AD-A099 337 GEOLOGICAL SURVEY BATON ROUGE LA WATER RESOURCES DIV F/G 8/8
METHODS AND APPLICATIONS OF DIGITAL-MODEL SIMULATION OF THE RED--ETC(U)
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METHODS AND APPLICATIONS OF DIGITAL-MODEL SIMULATION OF THE RED RIVER ALLUVIAL AQUIFER, SHREVEPORT TO THE MOUTH OF THE BLACK RIVER, LOUISIANA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 79-114

Prepared in cooperation with the

U.S. Army Corps of Engineers

and the

U.S. Soil Conservation Service

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. USGS/WRD/WRI-81/037 ✓

2.

3. Recipient's Accession No.

4. Title and Subtitle
METHODS AND APPLICATIONS OF DIGITAL-MODEL SIMULATION OF THE RED RIVER ALLUVIAL AQUIFER, SHREVEPORT TO THE MOUTH OF THE BLACK RIVER, LOUISIANA

5. Report Date
May 1980

6.

7. Author(s)
A. H. Ludwig and J. E. Terry

8. Performing Organization Rept. No.
USGS/WRI-79-114 ✓

9. Performing Organization Name and Address

U.S. Geological Survey, Water Resources Division
P.O. Box 66492
Baton Rouge, Louisiana 70896

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
U.S. Army Corps of Engineers
New Orleans District
P.O. Box 60267
New Orleans, Louisiana 70160

13. Type of Report & Period Covered
Final

14.

15. Supplementary Notes

Prepared in cooperation with the U.S. Army Corps of Engineers and the U.S. Soil Conservation Service

16. Abstract (Limit: 200 words)

The Red River Waterways Project provides for the construction of five locks and dams on the Red River from the Mississippi River to Shreveport, La. The methodology used by the U.S. Geological Survey in studying the effects of the navigation pools on the ground-water-flow regime involved digital modeling of steady- and nonsteady-state conditions. The steady-state model, GWFLOW, computes the head response in an aquifer due to various boundary conditions. The nonsteady-state model, SUPERMOCK, was designed to simulate transient stress and response in an alluvial-flow system.

In addition to the simulation models, several computer programs were developed during the study to aid in the preparation of field data for input to the models and in the calibration of the models. Calibration techniques unique to each of the models were developed for the investigation.

17. Document Analysis a. Descriptors

*Groundwater, *Aquifer characteristics, *Alluvial aquifers, Groundwater movement, Model studies.

b. Identifiers/Open-Ended Terms

*Red River Valley, Digital modeling.

Approved for public release; distribution unlimited.

18. Availability Statement

Release unlimited

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
110

22. Price

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

METHODS AND APPLICATIONS OF DIGITAL-MODEL SIMULATION OF THE RED RIVER ALLUVIAL AQUIFER, SHREVEPORT TO THE MOUTH OF THE BLACK RIVER, LOUISIANA.

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9) Final repts. 12) 112

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11) May 80

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14 /WRD/ I- 79

I 79-114

U.S. DEPARTMENT OF THE INTERIOR

MARCH 3, 1849

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May 1980

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to

U.S. Geological Survey
P.O. Box 66492
Baton Rouge, Louisiana 70896

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

A dual system of measurements--inch-pound units and the International System (SI) of metric units--is given in this report. SI is a consistent system of units adopted by the Eleventh General Conference of Weights and Measures in 1960. The conversion factors for terms used in this report are as follows:

Multiply inch-pound unit	By	To obtain SI unit
acre	4,047	square meter (m^2)
inch (in.)	25.40	millimeter (mm)
inch per day (in/d)	25.40	millimeter per day (mm/d)
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)

METHODS AND APPLICATIONS OF DIGITAL-MODEL SIMULATION OF THE RED RIVER ALLUVIAL AQUIFER, SHREVEPORT TO THE MOUTH OF THE BLACK RIVER, LOUISIANA

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

ABSTRACT

The Red River Waterways Project of the U.S. Army Corps of Engineers provides for the construction of a series of locks and dams on the Red River from the Mississippi River to Shreveport, La. The locks and dams will cause a permanent rise in the level of the river, creating changes in the ground-water flow system. The U.S. Geological Survey, in cooperation with the Corps and the U.S. Soil Conservation Service, began an investigation in 1968 to study the effects of the planned navigation pools on the ground-water flow regime.

The Red River downstream from Shreveport flows through an alluvial valley that ranges from 2 to 12 miles (3.2 to 19 kilometers) in width. Along the thalweg of the valley, the alluvium ranges from 75 to 200 feet (23 to 61 meters) in thickness and is composed of a silt and clay layer, underlain by a coarse sand and gravel aquifer. The aquifer is hydraulically connected in varying degrees to the Red River and its major tributaries.

The methods used in the investigation involved digital modeling of steady- and nonsteady-state conditions. The nonsteady-state model, utilizing a program called SUPERMOCK, was designed to simulate transient stress and response in a ground-water flow system that includes a water table in a confining layer above an artesian aquifer. The steady-state model, utilizing a program called GWFLOW, computes the head response in an aquifer due to various boundary conditions.

Principal data requirements for the models include climatic data, definition of the hydraulic characteristics of the upper confining layer and aquifer, water-table levels in the upper confining layer and potentiometric levels in the aquifer, and stream-stage data for the Red River and its tributaries.

In addition to the simulation models, several computer programs were developed to aid in preparation of data and in the calibration of the models. The programs were designed to compute the harmonic-mean water level at each observation well (AVERAGE), compute the harmonic-mean conductivity for layered

materials and the potential upward movement of water due to evapotranspiration at the land surface (ATMOFLUX), compute daily evapotranspiration (POTEET), provide main-stem and tributary stream-stage data sets for the nonsteady-state model (RIVCHANGE and TRIBCHANGE), and to compute the change in the rate of evapotranspiration due to a change in protentiometric head (DELETDELH).

Calibration techniques unique to each of the models were developed for the investigation. The calibration procedure for the nonsteady-state model involved reproducing, by manipulation of model parameters within plausible limits, observed water-table and potentiometric levels while maintaining reasonable limits on the rate of accretion to the aquifer.

INTRODUCTION

Background of the Investigation

The Red River Waterways Project of the U.S. Army Corps of Engineers was authorized by the 90th Congress in the Rivers and Harbors Act of 1958. Project plans include a 9- by 200-foot (2.7- by 61-m) navigation channel, beginning at the confluence of the Red and Mississippi Rivers and winding northwestward along the present course of the Red River to Shreveport, La. From Shreveport the channel will follow Twelvemile and Cypress Bayous to a point in Lake O' the Pines Reservoir near Daingerfield, Tex. (fig. 1). A series of eight locks and dams will be required to provide the navigation depths and the necessary 225-foot (69-m) lift from the Mississippi River to the head of navigation.

The natural ground-water flow system in the Red River alluvial valley will be altered by the formation of navigation pools except at locks 7 and 9, which are to be built into existing dams on Caddo Lake and Lake O' the Pines. Predominant effects of the navigation pools on the ground-water regime will be a rise in water levels and changes in the ground-water flow pattern. In April 1963, at the request of the Corps of Engineers, the U.S. Geological Survey began a preliminary study of the preconstruction and postconstruction ground-water conditions. The study characterized, using available data, the existing ground-water conditions in the valley and provided steady-state projections of the effects of proposed navigation structures on ground-water levels. The projections were made with the aid of an analog model.

In 1968 the Corps requested that the Geological Survey refine the projections made in the earlier study and that a continuing ground-water data-collection program in the Red River Valley be established. The study area was the alluvial valley from the confluence of the Red and Black Rivers to Shreveport, La., a distance of 241 river miles or 388 km (fig. 2). The Corps of Engineers considered several arrangements of either five or six locks and dams within this reach of the river. An arrangement of five locks and dams, known as the B-3 modified plan, was considered the most feasible plan of construction.

The effects of increased river stages, caused by the formation of navigation pools, on the ground-water regime were projected for steady- and nonsteady-

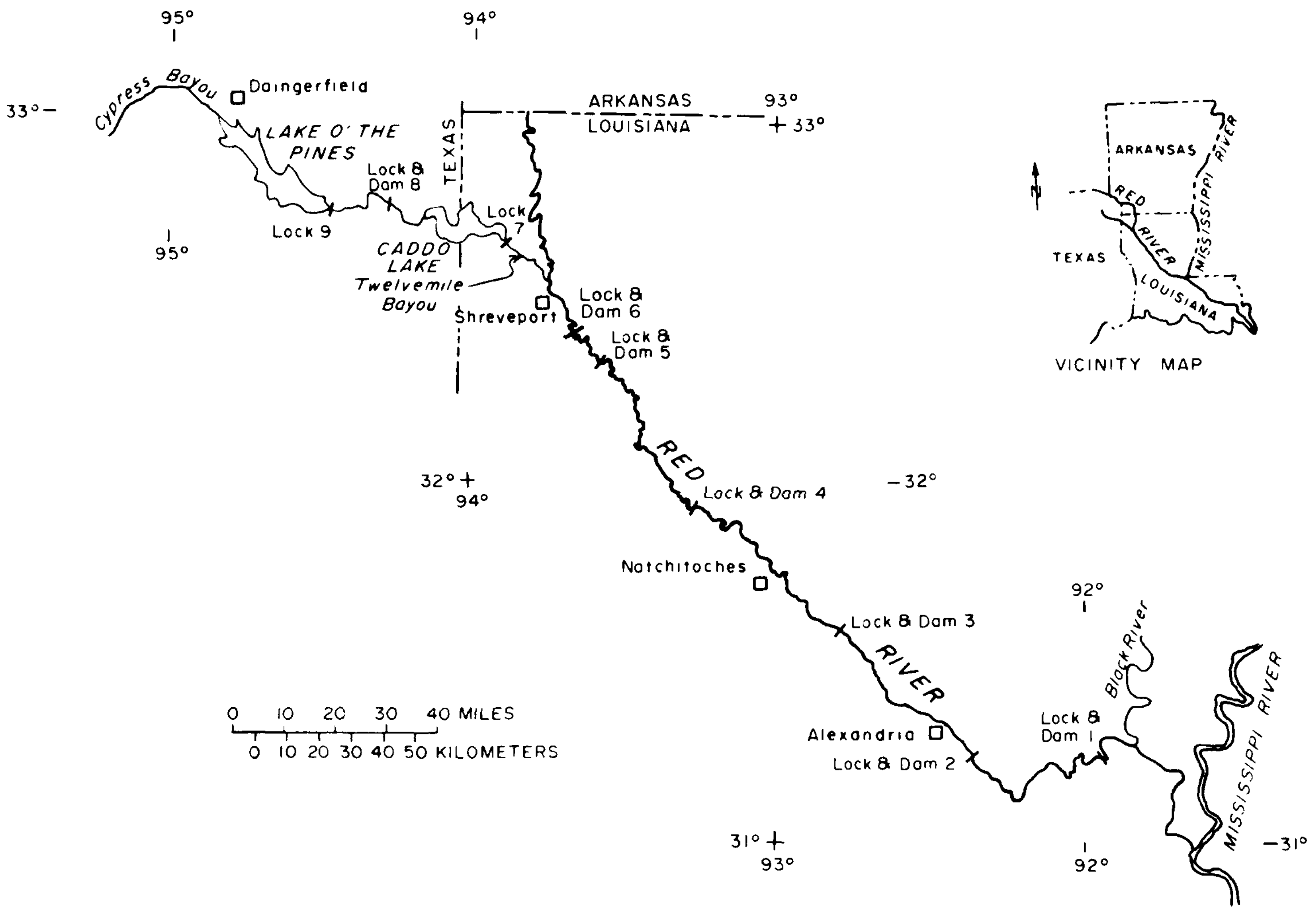


Figure 1.--Planned navigation features, Red River Waterways Project.

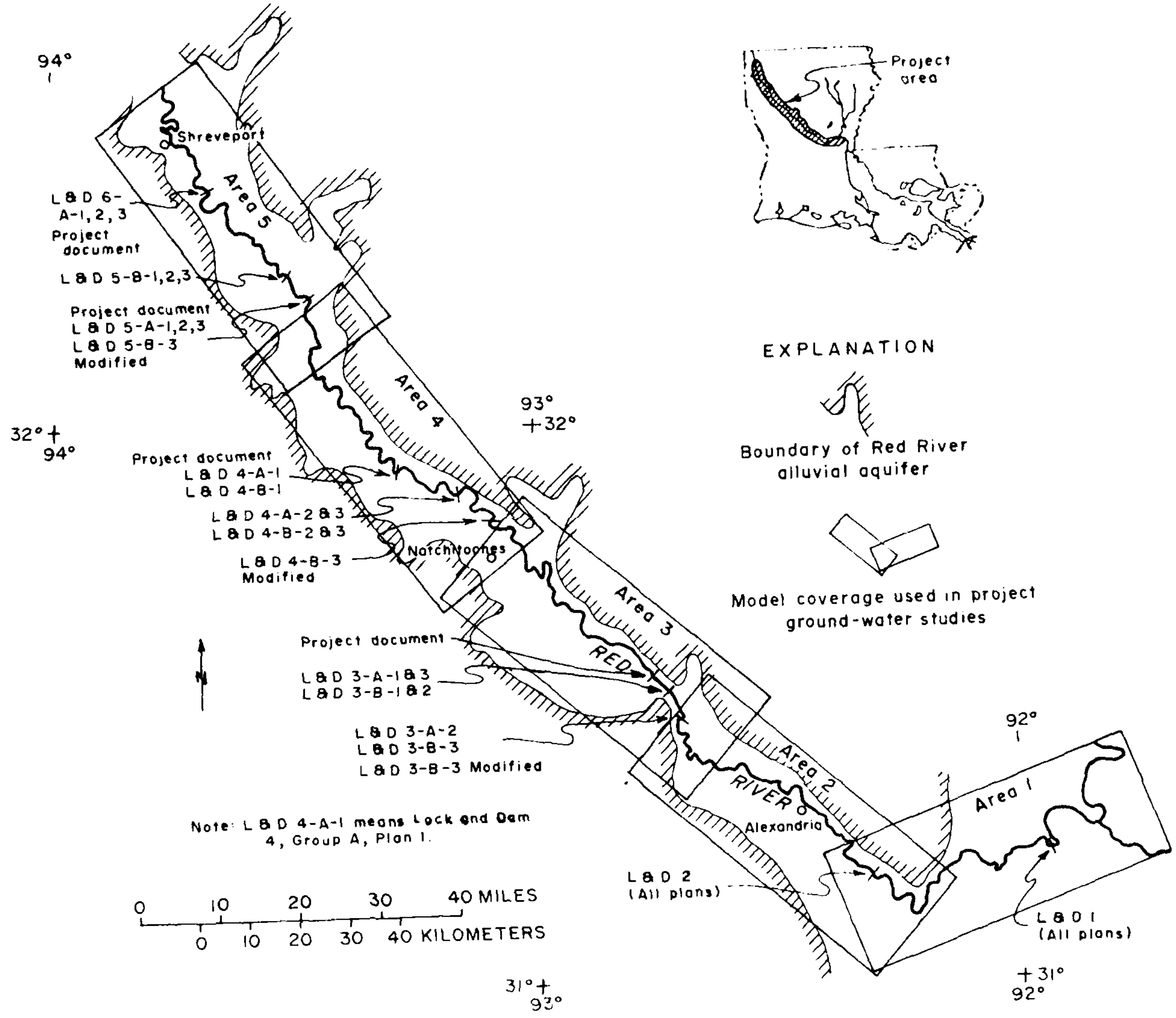


Figure 2.--Location of project area and model coverage

state conditions. The steady-state change in potentiometric surface was projected from the average postconstruction river stages. Nonsteady-state projections, used to determine the effect of the project on agriculture, were made for specific periods within a typical calendar year. Because of the size of the project area and the complexity of the flow regime, digital-modeling techniques were used.

Results of the steady- and nonsteady-state analyses for each of the five lock-and-dam areas were provided to the Corps of Engineers, 1975-76, in a series of five administrative reports that were later released to the open file (Ludwig, 1979a, b; Ludwig and Reed, 1979; Ludwig and Terry, 1979a, b). Average depths to the water table for specific periods of interest were prepared for the U.S. Soil Conservation Service on punched IBM computer cards. Basic-data reports containing ground-water quality analyses (Ludwig, 1974) and ground-water levels through June 1975 (Stephens, 1976) were published as open-file reports.

Purpose and Scope

The purpose of this report is to describe the methods used in the study and to show their application to the Red River Waterways Project. The discussion is intended to be sufficiently detailed that the reader can obtain a basic understanding of the methodology employed in the study. The discussion covers (1) development and management of the basic-data network and the types of data collected, (2) conceptualization of the geohydrology of the study area, (3) descriptions of predictive models used and data requirements of the models, (4) presentation of peripheral digital-computer programs used to generate or manipulate data for use in the models, (5) calibration of the models, (6) descriptions of output from the models, and (7) possible utilization of the calibrated Red River models for other uses. Examples of program input and output (taken from analyses of Lock and Dam 3 area) are shown.

DATA COLLECTION

The objective of the data-collection program for the Red River study was to obtain the data necessary for the determination of the hydrologic characterics of the flow regime in the Red River alluvium and the climatic factors and agricultural practices which affect it. To accomplish these objectives, work activities were divided among the participating agencies as follows: The Geological Survey mapped the principal hydrologic boundaries, inventoried existing wells suitable for periodic measurements, drilled test holes and installed observation wells, analyzed samples of alluvial material for hydraulic conductivity and grain size, installed and operated a series of surface-water gages on tributary streams, and analyzed ground-water samples from selected wells for chemical constituents. The U.S. Soil Conservation Service installed shallow piezometers at observation-well sites, monitored crop-observation plots to establish the relationship between yield and soil-moisture conditions, mapped soil profiles, inventoried land-use practices, and measured water levels in the network of Geological Survey and Soil Conservation Service observation wells and piezometers. The Corps of Engineers provided average preconstruction and postconstruction stage profiles of the Red River to be used in developing input to the steady-state model. The Corps also provided time-variant preconstruction and postconstruction stage data in the form of 5-day averages at 2-mile (3.2-km) increments for the period December 1967 to September 1973 for the entire reach of the Red River in the project area.

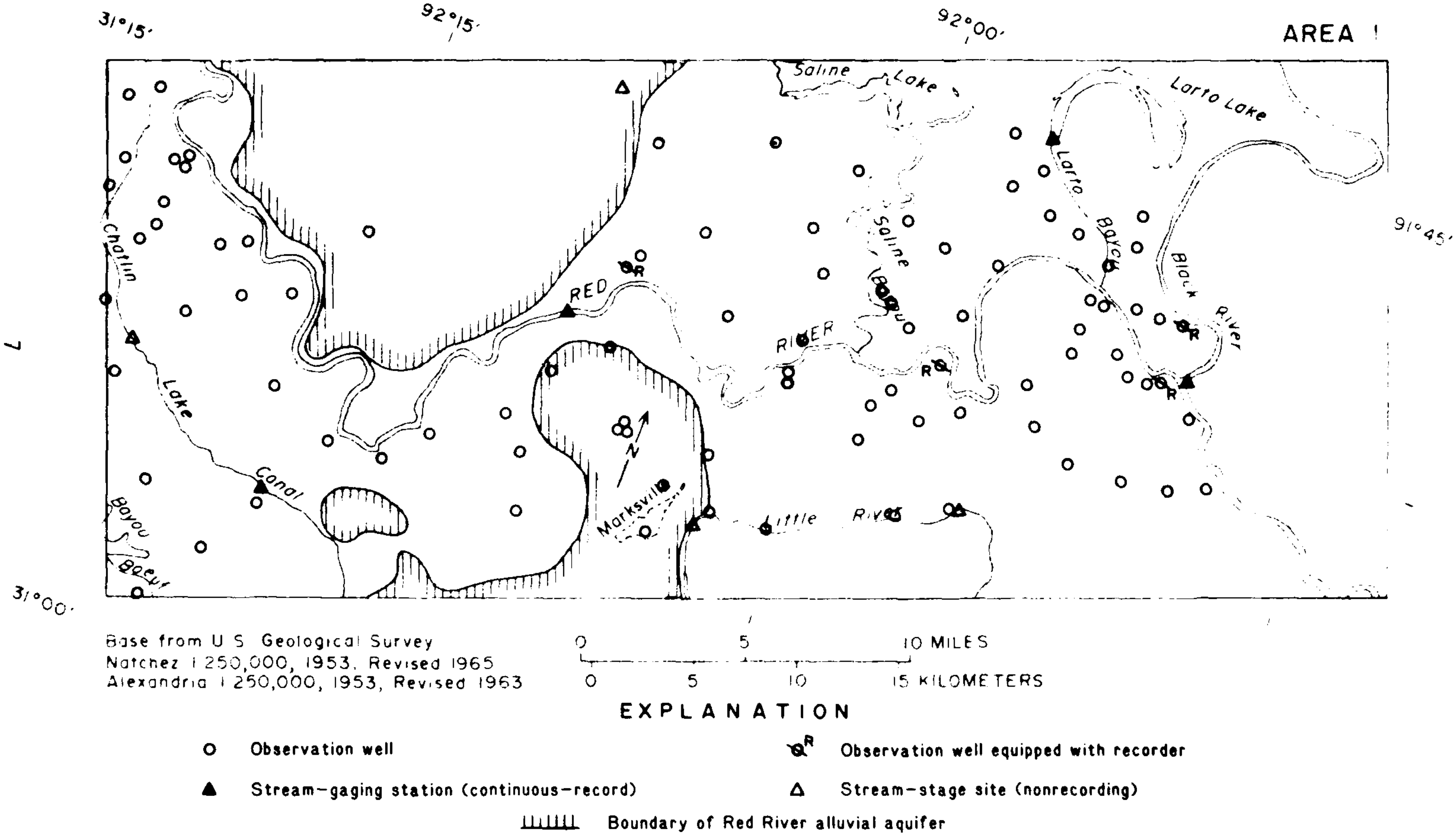
The test-drilling program conducted by the Geological Survey was completed during a series of field sessions from 1968 to 1971. Approximately 350 test holes were drilled in the valley, from Shreveport to the mouth of the Black River. Test holes were drilled with solid-stem power-auger drilling equipment, and soil samples were collected at selected depths for analyses of hydraulic conductivity and particle-size distribution. Most of the test holes were drilled and logged through the entire alluvial section and into the underlying Tertiary bedrock. The test holes were cased with 1¼-inch (32-mm) galvanized-iron pipe and screened with 3-foot (0.9-m), 60-gage well screens. The screens were set opposite coarse sand and gravel at depths ranging from 20 to 140 ft (6 to 43 m) below the land surface. The locations of the observation wells are shown in figures 3A-E.

In the vicinity of the proposed construction sites and along the river, the wells are more closely spaced in anticipation of greater variations in water levels in these areas. At greater distances from the river, fewer wells are required. The amount of pumpage from the alluvium is small; therefore, where little change was expected, the data from a particular well could be extrapolated over a relatively large area. The density of wells ranged from one well per square mile (2.6 km^2) in the vicinity of the locks and dams to about one well per 3 mi^2 (7.8 km^2) elsewhere in the valley.

Shallow piezometers were placed adjacent to most of the observation wells to obtain data on the position of the water table in the upper confining layer. The piezometers consisted of lengths of 3/4-inch (19-mm) galvanized-iron pipe, driven into the ground to selected depths ranging from 1 to 20 ft (0.3 to 6.1 m) below the land surface. The lower end of the pipe was left open to the soil to allow movement of water into and out of the pipe. Two to five piezometers were installed at each observation-well location, depending on the variations in lithology in the upper section.

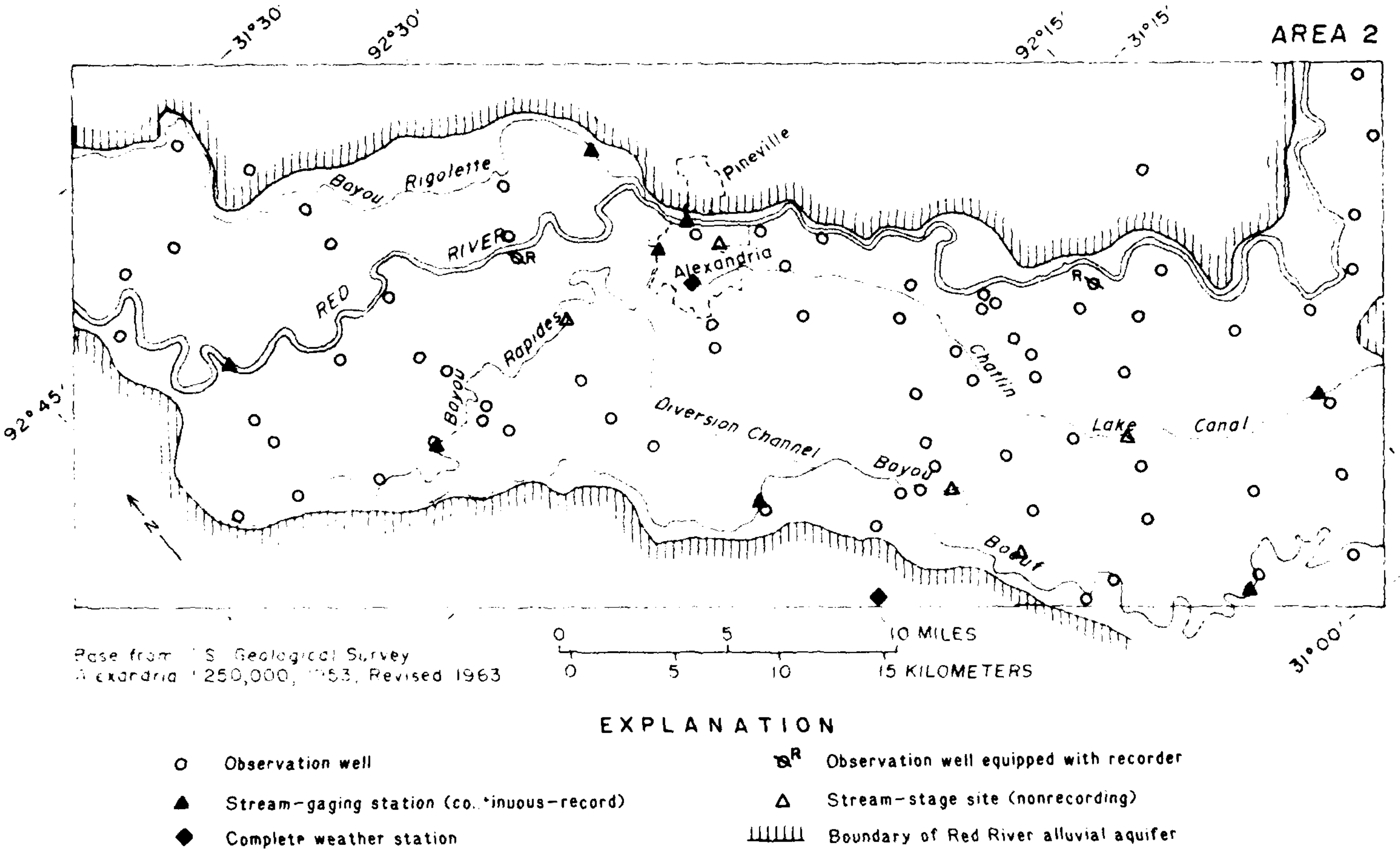
Water-level measurements in all observation wells and piezometer tubes were made monthly by Soil Conservation Service personnel. Digital recorders were installed on 16 wells in the study area. Fourteen of the wells were near the Red River to provide daily water-level data for the computation of aquifer diffusivity. In addition, water samples were collected from all of the observation wells at the time of installation and from many piezometer tubes and analyzed for chemical quality.

Stream-stage data were collected from a network of 45 continuous recorders, staff gages, and wire-weight gages (figs. 3A-E). Most of the gages were part of the regular surface-water data-collection network operated by the Geological Survey and the Corps of Engineers. However, 14 additional gages were installed at intervals along tributary streams between existing recording gages and on



Base from U.S. Geological Survey
Natchez 1:250,000, 1953, Revised 1965
Alexandria 1:250,000, 1953, Revised 1963

Figure 3A.--Data-collection network, Lock and Dam 1 area.



Base from U.S. Geological Survey
Alexandria 1:250,000, 1953, Revised 1963

Figure 3B.--Data-collection network, *Lock and Dam 2 area*

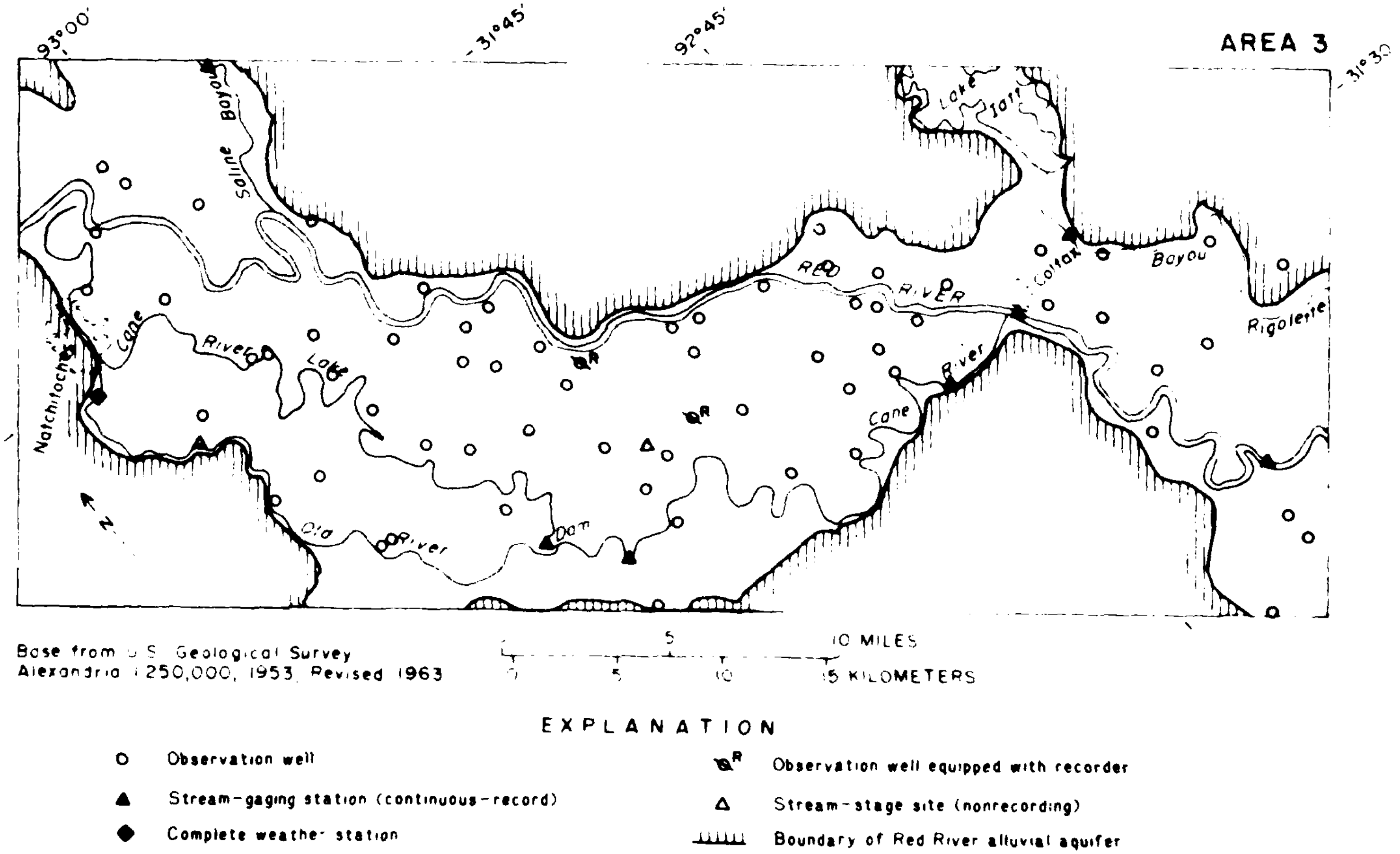


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Figure 3C. Data-collection network, Lock and Dam 3 area

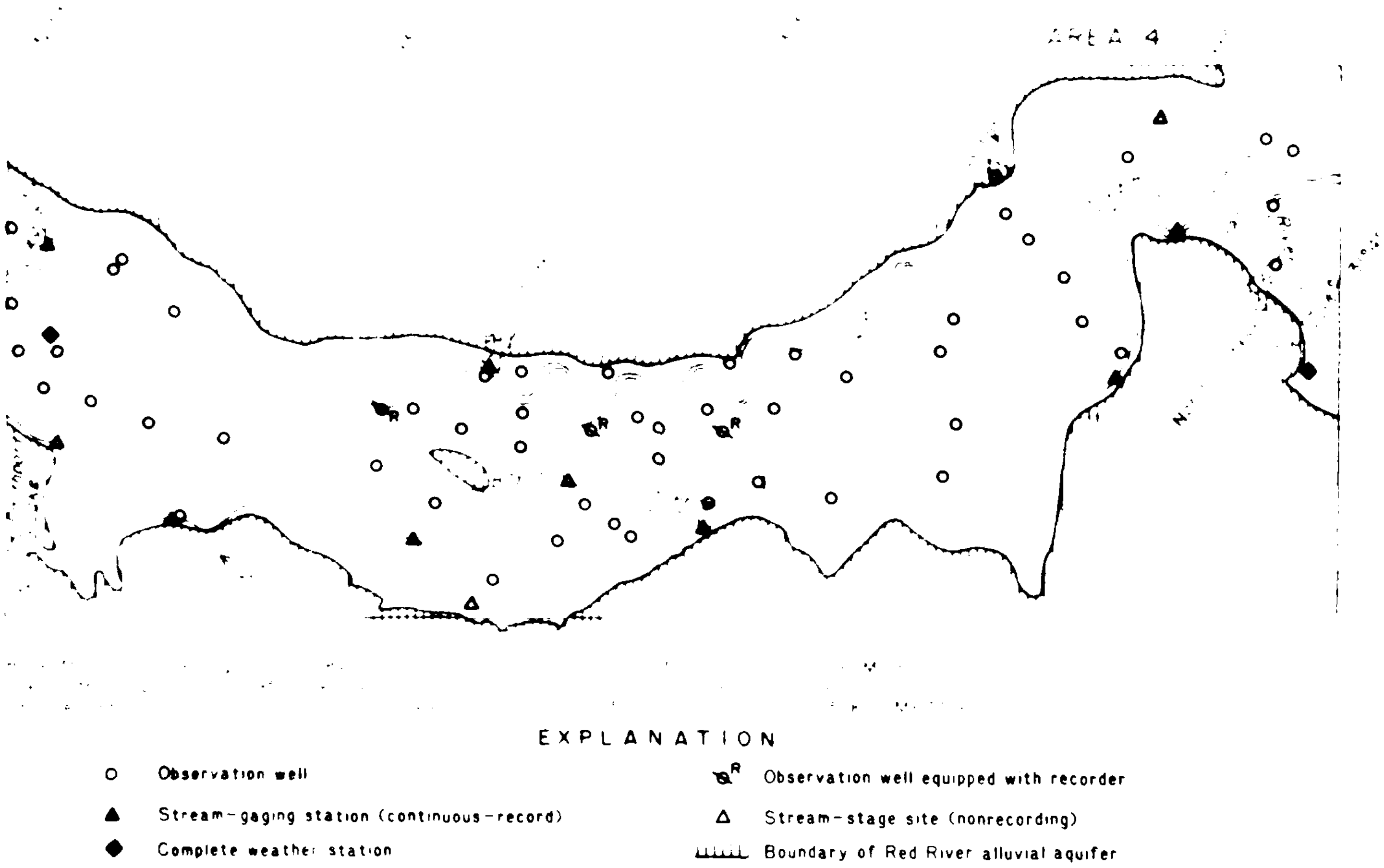


Figure 3D.—Data collection network, Lock and Dam 4 area

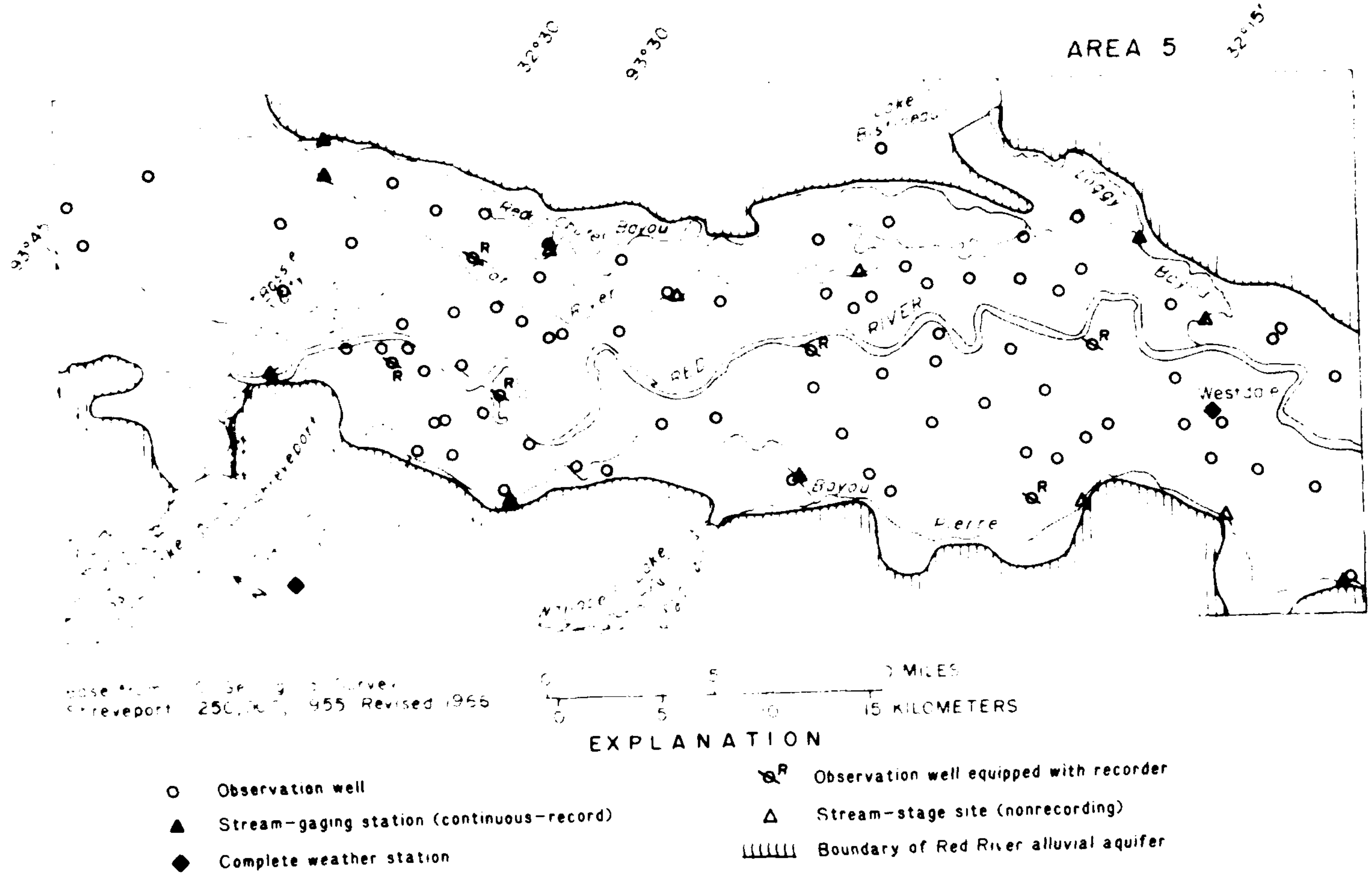


Figure 3E --Data-collection network, Lock and Dam 5 area lakes in the valley. These gages provide supplementary data for the determination of stream profiles. Climatic data, including maximum and minimum daily temperature and daily precipitation, were obtained from five National Weather Service stations in and near the valley (figs. 3A-E).

MODELING THE HYDROLOGIC SYSTEM

Conceptual Model

The Red River flows southeastward through central and northwestern Louisiana. From Shreveport to the vicinity of Marksville, the river is confined in a valley ranging from 2 to 12 mi (3.2 to 19 km) in width. The uplands bordering the valley rise as much as 150 ft (46 m) above the general level of the valley. Downstream from Marksville, the Red River Valley and the Mississippi River valley merge to form the broad Mississippi River alluvial plain. The flood plain is characterized by very low relief, meandering stream courses, oxbow lakes, and other alluvial features. The dominant features are natural levees, which form the topographic highs, and backswamps, which are the topographic lows. The natural levees rise from 10 to 20 ft (3 to 6 m) above the adjoining backswamps. Natural levees occur along abandoned channels of the Red River and on tributary streams, as well as along the present course of the river.

Elevations in the valley range from 40 ft (12.2 m) above mean sea level (now generally referred to as National Geodetic Vertical Datum of 1929), near the confluence of the Red and Black Rivers, to 170 ft (52 m) above sea level, at Shreveport.

The average annual precipitation in the valley ranges from 57 in. (1,448 mm), at Alexandria, to 43 in. (1,092 mm), at Shreveport. The greatest precipitation generally occurs in April and May, and the least in September and October. The climate of the area is classified as humid; that is, precipitation equals or exceeds potential evapotranspiration. Favorable climatic conditions and rich soil support abundant vegetal growth. In general, row crops, principally cotton and soybeans, are grown on the natural levees. The lower levels of the natural levees are used mainly for pasture or soybeans, and the backswamp areas are mostly forested.

Formations of Tertiary age underlie the valley alluvium and crop out along the valley walls. The beds are composed primarily of clay, but locally they contain sand lenses. The beds form a nearly impermeable boundary to the alluvial aquifer. In many places, Pleistocene terrace deposits overlie the Tertiary deposits in the upland. The terrace deposits, which are remnants of older and higher flood plains of the Red River, are most prevalent in the lower end of the valley, where they are as much as 200 ft (61 m) thick. The Marksville Prairie is a terrace remnant in the Red River flood plain. The terrace deposits are composed of a heterogeneous sequence of sand, silt, and clay. Gravel layers occur in the terrace deposits and locally are the source of large quantities of water.

The alluvium in the valley generally ranges from about 75 ft (23 m) in thickness, in the upper end of the area, to about 200 ft (61 m), downstream from Marksville. The alluvium can be divided into two segments: a lower unit or aquifer, which is composed of coarse sand and gravel grading upward to fine sand, and an upper confining layer, which is composed of clay, silt, and fine sand. The upper confining layer averages about 30 ft (9.1 m) in thickness and ranges from a few feet to 140 ft (43 m). The aquifer ranges from 5 ft (1.5 m) in thickness beneath some channel-fill and backswamp deposits to 150 ft (46 m) in the lower end of the valley. The thicknesses of the two segments vary from place to place. Differences of as much as 100 ft (30 m) in the thickness of the upper confining layer within short distances have been noted in Lock and Dam 1 area. To a lesser extent, variations in thickness occur at many places in the valley, primarily as the result of fine-grained deposition in former channels of the Red River.

Throughout the Red River Valley, the Red River and its major tributaries are hydraulically connected in varying degrees to the Red River alluvial aquifer. Therefore, changes in stream stages resulting from the construction of the proposed locks and dams would induce similar changes in the potentiometric surface of the aquifer. The potentiometric surface refers to the level to which water will rise in wells tapping the aquifer. Also, throughout the Red River Valley a water table exists as the upper surface of the zone of saturation in the fine-grained material above the aquifer. The altitude of the water table at any point is a function of the transient flow through the fine-grained material above the aquifer and the transient head in the aquifer. Therefore, induced changes in the position of the potentiometric surface would indirectly cause changes in the position of the water table.

Rainfall on the flood plain is the primary source of recharge for the alluvial aquifer. Moisture reaches the aquifer indirectly by infiltrating the fine-grained material in the confining layer above the aquifer. An unknown, but probably very small, amount of recharge is derived from the formations of Tertiary age that underlie and flank the valley. Most of the water moving downgradient through the terrace deposits is discharged into the tributary streams that flow along the margin of the valley.

Water levels in most wells tapping the aquifer rise above the base of the fine-grained material overlying the aquifer, an indication that the water is under confined or semiconfined conditions. A zone of saturation in the upper fine-grained material, extending from near the land surface down to the aquifer, indicates the presence of water-table conditions. These two conditions exist simultaneously because of the great difference in hydraulic conductivity between the fine-grained material overlying the aquifer and the aquifer itself. The position of the water table may be either above or below the potentiometric level in the aquifer, as reflected by the direction of the resultant vertical flow in the fine-grained material between the water table and the top of the aquifer. Accretion, as defined by Stallman (1956), is the rate at which water is gained or lost through the aquifer surface in response to precipitation and 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.

The natural movement of water in the alluvium is toward discharge points along the Red River and its tributaries in the valley. Because pumpage of water from wells is not significant, water levels in the alluvium fluctuate in response to seasonal variations in precipitation, evapotranspiration, and to changes in river stage.

The recharge, movement, and discharge of water from the alluvial aquifer are shown graphically in the idealized section in figure 4. The direction of water movement, indicated by arrows, shows that the aquifer is being recharged in zone 1 where the gradient is downward through the clay and silt. 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 times. Seasonal weather changes, changes in river stage, and pumping may cause variations in the magnitude and direction of water movement in the aquifer.

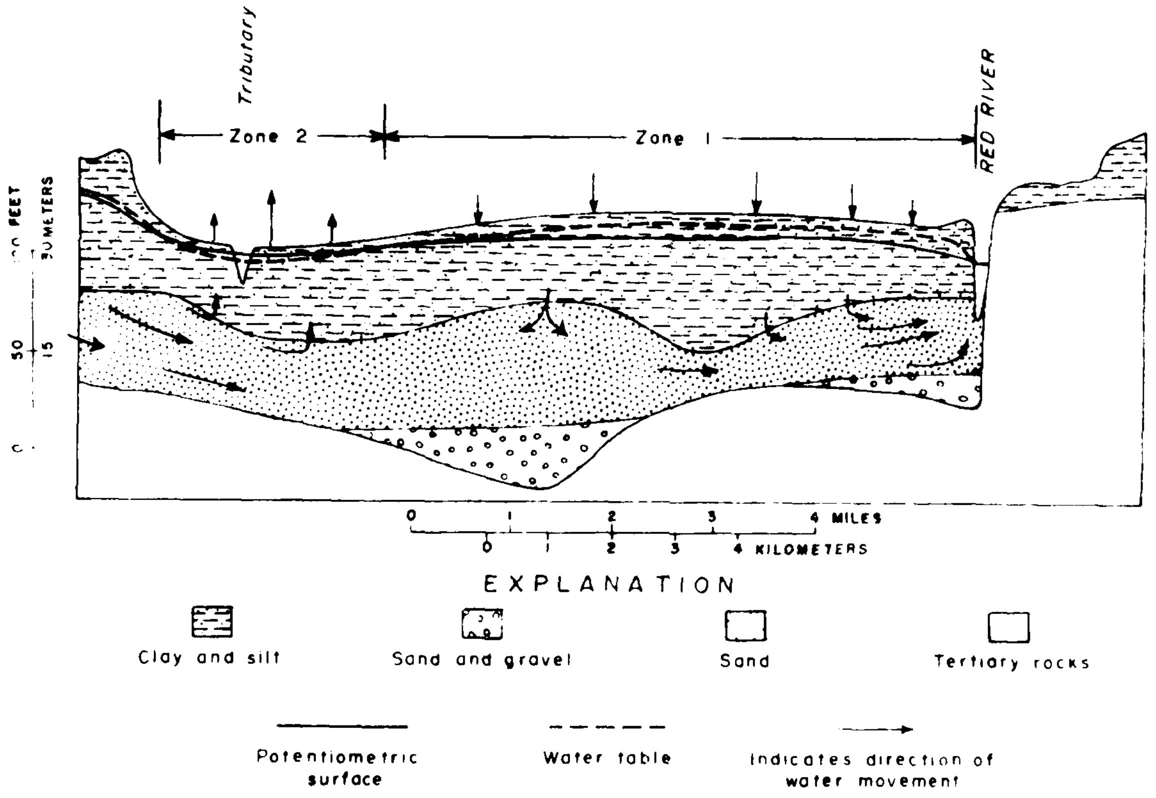


Figure 4.--Idealized hydrogeologic section of the Red River Valley

Digital Model

Two types of digital models were used in the analyses. A steady-state model, GWFLOW (Bedinger and others, 1973), was used to provide projections of changes in the potentiometric surface. A nonsteady-state model, SUPERMOCK (Reed and others, 1976), was used to simulate fluctuations of the head in the aquifer and the water table. For purposes of analysis, the project area was divided into five overlapping model areas. Each area contained one or more of the proposed lock-and-dam construction sites. These areas are identified by referring to a particular lock-and-dam area (fig. 2). To aid the Corps of Engineers in determining the best arrangement of locks and dams, steady-state analyses were run for all alternate plans, including the B-3 modified plan. Specifications for dam locations and pool elevations for the plans considered are shown in table 1. The nonsteady-state model was used to make projections for the B-3 modified plan only.

The framework for the digital models consisted of a rectangular grid of 34 rows and 80 columns superimposed on a map of the area having a scale of 1:62,500. The spacing between each intersection (node) in the grid represented a distance of 0.5 mi (0.8 km). Thus, each model represented a 17- by 40-mile (27- by 64-km) area. Five such models were used, each representing a lock-and-dam area, to cover the 190-mile (306-km) reach of navigation channel in the study area (figs. 2, 3A-E).

The examples used in this report to illustrate the various model inputs and outputs are taken from the analysis of Lock and Dam 3 area. The tables and alphameric maps employed are representations of the modeled area; each symbol or figure represents a value for a grid node (which represents an area 0.5 by 0.5 mi, or 0.8 by 0.8 km).

To provide for continuity in modeling the entire navigation reach, the models were designed to include an area of overlap on the adjacent model. Adjacent models were overlapped a minimum distance equivalent to 6 mi (9.7 km). This overlap aided in the identification of errors associated with model boundary conditions and enabled the preparation of a complete suite of data for the navigation reach. As the models for adjacent areas were analyzed, the data developed for areas common to each model were examined and compared to determine the extent of boundary effects. Model boundaries parallel to the river were placed at a distance far enough from the river so that the effects of river-induced water-level changes would not extend to the boundaries.

Nonsteady State

Nonsteady-state analyses for the investigation were made by using three digital programs called SUPERMOCK, DATE, and HYDROG (Reed and others, 1976), which were developed particularly for this study. SUPERMOCK was designed to simulate transient stress and response in a ground-water flow system that includes a water table in the confining layer above an artesian aquifer. The model incorporates all the components of stress in the flow field. SUPERMOCK models three component layers: a soil-moisture-accounting component, a vertical-flow component, and a horizontal-flow component (fig. 5). DATE assigns calendar

Table 1.--Specifications for lock and dam arrangements studied in the investigation

Plan designation	Lock and dam number	River mile (1967 mileage)	Pool elevation (feet above mean sea level)
Project document	1	44	40
	2	87	60
	3	152	95
	4	206	115
	5	243	135
	6	270	150
Group A, plan 1	1	44	40
	2	87	65
	3	145	95
	4	206	115
	5	243	135
	6	270	150
Group A, plan 2,	1	44	40
	2	87	60
	3	137	90
	4	195	115
	5	243	135
	6	270	150
Group A, plan 3	1	44	40
	2	87	65
	3	145	90
	4	195	115
	5	243	135
	6	270	150
Group B, plan 1	1	44	40
	2	87	65
	3	145	95
	4	206	120
	5	250	145
Group B, plan 2	1	44	40
	2	87	65
	3	145	90
	4	195	120
	5	250	145
Group B, plan 3	1	44	40
	2	87	60
	3	137	90
	4	195	120
	5	250	145
Group B, plan 3 modified	1	44	40
	2	87	58
	3	137	87
	4	185	115
	5	243	145

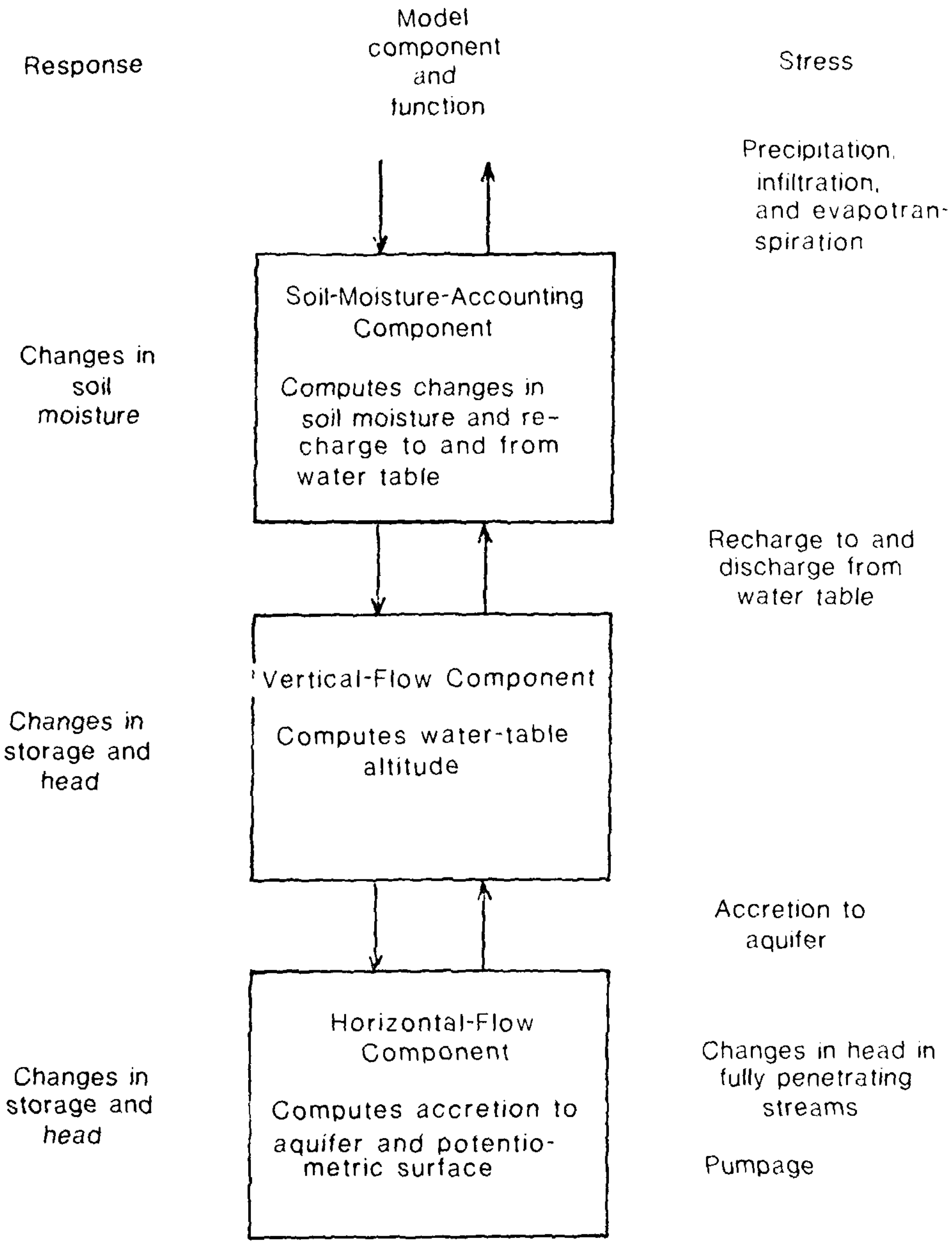


Figure 5.--Relation between soil-moisture-accounting, vertical-flow, and horizontal-flow components of SUPERMOCK program. (From Reed and others, 1976.)

dates to data computed at observation nodes in SUPERMOCK and, for calibration, makes comparisons between computed potentiometric and water-table levels from SUPERMOCK and observed field values. HYDROG produces hydrographs using output from DATE. The use of output from DATE and HYDROG is discussed later in this report under "Calibration of Models."

For ease in parameter modification and for adequate modeling control, [illegible] data components are read into the model by discrete subareas, each containing one observation well at which control data had been collected. The configuration of these subareas was determined using the Thiessen polygon method. Data that are entered into, or computed by, SUPERMOCK in this manner are: the hydraulic conductivities of the upper confining layer, aquifer storage coefficients, specific-yield values of the confining layer, and evapotranspiration. The values of these parameters were determined by calibration. In order to maintain control over calibration cause and effect, the value designated for each of these parameters at the control points was assigned to all nodes within each polygon (subarea) in the model area.

The soil-moisture-accounting component in SUPERMOCK is a parametric rainfall accretion model in which the parameters have physical significance. This component computes changes in soil-moisture storage, and recharge to and discharge from the zone of aeration to the water table. Seven parameters used in the soil-moisture-accounting procedure help define the hydraulics of the soil as related to infiltration, storage, and drainage. The values of these parameters were chosen arbitrarily by a trial-and-error procedure in which infiltration was computed based upon the value of the soils parameters and daily precipitation and evaporation. Plausibility limits for the parameters are defined in the soils literature. Within these limits, the values of the soils parameters were adjusted until a combination was found that produced reasonable infiltration rates for the types of soils found in the Red River Valley. These seven parameters are:

- SMSIN -

This parameter defines the initial value for surface-moisture storage, in inches. Surface-moisture storage (SMS) is carried by the model in an array containing values for SMS at each node in the grid. In the first time step of the model, each member of this array is set equal to SMSIN. For the Red River models, the value used in each lock-and-dam area was 1.0 in. (25.4 mm).

- KSAT -

This parameter defines the saturated hydraulic conductivity for soil, in inches per day. For the Red River models, a value of 10.0 in/d (254 mm/d) was used. This value was within plausible limits and seemed to produce the best results based upon observed data.

- DRN -

This parameter defines the maximum drainage rate for soil, in inches per day. It controls the amount of infiltration, or recharge, to the water table when an excess in soil moisture is available. A value of 10.0 in/d (254 mm/d) was used in the Red River models.

- SWF -

This parameter defines the suction (tension) of the soil at field capacity, in inches. The value used in the Red River models was 120 in. (3,050 mm). This is a typical value for soils in the project area and was obtained from the soils literature.

- RGF -

This parameter defines the ratio of wilting-point tension to tension at field capacity (dimensionless). The value used in the Red River models was 40.0. This value also was obtained from the soils literature and is a typical value for the project area.

- SMSM -

This parameter defines the maximum amount of water, in inches, that can be held in surface-moisture storage. The value for SMSM was obtained by a calibration process in which observed hydrographs at control wells were compared with computed hydrographs at the same locations. A value of 1.0 in. (25.4 mm) for this parameter was used in the Red River models.

- XNORM -

This dimensionless parameter defines the limits of the recharge rate. It was set to 3 in all models of the Red River. This value allows the recharge rate to range from zero, for SMS ≤ 0.5x(SMSM), to 0.15x(DRN), for SMS=SMSM.

The value of each of these parameters was held constant for the entire model and was entered to SUPERMOCK on a data input card.

The stress on the soil-moisture-accounting component is the daily difference between precipitation and potential evapotranspiration which is input to SUPERMOCK on cards. When the stress is positive, infiltration to soil moisture is computed as a function of precipitation in excess of evapotranspiration, the amount of moisture already in storage, and the hydraulic properties of the soil. Infiltration, or positive downward flux, is computed by the model, using a modified version of a routine from a model by Dawdy, Lichty, and Bergmann (1972, p. B5-B8). This routine, which uses 5-minute rainfall periods, was modified to correspond to the 1-day rainfall periods used in this model.

Overland runoff, or infiltration residual computed in the routine of Dawdy, Lichty, and Bergmann (1972), was dropped from the soil-moisture-accounting procedure in SUPERMOCK. Due to the 1-day rainfall period, it was necessary to impose an upper limit (SMSM), as previously mentioned, on soil-moisture storage because redistribution of moisture occurred only once each day. The value of this limit used in the Red River models was 1 in. (25.4 mm). 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. Evapotranspiration, or negative stress, is subtracted from soil-moisture storage up to the amount of water available. When soil moisture is reduced to zero, evapotranspiration is derived from ground-water storage in the water-table zone in the confining bed until soil moisture is replenished from rainfall.

The vertical-flow component in SUPERMOCK computes the elevation of the water table in the fine-grained material above the aquifer as a function of the elevation of the water table in the preceding time step, the elevation of the potentiometric surface, and recharge from the soil-moisture zone. By use of this water-table elevation, flow to or from the aquifer can be determined and used by the horizontal-flow component. SUPERMOCK computes the redistribution of soil moisture (recharge) to the water table 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), SUPERMOCK sets recharge to the water table to zero. Initially, the model takes evapotranspiration from soil moisture and then from ground-water storage in the upper confining layer after soil moisture is depleted. The limit on evapotranspiration from ground water is the steady-state rate of upward movement of water, as determined by the method of Ripple, Rubin, and van Hylckama (1972). ATMOFLUX, a peripheral data-preparation program developed for the investigation, was used to compute these data. ATMOFLUX uses a method requiring 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 $\underline{S_{1/2}}$, soil suction at which the unsaturated conductivity is one-half the saturated conductivity, are used to express the limiting steady-state evapotranspiration in a nondimensional form. Values of $\underline{n}$, ranging from 2 for clays to 5 for sands, and values of $\underline{S_{1/2}}$, ranging from 1 for sands to 2 for finer materials, were used in this study. Output from ATMOFLUX includes punched cards containing values of evapotranspiration divided by saturated hydraulic conductivity for depths to the water table ranging from 1 to 30 ft (0.3 to 9.1 m) for four ranges in hydraulic conductivity associated with each soil coefficient, $\underline{n}$. These punched cards are used as input to SUPERMOCK. The actual limiting rate of evapotranspiration used by SUPERMOCK was obtained by multiplying the computed upward rate associated with depth to the water table at a particular time by the saturated hydraulic conductivity of the upper segment (HCU) of the upper confining layer in a particular subarea. The method of Ripple, Rubin, and van Hylckama (1972) assumed bare soil and moisture transport to the land surface. Practically all the Red River project area is covered by vegetation. Therefore, moisture transport was calculated to the base of the root zone.

The horizontal-flow component in SUPERMOCK computes the transient elevation of the potentiometric surface in the aquifer. In the Red River models, the stresses on the aquifer that were simulated included the imposition of time-variant stream stages for the main stem of the Red River and its major tributaries and accretion, which is computed by SUPERMOCK as a function of the water-table elevation. Where a computed water table does not exist, the model uses infiltration, or recharge, from the soil-moisture zone as accretion to the aquifer.

The time-step increment used in the nonsteady-state analyses of the Red River models was 10 days. Time-variant stream-stage and climatic data were used as input, and the potentiometric surface and water-table elevations at each node in the grid were computed for each time step.

Calibration of the nonsteady-state model was based upon preconstruction stream stages and comparisons of computed and observed hydrographs at observation wells. After calibration, the model was used to compute postconstruction elevations of the potentiometric surface and water table. Postconstruction output was based upon the imposition of postconstruction stream stages on the main stem of the Red River. The availability of the time-varying elevation of the water table allowed the computation of average depths to the water table for specific periods of interest requested by the Soil Conservation Service.

Steady State

Steady-state projections of the postconstruction potentiometric surface in the Red River alluvial aquifer were made using techniques developed during similar studies in the Arkansas River valley (Bedinger and others, 1970). During the Arkansas River study, these techniques were applied to analog modeling. For the Red River investigation, these techniques were incorporated into a digital model called GWFLOW (Bedinger and others, 1973). GWFLOW is a two-dimensional representation of an aquifer.

The principal data needs of the GWFLOW model for use in steady-state analysis are transmissivity of the aquifer, the ratio of change in evapotranspiration to change in aquifer head ($\Delta ET/\Delta H$), change in stream stages, and thickness and hydraulic conductivity of streambed material. To determine the change in head at any point in the aquifer resulting from a change in river stage, the initial potentiometric surface on the stream boundaries is the change in river stage and is zero at all other nodes in the aquifer.

In the steady-state models of the Red River alluvial aquifer, transmissivity was varied over the modeled area, and $\Delta ET/\Delta H$ was entered as varying by discrete subareas. The method used to determine values of $\Delta ET/\Delta H$ is discussed later under "Preparation of Digital-Model Input" and "Calibration of Models." Stress on the models was imposed at appropriate stream nodes as changes in stream stage from preconstruction to postconstruction conditions. The direct effects of changes in stage for streams with partial hydraulic connection were simulated by applying nonuniform streambed thickness and holding the hydraulic conductivity of the streambed material constant. The values of $\Delta ET/\Delta H$ have a definite controlling effect on the magnitude of change in the potentiometric surface and on the area of influence of stream-stage change.

Time-step increments for GWFLOW were based on computation times entered on cards. The computation times used in the Red River models, which were those that were recommended for GWFLOW, ranged from 0.00130 to 40,000 days in logarithmic increments. Although analyses indicated that most of the water-level changes had taken place in the first 2-3 years, computation times were extended to 40,000 days to insure complete equilibrium. Primary output from the models consisted of changes in the potentiometric surface at each node in the 0.5-mile (0.8-km) grid. This output was used to contour changes in the potentiometric surface in the aquifer resulting from an increase in river stage.

PREPARATION OF DIGITAL-MODEL INPUT

Preparation of input data for use in the GWFLOW and SUPERMOCK models involved the collection and manipulation of field data. Some of the data required, and also the data format, are common to both GWFLOW and SUPERMOCK. However, because of the greater complexity of the SUPERMOCK model, more detailed and varied types of input were required for it than for the GWFLOW model.

Several data-preparation computer programs, hereinafter termed "peripheral programs," were developed during the investigation to process data required by the models. These programs will be discussed in the following sections. Source listings and data-input requirements of these peripheral programs are included as attachments at the end of this report.

Some of the data read into GWFLOW were dependent upon parameter values determined during the calibration of the nonsteady-state model. Therefore, nonsteady-state analyses for each lock-and-dam area were made before the corresponding steady-state analyses for that area. For purposes of discussion, preparation of data for the two models will also be discussed in that order.

Nonsteady-State Model

Varied types of data were prepared for entry into the nonsteady-state model in order to adequately define the flow field. Most of this input is in the form of alphameric maps that are representations of the modeled area. Many of these maps are outputs from the peripheral programs mentioned previously. The primary data input to the model are depicted in the generalized flow chart in figure 6.

Root Depth

Root depths of vegetation are key factors required by SUPERMOCK in determining the effective depth to the water table for computation of evapotranspiration. Evapotranspiration is modeled as depleting the moisture content in

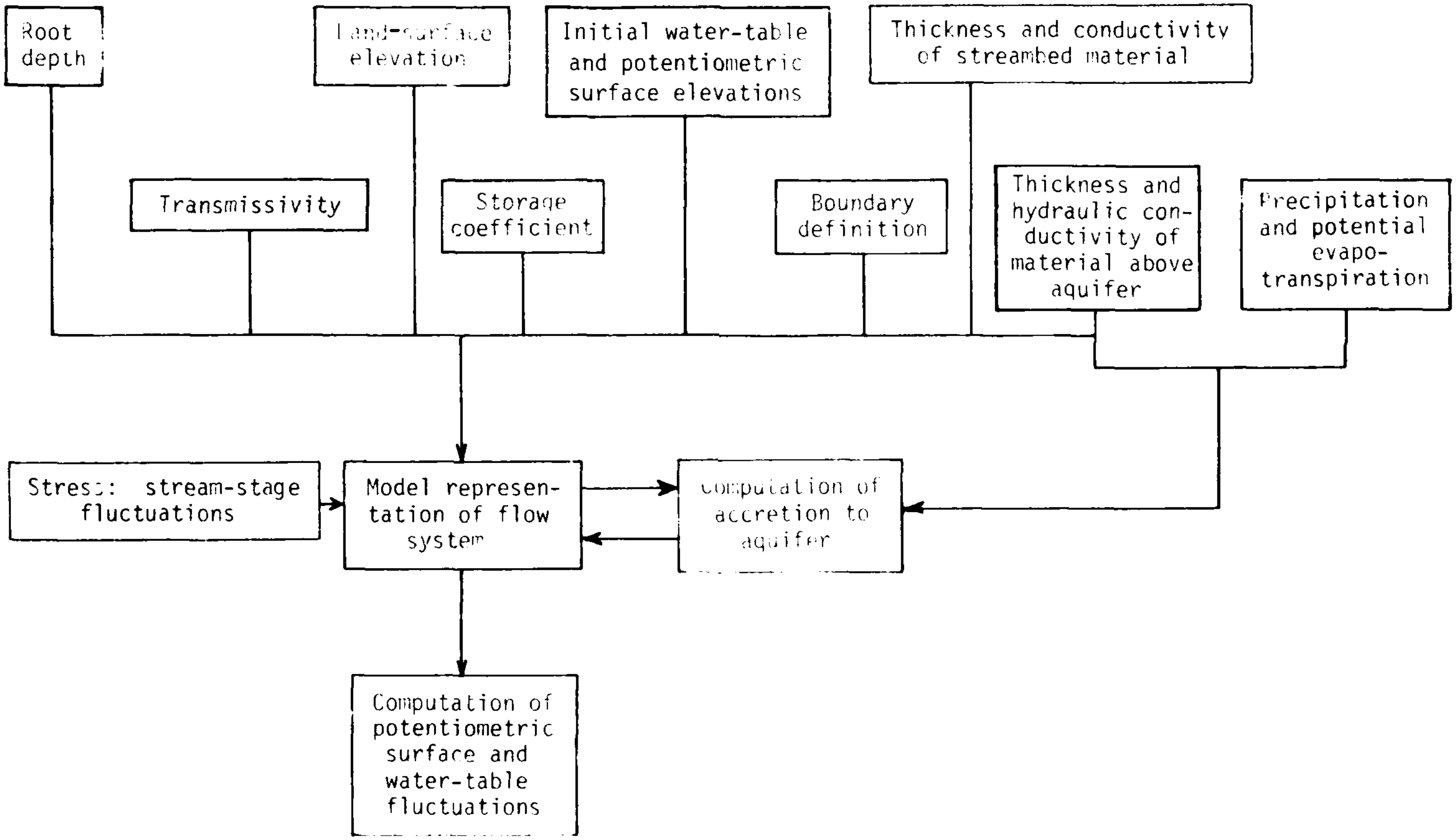


Figure 6.--Flow diagram of digital-model procedure for nonsteady-state analysis

the soil layer between land surface and the base of the root zone. Upward flow from the water table occurs as a response to this surficial depletion.

Cropping patterns to the nearest 40-acre (162,000-m^2) plot and the effective root depths for the various types of vegetal cover were determined by the Soil Conservation Service. This information was based upon 1971 cropping patterns that were assumed to be representative of the project area for the calibration period.

The root-depth data for each lock-and-dam area were entered into SUPERMOCK in the form of an alphameric map on cards. The various types of vegetal cover, their associated root depths, and the symbols representing those depths are tabulated below:

Vegetal cover	Root depth (feet)	Map symbol
Cotton-------------------------------	2.3	C
Soybeans-----------------------------	2.3	S
Pasture------------------------------	2.5	P
Orchards-----------------------------	5.0	O
Woodlands----------------------------	5.0	W
Uplands------------------------------	5.0	U
Urban areas--------------------------	2.5	E

An example of an alphameric root-depth map is shown in figure 7. (All examples are for Lock and Dam 3 area.)

Land-Surface Elevation

The elevation of the land surface, in feet above Mean Sea Level Datum of 1929 (now referred to as National Geodetic Vertical Datum of 1929), was used in the nonsteady-state models as a reference point for determining (1) the depth to the water table, (2) the relation of the potentiometric surface to land surface, and (3) the elevation of the top of the aquifer.

Land-surface elevations were obtained from two sources: instrument levels and topographic maps. The land-surface elevation at each of the observation wells was determined by instrument and assigned to the node nearest the well. At all other nodes in each of the lock-and-dam-area models, these data were picked from topographic maps. The appropriate set of data was read into SUPERMOCK for each lock-and-dam area in the form of a numeric map. Land-surface elevations at each node were estimated to the nearest foot.

Topographic map coverage, including map contour interval, is shown in figure 8.

Figure 7.--Example of alphameric root-depth map.

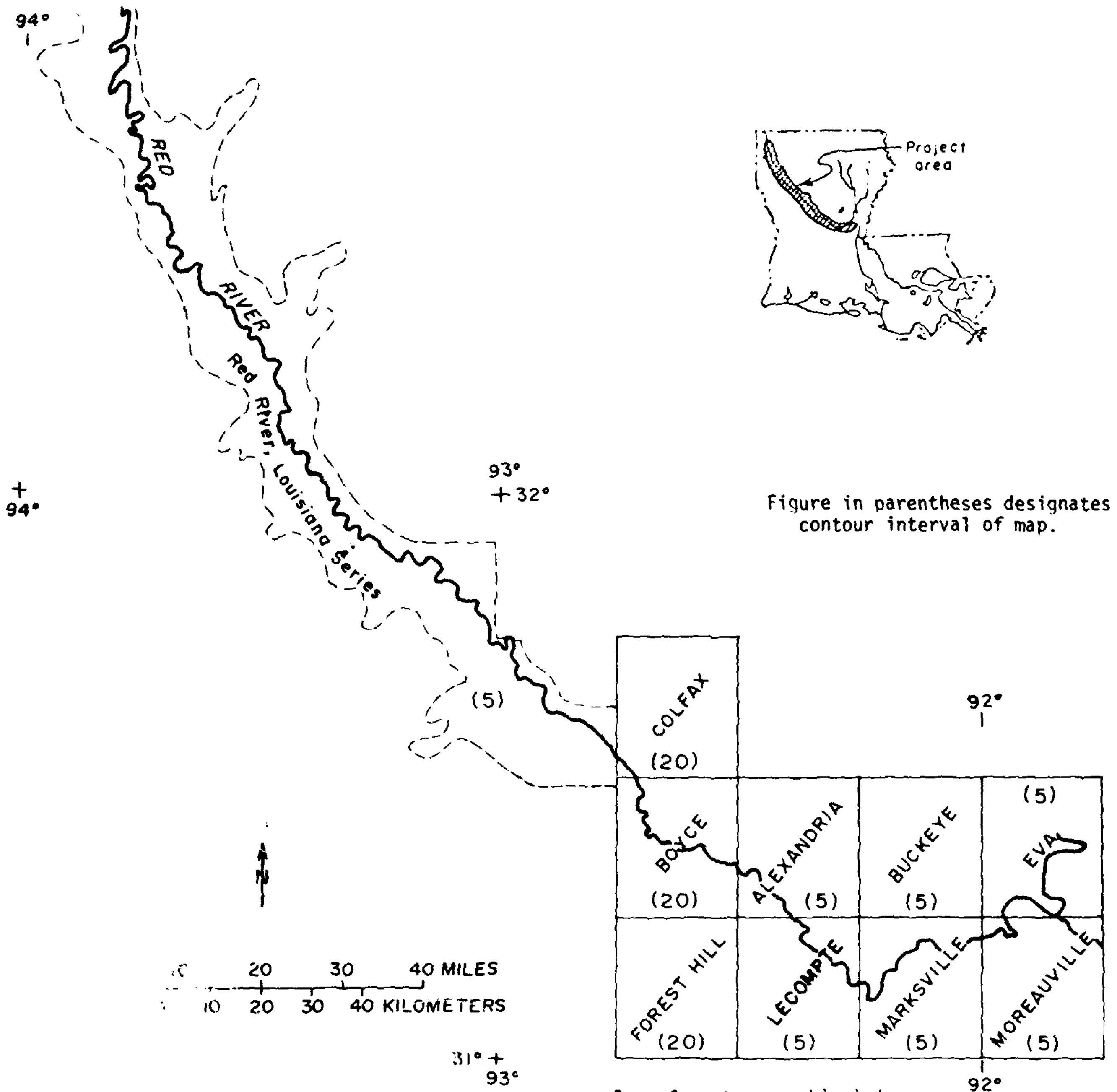


Figure in parentheses designates contour interval of map.

Base from topographic index map.

Figure 8.--Topographic coverage of the project area.

Initial Potentiometric Surface and Water Table

The elevation of the water table and potentiometric surface is required by SUPERMOCK as the starting point for computations. In the first time step in the model, the elevation of the water table is set equal to the elevation of the potentiometric surface at corresponding nodes. Therefore, the data input that must be prepared is the initial potentiometric surface.

In the Red River models, the average potentiometric surface for the period of record was used to represent the initial preconstruction potentiometric surface. The elevation of the average potentiometric surface in the aquifer was based on a minimum of 4 years of record. These data were collected from the joint Geological Survey-Soil Conservation Service observation-well network in the valley. Measurements were made monthly in the 350-well network. Water-level measurements at each observation well in a particular lock-and-dam area were averaged on a time-weighted basis using a digital program called AVERAGE, which was developed for this purpose. The only data required by the AVERAGE program are water levels and corresponding dates of measurement at each observation well. A program-source listing, containing input requirements and formats, and an example of program output are included in attachment A. The average values determined from this procedure were plotted and manually contoured to obtain the elevation of the preconstruction potentiometric surface in that lock-and-dam area. The resulting average potentiometric surface represents a hypothetical dynamic-equilibrium condition of head in the aquifer for preconstruction conditions. From the contour map, the elevation of the potentiometric surface was picked for each node in the grid covering a lock-and-dam area. These values were coded into a numeric map containing elevations to the nearest foot at each node. The map was converted into data cards that were used as input to SUPERMOCK.

Observed Potentiometric Surface and Water-Table Elevations

For purposes of calibration, observed levels of the water table and the potentiometric surface were compared with corresponding values computed by SUPERMOCK. The comparisons were made in the DATE program (Reed and others, 1976) that was run in sequence with the SUPERMOCK model. The observed data used in DATE consisted of the spring "high" and fall "low" water table and potentiometric levels for one or more years.

The observed potentiometric levels for the high in the spring and the low in the fall of specified years were read into DATE as exact values. However, because the position of the water table at some sites known only within a certain range, several input format options are allowed. Water-table values may be entered as being greater than or less than a given value, as being within a closed range, as an exact value, or as being unknown.

An example of a calibration table produced by DATE and a discussion of the use of the data are given in the section "Calibration and Verification of the Nonsteady-State Model." Observed data are printed in the table according to the format in which they were entered to DATE. Use of the observed data for comparisons with computed data was invaluable in the calibration process.

Transmissivity

The transmissivity of the alluvial aquifer in the study area ranges from 3,000 to 15,000 ft^2/d (279 to 1,390 m^2/d). These values were determined at selected sites by analysis of pumping-test data and by analysis of aquifer response to river-stage fluctuations. These data were extrapolated to other areas of the valley by developing relationships between hydraulic conductivity and particle size at the pumping-test sites and extending these values, on the basis of grain-size relationships and thickness, to test-hole sites.

Pumping tests conducted by the Geological Survey as part of earlier studies of the alluvium (Newcome, 1960) provided values of transmissivity at six locations in the valley. Transmissivity values, determined from these tests, ranged from 5,300 to 13,000 ft^2/d (492 to 1,210 m^2/d). The hydraulic conductivity ranged from 130 to 160 ft/d (40 to 49 m/d).

Approximately 150 samples of aquifer material were collected from test holes and analyzed for hydraulic conductivity and particle size during the investigation. From these analyses, a relationship was developed between hydraulic conductivity and particle size, using the method of Johnson and Bedinger (1967). From this relationship, an average value of hydraulic conductivity was developed for the alluvial aquifer. Conductivity values obtained by this method were compared with those determined from pumping tests. From these analyses, an average value of hydraulic conductivity of 147 ft/d (45 m/d) was determined for the alluvial aquifer. This value was checked at several locations near the river by using the RIVER-INDUCED FLUCTUATIONS computer program (Bedinger and others, 1973). The transmissivity at each of the test-hole sites was then computed by multiplying the average conductivity by the thickness of aquifer material noted in the test-hole logs.

Transmissivity values for the terrace deposits were estimated using thicknesses obtained from logs of test holes in the deposits. The average hydraulic conductivity was assumed to be 147 ft/d (45 m/d). Terrace deposits were assigned transmissivity values where they are areally extensive and are considered to be hydraulically connected with the alluvial aquifer.

The formations of Tertiary age, which underlie the alluvium and form the uplands bordering the valley, are composed primarily of silt and clay and are relatively impermeable compared with the alluvial aquifer. Estimated transmissivities for sand units in these formations ranged from 50 to 700 ft^2/d (4.7 to 65 m^2/d) in areas where they are in hydraulic connection with the alluvial aquifer. These estimates were based upon geologic and pumping-test data collected during earlier studies (Newcome, 1960).

After transmissivity values had been plotted and contoured for the project area, alphameric maps were prepared for each lock-and-dam area; and the data were punched on cards for input to the models. An example of an alphameric transmissivity map from the study and explanation of symbols are shown in figure 9.

```
TRANSMISSIVITY MAP OF AQUIFER
EXPLANATION

SYMBOL          TRANSMISSIVITY
   A ------------ [illegible]
   B ------------ [illegible]
   C ------------ [illegible]
   D ------------ [illegible]
   E ------------ [illegible]
   H ------------ [illegible]
   I ------------ [illegible]
   ! ------------ [illegible]
```

Figure 9.--Example of alphameric transmissivity map.

Additional checks were made on the modeled transmissivity values during calibration of the nonsteady-state models. However, only minor adjustments were made, and the maps were used virtually as initially prepared in both the steady- and nonsteady-state models.

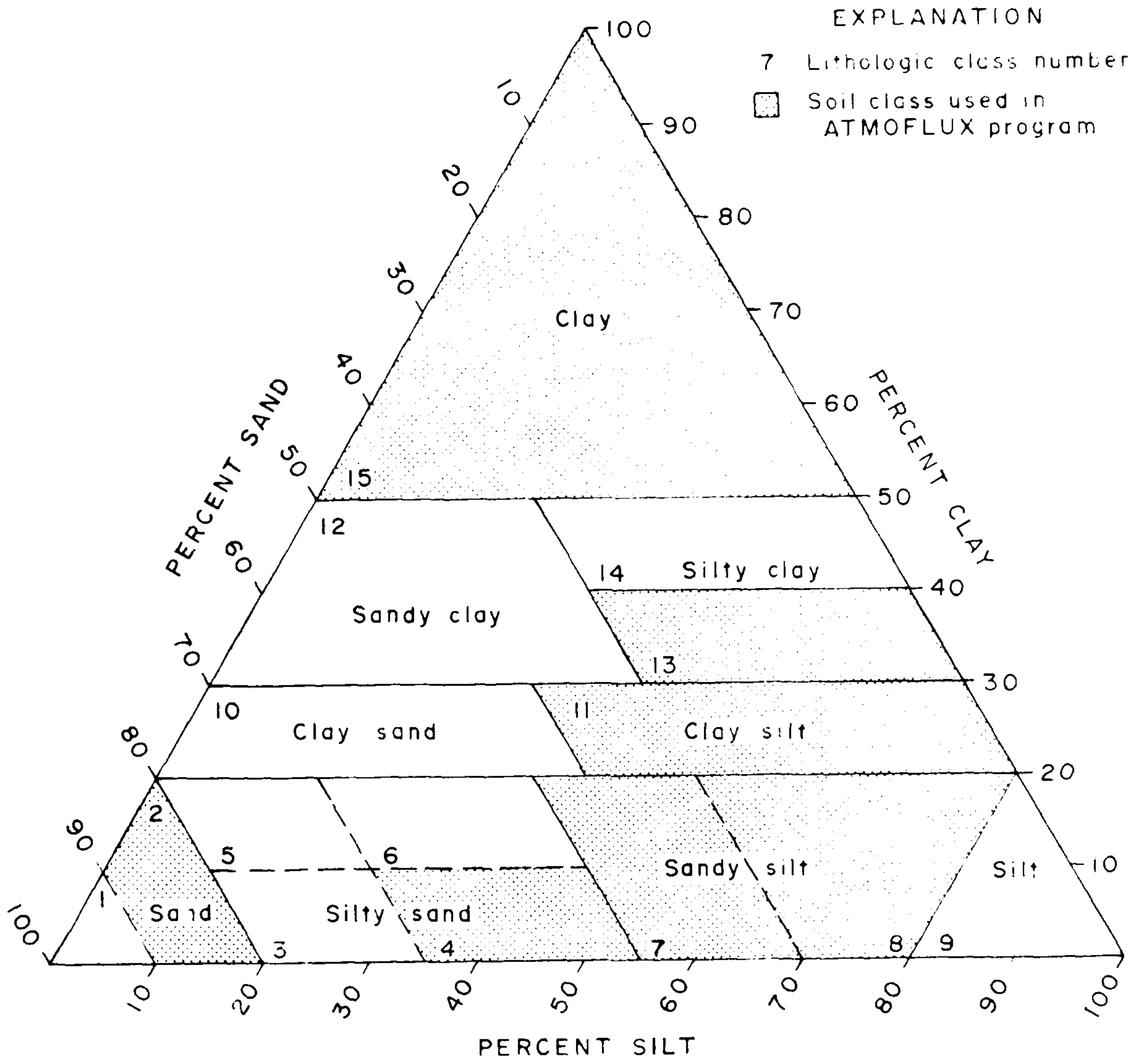
Conductivity of the Upper Confining Layer

Movement of water to or from the alluvial aquifer takes place through the upper confining layer, which overlies the aquifer nearly everywhere in the valley. The upper confining layer, which is composed of a heterogeneous sequence of clay, silt, and sand, ranges in thickness from a few feet to 140 ft (43 m). Movement of water through the upper confining layer was modeled as being one-dimensional vertical flow. To provide for greater flexibility in modeling the vertical-flow component, the upper confining layer was modeled as 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.

Both the upper and lower segments were assigned values of hydraulic conductivity, designated HCU and HCL, respectively. These values were entered in SUPERMOCK by discrete subareas--each subarea having a unique value for HCU and HCL. Each node within a subarea was assigned the same value for HCU and HCL. Initially, HCU and HCL values in a particular subarea were set equal to the same value. This value represented the harmonic mean of the conductivities for materials in the upper confining layer in that subarea. These harmonic-mean conductivities were computed using a digital program, ATMOFLUX, shown in attachment B. The ATMOFLUX program uses as input the thickness and lithologic class for materials in the upper confining layer. Lithologic data for the upper confining layer were obtained from test-hole logs. The scheme used in the study for associating lithologic class and hydraulic conductivity is shown in figure 10.

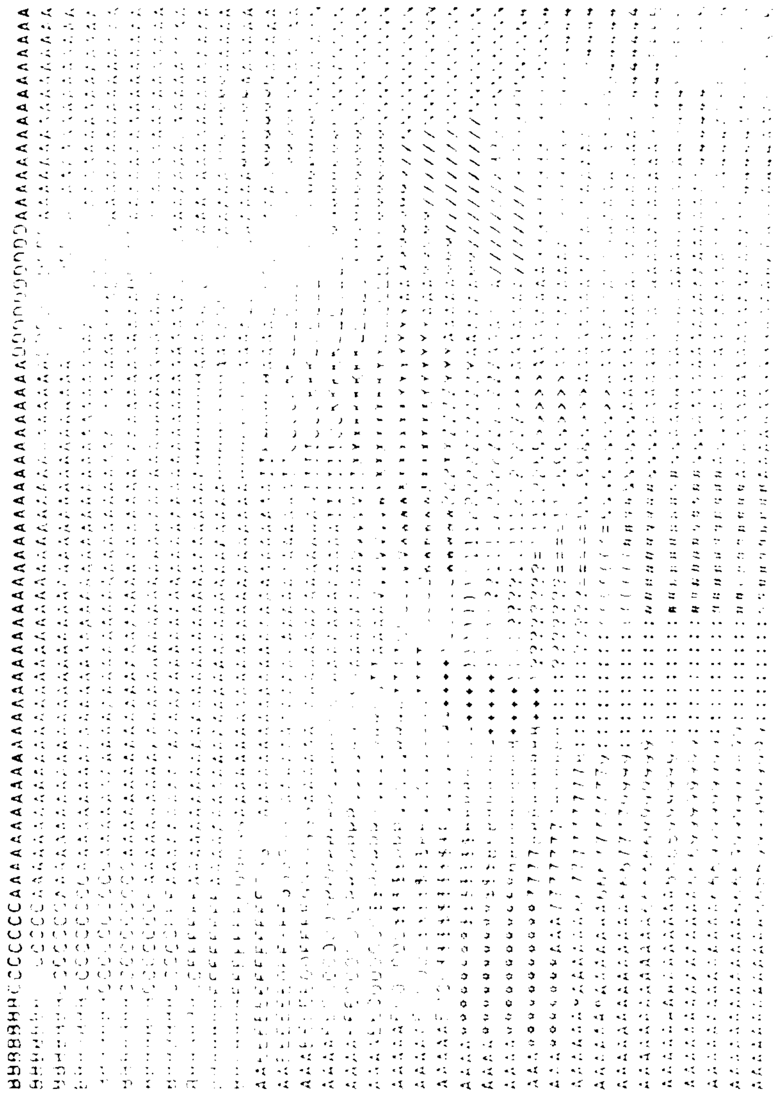
Hydraulic-conductivity values ranging from 3.0 to 1.0×10^{-5} ft/d (0.9 to 3×10^{-6} m/d) were selected as being the physical plausibility limits within which adjustments could be made to the vertical hydraulic conductivity of the upper confining layer. This range represents the conductivity of materials ranging from fine sand to dense clay. Because of the lateral variability of 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 during calibration was to remain within the physical plausibility limits.

An example of an alphameric map and the accompanying table defining the value of HCU and HCL for each subarea of a lock-and-dam area are shown in figure 11.

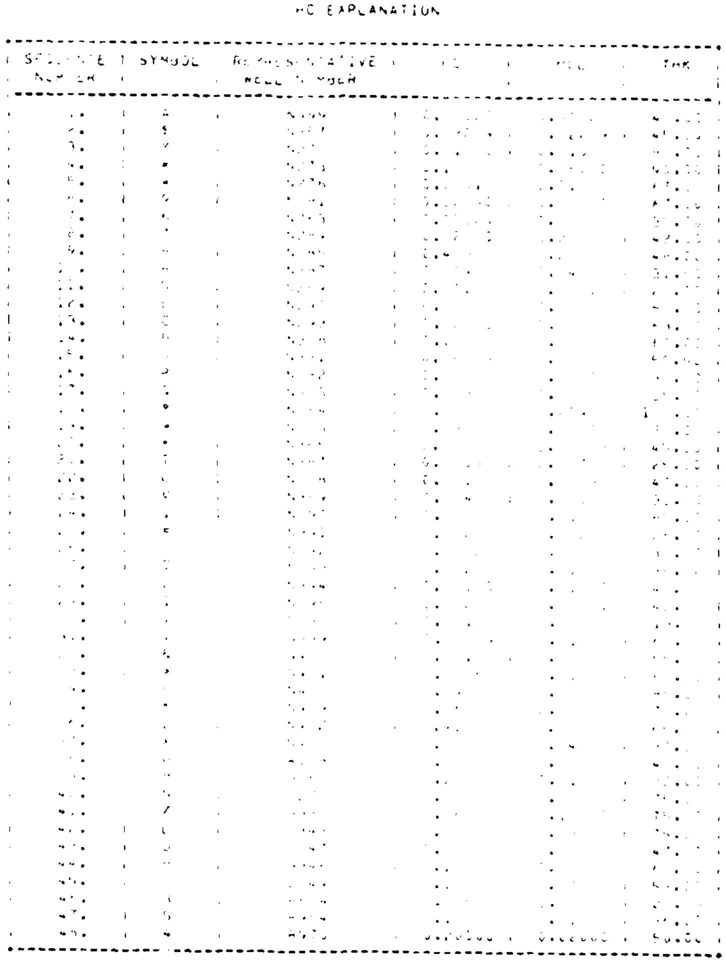


Lithologic class number (I)	Hydraulic conductivity HC(I), (ft/d)	Lithologic class number (I)	Hydraulic conductivity HC(I), (ft/d)
2	2.65	11	0.04
4	0.667	13	0.01
7	0.1	15	0.0004
8	0.133		

Figure 10.--Trilinear graph of soil-classification scheme showing hydraulic-conductivity values for soil classes used in ATMOFLUX program.



AREA DEFINITION MAP FOR HYDRAULIC CONDUCTIVITY AND EVAPOTRANSPIRATION



HC EXPLANATION

SEQUENCE NUMBER | SYMBOL | REPRESENTATIVE WELL NUMBER | THK

Figure 11.--Example of alphameric map of vertical hydraulic conductivity and explanation of symbols.

Relation of Evapotranspiration to Depth to Water

Because the entire valley is covered by vegetation, the removal of water by evapotranspiration is not at the land surface but is at the base of the root zone in the fine-grained layer. To determine the rate of evapotranspiration from the root zone for different depths to water, a function expressing the relationship between dimensionless evapotranspiration and depth to water below the root zone (GWETO) is used by the model. Values of the GWETO function were computed by the ATMOFLUX program (attachment F) and were entered to the model on cards. GWETO includes four different functional relations between evapotranspiration and saturated hydraulic conductivity. The values of the GWETO function for the four ranges in hydraulic conductivity and for depths of from 1 to 30 ft (0.3 to 9.1 m) to the water table are shown in figure 12. The appropriate relation is chosen during program execution based on the value of HCU. The value of evapotranspiration is computed in the program as the product of GWETO at a particular depth to water and the upper hydraulic conductivity (HCU). A detailed discussion of the determination of the GWETO function is given in Reed, Bedinger, and Terry (1976, p. 52).

```
                                 ET EXPLANATION

+------------------------------------------------------------------------------+
|  DEPTH TO   |    HC<.004    | .004<HC<.040  | .040<HC<.400  | .400<HC        |
| WATER TABLE |               |               |               |                |
|    (FT)     |               |               |               |                |
|------------------------------------------------------------------------------|
|      1      |    2.6815     |    1.8021     |    1.5209     |    0.3824      |
|      2      |    1.1486     |    0.6498     |    0.4747     |    0.0376      |
|      3      |    0.6605     |    0.3068     |    0.1821     |    0.0056      |
|      4      |    0.4311     |    0.1633     |    0.0763     |    0.0014      |
|      5      |    0.3030     |    0.0945     |    0.0351     |    0.0004      |
|      6      |    0.2240     |    0.0565     |    0.0178     |    0.0002      |
|      7      |    0.1719     |    0.0383     |    0.0096     |    0.0001      |
|      8      |    0.1356     |    0.0262     |    0.0056     |    0.0000      |
|      9      |    0.1198     |    0.0187     |    0.0037     |    0.0000      |
|     10      |    0.0955     |    0.0138     |    0.0024     |    0.0000      |
|     11      |    0.0758     |    0.0104     |    0.0016     |    0.0000      |
|     12      |    0.0644     |    0.0081     |    0.0012     |    0.0         |
|     13      |    0.0553     |    0.0064     |    0.0008     |    0.0         |
|     14      |    0.0481     |    0.0051     |    0.0006     |    0.0         |
|     15      |    0.0421     |    0.0042     |    0.0005     |    0.0         |
|     16      |    0.0372     |    0.0034     |    0.0004     |    0.0         |
|     17      |    0.0331     |    0.0029     |    0.0003     |    0.0         |
|     18      |    0.0296     |    0.0024     |    0.0002     |    0.0         |
|     19      |    0.0266     |    0.0020     |    0.0002     |    0.0         |
|     20      |    0.0241     |    0.0018     |    0.0001     |    0.0         |
|     21      |    0.0219     |    0.0015     |    0.0001     |    0.0         |
|     22      |    0.0200     |    0.0013     |    0.0001     |    0.0         |
|     23      |    0.0183     |    0.0012     |    0.0001     |    0.0         |
|     24      |    0.0168     |    0.0010     |    0.0001     |    0.0         |
|     25      |    0.0155     |    0.0009     |    0.0001     |    0.0         |
|     26      |    0.0144     |    0.0008     |    0.0000     |    0.0         |
|     27      |    0.0134     |    0.0007     |    0.0000     |    0.0         |
|     28      |    0.0124     |    0.0006     |    0.0000     |    0.0         |
|     29      |    0.0116     |    0.0006     |    0.0000     |    0.0         |
|     30      |    0.0108     |    0.0005     |    0.0000     |    0.0         |
+------------------------------------------------------------------------------+
```

Figure 12.--Example of GWETO functions for computation of evapotranspiration.

Thickness of Streambed Material

The Red River and its tributaries do not fully penetrate the alluvial aquifer at all places along their channel. The fine-grained material that exists beneath the stream channels in places retards the movement of water to or from the aquifer. As a result, for preconstruction conditions, water levels in observation wells as close as 200 ft (61 m) to the streams may differ by as much as 3 to 5 ft (0.9 to 1.5 m) from stream levels during transient conditions.

In SUPERMOCK, grid nodes assigned to the main stem of the Red River may optionally be specified as fully or partially penetrating the aquifer. All tributary stream entries are assumed to be partially penetrating. The model requires that all partially penetrating stream nodes be assigned a streambed thickness.

The thickness of material beneath the stream channels was not known initially except through qualitative estimates based on logs of test holes near the stream channels. Therefore, the effective thickness was determined from analysis of SUPERMOCK's response to different thicknesses as indicated by the differences in the computed and observed potentiometric surface at control wells near a stream. The reasonableness of the annual accretion to the aquifer necessary to maintain a computed potentiometric level equal to the observed level at those wells was also considered. An arbitrary value of thickness was assigned to each node in the model that represents a point on a stream channel. Maps showing streambed thickness were then prepared for each of the modeled areas. Separate symbols were used for each stream, and an arbitrary value of thickness was given to each symbol. During calibration, additional symbols were introduced where needed to represent different thicknesses. Where changes were not required, the symbols used initially were retained for ease in identifying various modeled stream channels. For reaches of a stream where zero thickness seemed to be indicated by model response, a very small nonzero value was assigned. The program logic in SUPERMOCK computes no flow through the streambed if a zero thickness is coded for the node in the streambed-thickness map. An example of a streambed-thickness map and its accompanying legend are shown in figure 13. The thickness value associated with the symbols H and C is printed as zero because of the print format in SUPERMOCK. The value is actually a small nonzero fraction. The blank in the explanation indicates a nonstream node and therefore has no streambed thickness associated with it. The 3's around the edge of the model indicate a no-flow boundary.

The thicknesses shown on the maps do not necessarily indicate the physical thickness of fine-grained material at a given location. A single value of 5×10^{-3} ft/d (1.5×10^{-3} m/d) was used in the model as the hydraulic conductivity of the fine-grained material. Therefore, the thickness was adjusted to obtain the correct ratio of hydraulic conductivity to thickness for calibration. Also, because of the 0.5-mile (0.8-km) grid spacing used in the models, any modeled watercourse is effectively 0.5 mi (0.2 km) wide. Thus, the modeled thicknesses must represent the flow characteristics through streambed materials in generally much narrower streams. A near-zero thickness of streambed

```
333333333333333333333333333333333333333333333333333333333333333333333333333333333
3           B                                                                   3
3            H                                                                  3
3            B                                                                  3
3             H                                                                 3
3             B                                                                 3
3            B                                                                  3
3             B                                                C                3
3  FF         B                                                C                3
3 F F          H                                               CC        C      3
3F  FFFFFF    H H                                               C      CC C     3
3         F    H H                                              CCCCCCC    C    3
3    A     F  H H H                                                       C     3
3    A     F F H FFFF                       HHHHHHHHGAA                    C    3
3  AA       F   F    F   JJH HH           HH          A FFFII              C  CC3
3  A                 F   J  H  H       HHH             G     FF             CC  3
3  A    AA            JKK      H    HHH                        FFF              3
3   A  A  A    A                HHHH                             FFF            3
3    A A  AAA  AA                                                 FL            3
3     A      AA AAA AA                                HHHJDDD     B   L         3
3              A AAA A                                 G     D     B  BH        3
3               AA A A                                 G      DD DDDBB H      F 3
3               A    II                             GGGG        D      GGG     F3
3            DD      GG                               J                  G GG  F3
3             D      FFFFFF              GGG        H                    G G FF 3
3              D         G  AAAA         G G   DD   J                    GGG    3
3              D          IA AAAA       JD GDDD D   D                           3
3              G                J      J   G DD  DDD                            3
3               G                J     GG                                       3
3                DGGGI        KKJDDDD D                                         3
3                     GGDD   K  J  D D                                          3
3                         DDDD                                                  3
3                                                                               3
333333333333333333333333333333333333333333333333333333333333333333333333333333333
```

Map of thickness of streambed and lakebed material

```
SYMBOL                THICKNESS(ft)
   3 -----------------    (OUTSIDE SYSTEM)
   A -----------------   20.
   B -----------------   20.
   C -----------------    1.
   D -----------------    5.
     -----------------    0.
   F -----------------    5.
   G -----------------   10.
   H -----------------    0.
   I -----------------   15.
   J -----------------    2.
   K -----------------    1.
   L -----------------   40.
```

Figure 13.--Example of alphameric streambed-thickness map for nonsteady-state analysis.

material is an indication that at that point the river and aquifer are in perfect hydraulic connection.

Changes in the preconstruction streambed-thickness map required in the postconstruction analysis included only the addition of nodes reflecting postconstruction changes in the position of the navigation channel. The added nodes were assigned the same thickness value as adjoining river nodes.

Specific Yield and Storage Coefficient

The introduction of specific-yield values and aquifer-storage coefficients into the model was done in alphameric form by discrete subareas identical with those used for the entry of HCU and HCL. An example of an alphameric map of specific-yield values and storage coefficients and the explanation for each are shown in figure 14. The scheme for applying calibration values to identical subareas was used so that, during the calibration process, modifications could be made to the values represented by symbols in any one subarea without substantially affecting adjacent areas.

Specific-yield values were limited to a plausibility from $1x10^{-2}$ to $2x10^{-1}$, and the storage coefficient was allowed to vary from $1x10^{-3}$ to $1x10^{-5}$. The final specific-yield values and aquifer storage-coefficient values were adjusted in the calibration procedure by a trial-and-error process within these limits.

Precipitation and Potential Evapotranspiration

Daily precipitation and evapotranspiration data are required by SUPERMOCK. Climatic information used in preparing these data was obtained from National Weather Service stations in, or near, each lock-and-dam area. Data from Weather Service stations at Alexandria, Natchitoches, Westdale, and Shreveport were used in Lock and Dam 2-5 areas, respectively (fig. 3). Data for Lock and Dam 1 area were taken from the Jonesville station, which is about 20 mi (32 km) north of that area.

Daily precipitation, in inches, was taken directly from Weather Service records and coded for card input to SUPERMOCK. The model assumes uniform distribution of precipitation throughout the grid area. Therefore, no nodal specifications were required. SUPERMOCK required that the precipitation data begin on or before the first day of the simulation run and continue through the duration of the period analyzed.

Daily potential-evapotranspiration data were not directly available. Therefore, a computation scheme was required to derive the data. Potential evapotranspiration is the combination of evaporation from the ground surface and transpiration from plants when there is complete vegetal coverage and soil moisture is adequate. Potential evapotranspiration was computed by the method of Thornthwaite (1948). This computation scheme was incorporated into a digital-computer program called POTEET, which was modified from a program

Coefficient of storage map

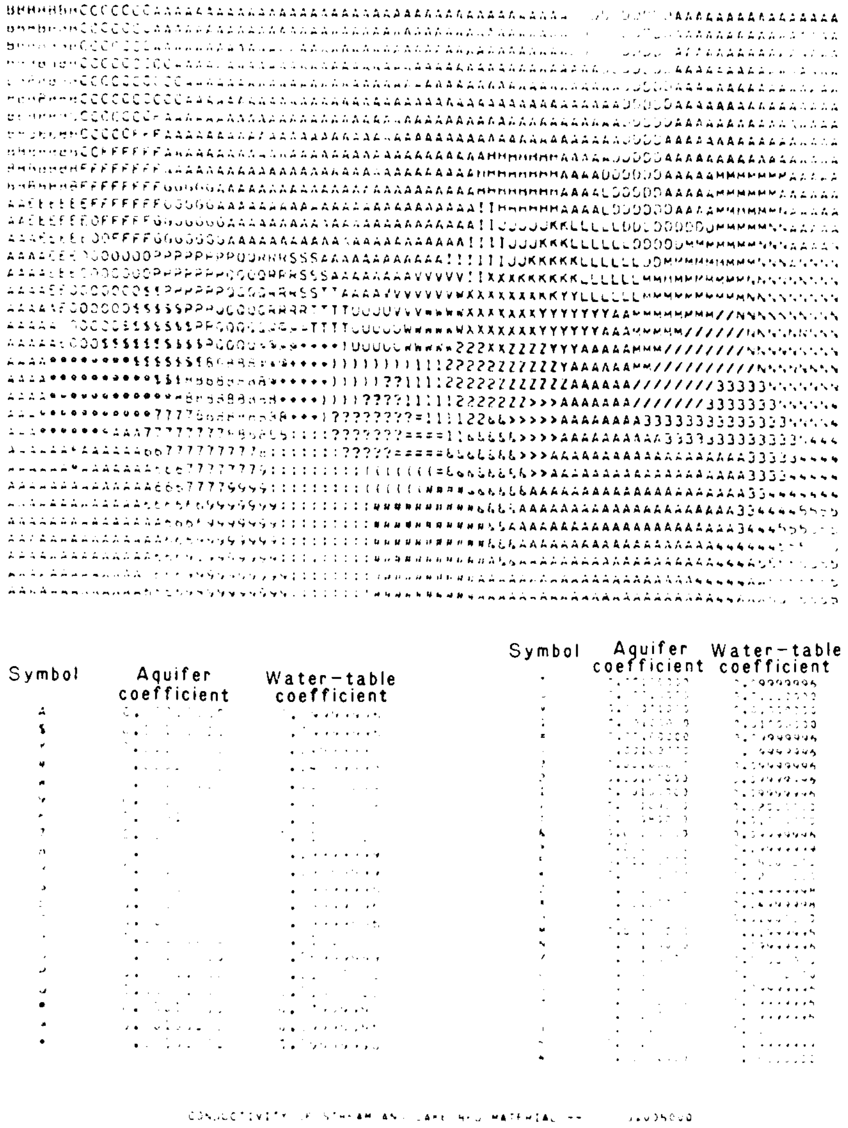


Figure 14.--Example of alphameric specific yield and storage-coefficient map and explanation of symbols.

developed by E. P. Weeks (written commun., 1973). The principal data requirements of this program are minimum and maximum daily air temperatures, monthly average temperatures during the period for which potential evapotranspiration is to be computed, and latitude. A source program listing and complete data requirements for POTEET are included in attachment C. Primary output from POTEET consists of punched computer cards that are in a format compatible with input requirements for SUPERMOCK.

River Stage

Two complete sets of time-variant stream-stage data for the Red River and its major tributaries were required for nonsteady-state analysis. Preconstruction conditions in each lock-and-dam area were simulated and the nonsteady-state model was calibrated to reproduce observed water-table levels and potentiometric-surface elevations at control wells. After successful calibration, the preconstruction stages were replaced by time-variant postconstruction stages, and production runs were made simulating postconstruction conditions in the flow field. Datum for all stream-stage data used in the nonsteady-state model was Mean Sea Level Datum of 1929.

The Corps of Engineers provided time-variant preconstruction and postconstruction stages on the main stem of the Red River for the period December 1967 to September 1973. These data consisted of sets of 5-day-average stages at approximately 2-mile (3.2-km) intervals for the entire reach of the Red River in the project area. Each set of associated stage and river-mile data was identified by a sequence number, increased by 5 for each set, to correspond to the time (day) on which the average stages were based. The preconstruction and postconstruction stages comprised two separate data sets, each residing on a separate 7-track magnetic tape. These data sets were transferred to 9-track tapes and used as master input-data sets for the creation of separate lock-and-dam-area main-stem river-stage-data sets, as needed.

The individual lock-and-dam-area sets for the main stem of the Red River were created by use of a digital program called RIVCHANGE, developed specifically for that purpose. The source-program listing of RIVCHANGE and data-input requirements and formats are included in attachment D. Input requirements for RIVCHANGE include the following: (1) beginning and ending sequence numbers corresponding to the beginning and ending dates of a period of time encompassing the period to be analyzed for a particular lock-and-dam area; (2) a number equal to an interpolated sequence number within the period specified in (1) at which computation of 10-day averages is to begin; (3) the length of time, in days, for which computation of 10-day averages is to continue; (4) the beginning and ending river miles in a particular lock-and-dam area; and (5) grid nodes and associated river miles at which 10-day-average river stages were desired. Node designation and associated river mile were determined manually, beginning at the downstream end of the model and proceeding upsteam sequentially to the upstream end of the model area.

RIVCHANGE was designed to interpolate in time and space and compute 10-day-average stages at specified river miles associated with river-stage nodes in the model of a particular lock-and-dam area. The program first located the specified time period within the master data set and determined the reach of the river to be analyzed. The spatial interpolation was based on river miles and the temporal interpolation was based on sequence numbers and associated calendar dates. As enough daily data became available from the interpolation, RIVCHANGE began computing 10-day-average stages, beginning with the day designated by the beginning sequence number for computations, and continuing for the number of days specified.

Output from RIVCHANGE consisted of 10-day-average river stages associated with specified grid nodes. Each set of average data was identified by a sequence number and a calendar date. These data were printed and also stored in a sequential data set on a magnetic disk pack. The disk data set could then be accessed by SUPERMOCK to obtain main-stem river stage every 10 days for the duration of a simulation period.

Preconstruction and postconstruction main-stem data sets were created by RIVCHANGE. Differences in the preparation of preconstruction- and postconstruction-area data sets involved accessing different master data sets and specifying a different set of associated grid nodes and river miles.

Time-variant 10-day-average stages on significant tributaries to the Red River were also required by SUPERMOCK. A digital program called TRIBCHANGE was developed to provide these data in a suitable form. Input requirements for TRIBCHANGE include the following: (1) the total number of tributary-stream nodes to which stages would be assigned, (2) a beginning sequence number--identical with that for the main-stem data set-for computing sequence numbers for sets of tributary-stream output, (3) manually computed 10-day-average stages at gaging stations on each stream, and (4) associated grid nodes and stream miles for each stream. Data for any number of streams can be used as input to TRIBCHANGE, and the entire tributary-stream data set may be created in one run of the program.

TRIBCHANGE was designed to interpolate only spatially because the 10-day averages entered to it were computed manually for the needed time increments. At nodes where tributary streams enter the Red River, the 10-day-average data from the main-stem-data set were entered to TRIBCHANGE as data for the base gage on that stream.

Output from TRIBCHANGE consisted of 10-day-average stages every 10 days at all specified grid nodes for tributary streams in a particular lock-and-dam area. Each set was identified by a sequence number identical with the sequence number of a corresponding average set in the main-stem-data set.

Data from TRIBCHANGE were printed and also stored in a sequential data set on a magnetic disk pack. This disk data set was then accessed by SUPERMOCK to obtain 10-day average tributary-stream stages every 10 days during the duration of a run.

Both preconstruction and postconstruction tributary-stream-data sets were created by TRIBCHANGE. Changes in data used as input to the program for postconstruction included changes in base-gage data at the mouth of streams emptying directly into the Red River, thereby reflecting increased postconstruction stages on the Red River.

A source program listing of *TRIBCHANGE* and input data requirement and formats are included in attachment E.

Steady-State Model

The data requirements of the GWFLOW model are less complicated than those of SUPERMOCK. GWFLOW simulates only the response of the aquifer to imposed stresses and does not consider the effects upon the overlying water table. Data required by SUPERMOCK for modeling a water table and activities in the unsaturated zone are not required by GWFLOW. A generalized flow chart showing the major input data necessary for GWFLOW is presented in figure 15.

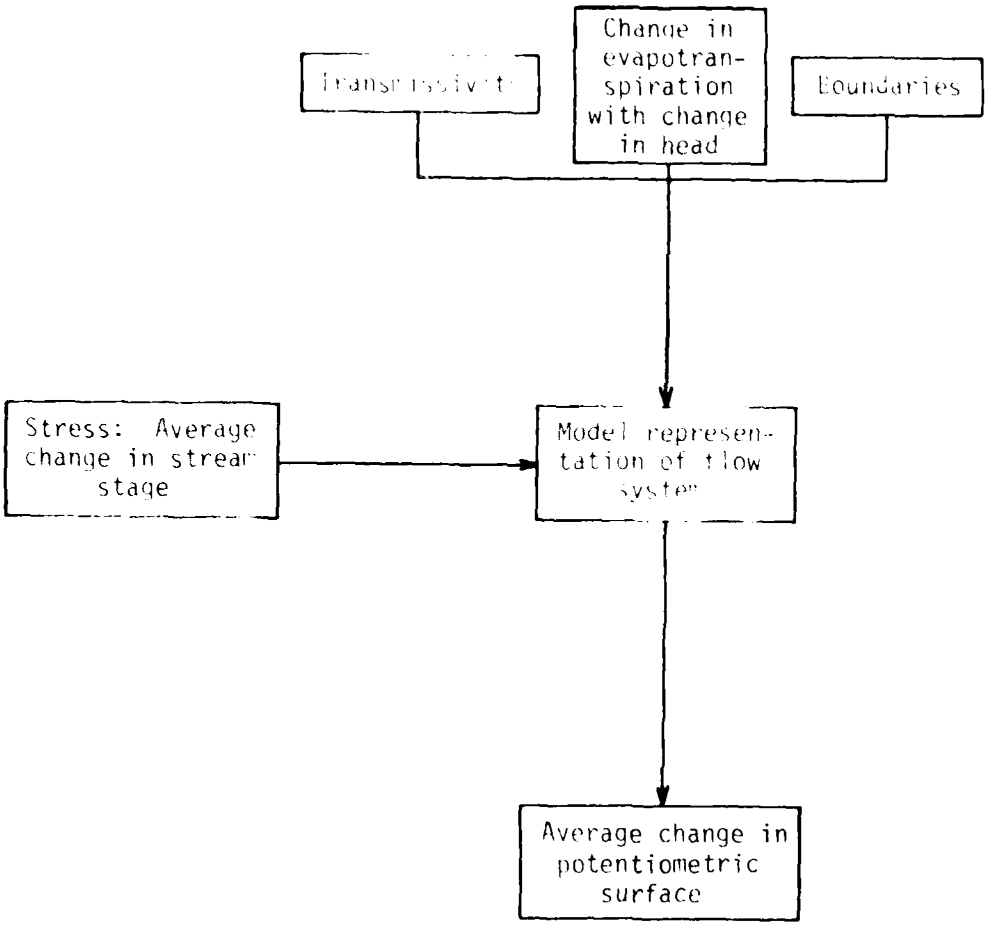


Figure 15.--Flow diagram of digital-model procedure for steady-state analysis

Transmissivity

The transmissivity of the aquifer may be entered to GWFLOW as constant over the grid area or as a spatially varying parameter. For the Red River models, transmissivity was entered as spatially varying. An alphameric map was used in which each symbol represented a different value of transmissivity. The map was identical with that used in the SUPERMOCK model. (See fig. 9.)

Change in Evapotranspiration with Change in Potentiometric Surface

GWFLOW allows for values representing the change in evapotranspiration with respect to a change in head ($\Delta ET/\Delta H$) to be entered as either constant over the grid area, varying, or not modeled at all. For the Red River models, $\Delta ET/\Delta H$ was varied by discrete subareas, as represented by different symbols in an alphameric map of the grid. The alphameric map for $\Delta ET/\Delta H$ was identical with the map used in SUPERMOCK for identifying evapotranspiration and hydraulic conductivity of the confining layer. (See fig. 16.)

Values of $\Delta ET/\Delta H$ were determined with the aid of a digital-computer program called DELETDELH. Input data requirements, program listing, and an example of program output are shown in attachment F. The computation scheme in this program is based on a method given by Ripple, Rubin, and van Hylckama (1972). Primary input to the program includes the following: (1) the upper and lower hydraulic conductivities (HCU and HCL) of the confining layer in each subarea, as determined from calibration of SUPERMOCK; (2) the thickness of material from the base of the root zone to the top of the aquifer in each subarea; and (3) values of evapotranspiration divided by saturated hydraulic conductivity (GWETO) for depths to the zone of saturation of from 1 to 30 ft (0.3 to 9.1 m) for four ranges in hydraulic conductivity, as computed by ATMOFLUX. Using these data, DELETDELH computes, for each subarea, values of $\Delta ET/\Delta H$ for depths to water of from 1 to 30 ft (0.3 to 9.1 m).

Values of $\Delta ET/\Delta H$ are computed by DELETDELH by the following procedure. Input values of GWETO (ratio of limiting rate of evapotranspiration to hydraulic conductivity) were multiplied by the input value of HCU to convert the dimensionless GWETO value into a limiting rate of evapotranspiration (in feet per day) from the water table. This flow was then routed down to the base of the confining layer, using input data on HCL and thickness of the confining layer, to obtain the artesian head (expressed as depth to water) necessary to sustain this flow. The flow is largest for the shallowest computed depth to water (1 ft, or 0.3 m) and decreases with increasing depth to water. The steady-state model uses changes in head and flow as boundary conditions. Change in flow per unit of head change ($\Delta ET/\Delta H$) was computed by DELETDELH for an input value of depth to water by dividing differences in flow by differences in depth to water. An example of results of the computations is shown in attachment F.

The relation between evapotranspiration and depth to water is a curvilinear function. The function is computed by the program DELETDELH. Output from this program are tables of $\Delta ET/\Delta H$ values for depths of from 1 to 30 ft (0.3 to 9.1 m) to water. The model calculates the change in evapotranspiration with change in water level as a linear function. Therefore, an iterative procedure is used with the steady-state model to select the value of [illegible] for the change in evapotranspiration from the initial water level to the final water level. The model is run initially with [illegible] not modeled, and change in river stage as the only stress on the model. The model is [illegible] with change in river stage and the [illegible] value [illegible] change from the initial head to the final head determined [illegible] during the initial run. (See fig. 29.) The computed head change [illegible] subtracted from the average preconstruction water level to [illegible] water level. Then, from the table of [illegible] values, a second [illegible] chosen corresponding to the computed water level. [illegible] using the second value of [illegible]. This process is repeated until the model-computed head is equal to the final head [illegible].

An example of the alphanumeric representation of [illegible] lock-and-dam area and the list of input values are [illegible].

Thickness of Streambed Material

GWFLOW allows the thickness of streambed material to be entered as either constant or as a unique value at each node or at all [illegible] of the stream courses. For the Red River models, values of streambed thickness were determined in the calibration of SUPERMOCK. The thickness values [illegible] those found through calibration to reproduce observed potentiometric levels of observation wells near the stream and still maintain reasonable annual accretion summations at the wells. The only difference in the streambed thickness map used in GWFLOW and that calibrated in SUPERMOCK was at [illegible] where small, nonzero thicknesses were applied in the nonsteady state. In these instances, zeros were inserted in the thickness map for steady-state analysis. The reason for these changes involves model treatment of [illegible] nodes. A very small thickness of streambed material causes computational problems in GWFLOW. An example of a streambed-thickness map [illegible] is shown in figure 17.

Head Conditions in Confined Aquifer (Node-level Map[illegible]

GWFLOW requires that a node-level map be entered on [illegible]. The node-level map is a numeric map indicating the head condition that exists [illegible] aquifer at each nodal location. An example of a node-level map [illegible] is shown in figure 18. SUPERMOCK uses the same scheme for node identification but computes its own node-level map, based upon other input data. A type-1 node indicates a point inside the flow system where the head is [illegible]. At a stream node, a 1 indicates partial penetration of the aquifer by the stream. A type-2 node indicates a point inside the flow system where the head is specified. For example, a 2 would be coded for a stream node where the stream fully penetrates the aquifer. A type-3 node indicates [illegible] the flow system, a no-flow boundary. In the Red River models, [illegible] daries of the node-level maps were coded as 3. Nodes coded as [illegible] determined by inspection of the streambed-thickness map used in SUPERMOCK. A 2 was coded at each node where a small nonzero thickness [illegible] assigned in SUPERMOCK. As mentioned previously, a zero thickness [illegible] to these nodes in the streambed-thickness map for GWFLOW. All remaining nodes in the GWFLOW node-level maps were coded as type 1.

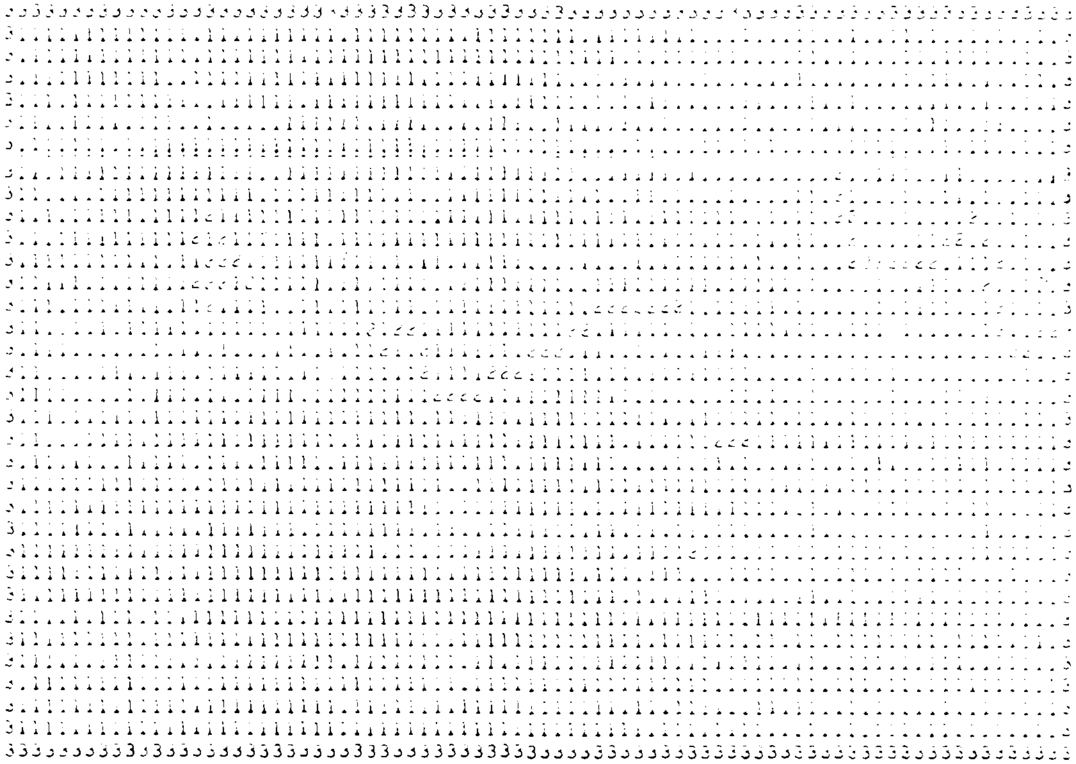
MAP OF CHANGE IN EVAPOTRANSPIRATION PER UNIT CHANGE IN HEAD

```
SYMBOL   CHANGE IN EVAPOTRANSPIRATION IN FEET
          PER DAY PER UNIT CHANGE IN HEAD

                                                        0.000010
                                                        0.000007
                                                        [illegible]
                                                        [illegible]
                                                        [illegible]
```

```
33333333333333333333333333333333333333333333333333333333333333333333333333333333
3           B                                                                  3
3            B                                                                 3
3            B                                                                 3
3             B                                                                3
3             B                                                                3
3            B                                                                 3
3             B                                                                3
3  FF         B                                                                3
3 F F                                                                          3
3FFFFFFFFF                                                                     3
3         F                                                                    3
3    A     F                                                                   3
3    A     F F   FFFF                              GAA                         3
3  AA       F   F    F   JJ                         AA FFFII                   3
3  A                 F   J                            G     FF                 3
3  A    AA            JKK                                       FFF            3
3   A  A  A    A                                                FFF            3
3    A A  AAA  AA                                                BL            3
3     A      AA AAA AA                                  GDDD     B   L         3
3              A AAA A                                G     D     B  BB        3
3               AA A A                                G      DD JJJBB B       F3
3               H    II                            GGGG        D     GGGG     F3
3            DD      GG                             G                   GGGG  F3
3             D      FFFFFF              GGG                            G GGFF 3
3              D         G  AAAA         G G   JJ   J                   GGG    3
3              D          IH AAAA       JJ GDDD D   D                          3
3              G                J      J   G DD  DDD                           3
3               G                J     GG                                      3
3                GGGGI        HKJDDDD J                                        3
3                     GGGG   K  J  D J                                         3
3                         DDDD                                                 3
3                                                                              3
33333333333333333333333333333333333333333333333333333333333333333333333333333333

Map of thickness of streambed and lakebed material

SYMBOL             THICKNESS (FT)
  A                    20.
  B                    20.
  C                     0.
  D                     5.
                        0.
  F                     5.
  G                    10.
  H                     0.
  I                    15.
  J                     2.
  K                     1.
  L                    40.

INITIAL ELEVATION OF POTENTIOMETRIC SURFACE --     0.

NUMBER OF ROWS --     34    NUMBER OF COLUMNS --     80

NODE SPACING --     2640.0FEET
```

Figure 17.--Example of alphameric streambed-thickness map for steady-state analysis

```
NODE LEVEL MAP OF FLOW SYSTEM

EXPLANATION

1 -- INSIDE FLOW SYSTEM WITH HEAD NOT SPECIFIED
2 --INSIDE FLOW SYSTEM WITH HEAD SPECIFIED
3 -- OUTSIDE FLOW SYSTEM OR FLOW BOUNDARY
```



```
Coefficient of storage --   0.002000

Conductivity of streambed and layered material --   0.005000
```

Figure 18.--Example of node-level map

Changes in Stream Stage

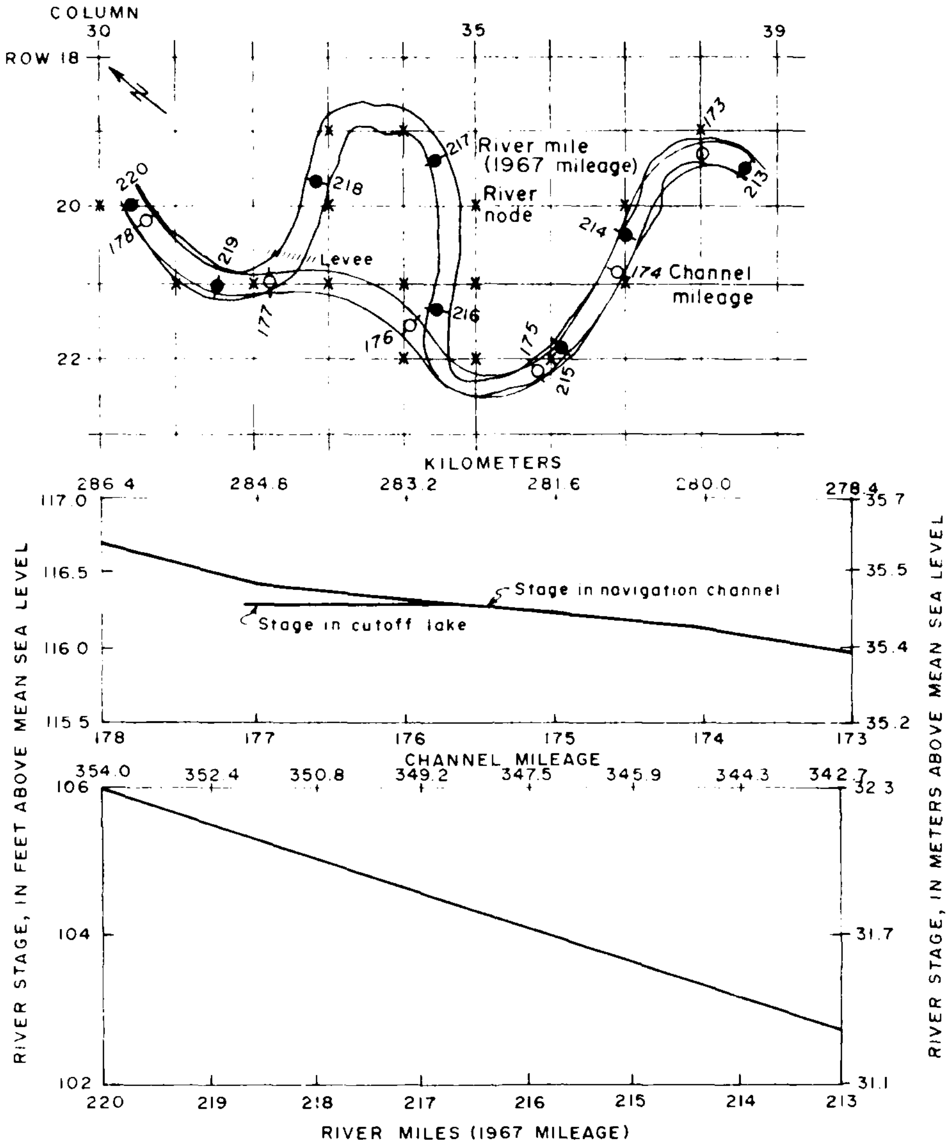
Stream-stage data were entered to [illegible] as average changes in stage at specified grid nodes. For the Red River models, these average changes in stage were based on the differences between the preconstruction and the projected postconstruction profiles of the Red River, which were supplied by the Corps of Engineers. These changes in stage were applied to nodes representing the stream channel. Figure 19 shows plan-and-profile views of a segment of the river and illustrates the method for computing stage differences. Nodes representing the locations of existing and proposed channels are indicated by an "X" in the illustration. The difference in stage was incremented in 0.5-foot (0.15-m) steps. Thus, the model input consisted of a series of 0.5-foot (0.15-m) increments of stage change at specified nodes or groups of nodes representing the location of the river.

Where the navigation channel departs from the existing channel, levees are to be constructed across the existing channel near the upper ends of the cutoff channels, thus forming cutoff lakes (fig. 19). The lakes formed by this operation will be open to the navigation channel at the lower end of the cutoff. Because of the differences in elevations of the water surfaces in the navigation channel and the cutoff lakes, the change in stage along the course of a cutoff lake was computed as the difference in elevation between the navigation channel at the point of departure of the cutoff lake and the stage profile on the preconstruction channel.

It was assumed that the stages of tributary streams will remain unchanged through the postconstruction period, except where affected by backwater from navigation pools. At the mouth of each tributary stream, the change in water-surface elevation was set equal to the change in the main stem at that point. This change in water-surface elevation was extrapolated upstream to a point-of-zero change where the projected backwater profile intersected the natural-stream profile.

CALIBRATION AND VERIFICATION OF THE NONSTEADY-STATE MODEL

Calibration and verification (Matalas and Maddock, 1976) of the nonsteady-state model was based on simulating the observed water-table levels and potentiometric heads at observation-well locations. Calibration was effected within established error criteria by adjusting model parameters within established plausibility ranges. Computations were made using river-stage and climatic data for a 4-year period of record to provide sufficient time for inclusion of antecedent conditions. Visual inspection of computed 4-year hydrographs indicated that most of the antecedent conditions were satisfied during the first calibration year and that all had been satisfied by the end of the second year. The third and fourth years of the observed water-level data were split into two periods. The fourth year was chosen as the calibration period for obtaining a match of simulated and measured hydrographs by adjusting model parameters. The model results for the third year were used for verification evaluation by comparing differences between the measured and simulated hydrographs.



Stream-stage data for input to GWFLOW

Change (ft)	Row	Column	Change (ft)	Row	Column	Change (ft)	Row	Column	Change (ft)	Row	Column
10.5	20	30	11.5	19	33	12.0	20	35	12.5	22	35
				19	34		21	34		22	36
11.0	21	31		20	33		21	35	13.0	19	38
	21	32		21	33		22	34		20	37
										21	37

Figure 19.--Plan-and-profile views of a segment of river channel showing the method for computing stage change.

In the calibration process, all computed water-table and potentiometric-surface elevations of observation-well locations in the grid were passed by SUPERMOCK on a magnetic-disk data set to DATE. DATE performed several functions, including (in sequence): (1) converting mean sea level elevations to depths below land surface; (2) assigning calendar dates to all water levels; (3) choosing the spring high and the fall low water level for the water table and potentiometric surface for 1 or more years, as specified; (4) comparing these high and low computed values with observed data entered to it on cards; (5) printing a calibration table for analysis; and (6) passing all computed water-table and potentiometric-surface levels for the observation nodes in card images to HYDROG (Reed and others, 1976) on a magnetic-disk data set. An example of the calibration table produced by DATE is shown in figure 20. Using these computed data as input, HYDROG plotted hydrographs for both the potentiometric surface and the water table. These computed hydrographs were compared visually with observed hydrographs to check for differences between the two in fluctuations and depths to water.

The parameters that were modified, within predetermined plausibility ranges, during calibration of the nonsteady-state models included the upper and lower hydraulic conductivities of the confining layer (HCU and HCL) in each subarea of the grid, aquifer-storage coefficient in each subarea (S), specific yield in each subarea (WTSTO), and streambed thicknesses (AM). In order to match observed data, a general calibration table from DATE was inspected to determine in which subareas simulated water-table and (or) potentiometric-surface levels were within responding predetermined error criteria. In addition, computed potentiometric-surface and water-table hydrographs from HYDROG were compared to hydrographs developed from observed measurements. After a thorough analysis of a run, indicated changes were made to appropriate parameters, and a new computer run was made. Normally, from 20 to 25 runs were required to calibrate each nonsteady-state model.

The magnitude and direction of changes that were caused by modification of parameters during calibration of the nonsteady-state model are discussed in the following paragraphs.

The hydraulic conductivity of the upper segment of the confining layer (HCU) limits recharge to the water table and thus the aquifer. For positive accretion, an increase in the modeled value of HCU in a particular subarea causes an increase in elevation of the water table and very likely an increase in the elevation of the potentiometric surface unless the conductivity of the lower segment of the confining layer (HCL) is very low. A decrease in the modeled value of HCU has the opposite effect and would likely cause a decrease in the elevation of both the water table and the potentiometric surface.

As previously mentioned, HCL is the designation of the hydraulic conductivity of the confining layer from the water table to the top of the aquifer. An increase in the modeled value of HCL generally results in an increase in the elevation of the potentiometric surface and a decrease in the water table. Decreasing the modeled value of HCL has the opposite effect; that is, the water table will rise and the potentiometric surface will fall.

POTENTIOMETRIC SURFACE

WELL NUMBER	MEASURED DEPTH BELOW LAND SURFACE (ft)	COMPUTED DEPTH BELOW LAND SURFACE (ft)	DIFFERENCE *
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

TOTAL = [illegible]

AVERAGE = [illegible]

[illegible] = [illegible] STANDARD
[illegible] = [illegible] DEVIATION = [illegible]

WATER TABLE

WELL NUMBER	MEASURED DEPTH BELOW LAND SURFACE (ft)	COMPUTED DEPTH BELOW LAND SURFACE (ft)
[illegible]	**	15.4
[illegible]	**	[illegible]
[illegible]	**	[illegible]
[illegible]	5.[illegible]<WL	[illegible]
[illegible]	**	[illegible]
[illegible]	**	[illegible]
[illegible]	[illegible]<WL< 5.8	[illegible]
[illegible]	**	[illegible]
[illegible]	**	[illegible]
[illegible]	**	[illegible]
[illegible]	12.0<WL< 12.6	[illegible]
[illegible]	**	[illegible]
[illegible]	**	[illegible]
[illegible]	3.0	[illegible]
[illegible]	**	[illegible]
[illegible]	15.[illegible]<WL	[illegible]
[illegible]	0.5<WL< 1.5	[illegible]
[illegible]	[illegible]	12.9
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	15.[illegible]<WL	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	15.[illegible]<WL	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	15.[illegible]<WL	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	15.[illegible]<WL	[illegible]
[illegible]	[illegible]<WL	[illegible]
[illegible]	5.9	[illegible]
[illegible]	[illegible]<WL< [illegible]	[illegible]
[illegible]	[illegible]<WL< [illegible]	[illegible]
[illegible]	[illegible]<WL< [illegible]	[illegible]
[illegible]	14.[illegible]<WL	[illegible]
[illegible]	[illegible]<WL< [illegible]	[illegible]
[illegible]	[illegible]<WL< [illegible]	[illegible]
[illegible]	[illegible]<WL< [illegible]	[illegible]
[illegible]	[illegible]<WL< [illegible]	[illegible]
[illegible]	**	[illegible]
[illegible]	**	[illegible]
[illegible]	5.[illegible]<WL< 10.0	[illegible]
[illegible]	**	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	2.5	[illegible]

---

* [illegible]

** NO MEASURED WATER LEVELS AVAILABLE AT THIS SITE.

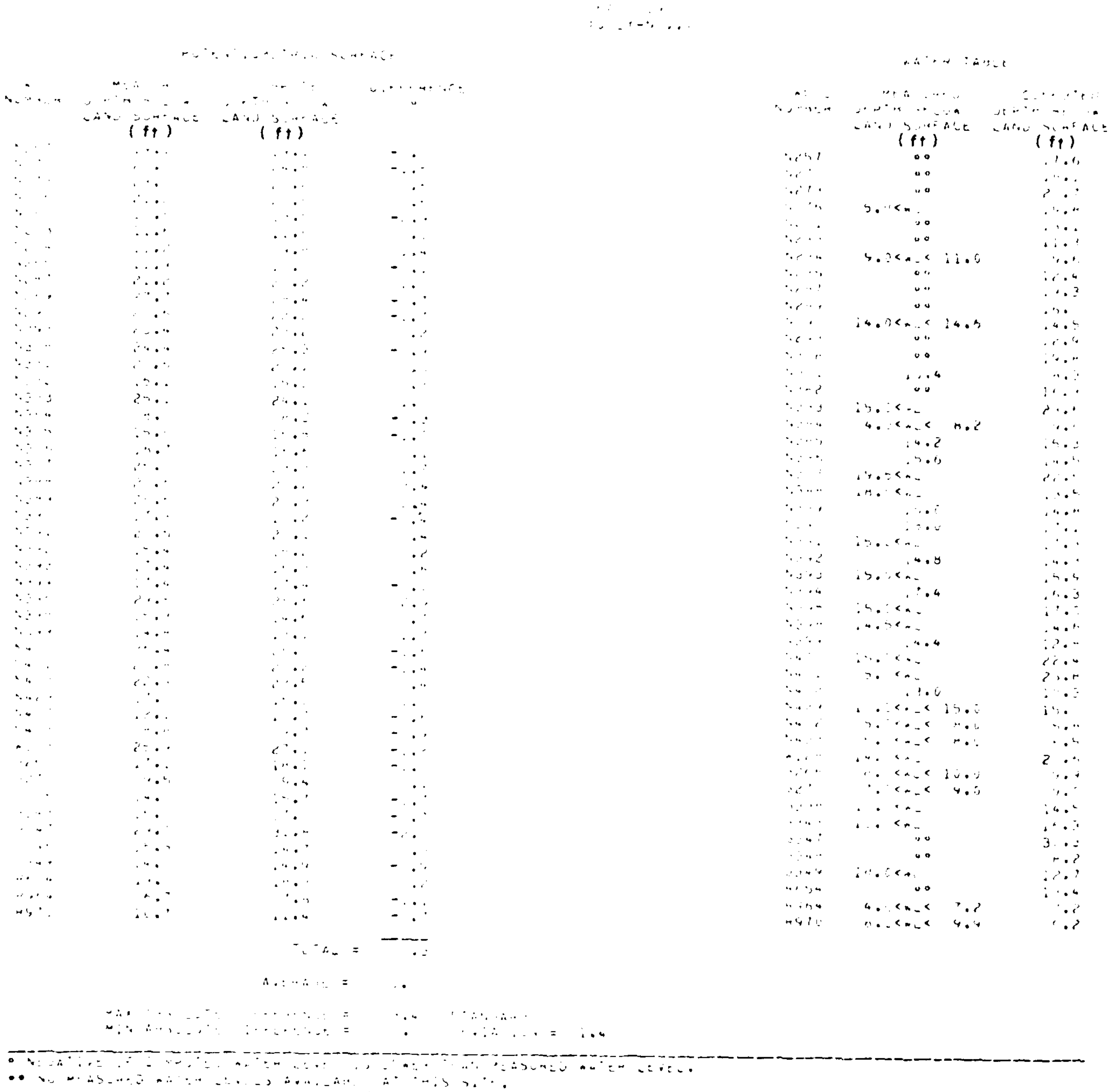


Figure 20.--Examples of spring and fall calibration charts from DATE program.

If negative accretion is occurring--that is, the water table has dropped below the potentiometric surface and water is moving up from the aquifer--increases in the modeled value of HCL will raise the water table and lower the potentiometric surface. Decreases in the modeled value of HCL will lower the water table and raise the potentiometric surface. Changes in the modeled value of HCU will either raise or lower both surfaces.

Adjustments to the storage-coefficient (S) and specific-yield (WTSTO) values can be used to control the fluctuations of the potentiometric surface and water table, respectively. Increases in modeled values of either of the two parameters will cause smaller fluctuations, and decreases in these values will cause larger fluctuations. Modifications to these parameters are very useful during calibration for adjusting computed water levels for the spring and fall that differ from observed values by about the same magnitude but in opposite directions.

The thickness of streambed materials can be adjusted to produce a change in the computed water-table and potentiometric levels near the stream. In the Red River Valley, the movement of water generally is from the alluvial aquifer to the river or stream. Therefore, if the modeled thickness of streambed material is too small, computed water levels in observation wells near the stream are lower than the observed levels unless the recharge rate is increased substantially. If increasing the conductivities of the upper confining layer in the affected subareas does nothing more than increase computed accretion values to unreasonable levels without an appreciable rise in water levels, the streambed thickness is too small. The upper plausibility limit on accretion was 1 ft/yr (0.3 m per year). An example of a table of annual accretion summations at observation wells is shown in figure 21.

MODEL OUTPUT

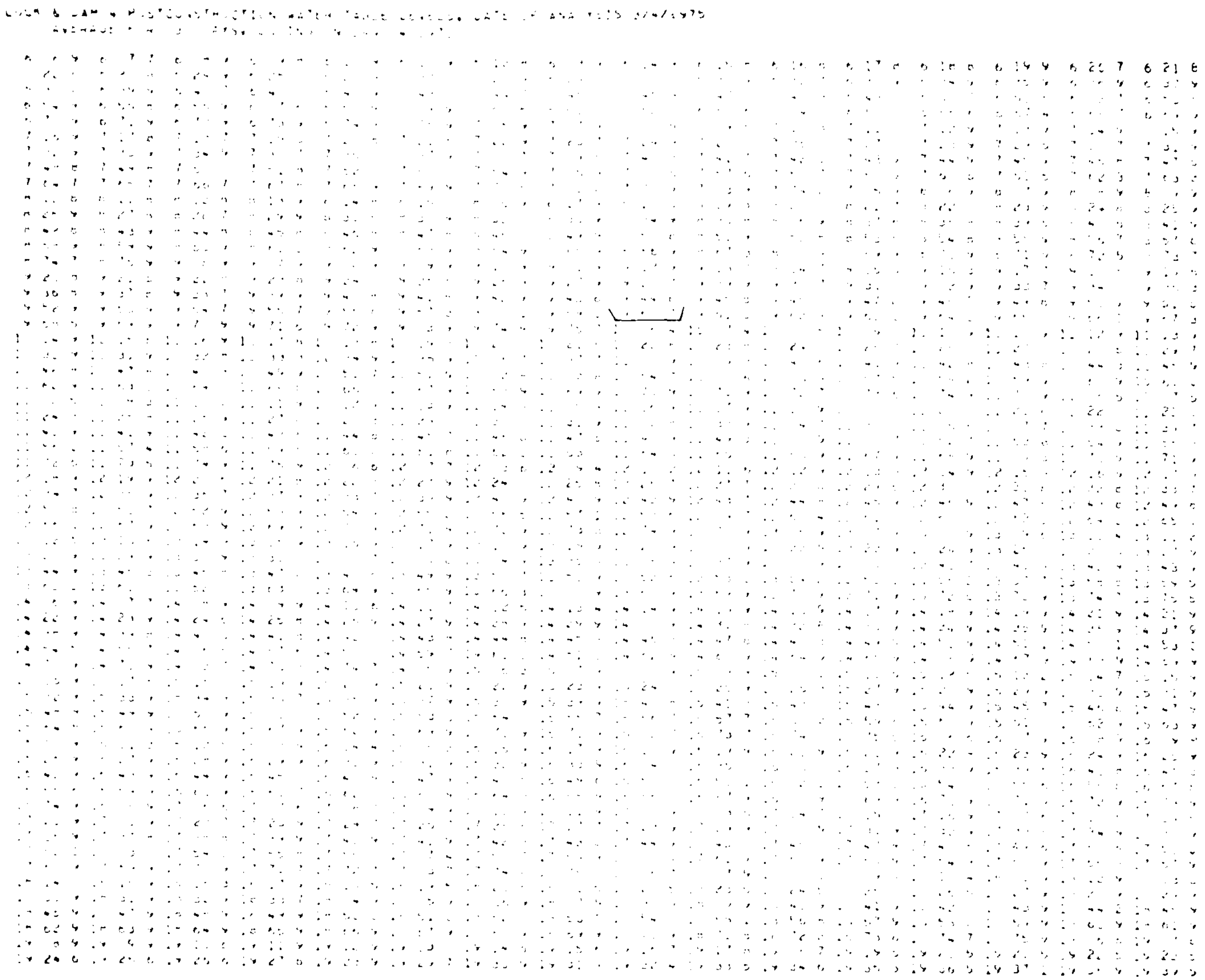
The output from the nonsteady-state model, in addition to that used for calibration, was designed to display the results of the analysis in a form suitable for the determination of the effects of the water table on agriculture. The critical parameter influencing agricultural production is the depth to the water table below land surface. The depth to the water table has a significant effect when it is within the root zone, or within approximately 5 ft (1.5 m) of the land surface. Times of occurrence of shallow depths to the water table are also significant. The most critical periods occur during the plowing, planting, growing, and harvesting seasons of the year. For this reason, output from the model was designed to show the average depth to the water table for either one or two 10-day time frames during these critical periods. A series of 30-day time frames was used to represent water-table conditions during the dormant season. In this manner, the year was divided into 21 time frames associated with specific calendar dates. The dates were selected by the Soil Conservation Service. The actual output consisted of data, punched on computer cards, showing the computed depth to the water table below land surface, to the nearest foot, at each node in the model. Figure 22 is an example of part of the data, in printout form, showing the node location (row and column) and depth to the water table for a particular time frame.

```
                                              ACCRETION SUMMATION (FT.)

                                                 CALENDAR YEAR 1972

WELL NO.  ROW  COL  ACSUM      WELL NO.  ROW  COL  ACSUM      WELL NO.  ROW  COL  ACSUM      WELL NO.  ROW  COL  ACSUM
   N267    19   15   0.25         N270    19   54   0.23         N273    29   42   0.52         N276    18   42   0.00
   N261    31   22   0.54         N263    28   17   0.54         N264    26   19   0.30         N265    22   23  -0.08
   N287    17   28   0.35         N289    16   30   0.04         N290    15    6   0.32         N293     7    9   0.38
   [illegible]  7    5   0.10     N381    16   10   0.20         N382    17   19   0.68         N383    18   24   0.29
   [illegible] 22   12   0.02     N385    19   28   1.00         N386    20   30   0.15         N387    18   32   0.04
   [illegible] 19   35   0.04     N389    17   41   0.19         N390    23   42   0.07         N391    25   40   0.18
   N392    27   39  -0.02         N393    24   37   0.12         N394    22   45   0.01         N395    15   46   0.00
   [illegible] 21   34   0.16     N399    29   30  -0.00         N400    26   47   0.01         N401    25   51   0.01
   N402    10   12   0.40         N429    15   53   0.90         N432    21   51   0.81         N433    18   49   0.57
   [illegible] 11   19   0.00     G268    16   67   1.17         G270    18   73   0.32         G338    19   70   1.05
   G343    14   57   0.07         G347    13   50   1.35         G348    11   50   0.21         G349    12   63   1.26
   R954    24   71   0.46         R964    29   79  -0.13         R970    28   78   0.46
```

Figure 21.--Example of accretion-summation chart.



NOTE.—Figure shows row-column designation, and depth to water. Example underlined means: Row 9, column 60, 7 foot depth to water.

Figure 22.--Example of computed output from nonsteady-state model.

Depths to the water table of as much as 9 ft (2.7 m) below land surface are shown in the printout. Because the table format prints depth as only a single-digit integer, a 9 indicates a depth of 9 ft (2.7 m) or more.

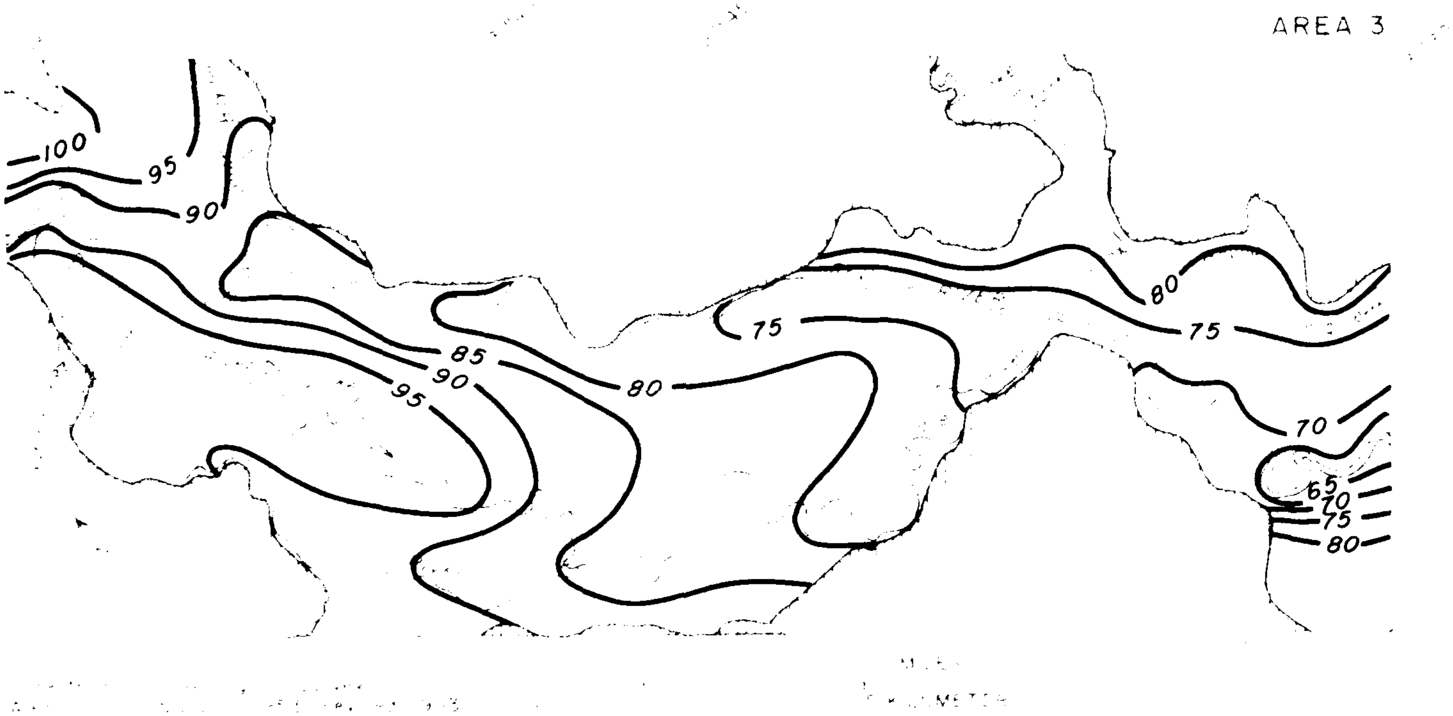
The combination of depth to water table, soil type, and cropping pattern was used by the Soil Conservation Service to determine the beneficial or adverse effects of project-induced changes in water levels. Crop yields obtained during the calibration period were used as the standard for determining the net project effects.

Output from the steady-state analysis consisted primarily of head-change data, shown as tabulations or as maps. Maps of head change with time are available from the model, but only the final or steady-state output was considered significant because it represented the dynamic equilibrium conditions resulting from the change in river stage. This head-change map was used to compute the average postconstruction potentiometric surface. The elements of this computation are shown in figures 23-26. Figure 23 shows the preconstruction potentiometric surface in a lock-and-dam area. The computed head change is shown as a grid plot to the same scale as the model grid (fig. 24) and as a complete contour map (fig. 25). The head change was added algebraically to the preconstruction potentiometric surface to produce the resultant potentiometric configuration shown in figure 26. This method is based on the principle of superposition that assumes that the flow field in the aquifer can be considered a linear system and that the head change component can be analyzed independently. The principle of superposition allows the postconstruction condition to be determined as the sum of the preconstruction head and the head-change component.

CONTINUING STUDIES

The modeling procedures developed for this study, particularly those for the modeling of nonsteady flow, were designed to provide data for an assessment of the effects of project-induced water-level changes on agriculture. However, these procedures can be applied to a variety of situations in connection with the Red River Waterways Study. The calibrated models can, with the appropriate boundary changes, be used to analyze the effects of any arrangement of locks and dams or pool stages. Although the results of the study were primarily concerned with agriculture, the nonsteady-state model can be modified to determine the effects of raised water levels in urban areas. The higher water levels may cause flooding of basements, septic tanks, or sewer systems, or may, because of increased moisture content of surficial clays, cause differential movement of footings of buildings, swimming pools, or bridges. The models can also be used to aid in the design of well fields and surface-drainage systems that may be needed in places where shallow water-table levels are anticipated.

To achieve the greatest benefit from the study, the water-level-observation network developed for the study should be maintained and water-level measurements continued through the construction phase to verify the predictions made during the study. The data would provide a definition of the actual ground-water conditions resulting from the stage changes and would provide a means of



EXPLANATION

——80—— Potentiometric contour
Shows elevation of potentiometric surface
Contour interval is 5 feet (1.5 meters)
Datum is mean sea level

Boundary of Red River alluvial aquifer

Figure 23.—Average preconstruction potentiometric surface, Lock and Dam 3 area

```
                    TIME IN DAYS-- 40000.00000

                    80  COLUMNS;  ROWS  16  THROUGH  34

0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

1.3   1.8   2.4   3.1   4.3   5.0   5.3   3.7   2.2   1.5   1.1   0.9   0.7   0.5   0.4   0.4   0.0

1.2   1.8   2.3   2.9   3.6   4.2   4.6   4.6   2.4   1.6   1.2   0.9   0.7   0.5   0.4   0.4   0.0

1.2   1.7   2.2   2.7   3.2   3.8   4.4   5.0   2.6   1.7   1.3   0.9   0.7   0.5   0.4   0.4   0.0

1.2   1.7   2.2   2.6   3.0   3.6   4.7   4.7   2.9   1.9   1.4   1.0   0.7   0.5   0.4   0.4   0.0

1.3   1.7   2.1   2.5   2.9   3.4   4.3   4.3   3.5   2.3   1.5   1.0   0.7   0.5   0.4   0.4   0.0

1.4   1.8   2.2   2.5   2.9   3.3   3.5   3.7   3.5   2.4   1.6   1.0   0.7   0.5   0.4   0.4   0.0

1.5   1.9   2.2   2.5   2.9   3.4   3.6   3.6   3.4   2.4   1.6   1.0   0.7   0.5   0.4   0.3   0.0

1.6   1.9   2.2   2.5   2.9   3.3   3.2   3.0   2.7   2.1   1.4   1.0   0.6   0.4   0.3   0.2   0.0

1.8   2.0   2.2   2.6   2.9   3.1   2.8   2.5   1.9   1.3   0.8   0.7   0.4   0.2   0.2   0.1   0.0

1.9   2.1   2.3   2.5   2.6   2.5   2.4   2.0   1.4   0.8   0.3   0.2   0.1   0.1   0.0   0.0   0.0

2.3   2.4   2.4   2.4   2.4   2.2   2.1   1.7   1.0   0.5   0.1   0.0   0.0   0.0   0.0   0.0   0.0

3.1   2.9   2.7   2.3   2.1   1.9   1.8   1.3   0.6   0.2   0.1   0.0   0.0   0.0   0.0   0.0   0.0

4.1   3.8   3.1   2.4   1.4   1.3   1.2   0.7   0.2   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0

5.7   5.3   3.6   2.4   1.2   1.0   0.7   0.5   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

9.5   6.1   3.9   2.2   0.9   0.7   0.5   0.4   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

8.5   5.5   3.3   1.8   0.8   0.3   0.3   0.3   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

8.2   4.1   2.2   1.0   0.3   0.2   0.2   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

6.2   2.4   1.0   0.4   0.1   0.1   0.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

NOTE.—Eight sheets of printout required for complete coverage of a single modeled area.

Figure 24.--Example of computed output from steady-state model showing a section of head-change map.

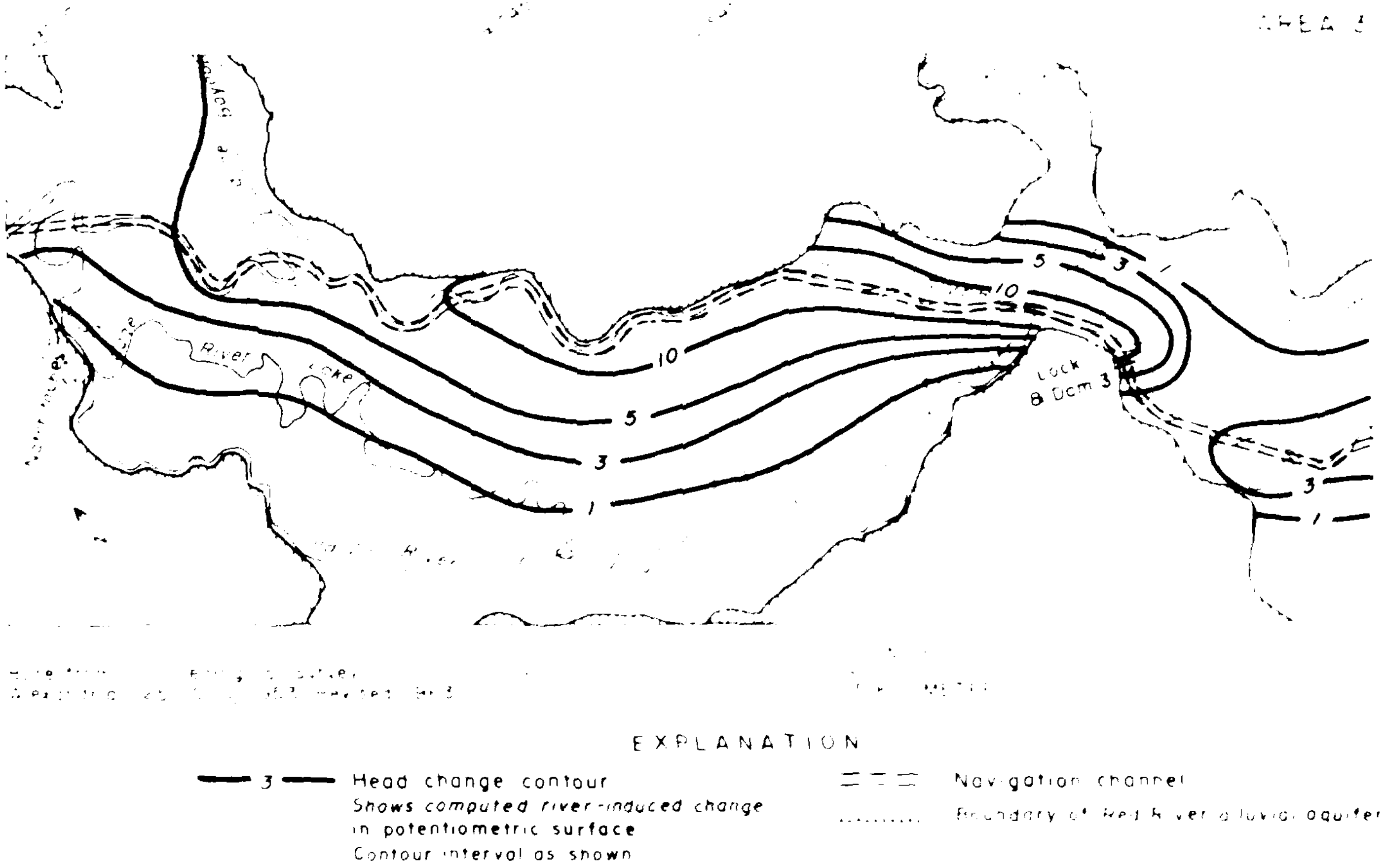


Figure 25. Contour map showing computed head [illegible]

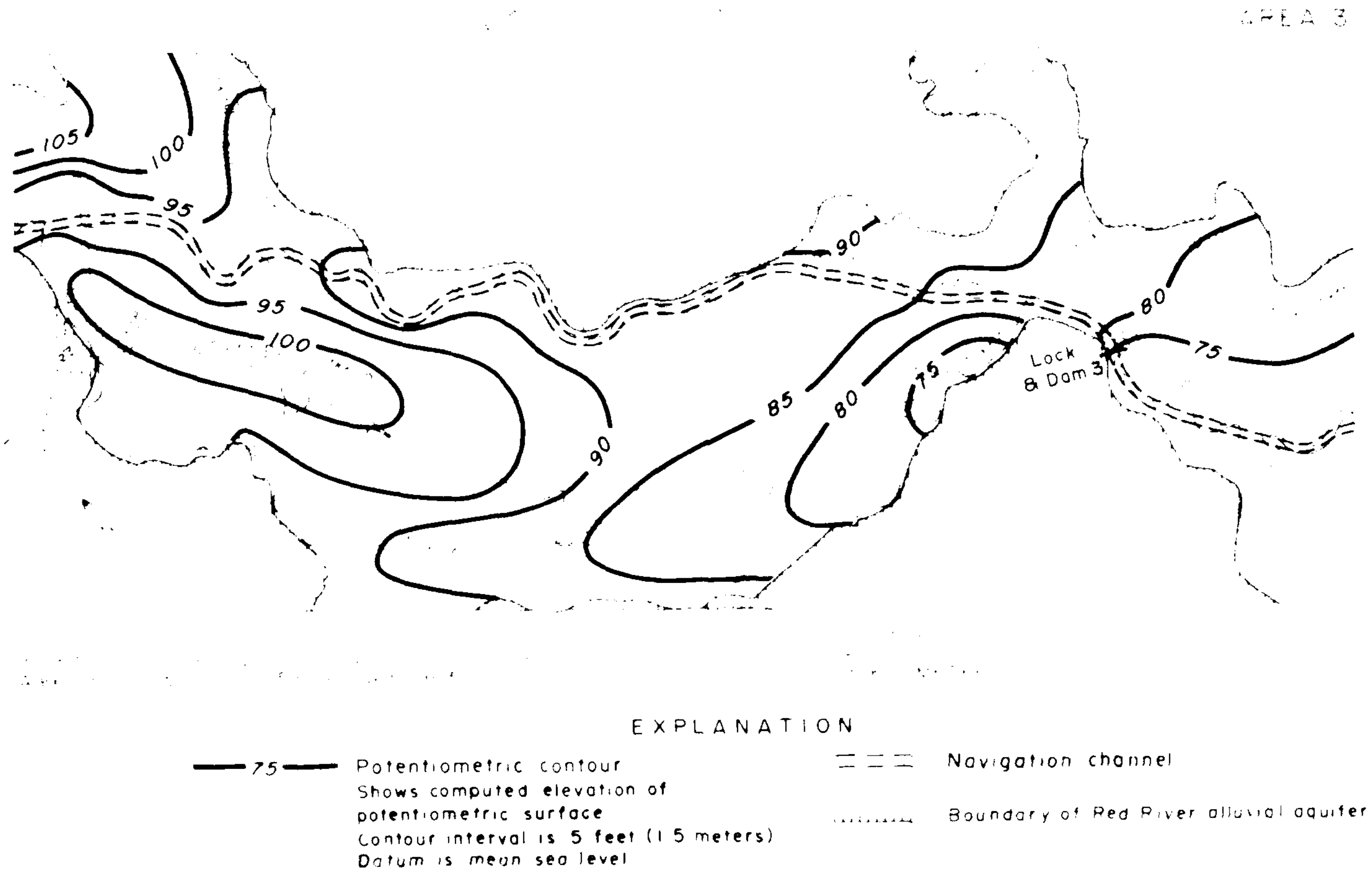


Figure [illegible]. Computed average postconstruction potentiometric surface, Lock and Dam 3 area comparison of observed and predicted water levels. From these comparisons, adjustments could be made, if necessary, to the modeling techniques. Once verified, the model would have application in future studies of alluvial systems.

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ATTACHMENTS

The following attachments give the program listings and show the input data requirements for the peripheral programs used in conjunction with the SUPERMOCK and GWFLOW models. The relation of the peripheral programs to the models in shown in figure 27. Examples of printed output (figs. 28, 29) from the AVERAGE and DELETDELH programs are given along with the respective documentation. Output from the AVERAGE program is not used directly in the GWFLOW model, but it provides control for the contour map of the average preconstruction potentiometric surface used in conjunction with the output from the GWFLOW model. Primary output from the ATMOFLUX and POTEET programs is punched on cards and that from the RIVCHANGE and TRIBCHANGE programs is stored on disk data sets. Examples of output from these four programs are not shown.

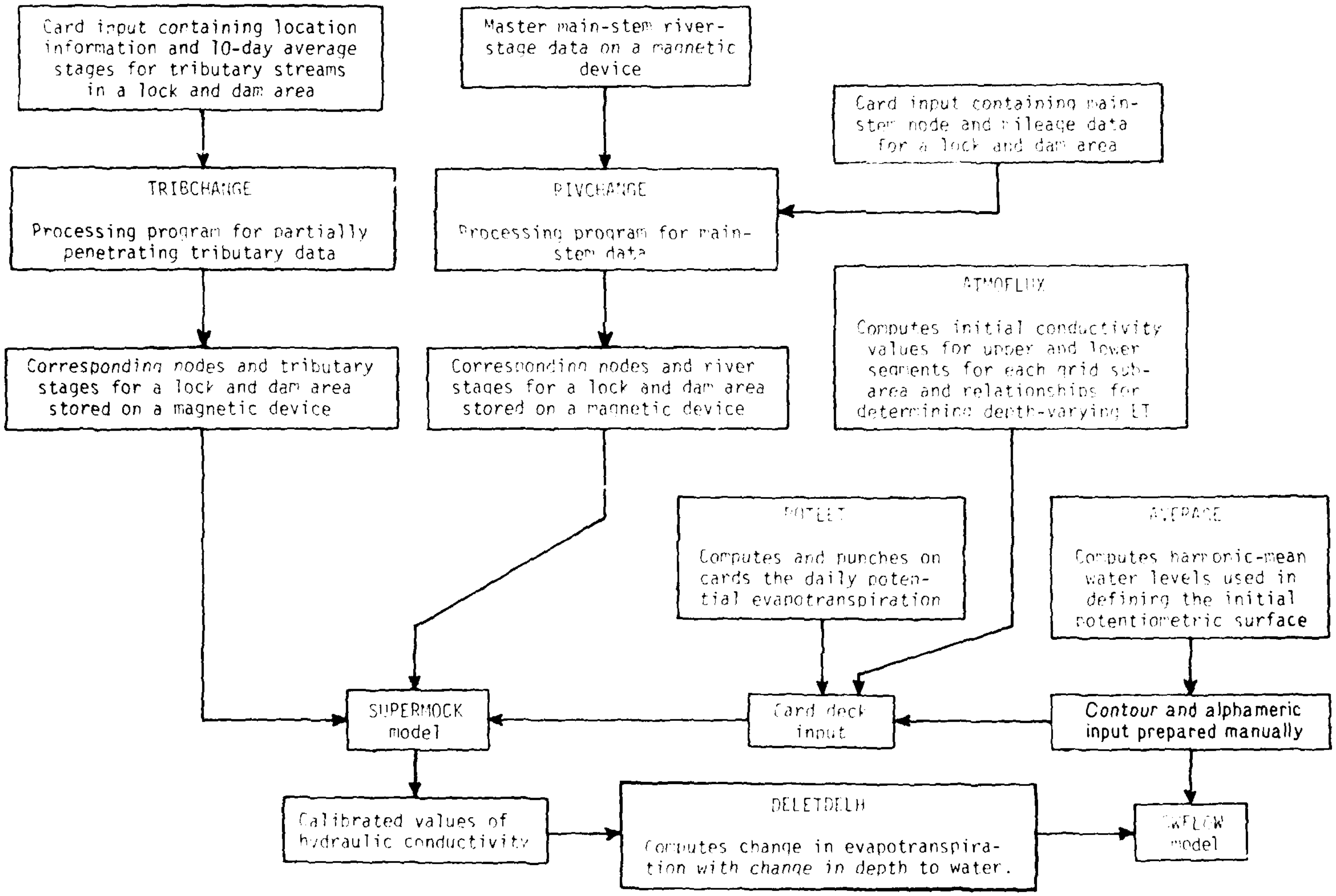

Figure 27.--Generalized chart showing relationship of digital programs that prepare data for input to SUPERMOCK and GWFLOW models.

ATTACHMENT A

AVERAGE Program

Table 2.—*Input data for AVERAGE program*

Reference	Number of cards	Columns	Format	Program variable	Input item	Remarks
Dates	1	1-2	I2	IM0N	Beginning month for period of interest.	These should be two-digit numeric values.
		3-4	I2	IYR	Beginning year for period of interest.	
		5-6	I2	JM0N	Ending month for period of interest.	
		7-8	I2	JYR	Ending year for period of interest.	
The following will be read repetitively for each well entered						
Well data	1	61-67	F7.2	ELEV	Land-surface elevation at well.	
		80	I1	IN0	Card number.	
	1	20-24	F5.1	DEPTH	Depth of well.	
		80	I1	IN0	Card number.	
	1 or more	21-69	12A4, 2A1	IHED(I)	Heading information for well.	The program will continue to look for cards in this format until IN0<1.
		79-80	I2	IN0	Card number.	

Water-level data	1 or more	20-75	4(3I2, A1,F6.2, 1X)	MO(I), ID(I), IY(I), SIN(I), WL(I), I=1,4	MO(I)--month water-level measurement taken. ID(I)--Day measurement taken. IY(I)--Year measurement taken. SIN(I)--Sign of water level. WL(I)--Water level, in feet below land surface.	The program will continue to look for cards in this format until an end of file is encountered.
		78-80	I3	JNUM	Card number.	

Table 3.—AVERAGE program listing

```
C     *********************************************************************
C
C                                 AVERAGE
C                                   BY
C                               JOHN TERRY
C
C
C       THIS PROGRAM COMPUTES THE HARMONIC (TIME-WEIGHTED) AVERAGE WATER
C     LEVEL FOR A SPECIFIED PERIOD OF RECORD FOR ANY NUMBER OF WELLS.
C     THE PROGRAM IS DESIGNED TO READ WL1 AND WL2 CARDS IN THE USGS
C     GROUND-WATER FORMATS. HOWEVER, IT COULD BE REFORMATTED TO ACCEPT
C     WATER-LEVEL CARDS AS THEY ARE PUNCHED FOR SYSTEM 2000.
C
C     *********************************************************************
C
      DIMENSION IDAY(12),SIGN(3),IHED(200),MO(4),ID(4),IY(4),WL(4),
     1 SIN(4),IMO(4),IID(4),IIY(4),AWL(4)
      DATA JM,JD,JY,WLM/0,0,0,0.0/
      DATA SIGN/'+','-',' '/
      DATA IDAY/31,28,31,30,31,30,31,31,30,31,30,31/
      IRD=5
      IPT=6
      IZT=0
C
C     IMON -- BEGINNING MONTH FOR DESIRED PERIOD OF RECORD.
C
C     IYR -- BEGINNING YEAR FOR DESIRED PERIOD OF RECORD.
C
C     JMON -- ENDING MONTH FOR DESIRED PERIOD OF RECORD.
C
C     JYR -- ENDING YEAR FOR DESIRED PERIOD OF RECORD.
C
      READ (IRD,45) IMON,IYR,JMON,JYR
C
C     ELEV -- LAND-SURFACE ELEVATION AT WELL.
C
C     INO -- CARD NUMBER.
C
    1 READ (IRD,46,END=44) ELEV,INO
      MQ=0
      ISM=0
      JSM=0
C
C     DEPTH -- DEPTH OF WELL.
C
C     INO -- CARD NUMBER.
C
      READ (IRD,47) DEPTH,INO
      IF (DEPTH.EQ.0.0) DEPTH=999.99
      JM=0
```

Table 3.—*AVERAGE program listing*—Continued

```
      WW=0.0
      PAX=9999.
      NP=1
      NTM=0
      NQ=14
      PIN=-999.9
      AVFL=999.99
      PAXFL=999.99
      PINFL=999.99
C
C     IHED(I) -- HEADING INFORMATION FOR WELL.
C
C     INO -- CARD NUMBER.
C
    2 READ (IRD,48) (IHED(I),I=NP,NQ),INO
      IF (INO.LT.1) GO TO 3
      NP=NP+14
      NQ=NQ+14
      GO TO 2
    3 MQ=MQ+1
      M=1
C
C     MO(I) -- MONTH WATER-LEVEL MEASURMENT TAKEN.
C
C     ID(I) -- DAY WATER-LEVEL MEASUREMENT TAKEN.
C
C     IY(I) -- YEAR WATER-LEVEL MEASUREMENT TAKEN.
C
C     SIN(I) -- SIGN OF WATER-LEVEL VALUE.
C
C     WL(I) -- WATER LEVEL
C
    4 READ (IRD,49) (MO(I),ID(I),IY(I),SIN(I),WL(I),I=1,4),JNUM
      IF (MQ.NE.1) GO TO 9
      IF (IYR.EQ.0) GO TO 8
      DO 7 IT=1,4
      IF (IY(IT)-IYR) 7,5,6
    5 IF (MO(IT).LT.IMON) GO TO 7
    6 IF (ISM.EQ.1) GO TO 7
      ISM=1
      M=IT
    7 CONTINUE
      IF (ISM.EQ.1) GO TO 8
      IF (JNUM.EQ.0) GO TO 1
      GO TO 4
    8 LM=MO(M)
      LD=ID(M)
      LY=IY(M)
      LPM=0
    9 DO 10 I=M,4
```

Table 3.—[illegible] program [illegible]—Continued

```
      IF (SIN(I).EQ.SIGN(1)) WL(I)=WL(I)*(-1.0)
   10 CONTINUE
      IF (JYR.EQ.0) GO TO 14
      IF (JSM.EQ.1) GO TO 37
      DO 13 JT=M,4
      IF (IY(JT)-JYR) 13,11,12
   11 IF (MO(JT).LE.JMON) GO TO 13
   12 JSM=1
      IF (JT.EQ.M) GO TO 37
      MO(JT)=MO(JT-1)
      ID(JT)=ID(JT-1)
      IY(JT)=IY(JT-1)
      WL(JT)=WL(JT-1)
   13 CONTINUE
   14 IF (M.EQ.4) GO TO 36
      DO 33 I=M,3
      IKO=0
      JT=0
      IJJ=0
      JJJ=0
      IF (JM.EQ.0) GO TO 15
      GO TO 28
   15 IF (MO(I+1).NE.0) GO TO 16
      MO(I+1)=MO(I)
      ID(I+1)=ID(I)
      IY(I+1)=IY(I)
      WL(I+1)=WL(I)
      GO TO 30
   16 IF (MO(I).NE.MO(I+1).OR.IY(I).NE.IY(I+1)) GO TO 17
      BA=(1.0+(ID(I+1)-ID(I)))/2.0
      WW=WW+(WL(I)*BA)+(WL(I+1)*(BA-1.0))
      NTM=NTM+(ID(I+1)-ID(I))
      GO TO 30
   17 IF (IY(I).NE.IY(I+1)) GO TO 20
      IF (MOD(IY(I),4).EQ.0) IDAY(2)=29
      K=MO(I+1)-MO(I)
      IF (K.EQ.1) GO TO 19
      IA=MO(I)+1
      IB=MO(I+1)-1
      DO 18 J=IA,IB
   18 JJJ=JJJ+IDAY(J)
   19 NDY=IDAY(MO(I))-ID(I)
      BA=(1.0+NDY+JJJ+ID(I+1))/2.0
      WW=WW+(WL(I)*BA)+(WL(I+1)*(BA-1.0))
      NTM=NTM+JJJ+ID(I+1)+NDY
      GO TO 30
   20 IF ((IY(I+1)-IY(I)).GT.1) GO TO 26
   21 KP=MO(I)+1
      IF (MOD(IY(I),4).EQ.0) IDAY(2)=29
      IF (KP.GT.12) GO TO 23
```

Table 3.—*AVERAGE program listing*—Continued

```
      DO 22 J=KP,12
   22 JJJ=JJJ+IDAY(J)
      IDAY(2)=28
   23 IF (MO(I+1).EQ.1) GO TO 25
      IPP=MO(I+1)-1
      IF (MOD(IY(I+1),4).EQ.0) IDAY(2)=29
      DO 24 J=1,IPP
   24 IJJ=IJJ+IDAY(J)
   25 NDY=IDAY(MO(I))-ID(I)
      BA=(1.0+JT+NDY+JJJ+IJJ+ID(I+1))/2.0
      WW=WW+(WL(I)*BA)+(WL(I+1)*(BA-1.0))
      NTM=NTM+NDY+JJJ+IJJ+ID(I+1)+JT
      GO TO 30
   26 KP=(IY(I+1)-IY(I))-1
      KKI=365
      DO 27 J=1,KP
      IF (MOD((IY(I)+J),4).EQ.0) KKI=366
   27 JT=JT+KKI
      GO TO 21
   28 IKO=1
      DO 29 K=1,4
      IMO(K)=MO(K)
      IID(K)=ID(K)
      IIY(K)=IY(K)
      AWL(K)=WL(K)
      IF (K.EQ.1) GO TO 29
      MO(K)=MO(K-1)
      ID(K)=ID(K-1)
      IY(K)=IY(K-1)
      WL(K)=WL(K-1)
   29 CONTINUE
      MO(1)=JM
      ID(1)=JD
      IY(1)=JY
      WL(1)=WLM
      GO TO 15
   30 IDAY(2)=28
      IF (IKO.NE.1) GO TO 32
      DO 31 K=1,4
      MO(K)=IMO(K)
      ID(K)=IID(K)
      IY(K)=IIY(K)
   31 WL(K)=AWL(K)
      IKO=0
      JM=0
      GO TO 15
   32 LLM=MO(I+1)
      LLD=ID(I+1)
      LLY=IY(I+1)
      WPD=WL(I+1)
```

Table 3.—*AVERAGE program listing*—Continued

```
   33 CONTINUE
      DO 35 N=M,4
      PIN=AMAX1(PIN,WL(N))
      PAX=AMIN1(PAX,WL(N))
      IF (PIN.NE.WL(N)) GO TO 34
      MA=MO(N)
      MD=ID(N)
      MY=IY(N)
   34 IF (PAX.NE.WL(N)) GO TO 35
      NMA=MO(N)
      NMD=ID(N)
      NMY=IY(N)
   35 CONTINUE
   36 JM=MO(4)
      JD=ID(4)
      JY=IY(4)
      WLM=WL(4)
   37 IF (JNUM.NE.0) GO TO 3
      WW=WW+WPD
      NTM=NTM+1
      AVE=WW/NTM
      IF (ELEV.EQ.0.0) GO TO 38
      AVEL=ELEV-AVE
      PAXEL=ELEV-PAX
      PINEL=ELEV-PIN
   38 IF (MOD(IZT,3).EQ.0) GO TO 39
      WRITE (IPT,54)
      GO TO 40
   39 WRITE (IPT,50)
   40 WRITE (IPT,51)
      WRITE (IPT,52) (IHED(I),I=1,NQ)
      WRITE (IPT,53) LM,LD,LY,LLM,LLD,LLY
      WRITE (IPT,54)
      WRITE (IPT,55)
      WRITE (IPT,56)
      WRITE (IPT,55)
      WRITE (IPT,54)
      WRITE (IPT,58) DEPTH,AVE,AVEL,PIN,MA,MD,MY,PAX,NMA,NMD,NMY,PINEL,P
     1AXEL
      IF (PAX) 41,42,42
   41 WRITE (IPT,57)
      GO TO 43
   42 WRITE (IPT,54)
   43 WRITE (IPT,51)
      WRITE (IPT,59)
      IZT=IZT+1
      GO TO 1
   44 STOP
C
   45 FORMAT (4I2)
```

Table 3.—*AVERAGE program listing*—Continued

```
   46 FORMAT (60X,F7.2,12X,I1)                                          AVE 251
   47 FORMAT (19X,F5.1,55X,I1)                                          AVE 252
   48 FORMAT (20X,12A4,2A1,8X,I2)                                       AVE 253
   49 FORMAT (19X,4(3I2,A1,F6.2,1X),2X,I3)                              AVE 254
   50 FORMAT (1H1)                                                      AVE 255
   51 FORMAT (1H0,15X,'-------------------------------------------------AVE 256
     1------------------------------------------------------')          AVE 257
   52 FORMAT (19X,12A4,2A1,12A4,2A1)                                    AVE 258
   53 FORMAT (44X,'(BEGINNING DATE ',I2,'/',I2,'/',I2,')',4X'(ENDING DATAVE 259
     1E ',I2,'/',I2,'/',I2,')')                                         AVE 260
   54 FORMAT (1H )                                                      AVE 261
   55 FORMAT (24X,'-------------',3X,'-------------',3X,'------------',3AVE 262
     1X,'-------------',3X,'----',3X,'-------------',3X,'----')         AVE 263
   56 FORMAT (24X,'DEPTH OF WELL',3X,'AVERAGE DEPTH',3X,'AVERAGE MEAN',3AVE 264
     1X,'MAXIMUM DEPTH',3X,'DATE',3X,'MINIMUM DEPTH',3X,'DATE'/42X,'BELOAVE 265
     2W LAND',6X,'SEA LEVEL',6X,'BELOW LAND',13X,'BELOW LAND'/44X,'SURFAAVE 266
     3CE',6X,'ELEVATION',9X,'SURFACE',16X,'SURFACE')                    AVE 267
   57 FORMAT (25X,'(NEGATIVE DEPTHS ARE ABOVE LSD)')                    AVE 268
   58 FORMAT (1H,28X,F5.1,9X,'*',1X,F6.2,7X,'*',1X,F6.2,9X,F6.2,4X,I2,'/AVE 269
     1',I2,'/',I2,5X,F6.2,4X,I2,'/',I2,'/',I2/71X,'(ELEV ',F6.2,')',11X,AVE 270
     2'(ELEV ',F6.2,')')                                                AVE 271
   59 FORMAT (25X,'* ALL AVERAGES ARE TIME-WEIGHTED AVERAGES'/25X,'(IF EAVE 272
     1LEVATION OR DEPTH IS EQUAL TO 999.99 THEN NO ELEVATION OR DEPTH WAAVE 273
     2S AVAILABLE AT WELL)')                                            AVE 274
      END                                                               AVE 275-
```

```
---------------------------------------------------------------------------------------------
     G-134. U.S. GEOL. SURVEY. (SEC. 32, T. 8S., R. 2W.) BORED OBSERVATION ARTESIAN WELL IN THE
TERRACE AQUIFER OF PLEISTOCENE AGE. DIAM 1.25 IN, DEPTH 69 FT, SCREENED 66-69. MP TOP OF CASING,
3.00 FT ABOVE LSD.
                          (BEGINNING DATE  8/ 3/64)     (ENDING DATE  6/ 2/75)

     -------------   -------------   ------------   -------------   ----   -------------   ----
     DEPTH OF WELL   AVERAGE DEPTH   AVERAGE MEAN   MAXIMUM DEPTH   DATE   MINIMUM DEPTH   DATE
                      BELOW LAND      SEA LEVEL      BELOW LAND             BELOW LAND
                       SURFACE       ELEVATION        SURFACE                SURFACE
     -------------   -------------   ------------   -------------   ----   -------------   ----

         69.0         *  51.05        *  86.02          52.90     11/ 1/71      46.20      6/ 2/75
                                                    (ELEV  84.17)           (ELEV  90.87)

---------------------------------------------------------------------------------------------
     * ALL AVERAGES ARE TIME-WEIGHTED AVERAGES
     (IF ELEVATIONS OR DEPTH ARE EQUAL TO 999.99 THEN NO ELEVATION OR DEPTH WAS AVAILABLE AT WELL)
```

Figure 28.--Example of output from AVERAGE program.

ATTACHMENT B

ATMOFLUX Program

Table 4.—*Input data for ATM FLUX program*

Reference	Number of cards	Columns	Format	Program variable	Input item	Remarks
Data defining the depth of the fine-grained material and hydraulic conductivity of lithologic types	1	1-2	F(2)	NHC	Number of lithologic class identifications and associated hydraulic conductivities to be read on next card.	Maximum value is 15.
	1-X	1-NHC*10	NHC [F(2), F(8,6)]	I,HC(I), J=1,NHC	Lithologic type, I, and hydraulic conductivity of the type, HC(I).	I≤15. $X=\frac{NHC*10}{80}$.
Soil coefficients and corresponding constant coefficients representing soil-water suction at which unsaturated hydraulic conductivity divided by saturated hydraulic conductivity equals 1/2.	1	1-2	F(2)	NEXP	Number of input values of EXP(I).	Maximum value is 10.
	1	1-80	NEXP(F(2), F(6))	EXP(I), SUCTION (I), I=1, NEXP	EXP(I)--Values for the integer soil coefficient, N, corresponding to values of suction (I). SUCTION (I)--Constant coefficient representing soil-water suction at which unsaturated hydraulic conductivity divided by saturated hydraulic conductivity equals 1/2.	
Upper limits for saturated hydraulic conductivity	1	1-72	10F(8,6)	EXP_LIMIT (I),I=1, NEXP(I)-1	Upper limit of saturated hydraulic conductivity for each class, EXP(I).	These values must be coded in ascending order.

Log data for each observation well	Any number	5-8	A(4)	WELL_NO	Well identification number	One data card for each representative observation well is required. If TH(12)>0, then it is assumed that the log is continued on the next card.
		9-80	12(F(2), F(4))	LCD(I), TH(I), I=1,12	LCD(I)--Lithologic type number for the Ith unit in the log. TH(I)--Thickness of the Ith unit.	
		1-78	13(F(2), F(4))	LCD(I), TH(I), I=13,25	(Same as preceding.)	Optional card--enter only if TH(12)>0. (Can be blank.)

Table 5.—*ATMOFLUX program listing*

```
FT:PROC OPTIONS(MAIN);
/*  *******************************************************

                          ATMOFLUX

    THIS PROGRAM COMPUTES POTENTIAL UPWARD MOVEMENT( DUE TO
    EVAPOTRANSPIRATION AT THE LAND SURFACE) FOR DEPTHS TO THE WATER
    TABLE FROM 1 TO 30 FT.THE PROGRAM
    COMPUTES THE HARMONIC-MEAN HYDRAULIC CONDUCTIVITY FOR LAYERED
    MATERIAL BY: KSAT(HAR. MEAN HYD. COND.)=SUM(THICKNESS)/
    SUM(THICKNESS*HYD.COND.).     IT ASSIGNS N AND S1/2 VALUES TO A
    LOG DEPENDING ON CALCULATED VALUES OF KSAT AND INPUT VALUES OF
    EXP,SUCTION, AND EXP_LIMIT. THIS PROGRAM USES
    N(GARDNER'S EXPONENT), AND S1/2(TENSION AT WHICH
    UNSATURATED H.C./SATURATED H.C. = 1/2) TO COMPUTE VERTICAL FLOW
    AS A FUNCTION OF DEPTH. THE  FUNCTION IS EQ. 23(P.A9) OF
    RIPPLE, ET AL, WSP 2019-A.

    *******************************************************
                                                          */
   DCL HC(15)INIT((15)0.),FINE(2:5,30),           LCD(25),TH(25),
   SUCTION(10)INIT((10)0.),EXP_LIMIT(9),(L,KSAT) DEC FLOAT(6),
   EXP(10) BINARY FIXED(15,0),WELL_NO CHAR(4),PUNCH FILE OUTPUT:
   ON ENDFILE(SYSIN) GO TO D1:
   GET FILE(SYSIN) EDIT
   (NHC,(I,HC(I) DO J=1 TO NHC))
/*
    NHC - NUMBER OF HYD. COND. TO BE READ(MAXIMUM = 15)
    I - NUMBER REFERRING TO A LITHOLOGIC TYPE. MAY BE ARBITRARILY
    CHOSEN WITHIN THE RANGE OF 1-15.
    HC(I) - HYD. COND.(FT/DAY) OF LITHOLOGIC TYPE I.
                                                          */
   (COL(1),F(2),SKIP(1),(NHC)(F(2),F(8,6)))
   (NEXP,(EXP(I),SUCTION(I) DO I=1 TO NEXP))
/*
    NEXP - NUMBER(MAXIMUM = 10) OF INPUT VALUES OF N.
    EXP(I) - VALUE OF N CORRESPONDING TO SUCTION(I).
    SUCTION(I) - VALUE OF S1/2 (IN FEET) CORRESPONDING TO EXP(I).
                                                          */
   (COL(1),F(2),SKIP(1),(NEXP)(F(2),F(6)))
   ((EXP_LIMIT(I) DO I=1 TO NEXP-1))
/*
    EXP_LIMIT(I) - UPPER LIMIT OF KSAT FOR EXP(I). NUMBER OF VALUES
    IS NEXP-1 (MAX = 9). EXP_LIMIT VALUES MUST BE ARRANGED IN ASCENDING
    ORDER, (SMALLEST FIRST AND LARGEST LAST). SINCE THERE IS
    A CORRESPONDENCE BETWEEN EXP(I) AND EXP_LIMIT(I), EXP(I) WILL
    ALSO BE CODED IN ASCENDING ORDER.
                                                          */
   (COL(1),10 F(8,6));
   PUT FILE(SYSPRINT) EDIT
   ('H.C. LIMIT','S1/2','EXPONENT','(FT/DAY)','(FT)')
```

Table 5.—*ATMOFLUX program listing*—Continued

```
  (X(12),A,X(4),A,COL(1),A,X(5),A,X(5),A)
  ((EXP(I),'<',EXP_LIMIT(I),SUCTION(I) DO I=1 TO NEXP-1))
  ((NEXP-1)(COL(1),X(3),F(2),X(7),A,F(8,5),X(5),F(4)))
  (EXP(NEXP),SUCTION(NEXP))
  (COL(1),X(3),F(2),X(21),F(4));
  SUCTION=30.48*SUCTION;
  DO K=1 TO NEXP;
  N=EXP(K);
  S12=SUCTION(K);
  RN=N;
  N1=N-1;
  F=3.14159/(RN*SIN(3.14159/RN));
  X=S12*F/30.48;
  IF X<1. THEN X=1.;
  DO I=1 TO 30;
     L=30.48*I;
     A=(S12*F/L)**N;
     DO J=1 TO 100;
        XN=X**N;
        XN1=XN/X;
        XN2=XN1/X;
        U=(XN-XN1-A)/(N*XN1-N1*XN2);
        X=X-U;
        IF U<0. THEN U=-U;
        IF U<3.E-6 THEN GO TO C2;
        END;
     J=100;
C2:  FINF(N,I)=X-1.;
     END;
  K=1;
  L=10;
  DO J=1,3;
  PUT FILE(PUNCH) EDIT
  ((FINF(N,I) DO I=K,L),N)
  (COL(1),10F(7,6),X(6),'N=',F(2));
  K=K+10;
  L=L+10;
  END;
  END;
A1:GET FILE(SYSIN) EDIT
  (WELL_NO,(LCD(I),TH(I) DO I=1 TO 12))
/*
   WELL_NO - WELL NUMBER.
   LCD(I) - LITHOLOGIC-TYPE NUMBER FOR THE ITH UNIT IN THE LOG
   TH(I) - THICKNESS(FT) OF THE ITH UNIT IN THE LOG.
                                    */
  (COL(1),X(4),A(4),12 (F(2),F(4)));
  IF TH(12)>0. THEN DO;
     GET FILE(SYSIN) EDIT
     ((LCD(I),TH(I) DO I=13 TO 25))
/*
   IF TH(12)>0 THEN IT IS NECESSARY TO HAVE A SECOND CARD(CAN BE
```

```
   BLANK) FOR LCD,TH.
                                                        */
     (COL(1),13 (F(2),F(4)));

     END;

  THC,THK=0.;

  DO I=1 TO 25;

     THICK=TH(I);

     IF THICK<=0. THEN GO TO A2;
     THK=THK+THICK;
     HYD_COND=HC(LCD(I));
     IF HYD_COND<=0. THEN DO;
        PUT FILE(SYSPRINT) EDIT
        ('WELL NUMBER ',WELL_NO,', UNIT ',I,', CODE= ',LCD(I),
        ', HYDRAULIC CONDUCTIVITY = 0')
        (PAGE,A,A(4),A,F(2),A,F(2),A);
        GO TO A1;
        END;
     THC=THC+THICK/HYD_COND;
     END;
A2:KSAT=THK/THC;
  DO I=1 TO NEXP-1;
     IF KSAT<EXP_LIMIT(I) THEN DO;
        N=EXP(I);
        GO TO C1;
        END;
     END;
  N=EXP(NEXP);
C1:PUT FILE(SYSPRINT) EDIT
  ('WELL NUMBER ',WELL_NO,'SATURATED HYDRAULIC CONDUCTIVITY = ',KSAT,
  ' FT/DAY','GARDNER''S EXPONENT = ',N)
  (PAGE,A,A(4),COL(1),A,F(7,4),A,COL(1),A,F(2))
  ('DEPTH','TO','WATER','(FT)',' ET/SHC ','FT(FT/DAY)')
  (SKIP(2),A,COL(1),X(2),A,X(19),  COL(1),A,X(20),
  COL(1),X(1),A,X(4),A,X(4),A)
  ((I,EINF(N,I),KSAT*EINF(N,I) DO I=1 TO 30))
  (30 (COL(1),X(2),F(2),X(5),F(8,5),X(5),F(8,5)));
  PUT FILE(PUNCH) EDIT
  (WELL_NO,KSAT,KSAT,THK,'.1')
  (COL(1),A(4),X(6),3 F(10,5),X(6),A);
  GO TO A1;
  D1:END ET;
```

ATTACHMENT C

POTEET Program

Table 6.—*Input data for POTEVT program*

Reference	Number of cards	Columns	Format	Program variable	Input item	Remarks
Number of weather bureau stations	1	1-2	I2	NSTAS	Number of weather bureau stations to be read.	
Average monthly temperatures	1	1-72	12F6.2	AMT(J)	Average monthly temperature in degrees Fahrenheit.	
Latitude	1	1-8	F8.3	STALAT	Station latitude as a decimal number.	
Number of years	1	1-2	I2	NYR	Number of years of station record to be read.	
Data defining period of record	1	1-4	I4	MØ	Total number of days in period to be processed.	
		5-9	F5.0	DSE	Number of days since spring (vernal) equinox to beginning period of record.	For example, DSE =-80 or -81 for January 1.
Year	1	1-4	I4	IYEAR	Calendar year for which potential ET is computed.	
Days per month	1	1-24	12I2	MDAY(I), I=1,12	Number of days in each calendar month.	

Maximum temperature data	1	10-11	I2	IYRD	Calendar year of data to be read.	
		12-13	I2	IM0ND	Calendar month of data to be read.	
		15-74	10F6.2	TEMP(J), J=1,10	First 10 maximum-temperature values for a month.	
	1	15-74	10F6.2	TEMP(J), J=11,20	Second 10 maximum-temperature values for a month.	These two cards are read with one read statement. IST0PM= last day of month.
	1	15-80	11F6.2	TEMP(J), J=21, ISTOPM	Maximum-temperature values from 21st day to end of month.	
Minimum temperature data	1	10-11	I2	IYRD	Calendar year of data to be read.	
		12-13	I2	IM0ND	Calendar month of data to be read.	
		15-74	10F6.2	TEMP(J), J=1,10	First 10 minimum-temperature values for a month.	
	1	15-74	10F6.2	TEMP(J), J=11,20	Second 10 minimum-temperature values to be read.	These two cards are read with one read statement. IST0PM= last day of month.
	1	15-80	11F6.2	TEMP(J), J=21, IST0PM	Minimum-temperature values from 21st day to end of month.	

Table 7.—*POTEET program listing*

```
C     ***************************************************************
C
C                             POTEET
C
C
C       THIS PROGRAM COMPUTES DAILY POTENTIAL EVAPOTRANSPIRATION,
C     IN INCHES PER DAY, USING A METHOD DEVELOPED BY C. W. THORNTHWAITE.
C     PRIMARY INPUT IS DAILY MAXIMUM AND MINIMUM AND MONTHLY AVERAGE
C     TEMPERATURE DATA FROM WEATHER BUREAU STATIONS.
C
C     ***************************************************************
C
      COMMON/C2/IRD,IPT,IPCH
      REAL MINT(1850),MAXT(1850)
      DIMENSION AMT(12),PE(1850)
      IRD=1
      IPCH=16
      IPT=6
C
C     NSTAS=NUMBER OF WEATHER BUREAU STATIONS FOR WHICH POT ET IS COMPUT
C
      READ (IRD,11) NSTAS
      DO 5 IJKLMN=1,NSTAS
C
C     AMT=AVERAGE MONTHLY TEMPERATURE, IN DEGREES F
C
      READ (IRD,10) (AMT(J),J=1,12)
C
C     HTI=THORNTHWAITE HEAT INDEX
C
      HTI=0.0
      DO 3 J=1,12
      IF (AMT(J)-32.) 1,1,2
    1 HI=0.0
      GO TO 3
    2 HI=((AMT(J)-32.)/9.)**1.514
    3 HTI=HTI+HI
C
C     A=THORNTHWAITE'S EXPONENT
C
      A=(6.75E-07*(HTI**3.))-(7.71E-05*(HTI**2.))+(1.79E-02*HTI)+4.9E-01
      PI=3.14160
C
C     STALAT=STATION LATITUDE, AS A DECIMAL NUMBER.
C
      READ (IRD,9) STALAT
C
C     AMP=AMPLITUDE OF SINE-WAVE VARIATION IN DAYLIGHT FACTOR
C
      AMP=(1.86E-05*(STALAT**3.))-(2.087E-03*(STALAT**2.))+(8.517E-02*ST
```

Table 7.—*POTEET program listing*—Continued

```
     1ALAT)
C
C     NYR=NUMBER OF YEARS OF STATION RECORD FOR THE GIVEN STATION TO BE
C     ANALYZED
C
      READ (IRD,11) NYR
C
C     MO=TOTAL NUMBER OF DAYS IN PERIOD TO BE PROCESSED.
C
C     DSE=DAYS SINCE SPRING EQUINOX TO BEGINNING OF RECORD TO BE ANALYZE
C          (-80 OR-81 FOR JANUARY 1)
C
      READ (IRD,8) MO,DSE
C
C     IYEAR=CALENDAR YEAR FOR WHICH POTENTIAL ET IS COMPUTED
C
      READ (IRD,7) IYEAR
      CALL READSO(MAXT,MO,IRD)
      CALL READSO(MINT,MO,IRD)
      PESUM=0.
      NO=MO-30
      DO 4 I=1,NO
      K=I+30
      TSUM=MAXT(K)+MINT(K)
      TEMP=(TSUM/2.-32.)/1.8
      IF (TEMP.LT.0.) TEMP=0.
C
C     DLF=DAY LENGTH FACTOR. THE RATIO OF HOURS OF DAYLIGHT TO 12
C
      DLF=1.0+((AMP-1.)*SIN(PI*(I+DSE)/183.))
      UPE=.021*(((10.*TEMP)/HTI)**A)
      PE(I)=UPE*DLF
    4 PESUM=PESUM+PE(I)
    5 CONTINUE
      WRITE (IPCH,6) (PE(I),I=1,MO)
      WRITE (IPT,12) PESUM
      STOP
C
    6 FORMAT (10F7.4,3X,'PE')
    7 FORMAT (I4)
    8 FORMAT (I4,F5.0)
    9 FORMAT (F8.3)
   10 FORMAT (12F6.2)
   11 FORMAT (I2)
   12 FORMAT (1X,'PESUM=',F8.4)
      END
```

Table 7.—*POTEET program listing*—Continued

```
      SUBROUTINE READSO(SO,ICNT,IRD)
C     ******************************************************************
C
C       READSO INPUTS THE NUMBER OF DAYS IN EACH MONTH AND MAX. AND MIN.
C     TEMPERATURES.
C
C     ******************************************************************
C
      DIMENSION SO(1850),MDAY(12),TEMP(1850),IYR(1850),MON(1850),
     1 IDAY(1850)
C
C     MDAY(IQ) -- ARRAY CONTAINING THE NUMBER OF DAYS IN EACH CALENDAR
C                 MONTH.
C
      READ (IRD,9) (MDAY(IQ),IQ=1,12)
      I=0
C
C     IYRD -- CALENDAR YEAR
C
C     IMOND -- CALENDAR MONTH
C
C     TEMP(J) -- TEMPERATURES FOR FIRST 10 DAYS OF MONTH.
C
    1 READ (IRD,7) IYRD,IMOND,(TEMP(J),J=1,10)
      IF (IMOND-2) 4,2,4
    2 IXY=IYRD/4
      IF ((IXY*4)-IYRD) 4,3,4
    3 MDAY(2)=29
    4 ISTOPM=MDAY(IMOND)
C
C     TEMP(J) -- TEMPERATURES FOR DAY 11 TO END OF MONTH.
C
      READ (IRD,8) (TEMP(J),J=11,ISTOPM)
      MDAY(2)=28
      DO 5 J=1,ISTOPM
      I=I+1
      IYR(I)=IYRD
      MON(I)=IMOND
      IDAY(I)=J
      SO(I)=TEMP(J)
    5 CONTINUE
      IF (I-ICNT) 1,6,6
    6 CONTINUE
      RETURN
C
    7 FORMAT (9X,2I2,1X,10F6.2)
    8 FORMAT (14X,10F6.2,/,14X,11F6.2)
    9 FORMAT (12I2)
      END
```

ATTACHMENT D

RIVCHANGE Program

Table 3.—Input data for [illegible] program

Reference	Number of cards	Columns	Format	Program variable	Input item	Remarks
Beginning date	1	1-2	I2	IM0N	Beginning month.	
		3-4	I2	IDAY	Beginning day.	
		5-6	I2	IYEAR	Beginning year.	
Control data	1	1-5	I5	ICNT	Number of days in period of record.	
		6-10	I5	NDAYS	Time increment, in days.	
		11-15	I5	NSTAGE	Number of nodes to which river-stage values will be assigned.	
Nodes and river miles	Depends on NSTAGE	1-80	8(I4, F6.1)	IJ(I), RM(I), I=1, NSTAGE	IJ(I)--Array holding node levels. RM(I)--Array holding river miles corresponding to nodes in IJ.	
Control data	1	1-5	I5	IUM	Number of corresponding river miles and river stages for each time step in the input master-data set.	
	1	1-5	I5	ISTART	Sequence number of day relative to input master-data set where computation is to begin.	
	1	1-5	I5	IBEGN	Sequence number of day in input master-data set where interpolation is to begin.	

Control data--Continued		6-10	I5	IEND	Sequence number of day in input master-data set where interpolation is to end.	
The following data will be read repetitively until DAY=IEND						
River-stage data from input master-data set	None	-------	20A4	DUMMY	Read date from input file as dummy data.	These data are read from a magnetic disk pack. When DAY=IBEGN, processing begins; when DAY=IEND, processing ends.
	None	-------	F10.3	DAY	Sequence number on input data.	
	None	-------	8F10.3	GMM(I), EEL(I), I=1, IUM	GMM(I)--Array holding river miles on input data set. EEL(I)--Array holding river stages corresponding to river miles in GMM.	

Table 9.—RIVCHANGE program listing

```
C     ****************************************************************
C
C                        --  RIVCHANGE  --
C                  INTERPOLATION AND AVERAGING
C                            PROGRAM
C                        (FOR MAINSTEM)
C
C     ****************************************************************
C
C          THIS PROGRAM IS DESIGNED TO PROVIDE THE GROUND-WATER FLOW
C     SIMULATION MODEL, SUPERMOCK, WITH 10-DAY AVERAGE RIVER-STAGE DATA
C     EVERY 10 DAYS FOR SPECIFIED CORRESPONDING NODE LEVELS AND RIVER
C     MILES.
C          PRIMARY INPUT IS CORRESPONDING RIVER-STAGE AND RIVER MILE DATA
C     IN 5-DAY INCREMENTS WHICH CAN BE READ FROM EITHER MAGNETIC TAPE
C     OR DISK FILES OR FROM CARDS. NODE LEVELS AND THEIR APPROPRIATE RIV
C     MILES ARE READ FROM CARDS.
C          THE PROGRAM INTERPOLATES FOR BOTH TIME AND RIVER MILES AND
C     COMPUTES 10-DAY AVERAGES FOR THE ENTIRE PERIOD OF RECORD.
C          THE FIRST RECORD IN THE OUTPUT DATA SET TELLS YOU HOW MANY NOD
C     LEVELS YOU HAVE RIVER STAGE FOR, HOW MANY GROUPS OF 10-DAY
C     AVERAGES YOU HAVE, AND THE TIME INCREMENT, IN DAYS.
C          THE DATA ARE WRITTEN ONTO A MAGNETIC STORAGE DEVICE IN
C     UNFORMATTED, VARIABLE-LENGTH RECORDS.
C
C     ****************************************************************
C
C     *** INPUT DATA ***
C
C     IMON - BEGINNING MONTH;
C     IDAY - IDAY + 10 = DAY OF FIRST 10-DAY AVERAGE OUTPUT;
C     IYEAR - BEGINNING YEAR
C
C     ICNT - NUMBER OF DAYS PERIOD OF RECORD COVERS.
C
C     NDAYS - TIME INCREMENT
C
C     NSTAGE - NUMBER OF NODE LEVELS
C
C     IJ - ARRAY HOLDING NODE LEVELS
C
C     RM - ARRAY HOLDING RIVER MILES CORRESPONDING TO NODE LEVELS.
C
C     IUM - NUMBER OF CORRESPONDING RIVER MILES AND RIVER STAGES FOR EAC
C           H TIME STEP IN THE INPUT DATA SET.
C
C     ISTART - SEQUENCE NUMBER OF DAY RELATIVE TO INPUT DATA SET WHERE
C              COMPUTATION TO BEGIN.
C
C     IBEGN - SEQUENCE NUMBER OF DAY IN INPUT DATA SET WHERE INTERPOLATI
```

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METHODS AND APPLICATIONS OF DIGITAL-MODEL SIMULATION OF THE RED--ETC(U)
MAY 80 A H LUDWIG, J E TERRY
UNCLASSIFIED USGS/WRD/WRI-81/037 NL

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Table 9.—*RIVCHANGE program listing*—Continued

```
C               TO BEGIN.
C
C     IEND  - SEQUENCE NUMBER OF DAY IN INPUT DATA SET WHERE INTERPOLATI
C               TO END.
C
C     DUMMY - DATE ON INPUT DATA SET.
C
C     DAY - SEQUENCE NUMBER ON INPUT DATA SET (MULTIPLES OF FIVE).
C
C     GMM - ARRAY HOLDING RIVER MILES ON INPUT DATA SET.
C
C     EFL - ARRAY HOLDING RIVER STAGES CORRESPONDING TO RIVER MILES ON
C             INPUT DATA SET.
C
C     *** OUTPUT DATA ***
C
C     NSTAGE - NUMBER OF NODE LEVELS.
C
C     NOSET - NUMBER OF GROUPS OF 10-DAY AVERAGES (RECORDS) YOU
C               HAVE IN OUTPUT DATA SET.
C
C     NDAYS - TIME INCREMENT
C
C     IMON,IDAY,IYEAR - MONTH, DAY, AND YEAR. EACH OUTPUT RECORD IS
C                         DATED.
C
C     J - SEQUENCE NUMBER OF EACH RECORD IN OUTPUT DATA SET.
C
C     IJ - ARRAY HOLDING NODE LEVELS IN OUTPUT DATA SET.
C
C     H - ARRAY HOLDING RIVER-STAGE VALUES CORRESPONDING TO NODE LEVELS
C         IN OUTPUT DATA SET.
C
C     ******************************************************************
C
      DIMENSION IJ(200),RM(200),H(200),GH(50,200),GM(50),EL(50,2)
      DIMENSION JDAY(12),GMM(150),EEL(150,2),DUMMY(20)
      DATA JDAY/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA GH/10000*0./
      IRD=5
      ITP=10
      IDA=9
      IPT=6
      READ (IRD,18) IMON,IDAY,IYEAR
      IF (MOD(IYEAR,4).EQ.0) JDAY(2)=29
      READ (IRD,19) ICNT,NDAYS,NSTAGE
      READ (IRD,20) (IJ(I),RM(I),I=1,NSTAGE)
      READ (IRD,24) IUM
      READ (IRD,24) ISTART
      READ (IRD,24) IBEGN,IEND
```

Table 9.—*RIVCHANGE program listing*—Continued

```
    1 READ (ITP,21) DUMMY
      READ (ITP,25) DAY
      I1DAY=DAY
      READ (ITP,26) (GMM(I),EEL(I,1),I=1,IUM)
      IF (I1DAY.NE.IBEGN) GO TO 1
      JZ=0
      IZ=0
      DO 2 J=1,IUM
      IF (GMM(J).GE.RM(1).AND.IZ.EQ.0) IZ=J-1
      IF (GMM(J).GE.RM(NSTAGE).AND.JZ.EQ.0) JZ=J
    2 CONTINUE
      NUM=0
      DO 3 I=IZ,JZ
      NUM=NUM+1
      GM(NUM)=GMM(I)
    3 EL(NUM,1)=EEL(I,1)
      CDAYS=ISTART-I1DAY
      IXIN=ISTART
      IS=ISTART/10
    4 READ (ITP,21) DUMMY
C     WRITE(IPT,201)DUMMY
      READ (ITP,25) DAY
C     WRITE(IPT, 30)DAY
      READ (ITP,27) (EEL(I,2),I=1,IUM)
      NZ=IZ
      DO 5 J=1,NUM
      EL(J,2)=EEL(NZ,2)
    5 NZ=NZ+1
C     WRITE(IPT, 30)(EL(I,2),I=1,NUM)
      I2DAY=DAY
      IX=I2DAY-I1DAY
      ID1=I1DAY+1
      IF (ID1.LT.ISTART) ID1=ISTART
      DO 6 J=ID1,I2DAY
      JJ=J-I1DAY
      JTH=(J-ISTART)/10+IS
      DO 6 I=1,NUM
      DEL=(EL(I,2)-EL(I,1))/IX
    6 GH(I,JTH)=EL(I,1)+DEL*JJ+GH(I,JTH)
      DO 7 I=1,NUM
    7 EL(I,1)=EL(I,2)
      I1DAY=I2DAY
      IF (DAY-IEND) 4,8,8
    8 DO 9 I=1,50
      DO 9 J=1,200
    9 GH(I,J)=GH(I,J)/10.
      NQSET=ICNT/NDAYS
      WRITE (IDA) NSTAGE,NQSET,NDAYS
      WRITE (IPT,28) NSTAGE,NQSET,NDAYS
      ISTATH=ISTART/10
```

Table 9.—*RIVCHANGE program listing*—Continued

```
      DO 17 J=ISTATH,JTH
      DO 13 I=1,NSTAGE
      DO 10 K=1,NUM
      IF (RM(I).GE.GM(K)) GO TO 10
      GO TO 11
   10 CONTINUE
      K=NUM
      GO TO 12
   11 IF (K.EQ.1) GO TO 12
      KS=K-1
      H(I)=(RM(I)-GM(KS))/(GM(KS+1)-GM(KS))*(GH(KS+1,J)-GH(KS,J))+GH(KS,
     1J)
      GO TO 13
   12 H(I)=GH(K,J)
   13 CONTINUE
      IDAY=IDAY+10
      IF (IDAY.LE.JDAY(IMON)) GO TO 16
      IDAY=IDAY-JDAY(IMON)
      IMON=IMON+1
      IF (IMON.LE.12) GO TO 16
      IMON=1
      IYEAR=IYEAR+1
      IF (MOD(IYEAR,4)) 15,14,15
   14 JDAY(2)=29
      GO TO 16
   15 JDAY(2)=28
   16 WRITE (IDA) IMON,IDAY,IYEAR
      WRITE (IPT,22) IMON,IDAY,IYEAR
      WRITE (IDA) J
      WRITE (IPT,29) J
      WRITE (IDA) (IJ(I),H(I),I=1,NSTAGE)
      WRITE (IPT,23) (IJ(I),H(I),I=1,NSTAGE)
   17 CONTINUE
      STOP
C
   18 FORMAT (3I2)
   19 FORMAT (16I5)
   20 FORMAT (8(I4,F6.1))
   21 FORMAT (20A4)
   22 FORMAT (1X,I2,'/',I2,'/',I2)
   23 FORMAT (7(1X,I4,1X,F6.2))
   24 FORMAT (2I5)
   25 FORMAT (F10.3)
   26 FORMAT (8F10.3)
   27 FORMAT (4(10X,F10.3))
   28 FORMAT (1X,5I5)
   29 FORMAT (1X,I5)
      END
```

ATTACHMENT E

TRIBCHANGE Program

Table 10.—*Input data for TRIPCHANGE program*

Reference	Number of cards	Columns	Format	Program variable	Input item	Remarks
Heading	1	1-80	20A4	DUM	Title heading for printed output.	
Control data	1	1-5	I5	NSTRMS	Number of tributary streams to be processed.	
		6-10	I5	NDATA	Number of 10-day averages being entered for each stream gage.	
	1	1-5	I5	NAVE	Number of 10-day average records to be in output.	
		6-10	I5	NSTOT	Number of nodes to be assigned a tributary-stream stage.	
The following will be read repetitively for each stream:						
Stream data	1	1-5	I5	NGAGES	Number of gages on the stream for which data will be entered.	
		6-10	I5	NSTAGE	Number of nodes applicable to this stream.	
	The following will be read repetitively for each gage on each stream:					
	1	1-5	F5.2	GEL(I)	Array holding the datum elevation for each gage on the stream.	
		6-10	F5.2	GM(I)	Stream mile of gage.	
	Depends on NDATA	1-75	15F5.2	GH(I,J), J=1,NDATA, I=1,NGAGES	Array holding input 10-day-average stream stages for each gage on the stream.	

Output nodes and stream miles	Depends on NSTAGE	1-80	8(I4, F6.1)	IJ(I), RM(I)	IJ(I)--Array holding nodes for which tributary stream output is desired. RM(I)--Corresponding river-mile location of each node.	These arrays accumulate all of the corresponding output nodes and river miles for all of the streams to be processed.

Table 11.—*TRIBCHANGE program listing*

```
C     ******************************************************************
C
C                         --   TRIBCHANGE   --
C                       INTERPOLATION PROGRAM
C                      (FOR TRIBUTARY STREAMS)
C
C     ******************************************************************
C
C         THIS PROGRAM PROVIDES 10-DAY-AVERAGE STREAM-STAGE DATA
C     CORRESPONDING TO SPECIFIC NODE LEVELS FOR TRIBUTARY STREAMS
C     IN THE AREA.
C         10-DAY-AVERAGE DATA FOR DIFFERENT GAGING SITES FOR EACH
C     STREAM ARE READ . INTERPOLATION FOR DISTANCE IS PERFORMED
C     IN ORDER TO DETERMINE STAGES FOR PARTICULAR NODES.
C         OUTPUT IS  WRITTEN ON MAGNETIC DISK FILE TO BE REFERENCED BY
C     MODELING PROGRAM.
C
C     ******************************************************************
C     ******************************************************************
C
C     *** INPUT DATA ***
C
C     DUM - TITLE HEADING FOR PRINTED OUTPUT.
C
C     NSTRMS - NUMBER OF TRIBUTARY STREAMS.
C
C     NDATA - NUMBER OF 10-DAY AVERAGES BEING ENTERED FOR EACH STREAM.
C
C     NAVE - NUMBER OF 10-DAY AVERAGE RECORDS TO BE IN OUTPUT.
C
C     NSTOT - TOTAL NUMBER OF NODES TO BE ASSIGNED A STREAM STAGE.
C
C     -- REPETITIVE FOR EACH STREAM --
C
C     NGAGE - NUMBER OF GAGES ON STREAM.
C
C     NSTAGE - NUMBER OF NODES APPLICABLE TO THIS STREAM.
C
C     GEL - ELEVATION OF GAGE.
C
C     GM - STREAM MILE OF GAGE.
C
C     GH - ARRAY HOLDING 10-DAY-AVERAGE STREAM STAGES.
C
C     IJ - ARRAY HOLDING NODE LEVELS.
C
C     RM - ARRAY HOLDING STREAM MILES CORRESPONDING TO NODE LEVELS.
C
C     *** OUTPUT DATA ***
C
```

Table 11.—*TRIBCHANGE program listing*—Continued

```
C     DUM - TITLE HEADING (IN PRINT ONLY).
C
C     NSTOT - TOTAL NUMBER OF NODES.
C
C     NAVE - NUMBER OF 10-DAY-AVERAGE RECORDS IN OUTPUT (PRINT ONLY).
C
C     IJ - ARRAY HOLDING ALL NODES.
C
C     K - SEQUENCE NUMBER FOR EACH RECORD WRITTEN.
C
C     H - ARRAY HOLDING STREAM-STAGE VALUES CORRESPONDING TO SPECIFIED
C          NODE LEVELS AND STREAM MILES.
C
C     ******************************************************************
C
      DIMENSION GH(7,300),IJ(300),RM(300),H(201,182),GM(7),GFL(7)
      DIMENSION DUM(20)
      DATA H/36582*0./
      DATA IRD/5/,IDA/2/,IPT/6/
      READ (IRD,9) DUM
      READ (IRD,10) NSTRMS,NDATA
      READ (IRD,10) NAVE,NSTOT
      ITT=0
      DO 7 IS=1,NSTRMS
      READ (IRD,10) NGAGES,NSTAGE
      DO 1 I=1,NGAGES
      READ (IRD,11) GFL(I),GM(I)
      READ (IRD,11) (GH(I,J),J=1,NDATA)
    1 CONTINUE
      IT=ITT+1
      ITT=ITT+NSTAGE
      READ (IRD,12) (IJ(I),RM(I),I=IT,ITT)
      DO 6 J=1,NAVE
      DO 5 I=IT,ITT
      DO 2 K=1,NGAGES
      IF (RM(I).GE.GM(K)) GO TO 2
      GO TO 3
    2 CONTINUE
      K=NGAGES
      GO TO 4
    3 IF (K.EQ.1) GO TO 5
      KS=K-1
      H(I,J)=(RM(I)-GM(KS))/(GM(KS+1)-GM(KS))*(GH(KS+1,J)-GH(KS,J)+GFL(K
     1S+1)-GFL(KS))+GFL(KS)+GH(KS,J)
      GO TO 5
    4 IF (RM(I).GT.GM(K)) GO TO 5
      H(I,J)=GH(K,J)+GFL(K)
    5 CONTINUE
    6 CONTINUE
    7 CONTINUE
```

Table 11.—*TRIBCHANGE program listing*—Continued

```
      WRITE (IPT,13) DUM
      WRITE (IPT,14) NSTOT,NAVE
      WRITE (IDA) NSTOT
      WRITE (IDA) (IJ(I),I=1,NSTOT)
      WRITE (IPT,14) NSTOT
      WRITE (IPT,15) (IJ(I),I=1,NSTOT)
      K=9
      DO 8 J=1,NAVE
      WRITE (IPT,14) K
      WRITE (IDA) K
      WRITE (IPT,16) (IJ(I),H(I,J),I=1,NSTOT)
      WRITE (IDA) (IJ(I),H(I,J),I=1,NSTOT)
      K=K+1
    8 CONTINUE
      STOP
C
    9 FORMAT (20A4)
   10 FORMAT (2I5)
   11 FORMAT (15F5.2)
   12 FORMAT (8(I4,F6.1))
   13 FORMAT (1X,20A4)
   14 FORMAT (1X,2I5)
   15 FORMAT (20(1X,I4))
   16 FORMAT (10(1X,I4,1X,F6.1))
      END
```

ATTACHMENT F

DELETDELH Program

Table 12.—*Input data for [illegible] program*

Reference	Number of cards	Columns	Format	Program variable	Input item	Remarks	
Evapotranspiration divided by saturated hydraulic conductivity	12	1-70	10F(7,6)	ET	Values of evapotranspiration divided by saturated hydraulic conductivity for 1-30 ft above the water table for four ranges in vertical hydraulic conductivity.	These cards are output from ATMOFLUX.	
Data for individual observation wells	1-X	1-4	A(4)	WELLNO	Observation-well identification number.		X=Number of observation wells.
		11-20	F(10)	HCU	Vertical hydraulic conductivity from land surface to water table.	These are calibrated values from SUPER-MOCK.	
		21-30	F(10)	HCL	Vertical hydraulic conductivity from water table to top of aquifer.		
		31-40	F(10)	THICK	Thickness of material from land surface to top of aquifer.		
		41-50	F(10)	DTW	Average depth to water.		

Table 13.—*DELETDELH program listing*

```
DELET:/*  ************************************************

                         DELTAET / DELTAH

          THIS PROGRAM COMPUTES DELTA ET / DELTA H USING
          THE RIPPLE FUNCTIONAL.

          ***********************************************
                                                         */
   PROCEDURE OPTIONS(MAIN);
   DECLARE ET(2:5,30),GWETO(30),DET(30),WELLNO CHAR(4);
   ON ENDFILE(SYSIN) GO TO END1;
   /*
   READ VALUES OF ET/SAT.HYD.COND. FOR DEPTHS OF 1 TO 30
   FEET ABOVE THE WATER TABLE FOR FOUR RANGES IN VERTICAL
   HYDRAULIC CONDUCTIVITY.
                                                         */
   GET FILE(SYSIN) EDIT(ET)(COL(1),10 F(7,6),X(10));
   /*
   READ DATA FOR INDIVIDUAL OBSERVATION WELLS - ID. NUMBER,
   VERTICAL HYDRAULIC CONDUCTIVITY FOR MATERIAL FROM LAND SURFACE
   TO THE WATER TABLE AND FROM THE WATER TABLE TO TOP OF THE
   AQUIFER, THICKNESS FROM LAND SURFACE TO TOP OF AQUIFER,
   AND AVERAGE DEPTH TO WATER.
                                                         */
IN1:GET FILE(SYSIN) EDIT(WELLNO,HCU,HCL,THICK,DTW)(COL(1),A(4),X(6),
   4 F(10));
   IF HCU<.04 THEN DO;
         IF HCU<.004 THEN IEXP=2;
         ELSE IEXP=3;
         END;
   ELSE DO;
         IF HCU<.4 THEN IEXP=4;
         ELSE IEXP=5;
         END;
   X,E,F=0.;
   DO I=1 TO 30;
         E,F=0.;
         X=X+1.;
         Y=X;
         J=I;
A1:      IF J>30 THEN ETO=0.;
         ELSE ETO=HCU*ET(IEXP,J);
         IF THICK>Y THEN DO;
               FLOW=HCL*(Y-X)/(THICK-Y);
               IF ETO>FLOW THEN DO;
                     Y=Y+1.;
                     J=J+1;
                     E=ETO;
                     F=FLOW;
                     GO TO A1;
```

Table 13.—*DELETDELH program listing*—Continued

```
           END;
        ELSE DO;
           G=E-F-ETO+FLOW;
           IF G>0. THEN GWETO(I)=F-(E-ETO)*(E-F)/G;
           ELSE GWETO(I)=0.;
           GO TO A2;
           END;
        END;
     ELSE DO;
        IF F>.0000005 THEN DO;
           EETO=E-ETO;
           EHYT=ETO+HCL+EETO*(Y-THICK);
           DY=(SQRT(EHYT**2+4.*HCL*(THICK-X)*EETO)-EHYT)
           /(2.*EETO);
           GWETO(I)=ETO+EETO*(Y-THICK+DY);
           END;
        ELSE GWETO(I)=ETO;
        END;
A2:  IF GWETO(I)>.00822 THEN GWETO(I)=.00822;
     END;
  J=DTW+.5;
  DO I=1 TO 30;
  IF J<=1 THEN GWETOJ=GWETO(1);
  IF J>30 THEN GWETOJ=0.;
  IF J>1&J<=30 THEN GWETOJ=GWETO(J);
  IF I¬=J THEN DET(I)=(GWETO(I)-GWETOJ)/(J-I);
  ELSE DO;
     IF J=1 THEN DET(I)=GWETO(1)-GWETO(2);
     IF J>1&J<30 THEN DET(I)=(GWETO(J-1)-GWETO(J+1))/2.;
     IF J=30 THEN DET(I)=GWETO(29)-GWETO(30);
        END;
     END;
  PUT FILE(SYSPRINT) EDIT(WELLNO,'HCU= ',HCU,'HCL= ',HCL,
  'AVE. DTW = ',DTW,'THICKNESS= ',THICK,
  'DTW(FT)  ET(FT/DAY)  DET/DH(1/DAY)',
  (I,GWETO(I),DET(I) DO I=1 TO 30))
  (PAGE,A(4),4 (SKIP(1),A,F(10,5)),SKIP(2),A,
  30 (COL(5),F(2),X(3),F(10,7),X(5),F(10,7)));
  GO TO IN1;
END1:END DELET;
```

```
 329
HCU=     0.02000
HCL=     0.00500
AVE. DTW =     3.00000
THICKNESS=   14.00000

DTW(FT)  ET(FT/DAY)  DET/DH(1/DAY)
      1    0.0021079       0.0002980
      2    0.0017863       0.0002745
      3    0.0015119       0.0002880
      4    0.0012104       0.0003014
      5    0.0009873       0.0002623
      6    0.0007551       0.0002523
      7    0.0005939       0.0002295
      8    0.0004560       0.0002112
      9    0.0003467       0.0001942
     10    0.0002647       0.0001782
     11    0.0002044       0.0001634
     12    0.0001601       0.0001502
     13    0.0001266       0.0001385
     14    0.0001020       0.0001282
     15    0.0000832       0.0001191
     16    0.0000686       0.0001110
     17    0.0000572       0.0001039
     18    0.0000482       0.0000976
     19    0.0000410       0.0000919
     20    0.0000352       0.0000869
     21    0.0000304       0.0000823
     22    0.0000264       0.0000782
     23    0.0000232       0.0000744
     24    0.0000204       0.0000710
     25    0.0000180       0.0000679
     26    0.0000160       0.0000650
     27    0.0000144       0.0000624
     28    0.0000128       0.0000600
     29    0.0000116       0.0000577
     30    0.0000104       0.0000556
```

Figure 29.--Example of output from DELETDELH program.

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