HYDRAULIC CHARACTERISTICS AND WATER-SUPPLY POTENTIAL OF THE AQUIFERS IN THE VICINITY OF THE WASTEWATER TREATMENT PLANT, SOUTH BEND, INDIANA

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 49-74

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Hydraulic characteristics and water-supply potential of the aquifers in the vicinity of the wastewater treatment plant, South Bend, Indiana			5. Report Date May 1975
			6.
7. Author(s) James R. Marie			8. Performing Organization Rept. No. WRI 49-74
9. Performing Organization Name and Address U.S. Geological Survey 1819 N. Meridian Street Indianapolis, Indiana 46202			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey 1819 N. Meridian Street Indianapolis, Indiana 46202			13. Type of Report & Period Covered Final
			14.

15. Supplementary Notes Prepared in cooperation with the Indiana Department of Natural Resources, Division of water, and the city of South Bend

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Model-simulated water levels agree very well with those observed, both before and during dewatering. Model results indicate that the hydrologic system can sustain withdrawal of 28 million gallons per day (106,300 cubic metres per day) indefinitely with little effect on ground-water levels. The quantity that would be diverted from the St. Joseph River is less than 10 percent of the estimated minimum daily flow.

17. Key Words and Document Analysis. 17a. Descriptors

*Computer model, water supply, groundwater, drawdown, *aquifer characteristics, surface-groundwater relationships, *dewatering

17b. Identifiers/Open-Ended Terms

None

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	31
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

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February 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

Rogers C. B. Morton, Secretary

GEOLOGICAL SURVEY

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Multiply English units	By	To obtain SI units
Length		
inches (in)	25.4	millimetres (mm)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
Area		
acres	4047	square metres (m^2)
square miles (mi^2)	2.590	square kilometres (km^2)
Flow		
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	.01093	cubic metres per second per square mile [$(m^3/s)/mi^2$]
gallons per minute (gal/min)	.06309	litres per second (l/s)
million gallons per day (mgal/d)	9.08×10^{-7}	cubic metres per day (m^3/d)
Hydraulic Units		
Transmissivity, ft^2/d -	convert to m^2/d -	(multiply by 0.0929).
Hydraulic conductivity, ft/d -	convert to m/d -	(multiply by 0.3048).
feet per mile (ft/mi)	.1894	metres per kilometre (m/km)

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ABSTRACT

An intensive study was made of a 24-square mile (62-square kilometre) area surrounding the South Bend wastewater treatment plant. This was done: 1) to document the effects of dewatering about 40 feet (12 metres) of the 130-feet (40-metre) thick aquifer during construction at the plant; 2) to define the hydrologic system in order to allow development of a predictive model; and 3) to select and evaluate one possible water-supply development plan as a model demonstration.

Model-simulated water levels agree very well with those observed, both before and during dewatering. Consequently, the model was used to predict effects of developing 28 million gallons per day (106,300 cubic metres per day) from three hypothetical well fields. Model results indicate that the hydrologic system can sustain this withdrawal indefinitely with little effect on ground-water levels. The quantity diverted from the St. Joseph River is less than 10 percent of the estimated minimum daily flow.

INTRODUCTION

Purpose and Scope

Late in January 1972, pumping was begun to lower the ground-water level during construction to expand the South Bend wastewater treatment plant. The ground-water level was to be lowered 40 ft (12 m) from a total saturated thickness of 130 ft (40 m) under an area of 3.5 acres (14,164 m^2) where two large, 200-ft (61-m) diameter "upflow clarifiers" were to be installed. To lower the water level, 13 permanent wells, most of them 130 to 140 ft (40 to 43 m) deep with 60-ft (18-m) screens, were installed in the outwash aquifer underlying the plant site. The design capacitites of the wells ranged from 2,100-5,400 gal/min (130-340 l/s), with a total yield of 66 mgal/d (250,000 m /d). It was anticipated that all the wells would have to be pumped at a maximum rate for 30 days to dewater the construction site to the depth required. However, maximum pumping was not planned because the construction schedule allowed dewatering over a much longer period.

At the time dewatering was to begin, other wells in the outwash aquifers underlying the area were providing water for South Bend's municipal pumping station (about 5 mgal/d) or (19,000 m^3/d) in Pinhook Park and a small additional amount (estimated at 0.5 mgal/d or 1,900 m^3 /d) for private supplies. Consequently, the proposed dewatering and the possible high pumping rates from the glacial outwash aquifers offered an opportunity to study the aquifer and its response to pumping conditions far in excess of those normally imposed. Data derived from a detailed study of the dewatering could yield valuable information concerning the long-term water-supply potential of the aquifer--this was the main purpose of the investigation. Secondary objectives were: 1) to document the withdrawals and their effects both at the construction site and on the adjacent areas, because many people in the affected area depend upon private wells for their own water supplies; 2) to define the aquifer system in sufficient detail to allow development of a model that could be used to evaluate alternative public water-supply plans; and 3) to select and evaluate one plan as an example of how such a model could be used.

The area studied in detail consists of 4 mi^2 (10.4 km^2) of the St. Joseph River valley surrounding the wastewater treatment plant on the north edge of South Bend, Indiana (fig. 1). An additional 20 mi^2 (52 km^2) was studied in enough detail to allow design of a model.

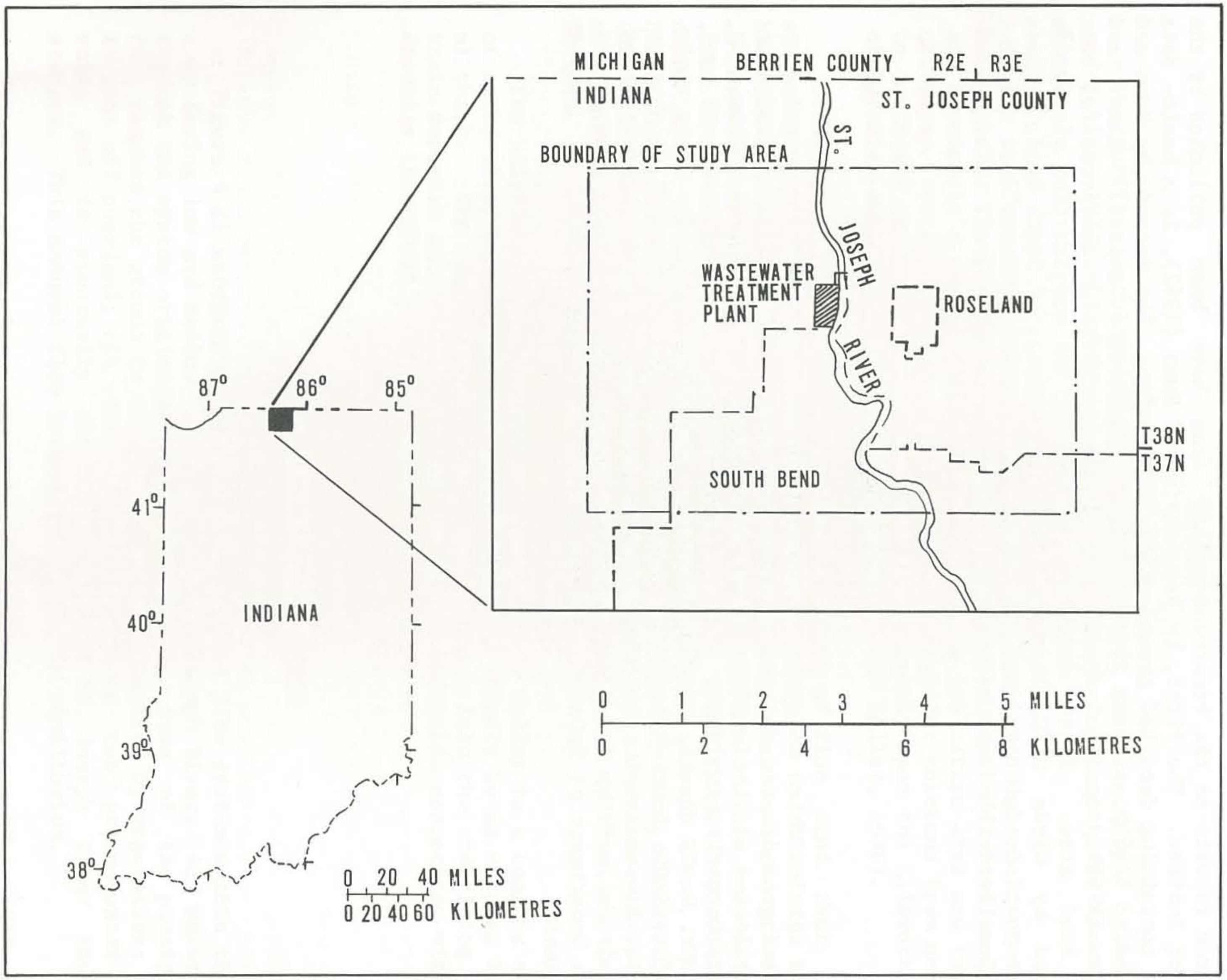

Figure 1.-- Location of the study area.

Previous Investigations

Three reports on the treatment plant area have been published by the State of Indiana. The first, by Rosenshein and Hunn (1962), is a basic- data report containing detailed ground-water information. The second, by Hunn and Rosenshein (1969), is an interpretive ground-water report. Klaer and Stallman (1948) prepared an evaluation of the ground-water resources of the South Bend area. Three detailed reports of the construction site were provided by Clyde E. Williams and Associates, Inc., of South Bend. These last reports contain the data and results of two aquifer tests and detailed logs of wells drilled at the treatment plant.

Acknowledgments

The data on which the present report is based were taken in part from the published ground-water reports on South Bend and St. Joseph County. Detailed data collected at the construction site were furnished by Mr. Bernard E. Brennan, formerly with Clyde E. Williams and Associates, Inc., South Bend, and by Mr. D. C. Irwin, Project Engineer, Wastewater Treatment Plant, South Bend. Mr. Irwin furnished pumping schedules of the dewatering wells and water-level measurements made in the observation wells in the project area. The study was made by the U.S. Geological Survey in cooperation with the Indiana Department of Natural Resources, Division of Water, and the city of South Bend.

THE HYDROLOGIC SYSTEM

Geology

The surficial geology of the treatment plant area, as mapped by Schneider and Keller (1970), is shown on figure 2. Lithologic sections are shown on figure 3.

The aquifers underlying the study area consist of glacial outwash sand and gravel. The principal aquifer is the lower sand and gravel zone--Hunn and Rosenshein's unit 4 (1969). It underlies the entire area and ranges in thickness from 20 to 70 ft (6 to 21 m). The aquifer thickens from northwest to southeast across the study area and lies directly upon the Ellsworth Shale of Devonian and Mississippian age (Schneider and Keller, 1970).

Overlying the principal aquifer is a zone of fine sand that locally contains considerable silt and clay and ranges from 10 to 40 ft (3 to 12 m) in thickness. Overlying the fine-sand zone is another sand and gravel zone that ranges in thickness from 10 to 60 ft (3 to 18 m). This sand and gravel zone is a north-trending valley-train deposit underlying, but considerably wider than, the present valley occupied by the St. Joseph River. This zone extends to the south, or upvalley, out of the study area. Downvalley, the zone thins (due both to physical thinning and to decrease in saturated thickness) and effectively disappears 1.5 mi (2.4 km) north of the treatment plant.

The alluvium of the present St. Joseph River valley is a complex sequence of muck, clay, silt, sand, and gravel that may locally be as much as 20 ft (6 m) thick. The St. Joseph River has cut down into the underlying valley-train deposits and appears to be in direct hydraulic connection with these deposits throughout the study area.

The Natural Flow System

Figure 4 illustrates the idealized, natural flow system within the study area during low and medium flow in the St. Joseph River. All water moving through the system originates as precipitation. Some of the precipitation that reaches the ground is evaporated or is transpired by vegetation; some of it runs off overland; the remainder infiltrates to the ground-water reservoirs and is eventually discharged into the St. Joseph River and other streams. This natural flow system is in dynamic equilibrium.

The average annual precipitation on the study area is 37 in (940 mm). Of this amount, 10.5 in (270 mm) infiltrates into the ground-water reservoirs and eventually discharges into the St. Joseph River (L. G. Davis, oral commun., 1973).

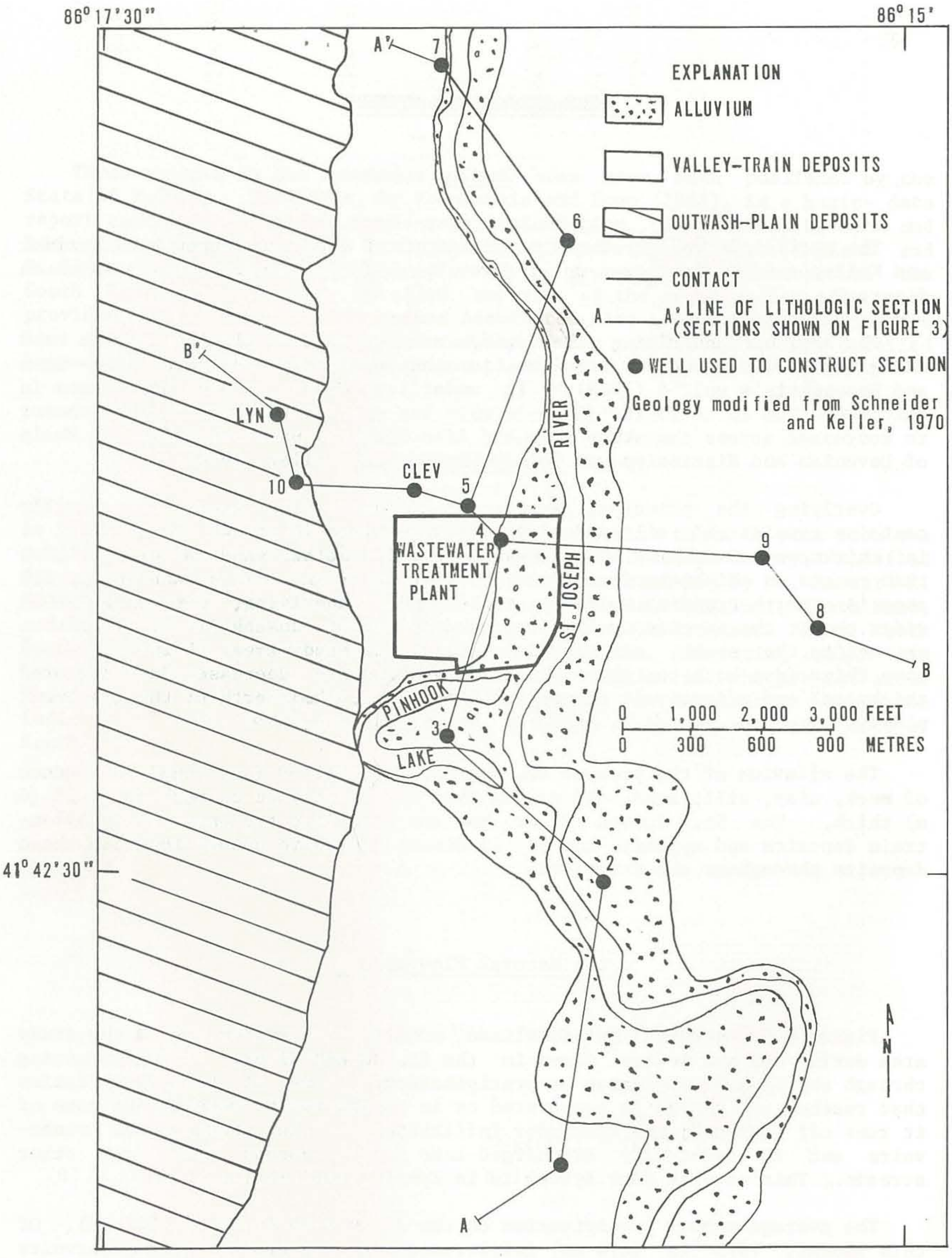

Figure 2.-- Generalized surficial geology of the treatment plant site.

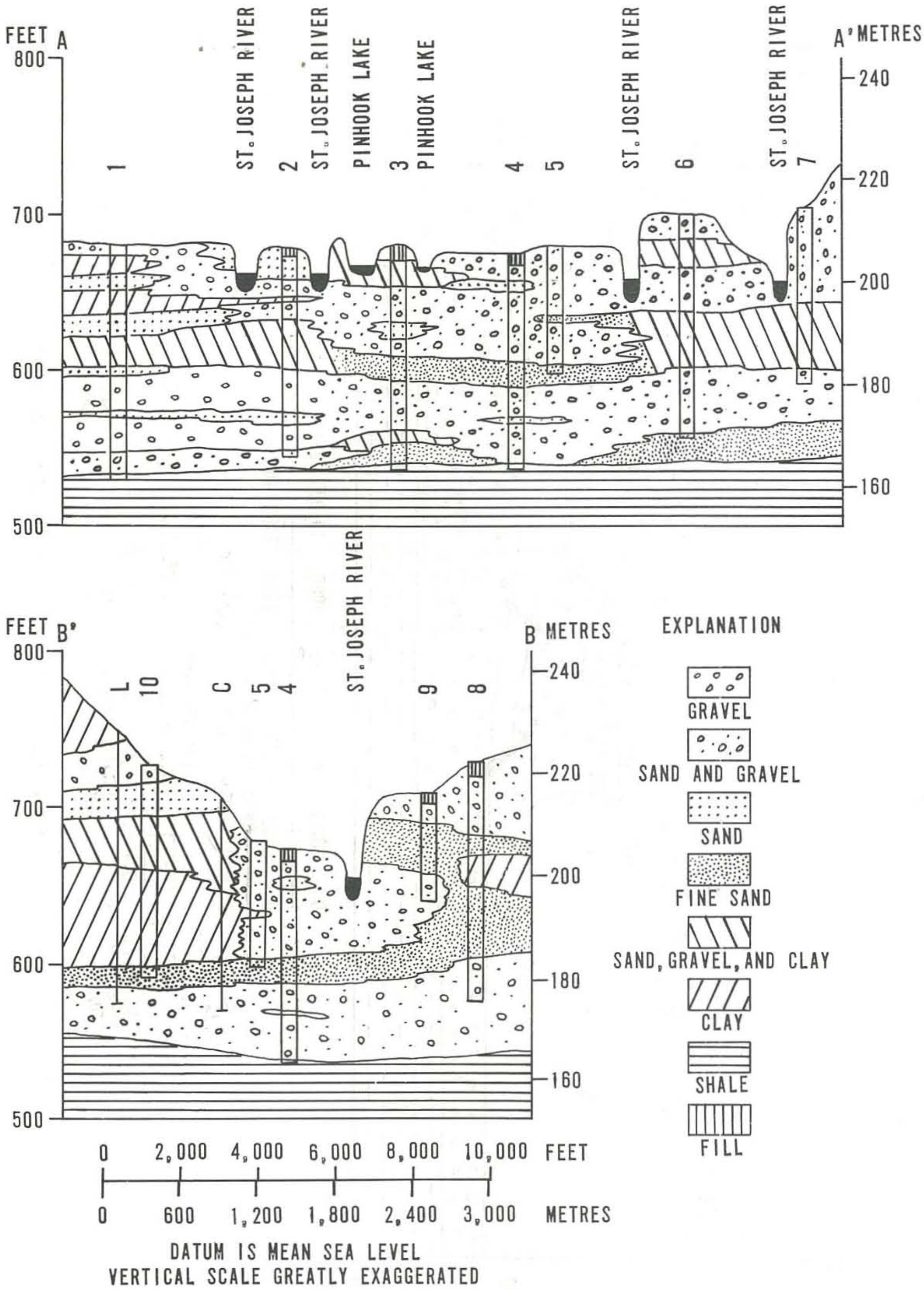

Figure 3.-- Geologic sections of the treatment plant site.

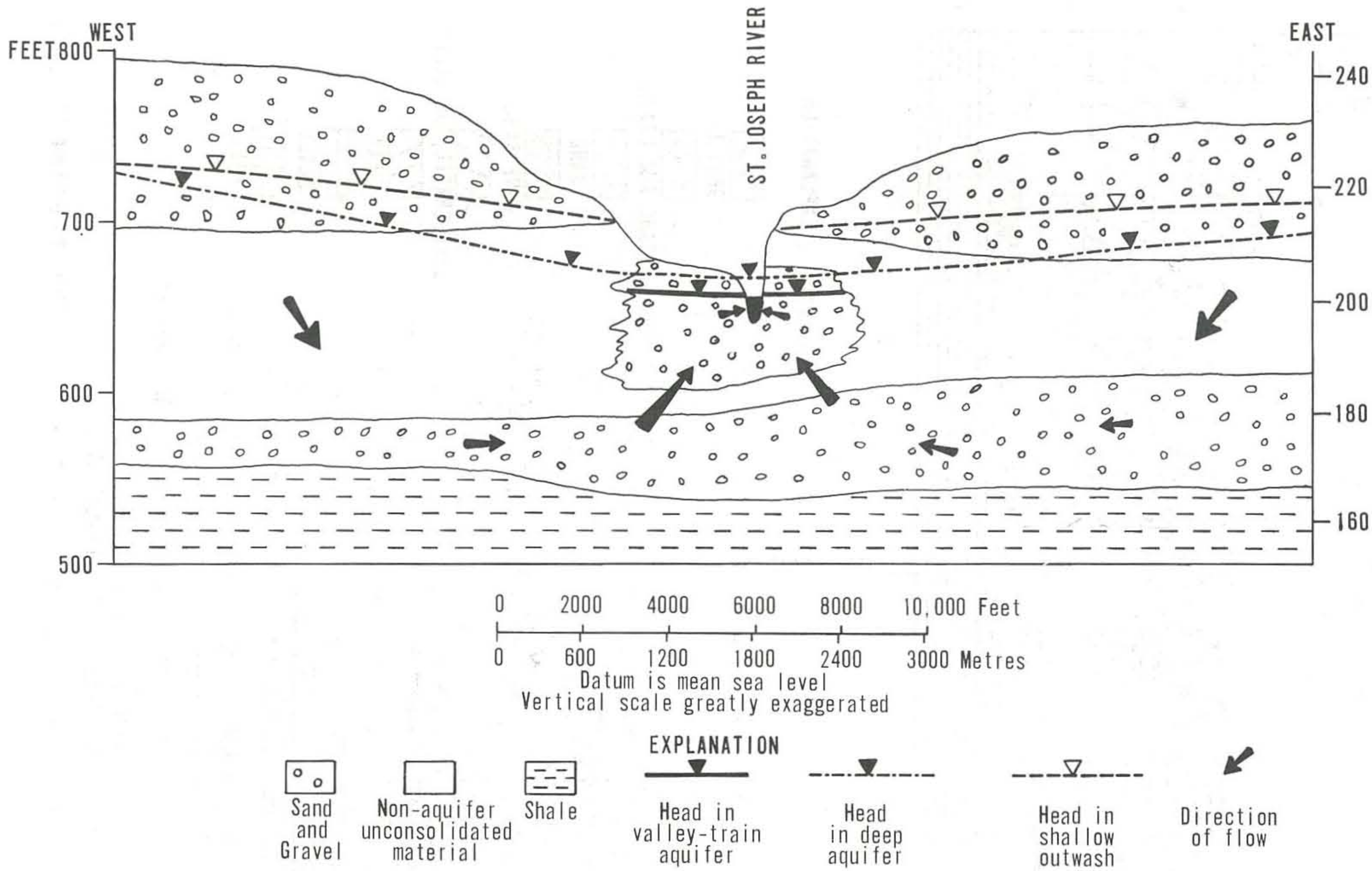

Figure 4.-- Generalized natural flow system in the study area

Changes Caused by Pumping

When pumping begins, a cone of depression is formed around each well because the water being pumped by the well is initially taken from storage within the aquifer. As pumping continues, the cone of depression grows, as more and more water is removed from storage. The cone of depression will continue to grow until the water removed is balanced by water received--either by a decrease in the amount of water naturally discharged from the aquifer or by an increase in the amount of water recharged to the aquifer, at which time a new equilibrium is established.

At the treatment plant site, all of the above mechanisms supply water to the dewatering wells. Pumping the wells lowers the water table--a withdrawal from storage. Water moving naturally within the aquifer toward the St. Joseph River is diverted into the wells--a reduction in natural discharge from the aquifer. The natural ground-water gradient toward the river was reversed by pumping, inducing water to flow from the river and into the aquifer--an increase in recharge to the aquifer. The cone of depression resulting from the quantities of water taken from the three sources is described in the next section.

SIMULATION OF THE HYDROLOGIC SYSTEM BY DIGITAL MODEL

Description of the Model

The area modeled for this study consists of 13.8 mi^2 (35.7 km^2) centered on the wastewater treatment plant. The area extends east and west to coincide with the local surface-water divides of the St. Joseph River basin. The area extends north and south from the treatment plant along the St. Joseph River for about 2 mi (3 km) to an arbitrary boundary beyond the expected effects caused by pumping.

The digital model used to simulate the hydrologic system at the wastewater treatment plant is the alternating-direction, iterative digital model described by Trescott (1973).

The model layout used in this study is rectangular, with 55 nodes north-south and 32 nodes east-west. The central area (roughly 44 by 16 nodes) is composed of nodes that are 200 ft (61 m) on a side. The remaining nodal sizes are, with a few exceptions, progressively doubled in all directions to the limit of the model. The total area modeled is 13.8 mi^2 (35.7 km^2).

This model, like any other, is an approximation of the hydrologic system that it is intended to simulate. The closeness of fit of the model to real-world conditions and to changes therein depends, in large degree, on the assumptions made by the hydrologist-modeler. The present model is based on the following assumptions:

1. All flow within the aquifer during pumping is two-dimensional (no vertical flow components).
2. Recharge from precipitation is uniform in time and space.
3. All recharge to the deep aquifer is derived from vertical leakage through confining beds. This recharge varies as the head in the aquifer varies.
4. The aquifers are isotropic and homogeneous within the boundaries indicated for the various values of transmissivity and storage coefficient.
5. All wells fully penetrate the aquifer.
6. All pumping wells are 100-percent efficient.
7. The river is a uniformly deep stream with a uniform gradient and is in hydraulic connection with the aquifer.

Modeled Hydraulic Characteristics

The estimated transmissivities for both the valley-train and the deep sand and gravel aquifers underlying the area were modified from Hunn and Rosenshein (1969). These are shown on figure 5 and outlined in detail below.

The lower sand and gravel aquifer that underlies the entire area has a transmissivity ranging from 2,000 to 37,000 ft^2/d (186 to 3,400 m^2/d) and a storage coefficient ranging from 0.00004 to 0.00008. The valley-train aquifer has a transmissivity ranging from 2,600 to 33,400 ft^2/d (240 to 3,100 m^2/d) and a storage coefficient determined to be 0.16. The fine-sand zone that separates the valley-train aquifer from the lower sand and gravel aquifer has a vertical hydraulic conductivity of 0.8 ft/d (0.2 m/d). ~~Streambed hydraulic conductivity is 112 ft/d (34 m/d).~~

The hydraulic characteristics of the various aquifers were determined by using hydrogeologic data from several sources. First, three aquifer tests using multiple observation wells were made at the plant site: two in the valley-train aquifer and one in the lower aquifer. One test in each aquifer was analyzed by W. G. Keck and Associates, Inc., of Okemos, Michigan. All three tests were analyzed by the author. Transmissivities determined by the various methods and by different individuals did not vary by more than 12 percent. The storage coefficient of the lower aquifer was also in similar agreement. The storage coefficient of the valley-train aquifer had a wider range--from 0.12 to 0.23, with most values being 0.16 to 0.17. A value of 0.16 was assumed and is used in the model.

Vertical hydraulic conductivity of the fine-sand zone between the two aquifers was determined by a method described by Stallman (1965). Values obtained ranged from 0.8 to 2.9 ft/d (0.24 to 0.88 m/d). Head distribution in the lower aquifer was reasonably duplicated in the model by using a value of 0.8 ft/d (0.24 m/d).

Streambed hydraulic conductivity was obtained from aquifer test data by a combination of methods described by Stallman (1963) and Norris and Fidler (1969). The values ranged from 101 to 117 ft/d (31 to 36 m/d). A value in this range is also indicated by the streambed material (sand and gravel) observed at the streamflow measuring section a few hundred feet downstream from the treatment plant. Head distribution in the valley-train aquifer was again reasonably duplicated by the model using a vertical hydraulic conductivity of 112 ft/d (34 m/d). Aquifer tests, well logs, and published transmissivity data were used to define areal distribution of transmissivity in both the valley-train and the deep sand and gravel aquifers.

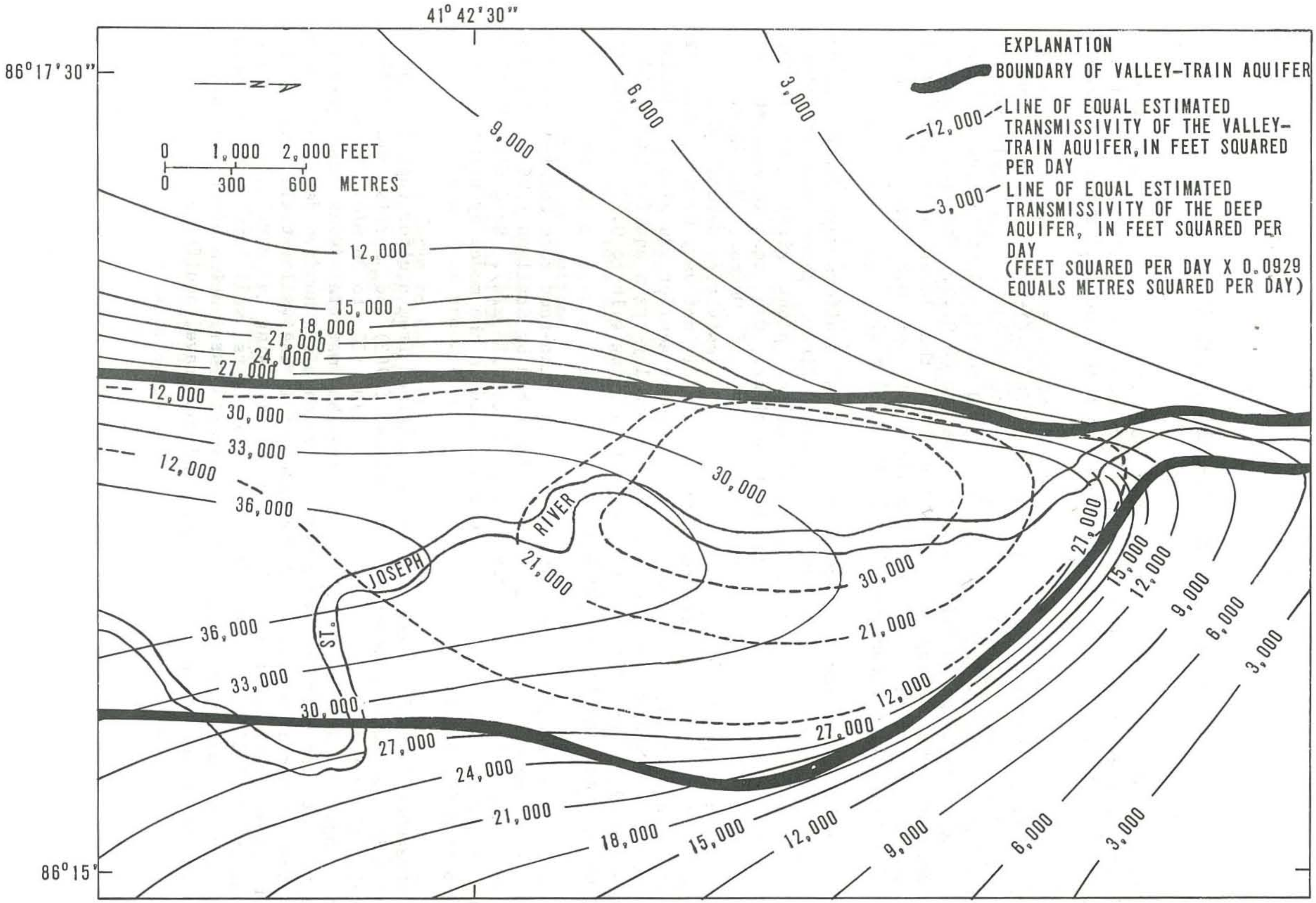

Figure 5.-- Estimated transmissivity of the aquifers in the study area.

Verification of the Model

Before the model could be used as a predictive tool, it was necessary to verify that the values used for: 1) hydraulic conductivity at the stream-aquifer interface, 2) vertical hydraulic conductivity of the fine-sand zone, 3) transmissivity, 4) storage coefficient, and 5) recharge in the model would duplicate known field conditions to an acceptable accuracy. First, the pre-pumping head distribution in the valley-train aquifer was simulated to verify the hydraulic conductivity of the zone at the stream-aquifer interface obtained from aquifer test analysis. Then, the pre-pumping head distribution in the lower sand and gravel was simulated to establish the validity of the vertical hydraulic conductivity for the fine-sand zone arrived at from analysis of another of the aquifer tests. Both of these simulations were used to check the areal transmissivity modified from- Hunn and Rosenshein (1969) and to verify the recharge value obtained from streamflow data. Finally, the effects resulting from pumping during the first 8 months (Feb. to Sept. 1972) of dewatering were simulated to allow checks on all input data that were to be used for the predictive model. These simulations are discussed in detail below.

Hydraulic Conductivity of the Stream-Aquifer Interface

Hydraulic conductivity of the streambed was determined to be within the range of 101 to 117 ft/d (31 to 36 m/d) from an aquifer test that was designed to yield this type of data. To verify this value, the model at steady state had to reproduce the pre-pumping head distribution observed in the valley-train aquifer. The pre-pumping head was defined by water levels in three shallow observation wells installed at the construction site and by 26 water levels reported from other wells at various times in the past. The water levels in the three wells at the site indicate a downvalley gradient of 1.47 ft/1,000 ft (1.47 m/km) and that the head in the aquifer was 0.6 ft (0.2 m) higher than the stream stage elevation of 655 ft (200 m) at the stream-aquifer interface at the staff gage. The other water-level measurements indicated the general areal distribution of head within the valley-train aquifer.

Figure 6 shows the St. Joseph River and the valley-train aquifer as they were modeled.

The transmissivities shown on figures 5 and 7, a uniform recharge of 0.78 $(ft^3/s)/mi^2$ $[0.08\ (m^3/s)/km^2]$, and a uniform river gradient of 4 ft/mi (0.46 m/km) were used as input for the model. These data were used to close on a value of hydraulic conductivity at the stream-aquifer interface by trial and error, assuming a thickness of 1 ft (0.3 m) for the interface zone.

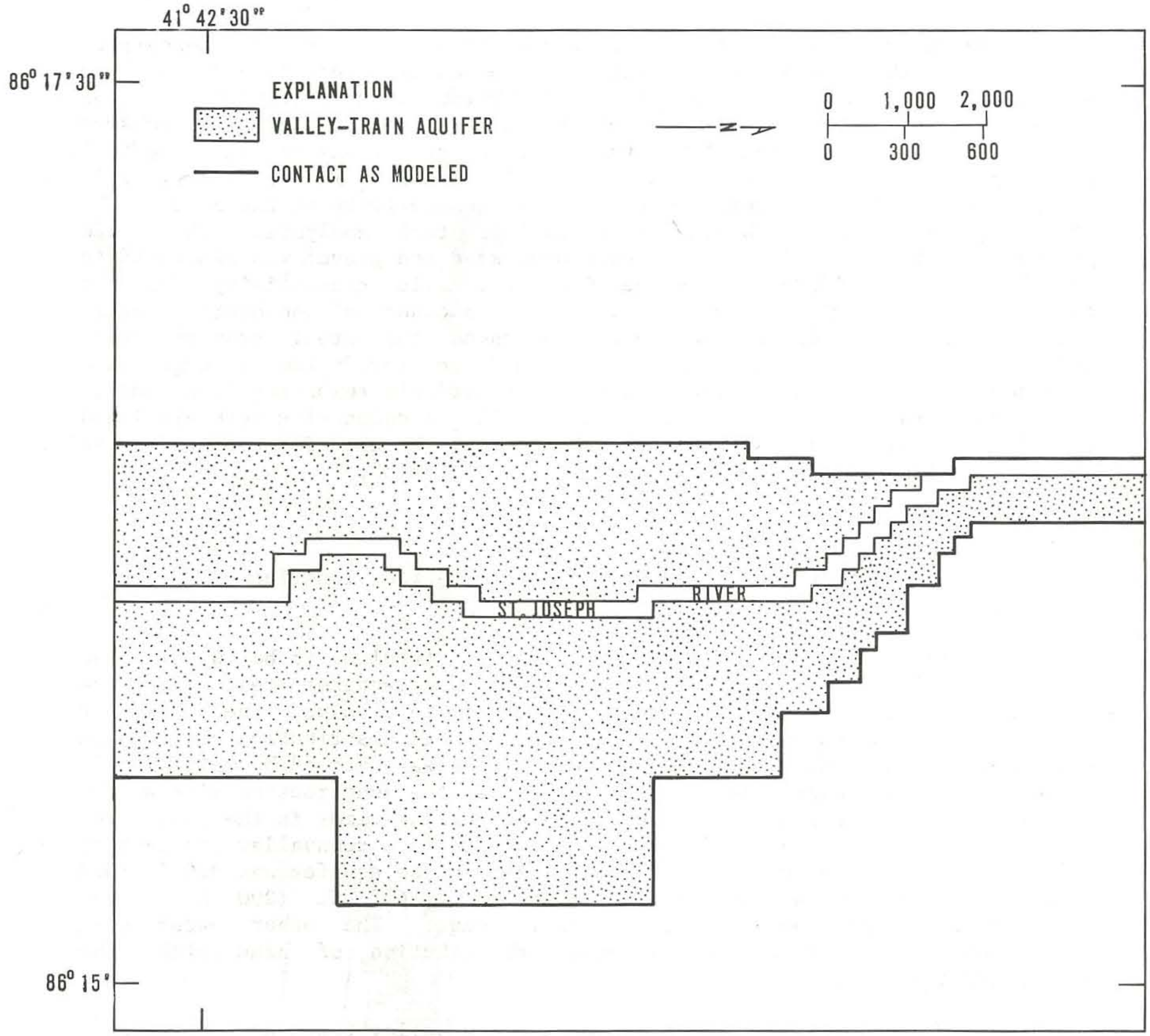

Figure 6.-- Location of the St. Joseph River and the underlying hydraulically connected valley-train aquifer within the central 5.9 square miles (15.3Km^2) of the modeled area.

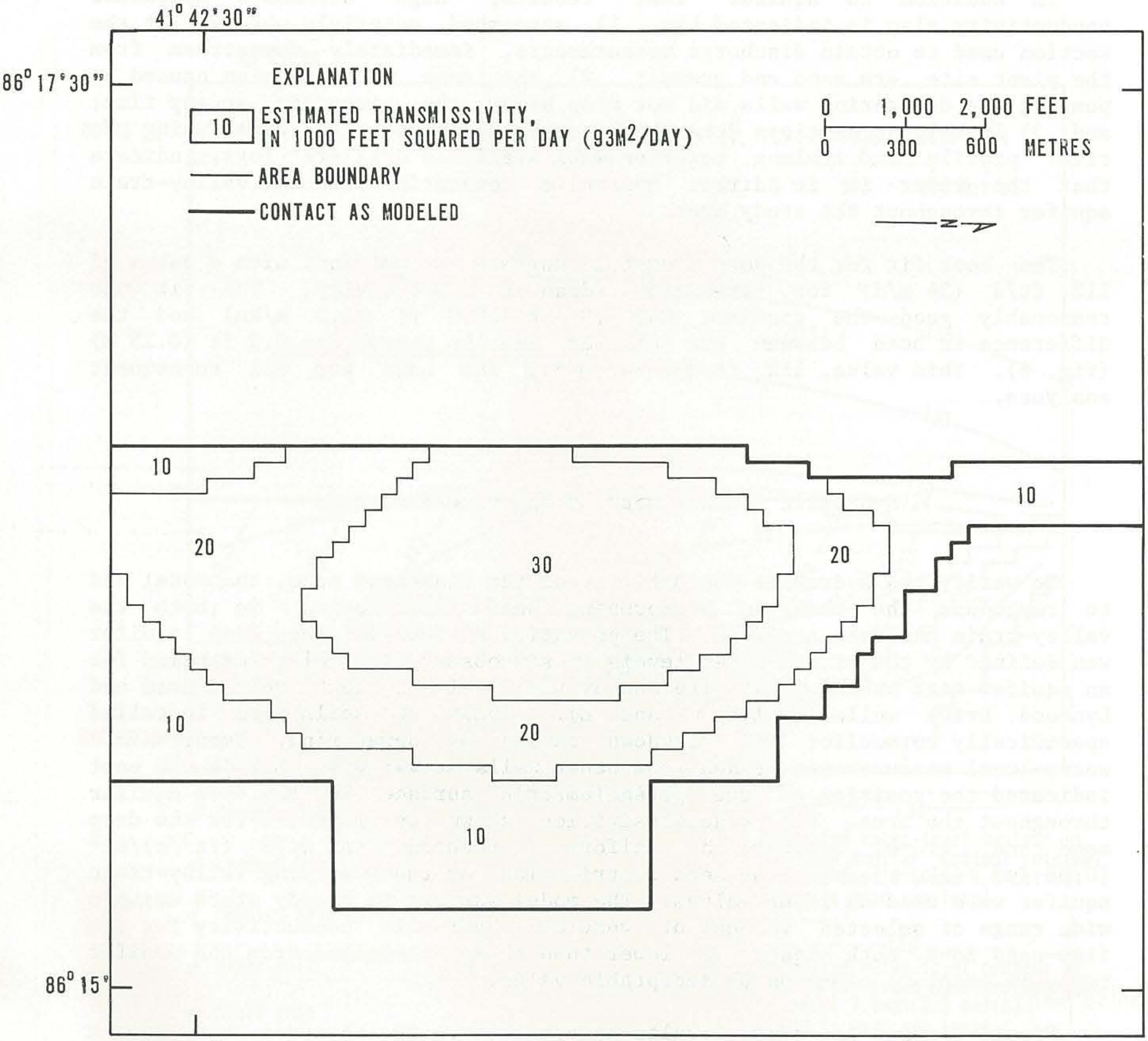

Figure 7.-- Estimated transmissivity of the valley-train aquifer.

In addition to aquifer test results, high streambed hydraulic conductivity also is indicated by: 1) streambed materials observed at the section used to obtain discharge measurements, immediately downstream from the plant site, are sand and gravel; 2) the cone of depression caused by pumping the dewatering wells did not drop below the streambed at any time; and 3) lithologic sections drawn both across and along the river using the river profile and thalweg, together with available drillers' logs, indicate that the river is in direct hydraulic connection with the valley-train aquifer throughout the study area.

The best fit for the potentiometric surface was obtained with a value of 112 ft/d (34 m/d) for streambed hydraulic conductivity. The fit was reasonably good--the gradient was 1.3 ft/1,000 ft (1.3 m/km) and the difference in head between the aquifer and the stream was 0.5 ft (0.15 m) (fig. 8). This value, 112 ft/d (34 m/d), was used for all subsequent analyses.

Hydraulic Conductivity of the Fine-Sand Zone

To verify the hydraulic conductivity of the fine-sand zone, the model had to reproduce the observed pre-pumping head distribution in both the valley-train and deep aquifers. The potential surface in the deep aquifer was defined by the static water levels in six observation wells installed for an aquifer test at the plant site and by the levels in the Cleveland Road and Lynwood Drive wells (wells C and L). These two wells were installed specifically to monitor the drawdown caused by dewatering. Twenty- four water-level measurements taken from other wells at various times in the past indicated the position of the potentiometric surface in the deep aquifer throughout the area. The transmissivities shown on figure 9 for the deep sand and gravel aquifer, a uniform recharge of 0.78 $(ft^3/s)/mi^2$ [0.08 $(m^3/s)km^2$] and the head distribution for the overlying valley-train aquifer were used as input values. The model was run to steady state using a wide range of selected values of vertical hydraulic conductivity for the fine-sand zone, both higher and lower than those determined from the aquifer test, in order to close on an acceptable value.

Figure 8 shows the model results as compared to the observed heads when a value of 0.8 ft/d (0.2 m/d) was used for the vertical hydraulic conductivity of the fine-sand zone. This value is on the low side of the range determined from the aquifer test. The model produced a head difference between the lower and upper aquifers within 0.5 ft (0.15 m) of that recorded in the observation wells ("P" on fig. 8) at the plant site. The heads produced by the model were also within 1 ft (0.3 m) of those observed for both wells C and L. The value of 0.8 ft/d (0.2 m/d) is, therefore, considered to be a valid vertical hydraulic conductivity that could be used in a multilayer model for more precise predictions of effects of alternate water-development plans.

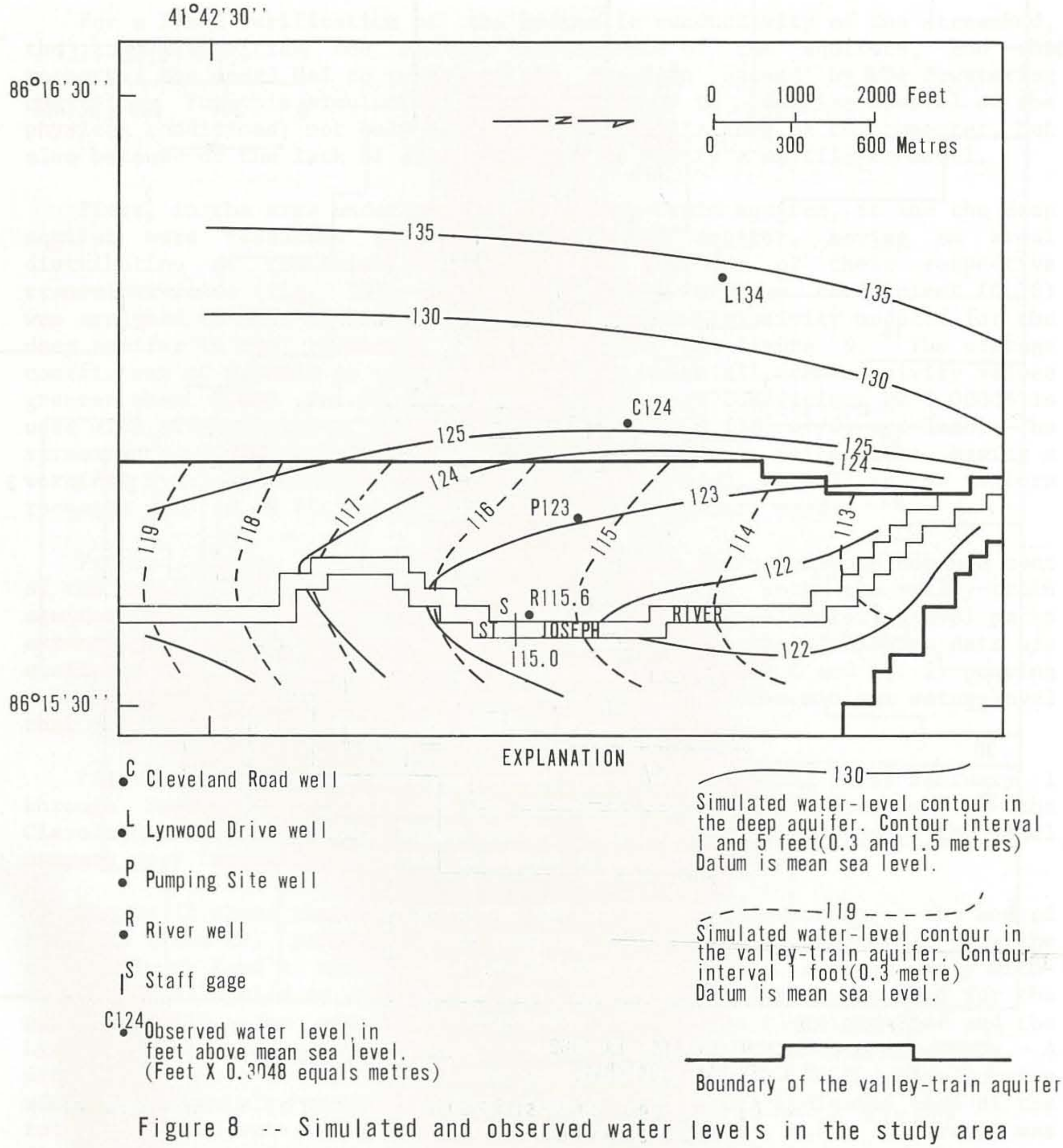

Figure 8 -- Simulated and observed water levels in the study area

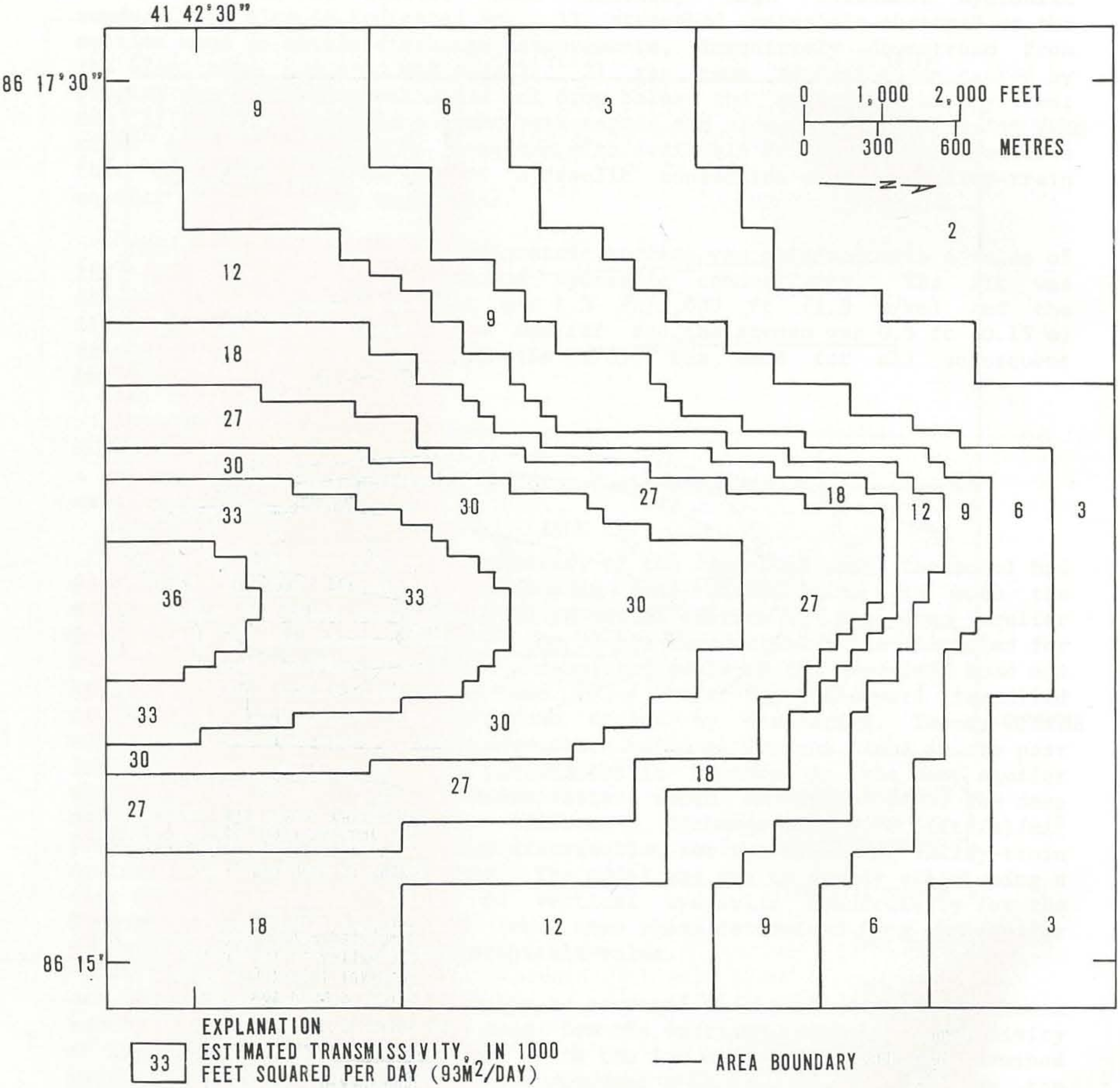

Figure 9.-- Estimated transmissivity of the deep sand and gravel aquifer.

Final Verification: Drawdown Caused by Pumping

For a final verification of the hydraulic conductivity of the streambed, the transmissivities and storage coefficients of the aquifers, and the recharge, the model had to reproduce the drawdown caused by the dewatering operation. For this simulation, it was necessary to idealize several of the physical conditions; not only because of the limitations of the computer, but also because of the lack of data necessary to verify a multilayer model.

First, in the area underlain by the valley-train aquifer, it and the deep aquifer were idealized as a single uniform aquifer, having an areal distribution of transmissivity equal to the sum of their respective transmissivities (fig. 10). Further, a uniform storage coefficient (0.16) was assigned to this combined aquifer. The transmissivity modeled for the deep aquifer in the remaining area is shown on figure 9. The storage coefficient of 0.00008 is used in conjunction with all transmissivity values greater than 2,000 ft^2/d (186 m^2/d). A storage coefficient of 0.00004 is used with transmissivity values of 2,000 ft^2/d (186 m^2/d) and less. The streambed conditions verified above, a 1-ft (0.3-m) thick zone having a vertical hydraulic conductivity of 112 ft/d (34 m/d), as well as the uniform recharge rate [0.78 $(ft^3/s)\ mi^2$ or 0.05 $(m^3/s) km^2$], were used.

Further, it was considered valid to omit the fine-sand zone because most of the wells used in dewatering were screened in both the valley-train aquifer and the deep aquifer with 50-in (1,270 mm)-diameter gravel packs extending the full depth of the well. Also, only the following data are available to verify the model: 1) hydrographs for wells C and L, 2) pumping schedules and rates for the dewatering wells, and 3) the minimum water level that was maintained at the construction site.

Figure 11 shows the average 30-day dewatering pumping rates February 1 through September 27, 1972 and the observed and simulated drawdowns in the Cleveland Road and Lynwood Drive wells. The drawdowns produced by the model compare very favorably with the observed drawdowns.

Figure 12 shows the configuration of the cone of depression at the end of 150 days (June 29) pumping. This pumping also includes withdrawals from the city of South Bend's well field in Pinhook Park (P-1). Average daily withdrawals (4.67 mgal/d or 17,700 m^3/d) at Pinhook Park were used for the period. Again, the simulated drawdowns at both the Cleveland Road and the Lynwood Drive wells compared very well with the observed drawdowns. A drawdown of about 30 ft (9 m) was estimated for the clarifier construction site, which was also shown by the model. The model indicated that of the total amount of water pumped during this 150-day period, about 70 percent was diverted directly from the St. Joseph River.

As a point of interest, streambed hydraulic conductivity in the range usually suggested for similar areas in Indiana (4 ft/d or 1.22 m/d) were then substituted in the model to see what effects this lower permeability would have. When the model was rerun using this value, the wells pumped the aquifer dry in less than 30 days.

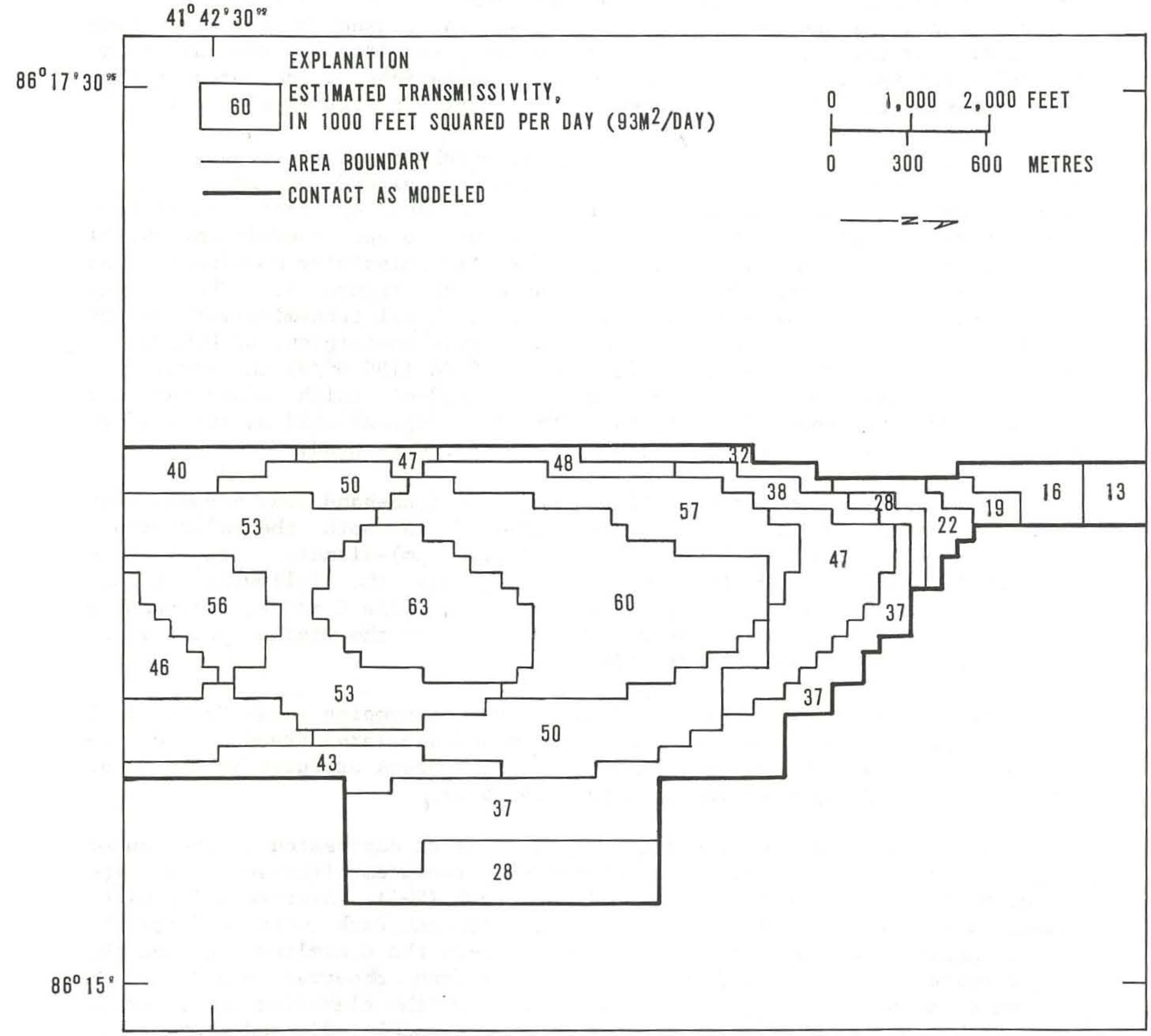

Figure 10.— Estimated composite transmissivity modeled.

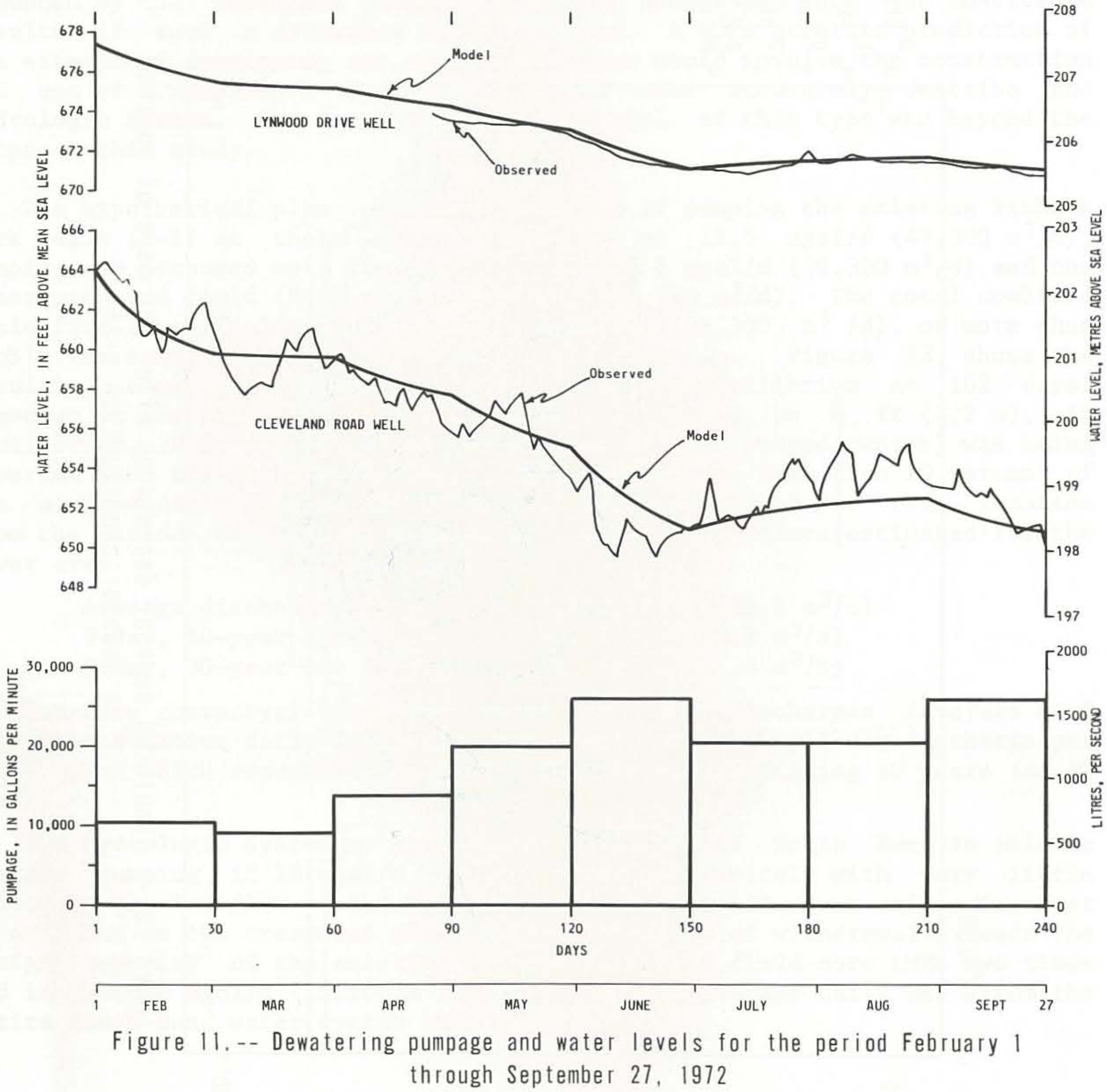

Figure 11.-- Dewatering pumpage and water levels for the period February 1 through September 27, 1972

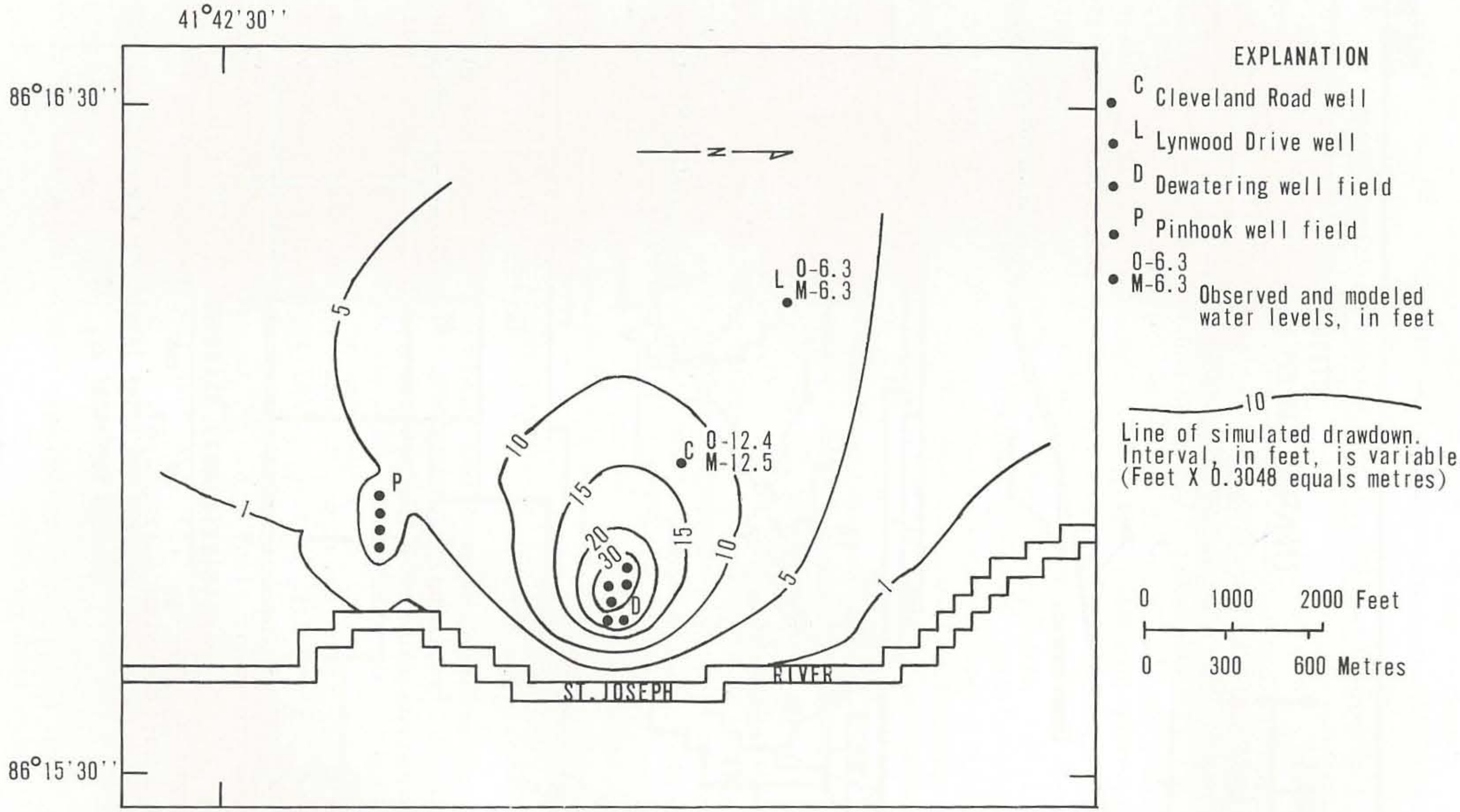

Figure 12.-- Simulated cone of depression after 150 days of pumping to dewater construction site

The results of this final verification showed that the model can reproduce known field conditions with acceptable accuracy and is ready to use as a predictive tool.

Predicted Effects of Future Pumping

The purpose of this application of the model is to indicate its value in predicting the effects of pumping from hypothetical well fields in the Pinhook Lake area. It is stressed that the results given below are those produced by the idealized model described above and not the inevitable results if such a plan were to be effected. A more accurate prediction of the effects of developing any alternative plan would involve the construction and use of a multilayer model that would more accurately describe the hydrologic system. The development of a model of this type was beyond the scope of this study.

The hypothetical plan evaluated consists of pumping the existing Pinhook Park wells (P-1) at their design capacity of 12.5 mgal/d (47,300 m^3/d), pumping one proposed well field (P-2) at 10.4 mgal/d (39,300 m^3/d) and the other proposed field (P-3) at 5.2 mgal/d (19,700 m^3/d). The total combined yield from these fields would be 28.1 mgal/d (106,300 m^3/d), or more than double the existing Pinhook Park well field capacity. Figure 13 shows the resulting cone of depression, which reached equilibrium at 162 days. Drawdown at the clarifier site ("C" on fig. 13) would be 4 ft (1.2 m). At equilibrium, 32 ft^3/s (0.9 m^3/s) (73 percent of the pumped water) was being diverted from the St. Joseph River. This quantity is less than 10 percent of the minimum daily flow of 350 ft^3/s (9.9 m^3/s) estimated for this location from the period of record available. Other flow values estimated for the river are:

Average discharge	3,150 ft^3/s (89.2 m^3/s)
7-day, 10-year low flow	821 ft^3/s (23.2 m^3/s)
1-day, 30-year low flow	415 ft^3/s (11.8 m^3/s)

The low-flow characteristics shown above are the discharges (average of 7 lowest consecutive daily discharges per year; or lowest 1-day discharge per year) below which streamflow will fall at intervals averaging 10 years (or 30 years).

The hydrologic system as modeled for this area of South Bend is able to sustain pumping if 28 mgal/d (106,300 m^3/d) indefinitely with very little effect on the low flow of the St. Joseph River and will cause only a few feet of drawdown in the treatment plant area. This rate of withdrawal exceeds the design capacity of the existing Pinhook Park well field more than two times and is about 4 mgal/d (15,100 m^3/d) more than the average daily use from the entire South Bend water system during 1967.

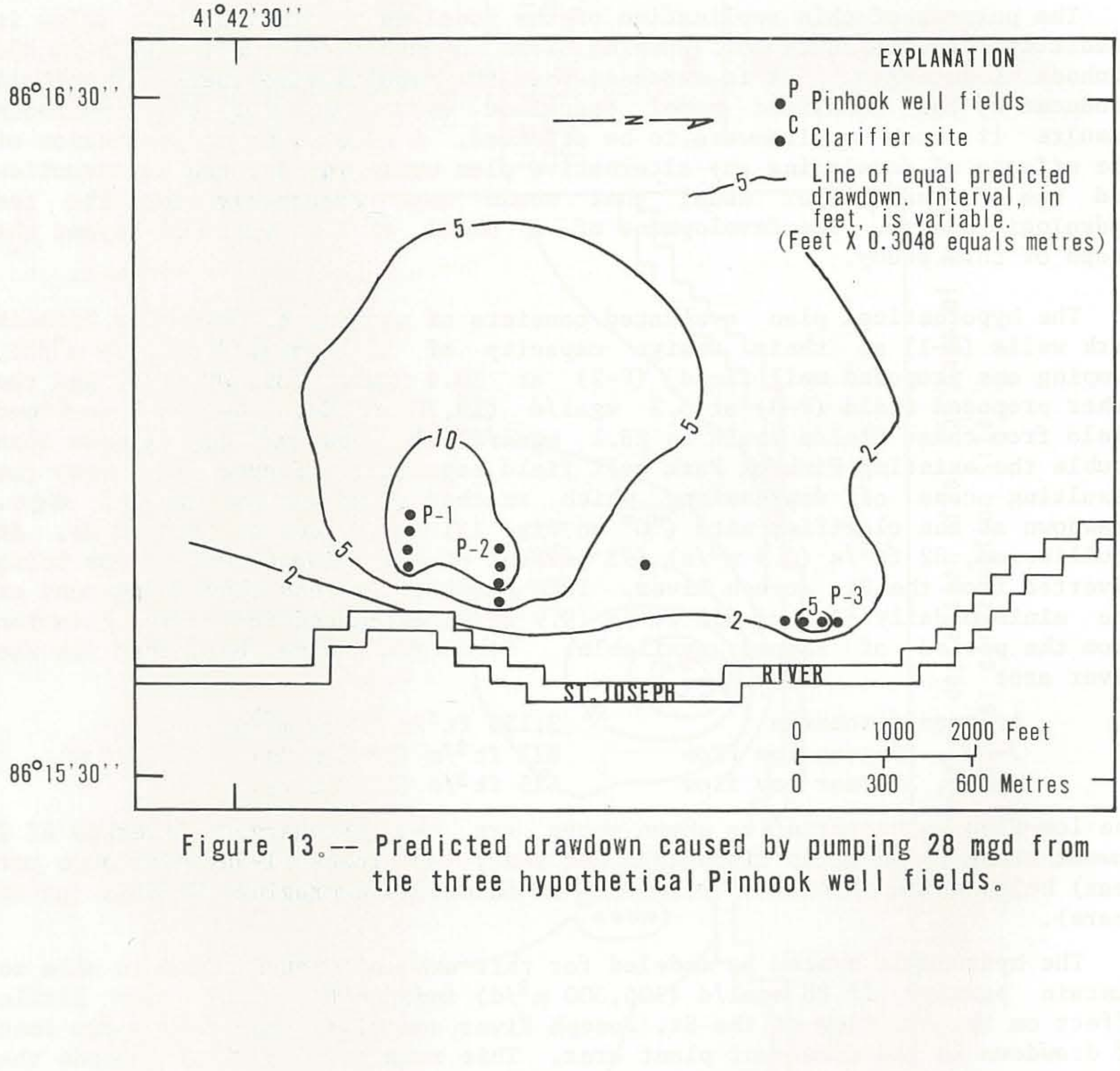

Figure 13.-- Predicted drawdown caused by pumping 28 mgd from the three hypothetical Pinhook well fields.

SUMMARY AND CONCLUSIONS

It is stressed that the effects of future pumping, as hypothesized here, are not absolute, but are merely those resulting from one interpretation of available data. If the hydrologic system were to be accurately defined during a project of greater scope, the effects of any possible alternative water plan could be predicted and with corresponding accuracy.

In summary, the close correlation between observed and simulated drawdowns for the 240-day dewatering period indicates that the model is valid for that pumping duration. If the assumptions made in extending the pumping period to allow a yield of 28 mgal/d (106,300 m^3/d) from the hypothetical Pinhook well fields are valid, then the model results are also valid.

The model results indicate that the hydrologic system in the Pinhook Lake area can sustain a withdrawal of 28 mgal/d (106,300 m^3/d) indefinitely with little effect on the water levels in the area. This rate of withdrawal exceeds the design capacity of the existing Pinhook Park well field more than two times and is about 4 mgal/d (15,100 m^3/d) more than the average daily use from the entire South Bend water system during 1967.

The programmed rate of 28 mgal/d (106,300 m^3/d) should not be considered as the maximum possible sustained yield from this area. This rate and its effects are only the result of the selected hypothetical well-field configuration imposed on the idealized model and, consequently, only indicate one of many possible sets of pumping alternatives and resulting effects.

SELECTED REFERENCES

Hunn, J. D., and Rosenshein, J. S., 1969, Geohydrology and ground-water potential of St. Joseph County, Indiana: Indiana Dept. Natural Resources, Div. Water Bull. 33, 20 p.

Indiana State Board of Health, 1968, Data on Indiana Public Water Supplies: Indiana State Board of Health Bull. S.E. 10, 83 p.

Klaer, F. H., Jr., and Stallman, R. W., 1948, Ground-water resources of St. Joseph County, Indiana, pt. 1, South Bend area: Indiana Dept. Conserv., Div. Water Bull. 3, 177 p.

Norris, S. E., and Fidler, R. E., 1969, Hydrogeology of the Scioto River Valley near Piketon, South-central Ohio: U.S. Geol. Survey Water-Supply Paper 1872, 70 p.

Rosenshein, J. S., and Hunn, J. D., 1962, Ground-water resources of northwestern Indiana, preliminary report--St. Joseph County: Indiana Dept. Conserv., Div. Water Resources Bull. 15, 318 p.

Schneider, A. F., and Keller, S. J., 1970, Geologic map of the 1° x 2° Chicago quadrangle, Indiana, Illinois, and Michigan, showing bedrock and unconsolidated deposits: Indiana Dept. Natural Resources, Geol. Survey Regional Geologic Map 4.

Stallman, R. W., 1963, Type curves for the solution of single-boundary problems, in Bentall, Ray, compiler, Shortcuts and special problems in aquifer tests: U.S. Geol. Survey Water-Supply Paper 1545-C, p. C45-C47.

______1965, Effects of water-table conditions on water-level changes near pumping wells: Water Resources Research, v. 1, no. 2, p. 295-312.

Trescott, P. C., 1973, Iterative digital model for aquifer evaluation: U.S. Geol. Survey Open-file Report, 63 p.