UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DIGITAL MODEL OF THE BAYOU BARTHOLOMEW ALLUVIAL AQUIFER-STREAM SYSTEM, ARKANSAS

MARCH 3, 1849

Open-File Report 79-685

Prepared in cooperation with the
Arkansas Geological Commission

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DIGITAL MODEL OF THE BAYOU BARTHOLOMEW ALLUVIAL AQUIFER-STREAM SYSTEM, ARKANSAS

By J. E. Reed and M. E. Broom

Open-File Report 79-685

Prepared in cooperation with the
Arkansas Geological Commission

Little Rock, Arkansas
1979

CONTENTS

CONTENTS

Page

Attachment A, Computer program—Continued

Description of program—Continued

ILLUSTRATIONS

Page

Figure 1-7. Map showing:

ILLUSTRATIONS

TABLES

TABLES

CONVERSION FACTORS

Multiply inch-pound unit	By	To obtain metric unit
acre	4.047×10^3	square meter (m^2)
acre-foot (acre-ft)	1.233×10^{-6}	cubic kilometer (km^3)
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)
foot (ft)	3.048×10^{-1}	meter (m)
gallon per minute (gal/min)	6.309×10^{-2}	liter per second (L/s)
inch (in.)	2.540×10^1	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square foot per day (ft^2/d)	9.290×10^{-2}	square meter per day (m^2/d)
square mile (mi^2)	2.590	square kilometer (km^2)

DIGITAL MODEL OF THE BAYOU BARTHOLOMEW ALLUVIAL AQUIFER-STREAM SYSTEM, ARKANSAS

By J. E. Reed and M. E. Broom

ABSTRACT

A digital model of the aquifer-stream system was calibrated for the purpose of predicting hydrologic responses to stresses of water development. The simulated-time span for model calibration was from 1953 to 1970, during which time the system was stressed largely by ground- and surface-water diversions for rice irrigation.

The model was calibrated by comparing ground-water-level and streamflow data with model-derived ground-water levels and streamflow. In the calibrated model, the ratio of model-derived to observed streamflows for 17 subbasins averaged 1.1; the ratios among the subbasins ranged from 0.8 to 1.6. The average deviation of the differences between model-derived and observed ground-water levels at 47 nodes was 0.2; the average among the nodes ranged from 2.3 to 10.4. The average standard deviation of the differences between the model-derived and observed ground-water levels was 3.5; the average among the nodes ranged from 0.4 to 10.5.

The model will provide projections of changes in the potentiometric surface resulting from (1) changes in the rate or distribution of ground-water pumpage or (2) changes in the stage of streams and reservoirs. The model will provide only approximate projections of the streamflow.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the Arkansas Geological Commission, began a study in 1971 of the Bayou Bartholomew alluvial aquifer-stream system (fig. 1). The purpose of the study was to develop a water-management model for predicting hydrologic responses in the system to stresses of water development. Development to the present (1978) includes flood-control levees along the Arkansas and Mississippi Rivers, nagivation pools in the Arkansas River, cleared lands, drainage canals, and diversion of ground and surface water for crop irrigation, fish farming, and the manufacture of paper.

Hydraulic connection between the alluvial aquifer and the streams provided the basis for this system study. Although the aquifer-stream connection is simply conceived, many water facts are required to label the locations, times, and quantities of water exchange between the aquifer and the streams. In addition, the accounting of inflow and outflow in any one of the several stream basins in the study area is complicated to some extent by interbasin flows. The surface water can move between the basins by way of flood-control and irrigation canals; the ground water, mostly uninfluenced by the basin boundaries in areas of heavy ground-water withdrawals, can move by way of the alluvial aquifer from areas of recharge in some basins to areas of discharge in other basins.

The study was completed in two phases. The first phase, the results of which are contained in Broom and Reed (1973), dealt inclusively with defining the characteristics and properties of the system and making an electrical-analog analysis of the ground-water flow. The most significant results of the analog analysis concerned the areas and the amounts of aquifer recharge. Of

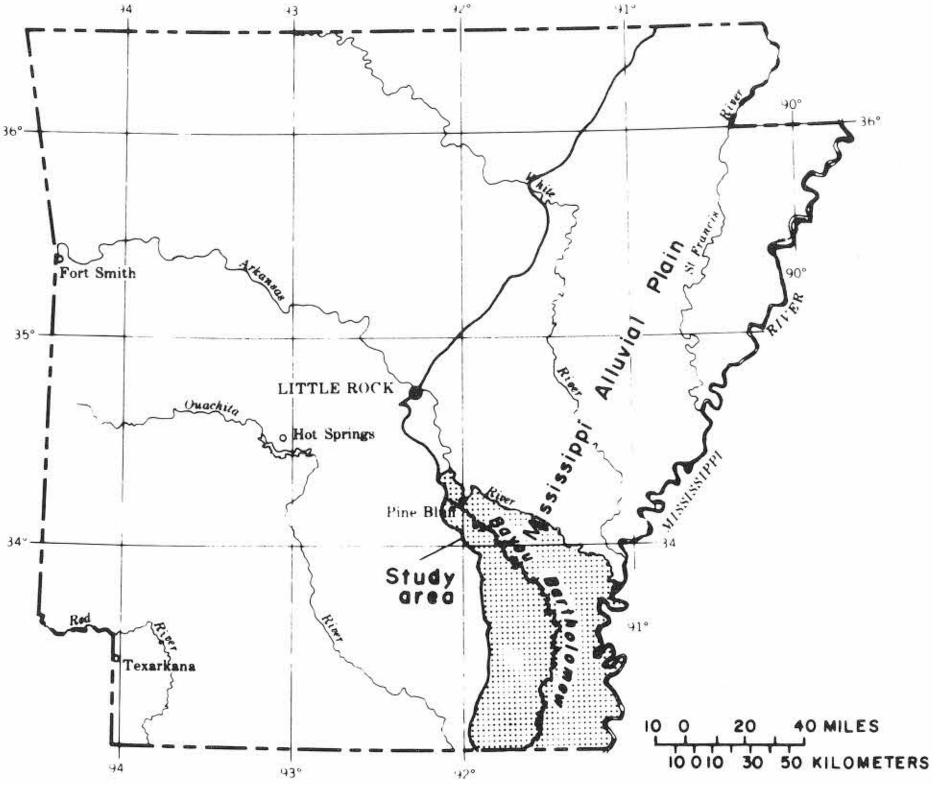


Figure 1.—Location of the study area.

an estimated total recharge of 161,000 acre-ft to the aquifer in 1970, the analog analysis indicated that 70 percent of the recharge occurred along aquifer-stream boundaries. This recharge was in the form of induced recharge or stream capture, resulting from heavy ground-water withdrawals.

This report contains the results of the second phase of the study which dealt exclusively with the calibration of a digital model that would simulate both ground-water and surface-water segments of the system, and thereby afford a more comprehensive water-management model. Data for defining the aquifer properties and the hydrologic character of the streambed material in the digital model consisted mostly of calibrated values from the analog model.

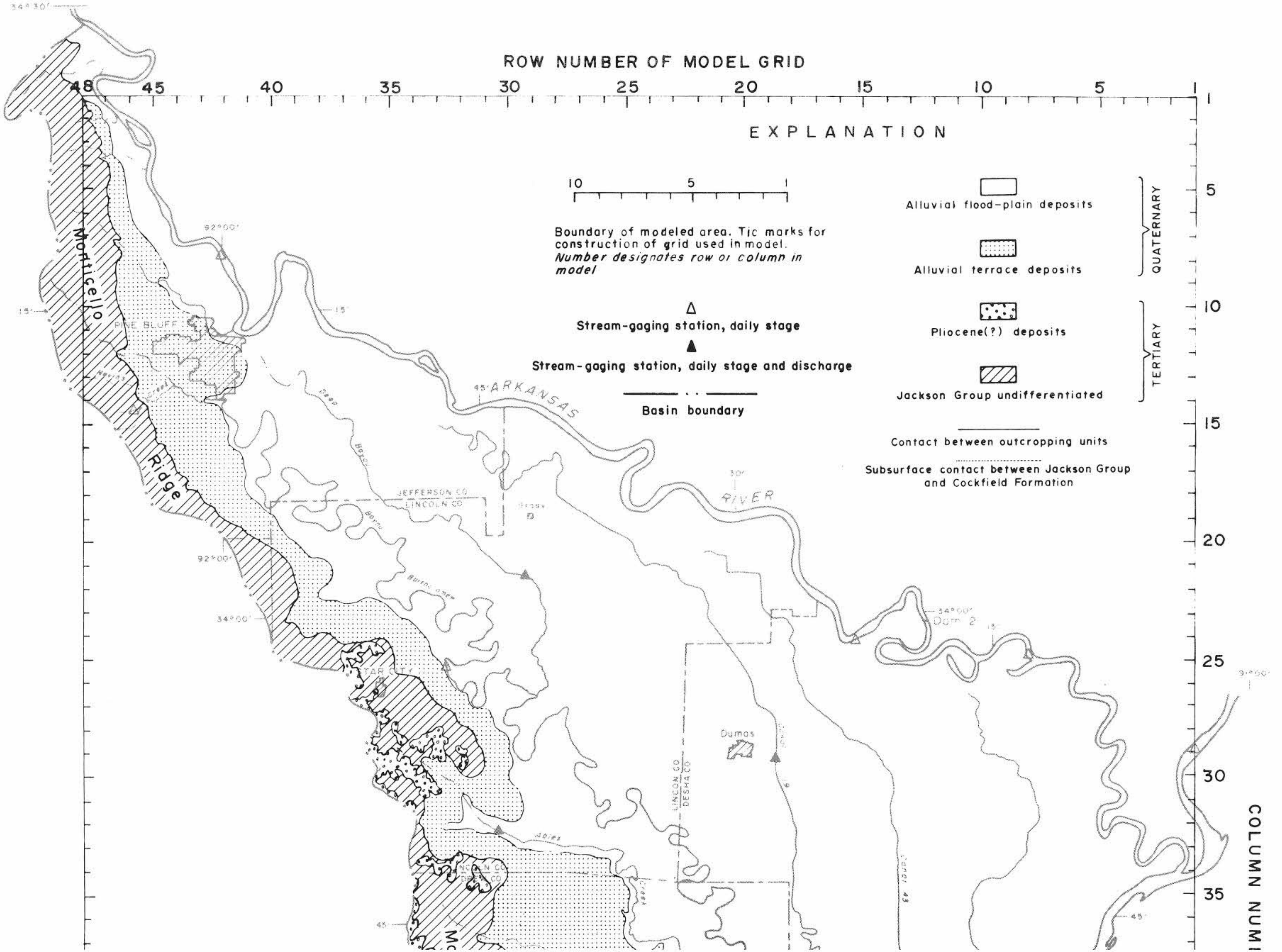
The reader is referred to Broom and Reed (1973) for additional description of the physical features of the system.

DIGITAL MODEL OF THE SYSTEM

Ground-Water Segment

Natural Framework

The alluvial aquifer, composed of sand and gravel, occurs relatively uniformly in the alluvial flood-plain and terrace deposits (fig. 2). The aquifer is overlain by semiconfining clay and silt beds in the flood-plain and terrace deposits, and the aquifer is underlain mostly by a thick confining clay bed in the Jackson Group, undifferentiated in this area. The aquifer wedges out against the Jackson Group along the Monticello Ridge in the area mostly north of Ashley County (fig. 2). The contact between the Jackson Group and the aquifer represents an impermeable boundary. South of the Monticello Ridge, the aquifer extends westward into the Saline and Ouachita River basins. The average thickness of the aquifer is about 100 ft, and


ROW NUMBER OF MODEL GRID
48
45
40
35
30
25
20
15
10
5
1
COLUMN NUM
EXPLANATION
10
5
1
Boundary of modeled area. Tic marks for construction of grid used in model. Number designates row or column in model
Stream-gaging station, daily stage
Stream-gaging station, daily stage and discharge
Basin boundary
Alluvial flood-plain deposits
Alluvial terrace deposits
QUATERNARY
Pliocene(?) deposits
Jackson Group undifferentiated
TERTIARY
Contact between outcropping units
Subsurface contact between Jackson Group and Cockfield Formation
Monticello
Ridge
PINE BLUFF
ARKANSAS
RIVER
JEFFERSON CO
LINCOLN CO
LINCON CO
DESHA CO
STAR CITY
Dumas
Dam 2
Canal 43
Bayou
Deep
Ables
Creek
34°30'
34°00'
92°00'
91°00'
15'
30'
45'

it underlies about 3,200 mi^2 of the study area. Practically all groundwater pumpage in the area, largely for rice irrigation, is derived from this aquifer.

The lateral boundaries for the modeled area of the aquifer are as follows: The Arkansas and Mississippi Rivers, respectively, form the north and east boundaries (fig. 2). The contact between the alluvial-terrace deposits and the Jackson Group forms the west boundary to the southern edge of the Monticello Ridge; south of the ridge, the west boundary is formed by the Saline and Ouachita Rivers. The southern boundary was arbitrarily set at 5 mi south of the Arkansas-Louisiana border.

Digital Simulation

The alluvial aquifer was treated as a two-dimensional planar model. The orientation and numbering system of the model grid are also shown in figure 2. The node spacing for the digital model, retained from the analog model (Broom and Reed, 1973) equals 7,040 ft in the system. Location of a node within the model grid is by the notation (I,J), where I and J are the row number and column number, respectively.

Transmissivity values in the aquifer, ranging from 0 to 43,000 ft^2/d, are shown alphamerically in figure 3 (note that fig. 3, as well as all other computer-printed maps in this report, must be rotated 90° clockwise to be oriented in the same direction as fig. 2). The boundary of the aquifer at the contact with the Jackson Group (fig. 2) was modeled by assigning zero transmissivity values to the nodes that fell outside the area of the aquifer (fig. 3). The distribution of the transmissivities in the digital model is the same as used in the analog model (Broom and Reed, 1973), except that the aquifer coverage was extended in the southwest in the digital model

(fig. 2) to include a part of the Saline and Ouachita River basins. The purpose of extending the aquifer coverage in the digital model was to determine the westward extent of pumping influence from the study area. Transmissivity values of the aquifer in the area of extension were partly estimated from an aquifer-thickness map from Boswell, Cushing, and Hosman (1968, pl. 1).

The storage coefficient (STØ) and soil parameters (HCU, HCL, SMM, SMN, and NEXP) are constants whose values are assigned to subareas of the system defined by a two-dimensional array, termed JAREA. A subarea map of the JAREA is shown in figure 4.

The initial storage coefficient was based on the analog-model calibration. Analog-model values for storage coefficient ranged from 0.03 to 0.24 (Broom and Reed, 1973, p. 50). For ease in calibration of the digital model, storage coefficients were averaged throughout each subarea of the JAREA. These smoothed values, which ranged from 0.03 to 0.21, were used as input to the digital model. Calibration of the model required modification of values to improve the fit between model-derived and observed data. The final range of storage-coefficient values was from 0.06 to 0.21. Initial and final storage coefficients for each subarea of the JAREA are shown in table 1.

The parameters HCU, HCL, SMM, SMN, and NEXP reflect the characteristics of the soil and the clayey and silty material that overlie the alluvial aquifer. The overlying material controls aquifer accretion (vertical recharge and discharge) from infiltration of precipitation and loss to evapotranspiration. HCU is a factor determining infiltration and represents the hydraulic conductivity of the soil. HCL is a factor in determining

```
                                  COLUMN NUMBER
       5   10   15   20   25   30   35   40   45   50   55   60   65   70   75 78
 1 ***************************************************************EFEE**********F
   *                              EEF               EFE         EEEFEE         EF
   *                          CCDEEEEE             EEEEEEEE    EEEEEEEE        EE
   *                        CCCCDEEEEEEE    EE    EEFFEEEEEEE EEFEEFEEFEEEEEEEFEE
 5 *                       CCCCCDEEEEEEEE  EFFEE  EEFEEEEEEEEEEEEEEEEEEFEEEEEEEEE
   *                      CCCCCCDEEEEEEEE EEFEEE  EEFEEEEEEEEEEEEEEEEEEEEEEEEEEEE
   *                     CCCCCCDDEEEEEEEEEEEEEEEFEEEEEEEEEEEEEEEEEEEEEEFEEEDDEEEE
   *                     CCCCDDEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEDDEEEE
   *                      CCCDEFFFEDDEEEEEEEEEEEFEEEEEEEEEEEEEEEEEEEEFEEEEEEEEEEE
10 *                      CCCDEFGFEDDEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
   *                      CCCDEFGFFEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
   *                      CCCDEFGGFFFEEEEEEEEEEEEEDDEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
   *                      CCDDEFFGGGFEEEEEEEEEEEEEDDEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
   *                     DDDDEEEFGGGFEEEEEFFFFFFEEDDEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
15 *                    DDDEEDDEFFGGFEEEFFFGGGGFFFFFFFEEEEEEEEFFFFFEEEEEEEEEEEEEE
   *                   FFEEEEDDEEFGGFEEFFGGGGGGGGGGGGFFEDDEEEFFGGGFFEEEEEEEEEEEEE
   *                DEEFFEEFFEDDFFGGFEEFGGGGHHGGGGGGGGFEDDEEEFGGGGGFFEEEEEEEEEEEE
   *                DEEFFEDEEEEEEEFFFEFFGHHHHHHHHHHHHGFEEEEEEFFGHHGGFEEDDDEEEEEEE
   *                DDEEEEDDEEFFFEEEEEFGHHHHHHHHHHHHHHFFFFFEEEFGGHHGFFEDDDEEEEEEE
20 *                DDEEDEEDDEFGFFEEFFFGHHHHGGGGGGGGGGGGGGFFEEFGGHHGGFFEEEEEEEEEE
   *               DDDEEDEDEEEFGGFFFFGGHHHGGGGFFFFFFFFGGHHGFFFFGGHHHGGFFFFEEEEEEE
   *               DDDEEDDDEEEFGGGGGGHHHHGGGGFFEEFEEEFFFGHHGGGGHHHIIHGGGGFFFFFFEE
   *               EEEEEEEEEFFFGGGGGGGGGGGFFEEEEEEEEEEEFFGGHHHHHHIIIIHHHGGGGGGFFF
   *              FEEEFFFFFFFGFFFFFFFFFGGGGFFEEEEFEEEEEEFFFGGGHIIIIIIIIHHHHHHGGGG
25 *             EEEFEFGGGGGGFFEEEEEEEEFFGGFFFEDDDDDDDDEEEFFGGHIIIIIIIIIIIHHHHGGG
   *             EDEEEFGHHHGFFEDDDDDDDEFFFFEEDDDDDDDDDDDEDEFFGHHIIIIIIIIIIIIIIHHH
   *            EEDEEEFHGGGFFEDCCCCCCCDEFFEDDDDDDDDDDDDDDDDEFFGHHIIIIIIIIIIIIIIHH
   *           EEDDEEEFGFFFFEDCBBBBBBCDEEDCDDCCCCCCCCCCCCDCCDEFFGHHHHIIHHHHHIIIII
   *           EEDDEEFFFFEEEDCBBBBBBBBBBCDDCBCCCBBB     CBBCDEFFGHHHHHHHHHHHHIIII
30 *           EDDDEFFFFEDDDCBBBBBB  BB   BBBBBBB          BCDEFFGGHHHGGHHHHHHIII
   *            DDEFFFFFEDCCCBB BBB                        BBCDEEFFGGGGGGGGHHHHHI
   *          FEEEFFFFEDCBBBB  BBBB                        BBCDDEEFFFFFFGGGGGHHHH
   *         FFEEEFFFEDCBBBB                               BBBCDDEEEEEEFFFGGGGHHH
   *         FFEEEFFEDCBBBB                       F F     CBBBBCDDEEEEEEEFFGGGGGH
35 *        FFFEEEFFEDCBBB                        FFFEDDDDCBBBBCDDDDEEEEEEFFFGGGG
   *        EEFFEEEEEDCBBB                        FFFFEEDDDCCBBBCDDDDEFGFEEFFFGGG
   *       EEEEEDDDDDDCBB                         FFFFFFEDDDDCBBBCDDEFGHGFEEEFFGG
   *      EEEEDDDDDDDCBBB                         GGGGGGFEEDDDCBBBCDFGHIHGFEDDEFF
   *      EEEDDCCCCCCB                            FFFGGGGFEEEDDCBBCDEFGHIHGFEDDEF
40 *       EEDCCCCCCBB                            FFFFFFFEEEEEEDCBBCDEFGHGFEEDDDE
   *     EEEEDCCCCCBB                             EFEEEEE  E EFEDCBCDDEFGFEDDDDDE
   *    EDDDDCCCCBBB                              EEEE       FEDDDCBCDDEFEDDDDDDD
   *    DCCCCCBBBBB                                           FEDDDCDDDDEDDDDDDDD
   * CCDCBBBBBBBB                                               EEDDDDDDDDDDEEEEE
45 CCCCCBBBBBBBB                                                FEEEDDDDDDDEE EEE
   BBBBBB                                                        EEDDDDDDDEE    *
   *BBBB                                                          EEEEEEEE      *
48 ******************************************************************************
```

EXPLANATION

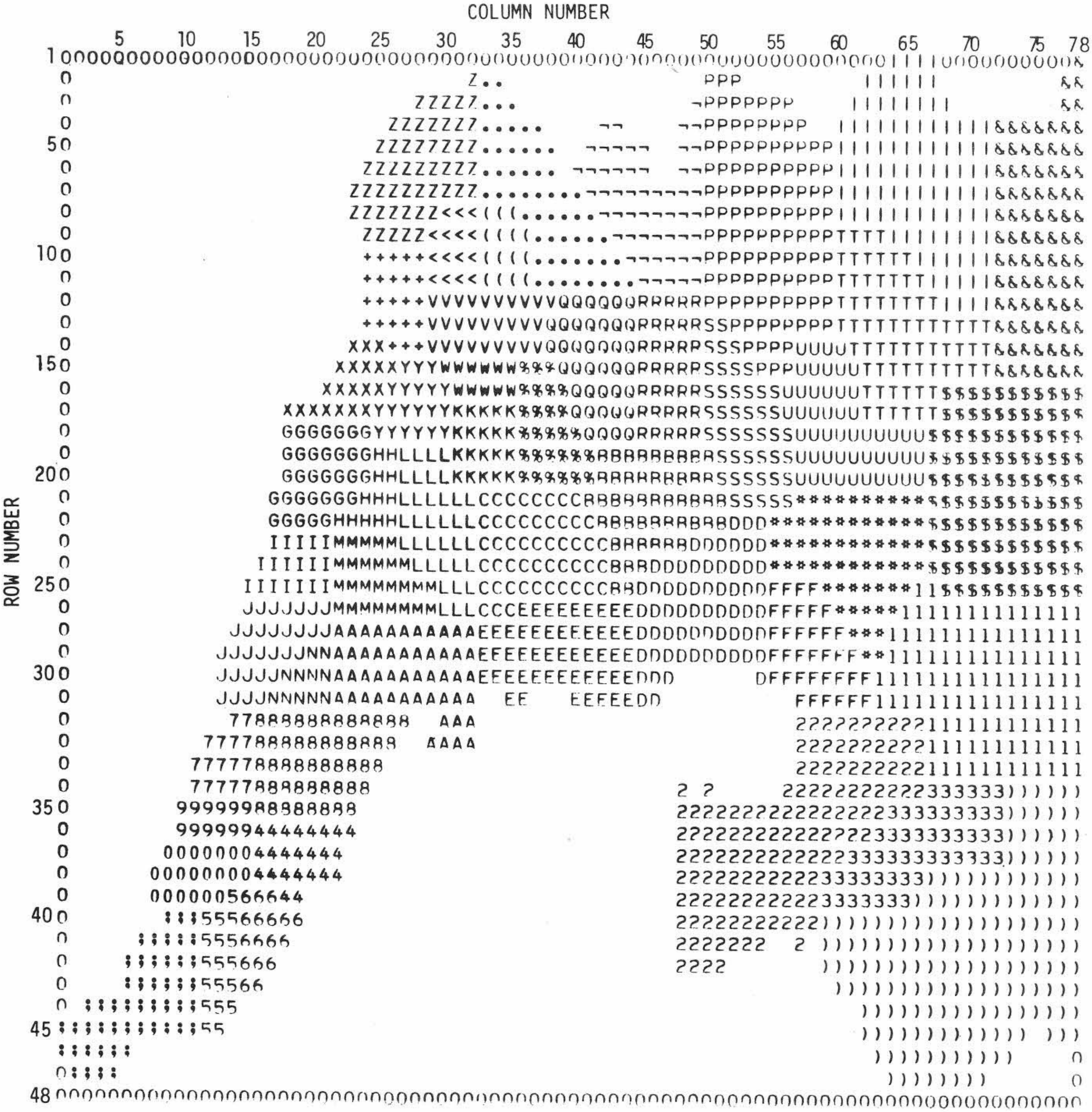
Code

Transmissivity (ft^2/d)

* = 0.0000E+00
  = 0.0000E+00
B = 5.0000E+03
C = 1.1000E+04
D = 1.6000E+04

E = 2.1000E+04
F = 2.7000E+04
G = 3.2000E+04
H = 3.7000E+04
I = 4.3000E+04

Figure 3.—Modeled transmissivity of the alluvial aquifer.



EXPLANATION

Code	Sub-area	Code	Sub-area	Code	Sub-area	Code	Sub-area	Code	Sub-area
1	1	A	11	K	21	U	31	|	41
2	2	B	12	L	22	V	32	&	42
3	3	C	13	M	23	W	33	$	43
4	4	D	14	N	24	X	34	*	44
5	5	E	15	%	25	Y	35	)	45
6	6	F	16	P	26	Z	36	:	46
7	7	G	17	Q	27	.	37	¬	47
8	8	H	18	R	28	<	38	0	0
9	9	I	19	S	29	(	39		0
0	10	J	20	T	30	+	40		

Figure 4.—Subareas of the JAREA

Table 1.—*Initial and final values for storage coefficient*

Subarea number	Storage coefficient	
	Initial	Final
1	0.0500	0.1000
2	.1400	.1400
3	.1200	.2000
4	.1200	.1200
5	.1000	.1000
6	.0900	.0900
7	.1000	.1000
8	.1800	.1800
9	.1000	.1000
10	.1400	.1400
11	.0800	.0800
12	.0600	.0600
13	.1100	.1100
14	.0600	.0600
15	.1100	.1100
16	.1000	.1000
17	.1200	.2000
18	.1800	.1800
19	.0800	.0800
20	.1600	.1600
21	.1900	.1900
22	.1500	.0800
23	.2000	.2000
24	.1200	.1200
25	.1500	.1500
26	.0300	.1000
27	.1200	.1200
28	.0900	.0900
29	.0600	.1000
30	.0600	.1000
31	.0400	.1000
32	.2100	.2100
33	.1200	.1200
34	.0900	.0900
35	.2000	.2000
36	.0900	.0900
37	.0700	.0700
38	.1800	.1800
39	.1600	.1600
40	.0800	.0800
41	.0600	.0600
42	.0300	.1000
43	.0300	.1000
44	.0600	.0600
45	.2000	.2000
46	.0300	.1000
47	.0400	.1000

aquifer accretion and represents the hydraulic conductivity of the material between the soil and the aquifer. SMM represents the maximum moisture that can be stored in the unsaturated zone at a model node. SMN represents the equilibrium soil-moisture content; moisture will drain to the aquifer if the moisture content is greater than SMN, and moisture will be replenished by upward flow from the aquifer if the moisture content is less than SMN. NEXP is the exponent (n) in equation 10 by Ripple, Rubin, and van Hylckama (1972) that postulates the relationship between the hydraulic conductivity of unsaturated soil and soil-water suction,

$$K=K(S)=K_{sat}/((S/S_{1/2})^{n}+1),$$

where

K=hydraulic conductivity for liquid flow, cm/d,

K_{sat}=hydraulic conductivity of water-saturated soil, cm/d,

S=soil-water suction, defined as the negative of the soil-water pressure head, cm of water,

$S_{1/2}$=a constant coefficient representing S at $K=1/2K_{sat}$, cm of water, and

n=an integer soil coefficient that usually ranges from 2 for clays to 5 for sands.

A limiting evapotranspiration rate at each model node was computed by multiplying a dimensionless value relative to NEXP and depth to water (table 2) by HCL for the node. The derivation of the dimensionless values and a FORTRAN program for computing the dimensionless values in table 2 are given on pages 54-55 of Reed, Bedinger, and Terry (1976).

Table 2.—*Dimensionless values for computing limiting evapotranspiration rates*

DEPTH TO WATER (FT)	NEXP=2	NEXP=3	NEXP=4	NEXP=5
1	2.68148	1.80207	1.52086	0.38240
2	1.14862	0.64980	0.47475	0.03764
3	0.66504	0.30684	0.18209	0.00562
4	0.43112	0.16335	0.07632	0.00136
5	0.30304	0.09449	0.03514	0.00045
6	0.22403	0.05847	0.01783	0.00018
7	0.17191	0.03827	0.00985	0.00008
8	0.13580	0.02624	0.00584	0.00004
9	0.10981	0.01870	0.00367	0.00002
10	0.09052	0.01377	0.00242	0.00001
11	0.07583	0.01041	0.00165	0.00001
12	0.06441	0.00806	0.00117	0.00000
13	0.05535	0.00636	0.00085	0.00000
14	0.04806	0.00510	0.00063	0.00000
15	0.04210	0.00416	0.00048	0.00000
16	0.03718	0.00343	0.00037	0.00000
17	0.03306	0.00286	0.00029	0.00000
18	0.02959	0.00241	0.00023	0.00000
19	0.02664	0.00205	0.00019	0.00000
20	0.02410	0.00176	0.00015	0.00000
21	0.02190	0.00152	0.00012	0.00000
22	0.02000	0.00132	0.00010	0.00000
23	0.01832	0.00116	0.00009	0.00000
24	0.01685	0.00102	0.00007	0.00000
25	0.01555	0.00090	0.00006	0.00000
26	0.01439	0.00080	0.00005	0.00000
27	0.01336	0.00072	0.00004	0.00000
28	0.01244	0.00064	0.00004	0.00000
29	0.01160	0.00058	0.00003	0.00000
30	0.01085	0.00052	0.00003	0.00000

The reason for the existence of a limiting flux is discussed on page A8 of Ripple, Rubin, and van Hylckama (1972), and the limiting flux is defined by equation 23 of their report.

Initial values for the five parameters representing characteristics of the fine-grained material above the aquifer were constant for the entire model and were HCU=0.03 ft/d, HCL=0.03 ft/d, SMM=1 ft, SMN=0.5 ft, and NEXP=4. These values were adjusted during calibration to improve the fit between the model and the observed data. The final values for the parameters are given in table 3.

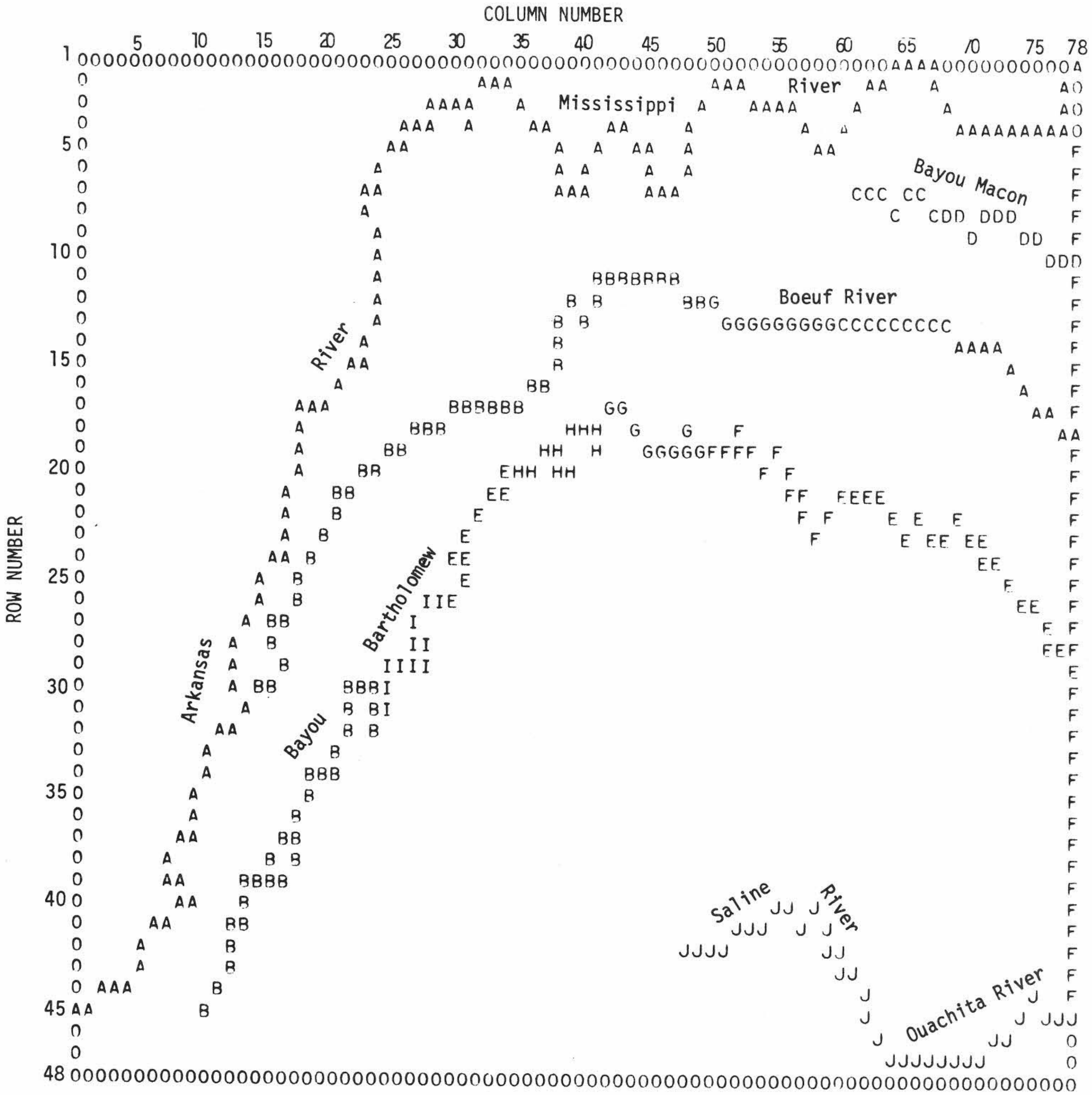
Another parameter of the ground-water segment of the model is the APS (streambed parameter), which reflects the degree of hydraulic connection between the stream and the aquifer. Streambeds were modeled for the Mississippi and Arkansas Rivers, Boeuf River, Bayous Macon and Bartholomew, and the Ouachita and Saline Rivers (fig. 5). The beds of streams that had no significant hydraulic connection with the aquifer, based on head-stage comparisons, were not modeled.

Except for the Saline and Ouachita Rivers, the values of APS at all stream boundaries were inferred from the analog-model analysis. The data from the analog model, converted into hydraulic terms, have units the same as transmissivity (ft^2/d) and represent the hydraulic conductivity of the streambed material multiplied by the horizontal area of the streambed at a node, divided by the thickness of the streambed material.

The APS final values in the digital model are the same as the initial values except for part of the lower reach of the Boeuf River where, in the calibration of the digital model, the Boeuf River streambed was indicated to have a lower APS than the initial value between column numbers 50-68 (fig. 5).

Table 3.—*Parameter values of the fine-grained materials overlying the aquifer*

SUBAREA NUMBER	HCU (FT/D)	HCL (FT/D)	SMM (FT)	SMN (FT)	NEXP
1	2.0000	0.0015	1.00	0.75	2
2	2.0000	0.0000	1.00	0.75	2
3	2.0000	0.0030	1.00	0.75	2
4	0.1200	0.0020	1.00	1.00	4
5	0.1200	0.0001	1.00	0.50	4
6	0.1200	0.0002	1.00	0.50	4
7	0.1100	0.0010	1.00	0.50	4
8	0.1100	0.0010	1.00	0.50	4
9	0.1100	0.0040	1.00	0.50	4
10	0.1100	0.0030	1.00	0.50	4
11	0.1100	0.0002	1.00	0.50	4
12	0.2000	0.0005	1.00	0.50	4
13	0.2000	0.0010	1.00	0.50	4
14	0.2000	0.0005	1.00	0.50	4
15	0.2000	0.0010	1.00	0.50	4
16	0.2000	0.0005	1.00	0.50	4
17	0.0250	0.0080	1.00	0.50	4
18	0.0250	0.0040	1.00	0.50	4
19	0.0250	0.0150	1.00	0.50	4
20	0.0250	0.0005	1.00	0.50	4
21	0.2500	0.0020	1.00	0.50	4
22	0.2500	0.0005	1.00	0.50	4
23	0.2500	0.0018	1.00	0.50	4
24	0.2500	0.0020	1.00	0.75	4
25	2.0000	0.0005	1.00	0.75	4
26	1.0000	0.0400	1.00	1.00	2
27	0.0400	0.0020	1.00	0.50	4
28	0.0900	0.0010	1.00	0.50	4
29	0.0900	0.0100	1.00	1.00	2
30	0.1000	0.0020	1.00	0.50	4
31	0.1000	0.0010	1.00	1.00	2
32	0.0500	0.0010	1.00	0.50	4
33	0.0500	0.0030	1.00	0.50	4
34	0.0500	0.0080	1.00	0.50	4
35	0.0500	0.0015	1.00	0.50	4
36	0.0300	0.0200	1.00	0.50	4
37	0.0300	0.0100	1.00	0.50	4
38	0.0300	0.0005	1.00	0.50	4
39	0.0300	0.0003	1.00	0.50	4
40	0.0300	0.0010	1.00	0.50	4
41	2.0000	0.0010	1.00	0.50	4
42	0.1000	0.0020	1.00	0.50	4
43	0.1000	0.0005	1.00	0.50	4
44	0.1000	0.0000	1.00	0.50	4
45	0.1000	0.0000	1.00	0.50	4
46	0.1000	0.0020	1.00	0.50	4
47	0.1000	0.0040	1.00	0.50	4



EXPLANATION

Code	APS (ft^2/d)	Code	APS (ft^2/d)
A	$1.0X10^9$	G	$7.3X10^3$
B	$8.4X10^2$	H	$5.0X10^3$
C	$7.6X10^4$	I	$1.5X10^4$
D	$6.4X10^2$	J	$1.0X10^4$
E	$2.2X10^4$	0	0.0
F	$3.2X10^3$		0.0

Figure 5.—Modeled values of APS

The Mississippi and Arkansas Rivers (fig. 5), forming specified head boundaries in the conceptual model of the system, have a very high constant value of APS ($1X10^9$ ft^2/d). These rivers fully incise the fine-grained material in the upper part of the flood-plain deposits, causing minimal resistance to flow through the streambeds. A similarly low resistance to flow occurs through the streambed of Boeuf River in its lowermost reach.

The APS value ($1.0X10^4$ ft^2/d) for the Ouachita and Saline Rivers (fig. 5) was chosen only on the basis of stream size, believing that the APS value was between the average APS value of Bayou Bartholomew and the APS value of the Arkansas and Mississippi Rivers. In any case, the influence of pumping in the study area did not extend to this boundary, and, therefore, the calibration of the model was not affected by the chosen APS value for the Ouachita and Saline Rivers. A better defined APS value for the Saline and Ouachita Rivers would be desirable if the model should be used to predict the effects of any future pumping in this part of the aquifer.

The southern boundary of the digital model (fig. 5) was represented by a fictitious streambed with the APS value ($3.2X10^3$ ft^2/d) equal to the hydraulic resistance produced by eight model nodes in series. The average transmissivity in this part of the aquifer was assumed to be $2.6X10^4$ ft^2/d. The stage of the stream was assumed to be constant and was set equal to 73 ft above sea level. This head value was obtained by extrapolating the potentiometric gradient at the southern boundary and averaging the potentiometric surface at a distance of eight model nodes. Subsequent model analysis indicated that the arbitrary location of the southern boundary did not appreciably affect the calibration of the model.

Surface-Water Segment

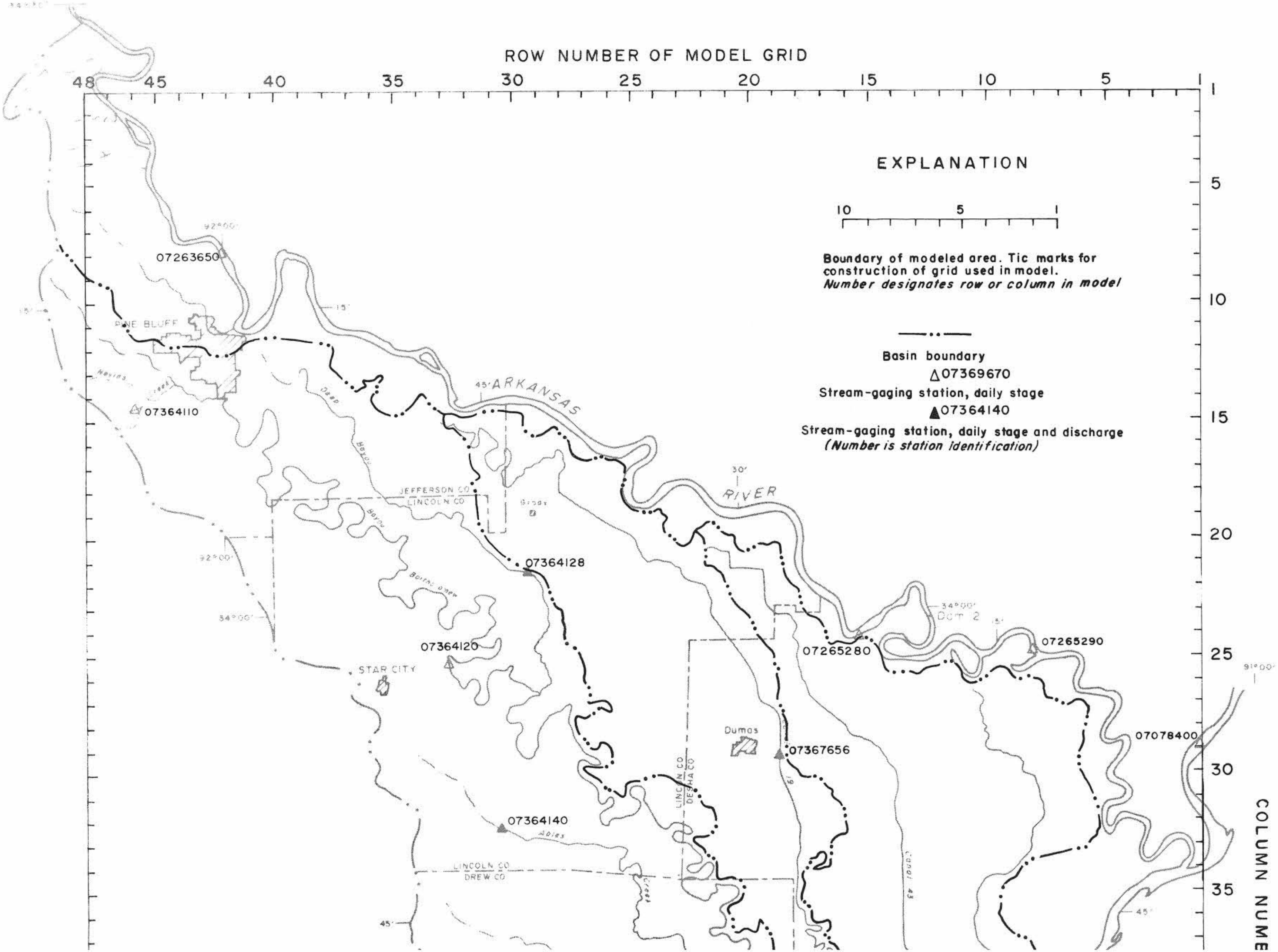
Natural Framework

The basin boundaries of the principal streams in the study area are shown in figure 6. The Monticello Ridge and levees along the Arkansas and Mississippi Rivers form the basin boundaries on the north, west, and east for about 90 percent of the area. Thus, most of the water is derived within the area and drains southward to the Ouachita River in Louisiana. The rest of the area (about 10 percent) drains to the Arkansas and Mississippi Rivers.

The study is concerned with streamflow only in the basins lying fully within the study area. These basins are drained by Bayou Bartholomew, Boeuf River, and Bayou Macon. Basin and streamflow characteristics for these basins are tabulated in Broom and Reed (1973).

The Bayou Bartholomew basin (fig. 6), the largest of the basins, has a drainage area of 1,480 mi^2 and a channel length to the State boundary of 280 mi. The Boeuf River basin has a drainage area of 780 mi^2 and a channel length of 145 mi, as measured to the State boundary along Canal 19, the Boeuf River Diversion Canal, and the Boeuf River. The Bayou Macon basin has a drainage area of 500 mi^2 and a channel length of 101 mi, as measured to the State boundary along Canal 43, Macon Lake, Lake Chicot, Ditch Bayou, and Bayou Macon.

Precipitation, according to National Weather Service records, differs little in distribution between the basins. The mean-annual precipitation is about 51 in. and the mean-monthly precipitation ranges from 5.5 in. in January to 2.8 in. in October.


ROW NUMBER OF MODEL GRID
48
45
40
35
30
25
20
15
10
5
1
COLUMN NUME
EXPLANATION
10 5 1
Boundary of modeled area. Tic marks for construction of grid used in model.
Number designates row or column in model
Basin boundary
△07369670
Stream-gaging station, daily stage
▲07364140
Stream-gaging station, daily stage and discharge
(Number is station identification)
ARKANSAS
RIVER
PINE BLUFF
STAR CITY
Dumas
Grady
JEFFERSON CO
LINCOLN CO
LINCOLN CO
DESHA CO
LINCOLN CO
DREW CO
07263650
07364110
07364128
07364120
07364140
07367656
07265280
07265290
07078400
92°00'
34°00'
91°00'
45'
30'
15'
Canal 43
Bayou Bartholomew
Deep Bayou
Creek

The combined mean-annual discharge from the basins--Bayou Bartholomew, Boeuf River, and Bayou Macon--is about 3,000 ft^3/s or 2,200,000 acre-ft. This discharge is estimated largely from gaged flow along the State boundary (fig. 6) but includes about 200 ft^3/s that bypasses the gaging stations.

Digital Simulation

The surface-water segment of the digital model uses the array IAREA in which subareas or "subbasins" within the basins are delineated (fig. 7). At each node in the subbasins, precipitation excess, stream capture (aquifer recharge), pumpage from streams, and return flow to streams from irrigation are summed algebraically and totaled in each subbasin to obtain net increase or decrease in streamflow for each subbasin. Return flow is assigned to the node where the irrigation water is withdrawn. Actually, the irrigation water is not always used or returned in the vicinity of its withdrawal from the aquifer or stream. However, transport distances are usually less than a mile, and the relatively coarse node spacing (7,040 ft) would minimize the effects of the distances between the points of withdrawal, use, and return flow.

Model Conditions and Stresses

The time period used for analyses with this model was 18 years, from 1953 through 1970. Because of this long time span, monthly time steps were used in the model. Mass-balance calculations in the model indicate that the model was not strained enough by these large time steps to create gross errors.

The initial condition for the model was the potentiometric surface for the spring of 1953. This potentiometric surface was used as input to the model as a symbolic map with values rounded to the nearest 5 ft. In addition,

ROW NUMBER

```
                                    COLUMN NUMBER

       5   10   15   20   25   30   35   40   45   50   55   60   65   70   75 78
 1 RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRVVVVRRRRRRRRRRV
   R                              UUV               VVV         VVVVVV         VV
   R                          UUUUUVVV             VVVVVVVV    VVGQQQVV        VV
   R                        UUUUUUUVVVVV    VV    VVVVVVVVVV  VVQGGQQVVVVVVVVVVVV
 5 R                       UUOOUOOOVVVVVV  VVVVV  VVVVVVVPPVVVPQQQQQQVVVVVQVVVVVS
   R                      UUUOOOOOOVVVVVV VVVVVV  VVVVVVVPPPPPPQQQQQQQVVVGQSVVVVS
   R                     UUUOOOOOOOOVVVVVVVPPPVVVVVVVVVPPPPPPPPQQQQQQQQQQQSSSSVSS
   R                     UUUOOOOOOOOVVVOOVPPPPPVPPPPVVPPPPPPPPPQQQQQQQQQQQQQSSSSS
   R                      UUOOOOOOOOOOOOOOOOOPPPPPPPPPPPPPPPPPQQQQGMMMMMGSSSGQSSS
10 R                      UUOOOOOOOOOOOOOOONNPPPPPPPPPPPPPPPPMMMMMMMMMMMMSSSSSSSS
   R                      UOOOOOOOOOOOOOOONNGGGHHHHHPPPPPPMMMMMMMMMMMMMMMSSSSSSSS
   R                      UOOOONNNNNNNOONGNGHHKKKHHHPPMMMMMMMMMMMMMMMMMMMMMSSSSSS
   R                      UOOOONNNNNNNNNGHGHHHKKKKIIIIIIIIIIIMMMMMMMMMMMMMMMMSSSS
   R                     UNOOONNNNNNNNNNGHHHHKKKKKIIIIIIIIIMMMMMMMMMMMMMMMMMMSSSS
15 R                    UUNNNNNNNNNNNNNNGHHHJJKKKKKIIIIIILMMMMMMMMMMMMMMMMMMMSSSS
   R                   UUUNNNNNNNGGGNNGGHHJJKKKKKLLLLLLLLLLLMMMMMMMMMMMMMMMMMSSSS
   R                UUUUNNNNNNNNNGGGGGHHHJJDDEKKKELLLLLLLLLMMMMMMMMMMMMMMMMMMMMSS
   R                UUNNNNNFFFFGGGGGGGHHDDDDEEEKEEELEEELLLLMMMMMMMMMMMMMMMMMMMSSS
   R                UUNNNFFFFFFGGGGGGDDDEEDEEEEEEEEEEEEELEMMMMMMMMMMMMMSSSSMSSSSS
20 R                UUNNFFFFFFFGGGGGDDDDDEEEEEEEEEEEEEEEEEEMMMEEEMMMMMSSSSSSSSSSS
   R               UUNFFFFFFFGGGDDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEEMMMESSSSSSSSSSS
   R               UUFFFFFFFGGGDDDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEESSSSSSSSS
   R               UUFFFFFFGGGGGDDDDDDDDEEEEEEEEEEEEEEEEEEEEEESSSEEEEEEEEEESSSSSS
   R              UUFFFFFFGGGGGGDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEESSSSSSSSSSEESSSSSS
25 R             UFFFFGFGGGGGGGDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEESSSSSSSSSSSEESSSS
   R             UFFFGGGGGGGDGDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEAASSSSSSSSSSSSEESSS
   R            UFFFFGGGGDDDDDDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEAAASSSSSSSSSSSSSSSS
   R           UUFFFFGGDDDDDDDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEEAAAAAAAAAAASSSSSSSS
   R           UFFFFGGGDDDDDDDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEAAAAAAAAAAAAAAAASSSS
30 R           UFFFGGGCCBBBDDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEAAAAAAAAAAAAAAAAAAASSS
   R            UFCCCCCCBBBDDDDDDDDDEEEEEEEEEEEEEE     EEEAAAAAAAAAAAAAAAAAAAAASS
   R          UUCCCCCCCCBBBDDDDDDDDDEEEEEEEE               TAAAAAAAAAAAAAAAAAAAAS
   R         UUUCCCCCCCBBBDDDDDDDDDDEEEEEEE                TTAAAAAAAAAAAAAAAAAAAS
   R         UUUCCCCCBBBBBBDDDDDD                 T T     TTTTAAAAAAAAAAAAAAAAAAS
35 R        UUCCCCCCBBBBBBDDD D                   TTTTTTTTTTTTTAAAAAAAAAAAAAAAAAS
   R        UUUCCCCBBBBBBBB                       TTTTTTTTTTTTTTAAATAAAAAAAAAAAAS
   R       UUCCCCCCBBBBBBBB                       TTTTTTTTTTTTTTTTTTTAAAAAAATTTTS
   R      UUUCCCCCBBBBBBBBB                       TTTTTTTTTTTTTTTTTTTTAAAAATTTTTS
   R      UUUCCBBBBBBBBBBB                        TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTS
40 R       UUBBBBBBBBBBB                          TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTS
   R     UUUUUBBBBBBBB                            TTTTTTT  T TTTTTTTTTTTTTTTTTTS
   R    UUUUUUBBBBBBB                             TTTT       TTTTTTTTTTTTTTTTTTTS
   R    UUUUUBBBBBBB                                          TTTTTTTTTTTTTTTTTTS
   R UUUUUUUUUBBBBBB                                            TTTTTTTTTTTTTTTTS
45 UUUUUUUUUUBBBBB                                              TTTTTTTTTTTTT TTT
   UUUUUUUUBBBBBB                                                TTTTTTTTTTT    R
   UUUUUUUBBBBBB                                                  TTTTTTTT      R
48 UUUUUUBBBBBRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
```

EXPLANATION

Code	Subbasin	Code	Subbasin	Code	Subbasin	Code	Subbasin	Code	Subbasin
A	1	F	6	K	11	P	16	V	21
B	2	G	7	L	12	Q	17	R	0
C	3	H	8	M	13	S	18		0
D	4	I	9	N	14	T	19		
E	5	J	10	O	15	U	20		

Figure 7.—Subbasins of the IAREA.

potentiometric-surface altitudes (rounded to the nearest foot) were read in for 47 nodes representing observation-well locations. Hydrographs displaying computed and observed data were printed for these locations. Data for the 1953 map were based on spring water-level measurements made in 65 wells scattered throughout the study area.

Stress applied to the ground-water segment of the model consisted of ground-water pumpage, fluctuations in stream stage, and vertical flow (recharge and evapotranspiration) between the aquifer and the land surface.

A field inventory was made of pumpage from the system in 1970. The ground-water pumpage for agricultural use, largely for rice irrigation, was assigned to 276 model nodes (table 4) and totaled about 173,000 acre-ft. The ground-water pumpage for nonagricultural use, largely for one industry, was assigned to two nodes (table 4) and totaled 12,000 acre-ft. The areal distribution of pumpage for agricultural use was kept the same in the model for the years 1953-69 as in 1970 because the effects of any changes in the distribution of wells would be minimized by the coarse node spacing of the model grid. The annual pumpage assigned to each node for 1953-70 was based on the crop acreage for the year and the 1970 application rate of water per acre. The monthly and annual distribution of the ground water (as well as surface water) for agricultural use for the years 1953-70 was assigned to the nodes in the ratios shown in table 5. The monthly pumpage was assigned as a percentage of the annual pumpage. May and September were each assigned 10 percent; June was assigned 20 percent; July and August were each assigned 30 percent; and all other months were assigned zero percent.

The monthly pumpage of ground water for nonagricultural use was assigned as a share of the annual pumpage (table 6), based on the number of days in the month.

Table 4.—*Pumpage from the system, 1970*

GROUND WATER FOR AGRICULTURAL USE

ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT
35	12	909	37	12	1450	36	13	1787	38	13	963	30	14	320	33	14	356	35	14	783	37	14	1306
28	15	576	29	15	1935	31	15	189	34	15	270	35	15	270	25	16	954	26	16	1152	27	16	590
28	16	527	29	16	811	32	16	680	34	16	959	25	17	954	26	17	720	27	17	332	31	17	695
32	17	414	33	17	1004	34	17	1467	24	18	959	25	18	1310	26	18	1692	29	18	923	30	18	811
32	18	977	33	18	675	34	18	428	21	19	428	22	19	396	25	19	531	28	19	1189	29	19	311
30	19	356	31	19	675	20	20	383	21	20	779	23	20	648	24	20	977	25	20	585	27	20	2080
29	20	990	20	21	239	27	21	392	28	21	977	29	21	1685	30	21	693	18	22	234	19	22	235
20	22	879	21	22	221	29	22	1800	19	23	290	20	23	810	21	23	1203	22	23	1193	23	23	257
25	23	1315	26	23	1951	28	23	1096	29	23	910	30	23	496	17	24	374	18	24	689	22	24	740
26	24	100	27	24	225	28	24	400	32	24	311	15	25	230	16	25	716	17	25	171	18	25	459
20	25	540	23	25	239	24	25	81	25	25	50	26	25	176	7	26	1026	8	26	365	16	26	468
19	26	189	22	26	324	26	26	599	7	27	509	8	27	360	9	27	495	14	27	450	16	27	428
17	27	59	18	27	789	19	27	387	20	27	311	23	27	450	6	28	1256	7	28	450	9	28	671
10	28	221	11	28	446	15	28	374	16	28	342	24	28	698	25	28	1013	27	28	676	10	29	230
16	29	1054	18	29	666	19	29	702	27	29	1200	28	29	1000	5	30	234	6	30	333	7	30	81
9	30	383	10	30	441	14	30	369	17	30	1575	18	30	324	26	30	243	27	30	200	8	31	225
9	31	450	11	31	1045	12	31	356	13	31	400	15	31	351	17	31	581	18	31	14	20	31	248
21	31	360	5	32	360	9	32	1215	11	32	464	14	32	347	15	32	1112	16	32	212	18	32	666
20	32	1215	8	33	450	9	33	225	10	33	225	11	33	527	13	33	400	14	33	563	15	33	563
18	33	81	19	33	540	21	33	450	11	34	900	16	34	1054	17	34	900	18	34	351	19	34	1297
21	34	860	23	34	2751	11	35	554	15	35	117	17	35	644	18	35	743	25	35	200	26	35	200
12	36	230	15	36	3263	18	36	450	22	36	99	9	37	1067	11	37	810	12	37	50	17	37	585
21	37	626	29	37	495	12	38	99	12	39	680	17	39	401	20	39	675	26	39	336	8	40	437
10	40	1346	12	40	306	16	40	347	27	40	296	28	40	541	29	40	517	9	41	540	18	41	540
21	41	875	11	42	473	12	42	473	14	43	428	15	43	387	13	44	883	16	44	1715	17	44	644
13	45	261	14	45	1058	16	45	698	18	45	581	30	45	836	10	46	200	11	46	434	15	47	735
21	47	785	14	48	504	13	49	729	15	49	351	17	49	477	18	49	887	14	50	1041	17	50	1532
17	51	1571	17	52	411	18	52	477	17	53	1205	17	54	329	13	55	554	17	55	450	18	55	783
19	55	726	20	55	648	13	56	235	15	57	351	31	57	750	7	58	531	15	58	380	18	58	1377
29	58	336	30	58	683	14	59	230	15	59	425	20	59	26	27	59	254	28	59	422	29	59	776
31	59	283	12	60	527	21	60	531	27	60	463	29	60	978	30	60	527	31	60	186	10	61	451
18	61	252	27	61	1785	30	61	120	31	61	322	35	61	326	17	62	158	23	62	765	26	62	231
33	62	126	34	62	706	35	62	97	36	62	534	7	63	1305	21	63	360	29	63	408	34	63	161
35	63	316	21	64	275	36	65	1307	20	66	40	19	67	455	10	68	325	19	70	780	22	70	459
7	72	554	20	72	568	7	73	1085	25	73	330												

GROUND WATER FOR NONAGRICULTURAL USE

ROW	COL	AC.FT
39	69	840
36	71	11300

SURFACE WATER FOR AGRICULTURAL USE

ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT	ROW	COL	AC.FT
33	18	216	31	19	675	29	20	990	28	22	1278	30	23	100	21	24	270	30	24	666	19	26	158
7	27	509	18	27	153	20	29	576	17	30	194	19	30	324	17	31	369	20	31	572	21	31	963
19	32	414	21	32	360	14	34	977	16	36	720	21	36	572	10	37	2372	12	37	342	21	39	1652
10	40	882	10	41	563	19	41	126	10	42	1517	11	42	207	10	43	765	20	44	378	20	47	231
16	53	3150	9	54	1230	13	54	1058	17	54	1008	14	55	806	17	55	572	19	55	1454	13	56	450
17	56	1350	7	57	266	7	58	572	6	60	451	8	60	1661	13	61	351	8	63	1022	11	63	522
13	63	451	8	64	2561	8	66	788	14	66	810	15	67	900	16	67	191	9	68	653	14	68	1800
9	71	1152	7	72	377	9	72	3695	23	29	1800	35	15	792									

Table 5.—*Ratios for distributing pumpage for agricultural use in the model*

```
MONTHLY PUMPAGE TO TOTAL PUMPAGE FOR YEAR

MONTH   JAN   FEB   MAR   APR   MAY   JUN   JUL   AUG   SEP   OCT   NOV   DEC
RATIO 0.00  0.00  0.00  0.00  0.10  0.20  0.30  0.30  0.10  0.00  0.00  0.00

GROUND-WATER PUMPAGE FOR YEAR TO GROUND-WATER PUMPAGE FOR 1970

YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO
1953  0.9770 1954   0.8860 1955   0.7940 1956   0.7030 1957   0.5950 1958   0.6590 1959   0.7060 1960   0.7090 1961   0.7120
1962  0.7780 1963   0.8410 1964   0.8040 1965   0.8570 1966   0.9470 1967   0.9550 1968   1.1580 1969   1.0660 1970   1.0000


SURFACE-WATER PUMPAGE FOR YEAR TO SURFACE-WATER PUMPAGE FOR 1970

YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO  YEAR   RATIO
1953  1.0400 1954   0.9580 1955   0.8740 1956   0.7840 1957   0.6570 1958   0.7170 1959   0.7860 1960   0.7940 1961   0.8060
1962  0.8720 1963   0.8680 1964   0.8760 1965   0.8940 1966   0.9820 1967   0.9820 1968   1.1820 1969   1.0660 1970   1.0000
```

Table 6.—*Distribution of ground-water pumpage (acre-ft) for nonagricultural use, 1953-70*

```
ROW= 39,COL= 69
YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE
1953   11200 1954   11200 1955   11200 1956   26900 1957   26900 1958   26900 1959   26900 1960   26900
1961   26900 1962   26900 1963   26900 1964     840 1965     840 1966     840 1967     840 1968     840
1969     840 1970     840
ROW= 36,COL= 71
YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE YEAR PUMPAGE
1953       0 1954       0 1955       0 1956       0 1957       0 1958       0 1959       0 1960       0
1961       0 1962       0 1963       0 1964   26900 1965   11300 1966   11300 1967   11300 1968   11300
1969   11300 1970   11300
```

Changes in stream stage, at places where the streambed material is sufficiently permeable, constitute an important stress upon the aquifer. Stream stages were modeled as monthly averages, based on records for the period 1953-70, at 16 gaging stations (fig. 6) and were supplemented with partial records at eight others. At the node where the gaging station is located, stream stage in the model was specified equal to the sum of the average gage height for the month, plus the altitude at which gage height is equal to zero. For other nodes along a stream, interpolations or extrapolations were made from average-monthly altitudes at the nearest gaging stations. The interpolations and extrapolations were based on the number of model nodes between the points, not on the river distance between them.

Vertical flow between the aquifer and the land surface occurs as a response of the unsaturated zone above the aquifer to the climatic stresses of precipitation and potential evapotranspiration. Precipitation data were collected for the period 1953-70 at 13 weather stations scattered throughout the modeled area. A monthly precipitation was computed for each subbasin (defined by the IAREA) by averaging the monthly data from the weather stations within the subbasin. If the subbasin contained no weather station, a monthly precipitation was computed as a weighted average of all 13 weather stations, each weighted average being inversely proportional to the distance from the subbasin to the weather station. Of the 2,423 data items for monthly precipitation, 99 were 10 in. or greater, 154 were less than 1 in., and 15 were less than 0.01 in. The greatest monthly precipitation for the period of record was 20.27 in. for April 1958, recorded at Hamburg in Ashley County (fig. 6). Of the stations, 10 recorded less than 0.01 in. for October 1963.

Estimates of potential evapotranspiration were made by applying a coefficient of 0.8 to monthly pan-evaporation data collected near Stuttgart, Ark., about 30 mi northeast of the study area. Yearly totals of evapotranspiration using this estimate ranged from 31.19 in. for 1957 to 50.94 in. for 1963 and averaged 42.88 in. for 1953-70. The smallest monthly estimate was 0.68 in. for January 1957, and the largest was 8.04 in. for May 1962.

The stresses applied to the surface-water segment of the model included precipitation, interflow between surface and ground water, diversion of surface water for irrigation, and return flow of unconsumed irrigation water. The interaction of the climatic stresses with the representation of the unsaturated zone in the model determines the relative amounts of runoff and infiltration. Interflow between surface and ground water in the model is a function of input data on stream stage, APS (streambed parameter), and model-derived potentiometric head.

Surface-water diversion, or pumpage for agricultural use, totaled about 52,000 acre-ft in 1970 and was assigned to 61 notes in the model (table 4). The monthly and annual distribution of the surface-water pumpage for agriculture for the years 1953-70 was assigned to nodes in the ratios shown in table 5. There was no significant surface-water pumpage for nonagricultural use in the stream basins lying wholly within the study area.

Return flow in the study area was estimated to be 25 percent of the applied water for rice irrigation (Broom and Reed, 1973, p. 49), the predominant use of water from the system. Largely through periodic draining of the flooded ricefields during the growing season, the return flow becomes part of the surface runoff. The model handled the return flow by first taking the 25 percent of the applied water in a given month and adding this amount to the runoff for the succeeding month. Then the model examined the total water available for runoff in the given month and reduced this quantity by the amounts of infiltration and evaporation (runoff=precipitation+75 percent of the applied water minus the infiltration minus the evaporation). The runoff was then compared with the precipitation and any excess over the precipitation was added to the return flow for the month.

Model Calibration

Parameter Adjustments

Initial values of 0.03 ft/d for HCU and HCL, 4 for NEXP, 1 ft for SMM, and 0.5 ft for SMN were used for all the subareas in the JAREA (fig. 4). These values produced a 1.44 average ratio of model streamflow to measured streamflow for the 17 subbasins of the IAREA (fig. 7), which lie within the Bayou Bartholomew, Boeuf River, and Bayou Macon basins (fig. 6). The individual subbasins had streamflow ratios ranging from 0.80 to 2.19. Also, ground-water levels calculated by the model in the first run were higher than observed water levels. For the second run, HCU was changed to 0.1. This change produced an average streamflow ratio of 0.90 and individual subbasin-streamflow ratios of 0.39 to 1.12; however, ground-water levels were even higher than for the first run. HCL was changed to 0.001 ft/d and HCU was not changed for the third run. The change produced an average streamflow ratio of 1.08 and individual streamflow ratios of 0.52 to 1.68. The average of model-derived ground-water levels after the third run was nearly the average of the observed levels, although the standard deviation of the difference between the two was high. In succeeding runs, values of HCU, HCL, NEXP, and SMN were not kept uniform but were modified in the different subareas. The nonuniform initial values for storage coefficient were also modified. The calibrated values of HCU, HCL, NEXP, SMN, and storage coefficient are shown in table 3. The average ratio of model-derived streamflow to observed streamflow in the calibrated model was 1.14, and the individual subbasin ratios ranged from 0.84 to 1.57, as shown in table 7. The average and standard deviation of the differences between model-derived ground-water levels and observed ground-water levels are shown in table 8.

Values of APS were adjusted in the calibration of the model only along the lower reach of Boeuf River (fig. 5) in order to improve the match between computed and observed ground-water levels. The APS values were changed from $1X10^9$ ft^2/d to $7.3X10^3$ ft^2/d at row 13, columns 50-58 and from $1X10^9$ ft^2/d to $7.6X10^4$ ft^2/d at row 13, columns 59-68.

System Responses to Parameter Adjustments

Because of the interaction between surface-water and ground-water segments of the model, adjustments to model parameters generally affected both computed streamflow and ground-water levels but not necessarily to the same extent. Adjustments made to improve computed streamflow sometimes adversely affected computed ground-water levels, and, conversely, adjustments made to improve computed ground-water levels sometimes adversely affected computed streamflow. Practically all the streamflow in the study area is runoff caused by precipitation. Other stresses on streamflow, such as diversion for irrigation, return flow from irrigation water, and seepage into or from the aquifer, are only a small part of the average flow, probably less than 5 percent. The significant parameters in the model that control the computed streamflow are those that are involved in the model's computation of infiltration. The parameters involved in the model computation of infiltration are hydraulic conductivity of the soil (HCU), the amount that unsaturated-zone moisture is below the maximum limit (SMM), and the amount of rainfall

Table 7.—*Ratios of model-derived streamflow to observed streamflow for the entire model run, 1953-70*

Subbasin number	Gaging-station number	Ratio
1	07364300	1.41
2	07364120	.84
3	07364128	1.08
4	07364150	.91
5	07364200	1.02
6	07367656	.87
7	07367659	1.30
8	07367660	1.57
9	07367661	1.42
10	07367662	.96
11	07367663	1.06
12	07367664	1.11
13	07367700	1.18
14	07369660	1.06
15	07369650	.96
16	07369670	1.11
17	07369700	1.46
All subbasins		1.14

Table 8.—*Average and standard deviation of the differences between model-derived ground-water levels and observed ground-water levels*

Model node		Well number	Average	Standard deviation	Number of comparisons
Row	Column				
28	66	17S06W35CAB1	-1.11	1.51	16
34	62	17S07W10CAA1	1.59	.82	16
36	66	18S08W01DBA1	-.59	1.69	18
37	18	07S08W32AAA1	2.16	2.15	10
40	14	06S09W26DDB1	.83	1.75	13
40	15	07S09W02BCA1	-1.59	2.25	10
34	14	06S07W32CCC1	-1.21	1.54	13
34	16	07S07W18ADA1	-2.08	2.13	13
35	13	06S08W24DCC1	-.45	2.48	16
38	13	06S08W30DAB1	-1.91	2.22	12
28	24	09S06W03BAD1	-.56	1.78	11
20	47	13S04W22ABA1	.61	1.45	16
24	37	11S05W28ADB1	-1.14	1.04	12
26	50	14S05W20BAA1	-1.80	1.54	17
28	38	11S06W34DAC1	.06	2.95	2
28	59	16S06W23BCC1	-.24	1.34	10
20	23	08S04W31CBA1	-1.11	2.05	16
21	25	09S04W06DAA1	-.20	2.30	18
24	20	08S05W08BDA1	-.61	1.96	18
28	18	07S06W28CBB1	-.14	2.05	12
18	34	11S04W02ADC1	.04	1.14	7
21	28	09S04W30BAA1	-.08	3.45	13
24	24	09S05W04AAD1	.20	1.14	9
29	19	08S06W06AAA1	-2.24	3.93	13
17	37	11S04W25ADA1	1.15	2.91	18
13	55	15S03W24AAA1	3.21	1.20	16
15	42	12S03W27AAC1	-.23	1.94	16
16	47	13S03W32DDD1	-2.27	2.91	15
17	52	14S03W32BCD1	.92	2.06	11
13	63	17S02W10AAA1	-1.23	1.27	16
15	59	16S03W15DAC1	1.58	3.43	12
13	33	10S03W26DAC1	.67	1.81	18
15	33	10S03W28BBB1	-.26	1.54	11
15	25	08S03W33DCC1	.16	2.42	14
16	27	09S03W18DDD1	1.10	2.55	15
7	27	09S01W17ACC1	1.05	3.16	8
8	38	11S01W30CBA1,2	-1.26	2.30	18
10	32	10S02W21BCA1	.52	2.28	10
10	34	11S02W03BCA1	1.39	2.48	9
13	26	09S03W11CDD1	-.29	2.45	15
7	69	18S01W19DAB1	1.20	1.52	13
7	74	19S01W29DCD1	1.89	3.88	15
22	71	19S04W06BAB1	-1.60	2.21	4
26	62	17S05W07BAA1	1.17	1.30	16
39	69	18S08W29BCD1	10.36	10.46	18
41	9	05S09W20DBA1	-1.68	.36	12
6	43	12S01W33BAA1	-1.53	2.11	17
All--------------------------------			.16	3.46	628

during the month. An increase in HCU decreases runoff by increasing infiltration. An increase in HCL also increases infiltration because the unsaturated zone drains more rapidly.

Adjustments were made to model-derived ground-water levels by changing the parameters that affected the rate and direction of vertical flow above the aquifer. One such change was increasing or decreasing the rate of recharge by varying APS at stream nodes. Increasing APS caused ground-water levels in wells near the stream to approach the stream stage, and decreasing APS permitted ground-water levels in wells near the stream to differ from the stream stage. Vertical discharge by evapotranspiration from ground water can be increased by using a smaller number for the integer soil coefficient (NEXP). Where water levels in the model were at shallow depths, the preceding change lowered them.

Fluctutations in water level are a function of the storage coefficient, as well as other factors. Decreasing or increasing the storage coefficient increases or decreases, respectively, the amplitude of water-level fluctuations. The water-level data used to calibrate the model were measurements made in the spring. These measurements showed little information about water-level fluctuations throughout any one year. Consequently, water-level fluctuations that were used in calibration were for periods greater than 1 year.

Utility of the Model

Assessment

The surface-water segment of the model only approximates the natural-flow system. This judgment is supported by the ratios of model-derived streamflow to observed streamflow (table 7). One facet of the surface-water segment that is neglected is the routing of streamflow caused by storage of water in the stream channel and other factors. The model calculates streamflow as if all precipitation excess produced during a month actually leaves the basin during the month and that there is no carry-over that affects runoff during the succeeding month. This lack of channel storage in the model also causes a poor match of model data to measured data during the low-flow months.

Use of monthly rainfall data for computing infiltration is also unrealistic. Monthly rainfall totals are poor measures of rainfall intensity, which is the most important factor in determining precipitation excess and infiltration. A better procedure might be to use daily precipitation and compute a daily infiltration, which would be constant for groups of nodes, for instance the subbasins. However, it might be difficult to preserve the node-by-node interaction between unsaturated-zone moisture and ground water.

The surface-water segment of the model, however rough it may be, serves as a check on the recharge rate to ground water. Without such a check, it is commonly necessary to specify a limit on the recharge rate to the aquifer. This limit, which is some fraction of the rainfall, serves as an upper plausibility limit for recharge.

The average and standard deviation of the differences between model-derived and measured ground-water levels indicate that the model-derived water levels are only an approximation to measured water levels. However, the standard deviation of 3.46 ft for all 628 comparisons (table 8) should be interpreted in terms of the coarse node spacing of 7,040 ft. Model studies in the alluvial aquifer along the Red River in Louisiana generally have a standard deviation of 1 to 2 ft, corresponding to a node spacing of 2,640 ft (A. H. Ludwig, oral commun., 1976).

Table 8 indicates that the poorest match between observation-well records and model output was at node (39, 69), corresponding to observation well 18S08W29BCD1. The pumpage specified for this node is shown in table 6. The model-derived water levels shown in figure 8 reflect this applied stress. Differences between model-derived and measured water levels at this location might be explained in two ways; either as a difference between the modeled and the real value of some hydrologic parameter or a difference between the modeled stress and the real stress. The model-derived water level was rising for the period 1953-55 in response to a constant stress in the model. This rise suggested that the modeled transmissivity in the vicinity of this node was too high. However, there was a closer correspondence between model-derived and measured water levels in the period 1956-63, when a greater pumping stress was applied to the model. If modeled transmissivity in the vicinity of this node had been decreased to produce a match for the period 1953-55, the model-derived water level would have been too low in the period 1956-63. The natural system did not show the sharp change in water level in 1956 that the model did in response to a more than doubling of model stress. Similarly, the sharp rise in model-derived water level in 1964, caused by reduction of pumping by 97 percent, was not reflected in the water levels in the observation well. The water level in the well showed some recovery during 1963-67, but the greatest rate of recovery in the observation well was for 1967-70. Obviously, either the model stress was not the same as the stress on the real system or the observation well was responding to local conditions and did not reflect the effects of the total pumpage. To have improved the match of model output to measured water levels in the vicinity of node (39, 69) would probably have required that this area be modeled on a larger scale with pumpage distributed

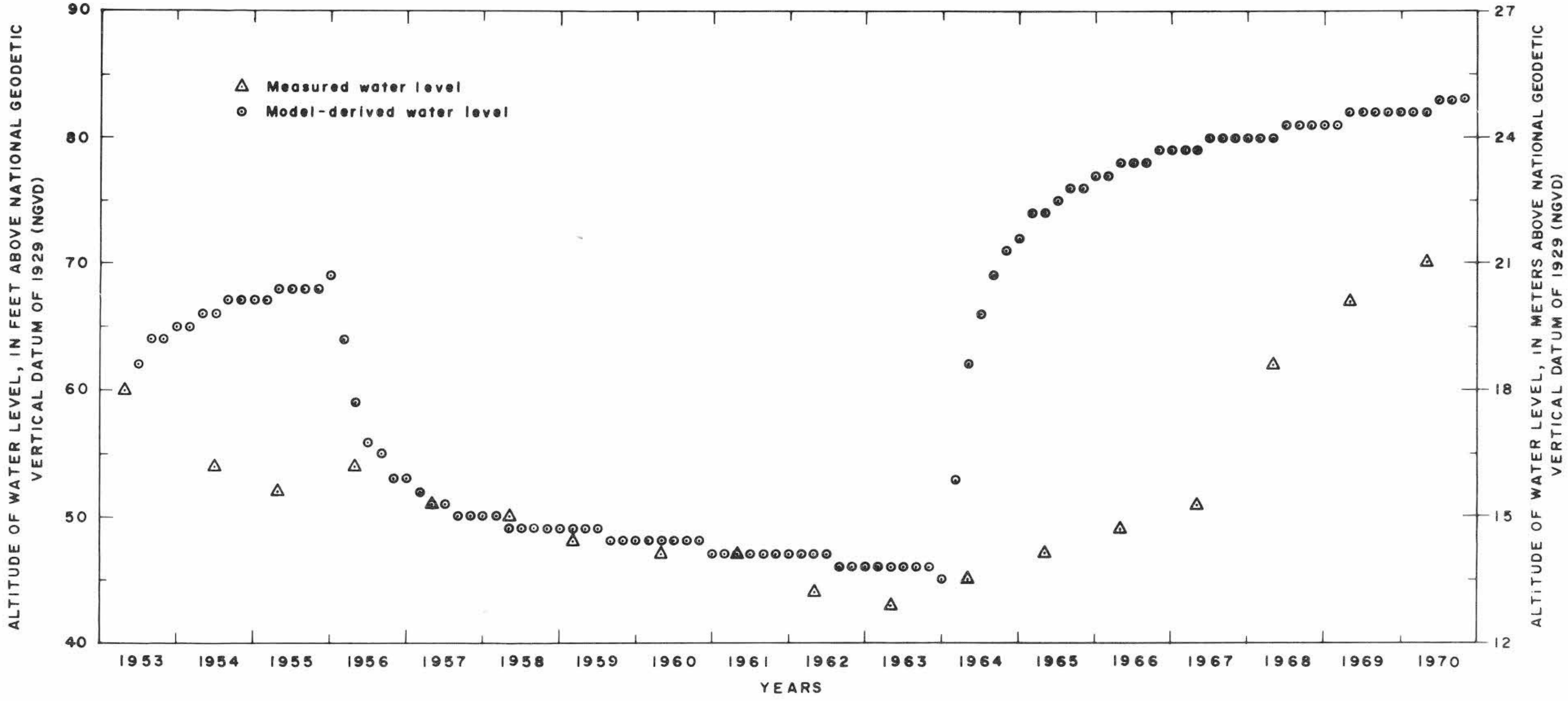


Figure 8.—Comparison of model-derived water levels at node (39, 69) and measured water levels in well 18S08W29BCD.

over several nodes, instead of being lumped at one node as it was in the present model.

In the analog model of the aquifer, the Arkansas and Mississippi Rivers were represented by direct connection of stream nodes to the voltage generator simulating the stream hydrograph. This direct connection eliminated any drop in potential between the stream node in the model and the function generator. The same effect could have been achieved in the digital model by making the APS very large relative to the transmissivity. The largest transmissivity along the Arkansas and Mississippi Rivers was modeled as 27,000 ft^2/d. APS was then arbitrarily chosen as $1X10^9$ ft^2/d in order to make a small head difference between stream stage and aquifer head at stream nodes. This choice of transmissivity insured that the vertical head change between aquifer and stream was small compared with the head change between nodes, and thus a near-perfect connection between the streams and the aquifer was simulated. Stream nodes in the analog model had no capacitors, representing storage of water in the aquifer, connected to them. The logic in the digital program required that a storage coefficient greater than zero be assigned to stream nodes within the areal extent of the alluvial aquifer. Therefore, in the digital model, large changes in aquifer storage and large interflows occurred at stream nodes as a result of stage fluctuations in the Arkansas and Mississippi Rivers. These large changes in storage and interflow average themselves with time, but the interflow and change in storage for any given month are probably not correct. APS should be reduced for these two streams if realistic values for monthly changes in storage and interflow are desired.

Application

The model, calibrated but not verified, is most applicable to projection of response to changes in stress in the ground-water regimen of the system. For example, projection of changes in the potentiometric surface of the aquifer resulting from changes in the rate or areal distribution of pumping can be easily made, requiring only the data cards specifying the changes in the rate and location of pumping. Projection of changes in the potentiometric surface near stream boundaries resulting from dam construction can be made with similar ease, requiring only the input change of stream or reservoir stage.

Projection of changes in the ground-water regimen can also be made for changes in the basic framework of the system, such as the construction of canals, dredging or straightening of streams, land clearing, and urbanization. These projections, however, would usually require additional data from test boring and hydraulic conductivity tests to arrive at the new values of streambed and soil parameters.

REFERENCES

Boswell, E. H., Cushing, E. M., and Hosman, R. L., 1968, Quaternary aquifers in the Mississippi embayment: U.S. Geological Survey Professional Paper 448-E, 15 p.

Broom, M. E., and Reed, J. E., 1973, Hydrology of the Bayou Bartholomew aquifer-stream system, Arkansas: U.S. Geological Survey Open-File Report, Little Rock, Ark., 91 p.

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

Peaceman, D. W., and Rachford, H. H., Jr., 1955, The numerical solution of parabolic and elliptical difference equations: Journal Soc. Indus. Appl. Math., v. 3, no. 11, p. 28-41.

Pinder, G. F., and Bredehoeft, J. D., 1968, Application of the digital computer for aquifer evaluation: Water Resources Research, v. 4, no. 5, p. 1069-1093.

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

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

Trescott, P. D., Pinder, G. F., and Larson, S. P., 1976, Finite-difference model for aquifer simulation in two dimensions, with results of numerical experiments: U.S. Geological Survey Techniques of Water Resources Investigations, book 7, chap. C1, 116 p.

ATTACHMENT A

COMPUTER PROGRAM

Mathematical Techniques

Finite-Difference Equation

The partial differential equation for ground-water flow in two dimensions in an isotropic nonhomogeneous confined aquifer may be written as

$$\partial(T\partial h/\partial x)/\partial x + \partial(T\partial h/\partial y)/\partial y = S\partial h/\partial t + W(x,y,t), \tag{1}$$

where T is transmissivity (ft^2/d), h is hydraulic head (ft), S is the storage coefficient (dimensionless), and W is the volume of recharge or discharge per unit area (ft/d). This is a simplified form, allowed by the condition that the aquifer is isotropic, of the differential equation developed by Pinder and Bredehoeft (1968). The reader is referred to that source for development and discussion of the equation.

The preceding equation, which allows continuous variation in x, y, and t, can be converted into an equation that contains only discrete variables by replacing the derivatives with finite differences expressed for the point $x=j$, $y=i$, $t=k-\frac{1}{2}$. Equation 1 then becomes

$$\begin{aligned}
&(1/a^2)(T_{i,j+\frac{1}{2}}(h_{i,j+1,k-\frac{1}{2}} - h_{i,j,k-\frac{1}{2}}) - T_{i,j-\frac{1}{2}}(h_{i,j,k-\frac{1}{2}} - h_{i,j-1,k-\frac{1}{2}}) \\
&\quad + T_{i+\frac{1}{2},j}(h_{i+1,j,k-\frac{1}{2}} - h_{i,j,k-\frac{1}{2}}) + T_{i-\frac{1}{2},j}(h_{i,j,k-\frac{1}{2}} - h_{i-1,j,k-\frac{1}{2}})) \\
&\qquad = (S/\Delta t)(h_{i,j,k} - h_{i,j,k-1}) + W_{i,j,k-\frac{1}{2}}\ .
\end{aligned} \tag{2}$$

In this equation, the continuous variables y, x, t have become the discrete variables i, j, k and the notation is in subscript form. In equation 2, <u>a</u> represents the node spacing which is the common value of $a=\Delta x=\Delta y$. Equation 2 is not completely discretized, as some of the subscripts indicate values between the integral values desired. The transmissivities in equation 2 are expressed in terms of transmissivities at the nodal locations. For example

$$T_{i,j+\frac{1}{2}} = 2\, T_{i,j}T_{i,j+1}/(T_{i,j} + T_{i,j+1}). \tag{3}$$

Changing the time indices $k-\frac{1}{2}$ to k for nodes lying along a row (j subscript changing) and to k-1 for nodes lying along a column (i subscript changing), and multiplying both sides of the equation by $\underline{a}^2$, equation 2 then becomes

$$\begin{aligned}&T_{i,j+\frac{1}{2}}(h_{i,j+1,k}-h_{i,j,k})-T_{i,j-\frac{1}{2}}(h_{i,j,k}-h_{i,j-1,k})\\&+T_{i+\frac{1}{2},j}(h_{i+1,j,k-1}-h_{i,j,k-1})-T_{i-\frac{1}{2},j}(h_{i,j,k-1}-h_{i-1,j,k-1})\\&\qquad=a^2((S/\Delta t)(h_{i,j,k}-h_{i,j,k-1})+W_{i,j,k}),\end{aligned}\tag{4}$$

where $W_{i,j,k}=Q_{i,j,k}/a^2-(H_{i,j,k}-h_{i,j,k})(k'/b')(A_s/a^2)-R_{i,j,k}$; Q is the pumping rate at node (i,j) from times k-1 to k, ft^3/d; H is the stream stage at node (i,j) from k-1 to k, ft; k'/b' is the hydraulic conductivity divided by the thickness of streambed material at (i,j); ft/d; A_s is the area of streambed at (i,j), ft^2; and R is the recharge rate at (i,j) from k-1 to k, ft/d.

Another way to change equation 2 would be to let $k-\frac{1}{2}$ go to k in the column directions and to k-1 in the row directions. Then the equivalent of equation 4 would be

$$\begin{aligned}&T_{i,j+\frac{1}{2}}(h_{i,j+1,k-1}-h_{i,j,k-1})-T_{i,j-\frac{1}{2}}(h_{i,j,k-1}-h_{i,j-1,k-1})\\&+T_{i+\frac{1}{2},j}(h_{i+1,j,k}-h_{i,j,k})-T_{i-\frac{1}{2},j}(h_{i,j,k}-h_{i-1,j,k})\\&\qquad=a^2((S/\Delta t)(h_{i,j,k}-h_{i,j,k-1})+W_{i,j,k}).\end{aligned}\tag{5}$$

Alternating-Direction Implicit Procedure

The alternating-direction-implicit procedure (Peaceman and Rachford, 1955, p. 33) applies equations 4 and 5 alternately. That is, for a given time step, Δt, equation 4 is first used with a time step $\Delta t/2$ to compute head. This head is then used in equation 5 also with time step $\Delta t/2$ to compute head at $t+\Delta t$.

The method of solving either equation 4 or 5 is a special case of Gaussian elimination that is commonly called the Thomas algorithm (Trescott and others, 1976, p. 16). Both equations 4 and 5 have only three unknown heads; that is, heads with a k subscript. Writing equation 4 with the unknown heads on the left side of the equation and the known elements on the right gives

$$A_j X_{i,j-1,k} + B_j X_{i,j,k} + C_j X_{i,j+1,k} = D_j , \tag{6}$$

where

$A_j = T_{i,j-\frac{1}{2}},$

$B_j = -(T_{i,j+\frac{1}{2}} + T_{i,j-\frac{1}{2}} + K'A_s/b' + a^2S/\Delta t),$

$C_j = T_{i,j+\frac{1}{2}},$ and

$$D_j = -T_{i+\frac{1}{2},j}\, h_{i+1,j,k-1} - T_{i-\frac{1}{2},j}\, h_{i-1,j,k-1} + (T_{i+\frac{1}{2},j} + T_{i-\frac{1}{2},j} - a^2S/\Delta t)\, h_{i,j,k-1}$$

$$- H_{i,j,k}\, K'A_s/b' + Q_{i,j,k} - a^2 R_{i,j,k}.$$

Two dummy arrays, E and F, are computed by forward substitution, as follows

$$E_j = D_j - A_jE_{j-1}/(A_jF_{j-1} + B_j), \tag{7}$$

$$F_j = -C_j/(A_jF_{j-1} + B_j) . \tag{8}$$

Let the subscript 1 represent the first node in the row, and n represent the last node in the row. Then, since A_1 and $C_n = 0$,

$$E_1 = D_1/B_1, \tag{9}$$

$$F_1 = -C_1/B_1 , \tag{10}$$

and

$$F_n = 0.$$

The unknown head can be expressed in terms of the dummy arrays and the head at the adjacent node as

$$X_{i,j,k} = E_j + F_j X_{i,j+1,k} \ . \tag{11}$$

Since

$$F_n = 0,$$

then

$$X_{i,n,k} = E_n \ . \tag{12}$$

The procedure used to solve equation 4 is to start with the first element of the first row and calculate the first members of the E and F arrays by equations 9 and 10. Then, proceeding along the first row, the other members of the E and F arrays are calculated by equations 7 and 8. When the end of the row is reached, the head at the last node in the row is calculated by equation 12. Moving backward on the row, all the heads are then calculated by equation 11. After the head is calculated for the first node, then the procedure moves to the next row and the preceding process is repeated until all the rows in the model have been used in this procedure. Then, starting with the first node in the first column , equation 5 would be applied to the model in a columnwise calculation analogous to the row calculations. If $\underline{i}$ were exchanged for $\underline{j}$ and $\underline{j}$ for $\underline{i}$ in equations 6 through 12 and the subscripts permutated so that the $\underline{i}$ subscript comes before the $\underline{j}$, the resulting equations would also define the column calculations. Head calculations are then made on a column-by-column sweep of the model based on equation 5. Completion of one row calculation and one column calculation constitutes a single time step for the model.

Description of Program

Data Manipulation

The program does little data manipulation. Most of the data are used in the form in which they are read. The program uses the IAREA and JAREA arrays to count the number of model nodes, in statement 218, and aquifer nodes, in statement 222 of the program listing (attachment C), within each subbasin. These two counts are used in conversion of units within the program. Ground-water withdrawals are converted to cubic feet per day in the Q array for use in the ground-water model, and water used for irrigation is converted to feet per node in the SAVE array for use in computing infiltration and runoff. Precipitation and potential evapotranspiration are converted from inches to feet in statement 296.

Unsaturated-Zone Model

The part of the model that computes runoff and accretion to the aquifer at a node is contained in lines 306-378 of the program listing (attachment C). In lines 306 and 307, the unsaturated-zone moisture and precipitation that apply to the node are determined from the node's location. The total water (feet) available at the node is determined in line 308 by adding precipitation and irrigation application. Lines 309 through 323 select the values of HCU, HCL, SMN, and NEXP to be used at the node. A point infiltration (feet) is computed in line 324 and used to compute runoff for a month for the node using either the functions in line 325 or 326, depending on whether the total water available is greater than point infiltration. The functional relationships in lines 325 and 326 are similar to relationships used by Dawdy, Lichty, and Bergmann (1972, p. B7) for rainfall-runoff models using time increments of a fraction of a day. The reason for using such a relationship in a model of monthly-precipitation excess was to enable the model to produce runoff during summer months when point infiltration might be greater than rainfall. In line 327, unsaturated-zone moisture is incremented by the amount of water left over after runoff is subtracted. In lines 328 to 330, monthly evapotranspiration is subtracted from moisture; the full potential evapotranspiration is deducted if the moisture is equal to or greater than the limit, and a fraction of the potential evapotranspiration is subtracted if moisture is less than the limit, the fraction depending on the relative dryness of the unsaturated zone. In line 331, the moisture is checked to see if it is negative. If so, it is set to zero. Lines 332 to 335 compare moisture with the maximum amount and add the excess, if any, to runoff. Lines 336 through 344 compare runoff to precipitation. If runoff is less than precipitation, runoff is identified as precipitation excess and return-flow increment is set to zero. If runoff exceeds precipitation, rainfall excess is set equal to precipitation and the return-flow increment is assigned the excess that runoff exceeds precipitation. Lines 346 and 347 truncate the depth to water to a whole number. Lines 345 and 348 compare unsaturated-zone moisture with the equilibrium moisture content. If moisture is less than equilibrium, lines 349 to 359, which model discharge from the aquifer, are executed; otherwise, lines 360 to 370, which model recharge to the aquifer, are executed. Vertical-flow rates computed here are in feet per day. In line 349, if depth to water is greater than 30 ft (9.1 m), the vertical discharge rate is set to zero. This means that the ET functional is truncated at 30 ft (9.1 m). If depth to water is less than 1 ft (0.3 m), it is set equal to 1 ft (0.3 m). In line 353, unsaturated-zone moisture is increased by the amount of upward movement from the aquifer during the month. After the increase, in lines 354-357, moisture is compared with the equilibrium moisture content, and if moisture is greater, the vertical flux is adjusted to the amount needed to bring moisture to the equilibrium moisture content. Vertical discharge is therefore limited by either the ability of the material to transmit water or by the capacity of the material to store it. Lines 360 to 370 model recharge to the aquifer. If the water level is above land surface, no recharge occurs as specified by line 361. A maximum drainage rate is computed by the expression in line 363. This expression is a linear function of HCL and the amount that moisture is in excess of the equilibrium moisture content. Recharge is limited either by this expression or, in lines 365-368, by the amount that moisture is in excess of the equilibrium moisture content. Finally, in lines 371-378 the results of the computations for a node are included in other arrays.

Ground-Water Model

The ground-water model analyzes the interaction of the aquifer with the applied stress of pumpage, accretion, and interflow with surface water. The computed response of the ground-water model to the stress is given by equations 4 and 5. The program computes the E and F arrays for the Thomas algorithm in lines 396-399 for the row operations to solve equation 4 and in lines 442-445 for the column operations to solve equation 5. The back substitution to compute head is in lines 406 and 413 for the rows and in lines 453 and 464 for the columns. The program uses the input values of APS to compute the interflow between the stream and the aquifer unless there was a flow deficit, in the model, for the subbasin for the previous month. If there was a flow deficit for the previous month, no interflow is computed for the current month. The determination of the coefficient involving interflow is in statements 379-387 for the rows and statements 424-433 for the columns. The computation of the amount of interflow is in statements 407-410 for the rows and 457-462 for the columns.

KS, KJ, and KK are variables that indicate the position of the stream head in the array of monthly data. The array containing the pumping rate, Q, is calculated by applying monthly and yearly use factors to the input data for 1970 and adding the monthly industrial use calculated from the yearly data. The sign of the pumping rate is changed to negative in the program. The monthly accretion for each node is converted into cubic feet per day and added algebraically to the monthly pumping rate. The resulting sum is contained in the Q array.

Mass Balance

The mass-balance calculations are in lines 477-480 and 499-506. The monthly sums of change in storage, pumpage, interflow between aquifer and streams, and accretion are computed in lines 477-480. These monthly sums are added to sums for the entire model run in lines 499-502. The flux in the model for the month is computed in lines 503 and is one-half of the absolute values of the monthly sums. This is equivalent to stating that if flow into the model is equal to flow out of the model, flux in the model should equal one-half of inflow plus outflow. Storage in the aquifer is treated as a source of water in the mass-balance computation. The balance for the month is computed in line 504 by dividing the algebraic sum of inflow and outflow by the flux. A similar balance for the entire model run is computed in line 506. The monthly and run balances are compared with the input value of BALERR in line 507. If either of the two balances exceeds BALERR, the month, year, and values of the two balances are printed.

Surface-Water Model

The surface-water model combines precipitation excess, surface-water pumpage, interflow with ground water, and return flow from irrigation. There is no flow routing in the surface-water model. Precipitation excess and other components affecting the streamflow are computed for the present month with no carryover to succeeding months except for return flow and a runoff deficit. The runoff computed for a given node is added to the total for the subbasin in line 374. The ground-water interflow, surface-water pumpage, and return flow from irrigation for the subbasin are algebraically added to precipition excess and the total runoff is converted into cubic feet per second in lines 473 to 474. In line 486, the variable SUO is set equal to the runoff deficit, a negative number, for the particular subbasin. If there was no runoff deficit in this subbasin for the previous month, the value of SUO will be zero. The runoff from the subbasin, plues runoff from tributary subbasins, is added to SUO in line 488. If SUO is less than zero and the drainage area for the station is wholly within the model, the runoff deficit for the month is assigned the value for SUO, and runoff for this station and this month is assigned zero flow in lines 490-492. If SUO is greater than zero or the station is on a stream with drainage area outside the model, runoff deficit is set equal to zero and the runoff (or change in runoff for stations with drainage area outside the model) is set equal to SUO in lines 495 and 496. The runoff deficit is included to prevent negative streamflow, a physical impossibility. The runoff deficit is also used as a check on possible recharge from the stream to the aquifer in lines 382-384, 409-410, 428-430, and 461-462. If a runoff deficit occurred for a given subbasin for the previous month (RODEF< 0), the factor (APST) representing hydraulic connection between the stream and the aquifer is set to zero at the specified node.

Calibration Aids

The model creates such a great number of computational results that it is desirable to condense the information produced. The standard for judging the model output is the observed data, which consist of field measurements. It is desirable then to have a comparison between model results and field data in a compact form. One method is to have statistical measures of correspondence between the two items; the other method is to have hydrographs for comparing model output with data input.

The program computes the ratio of model flow to observed flow for each of the subbasins that are wholly within the model (subbasin numbers 1-17) for each month, each year, and for the entire model run. The program also computes the average and standard deviation of the monthly ratios for each year, and the average and standard deviation of the ratios, for the same month, for different years. The program code for computing streamflow ratios during each monthly time step is in lines 557-576. The monthly ratio is computed and stored by station number and month as a character string in array AC in line 566. The character representation makes it possible to print a blank for missing data. The conversion between numeric and character data is made in the program by three statements of the form listed below.

```
RESULT = numeric variable + RUP;
C8 = RESULT;
character variable = C5.
```

RESULT is a decimal number of five digits; three before, and two after, the decimal point. RUP is a roundoff factor that is defined equal to 0.005 in line 26. C8 is a string of eight characters and C5 is a string of five characters defined as the fourth through eighth characters of C8. This three-step conversion results in the numeric data being in the form 'DD.DD', where D represents a decimal digit. If the numeric data are larger than 99.99, there will be a loss of digits by truncation on the left. The sums, and sums of squares, of monthly ratios are saved for yearly and model-run statistics in lines 567-570. The sum of modeled- and observed-flow volumes are computed for the year in lines 571 and 572, respectively. The number of items is counted by month and by station in lines 573 and 574. In line 599, a test is made for the first month of a year of the last month of a model run. If the test is met, the program performs a series of operations through line 656. The ratio of the modeled flow to observed flow for the station and year is computed and converted to characters in lines 601-606. In lines 607-627, the average and the standard deviations for the monthly ratios for the station and year are computed. In lines 629-635, the sum of the modeled flow for all stations for the year is divided by the sum of the observed flow. Lines 636-642 compute the year and the month for the output. Lines 643-652 are the print statements for this group of output, an example of which is shown in table A1. The modeled- and observed-flow volumes for the year are added to the totals for the run in lines 654 and 655. The arrays containing information for the year are set to zero in lines 656 in preparation for the computations for the next year. Lines 713-735 are statements that compute the average and standard deviation of the monthly ratios for each month and each station. Lines 736-741 compute the ratio of modeled to observed flow for the entire model run for each station. Lines 743-749 compute the same ratio for the combined flow of all the stations. Lines 750-766 are the print statements for these data, an example of which is shown in table A2.

Plots of model-derived and observed monthly flow for each station are printed out as an option of the program. An example of these plots is shown in figure A1. The flows are plotted on a logarithmic scale from 0.1 to 10,000 ft^3/s ($2.8X10^{-3}$ to $2.8X10^3$ m^3/s). The model-derived flows are plotted as zero, the measured flows are plotted as M, and if both flows fall on the same position, a B is plotted. Lines 512-526 of the program convert the data to a logarithmic scale and store the model output in array IHYD and the measured flow in array JHD. The option for printing the graph is in lines 893-935 of the program. Lines 896-904 establish the lines of the grid. Lines 905-919 position the symbols for the data according to the scaled IHYD and JHYD arrays. Lines 920-933 are print statements for the graph.

Table A1.—*Ratios of model-derived streamflow to measured streamflow for 1957.*

SUB-BASIN NO.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AV.	S.D.	YEAR
1	7.86	2.10	0.81	2.66	0.30	2.03	2.93	2.28	1.57	7.59	2.41	1.83	2.86	2.39	2.27
2	4.37	0.85	0.46	0.96	0.28	0.79	2.47	0.22	1.05	0.74	1.38	0.75	1.19	1.16	0.95
3	3.30	0.83	1.63	1.15	1.03	1.23	4.52	0.50	0.80	0.87	1.09	1.70	1.55	1.18	1.27
4	5.86	1.34	0.60	1.61	0.28	0.49	2.98	1.53	2.23	1.34	1.50	0.67	1.70	1.52	1.20
5										1.91	2.76	0.66	1.77	1.05	1.47
6															
7	2.67	0.95	0.82	1.51	0.96	1.08	2.48	1.57	2.01	1.22	1.37	0.92	1.46	0.62	1.33
8	4.25	1.13	1.51	1.99	1.61	2.80	8.27	7.36	3.28	1.62	1.39	1.23	3.04	2.43	1.80
9	2.50	1.06	1.19	1.65	1.38	1.30	2.81	2.37	2.33	1.50	1.39	1.31	1.73	0.60	1.52
10	1.18	1.30	1.50	1.77	1.33	1.15	1.72	2.67	8.62	2.64	0.69	1.16	2.15	2.12	1.20
11	1.27	1.09	1.76	1.26	1.39	2.20	1.54	1.31	2.73	1.55	0.73	0.71	1.46	0.57	1.10
12	1.37	1.26	1.58	1.47	1.88	2.46	1.48	1.81	4.04	1.88	0.95	1.41	1.80	0.80	1.36
13										2.23	1.20	0.98	1.47	0.67	1.23
14	2.87	0.77	1.60	1.57	1.61	1.03	2.18	1.41	1.80	1.20	0.82	0.76	1.47	0.63	1.18
15	3.04	1.01	1.60	2.23	1.60	2.24	1.22	0.67	2.36	2.13	0.65	0.51	1.61	0.81	1.23
16	10.28	1.04	1.16	2.43	1.29	2.20	1.59	0.36	2.15	1.73	1.28	0.43	2.16	2.64	1.43
17										2.86	2.18	0.72	1.92	1.09	1.62

RATIO OF MODEL FLOW VOLUME TO OBSERVED FLOW VOLUME = 1.39

Table A2.—*Average and standard deviations of monthly-flow and total flow-volume ratios*

```
SUB-
BASIN JANUARY    FEBRUARY   MARCH       APRIL       MAY         JUNE
 NO.    AV.  S.D.   AV.  S.D.   AV.  S.D.   AV.  S.D.   AV.  S.D.   AV.  S.D.

  1    2.49  2.52  2.16  0.87  1.21  0.72  1.23  1.09  1.40  2.79  2.84  3.62
  2    1.15  1.15  1.14  0.48  0.86  0.50  1.02  0.78  1.05  2.11  1.04  1.38
  3    1.01  1.04  5.7918.02  1.76  1.61  1.78  1.82  1.00  1.25  1.07  1.42
  4    1.40  1.47  1.16  0.48  0.84  0.48  1.68  3.05  0.63  0.53  0.76  0.65
  5    0.98  0.63  1.69  1.30  0.91  0.48  1.48  2.13  0.51  0.41  0.61  0.55
  6    0.48  0.35  0.91  0.48  0.81  0.25  0.92  0.59  1.09  0.89  1.15  0.76
  7    1.26  1.29  1.18  0.23  1.75  1.98  1.52  1.01  1.59  1.17  1.98  1.33
  8    9.6425.79  1.64  0.86  2.16  2.58  6.9418.04  2.49  2.0812.6731.63
  9    1.95  2.40  1.48  0.61  1.70  1.57  2.16  1.69  2.24  2.75  3.28  3.99
 10    0.83  0.57  0.90  0.30  1.47  1.54  2.52  4.4410.6232.48  9.1821.75
 11    0.92  0.65  1.09  0.34  1.32  0.80  1.86  1.66  1.77  1.47  2.60  2.05
 12    1.56  1.77  1.59  0.74  1.65  0.80  2.08  1.88  1.37  0.82  1.17  1.22
 13    1.00  0.51  1.37  0.41  1.29  0.50  1.76  1.24  1.39  0.94  1.92  1.44
 14    1.10  0.71  1.33  0.77  1.43  1.23  1.99  1.71  2.71  6.06  5.9711.82
 15    1.18  1.05  0.99  0.37  1.02  0.45  1.51  1.19  1.20  0.64  0.89  0.69
 16   15.4100.49  1.33  0.68  1.00  0.76  1.34  1.02  1.09  1.05  0.78  0.74
 17    1.21  0.71  1.89  0.98  1.20  0.63  2.27  1.94  1.17  0.82  1.31  1.61
       JULY        AUGUST      SEPTEMBER   OCTOBER     NOVEMBER    DECEMBER
        AV.  S.D.   AV.  S.D.   AV.  S.D.   AV.  S.D.   AV.  S.D.   AV.  S.D.  VOL.

  1    2.52  2.44  1.49  1.03  1.12  0.47  4.76  4.69  9.1618.46  3.71  4.84  1.41
  2   25.8790.7146.9518.0941.1702.1936.1499.8022.6880.28  1.60  1.95  0.84
  3    1.89  1.70  1.82  1.24  1.81  1.3410.5033.68  1.49  1.48  0.84  0.52  1.08
  4    2.80  3.6712.3237.96  1.97  1.02  1.65  1.55  1.76  1.03  1.41  1.00  0.91
  5    1.88  1.26  1.91  2.21  1.90  1.12  1.23  0.76  1.99  1.10  2.03  1.86  1.02
  6    2.28  2.12  1.40  0.63  1.00  0.49  1.93  2.66  1.69  1.80  0.81  0.24  0.87
  7   20.7953.82  9.5720.4167.8590.10  3.21  4.28  7.9413.19  2.01  3.87  1.30
  8   13.0004.11  8.74  9.0711.3421.0582.5034.1764.7842.3412.9244.32  1.57
  9   23.3569.64  7.9812.3511.1721.4723.7597.5087.1696.67  3.67  8.52  1.42
 10    3.02  3.16  3.10  4.69  3.95  7.39  1.71  1.63  7.9625.49  1.08  0.78  0.96
 11    3.63  2.36  2.94  2.06  2.48  2.01  8.8417.0214.1034.58  1.27  0.84  1.06
 12    2.64  1.89  2.14  1.20  2.66  1.4913.0328.15  6.60  9.64  1.76  2.16  1.11
 13    2.48  1.19  2.62  1.32  2.18  0.89  2.02  0.94  2.32  1.12  1.36  0.52  1.18
 14    8.5812.9610.0720.87  4.05  6.0817.1738.7347.3220.21  2.31  1.79  1.06
 15    4.5412.6324.4093.29  2.40  5.43  1.04  1.06  1.26  1.08  1.16  0.73  0.96
 16   89.6253.5782.1923.0731.1715.2833.7198.7492.2530.5341.4024.58  1.11
 17    2.28  1.18  1.97  1.23  2.30  1.35  1.85  1.73  2.69  2.73  2.29  2.07  1.46

RATIO OF MODEL FLOW VOLUME TO OBSERVED FLOW VOLUME =  1.14
```

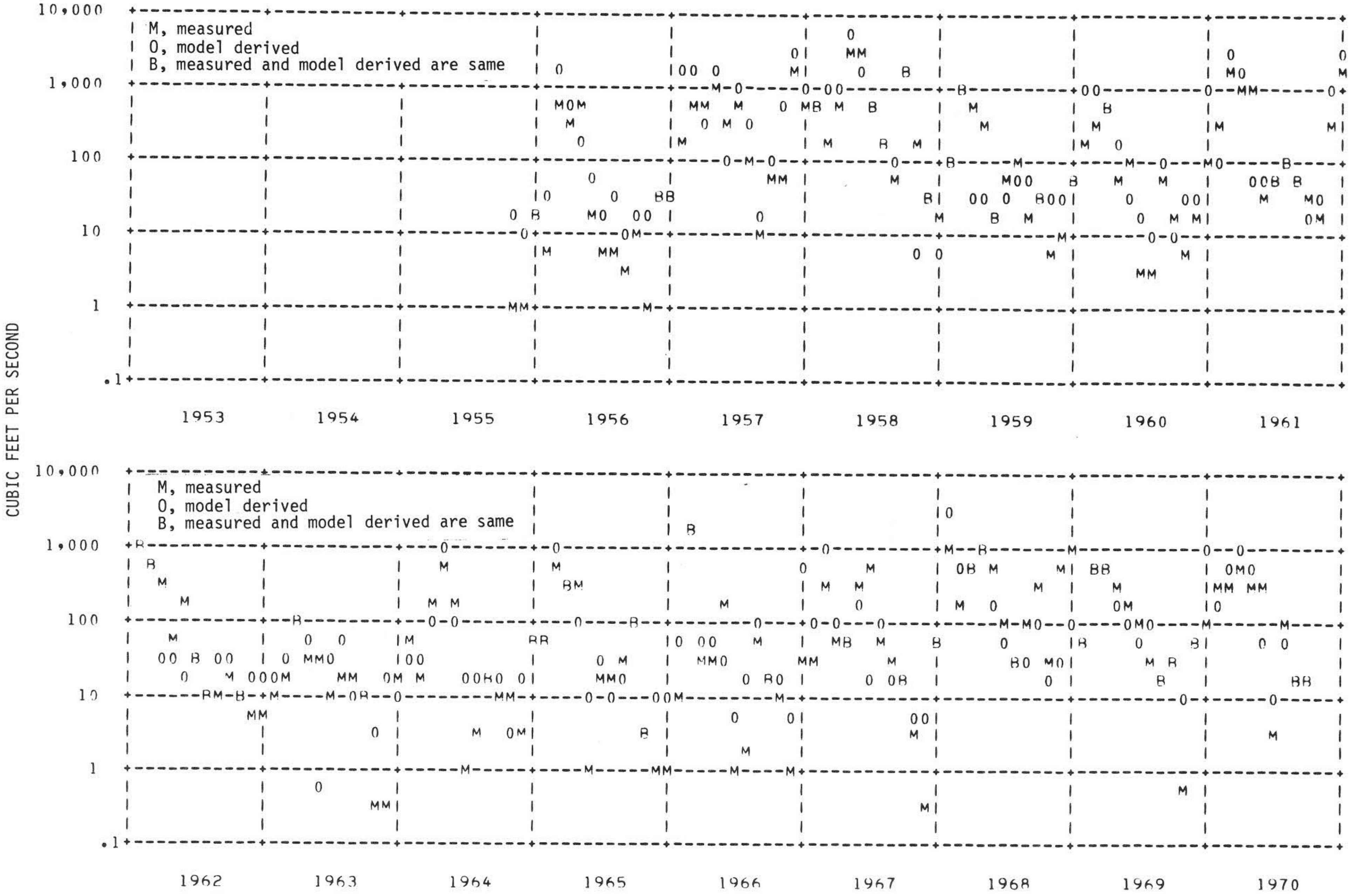


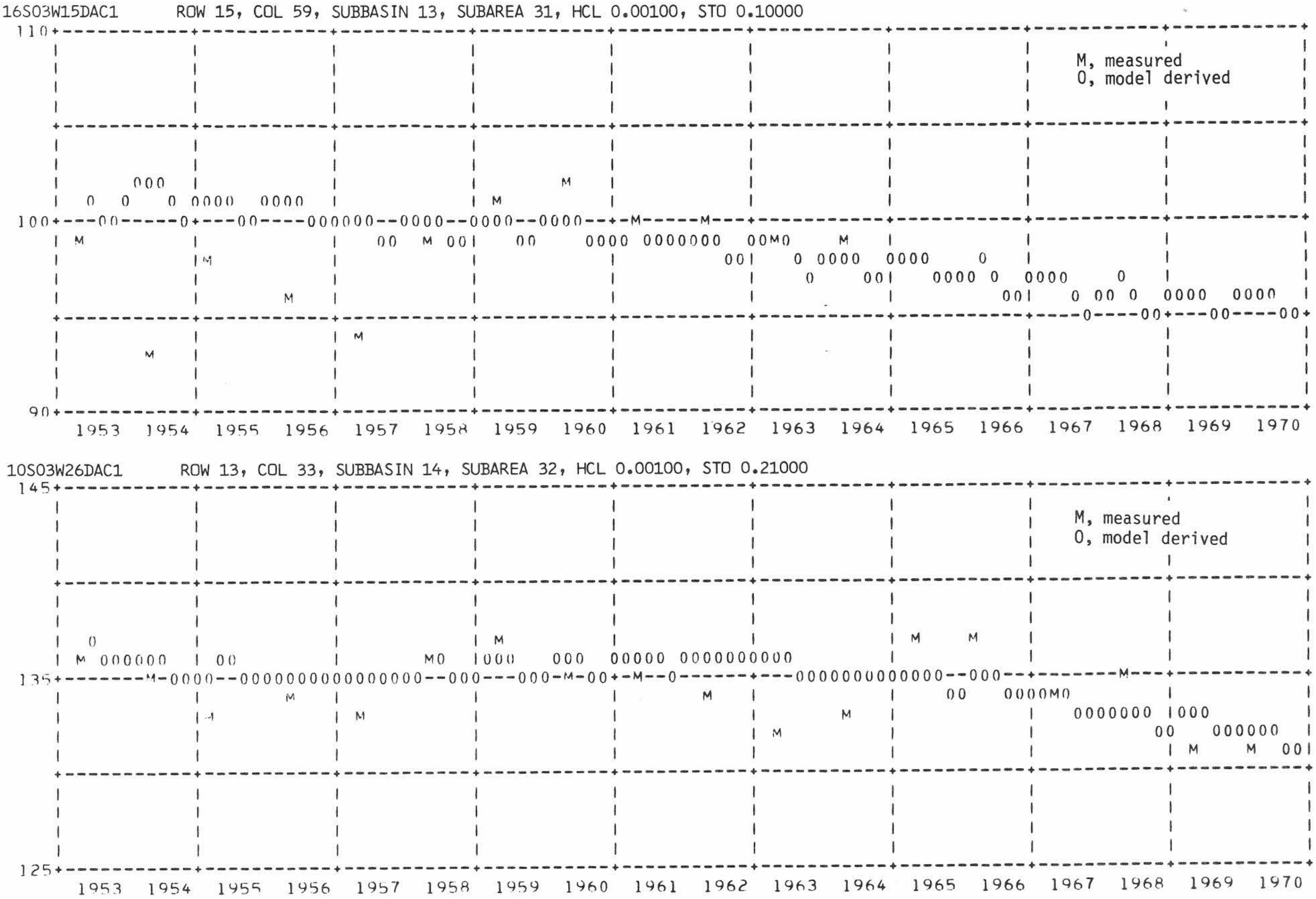
Figure A1.—Comparison of model-derivded streamflow and measured streamflow in Chemin-A-Haut Creek at gaging station number 07364300 (fig. 6).

The program compares model-derived and observed water levels and computes the average and standard deviation of the difference between them. The basic computations are in lines 237-242 and 591-596. In these lines, the variable X is the difference between model-derived and observed water levels, WLSUM is the sum of the differences for a particular well, WLSQ is the sum of the squares of the differences, and WLNUM is the number of comparisons between model-derived and observed data. The averages and standard deviations are computed and converted to characters in lines 767-810; and are then printed according to the statements of lines 811-826. An example of this output is shown in table A3.

Graphs showing model-derived and observed water levels are prepared by the program as visual aids to model calibration. An example showing these graphs for two sites is shown in figure A2. The output from the model is plotted as the symbol 0 and the measured water levels are plotted as M on this graph. The vertical scale of the graphs has a 20-ft (6.1-m) span and is positioned so that the initial water level is near the center of the graph (line 234). Model-derived water levels for even-numbered months are stored in the array KHYD (lines 235-236, 589-590). Lines 828-892 are the program steps that construct and print the graphs. The grid for the graphs is constructed in lines 829-835. The horizontal position on the graph, JKO, for model data is calculated in line 842. The vertical position, IKO, is calculated in lines 843-854, as well as an off-scale number, II. The variable II indicates the number of multiples of 20 that would have to be added to the graph scale to have a true scale for the point. Positive numbers for II mean that the true value for the point is greater than that shown by the scale and negative values for II means that the true value is less than that shown by the graph scale. Zero, or SYMBOL (27), is plotted for points that are on scale. Off-scale points are indicated by printing a character whose position in the

Table A3.—*Average and standard deviations of model-derived and measured water-level altitudes*

ROW	COL	WELL NUMBER	SUBBASIN NO. (JAREA MAP)	AVERAGE	STANDARD DEVIATION	NO. OF COMPARISONS	SUBAREA NO. (JAREA MAP)	HCL	STO	NEXP
28	66	17S06W35CAB1	1	-1.11	1.51	16	1	0.00150	0.10000	2
34	62	17S07W10CAA1	1	1.59	0.82	16	2	0.00000	0.14000	2
36	66	18S08W01DBA1	1	-0.59	1.69	18	3	0.00300	0.20000	2
37	18	07S08W32AAA1	2	2.16	2.15	10	4	0.00200	0.12000	4
40	14	06S09W26DDB1	2	0.83	1.75	13	5	0.00010	0.10000	4
40	15	07S09W02BCA1	2	-1.59	2.25	10	6	0.00020	0.09000	4
34	14	06S07W32CCC1	3	-1.21	1.54	13	7	0.00100	0.10000	4
34	16	07S07W18ADA1	3	-2.08	2.13	13	8	0.00100	0.18000	4
35	13	06S08W24DCC1	3	-0.45	2.48	16	9	0.00400	0.10000	4
38	13	06S08W30DAB1	3	-1.91	2.22	12	10	0.00300	0.14000	4
28	24	09S06W03BAD1	4	-0.56	1.78	11	11	0.00020	0.08000	4
20	47	13S04W33ABA1	5	0.61	1.45	16	12	0.00050	0.06000	4
24	37	11S05W28ADB1	5	-1.14	1.04	12	13	0.00100	0.11000	4
26	50	14S05W20BAA1	5	-1.80	1.54	17	14	0.00050	0.06000	4
28	38	11S06W34DAC1	5	0.06	2.95	2	15	0.00100	0.11000	4
28	59	16S06W23BCC1	5	-0.24	1.34	10	16	0.00050	0.10000	4
20	23	08S04W31CBA1	6	-1.11	2.05	16	17	0.00800	0.20000	4
21	25	09S04W06DAA1	6	-0.20	2.30	18	18	0.00400	0.18000	4
24	20	08S05W08BDA1	6	-0.61	1.96	18	19	0.01500	0.08000	4
28	18	07S06W28CBB1	6	-0.14	2.05	12	20	0.00050	0.16000	4
18	34	11S04W02ADC1	7	0.04	1.14	7	21	0.00200	0.19000	4
21	28	09S04W30BAA1	7	-0.08	3.45	13	22	0.00050	0.08000	4
24	24	09S05W04AAD1	7	0.20	1.14	9	23	0.00180	0.20000	4
29	19	08S06W06AAA1	7	-2.24	3.93	13	24	0.00200	0.12000	4
17	37	11S04W25ADA1	8	1.15	2.91	18	25	0.00050	0.15000	4
13	55	15S03W24AAA1	9	3.21	1.20	16	26	0.04000	0.10000	2
15	42	12S03W27AAC1	10	-0.23	1.94	16	27	0.00200	0.12000	4
16	47	13S03W32DDD1	12	-2.27	2.91	15	28	0.00100	0.09000	4
17	52	14S03W32BCD1	12	0.92	2.06	11	29	0.01000	0.10000	2
13	63	17S02W10AAA1	13	-1.23	1.27	16	30	0.00200	0.10000	4
15	59	16S03W15DAC1	13	1.58	3.43	12	31	0.00100	0.10000	2
13	33	10S03W26DAC1	14	0.67	1.81	18	32	0.00100	0.21000	4
15	33	10S03W28BBB1	14	-0.26	1.54	11	33	0.00300	0.12000	4
15	25	08S03W33DCC1	14	0.16	2.42	14	34	0.00800	0.09000	4
16	27	09S03W18DDD1	14	1.10	2.55	15	35	0.00150	0.20000	4
7	27	09S01W17ACC1	15	1.05	3.16	8	36	0.02000	0.09000	4
8	38	11S01W30CBA1,2	15	-1.26	2.30	18	37	0.01000	0.07000	4
10	32	10S02W21BCA1	15	0.52	2.28	10	38	0.00050	0.18000	4
10	34	11S02W03BCA1	15	1.39	2.48	9	39	0.00030	0.16000	4
13	26	09S03W11CDD1	15	-0.29	2.45	15	40	0.00100	0.08000	4
7	69	18S01W19DAB1	17	1.20	1.52	13	41	0.00100	0.06000	4
7	74	19S01W29DCD1	18	1.89	3.88	15	42	0.00200	0.10000	4
22	71	19S04W06BAB1	18	-1.60	2.21	4	43	0.00050	0.10000	4
26	62	17S05W07BAA1	18	1.17	1.30	16	44	0.00000	0.06000	4
39	69	18S08W29BCD1	19	10.36	10.46	18	45	0.00000	0.20000	4
41	9	05S09W20DBA1	20	-1.68	0.36	12	46	0.00200	0.10000	4
6	43	12S01W33BAA1	21	-1.53	2.11	17	47	0.00400	0.10000	4
35	70	ROW 35, COL 70	1			0	3	0.00300	0.20000	2
36	71	ROW 36,COL 71	1			0	3	0.00300	0.20000	2
40	69	ROW 40, COL 69	19			0	45	0.00000	0.20000	4
ALL				0.16	3.46	628				


16S03W15DAC1 ROW 15, COL 59, SUBBASIN 13, SUBAREA 31, HCL 0.00100, STO 0.10000

10S03W26DAC1 ROW 13, COL 33, SUBBASIN 14, SUBAREA 32, HCL 0.00100, STO 0.21000

Figure A2.—Comparison of model-derived water levels and measured water levels for two observation wells.

SYMBOL array is greater or less than 27, depending on the value of II. The 36 characters in the SYMBOL array are shown in lines 68-71. The horizontal position for the measured water levels is computed in line 860. The vertical position and the off-scale indication are computed in lines 861-872. SYMBOL (13) or M is printed for on-scale measured data. Differing characters from the SYMBOL array are picked for off-scale data, as explained above. Lines 876-891 are print statements for the graphs.

Input Data

The program reads input data from two sources; a card file (file name SYSIN) and a magnetic disk file (file name IN1). The disk file IN1 has the PL/1 attributes RECORD and SEQUENTIAL. Specifications of the DD card referring to IN1 will depend upon the manner in which IN1 is written. Table A4 contains a description of data for SYSIN and table A5 outlines the data for IN1.

Table A4.—*Input data read from SYSIN file*

Number of cards[1]	Variables	Format[2]	Remarks
1	XS,SMSI,RFC,BALERR, SMDEF,SNDEF,HCUDEF, HCLDEF,NEXPDEF, IDEP	Col(1),10F(5)	XS--node spacing, ft. SMSI--initial unsaturated zone moisture (uniform), ft. RFC--relative amount, between 0 and 1, of irrigation water that becomes return flow to streams, dimensionless. BALERR--limit on mass-balance error. SMDEF--value of SMAX assigned to nodes outside the aquifer, ft. SNDEF--value of SMIN assigned to nodes outside the aquifer, ft. HCUDEF--value of HCU assigned to nodes outside the aquifer, ft^2/d. HCLDEF--value of HCL assigned to nodes outside the aquifer, ft^2/d. NEXPDEF--value of NEXP assigned to nodes outside the aquifer, ft^2/d. IDEP--value of depth to water assigned to nodes outside the aquifer, ft.
1	TITLE	Col(1),A(80)	TITLE--80 character identifications printed on computer output.
(NMAPS+1,10)	NMAPS,(MAPMON(I), MAPYR(I),I=1 to NMAPS)	Col(1),F(3), X(5),(NMAPS) (F(2),X(1), F(4),X(1)	NMAPS--number of alphameric potentiometric maps printed. MAPMON(I),MAPYR(I)--the month and year for the Ith map, must be in increasing sequence.
1	OPTION(I),I=1 to 6	Col(1),6(X(9), F(1)))	OPTION(1)=1, prints monthly model-derived flow for each subbasin. OPTION(2)=1, prints statistic comparison between computed and measured streamflow and water levels. OPTION(3)=1, prints water level table for selected nodes. OPTION(4)=1, prints hydrograph showing computed and measured water level. OPTION(5)=1, prints input card data. OPTION(6)=1, prints hydrograph showing computed and measured streamflow.
NHYD*(NYEARS, 10)	(MWL(I,J),WL(I,J), J=NSTART to IYEND), I=1 to NHYD	(NHYD)(col(1), (NYEARS)(F(2), X(1),F(4,1), X(1)))	MWL(I,J)--month water level was measured in year J for WELLNO(I). WL(I,J)--measured water level in year J for WELLNO(I), ft above datum.
1	XMU(I),I=1 to 12	Col(1),12F(5)	XMU(I)--relative water use for irrigation during Ith month.
(NYEARS,16)	GU(I),I=1 to NYEARS	Col(1),(NYEARS) F(5)	GU(I)--multiplier for GPUMP in the Ith year since beginning.
(NWELLS,8)	IG(I),JG(I), GPUMP(I),I=1 to NWELLS	Col(1),(NWELLS) (2F(2),F(6))	GPUMP(I) is the yearly ground-water pumpage, in acre-ft, for irrigation at node (IG(I),JG(I)). The monthly pumpage (acre-ft) for irrigation during month I of year J for node (R,C) is given by XMU(I)*GU(J-NSTART+1)*GPUMP(K) and R=IG(K), C=JG(K).
(NYEARS,16)	SU(I), I=1 to NYEARS	Col(1),(NYEARS) F(5)	SU(I)--multiplier for SPUMP in the Ith year since beginning.
(NLIFTS,8)	IS(I),JS(I), SPUMP(I), I=1 to NLIFTS	Col(1),(NLIFTS) (2F(2),F(6))	SPUMP(I) is the yearly surface-water diversion, in acre-ft, for irrigation at node (IS(I),JS(I)). The monthly diversion (acre-ft) for irrigation during month I of year J for node (R,C) is given by XMU(I)*SU(J-NSTART+1)*SPUMP(K) and R=IS(K), C=JS(K).
NIND* (NYEARS+1, 16)	ID(I),JD(I), (DPUMP(I,J),J=1 to NYEARS), I=1 to NIND	(NIND)(col(1), 2F(2),X(1), (NYEARS)F(5))	DPUMP(I,J) is the yearly industrial and municipal pumpage, acre-ft, from ground water during the Jth year since the beginning at node (ID(I),JD(I)).

Table A 4.—*Input data read from SYSIN file*—Continued

Number of cards[1]	Variables	Format [2]	Remarks
(NHYD,4)	WELLNØ(J),IHY(I), JHY(I),I=1 to NHYD	Col(1),(NHYD) (A(15),X(1), 2F(2))	A water-level table (if ØPTIØN(3)=1) and (or) water-level hydrograph (if ØPTIØN(4)=1) will be printed for WELLNØ(I) located at node (IHY(I),JHY(I)). WELLNØ(I) is a 15-character identification for the Ith well.
(NSTATION* NSTATION,80)	UPSTREAM(I), I=1 to NSTATION*NSTATION	Col(1),(NSTATION* NSTATION)F(1)	Code UPSTREAM (I,J)=1 if subbasin J is part of the drainage area of subbasin I (UPSTREAM(I,I)=1 always). Code UPSTREAM(I,J)=0 otherwise.
(NSTATION,10)	STATION_NUMBER(I), I=1 to NSTATION	Col(1),(NSTATION) A(8)	STATION_NUMBER(I) is the 8-character identification for subbasin I.
(NC,16)	HCU(I),I=1 to NC	Col(1),(NC)F(5)	HCU(I) is the vertical hydraulic conductivity of the soil for all nodes whose JAREA=I, ft^2/d.
(NC,16	HCL(I),I=1 to NC	Col(1),(NC)F(5)	HCL(I) is the vertical hydraulic conductivity of the unsaturated zone between the soil and the aquifer for all nodes whose JAREA=I, ft^2/d.
12	(ET(I,J),J=1 to 30), I=2 to 5	Col(1), 12(10F(7), X(10))	ET(I,J) is (rate of upward flow from the aquifer in response to evapotranspiration from the soil)/(hydraulic conductivity of the unsaturated zone) for I=NEXP(JAREA) and J=depth to water (truncated to whole number of feet). The rate of upward movement at the node is computed as ET(I,J)*HCL(JAREA).
(NC,40)	NEXP(I),I=1 to NC	Col(1),(NC)F(2)	NEXP(I) is the integer soil exponent used as an index for the ET array and applies to all nodes whose JAREA=I. Permissible values for NEXP are 2, 3, 4, or 5.
(NC,16)	SMM(I), I=1 to NC	Col(1),(NC)F(5)	SMM(I) is the upper limit on unsaturated zone moisture for all nodes whose JAREA=I, ft.
(NC,16)	SMN(I), I=1 to NC	Col(1),(NC)F(5)	SMN(I) is the drainable limit of unsaturated zone moisture for all nodes whose JAREA=I, ft.
(NC,16)	STØ(I),I=1 to NC	Col(1)(NC)F(5,5)	STØ(I) is the storage coefficient for the aquifer for all nodes whose JAREA=I, dimensionless.
(NST,20)	JI(I), I=1 to NST	Col(1),(NST)F(4)	JI(I) is the row sequence number for the Ith nonzero value, in column sequence, in the APS array. Column sequence means (APS(I,J),I=1 to M), J=1 to N, and row sequence means (APS(I,J),J=1 to N), I=1 to M. JI(I)=K means that the Ith nonzero value for APS, in column sequence, is also the Kth nonzero value for APS in row sequence. Stream head is read in only for nodes with APS > 0. Stream head is read in by row sequence as part of array DATAIN. JI is used as a pointer to the proper member of DATAIN when the ground-water model is solving by columns.

---

[1] (A,B) represents the number n, where n is the least integer such that $n \geq \frac{A}{B}$.

[2] Readers unfamiliar with PL/1 formats should consult a PL/1 language manual.

Table A 5.—*Input data read from IN1 file*

Bytes	Variables	Remarks
4*M*(N+1)	(R(I,J), J=1 to N+1), I=1 to M	R(I,J) is the harmonic-mean transmissivity between nodes (I,J) and (I,J-1), ft^2/d.
4*(M+1)*N	(C(I,J), J=1 to N), I=1 to M+1)	C(I,J) is the harmonic-mean transmissivity between nodes (I,J) and (I-1,J), ft^2/d.
2*M*N	(JAREA(I,J), J=1 to N), I=1 to M	JAREA(I,J)=K indicates that the Kth member of HCU,HCL,NEXP,SMM,SMN, and ST0 arrays is to be used at node (I,J).
4*M*N	(APS(I,J), J=1 to N), I=1 to M	APS(I,J) is (area of streambed)*(hydraulic conductivity of streambed material)/(thickness of streambed material) at node (I,J), ft^2/d.
4*M*N	(ELEV(I,J), J=1 to N), I=1 to M	ELEV(I,J) is the average elevation of land surface for node (I,J), feet above datum.
4*(M+2)*(N+2)	(H1(I,J), J=0 to N+1), I=0 to M+1	H1(I,J) is the initial elevation of the potentiometric surface at node (I,J), feet above datum.
2*M*N	(IAREA(I,J), J=1 to N), I=1 to M	IAREA(I,J)=K indicates that node (I,J) is in subbasin K.
4*(NSTATIONS +NST+MSTA+1	DATAIN(I), I=1 to NSTATIONS +NST+MSTA+1)	DATAIN(1) is monthly evaporation, in. DATAIN(1+K), K=1 to NSTATIONS, is monthly precipitation for subbasin K, in. DATAIN(1+NSTATIONS+K), K=1 to NST, is the average monthly stream elevation corresponding to the Kth nonzero member, in row sequence, of the APS array, feet above datum. DATAIN(1+NSTATIONS+NST+K), K=1 to MSTA is the mean monthly flow for subbasin K, ft^3/s. The DATAIN array is read once for each month or a total of 12*NYEARS times.

ATTACHMENT B

DEFINITIONS OF PROGRAM VARIABLES

No definitions are given here for PL/1 syntax or built-in functions, DO variables, procedure names, or label names.

DEFINITIONS OF PROGRAM VARIABLES

A--Array representing character map of the potentiometric surface. Indices are nodal position.

AC--Array containing character representation of numeric data that compare model-derived and observed data.

ACCR--Accretion at a node, feet.

ACCRETION--Array containing accretion, cubic feet before line 471 and acre-feet thereafter. Index refers to subbasin number.

ACFT--Conversion for feet per node to acre-feet.

ACX2--Accretion at a node, cubic feet per day.

AFS--Conversion for acre-feet per month to cubic feet per second.

APS--Array containing hydraulic conductivity of streambed material multiplied by area of streambed within a node divided by thickness of streambed material (K'/b'* area), square feet per day. Indices are nodal positions.

APST--APS at a node, square feet per day.

AS--Array containing storage coefficient multiplied by area of a node, square feet per day. Indices refer to nodal location.

AST--AS at a node, square feet per day.

AVM--Model-derived flow volume for a year, cubic feet per second days.

AVO--Observed flow volume for a year, cubic feet per second days.

B--Parameter in the forward substitution part of the Thomas algorithm.

BAL--Precipitation plus the part of irrigation water not returned to streams, feet.

BALANCE--Mass balance for a month, dimensionless.

BALERR--Limit on mass-balance error.

C--Array containing harmonic-mean transmissivity in the column direction, square feet per day. Indices are nodal locations.

CA--Cumulative accretion, acre-feet.

CB--Cumulative mass balance, dimensionless.

CF--Cumulative volume of flow for model, acre-feet.

CFAD--Conversion for cubic feet per day to acre-feet per month.

CHYD--Array containing character representation of hydrograph data. First index refers to line number, second index refers to position on a line.

CIJ--C for a node, square feet per day.

CIP--C for the next node in the column increasing direction, square feet per day.

CP--Cumulative pumpage, acre-feet.

CR--Cumulative stream recharge, acre-feet.

CRFC--The proportion of applied irrigation water that is not return flow to streams, dimensionless.

CS--Cumulative change in aquifer storage, acre-feet.

C5--Intermediate result in conversion of numeric data to character.

C8--Intermediate result in conversion of numeric data to character, used to prevent truncation of data.

D--Parameter in the forward-substitution part of the Thomas algorithm.

DATAIN--Array containing block of monthly data read from disk.

DATUM--Observed monthly discharge for a station, cubic feet per second.

DELTA-STORAGE--Array containing monthly changes in storage, cubic feet before line 470 and acre-feet thereafter. Index refers to subbasin number.

DPUMP--Array containing yearly industrial ground-water pumpage, acre-feet. First index refers to sequence number of industrial pumpage, second index refers to year.

DSAV--Array containing part of the change in aquifer storage, cubic feet. Index refers to subbasin number.

E--Array computed by forward substitution in the Thomas algorithm. Index refers to position in a row (column).

ELEV--Array containing altitude of land surface, feet. Indices refer to nodal locations.

ET--Array containing limiting dimensionless evapotranspiration from the water table. First index represents Gardner's exponent; second index represents depth to water, feet.

EVAP--Monthly potential evapotranspiration, feet.

F--Array computed by forward substitution in the Thomas algorithm. Index refers to position in a row (column).

FLUX--Monthly volume of flow, acre-feet.

FRT--Potential infiltration, feet.

GPUMP--Array containing yearly agricultural ground-water pumpage for the reference year, acre-feet. Index is the sequence number for agricultural ground-water pumpage.

GU--Array containing yearly agricultural ground-water use expressed as a ratio to the reference year, dimensionless. Index refers to year.

GW-PUMPAGE--Array containing monthly ground-water pumpage, acre-feet. Index is the subbasin number.

HCL--Array containing vertical hydraulic conductivity of the unsaturated zone between the soil and the aquifer, square feet per day. Index refers to subarea number.

HCLDEF--Value of HCL assigned to nodes outside the extent of the aquifer.

HCLJA--HCL for a node.

HCU--Array containing vertical hydraulic conductivity of the soil, square feet per day. Index refers to subarea number.

HCUDEF--Value of HCU assigned to nodes outside the extent of the aquifer.

HCUJA--HCU for a node.

HDAS--Part of the monthly change in aquifer storage for a node, cubic feet.

HD2--Computed head at the end of a computational step.

HIJ--Potentiometric head at a node.

HPLUS--Potentiometric head at the next node, in the increasing row (column) direction.

HS--Component of D representing flow between aquifer and stream.

HYD--Array containing water-level altitudes for a year, feet. First index is sequence for well number, second index represents month.

H1--Array containing potentiometric head at beginning of computational step, feet. Indices are nodal location.

H2--Array containing potentiometric heads computed for end of a computational step, feet. Indices are nodal location.

IA--Subbasin number for a node, dimensionless.

IAREA--Array containing subbasin numbers, dimensionless. Indices indicate nodal location.

ID--Array containing row locations for industrial ground-water pumpage. Index represents sequence number for industrial pumpage.

IDEP--Value of depth to water assigned to nodes outside the extent of the aquifer, feet.

IDEPTH--Depth to water as truncated to whole number, feet.

IDYR--Year, for water-level table output.

IG--Array containing row location for agricultural ground-water pumpage. Index represents sequence number for agricultural ground-water pumpage.

IH--Ordinate for surface-water hydrographs.

IHI--Lowest multiple of 5 ft that exceeds the highest potentiometric-surface altitude for a month.

IHY--Array containing row locations for points included in water-level table. Index is sequence number for well numbers.

IHYD--Array containing model-determined stream-discharge hydrographs. First index is subbasin number, second index is year, third index is month.

II--Off-scale indicator for water-level hydrographs.

IKO--Ordinate for water-level hydrographs.

IK1--Ordinate for model-derived discharge for surface-water hydrographs.

IK2--Ordinate for measured discharge for surface-water hydrographs.

ILIM1--Number indicating (0=no, 1=yes) whether any subbasin has all of its drainage area included in the model.

ILIM2--Number indicating (0=no, 1=yes) whether any subbasin has part of its drainage area outside the area of the model.

ILO--Greatest multiple of 5 ft that is less than the lowest potentiometric-surface altitude for a month.

ILS--The greatest integer that is less than or equal to NLIFTS divided by KX.

IM--Abscissa for hydrographs, represents every month for water-level hydrographs, every month for surface-water hydrographs.

IMEND--Ending month of model run.

IMF--Ending month for hydrographs.

IMON--Month number.

IMS--Beginning month for hydrographs.

IN1--Name of input disk-data set.

IR--The number of 5-ft intervals required for a map of the potentiometric surface.

IS--Array containing row locations for surface-water pumpage.

ISKIP--Number of blocks of monthly input data on disk file to be skipped at beginning of model run.

ISTART--Beginning year for surface-water hydrographs.

IW--Index representing a particular well or station

IWG--The greatest integer that is less than or equal to NWELLS divided by KY.

IY--Year for hydrographs.

IYEND--Ending year of model run.

IYP--Greatest integer that is less than or equal to NYEARS divided by KP.

IYR--Year.

IYY--Greatest integer that is less than or equal to NYEARS divided by KY.

JA--Subarea number at a node.

JAREA--Array defining the subareas to which HCU, HCL, NEXP, SMM, SMN, and STO values apply. Indices indicate nodal location.

JD--Array containing column location for industrial ground-water pumpage. Index is sequence number of industrial ground-water pumpage.

JG--Array containing column locations for agricultural ground-water pumpage.

JHY--Array containing column locations for points included in water-level tables. Index is sequence number for well numbers.

JHYD--Array containing measured stream-discharge hydrographs. First index is subbasin number, second index is year, third index is month.

JH1--Beginning month for water-level tables.

JH2--Ending month for water-level tables.

JI--Array containing row sequence numbers for stream nodes. Index is column sequence number for stream nodes.

JKO--Abscissa for hydrographs.

JLS--Remainder when NLIFTS is divided by KX.

JS--Array containing row locations for surface-water pumpage. Index is sequence number for surface-water pumpage.

JWG--Remainder when NWELLS is divided by KG.

JYP--Remainder when NYEARS is divided by KP.

JYY--Remainder when NYEARS is divided by KY.

KC--The number indicating the member of the SYMBOL array that represents a given 5-ft interval of the potentiometric-surface map.

KG--The smaller of 8 and NWELLS.

KHY--Month for water-level tables.

KHYD--Array containing water-level tables. First index is sequence number for well numbers, second index is the year, third index is the bimonthly position within the year.

KH1--Beginning month for water-level tables.

KH2--Ending month for water-level tables.

KI--Column sequence number for a node where there is interflow between aquifer and stream.

KJ--Number indicating position of stream head in the array of monthly data; used when interflow between the stream node and the aquifer is computed.

KK--Number indicating position of stream head in the array of monthly data; used when computing the D parameter along a column of the model.

KMAP--Sequential index for MAPMON, MAPYR arrays.

KP--The smaller of 8 and NYEARS.

KS--Number indicating position of stream head in the array of monthly data; used when computing the D parameter along a row of the model.

KSTA--The number of subbasins whose drainage areas lie, at least partly, outside the model area.

KX--The smaller of 8 and NLIFTS.

KY--The smaller of 9 and NYEARS.

KYR--Index to GU, SU, DPUMP arrays, refers to year.

L--Number of months in model run.

LINE 1, LINE 2, LINE 3--Arrays containing one line of the hydrograph grid. Index is position in the line.

M--The number of rows in the model.

MAPMON--Array containing months for which an output map will be printed. Index is sequential number in printing order.

MAPYR--Array containing years for which an output map will be printed. Index is sequential number in printing order.

MNX--The larger of M and N.

MONTH--Month for which next potentiometric surface map will be printed.

MSTA--The number of subbasins whose drainage areas lie wholly within the model boundaries.

MWL--Array containing month of water-level measurement. First index is sequence number for well numbers, second index is the year.

MYEAR--Year for which next potentiometric-surface map will be printed.

M1--M plus 1.

N--The number of columns in the model.

NC--Number of subareas, defines the extent of several arrays.

NDATA--Number of items of data in one monthly block read from disk.

NEXP--Array contains reference number to ET function. Index is subarea number.

NEXPDEF --Value of NEXP assigned to nodes outside the extent of the aquifer.

NHYD--Number of nodel locations for water-level tables or hydrographs.

NIND--Number of nodes where industrial ground-water use occurs.

NLIFTS--Number of nodes where irrigation water is pumped from streams.

NMAPS--Number of potentiometric-surface maps that will be printed.

NMON--Beginning month of model run.

NST--Number of stream nodes in the ground-water model.

NSTART--Beginning year of model run.

NSTATIONS--Number of subbasins.

NS1--Number of subbasins plus one.

NUM--Value of NEXP at a node.

NWELLS--Number of nodes where irrigation water is pumped from the aquifer.

NYEARS--Number of years in model run.

N1--N plus 1.

OPTION--Array containing switches for optional output.

PAC--Monthly pumpage per area of node, feet.

PPT--Monthly precipitation at a node, feet.

PRECIP-EXCESS--Array containing monthly rainfall excess in feet before line 483 and in inches thereafter. Index is subbasin number.

PUMP--Monthly pumpage at a node, acre-feet.

Q--Array containing the algebraic sum of accretion to, and pumpage from, the aquifer in a given month, cubic feet per day. Indices are nodal location.

R--Array containing harmonic-mean transmissivity in the row direction, square feet per day. Indices are nodal location.

RATIO--Relative moisture content of unsaturated zone.

RE--Rainfall excess for a node, feet.

RESULT--Intermediate result in converting numeric data to character.

RETURN-FLOW--Array containing return flows in feet per node before line 475 and in acre-feet thereafter. Index is subbasin number.

RF--Runoff in excess of precipitation for a node, feet.

RFC--Relative amount of irrigation water that becomes return flow to streams.

RJP--R for the next node in the row increasing direction, square feet per day.

RN--Array containing number of measured monthly discharges. First index is subbasin number, second index is month.

RODEF--Array containing runoff deficits (excess of seepage to ground water over streamflow), cubic feet per second. Index is subbasin number.

RSUM--Array containing model-derived monthly discharge, cubic feet per second. Index is subbasin number.

RSUMI--Value of RSUM for a subbasin.

RTFS--Array containing applied irrigation water for a month in feet per node multiplied by RFC and added in succeeding month to return flow. Index is subbasin number.

RUP--Number used (for rounding) in conversion from numeric data to character.

RUPSQ--Value of RUP squared.

RVM--Array containing volume of model-derived streamflow for a complete model run, cubic feet per second days. Index is subbasin number.

RVO--Array containing volume of measured streamflow for a complete model run, cubic feet per second days. Index is subbasin number.

RX--Runoff for a node, feet per node.

RY--Runoff in excess of precipitation for a node, feet per node.

S--Value of SMD for a subbasin.

SAVE--Array containing monthly applied irrigation water, feet per node. Indices are nodal location.

SM--Unsaturated-zone moisture for a node, feet.

SMAX--Upper limit on unsaturated-zone moisture for a node, feet.

SMD--Array containing sum of squares of ratios of model-derived to measured streamflow. First index is subbasin number, second index is month.

SMDEF--Value of SMAX assigned to nodes outside the extent of the aquifer, feet.

SMIN--Equilibrium (no vertical flow) moisture content of unsaturated zone for a node, feet.

SMM--Array containing upper limit on unsaturated-zone moisture content, feet. Index is subarea number.

SMN--Array containing drainable limit on unsaturated-zone moisture content, feet. Index is subarea number.

SMO--Array containing sum of ratios of model-derived to measured streamflow. Index is subbasin number.

SMR--Array containing sum of ratios of model-derived to measured-monthly streamflow. First index is subbasin number, second index is month.

SMRIJ--Value of SMR for a subbasin and month.

SMS--Array containing unsaturated-zone moisture, feet. Indices are nodal locations.

SMSI--Initial unsaturated-zone moisture, feet.

SNDEF--Value of SMIN assigned to nodes outside the extent of the aquifer, feet.

SPACE--Amount that unsaturated-zone moisture differs from the equilibrium content, feet.

SPUMP--Array containing yearly surface-water pumpage for the reference year, acre-feet. Index is the sequential number for surface-water pumpage.

SSQ--Array containing sum of squares of ratios of model-derived to measured streamflow. Index is subbasin number.

STATION-NUMBER--Array containing station numbers or stream names for subbasins. Index is subbasin number.

STO--Array containing storage coefficient. Index is subarea number.

STOR--Array containing change in storage between dates of potentiometric surface maps, acre-feet.

STREAM-RECHARGE--Array containing monthly interflow between streams and the aquifer, in cubic feet before line 469 and in acre-feet thereafter. Index is subbasin number.

SU--Array containing yearly surface-water use expressed as a ratio to the reference year. Index refers to year.

SUMA--Monthly accretion for the model, acre-feet.

SUMP--Monthly pumpage for the model, acre-feet.

SUMR--Monthly stream-aquifer interflow for the model, acre-feet.

SUMS--Monthly change in aquifer storage for the model, acre-feet.

SUO--Sum of runoff deficit plus runoff for the current month for a node, cubic feet per second.

SW-PUMPAGE--Array containing monthly surface-water pumpage, acre-feet. Index is the subbasin number.

SWL--Sum of model-derived water levels minus measured water levels for a well, feet.

SYMBOL--Array containing 36 characters used for printing maps of the potentiometric surfaces and hydrographs.

SYSIN--Name of input card data set.

TITLE--String of 80 characters (card image) used for identification for model output.

TOP--Array containing altitude corresponding to top line of hydrograph grid, feet. Index is sequence number for well numbers.

TOTAL-RUNOFF--Array containing monthly streamflow within a subbasin, in feet per node per month before line 473 and in cubic feet per second thereafter. Index is subbasin number.

T2--Number of days in the month.

UPSTREAM--Array containing numbers that indicate (0=no, 1=yes) the subbasins that are included in the drainage area for a given station. First index is the subbasin number of the station, second index is the subbasin number for other subbasins. UPSTREAM (I,J)=1 if subbasin J is included in the drainage area of subbasin I.

W--Sum of model-derived water levels minus measured water levels for all wells.

WC--Array containing character representation of numeric data for comparison of model-derived, and measured, streamflow (WC(1,1) only) and water levels. For ground-water data the first index is the sequence number, the second index represents the mean (1) or the standard deviation (2).

WELLNO--Array containing well numbers for points of comparison between model-derived water levels and measured water levels. Index is the sequence number for well numbers.

WL--Array containing the measured water-level data, feet above mean sea level. First index is the sequence number for well numbers, second index is the year.

WLNUM--Array containing the number of measured water levels for a well. Index is sequence number for well numbers.

WLSQ--Array containing sum of squares of model-derived water levels minus measured water levels, square feet. Index is sequence number for well numbers.

WLSUM--Array containing sum of model-derived water levels minus measured water levels, feet. Index is sequence number for well numbers.

X--Dummy variable representing a specific member of an array or an intermediate step in a computation.

XDAY--Array containing the number of days in all 12 months in a year. Index is the month.

XMN--Minimum altitude of the model-derived potentiometric surface for a given date, feet.

XMRI--Ratio of model-derived streamflow to measured streamflow for the station and the month.

XMU--Array containing monthly use of water, as ratio of yearly use, for irrigation. The index is the month.

XMUN--Value of XMU for the month.

XMX--Maximum altitude of the model-derived potentiometric surface for a given date, feet.

XNM--Array containing number of comparisons, in a year, of model-derived streamflow to measured streamflow. Index is subbasin number.

XNODES--Array containing number of nodes in a subbasin. Index is the subbasin number.

XS--Node spacing of the model, feet.

XSEC--Conversion for feet per month per node to cubic feet per second.

XYX--Relative water use for irrigation for a given month.

X2--Area of a node, square feet.

Y--Dummy variable representing a specific member of an array or an intermediate result in a computation.

YNODES--Array containing the number of aquifer nodes in a subbasin. Index is the subbasin number.

Z--Time step in the model and equal to the number of days in the month divided by 2.

ATTACHMENT C

PROGRAM LISTING

PREPROCESSOR INPUT

```
|(NOUFL):RR:PROC OPTIONS(MAIN) REORDER;
|% DCL(M.N,NYEARS.NWELLS.NLIFTS.NIND.NSTATIONS.NST.NDATA.NSTART.NMON.
|   IYY.JYY,IWG,JWG.ILS.JLS.IYP.JYP.RUP,NC.NHYD.L.IMEND.IYEND.
|         KSTA.ILIM1,ILIM2,MNX.M1.N1.MSTA.KY.KG.KX.KP) CHARACTER;
|% M='48';
|% N='78';
|% MNX='78';
|% L='204';
|% NMON='10';
|% NSTART='1970';
|% IYEND='1987';
|% NHYD='50';
|% IMEND='9';
|% M1='49';
|% N1='79';
|% NYEARS='18';
|% NWELLS='276';
|% NLIFTS='61';
|% NIND='2';
|% NSTATIONS='21';
|% MSTA='17';
|% KSTA='4';
|% NC='47';
|% NST='332';
|% NDATA='421';
|% RUP='.005';
|% ILIM1='1';
|% ILIM2='1';
|% KY='9';
|% KG='8';
|% KX='8';
|% KP='8';
|% IYY='2'     /* IYY=FLOOR(NYEARS/KY) */   ;
|% JYY='0'     /* JYY=MOD(NYEARS.KY) */ ;
|% IWG='34'    /* IWG=FLOOR(NWELLS/KG) */   ;
|% JWG='4'     /* JWG=MOD(NWELLS.KG) */ ;
|% ILS='7'     /* ILS=FLOOR(NLIFTS/KS) */   ;
|% JLS='5'     /* JLS=MOD(NLIFTS.KS) */ ;
|% IYP='2'     /* IYP=FLOOR(NYEARS/KP) */   ;
|% JYP='2'     /* JYP=MOD(NYEARS.KP) */ ;
|   DCL A(M.N) CHAR(1),AC(MSTA.25) CHAR(5) INIT((25*MSTA)(5)' ').
|   ACCRETION(NSTATIONS).APS(M.N).AS(M.N).
|              AVM(MSTA) INIT((MSTA)0.).AVO(MSTA) INIT((MSTA)0.).C(M1.N1).
|   CHYD(23.109) CHAR(1).
|   DATAIN(NDATA),DPUMP(NIND.NYEARS).ELEV(M.N).ET(2:5.30).GPUMP(NWELLS).
|   GU(NYEARS),GW_PUMPAGE(NSTATIONS).HCU(NC).HCL(NC).HYD(NHYD.12).
|   H1(0:M1.0:N1).H2(0:M1.0:N1).IAREA(M.N).ID(NIND).
|   IHYD(MSTA.NSTART:IYEND.12) INIT((MSTA*NYEARS*12)24).
```

```
INF
   IG(NWELLS).IHY(NHYD).IS(NLIFTS).JAREA(M.N).JD(NIND).JG(NWELLS),
   JHY(NHYD).JI(NST),
   JHYD(MSTA.NSTART:IYEND.12) INIT((MSTA*NYEARS*12)24),
   JS(NLIFTS).KHYD(NHYD.NSTART:IYEND.6).
   LINE1(109) CHAR(1) INIT((9)('+'.(11)(1)'-').'+').
   LINE2(109) CHAR(1) INIT((9)('|'.(11)(1)' ').'|').
   LINE3(109) CHAR(1) INIT((109)(1)' ').
   MAPMON(L) INIT((L)13),MAPYR(L) INIT((L)0).
   MWL(NHYD.NSTART:IYEND).
   NEXP(NC),          OPTION(6). Q(M.N).PRECIP_EXCESS(NSTATIONS),R(M,N1),
   RETURN_FLOW(NSTATIONS),RN(MSTA,12) INIT((12*MSTA)0.).
   RODEF(NSTATIONS),RSUM(NSTATIONS).
   RTFS(NSTATIONS).RVM(MSTA) INIT((MSTA)0.).RVO(MSTA) INIT((MSTA)0.),
   SAVE(M,N).SMM(NC).SMN(NC).
   SMD(MSTA.12) INIT((12*MSTA)0.).SMR(MSTA.12) INIT((12*MSTA)0.).
   SMO(MSTA) INIT((MSTA)0.),SSQ(MSTA) INIT((MSTA)0.).SMS(M,N).
                     SPUMP(NLIFTS),STATION_NUMBER(NSTATIONS)CHAR(3).
   STO(0:NC) INIT(0.).
   STOR(NSTATIONS).STREAM_RECHARGE(NSTATIONS).
   SU(NYEARS).SW_PUMPAGE(NSTATIONS).                    SYMBOL(36)CHAR(1)
                 INIT('A','B','C','D','E'.'F','G'.'H','I','J'.'K','L'.
   'M','N','O','P'.'Q'.'R','S'.'T'.'U'.'V','W'.'X','Y'.'Z'.'0'.'1'.
   '2','3','4','5','6','7','8'.'9'),TITLE CHAR(30).TOP(NHYD).
   TOTAL_RUNOFF(NSTATIONS).
   UPSTREAM(NSTATIONS.NSTATIONS).WELLNO(NHYD) CHAR(15).
   WC(NHYD,2) CHAR(5) INIT((NHYD)(5)' ').WL(NHYD.NSTART:IYEND).
   WLSUM(NHYD) INIT((NHYD)0.).WLSQ(NHYD) INIT((NHYD)0.).
   WLNUM(NHYD) INIT((NHYD)0.).
   XDAY(12)INIT(31.,28..31..30..31..30.,31..31.,30.,31..30..31.).
   XMU(12).XNODES(NSTATIONS).XNM(MSTA) INIT((MSTA)0.).
   YNODES(NSTATIONS).
   (APST,AST.B.CIJ.CIP.D.HDAS,HD2,HIJ.HPLUS.HS.RIJ.RJP)DEC FLOAT(16).
   C8 CHAR(8),C5 CHAR(5) DEF C8 POS(4).RESULT FIXED DECIMAL(5.2).
   IN1 FILE RECORD SEQUENTIAL.
   (SUMS.SUMP,SUMR.SUMA,CS.CP.CR.CA.CF.FLUX)DEC FLOAT(16).
   (E(0:MNX).F(0:MNX),DELTA_STORAGE(NSTATIONS).DSAV(NSTATIONS))
   DEC FLOAT(16);
   OPEN FILE(IN1) INPUT;
   READ FILE(IN1) INTO(R);
   READ FILE(IN1) INTO(C);
   READ FILE(IN1) INTO(JAREA);
   READ FILE(IN1) INTO(APS);
   READ FILE(IN1) INTO(ELEV);
   READ FILE(IN1) INTO(H1);
   READ FILE(IN1) INTO(IAREA);
   GET FILE(SYSIN) EDIT
   (XS,SMSI.RFC.BALERR.SMDEF.SNDEF.
   HCUDEF.HCLDEF.NEXPDEF.IDEP.TITLE.
   NMAPS,(MAPMON(I).MAPYR(I) DO I=1 TO NMAPS).OPTION.
   ((MWL(I.J).WL(I.J) DO J=NSTART TO IYEND) DO I=1 TO NHYD))
```

```
(COL(1).10 F(5).COL(1).A(80).COL(1).F(3).X(5).(NMAPS)(F(2).X(1).
F(4).X(1)).COL(1).6 (X(9).F(1)),(NHYD)(COL(1).(NYEARS)(F(2).
X(1),F(4.1).X(1))));
GET FILE(SYSIN) EDIT
(XMU.GU,(IG(I).JG(I).GPUMP(I) DO I=1 TO NWELLS).SU,(IS(I).JS(I).
SPUMP(I) DO I=1 TO NLIFTS).(ID(I),JD(I).(DPUMP(I.J) DO J=1 TO NYEAR
) DO I=1 TO NIND).(WELLNO(I).IHY(I).JHY(I) DO I=1 TO NHYD).UPSTREAM
STATION_NUMBER,HCU.HCL,ET.NEXP.SMM,SMN.
(STO(I) DO I=1 TO NC),JI)
(COL(1),12 F(5).COL(1).(NYEARS)F(5).COL(1).(NWELLS)(2 F(2).F(6)).
COL(1),(NYEARS)F(6).COL(1),(NLIFTS)(2 F(2).F(6)),
(NIND)(COL(1),2 F(2),X(1),(NYEARS)F(6)).COL(1).(NHYD)(A(15).X(1).
2 F(2)),COL(1),(NSTATIONS*NSTATIONS)F(1).COL(1).(NSTATIONS)A(8).
2 (COL(1),(NC)F(5)).    COL(1).12 (10 F(7),X(10)).COL(1).(NC)
F(2).2 (COL(1).(NC)F(5)).COL(1).       (NC)F(5,5).COL(1).(NST)F(4));
KMAP=1;
MONTH=MAPMON(1);
MYEAR=MAPYR(1):
IMON=NMON;
IYR=NSTART;
NS1=NSTATIONS+1:
CRFC=1.-RFC:
X2=XS*XS;
ACFT=43560./X2;
SMS=SMSI;
CS.CP.CR.CA.CF=0.:
STOR.RETURN_FLOW.RODEFF=0.:
AS=0.;
H2=0.:
E.F=0.;
DSAV=0.:
XNODES.YNODES=0.:
HPLUS=0.:
RUPSQ=RUP*RUP;
IF OPTION(5)¬=1 THEN GO TO D1:
PUT FILE(SYSPRINT) EDIT
('NUMBER OF ROWS= '.M,',NUMBER OF COLUMNS= '.N.
'DISTANCE BETWEEN NODES='.XS.' FEET'.'STARTING DATE= '.IMON.'/1/'.
IYR.'NUMBER OF MONTHS IN MODEL RUN= ',L.
'NUMBER OF YEARS OF PUMPING RECORD= '.NYEARS.
'NUMBER OF NODES WHERE AGRI GW WITHDRAWAL OCCURS= '.NWELLS,
'NUMBER OF NODES WHERE AGRI SW WITHDRAWAL OCCURS= '.NLIFTS,
'NUMBER OF NODES WHERE NON-AGRI GW WITHDRAWAL OCCURS= '.NIND.
'NUMBER OF DRAINAGE SUBDIVISIONS(GAGING STATIONS OR SUB-BASINS)= '.
 NSTATIONS .'NUMBER OF STREAM NODES (APS>0) = ',NST,
'INITIAL VALUE OF SOIL MOISTURE STORAGE= ',SMSI.' FEET',
'NUMBER OF WELLS FOR WHICH WATER LEVELS WILL BE PRINTED= ',NHYD.
'NUMBER OF DRAINAGE SUBDIVISIONS WHOLLY WITHIN THE MODEL= '.NSTA)
(PAGE,A,F(2).A,F(2),COL(1).A.F(5),A,COL(1),A.F(2).A.F(4).COL(1).A,
F(3),COL(1).A.F(2).2 (COL(1).A.F(4)),2 (COL(1),A.F(2)).COL(1).A.
```

```
|    F(4).COL(1).A.F(4.1).A,2 (COL(1).A.F(2)));
|    PUT FILE(SYSPRINT) EDIT
|    ('STATION NUMBER--IAREA--OTHER GAGING STATIONS IN DRAINAGE AREA')
|    (SKIP(2).A);
|    DO I=1 TO NSTATIONS;
|         PUT FILE(SYSPRINT) EDIT
|         (STATION_NUMBER(I).I)
|         (COL(1).X(3).A(8),X(8).F(2));
|         DO J=1 TO NSTATIONS;
|              IF I=J THEN GO TO S1;
|              IF UPSTREAM(I.J)<1. THEN GO TO S1;
|              PUT FILE(SYSPRINT) EDIT
|              (STATION_NUMBER(J))
|              (X(2).A(8));
|S1:           END;
|         END;
|    PUT FILE(SYSPRINT) EDIT
|    ('RATIO OF MONTHLY AGRI PUMPAGE TO TOTAL AGRI PUMPAGE FOR YEAR'.
|    'MONTH  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC'.
|    'RATIO'.XMU.
|     'RATIO OF AGRI GW PUMPAGE FOR YEAR TO AGRI GW PUMPAGE FOR 1970',
|     ('YEAR  RATIO  ' DO I=1 TO KY).
|     (IYR+I-1.GU(I) DO I=1 TO NYEARS).
|     'RATIO OF AGRI SW PUMPAGE FOR YEAR TO AGRI SW PUMPAGE FOR 1970'.
|     ('YEAR  RATIO  ' DO I=1 TO KY),
|     (IYR+I-1.SU(I) DO I=1 TO NYEARS).
|     'LOCATION AND AMOUNT OF AGRI GW PUMPAGE FOR 1970'.
|     (' ROW COL AC.FT' DO I=1 TO KG).
|     (IG(I).JG(I).GPUMP(I) DO I=1 TO NWELLS))
|    (PAGE.A.SKIP(2),A.COL(1).A.12 F(5.2).SKIP(3).A.SKIP(2).(KY)A,
|         (IYY)(COL(1),(KY)(F(4).X(1).F(7.4).X(1))),
|    COL(1),                      (JYY)(F(4).X(1),F(7,4).X(1)).
|    SKIP(3).A,SKIP(2).(KY)A.
|         (IYY)(COL(1).(KY)(F(4).X(1).F(7,4),X(1))),
|    COL(1),                      (JYY)(F(4).X(1),F(7,4).X(1)).
|    PAGE,A,SKIP(2),(KG)A,
|         (IWG)(COL(1).(KG)(2 F(4).F(6))).COL(1),(JWG)
|    (2 F(4),F(6)));
|    PUT FILE(SYSPRINT) EDIT
|    ('LOCATION AND AMOUNT OF AGRI SW PUMPAGE FOR 1970'.
|     (' ROW COL AC.FT' DO I=1 TO KX).
|     (IS(I).JS(I),SPUMP(I) DO I=1 TO NLIFTS).
|     'YEARLY NON-AGRI GW PUMPAGE(ACRE-FT)'.
|     ('ROW= '.ID(I).',COL= '.JD(I).('YEAR PUMPAGE ' DO K=1 TO KP).
|    (IYR+J-1,DPUMP(I,J) DO J=1 TO NYEARS) DO I=1 TO NIND),
|    'DTW |    POT.ET./HYD.COND.',
|    '(FT)| NEXP=2 | NEXP=3 | NEXP=4 | NEXP=5',
|    '----------------------------------------'.
|     (J,('|',ET(I,J) DO I=2 TO 5) DO J=1 TO 30))
|                   (PAGE.A.SKIP(2),(KX)A,       (ILS)(COL(1).(KX)
```

```
    (2 F(4).F(6))).COL(1).                    (JLR)(2 F(4).F(6)).
    PAGE.A.(NIND)(COL(1).2 (A.F(2)).COL(1).(KP)A,         (IYP)
    (COL(1),(KP)(F(4).X(1).F(7).X(1))).COL(1).(JYP)
    (F(4),X(1).F(7),X(1))),
    PAGE.A.2 (COL(1).A).30 (COL(2).F(2).X(1).4 (A.F(9.5)))):
D1:PUT FILE(SYSPRINT) EDIT(TITLE.
     'HC= HYDRAULIC CONDUCTIVITY OF FINE-GRAINED MATERIAL OVERLYING THE'
    .' AQUIFER, FT/DAY',
     'SMM= MAXIMUM AMOUNT(FEET) OF WATER STORED ABOVE THE WATER TABLE'.
     'SMN= RETENTION(FEET) OF WATER TO DRAINAGE ABOVE THE WATER TABLE'.
    'S= STORAGE COEFFICIENT'.
    ' AREA    HC(UPPER)    HC(LOWER)    NEXP  SMM  SMN   S'.
    (I,HCU(I).HCL(I).NEXP(I).SMM(I).SMN(I).        STO(I) DO I=1 TO NC))
    (PAGE,A(80).COL(1).A.A,4 (COL(1),A).(NC)(COL(1).F(5),X(4).F(9,4).
    X(4).F(9,4),X(4),F(4).F(5,2).F(5,2).     F(7.4))):
    DO I=1 TO M;
         DO J=1 TO N:
              IA=IAREA(I.J);
              IF IA<1 THEN GO TO E1:
              XNODES(IA)=XNODES(IA)+1.;
              AST=STO(JAREA(I.J))*X2:
              IF AST=0. THEN GO TO E1:
              AS(I,J)=AST:
              YNODES(IA)=YNODES(IA)+1.;
              DSAV(IA)=-H1(I.J)*AST+DSAV(IA);
E1:           END:
         END:
    KH1=IMON;
    KH2=IMON+L;
    IF KH2>12 THEN KH2=12:
    KHY=KH1:
    DO KO=1 TO NHYD;
         I=IHY(KO):
         J=JHY(KO):
         HYD(KO,KHY)=H1(I.J);
         TOP(KO)= 5.*FLOOR(H1(I.J)/5. +.5)+10.;
         IF MOD(IMON,2)=0 THEN KHYD(KO.IYR.IMON/2)=FLOOR(TOP(KO)
         -H1(I,J)+1.5);
         IF MWL(KO.IYR)=IMON THEN DO;
              X=H1(I,J)-WL(KO.IYR);
              WLSUM(KO)=WLSUM(KO)+X:
              WLSQ(KO)=WLSQ(KO)+X*X:
              WLNUM(KO)=WLNUM(KO)+1.:
              END:
         END;
    IF IMON>1 THEN DO:
         ISKIP=IMON-1;
         READ FILE(IN1) IGNORE(ISKIP);
         END:
    CALL GW:
```

```
|GW:PROCEDURE REORDER;
|    DO K=1 TO L;
|           READ FILE(IN1) INTO(DATAIN);
|           XMUM=XMU(IMON);
|           T2=XDAY(IMON);
|           XSEC=X2/(86400.*T2);
|           AFS=ACFT*XSEC;
|           CFAD=43560./T2;
|           Z=T2/2.;
|           SAVE,Q=0.;
|           DELTA_STORAGE=DSAV;
|           DSAV=0.;
|           GW_PUMPAGE,SW_PUMPAGE,STREAM_RECHARGE,
|           ACCRETION,PRECIP_EXCESS,RTFS,TOTAL_RUNOFF=0.;
|           KYR=IYR-NSTART+1;
|           XYX=XMUM*GU(KYR);
|           DO KT=1 TO NWELLS;
|                I=IG(KT);
|                J=JG(KT);
|                IA=IAREA(I,J);
|                PUMP=GPUMP(KT)*XYX;
|                Q(I,J)=-PUMP*CFAD;
|                PAC=PUMP*ACFT;
|                SAVE(I,J)=SAVE(I,J)+PAC;
|                RTFS(IA)=RTFS(IA)+PAC;
|                GW_PUMPAGE(IA)=PUMP+GW_PUMPAGE(IA);
|                END;
|           XYX=XMUM*SU(KYR);
|           DO KT=1 TO NLIFTS;
|                I=IS(KT);
|                J=JS(KT);
|                IA=IAREA(I,J);
|                PUMP=SPUMP(KT)*XYX;
|                PAC=PUMP*ACFT;
|                SAVE(I,J)=SAVE(I,J)+PAC;
|                RTFS(IA)=RTFS(IA)+PAC;
|                SW_PUMPAGE(IA)=PUMP+SW_PUMPAGE(IA);
|                END;
|           DO KT=1 TO NIND;
|                I=ID(KT);
|                J=JD(KT);
|                IA=IAREA(I,J);
|                PUMP=DPUMP(KT,KYR)*T2/365.;
|                Q(I,J)=-PUMP*CFAD+Q(I,J);
|                GW_PUMPAGE(IA)=PUMP+GW_PUMPAGE(IA);
|                END;
|           DO I=1 TO NS1;
|                DATAIN(I)=DATAIN(I)/12.;
|                END;
|           EVAP=DATAIN(1);
```

```
KS=NS1;
DO I=1 TO M;
    DO J=1 TO N;
        IA=IAREA(I,J);
        IF IA=0 THEN GO TO G1;
        JA=JAREA(I,J);
        AST=AS(I,J)/2;
        SM=SMS(I,J);
        PPT=DATAIN(IA+1);
        BAL=PPT      +CRFC*SAVE(I,J);
        IF AST>0. THEN DO;
            SMAX=SMX(JA);
            SMIN=SMN(JA);
            HCLJA=HCL(JA);
            HCUJA=HCU(JA);
            NUM=NEXP(JA);
            HIJ=H1(I,J);
            END;
        ELSE DO;
            SMAX=SMDEF;
            SMIN=SNDEF;
            HCUJA=HCUDEF;
            HCLJA=HCLDEF;
            NUM=NEXPDEF;
            END;
            FRT=HCUJA   *T2*(1.-SM/SMAX);
            IF BAL<FRT THEN RX=BAL*BAL/(2.*FRT);
            ELSE RX=BAL-FRT/2.;
            SM=SM+BAL-RX;
            RATIO=SM/SMAX;
            IF RATIO>1. THEN RATIO=1.;
            SM=SM-EVAP*RATIO;
            IF SM<0. THEN SM=0.;
            IF SM>SMAX THEN DO;
                RX=RX+SM-SMAX;
                SM=SMAX;
                END;
            RY=RX-PPT;
            IF RY>0. THEN DO;
                RF=RY;
                RE=PPT;
                END;
            ELSE DO;
                RF=0.;
                RE=RX;
                END;
        SPACE=SM-SMIN;
        IF AST>0. THEN IDEPTH=ELEV(I,J)-HIJ;
        ELSE IDEPTH=IDEP;
        IF SPACE<0. THEN DO;
```

```
     IF IDEPTH>30 THEN ACCR=0.;
     ELSE DO;
          IF IDEPTH<1 THEN IDEPTH=1;
          ACCR=-HCLJA  *ET(NUM,IDEPTH);
          SM=SM-ACCR*T2;
          IF SM>SMIN THEN DO;
               ACCR=ACCR+(SM-SMIN)/T2;
               SM=SMIN;
               END;
          END;
     END;
ELSE DO;
     IF IDEPTH<0 THEN ACCR=0.;
     ELSE DO;
          ACCR=HCLJA  *SPACE/(SMAX-SMIN);
          SM=SM-ACCR*T2;
          IF SM<SMIN THEN DO;
               ACCR=ACCR+(SM-SMIN)/T2;
               SM=SMIN;
               END;
          END;
     END;
SMS(I,J)=SM;
PRECIP_EXCESS(IA)=PRECIP_EXCESS(IA)+RE;
RETURN_FLOW(IA)=RETURN_FLOW(IA)+RF;
TOTAL_RUNOFF(IA)=TOTAL_RUNOFF(IA)+RX;
IF AST=0. THEN GO TO G1;
ACX2=ACCR*X2;
Q(I,J)=Q(I,J)+ACX2;
ACCRETION(IA)=ACCRETION(IA)+ACX2*T2;
APST=APS(I,J);
IF APST>0. THEN DO;
     KS=KS+1;
     IF RODEF(IA)<0. THEN DO;
          APST=0.;
          HS=0.;
          END;
     ELSE HS=DATAIN(KS)*APST;
     END;
ELSE HS=0.;
CIJ=C(I,J);
RIJ=R(I,J);
CIP=C(I+1,J);
RJP=R(I,J+1);
D=-CIJ*H1(I-1,J)-CIP*H1(I+1,J)-Q(I,J)-RIJ*E(J-1)
+(CIJ+CIP-AST)*HIJ-HS;
B=-(RIJ+RJP+APST+AST)+RIJ*F(J-1);
IF B=0. THEN E(J),F(J)=0.;
ELSE DO;
     E(J)=D/B;
```

INF

```
                           F(J)=-RJP/B;
                           END;
G1:                    END;
                   KJ=KS;
                   DO J=N TO 1 BY -1;
                        IF AS(I,J)=0. THEN GO TO G2;
                        IA=IAREA(I,J);
                        HD2=E(J)+F(J)*HPLUS;
                        APST=APS(I,J);
                        IF APST>0. THEN DO;
                             IF RODEF(IA)>=0. THEN STREAM_RECHARGE(IA)=
                             (DATAIN(KJ)-HD2)*APST*Z+STREAM_RECHARGE(IA);
                             KJ=KJ-1;
                             END;
                        H2(I,J)=HD2;
                        HPLUS=HD2;
G2:                     END;
                   END;
              H1=H2;
              KS=0;
              DO J=1 TO N;
                   DO I=1 TO M;
                        IA=IAREA(I,J);
                        AST=AS(I,J)/Z;
                        IF AST=0. THEN GO TO G3;
                        APST=APS(I,J);
                        IF APST>0. THEN DO;
                             KS=KS+1;
                             KK=JI(KS)+NS1;
                             IF RODEF(IA)<0. THEN DO;
                                  APST=0.;
                                  HS=0.;
                                  END;
                             ELSE HS=DATAIN(KK)*APST;
                             END;
                        ELSE HS=0.;
                        CIJ=C(I,J);
                        RIJ=R(I,J);
                        CIP=C(I+1,J);
                        RJP=R(I,J+1);
                        D=-RIJ*H1(I,J-1)-RJP*H1(I,J+1)-Q(I,J)-CIJ*E(I-1)
                        +(RIJ+RJP-AST)*H1(I,J)-HS;
                        B=-(CIJ+CIP+APST+AST)+CIJ*F(I-1);
                        IF B=0. THEN E(I),F(I)=0.;
                        ELSE DO;
                             E(I)=D/B;
                             F(I)=-CIP/B;
                             END;
G3:                     END;
                   KI=KS;
```

```
                  DO I=M TO 1 BY -1:
                       AST=AS(I•J);
                       IF AST=0. THEN GO TO G4;
                       IA=IAREA(I•J);
                       HD2=E(I)+F(I)*HPLUS;
                       HDAS=HD2*AST:
                       DELTA_STORAGE(IA)=DELTA_STORAGE(IA)+HDAS;
                       DSAV(IA)=DSAV(IA)-HDAS;
                       APST=APS(I•J);
                       IF APST>0. THEN DO:
                            KK=JI(KI)+NS1;
                            KI=KI-1:
                            IF RODEF(IA)>=0. THEN STREAM_RECHARGE(IA)=
                            (DATAIN(KK)-HD2)*APST*Z+STREAM_RECHARGE(IA);
                            END:
                       H2(I•J)=HD2;
                       HPLUS=HD2:
G4:                    END;
                  END:
             H1=H2;
             STREAM_RECHARGE=STREAM_RECHARGE/43560.:
             DELTA_STORAGE=DELTA_STORAGE/43560.:
             ACCRETION=ACCRETION/43560.;
             RETURN_FLOW=RETURN_FLOW/ACFT:
             TOTAL_RUNOFF=TOTAL_RUNOFF*XSEC-(STREAM_RECHARGE+SW_PUMPAGE
             -RETURN_FLOW)*AFS;
             SUMS•SUMP•SUMR•SUMA=0.;
             DO I=1 TO NSTATIONS:
                  SUMS=SUMS+DELTA_STORAGE(I):
                  SUMP=SUMP+GW_PUMPAGE(I);
                  SUMR=SUMR+STREAM_RECHARGE(I);
                  SUMA=SUMA+ACCRETION(I):
                  RTFS(I)=RFC*RTFS(I):
                  STOR(I)=STOR(I)+DELTA_STORAGE(I);
                  PRECIP_EXCESS(I)=12.*PRECIP_EXCESS(I)/XNODES(I);
                  END;
             DO I=1 TO NSTATIONS;
                  SUO=RODEF(I):
                  DO J=1 TO NSTATIONS:
                       SUO=SUO+UPSTREAM(I•J)*TOTAL_RUNOFF(J):
                       END:
                  IF SUO<=0.&I<=MSTA THEN DO;
                       RODEF(I)=SUO;
                       RSUM(I)=0.;
                       END:
                  ELSE DO;
                       RODEF(I)=0.;
                       RSUM(I)=SUO;
                       END:
                  END;
```

```
          CS=CS+SUMS;
          CP=CP+SUMP;
          CR=CR+SUMR;
          CA=CA+SUMA;
          FLUX=.5*(ABS(SUMS)+ABS(SUMP)+ABS(SUMR)+ABS(SUMA));
          BALANCE=(SUMS+SUMP-SUMR-SUMA)/FLUX;
          CF=CF+FLUX;
          CB=(CS+CP-CR-CA)/CF;
          IF ABS(BALANCE)>BALERR|ABS(CB)>BALERR THEN
          PUT FILE(SYSPRINT) EDIT(IMON,'/',IYR,', MONTH BALANCE =',
          BALANCE,', RUN BALANCE =',CB)
          (COL(1),F(2),A,F(4),2 (A,F(10,6)));
          IF OPTION(6)¬=1 THEN GO TO H7;
          DO I=1 TO MSTA;
                RSUMI=RSUM(I);
                IF RSUMI<.05 THEN IH=23;
                ELSE IH=18.5-4.*LOG10(RSUMI);
                IF IH<1 THEN IH=1;
                IHYD(I,IYR,IMON)=IH;
                DATUM=DATAIN(404+I);
                IF DATUM<.05 THEN DO;
                     IF DATUM<0. THEN IH=24;
                     ELSE IH=23;
                     END;
                ELSE IH=18.5-4.*LOG10(DATUM);
                IF IH<1 THEN IH=1;
                JHYD(I,IYR,IMON)=IH;
                END;
 H7:      IF OPTION(1)¬=1 THEN GO TO G8;
          PUT FILE(SYSPRINT) EDIT
          (IMON,'/',IYR,', MONTH BALANCE =',BALANCE,', RUN BALANCE =',CB,
          'IAREA','GW PUMPAGE(AC.FT.)','SW PUMPAGE(AC.FT.)',
          'STREAM RECHARGE(AC.FT.)','STORAGE CHANGE(AC.FT.)',
          'ACCRETION(AC.FT.)',
           (I,GW_PUMPAGE(I),SW_PUMPAGE(I),STREAM_RECHARGE(I),
          DELTA_STORAGE(I),ACCRETION(I) DO I=1 TO NSTATIONS),
           ('IAREA','ACCRETION(INCHES)','PRECIP(INCHES)',
          'PRECIP EXCESS(INCHES)','RETURN FLOW(AC.FT.)',
          'STREAMFLOW(CFS)' DO I=1 TO ILIM1),
           (I,ACCRETION(I)*ACFT*12./YNODES(I),DATAIN(I+1)*12.,
          PRECIP_EXCESS(I),RETURN_FLOW(I),RSUM(I)
          DO I=1 TO MSTA),
           ('IAREA','ACCRETION(INCHES)','PRECIP(INCHES)',
          'PRECIP EXCESS(INCHES)','RETURN FLOW(AC.FT.)',
          'CHANGE IN FLOW(CFS)' DO I=1 TO ILIM2),
           (I,ACCRETION(I)*ACFT*12./YNODES(I),DATAIN(I+1)*12.,
          PRECIP_EXCESS(I),RETURN_FLOW(I),RSUM(I)
          DO I=MSTA+1 TO NSTATIONS))
          (PAGE,F(2),A,F(4),2 (A,F(5,2)),  SKIP(2),A,COL(8),A,COL(28),A,
          COL(48),A,COL(73),A,COL(96),A,(NSTATIONS)(COL(3),F(2),COL(13),
```

```
               F(10),COL(33),F(10),COL(58),F(10),COL(82),F(10),COL(101),F(10)
              ,(ILIM1)(SKIP(2),A,COL(8),A,COL(27),A,COL(43),A,COL(66),A,
               COL(87),A),(MSTA)(COL(3),F(2),COL(11),F(10,2),COL(27),F(10,2),
               COL(48),F(10,2),COL(69),F(10),COL(89),F(10)),(ILIM2)(SKIP(2),
               A,COL(8),A,COL(27),A,COL(43),A,COL(66),A,COL(87),A),(MSTA)
               (COL(3),F(2),COL(11),F(10,2),COL(27),F(10,2),COL(48),F(10,2),
               COL(69),F(10),COL(89),F(10)));
G8:            IF OPTION(2)¬=1 THEN GO TO G7;
               DO I=1 TO MSTA;
                    DATUM=DATAIN(404+I)*T2;
                    IF DATUM<0. THEN AC(I,IMON)='      ';
                    ELSE DO;
                    IF DATUM<1.4 THEN DATUM=1.4;
                    RSUMI=RSUM(I)*T2;
                    XMRI=RSUMI/DATUM;
                    RESULT=XMRI+RUP;
                    C8=RESULT;
                    AC(I,IMON)=C5;
                    SMR(I,IMON)=SMR(I,IMON)+XMRI;
                    SMD(I,IMON)=SMD(I,IMON)+XMRI*XMRI;
                    SMO(I)=SMO(I)+XMRI;
                    SSQ(I)=SSQ(I)+XMRI*XMRI;
                    AVM(I)=AVM(I)+RSUMI;
                    AVO(I)=AVO(I)+DATUM;
                    RN(I,IMON)=RN(I,IMON)+1.;
                    XNM(I)=XNM(I)+1.;
                    END;
                    END;
G7:            IMON=IMON+1;
               IF IMON>12 THEN DO;
                    IMON=1;
                    IYR=IYR+1;
                    IF MOD(IYR,4)=0 THEN XDAY(2)=29.;
                    ELSE XDAY(2)=28.;
                    END;
               KHY=KHY+1;
               DO KO=1 TO NHYD;
                    I=IHY(KO);
                    J=JHY(KO);
                    HYD(KO,KHY)=H2(I,J);
               IF MOD(IMON,2)=0 THEN KHYD(KO,IYR,IMON/2)=FLOOR(TOP(KO)
               -H2(I,J)+1.5);
               IF MWL(KO,IYR)=IMON THEN DO;
                    X=H2(I,J)-WL(KO,IYR);
                    WLSUM(KO)=WLSUM(KO)+X;
                    WLSQ(KO)=WLSQ(KO)+X*X;
                    WLNUM(KO)=WLNUM(KO)+1.;
                    END;
                    END;
               IF OPTION(2)¬=1 THEN GO TO G9;
```

```
IF(IMON¬=1)&(K¬=L) THEN GO TO G9;
DO I=1 TO MSTA;
      IF AVO(I)<1. THEN AC(I,15)='        ';
      ELSE DO;
            RESULT=AVM(I)/AVO(I)+RUP;
            C8=RESULT;
            AC(I,15)=C5;
            END;
      Y=XNM(I);
      IF Y<.5 THEN DO;
            AC(I,13)='        ';
            AC(I,14)='        ';
            END;
      ELSE DO;
            S=SMO(I);
            RESULT=S/Y+RUP;
            C8=RESULT;
            AC(I,13)=C5;
            IF Y<1.5 THEN AC(I,14)='        ';
            ELSE DO;
            X=(SSQ(I)-S*S/Y)/(Y-1.);
            IF X<RUPSQ THEN AC(I,14)=' 0.00';
            ELSE DO;
            RESULT=SQRT(X)+RUP;
            C8=RESULT;
            AC(I,14)=C5;
            END;
            END;
            END;
      END;
X=SUM(AVO);
IF X<1.5 THEN WC(1,1)='        ';
ELSE DO;
      RESULT=SUM(AVM)/X+RUP;
      C8=RESULT;
      WC(1,1)=C5;
      END;
IF IMON=1 THEN IDYR=IYR-1;
ELSE IDYR=IYR;
IF IDYR=NSTART THEN JH1=NMON;
ELSE JH1=1;
IF K=L THEN JH2=IMON-1;
ELSE JH2=12;
IF JH2=0 THEN JH2=12;
PUT FILE(SYSPRINT) EDIT
(TITLE,'RATIO OF MODEL FLOW TO OBSERVED FLOW FOR ',IDYR,
'MONTH  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV',
'  DEC  AV. S.D. YEAR','AREA',(I,('      ' DO IJ=1 TO JH1-1),
(AC(I,J) DO J=JH1 TO JH2,13 TO 15) DO I=1 TO MSTA),
'RATIO OF MODEL FLOW VOLUME TO OBSERVED FLOW VOLUME = ',
```

```
      WC(1,1))
      (PAGE,A(80),COL(1),A,F(4),COL(1),A,A,COL(1),A,
      (MSTA)(COL(1),F(5),(JH1-1)A,(JH2-JH1+1)A(5),
      (12-JH2)X(5),3 A(5)),SKIP(2),A,A(5));
   SMO,SSQ=0.;
      RVM=RVM+AVM;
      RVO=RVO+AVO;
      XNM,AVM,AVO=0.:
G9:   IF OPTION(3)¬=1 THEN GO TO F2;
      IF KHY<KH2 THEN GO TO F2;
      PUT FILE(SYSPRINT) EDIT
      (TITLE,
       'ALTITUDE OF WATER LEVEL IN SELECTED WELLS FOR ',IYR,
       'RW,CL WELL NUMBER       JAN 1 FEB 1 MAR 1 APR 1 MAY 1 JUN 1 '
      ,'JUL 1 AUG 1 SEP 1 OCT 1 NOV 1 DEC 1',
       (IHY(I),',',JHY(I),WELLNO(I),('          ' DO IJ=1 TO KH1-1),
      (HYD(I,J) DO J=KH1 TO KH2) DO I=1 TO NHYD))
      (PAGE,A(80),SKIP(2),
           A,F(4),SKIP(2),A,A,(NHYD)(COL(1),F(2),A,F(2),X(1),A(15),
      (KH1-1)A,(KH2-KH1+1)F(6,1)));
      IF KH2=12 THEN DO;
          KH1=1;
          KHY=0:
          KH2=L-K;
          IF KH2>12 THEN KH2=12;
          END:
F2:   IF(IMON¬=MONTH)|(IYR¬=MYEAR) THEN GO TO F1:
      KMAP=KMAP+1:
      MONTH=MAPMON(KMAP):
      MYEAR=MAPYR(KMAP);
      XMX=-1.E+50:
      XMN= 1.E+50:
      DO I=1 TO M;
          DO J=1 TO N;
              IF AS(I,J)=0. THEN A(I,J)=' ':
              ELSE DO:
                  HIJ=H2(I,J);
                  IF HIJ>XMX THEN XMX=HIJ:
                  IF HIJ<XMN THEN XMN=HIJ:
                  KC=HIJ/5.+1.:
                  KC=KC-FLOOR((KC-1)/36)*36:
                  A(I,J)=SYMBOL(KC);
                  END:
              END;
          END;
      ILO=XMN/5.:
      IHI=XMX/5.+1.;
      IR=IHI-ILO:
      PUT FILE(SYSPRINT) EDIT
      (TITLE,
```

```
      -        'MAP OF POT. SURFACE FOR '.IMON.'/ 1/'.IY-.
               'MAX= ',XMX,'MIN= '.XMN,A.
               (SYMBOL(I-FLOOR((I   )/36)*36+1).5*I,' TO '.5*(I+1)
               DO I=ILO TO IHI-1).'IAREA'.'STORAGE CHNGE(AC.FT.)',
               (I.STOR(I) DO I=1 TO NSTATIONS))
               (PAGE,A(80),SKIP(2).
                     A.F(2).A.F(4),2 (SKIP(2).A.F(5.1)).SKIP(2).(M)(COL(1).
               (N)A(1)),SKIP(2),(IP)(COL(1).A(1).X(5).F(3).A,F(3)).PAGE,A.
               COL(10),A,               (NSTATIONS)(COL(1).F(2),COL(10).F(10)));
               STOR=0.;
F1:            RETURN_FLOW=RTFS;
               END;
          END GW;
               IF OPTION(2)¬=1 THEN GO TO F4;
               DO I=1 TO MSTA:
                    DO J=1 TO 12;
                         X=RN(I.J);
                         IF X<.5 THEN DO:
                              AC(I.2*J-1)='      ';
                              AC(I.2*J)='      ';
                              END;
                         ELSE DO;
                         SMRIJ=SMR(I.J);
                         IF X<1.5 THEN Y=0.;
                         ELSE
                         Y=(SMD(I.J)-SMRIJ*SMRIJ/X)/(X-1.);
                         IF Y<RUPSQ THEN AC(I.2*J)=' 0.00';
                         ELSE DO:
                         RESULT=SQRT(Y)+RUP:
                         C8=RESULT:
                         AC(I.2*J)=C5:
                         END:
                         RESULT=SMRIJ/X+RUP;
                         C8=RESULT;
                         AC(I,2*J-1)=C5:
                         END;
                         END:
                    IF RVO(I)<1. THEN AC(I.25)='      ';
                    ELSE DO:
                    RESULT=RVM(I)/RVO(I)+RUP;
                    C8=RESULT:
                    AC(I.25)=C5;
                    END;
                    END;
               X=SUM(RVO):
               IF X<1.5 THEN WC(1.1)='      ';
               ELSE DO;
                    RESULT=SUM(RVM)/X+RUP;
                    C8=RESULT:
                    WC(1.1)=C5;
```

```
     END;
PUT FILE(SYSPRINT) EDIT
( TITLE.'AVERAGE AND STANDARD DEVIATION OF RATIOS OF MONTHLY ',
'MODEL FLOW TO OBSERVED FLOW','MONTH',
'JANUARY   FEBRUARY  MARCH      APRIL      MAY        JUNE       ',
('  AV. S.D.' DO J=1 TO 6 ),          'AREA',
(I,(AC(I,J) DO J=1 TO 12) DO I=1 TO MSTA),
  TITLE,'AVERAGE AND STANDARD DEVIATION OF RATIOS OF MONTHLY ',
'MODEL FLOW TO OBSERVED FLOW','MONTH',
'JULY      AUGUST    SEPTEMBER OCTOBER   NOVEMBER  DECEMBER  ',
('  AV. S.D.' DO J=1 TO 6 ),' VOL.','AREA',
(I,(AC(I,J) DO J=13 TO 25) DO I=1 TO MSTA),
'RATIO OF MODEL FLOW VOLUME TO OBSERVED FLOW VOLUME = ',
WC(1,1))
(PAGE,A(80),COL(1),A,A, COL(1),2 A,COL(6), 6 A(10),  COL(1),A,
(MSTA)(COL(1),F(5),12 A(5)),
 PAGE,A(80),COL(1),A,A, COL(1),2 A,COL(6), 6 A(10),A,COL(1),A,
(MSTA)(COL(1),F(5),13 A(5)),SKIP(2),A,A(5));
DO I=1 TO NHYD;
     X=WLNUM(I);
     IF X<.5 THEN DO;
          WC(I,1)='      ';
          WC(I,2)='      ';
          END;
     ELSE DO;
          SWL=WLSUM(I);
          RESULT=SWL/X+RUP;
          C8=RESULT;
          WC(I,1)=C5;
          IF X<1.5 THEN WC(I,2)='      ';
          ELSE DO;
               Y= (WLSQ(I)-SWL*SWL/X)/(X-1.);
               IF Y<RUPSQ THEN WC(I,2)=' 0.00';
               ELSE DO;
                    RESULT=SQRT(Y)+RUP;
                    C8=RESULT;
                    WC(I,2)=C5;
                    END;
               END;
          END;
     END;
X=SUM(WLNUM);
IF X<.5 THEN DO;
     AC(1,1)='     ';
     AC(1,2)='     ';
     END;
ELSE DO;
     W=SUM(WLSUM);
     RESULT=W/X+RUP;
     C8=RESULT;
```

```
                 AC(1,1)=C5;
                 IF X<1.E THEN AC(1,2)='        ';
                 ELSE DO;
                      Y=(SUM(WLSQ)-W*W/X)/(X-1.);
                      IF Y<RUPSQ THEN AC(1,2)=' 0.00';
                      ELSE DO;
                           RESULT=SQRT(Y)+RUP;
                           C8=RESULT;
                           AC(1,2)=C5;
                           END;
                      END;
                 END;
            PUT FILE(SYSPRINT) EDIT
            (TITLE,'AVERAGE AND STANDARD DEVIATION OF (MODEL - OBSERVED',
            ' WATER LEVEL ALTITUDE)','RW,CL|WELL NUMBER     |AREA|',
            'AVERAGE|STAND.DEV.|NUMBER|INDEX|   HCL   |    S    | N',
         (IHY(I),',',JHY(I),'|',WELLNO(I),'|',IAREA(IHY(I),JHY(I)),
                                              '|',WC(I,1),'|',WC(I,2),'|',
            WLNUM(I),'|',JAREA(IHY(I),JHY(I)),'|',
            HCL(JAREA(IHY(I),JHY(I))),'|',
            STD(JAREA(IHY(I),JHY(I))),'|',
           NEXP(JAREA(IHY(I),JHY(I))) DO I=1 TO NHYD),
                                       'ALL',AC(1,1),AC(1,2),X)
            (PAGE,A(80),SKIP(2),A,A,SKIP(2),A,A,(NHYD)(COL(1),F(2),A,
            F(2),A,A(15),A,F(3),X(1),
                           A,X(2),A(5),A,X(5),A(5),A,X(3),F(3),
            A,F(5),A,F(7,5),A,F(7,5),A,F(2)),
            COL(3),A,COL(30),A(5),COL(41),A(5),COL(50),F(3));
F4:         IF OPTION(4)¬=1 THEN GO TO F3;
            DO IW=1 TO NHYD;
                 DO I=1 TO 16 BY 5;
                      CHYD(I,*)=LINE1(*);
                      DO J=1 TO 4;
                           CHYD(I+J,*)=LINE2(*);
                           END;
                      END;
                 CHYD(21,*)=LINE1(*);
                 DO IY=NSTART TO IYR;
                      IF IY=NSTART THEN IMS=NMON/2;
                      ELSE IMS=1;
                      IF IY=IYR THEN IMF=IMON/2;
                      ELSE IMF=6;
                      DO IM=IMS TO IMF;
                           JKO=(IY-NSTART)*6+IM+1;
                           IKO=KHYD(IW,IY,IM);
                           II=0;
G5:                        IF IKO<1 THEN DO;
                                II=II+1;
                                IKO=IKO+20;
                                GO TO G5;
```

```
                            END;
 G6:                    IF IKO>21 THEN DO;
                            II=II-1;
                            IKO=IKO-20;
                            GO TO G6;
                            END;
                        CHYD(IKO.JKO)=SYMBOL(27+II);
                        END;
                    END;
                DO J=NSTART TO IYR;
                    IF MWL(IW.J)¬=0 THEN DO;
                        JKO=(J-NSTART)*6+MWL(IW.J)/2+1;
                        IKO=FLOOR(TOP(IW)-WL(IW.J)+1.5);
                        II=0;
 H5:                    IF IKO<1 THEN DO;
                            II=II+1;
                            IKO=IKO+20;
                            GO TO H5;
                            END;
 H6:                    IF IKO>21 THEN DO;
                            II=II-1;
                            IKO=IKO-20;
                            GO TO H6;
                            END;
                        CHYD(IKO.JKO)=SYMBOL(13+II);
                        END;
                    END;
                IF MOD(IW.2)=1 THEN DO;
                    PUT FILE(SYSPRINT) EDIT(TITLE)(PAGE.A(80));
                    END;
                PUT FILE(SYSPRINT) EDIT
                (WELLNO(IW).', ROW '.IHY(IW).', COL '.JHY(IW).
                '. AREA '.IAREA(IHY(IW),JHY(IW)).
                '. INDEX='.JAREA(IHY(IW),JHY(IW)).
                '. HCL='.HCL(JAREA(IHY(IW).JHY(IW))).
                '. S='.  STO(JAREA(IHY(IW).JHY(IW))).
                          TOP(IW).(CHYD(I.*) DO I=1 TO 10).
                TOP(IW)-10..(CHYD(I,*) DO I=11 TO 20).TOP(IW)-20..
                CHYD(21,*).(J DO J=NSTART TO IYR))
                (SKIP(2),COL(1).A(15).4 (A.F(2)),2 (A,F(7.5)).
                                        2 (COL(1).F(4),10 (COL(5).
                109 A(1))),
                COL(1),F(4).COL(5),109 A(1).COL(5).(IYR-NSTART+1)F(6));
                END;
 F3:        IF OPTION(6)¬=1 THEN GO TO F5;
            DO IW=1 TO MSTA;
                DO K=0 TO 1;
                DO I=2 TO 18 BY 4;
                    CHYD(I.*)=LINE1(*);
                    DO J=1 TO 3;
```

```
|                      CHYD(I+J,*)=LINE2(*);
|                      END;
|                 END;
|            CHYD(22,*)=LINE1(*);
|            CHYD(23,*)=LINE3(*);
|            CHYD( 1,*)=LINE3(*);
|                 ISTART=NSTART+K*9;
|                 DO IY=ISTART TO ISTART+8;
|                      DO IM=1 TO 12;
|                           JKO=(IY-ISTART)*12+IM+1;
|                           IK1=IHYD(IW,IY,IM);
|                           IK2=JHYD(IW,IY,IM);
|                           IF(IK1<24)&(IK2<24) THEN DO;
|                                IF IK1=IK2 THEN CHYD(IK1,JKO)='B';
|                                ELSE DO;
|                                     CHYD(IK1,JKO)='O';
|                                     CHYD(IK2,JKO)='M';
|                                     END;
|                                END;
|                           END;
|                      END;
|                 IF K=0 THEN PUT FILE(SYSPRINT) EDIT
|                 (TITLE,STATION_NUMBER(IW),', AREA ',IM)
|                 (PAGE,A(80),SKIP(2),A(8),A,F(2));
|                 PUT FILE(SYSPRINT) EDIT
|                 (CHYD(1,*),'10,000  ',(CHYD(I,*) DO I=2 TO 5),
|                 ' 1,000  ',(CHYD(I,*) DO I= 6 TO  9),
|                 '   100  ',(CHYD(I,*) DO I=10 TO 13),
|                 '    10  ',(CHYD(I,*) DO I=14 TO 17),
|                 '     1  ',(CHYD(I,*) DO I=18 TO 21),
|                 '      .1',CHYD(22,*),CHYD(23,*),
|                 (J DO J=ISTART TO ISTART+8))
|                 (SKIP(2),COL(9),109 A(1),5 (COL(1),A,4 (COL(9),
|                 109 A(1))),COL(1),A,2 (COL(9),109 A(1)),
|                 COL(6),9 (X(3),F(4)));
|                 END;
|            END;
|F5:CLOSE FILE(IN1);
|   END BB;
```

PREPROCESSOR DIAGNOSTIC MESSAGES PRODUCED