UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRECONSTRUCTION AND POSTCONSTRUCTION GROUND-WATER LEVELS, LOCK AND DAM 2, RED RIVER VALLEY, LOUISIANA

Open-File Report 79-919

Prepared in cooperation with the

U.S. Army Corps of Engineers

and the U.S. Soil Conservation Service

Cooperative Ground-Water Study

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Baton Rouge, Louisiana

June 1979

PREFACE

This report was originally released to the U.S. Army Corps of Engineers, New Orleans District, as an administrative report, for official use only, in December 1975. This open-file version is unchanged from the original administrative report except for minor editing and addition of a more comprehensive and updated list of "Selected References."

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) OF METRIC UNITS

For those readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound units	By	To obtain SI units
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

PRECONSTRUCTION AND POSTCONSTRUCTION GROUND-WATER LEVELS, LOCK AND DAM 2, RED RIVER VALLEY, LOUISIANA

By A. H. Ludwig

ABSTRACT

Proposed construction of a series of locks and dams in the Red River in Louisiana will cause a permanent increase in average river stage. The potentiometric surface of the shallow alluvial aquifer and the water table in the fine-grained material confining the aquifer will be affected. The purpose of this study, using digital-modeling techniques, was to predict the postconstruction potentiometric surface and the water table so that potential effects of the water-level changes could be evaluated.

Plans for Lock and Dam 2 at mile 87 (kilometer 140) above the mouth of the Red River call for a pool elevation of 58 feet (17.7 meters) and will cause an average increase in river stage of 12.5 feet (3.8 meters). As a result, ground-water levels will be raised 1 foot (0.3 meter) or more within 4 miles (6.4 kilometers) of the river and will be near land surface in low areas. The potentiometric surface may be as much as 1-2 feet (0.3-0.6 meter) above land surface south of Latanier along Chatlin Lake Canal and south of the Anandale area of Alexandria. The magnitude of ground-water-level fluctuations near the river will be reduced.

INTRODUCTION

The navigation plans of the U.S. Army Corps of Engineers include a series of locks and dams on the Red River between the confluence of the Red and Black Rivers and Shreveport, La. Various plans, which include a five- or six-lock-and-dam arrangement, have been proposed. The locations of the proposed dams are shown in figure 1. Plans for a modified version of the five-lock-and-dam arrangement, called the B-3 modified plan, have been adopted by the Corps. The U.S. Geological Survey is evaluating the effects on ground-water levels of all proposals. The results of this investigation are to be used by the U.S. Soil Conservation Service to evaluate the beneficial or adverse effects of changes in ground-water levels.

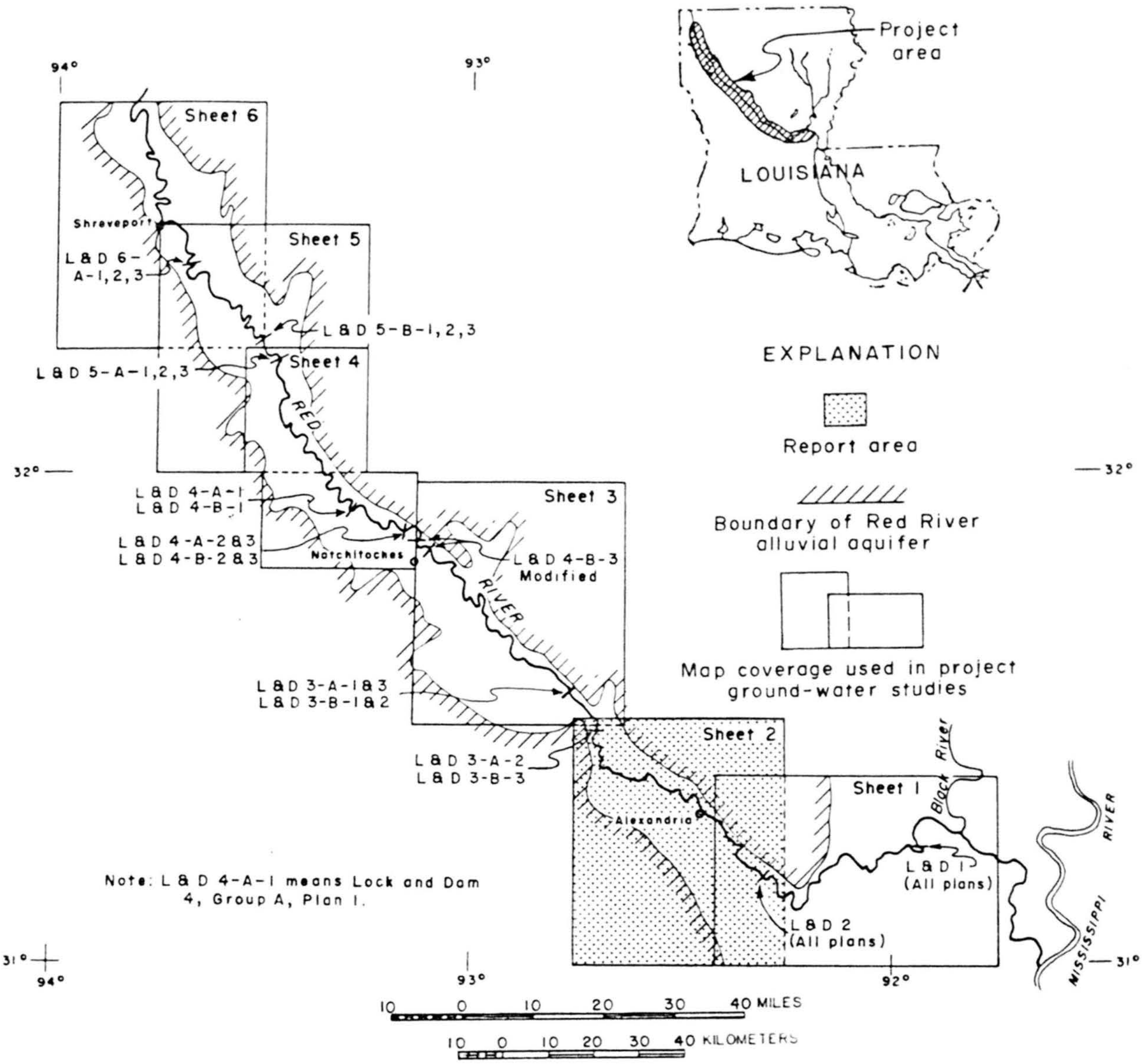

Figure 1.—Location of report area.

This report is the first in a series that will present analyses of preconstruction and postconstruction ground-water conditions in the Red River Valley, La. Subsequent reports on the remaining lock and dam areas will be prepared in the following sequence: Lock and Dam 1, Lock and Dam 4, Lock and Dam 3, Lock and Dam 5, and Lock and Dam 6. The ground-water studies are being made by the Geological Survey in cooperation with the Corps of Engineers and the Soil Conservation Service.

PURPOSE AND SCOPE

This report gives the results of a study to define the present ground-water levels and to determine the effects of proposed navigation structures on ground-water levels in the Lock and Dam 2 area (fig. 1).

Lock and Dam 2 is to be located at mile 87 (kilometer 140), 1967 mileage, (realined mile 75, or kilometer 121) on the Red River. Various plans, consisting of three different pool stages upstream from Lock and Dam 2, have been considered by the Corps. These plans include a 65-foot (19.8-m) pool stage (group A, plans 1 and 3; group B, plans 1 and 2), a 60-foot (18.3-m) pool stage (group A, plan 2; group B, plan 3), and a 58-foot (17.7-m) pool stage (group B, plan 3, modified). The plan for a 58-foot (17.7-m) pool stage (B-3, modified) has been selected for implementation by the Corps. However, in addition to an investigation of the effects of the B-3 modified plan, the Corps has requested that each of the alternate plans be analyzed. The pool stages referred to herein indicate the elevation of the pool at the proposed damsite, in feet above mean sea level.

Two types of analyses were made in this investigation, steady and nonsteady state. Steady-state analysis was made to determine the change from average preconstruction to average postconstruction ground-water levels in the aquifer. This report presents a definition of the average preconstruction potentiometric surface and the results of a steady-state determination of the postconstruction potentiometric surface. The potentiometric surface refers to the level to which water will rise in wells tapping the coarse sand and gravel aquifer beneath the Red River Valley. Steady-state projections of the potentiometric surface were made for all plans studied by the Corps. Nonsteady state refers to the variations in the position of the water table with time. Nonsteady-state analyses of the preconstruction and postconstruction water table are presented for the group B, plan 3, modified dam scheme. The water table is the upper surface of the zone of saturation. In the Red River Valley, this surface generally lies in the fine-grained material above the aquifer.

Steady- and nonsteady-state analyses were made with the use of digital-modeling techniques discussed later in the report.

DESCRIPTION OF THE AQUIFER SYSTEM

The Red River in the Lock and Dam 2 area flows within an alluvial valley, ranging from 5 to 10 mi (8 to 16 km) in width. Terraces, rising as high as 130 ft (40 m) above the flood plain, border the valley downstream from Alexandria. Upstream from Alexandria, outcrops of clay beds of Miocene age form the valley walls. These beds constitute a nearly impermeable boundary to the alluvial valley.

The alluvium in the valley is as thick as 150 ft (46 m) and averages about 90 ft (27 m). The alluvium can be divided into two parts: a lower unit, or aquifer, which is generally composed of coarse sand and gravel, grading upward to fine sand, and an upper confining layer, which is composed of silt, clay, and fine sand (fig. 2).

Recharge to the alluvial aquifer is derived from infiltration of rainfall, underflow from adjacent terrace deposits, and during periods of high river stage, by recharge from the river. The geologic formations underlying the alluvial valley are not considered to be significant sources of recharge.

Water levels in wells tapping the aquifer rise above the base of the fine-grained material, an indication that the water is contained under artesian or semiartesian conditions. A zone of saturation in the upper fine-grained material, extending from near the land surface down to the aquifer, suggests the presence of water-table conditions. These two conditions exist simultaneously because of the great difference in hydraulic conductivity between the silt and clay cap and the aquifer.

The water table may be above or below the potentiometric surface, depending on the direction of the resultant vertical flow or accretion through the fine-grained material. Accretion, as defined by Stallman (1956), is the rate at which water is gained or lost through the aquifer surface in response to precipitation or evapotranspiration. Positive accretion or recharge takes place where the hydraulic gradient is vertically downward. Conversely, negative accretion, or discharge, takes place where the hydraulic gradient is upward.

Movement of water in the alluvial aquifer is mainly toward the Red River, whose present bed is incised into the aquifer throughout its course in the area. At most times, water is discharged into the river. The pumpage of water from wells in the area is not significant.

The recharge, movement, and discharge of water from the alluvial aquifer are shown graphically in the idealized alluvial section in figure 2. The direction of water movement, indicated by arrows, shows that the aquifer is being recharged by water from the terrace deposits and by infiltration in zone 1 through the silt and clay cap. Discharge takes place to the Red River and vertically upward in zone 2. The flow conditions shown in the diagram may change. At any given location, the rate of accretion is neither constant nor in the same direction at all

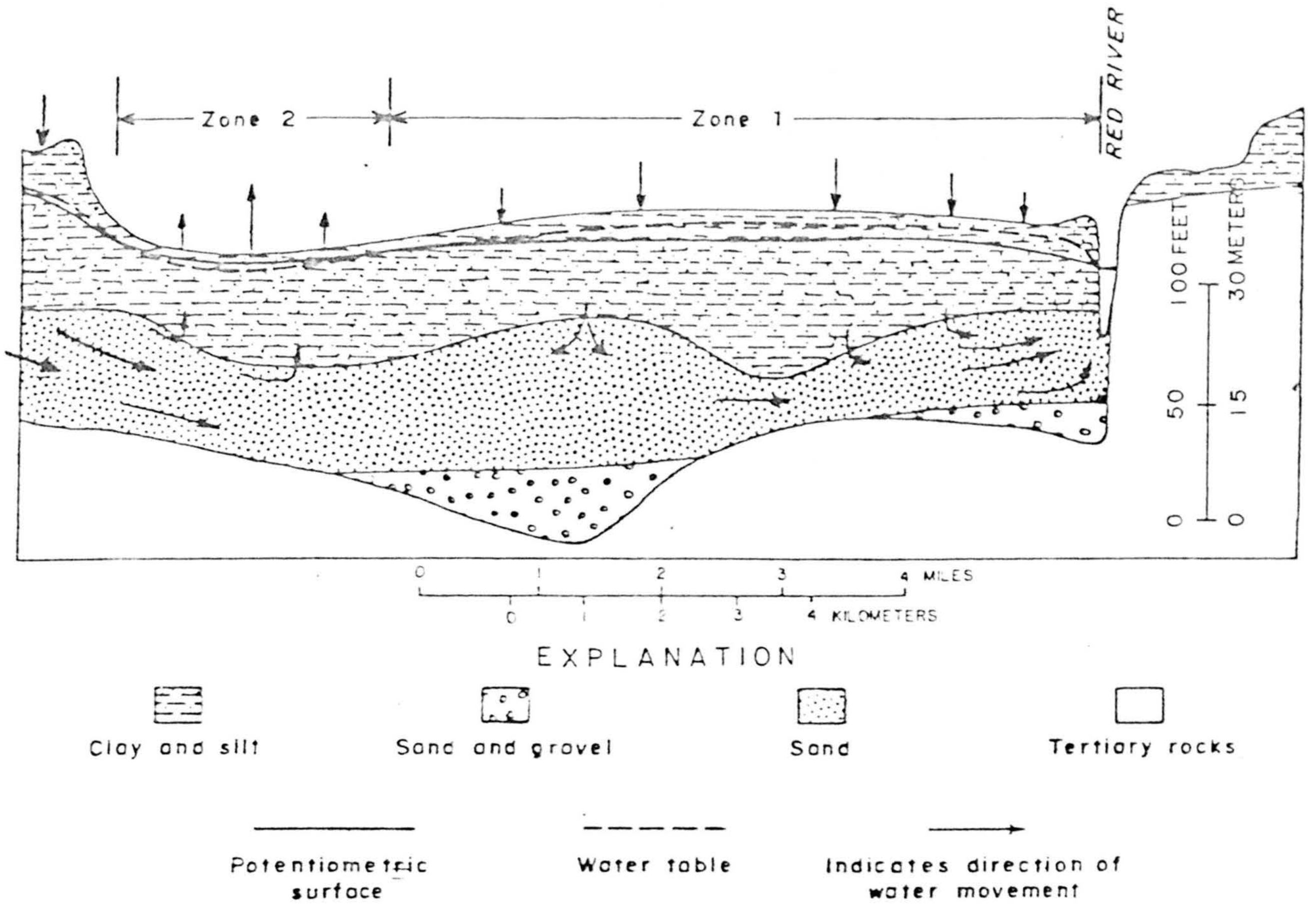

Figure 2.—Idealized hydrogeologic section of the Red River Valley.

times. Seasonal climatic changes, changes in river stage, and pumping may cause variations in the magnitude and direction of water movement in the aquifer.

MODELING PROCEDURE

Digital-modeling techniques were used to analyze the effects of a permanent change in river stage on ground-water levels in the Lock and Dam 2 area. The framework for the digital model of the aquifer consisted of a rectangular grid of 34 rows and 80 columns, superimposed on a map of the Lock and Dam 2 area, having a scale of 1:62,500 (pl. 1). The spacing between each intersection (node) in the grid represented a distance of 0.5 mi (0.8 km). Thus, the model represented a 17- by 40-mile (27- by 64-km) area.

Ground-water movement in the aquifer was modeled as being two-dimensional horizontal flow in a confined system and one-dimensional vertical flow in the upper confining layer. The average hydraulic conductivity of the aquifer, determined from aquifer tests and from laboratory analysis of aquifer samples, was 147 ft/d (45 m/d); and the transmissivity ranged from 1,600 to 13,300 ft^2/d (150 to 1,240 m^2/d). The vertical hydraulic conductivity of the upper layer ranged from $1x10^{-4}$ to $6x10^{-1}$ ft/d ($3x10^{-5}$ to $2x10^{-1}$ m/d). The specific yield of the upper layer, in which the water table generally occurs, ranged from $1x10^{-2}$ to $2x10^{-1}$. The storage coefficient of the aquifer ranges from $2x10^{-2}$ to $8x10^{-4}$. Hydraulic conductivity and storage values for the upper layer and storage values for the aquifer were calculated from calibration of the model.

The Red River was assumed to penetrate the aquifer and to be hydraulically connected with it. Tributary streams, such as Bayous Rigolette, Rapides, and Boeuf and Chatlin Lake Canal, do not penetrate the aquifer and are separated from it by less permeable fine-grained materials. The fine-grained material ranges from 10 to 25 ft (3 to 8 m) in thickness, and laboratory analyses of soil samples indicated that it has a hydraulic conductivity of $5x10^{-3}$ ft/d ($2x10^{-3}$ m/d).

Climatic data used in the model were taken from National Weather Service records at the Alexandria station. Daily rainfall amounts were applied uniformly to all points in the model.

The limits of the model were treated as boundaries across which there was no flow. Because of this treatment, analytical errors occur within the modeled areas at and near these boundaries. The errors diminish with distance from the boundaries. In the Lock and Dam 2 area, these errors were negligible within 3 mi (4.8 km) of the model boundaries. For this reason, water levels projected for the area within 3 mi (4.8 km) of the model boundaries were not included with the projected water levels generated by the model.

An essential part of the analysis involved the calibration procedure to insure that the aquifer model would respond properly to external stress. The model was calibrated in the following manner: (1) Observed river-stage fluctuations and accretion rates were simulated in the aquifer model, and the resultant head distribution in the aquifer was computed. Accretion was computed in the model as a function of the hydraulic conductivity and thickness of the upper confining layer, precipitation, and potential evapotranspiration. River-stage and climatic data for 1968 through 1971 and test-hole logs were used for this purpose. This analysis resulted in synthetic hydrographs of potentiometric and water-table fluctuations for 30 nodes in the model. The nodes in the aquifer model coincide with the physical locations of observation wells in the field. (2) The computed water-level values were compared with the observed measurements for the same period of time. (3) The values of the modeled parameters (for example, hydraulic conductivity and storage of the upper confining layer and aquifer and the degree of connection between streams and the aquifer) were adjusted, and a new head distribution in the aquifer was computed. This sequence of steps was repeated until a suitable match between computed and observed potentiometric levels was obtained. A difference of 1 ft (0.3 m) or less between the computed and the observed potentiometric levels was considered to be acceptable. The position of the water table with respect to the potentiometric surface was determined in the model as a function of the magnitude and direction of the accretion component.

The procedure described here applies to the calibration of the nonsteady-state model, but the resultant calibration was also used for the steady-state model.

STEADY-STATE ANALYSIS

The steady-state projections of the potentiometric surface were made by using analog-modeling techniques originally developed for similar studies in the Arkansas River valley (Bedinger and others, 1970). These techniques were later adapted for use with a digital computer (Bedinger and others, 1973). The model representation of the aquifer for the steady-state analysis basically includes three parameters: transmissivity of the aquifer, the change in evapotranspiration from the aquifer with change in head in the aquifer, and the hydrologic boundaries of the aquifer (fig. 3). The relation between evapotranspiration and depth to water was determined from the nonsteady-state model calibration. The change in river stage from average preconstruction to average postconstruction conditions was simulated to produce the resultant changes in the potentiometric surface in the artesian aquifer.

Preconstruction Potentiometric Surface

The average preconstruction potentiometric surface is the datum from which projections of postconstruction conditions were made. The

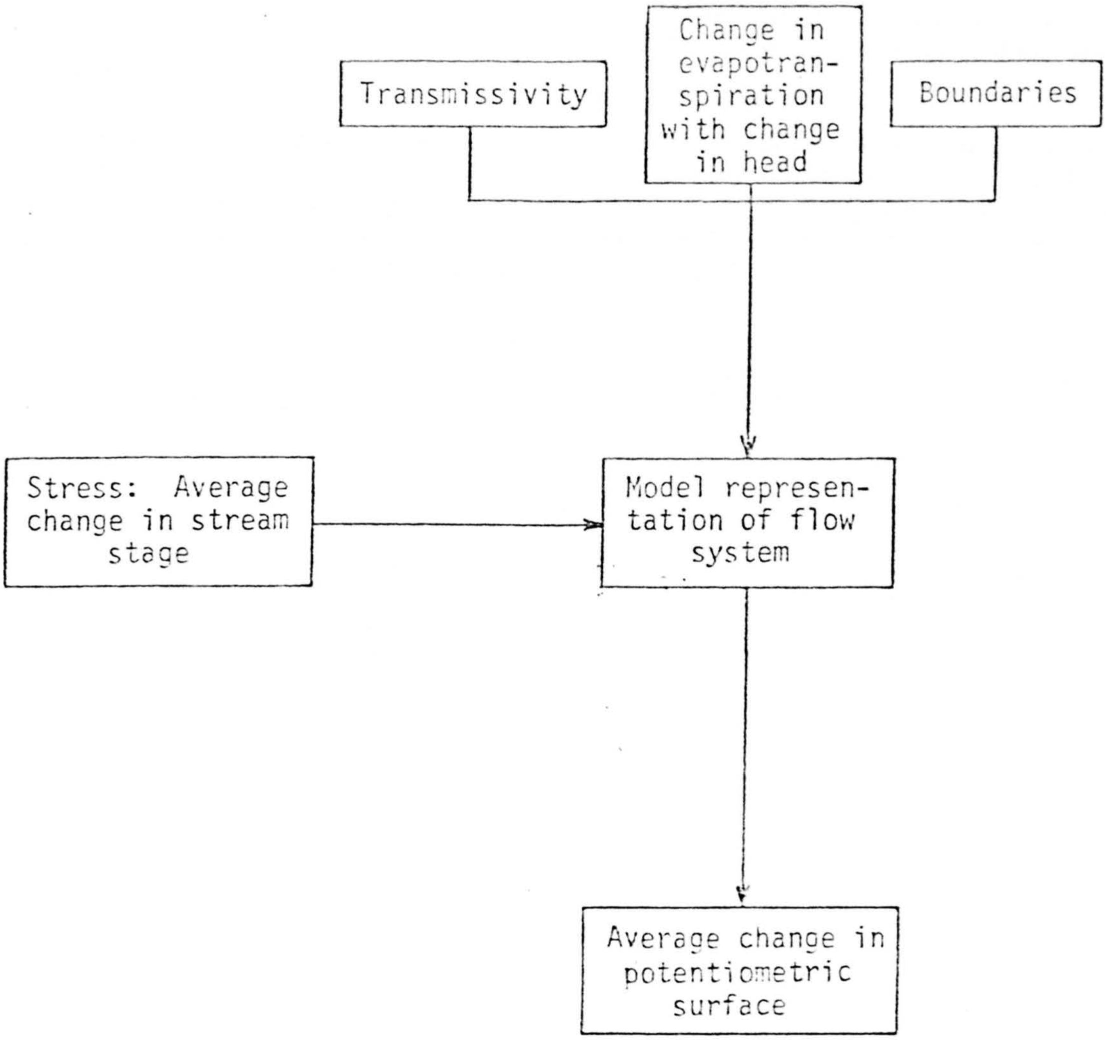

Figure 3.—Flow diagram of digital-model procedure for steady-state analysis.

elevation of the average preconstruction potentiometric surface in the Lock and Dam 2 area was determined from data collected from the joint Geological Survey-Soil Conservation Service observation-well network. The preconstruction potentiometric surface was contoured manually (pl. 1) using time-weighted averages of monthly water-level readings taken from August 1968 through June 1973.

The average preconstruction potentiometric surface in the Lock and Dam 2 area ranges from 46 to 82 ft (14 to 25 m) above mean sea level (pl. 1). The greatest depths to water are in areas adjacent to the Red River and beneath natural-levee deposits flanking Bayou Rapides and Bayou Boeuf. Water levels are nearest the land surface in the backswamp areas.

In most places the gradient of the potentiometric surface is toward the river. At Alexandria the slope is about 5 ft/mi (0.9 m/km).

Postconstruction Potentiometric Surface

A 65-foot (19.8-m) pool stage upstream from Lock and Dam 2 (group A, plans 1 and 3; group B, plans 1 and 2) (pl. 2) would cause a permanent increase in river stage, ranging from 19.5 ft (5.9 m) at the dam to 3.5 ft (1.1 m) above the present average river stage at the upper end of the pool. Ground-water levels would rise a similar amount adjacent to the river but would gradually diminish with distance from the river. Rises of at least 1 ft (0.3 m) in ground-water levels would occur as much as 6 mi (9.7 km) from the river. The projected potentiometric surface is shown on plate 2.

As seen from the contour lines (pl. 2), the postconstruction ground-water gradient would be toward the river, similar to the existing gradient, but the gradient would be less steep. The closely spaced contour lines radiating from the location of the proposed damsite indicate that a strong potential would exist for ground-water seepage through the aquifer and around the dam.

Comparison of the projected potentiometric surface with land-surface elevations indicates that the potentiometric surface would be above the land surface in some places. The projected potentiometric surface would be as much as 6 ft (1.8 m) above the land surface in the Chatlin Lake Canal area, south of Latanier; as much as 3 ft (0.9 m) above the land surface in the area immediately south of the Anandale area of Alexandria; and as much as 4 ft (1.2 m) above the land surface in parts of the Bayou Rapides backswamp area, between Boyce and McNutt. The projected potentiometric surface would be at or near the land surface in much of the low-lying area within 3 to 4 mi (4.8 to 6.4 km) of the river.

A 60-foot (18.3-m) pool stage (group A, plan 2; group B, plan 3) (pl. 3) would cause a permanent increase in river stage, ranging from

14.5 ft (4.4 m) at the dam to 4.0 ft (1.2 m) above the present average river stage at the upper end of the pool. Analysis of the induced head change in the aquifer indicated that rises of ground-water levels of 1 ft (0.3 m) or more would occur as much as 5 mi (8 km) from the river.

The projected potentiometric surface would be as much as 3 ft (0.9 m) above the land surface in the area along Chatlin Lake Canal, south of Latanier, and as much as 2 ft (0.6 m) above the land surface in places south of the Anandale area of Alexandria. These areas encompass about 4 mi^2 (10.4 km^2).

A 58-foot (17.7-m) pool stage (group B, plan 3, modified) (pl. 4) will result in a permanent change of 12.5 ft (3.8 m) in river stage at the proposed lock and dam site. Increases of 1 ft (0.3 m) or more in ground-water levels will occur as much as 4 mi (6.4 km) from the river.

As a result of the permanent change in river stage, the projected potentiometric surface will be as much as 2 ft (0.6 m) above the land surface in the area along Chatlin Lake Canal, south of Latanier, and as much as 1 ft (0.3 m) above land surface south of the Anandale area of Alexandria. These areas encompass about 2 mi^2 (5.2 km^2).

NONSTEADY-STATE ANALYSIS

Nonsteady-state analyses were made by using digital-modeling procedures recently developed by the Geological Survey (Reed and others, 1976). The nonsteady-state model has the same map representation as the steady-state model. However, the nonsteady-state model incorporates several additional parameters, as shown in figure 4. Data for each of these parameters were assigned to the appropriate node or nodes in the model. Accretion and river stage, the major stresses on the aquifer, were applied to the model in successive 10-day time increments. The computations resulted in potentiometric and water-table elevations at all nodal points in the model for each time increment.

The data developed from the nonsteady-state analysis are to be used by the Soil Conservation Service for analysis of the effects of water levels on agriculture and other activities in the area.

The nonsteady-state model used in this analysis includes an average value of hydraulic conductivity of fine-grained material at each control point to compute the position of the water table. Stratification of the fine-grained material is highly variable and may cause local variations between computed and observed water levels.

Computed water-table elevations represent the average conditions in a 0.25 mi^2 (0.65-km^2) area in the model. The position of the water table at a given point may be influenced by local geologic and drainage features. Land-surface elevation was used in the model as a reference point for computing the position of the water table. Except for elevations of control points, which were determined by instrument, land-

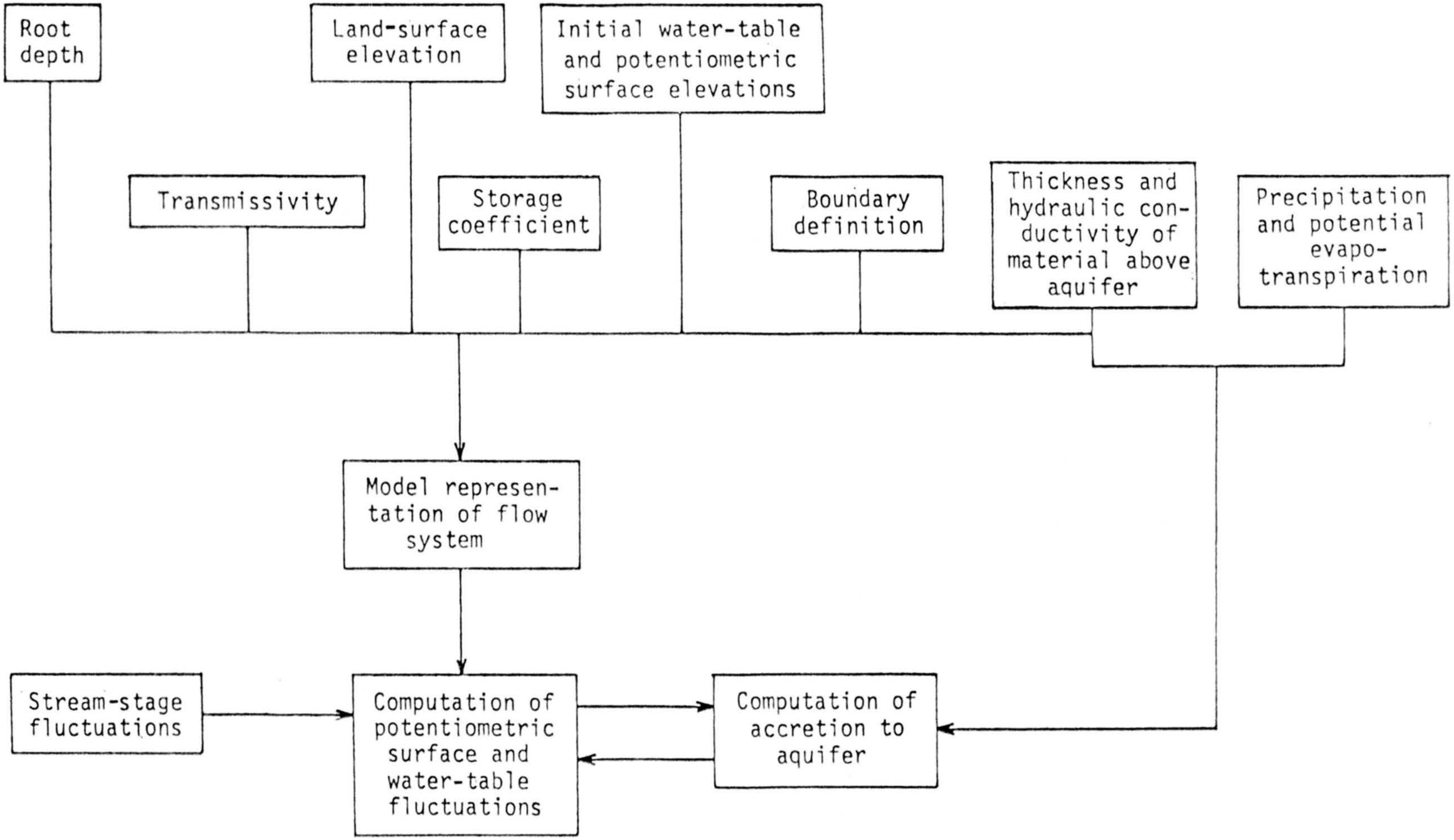

Figure 4.—Flow diagram of digital-model procedure for nonsteady-state analysis.

surface elevations for all nodes in the model were obtained from topographic maps of the area. Topographic maps for the Alexandria, Lecompte, and Marksville quadrangles have 5-foot (1.5-m) contour intervals. The Woodworth and Boyce quadrangles have 20-foot (6.1-m) contour intervals. Land-surface elevations determined from topographic maps are generally accurate to one-half the contour interval.

Preconstruction Water Table

The computed preconstruction water table ranges from land surface to about 28 ft (8.5 m) below the land surface. The water table generally is nearest the land surface in March or April and gradually declines to a low in September or October. The magnitude of water-table fluctuations varies according to the proximity of a particular location to the river. The water table near the river fluctuates greatly, reflecting the wide variations in potentiometric head induced by the river. At greater distances from the river, water-table fluctuations are smaller, changing in response to local changes in accretion. Computed hydrographs for two well sites, R-947 and R-945 (figs. 5 and 6), are given as examples to show the characteristic cyclic pattern of annual water-table fluctuations. The computed water level at the site of well R-947, which is about 0.5 mi (0.8 km) from the river (pl. 1), fluctuates as much as 14.4 ft (4.4 m) annually. The computed water level at the site of well R-945, about 3 mi (4.8 km) from the river (pl. 1), fluctuates about 1.8 ft (0.5 m) annually.

Postconstruction Water Table

The computed postconstruction water table reflects the attenuation of river-stage fluctuations and increase in head resulting from the formation of a pool upstream from the proposed lock and dam site. Near the river the water table is expected to fluctuate as much as 13 ft (4 m), or approximately half the magnitude of preconstruction fluctuations. However, the water table will be closer to the land surface. Computed water-table hydrographs of well sites R-947 and R-945 (figs. 7 and 8) show, respectively, a representation of postconstruction conditions near and at a distance from the river. The hydrograph for the site of well R-947 shows a water-table fluctuation of approximately 10 ft (3 m), ranging from 4 to 14 ft (1.2 to 4.3 m) below the land surface. By comparison, the hydrograph for preconstruction conditions at that site (fig. 5) shows a fluctuation of 14.4 ft (4.4 m), ranging from 13.4 to 27.8 ft (4.1 to 8.5 m) below the land surface. The computed postconstruction water table at the site of well R-945 ranges from land surface to 1.2 ft (0.4 m) below the land surface. The computed preconstruction water table for the same location (fig. 6) ranges from land surface to 1.8 ft (0.5 m) below the land surface.

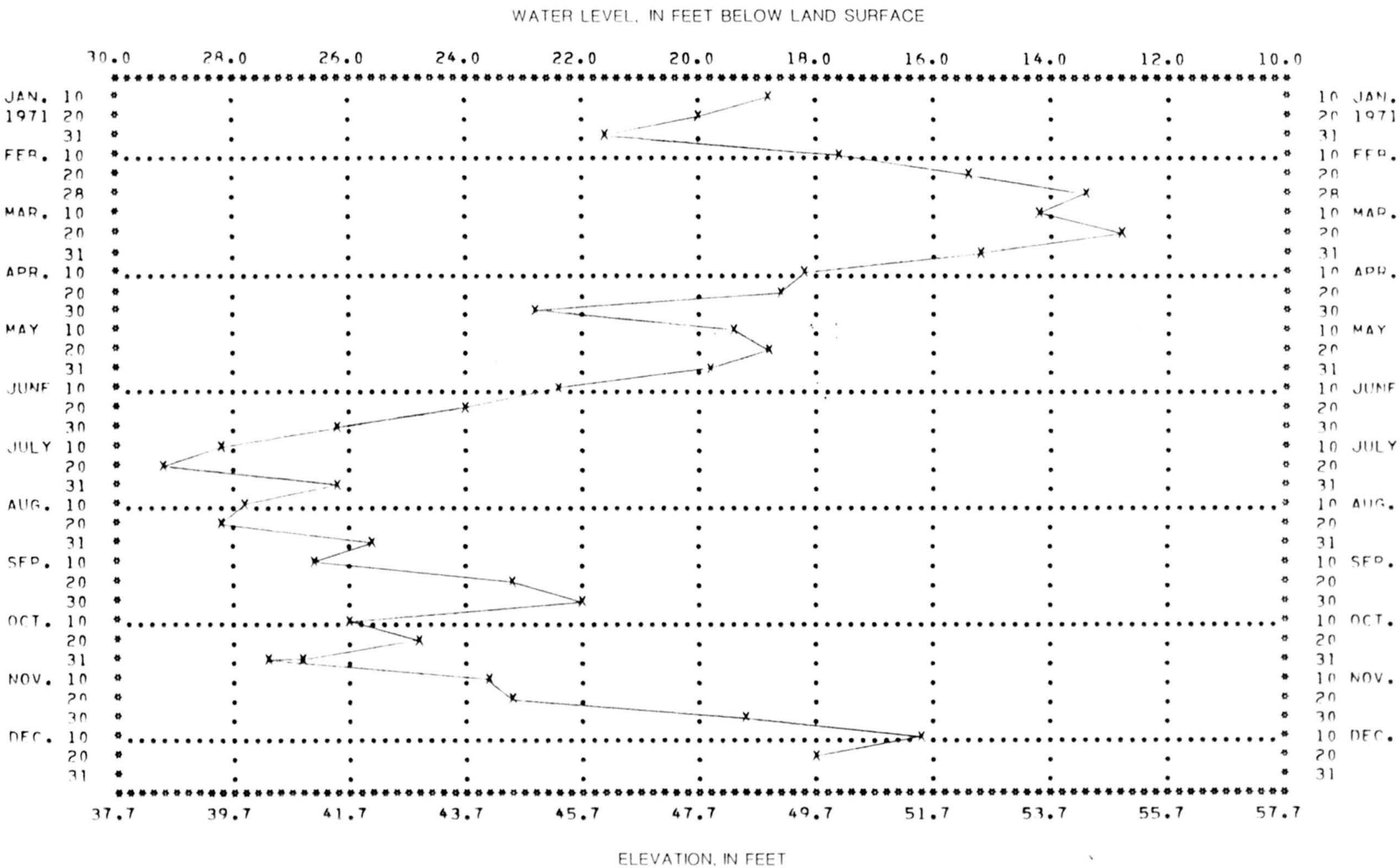

Figure 5.—Computed preconstruction water-table hydrograph, well R-947.

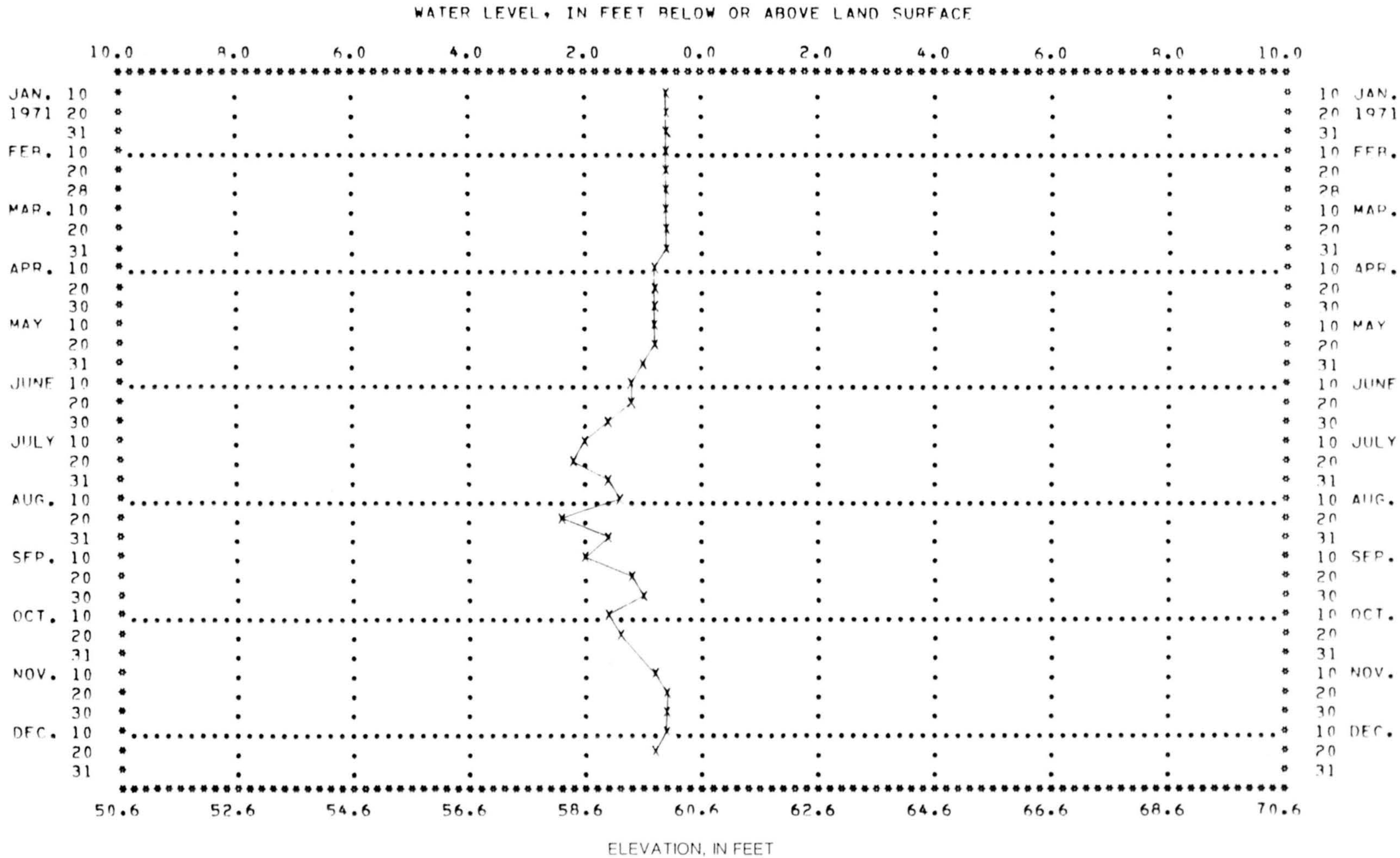

Figure 6.— Computed preconstruction water-table hydrograph, well R-945.

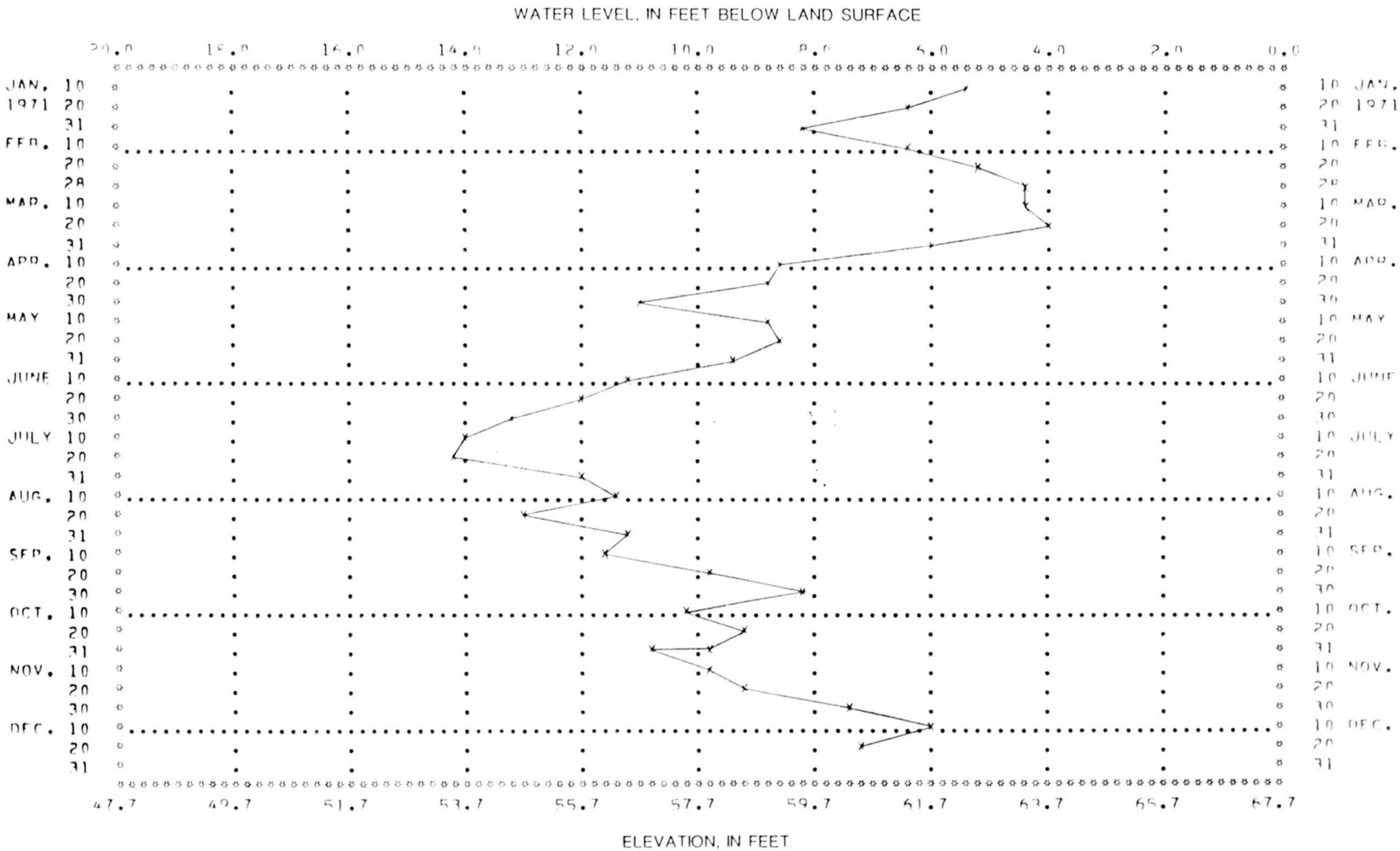

Figure 7.—Computed postconstruction water-table hydrograph, well R-947.

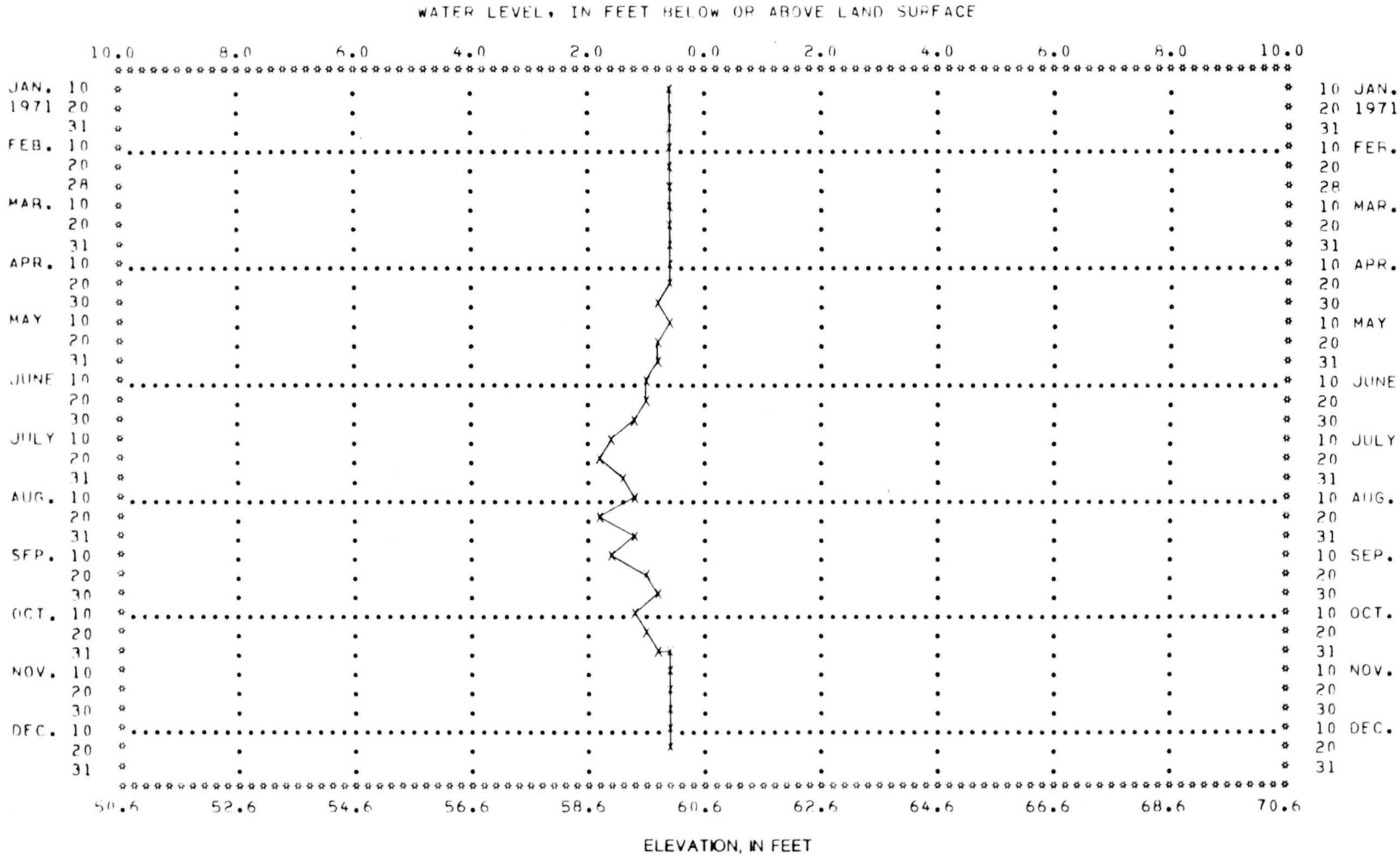

Figure 8.—Computed postconstruction water-table hydrograph, well R-945.

SUMMARY

Lock and Dam 2 is to be located at mile 87 (kilometer 140), 1967 mileage, (realined mile 75 or kilometer 121) on the Red River, and the pool stage upstream from the dam will be at an elevation of 58 ft (17.7 m) above mean sea level. Construction of Lock and Dam 2 will cause a permanent increase in the river stage of 12.5 ft (3.8 m) at the dam. As a result of the increased river stage, ground-water levels will be raised 1 ft (0.3 m) or more to a distance of 4 mi (6.4 km) from the river. The potentiometric surface may be as much as 2 ft (0.6 m) above the land surface in the area along Chatlin Lake Canal, south of Latanier, and as much as 1 ft (0.3 m) above the land surface south of the Anandale area of Alexandria. These areas encompass about 2 mi^2 (5.2 km^2). In addition, the potentiometric surface will be at or near the land surface in much of the low-lying area within 4 mi (6.4 km) of the river. Because of the attenuation in river stage caused by the formation of a pool upstream from Lock and Dam 2, the magnitude of ground-water-level fluctuations will be reduced to approximately half that of existing fluctuations. However, the water levels will be closer to the land surface.

SELECTED REFERENCES

Bedinger, M. S., Reed, J. E., and Griffin, J. D., 1973, Digital-computer programs for analysis of ground-water flow: U.S. Geological Survey open-file report, 85 p.

Bedinger, M. S., Reed, J. E., Wells, C. J., and Swafford, B. F., 1970, Methods and applications of electrical simulation in ground-water studies in the lower Arkansas and Verdigris River valleys, Arkansas and Oklahoma: U.S. Geological Survey Water-Supply Paper 1971, 71 p.

Ludwig, A. H., 1974, Quality of water in the Red River alluvial aquifer, Shreveport, to the mouth of the Black River, Louisiana: U.S. Geological Survey open-file report, 7 p.

______1979, Preconstruction and postconstruction ground-water levels, Lock and Dam 1, Red River Valley, Louisiana: U.S. Geological Survey Open-File Report 79-918, 17 p.

Ludwig, A. H., and Terry, J. E., 1979, Preconstruction and postconstruction ground-water levels, Lock and Dam 3, Red River Valley, Louisiana: U.S. Geological Survey Open-File Report 79-920, 21 p.

Newcome, Roy, Jr., 1960, Ground-water resources of the Red River Valley alluvium in Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Pamphlet 7, 21 p.

Newcome, Roy, Jr., and Sloss, Raymond, 1966, Water resources of Rapides Parish, Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Bulletin 8, 104 p.

Reed, J. E., Bedinger, M. S., and Terry, J. E., 1976, Simulation procedure for modeling transient water-table and artesian stress and response: U.S. Geological Survey Open-File Report 76-792, 173 p.

Stallman, R. W., 1956, Numerical analysis of regional water levels to define aquifer hydrology: American Geophysical Union Transactions, v. 37, no. 4, p. 451-460.

Stephens, J. W., 1976, Records of wells, water-level measurements, and drillers' logs, Red River Valley, Louisiana: U.S. Geological Survey Open-File Report 76-759, 335 p.