THE DETERMINATION OF THE IMPACT OF AN EARTHEN-FILL DAM ON THE GROUND-WATER FLOW USING A MATHEMATICAL MODEL

By

JAMES WESLEY NANEY

Bachelor of Science

Oklahoma College of Liberal Arts

Chickasha, Oklahoma

1969

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
July, 1974

THE DETERMINATION OF THE IMPACT OF
AN EARTHEN-FILL DAM ON THE
GROUND-WATER FLOW USING A
MATHEMATICAL MODEL

Thesis Approved

Douglas C. Kent
Thesis Adviser

Alex R. Ross

Zuhair Al Shaieb

D D Durham
Dean of the Graduate College

PREFACE

This thesis is a study of the impact of an earthen-fill dam on the ground-water flow regime. The basic approach was to adapt and apply an existing mathematical model to the problem of seepage from an earthen structure. A thorough review of existing hydrologic and geohydrologic data for the area to be modeled was completed. The data obtained by core drilling and well monitoring during this study was correlated with existing data for the area. These data were used as the boundary parameters for the mathematical model applied to the problem.

Several of the mathematical models available for ground-water flow problems were reviewed and one was selected and adapted to the IBM 360-50 computer for this study.

I would like to express my gratitude to Dr. Douglas C. Kent for his diligent review and helpful suggestions in the research and writing of this thesis. I would also like to thank Dr. Alex R. Ross and Dr. Zuhair Al Shaieb for their editorial comments and suggestions.

My sincere thanks to Dr. Donn G. DeCoursey, Director, and to the staff of the Southern Great Plains Research Watershed, Agricultural Research Service at Chickasha, Oklahoma for their assistance and encouragement in this study. The research for this thesis was a part of the research conducted under a cooperative research agreement between the Department of Geology at Oklahoma State University and the Southern Great Plains Research Watershed, ARS, at Chickasha.

Special thanks go to Mr. R. William Nelson for his generosity in the use and adaptation of his mathematical model for this thesis. Thanks also to Mr. Edward Seely for his assistance in writing computer programs used in this thesis, and to Mr. Samuel C. Bingaman who aided in the collection and reduction of data used in the study. A very special thanks to Mrs. Betty L. Golden who provided secretarial assistance and editorial insight toward the completion of this thesis and to Mr. Justin Giddens who drafted the final figures.

More than any of those mentioned above, I want to thank my wife, Mary, for her loving consideration and understanding during the several months required for the completion of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

CHAPTER I

INTRODUCTION

Background

This study was done in cooperation with the Southern Great Plains Research Watershed at Chickasha, Oklahoma. The station was established in 1961 and since that time, has been conducting studies on the effects of upstream land management practices on the flow regime along the main stem of the Washita River from Anadarko to Alex, Oklahoma. The ground-water segment of the hydrologic cycle has been under investigation to determine its impact on the flow regime in the main stem of the Washita River. In order to evaluate adequately the effects of ground-water flow on the main stem, it was first necessary to determine the impact of upstream changes and improvements on the local ground-water flow.

Objectives

The objective of this study was to determine the impact on the ground-water flow regime associated with an earthen-fill dam on a typical upstream tributary of the Washita River. A mathematical model was used to distribute hydrogeologic parameters in order that a more realistic potential head response could be determined for water seeping either under or around a dam. Using this information, the time of travel, quantity and quality of both subsurface flow downstream and effluent flow can be more accurately predicted.

The validity of the mathematical model was tested by determining how well the mathematically determined distribution of the coefficients of permeability and the mathematically produced piezometric surfaces would compare with measured data.

The distribution of the coefficient of permeability, determined mathematically, was compared with maps prepared using pump test or laboratory data. The piezometric surface maps developed mathematically were compared with the measured piezometric surface. A comparison of the mathematically predicted piezometric surface and the actual piezometric surface measured both "Before" and "After" the construction of the dam was also used to determine the validity of the predicted subsurface flow downstream from the dam. When it was determined that the predicted piezometric surface reasonably described the water-level conditions after dam construction, values from this surface were selected as input to a mathematical model. The model was used to determine the rate of subsurface flow under and around the dam and the downstream distance where effluent conditions would appear as base flow.

Procedure

Site 13 on the Sugar Creek watershed of the Washita River was selected for extensive instrumentation. The dam at Site 13 is about 1,000 feet wide and is east trending across a broad flat alluvial flood plain. There was initially very little channel present in the valley and a shallow water table existed during wet periods. The bedrock at the edges of the valley and against which the dam abuts on either end are the Rush Springs Formation (sandstone) of Permian age and the underlying Marlow Formation (shale).

A network of some 96 piezometers was installed at this site to monitor the changes in ground-water levels "Before" and "After" the dam was completed and filled with water. The piezometers were installed using for the most part, hand-driven, 1/2-inch steel casing. In addition, thirty-one 1-1/2-inch casings were set in holes, drilled using the rotary method, to deeper depths than it was possible to hand drive the smaller casing. The distribution of these instruments is shown in Figure 1.

Piezometer measurements made prior to the completion of the structure and continuing through the first filling of the structure indicated that there was hydraulic transmission from the water stored in the reservoir to the water moving in the subsurface downstream from the structure (32). Site 13 was considered an excellent location to test out a mathematical model which could be applied to predict the impact of these structures on ground-water flow because of a history of apparent seepage from the reservoir. The topographic and physical features of the Site 13 drainage area were also typical of many of the watersheds where floodwater retarding structures have been built in the Southern Great Plains (5).

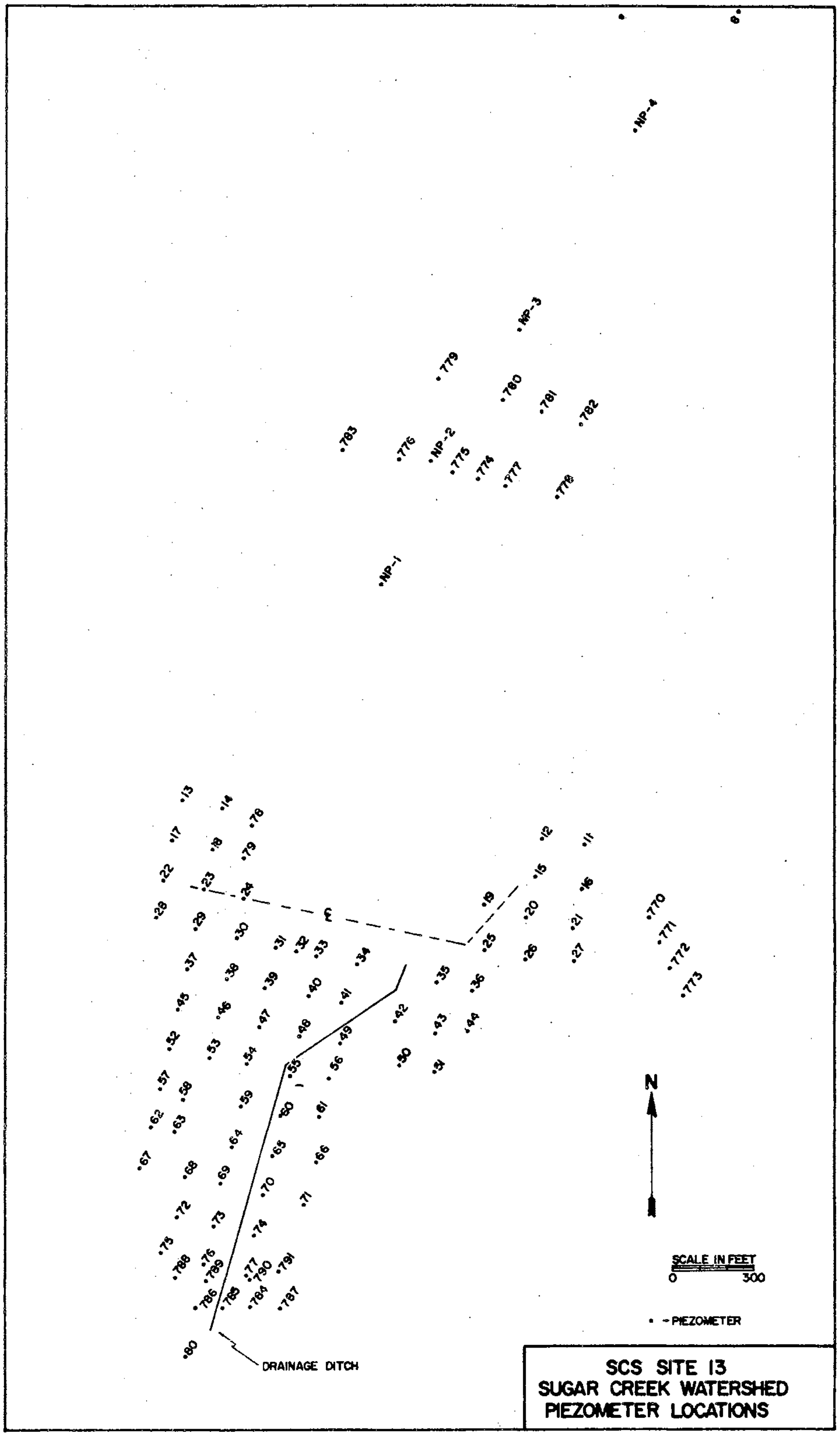

SCS SITE 13
SUGAR CREEK WATERSHED
PIEZOMETER LOCATIONS
N
SCALE IN FEET
0 300
• - PIEZOMETER
DRAINAGE DITCH
NP-1
NP-2
NP-3
NP-4

FIGURE 1

CHAPTER II

DESCRIPTION OF STUDY AREA

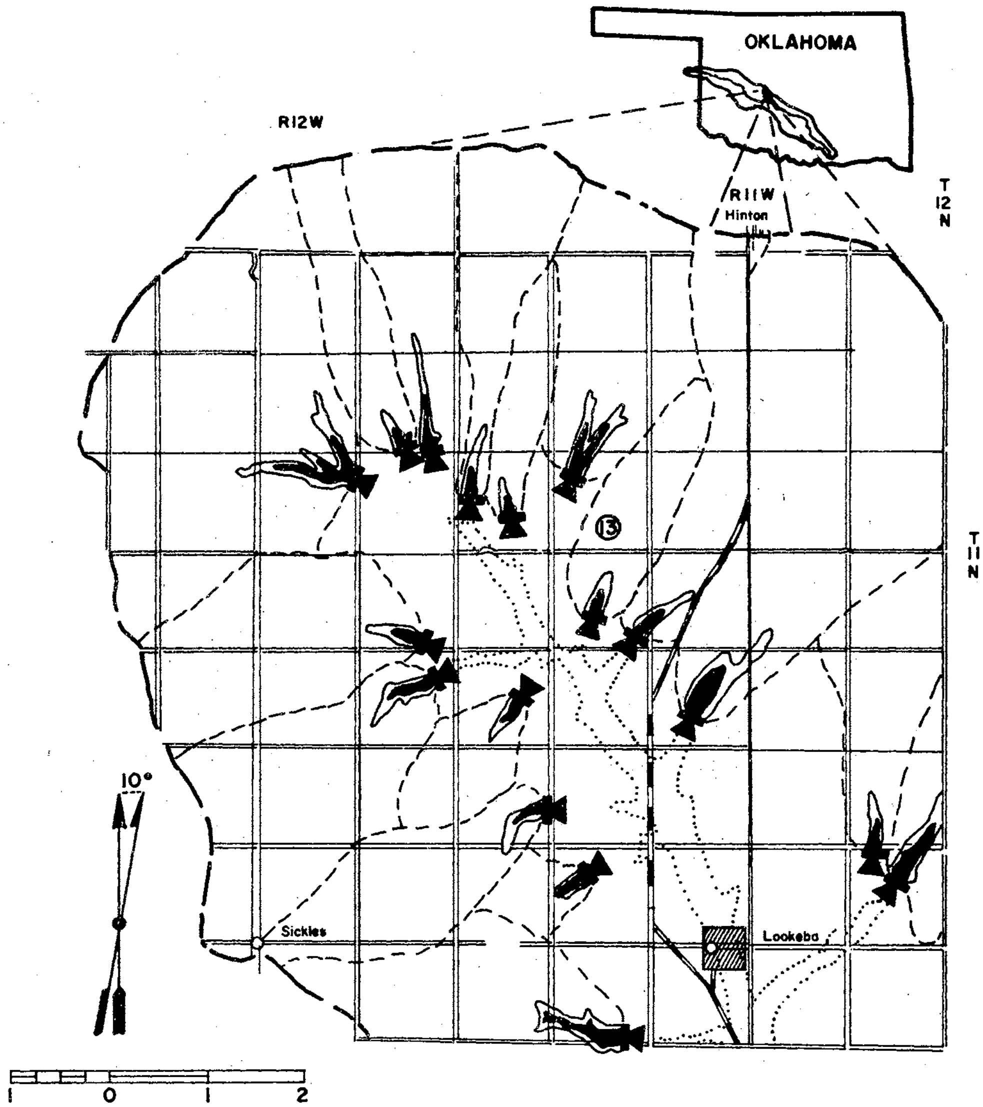
Geographic Location

The Site 13 floodwater retarding structure is an earthen-fill dam which is located 4 miles south and 1-1/2 miles west of the town of Hinton, Oklahoma in Caddo County (Figure 2). The structure is built across a tributary to Sugar Creek which is a tributary to the Washita River. The drainage area into the structure is approximately 1,165 acres, or just under 2 square miles (25). The valley is southwest trending and is confluent with Sugar Creek approximately 1,500 feet downstream from the structure.

Economy

In the upper Sugar Creek Watershed, the economy is primarily agriculture. To the west of the study area is a heavily developed area of irrigation wells which are used to provide water for growing of peanuts and melons (5) (30). The cultivation occurs in the silty to sandy alluvial material as well as in the shallow soil profile which has developed on the flat surface of the upper extent of the Rush Springs sandstone.

Within the perimeter of the Site 13 study area, the primary economic activity is raising cattle. These graze on the grasslands in the alluvial area above and below the structure. Along the east abutment



LEGEND

- Area Subject to Flooding
- Hard Surface Road
- Dirt or Unimproved Road
- Town or Community
- Floodwater Retarding Structure
- Drainage Area Boundary
- Watershed Boundary
- (13) Structure Number

LOCATION MAP OF FLOODWATER RETARDING STRUCTURES

FIGURE 2

near the watershed divide, some small grain is grown. There are two hybrid walnut groves along the abutments on either side and downstream from the structure; however, these are not considered an economic enterprise at present.

Geology

General

There are three geologic units exposed in the Site 13 study reach (9). Two of these units are Permian in age while the third is Quaternary. A geologic map of the upper Sugar Creek watershed by Levings was used as a base map for this study (Figure 3). Both field work in the Site 13 study reach area and the drill hole logs and cores obtained by the Soil Conservation Service and the Agricultural Research Service were used to describe the alluvium and bedrock as well as their hydraulic properties.

Permian System

The Marlow Formation and the Rush Springs Formation, which together make up the White Horse Group, are the two Permian strata that crop out in the Site 13 study area (1). The Marlow Formation outcrops in the study area only in badly eroded gullies and along roadsides near the alluvium contact in the Site 13 study area. It is the older of the two Permian strata, and can be characterized as a red brown siltstone with lenses of very fine sandstone and gypsiferous stringers. The Marlow Formation is in contact with the alluvium generally in the subsurface of the Site 13 study area and is of primary significance in this study because it serves as a lower boundary for determining the extent of

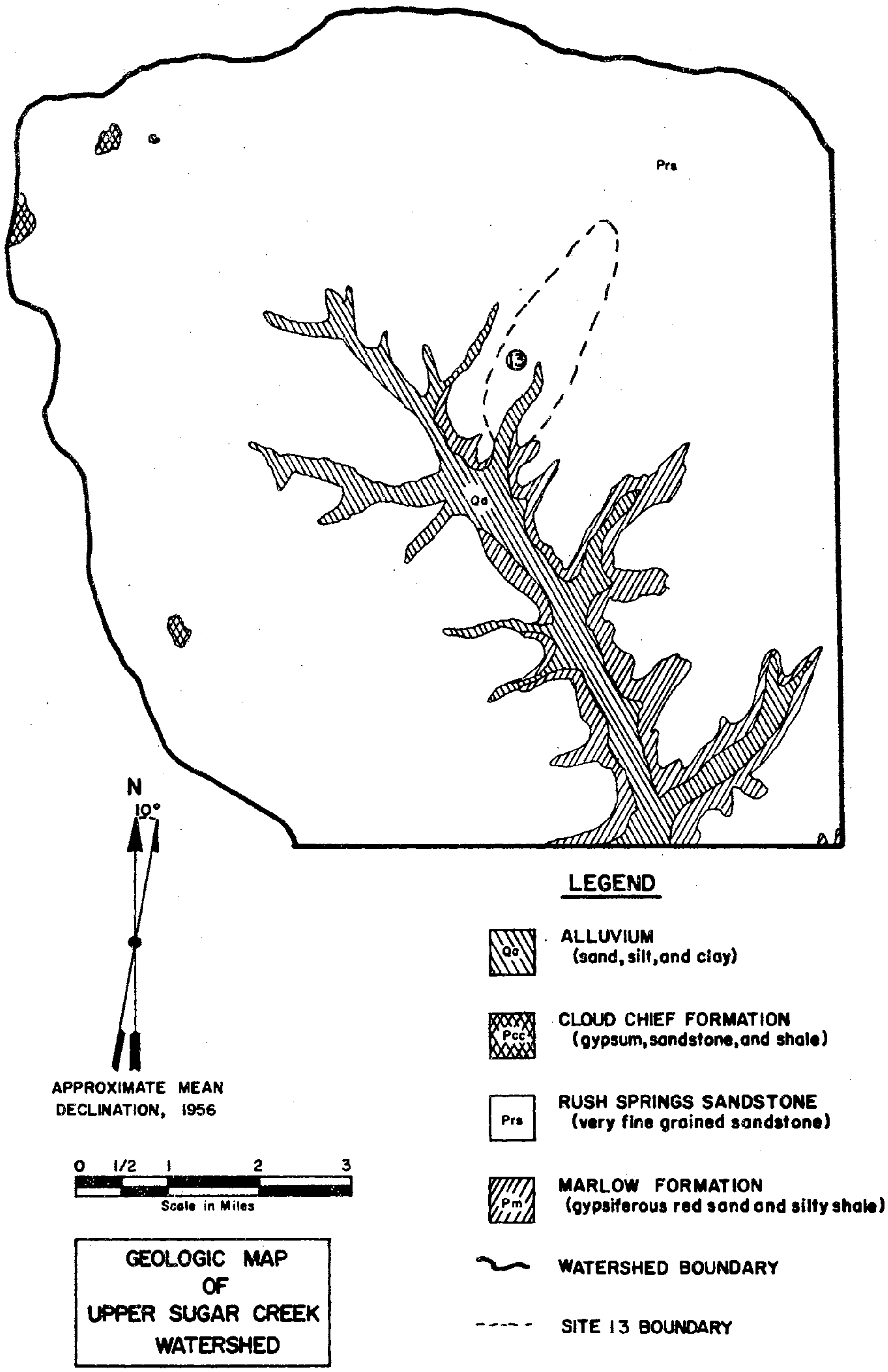

Prs
Qa
13
N
10°
APPROXIMATE MEAN DECLINATION, 1956
0 1/2 1 2 3
Scale in Miles
GEOLOGIC MAP OF UPPER SUGAR CREEK WATERSHED
LEGEND
Qa ALLUVIUM (sand, silt, and clay)
Pcc CLOUD CHIEF FORMATION (gypsum, sandstone, and shale)
Prs RUSH SPRINGS SANDSTONE (very fine grained sandstone)
Pm MARLOW FORMATION (gypsiferous red sand and silty shale)
WATERSHED BOUNDARY
SITE 13 BOUNDARY

FIGURE 3

ground-water seepage movement out of the Site 13 reservoir. The Marlow Formation is overlain disconformably throughout the Site 13 study area by the Rush Springs Formation. The contact zone between these two formations is difficult to map because it is gradational in nature and the texture of the underlying sandy siltstone of the Marlow Formation and overlying fine-grained sandstone of the Rush Springs Formation has similar weathering characteristics. The Rush Springs Formation is composed of sub-angular to sub-rounded quartz grains with calcite and iron cementing agents which are typical of the Permian strata of the area. The Rush Springs Formation is primarily a reddish brown to reddish orange silty fine to medium grained cross-bedded sandstone and appears in road cuts as erosion-resistant steep walls. Near the watershed divides of the Site 13 area, the thickness of the Rush Springs Formation is as much as 100 feet. The Rush Springs Formation thins to only a few feet in the area of the dam site and therefore is not a significant aquifer for an irrigation supply in the study area.

Quaternary System

The Quaternary system exposed in the Site 13 study area is made up entirely of nonindurated flood plain alluvium. These materials range in size from clays through coarse sands, but are primarily in the clay, silt, and very fine sand range. Nearly 40 percent of the watershed area of the Site 13 study area is overlain by these alluvial sediments. The dam is built with a relatively impermeable core extending along its entire length and rests upon 50 to 60 feet of silt and fine sand. Gradational variations of the grain size of sediments within the alluvium commonly occur both vertically and horizontally.

The thickness of the alluvium ranges from zero feet at the bedrock contacts on either side of the valley to as much as 100 feet near the center of the valley. However, most of the sediments encountered at depths below 50-52 feet were impermeable clays. The top of the clay was used as a lower hydraulic boundary in modeling the center of the valley. Using the clay as a lower boundary a more or less rectangular cross section can be visualized which is approximately 1,000 feet wide and 50 feet deep. Seepage from the structure can be considered to flow through this cross section.

Topography

The land surface of the Site 13 study area is moderate to sharply rolling with the more erosion-resistant sandstone in the Rush Springs Formation acting as a controlling feature which generally exhibits steep sided gullies and canyons. A dendritic drainage pattern is characteristic of the upper reaches of the Sugar Creek Watershed and in the Site 13 drainage area, where the topographic relief ranges from 1,395 feet on the valley floor to 1,475 feet in the watershed divide.

The channel that controls the flow down the Site 13 tributary valley is very shallow and practically nonexistent in the upper reaches. The channel downstream from the structure has been modified into a drainage ditch by the Soil Conservation Service in order to help relieve high water table conditions after the structure was built. A topographic map of the area with the dam in place is shown in Figure 4.

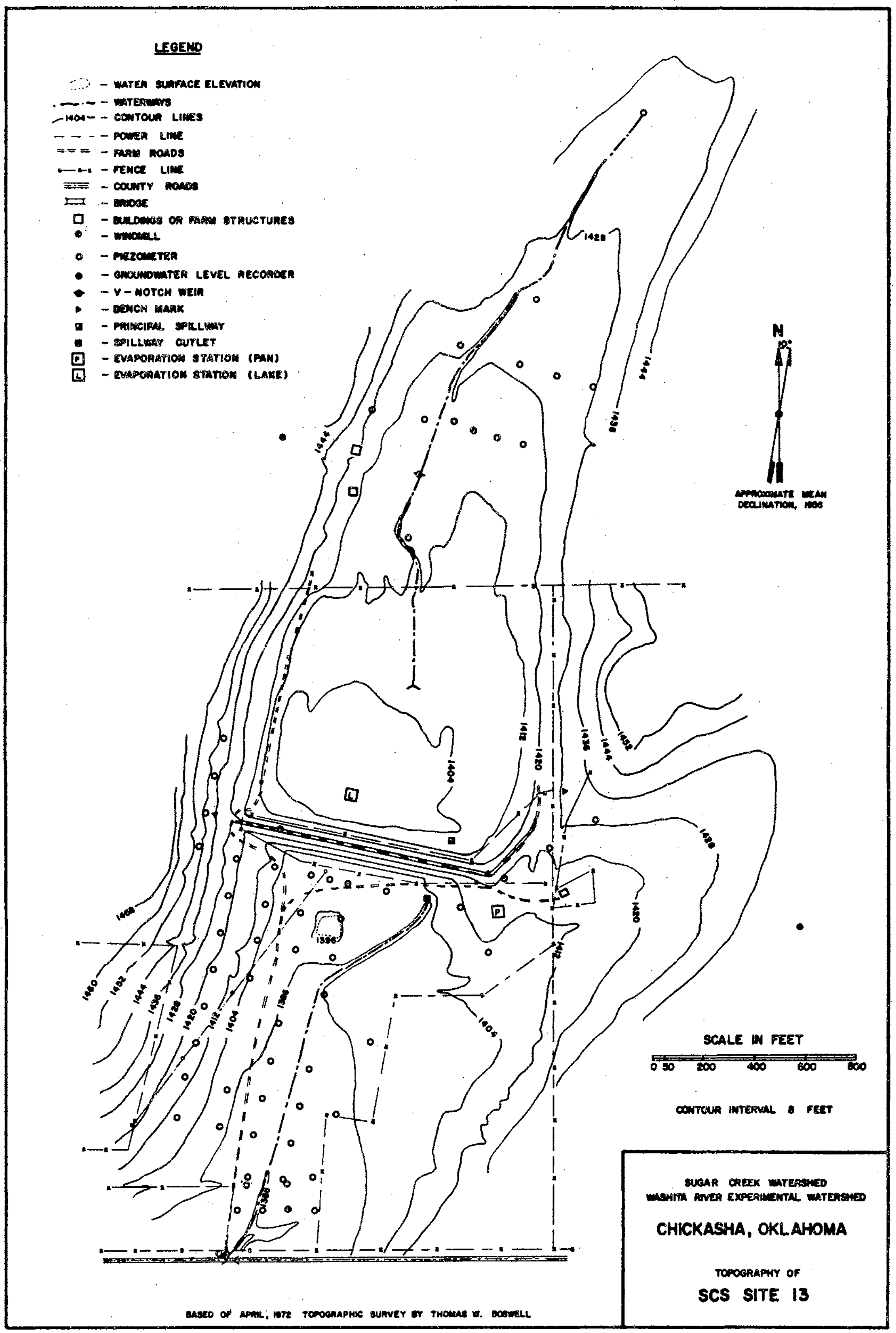

LEGEND
– WATER SURFACE ELEVATION
– WATERWAYS
1404 – CONTOUR LINES
– POWER LINE
– FARM ROADS
– FENCE LINE
– COUNTY ROADS
– BRIDGE
– BUILDINGS OR FARM STRUCTURES
– WINDMILL
– PIEZOMETER
– GROUNDWATER LEVEL RECORDER
– V – NOTCH WEIR
– BENCH MARK
– PRINCIPAL SPILLWAY
– SPILLWAY OUTLET
P – EVAPORATION STATION (PAN)
L – EVAPORATION STATION (LAKE)
N
APPROXIMATE MEAN DECLINATION, 1966
SCALE IN FEET
0 50 200 400 600 800
CONTOUR INTERVAL 8 FEET
SUGAR CREEK WATERSHED
WASHITA RIVER EXPERIMENTAL WATERSHED
CHICKASHA, OKLAHOMA
TOPOGRAPHY OF
SCS SITE 13
BASED OF APRIL, 1972 TOPOGRAPHIC SURVEY BY THOMAS W. BOSWELL

FIGURE 4

CHAPTER III

METHODS AND PROCEDURES

Data

Continuous recorder wells and piezometers were strategically located and drilled to varying depths to determine the extent of transient or vertical movement of ground-water flow near the dam. The additional piezometers were installed in groups of three on the downstream side and on the top of the dam (Figure 5) and were used to monitor differences in piezometric head through the structure. Water level observations since August 1973, in the piezometer banks indicate that pressure head differences occurring at different depths near the base of the dam were less than 2-1/2 feet and therefore, vertical flows within the system were considered negligible. The hydrographs for the piezometer banks at Site 13 are shown in Figures 6, 7, 8, and 9. Because vertical flow was found to be insignificant, it was possible to use a two dimensional, steady state mathematical model to describe the flow system.

Three holes were core drilled, one below (Well No. 784) and two above the dam (Wells No. 774 and 783). Samples from these holes were analyzed in the laboratory to determine both vertical and horizontal permeabilities of the alluvial sediments on which the dam was built.

A Damco rotary drilling rig was used for the coring. Because unconsolidated and bedrock materials from both the saturated and unsaturated zone were to be cored, special types of coring equipment were

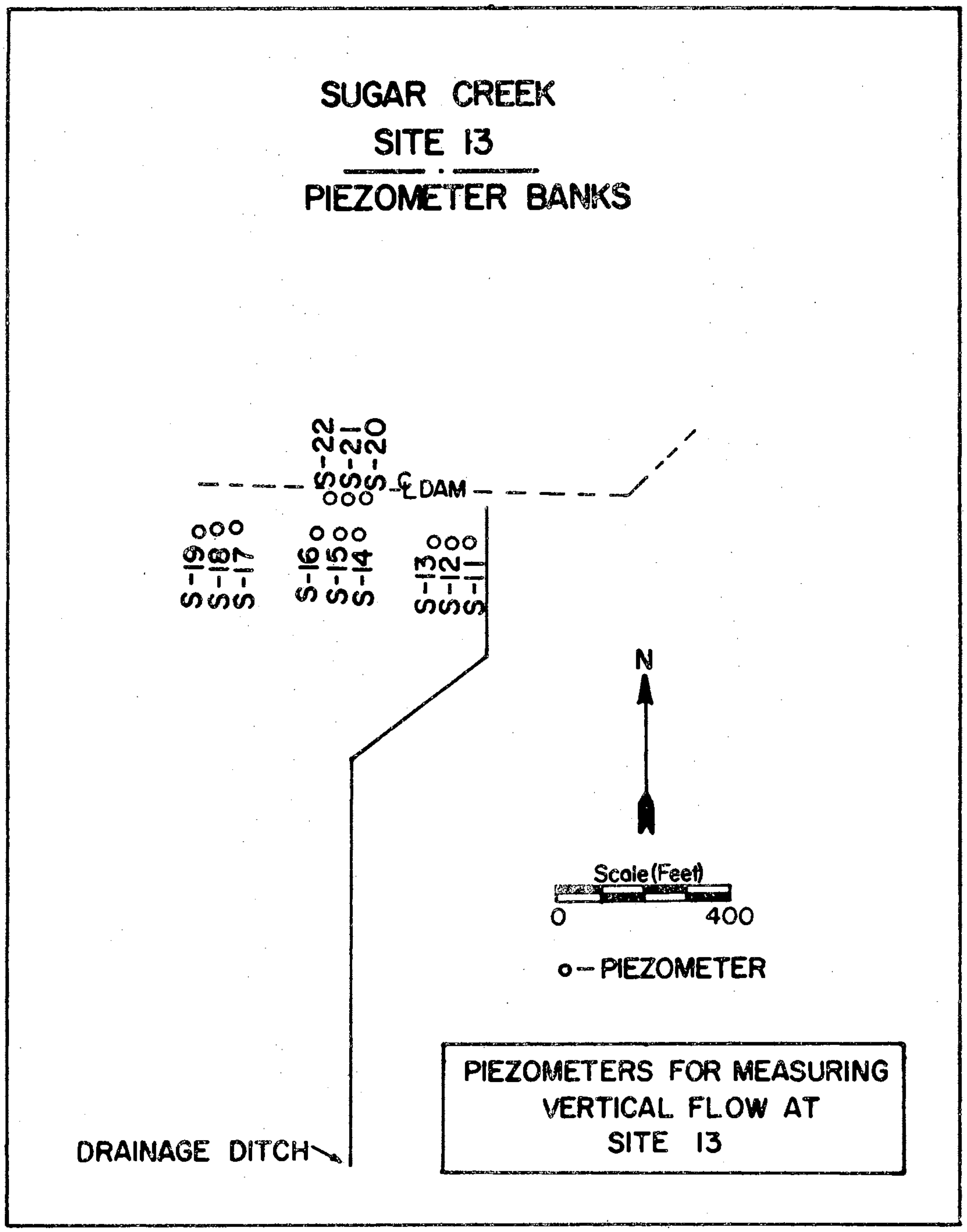

SUGAR CREEK
SITE 13
PIEZOMETER BANKS
S-22
S-21
S-20
℄ DAM
S-19
S-18
S-17
S-16
S-15
S-14
S-13
S-12
S-11
N
Scale (Feet)
0
400
o – PIEZOMETER
PIEZOMETERS FOR MEASURING VERTICAL FLOW AT SITE 13
DRAINAGE DITCH

FIGURE 5

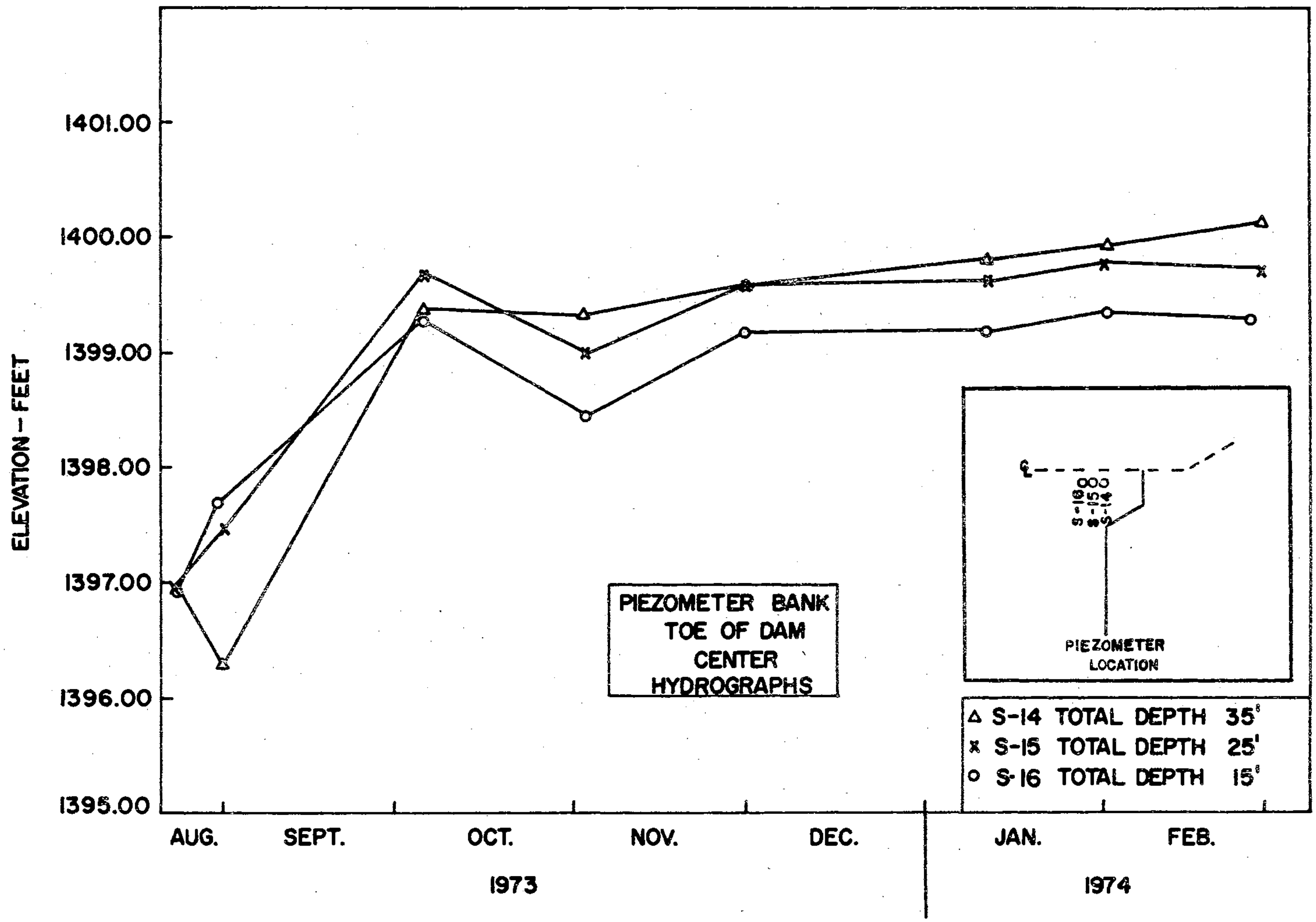
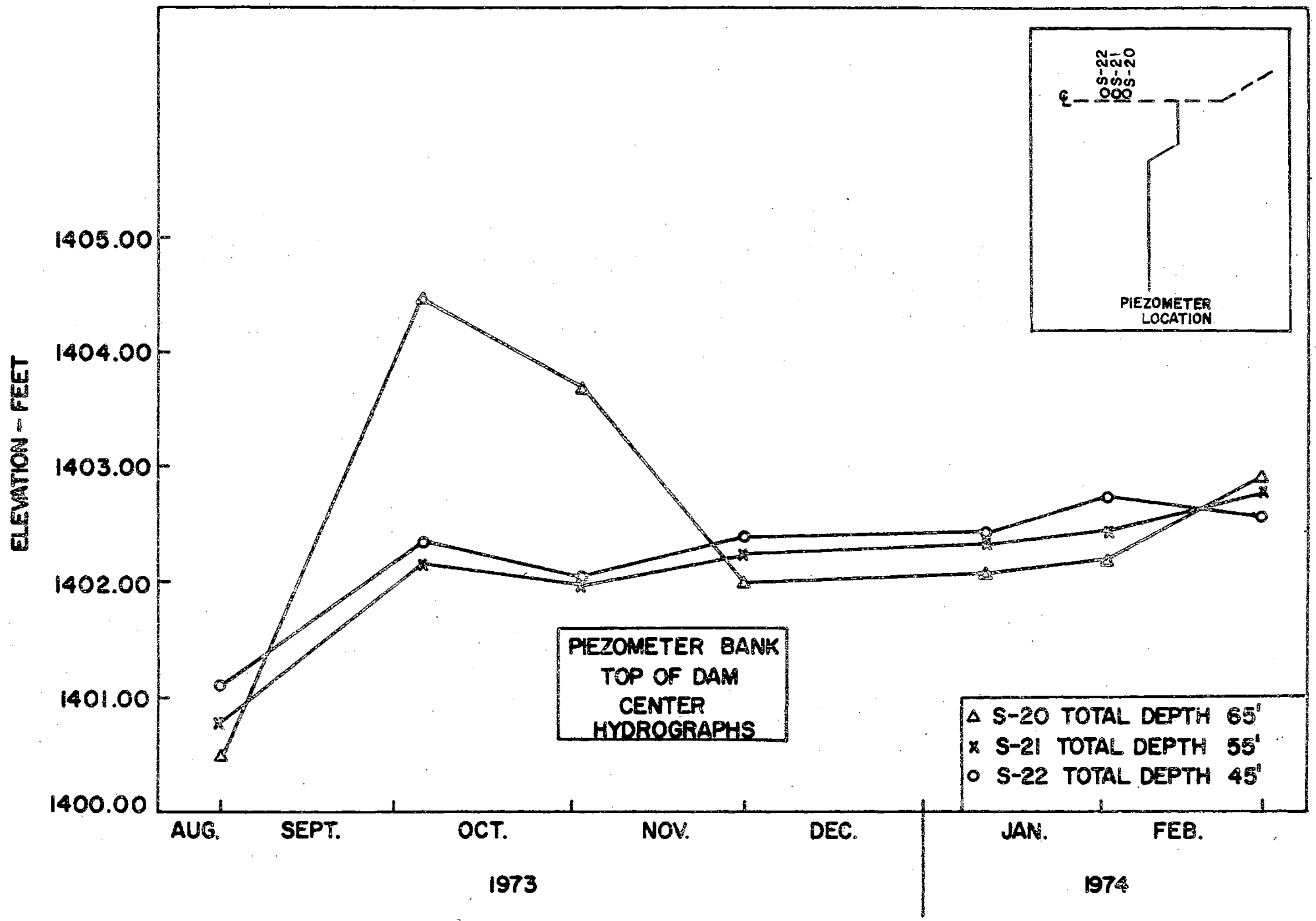

1401.00
1400.00
1399.00
1398.00
1397.00
1396.00
1395.00
ELEVATION – FEET
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
1973
1974
PIEZOMETER BANK
TOE OF DAM
CENTER
HYDROGRAPHS
PIEZOMETER
LOCATION
S-16
S-15
S-14
△ S-14 TOTAL DEPTH 35'
× S-15 TOTAL DEPTH 25'
○ S-16 TOTAL DEPTH 15'

FIGURE 6



PIEZOMETER LOCATION
S-22
S-21
S-20
1405.00
1404.00
1403.00
1402.00
1401.00
1400.00
ELEVATION - FEET
PIEZOMETER BANK
TOP OF DAM
CENTER
HYDROGRAPHS
△ S-20 TOTAL DEPTH 65'
x S-21 TOTAL DEPTH 55'
o S-22 TOTAL DEPTH 45'
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
1973
1974

FIGURE 7

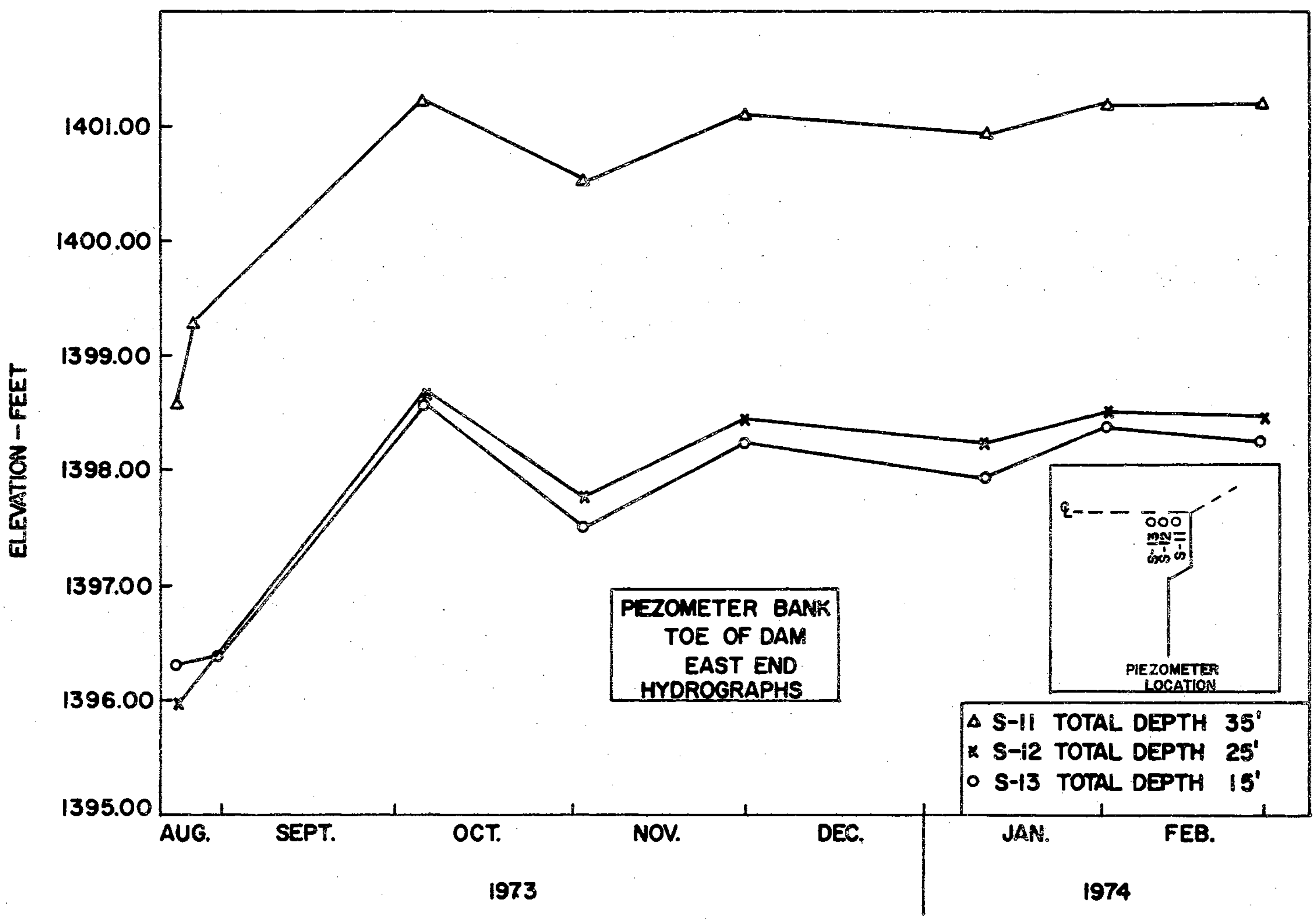

1401.00
1400.00
1399.00
1398.00
1397.00
1396.00
1395.00
ELEVATION — FEET
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
1973
1974
PIEZOMETER BANK
TOE OF DAM
EAST END
HYDROGRAPHS
PIEZOMETER LOCATION
S-11
S-12
S-13
△ S-11 TOTAL DEPTH 35'
x S-12 TOTAL DEPTH 25'
o S-13 TOTAL DEPTH 15'

FIGURE 8

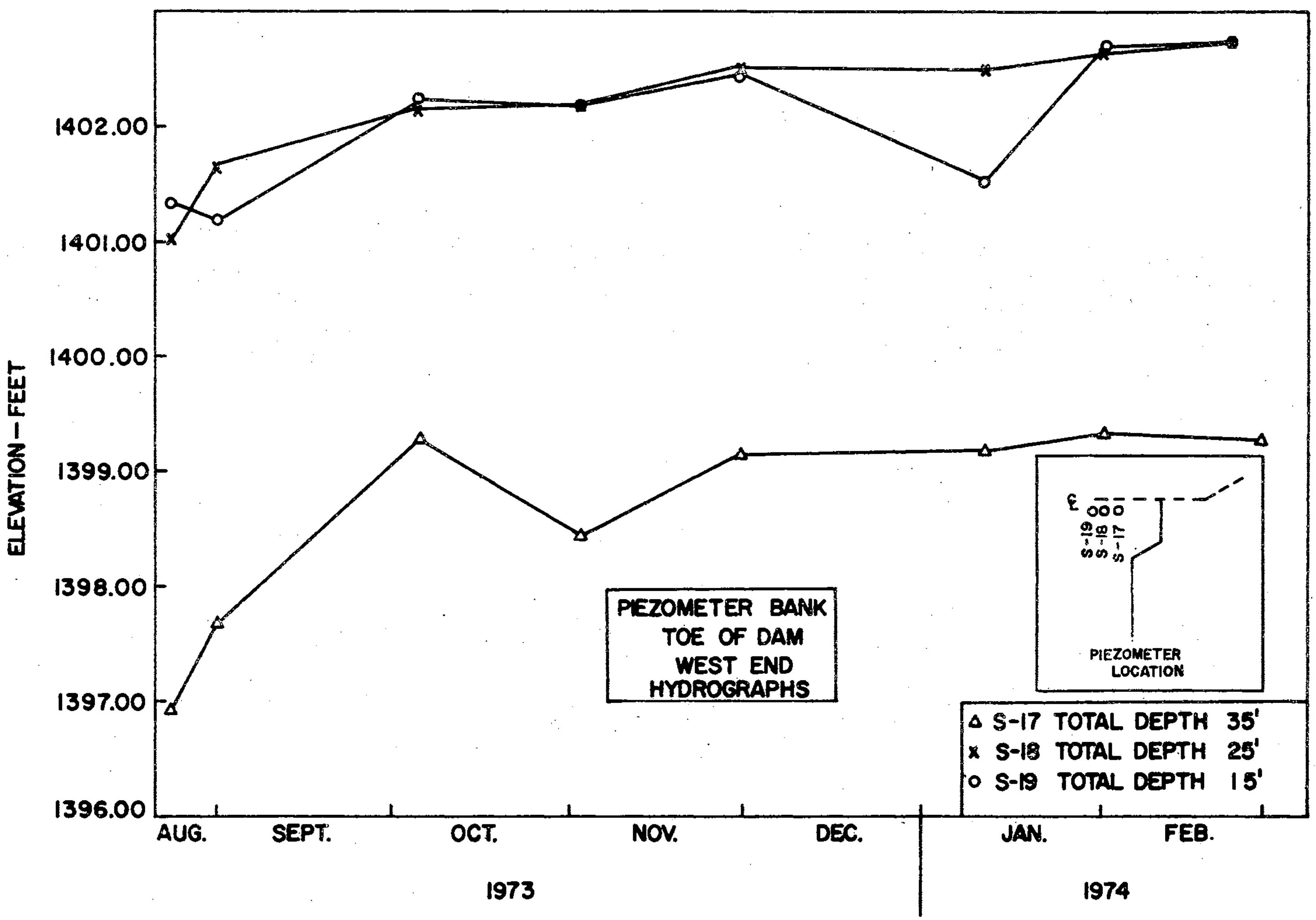

1402.00
1401.00
1400.00
1399.00
1398.00
1397.00
1396.00
ELEVATION — FEET
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
1973
1974
PIEZOMETER BANK
TOE OF DAM
WEST END
HYDROGRAPHS
S-19
S-18
S-17
PIEZOMETER
LOCATION
Δ S-17 TOTAL DEPTH 35'
x S-18 TOTAL DEPTH 25'
o S-19 TOTAL DEPTH 15'

FIGURE 9

necessary. Mr. Bob R. Toland, driller for the Agricultural Research Service in Bushland, Texas, was employed for this field investigation. Similar procedures had been used during an investigation in the lower Sugar Creek Watershed in 1970 (9).

Laboratory Procedures

A Soil Test Model K-670 high pressure permeameter was used for the laboratory determination of the coefficient of permeability. The permeameter test runs were made on the small 3/4-inch diameter, vertical and horizontal plugs which were obtained from the larger 3-inch piston and push tube cores. Selection of the plugs was made on the basis of changes in visual appearance of the material. The visual descriptions of these materials are listed in Table 1. Using this permeameter test, both constant head and falling head permeabilities were obtained for the material and the results of the analyses are shown in Table 2. Values obtained from the permeability tests were expressed in gallons per day per square foot. These values were corrected to a field temperature of 16° C. for use as field permeabilities. The cumulative distribution of sediment size was determined for each plug sample using the visual accumulation tube method (31). The resulting statistics of the sediment distribution are also shown in Table 2.

Evaluation of Pump Test Data

Ideally, a pump test in the field would represent a measure of the amount of water that can travel through the subsurface material in response to a constant pumping rate. However, it has been found in these investigations and in other pump tests studies that well completion

TABLE I

DESCRIPTION OF CORE SAMPLES

	Data Number Sample/Data/Depth No. No. (ft.)	Detailed Laboratory Description type, size; color; other
NORTH WELL	5A/774/0-.1	Silt and clay; black
	5B/774/.1-1.0	Sand, very fine; red brown with vertical black silt streaks and vertical rootlets; no visible crossbedding
	4A/774/5.1-5.4	Sand, very fine; red brown with laminated silt streak; no visible crossbedding
	4B/774/5.4-5.9	Silt and clay; gray
	4C/774/5.9-6.6	Silt and clay; gray and buff
	7A/774/7.4-7.7	Sand, very fine; brown and silt; black
	7B/774/7.7-8.7	Sand, very fine and fine; brown
	3A/774/11.0-12.5	Silt and clay; black
	10A/774/18.7-18.9	Sand, very fine and fine; red brown with silt
	10B/774/18.9-19.8	Sand, very fine and fine; red brown
	1A/774/23.7-24.9	Sand, very fine; red brown, massive, no visible crossbedding
	1B/774/23.2-23.7	Sand, very fine and silt; dark gray brown; massive, no visible crossbedding
	8A/774/49.3-50.7	Sand, very fine and fine; red brown
SOUTH WELL	2B/784/1.5-2.2	Sand, very fine; buff
	2A/784/1.2-1.5 2.2-2.7	Sand, very fine and silt; dark brown; massive, no visible crossbedding
	9A/784/3.0-3.3	Sand, very fine and silt; brown
	9B/784/3.3-3.6	Silt; brown
	6A/784/3.6-4.5	Sand, very fine; red brown; with short vertical streaks of black silt and with vertical streaks of light gray very fine and fine sand; massive, no visible crossbedding
	11A/784/60.0-60.4	Clay; dark gray
	11B/784/60.4-60.5	Sand, fine; tan
	11C/784/60.5-61.3	Clay; dark gray
BEDROCK	12A/Bedrock/38.5-38.7	Sandstone; massive, well cemented
	12B/Bedrock/38.7-39.0	Sandstone; with horizontal fractures filled with soft sandy clay
	12C/Bedrock/39.0-40.0	Siltstone, with sandstone; medium hard
	12/D/Bedrock/40.0-40.4	Sandstone and sandy clay; alternating lenses
	12E/Bedrock/40.4-40.5	Sandstone, friable

TABLE II

ANALYSES OF CORED SAMPLES

	Data Number	Grain Size Distribution			Permeability		
	Sample/Data/Depth No. No. (ft.)	% by Weight of Fine Fraction (<.062mm)	Grain Size D_{50} (mm)	Uniformity Coeff. $\frac{60mm}{10mm}$	Falling Head 24°C/16°C (gpd/ft^2)	Constant Head 24°C/16°C (gpd/ft^2)	Direction
NORTH WELL	5A/774/0-.1	Not sampled	(Too thin)				
	5B/774/0.1-1.1	29.5	.07	1.29	2.09/1.71	1.64/1.35	Horizontal
	5B/774/0.1-1.1	10.7	.105	1.88	2.82/2.31	2.56/2.10	Vertical
	4A/774/5.1-5.4	35.6	.069	1.5	14.35/11.77	9.12/7.48	Horizontal
	4A/774/5.1-5.4	17.1	.081	1.53	4.94/4.05	4.06/3.33	Vertical
	4B/774/5.4-5.9	65.8	.05	1.54	Impermeable	Impermeable	Vertical
	4C/774/5.9-6.6	Not sampled	(Impermeable)				
	7A/774/7.4-7.7	Not sampled	(Too thin)				
	7B/774/7.7-8.7	15.4	.08	1.5	2.1/1.73	2.80/2.30	Horizontal
	7B/774/7.7-8.7	11.3	.071	1.5	3.33/2.73	3.57/2.93	Vertical
	3A/774/11.0-12.5	66.1	.04	2.09	Impermeable	Impermeable	Vertical
	3A/774/11.0-12.5	59.8	.059	1.61	Impermeable	Impermeable	Horizontal
	10A/774/18.7-18.9	24.4	.072	1.32	3.91/3.2	5.05/4.14	Horizontal
	10B/774/18.9-19.8	19.7	.08	1.47	Lost	Lost	Vertical
	1B/774/23.2-23.7	41.9	.067	1.29	Impermeable	Impermeable	Vertical
	1B/774/23.2-23.7	39.6	.068	13.33	Impermeable	Impermeable	Horizontal
	1A/774/23.7-24.9	18.6	.078	1.4	21.06/17.27	15.87/13.02	Horizontal
	1A/774/23.7-24.9	20.2	.079	1.44	4.67/3.83	5.79/4.74	Vertical
	8A/774/49.3-50.7	12.2	.085	1.48	8.83/7.24	10.66/8.74	Horizontal
	8A/774/49.3-50.7	10.9	.085	1.51	38.87/31.87	41.86/34.32	Vertical
BEDROCK	12A/Bedrock/38.5-38.7	Not sampled	(Too thin)				
	12B/Bedrock/38.7-39.0	Not sampled	(Too thin)				
	12E/Bedrock/40.4-40.5	Not sampled	(Too thin)				
	12C/Bedrock/39.0-40.0	71.8	.04	2.04	Impermeable	Impermeable	Horizontal
	12D/Bedrock/40.0-40.4	45.5	.066	1.64	Impermeable	Impermeable	Horizontal
SOUTH WELL	2A/784/2.2-2.7	30.3	(wax contaminated)		43.39/35.58	33.49/27.46	Vertical
	2B/784/1.5-2.2	8.3	.078	1.27	3.03/2.48	2.62/4.15	Horizontal
	2B/784/1.5-2.2	15.7	.077	1.81	54.91/45.03	41.49/34.02	Vertical
	2A/784/2.2-2.7	32.8	.07	1.36	18.47/15.15	61.59/50.51	Horizontal
	9A/784/2.5-3.3	40.8	.06	1.4	1.87/1.53	1.31/1.07	Horizontal
	9B/784/3.3-3.6	34	.07	1.36	.74/.61	1.28/1.05	Horizontal
	6A/784/3.6-5.0	17	.085	1.5	1.12/.92	.575/.472	Horizontal
	6A/784/3.6-5.0	35.8	.073	1.39	.956/.984	.991/.813	Vertical
	11A/784/60.0-60.4		Clay		Impermeable	Impermeable	
	11C/784/60.5-61.4		Clay		Impermeable	Impermeable	
	11B/784/60.4-60.5	Not sampled	(Too thin)				

plays a vital part in the accuracy and acceptability of field pump test data. In these particular tests, stainless steel well screens having slot size 8 and 14 were used because it was known that the materials to be tested were very fine. Actually, the openings of size 14 screens were too large, but due to economic considerations, it was necessary to use those screens which were used in other areas. Because the materials in the Site 13 alluvium contained a large percentage of silt size material and some cohesive clay materials, well completion was difficult.

The low range of permeabilities derived from the laboratory permeameter tests does correspond to the very low range of permeabilities derived by the field pump testing methods used. The results of the pump tests are compared with the laboratory permeabilities in Table 3. The method used in the Site 13 study was the Jacob's modification of a non-equilibrium method since it was not possible to maintain constant pumping rates over long periods of time in these tests. Drawdown versus log time curves developed from the Site 13 pump tests are shown in Figures 10 and 11. Using these two methods of determining the coefficient of permeability, acceptable values of permeability were assigned to the sediments at the selected pump test sites and were used as input data to the mathematical model.

Permeability Distribution

The results of both pump test and laboratory analyses are presented in the extension of the permeability versus grain size distribution envelope in Figure 12. A grouping of permeabilities from pump test and laboratory analysis of samples taken during rotary drilling operations were done using the methods developed by Kent (7), for materials in

TABLE III

SUMMARY OF PUMP TEST ANALYSES

	K gpd/ft^2 x 0.161[1] =		K ft/day	S
North Wells				
777	13.2		2.12	0.00200
776	11.8		1.89	0.00084
780	14.4		2.31	0.00018
		Average	2.10	0.00100
South Wells				
789	18.9		3.04	0.00156
790	1.1		0.17	0.00024
786	1.9		0.30	0.00026
785	1.3		0.21	0.00024
		Average	0.93	0.00057

Average of all observation wells, K = 1.43 ft/day

Average of all observation wells, S = 0.00076

1/ Source: R. K. Linsley, M. A. Kohler, and J. L. Paulhus, Applied Hydrology, pp. 666, 1949.

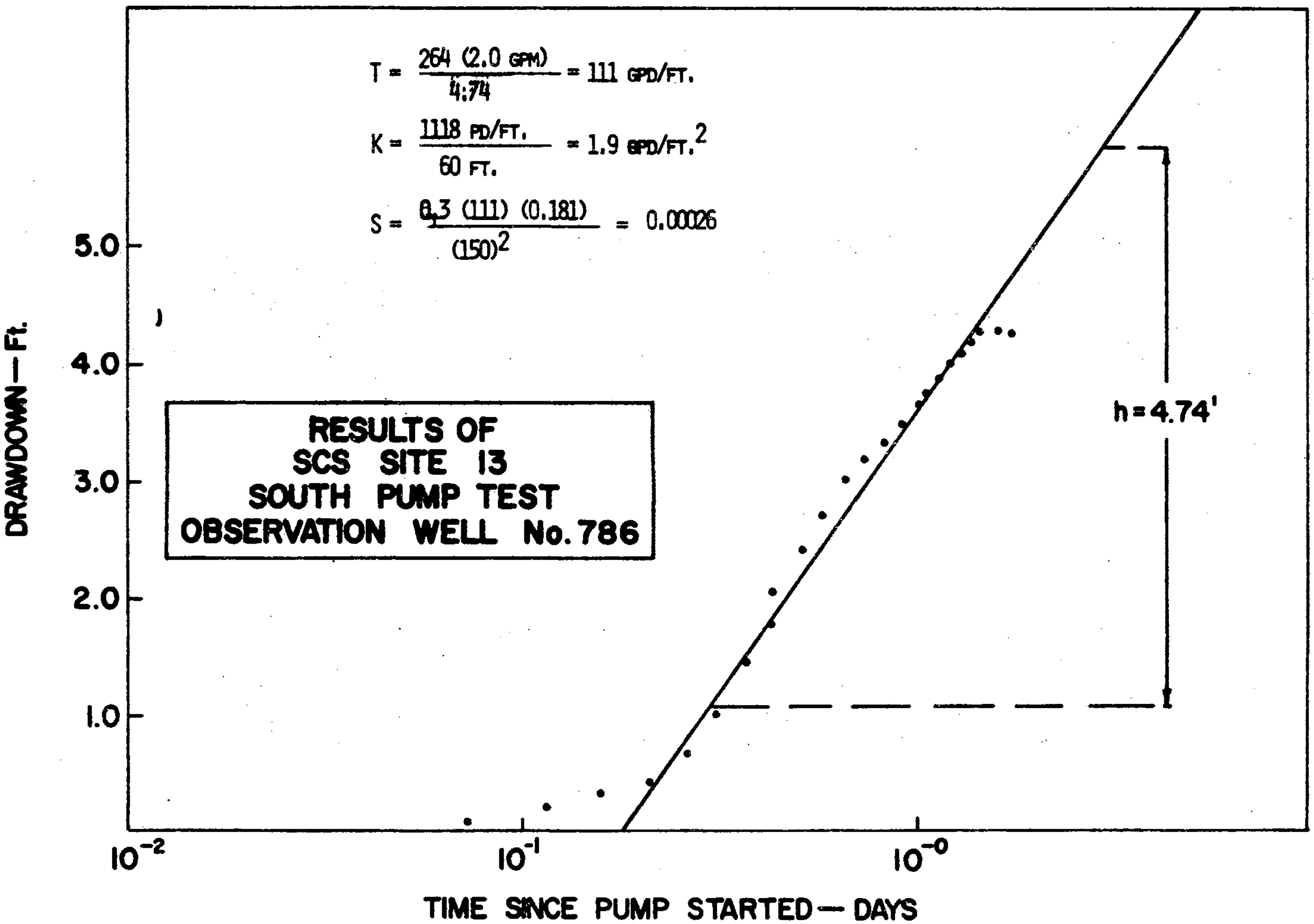
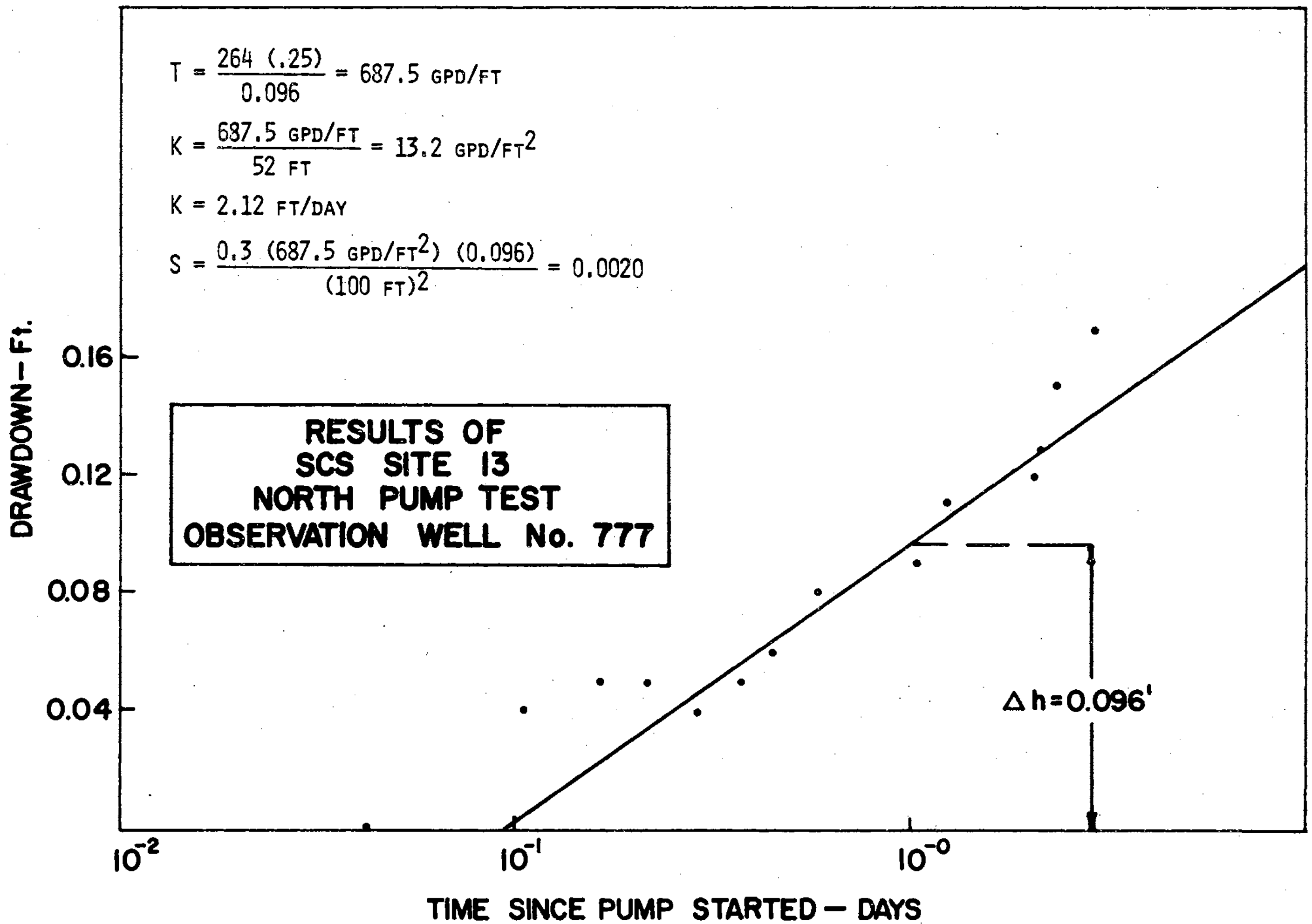

T = 264 (2.0 GPM) / 4.74 = 111 GPD/FT.
K = 1118 PD/FT. / 60 FT. = 1.9 GPD/FT.2
S = 0.3 (111) (0.181) / (150)2 = 0.00026
RESULTS OF
SCS SITE 13
SOUTH PUMP TEST
OBSERVATION WELL No. 786
h = 4.74'
DRAWDOWN — Ft.
5.0
4.0
3.0
2.0
1.0
10-2
10-1
10-0
TIME SINCE PUMP STARTED — DAYS

FIGURE 10



T = 264 (.25) / 0.096 = 687.5 GPD/FT
K = 687.5 GPD/FT / 52 FT = 13.2 GPD/FT2
K = 2.12 FT/DAY
S = 0.3 (687.5 GPD/FT2) (0.096) / (100 FT)2 = 0.0020
RESULTS OF
SCS SITE 13
NORTH PUMP TEST
OBSERVATION WELL No. 777
DRAWDOWN – Ft.
0.16
0.12
0.08
0.04
Δ h=0.096'
10-2
10-1
10-0
TIME SINCE PUMP STARTED — DAYS

FIGURE 11

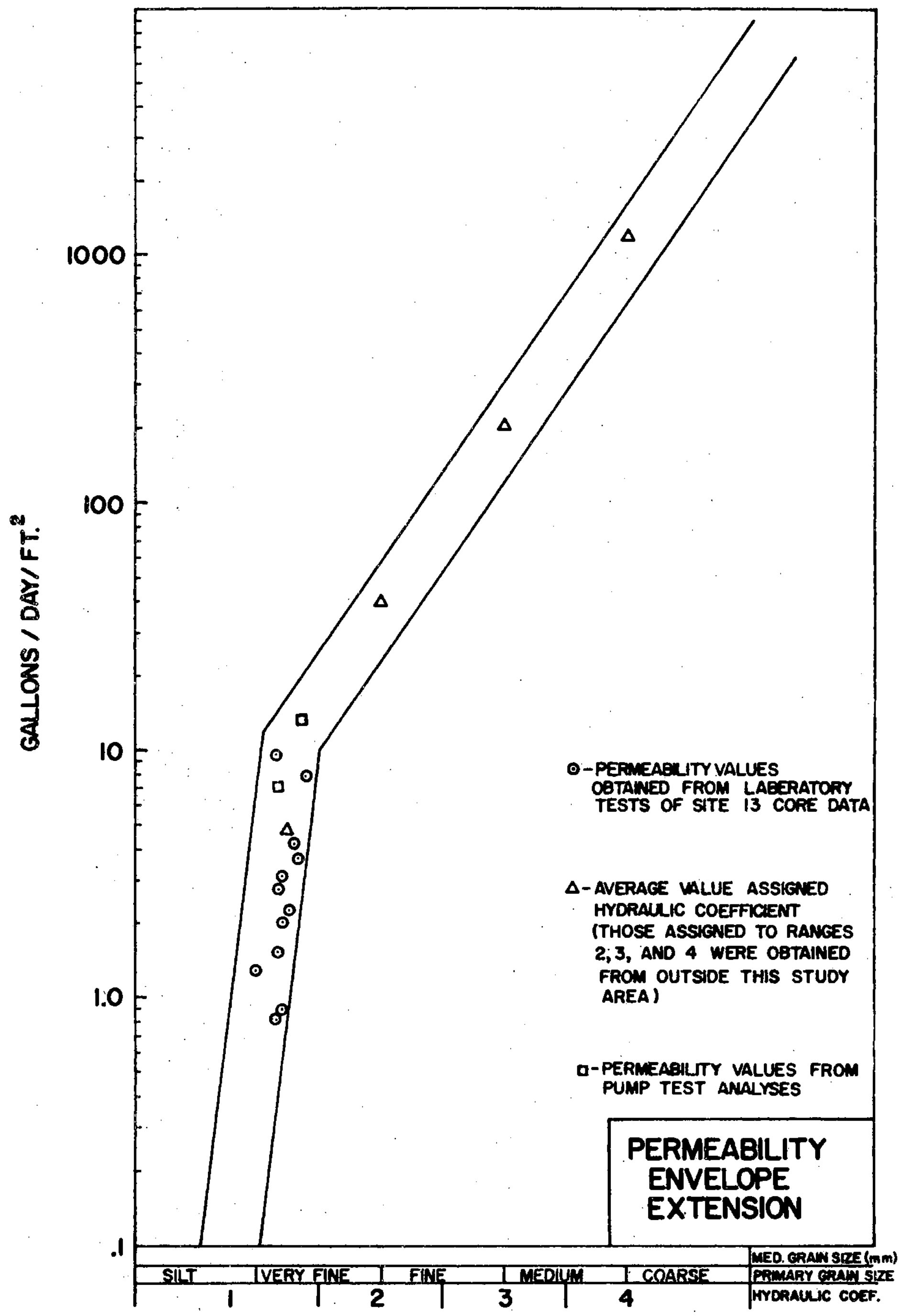

GALLONS / DAY / FT.²
1000
100
10
1.0
.1
⊙ - PERMEABILITY VALUES OBTAINED FROM LABERATORY TESTS OF SITE 13 CORE DATA
△ - AVERAGE VALUE ASSIGNED HYDRAULIC COEFFICIENT (THOSE ASSIGNED TO RANGES 2, 3, AND 4 WERE OBTAINED FROM OUTSIDE THIS STUDY AREA)
□ - PERMEABILITY VALUES FROM PUMP TEST ANALYSES
PERMEABILITY ENVELOPE EXTENSION
MED. GRAIN SIZE (mm)
SILT
VERY FINE
FINE
MEDIUM
COARSE
PRIMARY GRAIN SIZE
1
2
3
4
HYDRAULIC COEF.

FIGURE 12

lower Sugar Creek Valley at the Curly Chief pump test site. The method assigned permeability values to five ranges of grain-size distribution. Ranges 1 through 4 are shown in Figure 12 and range 5 is an estimated value for sections of the drill hole where no sample was recovered. The permeability value for the range 5 materials was 580 gallons per day per square foot, or 77 feet per day. The materials sampled at Site 13 were primarily silt to very fine sand and were in permeability range 1, which ranges from 0.5 to 1.5 feet per day. A contour map of both the measured and mathematically approximated permeabilities was superimposed over a hand drawn flow net of the Site 13 flow system. The average permeability from the contour map was assigned at the center of the individual flow-tube element. These values were then used to compute the travel time and discharge along the flow tubes.

The data obtained at the Site 13 pump test sites were used to extend the permeability envelope into the very fine sand and silt ranges. There were a total of 56 samples used in the laboratory determination of permeabilities at the site.

A single core sample was taken from the Rush Springs Formation on the west side of the valley. However, laboratory permeameter tests of the material in this core showed the section sampled to be impermeable. Because earlier tests in the Rush Springs Formation resulted in permeabilities of about 35 gallons per day per square foot, it was concluded that the single core was not representative of the study area (1) (30). Therefore, the higher value permeability was used for those flow tubes that fell within the Rush Springs Formation.

An isometric diagram of the several wells at the site was made to better understand the permeability distribution in the area. This representation of subsurface data is shown in Figure 13. This information was used for comparison with the computer simulated permeability distribution.

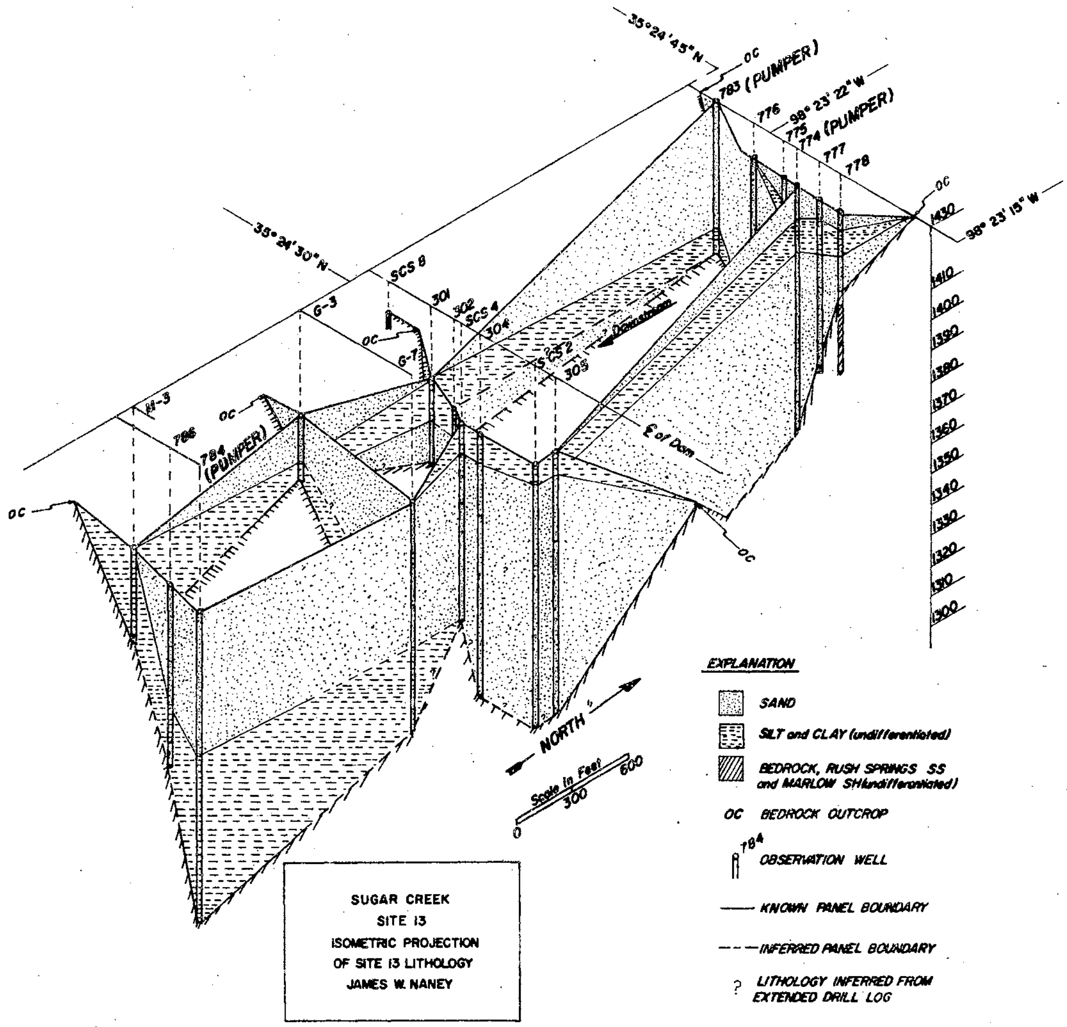

35°24'45"N
35°24'30"N
98°23'22"W
98°23'15"W
783 (PUMPER)
774 (PUMPER)
784 (PUMPER)
SCS 8
SCS 4
SCS 2
G-3
G-7
H-3
Downstream
℄ of Dam
NORTH
Scale in Feet
0
300
600
EXPLANATION
SAND
SILT and CLAY (undifferentiated)
BEDROCK, RUSH SPRINGS SS and MARLOW SH(undifferentiated)
OC BEDROCK OUTCROP
OBSERVATION WELL
KNOWN PANEL BOUNDARY
INFERRED PANEL BOUNDARY
? LITHOLOGY INFERRED FROM EXTENDED DRILL LOG
SUGAR CREEK
SITE 13
ISOMETRIC PROJECTION
OF SITE 13 LITHOLOGY
JAMES W. NANEY

FIGURE 13

CHAPTER IV

MATHEMATICAL MODELS

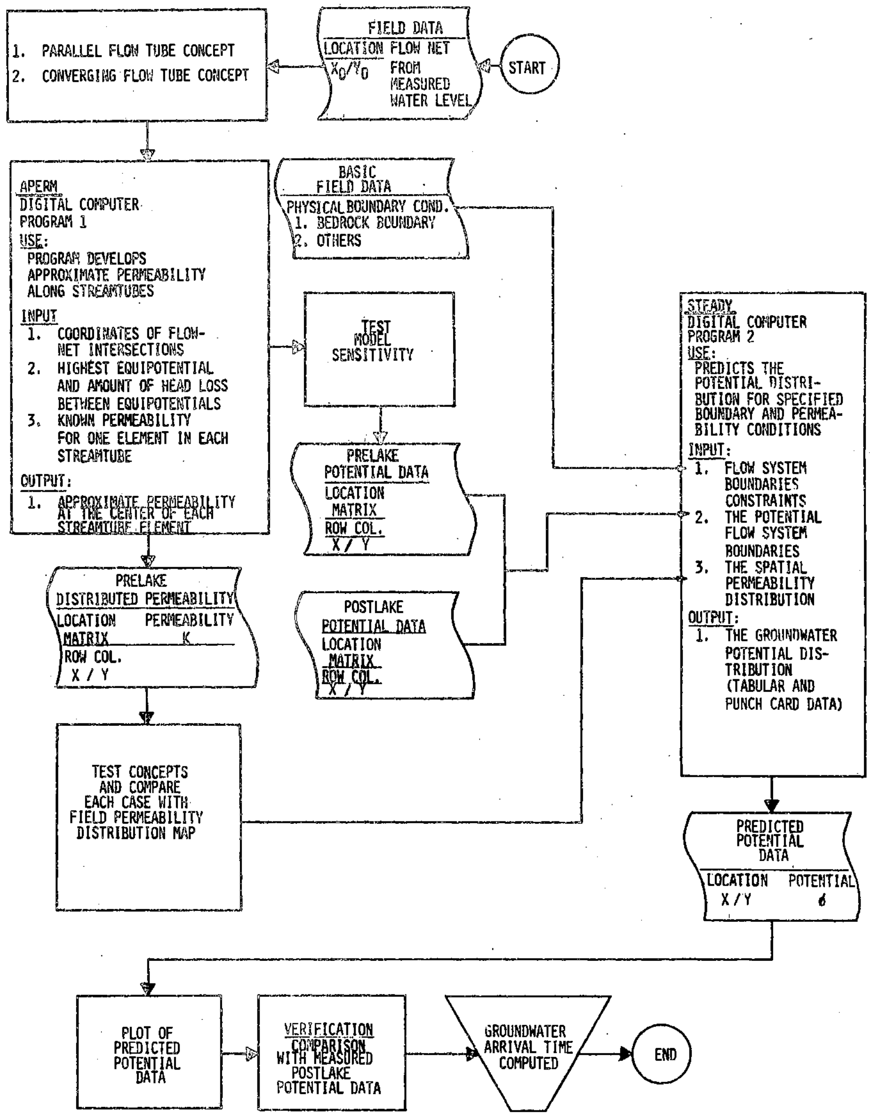
Model Selection and Adaptation

Mathematical models by Jepson (6), Knowles (8), Reddell (21), Szalay (26), and Nelson (14) were reviewed prior to the selection of the appropriate model for this study.

The model selected for this study was one developed by Nelson (14) under the auspices of the U. S. Atomic Energy Commission and is used to distribute the permeabilities over an area and to develop the time of travel for ground-water flow (10) (12) (16) (17). Nelson's steady state flow model consists of three submodels which have the following functions: STREAM is used to develop the equation of the ground-water flow lines; GENORO is a surface-fitting routine which distributes permeability from one known point over the area being modeled by an energy dissipating method; and STEADY calculates hydraulic potentials for conditions derived from STREAM and GENORO. A flow diagram used to show the concept and development of the adaptation of the model to the study at Site 13 is shown in Figure 14.

STEADY is used to solve the partial differential equations governing ground-water flow using the method of finite differences. Both forward and backward finite differencing is done at the node points. The Gauss-Sidel method of over relaxation for surrounding node

SYSTEM FOR PREDICTING GROUNDWATER FLOW RATES 1/



FLOW CHART OF GROUNDWATER SYSTEM MODEL

1/ SOURCE: R. W. NELSON, A COMPUTER SYSTEM FOR THE ANALYSIS OF FLOW AND WATER QUALITY IN LARGE HETEROGENEOUS GROUND WATER BASINS, PP. A-12, 1967

FIGURE 14

points is used to speed convergence between nodes. Successive overrelaxation techniques are used to speed convergence in the matrix. A detailed description of the model STEADY along with the theoretical development of the model and a complete description of the computer codes by Risenaur (24) appear in the literature (14). In order to apply STEADY, initial potential data must be input at each node and a value of permeability must be known for each node; i.e., point of intersection of a set of equispaced grid lines which is superimposed over the area to be modeled. The distance between nodes used in this study was 3/4 inch and the modeling was done in the two dimensional XY plane. There were 20 columns (X) and 24 rows (Y) forming a 480-node matrix of grid points which were superimposed over the study area.

STREAM, a second submodel, was used by Nelson to obtain the equations of the stream lines for the initial potential conditions, and GENORO, a third submodel developed by Oster (19) was used by Nelson to fit a surface to the equations generated by the submodel STREAM. The flow net developed for this data was developed by a hand approximation method described by Nelson (17). The flow nets used in this study are utilitarian; i.e., equal flow volume in each element is not required. Because STREAM was not well documented and because difficulties were encountered in adapting GENORO to the IBM 360-50 computer, an alternate method was used for obtaining input data for STEADY as it was adapted for the IBM 360-50 and used in this modeling effort.

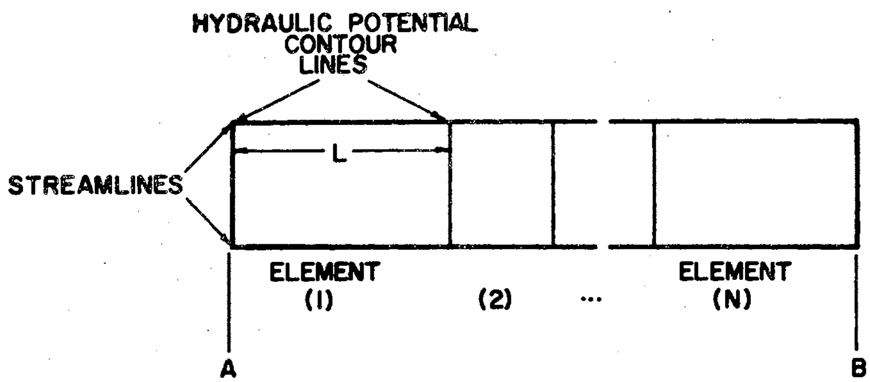
To replace STREAM, a flow net was developed manually. Ground-water levels in the study area were plotted for February 19, 1963 before the earthen dam was constructed. Hydraulic potentials were contoured for these data and a flow net was developed as discussed by DeWiest (3), Todd (29), and Walton (31).

A method of approximating mathematically and distributing saturated permeabilities across the region was developed to take the place of GENORO. The method appears in Appendix A (APERM) as written for the IBM 360-50 by Seely (27). The permeability at the center of each flow-tube element, which is that area within the flow net bounded by two consecutive potential contours and two consecutive streamlines, (Figure 15) is approximated. The length to width ratio of the flow-tube element and the resultant vector, from the intersection of the streamline and hydraulic potential contour line to the central point of each element, is used in the digital computer program (Appendix A) which distributes the permeabilities. APERM requires a known permeability value in one element of each streamtube, whereas GENORO requires only one known permeability value in the entire region being modeled.

Although the manually drawn flow net and the method, APERM, used to distribute permeability values are considered to be more of an approximation than the submodels STREAM and GENORO used by Nelson, they were considered a valid approach to use for the preliminary evaluation of the data from Site 13. In this modeling effort, the input for STEADY came from the permeability distributions developed using APERM, and from boundary conditions and potential surfaces measured at the site. The version of STEADY used has been adapted for use on the IBM 360-50 computer and the program is listed in Appendix B.

Hydraulic Potential Surface Mapping

The mapping of the hydraulic potential surface in the study area served three purposes. First, the study area was being modeled only



DESIGN OF A FLOW TUBE
SHOWING ELEMENT CONSTRUCTION

FIGURE 15

within the saturated zone; therefore, the potential measurements serve as an upper boundary to the system (Figure 14). The second purpose was that the predicted potential surface resulting from the effects of a dam must be mapped based on the potential surface which existed before the dam was constructed. The measured equipotential and flow-tube net for the "Before" case is shown in Figure 16. The third purpose was to verify the model predictions of the potential surface by developing a measured potential surface map representing the water table after the dam was built.

Two dates were selected for mapping the potential surface in this study. February 19, 1963, the "Before" case, was selected prior to any construction of the dam in order to give the natural conditions of the flow regime before the manmade structure was imposed upon the ground-water system. The structure of Site 13 was completed in January 1964 and the "After" date used in this study was August 13, 1973. At this time, both pump test sites had been installed and pump tests were completed at the site.

Boundary Conditions

Two different boundary conditions were considered for ground-water flow in the area of Site 13. The first can be characterized by ground water flowing parallel to the major axis of the valley within the alluvium. This boundary condition is referred to as "Concept 1" in Figure 14 and results in a series of closely spaced parallel flow tubes which represent flow toward Sugar Creek several hundred feet downstream from the Site 13 location (Figure 17).

The data from this conceptual approach (Concept 1, Figure 14) was

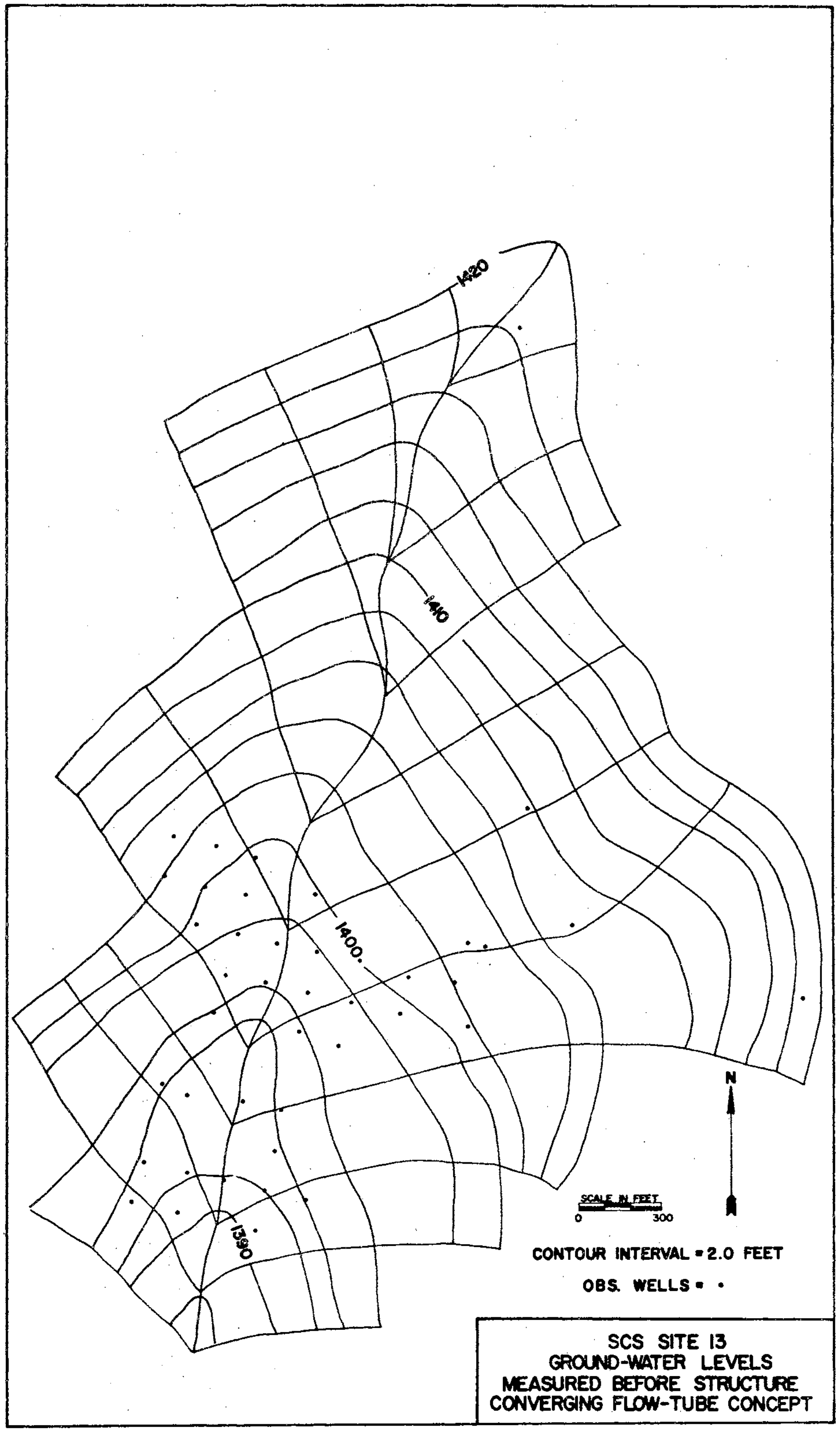

1420
1410
1400
1390
SCALE IN FEET
0
300
N
CONTOUR INTERVAL = 2.0 FEET
OBS. WELLS = •
SCS SITE 13
GROUND-WATER LEVELS
MEASURED BEFORE STRUCTURE
CONVERGING FLOW-TUBE CONCEPT

FIGURE 16

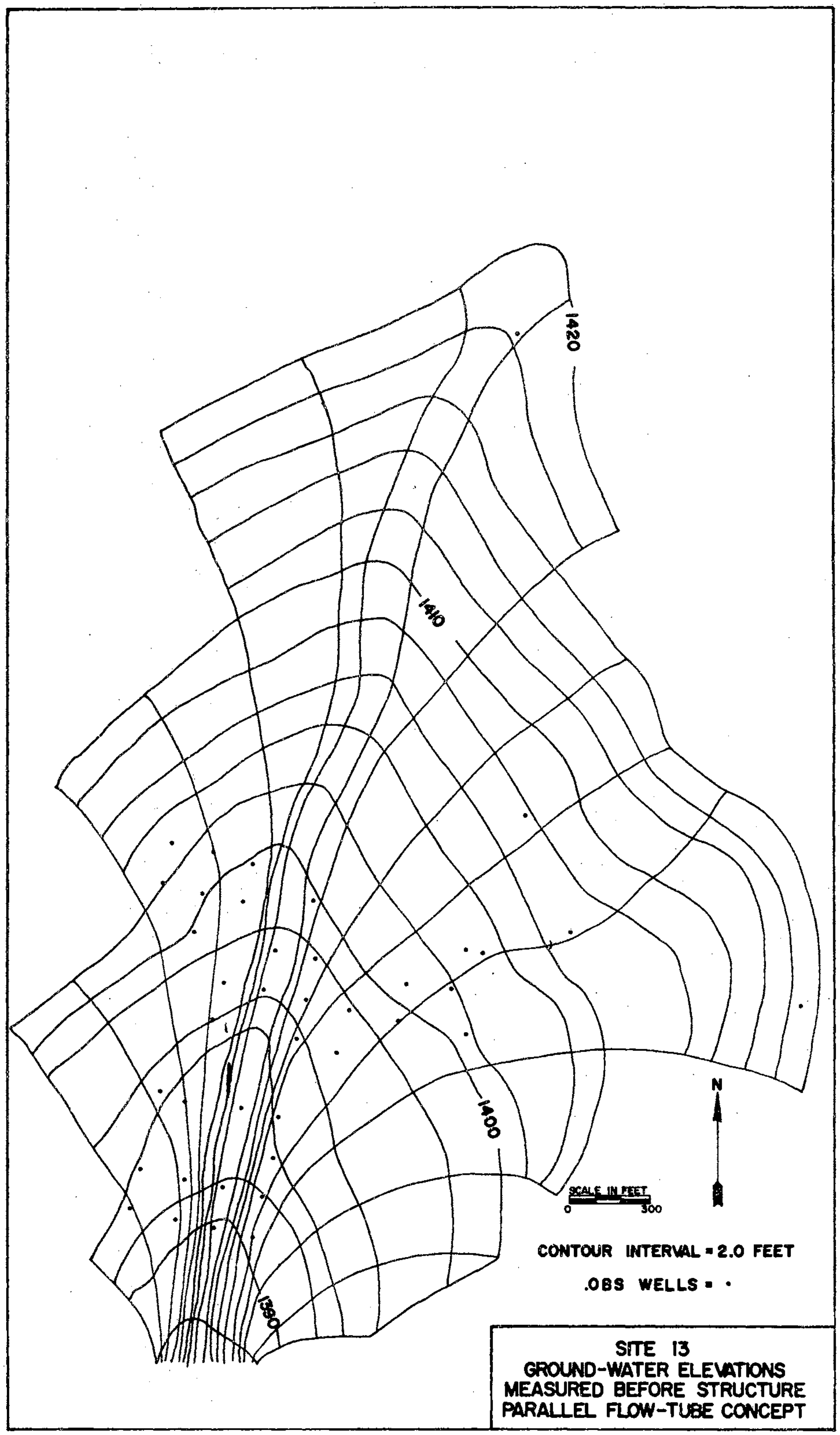
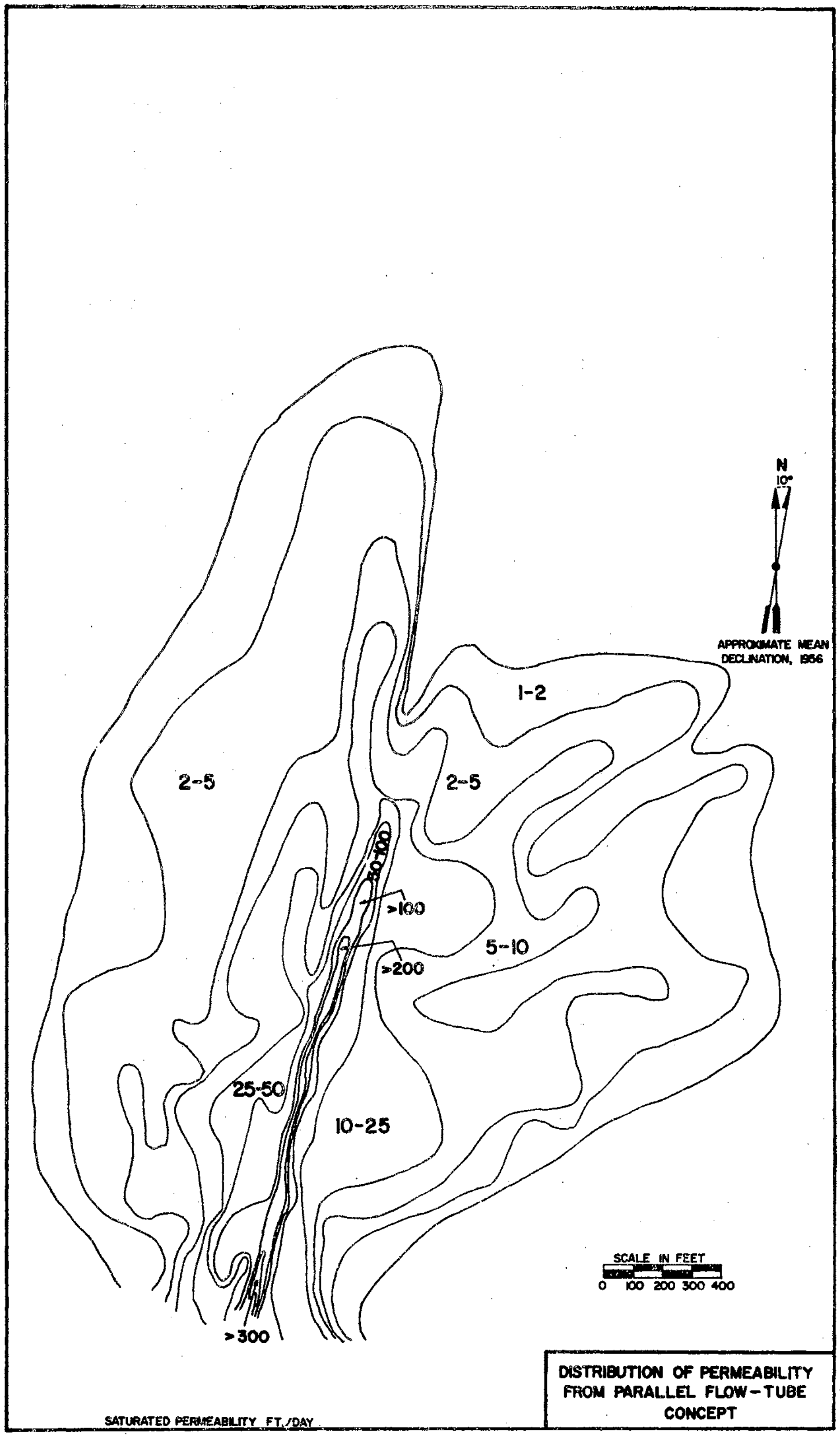

1420
1410
1400
1390
N
SCALE IN FEET
0
300
CONTOUR INTERVAL = 2.0 FEET
.OBS WELLS = ·
SITE 13
GROUND-WATER ELEVATIONS
MEASURED BEFORE STRUCTURE
PARALLEL FLOW-TUBE CONCEPT

FIGURE 17

plotted, digitized and used to develop a map of mathematically approximated permeabilities which appear in Figure 18. This permeability distribution map was compared to a map of the distribution of permeabilities which was measured in the field by pump test methods and by laboratory analyses of the cored materials and is shown in Figure 19. The mathematically approximated permeabilities are distributed along the flow tubes from one point of known permeability. The shape of each flow tube element, length to width ratio, determines the value of permeability necessary to cause the specified drop in hydraulic potential across the element. Using the parallel flow concept, permeability values as much as 300 times greater than measured permeability values were generated down the center of the valley. Therefore, a second boundary concept of ground-water flow was considered using the model.

The second boundary concept for ground-water flow was developed assuming that ground water flows from either side of the valley and converges at the major axis of the alluvium in the valley. This second or converging flow-tube concept is also indicated in Figure 14. As with the first concept, a flow net assuming converging flow was developed and digitized. A mathematically distributed permeability map (Figure 20) was constructed and this mapping of permeability was again compared to the permeability map developed from field and laboratory data (Figure 19). The results of comparing these permeability data are shown in Figures 21 and 22.

The second or converging flow concept provided a mathematical distribution of permeability which more nearly represented field measured permeabilities. Therefore, the converging flow boundary concept was assumed to be more realistic and was subsequently used to model the



N
10°
APPROXIMATE MEAN DECLINATION, 1956
1-2
2-5
2-5
50-100
>100
>200
5-10
25-50
10-25
>300
SCALE IN FEET
0 100 200 300 400
DISTRIBUTION OF PERMEABILITY FROM PARALLEL FLOW-TUBE CONCEPT
SATURATED PERMEABILITY FT./DAY

FIGURE 18

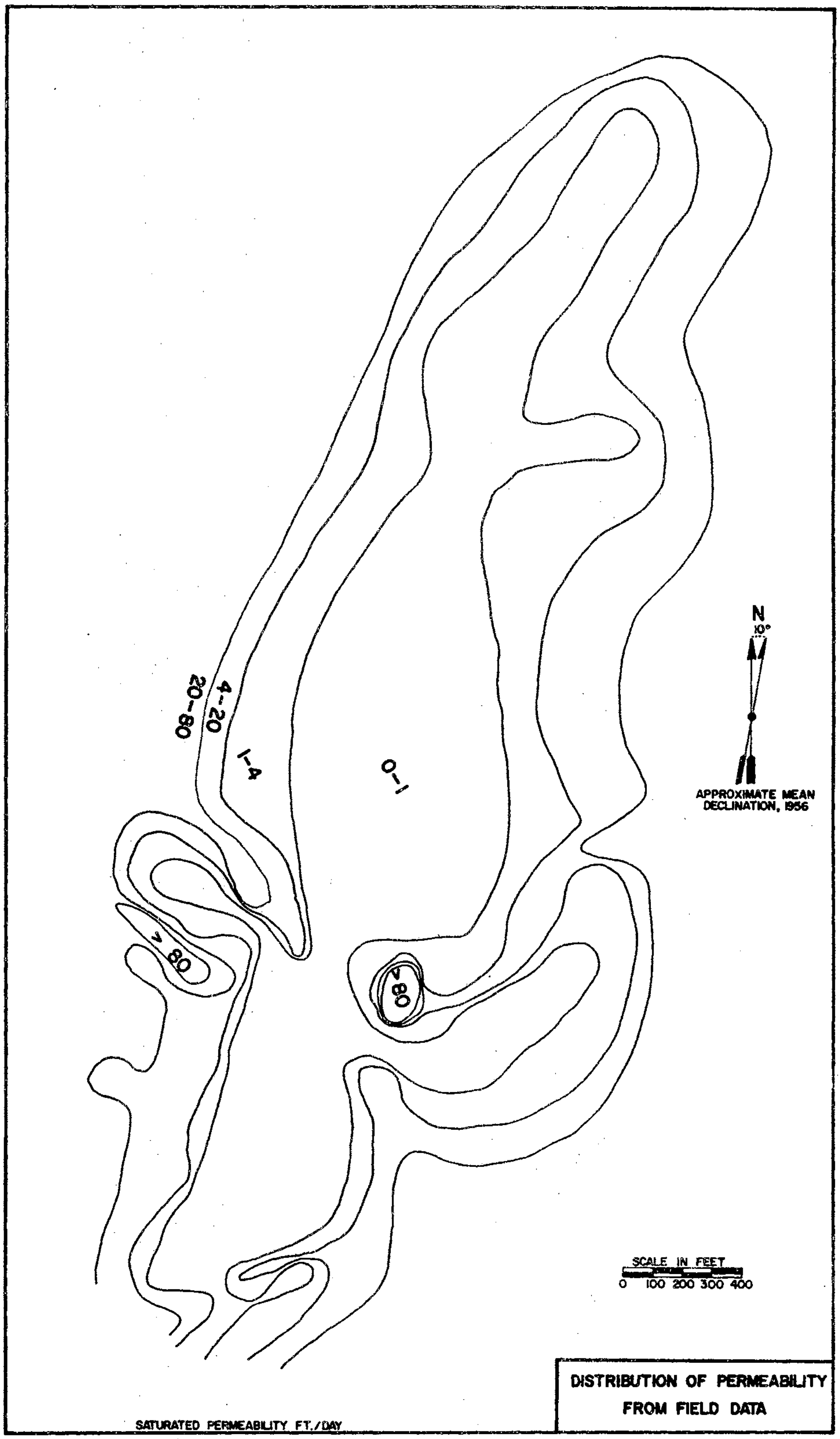

4-20
20-80
1-4
0-1
>80
>80
N
10°
APPROXIMATE MEAN DECLINATION, 1956
SCALE IN FEET
0 100 200 300 400
DISTRIBUTION OF PERMEABILITY FROM FIELD DATA
SATURATED PERMEABILITY FT./DAY

FIGURE 19

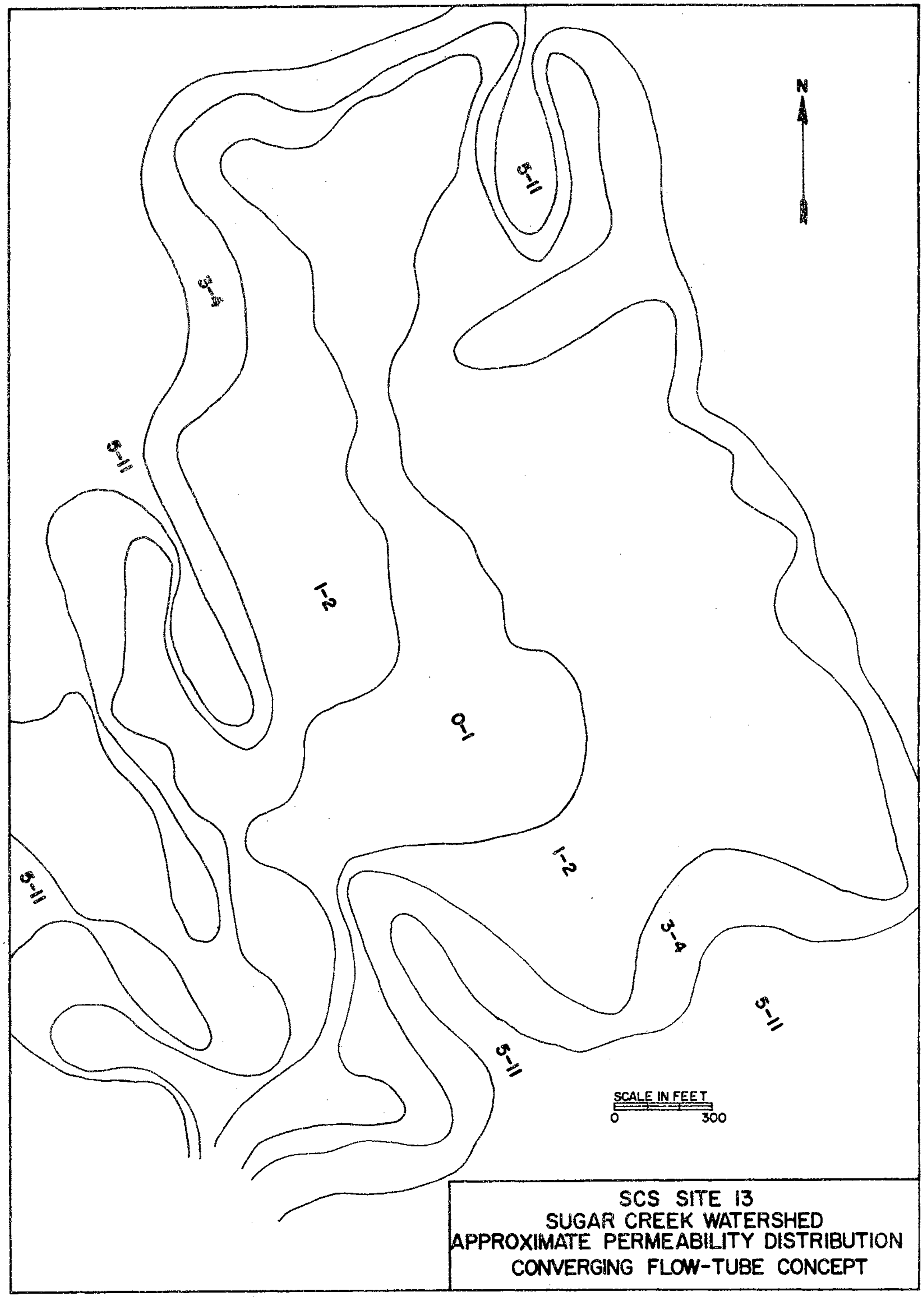

N
5-11
3-4
5-11
1-2
0-1
1-2
3-4
5-11
5-11
5-11
SCALE IN FEET
0
300
SCS SITE 13
SUGAR CREEK WATERSHED
APPROXIMATE PERMEABILITY DISTRIBUTION
CONVERGING FLOW-TUBE CONCEPT

FIGURE 20

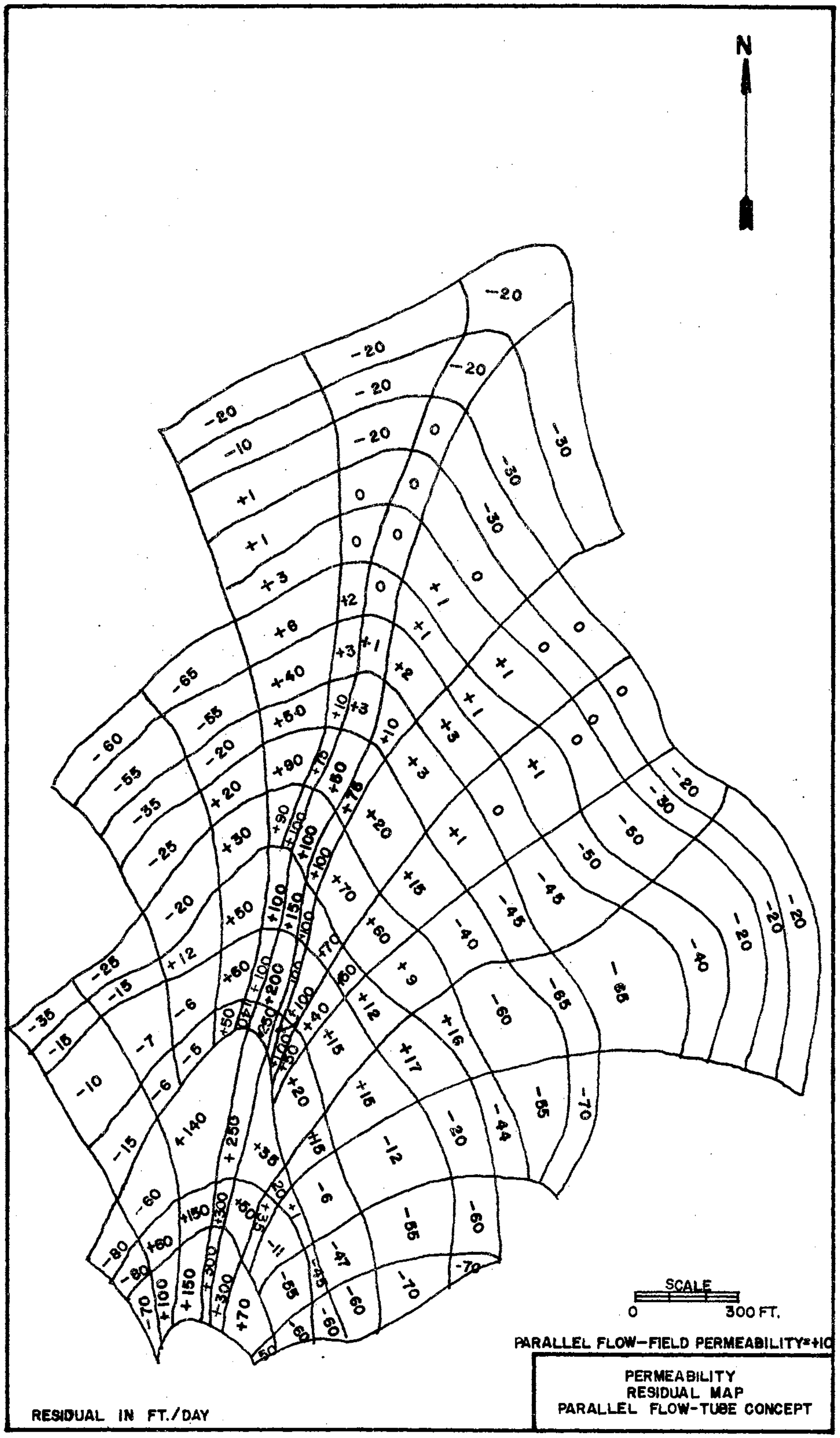

N
SCALE
0
300 FT.
PARALLEL FLOW—FIELD PERMEABILITY=+10
PERMEABILITY
RESIDUAL MAP
PARALLEL FLOW-TUBE CONCEPT
RESIDUAL IN FT./DAY

FIGURE 21

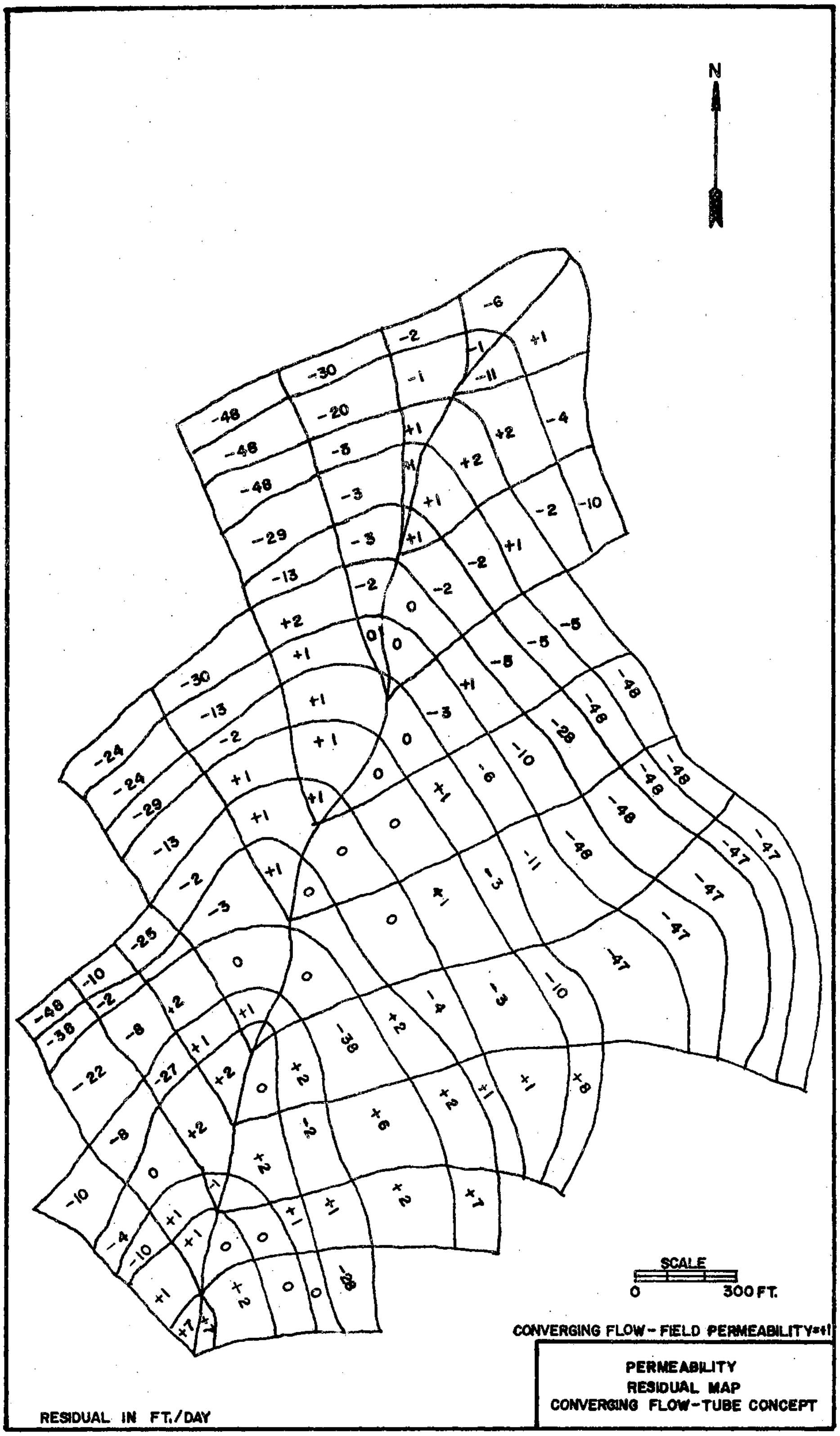

N
SCALE
0 300 FT.
CONVERGING FLOW - FIELD PERMEABILITY=41
PERMEABILITY
RESIDUAL MAP
CONVERGING FLOW-TUBE CONCEPT
RESIDUAL IN FT./DAY

FIGURE 22

ground-water flow at Site 13 after the structure filled with water. Distribution matrices of the predicted and measured saturated permeability values are presented in Figures 23 and 24, respectively.

Model Sensitivity

The accurate modeling of a ground-water flow system depends in large part on the correct selection of the number of control points used. In order to determine the minimum number of points which would adequately describe the system, a series of hydraulic potential maps was developed which used 0, 15, and 25 fixed valued points in the interior region of the Site 13 area. These maps are presented in Figures 25, 26, and 27, respectively. It does not appear that increasing numbers of interior fixed nodes significantly improve the output of the model. The model run with no fixed interior points was controlled only by those nodes which represented the lake surface and drain ditch bottom at the toe of the dam. Because no internal node points were required to improve the output, it was decided to use that output to represent predicted ground-water conditions after the structure filled with water.

Model Verification

The output from the model was verified by comparing the contour map of hydraulic potentials for the case without additional interior fixed points shown in Figure 25 with the contour map of hydraulic potentials developed from field water-level measurements after the structure filled with water. The date chosen was August 13, 1973, when the lake level was at an elevation of 1408.39 feet above mean sea level. The measured hydraulic potentials for that date are shown in Figure 28. The map in

FLOW-TUBE ELEMENT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13
1				3	1	1	1	2	2				
2				4	1	1	1	1	2	2			
3				3	1	1	1	1	2	2			
4				2	1	1	1	1	2	2	2		
5				2	1	1	1	1	2	2	3		
6				2	1	1	1	2	2	3	3		
7	5	11	7	2	1	2		2	2	7	7	7	
8	5	9	4	2	2	2		2	3	3	2	2	4
9	5	2	4	2	2				2	2	1	1	3
10	1	2	3	2	2				2	2	3	1	2
11	1	1	1								3	2	1

FLOW-TUBE NO.

Flow-tube elements numbered from highest to lowest hydraulic potential contour

Permeability is in ft/day

PREDICTED SATURATED PERMEABILITY AT FLOW-TUBE ELEMENT CENTER

Figure 23

FLOW-TUBE ELEMENT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13
1				20	30	1	1	7	3	50			
2				10	16	1	3	7	2	8	30	50	
3				30	16	1	5	6	1	3	30	50	
4				30	12	2	8	6	1	2	30	50	
5	50	50	50	30	8	2	47	7	1	2	30	50	50
6	50	50	50	15	4	3	80	38	1	2	30	50	50
7	50	30	30	10	1	5	80	30	2	4	30	30	30
8	10	10	30	5	1				1	1	2	8	5
9	3	10	10	1	1				1	1	1	2	2
10	2	1	1	1						1	1	1	1
11	2	1	1								1	1	1

FLOW-TUBE NO.

Flow-tube elements numbered from highest to lowest hydraulic potential contour

Permeability is in ft/day

MEASURED SATURATED PERMEABILITY AT THE FLOW-TUBE ELEMENT CENTER

Figure 24

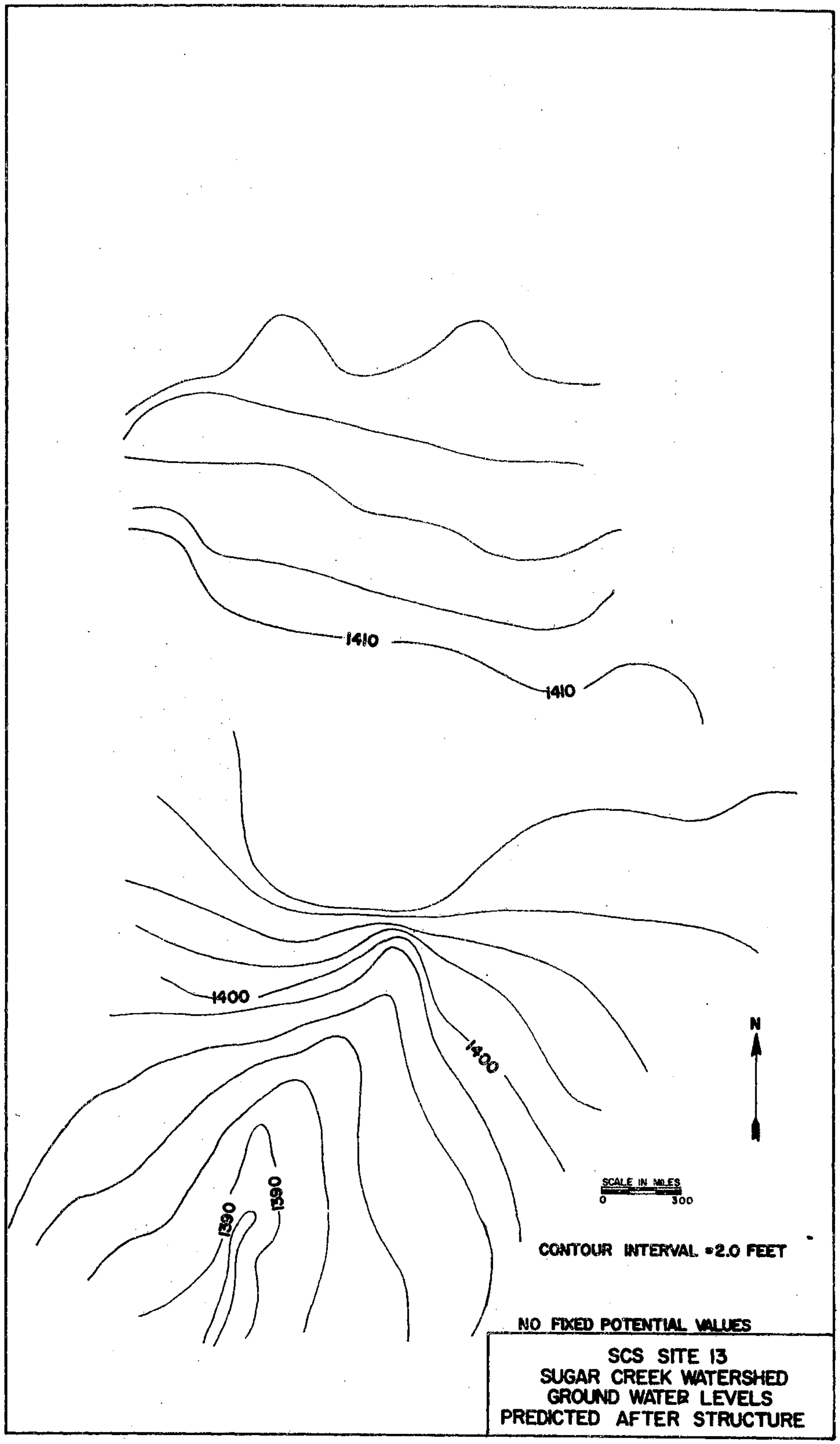

1410
1410
1400
1400
1390
1390
N
SCALE IN MILES
0
300
CONTOUR INTERVAL =2.0 FEET
NO FIXED POTENTIAL VALUES
SCS SITE 13
SUGAR CREEK WATERSHED
GROUND WATER LEVELS
PREDICTED AFTER STRUCTURE

FIGURE 25

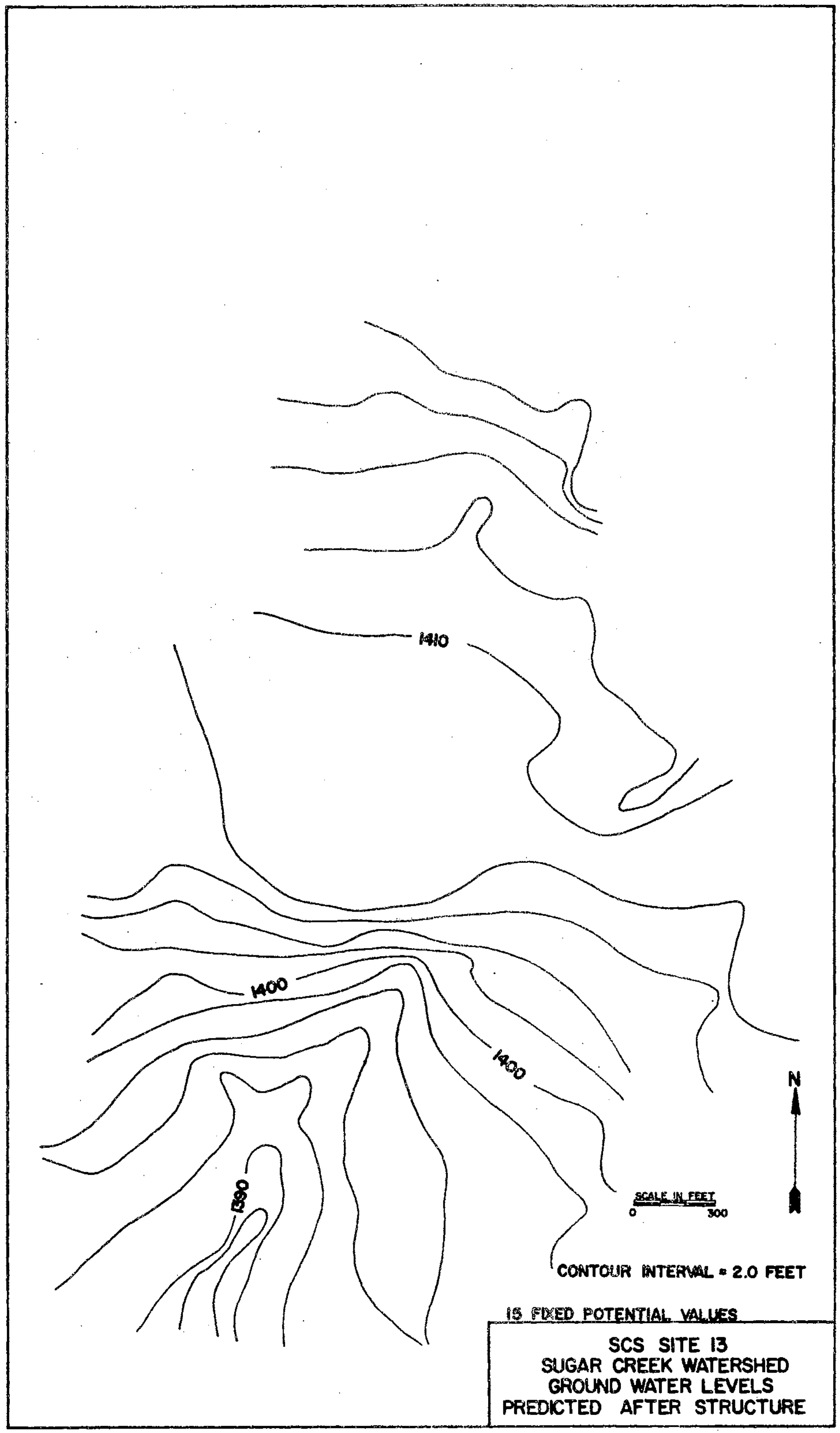

1410
1400
1400
1390
N
SCALE IN FEET
0
300
CONTOUR INTERVAL = 2.0 FEET
15 FIXED POTENTIAL VALUES
SCS SITE 13
SUGAR CREEK WATERSHED
GROUND WATER LEVELS
PREDICTED AFTER STRUCTURE

FIGURE 26

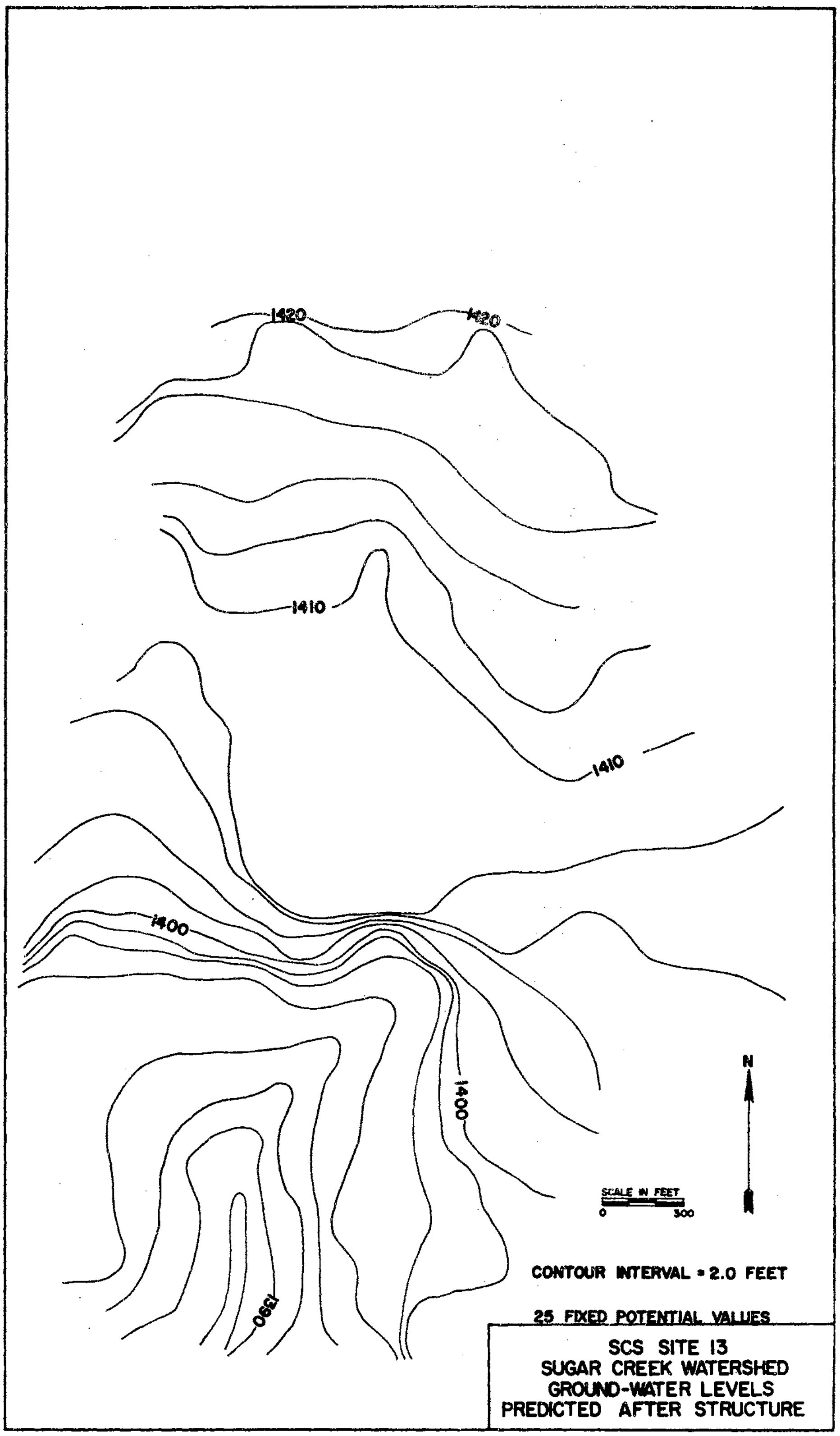

1420
1420
1410
1410
1400
1400
1390
N
SCALE IN FEET
0
300
CONTOUR INTERVAL = 2.0 FEET
25 FIXED POTENTIAL VALUES
SCS SITE 13
SUGAR CREEK WATERSHED
GROUND-WATER LEVELS
PREDICTED AFTER STRUCTURE

FIGURE 27

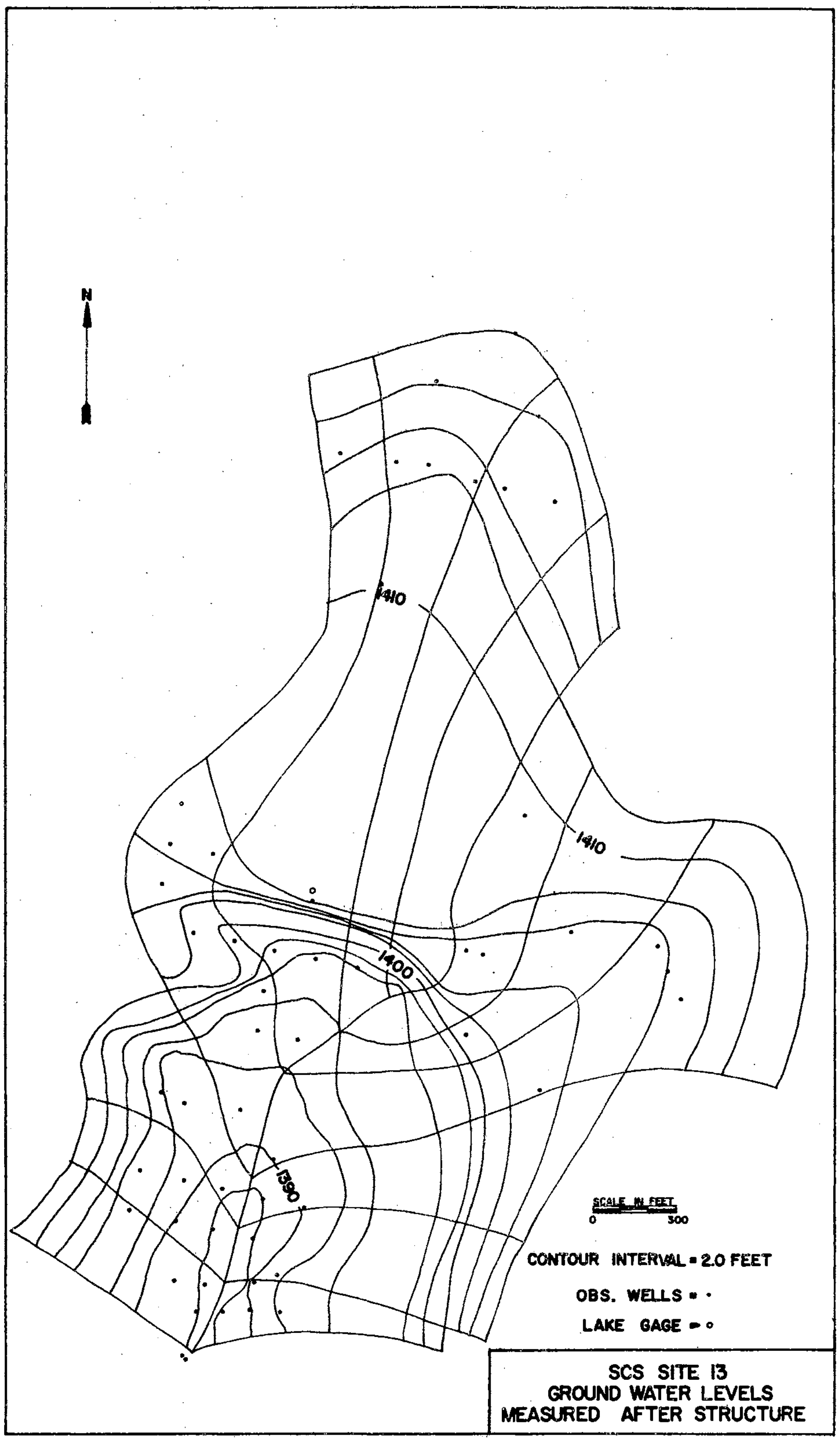

N
1410
1410
1400
1390
SCALE IN FEET
0
300
CONTOUR INTERVAL = 2.0 FEET
OBS. WELLS = •
LAKE GAGE = o
SCS SITE 13
GROUND WATER LEVELS
MEASURED AFTER STRUCTURE

FIGURE 28

Figure 29 shows the difference between predicted and measured hydraulic potential surface at each observation well. Although predicted potentials varied as much as 7 feet from measured potentials at some locations, the overall fit of the predicted potentials was within 2 feet of the observed data.

Ground-Water Travel Time Prediction

In addition to the prediction and verification of the hydraulic potential surface after the reservoir filled, the time of travel for water moving along each flow tube was developed. The results were tested against the time of travel for corresponding flow tubes of the measured flow net for the "After" conditions.

Because Darcian flow is assumed in the theoretical development of Nelson's model, it is valid to extend that assumption to the development of the ground-water travel times. The Darcian flow velocity can be described as

$$V = \frac{Q}{A} \tag{1}$$

where V = velocity of flow in each element (Darcian or discharge velocity), ft/day;

Q = discharge, ft^3/day;

A = area of each element, ft^2.

The Darcian velocity is converted to pore velocity in order to measure the actual rate of chemical transport with the water in the voids themselves. The conversion is made by the following relation:

$$v = \frac{V}{p} \tag{2}$$

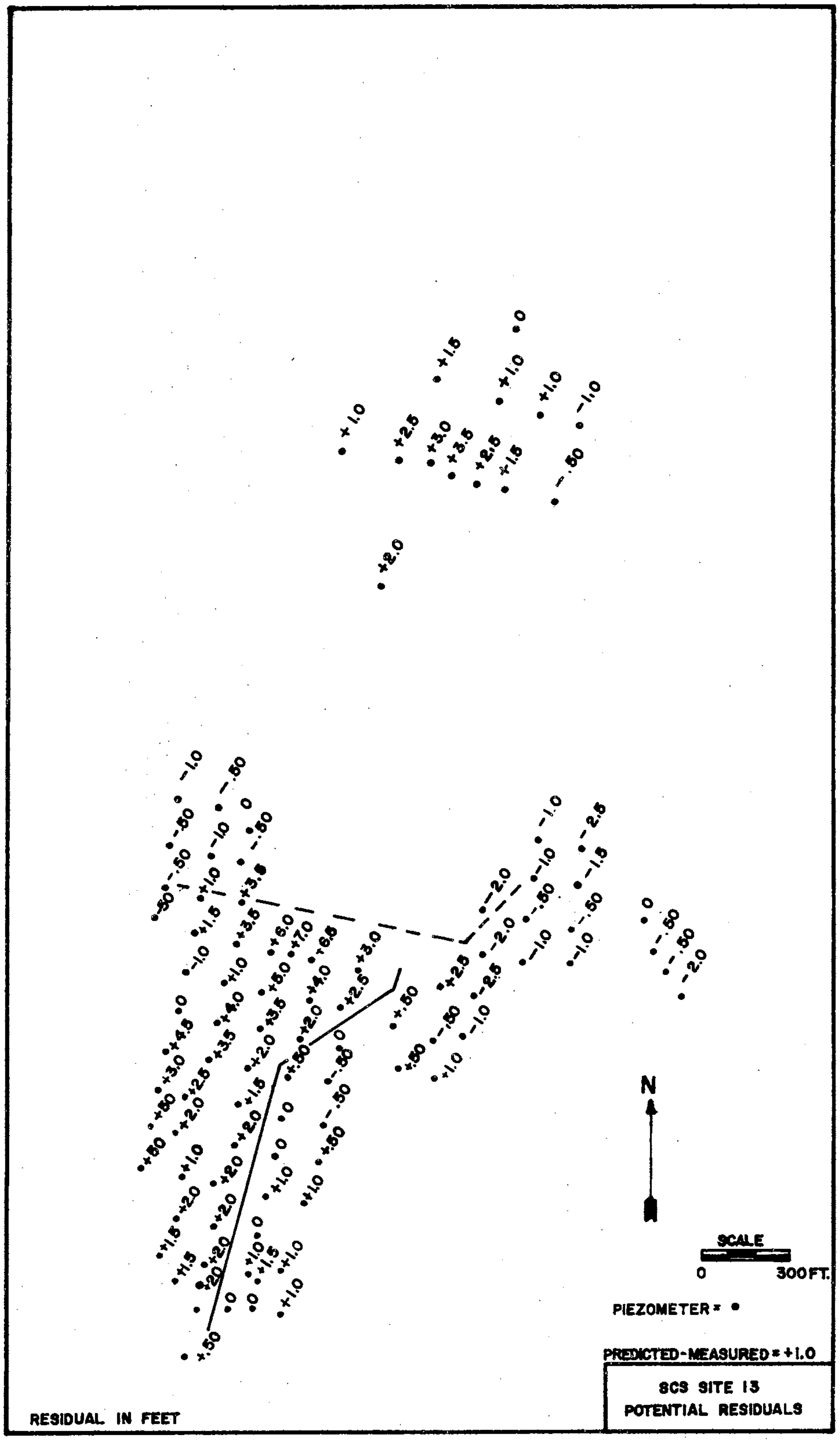

N
SCALE
0 300 FT.
PIEZOMETER = •
PREDICTED-MEASURED = +1.0
SCS SITE 13
POTENTIAL RESIDUALS
RESIDUAL IN FEET

FIGURE 29

where v = pore velocity, ft/day;

p = porosity (measured)[1];

V = Darcian velocity, ft/day.

The method used in this study for developing the time of travel of ground-water flow requires a flow net of hydraulic potential contour lines and stream lines for the flow system being studied.

The pore velocity can be computed using terms which are compatible with the flow net. The formula used to describe the pore velocity using the flow net is:

$$v = \frac{L}{\Delta t} = \frac{-K}{P}\frac{\Delta\phi}{L} \tag{3}$$

where v = pore velocity of flow in each element of the flow tube, ft/day;

K = saturated permeability, ft/day;

$\Delta\phi$ = potential drop across each element, ft;

P = porosity for each element;

L = length across each element, ft;

Δt = time of travel across each element, days.

The equation used to determine the time of travel along any flow tube, between any two points A and B, is developed from Equation 3 and is shown in Figure 30. The travel time is computed for the flow in each flow tube.

To compute travel times along the individual flow tubes using measured and predicted hydraulic potential data, a hydraulic potential

---

[1]Source: Leonard L. Myers, Use of Piezometers in Geologic Investigation, U. S. Soil Conservation Society, 1963.

TRAVEL TIME COMPUTATION

$$\frac{L}{\Delta T} = Q = \frac{-K}{P} \frac{\Delta\phi}{L}$$

$$\Delta T = \frac{P \; L^2}{K \; \Delta\phi}$$

WHERE: ΔT = TRAVEL TIME ACROSS EACH ELEMENT

P = POROSITY

L = DISTANCE ACROSS EACH ELEMENT

K = PERMEABILITY AT ELEMENT CENTER

$\Delta\phi$ = POTENTIAL DROP ACROSS ELEMENT

THUS:

$$T = \sum_{i=1}^{N} \frac{P_i \; L_i^2}{K_i \; \Delta\phi_i}$$

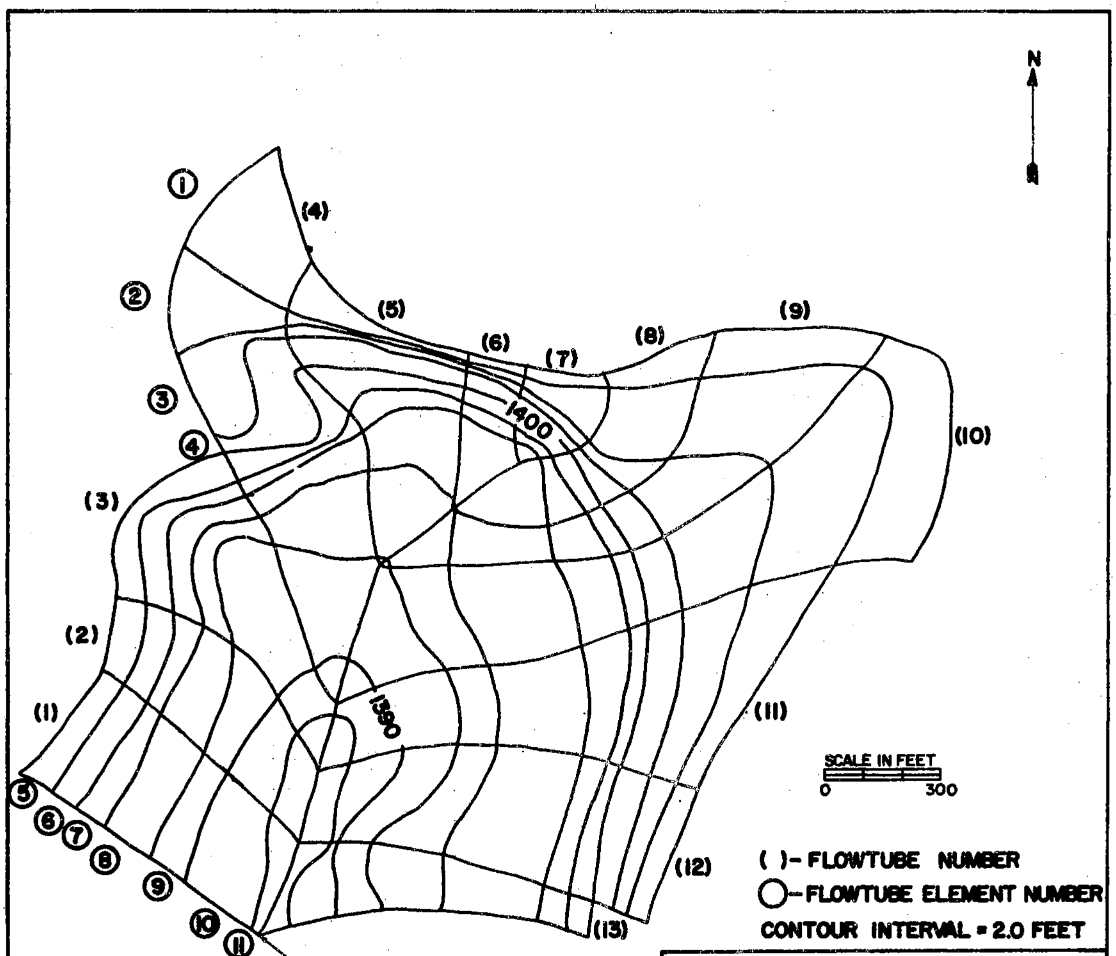
WHERE: T = TOTAL TIME OF TRAVEL ALONG ANY FLOW TUBE, DAYS;

N = NUMBER OF FLOW TUBE ELEMENTS

EQUATION FOR GROUND-WATER TRAVEL TIME COMPUTATION

FIGURE 30

contour line was selected to be point A or the initial point from which travel time was computed and the drainage ditch was assumed to be point B for each tube. The flow nets of the measured water surface elevations (Figure 31) and of the predicted water surface elevations (Figure 32) were used for the computation of travel times. These two maps are the same as those in Figures 25 and 28, but are labeled in a manner which will facilitate the determination of travel time. The results of these two sets of travel time as they are related to the maps in Figures 31 and 32 are compared in Table 4. The drainage ditch is the terminal point of travel and represents the point at which ground-water flow emerges as base flow in the ditch.



FLOWTUBES AND ELEMENTS FOR MEASURED DATA

FIGURE 31

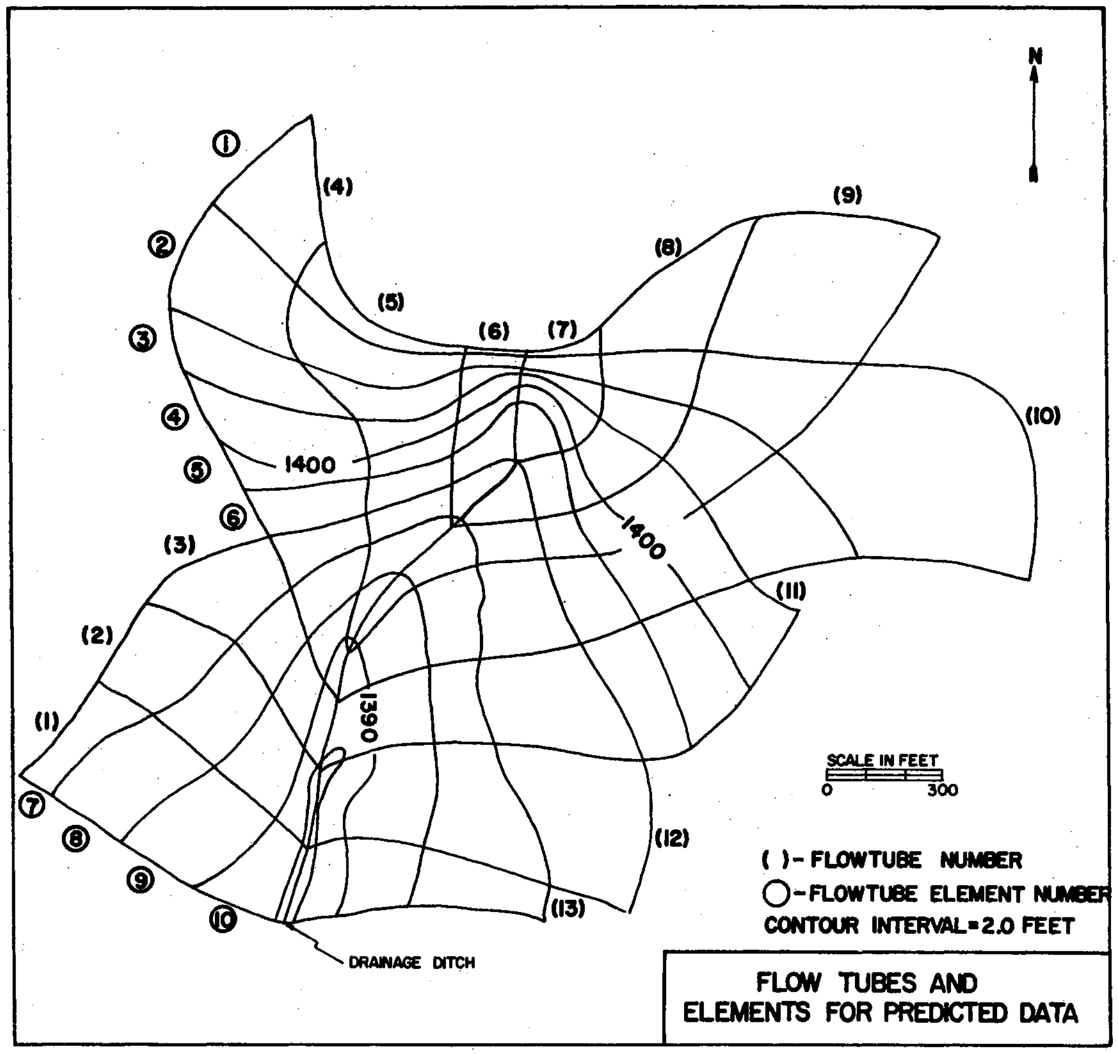

N
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
(12)
(13)
1400
1400
1390
DRAINAGE DITCH
SCALE IN FEET
0
300
( ) - FLOWTUBE NUMBER
○ - FLOWTUBE ELEMENT NUMBER
CONTOUR INTERVAL = 2.0 FEET
FLOW TUBES AND
ELEMENTS FOR PREDICTED DATA

FIGURE 32

TABLE IV

COMPARISON OF TRAVEL TIME AND VELOCITY COMPUTED FROM FLOW NETS USING PREDICTED AND MEASURED HYDROGEOLOGIC DATA

	Flow-Tube No.												
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Length (ft)												
Measured Flow Net	663	615	810	1,415	660	312	260	592	1,185	1,575	1,195	851	760
Predicted Flow Net	690	648	505	1,211	775	397	333	975	1,755	1,695	1,250	843	632
Predict./Meas. as %	104	105	62	86	117	127	128	165	148	108	105	99	83
	Total Travel Time (days) (Pore Velocity)												
Measured Flow Net	3,852	4,133	7,118	17,081	13,897	1,230	503	1,245	26,219	18,629	11,400	3,426	3,274
Predicted Flow Net	6,915	4,505	2,599	11,627	9,454	3,719	4,749	17,764	31,740	32,226	14,546	15,249	7,787
Predict./Meas. as %	180	109	36	68	68	302	944	1,426	121	173	128	445	238
	Average Pore Velocity (ft/day)												
Measured Flow Net	0.17	0.15	0.11	0.08	0.05	0.25	0.52	0.48	0.05	0.08	0.10	0.25	0.23
Predicted Flow Net	0.10	0.14	0.19	0.10	0.08	0.11	0.07	0.05	0.06	0.05	0.09	0.06	0.08
Predict./Meas. as %	58	93	172	125	160	44	13	10	120	63	90	24	35
	Average Darcian Velocity (ft/day)												
Measured Flow Net	0.06	0.05	0.04	0.03	0.02	0.09	0.18	0.17	0.02	0.03	0.04	0.09	0.08
Predicted Flow Net	0.04	0.05	0.07	0.04	0.03	0.04	0.02	0.02	0.02	0.02	0.03	0.02	0.03
Predict./Meas. as %	67	100	175	133	150	44	11	11	100	67	75	22	38

CHAPTER V

RESULTS

Isochronous maps of the ground-water travel time were developed for the measured and predicted flow regime, using pore velocity, after the structure filled with water (Figures 33 and 34). The ground-water travel time is also presented as isochronous maps for the Darcian flow velocity. These maps are shown in Figures 35 and 36 and show the Darcian or discharge flow rates to be about one-third of the flow rate within the pores. The maps developed from predicted data are not identical to the map drawn from measured data. It is, however, accurate enough, i.e., isochrone patterns are similar, to be used in making preliminary estimates of the time required for water leaving the structure to return downstream as base flow.

The ground-water discharge was computed for each flow tube in the predicted and measured flow nets used in the time of travel study. The amount of flow from each tube was computed using both the pore velocity and Darcian velocity. A summary of these data as well as the total ground-water discharge from the modeled area is presented in Table 5. The ratio of predicted to measured flow, expressed as a percent, is also given in Table 5.

This study has shown that a simplified version of a more sophisticated mathematical model may be used to predict the area of hydrologic impact of an earthen dam. The impact of the structure at Site 13 was

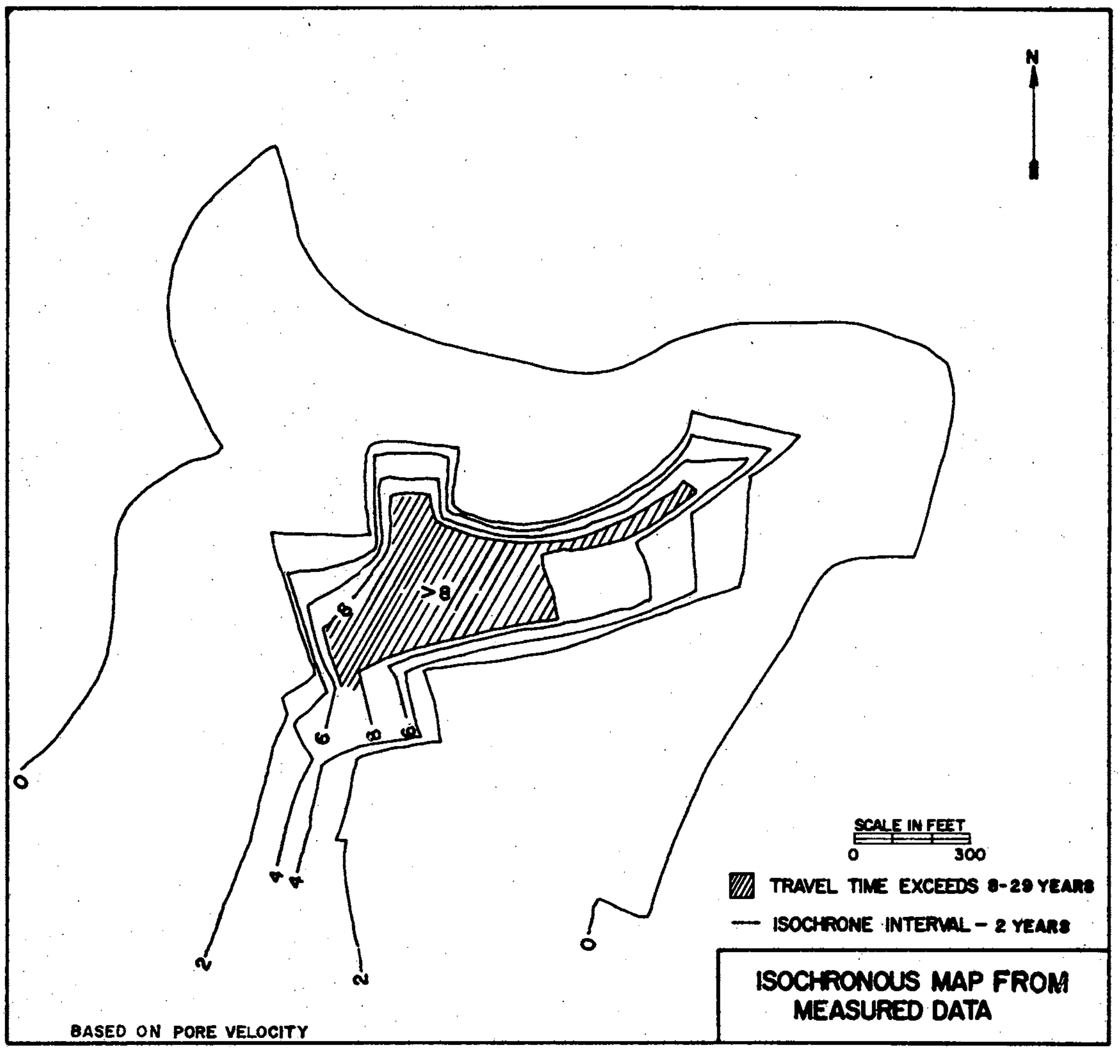

N
>8
SCALE IN FEET
0
300
TRAVEL TIME EXCEEDS 8-29 YEARS
ISOCHRONE INTERVAL – 2 YEARS
ISOCHRONOUS MAP FROM MEASURED DATA
BASED ON PORE VELOCITY

FIGURE 33

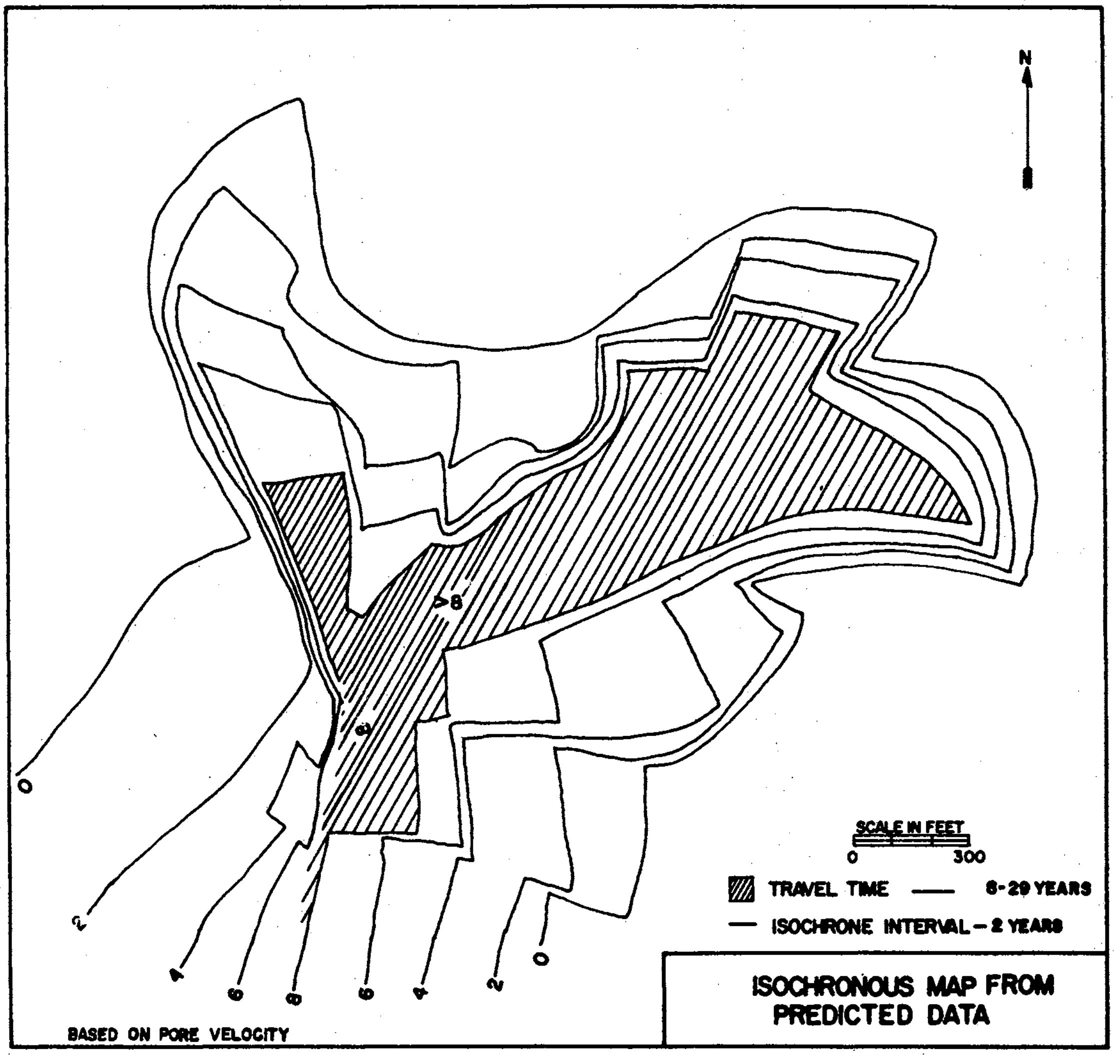

N
>8
8
0
2
4
6
8
6
4
2
0
SCALE IN FEET
0
300
TRAVEL TIME —— 8-29 YEARS
— ISOCHRONE INTERVAL - 2 YEARS
ISOCHRONOUS MAP FROM PREDICTED DATA
BASED ON PORE VELOCITY

FIGURE 34

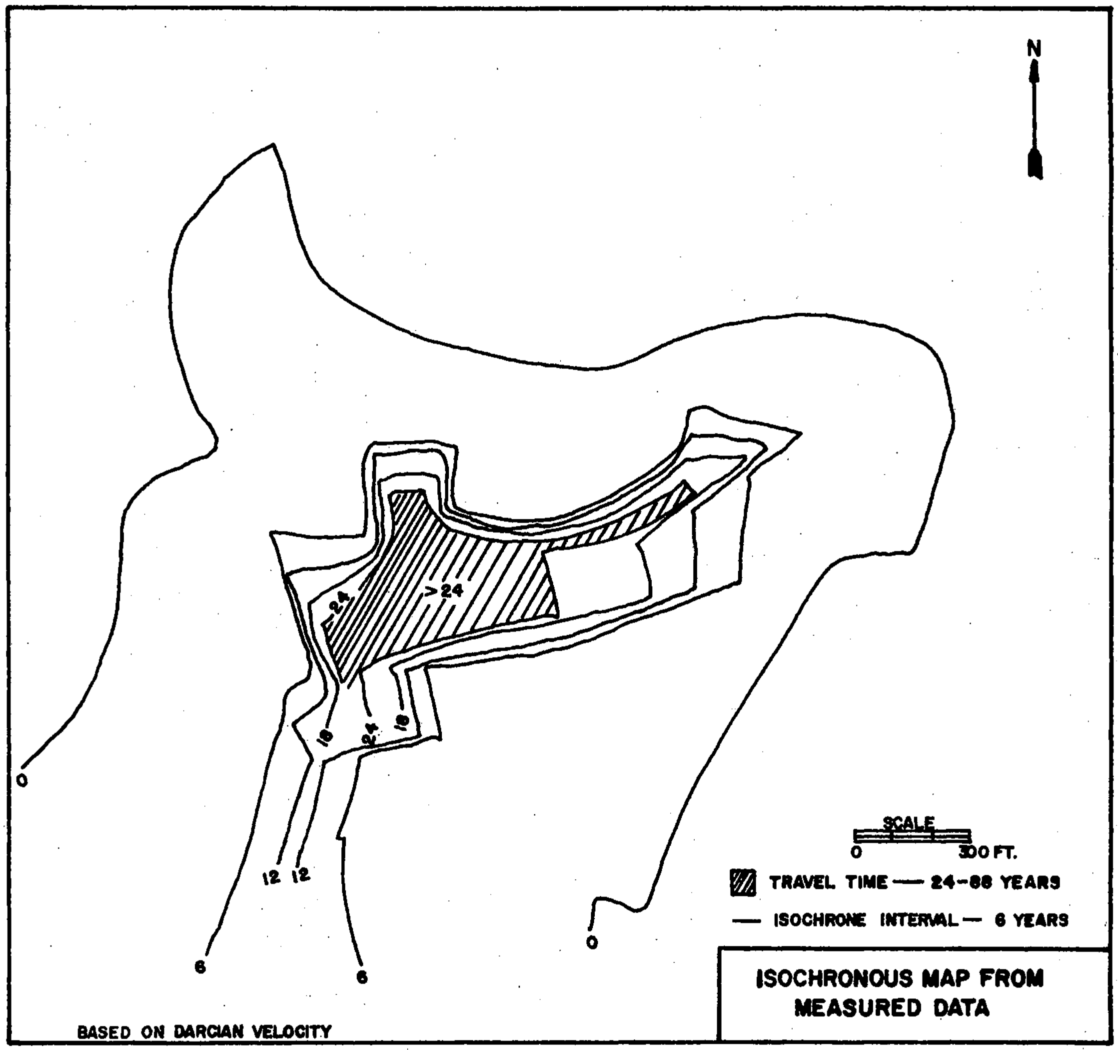

N
>24
24
18
24
18
12 12
6
6
0
0
SCALE
0
300 FT.
TRAVEL TIME — 24-88 YEARS
— ISOCHRONE INTERVAL — 6 YEARS
ISOCHRONOUS MAP FROM MEASURED DATA
BASED ON DARCIAN VELOCITY

FIGURE 35

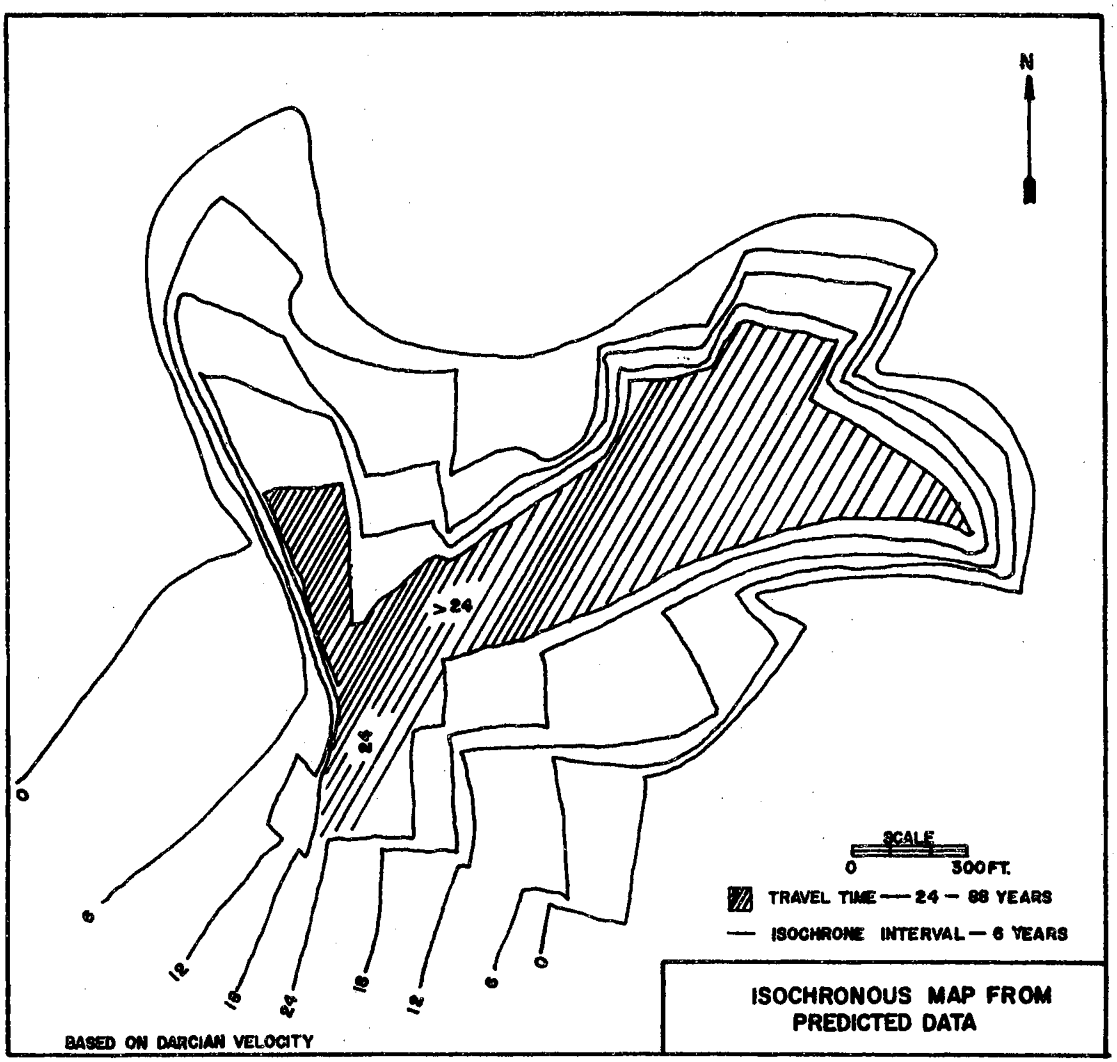

N
>24
24
0
6
12
18
24
18
12
6
0
SCALE
0
300 FT.
TRAVEL TIME — 24 – 88 YEARS
— ISOCHRONE INTERVAL — 6 YEARS
ISOCHRONOUS MAP FROM PREDICTED DATA
BASED ON DARCIAN VELOCITY

FIGURE 36

TABLE V

GROUND-WATER DISCHARGE BELOW SITE 13

Data from the MEASURED Flow Net	Flow Tube No./Flow-Tube Element No. 1/11	2/11	3/11	4/10	5/9	6/7	7/7	8/7	9/9	10/10	11/11	12/11	13/11	Total Flow
$V_{Dar.}$	0.064	0.025	0.016	0.022	0.194	0.077	3.360	0.430	0.135	0.033	0.018	0.031	0.050	
V_{Pore}	0.181	0.071	0.045	0.064	0.555	0.220	9.600	1.230	0.384	0.095	0.052	0.088	0.142	
W ft.	260	185	180	385	140	200	50	215	140	385	180	185	260	
H ft.	50	50	50	50	50	50	50	50	50	50	50	50	50	
Q_V ft^3/day	832	231	144	423	1,358	770	8,400	4,623	945	635	162	287	650	19,460

Data from the PREDICTED Flow Net	Flow-Tube No./Flow-Tube Element No. 1/11	2/11	3/10	4/10	5/10	6/8	7/6	8/8	9/10	10/10	11/11	12/11	13/11	Total Flow
$V_{Dar.}$	0.135	0.080	0.119	0.106	0.100	0.262	0.014	0.114	0.133	0.080	0.086	0.263	0.091	
V_{Pore}	0.384	0.229	0.342	0.302	0.286	0.750	0.041	0.327	0.380	0.228	0.245	0.750	0.258	
W ft.	200	200	20	130	440	230	140	230	440	130	25	200	200	
H ft.	50	50	50	50	50	50	50	50	50	50	50	50	50	
Q_V ft^3/day	1,350	800	119	689	2,200	3,013	98	1,311	2,926	520	108	2,630	910	16,674

Ratio expressed as percent of PREDICTED:MEASURED total ground-water flow in the area modeled - 85%

shown to be limited in both the lateral and downstream directions from the dam. The hydrologic impact at Site 13 will vary in response to lake level conditions. However, the hydraulic potentials predicted in this study show that the impact area will be limited to less than 1,000 feet downstream from the dam at lake surface elevations near the permanent pool elevation for the lake, which is 1,410 feet above mean sea level.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The objective of this study was to make an evaluation of the impact of an earthen-fill dam using a mathematical model as the principal investigatory tool. The sensitivity of the model, using varying boundary conditions, was determined and presented as a series of contour maps developed from predicted hydraulic potential data. Additional fixed nodes of hydraulic potential head were shown to be insignificant in evaluating the impact of the structure on the ground-water flow regime.

The modeling of the impact of an earthen-fill structure on the ground-water flow regime should be done with a method which maintains the integrity of the hydrologic and geohydrologic characteristics of the flow system being modeled. Two concepts of flow were considered in this study. The first concept, one of parallel flow tubes down the valley, was rejected after comparing the permeability distribution derived from that flow pattern to the distribution of permeabilities developed from field and laboratory data. The second flow concept, that of flow converging toward the center of the valley, was tested by the comparison of permeability distributions as in the first case. Based upon a better correlation of the second concept with the field data, the latter was selected for use in modeling the system.

Additional testing of the model was done by predicting the hydraulic potentials after a flood-water retarding structure had filled with water. These were compared to measured values for the same lake level conditions. The hydraulic potential surfaces in both the predicted and measured cases were similar over the study area.

A third test of the model was made by comparing the time of travel of ground-water flow from the predicted flow net to that derived from the measured potential data. As a result of this study, it was shown that the area impacted by water seeping from the structure extends only a few hundred feet downstream from the structure. It was also shown that as many as 88 years are required for water to travel in the subsurface from the structure to a point in the alluvium a few hundred feet downstream from the structure.

SELECTED BIBLIOGRAPHY

(1) Davis, Leon V. Geology and Groundwater Resources of Grady and Northern Stephens Counties, Oklahoma. Oklahoma Geological Survey, Bulletin No. 73, pp. 96-100, 1955.

(2) Davis, S. N. and R. J. M. DeWiest. Hydrogeology. New York, John Wiley and Sons, Inc., pp. 204-237, 1966.

(3) DeWiest, R. J. M. Geohydrology. New York, John Wiley and Sons, Inc., pp. 204-237, 1965.

(4) Freeze, R. A. Regionalization of Hydrogeologic Parameters for Use in Mathematical Models of Groundwater Flow. Proceedings of the International Geological Congress, Sec. II, pp. 177-190, 1972.

(5) ______________, Groundwater in the Rush Springs Sandstone, Caddo County Area, Oklahoma Water Resources Board, Publication No. 11, 1965.

(6) Jepson, Roland W. Steady Flow in Partially Saturated Soils by Inverse Formulation and Finite Differences. AEC Research and Development Report CSC-680901, 1968.

(7) Kent, D. C., J. W. Naney and B. B. Barnes. An Approach to Computerization of Geohydrologic Data. Groundwater. 1973.

(8) Knowles, T. R., B. J. Claiborn and D. M. Wells. A Digital Computer Model for Predicting Aquifer Response. 1971.

(9) Levings, G. W. A Groundwater Reconnaissance Study of the Upper Sugar Creek Watershed, Caddo County, Oklahoma. Unpublished M. S. Thesis. 1966.

(10) Nelson, R. William. In Place Determination of Permeability Distribution for Heterogeneous Porous Media Through Analysis of Energy Dissipation. Society of Petroleum Engineering Journal, pp. 32-42, 1968.

(11) Nelson, R. William. Flow in Heterogeneous Porous Mediums, One Darcian-Type Description of Two-Phase Systems. Water Resources Research, Vol. II, No. 3, pp. 487-495, 1966.

(12) Nelson, R. William. A Sequence for Predicting Waste Transport by Groundwater. Proceedings of First Annual Meeting American Water Resources Association, University of Chicago. 1965. Also reprinted in 1966. Reference number of Water and Sewage Works, Scranton Publishing, Chicago, pp. R-85-94.

(13) Nelson, R. William. Stream Functions for Three Dimensional Flow in Heterogeneous Porous Media. International Association of Science and Hydrology, 64, 290-301, 1963.

(14) Nelson, R. William. Steady Darcian Transport of Fluids in Heterogeneous Partially Saturated Porous Media, Part I, Mathematical and Numerical Formulation, AEC Research and Development Report HW-72335 TT.I. 1962.

(15) Nelson, R. William and D. B. Cearlock. Analysis and Predictive Methods for Groundwater Flow in Large Heterogeneous Systems Procedures of the National Symposium on Groundwater Hydrology sponsored by American Water Resources Association, pp. 301-316, 1967.

(16) Nelson, R. William and J. R. Eliason. Prediction of Water Movement through Soils - A First Step in Waste Transport Analysis. Procedures 21st Industrial Waste Conference, Purdue University Engineering Extension Bulletin No. 121, Vol. 2, pp. 744-758, 1966.

(17) Nelson, R. William. Notes from a Short Course and Workshop in Groundwater Engineering Methods, 1973.

(18) Newcomb, R. C., J. R. Strand, and F. J. Frank. Geology and Ground-Water Characteristics of the Hanford Reservation of the U. S. Atomic Energy Commission, Washington, U. S. Geological Survey Paper 717, pp. 5-37, 1972.

(19) Oster, C. A. Genoro, A General Data Fitting and Linear Functional Evaluation Computer Code for the IBM 7090. AEC Research and Development Report HW-76692, 1963.

(20) Rainwater, F. H. and L. L. Thatcher. Methods for Collection and Analysis of Water Samples. U. S. Geological Survey Water-Supply Paper 1454, 1960.

(21) Reddell, D. L. and D. K. Sunada. Numerical Simulation of Dispersion in Groundwater Aquifers. Hydrology Papers, Colorado State University, 1970.

(22) Remson, Irwin, G. M. Hornberger and F. J. Molz. Numerical Methods on Subsurface Hydrology, pp. 164-236, 1971.

(23) Risenaur, A. E. Methods for Solving Problems of Multidimensional Partially Saturated Flows in Soils, Journal of Geophysical Research, Vol. 68, pp. 5725-5733, 1963.

(24) Risenaur, A. E., R. W. Nelson and C. N. Knudsen. Steady Darcian Transport of Fluids in Heterogeneous Partially Saturated Porous Media, Part II, The Computer Program. AEC Research and Development Report HW-72335TT.22, 1963.

(25) Staff, Agricultural Research Service, Annual Research Report, Washita River Watershed, 1961-1972.

(26) Szalay, Miklos. Some Special Features of Boundary Value Problems in Seepage Flow. Proceedings of the Fifteenth Congress of the International Association for Hydraulic Research, Vol. 3, pp. 1-8, 1973.

(27) Seely, E. H. A Mathematical Formulation for Approximating Permeability Distributions. Unpublished (See Appendix), 1973.

(28) Taylor, G. S. and James N. Luthin. Computer Methods for Transient Analysis of Water Table Aquifers. Water Resources Research, 1969.

(29) Todd, D. K. Groundwater Hydrology. New York, John Wiley and Sons, Inc., pp. 78-111, 1959.

(30) Tonaka, H. H. and L. V. Davis. Groundwater Resources of the Rush Springs Sandstone in the Caddo County Area, Oklahoma. Oklahoma Geological Survey Circular 61, 1963.

(31) Walton, W. C. Groundwater Resource Evaluation. New York, McGraw-Hill Book Company, pp. 207-295, 1970.

(32) Yost, C. B. and J. W. Naney. Water Quality Effects of Seepage from Earthen Dams. Journal of Hydrology, Vol. 21, pp. 15-26, 1974.

APPENDIX A

COMPUTER PROGRAM LISTING FOR APERM WITH CONTROL CARDS

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C                                            APPENDIX  A



C                                         ***APERM***



C   ***THIS IS THE PROGRAM ,APERM, WHICH DISTRIBUTES THE MATHEMATICALLY ***
C   ***APPROXIMATED SATURATED PERMEABILITY ALONG EACH FLOW TUBE FROM ONE POINT***
C   ***OF KNOWN PERMEABILITY VALUE, AFTER SEELY,E.H., 1973***
      REAL L
      INTEGER ERCOD
      DEFINE FILE 1(50,320,U,IAV1),2(98,316,U,IAV2),3(1,320,U,IAV3)
      DIMENSION XBUFR(80),YBUFR(80),IPERM(49),PERM(49),TITLE(20),X(3),
     1 Y(3),XP(3),YP(3),DI(3),PRMST(79),XEP(79),NC(79),XS1(80),YS1(80),
     2 XS2(80),YS2(80),PERMU(5),YEP(79)
      DATA XBUFR,YBUFR/160*-1000./,SX,SY/2*0./
C
C   FILE 1 STORES STREAMLINES, FILE 2 STORES STREAMTUBES
C
C   INITIALIZE FILE 1 ON DISK, EACH LOCATION IS SET TO -1000., EACH
C   LOCATION IS THEN CHECKED IN PROCESSING AND IF EQUAL TO -1000. IS
C   ASSUMED NOT READ IN.
C
      DO 10 I=1,50
   10 WRITE (1'I) XBUFR,YBUFR
      KRD=2
      KPT=3
      READ(KRD,20) M,N
   20 FORMAT(2I4)
      READ(KRD,30) TITLE,RFPHI,DPHI
   30 FORMAT(20A4/F10.3,F5.2)
      WRITE(3,31) TITLE
   31 FORMAT('1***  COMPUTER-AIDED APPROXIMATE METHOD TO OBTAIN PERMEABI
     1LITY DISTRIBUTIONS  ***'//' ',20A4//)
      WRITE(3,32) M,N,RFPHI,DPHI
   32 FORMAT(' NO OF STREAMLINES =',I3,'   NO OF EQUIPOTENTIAL LINES =',
     1I3//' POTENTIAL INDEX LINE =',F8.2,'    DELTA POTENTIAL =',F5.1)
C
C   SEGMENT INPUT
C
   40 DO 45 K=1,3
      READ(KRD,35) I,J,X(J),Y(J),XP(J),YP(J),DI(J)
   35 FORMAT(2I4,2F6.3,2F10.4,F5.3)
      IF(I) 42,45,42
C   POINT READ IN IS NOT A REFERENCE POINT. CHECK INPUT.
   42 ERCOD=1
      CALL ERROR(ERCOD)
      CALL EXIT
   45 CONTINUE
      CALL STUPT(X,Y,XP,YP,A,B,C,D,XPO,YPO)
      IF (DI(2)) 48,48,47
   47 DLYP2=YP(2)-YP(1)
```

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      DLXP2=XP(2)-XP(1)
      DLXP3=XP(3)-XP(1)
      DLYP3=YP(3)-YP(1)
      XR=DLXP2/DLXP3
      SY=SQRT((DI(2)**2-DI(3)**2*XR**2)/(DLYP2**2-DLYP3**2*XR**2))
      IF (ABS(DLXP3)-ABS(DLXP2)) 890,891,891
  890 SX=SQRT((DI(2)**2-(SY*DLYP2)**2)/DLXP2**2)
      GO TO 893
  891 SX=SQRT((DI(3)**2-(SY*DLYP3)**2)/DLXP3**2)
  893 CONTINUE
      WRITE(3,991) SX,SY
  991 FORMAT('OSCALE CONVERSIONS IN INCHES/USERS UNIT FOR PLOTTED OUTPUT
     1'/  '    X =',E12.4,',    Y =',E12.4//)
C
C  BEGIN INPUT FOR REST OF SEGMENT
C
   48 READ (KRD,50) I,J,XT,YT
   50 FORMAT(2I4,2F6.3)
C
C  THE FIRST INDEX IS USED AS AN INDICATOR.  POSITIVE=NORMAL CONTINUATION
C                                            ZERO    =END OF SEGMENT
C                                            NEGATIVE=END OF ALL INPUT
C
   55 IF(I) 100,40,60
   60 READ (1'I) XBUFR,YBUFR
   70 XBUFR(J)= A*XT + C*YT + XPO
      YBUFR(J)= B*XT + D*YT + YPO
      ISAVE=I
   80 READ(KRD,50) I,J,XT,YT
      IF (I-ISAVE) 90,70,90
   90 WRITE (1'ISAVE) XBUFR,YBUFR
      GO TO 55
  100 M1=M-1
      N1=N-1
      READ (KRD,110) PERMU
  110 FORMAT(5A4)
      WRITE (KPT,124) PERMU
  124 FORMAT('OKNOWN PERMEABILITIES IN UNITS OF ',5A4/'  STREAMTUBE ELEM
     1ENT          PERMEABILITY'/)
      DO 150 I=1,M1
      READ(KRD,120) J,IPERM(J),PERM(J)
  120 FORMAT(2I4,F12.5)
      WRITE(KPT,125) J,IPERM(J),PERM(J)
  125 FORMAT(' ',6X,I3,',',I2,16X,F8.2)
      IF(PERM(J)) 130,130,140
C  PERMEABILITY IS ZERO
  130 ERCOD=2
      CALL ERROR(ERCOD)
      CALL EXIT
  140 IF(IPERM(J)) 145,145,150
C  STREAMTUBE INDEX FOR ELEMENT OF KNOWN PERMEABILITY IS ZERO OR NEGATIVE
  145 ERCOD=3
      CALL ERROR(ERCOD)
      CALL EXIT
```

80/80 LIST

```
0000000001111111111222222222233333333334444444444555555555566666666667777777777B
1234567890123456789012345678901234567890123456789012345678901234567890123456789O
CARD
  150 CONTINUE
C
C  MAIN PROCESSING LCCP
C
      DO 900 I=1,M1
      NDX=IPERM(I)
      READ(1'I) XS1,YS1
      IP=I+1
      READ(1'IP) XS2,YS2
      CALL WLCAL(XS1,YS1,XS2,YS2,NDX,W,L,XC,YC)
      C=PERM(I)*W/L
      DO 800 J=1,N1
      NC(J)=0
C  CHECK TO SEE IF LOCATION HAD A POINT READ IN
      IF(XS1(J)+1000.) 401,800,401
  401 IF(XS2(J)+1000.) 402,800,402
  402 IF(XS1(J+1)+1000.) 403,800,403
  403 IF(XS2(J+1)+10C0.) 404,800,404
  404 CALL WLCAL(XS1,YS1,XS2,YS2,J,W,L,XC,YC)
      PRMST(J)=C*L/W
      XEP(J)=XC
      YEP(J)=YC
      NC(J)=1
  800 CONTINUE
      NF1=(I-1)*2+1
      NF2=NF1+1
      WRITE(2'NF1) XEP,YEP
      WRITE(2'NF2) PRMST,NC
  900 CONTINUE
      CALL PRINT(M,N)
      WRITE(3'1) M,N,SX,SY,TITLE,PERMU
      CALL LINK(DGTM2)
      END


C                                               ***PLTIO***
C  ***PLTIO PLOTS THE DIGITIZED FLOWNET INTERSECTION POINTS***
      SUBROUTINE PLTIO(XORG,YORG)
      DIMENSION X(80),Y(80),TITLE(20),PERMU(5)
C
C  SX AND SY ARE IN INCHES PER USERS UNIT
C
      READ(3'1) M,N,SX,SY,TITLE,PERMU
      M1=M-1
C
C  SCREEN DATA FOR MIN AND MAX OF X AND Y
C
      XMAX=0.0
      XMIN=31.
      YMAX=0.0
      YMIN=31.
      DO 100 I=1,M
      READ (1'I) X,Y
      DO 90 J=1,N
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      IF (X(J)+1000.) 30,90,30
   30 IF (X(J)*SX-XMAX) 40,40,35
   35 XMAX=X(J)*SX
      GO TO 60
   40 IF (X(J)*SX-XMIN) 45,60,60
   45 XMIN=X(J)*SX
   60 IF(Y(J)*SY-YMAX) 80,90,65
   65 YMAX=Y(J)*SY
      GO TO 90
   80 IF (Y(J)*SY-YMIN) 70,90,90
   70 YMIN=Y(J)*SY
   90 CONTINUE
  100 CONTINUE
      NSW=0
      IF (YMAX-YMIN-28.) 200,200,110
  110 IF (XMAX-XMIN-28.) 120,120,130
  120 NSW=1
      WRITE (3,125)
  125 FORMAT(' X-Y SWITCH BECAUSE OF Y RANGE')
      GO TO 200
  130 WRITE (3,140)
  140 FORMAT(' TRUE SCALE PLOT NOT POSSIBLE')
  200 IF (YMIN) 210,220,220
  210 YMIN=YMIN-1.
  220 YORG=IFIX(YMIN)/SY
      IF(XMIN) 230,240,240
  230 XMIN=XMIN-1.
  240 XORG=IFIX(XMIN)/SX
      XS=SX*2.
      YS=SY*2.
C
C    THE SCALE IS DOUBLED BECAUSE OF IBM 1/2 SCALE SUBROUTINES
C
      CALL SCALF(XS,YS,XORG,YORG)
      RX=1.0
      RY=1.0
      YLOC=YORG-.2
      XLOC=XORG-.2
      CALL FGRID (0,XLOC,YLOC,RX,15)
      CALL FGRID(1,XLCC,YLOC,RY,15)
      XT=XLOC+15.
      YT=YLOC+15.
      CALL FGRID(0,XLOC,YT,RX,15)
      CALL FGRID(1,XT,YLOC,RY,15)
      XN=11./SX
      YN=16.0/SY
      CALL FCHAR(XN,YN,.40,.40,0.)
      WRITE(7,243) TITLE
  243 FORMAT(20A4)
      XN=XN+1.0/SX
      YN=YN-.75/SY
      CALL FCHAR(XN,YN,.30,.30,0.)
      WRITE(7,244) PERMU
  244 FORMAT('PERMEABILITY UNITS OF ',5A4)
```

80/80 LIST

```
0000000001111111111222222222233333333334444444444555555555566666666667777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      CALL DATSW(10,JTST)
      GO TO (500,245),JTST
  245 DO 400 I=1,M
      READ (1'I) X,Y
      DO 350 J=1,N
      IF (X(J)+1000.) 250,350,250
  250 CALL FPLOT(1,X(J),Y(J))
      CALL FPLOT(2,X(J),Y(J))
      CALL POINT(0)
      CALL POINT(1)
  350 CONTINUE
  400 CONTINUE
  500 RETURN
      END


C                                        ***PRINT(M,N)***
C   ***PRINT(M,N) WRITES DIGITIZED PERMEABILITY DATA ON PRINTER***
      SUBROUTINE PRINT(M,N)
      DIMENSION XEP(79),YEP(79),EPERM(79),NC(79)
      M1=M-1
      N1=N-1
      WRITE(3,10)
   10 FORMAT('0'/)
      WRITE (3,20)
   20 FORMAT('0ESTIMATED PERMEABILITIES AND APPROXIMATE CENTER FOR EACH
     1STREAM TUBE ELEMENT'/)
      WRITE (3,21)
   21 FORMAT('0STREAM TUBE   CENTER COORDINATES    ESTIMATED'/
     1'   INDICES           X          Y      PERMEABILITY'/)
      CALL DATSW(11,JTST)
      GO TO (400,25),JTST
   25 DO 100 I=1,M1
      NF1=(I-1)*2+1
      NF2=NF1+1
      READ(2'NF1) XEP,YEP
      READ(2'NF2) EPERM,NC
      DO 90 J=1,N1
      IF (NC(J)-1) 90,30,90
   30 WRITE (3,40) I,J,XEP(J),YEP(J),EPERM(J)
   40 FORMAT(' ' 2I4,3F12.4)
   90 CONTINUE
  100 CONTINUE
  400 RETURN
      END
C                                        ***WRPMR***
C   ***WRPMR IS AN ARRAY OF ROUTINES TO PLOT THE CENTER OF EACH FLOWTUBE***
C   ***ELEMENT,SET SIZE OF LETTERING, WRITE PLOT TITLE ,MARK FLOWNET***
C   ***INTERSECTIONS, WRITE DISTRIBUTED SATURATED PERM AT ELEMENT CENTER***
      SUBROUTINE WRPMR(XS1,YS1,XS2,YS2,XEP,YEP,PRMST,NC,XORG,YORG)
      DIMENSION XS1(80),YS1(80),XS2(80),YS2(80),XEP(79),YEP(79),PRMST(79
     1),NC(79)
      READ(3'1) M,N,SX,SY
C
```

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777780
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
C   SX AND SY ARE IN INCHES/USERS UNITS
C
C XS AND YS ARE THE CHARACTER SIZE FOR THE PERMEABILITY VALUE.
C YSA AND YSA ARE THE CHARACTER SIZE FOR THE INDEX VALUE.
C
      XS=.04
      YS=.04
      XSA=.04
      YSA=.04
C  A SET OF VALUES TWICE THE NORMAL CHARACTER SIZE ARE USED.
C  IN THE FCHAR ARGUMENTS BECAUSE THE IBM SUBROUTINES ARE 1/2 SCALE.
      XSDBL=2.*XS
      YSDBL=2.*YS
      XSADB=2.*XSA
      YSADB=2.*YSA
      M1=M-1
      N1=N-1
C
C WRITE TITLE,GRID, AND PERMEABILITY UNITS
C
C  ****              ****
C
      DO 800 I=1,M1
      READ (1'I) XS1,YS1
      READ (1'I+1) XS2,YS2
      NF1=I*2-1
      NF2=NF1+1
      READ(2'NF1) XEP,YEP
      READ(2'NF2) PRMST,NC
      DO 700 J=1,N1
      IF (NC(J)-1) 700,5,700
C FIND MAXIMUM X DISTANCE IN STREAMTUBE ELEMENT
    5 CN=5.
      YDFC=-1.5
      XC=XEP(J)
      YC=YEP(J)
      IF (INTST(XS1(J),YS1(J),XS2(J),YS2(J),XS,YS,CN,YDFC,XC,YC))
     1  100,200,100
  100 IF (INTST(XS2(J),YS2(J),XS2(J+1),YS2(J+1),XS,YS,CN,YDFC,XC,YC))
     1  105,200,105
  105 IF(INTST(XS2(J+1),YS2(J+1),XS1(J+1),YS1(J+1),XS,YS,CN,YDFC,XC,YC))
     1  110,200,110
  110 IF(INTST(XS1(J+1),YS1(J+1),XS1(J),YS1(J),XS,YS,CN,YDFC,XC,YC))
     1  115,200,115
C  CAN WRITE PERMEABILITY
  115 XN=XC-(CN)*.5*XS/SX
      YN=YC+YDFC*YS/SY
      CALL FCHAR(XN,YN,XSDBL,YSDBL,0.)
      WRITE(7,315) PRMST(J)
  315 FORMAT(F5.0)
      GO TO 400
  200 YDFC=.5
      CN=5.
      IF(INTST(XS1(J),YS1(J),XS2(J),YS2(J),XSA,YSA,CN,YDFC,XC,YC))
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
     1  210,400,210
  210 IF(INTST(XS2(J),YS2(J),XS2(J+1),YS2(J+1),XSA,YSA,CN,YDFC,XC,YC))
     1  220,400,220
  220 IF(INTST(XS2(J+1),YS2(J+1),XS1(J+1),YS1(J+1),XSA,YSA,CN,YDFC,XC,YC
     1)) 230,400,230
  230 IF(INTST(XS1(J+1),YS1(J+1),XS1(J),YS1(J),XSA,YSA,CN,YDFC,XC,YC))
     1   240,400,240
  240 XN=XC-CN*.5*XSA/SX
      YN=YC+YDFC*YSA/SY
      CALL FCHAR(XN,YN,XSADB,YSADB,0.)
      WRITE (7,365) I,J
  365 FORMAT(I2,',',I2)
C
C PLOT CENTER OF ELEMENT
C
  400 CALL FPLOT(1,XEP(J),YEP(J))
      CALL FPLOT(-2,XEP(J),YEP(J))
      CALL POINT(0)
  700 CONTINUE
  800 CONTINUE
      XNEW=XORG+34./SX
      CALL FPLOT(1,XNEW,YORG)
      RETURN
      END


C                                        ***WLCAL***
C   ***WLCAL CALCULATES VECTORS OF WIDTH AND LENGTH TO THE CENTER OF EACH ***
C   ***FLOWTUBE ELEMENT AND THE SATURATED PERMEABILITY IS ADJUSTED FROM THIS***
      SUBROUTINE WLCAL(XS1,YS1,XS2,YS2,NDX,W,L,XC,YC)
      REAL L
      DIMENSION XS1(80),XS2(80),YS1(80),YS2(80)
      DLX1=XS1(NDX+1)-XS1(NDX)
      DLX2=XS2(NDX+1)-XS2(NDX)
      DLX3=XS2(NDX)-XS1(NDX)
      DLX4=XS2(NDX+1)-XS1(NDX+1)
      DLY1=YS1(NDX+1)-YS1(NDX)
      DLY2=YS2(NDX+1)-YS2(NDX)
      DLY3=YS2(NDX)-YS1(NDX)
      DLY4=YS2(NDX+1)-YS1(NDX+1)
      L=(SQRT(DLX2**2+DLY2**2)+SQRT(DLX1**2+DLY1**2))*.5
      W= SQRT(DLX3**2+DLY3**2)+SQRT(DLX4**2+DLY4**2)*.5
      XC=(XS1(NDX)+XS1(NDX+1)+XS2(NDX)+XS2(NDX+1))*.25
      YC=(YS1(NDX)+YS1(NDX+1)+YS2(NDX)+YS2(NDX+1))*.25
      RETURN
      END


C                                     ***DGTM2***
C   ***DGTM2 CALLS SUBROUTINES WRMPR, PLTIO,AND  DATSW***
      DEFINE FILE 1(50,320,U,IAV1),2(98,316,U,IAV2),3(1,320,U,IAV3)
      DIMENSION XS1(80),YS1(80),XS2(80),YS2(80),XEP(79),YEP(79),PRMST(79
     1),NC(79)
   10 CALL PLTIO(XORG,YORG)
```

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      CALL WRPMR(XS1,YS1,XS2,YS2,XEP,YEP, PRMST,NC,XORG,YORG)
      CALL DATSW(12,JTST)
      GO TO (100,10),JTST
  100 CALL EXIT
      END


C                                      ***INTST***
C  ***INTST DETERMINES IF AN INTERSECTION OF THE DIAGONALS OF A FLOWTUBE***
C  ***ELEMENT IS POSSIBLE AND IF THE SATURATED PERMEABILITY CAN BE WRITTEN ***
      FUNCTION INTST(X1,Y1,X2,Y2,CSXI,CSYI,CN,YDFC,XC,YC)
C
C  THIS SUBROUTINE TAKES THE SPACE DEFINED BY A CHARACTER STRING OF CN
C  CHARACTERS CSX WIDE AND CSY HIGH, CENTERED WITH RESPECT TO THE ELEMENT
C  CENTER (XC,YC) AND TESTS IF THE LINE DEFINED BY THE TWO POINTS X1,Y1
C  AND X2,Y2 INTERSECTS THE SPACE.  IF THE LINE DOES INTERSECT THE SPACE
C  IT IS ASSUMED THAT THE SPACE CAN NOT BE WRITTEN IN.  A VALUE OF INTST
C  EQUAL TO 1 IS RETURNED IN NO INTERSECTION IS FOUND,ZERO OTHERWISE.
C
C  CSX AND CSY ARE CHARACTER SIZE IN INCHES IN THE X AND Y DIRECTIONS.
C  CN IS THE NUMBER OF CHARACTERS.
C  YDFC IS Y DISTANCE FROM CENTER AS A MULTIPLE OF CSY.
C  XC AND YC ARE X AND Y COORDINATES OF THE CENTER OF THE ELEMENT.
C
C  ---------------------------------------------------------------------------
C
C
      READ (3'1) M,N,SX,SY
      CSX=CSXI/SX
      CSY=CSYI/SY
      INTST=0
C  POINTS SHOULD BE ORDERED FROM LOW TO HIGH ON Y.
      IF (Y1-Y2) 10,10,20
   10 YA=Y2
      XA=X2
      X=X1
      Y=Y1
      GO TO 25
   20 YA=Y1
      XA=X1
      X=X2
      Y=Y2
   25 IF(YDFC) 40,40,30
   30 TOP=YDFC*CSY+CSY+YC
      BOTTM=YC
      GO TO 45
   40 TOP=YC
      BOTTM=YC+YDFC*CSY
   45 IF(TOP-Y) 200,200,50
   50 IF(BOTTM-YA) 60,200,200
C
C  TEST FOR BOTH Y AND YA BETWEEN TOP AND BOTTOM.
C
   60 IF (Y-TOP) 62,70,70
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

   62 IF (YA-BOTTM) 210,70,70
C
C  TEST FOR INTERSECTION OF LINE WITH TOP OR BOTTOM OF CHARACTER SPACE.
C
   70 IF (XA-X) 75,71,75
   71 IF (XA-(XC-(CN+1.)/2.*CSX)) 200,72,72
   72 IF (XA-(XC+(CN+1.)/2.*CSX)) 210,210,200
   75 B=(YA-Y)/(XA-X)
      IF (B) 80,210,80
   80 A=YA-B*XA
C
C  TEST BOTTOM LINE
C
      YT=BOTTM
      XT=(YT-A)/B
      IF (XT-(XC-(CN+1.)/2.*CSX)) 100,90,90
C  INTERSECTION IS POSSIBLE
   90 IF (XT-(XC+(CN+1.)/2.*CSX)) 210,210,100
C  INTERSECTION OCCURS IF PREVIOUS TEST IS NEGATIVE.
C
C  TEST TOP LINE
  100 YT=TOP
      XT=(YT-A)/B
      IF(XT-(XC-(CN+1.)/2.*CSX)) 200,110,110
C  INTERSECTION IS POSSIBLE
  110 IF(XT-(XC+(CN+1.)/2.*CSX)) 210,210,200
  200 INTST=1
  210 RETURN
      END



C                                    ***STUPT***
C  ***STUPT  THIS SUBROUTINE IS A TRANSFORMATION WHICH RETURNS THE***
C  ***COEFFICIENTS OF THE LINEAR FUNCTIONS OF THE UNIT VECTORS FROM DIGITIZED***
C  ***COORDINATES TO TO A SET OF COORDINATES IN THE ACTUAL SYSTEM MAPPED***
      SUBROUTINE STUPT(X,Y,XP,YP,A,B,C,D,XP0,YP0)
      DIMENSION X(3),Y(3),XP(3),YP(3)
      DLX2=X(2)-X(1)
      DLX3=X(3)-X(1)
      DLY2=Y(2)-Y(1)
      DLY3=Y(3)-Y(1)
      DLX2P=XP(2)-XP(1)
      DLX3P=XP(3)-XP(1)
      DLY2P=YP(2)-YP(1)
      DLY3P=YP(3)-YP(1)
      XR=DLX2/DLX3
      C=(DLX2P-DLX3P*XR)/(DLY2-DLY3*XR)
      A=(DLX2P-C*DLY2)/DLX2
      D=(DLY2P-DLY3P*XR)/(DLY2-DLY3*XR)
      B=(DLY2P-D*DLY2)/DLX2
      XP0=XP(1)-A*X(1)-C*Y(1)
      YP0=YP(1)-B*X(1)-D*Y(1)
C  A DIGITIZED POINT X,Y CAN NOW BE EXPRESSED IN ACTUAL SYSTEM COORDINATES AS
```

80/80 LIST

```
          00000000011111111112222222222333333333344444444445555555555666666666677777777778
          12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      C
      C         XP=A * X + C * Y + XPO
      C         YP= B * X + D * Y + YPO
      C
            RETURN
            END



      C                                     ***ERROR***
      C  ***ERROR IS A SUBROUTINE TO CHECK FOR ERRORS IN THE DIGITIZED COORDINATES***
      C  ***OF REFERENCE POINTS AND STREAMTUBE INDEX***
            SUBROUTINE ERROR(ERCOD)
            INTEGER ERCOD
            IF (ERCOD-1) 30,20,10
         10 WRITE (3,15)
         15 FORMAT(' EFROR IN ERROR CODE')
            RETURN
         20 WRITE (3,25)
         25 FORMAT(' POINT READ IN IS NOT A REFERENCE POINT. CHECK INPUT. **')
            RETURN
         30 IF (ERCOD-2) 50,40,40
         40 WRITE (3,45)
         45 FORMAT(' KNOWN PERMEABILITY IS ZERO. **')
            RETURN
         50 IF (ERCOD-3) 7C,60,60
         60 WRITE(3,65)
         65 FORMAT(' STREAMTUBE INDEX FOR ELEMENT OF KNOWN PERMEABILITY IS ZER
           1O OR NEGATIVE. **')
         70 RETURN
            END
      C
      C
      C
      C                                ***EXECUTE   APERM***
      C
      C
      C
      C
      C
      C  ***THE FOLLOWING IS A SAMPLE OF THE INPUT DATA USED TO CONVERT DIGITIZED***
      C  ***DATA TO ACTUAL SYSTEM DATA AND PLOT IT IN MAPPED FORM***
      C
      C  ***ALL CARDS BRACKETED WITH  ***  ARE COMMENTS AND MUST BE REMOVED FROM***
      C  ***THE DATA SET BEFORE THE PROGRAM WILL EXECUTE PROPERLY***
      C
      C  ***THE FOLLOWING CARD READS IN THE NUMBER OF STREAMLINES (FLOWTUBES+1) AND***
      C ***THE NUMBER OF EQUIPOTENTIAL DROPS IN THE DIGITIZED FLOWNET BEING PLOTTED***
        20  18
      C
      C  ***TITLE CARD FOLLOWS***
       SCS SITE 13 SUGAR CREEK WATERSHED --A BEFORE MAP USING CONVERGING FLOW--CPT2
      C
      C  *** HIGHEST EQUIPOTENTIAL LINE AND THE DROP BETWEEN EQUIPOTENTIALS FOLLOW***
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
     1420.  2.
C    ***THE NEXT 3 DATA CARDS ARE THE REFERENCE POINTS USED TO RELATE DIGITIZED***
C    ***POINTS TO MAP DISTANCES IN A  FLOWNET***
C
C    ***REFERENCE POINT NUMBERS  ARE IN COLUMNS 7&8, COLUMNS 11THRU 14 AND 17***
C    ***THRU 20 CONTAIN THE DIGITIZED  X&Y COORDINATES, COLUMNS 22THRU 25 ,32***
C    ***THRU 35 AND 42 THRU45 CONTAIN THE  DISTANCE IN INCHES FROM THE ORIGIN ***
C    ***TO THE REFERENCE POINT IN THE X,Y, &Z DIRECTIONS RESPECTIVELY***
C    ***COLUMNS 61 THRU 76 ARE FOR THE MAP TITLE AND COLUMNS 79 &80 THE SEGMENT***
C    ***OF THE MAP  BEING PLOTTED***
C
  00  01  .865  .969 10.0        9.0         .0               SITE 13 BEFORE V  01
  00  02  .861  .699 12.0        9.0         .0               SITE 13 BEFORE V  01
  00  03  .767  .555 13.0        8.0         .0               SITE 13 BEFORE V  01
C
C                                      ***MAP SEGMENT 1***
C
C    ***EACH CARD WHICH FOLLOWS REPRESENTS ONE INTERSECTION POINT ON THE FLOWNET**
C    ***COLUMNS 1 THRU 4 IS THE FLOWTUBE NO., COLUMNS 5 THRU 8 IS THE FLOWTUBE***
C    ***ELEMENT NO., COLUMNS 11THRU 14 AND COLUMNS 17 THRU 20 ARE THE DIGITIZED***
C    ***X AND Y COORDINATES RESPECTIVELY, AND COLUMNS 61 THRU 76 AND 79 THRU 80***
C    ***ARE THE TITLE AND SEGMENT NUMBERS ,RESPECTIVELY***

C    ***A BLANK CARD FOLLOWS  EACH MAP SEGMENT***
  01  13  .023  .266                                          SITE 13 BEFORE V  01
  01  14  .100  .187                                          SITE 13 BEFORE V  01
  01  15  .128  .147                                          SITE 13 BEFORE V  01
  01  16  .147  .124                                          SITE 13 BEFORE V  01
  01  17  .196  .059                                          SITE 13 BEFORE V  01
  01  18  .225  .012                                          SITE 13 BEFORE V  01
  02  10  .007  .591                                          SITE 13 BEFORE V  01
  02  11  .027  .545                                          SITE 13 BEFORE V  01
  02  12  .047  .495                                          SITE 13 BEFORE V  01
  02  13  .099  .369                                          SITE 13 BEFORE V  01
  02  14  .139  .301                                          SITE 13 BEFORE V  01
  02  15  .174  .258                                          SITE 13 BEFORE V  01
  02  16  .199  .204                                          SITE 13 BEFORE V  01
  02  17  .233  .111                                          SITE 13 BEFORE V  01
  03  10  .066  .666                                          SITE 13 BEFORE V  01
  03  11  .088  .617                                          SITE 13 BEFORE V  01
  03  12  .107  .583                                          SITE 13 BEFORE V  01
  03  13  .157  .496                                          SITE 13 BEFORE V  01
  03  14  .181  .455                                          SITE 13 BEFORE V  01
  03  15  .237  .313                                          SITE 13 BEFORE V  01
  03  16  .247  .259                                          SITE 13 BEFORE V  01
  03  17  .249  .235                                          SITE 13 BEFORE V  01
  04  10  .117  .725                                          SITE 13 BEFORE V  01
  04  11  .139  .682                                          SITE 13 BEFORE V  01
  04  12  .158  .643                                          SITE 13 BEFORE V  01
  04  13  .200  .567                                          SITE 13 BEFORE V  01
  04  14  .219  .527                                          SITE 13 BEFORE V  01
  04  15  .269  .407                                          SITE 13 BEFORE V  01
  05  07  .081  .972                                          SITE 13 BEFORE V  01
  05  08  .113  .911                                          SITE 13 BEFORE V  01
```

80/80 LIST

0000000001111111111222222222233333333334444444444555555555566666666667777777778
1234567890123456789012345678901234567890123456789012345678901234567890123456789 0

CARD					
595	05	09	.134	.857	SITE 13 BEFORE V 01
596	05	10	.166	.795	SITE 13 BEFORE V 01
597	05	11	.203	.734	SITE 13 BEFORE V 01
598	05	12	.221	.707	SITE 13 BEFORE V 01
599	05	13	.265	.619	SITE 13 BEFORE V 01
600	05	14	.276	.580	SITE 13 BEFORE V 01
601	05	15	.289	.537	SITE 13 BEFORE V 01
602	06	10	.257	.961	SITE 13 BEFORE V 01
603	06	11	.290	.879	SITE 13 BEFORE V 01
604	06	12	.329	.773	SITE 13 BEFORE V 01
605	06	13	.337	.741	SITE 13 BEFORE V 01
606	07	11	.361	.935	SITE 13 BEFORE V 01
607	14	10	.403	.962	SITE 13 BEFORE V 01
608	14	11	.359	.926	SITE 13 BEFORE V 01
609	15	06	.688	.991	SITE 13 BEFORE V 01
610	15	07	.636	.955	SITE 13 BEFORE V 01
611	15	08	.590	.917	SITE 13 BEFORE V 01
612	15	09	.535	.875	SITE 13 BEFORE V 01
613	15	10	.459	.829	SITE 13 BEFORE V 01
614	15	11	.391	.784	SITE 13 BEFORE V 01
615	15	12	.353	.755	SITE 13 BEFORE V 01
616	15	13	.337	.739	SITE 13 BEFORE V 01
617	16	03	.869	.996	SITE 13 BEFORE V 01
618	16	04	.846	.949	SITE 13 BEFORE V 01
619	16	05	.823	.913	SITE 13 BEFORE V 01
620	16	06	.784	.848	SITE 13 BEFORE V 01
621	16	07	.737	.799	SITE 13 BEFORE V 01
622	16	08	.646	.733	SITE 13 BEFORE V 01
623	16	09	.603	.721	SITE 13 BEFORE V 01
624	16	10	.524	.700	SITE 13 BEFORE V 01
625	16	11	.457	.657	SITE 13 BEFORE V 01
626	16	12	.419	.635	SITE 13 BEFORE V 01
627	16	13	.347	.601	SITE 13 BEFORE V 01
628	16	14	.317	.575	SITE 13 BEFORE V 01
629	16	15	.291	.544	SITE 13 BEFORE V 01
630	17	03	.961	.484	SITE 13 BEFORE V 01
631	17	04	.927	.503	SITE 13 BEFORE V 01
632	17	05	.889	.517	SITE 13 BEFORE V 01
633	17	06	.852	.536	SITE 13 BEFORE V 01
634	17	07	.817	.547	SITE 13 BEFORE V 01
635	17	08	.717	.555	SITE 13 BEFORE V 01
636	17	09	.682	.549	SITE 13 BEFORE V 01
637	17	10	.583	.531	SITE 13 BEFORE V 01
638	17	11	.551	.521	SITE 13 BEFORE V 01
639	17	12	.488	.499	SITE 13 BEFORE V 01
640	17	13	.383	.457	SITE 13 BEFORE V 01
641	17	14	.323	.437	SITE 13 BEFORE V 01
642	17	15	.271	.407	SITE 13 BEFORE V 01
643	18	08	.665	.297	SITE 13 BEFORE V 01
644	18	09	.647	.317	SITE 13 BEFORE V 01
645	18	10	.623	.332	SITE 13 BEFORE V 01
646	18	11	.595	.341	SITE 13 BEFORE V 01
647	18	12	.537	.346	SITE 13 BEFORE V 01
648	18	13	.413	.327	SITE 13 BEFORE V 01

80/80 LIST

```
        00000000011111111112222222222333333333344444444445555555555666666666677777777778
        12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 649     18  14  .351  .301                                           SITE 13 BEFORE V  01
 650     18  15  .318  .286                                           SITE 13 BEFORE V  01
 651     18  16  .273  .249                                           SITE 13 BEFORE V  01
 652     18  17  .250  .235                                           SITE 13 BEFORE V  01
 653     19  11  .596  .199                                           SITE 13 BEFORE V  01
 654     19  12  .539  .203                                           SITE 13 BEFORE V  01
 655     19  13  .445  .199                                           SITE 13 BEFORE V  01
 656     19  14  .383  .191                                           SITE 13 BEFORE V  01
 657     19  15  .355  .185                                           SITE 13 BEFORE V  01
 658     19  16  .296  .171                                           SITE 13 BEFORE V  01
 659     19  17  .233  .114                                           SITE 13 BEFORE V  01
 660     20  13  .449  .057                                           SITE 13 BEFORE V  01
 661     20  14  .407  .055                                           SITE 13 BEFORE V  01
 662     20  15  .373  .055                                           SITE 13 BEFORE V  01
 663     20  16  .325  .045                                           SITE 13 BEFORE V  01
 664     20  17  .251  .025                                           SITE 13 BEFORE V  01
 665     20  18  .225  .011                                           SITE 13 BEFORE V  01
 666
 667    C                           ***MAP SEGMENT 2***
 668     00  01  .275  .845  4.0      3.0      0.0                    SITE 13 BEFORE V  02
 669     00  02  .474  .695  5.0      5.0      3.11                   SITE 13 BEFORE V  02
 670     00  03  .077  .558  6.0      1.0      3.89                   SITE 13 BEFORE V  02
 671     05  06  .057  .013                                           SITE 13 BEFORE V  02
 672     06  06  .164  .177                                           SITE 13 BEFORE V  02
 673     06  07  .187  .134                                           SITE 13 BEFORE V  02
 674     06  08  .217  .065                                           SITE 13 BEFORE V  02
 675     06  09  .236  .021                                           SITE 13 BEFORE V  02
 676     07  01  .187  .655                                           SITE 13 BEFORE V  02
 677     07  02  .205  .590                                           SITE 13 BEFORE V  02
 678     07  03  .218  .525                                           SITE 13 BEFORE V  02
 679     07  04  .243  .447                                           SITE 13 BEFORE V  02
 680     07  05  .269  .356                                           SITE 13 BEFORE V  02
 681     07  06  .281  .313                                           SITE 13 BEFORE V  02
 682     07  07  .300  .227                                           SITE 13 BEFORE V  02
 683     07  08  .317  .169                                           SITE 13 BEFORE V  02
 684     07  09  .327  .103                                           SITE 13 BEFORE V  02
 685     07  10  .345  .019                                           SITE 13 BEFORE V  02
 686     08  01  .309  .739                                           SITE 13 BEFORE V  02
 687     08  02  .327  .681                                           SITE 13 BEFORE V  02
 688     08  03  .345  .611                                           SITE 13 BEFORE V  02
 689     08  04  .367  .549                                           SITE 13 BEFORE V  02
 690     08  05  .385  .467                                           SITE 13 BEFORE V  02
 691     08  06  .407  .391                                           SITE 13 BEFORE V  02
 692     08  07  .426  .303                                           SITE 13 BEFORE V  02
 693     08  08  .443  .213                                           SITE 13 BEFORE V  02
 694     08  09  .453  .159                                           SITE 13 BEFORE V  02
 695     09  01  .435  .817                                           SITE 13 BEFORE V  02
 696     09  02  .451  .753                                           SITE 13 BEFORE V  02
 697     09  03  .463  .675                                           SITE 13 BEFORE V  02
 698     09  04  .467  .605                                           SITE 13 BEFORE V  02
 699     09  05  .464  .501                                           SITE 13 BEFORE V  02
 700     09  06  .455  .405                                           SITE 13 BEFORE V  02
 701     09  07  .451  .387                                           SITE 13 BEFORE V  02
 702     10  01  .529  .881                                           SITE 13 BEFORE V  02
```

80/80 LIST

```
      00000000011111111112222222222333333333344444444445555555555666666666677777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 703    10  02  .543  .799                                                SITE 13 BEFORE V  02
 704    10  03  .525  .699                                                SITE 13 BEFORE V  02
 705    11  01  .688  .787                                                SITE 13 BEFORE V  02
 706    11  02  .619  .763                                                SITE 13 BEFORE V  02
 707    11  03  .527  .702                                                SITE 13 BEFORE V  02
 708    12  01  .693  .614                                                SITE 13 BEFORE V  02
 709    12  02  .645  .589                                                SITE 13 BEFORE V  02
 710    12  03  .591  .543                                                SITE 13 BEFORE V  02
 711    12  04  .553  .505                                                SITE 13 BEFORE V  02
 712    12  05  .507  .452                                                SITE 13 BEFORE V  02
 713    12  06  .465  .404                                                SITE 13 BEFORE V  02
 714    12  07  .451  .385                                                SITE 13 BEFORE V  02
 715    13  01  .738  .463                                                SITE 13 BEFORE V  02
 716    13  02  .694  .429                                                SITE 13 BEFORE V  02
 717    13  03  .659  .394                                                SITE 13 BEFORE V  02
 718    13  04  .613  .349                                                SITE 13 BEFORE V  02
 719    13  05  .575  .313                                                SITE 13 BEFORE V  02
 720    13  06  .543  .277                                                SITE 13 BEFORE V  02
 721    13  07  .507  .231                                                SITE 13 BEFORE V  02
 722    13  08  .467  .182                                                SITE 13 BEFORE V  02
 723    13  09  .453  .159                                                SITE 13 BEFORE V  02
 724    14  02  .740  .251                                                SITE 13 BEFORE V  02
 725    14  03  .698  .215                                                SITE 13 BEFORE V  02
 726    14  04  .657  .183                                                SITE 13 BEFORE V  02
 727    14  05  .614  .144                                                SITE 13 BEFORE V  02
 728    14  06  .567  .103                                                SITE 13 BEFORE V  02
 729    14  07  .517  .063                                                SITE 13 BEFORE V  02
 730    14  08  .473  .027                                                SITE 13 BEFORE V  02
 731    15  02  .793  .095                                                SITE 13 BEFORE V  02
 732    15  03  .763  .065                                                SITE 13 BEFORE V  02
 733    15  04  .731  .035                                                SITE 13 BEFORE V  02
 734  C  ***THE -1 ON THE NEXT CARD INDICATES THE END OF ALL DIGITIZED MAP SEGMENTS***
 735    -1
 736  C  ***THE FOLLOWING CARD IS THE SATURATED PERMEABILITY UNITS***
 737   FT/DAY
 738  C  ***THE CARDS WHICH FOLLOW  ARE THE KNOWN PERMEABILITY VALUES USED IN THE ***
 739  C  ***PROGRAM  APERM  , COLUMNS 1 THRU 4 ARE THE FLOWTUBE NO., COLUMNS 5 THRU***
 740  C  ***8 ARE THE FLOWTUBE ELEMENT NO., AND COLUMNS 10 THRU 16 ARE THE***
 741  C  ***SATURATED PERMEABILITY VALUES KNOWN AT THE CENTER OF THAT ELEMENT***
 742     1  13     4.02
 743     2  13     4.02
 744     3  13     4.02
 745     4  10     4.02
 746     5   7     4.02
 747     6   6     2.14
 748     7   3     2.14
 749     8   4     .402
 750     9   3     .938
 751    10   1     2.14
 752    11   1     4.02
 753    12   1     4.02
 754    13   6     2.28
 755    14   9     4.02
 756    15  15     1.34
```

80/80 LIST

```
     00000000011111111112222222222333333333344444444445555555555666666666677777777778
     12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 757   16  12    2.01
 758   17  14    2.01
 759   18  14    2.01
 760   19  16    1.50
 761   20  16    1.50
 762
 763
 764 C                                ***APPENDIX A IS COMPLETE***
```

APPENDIX B

COMPUTER PROGRAM LISTING FOR STEADY

ADAPTED TO IBM 360-50

WITH CONTROL CARDS

80/80 LIST

```
     00000000011111111112222222222333333333344444444445555555555666666666677777777778
     12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
     C                                   APPENDIX B
     C
     C
     C
     C                 ***STEADY STATE FLOW ANALYSIS PROGRAM***
     C
     C
     C   ***THIS PROGRAM LISTING IS AN ADAPTATION OF THE PROGRAM ' STEADY DARCIAN ***
     C   ***TRANSPORT OF FLUIDS IN HETEROGENEOUS PARTIALLY SATURATED POROUS MEDIA' ***
     C   ***FOR USE ON THE IBM 360-50 COMPUTER IN FORTRAN IV LANGUAGE***
     C
     C
     C   ***COMMENTS USED IN THESE PROGRAMS ARE TA<EN ,IN PART, FROM***
     C   ***STEADY DARCIAN TRANSPORT OF FLUIDS IN HETEROGENEOUS PARTIALLY***
     C   ***SATURATED PDROUS MEDIA, PT2, THE COMPUTER PROGRAM, REISENAUER,A.E.,***
     C   ***R.W.NELSON,AND E.N. KNUDSEN,1963***
     C
     C
                                          ***STEADY***
     C   ***STEADY CALLS SUBROUTINE CHLK1 AND CHLK2 IN PROPER SEQUENCE***
     C   ***THIS IS A SUBROUTINE REQUIRED FOR THE SYSEM TO RUN ON THE IBM 360-50***
     C
     C        STEADY
     C
            INTEGER*2 NO,MAT
            DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
            DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
            DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
            DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
            COMMON PHI,EK,NO
            COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
            COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
           1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
           2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
            COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
           1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NS<IP,J,K,I,NINEK,VINPHI,NCMAXJ,
           2NCMAXI,NCMAXK,NUM
            COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
           1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
           2DDUM4,DDUM5,ANGLE,PLOP
            COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
           1AXTERM,OTERM,CUNIT
            COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
            EQUIVALENCE (PLOP,DUM),(KEY,MUM)
            EQUIVALENCE (MAT,EK)
            IRSTRT=1
            CALL CHLK1
            CALL CHLK2(IRSTRT)
            STOP
            END
     C                                   ***RESTRT***
     C   ***RESTRT INITIALIZES ARRAYS IN PREPARATION FOR RESTARTING A SAVED PROBLEM***
     C
     C      RESTRT
```

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
C
      INTEGER*2 NO,MAT
      DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      IRSTRT=2
      REWIND 8
      READ(8) KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,
     1NSAT,N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,
     2NDUM1,NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      READ(8) IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,
     1ICOUNT,JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ
     2,NCMAXI,NCMAXK,NUM
      READ (8) BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3
     1,COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      READ (8) FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,
     1VTERM,AXTERM,OTERM,CUNIT
      READ (8) UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      NDXSML=1
      NDXLGE=1000
   10 IF (KIJTJT-(NDXLGE+10)) 50,50,20
   20 READ (8) (PHI(NDXV),NDXV=NDXSML,NDXLGE)
      READ (8) ( EK(NDXV),NDXV=NDXSML,NDXLGE)
      READ (8) ( NO(NDXV),NDXV=NDXSML,NDXLGE)
      NDXSML=NDXSML+1000
      NDXLGE=NDXLGE+1000
      GO TO 10
   50 READ (8) (PHI(NDXV),NDXV=NDXSML,KIJTOT)
      READ (8) ( EK(NDXV),NDXV=NDXSML,KIJTOT)
      READ (8) ( NO(NDXV),NDXV=NDXSML,KIJTOT)
      READ (8) NDY,DIFE,SDIFE,PSDIFE,CORR
      CALL CHLK2(IRSTRT)
      STOP
      END
C
C
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
                                          ***CHAIN LINK 1 ***
C   ***CHLK1 READS INPUT DATA AND PREPARES THE PROBLEM FOR CALCULATION***
C                          ***CHLK1 INCLUDES SUBROUTINES CUTTER AND TEST***
      SUBROUTINE CHLK1
C     STEADY DARCIAN FLOW IN SOILS
C     CHAIN LINK 1
C     ONE,TWO,OR THREE DIMENSIONAL STEADY STATE FLOW IN SOIL PROGRAM
C     UP TO 2000 NODE POINTS
C     CHAIN LINK 1 READS INPUT AND PREPARES FOR ITERATIONS THRU MATRIX
C     PROGRAMMER NOTE THE COORDINATE INDICES USED INTERNALLY DO NOT
C     CONFORM TO USUAL MATHEMATICAL CONVENTION.
C     COORDINATE          INTERNAL INDEX        EXTERNAL (DOCUMENT) INDEX
C         X                     K                             I
C         Y                     J                             J
C         Z                     I                             K
      INTEGER*2 NO,MAT
      DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
 5001 FORMAT(' ERROR EXIT ON LOADING BY COLUMN OF CHANGE Y= ',I3,'TO Y='
     1,I3,5X,'Z=',I3,' TO Z=',I3,2X,'CHANGES=',I5,2X,'FIRST NUMBER LOADE
     2D IS ',A4)
    1 FORMAT (I5,15A4)
    2 FORMAT (I2,E10.4)
    3 FORMAT (14I5)
    4 FORMAT (14(I3,F2.0))
   30 FORMAT (F5.0,3I5)
   60 FORMAT (7(I4,F6.0))
   70 FORMAT (7E10.4)
   71 FORMAT (4E10.4,I2)
  300 FORMAT (5I3)
  752 FORMAT (8F9.7)
 3009 FORMAT (4(I5,E10.4))
C     CASE IDENTIFICATION AND SWITCH SETTERS READ IN
      READ(5,1) NCASE,CODE
      READ(5,3) NSAT,NINPHI,NINEK,NCUT,NAVG,NAXI,NPUN,NBUG,NGRAP,NDUM3
C     READ-IN SOIL DATA FOR K CALCULATION ON NSAT=1
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      GO TO (600,2000),NSAT
  600 READ(5,2) NUM,CUNIT
      DO 705  M=1,NUM
      READ(5,71)UK1(M),UK2(M),UK3(M),STEK3(M),MEK3
      READ(5,70)CK1(M),(CK2(M,N),N=1,2),(CK3(M,N),N=1,MEK3),(CK4(M,N),N=
     11,2)
      IF(NDUM3)705,640,705
C     CALCULATE PERMEABILITY COUPLING RATIO FOR HETEROGENEOUS SOILS
  640 IF(M-1)650,650,655
  650 RWN=CK1(1)
  655 CK1(M)=CK1(M)/RWN
      CK2(M,1)=CK2(M,1)*CK1(M)
      CK2(M,2)=CK2(M,2)*CK1(M)
      DO 675 N=1,MEK3
  675 CK3(M,N)=CK3(M,N)*CK1(M)
      CK4(M,1)=CK4(M,1)*CK1(M)
C     UNIT CORRECT SOIL DATA IF NECESSARY
      IF (CUNIT-1.)706,705,706
  706 UK1(M)=UK1(M)*CUNIT
      UK2(M)=UK2(M)*CUNIT
      UK3(M)=UK3(M)*CUNIT
      CK2(M,1)=CK2(M,1)/CUNIT
      CK4(M,1)=CK4(M,1)*CUNIT**CK4(M,2)
      STEK3(M)=STEK3(M)*CUNIT
  705 CONTINUE
C     READ CASE INPUT
 2000 READ(5,3) NCMAXJ,NCMAXI,NCMAXK,ICMAXJ,ICMAXI,ICMAXK,JJ,II,KK,
     1NDUM1,NDUM2,NDUM4
      READ(5,70)DELZ,H,ANGLE,BEE,DEE,AYE,ELENG
      READ(5,70)PHIMAX,P1,DUM1,DUM2,DUM4
      READ(5,30)COR1,N1,N2,N3
C     SET-UP UNCUT DIMENSIONS FOR PHI READ-IN
      MAXJ=NCMAXJ
      MAXI=NCMAXI
      MAXK=NCMAXK
C     COMPUTE SINE AND COSINE OF ANGLE OF SYSTEM INCLINATION
      CANGLE=COS(ANGLE)
      DDUM4=H
      DDUM5=ELENG
      GO TO (4000,4001),NSAT
C     UNIT CORRECT COLUMN LENGTH
 4000 ELENG=ELENG*CUNIT
      DUM1 =RWN
      H=H*CUNIT
C     DETERMINE IF AND HOW MATRIX IS TO BE CUT-UP
 4001 IF(NCMAXI-ICMAXI) 2070,2071,2070
 2071 ICUT=1
      GO TO 2072
 2070 ICUT=NCMAXI/ICMAXI+1
C     READ INITIAL PHI,K,MATERIAL,AND CALC TYPE MATRICES
 2072 III=1
   15 GO TO (7,3000,21,21),III
C     INITIAL K IN
 3000 GO TO (3006,3001),NINEK
```

80/80 LIST

```
0000000001111111111222222222233333333334444444444555555555566666666667777777777778
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

      SANGLE=SIN(ANGLE)
 3006 READ (5,300) JB,JT,IB,IT,KKK
      IF (KKK) 3050,3050,3007
C     INITIAL K-WHOLE LINE
 3050 READ(5,70) (PLOP(K),K=1,MAXK)
      GO TO 2050
C     INITIAL K-BY POINTS OF CHANGE
 3007 READ(5,3009) ((KEY(JJJ),PLOP(JJJ)),JJJ=1,KKK)
      GO TO 20
C     MATERIAL AND CALC TYPES-BY POINTS OF CHANGE
   21 READ(5,300) JB,JT,IB,IT,KKK
      READ(5,4) ((KEY(JJJ),PLOP(JJJ)),JJJ=1,KKK)
      GO TO 20
C     INITIAL PHIS
    7 GO TO (750,3001),NINPHI
  750 READ(5,300)JB,JT,IB,IT,KKK
      IF(KKK)3051,3051,8
C     INITIAL PHI-WHOLE LINE
 3051 READ(5,752)(PLOP(K),K=1,MAXK)
C     WHOLE LINE IN ROUTINE
 2050 DO 751 J=JB,JT
      DO 751 I=IB,IT
      DO 751 K=1,MAXK
      JAM=MAXI*MAXK*(J-1)+MAXK*(I-1)+K
      IF (III-2) 2004,2005,2005
 2004 PHI(JAM)=PLOP(K)
      GO TO 751
 2005 EK(JAM)=PLOP(K)
  751 CONTINUE
      GO TO 22
C     WHOLE MATRIX IN ROUTINE
 3001 KIJTOT=MAXI*MAXK*MAXJ
      IF(III-2)3002,3003,3003
 3002 READ(5,752)(PHI(JAM),JAM=1,KIJTOT)
      GO TO 2008
 3003 READ(5,70) (EK(JAM),JAM=1,KIJTOT)
      GO TO 2009
C     ITITIAL PHI-BY POINTS OF CHANGE
    8 READ(5,60) (KEY(JJJ),PLOP(JJJ),JJJ=1,KKK)
C     POINT OF CHANGE ROUTINE
   20 KEY(KKK+1)=0
      IF(KKK-501) 4100,5000,5000
 4100 IF(IT-501) 4111,5000,5000
 4111 IF(JT-31) 3888,5000,5000
 5000 WRITE(6,5001) JB,JT,IB,IT,KKK,PLOP(1)
      LSW=9
      GO TO 2080
 3888 DO 9 J=JB,JT
      DO 9 I=IB,IT
      JJJ=1
      DO 9 K=1,MAXK
      IF (K-KEY(JJJ+1)) 10,11,10
   11 JJJ=JJJ+1
   10 JAM=MAXI*MAXK*(J-1)+MAXK*(I-1)+K
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      GO TO (12,2006,13,105),III
   12 PHI(JAM)=PLOP(JJJ)
      GO TO 9
 2006 EK(JAM)=PLOP(JJJ)
      GO TO 9
   13 MAT(JAM)=PLOP(JJJ)
      GO TO 9
  105 NO (JAM)=PLOP(JJJ)
    9 CONTINUE
C     GET ALL OF MATRICES
   22 IF(MAXI-IT)14,14,15
   14 IF(MAXJ-JT)2007,2007,15
C     SET-UP FOR NEXT MATRIX-PICK-UP PROPER MATRIX DIMENSIONS
 2007 GO TO (2008,2009,2010,2011),III
 2008 GO TO (2012,2013),NSAT
 2012 III=3
      NCUT=1
      GO TO 2022
 2013 III=2
      IF(ICUT-1)2020,2020,2021
 2021 IF(NCUT-2)2022,2020,2020
 2009 III=4
      GO TO 2022
 2010 III=4
      GO TO 2022
C     SIZE OF UNCUT MATRIX
 2020 MAXJ=NCMAXJ
      MAXI=NCMAXI
      MAXK=NCMAXK
      GO TO 15
C     SIZE OF CUT MATRIX
 2022 MAXJ=ICMAXJ
      MAXI=ICMAXI
      MAXK=ICMAXK
      GO TO 15
C     SET-UP TO CUT MATRIX IF NECESSARY
 2011 IDUMP=1
      IF(ICUT-1)2014,2014,2023
 2023 MAXJ=NCMAXJ
      MAXI=NCMAXI
      MAXK=NCMAXK
C     SUBROUTINE CUTTER REMOVES ROWS AND COLUMNS FROM A MATRIX
      CALL CUTTER
      GO TO (2014,2015),IDUMP
C     ERROR EXIT-ON FAILURE IN CUTTER ROUTINE
 2015 GO TO 2080
C     DETERMINE IF 1,2 OR 3D MATRIX
 2014 IF(MAXJ-1) 400,400,2030
  400 IF(MAXK-1)2031,2031,401
 2031 NSIZE=1
      GO TO 402
  401 NSIZE=2
      GO TO 402
 2030 NSIZE=3
```

80/80 LIST

```
 00000000011111111112222222222333333333344444444445555555555666666666677777777778
 12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 C      SUBROUTINE TESTS FOR ILLOGICAL CALC TYPE CHOICES
    402 CALL TEST
        GO TO (306,403),IDUMP
 C      ERROR EXIT-ILLOGICAL CALC TYPE CHOICE
    403 LSW=6
        GO TO 2080
 C      PRINT INITIAL CONDITIONS
    306 LSW=1
        IKTOT=MAXI*MAXK
        KIJTOT=MAXI*MAXK*MAXJ
 C      CHAIN LINK 2         HANDLES ITERATION THRU THE MATRIX AND
 C      CALCULATES PHI AT EACH POINT
   2080 CONTINUE
        RETURN
        END
 C
 C
 C                                             ***TEST***
 C   ***SUBROUTINE TEST CHECKS CALCULATION TYPES AND TERMINATES THE PROBLEM ***
 C   ***WITH AN ERROR MESSAGE IF AN ILLOGICAL CHOICE IS MADE***
        SUBROUTINE TEST
        INTEGER*2 NO,MAT
        DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
        DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
        DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
        DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
        COMMON PHI,EK,NO
        COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
        COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
       1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
       2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
        COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
       1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
       2NCMAXI,NCMAXK,NUM
        COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
       1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
       2DDUM4,DDUM5,ANGLE,PLOP
        COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
       1AXTERM,OTERM,CUNIT
        COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
        EQUIVALENCE (PLOP,DUM),(KEY,MUM)
        EQUIVALENCE (MAT,EK)
        DO 600 J=1,MAXJ
        DO 600 I=1,MAXI
        DO 600 K=1,MAXK
        JAM=MAXI*MAXK*(J-1)+MAXK*(I-1)+K
        IMAG=NO(JAM)
        IF(IMAG)500,500,40
     40 GO TO (50,60,70),NSIZE
     50 IF(IMAG-4)89,89,500
     60 IF (IMAG-10)89,89,500
     70 IF(IMAG-28)89,89,500
     89 IF (J-1)90,90,91
     90 IF(K-1)100,100,101
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
     100 IF(I-1)102,102,103
     102 GO TO (401,402,403),NSIZE
     401 GO TO (600,500,600,500),IMAG
     402 GO TO (600,500,500,500,500,500,600,500,500,500),IMAG
     403 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
        1,500,500,500,500,500,600,500,500,500,500,500,500,500),IMAG
     103 IF (I-MAXI) 104,105,105
     104 GO TO (404,405,406),NSIZE
     404 GO TO 600
     405 GO TO (600,500,500,500,600,500,600,500,600,500),IMAG
     406 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
        1,500,600,500,5C0,500,600,500,500,500,600,500,500,500),IMAG
     105 GO TO (407,408,409),NSIZE
     407 GO TO (600,500,500,600),IMAG
     408 GO TO (600,500,500,500,500,500,500,500,600,500),IMAG
     409 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
        1,500,500,500,500,500,500,500,500,500,600,500,500,500),IMAG
     101 IF(K-MAXK)106,1C7,107
     106 IF(I-1) 108,108,109
     108 GO TO (500,410,411),NSIZE
     410 GO TO (600,500,600,500,500,500,600,600,500,500),IMAG
     411 GO TO (600,500,500,500,500,500,500,500,500,500,600,500,500,500,500
        1,500,500,500,500,500,600,500,600,500,500,500,500,500),IMAG
     109 IF (I-MAXI)110,111,111
     110 GO TO (500,412,413),NSIZE
     412 GO TO 600
     413 GO TO (600,500,500,500,500,500,600,500,500,500,600,500,500,500,600
        1,500,600,500,600,500,600,500,600,500,600,500,600,500),IMAG
     111 GO TO (500,414,415),NSIZE
     414 GO TO (600,500,500,600,500,500,500,500,600,600),IMAG
     415 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,600
        1,500,500,500,500,500,500,500,500,500,600,500,600,500),IMAG
     107 IF (I-1)112,112,113
     112 GO TO (500,416,417),NSIZE
     416 GO TO (600,500,500,500,500,500,500,600,500,500),IMAG
     417 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
        1,500,500,500,5C0,500,500,500,600,500,500,500,500,500),IMAG
     113 IF (I-MAXI)114,115,115
     114 GO TO (50C,418,419),NSIZE
     418 GO TO (600,500,500,500,500,600,500,600,500,600),IMAG
     419 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
        1,500,500,500,6C0,500,500,500,600,500,500,500,600,500),IMAG
     115 GO TO (500,420,421),NSIZE
     420 GO TO (600,500,500,500,500,500,500,500,500,600),IMAG
     421 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
        1,500,500,500,500,500,500,500,500,500,500,500,600,500),IMAG
      91 IF(J-MAXJ)  92,93,93
      92 IF (K-1)200,20C,201
     200 IF (I-1)202,202,203
     202 GO TO (600,500,500,500,500,500,500,500,600,500,500,500,500,500,500
        1,500,500,500,500,500,600,600,500,500,500,500,500,500),IMAG
     203 IF(I-MAXI)204,205,205
     204 GO TO (600,500,500,500,600,500,500,500,600,500,500,500,600,500,500
        1,500,600,600,500,500,600,600,500,500,600,600,500,500),IMAG
```

80/80 LIST

```
0000000001111111111222222222233333333334444444444555555555566666666667777777777 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
  205 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,600,500,500
     1,500,500,500,500,500,500,500,500,500,600,600,500,500),IMAG
  201 IF(K-MAXK)2C6,2C7,207
  206 IF(I-1)208,208,209
  208 GO TO (600,500,600,500,500,500,500,500,600,600,600,600,500,500,500
     1,500,500,500,500,500,600,600,600,600,500,500,500,500),IMAG
  209 IF(I-MAXI)210,211,211
  210 GO TO 600
  211 GO TO (600,500,500,600,500,500,500,500,500,500,500,500,600,600,600
     1,600,500,500,500,500,500,500,500,500,600,600,600,600),IMAG
  207 IF(I-1)212,212,213
  212 GO TO (600,500,500,500,500,500,500,500,500,600,500,500,500,500,500
     1,500,500,500,500,500,500,500,600,600,500,500,500,500),IMAG
  213 IF(I-MAXI)214,215,215
  214 GO TO (600,500,500,500,500,600,500,500,500,600,500,500,500,600,500
     1,500,500,500,60C,600,500,500,600,600,500,500,600,600),IMAG
  215 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,600,500
     1,500,500,500,500,500,500,500,500,500,500,500,600,600),IMAG
   93 IF (K-1)300,300,301
  300 IF(I-1)302,302,303
  302 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,500,500,500,500,500,600,500,500,500,500,500,500),IMAG
  303 IF(I-MAXI)304,305,305
  304 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,500,600,500,500,500,600,500,500,500,600,500,500),IMAG
  305 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,500,500,500,500,500,500,500,500,500,600,500,500),IMAG
  301 IF(K-MAXK)306,307,307
  306 IF(I-1)308,308,309
  308 GO TO (600,500,500,500,500,500,500,500,500,500,500,600,500,500,500
     1,500,500,500,500,500,500,600,500,600,500,500,500,500),IMAG
  309 IF(I-MAXI)310,311,311
  310 GO TO (600,500,500,500,500,500,500,600,500,500,500,600,500,500,500
     1,600,500,600,500,600,500,600,500,600,500,600,500,600),IMAG
  311 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,600,500,500,500,500,500,500,500,500,500,600,500,600),IMAG
  307 IF(I-1)312,312,313
  312 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,500,500,500,500,500,500,500,600,500,500,500,500),IMAG
  313 IF(I-MAXI)314,315,315
  314 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,500,500,500,600,500,500,500,600,500,500,500,600),IMAG
  315 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,500,500,500,500,500,500,500,500,500,500,500,600),IMAG
  600 CONTINUE
      GO TO 700
  500 IDUMP=2
      LSW=6
  700 RETURN
      END
C
C
C                                     ***CUTTR***
C     ***SUBROUTINE CUTTR  REDUCES MATRIX SIZE BY REMOVING ROWS AND COLUMNS***
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      SUBROUTINE CUTTER
C     SUBROUTINE CUTTER REMOVES ROWS AND COLUMNS FROM A MATRIX
      INTEGER*2 NO,MAT
      DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NS<IP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      ICOUNT=0
    1 ICOUNT=ICOUNT+1
      GO TO (2,3,4,16,17,18,7),ICOUNT
C     TEST IF PROPOSED MATRIX CUT INCLUDES BOUNDARIES
    2 NDUM1=MAXK
      NDUM2=KK
      GO TO 5
    3 NDUM1=MAXI
      NDUM2=II
      GO TO 5
    4 NDUM1=MAXJ
      NDUM2=JJ
      GO TO 5
   16 NDUM1=KK
      NDUM2=1
      GO TO 5
   17 NDUM1=II
      NDUM2=1
      GO TO 5
   18 NDUM1=JJ
      NDUM2=1
    5 DIFF=(FLOAT(NDUM1)-FLOAT(NDUM2))/FLOAT(ICUT)
      IDIFF=IFIX (DIFF)
      XDIFF=FLOAT(IDIFF)
      IF(XDIFF-DIFF)6,1,6
C     ERROR EXIT-CUTTER ROUTINE-PROPOSED CUT DOES NOT INCLUDE BOUNDARY
C     LSW=7
    6 LSW=7
      IDUMP=2
      GO TO 15
C     MATRIX ROWS AND COLUMNS CUT OUT
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
       7 DO 8 M=1,NCUT
         JAM=0
         DO 8 J=1,MAXJ,ICUT
         DO 8 I=1,MAXI,ICUT
         KLEFT=MAXI*MAXK*(J-1)+MAXK*(I-1)+1
         KRIGHT=KLEFT+MAXK-1
         DO 8 K=KLEFT,KRIGHT,ICUT
         JAM=JAM+1
         GO TO (9,10),M
       9 PHI(JAM)=PHI(K)
         GO TO 8
      10 EK(JAM)=EK(K)
       8 CONTINUE
C        CALCULATE CUT DIMENSIONS
         MAXK=MAXK/ICUT+1
         MAXI=MAXI/ICUT+1
         MAXJ=MAXJ/ICUT+1
         JJ=JJ/ICUT+1
         II=II/ICUT+1
         KK=KK/ICUT+1
C        CHECK CALC CUT DIMENSIONS AGAINST INPUT CUT DIMENSIONS
         IF(MAXK-ICMAXK) 11,12,11
      12 IF(MAXI-ICMAXI) 11,13,11
      13 IF(MAXJ-ICMAXJ) 11,14,11
      14 DELZ=DELZ*FLOAT(ICUT)
         GO TO 15
C        ERROR EXIT-CUTTER ROUTINE-CALCULATED CUT DIMENSIONS DO NOT AGREE
C        WITH INPUT CUT DIMENSIONS-LSW=8
      11 LSW=8
         IDUMP=2
      15 RETURN
         END
C
C
C                                      ***CHAIN LINK 2***
C     ***CHLK2 CONTAINS SUBROUTINES STEP, KAY,FHI, INPUT, OUT, RELAX, SAVE,***
C     ***ADDRS,GMAN,GNO***
C     ***CHLK2 HANDLES THE ITERATION THROUGH THE MATRIX AND COMPUTES THE OPTIMUM***
C     ***OVERRELAXATION FACTOR***
         SUBROUTINE CHLK2(IRSTRT)
C        CHAIN LINK 2  HANDLES ITERATION THRU THE MATRIX AND CALCULATES
C        PHI AT EACH POINT
         INTEGER*2 NO,MAT
         DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
         DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
         DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
         DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
         COMMON PHI,EK,NO
         COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
         COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
        1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
        2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
         COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
        1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
C  THE FOLLOWING COMMON IS USED TO COMMUNICATE BETWEEN STEP AND CHLK2.
C  VALUES ARE DEFINED IN STEP AND ASSUMED TO BE THE SAME WHEN STEP IS RECALLED.
      COMMON ISIGN,KSIGN,NBT,NMID,NEND
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
  209 FORMAT (I1)
  401 FORMAT (3HOL=I3,3H Y=I3,3H Z=I3,3H X=I3,23H TERMS OF THE EQUATION
     1 5E12.4/13H DENOMINATORS  3E12.4,9H CONSTANT  E12.4/7I5)
 1000 FORMAT(15A4)
 1001 FORMAT(14I5)
 1003 FORMAT(F5.0,3I5)
 2090 FORMAT (2I5)
 2091 FORMAT(7E11.6)
 2094 FORMAT (7E10.4)
C     SUBROUTINE OUT HANDLES ALL PRINTOUT-WELL NEARLY
      GO TO (7000,7001),IRSTRT
 7000 IF (LSW-6) 1004,2,2
 1004 CALL OUT
C     INITIALIZE
      LSW=2
      NDY=0
      L=1
      HI=0.
C     CALCULATE INITIAL K ON NSAT=1
      GO TO(2016,2017),NSAT
C     ADDRS SUBROUTINE MERGES MATERIAL AND TYPE OF CALC MATRIX INTO
C     ONE SET OF MEMORY LOCATIONS
 2016 CALL ADDRS
      DO 17 J=1,MAXJ
      DO 17 I=1,MAXI
   63 DO 17 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(I-1)+K
C     SUBROUTINE GMAN PICKS UP MATERIAL MATRIX FROM MERGED MATRIX
      CALL GMAN(MAN,NO,JAM)
  760 FRACT=(PHI(JAM)-BEE*CANGLE*DELZ*FLOAT(I-1)+DEE*SANGLE*DELZ*FLOAT(K
     1-1)-(AYE*H/ELENG))*ELENG
C     SUBROUTINE KAY COMPUTES K A FUNCTION OF FRACT-(PHI)
      CALL       KAY
      EK(JAM)=FK
   17 CONTINUE
 2017 CORR=COR1
      NSKIP=1
      HTERM=0.
      VTERM=0.
      OTERM=0.
      AXTERM=0.
      DUM3=0.
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C     ROUTINE TO SELECT TYPE OF STEPPING
      IF(KK-1)2030,2030,2031
 2030 IF(II-1)2032,2032,2033
 2032 NTYPE=2
      GO TO 31
 2033 IF(II-MAXI)2034,2035,2035
 2034 NTYPE=3
      GO TO 31
 2035 NTYPE=4
      GO TO 31
 2031 IF(KK-MAXK)2036,2037,2037
 2036 IF(II-1)2038,2038,2039
 2038 NTYPE=9
      GO TO 31
 2039 IF(II-MAXI)2040,2041,2041
 2040 NTYPE=1
      GO TO 31
 2041 NTYPE=5
      GO TO 31
 2037 IF(II-1)2042,2042,2043
 2042 NTYPE=8
      GO TO 31
 2043 IF(II-MAXI)2044,2045,2045
 2044 NTYPE=7
      GO TO 31
 2045 NTYPE=6
C     ITERATION THRU MATRIX FROM THIS POINT
   31 PSDIFE=SDIFE
      SDIFE=0.
      DO 15 JPLANE=1,MAXJ
C     ROUTINE TO PICK-UP PROPER I,K MATRIX
      IF(JPLANE-1) 1,1,3
    1 J=JJ
      GO TO 4
    3 IF(JJ-J)6,5,5
    5 J=J-1
      IF(J-1)7,4,4
    7 J=JJ+1
      GO TO 4
    6 J=J+1
    4 INIT=1
      ICOUNT=1
      MDUM1=IKTOT*(J-1)
      DO 15IP=1,MAXI
      DO 15KP=1,MAXK
C     SUBROUTINE STEP SETS-UP STEPPING THRU MATRIX AND INDICES OF
C     SURROUNDING POINTS
      CALL        STEP
      I=(JAM-MDUM1          )/MAXK+1
      K=JAM-MDUM1       -MAXK*(I-1)
      IF(K) 6000,6000,6001
 6000 K=MAXK
      I=I-1
 6001 INIT=INIT
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C     NSKIP CONTROLS SKIPPING OF A POINT ON TYPE OF CALC=1
      GO TO(44,15),NSKIP
   44 BEFORE=PHI(JAM)
      IF(NDUM3)2021,314,2021
C     SUBROUTINE FHI COMPUTES TERMS OF PHI EQUATION
  314 CALL      FHI
      PHI(JAM)=AVTERM+HTERM+VTERM+OTERM+AXTERM
C     OVER-RELAXATION CORRECTION
      PHI(JAM)=BEFORE+(PHI(JAM)-BEFORE)*CORR
      GO TO (2021,2022),NSAT
C     CALCULATE K IF NSAT=1
C     SUBROUTINE GMAN PICKS UP MATERIAL MATRIX FROM MERGED MATRIX
 2021 CALL GMAN (MAN,NO,JAM)
      FRACT=(PHI(JAM)-BEE*CANGLE*DELZ*FLOAT(I-1)+DEE*SANGLE*DELZ*FLOAT(K
     1-1)-(AYE*H/ELENG))*ELENG
C     SUBROUTINE KAY COMPUTES K A FUNCTION OF FRACT-(PHI)
      CALL KAY
      EK(JAM)=FK
 2022 GO TO (83,83,84),NBUG
C     TERMWISE DEBUG PRINTOUT
   84 WRITE(6,401)L,J,I,K,AVTERM,HTERM,VTERM,OTERM,AXTERM,DENOM1,DENOM2,
     1DENOM3,DENCON,JAM,MH1,MH2,MV1,MV2,MO1,MO2
C     FIND HIGHEST DIFFERENCE POINT IN ITERATION
   83 DIFE=ABS((PHI(JAM)-BEFORE)/CORR)
      SDIFE=SDIFE+DIFE
      IF(HI-DIFE)46,5C4,504
   46 HI=DIFE
      IHI=I
      KHI=K
      JHI=J
C     TEST PHI AGAINST INPUT VALUE
  504 IF(ABS(PHI(JAM))-ABS(PHIMAX)) 15,301,301
C     ERROR EXIT-CALCULATED PHI BIGGER THAN INPUT MAX VALUE-LSW=9
  301 LSW=9
      GO TO 2
   15 CONTINUE
      DUM3=SDIFE/FLOAT(KIJTOT)
C     DEBUG PRINTOUT
C     SUBROUTINE OUT HANDLES ALL PRINTOUT-WELL NEARLY
   71 CALL OUT
C     THE USER SHOULD CODE A TEST FOR EXCESSIVE TIME HERE.  IT COULD BE
C     A SENSE SWITCH TEST OR A TEST BASED ON ELAPSED TIME.  IS1 SHOULD
C     BE SET TO 1 IF TIME HAS BEEN EXCEEDED, 2 OTHERWISE.  IF NO TEST
C     IS DESIRED THE OPTION WILL BE IGNORED IF IS1 IS ALWAYS SET TO 2.
      IS1=2
   70 GO TO (202,250),IS1
C     NEED TO ITERATE AGAIN
  250 IF(HI-P1)19,19,20
C     NO MORE ITERATION
   19 LSW=3
C     PUNCH PHI AND K MATRIX IF DESIRED
      GO TO (2,2093),NPUN
 2093 WRITE(7,2090) NCASE,KIJTOT
      WRITE(7,2091)  (PHI(JAM),JAM=1,KIJTOT)
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      GO TO (2092,2),NSAT
 2092 WRITE(7,2094) (EK(JAM),JAM=1,KIJTOT)
C     END OF CASE PRINTOUT-LSW=3
C     SUBROUTINE OUT HANDLES ALL PRINTOUT-WELL NEARLY
    2 CALL OUT
 5000 STOP
C     ITERATE AGAIN
C     RE-INITIALIZE
   20 HI=0.
      DUM3=0.
      L=L+1
 4000 LSW=2
C     SET UP OVER-RELAXATION CORRECTION
      IF (L-N1) 28,28,22
   22 CALL RELAX(NSAT,SDIFE,PSDIFE,CORR,NDY)
   34 COR1=CORR
   35 N1=N1+N2
      GO TO 31
   28 IF(L-N3)31,31,30
C     GO TO SAVE ROUTINE-ITERATION LIMIT EXCEEDED
   30 LSW=4
      GO TO 602
C     GO TO SAVE ROUTINE-TIME RUN OUT
  202 LSW=5
C     PRINT BEFORE SAVE
  602 CALL OUT
C     SAVE ROUTINE
  600 CALL SAVE
      STOP
C     START-UP AFTER SAVE
 7001 READ (5,209) NCHG
      IF(NCHG) 50,50,210
  210 READ(5,1000) CODE
      READ(5,1001) NAVG,NPUN,NBUG,NGRAP,NDUM1,NDUM2,NDUM4
      READ(5,2094) PHIMAX,P1,DUM1,DUM4
      READ(5,1003) COR1,N1,N2,N3
   50 WRITE(6,4100) NCASE
 4100 FORMAT('1CASE NO.',I5,' RESTARTED AFTER BEING SAVED')
      IF (LSW-4) 4000,4000,250
      END
C
C
C                                          ***ADDRS***
C  ***ADDRS MERGES THE INTEGER SYMBOLS FOR THE CALCULATION AND SOIL TYPE***
C  ***INTO A SINGLE COMPUTER WORD***
      SUBROUTINE ADDRS
      INTEGER*2 NO,MAT
      DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
```

80/80 LIST

```
         00000000011111111112222222222333333333344444444445555555555666666666677777777778
         12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
             1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
             2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
              COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
             1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
             2NCMAXI,NCMAXK,NUM
              COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
             1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
             2DDUM4,DDUM5,ANGLE,PLOP
              COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
             1AXTERM,OTERM,CUNIT
              COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
              EQUIVALENCE (PLOP,DUM),(KEY,MUM)
              EQUIVALENCE (MAT,EK)
         C THIS SUBROUTINE MERGES MATERIAL MATRIX,MAT, AND TYPE OF CALC MATRIX,
         C NO, INTO ONE MATRIX
              DO 10 I=1,KIJTOT
           10 NO(I)=NO(I)+MAT(I)*100
              RETURN
              END
         C                                         ***FHI***
         C ***FHI CALCULATES THE TERMS OF THE EQUATION FOR THE POTENTIAL***
              SUBROUTINE FHI
              INTEGER*2 NO,MAT
              DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
              DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
              DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
              DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
              COMMON PHI,EK,NO
              COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
              COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
             1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
             2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
              COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
             1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
             2NCMAXI,NCMAXK,NUM
              COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
             1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
             2DDUM4,DDUM5,ANGLE,PLOP
              COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
             1AXTERM,OTERM,CUNIT
              COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
              EQUIVALENCE (PLOP,DUM),(KEY,MUM)
              EQUIVALENCE (MAT,EK)
         C    SUBROUTINE FHI COMPUTES TERMS OF PHI EQUATION
         C    THIS VERSION OF FHI WILL HANDLE ONLY EQUAL GRID SPACING
              GO TO(1,2),NAVG
            1 DENOM1=EK(JAM)
              DENOM2=EK(JAM)
              DENOM3=EK(JAM)
              GO TO 3
         C    AVG K IN DENOMINATOR
            2 GO TO(11,12,13),NSIZE
           13 DENOM3=(EK(MO2)+EK(MO1))*.5
           12 DENOM2=(EK(MH1)+EK(MH2))*.5
```

80/80 LIST

```
 000000000111111111122222222223333333333444444444455555555556666666666777777777778
 12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
     11 DENOM1=(EK(MV1)+EK(MV2))*.5
      3 GO TO (4,5,6),NSIZE
C       1-D
      4 AVTERM=(PHI(MV1)+PHI(MV2))/2.
        DENCON=8.
        GO TO 7
C       2-D
      5 AVTERM=(PHI(MH1)+PHI(MH2)+PHI(MV1)+PHI(MV2))/4.
        DENCON=16.
        GO TO (8,9),NAXI
C       AXISYMMETRICAL
      9 AXTERM=(PHI(MH2)-PHI(MH1))/(8.*(FLOAT(K)+DUM2-1.))
        GO TO 8
C       3-D
      6 AVTERM=(PHI(MH1)+PHI(MH2)+PHI(MV1)+PHI(MV2)+PHI(MO1)+PHI(MO2))/6.
        DENCON=24.
        OTERM=((EK(MO2)-EK(MO1))*(PHI(MO2)-PHI(MO1)))/(DENCON*DENOM3)
      8 HTERM=((EK(MH2)- EK(MH1))*(PHI(MH2)-PHI(MH1)))/(DENCON*DENOM2)
      7 VTERM=((EK(MV2)- EK(MV1))*(PHI(MV2)-PHI(MV1)))/(DENCON*DENOM1)
        RETURN
        END
C
C
C                                         ***STEP***
C   ***STEP CONTROLS THE ORIGIN ANDAND THE STEPPING THROUGH THE MATRIX***
        SUBROUTINE STEP
        INTEGER*2 NO,MAT
        DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
        DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
        DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
        DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
        COMMON PHI,EK,NO
        COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
        COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
       1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
       2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
        COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAV,INIT,NTYPE,ICOUNT,
       1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
       2NCMAXI,NCMAXK,NUM
        COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
       1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
       2DDUM4,DDUM5,ANGLE,PLOP
        COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
       1AXTERM,OTERM,CUNIT
        COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
C   THE FOLLOWING COMMON IS USED TO COMMUNICATE BETWEEN STEP AND CHLK2.
C   VALUES ARE DEFINED IN STEP AND ASSUMED TO BE THE SAME WHEN STEP IS RECALLED.
        COMMON ISIGN,KSIGN,NBT,NMID,NEND
        EQUIVALENCE (PLCP,DUM),(KEY,MUM)
        EQUIVALENCE (MAT,EK)
C       SUBROUTINE STEP SETS-UP STEPPING THRU MATRIX AND FINDS SURROUNDING
C       POINTS
        NSKIP=1
      9 GO TO (10,11),INIT
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
    10 GO TO (12,13,14,15,16,17,18,19,20),NTYPE
C      INITIALIZE STARTING COORDINATES DEPENDING ON TYPE OF STEPPING
    12 III=II
       KKK=KK
       GO TO (21,22,23,24),ICOUNT
    13 III=II-1
       KKK=KK-1
       GO TO 24
    14 III=II
       KKK=KK-1
       GO TO (22,24),ICOUNT
    15 III=II
       KKK=KK-1
       GO TO 22
    16 III=II
       KKK=KK
       GO TO (21,22),ICOUNT
    17 III=II
       KKK=KK
       GO TO 21
    18 III=II
       KKK=KK
       GO TO (21,23),ICOUNT
    19 III=II-1
       KKK=KK
       GO TO 23
    20 III=II-1
       KKK=KK
       GO TO (23,24),ICOUNT
C      STEPPING DOWN-LEFT -COMPUTE LIMITS
    21 ISIGN=-1
       KSIGN=-1
       NBT=MDUM1        +KKK
       NMID=MDUM1        +MAXK*(III-1)+KKK
       NEND=MDUM1+1
       GO TO 25
C      STEPPING DOWN-RIGHT-COMPUTE LIMITS
    22 ISIGN=-1
       KSIGN=+1
       NBT=MDUM1       +KKK+1
       NMID=MDUM1       +MAXK*(III-1)+KKK+1
       NEND=MDUM1+MAXK
       GO TO 25
C      STEPPING UP-LEFT   -COMPUTE LIMITS
    23 ISIGN=+1
       KSIGN=-1
       NBT=MDUM1        +MAXK*(MAXI-1)+KKK
       NMID=MDUM1       +MAXK*III+KKK
       NEND=MDUM1        +MAXK*(MAXI-1)+1
       GO TO 25
C      STEPPING UP-RIGHT  -COMPUTE LIMITS
    24 ISIGN=+1
       KSIGN=+1
       NBT=MDUM1       +MAXK*(MAXI-1)+KKK+1
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      NMID=MDUM1      +MAXK*(III)+KKK+1
      NEND=IKTOT*J
   25 JAM=NMID
      INIT=2
      GO TO 26
C     COMPUTE AND TEST PHI INDEX
   11 JAM=JAM+ISIGN*MAXK
      IF(ISIGN*(JAM-NBT))26,26,27
   27 NBT=NBT+KSIGN
      NMID=NMID+KSIGN
      JAM=NMID
      IF(KSIGN*(NBT-NEND))26,26,28
   28 ICOUNT=ICOUNT+1
      INIT=1
      GO TO 9
C     ROUTINE TO FIND SURROUNDING POINTS
C     SIX NORMAL SURROUNDING POINTS
   26 MH1=JAM-1
      MH2=JAM+1
      MV1=JAM-MAXK
      MV2=JAM+MAXK
      MO1=JAM-IKTOT
      MO2=JAM+IKTOT
C     SPECIAL CASES ON SURROUNDING POINTS
      GO TO (200,201),NSAT
  200 CALL GNO(IMAGE,NO,JAM)
      GO TO 202
  201 IMAGE=NO(JAM)
  202 GO TO (100,101,102),NSIZE
C     1-D
  100 GO TO (103,131,105,106),IMAGE
C     2-D
  101 GO TO (103,131,105,106,107,108,111,112,115,116),IMAGE
C     3-D
  102 GO TO (103,131,105,106,107,108,109,110,111,112,113,114,115,116,
     1117,118,119,120,121,122,123,124,125,126,127,128,129,130),IMAGE
  103 NSKIP=2
      GO TO 131
  105 MV1=MV2
      GO TO 131
  106 MV2=MV1
      GO TO 131
  107 MH1=MH2
      GO TO 131
  108 MH2=MH1
      GO TO 131
  109 MO1=MO2
      GO TO 131
  110 MO2=MO1
      GO TO 131
  111 MV1=MV2
      MH1=MH2
      GO TO 131
  112 MV1=MV2
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      MH2=MH1
      GO TO 131
  113 MV1=MV2
      MO1=MO2
      GO TO 131
  114 MV1=MV2
      MO2=MO1
      GO TO 131
  115 MV2=MV1
      MH1=MH2
      GO TO 131
  116 MV2=MV1
      MH2=MH1
      GO TO 131
  117 MV2=MV1
      MO1=MO2
      GO TO 131
  118 MV2=MV1
      MO2=MO1
      GO TO 131
  119 MH1=MH2
      MO1=MO2
      GO TO 131
  120 MH1=MH2
      MO2=MO1
      GO TO 131
  121 MH2=MH1
      MO1=MO2
      GO TO 131
  122 MH2=MH1
      MO2=MO1
      GO TO 131
  123 MV1=MV2
      MH1=MH2
      MO1=MO2
      GO TO 131
  124 MV1=MV2
      MH1=MH2
      MO2=MO1
      GO TO 131
  125 MV1=MV2
      MH2=MH1
      MO1=MO2
      GO TO 131
  126 MV1=MV2
      MH2=MH1
      MO2=MO1
      GO TO 131
  127 MV2=MV1
      MH1=MH2
      MO1=MO2
      GO TO 131
  128 MV2=MV1
      MH1=MH2
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      MO2=MO1
      GO TO 131
  129 MV2=MV1
      MH2=MH1
      MO1=MO2
      GO TO 131
  130 MV2=MV1
      MH2=MH1
      MO2=MO1
  131 RETURN
      END
C
C
C                                      ***KAY***
C  ***KAY COMPUTES CAPILLARY CONDUCTIVITY AS A FUNCTION OF CAPILLARY PRESS***
      SUBROUTINE KAY
      INTEGER*2 NO,MAT
      DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBJG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
C     SUBROUTINE KAY CCMPUTES K A FUNCTION OF FRACT-(PHI)
   10 IF(UK1(MAN)-FRACT)21,22,22
   21 FK=CK1(MAN)
      GO TO 20
   22 IF(UK2(MAN)-FRACT)23,24,24
   23 FK=CK2(MAN,1)*FRACT+CK2(MAN,2)
      GO TO 20
   24 IF(UK3(MAN)-FRACT)25,26,26
   25 M=((FRACT-UK2(MAN))/STEK3(MAN))+1.
      FK=CK3(MAN,M)+(CK3(MAN,M+1)-CK3(MAN,M))*((FRACT-
     1(STEK3(MAN)*FLOAT(M-1)+UK2(MAN)))/STEK3(MAN))
      GO TO 20
   26 FK=CK4(MAN,1)/(ABS(FRACT)**CK4(MAN,2))
   20 RETURN
      END
C
C
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
C                                          ***OUT***
C  ***OUT WRITES OUT ALL MESSAGES AND OUTPUT OF THE PROBLEM***
      SUBROUTINE OUT
      INTEGER*2 NO,MAT
      DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AVE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DJM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
C     SUBROUTINE OUT HANDLES ALL PRINTOUT-WELL NEARLY
      DIMENSION KROW(14)
  101 FORMAT (19H1INITIAL CONDITIONS)
  102 FORMAT (22H1ITERATION IS COMPLETE)
  103 FORMAT (17H1CASE IS COMPLETE)
  104 FORMAT (58H1NUMBER OF ITERATIONS HAS EXCEEDED THE LIMIT-PROGRAM SA
     1VED)
  105 FORMAT (34H1TIME LIMIT EXCEEDED-PROGRAM SAVED)
  106 FORMAT (  '1ERROR EXIT-AN ILLOGICAL CHOICE OF CALCULATION TYPE HAS
     1BEEN MADE-CHECK INPUT DATA')
  107 FORMAT (59H1ERROR EXIT-PROPOSED MATRIX CUT DOES NOT INCLUDE BOUNDA
     1RIES)
  108 FORMAT (90H1ERROR EXIT-CALCULATED CUT MATRIX DIMENSIONS DO NOT AGR
     1EE WITH INPUT CUT MATRIX DIMENSIONS)
  109 FORMAT('1ERROR EXIT-A CALCULATED PIEZOMETRIC HEAD VALUE HAS EXCEED
     1ED THE INPUT LIMIT')
  301 FORMAT (1H0, 8HCASE NO.I5,2X,15A4)
  322 FORMAT (17H PIEZOMETRIC HEAD)
   66 FORMAT(20H SOIL IDENTIFICATION)
  206 FORMAT (37H TYPE OF PIEZOMETRIC HEAD CALCULATION)
  324 FORMAT (32H RELATIVE CAPILLARY CONDUCTIVITY)
  325 FORMAT (30H MOISTURE CONTENT DISTRIBUTION)
 2000 FORMAT(3H0Y=I3)
  306 FORMAT(3H0Z=I3)
  600 FORMAT(5H0    14I8)
 3006 FORMAT(1H0,I12,9I11)
   14 FORMAT(1H+,F16.5,10F10.5/(F17.5,10F10.5))
   68 FORMAT(1H+I10,27I4/(I11,27I4))
 3011 FORMAT(1H+,5X,1P10E11.4/(6X,1P10E11.4))
 4011 FORMAT(1H+,5X,1P10E11.4)
```

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 4000 FORMAT(1HO)
 4001 FORMAT(1H )
 1010 FORMAT (1H1)
  115 FORMAT(45HOTHE NUMBER OF ITERATIONS IN THIS CASE EQUALSI5)
   72 FORMAT (11HOITERATION=,I3,15H HI DIFFERENCE=,  E11.4,3H Y=,I3,3H Z
     1=,I3,3H X=,I3,22H   AVERAGE DIFFERENCE=,E11.4,17H   O-RELAX. COR.=
     2,E11.4)
      GO TO (1,2,3,4,5,6,7,8,9),LSW
C     INITIAL CONDITIONS PRINTED OUT-LSW=1
    1 WRITE(6,101)
      GO TO 15
C     ITERATION PRINTOUT-LSW=2
C     NBUG=1-NOTHING
C     NBUG=2-HI DIFFERENCE AND POINT AND AVDIFE
C     NBUG=3-ABOVE PLUS PHI AND K
    2 GO TO (100,10,30),NBUG
   30 WRITE(6,102)
      GO TO 15
C     END OF CASE PRINTOUT-LSW=3
    3 WRITE(6,103)
      GO TO 15
C     SAVE-TOO MANY ITERATIONS-LSW=4
    4 WRITE(6,104)
      GO TO 31
C     SAVE-EXCEEDED TIME LIMIT-LSW=5
    5 WRITE(6,105)
   31 GO TO (15,15,100),NBUG
C     ERROR EXIT-ILLOGICAL TYPE OF CALC CHOICE-LSW=6
    6 WRITE(6,106)
      GO TO 15
C     ERROR EXIT-CUTTER ROUTINE-PROPOSED CUT DOES NOT INCLUDE BOUNDARY
C     LSW=7
    7 WRITE(6,107)
      GO TO 15
C     ERROR EXIT-CUTTER ROUTINE-CALCULATED CUT DIMENSIONS DO NOT AGREE
C     WITH INPUT CUT DIMENSIONS-LSW=8
    8 WRITE(6,108)
      GO TO 15
C     ERROR EXIT-CALCULATED PHI BIGGER THAN INPUT MAX VALUE-LSW=9
    9 WRITE(6,109)
C     CASE NO. AND CASE IDENT PRINTED OUT
   15 WRITE(6,301) NCASE,CODE
      GO TO (16,19,18,19,19,16,16,16,19),LSW
C     INPUT PRINTOUT
   16 CALL INPUT
      WRITE(6,1010)
      IF (LSW-6)19,19,100
   18 GO TO (19,20),NGRAP
C     NON GRAPHICAL PHI MATRIX PRINTOUT
   19 WRITE(6,322)
      DO 2041 J=1,MAXJ
      WRITE(6,2000) J
      DO 41 I=1,MAXI
      IREV=MAXI+1-I
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      WRITE(6,306) IREV
      DO 211 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
  211 DUM(K)=PHI(JAM)
   41 WRITE(6,14) (DUM(K),K=1,MAXK)
 2041 WRITE(6,4000)
      GO TO (22,703,703,703,703,22,100,100,25),LSW
   22 GO TO (1000,1050),NSAT
C     MATERIAL MATRIX PRINTOUT
 1000 WRITE(6,66)
      DO 2213 J=1,MAXJ
      WRITE(6,2000) J
      DO 213 I=1,MAXI
      IREV=MAXI+1-I
      WRITE(6,306) IREV
      DO 212 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
  212 MUM(K)=MAT(JAM)
  213 WRITE(6,68) (MUM(K),K=1,MAXK)
 2213 WRITE(6,1010)
C     TYPE OF CALC MATRIX PRINTOUT
 1001 WRITE(6,206)
      DO 2207 J=1,MAXJ
      WRITE(6,2000) J
      DO 207 I=1,MAXI
      IREV=MAXI+1-I
      WRITE(6,306) IREV
      DO 208 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
  208 MUM(K)=NO(JAM)
  207 WRITE(6,68) (MUM(K),K=1,MAXK)
 2207 WRITE(6,1010)
      GO TO 100
C     GRAPHICAL PHI AND K MATRIX PRINTOUT
   20 NPR=1
 3013 GO TO(3000,3001),NPR
 3000 NCOL=14
      GO TO 3002
 3001 NCOL=10
 3002 LL=NCOL
  514 IF(LL-MAXK) 511,512,513
  511 LL=LL+NCOL
      GO TO 514
  512 LINE=MAXK/NCOL
      GO TO 503
  513 LINE=MAXK/NCOL+1
  503 GO TO (3503,3003),NPR
 3503 WRITE(6,322)
      GO TO 3004
 3003 WRITE(6,324)
 3004 DO 2011 J=1,MAXJ
      WRITE(6,2000) J
  515 DO 11 LL=1,LINE
      K1=(LL-1)*NCOL+1
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      IF(LL-LINE) 516,517,517
  516 K2=K1+NCOL-1
      GO TO 518
  517 K2=MAXK
  518 DO 610 K=K1,K2
      K3=K-(LL-1)*NCOL
  610 KROW(K3)=K
      GO TO (611,3005),NPR
  611 WRITE(6,600) (KROW(K),K=1,K3)
      GO TO 618
 3005 WRITE(6,3006) (KROW(K),K=1,K3)
  618 DO 11 I=1,MAXI
      IREV=MAXI+1-I
      WRITE(6,306) IREV
  519 DO 526 K=K1,K2
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
      K3=K-(LL-1)*NCOL
      GO TO  (3007,3008),NPR
 3007 DUM(K3)=PHI(JAM)
      GO TO 526
 3008 DUM(K3)=EK(JAM)
  526 CONTINUE
      GO TO (3009,3010),NPR
 3009 WRITE(6,14) (DUM(K),K=1,K3)
      WRITE(6,4000)
      WRITE(6,4001)
      GO TO 11
 3010 WRITE(6,4011) (DUM(K),K=1,K3)
      WRITE(6,4000)
      WRITE(6,4000)
      WRITE(6,4001)
   11 CONTINUE
 2011 WRITE(6,1010)
      GO TO (3012,702),NPR
 3012 NPR=2
      GO TO (3013,702),NSAT
  703 GO TO (1050,702),NSAT
C     NON GRAPHICAL K MATRIX PRINTOUT
 1050 IF(NDUM3)1052,1051,1052
 1051 WRITE(6,324)
      GO TO 1053
 1052 WRITE(6,325)
 1053 DO 2309 J=1,MAXJ
      WRITE(6,2000) J
      DO 309 I=1,MAXI
      IREV=MAXI+1-I
      WRITE(6,306) IREV
      DO 202 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
  202 DUM(K)=EK(JAM)
  309 WRITE(6,3011) (DUM(K),K=1,MAXK)
 2309 WRITE(6,1010)
  702 GO TO (1001,10, 24,24,24,1001,100,100,100),LSW
   24 GO TO (25,100,100),NBUG
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C       NO OF ITERATIONS PRINTED OUT
     25 WRITE(6,115) L
        GO TO 100
C       HI DIFFERENCE AND POINT PRINTED OUT
     10 WRITE(6,72) L,HI,JHI,IHI,KHI,DUM3,COR1
    100 RETURN
        END
C
C
C                                         ***INPUT***
C    ***INPUT HANDLES THE PRINTOUT FOR THE INPUT DATA GIVEN TO THE PROBLEM***
        SUBROUTINE INPUT
        INTEGER*2 NO,MAT
        DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
        DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
        DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
        DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
        COMMON PHI,EK,NO
        COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
        COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
       1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
       2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
        COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
       1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
       2NCMAXI,NCMAXK,NUM
        COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
       1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
       2DDUM4,DDUM5,ANGLE,PLOP
        COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
       1AXTERM,OTERM,CUNIT
        COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
        EQUIVALENCE (PLOP,DUM),(KEY,MUM)
        EQUIVALENCE (MAT,EK)
        WRITE(6,100)
    100 FORMAT (25H0INPUT DATA FOR THIS CASE)
        GO TO (1,2,3),NSIZE
      1 WRITE(6,50)
     50 FORMAT (31H0THIS IS A ONE DIMENSIONAL CASE)
        GO TO 4
      2 GO TO (5,6),NAXI
      5 WRITE(6,51)
     51 FORMAT (31H0THIS IS A TWO DIMENSIONAL CASE)
        GO TO 4
      6 WRITE(6,52)
     52 FORMAT (31H0THIS IS AN AXISYMMETRICAL CASE)
        GO TO 4
      3 WRITE(6,53)
     53 FORMAT (33H0THIS IS A THREE DIMENSIONAL CASE)
      4 GO TO (7,8),NSAT
      7 WRITE(6,54)
     54 FORMAT (34H0UNSATURATED SOIL CONDITIONS EXIST)
        WRITE(6,112)
    112 FORMAT(26H0 SOIL TYPE IDENTIFICATION)
        WRITE(6,55)
```

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
   55 FORMAT (47H     SOIL NUMBER    PERMEABILITY COUPLING RATIO)
      WRITE(6,56) (M,CK1(M),M=1,NUM)
   56 FORMAT (I12,E28.4)
      WRITE(6,57) CUNIT
   57 FORMAT (40H  THE CAPILLARY PRESSURES ARE SCALED BY E11.4  )
      GO TO 9
    8 WRITE(6,58)
   58 FORMAT (32H0SATURATED SOIL CONDITIONS EXIST)
    9 WRITE(6,200) DUM1
  200 FORMAT (39H  SATURATED PERMEABILITY FOR SOIL NO.1 ,  E11.4)
      WRITE(6,62)
   62 FORMAT(22H0DESCRIPTION OF MATRIX)
      GO TO (10,11,11,11,11,11,11),ICUT
  10  WRITE(6,59) NCMAXJ,NCMAXI,NCMAXK
   59 FORMAT(28H  MATRIX DIMENSIONS ARE  Y= I3,4H Z= I3,4H X= I3)
      GO TO 12
   11 WRITE(6,60) NCMAXJ,NCMAXI,NCMAXK,ICMAXJ,ICMAXI,ICMAXK
   60 FORMAT(37H  MATRIX DIMENSIONS ARE  CUT FROM Y= I3,4H Z= I3,4H X=
     1I3,7H TO Y" I3,4H Z= I3,4H X= I3)
   12 WRITE(6,201) JJ,II,KK
  201 FORMAT (53H  THE COORDINATES OF THE POINT OF DISTURBANCE ARE Y= I3
     1,4H Z= I3,3H X=I3)
      WRITE(6,115)
  115 FORMAT (30H0PARAMETERS DESCRIBING PROBLEM)
      WRITE(6,116) DELZ
  116 FORMAT(33H  DISTANCE BETWEEN NODE POINTS IS  E12.4)
      WRITE(6,117) DDUM5
  117 FORMAT(18H  COLUMN LENGTH IS  E12.4)
      WRITE(6,118) DDUM4
  118 FORMAT(39H  VERTICAL TRANSLATION OF THE ORIGIN IS  E12.4)
      WRITE(6,119) ANGLE
  119 FORMAT(39H  ANGLE OF INCLINATION OF THE SYSTEM IS  E12.4)
      WRITE(6,120) BEE,DEE,AYE
  120 FORMAT(47H  COEFF. OF THE CAPILLARY PRESSURE EQUATION ARE  3E12.4)
      WRITE(6,61)
   61 FORMAT (36H0PIEZOMETRIC HEAD CALCULATION METHOD)
      GO TO (13,14),NAVG
   13 WRITE(6,63)
   63 FORMAT ( 81H  RELATIVE CAPILLARY CONDUCTIVITY VALUES USED IN THE D
     1ENOMINATOR ARE NOT AVERAGED)
      GO TO 15
   14 WRITE(6,64)
   64 FORMAT ( 77H  RELATIVE CAPILLARY CONDUCTIVITY VALUES USED IN THE D
     1ENOMINATOR ARE AVERAGED)
   15 WRITE(6,128)
  128 FORMAT(27H0 OVERRELAXATION CORRECTION)
      WRITE(6,129)
  129 FORMAT (  '     USED THROUGH ITERATION       FACTOR')
      WRITE(6,130) N1,COR1
  130 FORMAT (I17,16X,  E11.4)
      WRITE(6,131) N2,N3
  131 FORMAT (46H     OVERRELAXATION FACTOR RECALCULATED EVERY ,I3,18H I
     1TERATION UP TO ,I3,16H ITERATIONS MAX.)
      WRITE(6,202)
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
  202 FORMAT (17HOPROGRAM CONTROLS)
      WRITE(6,126) P1
  126 FORMAT(51H  IF THE HI. DIFF. BETWEEN ITERATIONS  IS LESS THAN   E1
     X2.4,21H,THE CASE IS COMPLETE)
      WRITE(6,65) PHIMAX
   65 FORMAT(49H  IF A CALCULATED PIEZOMETRIC HEAD VALUE EXCEEDS   E11.4
     1,21H,AN ERROR EXIT OCCURS)
      WRITE(6,66)
   66 FORMAT (19HODUMMY INPUT VALUES)
      WRITE(6,68)
   68 FORMAT (34H      INTEGERS      FLOATING VALUES)
      WRITE(6,67) NDUM1,DUM1
   67 FORMAT (I12,E20.4)
      WRITE(6,67) NDUM2,DUM2
      WRITE(6,67) NDUM4,DUM4
      RETURN
      END
C
C
C                                        ***RELAX***
C  ***RELAX CALCULATES THE OVERRELAXATION FACTOR AT SPECIFIED INTERVALS***
      SUBROUTINE RELAX(NSAT,SDIFE,PSDIFE,CORR,NDY)
   22 QM=SDIFE/PSDIFE
      FLAMSQ=(QM+CORR-1.)**2/(QM*CORR**2)
      IF (1.-FLAMSQ) 26,25,25
   26 FLAMSQ=-FLAMSQ
      NDY=NDY+1
   25 CORR=2./(1.+SQRT(1.-FLAMSQ))
      IF(NSAT-1)29,29,34
   29 IF(1-NDY)27,23,23
   23 IF(FLAMSQ) 27,27,32
   27 CORR=0.65+CORR*0.175
      GO TO 34
   32 CORR=1.+(CORR-1.)*.15
   34 RETURN
      END
C                                       ***GMAN***
C  ***GMAN RETRIEVES THE INTEGER DESIGNATION FOR THE SOIL FROM MEMORY***
C  THIS SUBROUTINE PICKS UP THE MATERIAL MATRIX FROM THE MERGED MATRIX
C  MAN IS THE SOIL NUMBER
      SUBROUTINE GMAN(MAN,NO,JAM)
      INTEGER*2 NO,MAT
      DIMENSION NO(1)
      MAN=NO(JAM)/100
      RETURN
      END
C                                        ***GNO***
C  ***GNO RETRIEVES THE INTEGER DESIGNATION OF THE CALCULATION TYPE***

C  THIS SUBROUTINE RETURNS CALCULATION TYPE FROM THE MERGED MATRIX
      SUBROUTINE GNO(IMAGE,NO,JAM)
      INTEGER*2 NO,MAT
      DIMENSION NO(1)
      IMAGE=NO(JAM)-NO(JAM)/100*100
```

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      RETURN
      END
C
C
C                                     ***SAVE***
C ***SAVE STORES DATA FROM FINAL ITERATION WHEN ITERATION LIMIT IS ***
C ***EXCEEDED AND THIS DATA SERVES AS INITIAL VALUES IN A RESTART OF THE***
C ***MODEL***
      SUBROUTINE SAVE
      INTEGER*2 NO,MAT
      DIMENSION PHI(2000),EK(2000),NO(2000),MAT(2000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(15)
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      COMMON NDY,DIFE,SDIFE,PSDIFE,CORR
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      REWIND 8
      WRITE(8) KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,
     1NSAT,N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,
     2NDUM1,NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      WRITE(8) IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,
     1ICOUNT,JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ
     2,NCMAXI,NCMAXK,NUM
      WRITE (8) BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3
     1,COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDJM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      WRITE (8) FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,
     1VTERM,AXTERM,OTERM,CUNIT
      WRITE(8) UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      NDXSML=1
      NDXLGE=1000
   10 IF (KIJTOT-(NDXLGE+10)) 50,50,20
   20 WRITE(8) (PHI(NDXV),NDXV=NDXSML,NDXLGE)
      WRITE(8) ( EK(NDXV),NDXV=NDXSML,NDXLGE)
      WRITE(8) ( NO(NDXV),NDXV=NDXSML,NDXLGE)
      NDXSML=NDXSML+1000
      NDXLGE=NDXLGE+1000
      GO TO 10
   50 WRITE(8) (PHI(NDXV),NDXV=NDXSML,KIJTOT)
      WRITE(8) ( EK(NDXV),NDXV=NDXSML,KIJTOT)
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
          WRITE(8) ( NO(NDXV),NDXV=NDXSML,KIJTOT)
          WRITE(8) NDY,DIFE,SDIFE,PSDIFE,CORR
          RETURN
          END



C         ***A SAMPLE INPUT SET FOR THE NELSON MODEL FOLLOWS***
C    ***DETAILED EXPLANATION OF INPUT CARD TYPES AND THE OPTIONS AVAILABLE ARE***
C    ***FOUND IN "STEADY DARCIAN TRANSPORT OF FLUIDS IN HETEROGENEOUS PARTIALLY***
C    ***SATURATED POROUS MEDIA, PART 2, THE COMPUTER PROGRAM", REISENAUER,A.E.,***
C    ***ET AL,,AEC  R&D REPORT HW-72335 PT2,PP.19-33,1963.***



C    ***ALL CARDS WHICH ARE BRACKETED BY *** ARE COMMENT CARDS AND MUST BE***
C    ***REMOVED  FROM THE DATA SET BEFORE THE PROGRAM WILL EXECUTE PROPERLY***



C            ***THE FOLLOWING CARDS ARE THE INPUT DATA AND CONTROL CARDS***
C            ***FOR EXECUTING A  2-DIMENSIONAL STEADY STATE GROUNDWATER FLOW ***
C            ***PROBLEM AT SCS SITE 13 USING THE ADAPTATION OF THE NELSON MODEL***
C            ***LISTED ABOVE***



C    ***CARD TYPE 1 FOLLOWS ***
       2 SATURATED FLOW PROBLEM  SITE 13 AFTER  OOP (JWN)
C    ***CARD TYPE 2 FOLLOWS***
     2    1    1    1    2    1    2    2    1
C    ***CARD TYPE 6 FOLLOWS***
     1   24   20    1   24   20    1    4   13
C    ***CARD TYPE 7 FOLLOWS***
161.87E+00   0.0E+00   0.0E+00   0.0E+00   1.0E+00   1.0E+004209.4E+00
C    ***CARD TYPE 8 FOLLOWS***
   4.40E+02   1.0E-03
C    ***CARD TYPE 9 FOLLOWS***
 1.25   20   30  200
C    ***PIEZOMETRIC HEAD LOADED BY ROW INPUT OPTION ABOVE A BASE DATUM OF 1000***
C    ***FEET ABOVE MEAN SEA LEVEL***
C    ***A SERIES OF ALTERNATING CARD TYPES 10 AND 16  FOLLOW***
   1  1  1  1  5
     1  389.   6  388.   7  392.   8  392.   9  394.
   1  1  2  3  3
     1  395.   3  394.   6  390.   9  396.
   1  1  4  4  4
     1  395.   6  390.   7  388.   9  396.
   1  1  5  5  4
     1  396.   6  389.  11  398.  12  400.
   1  1  6  7  5
     1  396.   6  394.   7  390.   8  392.  12  400.
   1  1  8  9  6
     1  402.   3  400.   7  395.   9  394.  10  396.  16  408.
```

80/80 LIST

```
          00000000011111111112222222222333333333344444444445555555555666666666677777777778
          12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
1621        1  1 10 10  4
1622         1  402.    4  398.   13  406.   18  412.
1623        1  1 11 11  5
1624         1  402.    4  398.    8 408.4  12  406.   18  412.
1625        1  1 12 15  4
1626         1  406.    4  404.    7 408.4  13  410.
1627        1  1 16 16  4
1628         1  408.    6  410.    8 408.4  12  414.
1629        1  1 17 19  6
1630         1  408.    6  410.    7  408.   10  410.   12  414.   13  412.
1631        1  1 20 21  2
1632         1  414.   13  418.
1633        1  1 22 24  6
1634         1  420.    7  418.    9  420.   11  416.   12  418.   13  420.
1635      C  ***SATURATED PERMEABILITIES IN FT./DAY ARE READ IN BY ROW INPUT OPTION***
1636      C  ***A SERIES OF ALTERNATING CARD TYPES 10 AND 14 FOLLOW***
1637        1  1  1  1  6
1638          1  5.00E+00    6  1.00E+00    7  1.50E+00   10  2.00E+00
1639         11  4.00E+00   12  8.00E+00
1640        1  1  2  2  7
1641          1  5.00E+00    5  4.00E+00    6  1.50E+00    7  1.00E+00
1642         10  1.50E+00   11  2.00E+00   12  8.00E+00
1643        1  1  3  3  8
1644          1  5.00E+00    2  4.00E+00    3  2.00E+00    5  3.00E+00
1645          7  2.00E+00    8  1.00E+00   11  3.00E+00   12  6.00E+00
1646        1  1  4  4 12
1647          1  4.00E+00    2  3.00E+00    5  5.00E+00    6  3.00E+00
1648          7  2.00E+00    8  1.00E+00    9  2.00E+00   10  4.00E+00
1649         11  8.00E+00   12  3.00E+00   13  2.00E+00   16  4.00E+00
1650        1  1  5  5 11
1651          1  5.00E+00    2  4.00E+00    4  5.00E+00    5  4.00E+00
1652          7  2.00E+00    8  1.00E+00    9  2.00E+00   10  8.00E+00
1653         11  4.00E+00   12  2.00E+00   16  4.00E+00
1654        1  1  6  6  7
1655          1  5.00E+00    3  4.00E+00    5  1.10E+01    6  3.00E+00
1656          7  1.50E+00    8  1.00E+00    9  2.00E+00
1657        1  1  7  7  6
1658          1  5.00E+00    2  4.00E+00    5  9.00E+00    6  2.00E+00
1659          7  1.00E+00   14  1.50E+00
1660        1  1  8  8  7
1661          1  4.00E+00    5  3.00E+00    6  1.50E+00    7  1.00E+00
1662         13  2.00E+00   16  3.00E+00   19  4.00E+00
1663        1  1  9  9  5
1664          1  4.00E+00    4  5.00E+00    5  2.00E+00    8  1.00E+00
1665         18  2.00E+00
1666        1  1 10 10  7
1667          1  5.00E+00    4  4.00E+00    5  2.00E+00    6  5.00E+00
1668          7  2.00E+00    8  1.00E+00   19  2.00E+00
1669        1  1 11 11  7
1670          1  5.00E+00    3  4.00E+00    6  5.00E+00    7  2.00E+00
1671         10  1.00E+00   16  1.50E+00   19  2.00E+00
1672        1  1 12 12  7
1673          1  5.00E+00    3  4.00E+00    5  5.00E+00    7  2.00E+00
1674         10  1.00E+00   15  1.50E+00   18  2.00E+00
```

80/80 LIST

```
        00000000011111111112222222222333333333344444444445555555555666666666677777777778
        12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
1675     1  1 13 13  7
1676       1  5.00E+00    3  4.00E+00    5  5.00E+00    6  2.00E+00
1677       9  1.00E+00   15  1.50E+00   18  2.00E+00
1678     1  1 14 14  7
1679       1  5.00E+00    3  4.00E+00    5  5.00E+00    6  2.00E+00
1680       9  1.00E+00   14  1.50E+00   17  2.00E+00
1681     1  1 15 15  6
1682       1  5.00E+00    4  4.50E+00    5  2.00E+00    9  1.00E+00
1683      14  1.50E+00   16  2.00E+00
1684     1  1 16 17  5
1685       1  5.00E+00    5  4.00E+00    6  2.00E+00    9  1.00E+00
1686      14  2.00E+00
1687     1  1 18 19  4
1688       1  5.00E+00    5  4.00E+00    6  2.00E+00   15  4.00E+00
1689     1  1 20 23  7
1690       1  5.00E+00    5  4.00E+00    6  2.00E+00   12  6.00E+00
1691      13  4.00E+00   14  2.00E+00   15  4.00E+00
1692     1  1 24 24  3
1693       1  5.00E+00   10  4.00E+00   13  6.00E+00
1694    C  ***CALCULATION TYPES ARE READ IN BY ROW INPUT OPTION***
1695    C  ***A SERIES OF CARD TYPES  10 AND 15 FOLLOW***
1696     1  1  1  1  1
1697     11.
1698     1  1  2  2  8
1699     11.  37.  42.  71.  82. 103. 112. 121.
1700     1  1  3  3  9
1701     11.  27.  32.  42.  52.  71.  82. 128. 131.
1702     1  1  4  4 10
1703     11.  29.  32.  62.  71.  82.  92. 102. 137. 151.
1704     1  1  5  5  8
1705     11.  42.  71.  82. 112. 122. 148. 151.
1706     1  1  6  6 10
1707     11.  35.  42.  71.  82. 122. 132. 145. 157. 161.
1708     1  1  7  7 10
1709     11.  27.  32.  81.  92. 122. 132. 153. 198. 201.
1710     1  1  8  8  9
1711     11.  25.  32.  72.  82.  91. 102. 196. 201.
1712     1  1  9  9 10
1713     11.  29.  32.  42.  72.  82. 101. 112. 196. 201.
1714     1  1 10 10 11
1715     11.  39.  42.  62.  82. 101. 112. 132. 142. 196. 201.
1716     1  1 11 11  9
1717     11.  45.  52.  81. 122. 152. 162. 196. 201.
1718     1  1 12 12  8
1719     11.  37.  42.  52.  71. 132. 1910 201.
1720     1  1 13 13 10
1721     11.  35.  42.  52.  71. 132. 142. 152. 1810 201.
1722     1  1 14 14  9
1723     11.  49.  52.  71. 132. 142. 152. 166. 171.
1724     1  1 15 15  7
1725     11.  49.  52.  81. 132. 1610 171.
1726     1  1 16 16  9
1727     11.  59.  62.  81. 122. 132. 142. 1510 171.
1728     1  1 17 17  8
```

80/80 LIST

```
      00000000011111111112222222222333333333344444444445555555555666666666677777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
1729    11.  62.  72.  82. 112. 146. 1510 161.
1730    1  1 18 18  7
1731    11.  65.  72. 102. 112. 146. 151.
1732    1  1 19 19  7
1733    11.  65.  72. 102. 112. 146. 151.
1734    1  1 20 20  7
1735    11.  57.  62.  72.  82. 146. 151.
1736    1  1 21 21  8
1737    11.  55.  62. 102. 112. 132. 146. 151.
1738    1  1 22 22  9
1739    11.  59.  64.  72.  82. 112. 122. 146. 151.
1740    1  1 23 23  8
1741    11.  72.  84.  92. 112. 122. 146. 151.
1742    1  1 24 24  1
1743    11.
1744
1745
1746  C                           ***APPENDIX B IS COMPLETE***
```

VITA

James Wesley Naney

Candidate for the Degree of

Master of Science

Thesis: THE DETERMINATION OF THE IMPACT OF AN EARTHEN-FILL DAM ON THE GROUND-WATER FLOW USING A MATHEMATICAL MODEL

Major Field: Geology

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, October 6, 1935, son of Mr. and Mrs. George M. Naney.

Education: Graduated from Midwest City High School, Midwest City, Oklahoma in May, 1953; received the Bachelor of Science degree in Mathematics from Oklahoma College of Liberal Arts in 1969; completed requirements for the Master of Science degree at Oklahoma State University in July, 1974.

Experience: Mathematician with the Agricultural Research Service, U. S. Department of Agriculture, with special emphasis on ground-water investigations since 1969.