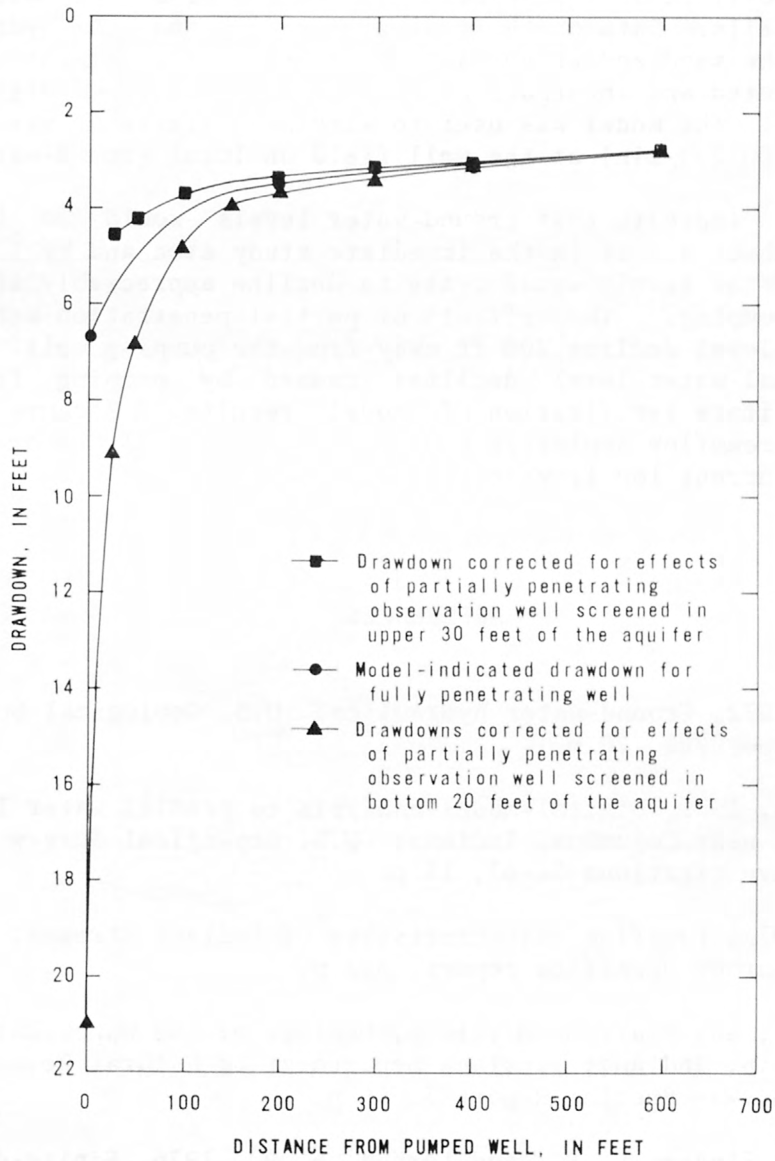


Figure 12.-- Effect of partial penetration of the aquifer on model-indicated water-level declines due to pumping from EBWC well field near Taylorsville, Ind.

SUMMARY

The recent installation of a well field near Taylorsville, Ind., caused speculation on possible adverse effects of pumping from the well field on local domestic wells. Data on the geologic setting and the hydraulic characteristics of the sand and gravel aquifer, reported by Watkins and Heisel (1970), were updated and incorporated into a two-dimensional digital ground-water flow model. The model was used to simulate effects of maximum anticipated pumping (700 gal/min) at the well field on local ground-water levels.

Model results indicate that ground-water levels would be lowered from less than 1 to about 4.5 ft in the immediate study area and by 1 to 2 ft in Taylorsville. Water levels would cease to decline appreciably after 5 years of continuous pumping. The effects of partial penetration were less than 0.2 ft of water-level decline 200 ft away from the pumping well. Field measurement of actual water-level declines caused by pumping from the well field will facilitate verification of model results. Because of the low pumping rate, streamflow depletion would be about equal to or less than 1 percent of the current low flows of the Driftwood River.

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