UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRECONSTRUCTION AND POSTCONSTRUCTION GROUND-WATER LEVELS, LOCK AND DAM 4, RED RIVER VALLEY, LOUISIANA

Open-File Report 79-921

Prepared in cooperation with the

U.S. Army Corps of Engineers

and the U.S. Soil Conservation Service

Cooperative Ground-Water Study

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRECONSTRUCTION AND POSTCONSTRUCTION GROUND-WATER LEVELS, LOCK AND DAM 4, RED RIVER VALLEY, LOUISIANA

By A. H. Ludwig and J. E. Reed

Open-File Report 79-921

Prepared in cooperation with the

U.S. Army Corps of Engineers

and the U.S. Soil Conservation Service

Cooperative Ground-Water Study

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."

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

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
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/year)
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 4, RED RIVER VALLEY, LOUISIANA

By A. H. Ludwig and J. E. Reed

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 4 at realined mile 154 (kilometer 250) above the mouth of the Red River call for a pool elevation of 115 feet (35 meters) and will cause an average increase in river stage ranging from 24 to 4.5 feet (7 to 1.4 meters). As a result, ground-water levels will be raised 1 foot (0.3 meter) or more between the Red River and Bayou Pierre from the dam to Coushatta, and below Campti, east of the river. The potentiometric surface may be at or near land surface in low areas between the Red River and Bayou Pierre, and above land surface locally upstream from the dam. The magnitude of ground-water-level fluctuations near the river will be reduced to less than half the present range.

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 that include an arrangement of either five or six locks and dams have been proposed. The locations of the proposed dams are shown in figure 1. Plans for a modified version of the arrangement for five locks and dams, called the B-3 modified plan, have been adopted by the Corps. The U.S. Geological Survey is evaluating the effects of each proposal on ground-water levels. The results of this investigation are being used by the Corps of Engineers and the U.S. Soil Conservation Service to evaluate the beneficial or adverse effects of changes in ground-water levels.

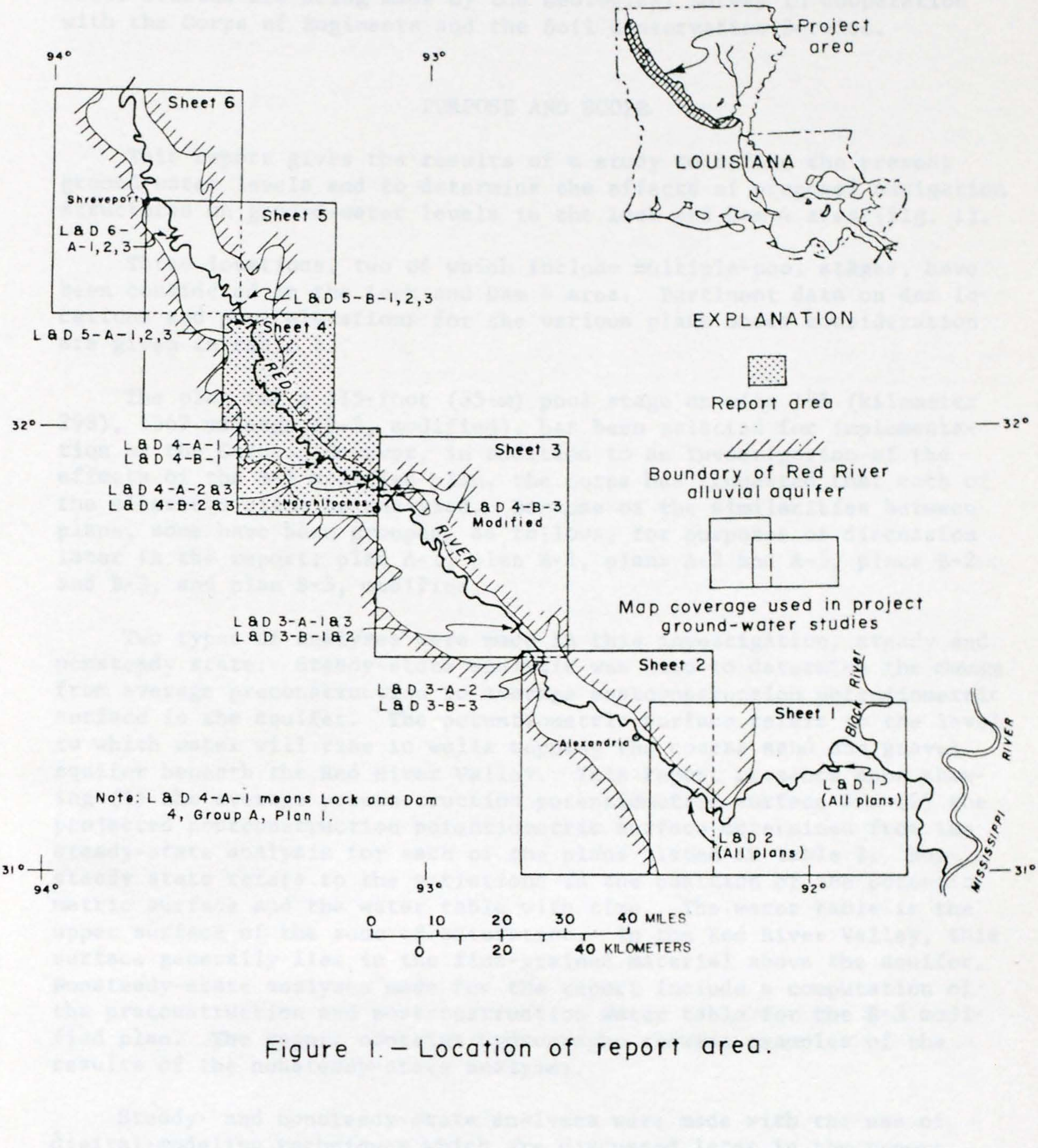


Figure 1.—Location of report area.

This report is the third in a series that will present analyses of preconstruction and postconstruction ground-water conditions in the Red River Valley, La. Previous reports covered Lock and Dam 1 and 2 areas. Subsequent reports on the lock and dam areas will be prepared in the following sequence: Lock and Dam 3 and Lock and Dam 5 and 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 4 area (fig. 1).

Three locations, two of which include multiple-pool stages, have been considered in the Lock and Dam 4 area. Pertinent data on dam locations and pool elevations for the various plans under consideration are given in table 1.

The plan for a 115-foot (35-m) pool stage at mile 185 (kilometer 298), 1967 mileage (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. Because of the similarities between plans, some have been grouped, as follows, for purposes of discussion later in the report: plan A-1, plan B-1, plans A-2 and A-3, plans B-2 and B-3, and plan B-3, modified.

Two types of analyses were made in this investigation, steady and nonsteady state. Steady-state analysis was used to determine the change from average preconstruction to average postconstruction potentiometric surface in the aquifer. 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. This report presents maps showing (1) the average preconstruction potentiometric surface and (2) the projected postconstruction potentiometric surface determined from the steady-state analysis for each of the plans listed in table 1. Nonsteady state refers to the variations in the position of the potentiometric surface and the water table with time. 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. Nonsteady-state analyses made for the report include a computation of the preconstruction and postconstruction water table for the B-3 modified plan. The report contains hydrographs showing examples of the results of the nonsteady-state analyses.

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

Table 1.--Locations of damsites and elevations of pool stages for alternate plans, Lock and Dam 4

[River mile: Distance, in miles, upstream from the mouth of Old River. Pool stage: Elevation of pool at the proposed damsite, in feet above mean sea level]

Plan	River mile		Pool stage	
	1967	Realined	Lower	Upper
A-1	206	171	95	115
A-2	195	161	90	115
A-3	195	161	90	115
B-1	206	171	95	120
B-2	195	161	90	120
B-3	195	161	90	120
B-3, modified	185	154	87	115

DESCRIPTION OF THE AQUIFER SYSTEM

The Red River in the Lock and Dam 4 area flows within an alluvial valley ranging from 4 to 7 mi (6.4 to 11.2 km) in width. Formations of Tertiary age underlie the valley alluvium and form the upland bordering the valley. The beds of Tertiary age are composed primarily of clay and silt and constitute a nearly impermeable boundary to the alluvial aquifer. In some places, terraces overlie the Tertiary outcrops in the uplands. However, except for isolated terraces in the northern part of the area, the terraces are not considered to be hydraulically connected with the alluvial aquifer.

The alluvium in the valley is as thick as 110 ft (34 m) and averages about 80 ft (24 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). The aquifer is as thick as 75 ft (23 m) and averages about 40 ft (12 m), and the upper confining layer is as thick as 60 ft (18 m).

Recharge to the alluvial aquifer is derived from infiltration of rainfall 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 confined 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 confining beds 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 vertical hydraulic gradient is downward. Conversely, negative accretion or discharge takes place where the vertical hydraulic gradient is upward.

Movement of water in the alluvial aquifer is toward the Red River and Bayou Pierre, the principal tributary to the Red River in the area. 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 infiltration in zone 1 through the clay and silt. Discharge takes place to the Red River and Bayou Pierre 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 times. Seasonal weather 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 river-induced effects of a permanent change in river stage on ground-water levels in the Lock and Dam 4 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 4 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.

To provide for continuity of data in modeling the entire navigation reach, the models for the various areas were designed to include an area of overlap on the adjacent model. At a minimum, adjacent models were overlapped a distance equivalent to 6 mi (9.6 km). The purpose of the overlap was to aid in the identification of errors in the projections associated with model boundary conditions and to enable the preparation of a complete suite of data for the navigation reach. In the Lock and Dam 4 area, the model for the Lock and Dam 3 area overlapped the downstream end, and the model for the Lock and Dam 5 area overlapped the upstream end of the Lock and Dam 4 area. Models for the upstream and downstream areas were analyzed concurrently with that for the Lock and Dam 4 area, and the data developed for areas common to each model

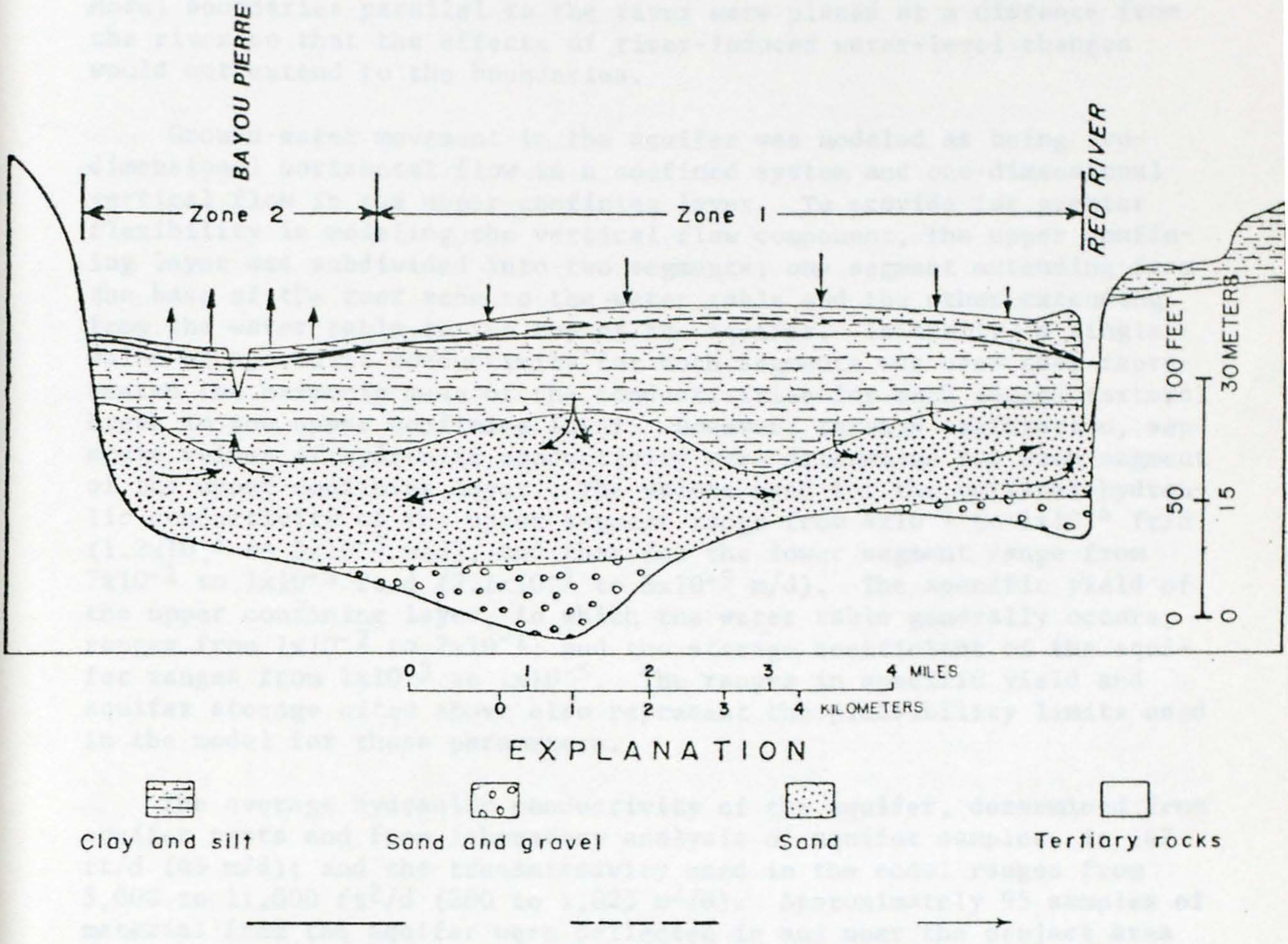


Figure 2.—Idealized hydrogeologic section of the Red River Valley.

were examined to determine the extent of boundary effects. The inclusion of unaffected data from the Lock and Dam 3 and 5 areas in the Lock and Dam 4 model enabled the determination of project-induced effects to the upstream and downstream boundaries of the Lock and Dam 4 model. Model boundaries parallel to the river were placed at a distance from the river so that the effects of river-induced water-level changes would not extend to the boundaries.

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. To provide for greater flexibility in modeling the vertical flow component, the upper confining layer was subdivided into two segments: one segment extending from the base of the root zone to the water table and the other extending from the water table to the top of the aquifer. Initially, a single value of hydraulic conductivity for both segments was used that represented the harmonic mean of the conductivities for each logged textural break in the upper confining layer. However, through calibration, separate values of hydraulic conductivity were determined for each segment of the upper confining layer. The values used for the vertical hydraulic conductivity of the upper segment range from 4×10^{-1} to 1×10^{-4} ft/d (1.2×10^{-1} to 3×10^{-5} m/d), and that for the lower segment range from 7×10^{-1} to 1×10^{-4} ft/d (2.1×10^{-1} to 3×10^{-5} m/d). The specific yield of the upper confining layer, in which the water table generally occurs, ranges from 1×10^{-2} to 2×10^{-1}; and the storage coefficient of the aquifer ranges from 1×10^{-3} to 1×10^{-5}. The ranges in specific yield and aquifer storage cited above also represent the plausibility limits used in the model for these parameters.

The average hydraulic conductivity of the aquifer, determined from aquifer tests and from laboratory analysis of aquifer samples, is 147 ft/d (45 m/d); and the transmissivity used in the model ranges from 3,000 to 11,000 ft^2/d (280 to 1,025 m^2/d). Approximately 95 samples of material from the aquifer were collected in and near the project area and were analyzed for hydraulic conductivity and particle size. A relationship was developed between hydraulic conductivity and particle size using the method of Bedinger, Reed, Wells, and Swafford (1970). From this relationship, an average value of hydraulic conductivity was developed for the alluvial aquifer. Transmissivity of the aquifer was determined by multiplying the average value of hydraulic conductivity by the thickness of aquifer material found from logs of test holes in the area. Test-hole logs were available from the sites shown as control points on plate 1. Transmissivity values were checked at two locations near the river (wells RR-176 and RR-226) by the method of river-induced fluctuations (Bedinger and others, 1973). Transmissivity maps were prepared from these data and used as input to the model.

The Red River and its tributaries in the Lock and Dam 4 area do not fully penetrate the alluvial aquifer in all places along their courses. Model analysis indicates that in many places the streams are separated from the aquifer by several feet of fine-grained material.

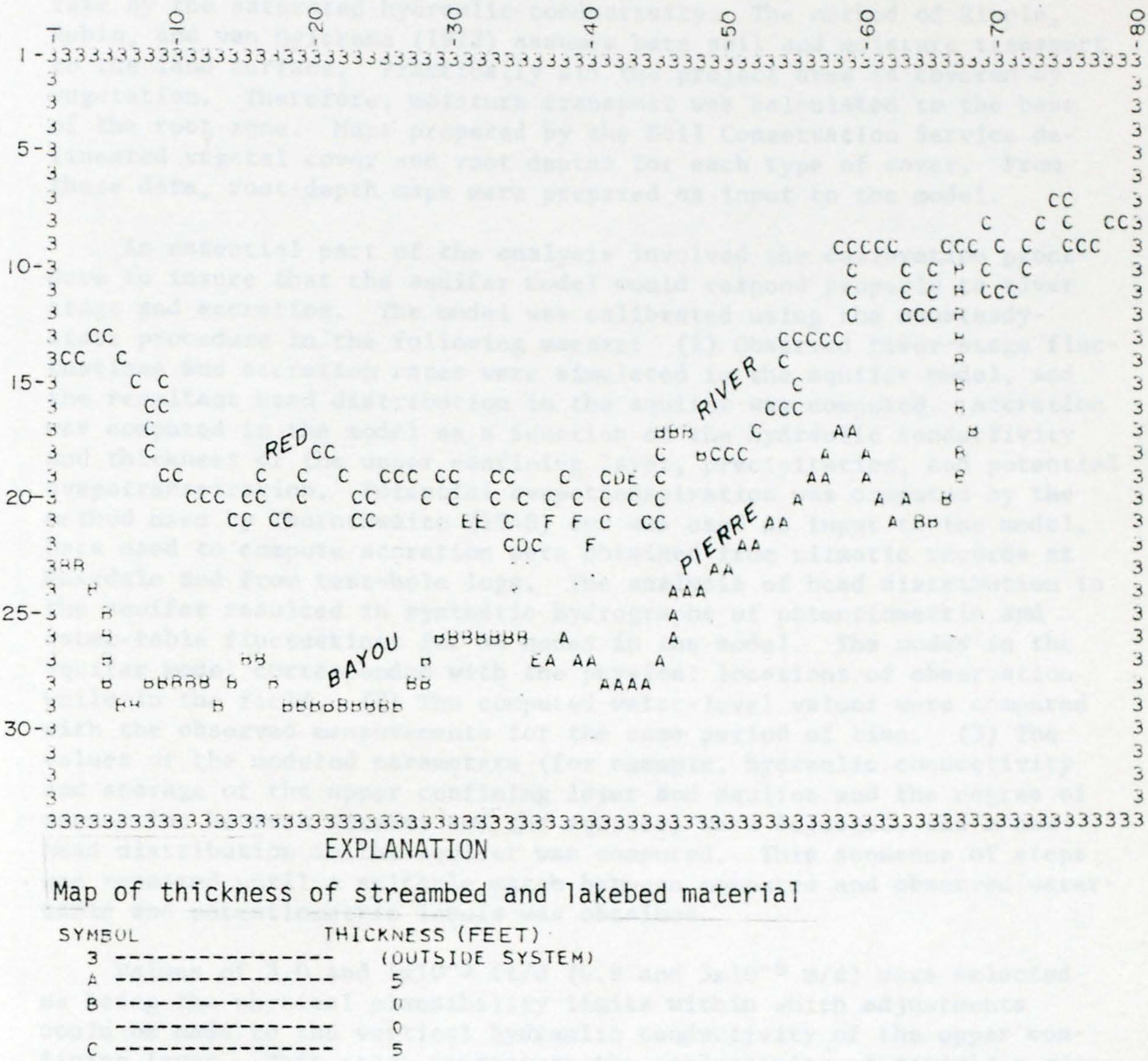
Figure 3 shows, in symbolic map form, the distribution of modeled thicknesses of fine-grained material determined from the calibration of the model. A symbol on the map can be referenced to a location along a stream (pl. 1) by first determining its node location (row and column) in figure 3, and then locating the same position on the grid outlined on plate 1.

The thicknesses shown in figure 3 do not necessarily indicate the physical thickness of fine-grained material at a given location. A single value of hydraulic conductivity ($5x10^{-3}$ ft/d, or $2x10^{-3}$ m/d) of the fine-grained material was used in the model. The thickness was adjusted to obtain the correct ratio of hydraulic conductivity to thickness for calibration. A symbol representing zero thickness of streambed material indicates that at that point the river and aquifer are in perfect hydraulic connection.

The climatic data used in the model were taken from National Weather Service records for the Westdale station, which is in the northern part of the area. (See pl. 1.) Daily rainfall amounts recorded for this station were applied uniformly to all points in the model.

Infiltration of rainfall was computed using a modified version of a routine from the model by Dawdy, Lichty, and Bergmann (1972, p. B5-B8). This routine was modified to correspond to the 1-day rainfall periods used in this model as contrasted with the 15-minute period used in the original model. Overland runoff, or infiltration residual, was dropped from the accounting procedure of the nonsteady-state model. Due to the 1-day rainfall period, redistribution of moisture occurred only once each day. Therefore, it was necessary to impose an upper limit on soil-moisture storage. The value of this limit used in the nonsteady-state model was 1 in. (25.4 mm). This can be compared with values ranging from 1.9 to 3.5 in. (48 to 89 mm) for "maximum moisture storage in the soil column at field capacity" (BMSM) reported in Dawdy, Lichty, and Bergmann (1972, p. B26, table 12). Because the surficial material of the Red River alluvium is generally fine grained, a limit of soil-moisture storage of 1 in. (25.4 mm) is reasonable. Redistribution of soil moisture to the water table was computed as a decaying exponential function of soil moisture throughout the range from 1 to 0.5 in. (25.4 to 12.7 mm). For soil moisture less than 0.5 in. (12.7 mm), recharge to the water table was specified to be zero.

Evapotranspiration was taken initially from soil moisture and then from ground water after soil moisture was depleted. The limit on evapotranspiration was the steady-state rate of upward movement of water, as determined by the method of Ripple, Rubin, and van Hylckama (1972). This method requires a specified relation between unsaturated hydraulic conductivity and soil suction (Ripple and others, 1972, p. A6, eq. 10). Two parameters of this specification, $\underline{n}$, an integer soil coefficient, and $\underline{S_{\frac{1}{2}}}$, soil suction at which the unsaturated conductivity is one-half the saturated conductivity, are used to express the limiting steady-state evaporation in a nondimensional form. Values of $\underline{n}$ ranging from 2 for clays to 5 for sands and values of $\underline{S_{\frac{1}{2}}}$ ranging from 1 for sands to 2



EXPLANATION

Map of thickness of streambed and lakebed material

SYMBOL	THICKNESS (FEET)
3	(OUTSIDE SYSTEM)
A	5
B	0
	0
C	5
D	2
E	1
F	10

Figure 3.—Symbolic map showing modeled thicknesses of streambed material, Lock and Dam 4.

for finer materials were used in this model. The actual limiting rate of evapotranspiration was obtained by multiplying the computed upward rate by the saturated hydraulic conductivity. The method of Ripple, Rubin, and van Hylckama (1972) assumes bare soil and moisture transport to the land surface. Practically all the project area is covered by vegetation. Therefore, moisture transport was calculated to the base of the root zone. Maps prepared by the Soil Conservation Service delineated vegetal cover and root depths for each type of cover. From these data, root-depth maps were prepared as input to the model.

An essential part of the analysis involved the calibration procedure to insure that the aquifer model would respond properly to river stage and accretion. The model was calibrated using the nonsteady-state procedure 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. Potential evapotranspiration was computed by the method used by Thornthwaite (1948) and was used as input to the model. Data used to compute accretion were obtained from climatic records at Westdale and from test-hole logs. The analysis of head distribution in the aquifer resulted in synthetic hydrographs of potentiometric and water-table fluctuations for 44 nodes in the model. The nodes in the aquifer model corresponded 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 water-table and potentiometric levels was obtained.

Values of 3.0 and $1x10^{-5}$ ft/d (0.9 and $3x10^{-6}$ m/d) were selected as being the physical plausibility limits within which adjustments could be made to the vertical hydraulic conductivity of the upper confining layer. This range represents the conductivity of materials ranging from fine sand to dense clay. Because of the extreme lateral variability of the upper alluvial materials, the initial conductivity values, as determined from test-hole logs, are not necessarily representative of the entire area as modeled. Therefore, the only constraints on adjusting vertical hydraulic conductivity values was to remain within the physical plausibility limits.

Results of the calibration for Lock and Dam 4 are given in tables 2 and 3. These tables are reproductions of model output showing comparisons of computed and observed water-table and potentiometric levels for the spring and fall seasons. The observed depth of the water table below land surface at some sites is shown as being within a range of values. This convention is necessary because of the differences in

Table 2.—*Comparison of computed and observed water levels, spring of 1972*

[Well number: N, Natchitoches Parish; V, Red River Parish; D, De Soto Parish]

	POTENTIOMETRIC SURFACE (IN FEET)		
WELL NUMBER	MEASURED DEPTH BELOW LAND SURFACE	COMPUTED DEPTH BELOW LAND SURFACE	DIFFERENCE
N290	18.6	17.7	0.9
N296	11.8	10.2	1.6
N299	12.8	12.5	0.3
N301	23.7	23.1	0.6
N302	22.2	22.6	-0.4
N303	25.7	27.9	-2.2
N304	24.7	23.3	1.4
N308	20.2	21.5	-1.3
N403	6.1	6.1	-0.0
N404	3.4	3.5	-0.1
N410	20.7	21.2	-0.5
N411	19.0	17.9	1.1
N425	1.5	1.5	-0.0
N426	20.0	21.5	-1.5
N427	12.0	12.4	-0.4
V141	9.0	9.4	-0.4
V143	21.5	20.4	1.1
V146	24.3	22.7	1.6
V148	13.0	12.4	0.6
V176	16.8	16.0	0.8
V201	15.7	16.5	-0.8
V202	20.4	20.5	-0.1
V203	29.2	28.6	0.6
V204	17.7	19.6	-1.9
V205	18.0	19.3	-1.3
V206	12.5	11.4	1.1
V207	13.0	11.8	1.2
V208	22.4	23.2	-0.8
V209	12.0	14.4	-2.4
V210	23.0	24.9	-1.9
V211	16.6	17.2	-0.6
V212	16.4	14.9	1.5
V213	25.0	26.1	-1.1
V214	2.0	3.3	-1.3
V215	9.0	9.5	-0.5
V222	8.9	10.0	-1.1
V224	13.0	14.7	-1.7
V225	12.0	13.5	-1.5
V226	21.0	20.5	0.5
V227	11.0	10.2	0.8
D392	23.5	21.8	1.7
D393	9.7	9.8	-0.1
D394	13.7	14.6	-0.9

	WATER TABLE (IN FEET)	
WELL NUMBER	MEASURED DEPTH BELOW LAND SURFACE	COMPUTED DEPTH BELOW LAND SURFACE
N290	7.0<WL< 12.5	9.4
N296	WL< 11.1	6.0
N299	10.0<WL< 12.9	12.4
N301	**	23.1
N302	0.2<WL< 1.5	0.1
N303	20.0<WL	26.2
N304	**	22.8
N308	**	21.5
N403	4.0<WL< 4.8	4.1
N404	4.0	3.4
N410	0.6	-0.2
N411	**	9.6
N425	**	1.2
N426	**	21.3
N427	**	7.4
V141	6.2	5.8
V143	**	20.4
V146	20.0<WL	22.7
V148	**	5.9
V176	13.0<WL< 15.7	13.5
V201	6.6<WL< 10.0	9.6
V202	20.2	19.5
V203	10.0<WL< 18.4	13.7
V204	4.2<WL< 12.0	8.4
V205	18.0<WL	18.9
V206	5.0<WL< 12.0	8.6
V207	3.0	4.9
V208	5.0<WL< 13.0	11.1
V209	12.5	11.6
V210	1.3	0.6
V211	8.5	8.5
V212	16.4	16.5
V213	21.0<WL	23.9
V214	4.3<WL< 5.0	3.1
V215	1.5<WL< 7.0	3.4
V222	7.0<WL< 10.0	8.3
V224	**	14.2
V225	**	12.6
V226	**	3.0
V227	**	8.9
D392	21.0<WL	22.7
D393	5.0<WL< 10.1	8.8
D394	10.0<WL	14.5

**No data available.

Table 3.—*Comparison of computed and observed water levels, fall of 1972*

[Well number: N, Natchitoches Parish; V, Red River Parish; D, De Soto Parish]

	POTENTIOMETRIC SURFACE (IN FEET)		
WELL NUMBER	MEASURED DEPTH BELOW LAND SURFACE	COMPUTED DEPTH BELOW LAND SURFACE	DIFFERENCE
N290	20.6	21.4	-0.8
N296	16.7	16.5	0.2
N299	20.3	18.7	1.6
N301	26.0	24.1	1.9
N302	29.1	29.6	-0.5
N303	33.1	35.8	-2.7
N304	26.0	25.8	0.2
N308	24.4	23.1	1.3
N403	13.8	13.7	0.1
N404	7.6	8.9	-1.3
N410	30.5	29.7	0.8
N411	26.2	25.7	0.5
N425	6.5	6.4	0.1
N426	23.1	23.5	-0.4
N427	19.9	19.3	0.6
V141	16.2	13.8	2.4
V143	23.1	21.4	1.7
V146	25.7	24.4	1.3
V148	17.8	18.2	-0.4
V176	21.5	23.0	-1.5
V201	23.3	23.0	0.3
V202	23.6	22.7	0.9
V203	38.2	38.1	0.1
V204	26.1	25.8	0.3
V205	20.2	21.4	-1.2
V206	15.8	15.5	0.3
V207	15.0	17.7	-2.7
V208	33.3	32.1	1.2
V209	19.7	18.9	0.8
V210	33.2	31.9	1.3
V211	23.1	21.8	1.3
V212	25.7	24.6	1.1
V213	36.4	34.5	1.9
V214	8.1	9.5	-1.4
V215	13.8	13.7	0.1
V222	17.2	15.2	2.0
V224	18.8	17.1	1.7
V225	15.2	16.8	-1.6
V226	29.3	28.2	1.1
V227	16.5	14.9	1.6
D392	25.5	26.3	-0.8
D393	15.4	15.1	0.3
D394	16.1	15.7	0.4

	WATER TABLE (IN FEET)	
WELL NUMBER	MEASURED DEPTH BELOW LAND SURFACE	COMPUTED DEPTH BELOW LAND SURFACE
N290	13.0<WL< 14.2	12.8
N296	11.1<WL< 15.5	13.1
N299	20.0<WL	18.6
N301	**	24.1
N302	20.0<WL	20.3
N303	20.0<WL	35.1
N304	**	25.4
N308	**	22.8
N403	8.0<WL< 13.6	12.3
N404	5.0<WL< 8.1	8.9
N410	5.0<WL< 10.6	10.4
N411	**	15.4
N425	**	5.9
N426	**	23.3
N427	**	18.4
V141	6.2<WL< 10.7	10.3
V143	**	21.4
V146	20.0<WL	24.3
V148	**	12.4
V176	20.0<WL	21.9
V201	14.0<WL< 20.1	16.7
V202	20.2<WL	20.5
V203	10.0<WL< 19.8	13.8
V204	12.5<WL< 15.7	12.6
V205	18.0<WL	20.6
V206	5.0<WL< 13.3	12.7
V207	5.0<WL< 9.2	8.0
V208	14.2<WL< 14.8	12.9
V209	13.0<WL< 14.9	15.4
V210	5.0<WL< 9.0	6.8
V211	21.0<WL	16.1
V212	20.0<WL	20.0
V213	21.0<WL	25.8
V214	8.8<WL< 15.0	9.9
V215	7.0<WL< 8.5	8.2
V222	13.0<WL< 14.4	13.4
V224	**	16.5
V225	**	15.6
V226	**	7.6
V227	**	13.0
D392	21.0<WL	25.3
D393	5.0<WL< 15.7	14.5
D394	10.0<WL	15.6

**No data available.

readings taken from the battery of shallow piezometers at a given location. At other sites the depth of the water table is shown as being greater or less than a given value.

STEADY-STATE ANALYSIS

The steady-state projections of the potentiometric surface were made by using modeling techniques originally developed for similar studies in the Arkansas River valley (Bedinger and others, 1970). These techniques originally were developed for use with analog models but were adapted in this study for use with digital models (Bedinger and others, 1973). The digital-model representation of the aquifer used 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. 4). 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.

The relation between evapotranspiration and depth to water uses the two values of vertical hydraulic conductivity as determined from the nonsteady-state model calibration. These two values represent the harmonic-mean saturated hydraulic conductivity of the material between land surface and the water table and between the water table and the potentiometric surface. The dimensionless evapotranspiration function, used in the nonsteady-state model, was multiplied by the upper hydraulic conductivity to obtain evapotranspiration values, in feet per day, for depths to the water table of as much as 30 ft (9.1 m) below land surface. A maximum value for evapotranspiration of 3 ft/yr (0.9 m/year) was used as a climatic limit. The head difference between the water table and the potentiometric surface was computed using the evapotranspiration rate and the hydraulic conductivity of the lower segment. The head difference was used to construct a curve of evapotranspiration versus depth to potentiometric surface. Chords were constructed on the curve representing the change in evapotranspiration from the present average depth to water to projected depths to water. From this relationship, a table of evapotranspiration as a function of depth to potentiometric surface was developed.

Preconstruction Potentiometric Surface

The average preconstruction potentiometric surface is the datum from which projections of postconstruction conditions were made. The elevation of the average preconstruction potentiometric surface in the Lock and Dam 4 area was determined from data collected from the joint Geological Survey-Soil Conservation Service observation-well network. The preconstruction potentiometric surface (pl. 1) was contoured manually using time-weighted averages of monthly water-level readings taken during the period January 1971 through December 1974.

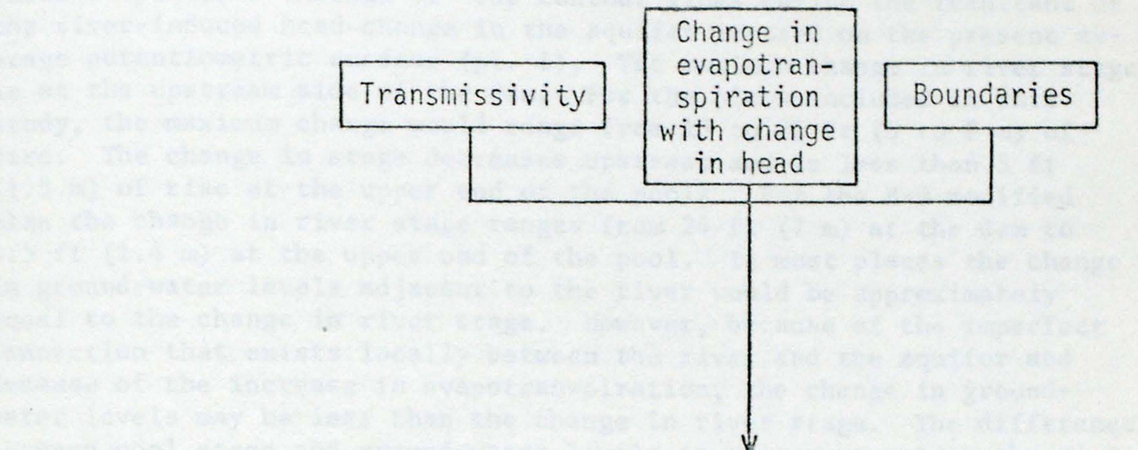


Figure 4.—Flow diagram of digital-model procedure for steady-state analysis.

Postconstruction Potentiometric Surface

The projected potentiometric surfaces for the plans analyzed are shown on plates 2 through 6. The contour lines define the resultant of the river-induced head change in the aquifer imposed on the present average potentiometric surface (pl. 1). The maximum change in river stage is at the upstream side of the dam. For the plans included in this study, the maximum change would range from 15 to 25 ft (5 to 8 m) of rise. The change in stage decreases upstream and is less than 5 ft (1.5 m) of rise at the upper end of the pools. For the B-3 modified plan the change in river stage ranges from 24 ft (7 m) at the dam to 4.5 ft (1.4 m) at the upper end of the pool. In most places the change in ground-water levels adjacent to the river would be approximately equal to the change in river stage. However, because of the imperfect connection that exists locally between the river and the aquifer and because of the increase in evapotranspiration, the change in ground-water levels may be less than the change in river stage. The difference between pool stage and ground-water levels is most apparent in the vicinity of the proposed damsites where the contours indicate a gradual slope of the potentiometric surface from the level of the upper pool to the lower pool. As a result, for a distance upstream from the damsite, the pool level would be above the average potentiometric surface, and the resultant hydraulic gradient would be from the river to the aquifer.

The induced change in ground-water levels would decrease with distance from the river because of the increased evapotranspiration and because of discharge to tributary streams, principally Bayou Pierre. The effect of the change in river stage would be greatest in the area between Red River and Bayou Pierre, but in some cases a permanent rise of 1 ft (0.3 m) or more in ground-water levels would extend more than 1 mi (1.6 km) beyond the bayou.

Comparison of the projected potentiometric surface for plans A and B-1, 2, and 3 with the land surface indicates that the potentiometric surface would be below land surface in most areas influenced by the increased river stage but would be at or near the land surface in low-lying areas between Red River and Bayou Pierre. Implementation of plans for a 120-foot (37-m) pool stage would obviously affect a larger area. The potentiometric surface would be above the land surface in isolated areas around cutoff lakes and along drainage channels near the river. In addition, a 120-foot (37-m) pool stage would cause the inundation of many low-lying areas on the inside of river meanders upstream from the proposed damsites.

Comparison of the projected potentiometric surface for the B-3 modified plan with land surface indicates that in addition to the areas described above, the potentiometric surface would be above the land surface in the low-lying area in the valley southeast of Campti and in areas near the mouth of Bayou Pierre. It was assumed in the analysis of the B-3 modified plan that in the lower end of Bayou Pierre, water would be diverted through a new channel and would enter the Red River downstream from the proposed damsite.

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 5. 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. Accretion was determined as stated previously in the discussion on modeling procedure. River-stage data for preconstruction and computed postconstruction conditions were developed by the Corps. The computations resulted in potentiometric and water-table elevations at all nodal points in the model for each time increment. The actual output from the analysis consisted of data, punched on computer cards, giving the computed depth of the water table below land surface at each node in the model for a specified series of calendar dates covering a period of 1 year. The dates were selected by the Soil Conservation Service to coincide with the planting, growing, harvesting, and dormant seasons. 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 edges of the model were treated as boundaries across which there was no flow. Because of this treatment, analytical errors occurred within the modeled areas at and near these boundaries. The errors diminished with distance from the boundaries but were considered to be significant within 3 mi (4.8 km) of the model boundaries. For this reason, nonsteady-state 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.

The nonsteady-state model used in this analysis uses average values 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 differences between computed and observed water levels locally.

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-surface elevations for all nodes in the model were obtained from topographic maps of the area, which have 5-foot (1.5-m) contour intervals. Land-surface elevations determined from topographic maps are considered to be accurate to one-half the contour interval.

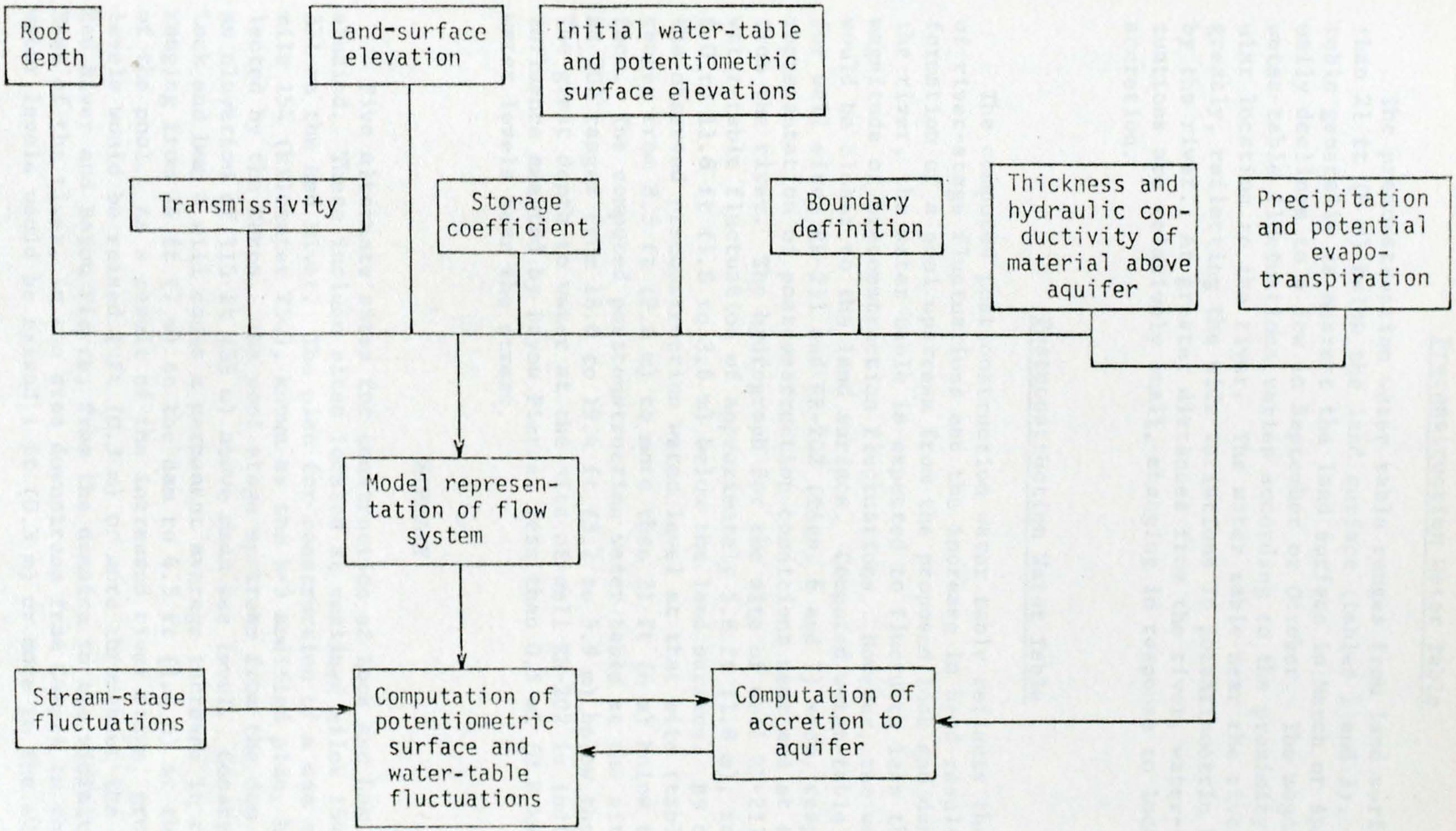


Figure 5.—Flow diagram of digital-model procedure for nonsteady-state analysis.

Preconstruction Water Table

The preconstruction water table ranges from land surface to more than 21 ft (6 m) below the land surface (tables 2 and 3). 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 relatively small, changing in response to local changes in accretion.

Postconstruction Water Table

The computed postconstruction water table reflects the attenuation of river-stage fluctuations and the 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 less than half the magnitude of preconstruction fluctuations. However, the water table would be closer to the land surface. Computed water-table hydrographs for well sites RR-211 and RR-202 (figs. 6 and 7) show, respectively, a representation of postconstruction conditions near and at a distance from the river. The hydrograph for the site of well RR-211 shows a water-table fluctuation of approximately 5.8 ft (1.8 m), ranging from 6.0 to 11.8 ft (1.8 to 3.6 m) below the land surface. By comparison, the observed preconstruction water level at that site (tables 2 and 3) ranges from 8.5 ft (2.6 m) to more than 21 ft (6 m) below the land surface. The computed postconstruction water table at the site of well RR-202 ranges from 18.6 to 19.4 ft (5.7 to 5.9 m) below the land surface. The great depth to water at the site of well RR-202 is indicative of the influence exerted by Bayou Pierre, less than 0.5 mi (0.8 km) west, on water levels near the stream.

SUMMARY

Five alternate sites for construction of Lock and Dam 4 were studied. These include sites located at realined miles 154, 161, and 171 on the Red River. The plan for construction of a dam at realined mile 154 (kilometer 250), known as the B-3 modified plan, has been selected by the Corps. The pool stage upstream from the dam is to be at an elevation of 115 ft (35 m) above mean sea level. Construction of Lock and Dam 4 will cause a permanent average increase in river stage ranging from 24 ft (7 m) at the dam to 4.5 ft (1.4 m) at the upper end of the pool. As a result of the increased river stage, ground-water levels would be raised 1 ft (0.3 m) or more throughout the area between Red River and Bayou Pierre, from the damsite to the vicinity of Coushatta. East of the river, in the area downstream from Campti to the damsite, water levels would be raised 1 ft (0.3 m) or more to the edge of the

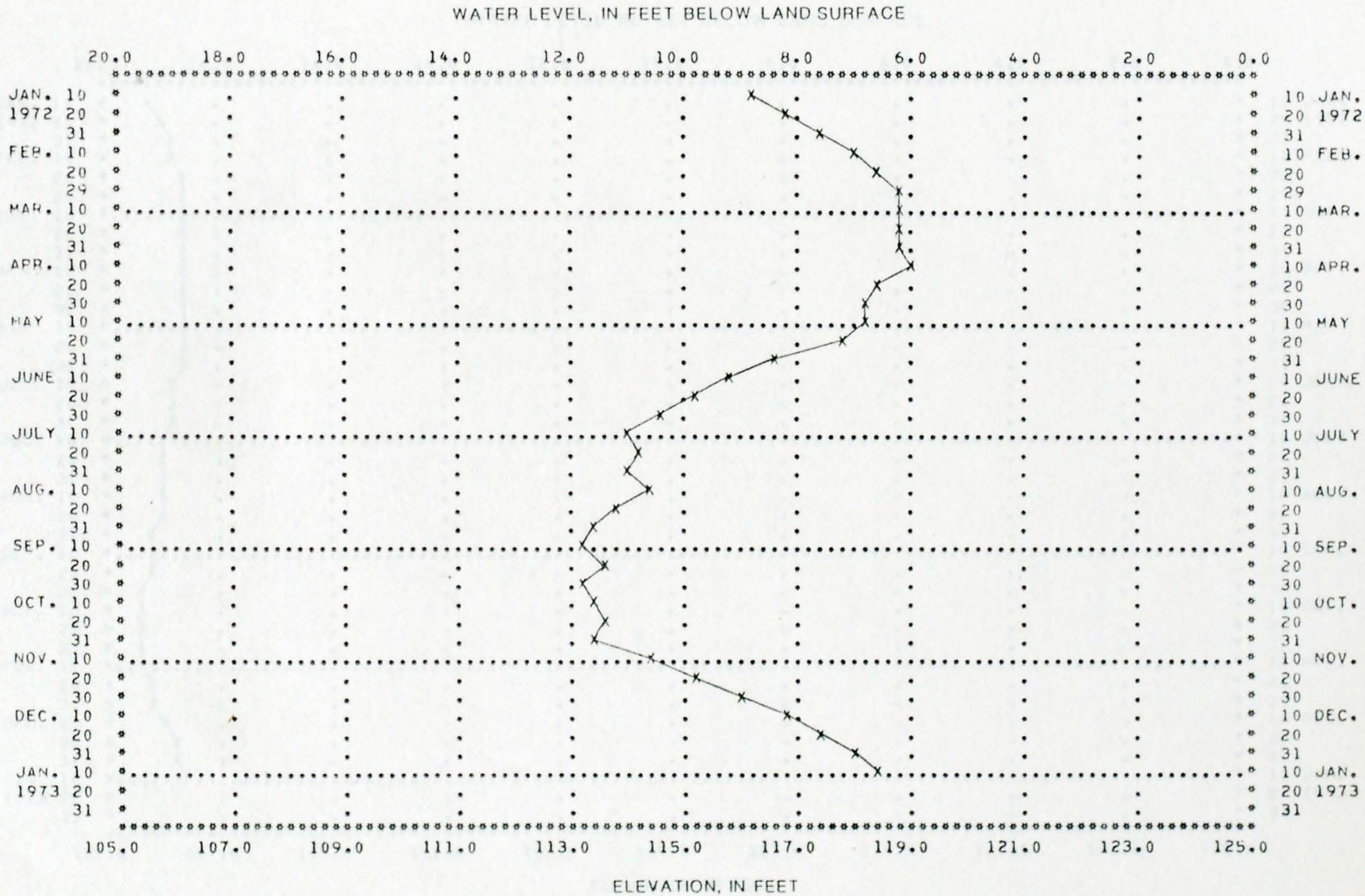


Figure 6.—Computed postconstruction water-table hydrograph, well RR-211.

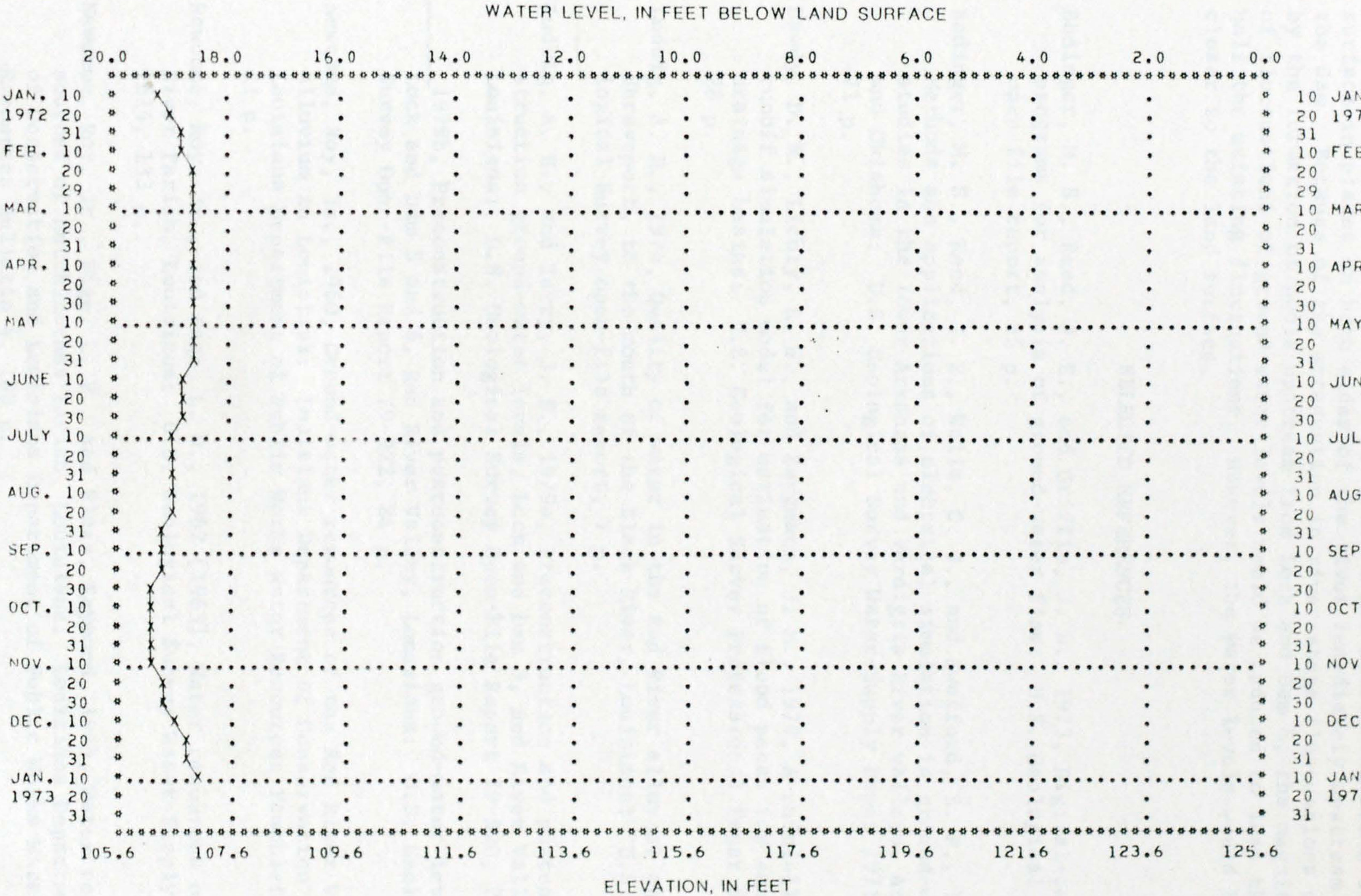


Figure 7.—Computed postconstruction water-table hydrograph, well RR-202.

valley. The potentiometric surface may be at or near the land surface in low-lying areas between Red River and Bayou Pierre and above land surface in places on both sides of the river immediately upstream from the dam. Because of the attenuation in river-stage fluctuations caused by the formation of pools upstream from Lock and Dam 4, the magnitude of fluctuations of ground-water levels would be reduced to less than half the existing fluctuations. However, the water levels would 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.

Dawdy, D. R., Lichty, R. W., and Bergmann, J. M., 1972, A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins: U.S. Geological Survey Professional Paper 506-B, 28 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.

Ludwig, A. H., and Terry, J. E., 1979a, 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.

______1979b, Preconstruction and postconstruction ground-water levels, Lock and Dam 5 and 6, Red River Valley, Louisiana: U.S. Geological Survey Open-File Report 79-922, 24 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 Page, L. V., 1962 [1963], Water resources of Red River Parish, Louisiana: U.S. Geological Survey Water-Supply Paper 1614, 133 p.

Newcome, Roy, Jr., Page, L. V., and Sloss, Raymond, 1963, Water resources of Natchitoches Parish, Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Bulletin 4, 189 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.

Ripple, C. D., Rubin, Jacob, and van Hylckama, T. E. A., 1972, Estimating steady-state evaporation rates from bare soils under conditions of high water table: U.S. Geological Survey Water-Supply Paper 2019-A, 39 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.

Thornthwaite, C. W., 1948, An approach toward a rational classification of climate: Geographical Review, January 1948, v. 38, p. 55-94.