EVALUATION OF THE GROUND-WATER RESOURCES OF THE LOWER SUSQUEHANNA RIVER BASIN, PENNSYLVANIA AND MARYLAND

UNITED STATES GEOLOGICAL SURVEY

Open-File Report 84-748

Prepared in cooperation with the

SUSQUEHANNA RIVER BASIN COMMISSION

EVALUATION OF THE GROUND-WATER RESOURCES

OF THE LOWER SUSQUEHANNA RIVER BASIN,

PENNSYLVANIA AND MARYLAND

by James M. Gerhart and George J. Lazorchick

UNITED STATES GEOLOGICAL SURVEY

Open-File Report 84-748

Prepared in cooperation with the

SUSQUEHANNA RIVER BASIN COMMISSION

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey, WRD
P.O. Box 1107
Harrisburg, Pennsylvania 17108-1107

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 234-5888)

CONTENTS

PLATES
[In pocket]

FIGURES

TABLES

FACTORS FOR CONVERTING INCH-POUND UNITS

TO INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	4047	square meter (m^2)
	Flow	
gallon per minute (gal/min)	0.000063	cubic meter per second (m^3/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft]	0.000207	cubic meter per second per meter [(m^3/s)/m]
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Stream leakage coefficient	
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)

FACTORS FOR CONVERTING INCH-POUND UNITS

TO INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply inch-pound unit	By	To obtain SI unit
Transmissivity		
gallon per day per foot [(gal/d)/ft]	0.01242	cubic meter per day per meter [(m^3/d)/m]
Yield		
gallon per minute per square mile [(gal/min)/mi^2]	0.000024	cubic meter per second per square kilometer [(m^3/s)/km^2]
gallon per day per square mile [(gal/d)/mi^2]	0.001461	cubic meter per day per square kilometer [(m^3/d)/km^2]
million gallons per day per square mile [(Mgal/d)/mi^2]	0.01691	cubic meter per second per square kilometer [(m^3/s)km^2]

EVALUATION OF THE GROUND-WATER RESOURCES OF THE LOWER SUSQUEHANNA RIVER BASIN, PENNSYLVANIA AND MARYLAND

By James M. Gerhart and George J. Lazorchick

ABSTRACT

Ground water in the 3,458-square-mile lower Susquehanna River basin occupies secondary openings in bedrock. The distribution of openings is a function of lithology, depth, and topography. Local flow systems account for most of the total ground-water flow. Average annual recharge for the lower basin is 1,857 million gallons per day, most of which discharges to streams. The water table is a subdued replica of land surface; its depth varies with topography, but is generally 20 to 70 feet below land surface. Ground water circulates to depths of 500 to 600 feet below the water table.

A digital model of regional, unconfined ground-water flow was developed and used to evaluate the ground-water resources of the lower basin. On the basis of lithologic and hydrologic differences, the area was subdivided into 21 hydrogeologic units, each with different hydrologic characteristics. Each unit was divided into two layers to handle decreasing secondary permeability with depth. A finite-difference grid with square blocks approximately one mile on a side was used. The model was calibrated under steady-state and transient conditions. The model-generated results were compared to estimated water-table altitudes and estimated base flows in the steady-state calibration. In the transient calibration, the model-generated results were compared to observed changes in water-table altitude from November 1, 1980 through April 22, 1981.

Hydraulic conductivity increases from hilltops to valley bottoms. The average hydraulic conductivity for carbonate units is about 21 feet per day, which is an order of magnitude greater than the corresponding averages for Paleozoic sedimentary, Triassic sedimentary, and crystalline units. The Cumberland Valley carbonate rocks have the greatest average hydraulic conductivity--about 174 feet per day in valley bottoms. The average gaining-stream leakage coefficient for all carbonate units is about 16 feet per day, which is two orders of magnitude greater than the corresponding averages for the other lithologies. The Cumberland Valley carbonate rocks have the greatest gaining-stream leakage coefficient--about 43 feet per day. The specific yields are 0.035, 0.020, 0.020 and 0.007 for the carbonate, Paleozoic sedimentary, crystalline, and Triassic sedimentary units, respectively.

The calibrated model was used to simulate the effects of a ground-water withdrawal of 1 inch per year on water-table altitudes and average annual base flows in the modeled area. The overall effect is least for the carbonate units and greatest for the Triassic sedimentary units. The model also was used to simulate a standardized potential yield for each unit by assuming that the maximum acceptable consequence of a hypothetical withdrawal scheme is an ultimate 50-percent reduction in average annual base flow. Based on this, the potiental yield for the modeled area is 891 million gallons per

day. The Cumberland Valley carbonate rocks have the greatest potential yield--0.47 million gallons per day per square mile. The carbonate units have the greatest average potential yield, followed by the Paleozoic sedimentary, crystalline, and Triassic sedimentary units. About 90 percent of the eventual decline in water-table altitudes and the eventual reduction in average annual base flows occurs within five years of the implementation of the hypothetical withdrawal scheme. Nearly all of the ground water withdrawn is derived from reduced discharge to streams.

The calibrated model can be used to provide estimates of the impacts of ground-water development schemes on regional ground-water levels and base flows of streams. It can not be used to simulate local cones of depression or local base-flow changes. The reliability of the model is a function of its approximation of the physical characteristics of the ground- water flow system, the two calibrations, various simplifying assumptions, and the lack of calibration under ground-water withdrawal conditions. It can be used in steady-state or transient mode to assess the effects of both natural and artificial stresses.

INTRODUCTION

In order to establish guidelines for the management of the ground-water resources in the three-state area of the Susquehanna River basin, the Susquehanna River Basin Commission (SRBC) has undertaken a Special Ground-Water Study (Susquehanna River Basin Commission, 1979) to determine the availability, distribution, and quality of ground water. The Special Ground-Water Study is partially funded by the Water Resources Council. In 1979, the SRBC and the U.S. Geological Survey entered into a cooperative agreement to evaluate the ground-water resources of several sub-basins within the Susquehana River basin. The ground-water resources of one of those sub-basins, the lower Susquehanna River basin, are the subject of this report.

The lower basin is in south-central and southeastern Pennsylvania and north-central and northeastern Maryland, and includes all or parts of 13 counties. The lower basin is primarily rural and ground water from wells and springs is an important source for municipal, industrial, agricultural, and domestic water use.

Furthermore, many surface-water supplies are sustained by ground-water base flow, especially in dry periods. Projected population growth in the Lancaster, York, Harrisburg area will lead to heavier demands on the ground-water resources of the lower basin.

The lower Susquehanna River basin investigation consists of two parts. The first part is an evaluation of the ground-water resources of the entire lower basin; the second part is a more detailed evaluation of the ground-water resources of one area of the lower basin, the area underlain by carbonate rocks in Lancaster County. This report presents the results of the evaluation of the ground-water resources of the entire lower Susquehanna River basin.

Purpose and Scope

The purpose of this report is to describe the development and use of a digital ground-water flow model to evaluate the ground-water resources of the lower Susquehanna River basin. The model is used to integrate the various hydrogeologic units and their differing characteristics, determine the sensitivity of each unit to those characteristics, and provide an estimate of the yields available from each unit as well as the impacts of obtaining those yields. In addition, this report describes the geometry, hydrologic characteristics, ground-water--surface-water relations, and natural sources and discharges for each unit.

A secondary purpose of this report is to fully document and demonstrate the use of the model so that it can be used properly by others to evaluate specific ground-water management alternatives for the lower Susquehanna River basin.

Area of Investigation

The area of investigation is the lower Susquehanna River basin in Pennsylvania and Maryland (fig. 1). The modeled area includes all of the lower basin except South Mountain and several major diabase sills. It extends from Blue Mountain on the north to Chesapeake Bay on the south and covers 3,458 mi^2. South Mountain, along the border between Cumberland and Adams Counties, was not included, even though it is within the lower basin. Relatively poor aquifers and the lack of data and development potential were the reasons for its exclusion. Major diabase sills were not included because of their relative impermeability. The area of investigation includes parts of nine counties in Pennsylvania--Franklin, Cumberland, Adams, York, Dauphin, Lebanon, Lancaster, Berks, Chester--and parts of four counties in Maryland--Carroll, Baltimore, Harford, Cecil. The major population centers are Lancaster, York, and Harrisburg, Pa. Other relatively large population centers are Lebanon, Carlisle, and Hanover, Pa., and Havre de Grace, Md.

Method of Investigation and Sources of Data

Ground-water flow modeling was selected as the best approach to accomplish the overall objective due to its capability to integrate the many aspects of a ground-water flow system. A ground-water flow model takes into account interaction between and interdependence of aquifer geometry, aquifer proper properties, recharge, discharge, boundary conditions, ground-water withdrawals, and ground-water--surface-water exchange. It enables one to quickly and easily assess the effects of changes to the system.

A three-dimensional ground-water flow model that is documented in Trescott (1975) was modified for this study. It was used in three-dimensional mode and was calibrated under steady-state and transient conditions. After calibration, it was used to estimate a standardized potential yield for each of the hydrogeologic units.

All available hydrogeologic data were incorporated into the model. The most important source of data was the inventory of water wells that is maintained by the U.S. Geological Survey in Pennsylvania. More than 4,000 wells

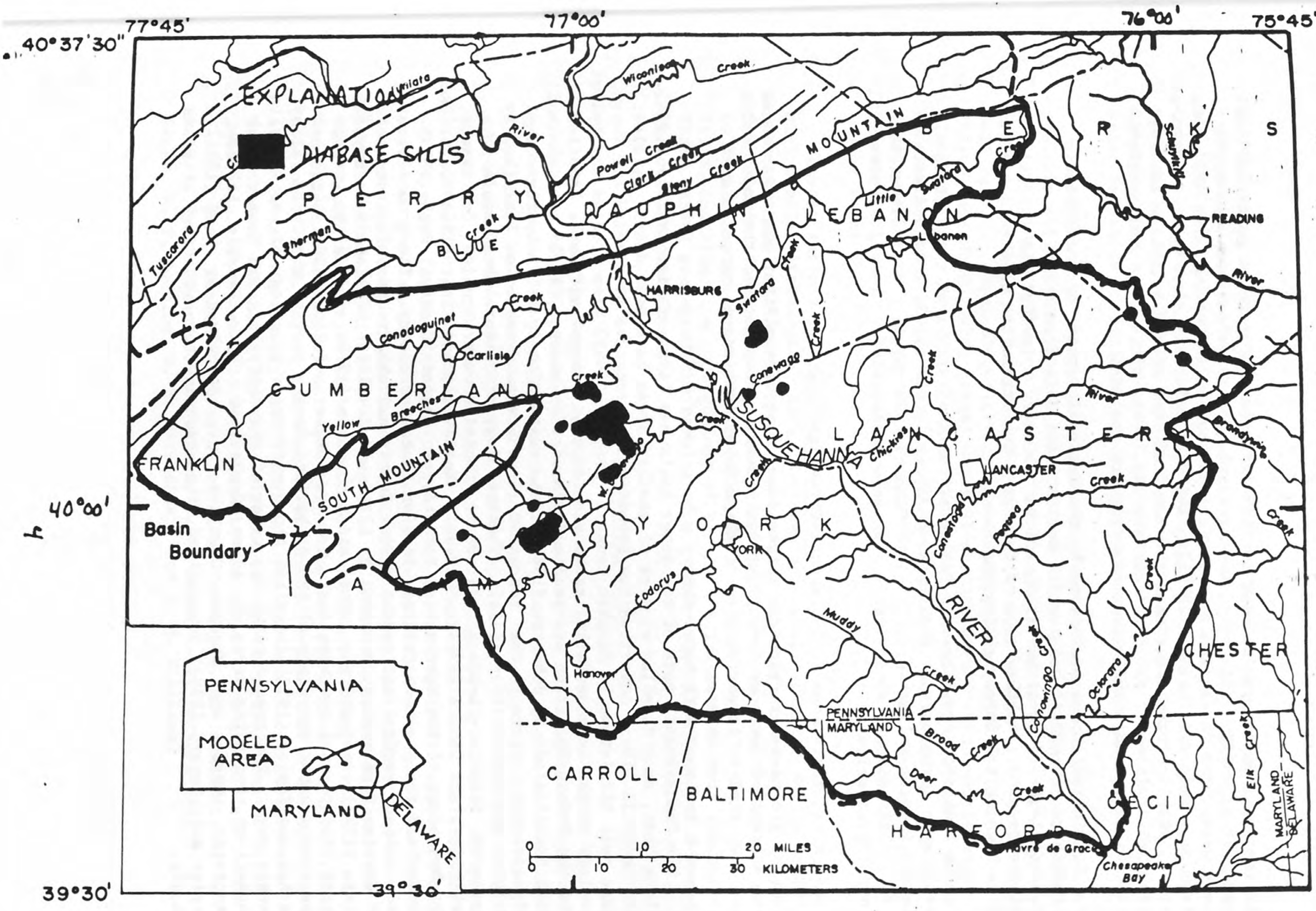


Figure 1. -- Location of modeled area in lower Susquehanna River basin.

in the lower basin are included in this inventory. Data such as water level, specific capacity, well depth, casing depth, and water-bearing zone depth were used. The Pennsylvania Geological Survey maintains a file of well data from area well drillers. This file, which contains the same types of data as above, also was used. Data for the Maryland part of the area were obtained from publications of the State of Maryland. Data similar to that available in the Pennsylvania well-inventory file are included.

Precipitation data published by the National Oceanic and Atmospheric Administration (NOAA) were used. Aquifer-test data from the files of the U.S. Geological Survey and from various published hydrologic investigations also were used. Another type of data used was streamflow data collected at U.S. Geological Survey gaging stations.

In addition, new data were collected for this study. A total of 265 wells were inventoried. A network of 320 wells was established and water levels in each well were measured in October 1980, April 1981, and October 1981. This network consisted of 227 newly inventoried wells and 93 previously inventoried wells.

Previous Investigations

The ground-water resources of the lower Susquehanna River basin have been the subject of numerous investigations. Nearly every part of the lower basin has been studied in one or more of these investigations--some parts more thoroughly than others.

The Pennsylvania part of the lower basin was first studied by Hall (1934). Since then, many detailed studies of smaller areas have been done. Meisler and Longwill (1961) described the ground-water resources of Olmsted Air Force Base near Middletown in Dauphin County. Meisler (1963) also studied the hydrogeology of the Lebanon Valley carbonate rocks in Lebanon and Berks Counties. The New Oxford Formation was studied by Wood and Johnston (1964) in Adams and York Counties and by Johnston (1966) in Lancaster County. The hydrogeology of carbonate rocks in the Lancaster 15-minute quadrangle was described by Meisler and Becher (1966, 1971). The hydrology of Swatara Creek basin in parts of Dauphin, Lebanon, and Berks Counties was studied by Stuart, Schneider, and Crooks (1967). Carswell, Hollowell, and Platt (1968) described the hydrology of the Martinsburg Formation in Dauphin County. Poth (1977) summarized the ground-water resources of Lancaster County. The ground-water resources of central and southern York County and the ground-water resources of Chester County were described by Lloyd and Growitz (1977) and McGreevy and Sloto (1977), respectively. Wood and MacLachlan (1978) studied the ground-water resources of northern Berks County. Becher and Root (1981) described the ground-water hydrology of the Cumberland County part of the Great Valley; Becher and Taylor (1982) described the ground-water hydrology of the Franklin County part. The ground-water resources of the Gettysburg and Hammer Creek Formations, including parts of Adams, Cumberland, York, Dauphin, Lebanon, Lancaster, Berks, and Chester Counties, were described by Wood (1981). Taylor and Royer (1981) summarized the ground-water resources of Adams County.

The State of Maryland has published the results of several investigations that include parts of the lower Susquehanna River basin. Dingman, Ferguson, and Martin (1956) described the water resources of Baltimore and Harford Counties; Overbeck, Slaughter, and Hulme (1958) studied the water resources of Cecil, Kent, and Queen Annes Counties; and Meyer and Beall (1958) described the water resources of Carroll and Frederick Counties. The ground-water resources of Harford County were further studied by Nutter (1977).

In addition to interpretive studies, several data compilations have been published. In Pennsylvania, McGreevy and Sloto (1976) presented hydrologic data from Chester County. In Maryland, Laughlin (1966) compiled records of wells and springs in Baltimore County; Nutter and Smigaj (1975) presented well records, chemical-quality data, and pumpage information from Harford County; and Woll (1978) listed chemical-quality data for the entire state. Also, beginning in 1961, the U.S. Geological Survey has published an annual compilation of surface-water and ground-water data in the series, "Water Resources Data for Pennsylvania" and "Water Resources Data for Maryland and Delaware". Prior to 1961, these data were published in U.S. Geological Survey Water-Supply papers.

Investigations in areas outside the lower Susquehanna River basin, but with similar lithologies, have also been published. Olmsted and Hely (1962) described the relations between ground water and surface water in Brandywine Creek basin, Chester County. The hydrology of the Stockton Formation, partly in Berks County, was studied by Rima, Meisler, and Longwill (1962). Nutter (1975) described the hydrogeology of Maryland's Triassic rocks. McGreevy and Sloto (1980) presented the results of a ground-water flow model of a small basin in Chester County.

Acknowledgments

This investigation was conducted in cooperation with the SRBC. The assistance of SRBC personnel in many phases of the investigation is appreciated. The authors also with to thank S. P. Larson for his help in modifying the digital model program, and J. V. Tracy for his suggestions concerning the use of the head-dependent stream leakage option and the model-calibration procedure. L. J. Torak was helpful in clarifying the formulation of hydraulic connection between model layers. A. E. Becher and J. H. Williams are acknowledged for their helpful suggestions pertaining to the approach to the problem. We also acknowledge S. Runkle of the Division of Comprehensive Resources, Bureau of Resources Programming, Pennsylvania Department of Environmental Resources for making data on ground-water use in Lancaster County available. The authors wish to thank the following persons at the Pennsylvania Geological survey: L. E. Taylor, for making drillers' records available; D. W. Royer, for sharing preliminary results of a hydrogeologic study in Lebanon County; and T. M. Dodge for her assistance in base-map preparation. Finally, for their efforts during the measurement of water levels in the observation-well network, the authors are grateful to A. E. Becher, T. E. Behrendt, S. A. Brua, N. S. duPont, D. A. Eckhardt, D. K. Fishel, D. L. Glenn, S. A. Hoffman, M. L. Kriz, R. L. Morningstar, G. E. Senko, R. S. Socolow, W. E. Werkheiser, and J. H. Williams.

PHYSICAL SETTING

Physiography

The modeled area includes parts of three physiographic provinces (fig. 2). The Great Valley of the Valley and Ridge Province consists of two northeast-southwest trending bands of differing lithology. The northern band contains shale and graywacke and the southern contains carbonate rocks. The Valley and Ridge province is separated from the Piedmont province by South Mountain in the southwestern part of the area and an outlier of the Reading Prong of the New England province in the northeastern part of the area. In the north-central part of the area, the Valley and Ridge and Piedmont provinces are in contact. The Piedmont province is subdivided into three sections. The Triassic Lowland contains interbedded shale, sandstone, and conglomerate that have been intruded by sills and dikes of diabase. It is bounded on the south by the Conestoga Valley, which is underlain by carbonate rocks and shale. The southernmost section of the Piedmont province is the Piedmont Upland. This section contains low-grade metamorphic rocks, mostly schist and gneiss with subordinate amounts of slate, marble, and metamorphosed igneous rocks. The Great Valley and Conestoga Valley are lowlands and the Triassic Lowland and Piedmont Upland are predominantly uplands. The highest altitude in the area is about 2,300 ft above sea level on Blue Mountain ridge and the lowest is sea level at the mouth of the Susquehanna River at Havre de Grace.

The Susquehanna River drains the area, traversing about 75 mi from Harrisburg in the northwest to Havre de Grace in the southeast. The major streams contributing flow to Susquehanna River are Conodoguinet, Yellow Breeches, Conewago, Codorus, Muddy, Broad, and Deer Creeks from the west; and Swatara, Conewago, Chickies, Pequea, Conowingo, and Octoraro Creeks and Conestoga River from the east. Stream-density differences are related to lithology, with fewer streams in areas underlain by carbonate rock.

Climate

NOAA temperature data at eight stations in the modeled area show an average annual temperature of about 53°F. (1941-70). Precipitation data for the same period show that the area receives an average of about 36 to 44 inches annually. In general, the amount of precipitation is greater toward the ridges and less along the Susquehanna River and in other lowland areas. Figure 3 shows the average annual precipitation at 22 NOAA stations (table 1) and a configuration of equal-precipitation lines. Precipitation varies seasonally, with about one-third of the average annual total occurring in June, July, and August. The areal distribution of precipitation is fairly uniform during the winter months, but the distribution of summer precipitation varies considerably because of thunderstorms.

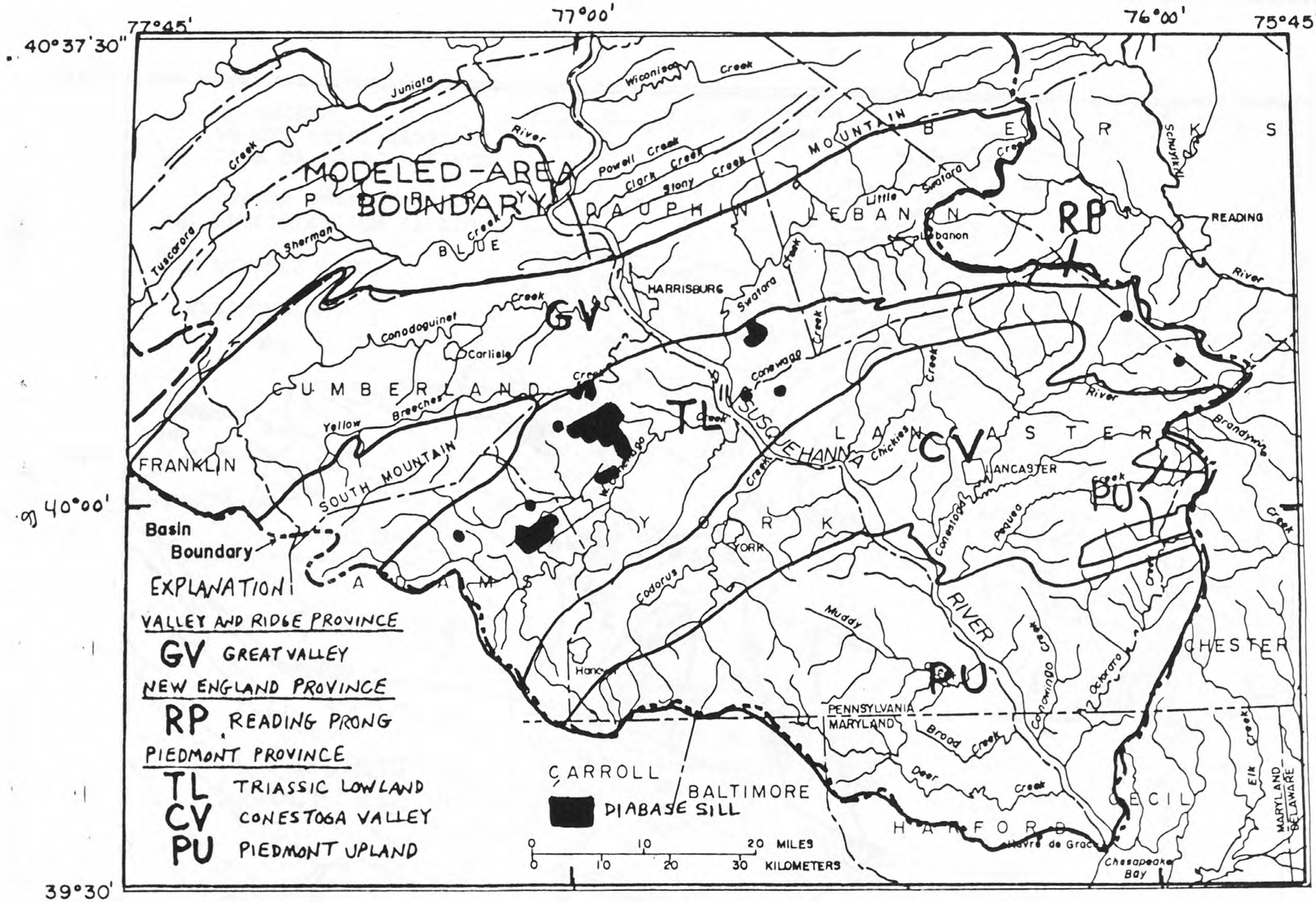


Figure 2. -- Physiographic provinces and subdivisions in modeled area.

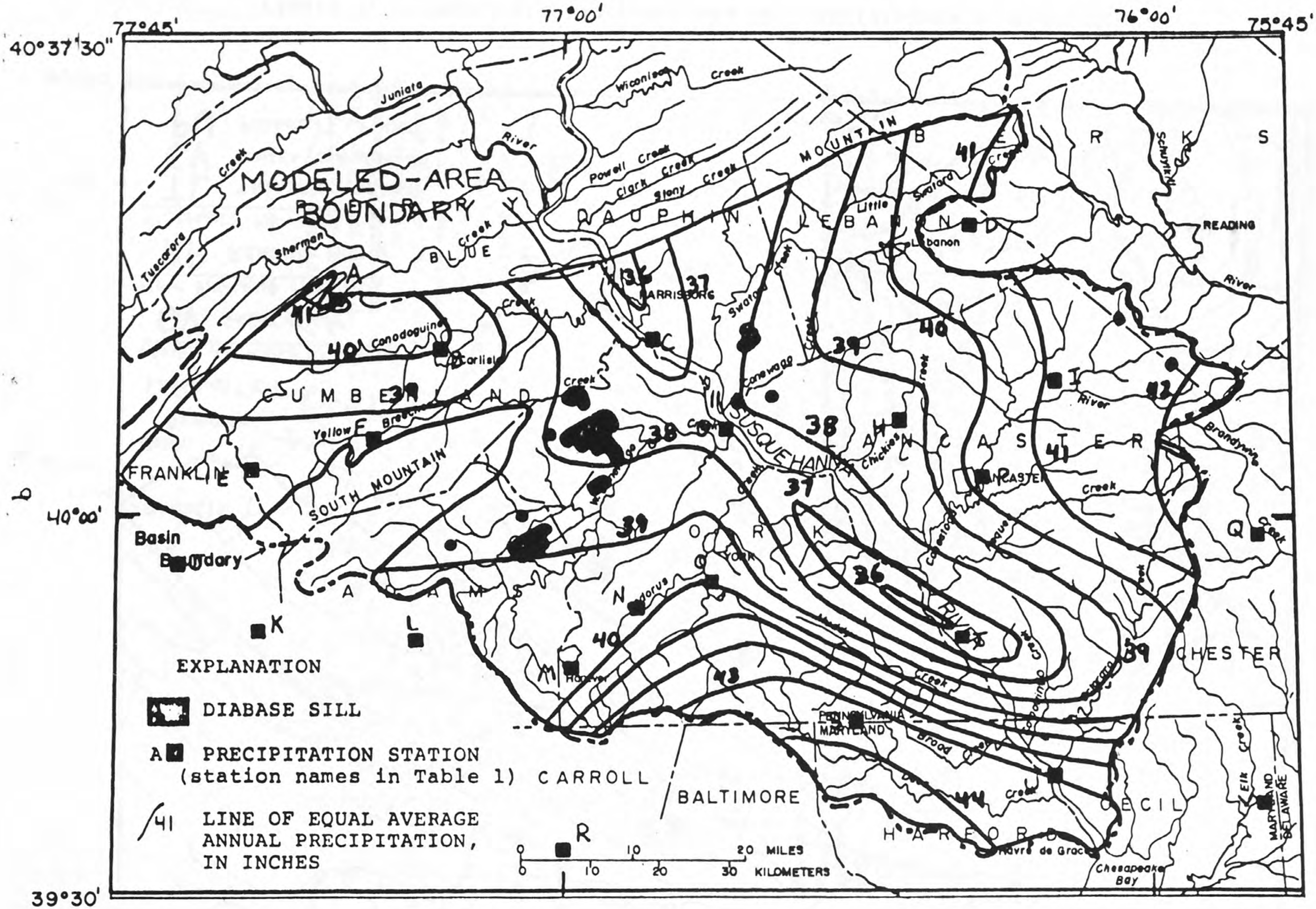


Figure 3. -- Average annual precipitation in modeled area.

Table 1.--Long-term average annual precipitation.

Station identifier 1/	Station name (NOAA)	Average annual precipitation (1941-70), in inches
A	Bloserville 1 N	41.0
B	Carlisle	40.1
C	Harrisburg FAA AP	36.5
D	Myerstown	41.1
E	Shippensburg	38.1
F	Huntsdale	38.5
G	York Haven	37.7
H	Landisville 2 NW	38.5
I	Ephrata	41.3
J	Chambersburg 1 ESE	39.7
K	South Mountain	44.8
L	Gettysburg	39.3
M	Hanover	39.1
N	Spring Grove	39.7
O	York 3 SSW Pump Sta	40.0
P	Lancaster 2 NE Filt Pl	40.5
Q	Coatesville 1 SW	42.8
R	Westminster 2 SSE	44.8 2/
S	New Park	43.9
T	Holtwood	36.1
U	Conowingo Dam	42.9 2/
V	Elkton	42.7 2/

1/ Station locations in figure 3.

2/ For 1931-60.

GEOLOGY

Structural History

The structure of the rocks in the modeled area is extremely complex. Several episodes of tectonism and millions of years of subsequent erosion have left the currently exposed rocks highly deformed and areally discontinuous.

In early Paleozoic time, the Piedmont Upland in the southeastern part of the area was the western shore of a continental land mass (Willard, 1976). Great thicknesses of sediment were eroded from this land mass and deposited over the remainder of the area, which was covered by a sea. At the end of the Ordovician and again at the end of the Paleozoic, compressive stresses originating to the southeast caused folding and faulting of these sediments, which later became the sedimentary rocks of the Great Valley and the Conestoga Valley. The rocks of the Conestoga Valley were more intensely deformed because they were closer to the source of stress.

At the beginning of the Mesozoic, the center of the area subsided, and thousands of feet of sediment accumulated in the resulting trough. These sediments became the rocks of the Triassic Lowland. During and after their deposition, they were intruded by dikes and sills of diabase.

From the Jurassic to the present, the area has been gradually uplifted and extensively eroded. The result is a deeply dissected, geologically complex, and intensely deformed area.

Stratigraphy

The three major categories of rocks are found in the modeled area. Igneous rocks are found mostly in the Triassic Lowland. Clastic sedimentary and carbonate rocks occur in the Great Valley, Triassic Lowland, and Conestoga Valley.

Metamorphic rocks are found in the Conestoga Valley and Piedmont Upland, as well as in the Reading Prong. The geologic map of Pennsylvania, published by the Pennsylvania Topographic and Geologic Survey (1980), gives detailed descriptions of the lithologies in each section, as well as their areal distributions. Detailed descriptions also are found in the referenced hydrogeological studies.

Rocks in the area are either Precambrian, Cambrian, or Ordovician in age, with the exception of those in the Triassic Lowland, which are predominantly Triassic (some diabase may be Jurassic). Precambrian rocks are found mostly in the Piedmont Upland and in the Reading Prong. Cambrian and Ordovician rocks are found in the Great Valley and Conestoga Valley. The age of many of the rocks in the Piedmont Upland is uncertain, but probably is Cambrian or Ordovician.

Due to metamorphism, the rocks in the Piedmont Upland, South Mountain, and the Reading Prong are not easily correlated. However, in the Great Valley, Conestoga Valley, and Triassic Lowland, individual formations have been recognized, mapped, and, in the case of the Great Valley and Conestoga Valley, correlated between sections.

The correlation and the estimated thicknesses of the Cambrian formations in the Great Valley and Conestoga Valley are shown in table 2. The Cambrian rocks in the Great Valley are not continuous across the width of the modeled area, but are separated by Ordovician rocks into western and eastern parts. Because of this and several lithologic differences, the stratigraphy of the Great Valley is shown in two separate columns in the table. The vertical spacing of the horizontal lines separating the formations in the table is not indicative of their relative thicknesses. The actual stratigraphic thicknesses of the formations differ because of shifting depositional environments and differential erosion.

In general, the stratigraphic thickness of the Cambrian sequence decreases eastward in the Conestoga Valley. The Cambrian sequence in the Franklin County part of the Great Valley is about 13,000 ft thick, whereas the Cumberland County sequence is about 10,000 ft thick. The Cambrian rocks in Dauphin County reach a thickness of about 4,500 ft, whereas the sequence in Lebanon County is only about 3,000 ft thick. The Cambrian rocks of the Conestoga Valley are about 4,000 ft thick in York County and about 10,000 ft thick in Lancaster County.

Ordovician stratigraphy in the Great Valley and Conestoga Valley is shown in table 3. The stratigraphic thicknesses differ, and in the Conestoga Valley and eastern Great Valley, there is a considerable gap in the Ordovician sequence due to a hiatus in deposition. The stratigraphic thickness of the Ordovician sequence is generally about 7,000 ft in all parts of the Great Valley. In the Conestoga Valley, however, the thickness ranges from less than 1,000 ft in York County to about 6,500 ft in Lancaster County.

Two units whose ages are uncertain are the Hamburg sequence and the Conestoga Formation. The Hamburg sequence is present as transported slices in the northern part of the Great Valley and is probably Early and Middle Ordovician in age. The Conestoga Formation occurs in the Conestoga Valley. It is probably Middle Cambrian to Early Ordovician in age and lies unconformably on Lower Cambrian rocks.

The stratigraphy in the Triassic Lowland is shown in table 4. The rocks in this section are unconformable with the underlying older rocks. Slight differences in lithology have resulted in the division of the section into western, middle, and eastern parts, each containing different formations. The stratigraphic thickness in the western part of the Triassic Lowland is greater than 20,000 ft. In the middle and eastern parts, the thickness ranges from about 10,000 to 17,500 ft.

Diabase dikes and sills of different thickness and areal extent intrude the sedimentary rocks of the Triassic Lowland. They are concentrated in the western part of the section.

Table 2.--Cambrian stratigraphy in modeled area.

[Compiled from Becher and Root, 1981; Lloyd and Growitz, 1977; Maclachlan and Root, 1966; Meisler, 1963; Meisler and Becher, 1971; and Pennsylvania Topographic and Geologic Survey, 1980. Numbers in parentheses are estimated thicknesses of formations, in feet.]

Great Valley				Conestoga Valley	
Western part		Eastern part			
Franklin, Cumberland Counties		York, Dauphin, Lebanon, Berks Counties		Adams, York, Lancaster, Chester Counties	
Conococheaque Group	Shadygrove Formation (650-1,000)	Conococheaque Group	Richland Formation (750-1,300)	Conococheaque Group	Millbach Formation (1,200-2,000)
			Millbach Formation (500-550)		
	Zullinger Formation (2,500-3,000)		Schaefferstown Formation (200-300)		Snitz Creek Formation (300-400)
			Snitz Creek Formation (350)		
Elbrook Formation (3,000-3,500)		Buffalo Springs Formation(>1,000)		Buffalo Springs Formation(1,500-3,800)	
Waynesboro Formation (1,000-1,500)		Leithsville Formation (1,000)		Zooks Corner Formation (1,600)	
Tomstown Formation (1,000-2,000)				Ledger Formation (1,000)	
				Kinzers Formation (300-600)	
				Vintage Formation (350-550)	
Antietam Formation (500-800)		Antietam Formation		Antietam Formation (100-200)	
Harpers Formation (2,750)					
Weaverton Formation	(1250)	Harpers Formation	(40)	Harpers Formation (800-1,000)	
Loudon Formation		Chickies Formation		Chickies Formation (400-900)	

Table 3.--Ordovician stratigraphy in modeled area.

[Compiled from Becher and Root, 1981; Carswell and others, 1968; Lloyd and Growitz, 1977; Maclachlan and Root, 1966; Meisler, 1963; Meisler and Becher, 1971; and Pennsylvania Topographic and Geologic Survey, 1980. Numbers in parentheses are estimated thicknesses of formations, in feet.]

Great Valley				Conestoga Valley	
Western part		Eastern part			
Franklin, Cumberland Counties		York, Dauphin, Lebanon, Berks Counties		Adams, York, Lancaster, Chester Counties	
Martinsburg Formation (1,000-3,000)		Martinsburg Formation (3,000-5,000)		Cocalico Formation (?)	
Chambersburg Formation (300 - 750)		Hershey Formation (200-1,000)			
		Myerstown Formation (200-250)		Myerstown Formation (200)	
St. Paul Group (600 - 1,000)		MISSING		MISSING	
		Annville Formation (180-250)		Annville Formation (200)	
Beekmantown Group	Pinesburg Station Formation (200-800)	Beekmantown Group	Ontelaunee Formation (500-800)	Beekmantown Group	Ontelaunee Formation (<600)
	Rockdale Run Formation (2,000-3,000)		Epler Formation (800-1,300)		Epler Formation (2,000-2,500)
	Stonehenge Formation (500-1,000)		Rickenbach Formation (200-300)		Stonehenge Formation (500-1,000)
	Stoufferstown Formation (<250)		Stonehenge Formation (600-1,300)		
Hamburg sequence- probably Lower and Middle Ordovician				Conestoga Formation - probably Middle Cambrian to Lower Ordovician	

Table 4.--Triassic stratigraphy in modeled area.

[Compiled from Johnston, 1966; Pennsylvania Topographic and Geologic Survey, 1980; Wood, 1981; and Wood and Johnston, 1964. Numbers in parentheses are estimated thicknesses of formations, in feet.]

Triassic Lowland		
Western part	Middle part	Eastern part
Adams, York, Cumberland, Dauphin, Lancaster Counties	Lebanon, Lancaster, Berks Counties	Lancaster, Chester, Berks Counties
Gettysburg Formation (15,500)	Hammer Creek Formation (9,400 - 12,200)	Hammer Creek Formation (9,400- 12,200
New Oxford Formation (4,800- 6,700)	New Oxford Formation (500 - 4,800)	Stockton Formation (2,300 6,000)

GROUND-WATER HYDROLOGY

The framework of the ground-water flow system consists of bedrock overlain by a mantle of weathered bedrock. The thickness of the weathered mantle is largely a function of topography. It generally is thickest on hilltops and slopes, and thinnest in draws and valleys where erosion by surface water is greatest. In addition, it is commonly thick along the flanks of major ridges because of mass wasting and slumping. The weathered mantle includes all the material from soil at land surface to unconsolidated rock fragments just above bedrock.

The weathered mantle is relatively porous and permeable and, because of its ability to accept precipitation, acts as a source of recharge to the bedrock below. Where the weathered mantle is saturated, ground water occupies the spaces between unconsolidated soil particles and rock fragments. The bedrock, on the other hand, has very low primary porosity and is less permeable than the weathered mantle. Ground water is found in the bedrock only because of the presence and development of secondary openings. Primary openings such as spaces between rock grains are either virtually nonexistent or of minor importance because of compaction and cementation. Secondary openings are caused by tectonic stresses and include openings along bedding planes, cleavage planes, joints, and faults. Commonly, these openings are enlarged by weathering processes and solution.

The number and size of the openings determine the secondary porosity of the bedrock; the degree to which the openings are interconnected determines its secondary permeability. The number, size, and interconnection of the secondary openings differ with depth below land surface and topographic setting. Secondary porosity and permeability decrease with depth due to the increase in pressure and the decrease in weathering and solution. Also, secondary porosity and permeability are relatively low under hilltops and relatively high under draws and valleys.

Ground water in the weathered mantle is under unconfined conditions. In contrast, ground water in the secondary openings in bedrock commonly is under confined conditions due to the essentially impermeable bedrock on the sides of the openings. However, because there are no well-defined, continuous confining beds, and because the degree of hydraulic connection between the weathered mantle and the secondary openings in the underlying bedrock is generally high, the entire ground-water flow system is considered as one complex unconfined aquifer.

The water table generally is a subdued replica of the land surface. It is deepest under hilltops and nearest land surface in draws and valleys. It commonly is in the lower part of the weathered mantle but it can also be in the bedrock, especially under hilltops. Streams generally are hydraulically connected to the water table; however, some stream reaches may be perched.

The flow system is recharged by precipitation that infiltrates the weathered mantle and percolates to the water table. Stream valleys are the discharge locations for ground water. Local flow systems dominate, with ground water discharging in stream valleys adjacent to its areas of recharge. Between areas of recharge and discharge, ground water flows in directions of decreasing potential, or from high to low water-table altitudes. Where the water table is above the bedrock, ground water may reach its discharge location without leaving the weathered mantle. Alternately, ground water may enter the bedrock and follow shallow or deep flow paths through connected secondary openings until it is discharged. Not all the ground water that discharges into stream valleys reaches streams; a minor amount will be lost to evapotranspiration where the water table is near the land surface.

CONCEPTUAL MODEL OF GROUND-WATER FLOW SYSTEM

Continuum methods of ground-water flow analysis, including most digital modeling, depend on the assumption of laminar flow through a medium with systematic primary porosity and permeability (Darcian aquifer). In this investigation, the aquifers have practically no primary porosity and permeability; virtually all ground-water flow occurs in secondary openings. Nevertheless, the aquifers were considered to be sufficiently similar to Darcian aquifers to permit analysis by continuum methods. This assumption was made because of the large scale (1 mi^2) at which the analysis was performed. An aquifer in which secondary openings are ubiquitous and intersecting may approximate a Darcian aquifer on a regional scale. In the lower basin, secondary openings generally occur as two or more intersecting sets of parallel planar openings. The spacing of the major openings is generally less than 50 ft and their width generally ranges from less than 1 inch to several inches. In addition to these characteristics of secondary openings, the assumption of applicability of continuum methods also was based in part on the qualitative correlation between features of the ground-water flow system in the modeled area and features of a similar but theoretical flow system in an idealized medium (Toth, 1963, fig. 2a).

Further support for the assumption that the ground-water flow system in the lower basin is continuous on a regional scale is provided by a water-table map of part of Lebanon County (Royer, written commun., 1982). Pumping to dewater two quarries in carbonate rock has caused changes in ground-water levels to occur at distances up to 6 miles from the quarry. Such widespread effects indicate regional continuity of the ground-water flow system.

The conceptual model used in this investigation is shown in the generalized diagram in figure 4. The general characteristics shown in the diagram are present throughout the area and are the major influences on the flow of ground water. The characteristics represent a condensation and summary of the results of previous hydrogeologic investigations. Although the general features of the conceptual model apply everywhere in the modeled area, their characteristics differ with lithology. For example, all lithologies are recharged by precipitation, but one lithology may accept recharge at twice the rate of another. Lithologies that have high secondary porosity and permeability generally will have thicker weathered mantles, deeper ground-water circulation, deeper water tables, less seasonal water-table fluctuation, and greater amounts of recharge and discharge. Because of their solubility, the carbonate rocks are apt to have relatively high secondary porosity and permeability; conversely, the igneous and well-cemented sedimentary and metamorphic rocks are likely to have fairly low secondary porosity and permeability.

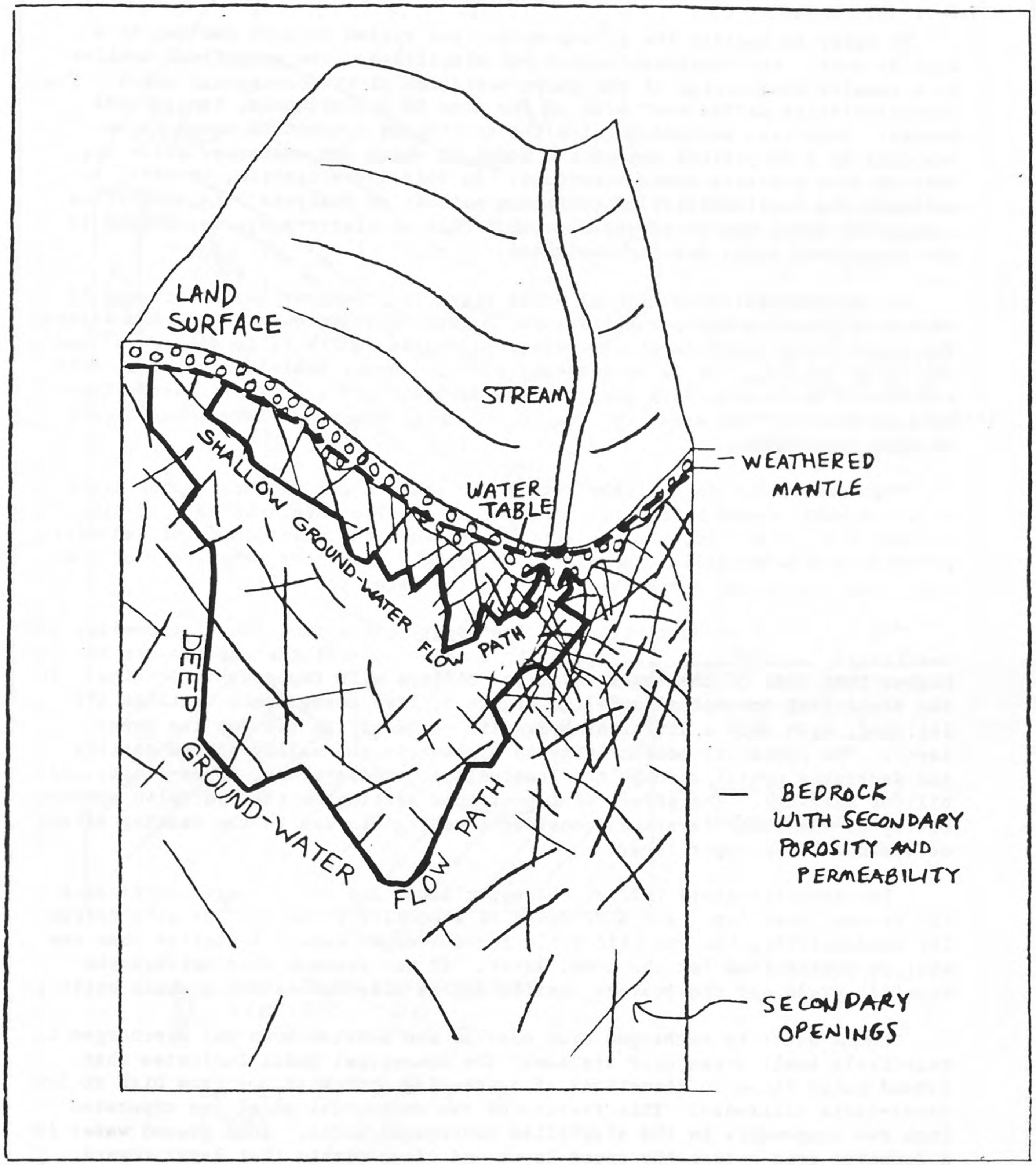


Figure 4.—Conceptual model of ground-water flow system.

Description

In order to analyze the ground-water flow system through the use of a digital model, the conceptual model was simplified. The unconfined aquifer is a complex combination of the characteristics of the conceptual model. The characteristics differ over much of the area in a continuous, gradational manner. Numerical methods require the continuous conceptual model to be replaced by a simplified conceptual model in which the characteristics are uniform over discrete space intervals. In this investigation, in order to maintain the applicability of continuum methods of analysis, the simplified conceptual model was constructed so that only the large-scale variations in the conceptual model were approximated.

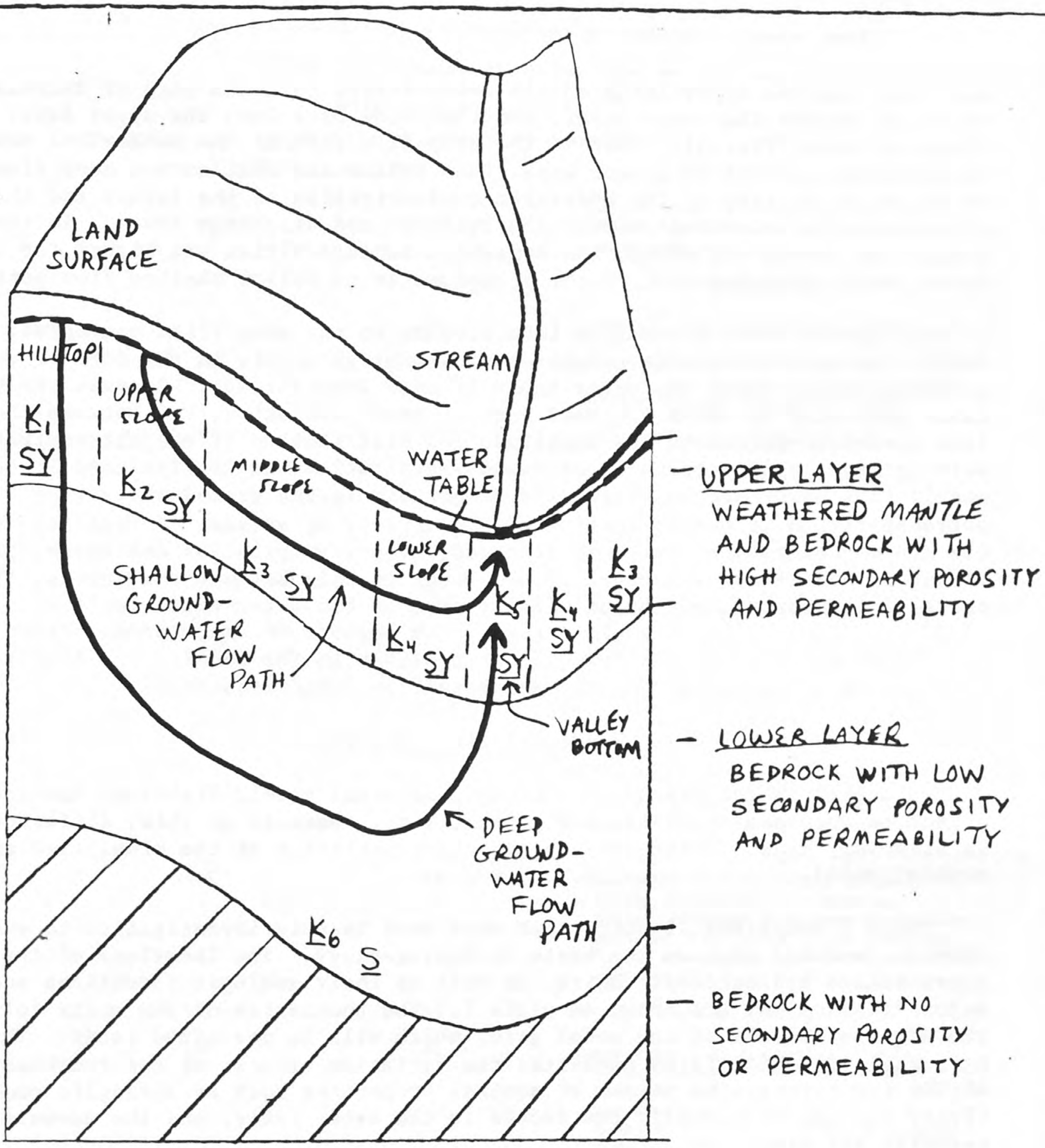
In the simplified conceptual model (fig. 5), the continuous decrease in secondary porosity and permeability with depth was approximated by two layers. The upper layer consists of the weathered mantle (where it is saturated) and the upper bedrock. It is bounded above by the water table and below by that bedrock in which secondary porosity and permeability are significantly lower. In most parts of the area, the weathered mantle comprises only a small part of the upper layer.

The lower layer is entirely within the bedrock and extends to the depth at which most ground-water circulation ceases. The thickness of both layers is constant for all topographic settings because the development of secondary porosity and permeability is related to depth. Therefore, the bases of the upper and lower layers are parallel with the water table (fig. 5).

The hydraulic conductivities of the layers are a function of secondary permeability. Accordingly, the hydraulic conductivity of the upper layer is higher than that of the lower layer and differs with topographic setting. In the simplified conceptual model in figure 5, five topographic settings are included, each with a different hydraulic conductivity (K) for the upper layer. The hydraulic conductivity is highest in the valley-bottom setting and decreases uphill through the lower-slope, middle-slope, upper-slope, and hilltop settings. The effect of topographic setting on the hydraulic conductivity of the lower layer was considered negligible due to the masking effect of the overlying upper layer.

The specific yield (SY) of the upper layer and the storage coefficient (S) of the lower layer are a function of secondary porosity. As with hydraulic conductivity, the specific yield for the upper layer is greater than the storage coefficient for the lower layer. It was assumed that neither the specific yield nor the storage coefficient is affected by topographic setting.

Ground water is recharged over most of the modeled area and discharged in relatively small areas near streams. The conceptual model indicates that ground water flows in directions of decreasing potential, or from high to low water-table altitudes. This feature of the conceptual model was separated into two components in the simplified conceptual model. Some ground water in a recharge area enters the upper layer and flows within that layer toward adjacent discharge areas (fig. 5). This corresponds to the shallow flow path of the conceptual model. On the other hand, because the upper and lower layers can maintain different potentials, some ground water in a recharge area



EXPLANATION

$\underline{K}$	HYDRAULIC CONDUCTIVITY
$\underline{SY}$	SPECIFIC YIELD
$\underline{S}$	STORAGE COEFFICIENT

$$\underline{K}_6 \leq \underline{K}_1 < \underline{K}_2 < \underline{K}_3 < \underline{K}_4 < \underline{K}_5$$

$$\underline{S} \ll \underline{SY}$$

Figure 5.--Simplified conceptual model of ground-water flow system.

may flow from the upper layer to the lower layer, follow a path of decreasing potential within the lower layer, and then flow back into the upper layer in a discharge area (fig. 5). This is the deep flow path of the conceptual model. The relative amounts of ground water that follow the shallow and deep flow paths are a function of the hydraulic conductivities of the layers and the differences in potential between the recharge and discharge areas. In the simplified conceptual model, the hydraulic conductivities are higher for the upper layer, allowing most of the ground water to follow shallow flow paths.

All ground water discharges into streams in the simplified conceptual model. In actuality, some ground-water discharge occurs in the form of evapotranspiration where the water table is near land surface. Because the water table generally is below the root zone of most vegetation, and because the data needed to determine the magnitude and distribution of evapotranspiration were not available, ground-water evapotranspiration was not included in the model. The effect on model results of not simulating ground-water evapotranspiration is overestimation of the effects of stress. In reality, when the ground-water flow system is stressed, evapotranspiration decreases, providing an additional source of ground water to help balance the stress. The decrease in evapotranspiration offsets some of the water-table decline and base-flow reduction that would occur if the capture of evapotranspiration was not a possiblity. Such capture is not possible in the model, so slightly exaggerated water-table declines and base-flow reductions result.

Hydrogeologic Subdivision

As stated in the discussion of the conceptual model, lithology has a great effect on secondary porosity and permeability. Because of this, differences in lithology cause differences in the characteristics of the simplified conceptual model.

Table 5 describes 21 units that were used in this investigation to subdivide the modeled area on the basis of hydrogeology. The locations of the approximated hydrogeologic units, as well as their geologic formations and major lithologies, are shown on plate 1. The boundaries of the units follow the edges of blocks in the model grid, which will be described later. This hydrogeologic subdivision permitted the variation by unit of the thicknesses of the two layers, the values of aquifer properties such as hydraulic conductivity and specific yield, the depths to the water table, and the amounts of recharge and discharge.

Lithology was the main criterion for subdivision, but two units were further subdivided on the basis of differences in hydrologic characteristics and one unit was further subdivided on the basis of topographic differences. The eastern Triassic sedimentary rocks (unit 6) were separated from the western Triassic sedimentary rocks (unit 5) because of differences in specific capacity. The southern Piedmont metamorphic rocks (unit 11) were separated from central Piedmont metamorphic rocks (unit 10) for the same reason. The Great Valley shales on the flank of Blue Mountain (unit 12) were separated from other Great Valley shales (units 1 and 21) because of their much higher altitude and steeper slope. The modeled area was initially subdivided into 11 units; these were further subdivided due to hydrogeologic differences, the importance of which became apparent only during model calibration. Four units

Table 5.--Hydrogeologic subdivision used in simplified conceptual model.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology	Area, in square miles	General description
1 PS	320	Western Great Valley shales and eastern Great Valley shales containing significant graywacke
2 C	74	Eastern Lebanon Valley carbonate rocks
3 X	70	Eastern Piedmont metamorphic rocks
4 C	270	Cumberland Valley carbonate rocks
5 TS	390	Western Triassic sedimentary rocks
6 TS	45	Eastern Triassic sedimentary rocks
7 C	75	Conestoga Valley carbonate rocks west of the Susquehanna River
8 X	153	Conestoga Valley metamorphic rocks west of the Susquehanna River
9 C	292	Northern Conestoga Valley carbonate rocks east of the Susquehanna River
10 X	757	Central Piedmont metamorphic rocks
11 X	172	Southern Piedmont metamorphic rocks
12 PS	53	Great Valley shales on flank of Blue Mountain
13 TS	156	Combination unit consisting of model blocks containing both Triassic sedimentary rocks (units 5 and 6) and Triassic and Jurassic(?) diabase
14 1/	29	Combination unit consisting of model blocks containing both Conestoga Valley carbonate rocks west of the Susquehanna River (unit 7) and Conestoga Valley metamorphic rocks west of the Susquehanna River (unit 8)
15 PS	55	Northern Conestoga Valley shales
16 1/	96	Combination unit consisting of model blocks containing both Conestoga Valley metamorphic rocks east of the Susquehanna River and Conestoga Valley carbonate rocks east of the Susquehanna River (units 9 and 17).
17 C	105	Southern Conestoga Valley carbonate rocks east of the Susquehanna River
18 TS	50	Triassic conglomerates
19 TS	105	Combination unit consisting of model blocks containing both Triassic conglomerates (unit 18) and Triassic sedimentary rocks (units 5 and 6)
20 C	20	Western Lebanon Valley carbonate rocks
21 PS	171	Eastern Great Valley shales not containing significant graywacke

1/ Combinations of C and X; not included in any general lithology.

(13, 14, 16, 19) are transitional units. They were included to better approximate the areal distribution of units where many grid blocks along a contact between two lithologies contain approximately equal parts of each lithology.

All but two hydrogeologic units can be grouped into four general lithologies--Paleozoic sedimentary rocks, carbonate rocks, crystalline rocks, and Triassic sedimentary rocks (table 5). These groupings will be used for purposes of comparison and discussion throughout the report. Units 14 and 16 do not fit into any of these groupings because they are combinations of the carbonate and crystalline units.

Layer Thickness

Hhe thicknesses of the two layers for each of the 21 hydrogeologic units (table 6) were determined from data on water-bearing zones in drilled wells. Data on the number of water-bearing zones were assumed to be representative of the degree of development of secondary porosity and permeability with depth. The thickness of the upper layer was obtained from data published in various hydrogeologic investigations conducted jointly by the U.S. Geological Survey and the Pennsylvania Geological Survey. For each hydrogeologic unit, the average depth below water level at which the number of water-bearing zones in wells diminishes sharply was taken to be the thickness of the upper layer. It ranges from 200 to 300 ft. The thickness of the lower layer was determined from water-bearing zone data reported by well drillers to the Pennsylvania Geological Survey. For each hydrogeologic unit, the average depth below water level below which no significant water-bearing zones were encountered was taken to be the total thickness of the ground-water flow system. The difference between this thickness and the thickness of the upper layer for each hydrogeologic unit is the thickness of the lower layer. It ranges from 300 to 400 ft.

DIGITAL MODEL OF GROUND-WATER FLOW SYSTEM

Background

The configuration of the water table in an unconfined aquifer is determined by five interdependent factors. They are the physical framework, the hydraulic properties, the distribution and amount of natural recharge and discharge, the interaction with associated surface-water systems, and artificial influences. The relation between the water-table configuration and these factors is quantitatively expressed by a partial differential equation. A digital, three-dimensional, ground-water flow model (Trescott, 1975), which uses finite-difference methods to approximate this partial differential equation, was modified for this investigation.

For such a model, a rectangular grid is superimposed on an area of investigation. From available hydrogeologic data, estimates are made of the appropriate interdependent factors above and are entered into the model program for each block of the grid. A finite-difference approximation equation containing estimates of the interdependent factors and describing their interrelations is then developed in the model program for each grid block. Each equation also contains an unknown variable--the water-table altitude for the grid block. The equations are then solved simultaneously in an iterative procedure to obtain the water-table altitude for each grid block.

Table 6.--Initial saturated thicknesses of upper and lower layers.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Saturated thickness, in feet	
		Upper layer	Lower layer
1	PS	200	300
2	C	200	350
3	X	200	300
4	C	200	400
5	TS	300	300
6	TS	300	300
7	C	200	350
8	X	200	300
9	C	200	350
10	X	200	300
11	X	200	300
12	PS	300	300
13	TS	300	300
14		200	350
15	PS	200	300
16		200	350
17	C	200	350
18	TS	300	300
19	TS	300	300
20	C	200	350
21	PS	200	300

The modified model simulates ground-water flow in two layers, with the upper layer being unconfined. The hydraulic conductivities in the three model directions [parallel to the rows (x) and columns (y) of the grid, and vertically (z)] are entered for both layers by hydrogeologic unit, making the formulation of the partial differential equation similar to that of equation 3 in Trescott (1975).

Data Discretization

Due to the extensive area and the scale at which the ground-water flow system was considered to be continuous, a uniform grid with square blocks 5,208 feet on a side was used. It consists of 84 rows and 98 columns; any particular grid block can be referred to by its row and column numbers, respectively (e.g. block 36-26). Two layers of these grid blocks were used to simulate the two layers of the simplified conceptual model. The grid was oriented with its rows parallel to the general structural trend (N. 60° E.) of many of the hydrogeologic units (plate 1).

The grid was superimposed on the area and the actual boundaries of the 21 hydrogeologic units were approximately delineated by grid-block edges (plate 1). The edges of each hydrogeologic unit are roughly correlative with lithologic contacts. Contacts in the area are not vertical, but due to the high ratio of grid-block dimension to aquifer thickness, the edges of each hydrogeologic unit were assumed to be vertical. Therefore, the gridded edges of units are the same for both layers. Within each grid block in each layer, aquifer characteristics and altitudes of various surfaces (water table, bases of layers, streams) are uniform in accordance with finite-difference methods.

Model Program Modifications

Several modifications were made to the original model program in Trescott (1975). The modified version used in this investigation is listed in attachment A. The instructions for its use are given in attachment B.

Due to the large scale of analysis, many characteristics of the simplified conceptual model were made uniform not only within each grid block, but also within each hydrogeologic unit. In terms of model input, the program was modified to permit the entry of layer thicknesses, hydraulic conductivities in the three model directions, specific yields, and storage coefficients by hydrogeologic unit instead of by grid block.

The program was also modified to include an option for head-dependent stream leakage (Tracy, written commun., 1979). With this option, the flow between the aquifers and streams can be evaluated. The entry of two leakage coefficients (gaining and losing) is permitted for each grid block having a stream.

Another option permitted the modification of average hydraulic conductivity of a hydrogeologic unit according to the dominant topographic setting of each grid block in that unit. The dominant topographic setting of each grid block was entered and five multiplication factors for each hydrogeologic unit were also entered. These factors correspond to the five topographic settings of the simplified conceptual model. The average hydraulic conductivity of a unit in all three model directions was multiplied by these factors to account for the effect of topography.

The program also was modified so that recharge could be varied during a transient-model simulation.

In addition, several output options were added to the model program, making the following information available by hydrogeologic unit:

1. Mass balances in both layers;
2. flow between layers;
3. flow between aquifer and streams;
4. flow to and from adjacent units for both layers; and
5. statistics on the agreement between model-generated and estimated water-table altitudes.

Program options also were added to write the following information to file, where it could be analyzed in auxiliary programs:

1. Differences between model-generated and estimated water-table altitudes for each grid block;
2. flow between aquifer and streams for each grid block; and
3. differences between model-generated water-table altitudes at the beginning and end of transient calibration simulations.

Finally, options to print maps of certain results were added to the model program. Maps of the differences between model-generated and estimated water-table altitudes and the head difference between layers were added.

The simulations made during this investigation were run on an IBM 3033 1/ computer at the Applied Physics Laboratory, Johns Hopkins University.

1/ Use of the brand name in this report is for indentification purposes only and does not constitute endorsement by the U.S. Geological Survey.

CALIBRATION OF MODEL UNDER

AVERAGE ANNUAL STEADY-STATE CONDITIONS

General Procedure

The purpose of the steady-state calibration was to determine the distribution and magnitudes of hydraulic conductivities and stream leakage coefficients. Simply stated, this calibration consisted of routing the ground-water recharge to the streams under a particular water-table configuration. Many combinations of hydraulic conductivity and stream leakage coefficients may produce an acceptable routing; a combination supported by hydrologic data was used.

The model was calibrated under average annual steady-state conditions because there is never a particular time when all parts of the modeled area are at steady state. Over the course of an average year, however, there is little or no net gain or loss of ground water from aquifer storage; therefore it was assumed that an average annual approach could be used.

There were relatively few large consumptive ground-water withdrawals in the area and they were not well documented in terms of rates of withdrawal and water-table decline. Therefore, no withdrawals were included in the steady-state calibration. This was considered reasonable because nearly all the water-table altitude data used to calibrate the model consisted of static water-level measurements in sporadically-pumped domestic wells.

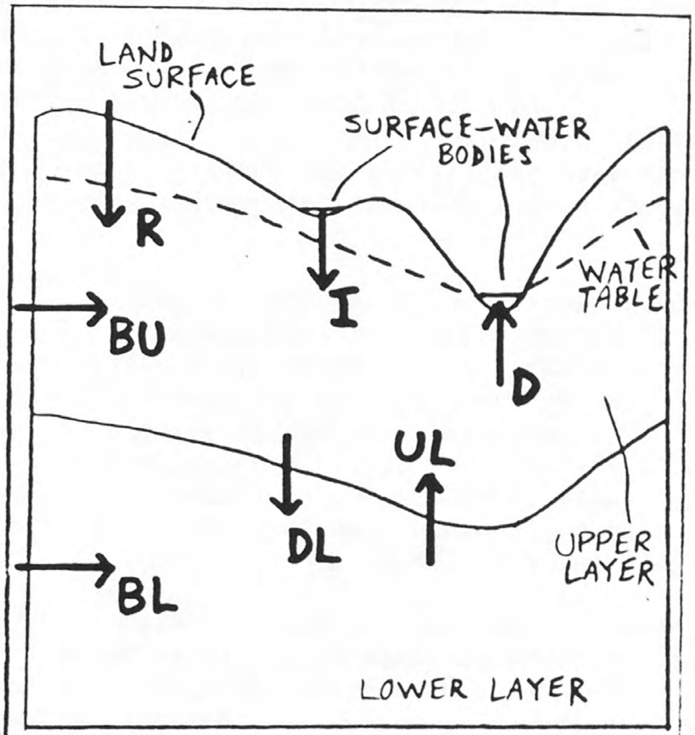
Model-generated water-table altitudes were statistically compared to estimated water-table altitudes during calibration. Also, as a further check, model-generated base flows for major subbasins were compared to estimated base flows obtained by graphical separation of streamflow hydrographs. The initial estimates of hydraulic conductivity and stream leakage coefficients for each hydrogeologic unit were adjusted during calibration. Aquifer geometry, model recharge, and boundary conditions were not adjusted.

Modeled Flow Components

The ground-water flow components used in the steady-state calibration are shown in figure 6. Ground water enters the aquifer by recharge to the upper layer, boundary flow from South Mountain, and infiltration from losing stream reaches. All ground water discharges into streams and lakes. Because two layers are used, flow between the layers is also included. The sources balance the sinks for both layers. The magnitudes of each component (except recharge) are determined from the hydraulic conductivity in both layers, the stream leakage coefficients, and the relations between water-table and stream altitudes.

Ground-Water Conditions

The average land-surface altitude for each grid block was estimated by overlaying a small template on each model grid block on 7 1/2-minute quadrangle maps. The land-surface altitudes at 16 equally-spaced points on the template were averaged to obtain the average land-surface altitude for each block.



$$R + BU + BL + I = D$$

$$R + BU + I + UL = D + DL$$

$$BL + DL = UL$$

EXPLANATION

R = RECHARGE

BU = BOUNDARY INFLOW IN UPPER LAYER

BL = BOUNDARY INFLOW IN LOWER LAYER

I = INFILTRATION FROM SURFACE-WATER BODIES

D = DISCHARGE TO SURFACE-WATER BODIES

DL = DOWNWARD FLOW BETWEEN LAYERS

UL = UPWARD FLOW BETWEEN LAYERS

Figure 6. -- Ground-water budget components in steady-state calibration.

The dominant topographic setting of each grid block was subjectively assigned by examining the topography within each block and its relation to the surrounding blocks. Again, 7½-minute quadrangle maps were used. Each block was assigned a topographic setting of either hilltop, upper-slope, middle-slope, lower-slope, or valley-bottom (the five settings shown in the simplified conceptual model in figure 5). The general distribution of these settings is shown in figure 7. Nearly 60 percent of the modeled area is middle-slope setting. Upper-slope blocks make up about 30 percent of the area and generally occur along prominent ridges and in highlands. Lower-slope blocks occur only along major stream valleys and comprise about 5 percent of the area. Very few blocks have a dominant topographic setting of hilltop or valley-bottom.

Water-level measurements were available for more than 4,000 wells in the area. One of the five topographic settings was assigned to each of these wells. The measured depths to water (below land surface) were statistically analyzed, grouping them by hydrogeologic unit and topographic setting. These depth measurements were made during different seasons and different years in different parts of the area. It was assumed that the large number of measurements would statistically overwhelm any seasonal or long-term bias in a particular area. It also was assumed that there was no bias due to different well depths or artificial stresses.

The median depths to water for the five topographic settings for each hydrogeologic unit are shown in table 7. Units with insufficient data were assigned depths to water which were in accord with those for units of similar lithology and physiography. For all units, the depth to water increases from valley-bottom to hilltop settings. In general, the deepest median water levels are found in the carbonate units. The differences in the medians between units are probably related to lithology and local relief.

From the average land-surface altitude, the dominant topographic setting, and the median depths to water, the average water-table altitude was calculated for each grid block. This will be referred to as the estimated water-table altitude. A generalized water-table map of the modeled area is shown in figure 8. During steady-state calibration, model-generated water-table altitudes for the upper layer were compared to these estimates until satisfactory agreement was obtained. Model generated water-table altitudes for the upper layer were assumed to represent the estimated water-table altitudes because the great majority of the more than 4,000 wells in which water levels were measured were drilled no deeper than 300 ft.

In the simplified conceptual model, the upper limit of the upper layer is the water table. The altitude of the top of the upper layer for a grid block was therefore considered to be equal to the estimated water-table altitude for that block. The appropriate thickness of the upper layer (table 6) was then subtracted from the estimated water-table altitude for each block to obtain the altitude of the base of the upper layer. Similarly, the appropriate thickness of the lower layer (table 6) was subtracted from the altitude of the base of the upper layer to obtain the altitude of the base of the lower layer (also the assumed base of the ground-water flow system). A diagram showing these relations for three typical grid blocks is shown in figure 9. A topographic map of each grid block is also included to show how

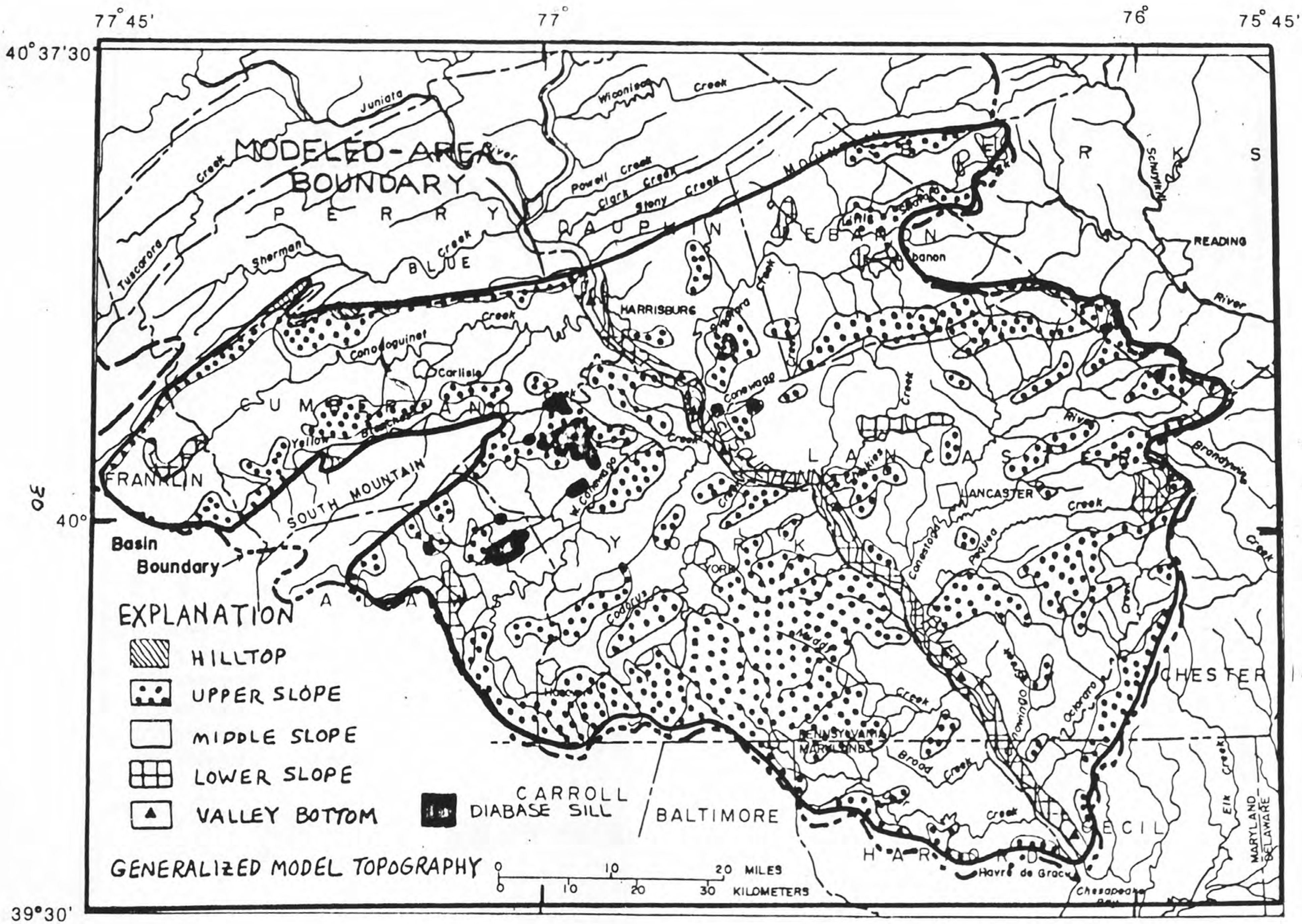


Figure 7.--Generalized topography in modeled area.

Table 7.--Median depth to water table for different topographic settings.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Median depth below land surface, in feet				
		Hilltop	Upper slope	Middle slope	Lower slope	Valley bottom
1	PS	34	28	23	18	12
2	C	56	47	38	29	20
3	X	70	50	30	20	10
4	C	83	64	46	32	18
5	TS	40	32	24	20	17
6	TS	40	32	24	18	11
7	C	43	36	28	20	13
8	X	40	35	30	20	9
9	C	46	38	30	22	15
10	X	37	32	28	19	9
11	X	37	33	29	19	9
12	PS	150	75	50	25	10
13	TS	45	39	33	24	14
14		42	35	26	18	10
15	PS	45	38	34	20	10
16		45	38	33	23	15
17	C	48	40	35	25	18
18	TS	100	70	50	35	25
19	TS	85	59	34	26	17
20	C	56	47	38	29	20
21	PS	29	26	23	22	21

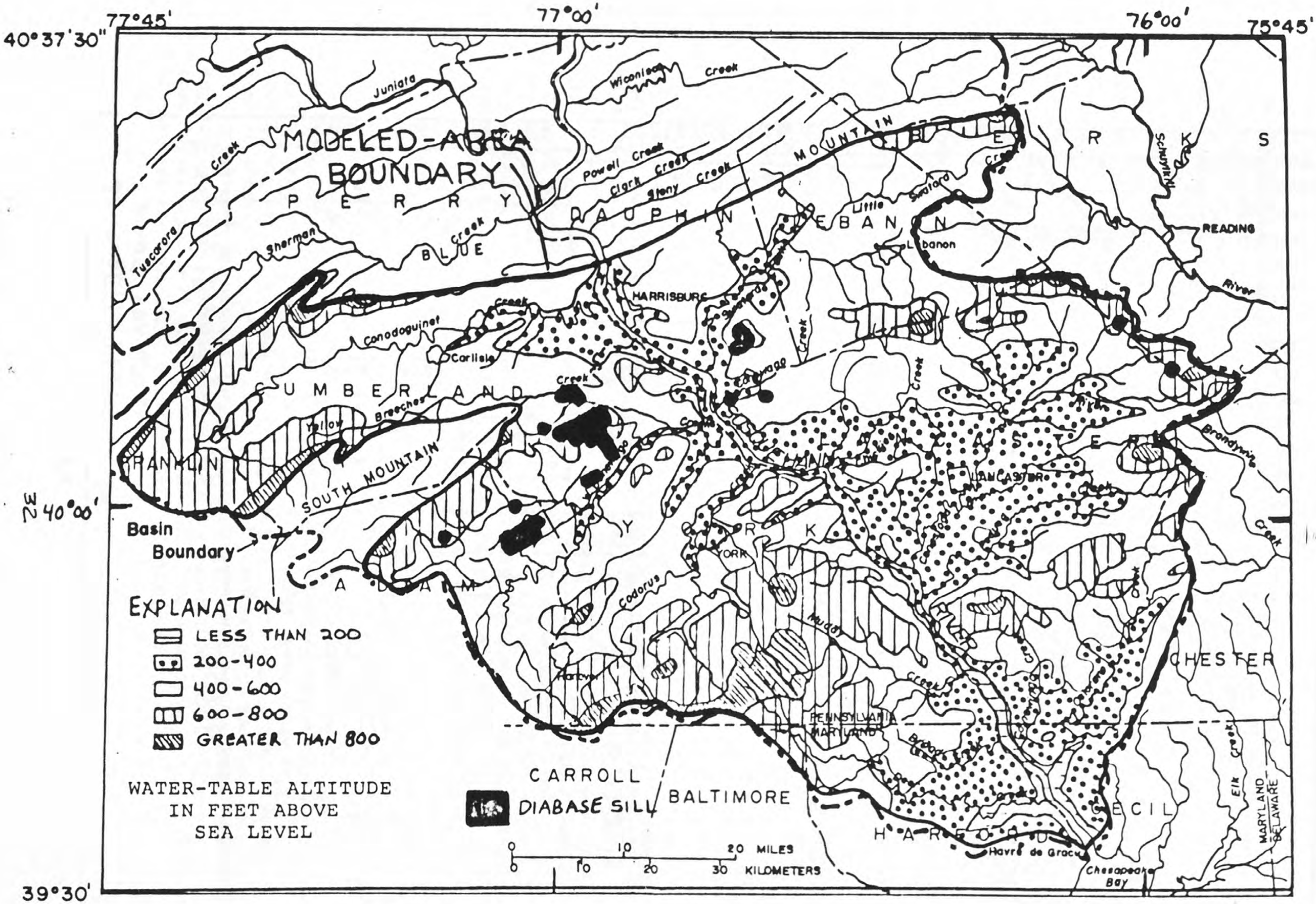


Figure 8. -- Generalized water-table altitude in modeled area.

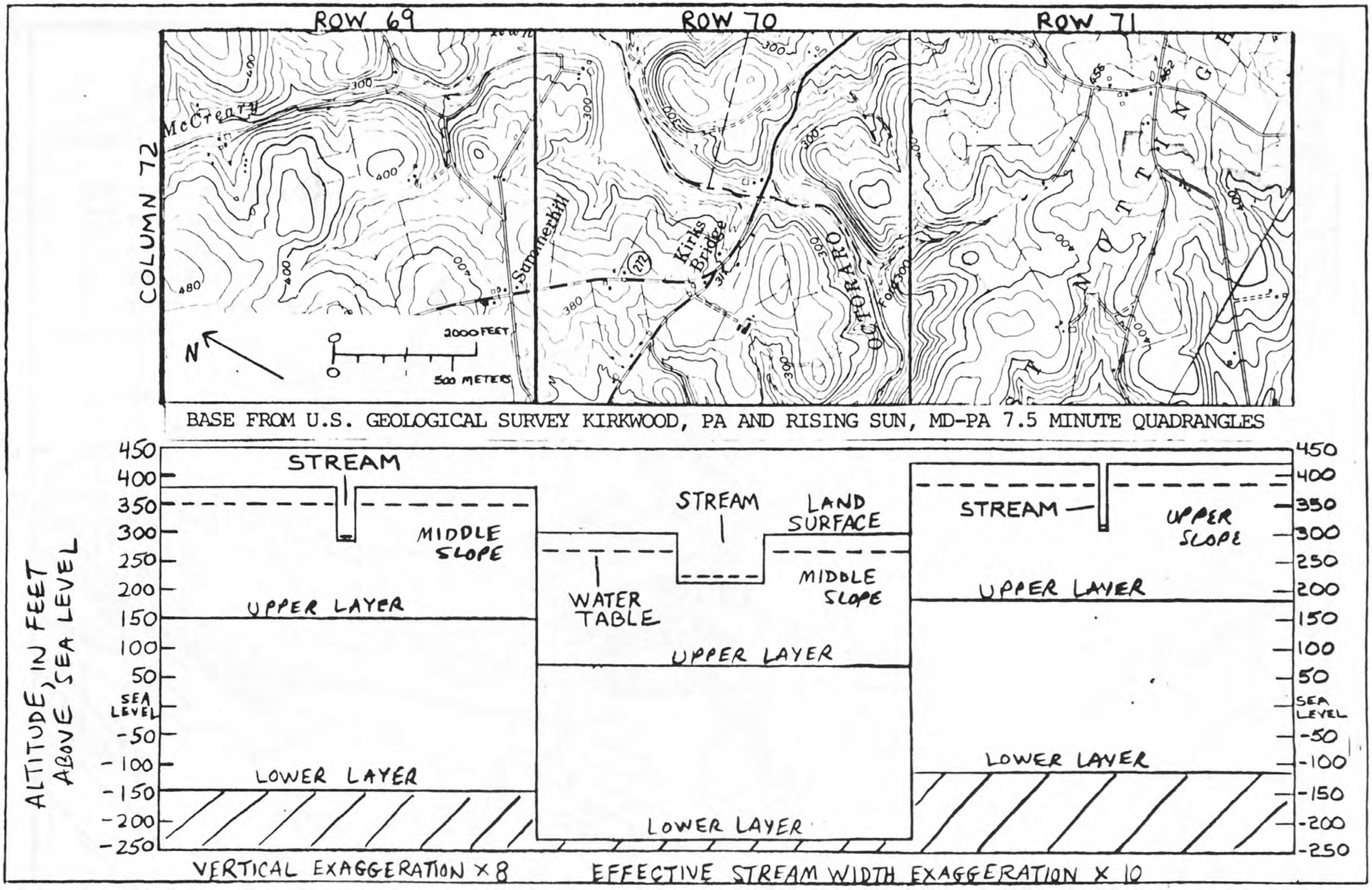


Figure 9. -- Correlation between actual and approximated geometry for three grid blocks in column 72.

the approciamted geometries are related to physiography. The three blocks are in the same hydrogeologic unit (10), so the thicknesses of the upper and lower layers are uniform for all three blocks. However, because the estimated water-table altitudes and the dominant topographic settings are different, the altitudes of the bases of the layers for the three blocks are not the same.

Surface-Water Conditions

Average annual surface-water conditions were assumed to be represented on 7 1/2-minute quadrangle maps. Streams indicated as being perennial were considered to be the discharge locations for the ground-water flow system. Lakes larger then 0.005 mi^2 (3.2 acres) also were included.

About 90 percent of the grid blocks contain at least one stream segment or lake. The average surface-water altitudes were estimated from land-surface contours on 7 1/2-minute quadrangle maps. The surface-water altitude for each of these blocks was calculated using an average of the stream segment and lake altitudes, weighted by their surface areas (fig. 10). For those stream seg-ments represented by single lines on the maps, a width of 15 ft was used in conjunction with the stream segment length to obtain the surface area. For those blocks located partly in the Susquehanna River, and upstream from hydropower dams, pool altitudes were used to estimate the surface-water altitude. Those blocks entirely in the Susquehanna River were treated differently and are discussed in the section on boundary conditions.

Figure 9 shows the estimated surface-water altitude for three typical grid blocks. The effective stream width for each block is proportional to the total surface area of the stream segments and lakes. It is calculated by dividing the total surface area by 5,208 ft (all stream segments and lakes are consolidated into one stream, with a length equivalent to one side of a grid block). The relation between the estimated water-table altitude and the estimated surface-water altitude for each of the three blocks is typical of the modeled area. The water table is above the surface-water bodies for all three blocks. In addition, the water table is higher above the surface-water bodies for the first and third blocks than it is for the middle block, because the first and third blocks have higher average land-surface altitudes.

Hydraulic Conductivity

Initial Estimates

Specific-capacity tests on 751 upper-layer wells were used to estimate the hydraulic conductivity of the upper layer. Most of the wells were drilled for domestic supply. The specific-capacity tests range in duration from 30 minutes to several days and well depth ranges from about 20 to 300 ft. Speci-fic capacity decreases with time during a test until the pumping cone of depression becomes stable. Specific capacity is also affected by well depth. In order to analyze the 751 specific capacities, the differences in test duration and well depth were normalized. The normalized specific capacities were then converted to hydraulic conductivities.

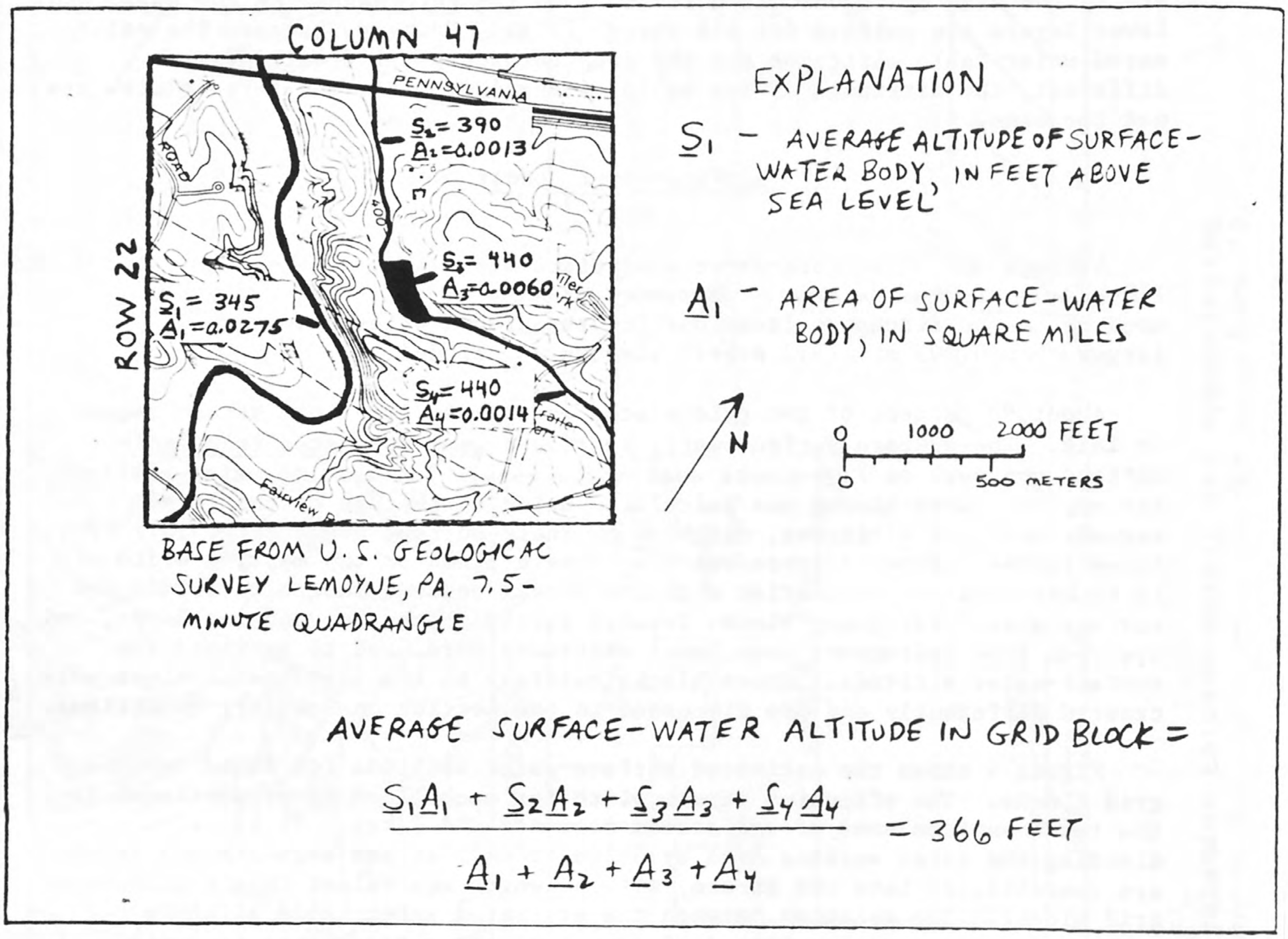


Figure 10. -- Method of estimating surface-water altitude for grid block 22-47.

By using the following equation (Walton, 1970, p. 315), a first approximation of transmissivity was determined:

$$\frac{Q}{s} = \frac{T}{264 \log\left(\frac{Tt}{2{,}693 r^2 S}\right) - 65.5} \qquad (1)$$

where,

$\frac{Q}{s}$ = specific capacity, in gallons per minute per foot of drawdown,

Q = discharge, in gallons per minute,

s = drawdown, in feet,

T = transmissivity, in gallons per day per foot,

S = specific yield,

r = radius of the well, in feet,

t = time after pumping started, in minutes.

A well radius of 0.25 ft, a specific yield of 0.05, and a time of 60 minutes were assumed. In this way, each of the 751 specific capacities was converted to a transmissivity. These calculated transmissivities are only rough estimates because equation 1 is derived for the case of a homogeneous, isotropic, artesian aquifer of infinite areal exent. To obtain specific capacity at steady-state conditions, each of these transmissivities was then reused in equation 1 with a time of 30 days, resulting in specific capacities normalized for test duration.

The 30-day specific capacities were then normalized to a well depth equal to the depth of the base of the upper layer. The following equation was used (modified from Walton, 1970, p. 319):

$$\frac{Q}{s} = \frac{(Q/s)_{30}}{K_p\left(1+7\sqrt{\frac{r}{2K_p m}}\cos\frac{K_p \pi}{2}\right)} \qquad (2)$$

where,

$(Q/s)_{30}$ = 30-day specific capacity, in gallons per minute per foot of drawdown,

K_p = ratio of length of open hole to layer thickness,

r = radius of well, in feet, and

m = thickness of layer, in feet.

A well radius of 0.25 ft was assumed. Equation 2 also is derived for a homogeneous, isotropic, artesian aquifer of infinite areal extent. However, the most critical assumption in this step was that the specific capacity was assumed to be uniform throughout the thickness of the upper layer. Also, equation 2 only applies to specific capacities under steady-state conditions. But by normalizing the specific capacities to 30 days before using equation 2, steady-state conditions were probably approximated.

The 751 normalized specific capacities were then substituted back into equation 1 to obtain the transmissivity of the upper layer at each site. A well radius of 0.25 ft, a specific yield of 0.05, and a time of 30 days were used. The transmissivity at each site was then divided by the thickness of the upper layer at each site to obtain the estimated hydraulic conductivity of the upper layer. The 751 hydraulic conductivities were then grouped by hydrogeologic unit and an average value was calculated for each unit to be used as an initial estimate in the model (table 8). This value was used to represent the hydraulic conductivity in the two horizontal model directions (x and y) in the upper layer.

The hydraulic conductivity of the lower layer was estimated similarly. Data were available on 173 wells which were open to the entire upper layer as well as part or all of the lower layer. The measured specific capacities were normalized in a manner similar to that used for the upper layer by using 30 days and the depth to the base of the lower layer. In 162 of the 173 wells, the normalized specific capacity was less than the average normalized specific capacity for the upper layer. It was assumed that none of the specific acapacity in these 162 wells was obtained from the upper layer. In other words, these wells were drilled into the lower layer because they did not encounter any significant water-bearing zones in the upper layer. Therefore, all the specific capacity for these wells was considered to originate in the lower layer. The normalized specific capacities of these 162 wells were substituted back into equation 1 and the transmissivities of the lower layer were obtained. After division by the appropriate thickness of the lower layer, the hydraulic conductivity of the lower layer at each test site was obtained. The average hydraulic conductivity of the lower layer for each hydrogeologic unit was then calculated. This value was used for the two horizontal model directions in the lower layer.

Because there were fewer data on the hydraulic conductivity of the lower layer, it was necessary to generalize. Ratios of upper- to lower-layer hydraulic conductivity were determined for those hydrogeologic units with sufficient data. These ratios were then extrapolated, on the basis of general lithology, to those units with insufficient data. The ratio for the Triassic sedimentary units is 2:1; ratios for the carbonate, Paleozoic sedimentary, and crystalline units are 10:1. Units 14 and 16 also have ratios of 10:1.

Table 8.--Initial estimates of average hydraulic conductivity for upper layer, and average hydraulic conductivities used in calibrated model.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology	Average hydraulic conductivity for upper layer, in feet per day: Initial estimate	Calibration value
1 PS	2.01	2.01
2 C	13.37	16.05
3 X	4.01	1.34
4 C	43.45	43.45
5 TS	2.01	2.67
6 TS	7.35	3.34
7 C	10.03	10.03
8 X	2.01	.67
9 C	28.74	11.36
10 X	6.69	1.34
11 X	1.34	.67
12 PS	2.01	.67
13 TS	2.01	.40
14	6.02	1.34
15 PS	2.01	2.01
16	15.37	2.01
17 C	14.44	6.69
18 TS	1.34	.13
19 TS	2.01	.40
20 C	6.69	2.67
21 PS	1.34	1.34

As indicated in the simplified conceptual model, aquifer properties for the upper layer not only differ by lithology, but also within lithology due to topography. For each hydrogeologic unit, the estimated average hydraulic conductivity of the upper layer was assumed to apply for all grid blocks with a middle-slope topographic setting. The estimated average hydraulic conductivity for those grid blocks with upper-slope and hilltop settings was multiplied by a factor (less than 1.0) that was determined from the relation between specific capacity and topographic setting for the appropriate general lithology, resulting in hydraulic conductivities less than the estimated average for that unit. By a similar process, those grid blocks with lower-slope and valley-bottom settings were assigned hydraulic conductivities greater than the estimated average. These multiplication factors are shown in table 9.

Specific-capacity data for the Triassic sedimentary units show very little topographic effect, so the estimated average hydraulic conductivity was initially used for all topographic settings. The carbonate, Paleozoic sedimentary, and crystalline units show topographic effects on specific capacity, so multiplication factors were used for those units. The Cumberland Valley carbonate rocks (unit 4) showed more topographic effect than other carbonate units, so a different set of multiplication factors was used. For the two units that contain both carbonate and crystalline rocks (14, 16), multiplication factors were used that are averages of the factors of the two lithologies involved.

Adjustments

Initial estimates of average hydraulic conductivity and final calibration values are shown in table 8. Differences between the two are due to adjustments made during steady-state calibration in order to obtain agreement between model-generated and estimated water-table altitudes. The initial ratios of average hydraulic conductivity between layers were not adjusted. Calibration values are less than initial estimates for fourteen units, greater for two units, and the same for five units. All adjustments to the initial estimates were within an order of magnitude. All major adjustments were downward. A possible reason for the initial estimates being too high is the assumption of uniform specific capacity throughout layer thickness.

Calibration values of average hydraulic conductivity, when grouped by general lithology, show that the carbonate units have the greatest average hydraulic conductivity, 21.2 ft/d. This average, as well as many other such averages in the report, is an area-weighted average of the values for all the units in each general lithology. The Paleozoic sedimentary and Triassic sedimentary units have an average hydraulic conductivity of 1.7 ft/d and the crystalline units have an average hydraulic conductivity of 1.1 ft/d. The relative differences between these average hydraulic conductivities are reflected in the density of streams (table 10). The carbonate units have the greatest average hydraulic conductivity and the fewest streams per square mile, whereas the crystallineunits have the least average hydraulic conductivity and the most streams per square mile. In general, a more permeable lithology will accept more recharge from precipitation, thereby reducing surface runoff and the number of streams necessary to handle it.

Table 9.--Initial estimates of multiplication factors used to modify average hydraulic conductivity for upper layer for topographic effect, and multiplication factors used in calibrated model.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Multiplication factors									
		Initial estimates					Calibration values				
		Hilltop	Upper slope	Middle slope	Lower slope	Valley bottom	Hilltop	Upper slope	Middle slope	Lower slope	Valley bottom
1	PS	0.6	0.8	1.0	1.5	2.0	0.6	0.8	1.0	1.5	2.0
2	C	.4	.7	1.0	2.0	3.0	.4	.7	1.0	2.0	3.0
3	X	.8	.9	1.0	1.3	1.5	.2	.5	1.0	1.3	1.5
4	C	.1	.5	1.0	2.5	4.0	.1	.5	1.0	2.5	4.0
5	TS	1.0	1.0	1.0	1.0	1.0	.5	.8	1.0	1.2	1.5
6	TS	1.0	1.0	1.0	1.0	1.0	.5	.8	1.0	1.2	1.5
7	C	.4	.7	1.0	2.0	3.0	.4	.7	1.0	2.0	3.0
8	X	.8	.9	1.0	1.3	1.5	.2	.5	1.0	1.3	1.5
9	C	.4	.7	1.0	2.0	3.0	.4	.7	1.0	2.0	3.0
10	X	.8	.9	1.0	1.3	1.5	.2	.5	1.0	1.3	1.5
11	X	.8	.9	1.0	1.3	1.5	.2	.5	1.0	1.3	1.5
12	PS	.6	.8	1.0	1.5	2.0	.1	.5	1.0	1.3	1.5
13	TS	1.0	1.0	1.0	1.0	1.0	.5	.8	1.0	1.2	1.5
14		.6	.8	1.0	1.7	2.3	.2	.5	1.0	1.5	2.0
15	PS	.6	.8	1.0	1.5	2.0	.6	.8	1.0	1.5	2.0
16		.6	.8	1.0	1.7	2.3	.6	.8	1.0	1.7	2.3
17	C	.4	.7	1.0	2.0	3.0	.4	.7	1.0	2.0	3.0
18	TS	1.0	1.0	1.0	1.0	1.0	.5	.8	1.0	1.2	1.5
19	TS	1.0	1.0	1.0	1.0	1.0	.5	.8	1.0	1.2	1.5
20	C	.4	.7	1.0	2.0	3.0	.4	.7	1.0	2.0	3.0
21	PS	.6	.8	1.0	1.5	2.0	.6	.8	1.0	1.5	2.0

Table 10.--Stream density for four general lithologies.

General lithology	Area, in square miles	Total stream length, in miles	Stream density (length/area)
Carbonate rocks	835	838	1.00
Paleozoic sedimentary rocks	599	763	1.27
Triassic sedimentary rocks	746	1,012	1.36
Crystalline rocks	1,151	1,699	1.48

Multiplication factors for topographic effect on the average hydraulic conductivity for the upper layer were adjusted for ten hydrogeologic units (table 9). Adjustments for topographic effects were necessary for the Triassic sedimentary units; but, because the specific-capacity data show little relation to topography, the multiplication factors there vary least from 1.0. Multiplication factors for hilltop and upper-slope settings for the crystalline units were adjusted to give lower hydraulic conductivities. This was considered reasonable because for those topographic settings for crystalline units, not many specific-capacity data were available to support the reliability of the initial estimates. Finally, the multiplication factors for the Great Valley shales on the flank of Blue Mountain (unit 12) were adjusted to reduce the hydraulic conductivity for grid blocks high on the flank of the mountain. As with the higher settings for the crystalline units, very few data formed the basis for the initial estimates for this unit.

The hydraulic conductivity for each grid block is the product of the average hydraulic conductivity for the unit (table 8) and the multiplication factor for the topographic setting of the block (table 9). The resulting hydraulic conductivities range from 0.065 ft/d for hilltop blocks in the Triassic conglomerates (unit 18) to 173.8 ft/d for valley-bottom blocks in the Cumberland Valley carbonate rocks (unit 4).

Hydraulic Connection Between Layers

Just as the hydraulic conductivities in the x and y directions were adjusted to obtain agreement between model-generated and estimated water-table altitudes, the vertical hydraulic conductivity can be adjusted to obtain agreement between model-generated and observed vertical-head differences. Unfortunately, vertical-head field data were scarce and inconclusive. In the absence of data, it was necessary to evaluate the effect of the vertical hydraulic conductivity on the ground-water flow system.

During steady-state calibration, a range of vertical hydraulic conductivities was used. The greatest vertical hydraulic conductivity used was equal to the horizontal hydraulic conductivities for each layer. Model-generated vertical-head differences in this case were generally less than 10 ft. The lowest vertical hydraulic conductivity used was two orders of magnitude less than the horizontal hydraulic conductivities. This resulted in model-generated vertical-head differences of several tens of feet to more than 100 ft. Although these differences are substantial, the effect on the ground-water flow system is not very significant. Because the lower layer has lower horizontal hydraulic conductivities than the upper layer, overall ground-water flow in the lower layer in both cases was less than 10 percent of the total. For the same reason, the differences in model-generated water-table altitude for the upper layer between the two cases were only about 1.0 ft. Therefore, the degree of vertical hydraulic connection between layers appears to be of little regional consequence. So, for convenience, vertical hydraulic conductivities equal to horizontal hydraulic conductivities were used for both layers. In addition, because the model results for the upper layer were relatively unaffected by the value of this variable, the model program was not modified to recalculate the coefficient (*TK*) which describes the vertical hydraulic connection between layers, as the saturated aquifer thickness varies during a simulation.

Stream Leakage Coefficients

Initial Estimates

Much of the recharge to and discharge from the ground-water flow system occurs locally. With 5,208-ft square grid blocks, some of the ground water recharging a block may discharge to streams or lakes within that same block. Because 90 percent of the grid blocks contain either a stream or a lake, a mechanism for handling this local phenomenon was incorporated into the model (for convenience, and because streams greatly outnumber lakes, the rest of the report will refer to streams instead of streams and lakes, and stream altitude instead of surface-water altitude). A head-dependent stream leakage option was used. This option (Tracy, written commun., 1979) permitted the use of a constant stream altitude for a grid block without the drawback of having to assign a constant water-table altitude to the block.

For a grid block with a gaining stream, ground water may discharge from the aquifer to the stream either through the streambed or adjacent to the stream through seeps and springs. The diagram in figure 11 illustrates these two discharge types and shows how they are calculated. Discharge through the streambed (Q_1) is dependent on the physiography (s, w_1), the streambed characteristics (K_S, b) and the difference between the stream altitude and the head in the aquifer beneath the streambed (Δh_1). Discharge through adjacent seeps and springs (Q_2) is dependent on the physiography (s, w_2, d), the aquifer characteristics (K_A), and the difference in water-table altitude between the ground-water divide and the area of seeps and springs (Δh_2). For any grid block, all the variables except Δh_1 and Δh_2 are constant.

In order to obtain estimates of the gaining-stream leakage coefficient, Δh_1 and Δh_2 were assumed to be equal and represented by the difference between the estimated water-table altitude and the estimated stream altitude for each block. The two equations for discharge (fig. 11), when added, result in a single equation with the total discharge equal to the product of the above altitude difference and a coefficient combining the constants of the two equations:

$$Q_T = \frac{K_S\, s\, w_1}{b} + \frac{2K_A\, s\, w_2}{d}\,(h_{WT} - h_S) \qquad (3)$$

where,

h_{WT} = estimated water-table altitude, in feet above sea level

h_S = estimated stream altitude, in feet above sea level, and

Q_T = total discharge, in cubic feet per second.

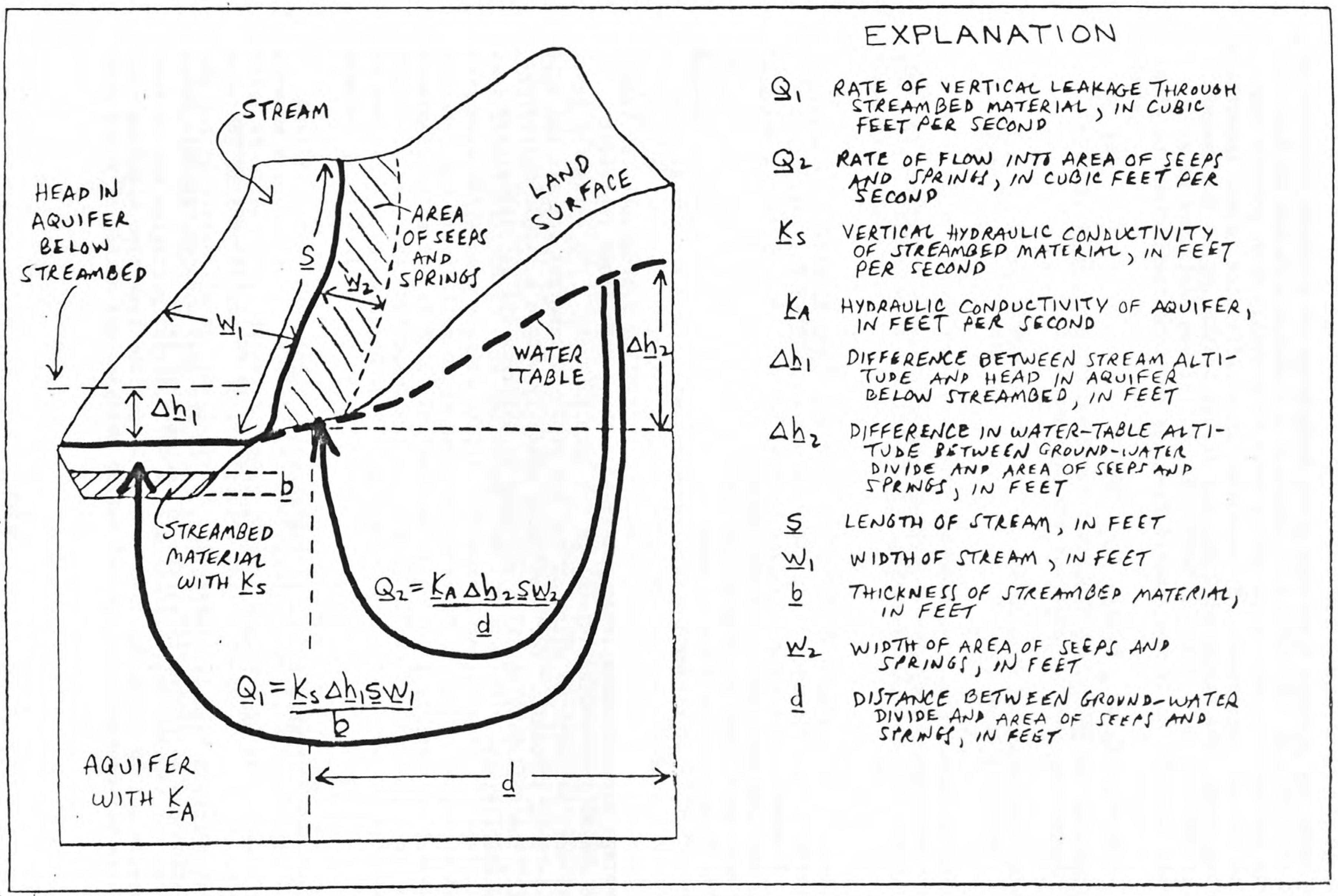


Figure 11. -- Two types of discharge to streams that are included in gaining-stream leakage coefficient.

Because seeps and springs discharge along both banks of a stream, the second term of the combined coefficient in equation 3 includes a factor of 2. Discharge through adjacent seeps and springs is probably much greater than discharge through streambeds. To emphasize this difference in the importance of the two terms, the factor of 2 and the stream length, s, in the second term were replaced by the stream perimeter, p. Stream perimeter is a measurable constant so it was removed from the combined coefficient to give:

$$Q_T = p \left(\frac{K_S\ w_1}{2b} + \frac{K_A\ w_2}{d} \right) h_{WT} - h_S \quad (4)$$

or,

$$Q_T = C\ p \left(h_{WT} - h_S \right) \quad (5)$$

where,

$C = \dfrac{K_S\ w_1}{2b} + \dfrac{K_A\ w_2}{d}$ = gaining-stream leakage coefficient, in feet per second.

Because constants such as K_S, w_1, b, w_2, and d are difficult to measure, the gaining-stream leakage coefficient was not calculated for every grid block. Instead, since K_A was assumed uniform within a hydrogeologic unit, it was assumed that the gaining-stream leakage coefficient was also uniform within each unit. The gaining-stream leakage coefficient for each unit was estimated from equation 5 for 26 subbasins within and adjacent to the modeled area for which daily streamflow data were available. Average annual base flow for each subbasin was estimated by using a graphical separation technique (Linsley, and others, 1949, p 400) on streamflow hydrographs for years with average precipitation (when possible). These base flows represent average annual ground-water discharge for each subbasin. The estimated base flow for each subbasin is equal to the sum of the discharges for all the grid blocks in that subbasin. For a subbasin entirely within a single hydrogeologic unit, the following equation was used to estimate the gaining-stream leakage coefficient:

$$B = C \sum_{1}^{n} p(h_{WT} - h_S) \quad (6)$$

where,

n = number of grid blocks in the subbasin, and

B = estimated base flow for the subbasin, in cubic feet per second.

The gaining-stream leakage coefficient, C, is the only unknown variable and the equation can be solved to obtain an estimate of it.

However, most of the 26 subbasins contain more than one hydrogeologic unit. For each of these subbasins, the following equation was used:

$$B = C_1 \sum_{1}^{n_1} p(p_{WT}-h_S) + C_2 \sum_{1}^{n_2} p(h_{WT}-h_S) + \ldots + C_{21} \sum_{1}^{n_{21}} p(h_{WT}-h_S) \qquad (7)$$

where,

$C_1, C_2, \ldots C_{21}$ = gaining-stream leakage coefficient for each hydrogeologic unit in the subbasin, in feet per second, and

$n_1, n_2, \ldots n_{21}$ = number of grid blocks in each hydrogeologic unit in the subbasin.

Thus, 26 equations resulted; most hydrogeologic units were represented in more than one equation. The equations were solved simultaneously to determine the initial estimates of gaining-stream leakage coefficient (C_1 through C_{21}) shown in table 11.

Certain reaches of some streams may be losing reaches. Therefore, losing-stream leakage coefficients were also needed. For a grid block with losing-stream reaches, only the term Q_1 in figure 11 is applicable; thus, the losing-stream leakage coefficient for each unit was less than the gaining coefficient. In the model program, a check was made before every iteration to determine whether the water-table altitude for a block was above or below the estimated stream altitude. If it was above, the appropriate gaining-stream leakage coefficient was used during that iteration; if it was below, the appropriate losing-stream leakage coefficient was used.

Data on losing reaches were too scarce for losing-stream leakage coefficients to be obtained directly for all but a few hydrogeologic units. Therefore, generalizations based on lithology were used to determine these coefficients. Ratios of gaining- to losing-stream leakage coefficients for each general lithology were estimated from the available losing-reach data. Carbonate units have a ratio of 2:1. Paleozoic sedimentary, Triassic sedimentary, and crystalline units have ratios of 10:1. Units 14 and 16 have intermediate ratios of 3:1. For both gaining- and losing-stream leakage coefficients, those hydrogeologic units with no representation in any of the 26 subbasins were assigned initial estimates equal to those for units of similar general lithology.

Aquifer-stream flow for a grid block also is dependent on the density of streams for the block. For a given hydrogeologic unit, a block with several miles of streams will experience more aquifer-stream flow than a block with only one mile of streams. To incorporate this into the model, the gaining- and losing-stream leakage coefficients for each block were weighted according to the stream density. The total perimeter of streams for each block was used as the weighting factor. The stream leakage coefficients for each hydrogeologic unit were multiplied by the total perimeter of the streams for each block to obtain the weighted stream leakage coefficients for each block.

Table 11.--Initial estimates of gaining-stream leakage coefficient, and gaining-stream leakage coefficients used in calibrated model.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Gaining-stream leakage coefficient, in feet per day	
		Initial estimate	Calibration value
1	PS	0.19	0.26
2	C	.80	8.64
3	X	1.30	.17
4	C	19.87	43.20
5	TS	.52	.16
6	TS	.04	.09
7	C	.17	4.32
8	X	.05	.05
9	C	1.90	1.90
10	X	.07	.07
11	X	.11	.11
12	PS	.19	.07
13	TS	.13	.08
14		.11	.10
15	PS	.19	.09
16		.95	.26
17	C	1.90	.26
18	TS	.13	.05
19	TS	.13	.05
20	C	.80	.22
21	PS	.19	.22

For a losing-stream reach, another variable was needed. The rate of flow from the stream to the aquifer increases as the water-table altitude decreases until a certain altitude is reached. This altitude, known as the stream leakage cutoff altitude, is the point at which the stream becomes hydraulically separated from the aquifer. When the water-table altitude drops below this cutoff altitude, an unsaturated portion of aquifer separates the stream from the water table. From then on, the rate of flow from the stream to the aquifer will not increase, but will remain at the rate that was in effect when the cutoff altitude was reached.

The cutoff altitude for each grid block was based on the average depth of streams for the block. Average water depths of 10, 5, and 2 ft were estimated for the Susquehanna River, major tributaries, and small streams, respectively. An average depth of 30 ft was estimated for large lakes and reservoirs and an average depth of 5 ft was estimated for smaller lakes. For blocks containing more than one of these types of water bodies, a weighted average of the above depths was calculated. The average depth of surface water for each block was then subtracted from the estimated stream altitude to obtain the cutoff altitude for each block.

Adjustments

Initial estimates of stream leakage coefficients for many hydrogeologic units were adjusted during steady-state calibration in order to obtain agreement between model-generated and estimated water-table altitudes. Final calibration values are shown in table 11. The calibration values are less than the initial estimates for eleven units, greater for six units, and the same for four units. All the adustments to the initial estimates are within about an order of magnitude, except for the Conestoga Valley carbonate rocks west of the Susquehanna River (unit 7), where the adjustment factor is 25. The adjustments were considered reasonable due to the generalized nature of the initial estimates. The initial ratios of gaining- to losing-stream leakage coefficients were maintained in the final calibration values.

Gaining-stream leakage coefficients (table 11) range from 0.05 ft/d for three units--the Conestoga Valley metamorphic rocks west of the Susquehanna River(unit 8), the Triassic conglomerates (unit 18), and the unit consisting of part Triassic conglomerates and part western and eastern Triassic sedimentary rocks (unit 19)--to 43.2 ft/d for the Cumberland Valley carbonate rocks (unit 4).

The area-weighted average value of gaining-stream leakage coefficient is greatest for the carbonate units--15.8 ft/d. The average gaining-stream leakage coefficients for the Paleozoic sedimentary, Triassic sedimentary, and crystalline units are 0.21, 0.11, and 0.08 ft/d, respectively. Two possible reasons for the great difference between the carbonate and other units are the higher hydraulic conductivites of the carbonate units and their lower stream density. There is more ground water flowing through the carbonate units and fewer discharge locations, so the gaining-stream leakage coefficients are necessarily higher.

Recharge

Recharge to the unconfined aquifer occurs as the result of precipitation infiltrating the weathered mantle and percolating to the water table. It occurs everywhere, except possibly in the immediate vicinity of streams. Because the grid blocks are large, at least some recharge occurs in every grid block. Recharge is a function of lithology, amount and intensity of precipitation, soil type, soil moisture, temperature, and other factors. For the steady-state calibration, it was assumed that model recharge depends only on the lithology and the amount of precipitation. Model recharge was determined as a percentage of the average annual precipitation for each hydrogeologic unit and each major gaged subbasin.

Model recharge was assumed to equal the average annual base flow because there is no net gain or loss of ground water from storage during an average year. Base flows during years with average precipitation (when possible) were estimated for 26 subbasins within and adjacent to the lower basin using a graphical separation technique on streamflow hydrographs (Linsley, and others, 1949, p. 400). By using precipitation data from NOAA stations in or near each subbasin, estimated base flow was converted to a percentage of annual precipitation. These percentages were assumed to be average annual percentages. Grouping the resulting 26 percentages by general lithology shows that the carbonate units have the highest average percentage (35). The Paleozoic sedimentary, Triassic sedimentary, and crystalline units have average percentages of 28, 27, and 22, respectively. As with the average hydraulic conductivities, and for the same reason, the relative differences between these average percentages are reflected in the stream density (table 10). By using these average percentages, and taking into account the lithologic and hydrologic differences between units, a preliminary percentage was assigned to each hydrogeologic unit (table 12).

The preliminary unit percentages in 13 major subbasins were refined. These subbasins and their estimated base flows are shown in figure 12. The other 13 subbasins were either too small or were not contained entirely within the modeled area. Each of the 13 major subbasins contains more than one hydrogeologic unit. Because the preliminary percentage for each unit was largely based on an average of the percentages estimated for all units of similar general lithology, its application to any particular unit of that general lithology may not be accurate. This would result in total base flows in some subbasins that are significantly different than the estimated base flows. Therefore, the preliminary unit percentages for the 13 major subbasins were modified to yield the estimated base flows. The preliminary percentages of every unit in a subbasin were modified equally. As a result, a unit may have a range of percentages assigned to it, with the different percentages applied to the different subbasins in which that unit is found (table 12). Most hydrogeologic units have several such percentages associated with them. A representative percentage (table 12) was estimated for each unit and used in those parts of the modeled area that are not contained in one of the 13 major subbasins.

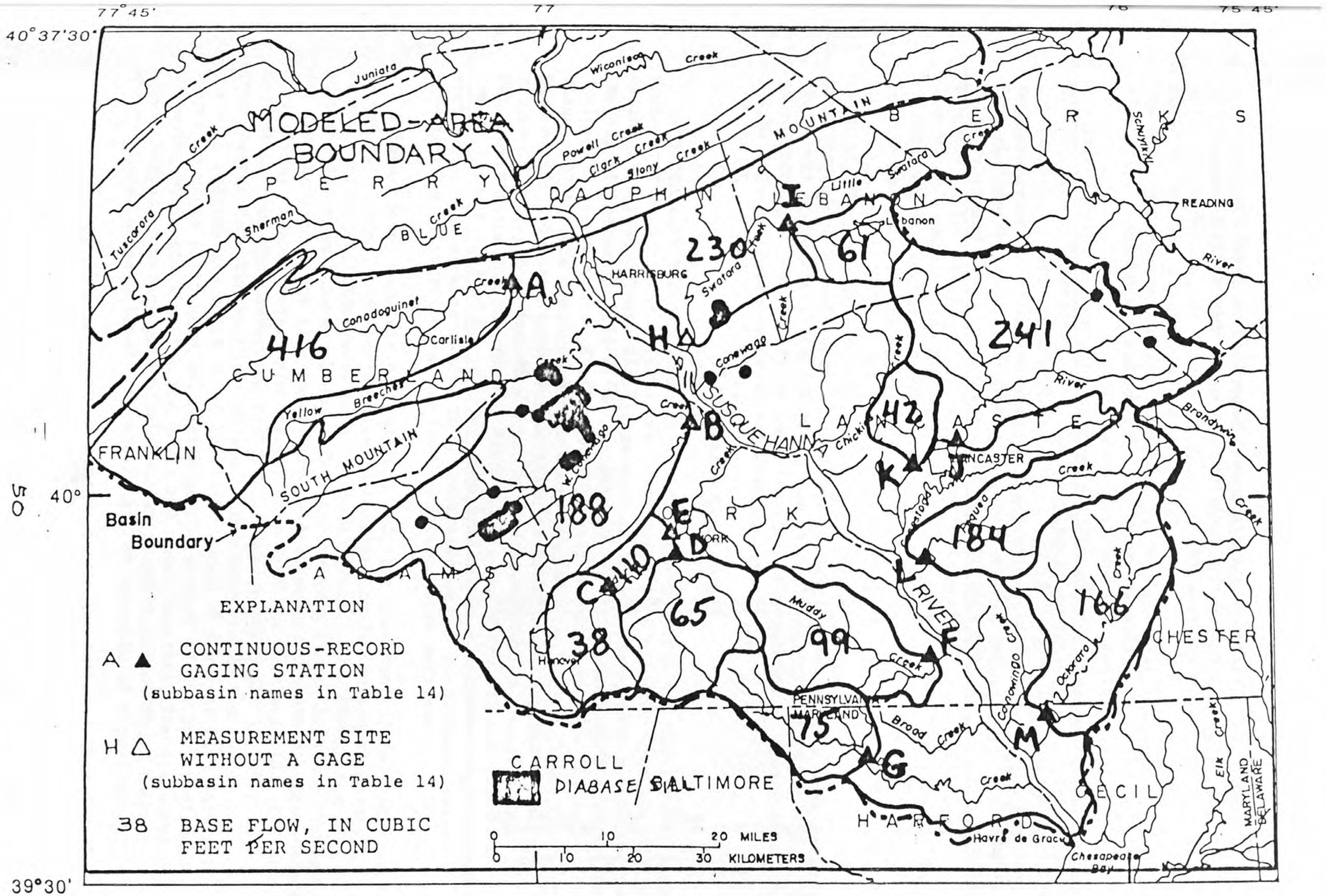


Figure 12. -- Estimated average annual base flows for major gaged subbasins in modeled area (base flows are for those parts of subbasins in modeled area).

Table 12.--Estimated average annual base flow as percentage of precipitation for each hydrogeologic unit in calibrated steady-state model.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Preliminary percentage of precipitation	Range of percentages used in 13 subbasins	Representative percentage of precipitation
1	PS	28	22-34	28
2	C	35	29-40	37
3	X	20	19-33	25
4	C	35	41	40
5	TS	27	18-21	20
6	TS	27	26	25
7	C	35	23-27	32
8	X	22	13-18	20
9	C	35	34-48	37
10	X	22	13-35	25
11	X	22	26	22
12	PS	20	14-26	20
13	TS	15	6-20	15
14		28.5	18-22	24
15	PS	28	27-31	28
16		28.5	27.5-41.5	30
17	C	32	35-45	35
18	TS	15	6-20	15
19	TS	15	6-20	15
20	C	30	24	30
21	PS	28	22-34	25

Each grid block was assigned a percentage. If the block was in a unit in one of the 13 major subbasins, it was assigned the percentage for that unit and that subbasin. If it was in a unit in an area not included in one of the major subbasins, it was assigned the representative percentage for that unit. The percentage for each grid block was multiplied by the average annual precipitation for each grid block (fig. 3) to determine the model recharge.

Ground water lost to consumptive withdrawals does not appear in streams as base flow. Therefore, model recharge equal to base flow is less than actual recharge from precipitation. The amount of actual recharge lost to consumptive withdrawals was minor. Based on water-use data reported to the Pennsylvania Department of Environmental Resources between 1972 and 1979 (Runkle, written commun., 1980), less than 11 Mgal/d of ground-water use occurred in the relatively heavily developed central part of Lancaster County. Consumptive use was even less. This is less than 5 percent of the estimated model recharge for that area. Ground-water use generally was even less in the rest of the modeled area.

Similarly, the amount of actual recharge lost to ground-water evapotranspiration is not included in model recharge. The lack of data on its distribution and magnitude did not allow it to be quantified for inclusion in model recharge. The effect of omitting these two amounts of ground water is a slight underestimation of the ground-water resources.

Boundary Conditions

Steady-state boundary conditions are shown in plate 1. The lateral boundaries for most of the modeled area were assumed to coincide with the surface drainage divides. These boundaries were designated as no-flow boundaries for both layers because there is no net gain or loss of ground water across them during an average year. The northern lateral boundary is Blue Mountain. Its ridge is a surface drainage divide along most of its length. There are several places, however, where the mountain is breached by streams and where ground water may flow into the area. The most obvious of these is near Harrisburg where the Susquehanna River enters the area. It was initially assumed that no ground water enters the modeled area in these locations and no-flow boundaries were used. This assumption caused no problems during steady-state calibration, so no-flow conditions were retained.

Because South Mountain was not included, but does contribute ground water to the model area, a different lateral boundary condition was necessary. Constant-flux conditions were used for both layers. Even though the rate of ground-water flow from South Mountain into the area is not constant throughout the year, constant flow rates were used under average annual steady-state conditions. Ground water entering the area from the northern side of South Mountain enters the Cumberland Valley carbonate rocks (unit 4), whereas ground water from the southern side of South Mountain enters one of two Triassic sedimentary units (5 or 13). The rates of constant flux into grid blocks in these units were calculated as the product of the intermediate hydraulic conductivities for the units and South Mountain, the estimated gradients between boundary grid blocks and adjacent blocks on South Mountain, the thickness of each layer, and the length of one side of a grid block.

Constant-head boundary conditions were used for those grid blocks entirely in the Susquehanna River. It was assumed that the heads in the aquifer for these blocks were equal to the river altitude. Only the heads for the upper layer were handled in this manner.

No-flow boundaries were placed around the edges of major diabase sills because diabase is essentially impermeable on a regional scale. It has a low average specific capacity, a low average yield, and essentially no ground-water circulation below 150 ft (Wood, 1981). Wood states "....diabase dikes and sills tend to act as barriers to the movement of water....". Dikes were not treated as no-flow boundaries. Because they are narrow, none of them occupy more than a small percentage of any one grid block. Thus, the assignment of zero hydraulic conductivity to an entire grid block was not warranted.

Results

Water-Table Altitudes

Non-parametric statistics were used to judge the adequacy of the steady-state calibration. The difference between estimated and model-generated water-table altitude was calculated for each grid block for each hydrogeologic unit. The median difference was then determined for each unit. In addition, four other percentiles--10, 25, 75, and 90--were used to evaluate the spread of the differences around the median. Calibration goals were to obtain a median difference of zero for each unit and to minimize the 10 and 90 percentiles. By meeting these goals, it was decided that the accuracy of the model would be in proper agreement with the accuracy of the hydrologic data and the averaging methods used to incorporate those data into the model.

A problem with using statistics to judge calibration is that the areal distribution of differences is not considered. So, in addition to statistical analysis, the distributional biases were examined for each unit. For example, a unit may have positive differences in its eastern half and an equal number of negative differences in its western half, and show a median difference of zero and low 10 and 90 percentiles. Obviously, the hydrologic characteristics used in the model to describe that unit are inappropriate. Separating the unit into two units with different hydrologic characteristics is a possible solution to this problem. In fact, this problem was encountered several times during steady-state calibration, and, in all cases, a more detailed hydrologic data analysis showed separate units to be an appropriate solution. Units 15, 17, 18, 19, 20, and 21 were the result of such separations (table 5). The problems arose from grouping significantly different geologic formations into one hydrogeologic unit.

Statistics describing the calibration are shown in table 13. As an example, the results for the northern Conestoga Valley shales (unit 15) show good agreement between the model-generated and estimated water-table altitudes. The median difference is 3 ft, 10 percent of the positive differences are more than 26 ft, and 10 percent of the negative differences are more than 33 ft. This range of differences was considered within the range of uncertainty in the estimated water-table altitudes for grid blocks approximately a square mile in area.

Median differences for all the hydrogeologic units are 11 ft or less. Three 10 and ten 90 percentiles deviate from zero by more than 50 ft; only one 10 and two 90 percentiles deviate from zero by more than 100 ft. Thirteen areally-continuous hydrogeologic units with adequate hydrologic data (units 1, 2, 4, 5, 7, 8, 9, 10, 11, 15, 17, 20, 21,) have area-weighted average 10 and 90 percentiles of 31 and -39 ft, respectively. On the other hand, eight discontinuous hydrogeologic units with less hydrologic control (units 3, 6, 12, 13, 14, 16, 18, 19) have area-weighted average 10 and 90 percentiles of 50 and -85 ft, respectively. Because they are discontinuous and are found in various parts of the area, these units probably have greater differences in hydrologic characteristics than units that occur in only one part of the area. In addition, these units also tend to have high local relief, making it more difficult to accurately estimate average water-table altitudes for large grid blocks. For these reasons, a greater range of 10 and 90 percentiles for the discontinuous hydrogeologic units was accepted.

As was stated before, distributional biases of negative and positive differences within a hydrogeologic unit were eliminated, usually by introducing additional hydrogeologic units. However, for the Cumberland Valley carbonate rocks (unit 4), distributional biases could not be correlated with differences between formations, so the unit was not separated into smaller units. The statistics in table 13 clearly indicate the problem. Many more grid blocks have positive than negative differences. The positive differences, which indicate that model-generated water-table altitudes are higher than estimated, are concentrated in the northern part of the unit, with the greatest differences found adjacent to the contact with the western Great Valley shales (unit 1). Most ground water in the carbonate rocks flows in a northeasterly direction, as indicated by regional water-table contour maps. The small streams in the northern part of the unit flow northward toward the contact and are too few to discharge all the ground water in the unit. Apparently, much of the ground water must discharge directly into the major stream in the valley--Conodoguinet Creek. However, most reaches of this stream are just north of the contact with the shales of unit 1, so ground water must first flow from the carbonate rocks into the shales. In the model, the shales have significantly lower hydraulic conductivity than the carbonate rocks, so the contact acts as a ground-water dam; model-generated water-table altitudes are higher than those estimated for the carbonate unit adjacent to the contact.

It is possible that the shales along the contact are more permeable than the shales in the rest of unit 1, but the specific capacities of wells in the shales near the contact are not significantly greater than those in other parts of the unit. In contrast to a band of higher permeability along the contact, several narrow avenues of higher permeability may permit the ground water in the carbonate rocks to reach Conodoguinet Creek. But regional water-table contour maps for the carbonate rocks do not indicate any areas of ground-water flow convergence near the contact. Consequently, it is not known which of these conditions exists. It is also possible that neither is correct and that the water-table configuration generated in the steady-state calibration is correct. This implies that the estimated water-table alti-tudes in the vicinity of the contact are incorrect--not an unreasonable possibility in cavernous carbonate terrane. As a result, calibration of the model for the Cumberland Valley carbonate rocks (unit 4) was considered adequate until additional hydrologic data are available to narrow down the alternatives.

Table 13.--Statistical comparison, by hydrogeologic unit, or estimated water-table altitudes and water-table altitudes generated in calibrated steady-state model.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Number of grid blocks	Percentiles of difference, in feet, between estimated and model-generated water-table altitude for upper layer 1/				
			10	25	Median	75	90
1	PS	329	30	15	0	-13	-26
2	C	76	22	14	5	- 2	-13
3	X	72	38	20	-2	-36	-73
4	C	277	37	25	11	- 2	-16
5	TS	401	29	17	2	-19	-46
6	TS	46	48	27	2	-47	-90
7	C	77	17	14	3	-10	-30
8	X	157	38	20	0	-30	-65
9	C	300	17	10	-1	-12	-24
10	X	778	41	23	-1	-26	-53
11	X	177	24	10	-3	-21	-39
12	PS	54	127	57	2	-56	-127
13	TS	160	35	14	-5	-40	-82
14		30	35	15	5	-31	-70
15	PS	57	26	13	3	-14	-33
16		99	25	16	1	-25	-55
17	C	108	25	15	-3	-16	-33
18	TS	51	86	27	-9	-48	-113
19	TS	108	53	41	-2	-51	-94
20	C	21	31	7	-4	-14	-33
21	PS	176	24	10	-4	-22	-39

1/ Negative differences indicate model-generated water-table altitude is less than estimated water-table altitude.

Base Flow

As discussed in the section on recharge, base flow was estimated for 26 subbasins in the modeled area. As a further check on the adequacy of the steady-state calibration, the base flows generated in the model for 13 major subbasins were compared to the estimated base flows (table 14). Model-generated base flows were within 12 percent of estimated base flows. The differences are caused by model-generated water-table altitudes that deviate from those estimated near subbasin divides. Such differences were considered within the range of error associated with hydrograph separation techniques.

Ground-Water Budgets

A result of the steady-state calibration was the quantification of the ground-water flow components for each grid block. Figure 13 shows the model-generated average annual rates of ground-water flow for the three grid blocks shown in figure 9. Included are model recharge, discharge, and flow between adjacent blocks. Also included is flow between layers. However, because vertical-head data were not available to calibrate the lower layer, any model-generated rates of flow between layers are only as accurate as the estimated aquifer characteristics of the lower layer.

Flow rates for individual grid blocks were added by hydrogeologic unit to obtain the average annual ground-water budgets for each unit. These total unit flow rates were then normalized with respect to area by dividing each rate by the area of the unit in which it applies (table 15). Model recharge is greatest [0.75 (Mgal/d)/mi^2] for the Cumberland Valley carbonate rocks (unit 4) and least [0.19 (Mgal/d)/mi^2] for the unit combining Triassic sedimentary rocks and diabase (unit 13). The Cumberland Valley carbonate rocks (unit 4) also gain the most ground water from South Mountain boundary flow [0.19 (Mgal/d)/mi^2] and the most from infiltration from streams [0.29 (Mgal/d)/mi^2]. The Conestoga Valley carbonate rocks west of the Susquehanna River (unit 7) gain the most ground water from adjacent units [0.20 (Mgal/d)/mi^2] and the eastern Triassic sedimentary rocks (unit 6) lose the most ground water to adjacent units [0.31 (Mgal/d)/mi^2]. Considering the total sources for each unit, the Cumberland Valley carbonate rocks (unit 4) have the greatest overall recharge, 1.27 (Mgal/d)/mi^2. The least overall recharge is 0.24 (Mgal/d)/mi^2 for the Triassic conglomerates (unit 18).

With respect to general lithology, the carbonate, Paleozoic sedimentary, crystalline, and Triassic sedimentary units have area-weighted average rates of model recharge of 0.69, 0.50, 0.45, and 0.29 (Mgal/d)/mi^2, respectively. Infiltration from streams occurs only in the carbonate units and averages 0.12 (Mgal/d)/mi^2. Carbonate units gain the most ground water from adjacent units [0.12 (Mgal/d)/mi^2]; the Palezoic and Triassic sedimentary units lose the most ground water to adjacent units [0.08 (Mgal/d)/mi^2]. The area-weighted average overall recharge rates are 0.99, 0.54, 0.46, and 0.37 (Mgal/d)/mi^2 for the carbonate, Palezoic sedimentary, crystalline, and Triassic sedimentary units, respectively.

Average annual flow rates for each component over the entire modeled area are shown in figure 14. These rates are the sums of rates for all the individual grid blocks. Annually, an average of 1,857 Mgal/d [0.54 (Mgal/d)mi^2]

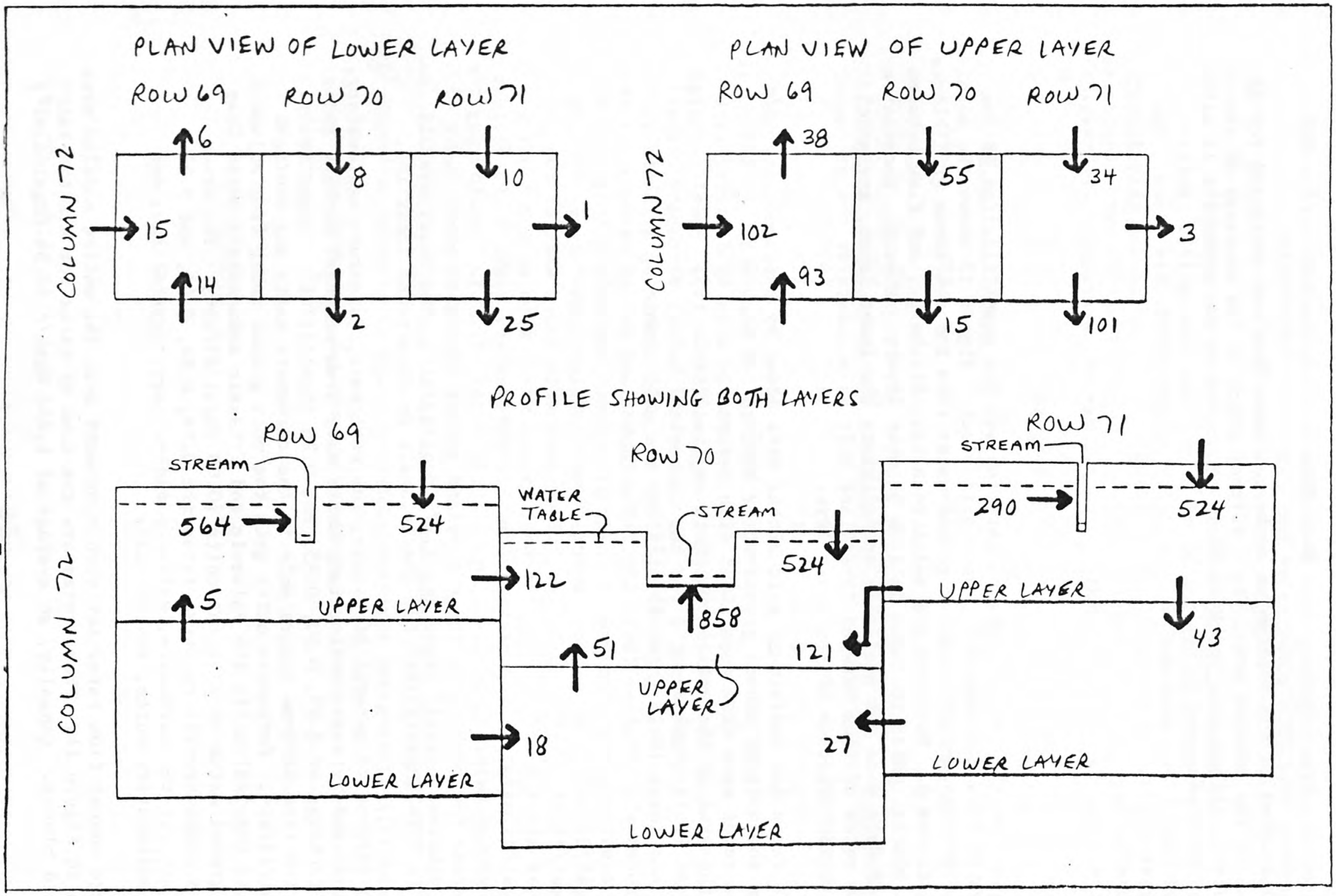


Figure 13. -- Flow rates, in thousand gallons per day, of ground-water budget components in calibrated steady-state model for three grid blocks in column 72.

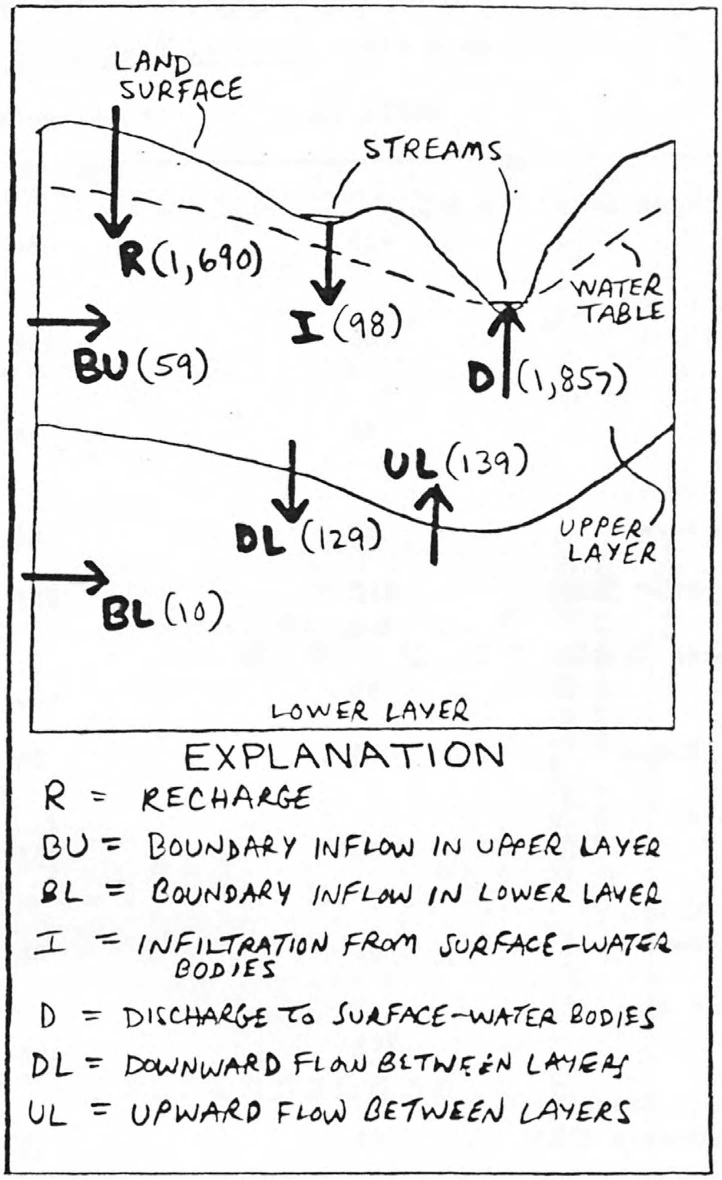


Figure 14. -- Flow rate, in million gallons per day, of ground-water budget components in calibrated steady-state model for entire modeled area.

Table 14.--Comparison, by gaged subbasin, of estimated base flows and base flows generated in calibrated steady-state model.

Subbasin 1/	Base flow, in cubic feet per second 2/	
	Estimated	Model-generated
A. Conodoguinet Creek near Hogestown	416	464
B. West Conewago Creek near Manchester	188	206
C. Codorus Creek at Spring Grove	38	38
D. South Branch Codorus Creek near York	65	64
E. Codorus Creek near York	110	121
F. Muddy Creek near Castle Fin	99	100
G. Deer Creek at Rocks	75	75
H. Swatara Creek at Middletown	230	251
I. Quittapahilla Creek near Bellegrove	61	66
J. Conestoga River at Lancaster	241	247
K. Little Conestoga Creek at Conestoga Country Club	42	40
L. Pequea Creek at Martic Forge	184	187
M. Octoraro Creek near Rising Sun	166	161

1/ Location of subbasins shown on figure 12.

2/ Base flow is for those parts of subbasins in modeled area.

Table 15.--Average annual ground-water budget for each hydrogeologic unit.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Flow rates in calibrated steady-state model, in million gallons per day per square mile: Sources					Sinks		
		Model recharge	South Mountain boundary flow	Infiltration from streams	Flow from adjacent units	Total	Discharge to streams	Flow to adjacent units	Total
1	PS	0.53	0.0	0.0	0.05	0.58	0.55	0.03	0.58
2	C	.68	0	.11	.16	.95	.92	.03	.95
3	X	.56	0	0	0	.56	.36	.20	.56
4	C	.75	.19	.29	.04	1.27	1.26	.01	1.27
5	TS	.34	.03	0	.05	.42	.38	.04	.42
6	TS	.51	0	0	.11	.62	.31	.31	.62
7	C	.51	0	.05	.20	.76	.75	.01	.76
8	X	.31	0	0	.01	.32	.25	.07	.32
9	C	.70	0	.02	.16	.88	.87	.01	.88
10	X	.46	0	0	0	.46	.45	.01	.46
11	X	.49	0	0	0	.49	.49	0	.49
12	PS	.43	0	0	0	.43	.21	.22	.43
13	TS	.19	.03	0	.05	.27	.16	.11	.27
14		.38	0	0	.14	.52	.28	.24	.52
15	PS	.53	0	0	.03	.56	.34	.22	.56
16		.67	0	0	.18	.85	.64	.21	.85
17	C	.70	0	0	.09	.79	.73	.06	.79
18	TS	.20	0	0	.04	.24	.18	.06	.24
19	TS	.24	0	0	.05	.29	.18	.11	.29
20	C	.50	0	0	.15	.65	.55	.10	.65
21	PS	.44	0	0	.04	.48	.40	.08	.48

is discharged into streams in the area. About 91 percent of the discharge to streams is model recharge [0.48 (Mgal/d)/mi^2]; about 5.3 percent is infiltration from streams [0.03 (Mgal/d)/mi^2]; and about 3.7 percent is boundary flow from South Mountain [0.02 (Mgal/d)/mi^2]. Less than 8 percent of the discharge to streams is ground water that flows upward from the lower layer [0.04 (Mgal/d)/mi^2].

Sensitivity Analysis

Sensitivity analysis involves changing the value of a single input variable in a model and making another simulation. Any changes in the results (model-generated water-table altitude and base flow) are then due only to the change made in that input variable. If the changes in results are great when a change is made to an input variable, the model is said to be sensitive to that variable. Conversely, slight changes in the results indicate model insensitivity to that variable.

Sensitivity analyses were performed on several key input variables prior to steady-state calibration. The results were used to guide adjustments to the input variables during calibration. The sensitivity of the model to the following variables was analyzed: Model recharge, hydraulic conductivity, gaining- and losing-stream leakage coefficients, South Mountain boundary flow, vertical hydraulic connection between layers, and the ratio of gaining- to losing-stream leakage coefficients. The changes in model recharge, hydraulic conductivity, and stream leakage coefficients had the greatest effect on the results. As a result of the precalibration sensitivity analysis, it was decided that the steady-state calibration should involve the adjustment of hydraulic conductivity and stream leakage coefficients. Model recharge was not adjusted during calibration because it was the best defined.

After the steady-state calibration was completed, formalized sensitivity analyses for model recharge, hydraulic conductivity, and gaining-stream leakage coefficient were done using the steady-state calibration simulation as a base. The value of each input variable in the steady-state calibration was increased by 50 percent and three new simulations were made, one for each input variable change. Differences between the three new sets of water-table altitudes and the steady-state calibration altitudes were than graphed along part of one model row for each of 13 hydrogeologic units. The units analyzed were those that are areally continuous and have adequate hydrologic data--units 1, 2, 4, 5, 7, 8, 9, 10, 11, 15, 17, 20, and 21. As an example of this procedure, the graph for unit 21 is shown in figure 15. Unit 21 was most sensitive to model recharge. Changes in gaining-stream leakage coefficient for unit 21 had a lesser but nearly uniform impact, whereas change in hydraulic conductivity in unit 21 resulted in quite different impacts between grid blocks.

Model recharge had the greatest influence on the model results for all units. Stream leakage coefficients generally had the next greatest effect, while most units were least sensitive to hydraulic conductivity. However, units 4, 7, and 9 (carbonate units) were more sensitive to hydraulic conductivity than stream leakage coefficient.

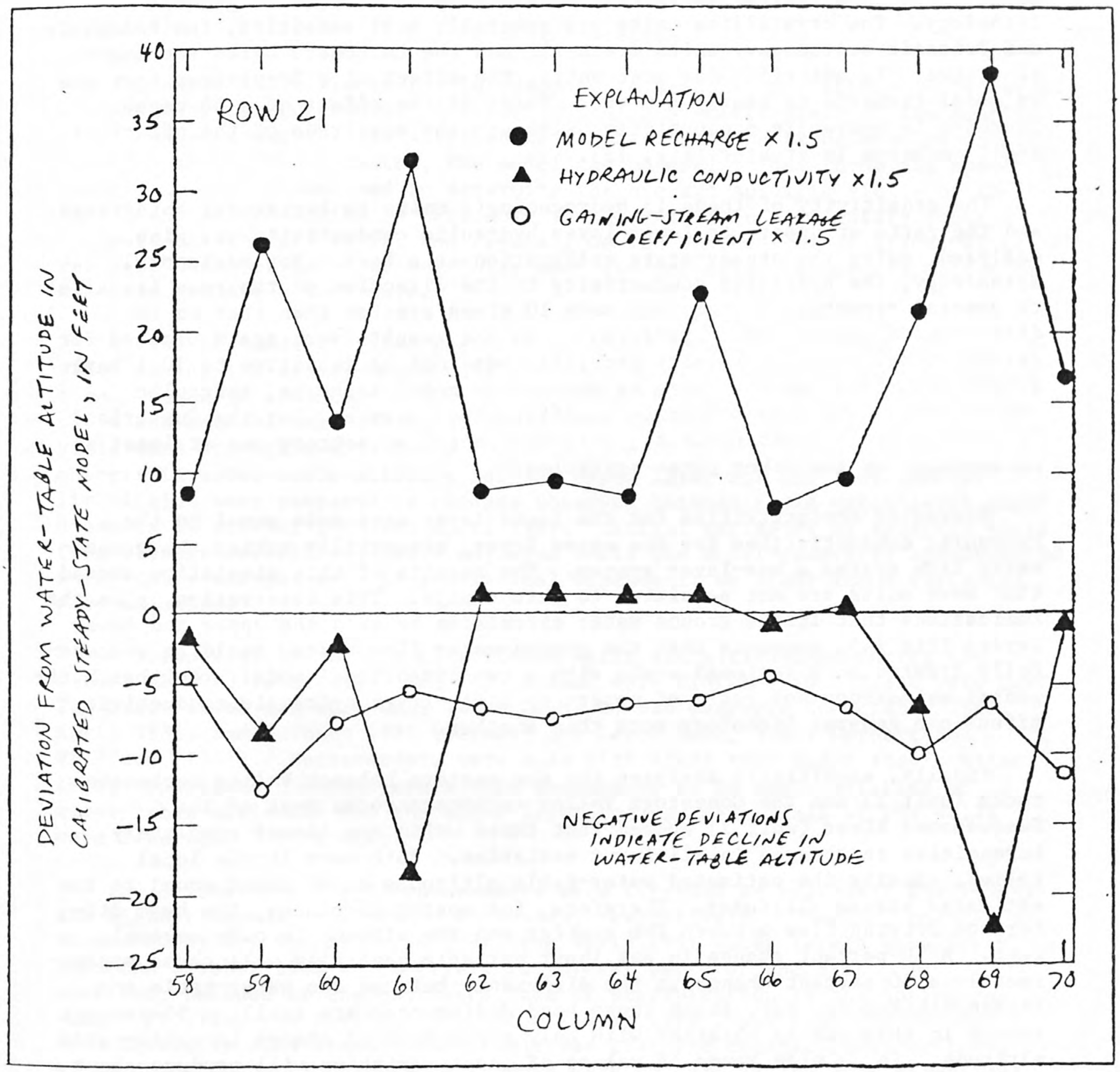


Figure 15. -- Sensitivity analysis of hydrogeologic unit 21 for model recharge, hydraulic conductivity, and gaining-stream leakage coefficient along part of row 21 of grid.

A general observation on the sensitivity of the hydrogeologic units to these three input variables is that sensitivity is related to general lithology. The crystalline units are generally most sensitive, the Paleozoic and Triassic sedimentary units are next, and the carbonate units are least sensitive. In addition, for most units, the effect of a 50-percent increase in model recharge is nearly a mirror image of the effect of a 50-percent increase in hydraulic conductivity, although the magnitude of the effect of model recharge is greater (fig. 15).

The sensitivity of these 13 hydrogeologic units to horizontal anisotropy and the ratio of upper- to lower-layer hydraulic conductivity was also analyzed, using the steady-state calibration as a base. For horizontal anisotropy, the hydraulic conductivity in the direction of the rows (parallel to general structural trend) was made 10 times greater than that in the direction of the columns. Differences in the results were again plotted for certain model rows. The units generally were not as sensitive to 10:1 horizontal anisotropy as they were to changes in model recharge, hydraulic conductivity, and stream leakage coefficients. However, for the Cumberland Valley carbonate rocks (unit 4), 10:1 horizontal anisotropy was at least as influential as the other three variables.

Hydraulic conductivities for the lower layer were made equal to the hydraulic conductivities for the upper layer, essentially making the ground-water flow system a one-layer system. The results of this simulation showed that most units are not sensitive to this change. This observation, plus the indications that little ground water circulates between the upper and lower layers (fig 14), suggests that the ground-water flow system could be successfully treated on a regional scale with a two-dimensional model. Neither horizontal anisotropy nor ratio of upper- to lower-layer hydraulic conductivity affect one general lithology more than another.

Finally, sensitivity analyses for the eastern Lebanon Valley carbonate rocks (unit 2) and the Conestoga Valley carbonate rocks west of the Susquehanna River (unit 7) showed that these units are almost completely insensitive to changes in all input variables. Both have little local relief, causing the estimated water-table altitudes to be about equal to the estimated stream altitudes. Therefore, for most grid blocks, the head difference driving flow between the aquifer and the streams is only several feet. A 50-percent change in any input variable generally will cause approximately a 50-percent change in the difference between the water-table and stream altitudes. But, since these head differences are small, a 50-percent change in them can be obtained with only a few feet of change in water-table altitude. So, a wide range of values of input variables will produce about the same model-generated water-table alti-tudes for most grid blocks for these two units. For example, for a block with a water-table altitude of 100 ft above datum and a stream altitude of 96 ft above datum, halving the recharge may generate a new water-table altitude of 98 ft above datum. Thus, a 50-percent change in recharge results in only a 2-ft change in water-table altitude. Calibration under such circumstances is difficult, because no matter what reasonable value of recharge is entered, good agreement between model-generated and estimated water-table altitudes results. Therefore, for units 2 and 7, the values of hydraulic conductivity and stream leakage coefficients were adjusted within the same range of values as in similar, less insensitive, units.

CALIBRATION OF MODEL UNDER TRANSIENT CONDITIONS

General Procedure

The water table fluctuates in response to seasonal variations in recharge. The range of fluctuation depends partly on the specific yield of the aquifer. If a change in water-table altitude is observed and the associated variation in recharge can be estimated, the model can be used to determine the specific yield. The model was used to determine the average specific yields of the four general lithologies -- carbonate rocks, Paleozoic sedimentary rocks, Triassic sedimentary rocks, and crystalline rocks. The lack of ground-water recharge data for each hydrogeologic unit did not allow the determination of specific yield for each unit.

Hydraulic conductivities and stream leakage coefficients that were determined during the steady-state calibration were used in the transient calibration. Recharge amounts for November 1, 1980 through April 22, 1981 were estimated and entered into the model along with the initial estimates of specific yield (and storage coefficient) for each general lithology. Model-generated changes in water-table altitude for the upper layer for the four general lithologies were compared to changes observed between field water-level measurements in October 1980 and April 1981. Initial estimates of specific yield (and storage coefficient) were adjusted until the model-generated and observed water-table changes were in statistical agreement; no other input variables were adjusted.

A network of 320 evenly-distributed wells was established during the summer of 1980 (plate 2). Only wells that were finished in bedrock were used. The water level for each well (attachment C) was measured in October 1980, April 1981, and October 1981 (Gerhart and Lazorchick, 1981; Gerhart and Williams, 1981). Measurements were made with steel tape under static water-level conditions. Water levels were considered to be representative of water-table altitudes for the upper layer because nearly all of the wells were less than 300 ft deep.

The October and April measurements were intended to represent the lowest and highest annual water-table altitudes, respectively. However, because of an unusually dry winter in 1980-81, the April 1981 water levels were lower than the October 1980 water levels in several parts of the area. In addition, because of the continued lack of precipitation in the spring and summer of 1981, the October 1981 water levels were lower than the October 1980 levels in many areas. The result was that the changes in water-table altitude between the three measurements were not all in the same direction; the water level increased in some wells and decreased in others. The distribution and amount of model recharge was therefore very important to the success of the calibration. The period between the October 1980 and April 1981 measurements was selected for transient calibration.

All transient calibration simulations were for a period of slightly less than nine months--August 1, 1980 through April 22, 1981. About three months were included prior to the October 1980 water-level measurements so that transient effects from recharge events preceding the measurements would be taken into account. Three months was considered to be a sufficient lead-in time to account for the most significant of such effects.

Each simulation was accomplished by dividing the period August 1, 1980 to April 22, 1981 into 10 recharge periods. Seven periods were a month in duration -- August, September, November, December, January, February, and March. October was split into two periods--the first being October 1-24 and the second being October 25-31, the week of the October 1980 measurement. The last recharge period was April 1-22, ending the week of the April 1981 measurement. Each recharge period consisted of three time steps of increasing length.

The graph in figure 16 illustrates the transient calibration procedure for grid block 46-78 in hydrogeologic unit 9. The estimated model recharge rates indicate that, for this grid block, the recharge generally decreased from October 1980 through January 1981 and then increased in February, March, and April of 1981. As shown in the figure, the use of these recharge rates in the model resulted in model-generated water-table altitudes which follow the same trend. The model-generated changes in water-table altitude that were used to compare to the observed changes between the October 1980 and April 1981 measurements were obtained by subtracting the water-table altitudes at the end of recharge period 4 from the altitudes at the end of recharge period 10. In this way, the model was calibrated against change in water-table altitude, rather than absolute altitude, so that any errors in the model-generated October 1980 altitudes would not affect the results. In grid block 46-78, the model-generated change (χ) was an increase of about 1.9 ft (fig. 16).

Modeled Flow Components

Flow components for the transient calibration are shown in figure 17. They are the same as those for the average annual steady-state calibration, plus components for the change in aquifer storage for each layer. When recharge increases, water enters aquifer storage, making the change-in-storage terms sinks (negative) in the balance equations in figure 17, because that water is removed from the active ground-water flow system. Conversely, when recharge decreases, ground water leaves aquifer storage and becomes part of the active ground-water flow system, and the two terms are considered sources (positive).

Ground-Water Conditions

The starting point of each transient calibration simulation--August 1, 1980--is about midway between the end of April and the end of October, usually the approximate times of the annual highest and lowest water-table altitudes, respectively. Therefore, estimated water-table altitudes were assumed to apply on August 1. Any errors introduced by this assumption were minimized by the use of the 3-month lead-in period and by the fact that changes in water-table altitude, and not absolute altitudes, were used in the calibration.

Surface-Water Conditions

Steady-state surface-water conditions were used in the transient calibration because comprehensive data on the changing surface-water conditions for the simulation period were lacking. Stream altitudes vary in response to

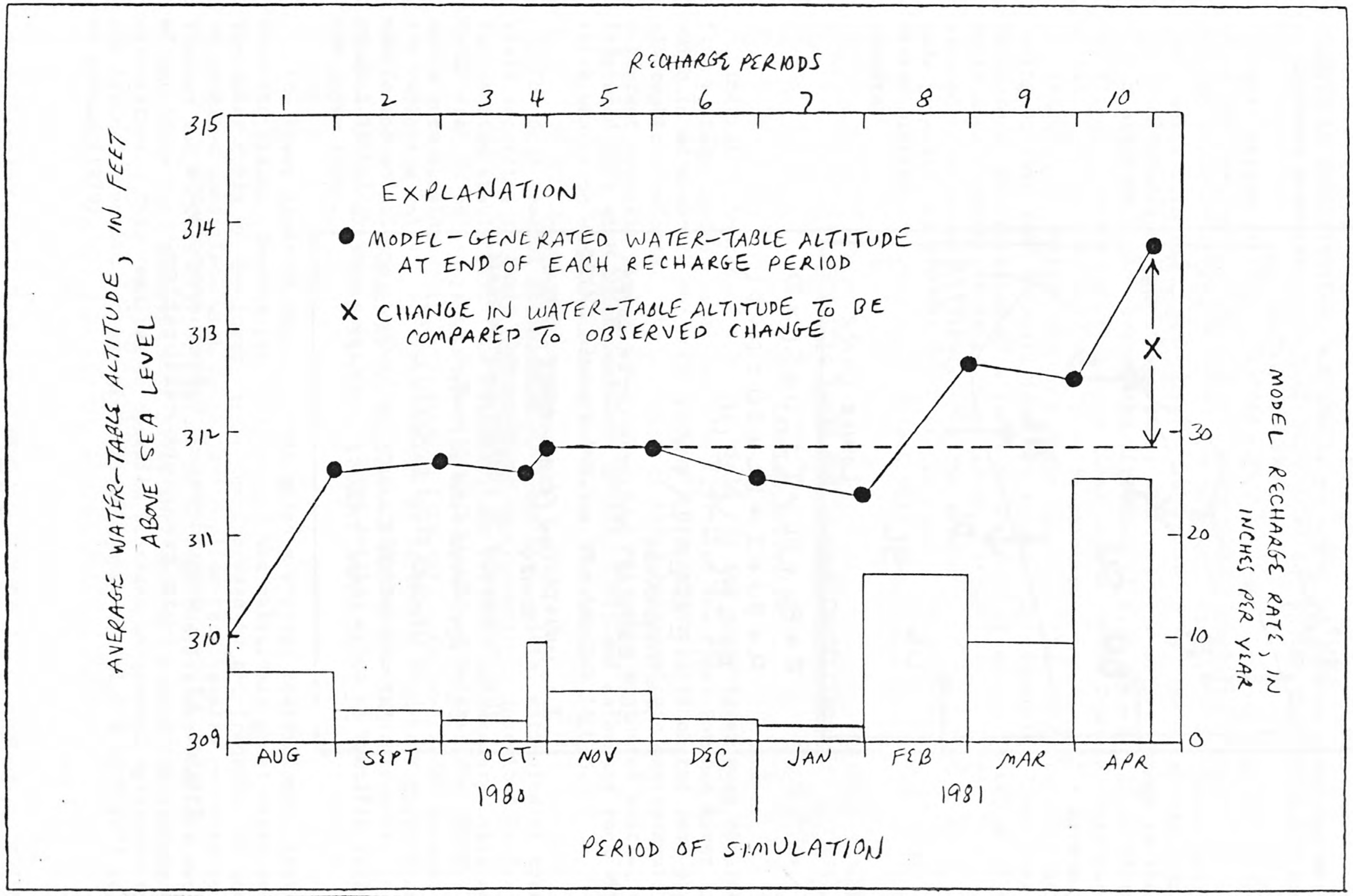
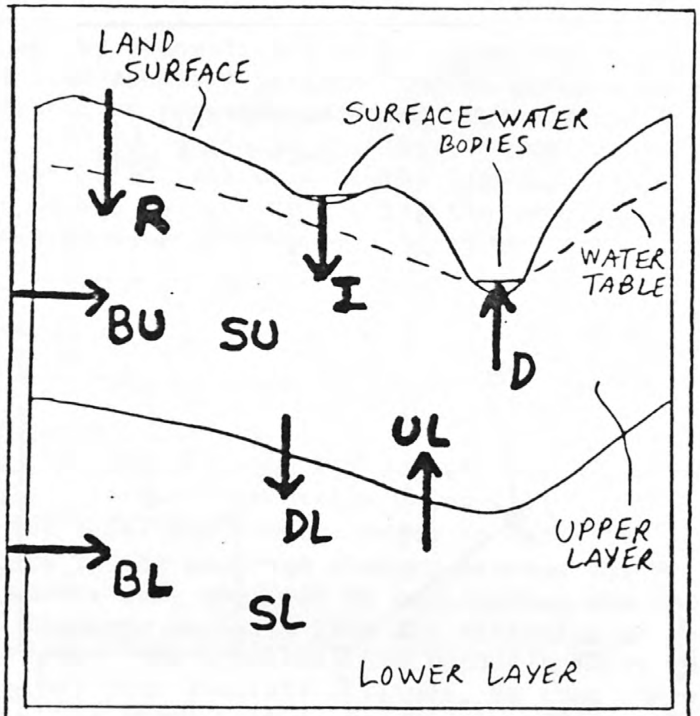


Figure 16.--Example of transient calibration procedure for grid block 46-78.



$$R + BU + BL + I \pm SU \pm SL = D$$

$$R + BU + I + UL \pm SU = D + DL$$

$$BL + DL \pm SL = UL$$

EXPLANATION

R = RECHARGE
BU = BOUNDARY INFLOW IN UPPER LAYER
BL = BOUNDARY INFLOW IN LOWER LAYER
I = INFILTRATION FROM SURFACE-WATER BODIES
D = DISCHARGE TO SURFACE-WATER BODIES
DL = DOWNWARD FLOW BETWEEN LAYERS
UL = UPWARD FLOW BETWEEN LAYERS
SU = STORAGE CHANGE IN UPPER LAYER
SL = STORAGE CHANGE IN LOWER LAYER

Figure 17. -- Ground-water budget components in transient calibration.

changes in precipitation, but the large number of streams precluded any synchronous measurement of their altitudes during the simulation period.

Most stream altitudes probably did not change by more than a few feet between October 1980 and April 1981. Calibration problems which may arise from such an error in stream altitude may be significant only for those hydrogeologic units with low local relief. For those units, the water-table and stream altitudes are about the same. Therefore, a slight change in the stream altitude could reverse the direction of flow between the aquifer and the stream. Because of their low local relief, units 2 and 7 (carbonate units) are the units most likely to be affected. For the major stream in the eastern Lebanon Valley carbonate rocks (unit 2), the change in altitude during October 1980 to April 1981 was slight. Quittapahilla Creek near Bellegrove, Pa. experienced a range in altitude of only 1.14 ft, as shown by daily mean gage-height data. The stream altitude variation for unit 7 was assumed to be equally slight. For the remaining units, the water-table altitude generally is significantly higher than the stream altitude and errors in stream altitude of even several feet will have only a slight effect on the results.

Specific Yield and Storage Coefficient

Initial Estimates

Initial estimates of specific yield for the upper layer were obtained from a study by Trainer and Watkins (1975) in the upper Potomac River basin, which is adjacent to the modeled area and contains parts of the same physiographic provinces. They recognized three hydrogeologic environments with different specific yields: fractured rock with thin weathered mantle, 0.005; fractured rock with thick weathered mantle, 0.01; and carbonate rock with thick weathered mantle and solution-enlarged fractures, 0.035.

The four general lithologies were assigned initial estimates of specific yield according to their hydrogeologic environments as described by Trainer and Watkins (table 16). The Paleozoic and Triassic sedimentary units were considered to be fractured rock with thin weathered mantle; the crystalline units were considered to be fractured rock with thick weathered mantle; and the carbonate units were considered to be carbonate rock with thick weathered mantle and solution-enlarged fractures. All the hydrogeologic units in a general lithology were assigned the same initial value of specific yield for the upper layer.

The lower layer of each unit was given a storage coefficient instead of a specific yield. Reasons for this include the relatively great depth below the water table of the lower layer, the increase in the frequency of encounter of confined conditions with depth, and aquifer-test results reported by Trainer and Watkins (1975). Values of storage coefficient that are two orders of magnitude less than specific yield were used throughout the transient calibration. This resulted in specific storages in general agreement with the typical specific storage of confined aquifers of 1.0×10^{-6} ft^{-1} reported by Lohman (1979).

Table 16.--Initial estimates of specific yield for the upper layer, and specific yields used in calibrated transient model.

General lithology	Specific yield	
	Initial estimate 1/	Calibration value
Carbonate rocks	0.035	0.035
Paleozoic sedimentary rocks	.005	.020
Triassic sedimentary rocks	.005	.007
Crystalline rocks 2/	.010	.020

1/ Based on Trainer and Watkins (1975).

2/ Units 14 and 16 included.

Adjustments

Initial estimates of specific yield (and storage coefficient) were adjusted (table 16) in order to obtain agreement between model-generated and observed water-table altitude changes for October 1980 to April 1981. The calibration values are equal to or greater than the initial estimates for all four general lithologies. Specific yields for the carbonate and Triassic sedimentary units are equal or essentially equal to the initial estimates. The calibration value for the crystalline units is twice the initial estimate and for the Paleozoic sedimentary units, it is four times greater than the initial estimate. Initial estimates of storage coefficient for the lower layer were adjusted to maintain the difference of two orders of magnitude between the specific yield and the storage coefficient.

Recharge

As in the steady-state calibration, model recharge for the 10 recharge periods in the transient calibration was determined as a percentage of precipitation. The percentages were estimated from U.S. Geological Survey streamflow hydrographs and NOAA precipitation data.

Recharge to the ground-water system was estimated for major storms during the nine-month transient calibration period. A method developed by Rorabaugh (1964) and Daniel (1976) was used. Every stream has a characteristic slope of recession (Δt) which describes the dissipation of a flood impulse. This slope is influenced by the geometry of the basin and its hydrologic characteristics and is the same for all floods. Once this slope is determined for a stream, the ground-water recharge from major storms can be estimated from the equation shown in figure 18. The calculation relies on the assumption that at a certain time, t_c, after a flood peak occurs (fig. 18), 50 percent of the ground-water recharge from the storm has entered the stream as base flow. Twice that amount, then, is the total ground-water recharge from the storm.

Because the method is based on streamflow, all factors that affect recharge are taken into account. The effects of lithology, amount and intensity of precipitation, soil type, soil moisture, temperature, and other factors are included in streamflow hydrographs. On the other hand, the method is based on several simplifying assumptions that are not strictly met in the subbasins in the area. For example, the hydrologic characteristics should be uniform throughout the basin, the distance from the stream to the basin divide should be uniform throughout the basin, and the water-table rise due to a storm should be uniform and instantaneous. Because these assumptions do not strictly apply in the modeled area, the recharge amounts calculated using this method were only estimates. Nevertheless, these estimates appeared to be reasonable both in magnitude and in comparison to each other.

Recharge estimates were obtained for eight gaged subbasins in and adjacent to the modeled area. These subbasins were selected because they represent the four general lithologies and they have well defined streamflow recessions. Six to ten major storms were analyzed for each of the eight subbasins.

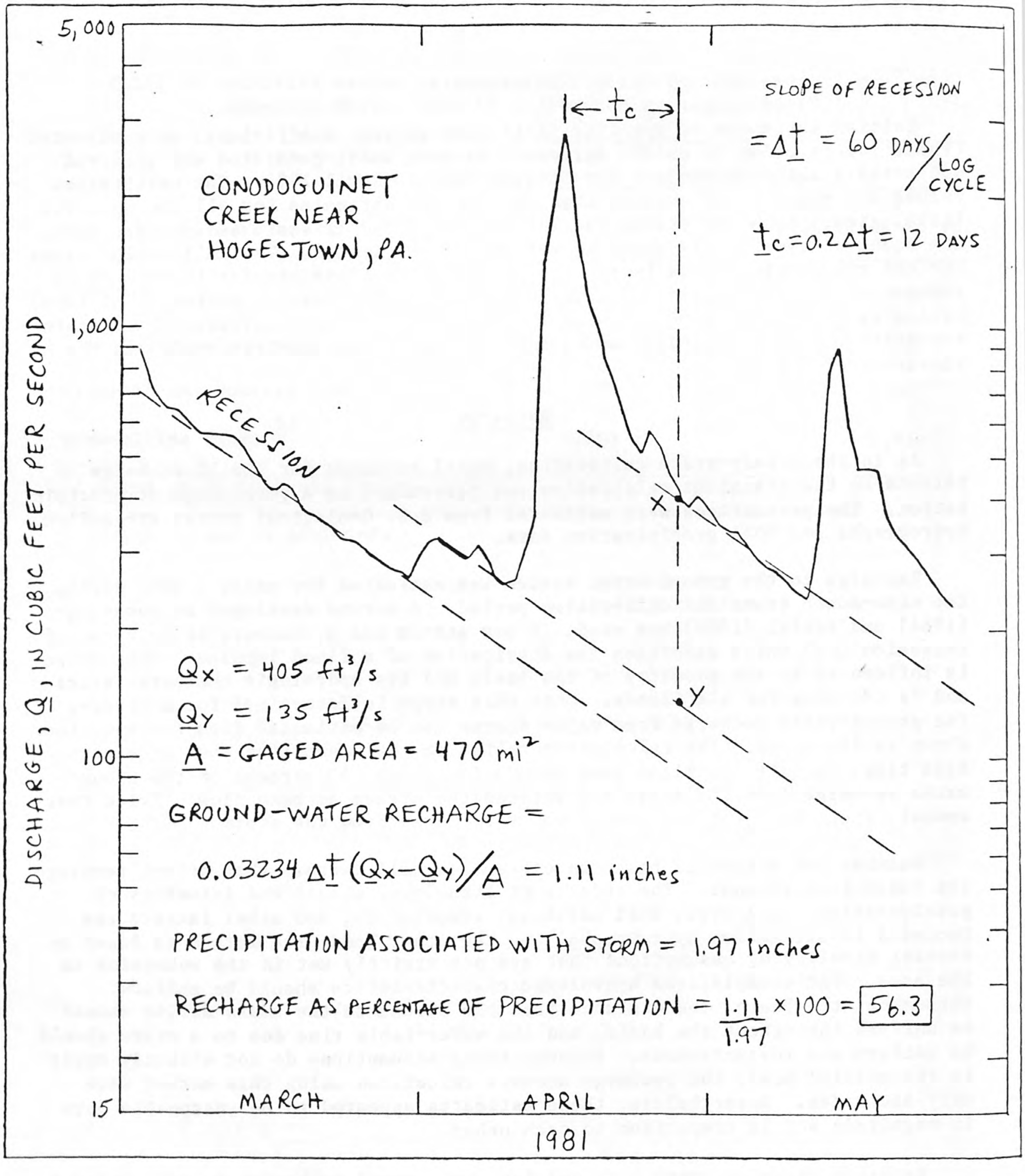


Figure 18. -- Example of technique used for estimating recharge from a storm as a percentage of percipitation.

For each major storm for each subbasin, precipitation was estimated from data collected at 24 NOAA stations. The percentage of precipitation that recharged the ground-water system was obtained for each major storm for each subbasin by dividing the estimated recharge by the precipitation (fig. 18). Each subbasin was then represented by six to ten percentages over the period of simulation. The percentages were plotted against time and a curve was fitted to the data for each subbasin (fig. 19). The curves for all the subbasins follow the same general trend -- low percentages from August through November and increasing percentages from December through April.

For each of the eight subbasins, the average percentages of precipitation that was recharge were determined from the intersections of the curve with the mid-point of each recharge period. Each hydrogeologic unit was then assigned one of these eight sets of percentages, based on its lithologic similarity to one of the eight subbasins (table 17).

Recharge may occur not only from major storms, but also from minor storms. Even though the percentage of precipitation that was recharge may be different for major and minor storms, it was assumed that the assigned percentage for each unit was applicable to the total precipitation. Total precipitation for each of the 10 recharge periods was obtained from NOAA data at 24 stations (table 18). Precipitation measured at each station was considered to apply to the area surrounding that station. In this way, 24 precipitation zones were delineated (fig 20). Seven artificial zones were added to fill in gaps in the distribution of actual stations. Precipitation for these seven zones was estimated from the weighted averages of the precipitation at adjacent stations.

Model recharge for each grid block for each recharge period was determined as the product of the average percentage for the appropriate hydrogeologic unit (table 17) and the total precipitation for the appropriate precipitation zone (table 18). As with the steady-state recharge, model recharge is less than actual recharge by the amounts of any consumptive use and evapotranspiration of ground water.

Boundary Conditions

During the early stages of the transient calibration, it was determined that the effects of all boundary conditions were significant only immediately adjacent to the boundaries. Because such a small part of the area is adjacent to boundaries, the boundary conditions have a minimal effect on the results for the entire area or even for individual hydrogeologic units. Therefore, the boundary conditions used in the steady-state calibration (plate 1) also were used in the transient calibration.

Results

Model-generated changes in water-table altitude for the upper layer for the four general lithologies were compared to the changes observed between October 1980 and April 1981. Non-parametric statistics--median, and 25 and 75 percentiles--were used to determine which specific yields produced the best agreement (table 19).

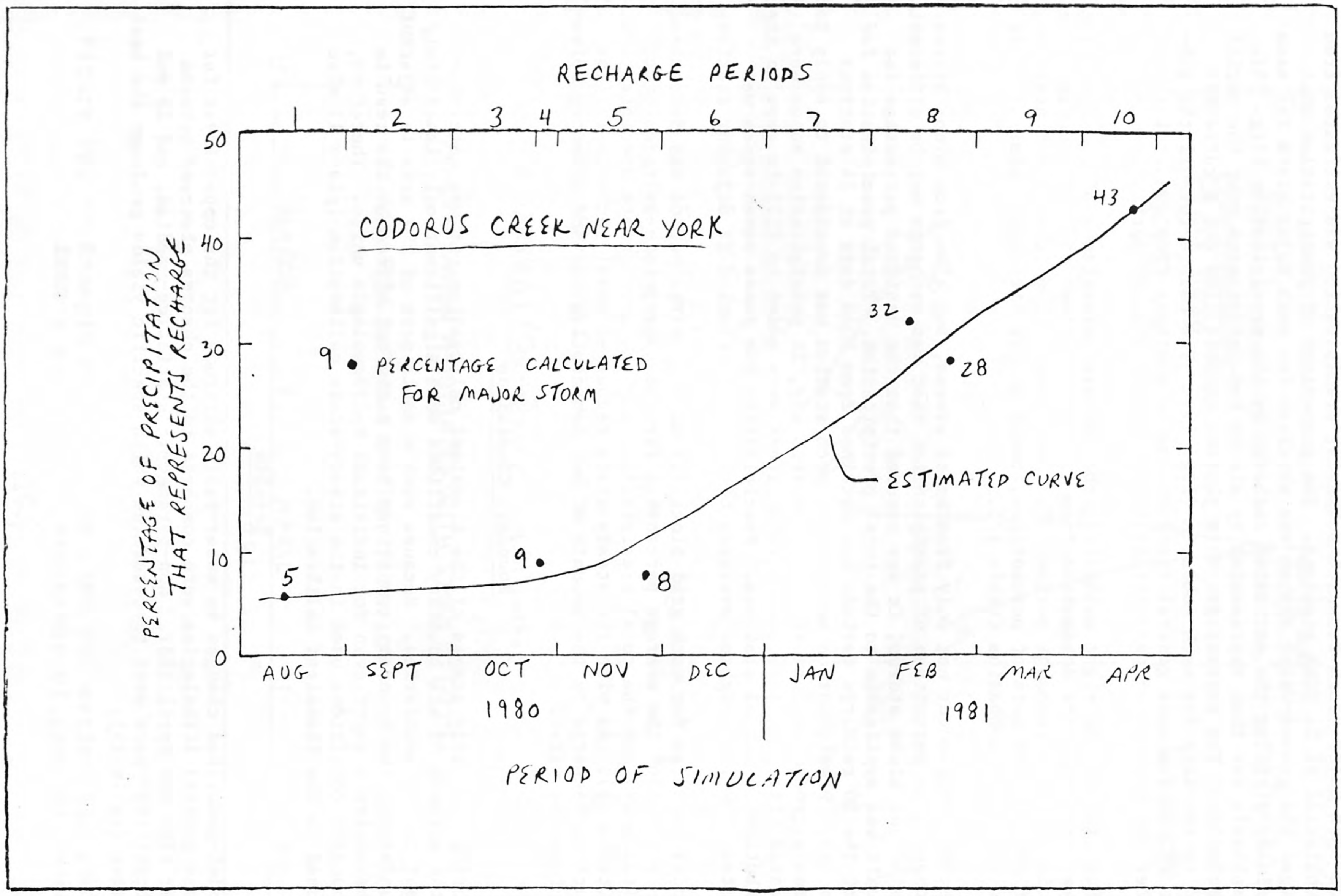


Figure 19. -- Example of procedure for estimating recharge for each recharge period as a percentage of percipitation for Codorus Creek near York.

Table 17.--Percentage of precipitation that represents ground-water recharge for each recharge period in calibrated transient model.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Percentage of precipitation									
		August 1980	September 1980	October 1-24,1980	October 25-31,1980	November 1980	December 1980	January 1981	February 1981	March 1981	April 1-22,1981
1	PS	11	9	7	7	18	27	32	36	40	43
2	C	17	14	11	11	28	41	46	51	58	67
3	X	7	7	8	10	12	17	23	26	27	24
4	C	17	14	11	11	28	41	46	51	58	67
5	TS	11	8	5	4	5	10	17	22	22	20
6	TS	11	8	5	4	5	10	17	22	22	20
7	C	23	14	10	9	11	20	33	44	43	39
8	X	6	7	7	8	10	15	22	29	36	43
9	C	23	14	10	9	11	20	33	44	43	39
10	X	6	7	7	8	10	15	22	29	36	43
11	X	15	21	22	20	17	15	15	17	20	25
12	PS	11	9	7	7	18	27	32	36	40	43
13	TS	11	8	5	4	5	10	17	22	22	20
14		6	7	7	8	10	15	22	29	36	43
15	PS	11	9	7	7	18	27	32	36	40	43
16		17	19	17	14	8	9	20	27	25	19
17	C	23	14	10	9	11	20	33	44	43	39
18	TS	11	8	5	4	5	10	17	22	22	20
19	TS	11	8	5	4	5	10	17	22	22	20
20	C	17	14	11	11	28	41	46	51	58	67
21	PS	11	9	7	7	18	27	32	36	40	43

Table 18.--Precipitation for each recharge period in calibrated transient model.

Station identifier	Station name (NOAA)	Precipitation, in inches August 1980	September 1980	October 1-24, 1980	October 25-31, 1980	November 1980	December 1980	January 1981	February 1981	March 1981	April 1-22, 1981
A	Chambersburg 1 ESE	3.30	1.14	0.53	1.38	3.89	1.13	0.18	5.08	1.55	4.67
B	Shippensburg	2.79	1.59	.60	1.72	3.43	1.08	.13	5.70	1.29	3.06
C	Bloserville 1 N	2.85	1.54	.61	1.80	2.64	.80	.36[3/]	6.62	1.15[2/]	1.59
D	Huntsville	3.66	1.37	.22	2.29	3.61	.78	.36	8.22	1.07	2.72
E	Harrisburg FAA AP	1.51	1.06	.64	2.30	3.65	.77	.43	5.93	1.02	2.07
F	Lebanon 2 W	1.77	2.73[3/]	.64	1.80	3.96[2/]	.81	.74[3/]	5.74	.93	4.06
G	Myerstown	1.51	2.73	.83	1.79	3.67	.64	.74	5.24	1.19	3.73
H	Strausstown	2.05	.81	.92	1.84	4.53	.91	.85	5.52[2/]	.76	3.63
I	Biglerville	1.71	1.53	.48	2.07	3.94	.86	.26	7.55	1.30	3.02
J	Gettysburg	3.31	2.03	.82	2.38	3.62	.79	.31	6.60	1.21	3.29
K	Hanover	3.47	1.20	.62	2.84	2.99	.57	.70	5.41	1.42	3.59
L	Spring Grove	4.36	1.05	.59	2.03	3.44	.51	.28	5.96	1.51	3.28
M	York 3 SSW pump sta	1.74	1.11	.63	1.94	3.63	.60	.35	5.68	1.64	2.92
N	York Haven	3.40	2.68	.55	2.13	2.93	.52	.27	5.29	1.41	2.82
O	Landisville 2 NW	2.64	1.67	.93	1.74	3.63	.62	.17	3.86	1.44	3.19
P	Ephrata	2.38	1.66	1.27	1.98	3.51[2/]	.89	.42	2.78	1.82	3.92
Q	Morgantown	1.80	1.16	1.31	2.63	2.70[2/]	.41	.39	4.70	2.33[2/]	3.68
R	Parkton 2 SW	2.92	1.01	1.21	1.79	3.61	.58	.54	6.49	1.23	3.93
S	New Park	2.00	.92	1.19	1.61	3.71[2/]	.50	.40	5.40	1.55	3.41
T	Holtwood	3.79	1.02	1.00	1.70	3.26	.62	.17	5.40[3/]	1.14	2.63
U	Lancaster 2 NE filt pl	1.53	1.44	.93[3/]	1.74[3/]	3.27	.64	.41	3.31	1.39	3.18
V	Honeybrook 1 S	1.18	2.10	1.35	2.54	3.25	.66	.49	3.85	1.68	3.19
W	Conowingo Dam	4.08	1.22	1.36	1.91	3.61	.65[3/]	.40[3/]	4.23	1.39	3.31
X	Coatesville 1 SW	2.18	1.62	1.76	2.74	3.14	.61	.42	4.25	1.71	3.17
AA	interpolated station	2.66	1.32	.49	2.13	3.30	.78	.38	6.91	1.08	2.12
BB	interpolated station	2.17	1.74	.55	2.16	3.55	.73	.31	6.39	1.25	2.68
CC	interpolated station	1.64	1.87	.64	2.06	3.80	.79	.58	5.84	.98	3.04
DD	interpolated station	2.65	1.56	.81	1.85	3.32	.60	.28	4.76	1.39	2.93
EE	interpolated station	2.30	1.52	1.26	2.18	3.23	.63	.36	4.33	1.46	3.01
FF	interpolated station	3.18	1.04	1.18	1.75	3.54	.59	.39	5.55	1.30	3.37
GG	interpolated station	3.18	1.33	1.42	2.20	3.31	.62	.34	4.59	1.45	3.05

1/ Location of stations on figure 20.

2/ Data for one storm missing; estimated from nearby stations.

3/ No data for period; estimated from nearby stations.

Table 19.--Statistical comparison, by general lithology, of observed and model-generated changes in water-table altitude in calibrated transient model.

[Negative changes indicate decline in water-table altitude.]

	Water-table altitude change from November 1, 1980 to April 22, 1981, in feet							
	Observed				Model-generated			
		Percentiles				Percentiles		
General lithology	Number of measurements	25	Median	75	Number of grid blocks	25	Median	75
Carbonate rocks	86	-0.7	1.2	3.5	859	0.2	1.6	4.8
Paleozoic sedimentary rocks	56	2.5	4.0	5.9	616	-.9	3.9	9.0
Triassic sedimentary rocks	70	3.0	5.1	8.6	766	-2.3	4.7	10.3
Crystalline rocks	99	-3.2	.3	4.8	1,184	-7.9	-.7	5.4

The model-generated and observed median altitudes for the carbonate, Paleozoic sedimentary, and Triassic sedimentary units agree to within 0.4 ft (table 19). On the other hand, the median altitudes for the crystalline lithology differ by 1.0 ft. The crystalline units occupy the southern and eastern parts of the area, where many observed water-level changes were negative, indicating declines in water-table altitude between October 1980 and April 1981. The precipitation zones (fig. 20) in this area do not exactly coincide with the areas of water-table decline and rise; hence, agreement between model-generated and observed medians is not as good for the crystalline units.

The ranges of model-generated and observed changes in water-table altitude, as expressed by the difference between the 25 and 75 percentiles, agree to within 0.4 ft for the carbonate units (table 19). However, the ranges of change for the other three lithologies do not agree. The model-generated range of change is greater than the observed range by 6.5, 7.0, and 5.3 ft for the Paleozoic sedimentary, Triassic sedimentary, and crystalline units, respectively. The most probable reason for the disagreement in ranges is the fact that every grid block in a lithology is assigned the same specific yield. In reality, specific yield is not uniform; instead, it probably differs with topographic setting and lithologic differences between individual rock beds. In addition, the specific yield is dependent on whether the water table is located in the weathered mantle or the bedrock. Variations in specific yield caused by these factors could not be systematically incorporated into the model due to insufficient data. This lack of specific-yield data, combined with the uncertainty in the model recharge values, limited the transient calibration to the determination of the uniform specific yield in each general lithology that resulted in the best agreement between median model-generated and median observed changes in water-table altitude.

Sensitivity Analysis

To determine the sensitivity of the model to specific yield, the calibration values of specific yield (and storage coefficient) were doubled and another transient calibration simulation was made. The values for the median, and the 25 and 75 percentiles were approximately halved. With all other model input variables constant, doubling specific yield will halve the fluctuation of the water table. Similarly, halving specific yield will double the fluctuation. The direct relation between specific yield and the range of fluctuation was responsible for the model being very sensitive to specific yield. This high degree of sensitivity permitted the determination of the calibration values of specific yield in table 16 to be very precise. However, they are only as accurate as the estimates of model recharge for the 10 recharge periods.

DIGITAL-MODEL EVALUATION OF GROUND-WATER RESOURCES

General Procedure

The main objective of this investigation was to evaluate the ground-water resources of the lower basin. To this end, two schemes of hypothetical stress were used in the calibrated model to compare the hydrogeologic units and their reactions to stress. The first scheme involved the imposition of equal stresses

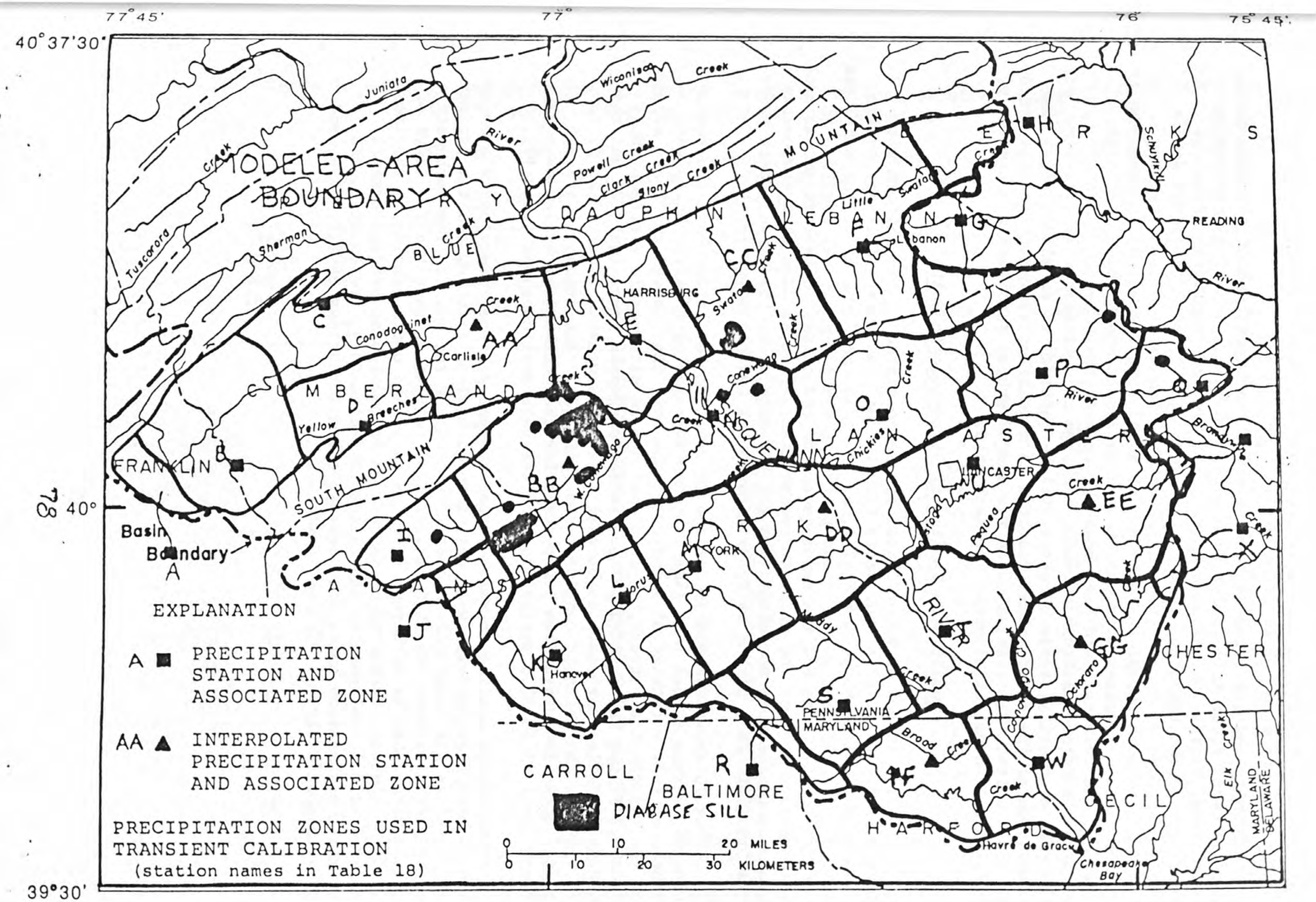


Figure 20.--Precipitation zones used in transient calibration.

for all units and the second scheme involved the imposition of stresses necessary to cause equal effects for each unit. In both schemes, surface-water conditions, hydrologic characteristics, and boundary conditions from the steady-state and transient calibrations were used. Model-generated water-table altitudes from the steady-state calibration were used as starting ground-water conditions. Average annual model recharge was used throughout both schemes. Stresses were implemented as reductions in model recharge. However, the results would have been the same if the stresses had been withdrawals or combinations of model-recharge reductions and withdrawals. For the sake of clarity, these stresses will be referred to as withdrawals. The simulation of the first scheme resulted in a qualitative ranking of the hydrogeologic units. The simulation of the second scheme resulted in estimates of a standardized potential yield for each unit.

Qualitative Ranking of Hydrogeologic Units

The first scheme of hypothetical stress consisted of the uniform withdrawal of 1.0 in/yr of ground water from the modeled area. This was equivalent to a total of about 166 Mgal/d, or about 33 (gal/min)/mi^2. The model was used under steady-state conditions so that the model-generated declines in water-table altitude and the model-generated reductions in average annual base flow would represent the ultimate (worst-case) effects. The flow components that are included in the simulation are the same as in the steady-state calibration (fig. 6), plus a withdrawal component for the upper layer.

Table 20 shows the median decline in water-table altitude and the reduction in average annual base flow for each hydrogeologic unit. Units were ranked so that a ranking of 1 indicates the unit that showed the least effect of the hypothetical stress. Median declines in water-table altitude range from 0.2 ft for the eastern Lebanon Valley carbonate rocks (unit 2) and the Conestoga Valley carbonate rocks west of the Susquehanna River (unit 7) to 10.9 ft for the Triassic conglomerates (unit 18). Reductions in average annual base flow range from 5.3 percent for the Cumberland Valley carbonate rocks (unit 4) to 22.8 percent for the Triassic conglomerates (unit 18).

The median decline in water-table altitude and the reduction in average annual base flow for each unit were then multiplied together and the products were used as the basis for an overall ranking of the units. The carbonate units generally have the highest rankings, indicating that the 1.0 in/yr of ground water that is withdrawn from the carbonate units results in the least adverse effects. Carbonate units have an area-weighted average overall ranking of 3.5, followed by the Paleozoic sedimentary, crystalline, and Triassic sedimentary units with average overall rankings of 8.7, 14.9, and 16.4, respectively.

Table 20.--Ranking of hydrogeologic units, based on effects of withdrawing 1 inch of ground water per year from modeled area.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeo-logic unit and general lithology		Median decline of water table, in feet	Ranking 1/	Percentage reduction of average annual base flow	Ranking 1/	Overall ranking 1/ 2/
1	PS	2.0	7	8.6	6	7
2	C	.2	1	7.8	5	1
3	X	3.1	10	11.2	14	11
4	C	.5	3	5.3	1	3
5	TS	3.8	12	13.4	16	14
6	TS	4.3	15	10.9	12	13
7	C	.2	1	10.4	10	2
8	X	7.4	17	15.3	18	17
9	C	.5	3	6.9	3	4
10	X	5.9	16	10.2	9	16
11	X	3.4	11	9.9	7	10
12	PS	9.0	18	13.2	15	18
13	TS	9.2	19	20.7	20	20
14		3.9	13	15.1	17	15
15	PS	3.9	13	10.1	8	12
16		1.9	6	7.7	4	6
17	C	1.8	5	6.2	2	5
18	TS	10.9	21	22.8	21	21
19	TS	9.3	20	19.8	19	19
20	C	2.8	9	10.7	11	9
21	PS	2.4	8	11.1	13	8

1/ Ranking of 1 indicates the unit with the least effect.

2/ Based on the product of median decline and percentage reduction.

Standardized Potential Yield

Procedure

The second scheme of hypothetical stress consisted of the uniform withdrawal from each hydrogeologic unit of the amount of ground water necessary to ultimately reduce the average annual base flow for each unit by about 50 percent. An exact 50-percent reduction for each unit was not simulated. The initial uniform withdrawal rate for each unit was determined by halving the average annual discharge to streams in table 15. However, ground-water flow between the units also was affected by the withdrawals, with some units obtaining more and some less ground water from adjacent units than is shown in table 15. The result was that withdrawing 50 percent of the average annual base flow from each unit did not reduce the base flow by exactly 50 percent. A trial-and-error procedure would be required to obtain the withdrawal rate for each unit which would yield an exact 50-percent reduction in base flow; such precision was not considered necessary for purposes of this evaluation. Therefore, simulated reductions in unit base flows actually ranged from 47 to 53 percent.

This scheme was simulated under transient conditions for 20 years, as well as under ultimate steady-state conditions. Flow components in the model are shown in figure 21. Potential yield and the effects of realizing it were analyzed on two levels: First, by hydrogeologic unit, and second, by grid block in a selected area.

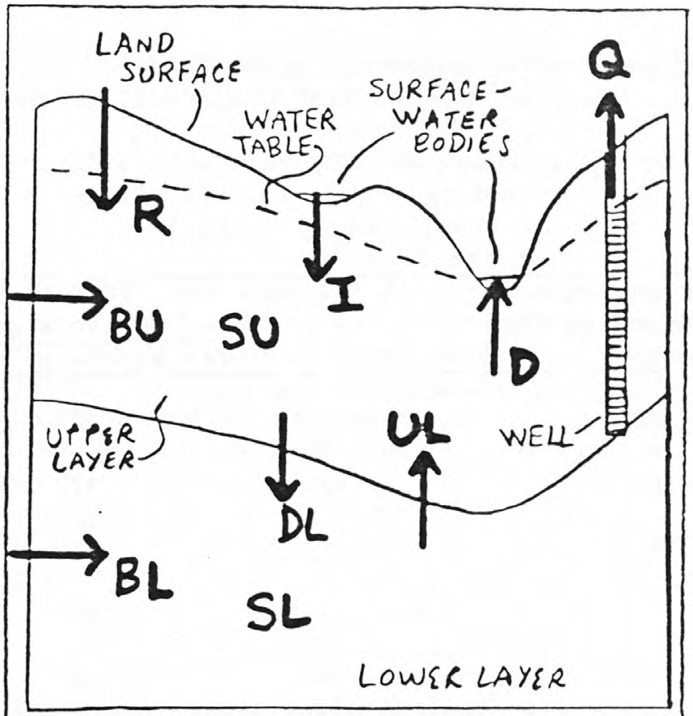
Results

Analysis by Hydrogeologic Unit

Standardized potential yield, based on an ultimate 50-percent reduction in average annual base flow, is shown in table 21 for each hydrogeologic unit. The Cumberland Valley carbonate rocks (unit 4) have the greatest potential yield, 0.47 Mgal/d. The Triassic conglomerates (unit 18) have the lowest potential yield, 0.08 Mgal/d. Carbonate units have an area-weighted average potential yield of about 0.40 (Mgal/d)/mi^2. Paleozoic sedimentary, crystalline, and Triassic sedimentary units have average potential yields of about 0.25, 0.23, and 0.16 (Mgal/d)/mi^2, respectively.

When all units are considered, the total potential yield of the modeled area is 891 Mgal/d [0.26 (Mgal/d)/mi^2]. Carbonate units occupy about 24 percent of the area and contribute about 37 percent of its total potential yield. On the other hand, the Triassic sedimentary units occupy about 22 percent of the area but contribute only about 13 percent of its total potential yield. The percentages of the total potential yield for the Paleozic sedimentary and crystalline units are about equal to their percentages of total modeled area.

The standardized potential yields in table 21 were converted to uniform withdrawal rates for each grid block of each hydrogeologic unit. They were entered into the model and a 20-year transient simulation was made. The results of this simulation show that, after 20 years, every unit is sufficiently close to steady-state conditions so that further changes in base flow and water-table altitude are insignificant. The 20-year duration of the



$$R + BU + BL + I \pm SU \pm SL = D + Q$$

$$R + BU + I + UL \pm SU = D + DL + Q$$

$$BL + DL \pm SL = UL$$

EXPLANATION

R = RECHARGE
BU = BOUNDARY INFLOW IN UPPER LAYER
BL = BOUNDARY INFLOW IN LOWER LAYER
I = INFILTRATION FROM SURFACE-WATER BODIES
D = DISCHARGE TO SURFACE-WATER BODIES
DL = DOWNWARD FLOW BETWEEN LAYERS
UL = UPWARD FLOW BETWEEN LAYERS
SU = STORAGE CHANGE IN UPPER LAYER
SL = STORAGE CHANGE IN LOWER LAYER
Q = WELL WITHDRAWAL IN UPPER LAYER

Figure 21. -- Ground-water budget components in transient model used for resource evaluation.

Table 21.--Standardized potential yield for each hydrogeologic unit, based on hypothetical withdrawal scheme.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Potential yield, in millions gallons per day	
		Per square mile	Per unit
1	PS	0.28	90
2	C	.37	27
3	X	.21	15
4	C	.47	127
5	TS	.19	74
6	TS	.24	11
7	C	.28	21
8	X	.14	21
9	C	.38	111
10	X	.24	182
11	X	.24	41
12	PS	.17	9
13	TS	.10	16
14		.14	4
15	PS	.24	13
16		.33	32
17	C	.38	40
18	TS	.08	4
19	TS	.11	12
20	C	.25	5
21	PS	.21	36

hypothetical withdrawal scheme was simulated with nine simulation periods, each with three time steps. Simulation periods and the time steps within them became longer as the simulation progressed. The simulation periods were 30 days, 61 days, 92 days, 182 days, 1 year, 2 years, 3 years, 5 years, and 8 years.

A unit was considered to have reached steady-state conditions when the rate of water-table decline was less than 0.1 ft per year in 95 percent of its grid blocks. Figure 22 is a graphical representation of the approach to steady-state conditions for unit 11. Steady-state conditions, as defined above, occur about 16 years after the hypothetical withdrawals begin. Both withdrawal effects (average annual base-flow reduction and median water-table decline) are on essentially horizontal parts of their curves by then. Almost all the effects occur within the first 5 years.

The same data that are shown graphically for unit 11 in figure 22 are shown in tabular form for each hydrogeologic unit in tables 22-24. The lengths of time needed to reach steady-state conditions for each unit are shown in table 22. For those units which did not reach steady-state conditions during the 20-year simulation, this length of time was extrapolated from a graph of the rate of change of the median water-table decline versus time. Unit 18 did not reach steady-state conditions within 100 years, but extrapolation beyond 100 years was not considered reasonable. In table 23, the reductions in average annual base flow are shown at the end of each simulation period for each unit. Table 24 shows the water-table declines at the end of each simulation period for each unit.

As shown in table 22, the Cumberland Valley carbonate rocks (unit 4) and the Conestoga Valley carbonate rocks west of the Susquehanna River (unit 7) reach steady-state conditions in the shortest time, 6 years. Based on area-weighted averages, steady-state conditions occur after about 9, 24, 24, and 33 years for the carbonate, Paleozoic sedimentary, Triassic sedimentary, and crystalline units, respectively. Unit 18 was not included in the average for the Triassic sedimentary units. The carbonate units, although they have the greatest specific yield, are the first to reach steady-state conditions because they also have the greatest hydraulic conductivities and stream leakage coefficients.

Tables 23 and 24 show higher rates of base-flow reduction and water-table decline in the early simulation periods and both tables show that by the end of the fourth year, all but two of the units (8 and 12) experience about 90 percent of their eventual effects. Ninety percent of the eventual effects occur by an area-weighted average of about 1.4 years in the carbonate units (tables 23 and 24). The Triassic sedimentary, Paleozoic sedimentary, and crystalline units experience 90 percent of their eventual effects by about 2.4, 2.8, and 4.1 years, respectively (tables 23 and 24). Therefore, almost all of the effects of the hypothetical withdrawal scheme occur within 5 years of its implementation.

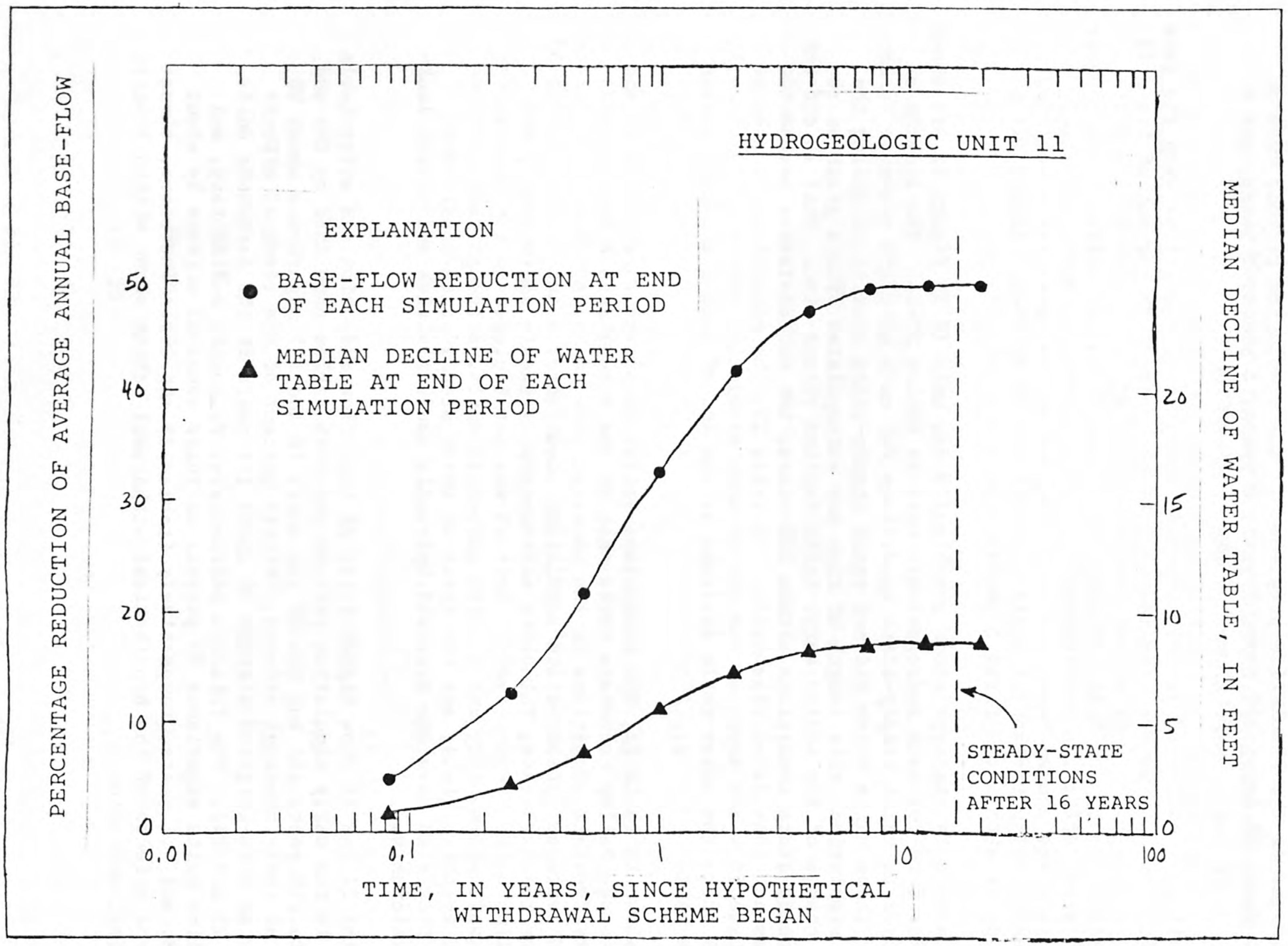


Figure 22. -- Percentage reduction in average annual base flow and median decline of water table for hydrogeologic unit 11 during 20-year simulation of hypothetical withdrawal scheme.

Table 22.--Time, since start of hypothetical withdrawal scheme, for each hydrogeologic unit to reach steady-state conditions.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Number of years before steady-state conditions are reached 1/
1	PS	16
2	C	7
3	X	90
4	C	6
5	TS	15
6	TS	7
7	C	6
8	X	35
9	C	11
10	X	31
11	X	16
12	PS	93
13	TS	42
14		29
15	PS	10
16		14
17	C	14
18	TS	100+
19	TS	40
20	C	23
21	PS	23

1/ Steady-state conditions are considered to occur when the rate of water-table decline becomes less than 0.1 feet per year in 95 percent of the grid blocks in a unit.

Table 23.--Percentage reduction of average annual base flow during 20-year simulation of hypothetical withdrawal scheme.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Percentage reduction after indicated time since hypothetical withdrawal scheme began								
		30 days	91 days	183 days	1 year	2 years	4 years	7 years	12 years	20 years
1	PS	9	20	30	39	45	48	50	50	50
2	C	27	36	41	46	49	51	51	51	51
3	X	6	16	25	36	44	48	49	50	50
4	C	25	34	40	46	49	50	50	50	50
5	TS	13	26	35	42	47	49	50	50	50
6	TS	10	23	32	40	45	47	47	47	47
7	C	27	37	42	46	49	51	52	52	53
8	X	2	7	12	21	31	41	46	48	49
9	C	17	30	37	44	48	51	51	51	51
10	X	3	8	15	25	36	45	48	50	50
11	X	5	13	22	32	42	47	49	50	50
12	PS	3	8	14	22	32	40	45	47	47
13	TS	7	16	25	34	42	46	47	48	48
14		5	12	21	31	40	45	48	48	49
15	PS	5	12	21	32	42	47	48	48	48
16		9	21	31	40	45	48	49	50	50
17	C	6	15	24	34	42	47	49	50	50
18	TS	5	13	22	33	41	47	49	50	51
19	TS	5	14	23	33	42	47	49	50	50
20	C	4	11	19	29	39	46	49	51	51
21	PS	7	17	26	36	43	48	49	50	50

Table 24.--Median decline of water table during 20-year simulation of hypothetical withdrawal scheme. [General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology		Median decline after indicated time since hypothetical withdrawal scheme began, in feet								
		30 days	91 days	183 days	1 year	2 years	4 years	7 years	12 years	20 years
1	PS	1.8	4.5	7.0	9.5	11.1	11.9	12.2	12.4	12.5
2	C	.6	.9	1.1	1.2	1.2	1.3	1.3	1.3	1.3
3	X	1.4	3.8	6.6	10.2	13.7	15.4	15.9	16.1	16.1
4	C	1.4	3.0	4.2	4.9	5.2	5.3	5.3	5.3	5.3
5	TS	3.1	7.0	10.2	12.9	14.8	15.9	16.2	16.3	16.5
6	TS	4.0	9.3	13.7	17.3	19.1	19.8	20.0	20.1	20.2
7	C	.5	.7	.7	.8	.9	.9	1.0	1.0	1.0
8	X	1.0	3.0	5.6	9.7	15.1	20.2	22.9	24.2	24.4
9	C	1.1	2.1	2.9	3.5	4.1	4.5	4.6	4.7	4.7
10	X	1.6	4.5	8.3	13.9	20.5	26.0	28.2	29.2	29.4
11	X	1.6	4.3	7.4	11.3	14.7	16.5	17.0	17.3	17.3
12	PS	1.2	3.5	6.7	11.9	19.2	27.6	33.7	38.3	40.3
13	TS	2.0	5.4	9.4	14.5	19.5	21.9	23.3	23.8	23.9
14		1.1	2.9	5.1	7.8	10.4	12.1	13.4	13.8	14.1
15	PS	1.6	4.3	7.6	12.1	16.7	19.3	20.2	20.4	20.4
16		2.0	5.0	7.7	10.2	11.9	12.9	13.1	13.4	13.5
17	C	1.5	3.9	6.6	9.8	12.8	14.6	15.1	15.4	15.5
18	TS	2.0	5.4	9.5	15.1	22.1	26.5	27.3	27.4	27.4
19	TS	2.1	6.0	10.4	16.2	21.2	24.3	25.0	25.3	25.7
20	C	1.0	2.8	5.0	7.7	11.4	14.5	15.8	16.4	16.5
21	PS	1.4	3.5	5.7	8.1	9.9	10.7	11.1	11.2	11.2

A ground-water budget for each hydrogeologic unit was calculated for two times during the simulation of the hypothetical withdrawal scheme. Table 25 shows the unit budgets at the end of 91 days and table 26 shows the unit budgets after steady-state conditions are achieved. Differences between these budgets and the average annual budgets in table 15 are due to the ground-water withdrawal component. In the model, withdrawals from each unit may be balanced by any or all of the following sources:

1. Decreased discharge to streams;
2. increased infiltration from streams;
3. decreased flow to adjacent units;
4. increased flow from adjacent units; and
5. decreased aquifer storage.

Near the beginning of the hypothetical withdrawal scheme, all withdrawals are balanced by aquifer storage. As the withdrawal scheme progresses, more of the withdrawals are balanced by the other four sources and the contribution of aquifer storage becomes less important. Finally, when steady-state conditions are reached, all withdrawals are balanced by the other four sources and no ground water is taken from aquifer storage.

In table 25, at the end of 91 days, aquifer storage is still a source of ground water that is balancing the withdrawals for each unit. However, considering that 91 days is only a small percentage of the total time needed to reach steady-state conditions, disproportionately large percentages of the withdrawals are already being balanced by the other four sources. This is another indication that most of the effects occur early in the hypothetical withdrawal scheme. Carbonate units show the quickest changeover from aquifer storage to the other four sources; after 91 days, an area-weighted average of 39 percent of the withdrawals are being balanced by ground water from aquifer storage. For the Triassic sedimentary, Paleozoic sedimentary, and crystalline units, the ground water being derived from aquifer storage after 91 days is 60, 67, and 80 percent, respectively, of the withdrawals.

In table 26, aquifer storage does not appear because a steady-state condition has been attained. Of the other four possible sources of ground water that can balance the withdrawals, decreased discharge to streams is the most significant for every hydrogeologic unit. Increased infiltration from streams is only of consequence for carbonate units 2, 4, 7, and 9. Flow between adjacent units generally is less than the average annual amounts shown in table 15.

Analysis in a Selected Area

The preceding analysis of yield potential and its effects was done for hydrogeologic units. It is possible to examine the results at a finer scale by determining the standardized potential yield and its effects for individual grid blocks. The Carlisle Pa., area was selected for use as an example of

Table 25.—Ground-water budget for each hydrogeologic unit after 91 days of hypothetical withdrawal scheme.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology	Simulated flow rates, in million gallons per day per square mile									
	Sources						Sinks			
	Model recharge	South Mountain boundary flow	Infiltration from streams	Flow from adjacent units	Water from storage	Total	Discharge to streams	Flow to adjacent units	Water withdrawn	Total
1 PS	0.53	0.0	0.0	0.05	0.17	0.75	0.44	0.03	0.28	0.75
2 C	.68	0	.16	.13	.09	1.06	.67	.02	.37	1.06
3 X	.55	0	0	0	.16	.71	.31	.19	.21	.71
4 C	.75	.19	.36	.03	.15	1.48	1.00	.01	.47	1.48
5 TS	.34	.03	0	.06	.08	.51	.29	.03	.19	.51
6 TS	.50	0	0	.13	.11	.74	.25	.25	.24	.74
7 C	.50	0	.07	.19	.05	.81	.51	.02	.28	.81
8 X	.32	0	0	.01	.13	.46	.24	.08	.14	.46
9 C	.70	0	.03	.14	.15	1.02	.63	.01	.38	1.02
10 X	.48	0	0	0	.19	.67	.41	.02	.24	.67
11 X	.48	0	0	.01	.18	.67	.42	.01	.24	.67
12 PS	.43	0	0	0	.16	.59	.19	.23	.17	.59
13 TS	.20	.03	0	.04	.08	.35	.14	.11	.10	.35
14	.39	0	0	.11	.12	.62	.24	.24	.14	.62
15 PS	.53	0	0	.03	.18	.74	.31	.19	.24	.74
16	.67	0	0	.18	.19	1.04	.51	.20	.33	1.04
17 C	.69	0	0	.09	.28	1.06	.63	.05	.38	1.06
18 TS	.19	0	0	.03	.08	.30	.15	.07	.08	.30
19 TS	.24	0	0	.04	.09	.37	.15	.11	.11	.37
20 C	.50	0	0	.14	.21	.85	.47	.13	.25	.85
21 PS	.44	0	0	.04	.14	.62	.34	.07	.21	.62

Table 26.—Ultimate ground-water budget for each hydrogeologic unit resulting from hypothetical withdrawal scheme.

[General lithologies: PS, Paleozoic sedimentary rocks; C, carbonate rocks; X, crystalline rocks; TS, Triassic sedimentary rocks.]

Hydrogeologic unit and general lithology	Simulated flow rates, in million gallons per day per square mile								
	Sources					Sinks			
	Model recharge	South Mountain boundary flow	Infiltration from streams	Flow from adjacent units	Total	Discharge to streams	Flow to adjacent units	Water withdrawn	Total
1 PS	0.53	0.0	0.0	0.05	0.58	0.28	0.02	0.28	0.58
2 C	.68	0	.19	.09	.96	.58	.01	.37	.96
3 X	.55	0	0	0	.55	.19	.15	.21	.55
4 C	.75	.19	.41	.02	1.37	.89	.01	.47	1.37
5 TS	.34	.03	0	.04	.41	.19	.03	.19	.41
6 TS	.50	0	0	.12	.62	.18	.20	.24	.62
7 C	.50	0	.10	.12	.72	.43	.01	.28	.72
8 X	.32	0	0	.01	.33	.13	.06	.14	.33
9 C	.70	0	.05	.10	.85	.46	.01	.38	.85
10 X	.48	0	0	0	.48	.23	.01	.24	.48
11 X	.48	0	0	0	.48	.24	0	.24	.48
12 PS	.43	0	0	0	.43	.11	.15	.17	.43
13 TS	.20	.03	0	.03	.26	.08	.08	.10	.26
14	.39	0	0	.09	.48	.14	.20	.14	.48
15 PS	.53	0	0	.03	.56	.18	.14	.24	.56
16	.67	0	0	.16	.83	.32	.18	.33	.83
17 C	.69	0	0	.09	.78	.37	.03	.38	.78
18 TS	.19	0	0	.03	.22	.08	.06	.08	.22
19 TS	.24	0	0	.04	.28	.09	.08	.11	.28
20 C	.50	0	0	.10	.60	.25	.10	.25	.60
21 PS	.44	0	0	.02	.46	.20	.05	.21	.46

such a detailed analysis (fig 23, plate 2). The area covers 35 mi^2 and consists of the Cumberland Valley carbonate rocks (unit 4) and the western and eastern Great Valley shales (units 1, 21). Potential yield and its effects on average annual base flow and water-table altitude for this area are based on the same hypothetical withdrawal scheme that was used in the analysis by hydrogeologic unit. That is, they are based on uniform withdrawals from each unit which result in an ultimate 50-percent reduction in average annual base flow for each unit.

Potential yield for the Carlisle area varies with hydrogeologic unit (fig. 23). The Cumberland Valley carbonate rocks yield 457,000 gal/d per grid block; the western Great Valley shales yield 272,000 gal/d per grid block; and the eastern Great Valley shales yield 204,000 gal/d per grid block.

Average annual base-flow reduction for each grid block after 91 days of the hypothetical withdrawal scheme is shown in figure 24. Base-flow reductions occur only for those grid blocks with streams. The stream reaches in the Cumberland Valley carbonate rocks experience a greater total loss of average annual base flow than the stream reaches in the Great Valley shales. The main reason is that there is more base flow contributed to the streams by the carbonate rocks, and, therefore, more base flow to be captured. But, in addition, the carbonate rocks react more quickly to stress than do the shales. So, at 91 days, they are nearer to steady-state conditions.

Average water-table decline for each grid block after 91 days of the hypothetical withdrawal scheme is shown in figure 25. The declines generally are greater in the Great Valley shales. Also, as shown by the Cumberland Valley carbonate rocks, the declines are much greater for those grid blocks not containing streams. After 91 days, significant portions of the withdrawals from these interstream grid blocks are still being balanced by the loss of ground water from storage. However, for grid blocks containing streams, the withdrawals are more quickly balanced by base-flow capture, resulting in less water-table decline. Declines near actual withdrawal sites would be greater than those shown on figure 25, because the declines shown are averages over the area of each grid block.

The reduction in average annual base flow for each grid block after steady-state conditions have been reached is shown in figure 26. As after 91 days, the total reductions are several times greater for the Cumberland Valley carbonate rocks than they are for the Great Valley shales. However, the reductions for the car bonates are less than 50 percent greater than they are after 91 days, whereas the reductions for the shales are more than 100 percent greater. Again, this is due to a difference in the rate of equilibration between the carbonate rocks and shales.

The same relation is seen in the water-table declines. Average declines at steady-state conditions are shown in figure 27. As after 91 days, the declines are greater for the shales and for those grid blocks without streams. However, between 91 days and the time at which steady-state conditions occur, the declines for the carbonate rocks increase less than 100 percent, whereas for the shales, they increase by more than 100 percent (up to 200 percent for some grid blocks). For both the carbonate rocks and shales, grid blocks having streams show less water-table decline between 91 days and the time at which steady-state conditions occur.

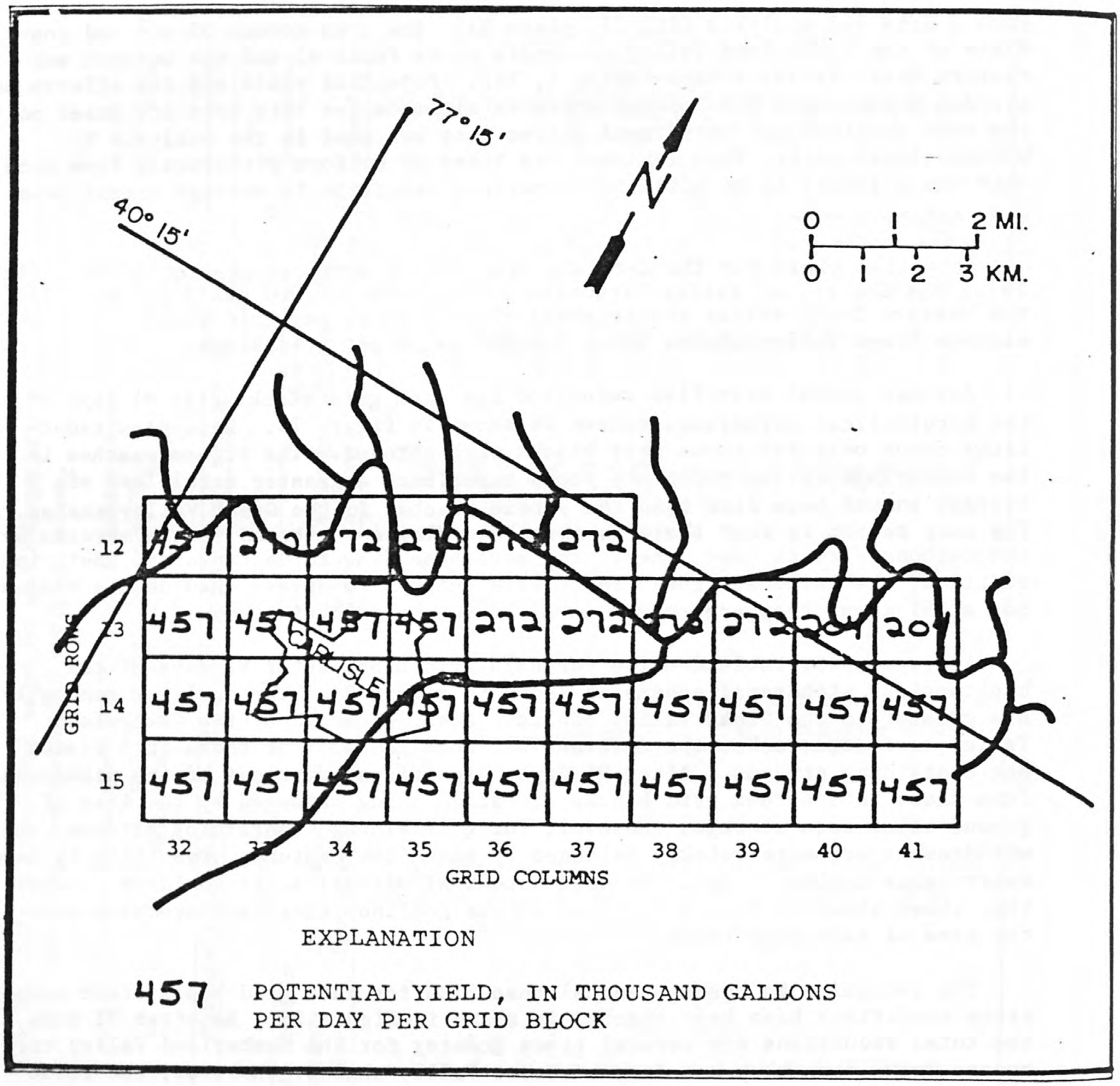


Figure 23. -- Standardized potential yield for each grid block in Carlisle area resulting from hypothetical withdrawal scheme.

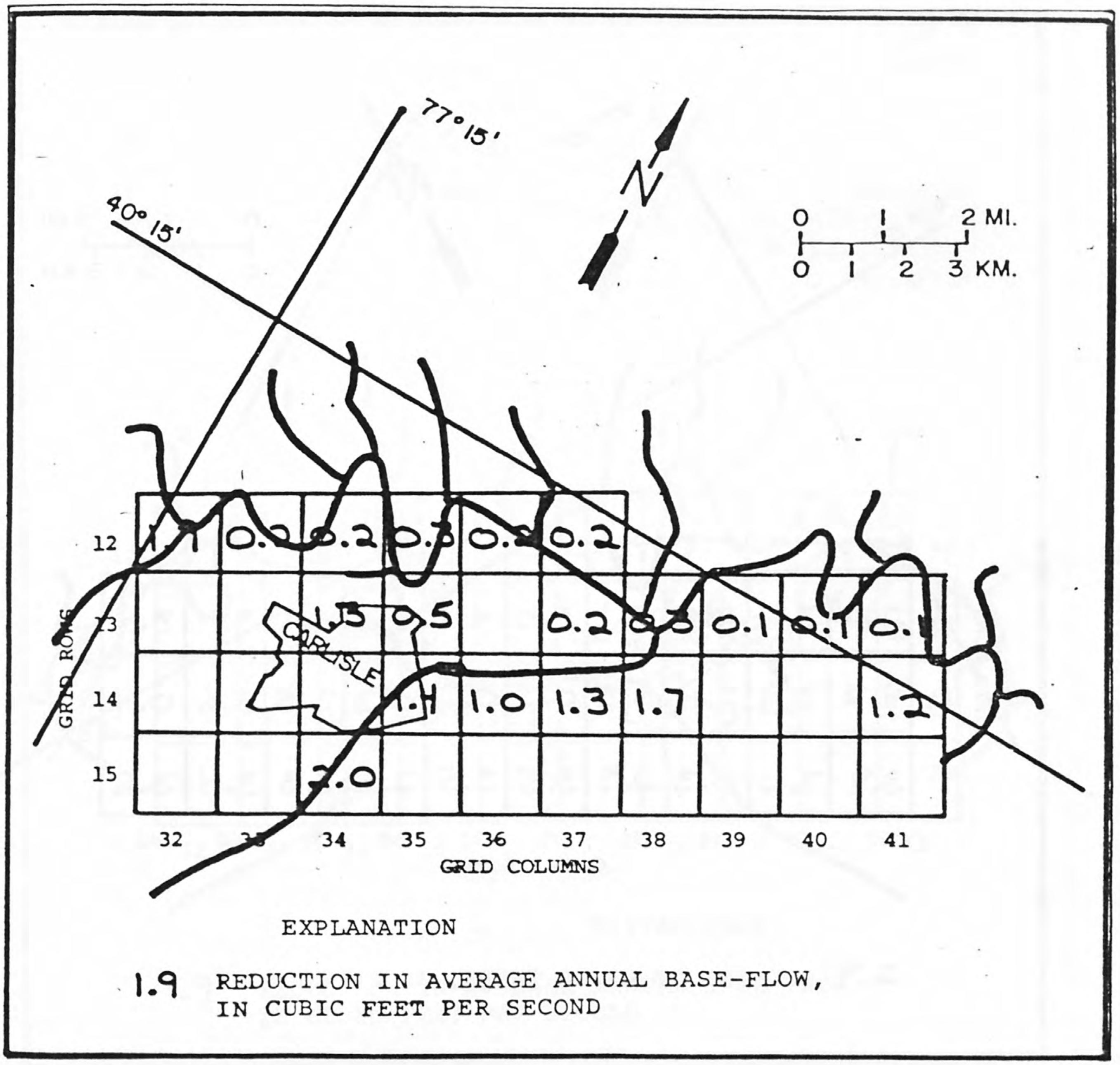


Figure 24. -- Reduction in average annual base flow for each grid block in Carlisle area after 91 days of hypothetical withdrawal scheme.

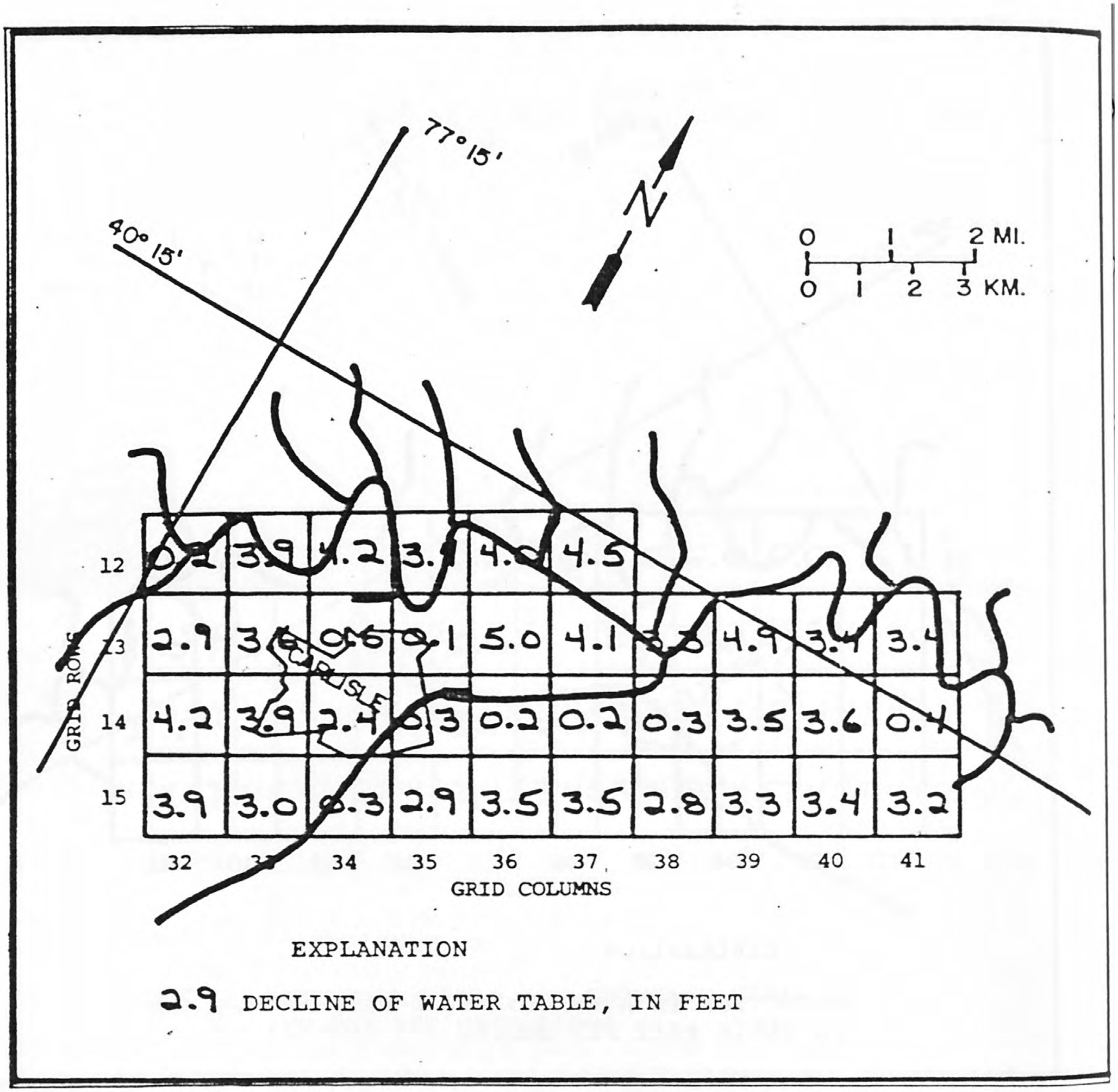


Figure 25. -- Decline of water table for each grid block in Carlisle area after 91 days of hypothetical withdrawal scheme.

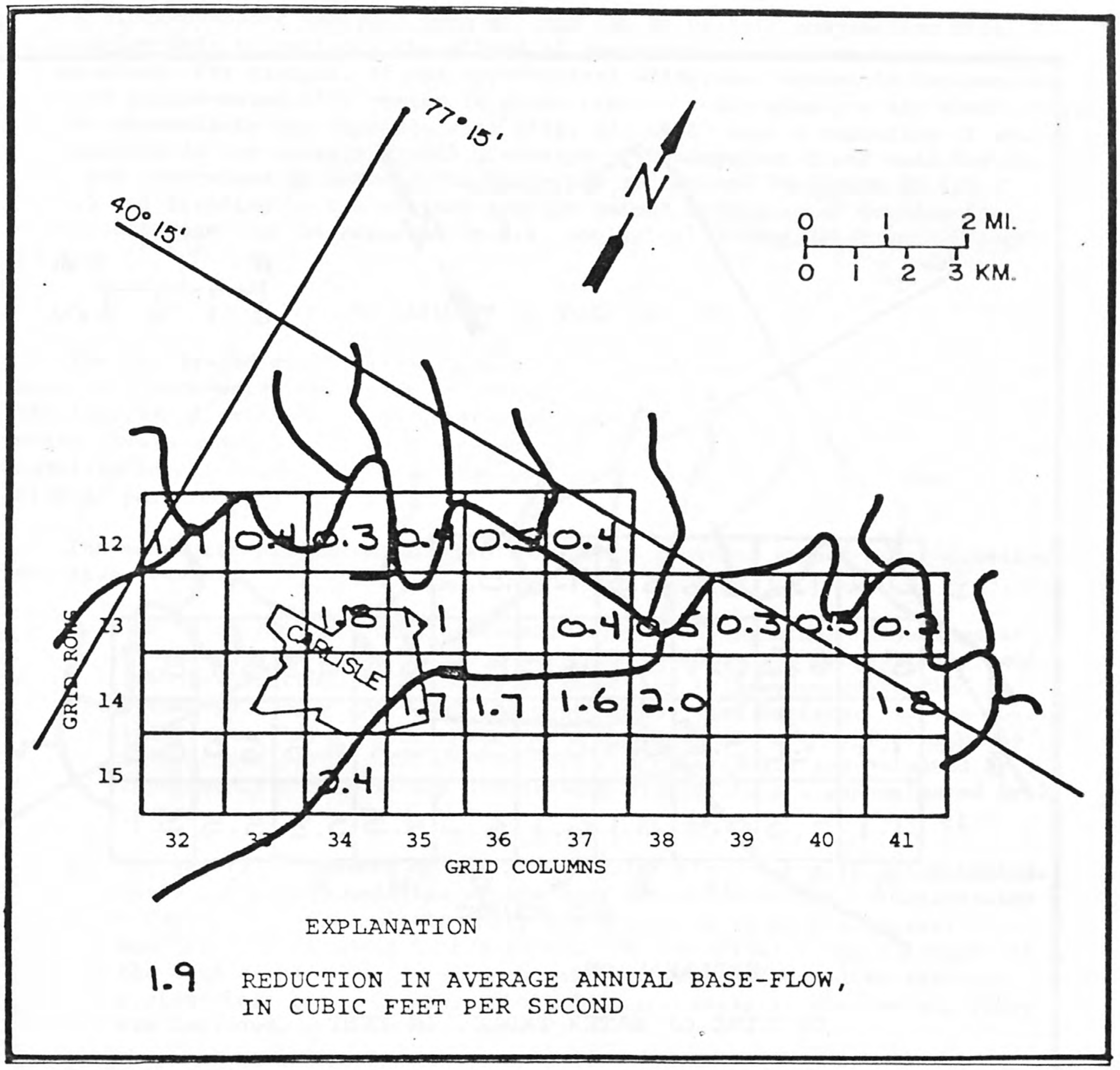


Figure 26. -- Ultimate reduction in average annual base flow for each grid block in Carlisle area resulting from hypothetical withdrawal scheme.

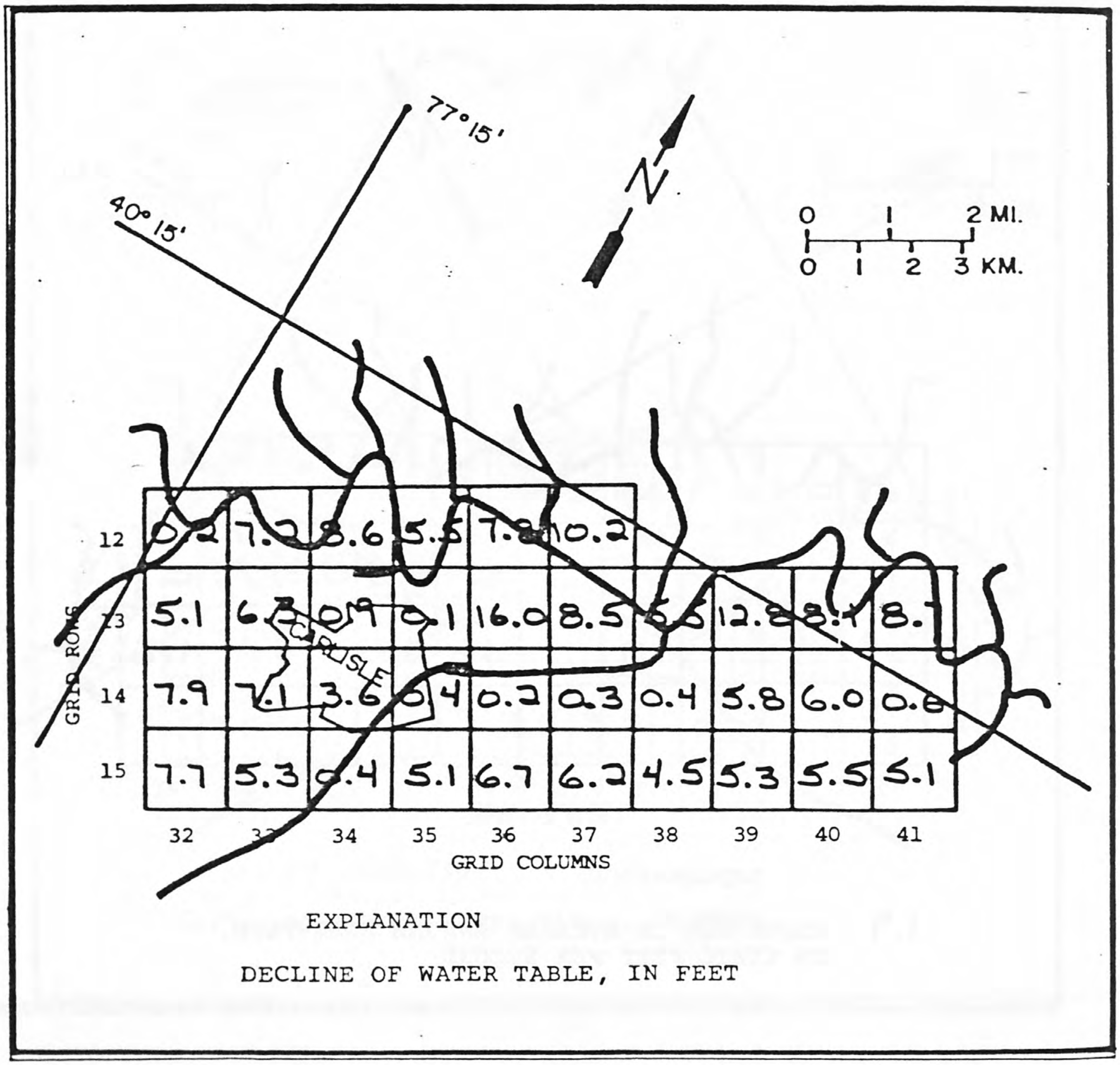


Figure 27. -- Ultimate decline of water table for each grid block in Carlisle area resulting from hypothetical withdrawal scheme.

A block-by-block analysis such as this can be used in conjunction with streamflow data to estimate the effect of ground-water withdrawals on streamflow. For example, if the hypothetical withdrawal scheme is implemented and the ground-water flow system is given time to reach steady-state conditions, the withdrawals in the Carlisle area (fig. 23) will cause a reduction of about 3.3 percent in the average annual discharge of Condoguinet Creek near Hogestown. This was determined by summing the base-flow reductions in figure 26 (19.7 ft^3/s) and dividing by the 48-year average annual discharge of Conodoguinet Creek near Hogestown as reported in U.S. Geological Survey Water-Data Report PA-80-2 (599 ft^3/s).

RELIABILITY OF MODEL RESULTS

The calibrated model can be used on a regional scale to guide the development of ground-water resources in the model area. It can provide estimates of the impacts of various ground-water development schemes on regional ground-water levels and base flows of streams. It can not provide estimates of site-specific impacts such as drawdown at particular well sites or stream infiltration at particular stream sites.

The model can provide acceptable answers to regional ground-water questions for five reasons:

1. The major controls on ground-water flow are simulated. Ground-water flow in the modeled area is controlled by secondary permeability, and the distribution of secondary permeability is in turn controlled by lithology, topography, and the depth below land surface. In the model, lithologic differences in secondary permeability are approximated by 21 hydrogeologic units; topographic differences are approximated by 5 topographic settings; and differences with depth are approximated by 2 layers.

2. The general framework of the ground-water flow system is approximated. The hydrologic boundaries of the area and the geometric relationships between the hydrogeologic units are approximated to the nearest one-half mile (one-half of a grid block dimension). The thickness of the zone of saturation for each unit and the surface-water drainage system--locations, lengths, altitudes, and areas of streams and lakes--are included.

3. A large data base was available to aid in the quantification of hydrologic characteristics. Physical data for more than 4,000 wells, specific-capacity data for more than 900 wells, daily streamflow data for 26 subbasins, and daily precipitation data for 28 stations were used to determine the water-table altitudes, hydraulic conductivities, stream leakage coefficients, specific yields, and model recharge.

4. The regional water-table configuration was generally reproduced in an average annual steady-state calibration. Reasonable hydraulic conductivities and stream leakage coefficients produced statistical agreement between model-generated and estimated water-table altitude.

5. Regional water-table changes were generally reproduced in a transient calibation. Reasonable specific yields produced statistical agreement between model-generated and observed changes in water-table altitude.

On the other hand, inherent in the development of the model are the many assumptions that are discussed throughout the report. The following is a summary of the model assumptions:

1. Secondary openings are interconnected on a regional scale.

2. Continuum methods can be used to analyze flow in the interconnected secondary openings.

3. Water-table conditions occur in the upper 200 to 300 feet of the ground-water flow system.

4. Diabase sills are barriers to regional ground-water flow.

5. Diabase dikes and faults do not disrupt ground-water flow on a regional scale.

6. Contacts between units are vertical.

7. Hydrologic characteristics are uniform within units and, in the case of hydraulic conductivity and depth to water table, within topographic settings.

8. There is hydraulic connection between and within all units.

9. The rows and columns of the grid are alined with the principal directions of hydraulic conductivity.

10. For each unit, the hydraulic conductivities in the three model directions are equal.

11. Streambeds are leaky and when the water table is at or above the top of the streambed, stream-aquifer flow is a function of the difference between stream and water-table altitude.

12. Stream altitudes are constant in time.

13. Model recharge is uniform within major subbasins and units.

14. Ground-water evapotranspiration is insignificant.

15. Current consumptive ground-water use is insignificant.

16. Model boundary conditions are constant in time.

The model was calibrated under natural unstressed conditions (average annual steady-state) and natural stressed conditions (November 1, 1980 through April 22, 1981 transient). It was not calibrated under conditions of ground-water withdrawal because withdrawals great enough to have a regional impact either did not exist or were not documented in terms of their associated rates of water-table decline. In addition, the specific yields determined in the transient calibration were based on water-table altitude changes for atypical natural stressed conditions--a winter and spring during which the water table declined in many parts of the lower basin. Therefore, when simulating stressed conditions, the model user should be aware that model-generated effects may not be the same as actual effects. However, the model-generated water-table declines and base-flow reductions are general indicators of the relative distribution and magnitude of the effects that would result from imposed stresses.

SUGGESTED USES OF MODEL

There are many ways to use the calibrated model to simulate the effects of both natural and artificial stresses on the ground-water flow system. The use depends on the objective; the model can be used in either steady-state or transient mode. In steady-state mode, the effects simulated are the ultimate effects. In transient mode, the effects at any desired time may be simulated.

Natural stresses caused by changes in recharge are variable and intermittent, so transient simulations are generally more appropriate. For example, periods of low recharge such as droughts are relatively temporary, and the ground-water flow system probably would never reach steady-state conditions under such a stress. A transient simulation would show the effects at different stages of a drought.

Artificial stresses tend to be more long-term. For example, major withdrawals of ground water commonly continue for many years at about the same rates, regardless of the natural stress conditions. In fact, if anything, most major ground-water withdrawals can be expected to increase. For this reason, steady-state simulations commonly are used to estimate the effects of artificial stresses. However, transient simulations also are useful, because many withdrawals, such as for irrigation, are intermittent.

Some uses of the model to evaluate the regional effects of natural stresses are:

1. Transient simulations of hypothetical droughts - simulations to assess the effects of droughts of varying severity and duration;

2. Transient simulations of hypothetical drought recovery - continuations of the simulations above with various amounts of recharge to estimate recovery times;

3. Transient simulation of current natural effects - an ongoing, updated simulation in which each recharge event is entered as it occurs.

Some uses of the model to evaluate the regional effects of artificial stresses are:

1. Steady-state simulations of individual, current, continuous withdrawals - simulations to assess the effects of each major continuous withdrawal;

2. Steady-state simulation of all current continuous withdrawals - a simulation to assess the combined effects of all major continuous withdrawals;

3. Transient simulations of individual, current, seasonal withdrawals - simulations to assess the effects of each major seasonal withdrawal;

4. Transient simulation of all current seasonal withdrawals - a simulation to assess the combined effects of all major seasonal withdrawals;

5. Steady-state simulation of an impoundment - a simulation to assess the effects of a major impoundment;

6. Steady-state simulation of urbanization - a simulation to assess the effects of reduced recharge due to urbanization;

7. Transient simulation of current continuous and seasonal withdrawals - an ongoing, updated simulation in which each new major continuous and seasonal withdrawal is entered as it occurs;

8. Steady-state simulations of projected continuous and seasonal withdrawals - simulations to assess the effects of various potential ground-water development schemes.

Simulations can be made which combine any of the natural and artificial stress situations above. Three of the more interesting are:

1. Transient simulations of current continuous and seasonal withdrawals during hypothetical droughts - simulations to assess the combined effects of all current, major, artificial stresses and low-recharge drought conditions of varying severity and duration;

2. Transient simulations of projected continuous and seasonal withdrawals during hypothetical droughts - simulations to assess the combined effects of various potential ground-water development schemes and low-recharge drought conditions of varying severity and duration;

3. Transient simulation of current continuous and seasonal withdrawals under current natural conditions - an ongoing, updated simulation in which the combined effects of current artificial and natural stresses are estimated.

The results of these types of simulations can be used to guide the development of ground-water resources in the area. They can be used in conjunction with reasonable limits of acceptable base-flow reduction or water-table decline to estimate the optimum amount and distribution of withdrawals.

SUMMARY

Ground water in the 3,458-mi^2 lower Susquehanna River basin generally occurs under unconfined conditions in bedrock and overlying weathered mantle. In bedrock, ground-water flow is controlled by secondary permeability. Secondary openings, commonly enlarged by weathering and solution, are responsible for the presence and flow of most ground water. The number, size, and interconnection of the secondary openings differ with lithologic differences, depth below land surface, and topographic setting.

The ground-water flow system is recharged by infiltration of precipitation. Recharge occurs nearly everywhere; discharge occurs in stream valleys. Local flow systems dominate, with ground water discharging in valleys adjacent to its areas of recharge.

The area was subdivided into 21 hydrogeologic units based on lithologic and hydrologic differences. The depth of ground-water circulation, the depth to the water table, recharge amounts, and hydrologic characteristics differ between units. The units range in area from 20 to 757 mi^2. Most units include several geologic formations. The major units can be grouped into four general lithologies: Paleozoic sedimentary rocks, carbonate rocks, crystalline rocks, and Triassic sedimentary rocks.

The ground-water flow system was divided into two layers to account for the decrease in secondary permeability with depth. The thickness of the layers differs between units and ranges from 200 to 300 ft for the upper layer and 300 to 400 ft for the lower layer.

The water table is a subdued replica of the land surface and generally intersects the land surface at streams. The average depths to the water table for each unit were determined for different topographic settings ranging from valley-bottom to hilltop. The depth to the water table ranges from zero at streams to 150 ft on the flank of Blue Mountain. For the intermediate topographic settings, the water table is generally 20 to 70 ft below land surface.

The three-dimensional digital ground-water flow model of Trescott (1975) was modified and used in three-dimensional mode to simulate ground-water flow. A grid consisting of square blocks 5,208 ft on a side was superimposed on the area. Each hydrogeologic unit consists of a number of grid blocks proportional to its area. The hydrologic characteristics are assumed uniform within each grid block.

Ground-water flow components included in both layers of the model are change in storage, flow from South Mountain, and flow between adjacent units. Included only for the upper layer are model recharge, discharge to streams, infiltration from streams, and withdrawal from wells (in ground-water resource evaluation). Flow between the upper and lower layers is also included.

The model was calibrated under average annual steady-state conditions. Water-table altitude for each grid block was estimated by subtracting the average annual depth to water from the average land-surface altitude. Average

annual stream altitudes were used. No-flow boundaries were placed around the edges of the area, except along South Mountain where constant-flux boundaries were used. No-flow boundaries also were placed at the edges of major diabase sills. Those grid blocks entirely within the Susquehanna River were designated as constant-head. The average annual model recharge was estimated by separating base flow from runoff on streamflow hydrographs.

Initial estimates of hydraulic conductivity and stream leakage coefficients for each unit were adjusted until satisfactory agreement was achieved between model-generated and estimated water-table altitudes. Non-parametric statistics were used to assess the calibration. The median differences between model-generated and estimated water-table altitudes for all units were less than 11 ft. For units with adequate hydrologic data, 80 percent of the differences were less than about 35 ft. It was not possible to accurately calibrate the model in the northern part of the Cumberland Valley carbonate rocks due to the lack of data on the nature of ground-water flow near the contact with the western Great Valley shales. The model-generated base flows for 13 major sub-basins were within 12 percent of the estimated base flows.

The hydraulic conductivity for the upper layer differs within each unit according to the dominant topographic position for each grid block. Valley-bottom blocks have the highest and hilltop blocks the lowest hydraulic conductivities. Hydraulic conductivities resulting from the steady-state calibration range from 0.065 ft/d for hilltop blocks in the Triassic conglomerates to 173.8 ft/d for valley-bottom blocks in the Cumberland Valley carbonate rocks. Carbonate units have the highest area-weighted average hydraulic conductivity (21.2 ft/d); crystalline units have the lowest (1.1 ft/d). The average hydraulic conductivity of the lower layer is 50 percent of that of the upper layer for the Triassic sedimentary units and 10 percent for the other units.

Because about 90 percent of the grid blocks contain a stream segment or lake, head-dependent stream leakage coefficients were used to allow some of the recharge in a block to discharge to streams in the same block. Two coefficients were determined for each unit--one for gaining-stream conditions and the other for losing-stream conditions. The gaining-stream leakage coefficients range from 0.05 ft/d for two Triassic sedimentary units and the Conestoga Valley metamorphic rocks west of Susquehanna River to 43.2 ft/d for the Cumberland Valley carbonate rocks. Carbonate units have the highest area-weighted average gaining-stream leakage coefficient (15.8 ft/d); crystalline units have the lowest (0.08 ft/d). The losing-stream leakage coefficients are 50 percent of the gaining-stream leakage coefficients for the carbonate units and 10 percent for most other units.

Average annual model recharge is 1,690 Mgal/d [0.48 (Mgal/d)/mi^2]. Ground-water flow from South Mountain c ontributes 69 Mgal/d [0.02 (Mgal/d)/mi^2] and 98 Mgal/d [0.03 (Mgal/d)/mi^2] is derived from infiltration from streams, bringing the overall amount of average annual recharge to 1,857 Mgal/d [0.54 (Mgal/d)/mi^2]. The Cumberland Valley carbonate rocks receive the greatest overall average annual recharge, 1.27 (Mgal/d)/mi^2; the Triassic conglomerates receive the least overall average annual recharge, 0.24 (Mgal/d)/mi^2. In the model, all ground water eventually is discharged into streams as base flow. Less than 8 percent of the total ground-water flow reaches the lower layer.

Of the three major input variables, the model is most sensitive to model recharge, followed by stream leakage coefficient and hydraulic conductivity. The crystalline units generally are the most sensitive to changes in all variables and the carbonate units are the least sensitive. The eastern Lebanon Valley carbonate rocks and the Conestoga Valley carbonate rocks west of the Susquehanna River are relatively insensitive to all reasonable changes.

The model was calibrated under transient conditions for November 1, 1980 through April 22, 1981. The hydraulic conductivities, stream leakage coefficients, and boundary conditions from the steady-state calibration were used. The model recharge was estimated from streamflow hydrographs for the major storms during the period.

The initial estimates of specific yield (and storage coefficient) for each general lithology were adjusted until satisfactory agreement was achieved between model-generated and observed changes in water-table altitude. Nonparametric statistics were used to assess the calibration. The median model-generated and observed water-table changes for each general lithology were within 1.0 ft. The agreement between the ranges of model-generated and observed changes was relatively poor.

The average specific yields for the upper layer are 0.035, 0.020, 0.020, and 0.007 for the carbonate, Paleozoic sedimentary, crystalline, and Triassic sedimentary units, respectively. The storage coefficients for the lower layer for each general lithology are assumed to be two orders of magnitude less than the corresponding specific yields for the upper layer. The model is sensitive to changes in specific yield; halving the specific yield will double the changes in water-table altitude.

The calibrated model was used to rank the hydrogeologic units according to their response to stress. A ground-water withdrawal of 1.0 in/yr was simulated under steady-state conditions. The effects on water-table altitude and average annual base flow were compared between units. This withdrawal has the least overall effect on the eastern Lebanon Valley carbonate rocks and the greatest overall effect on the Triassic conglomerates. In order of the least to the greatest overall effect, the ranking by general lithology is: Carbonate rocks, Paleozoic sedimentary rocks, crystalline rocks, and Triassic sedimentary rocks.

A standardized potential yield was estimated for each hydrogeologic unit by assuming that the maximum acceptable consequence of any withdrawal scheme is an ultimate 50-percent reduction in average annual base flow for each unit. The potential yield was therefore determined by simulating the uniform withdrawal of the amount of ground-water from each unit which causes such a reduction. A transient simulation was used in order to obtain the effects at various times during the first 20 years of the hypothetical withdrawal scheme, and a steady-state simulation was used to obtain the ultimate effects.

Potential yield of the entire area under this assumed condition is 891 Mgal/d [0.26 (Mgal/d)/mi^2]. The Cumberland Valley carbonate rocks have the greatest potential yield, 0.47 (Mgal/d)/mi^2; the Triassic conglomerates have the least, 0.08 (Mgal/d)/mi^2. From the greatest to the least potential yield, the order by general lithology is: Carbonate rocks, Paleozoic sedimentary rocks, crystalline rocks, and Triassic sedimentary rocks.

The time needed to reach steady-state conditions under the hypothetical withdrawal scheme is least for the Cumberland Valley carbonates rocks and the Conestoga Valley carbonate rocks west of the Susquehanna River (6 years) and greatest for the Triassic conglomerates (more than 100 years). The carbonate, Paleozoic sedimentary, Triassic sedimentary, and crystalline units require an area-weighted average of about 9, 24, 24, and 33 years, respectively, to reach steady-state conditions.

Nearly all of the eventual water-table declines and base-flow reductions caused by the implementation of the hypothetical withdrawal scheme occur within the first five years. The carbonate, Triassic sedimentary, Paleozoic sedimentary, and crystalline units experience 90 percent of their eventual water-table declines and base-flow reductions within area-weighted averages of 1.4, 2.4, 2.8, and 4.1 years, respectively.

Nearly all the hypothetically withdrawn ground water is derived from reduced discharge to streams. Significant amounts of ground water are removed from storage only for a relatively short time after the implementation of the hypothetical withdrawal scheme. After 91 days, the area-weighted average percentage of withdrawals derived from storage is 39, 60, 67, and 80 for the carbonate, Triassic sedimentary, Paleozoic sedimentary, and crystalline units, respectively.

The effects of the hypothetical withdrawals were examined in greater detail near Carlisle, PA. A block-by-block analysis of the effects indicates that the base flow captured annually is greater for the Cumberland Valley carbonate rocks than the Great Valley shales. On the other hand, the average water-table decline is greater for the Great Valley shales. A comparison of the effects after 91 days and at steady-state conditions shows that the effects approach their ultimate values more quickly for the Cumberland Valley carbonate rocks. For both the carbonate rocks and the shales, those grid blocks containing a stream experience less water-table decline and quicker equilibration of the stress.

The calibrated model can be used to provide estimates of the impacts of various ground-water development schemes on regional ground-water levels and regional base flows of streams. The reliability of the model is based on its inclusion of the major controls on ground-water flow, the general framework of the ground-water flow system, and hydrologic characteristics based on extensive data. In addition, the average annual steady-state calibration and the November 1, 1980 through April 22, 1981 transient calibration contribute to its reliability. On the other hand, model-generated water-table declines and base-flow reductions are only estimates because of the various simplifying assumptions and the lack of calibration under conditions of ground-water withdrawal.

The calibrated model can be used in steady-state or transient mode to assess the effects of both natural and artificial stresses. Some examples are the simulation of droughts, drought recovery, current seasonal and continuous withdrawals, projected seasonal and continous withdrawals, impoundments, urbanization, and various combinations of these. The model can not be used to simulate local cones of depression or local base-flow changes.

REFERENCES CITED

Becher, A. E., and Root, S. I., 1981, Groundwater and geology of the Cumberland Valley, Cumberland County, Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Water Resource Report 50, 95 p.

Becher, A. E., and Taylor, L. E., 1982, Groundwater resources in the Cumberland and contiguous valleys of Franklin County, Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Water Resource Report 53, 67 p.

Carswell, L. D., Hollowell, J. R., and Platt, L. B., 1968, Geology and hydrology of the Martinsburg Formation in Dauphin County, Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Ground Water Report W24, 54 p.

Daniel, J. F., 1976, Estimating groundwater evapotranspiration from streamflow records: Water Resources Research, v. 12, no. 3, p. 360-364.

Dingman, R. J., Ferguson, H. F., and Martin, R. O. R., 1956, The water resources of Baltimore and Harford Counties: Maryland Department of Geology, Mines, and Water Resources, Bulletin 17, 233 p.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: New Jersey, Prentice-Hall, 604 p.

Gerhart, J. M., and Lazorchick, G. J., 1981, Changes in ground-water levels in the Susquehanna River Basin, October 1980 - October 1981: Pennsylvania Geology, v. 12, no. 6, p. 4-8.

Gerhart, J. M., and Williams, J. H., 1981, Recovery of ground-water levels from drought conditions in two areas of the Susquehanna River Basin in Pennsylvania: Pennsylvania Geology, v. 12, no. 3 p. 2-6.

Hall, G. M., 1934, Ground water in southeastern Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Bulletin W2, 255 p.

Johnson, R. R., 1976, Elementary statistics: Massachusetts, Duxbury Press, 550 p.

Johnston, H. E., 1966, Hydrology of the New Oxford Formation in Lancaster County, Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Ground Water Report W23, 80 p.

Laughlin, C. P., 1966, Records of wells and springs in Baltimore County, Maryland: Maryland Geological Survey, Water Resources Basic Data Report No. 1, 403 p.

Linsley, R. K. Jr., Kohler, M. A., and Paulhus, J. L. H., 1949, Applied hydrology: New York, McGraw-Hill, 689 p.

Lloyd, O. B., and Growitz, D. J., 1977, Ground-water resources of central and southern York County, Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Water Resource Report 42, 93 p.

Lohman, S. W., 1979, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

MacLachlan, D. B., and Root, S. I., 1966, Comparative tectonics and stratigraphy of the Cumberland and Lebanon Valleys, guidebook for the 31st annual field conference of Pennsylvania geologists: Pennsylvania Geologic Survey, 90 p.

McGreevy, L. J., and Sloto, R. A., 1976, Selected hydrologic data, Chester County, Pennsylvania: U.S. Geological Survey Open-File Report, 138 p.

-----1977, Ground water resources of Chester County, Pennsylvania: U.S. Geological Survey Water Resources Investigation 77-67, 76 p.

-----1980, Development of a digital model of ground-water flow in deeply weathered crystalline rock, Chester County, Pennsylvania: U.S. Geological Survey Water-Resources Investigation 80-2, 42 p.

Meisler, Harold, 1963, Hydrogeology of the carbonate rocks of the Lebanon Valley, Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Ground Water Report W18, 81 p.

Pennsylvania Topographic and Geologic Survey, 1980, Geologic Map of Pennsylvania: Commonwealth of Pennsylvania.

Poth, C. W., 1977, Summary ground-water resources of Lancaster County, Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Water Resource Report 43, 80 p.

Rima, D. R., Meisler, H., and Longwill, Stanley, 1962, Geology and hydrology of the Stockton Formation in southeastern Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Bulletin W14, 111 p.

Rorabaugh, M. I., 1964, Estimating changes in bank storage and ground-water contribution to streamflow: International Association of Scientific Hydrology Pub., no. 63, p. 432-441.

Stuart, W. T., Schneider, W. J., and Crooks, J. W., 1967, Swatara Creek Basin of southeastern Pennsylvania -- An evaluation of its hydrologic system: U.S. Geological Survey Water-Supply Paper 1829, 79 p.

Susquehanna River Basin Commission, 1979, Special ground-water study plan-of-study: 80 p.

Taylor, L. E., and Royer, D. W., 1981, Summary ground-water resources of Adams County, Pennsylvania: Pennsylvania Geological Survey, Fourth Series, Water Resource Report 52, 50 p.

Toth, J., 1963, A theoretical analysis of groundwater flow in small drainage basins: Journal of Geophysical Research, v.68, no. 16, p. 4795-4812.

Trainer, F. W., and Watkins, F.A. Jr., 1975, Geohydrologic reconnaissance of the upper Potomac River Basin: U.S. Geological Survey Water-Supply Paper 2035, 68 p.

Trescott, P. C., 1975, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-File Report 75-438, 103 p.

Trescott, P. C., and Larson, S. P., 1976, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-File Report 76-591, 21 p.

U.S. Department of Commerce, 1966, Climatological data, Pennsylvania, Annual Summary, 1965: Environmental Science Services Administration, Volume 70, No. 13, 10 p.

-----1967, Climatological data, Pennsylvania, Annual summary, 1966: Environmental Science Services Administration, Volume 71, No. 13, 10 p.

-----1967, Climatological data, Maryland and Delaware, Annual summary, 1966: Environmental Science Services Administration, Volume 70, No. 13, 7 p.

-----1968, Climatological data, Pennsylvania, Annual summary, 1967: Environmental Science Services Administration, Volume 72, No. 13 10 p.

-----1968, Climatological data, Maryland and Delaware, Annual summary, 1967: Environmental Science Services Administration, Volume 71, No. 13, 8 p.

U.S. Department of Commerce, 1971, Climatólogical data, Maryland and Delaware, Annual summary, 1970: National Oceanic and Atmospheric Administration, Environmental Data Service, Volume 74, No. 13, 8 p.

-----1972, Climatological data, Pennsylvania, Annual summary, 1971: National Oceanic and Atmospheric Administration, Environmental Data Service, Volume 76, No. 13, 10 p.

-----1972, Climatological data, Maryland and Delaware, Annual summary, 1971: National Oceanic and Atmospheric Administration, Environmental Data Service, Volume 75, No. 13, 8 p.

-----1973, Climatological data, Pennsylvania, Annual summary, 1972: National Oceanic and Atmospheric Administration, Environmental Data Service, Volume 77, No. 13, 10 p.

-----1974, Climates of the states, Volume I - Eastern states: National Oceanic and Atmospheric Administration, New York, Water Information Center, Inc., 486 p.

-----1977, Climatological data, Annual summary, Pennsylvania, 1976: National Oceanic and Atmospheric Administration, Environmental Data Service, Volume 81, No. 13, 14 p.

-----1978, Climatological data, Annual summary, Pennsylvania, 1977: National Oceanic and Atmospheric Administration, Environmental Data Service, Volume 82, No. 13, 14 p.

-----1979, Climatological data, Annual summary, Pennsylvania, 1978: National Oceanic and Atmospheric Administration, Environmental Data Service, Volume 83, No. 13, 14 p.

-----1980-81, Climatological data, Pennsylvania, July 1980-May 1981: National Oceanic and Atmospheric Administration, Environmental Data and Information Service, Volume 85, Number 7 through Volume 86, Number 5.

-----1980-81, Climatological data, Maryland and Delaware, July 1980-May 1981: National Oceanic and Atmospheric Administration, Environmental Data and Information Service, Volume 84, Number 7 through Volume 85, Number 5.

U.S. Geological Survey, 1967, Water resources data for Pennsylvania, Part 1, Surface water records, 1966: Harrisburg, U.S. Geological Survey, Water Resources Division, 299 p.

-----1968, Water resources data for Pennsylvania, Part 1, Surface water records, 1967: Harrisburg, U.S. Geological Survey, Water Resources Division, 315 p.

-----1969, Water resources data for Maryland and Delaware, Part 1, Surface water records, 1967: Towson, U.S. Geological Survey, Water Resources Division, 149 p.

U.S. Geological Survey, 1972, Water resources data for Maryland and Delaware, Part 1, Surface water records, 1971: Towson, U.S. Geological Survey, Water Resources Division, 149 p.

-----1973, Water resources data for Pennsylvania, Part 1, Surface water records, 1972: Harrisburg, U.S. Geological Survey, Water Resources Division, 312 p.

-----1978, Water resources data for Pennsylvania, Water Year 1977, Volume 2, Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Data Report PA-77-2, 384 p.

-----1979, Water resources data for Pennsylvania, Volume 2, Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Data Report PA-78-2, Water Year 1978, 411 p.

-----1980, Water resources data for Pennsylvania, Volume 2, Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Data Report PA-79-2, Water Year 1979, 403 p.

-----1981, Water resources data for Pennsylvania, Volume 2, Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Data Report PA-80-2, Water Year 1980, 353 p.

-----1982, Water resources data for Pennsylvania, Water Year 1981, Volume 2, Susquehanna and Potomac River Basins: U.S. Geological Survey Water-Data Report PA-81-2, 345 p.

Walton, W. C., 1970, Groundwater resource evaluation: New York, McGraw-Hill, 664 p.

Willard, Bradford, 1976, Pennsylvania geology summarized: Pennsylvania Geological Survey, Fourth Series, Educational Series No. 4, 17 p.

Woll, R. S., 1978, Maryland ground-water information: chemical quality data: Maryland Geological Survey, Water Resources Basic-Data Report No. 10, 125 p.

Wood, C. R., 1981, Groundwater resources of the Gettysburg and Hammer Creek Formations, southeastern Pennsylvania: Pennsylvania Geological Survey, Water Resource Report 49, 87 p.

Wood, C. R., and MacLachlan, D. B., 1978, Geology and groundwater resources of northern Berks County, Pennsylvania: Pennsylvania Geological Survey, Water Resource Report 44, 91 p.

Wood, P. R., and Johnston, H. E., 1964, Hydrology of the New Oxford Formation in Adams and York Counties, Pennsylvania: Pennsylvania Geological Survey, Ground Water Report W21, 66 p.

ATTACHMENT A

Model program listing

The following is a listing of the model program used in this investigation. The modifications made by the authors to the original version in Trescott, (1975) are indicated by asterisks in columms 75-77.

```
C     --------------------------------------------------------------------
C     FINITE-DIFFERENCE MODEL FOR SIMULATION OF GROUND-WATER FLOW IN
C     THREE DIMENSIONS, SEPTEMBER, 1975 BY P.C. TRESCOTT, U. S. G. S.
C     WITH CONTRIBUTIONS TO MAIN, DATAI AND SOLVE BY S.P. LARSON
C     AND MODIFICATIONS BY J.M. GERHART AND G.J. LAZORCHICK, 1980-81     ***
C     --------------------------------------------------------------------
C
C                                                                        ***
C     CHANGES TO ORIGINAL CODE MARKED WITH *** IN COLUMNS 75-77.         ***
C     PURPOSE OF CHANGE NOTED BY COMMENTS WHERE FEASIBLE.                ***
C                                                                        ***
C     SPECIFICATIONS:
      REAL *8YSTR
C
      DIMENSION Y(400000),L(25),HEADNG(33),NAME(42),INFT(2,4),IOFT(9,5), ***
     1DUM(3)                                                             ***
C
      EQUIVALENCE (YSTR,Y(1))
C
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK,IEQN,KK ***
     3K,KKKK,IR,ISTAT,MLTCHK,ISBOUT,IJKMAP,IVHMAP,IZTOZ,ITABLE,          ***
     4LAYDDN,ISLEAK,IOCTAP,IWLWD,IPPOUT                                  ***
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
C
      DATA NAME/2*4H    ,4H   S,4HTART,4HING ,4HHEAD,4H    ,4H STO,4HRAG
     1E,4H COE,4HFFIC,4HIENT,2*4H    ,4H  TR,4HANSM,4HISSI,4HVITY,5*4H
     2 ,4H  TK,4H   T,4HOPOG,4HRAPH,4HIC S,4HETTI,4HNG  ,2*4H    ,4HBOT  ***
     3T,4HOM E,4HLEVA,4HTION,2*4H    ,4H   R,4HECHA,4HRGE ,4HRATE/
      DATA INFT/4H(20F,4H4.0),4H(8F1,4H0.4),4H(8E1,4H0.3),4H(40F,4H2.0)/ ***
      DATA IOFT/4H(1H0,4H,I2,,4H2X,2,4H0F6.,4H1/(5,4HX,20,4HF6.1,4H))  ,
     14H    ,4H(1H0,4H,I5,,4H14F9,4H.5/(,4H1H ,,4H5X,1,4H4F9.,4H5)) ,4H
     2    ,4H(1H0,4H,I5,,4H10E1,4H2.5/,4H(1H ,4H,5X,,4H10E1,4H2.5),4H)
     3,4H(1H0,4H,I5,,4H10E1,4H1.3/,4H(1H ,4H,5X,,4H10E1,4H1.3),4H)  ,4H  ***
     4(1H0,4H,I2,,4H2X,5,4H0F2.,4H0/(5,4HX,50,4HF2.0,4H))  ,4H    /     ***
C
      DEFINE FILE 2(8,1520,U,KKK)
C     ....................................................................
      KKK=0                                                              ***
      KKKK=0                                                             ***
C
C     ---READ TITLE, PROGRAM SIZE AND OPTIONS---
      READ (5,200) HEADNG
      WRITE (6,190) HEADNG
      READ(5,160) I0,J0,K0,ITMAX,NCH,NZNS,IR,ISTAT,MLTCHK                ***
      READ(5,165) ISBOUT,IJKMAP,IVHMAP,IZTOZ,ITABLE,LAYDDN,ISLEAK,       ***
     1IOCTAP,IWLWD,IPPOUT                                                ***
      WRITE(6,180)    I0,J0,K0,ITMAX,NCH,NZNS,IR,ISTAT,MLTCHK,ISBOUT,IJK ***
     1MAP,IVHMAP,IZTOZ,ITABLE,LAYDDN,ISLEAK,IOCTAP,IWLWD,IPPOUT          ***
      READ (5,210) IDRAW,IHEAD,IFLO,IDK1,IDK2,IWATER,IQRE,IPU1,IPU2,ITK
     1,IEQN
      WRITE (6,220) IDRAW,IHEAD,IFLO,IDK1,IDK2,IWATER,IQRE,IPU1,IPU2,ITK
     1,IEQN
```

```
      IERR=0
C
C     ---COMPUTE DIMENSIONS FOR ARRAYS---
      J1=J0-1
      I1=I0-1
      K1=K0-1
      I2=I0-2
      J2=J0-2
      K2=K0-2
      IMAX=MAX0(I0,J0)
      NCD=MAX0(1,NCH)
      ITMX1=ITMAX+1
      ISIZ=I0*J0*K0
      IK1=I0*J0
      IK2=MAX0(IK1*K1,1)
      ISUM=2*ISIZ+1
      L(1)=1
      DO 30 I=2,14
      IF (I.NE.8) GO TO 20
      L(8)=ISUM
      ISUM=ISUM+IK2
      IF (IK2.EQ.1) GO TO 10
      IK=I0
      JK=J0
      K5=K1
      GO TO 30
   10 IK=1
      JK=1
      K5=1
      GO TO 30
   20 L(I)=ISUM
      ISUM=ISUM+ISIZ
   30 CONTINUE
      L(15)=ISUM
      ISUM=ISUM+J0
      L(16)=ISUM
      ISUM=ISUM+I0
      L(17)=ISUM
      ISUM=ISUM+K0
      L(18)=ISUM
      ISUM=ISUM+IMAX
      L(19)=ISUM
      ISUM=ISUM+K0*3
      L(20)=ISUM
      ISUM=ISUM+ITMX1
      L(21)=ISUM
      ISUM=ISUM+3*NCD
      L(22)=ISUM
      ISUM=ISUM+NCD
      L(23)=ISUM
      IF (IWATER.NE.ICHK(6)) GO TO 40
      ISUM=ISUM+IK1
      L(24)=ISUM
      ISUM=ISUM+IK1
      IP=I0
```

```
      JP=J0                                                             MAN0960
      GO TO 50                                                          MAN0970
   40 ISUM=ISUM+1                                                       MAN0980
      L(24)=ISUM                                                        MAN0990
      ISUM=ISUM+1                                                       MAN1000
      IP=1                                                              MAN1010
      JP=1                                                              MAN1020
   50 L(25)=ISUM                                                        MAN1030
      IF (IQRE.NE.ICHK(7)) GO TO 60                                     MAN1040
      ISUM=ISUM+IK1                                                     MAN1050
      IQ=I0                                                             MAN1060
      JQ=J0                                                             MAN1070
      GO TO 70                                                          MAN1080
   60 ISUM=ISUM+1                                                       MAN1090
      IQ=1                                                              MAN1100
      JQ=1                                                              MAN1110
C                                                                         ***
C     INCREASE SIZE FOR INPUT OF MODEL PARAMETERS BY HYDROGEOLOGIC UNIT.  ***
C                                                                         ***
   70 LZNS=ISUM                                                           ***
      ISUM=ISUM+IK1                                                       ***
      LKXU=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LKXL=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LKYU=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LKYL=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LKZU=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LKZL=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LBZU=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LBZL=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LQRZ=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LSZU=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
      LSZL=ISUM                                                           ***
      ISUM=ISUM+NZNS                                                      ***
C                                                                         ***
C     INCREASE SIZE FOR HEAD DEPENDENT STREAM OPTION.                     ***
C                                                                         ***
      LRCG=ISUM                                                           ***
      ISUM=ISUM+ISIZ                                                      ***
      LRCL=ISUM                                                           ***
      ISUM=ISUM+ISIZ                                                      ***
      LRHSS=ISUM                                                          ***
      ISUM=ISUM+ISIZ                                                      ***
      LHB=ISUM                                                            ***
      ISUM=ISUM+ISIZ                                                      ***
C                                                                         ***
```

```
C     INCREASE SIZE FOR TOPOGRAPHIC MODIFICATION OF                      ***
C     HYDRAULIC CONDUCTIVITY.                                            ***
C                                                                        ***
      LPMULT=ISUM                                                        ***
      ISUM=ISUM+NZNS*5                                                   ***
      WRITE(6,170) ISUM                                                  ***
C                                                                       MAN1130
C     ---PASS INITIAL ADDRESSES OF ARRAYS TO SUBROUTINES---             MAN1140
      CALL DATAI(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7))MAN1150
     1,Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(23)),Y(L(MAN1160
     224)),Y(L(25)))                                                    MAN1170
      CALL STEP(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),MAN1180
     1Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(18)),Y(L(2MAN1190
     20)))                                                              MAN1200
      CALL SOLVE(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7))MAN1210
     1,Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(10)),Y(L(MAN1220
     211)),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(20)),Y(L(25)),Y(LRCG),Y(LRCL),  ***
     3Y(LRHSS),Y(LHB))                                                   ***
      CALL COEF(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),MAN1240
     1Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(23)),Y(L(2MAN1250
     24)),Y(L(25)),Y(LZNS),Y(LKXU),Y(LKYU),Y(LKZU),Y(LBZU),              ***
     3 Y(LSZU),Y(LKXL),Y(LKYL),Y(LKZL),Y(LBZL),Y(LSZL),Y(LPMULT),         ***
     4NZNS)                                                              ***
      CALL CHECKI(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)MAN1270
     1),Y(L(8)),Y(L(9)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(19)),Y(L(21)),Y(LMAN1280
     2(22)),Y(L(25)),Y(LRCG),Y(LRCL),Y(LRHSS),Y(LHB),                    ***
     3Y(LZNS),NZNS)                                                      ***
      CALL PRNTAI(Y(L(1)),Y(L(2)),Y(L(4)),Y(L(5)),Y(L(9)),Y(L(15)),Y(L(1MAN1300
     16)))                                                              MAN1310
C                                                                       MAN1320
C     ---START COMPUTATIONS---                                          MAN1330
C     ************************                                          MAN1340
C     ---READ AND WRITE DATA FOR GROUPS II AND III---                   MAN1350
      CALL DATAIN                                                       MAN1360
      IRN=1                                                             MAN1370
      NIJ=IO*JO                                                         MAN1380
      DO 80 K=1,KO                                                      MAN1390
      LOC=L(2)+(K-1)*NIJ                                                MAN1400
   80 CALL ARRAY(Y(LOC),INFT(1,2),IOFT(1,1),NAME(1),IRN,DUM)            MAN1410
      DO 90 K=1,KO                                                      MAN1420
      LOC=L(5)+(K-1)*NIJ                                                MAN1430
   90 CALL ARRAY(Y(LOC),INFT(1,1),IOFT(1,2),NAME(7),IRN,DUM)            MAN1440
      K=KO                                                              MAN1595
  120 IF (IWATER.NE.ICHK(6)) GO TO 130                                  MAN1590
      CALL ARRAY(Y(L(23)),INFT(1,4),IOFT(1,5),NAME(25),IRN,DUM)          ***
      CALL ARRAY(Y(L(24)),INFT(1,1),IOFT(1,1),NAME(31),IRN,DUM)         MAN1610
  130 IF(IQRE.EQ.ICHK(7)) CALL ARRAY(Y(L(25)),INFT(1,1),IOFT(1,4),NAME(3MAN1620
     17),IRN,DUM)                                                       MAN1630
C                                                                        ***
C     HEAD DEPENDENT STREAM OPTION ADDITIONS.                            ***
C                                                                        ***
      DO 134 K=1,KO                                                      ***
      LOC=LRCG+(K-1)*NIJ                                                 ***
  134 CALL ARRAY(Y(LOC),INFT(1,3),IOFT(1,4),24H  R  GAINING COEFFICIENT, ***
     1IRN,DUM)                                                           ***
```

```
      DO 135 K=1,KO
      LOC=LRCL+(K-1)*NIJ
  135 CALL ARRAY(Y(LOC),INFT(1,3),IOFT(1,4),24H  R   LOSING COEFFICIENT,
     1IRN,DUM)
      DO 136 K=1,KO
      LOC=LRHSS+(K-1)*NIJ
  136 CALL ARRAY(Y(LOC),INFT(1,1),IOFT(1,1),24H            FIXED R HEAD,
     1IRN,DUM)
      DO 137 K=1,KO
      LOC=LHB+(K-1)*NIJ
  137 CALL ARRAY(Y(LOC),INFT(1,1),IOFT(1,1),24H  R  LEAKAGE CUTOFF HEAD,
     1IRN,DUM)
C
C     INPUT OF MODEL PARAMETERS BY HYDROGEOLOGIC UNIT.
C
      CALL INPUT
      CALL MDAT
C
C     ---COMPUTE TRANSMISSIVITY FOR UNCONFINED LAYER---
      IF (IWATER.EQ.ICHK(6)) CALL TRANS(1)
C
C     ---COMPUTE T COEFFICIENTS---
      CALL TCOF
C
C     ---COMPUTE ITERATION PARAMETERS---
      CALL ITER
C
C     ---READ TIME PARAMETERS AND PUMPING DATA FOR A NEW PUMPING PERIOD-
  140 CALL NEWPER
C
      KT=0
      IFINAL=0
C
C     ---START NEW TIME STEP COMPUTATIONS---
  150 CALL NEWSTP
C
C     ---START NEW ITERATION IF MAXIMUM NO. ITERATIONS NOT EXCEEDED---
      CALL NEWITA
C
C     ---PRINT OUTPUT AT DESIGNATED TIME STEPS---
      CALL OUTPUT
C
C     ---LAST TIME STEP IN PUMPING PERIOD ?---
      IF (IFINAL.NE.1) GO TO 150
C
C     ---CHECK FOR NEW PUMPING PERIOD---
      IF (KP.LT.NPER) GO TO 140
C
      STOP
C
C     ---FORMATS---
C
C
C
  160 FORMAT(6I10,3I5)
```

```
 165 FORMAT(10I5)                                                                ***
 170 FORMAT ('0',54X,'WORDS OF VECTOR Y USED =',I7)                          MAN2030
 180 FORMAT ('0',62X,'NUMBER OF ROWS =',I5/60X,'NUMBER OF COLUMNS =',I5MAN2040
    1/61X,'NUMBER OF LAYERS =',I5//39X,'MAXIMUM PERMITTED NUMBER OF ITEMAN2050
    2RATIONS =',I5//48X,'NUMBER OF CONSTANT HEAD NODES =',I5,                ***
    3 //,54X,'NUMBER OF AQUIFER ZONES =',I5//76X,'IR =',                      ***
    4I1,//76X,'ISTAT =',I1//76X,'MLTCHK=',I1//76X,'ISBOUT=',I1//76X,'IJ  ***
    5KMAP=',I1//76X,'IVHMAP=',I1//76X,'IZTOZ=',I1//76X,'ITABLE=',I1//76  ***
    6X,'LAYDDN=',I1//76X,'ISLEAK=',I1,//,76X,'IOCTAP=',I1//76X,          ***
    7'IWLWD=',I1//76X,'IPPOUT=',I1)                                          ***
 190 FORMAT ('1',33A4)                                                     MAN2070
 200 FORMAT (20A4)                                                         MAN2080
 210 FORMAT (16(A4,1X))                                                    MAN2090
 220 FORMAT ('-SIMULATION OPTIONS:  ',11(A4,4X))                           MAN2100
 230 FORMAT (1H0,44X,'DIRECTIONAL TRANSMISSIVITY MULTIPLICATION FACTORSMAN2110
    1 FOR LAYER',I3,/,76X,'X =',G15.7/76X,'Y =',G15.7/76X,'Z =',G15.7) MAN2120
     END                                                                   MAN2130

     SUBROUTINE DATAI(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FACDAT0010
    1T,PERM,BOTTOM,QRE)                                                    DAT0020
C    ------------------------------------------------------------------DAT0030
C    READ AND WRITE DATA                                                   DAT0040
C    ------------------------------------------------------------------DAT0050
C                                                                          DAT0060
C    SPECIFICATIONS:                                                       DAT0070
     REAL *8PHI                                                            DAT0080
     REAL *8XLABEL,YLABEL,TITLE,XN1,MESUR                                  DAT0090
C                                                                          DAT0100
     DIMENSION NAME(42)                                                      ***
     DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), OLD(I0,J0,K0), T(I0,J0,K0DAT0110
    1), S(I0,J0,K0), TR(I0,J0,K0), TC(I0,J0,K0), TK(IK,JK,K5), WELL(I0,DAT0120
    2J0,K0), DELX(J0), DELY(I0), DELZ(K0), FACT(K0,3), PERM(IP,JP), BOTDAT0130
    3TOM(IP,JP), QRE(IQ,JQ), TF(3), A(I0,J0), IN(6), IOFT(9), INFT(2)  DAT0140
C                                                                          DAT0150
     COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,NDAT0160
    1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NCDAT0170
    2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK,IEQN,KK  ***
    3K,KKKK,IR,ISTAT,MLTCHK,ISBOUT,IJKMAP,IVHMAP,IZTOZ,ITABLE,               ***
    4LAYDDN,ISLEAK,IOCTAP,IWLWD,IPPOUT                                       ***
     COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR                   DAT0190
     COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)                          DAT0200
     COMMON /CK/ ETFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT  DAT0210
     COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(6),XN1,MESUR,PRNT(122),BLANKDAT0220
    1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100),DAT0230
    2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2                              DAT0240
     DATA NAME/2*4H    ,4H   S,4HTART,4HING ,4HHEAD,4H    ,4H STO,4HRAG  ***
    1E,4H COE,4HFFIC,4HIENT,2*4H    ,4H  TR,4HANSM,4HISSI,4HVITY,5*4H    ***
    2    ,4H  TK,4H   T,4HOPOG,4HRAPH,4HIC S,4HETTI,4HNG  ,2*4H    ,4HBOT  ***
    3T,4HOM E,4HLEVA,4HTION,2*4H    ,4H   R,4HECHA,4HRGE ,4HRATE/        ***
     RETURN                                                                DAT0250
C    ..................................................................DAT0260
C    ********************                                                  DAT0270
     ENTRY DATAIN                                                          DAT0280
C    ********************                                                  DAT0290
C                                                                          DAT0300
```

```
C     ---READ AND WRITE SCALAR PARAMETERS---                            DAT0310
      READ (5,330) NPER,KTH,ERR,LENGTH                                  DAT0320
      WRITE (6,340) NPER,KTH,ERR                                        DAT0330
      READ (5,460) XSCALE,YSCALE,DINCH,FACT1,(LEVEL1(I),I=1,9),FACT2,(LEDAT0340
     1VEL2(I),I=1,9),MESUR                                              DAT0350
      IF (XSCALE.NE.0.) WRITE (6,470) XSCALE,YSCALE,MESUR,MESUR,DINCH,FADAT0360
     1CT1,LEVEL1,FACT2,LEVEL2                                           DAT0370
C                                                                       DAT0380
C     ---READ CUMULATIVE MASS BALANCE PARAMETERS---                     DAT0390
      READ (5,450) SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFLDAT0400
     1XT,FLXNT                                                          DAT0410
      IF (IDK1.EQ.ICHK(4)) GO TO 20                                     DAT0420
      IF (IPU1.NE.ICHK(8)) GO TO 50                                     DAT0430
C                                                                       DAT0440
C     ---READ INITIAL HEAD VALUES FROM CARDS---                         DAT0450
      DO 10 K=1,KO                                                      DAT0460
      DO 10 I=1,IO                                                      DAT0470
   10 READ (5,360) (PHI(I,J,K),J=1,JO)                                  DAT0480
      GO TO 30                                                          DAT0490
C                                                                       DAT0500
C     ---READ INITIAL HEAD AND MASS BALANCE PARAMETERS FROM DISK---     DAT0510
   20 READ (4) PHI,SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFLDAT0520
     1XT,FLXNT                                                          DAT0530
      REWIND 4                                                          DAT0540
   30 WRITE (6,430) SUM                                                 DAT0550
      DO 40 K=1,KO                                                      DAT0560
      WRITE (6,440) K                                                   DAT0570
      DO 40 I=1,IO                                                      DAT0580
   40 WRITE (6,350) I,(PHI(I,J,K),J=1,JO)                               DAT0590
C                                                                       DAT0600
   50 DO 60 K=1,KO                                                      DAT0610
      DO 60 I=1,IO                                                      DAT0620
      DO 60 J=1,JO                                                      DAT0630
      WELL(I,J,K)=0.                                                    DAT0640
      TR(I,J,K)=0.                                                      DAT0650
      TC(I,J,K)=0.                                                      DAT0660
      IF (K.NE.KO) TK(I,J,K)=0.                                         DAT0670
   60 CONTINUE                                                          DAT0680
      RETURN                                                            DAT0690
C     *********************                                             DAT0700
      ENTRY ARRAY(A,INFT,IOFT,IN,IRN,TF)                                DAT0710
C     *********************                                             DAT0720
      READ (5,330) FAC,IVAR,IPRN,TF,IRECS,IRECD                         DAT0730
      IC=4*IRECS+2*IVAR+IPRN+1                                          DAT0740
      GO TO (70,70,90,90,120,120), IC                                   DAT0750
   70 DO 80 I=1,IO                                                      DAT0760
      DO 80 J=1,JO                                                      DAT0770
   80 A(I,J)=FAC                                                        DAT0780
      IF(IN(2).EQ.NAME(8).OR.IN(1).EQ.NAME(25)) GO TO 140                 ***
      WRITE (6,280) IN,FAC,K                                            DAT0790
      GO TO 140                                                         DAT0800
   90 IF (IC.EQ.3) WRITE (6,290) IN,K                                   DAT0810
      DO 110 I=1,IO                                                     DAT0820
      READ (5,INFT) (A(I,J),J=1,JO)                                     DAT0830
      DO 100 J=1,JO                                                     DAT0840
```

```
  100 A(I,J)=A(I,J)*FAC
  110 IF (IC.EQ.3) WRITE (6,IOFT) I,(A(I,J),J=1,J0)
      GO TO 140
  120 READ (2'IRN) A
      IF (IC.EQ.6) GO TO 140
      WRITE (6,290) IN,K
      DO 130 I=1,I0
  130 WRITE (6,IOFT) I,(A(I,J),J=1,J0)
  140 IF (IRECD.EQ.1) WRITE (2'IRN) A
      IRN=IRN+1
      RETURN
C     *********************
      ENTRY MDAT
C     *********************
      DO 150 K=1,K0
      DO 150 I=1,I0
      DO 150 J=1,J0
      IF (I.EQ.1.OR.I.EQ.I0.OR.J.EQ.1.OR.J.EQ.J0) T(I,J,K)=0.
      IF (IDK1.NE.ICHK(4).AND.IPU1.NE.ICHK(8)) PHI(I,J,K)=STRT(I,J,K)
      IF (K.NE.K0.OR.IWATER.NE.ICHK(6)) GO TO 150
      IF (I.EQ.1.OR.I.EQ.I0.OR.J.EQ.1.OR.J.EQ.J0) PERM(I,J)=0.
  150 CONTINUE
C     ............................. DELX .............................
      READ (5,330) FAC,IVAR,IPRN
      IF (IVAR.EQ.1) READ (5,330) (DELX(J),J=1,J0)
      DO 170 J=1,J0
      IF (IVAR.NE.1) GO TO 160
      DELX(J)=DELX(J)*FAC
      GO TO 170
  160 DELX(J)=FAC
  170 CONTINUE
      IF (IVAR.EQ.1.AND.IPRN.NE.1) WRITE (6,370) (DELX(J),J=1,J0)
      IF (IVAR.EQ.0) WRITE (6,300) FAC
C     ............................. DELY .............................
      READ (5,330) FAC,IVAR,IPRN
      IF (IVAR.EQ.1) READ (5,330) (DELY(I),I=1,I0)
      DO 190 I=1,I0
      IF (IVAR.NE.1) GO TO 180
      DELY(I)=DELY(I)*FAC
      GO TO 190
  180 DELY(I)=FAC
  190 CONTINUE
      IF (IVAR.EQ.1.AND.IPRN.NE.1) WRITE (6,380) (DELY(I),I=1,I0)
      IF (IVAR.EQ.0) WRITE (6,310) FAC
C     ............................. DELZ .............................
      READ (5,330) FAC,IVAR,IPRN
      IF (IVAR.EQ.1) READ (5,330) (DELZ(K),K=1,K0)
      DO 210 K=1,K0
      IF (IVAR.NE.1) GO TO 200
      DELZ(K)=DELZ(K)*FAC
      GO TO 210
  200 DELZ(K)=FAC
  210 CONTINUE
      IF (IVAR.EQ.1.AND.IPRN.NE.1) WRITE (6,390) (DELZ(K),K=1,K0)
      IF (IVAR.EQ.0) WRITE (6,320) FAC
```

```
C                                                                       DAT1400
C      ---INITIALIZE VARIABLES---                                       DAT1410
       B=0.                                                             DAT1420
       D=0.                                                             DAT1430
       F=0.                                                             DAT1440
       H=0.                                                             DAT1450
       SU=0.                                                            DAT1460
       Z=0.                                                             DAT1470
       IF (XSCALE.NE.0.) CALL MAP                                       DAT1480
       RETURN                                                           DAT1490
C      .................................................................DAT1500
C      ---READ TIME PARAMETERS AND PUMPING DATA FOR A NEW PUMPING PERIOD-DAT1510
C      *********************                                            DAT1520
       ENTRY NEWPER                                                     DAT1530
C      *********************                                            DAT1540
C                                                                       DAT1550
       READ (5,330) KP,KPM1,NWEL,TMAX,NUMT,CDLT,DELT                    DAT1560
C                                                                       DAT1570
C      ---COMPUTE ACTUAL DELT AND NUMT---                               DAT1580
       TM=0.0                                                           DAT1600
       DO 220 I=1,NUMT                                                  DAT1610
       DT=CDLT*DT                                                       DAT1620
       TM=TM+DT                                                         DAT1630
       IF (TM.GE.TMAX) GO TO 230                                        DAT1640
   220 CONTINUE                                                         DAT1650
       GO TO 240                                                        DAT1660
   230 DELT=TMAX/TM*DELT                                                DAT1670
       NUMT=I                                                           DAT1680
   240 WRITE (6,400) KP,TMAX,NUMT,DELT,CDLT                             DAT1690
       DELT=DELT*3600.                                                  DAT1700
       TMAX=TMAX*86400.                                                 DAT1710
       SUMP=0.0                                                         DAT1720
C                                                                       DAT1730
C      ---READ AND WRITE WELL PUMPING RATES---                          DAT1740
       IF(KP.GT.1) GO TO 265                                              ***
       WRITE (6,410) NWEL                                               DAT1750
       IF (NWEL.EQ.0) GO TO 265                                         DAT1760
       DO 245 K=1,KO                                                    DAT1761
       DO 245 I=1,IO                                                    DAT1762
       DO 245 J=1,JO                                                    DAT1763
   245 WELL(I,J,K)=0.0                                                  DAT1764
       DO 250 II=1,NWEL                                                 DAT1770
       READ (5,330) K,I,J,WELL(I,J,K)                                   DAT1780
       WRITE (6,420) K,I,J,WELL(I,J,K)                                  DAT1790
   250 WELL(I,J,K)=WELL(I,J,K)/(DELX(J)*DELY(I))                        DAT1800
C                                                                         ***
C      OPTION TO READ IN NEW RECHARGE RATE FOR EACH PUMPING PERIOD.       ***
C                                                                         ***
   265 IF(KP.EQ.1)  RETURN                                                ***
       PARAM=0.                                                           ***
       DO 270 I=1,IO                                                      ***
       DO 270 J=1,JO                                                      ***
   270 QRE(I,J)=0.                                                        ***
       READ(5,276) PARAM                                                  ***
       DO 272 I=1,IO                                                      ***
```

```
  272 READ(5,278) (QRE(I,J),J=1,J0)
      DO 274 I=1,I0
      DO 274 J=1,J0
  274 QRE(I,J)=QRE(I,J)*PARAM
      RETURN
C
C     ---FORMATS---
C
C
C
  276 FORMAT(E10.3)
  278 FORMAT(20F4.0)
  280 FORMAT (1H0,52X,6A4,' =',G15.7,' FOR LAYER',I3)
  290 FORMAT (1H1,45X,6A4,' MATRIX, LAYER',I3/46X,41('-'))
  300 FORMAT('1',72X,'DELX =',G15.7)
  310 FORMAT ('0',72X,'DELY =',G15.7)
  320 FORMAT ('0',72X,'DELZ =',G15.7)
  330 FORMAT (8G10.0)
  340 FORMAT ('0',51X,'NUMBER OF PUMPING PERIODS =',I5/49X,'TIME STEPS B
     1ETWEEN PRINTOUTS =',I5//51X,'ERROR CRITERIA FOR CLOSURE =',G15.7/)
  350 FORMAT ('0',I2,2X,20F6.1/(5X,20F6.1))
  360 FORMAT (8F10.4)
  370 FORMAT (1H1,46X,40HGRID SPACING IN PROTOTYPE IN X DIRECTION/47X,40
     1('-')//('0',12F10.0))
  380 FORMAT (1H-,46X,40HGRID SPACING IN PROTOTYPE IN Y DIRECTION/47X,40
     1('-')//('0',12F10.0))
  390 FORMAT (1H-,46X,40HGRID SPACING IN PROTOTYPE IN Z DIRECTION/47X,40
     1('-')//('0',12F10.0))
  400 FORMAT ('-',50X,'PUMPING PERIOD NO.',I4,':',F10.2,' DAYS'/51X,38('
     1-')//53X,'NUMBER OF TIME STEPS=',I6//59X,'DELT IN HOURS =',F10.3//
     253X,'MULTIPLIER FOR DELT =',F10.3)
  410 FORMAT ('-',63X,I4,' WELLS'/65X,9('-')//50X,'K',9X,'I',9X,'J    PU
     1MPING RATE'/)
  420 FORMAT (41X,3I10,2F13.2)
  430 FORMAT ('-',40X,' CONTINUATION - HEAD AFTER ',G20.7,' SEC PUMPING
     1'/42X,58('-'))
  440 FORMAT ('1',55X,'INITIAL  HEAD MATRIX, LAYER',I3/56X,30('-'))
  450 FORMAT (4G20.10)
  460 FORMAT (3G10.0,2(G10.0,9I1,1X),A8)
  470 FORMAT ('0',30X,'ON ALPHAMERIC MAP:'/40X,'MULTIPLICATION FACTOR FO
     1R X DIMENSION =',G15.7/40X,'MULTIPLICATION FACTOR FOR Y DIMENSION
     2=',G15.7/55X,'MAP SCALE IN UNITS OF  ',A11/50X,'NUMBER OF ',A8,' P
     3ER INCH =',G15.7/43X,'MULTIPLICATION FACTOR FOR DRAWDOWN =',G15.7,
     4' PRINTED FOR LAYERS',9I2/47X,'MULTIPLICATION FACTOR FOR HEAD =',G
     515.7,' PRINTED FOR LAYERS',9I2)
      END

      SUBROUTINE STEP(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FACT
     1,DDN,TEST3)
C     ------------------------------------------------------------------
C     INITIALIZE DATA FOR A NEW TIME STEP AND PRINT RESULTS
C     ------------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8PHI
```

```
      REAL *8XLABEL,YLABEL,TITLE,XN1,MESUR
C
      DIMENSION PHI(IO,JO,KO), STRT(IO,JO,KO), OLD(IO,JO,KO), T(IO,JO,KO
     1), S(IO,JO,KO), TR(IO,JO,KO), TC(IO,JO,KO), TK(IK,JK,K5), WELL(IO,
     2JO,KO), DELX(JO), DELY(IO), DELZ(KO), FACT(KO,3), DDN(IMAX), TEST3
     3(ITMX1), ITTO(50)
      DIMENSION IIDDN(84,98,2)
C
      COMMON /INTEGR/ IO,JO,KO,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK,IEQN,KK
     3K,KKKK,IR,ISTAT,MLTCHK,ISBOUT,IJKMAP,IVHMAP,IZTOZ,ITABLE,
     4LAYDDN,ISLEAK,IOCTAP,IWLWD,IPPOUT
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      COMMON /CK/ ETFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(6),XN1,MESUR,PRNT(122),BLANK
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100),
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2
      RETURN
C     ..................................................................
C     ********************
      ENTRY NEWSTP
C     ********************
      KT=KT+1
      IT=0
      DO 10 K=1,KO
      DO 10 I=1,IO
      DO 10 J=1,JO
   10 OLD(I,J,K)=PHI(I,J,K)
      DELT=CDLT*DELT
      SUM=SUM+DELT
      SUMP=SUMP+DELT
      DAYSP=SUMP/86400.
      YRSP=DAYSP/365.
      HRS=SUM/3600.
      SMIN=HRS*60.
      DAYS=HRS/24.
      YRS=DAYS/365.
      RETURN
C
C     ---PRINT OUTPUT AT DESIGNATED TIME STEPS---
C     *********************
      ENTRY OUTPUT
C     *********************
C
C     OPTION FOR MAPS OF DRAWDOWN AND VERTICAL
C     HEAD DIFFERENCE BETWEEN LAYERS.
C
      DO 15 K=1,2
      DO 15 I=1,84
      DO 15 J=1,98
   15 IIDDN(I,J,K)=0
      IF (KT.EQ.NUMT) IFINAL=1
      ITTO(KT)=IT
```

```
      IF (IT.LE.ITMAX) GO TO 20
      IT=IT-1
      ITTO(KT)=IT
      IERR=2
C
C     ---IF MAXIMUM ITERATIONS EXCEEDED,WRITE RESULTS ON DISK OR CARDS--
      IF (IDK2.EQ.ICHK(5)) WRITE (4) PHI,SUM,SUMP,PUMPT,CFLUXT,QRET,CHST
     1,CHDT,FLUXT,STORT,ETFLXT,FLXNT
      IF (IPU2.EQ.ICHK(9)) WRITE (7,230) SUM,SUMP,PUMPT,CFLUXT,QRET,CHST
     1,CHDT,FLUXT,STORT,ETFLXT,FLXNT
C
   20 IF (IFLO.EQ.ICHK(3)) CALL CHECK
      IF (IERR.EQ.2) GO TO 30
      IF (MOD(KT,KTH).NE.0.AND.IFINAL.NE.1) RETURN
   30 WRITE (6,210) KT,DELT,SUM,SMIN,HRS,DAYS,YRS,DAYSP,YRSP
      IF (IFLO.EQ.ICHK(3)) CALL CWRITE
      IT=IT+1
      WRITE (6,180) (TEST3(J),J=1,IT)
      I3=1
      I5=0
  352 I5=I5+40
      I4=MINO(KT,I5)
      WRITE (6,240) (I,I=I3,I4)
      WRITE (6,260)
      WRITE (6,250) (ITTO(I),I=I3,I4)
      WRITE (6,260)
      IF(KT.LE.I5) GO TO 353
      I3=I3+40
      GO TO 352
C
C     ---PRINT MAPS---
  353 IF (XSCALE.EQ.0.) GO TO 70
      IF (FACT1.EQ.0.) GO TO 50
      DO 40 IA=1,9
      II=LEVEL1(IA)
      IF (II.EQ.0) GO TO 50
   40 CALL PRNTA(1,II)
   50 IF (FACT2.EQ.0.) GO TO 70
      DO 60 IA=1,9
      II=LEVEL2(IA)
      IF (II.EQ.0) GO TO 70
   60 CALL PRNTA(2,II)
   70 IF (IDRAW.NE.ICHK(1)) GO TO 100
C
C     ---PRINT DRAWDOWN---
      DO 90 K=1,KO
      WRITE (6,200) K
      DO 90 I=1,IO
      DO 80 J=1,JO
   80 DDN(J)=STRT(I,J,K)-PHI(I,J,K)
   90 WRITE (6,170) I,(DDN(J),J=1,JO)
  100 IF (IHEAD.NE.ICHK(2)) GO TO 111
C
C     ---PRINT HEAD MATRIX---
      DO 110 K=1,KO
```

```
      WRITE (6,190) K
      DO 110 I=1,I0
  110 WRITE (6,170) I,(PHI(I,J,K),J=1,J0)
C
C     OPTION FOR MAPS OF DRAWDOWN AND VERTICAL
C     HEAD DIFFERENCE BETWEEN LAYERS.
C
  111 IF(IFINAL.NE.1) GO TO 120
      IF(IJKMAP.NE.1) GO TO 108
      MAPS=1
  109 DO 112 K=1,2
      DO 112 I=1,84
      DO 112 J=1,98
      IF(MAPS.EQ.1) WWW=STRT(I,J,K)-PHI(I,J,K)
      IF(MAPS.EQ.2) WWW=PHI(I,J,2)-PHI(I,J,1)
  112 IIDDN(I,J,K)=WWW
      DO 126 L=1,2
      IF(L.EQ.1.AND.MAPS.EQ.2) GO TO 126
      IF(MAPS.EQ.2) GO TO 107
      WRITE(6,600) L
      GO TO 106
  107 WRITE(6,650)
  106 WRITE(6,1000)
      DO 113 I=3,29
  113 WRITE(6,900) I,(IIDDN(I,J,L),J=3,26)
      WRITE(6,1100)
      DO 114 I=3,29
  114 WRITE(6,900) I,(IIDDN(I,J,L),J=27,50)
      WRITE(6,1200)
      DO 115 I=3,29
  115 WRITE(6,900) I,(IIDDN(I,J,L),J=51,74)
      WRITE(6,1300)
      DO 116 I=3,29
  116 WRITE(6,800) (IIDDN(I,J,L),J=75,96),I
      WRITE(6,1000)
      DO 117 I=30,56
  117 WRITE(6,900) I,(IIDDN(I,J,L),J=3,26)
      WRITE(6,1100)
      DO 118 I=30,56
  118 WRITE(6,900) I,(IIDDN(I,J,L),J=27,50)
      WRITE(6,1200)
      DO 119 I=30,56
  119 WRITE(6,900) I,(IIDDN(I,J,L),J=51,74)
      WRITE(6,1300)
      DO 121 I=30,56
  121 WRITE(6,800) (IIDDN(I,J,L),J=75,96),I
      WRITE(6,700)
      DO 122 I=57,82
  122 WRITE(6,900) I,(IIDDN(I,J,L),J=3,26)
      WRITE(6,1400)
      WRITE(6,700)
      DO 123 I=57,82
  123 WRITE(6,900) I,(IIDDN(I,J,L),J=27,50)
      WRITE(6,1500)
      WRITE(6,700)
```

```
      DO 124 I=57,82                                                      ***
  124 WRITE(6,900) I,(IIDDN(I,J,L),J=51,74)                               ***
      WRITE(6,1600)                                                       ***
      WRITE(6,700)                                                        ***
      DO 125 I=57,82                                                      ***
  125 WRITE(6,800) (IIDDN(I,J,L),J=75,96),I                               ***
      WRITE(6,1700)                                                       ***
  126 CONTINUE                                                            ***
      IF(MAPS.EQ.2) GO TO 120                                             ***
  108 IF(IVHMAP.NE.1) GO TO 120                                           ***
      MAPS=2                                                              ***
      GO TO 109                                                           ***
C                                                                       STP1040
C     ---WRITE ON DISK---                                               STP1050
  120 IF (IERR.EQ.2) GO TO 130                                          STP1060
      IF (KP.LT.NPER.OR.IFINAL.NE.1) RETURN                             STP1070
      IF (IDK2.EQ.ICHK(5)) WRITE (4) PHI,SUM,SUMP,PUMPT,CFLUXT,QRET,CHSTSTP1080
     1,CHDT,FLUXT,STORT,ETFLXT,FLXNT                                    STP1090
C                                                                       STP1100
C     ---PUNCHED OUTPUT---                                              STP1110
  130 IF (IPU2.NE.ICHK(9)) GO TO 160                                    STP1120
      IF (IERR.EQ.2) GO TO 140                                          STP1130
      WRITE (7,230) SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFSTP1140
     1LXT,FLXNT                                                         STP1150
  140 DO 150 K=1,KO                                                     STP1160
      DO 150 I=1,IO                                                     STP1165
  150 WRITE (7,220)  (PHI(I,J,K),J=1,JO)                                STP1170
  160 IF (IERR.EQ.2) STOP                                               STP1180
      RETURN                                                            STP1190
C                                                                       STP1200
C     ---FORMATS---                                                     STP1210
C                                                                       STP1220
C                                                                       STP1230
C                                                                       STP1240
  170 FORMAT ('0',I4,18F7.2/(5X,18F7.2))                                STP1250
  180 FORMAT ('1MAXIMUM HEAD CHANGE FOR EACH ITERATION:'/' ',39('-')/('0STP1260
     1',10F12.4))                                                       STP1270
  190 FORMAT ('1',55X,'HEAD MATRIX, LAYER',I3/56X,21('-'))              STP1280
  200 FORMAT ('1',55X,'   DRAWDOWN, LAYER',I3/59X,18('-'))              STP1290
  210 FORMAT (1H1,44X,57('-')/45X,'¢',14X,'TIME STEP NUMBER =',I9,14X,'¢STP1300
     1'/45X,57('-')//50X,29HSIZE OF TIME STEP IN SECONDS=,F14.2//55X,'TOSTP1310
     2TAL SIMULATION TIME IN SECONDS=',F14.2/80X,8HMINUTES=,F14.2/82X,6HSTP1320
     3HOURS=,F14.2/83X,5HDAYS=,F14.2/82X,'YEARS=',F14.2///45X,'DURATION STP1330
     4OF CURRENT PUMPING PERIOD IN DAYS=',F14.2/82X,'YEARS=',F14.2//)   STP1340
  220 FORMAT (10F8.4)                                                   STP1350
  230 FORMAT (4G20.10)                                                  STP1360
  240 FORMAT ('0TIME STEP :',40I3)                                      STP1370
  250 FORMAT ('0ITERATIONS:',40I3)                                      STP1380
  260 FORMAT (' ',10('-'))                                              STP1390
  600 FORMAT('1',10X,'LAYER  ',I1,'  DRAWDOWN MAP')                       ***
  650 FORMAT('1',10X,'MAP OF VERTICAL HEAD DIFFERENCE BETWEEN LAYERS')    ***
  700 FORMAT('1')                                                         ***
  800 FORMAT('0',24(1X,I4),2X,I2)                                         ***
  900 FORMAT('0',2X,I2,1X,24(1X,I4))                                      ***
 1000 FORMAT('1',9X,'3',4X,'4',4X,'5',4X,'6',4X,'7',4X,'8',4X,'9',3X,'10  ***
```

```
     1',3X,'11',3X,'12',3X,'13',3X,'14',3X,'15',3X,'16',3X,'17',3X,'18',
     23X,'19',3X,'20',3X,'21',3X,'22',3X,'23',3X,'24',3X,'25',3X,'26')
 1100 FORMAT('1',8X,'27',3X,'28',3X,'29',3X,'30',3X,'31',3X,'32',3X,'33'
     1,3X,'34',3X,'35',3X,'36',3X,'37',3X,'38',3X,'39',3X,'40',3X,'41',3
     2X,'42',3X,'43',3X,'44',3X,'45',3X,'46',3X,'47',3X,'48',3X,'49',3X,
     3'50')
 1200 FORMAT('1',8X,'51',3X,'52',3X,'53',3X,'54',3X,'55',3X,'56',3X,'57'
     1,3X,'58',3X,'59',3X,'60',3X,'61',3X,'62',3X,'63',3X,'64',3X,'65',3
     2X,'66',3X,'67',3X,'68',3X,'69',3X,'70',3X,'71',3X,'72',3X,'73',3X,
     3'74')
 1300 FORMAT('1',3X,'75',3X,'76',3X,'77',3X,'78',3X,'79',3X,'80',3X,'81'
     1,3X,'82',3X,'83',3X,'84',3X,'85',3X,'86',3X,'87',3X,'88',3X,'89',3
     2X,'90',3X,'91',3X,'92',3X,'93',3X,'94',3X,'95',3X,'96')
 1400 FORMAT('0',9X,'3',4X,'4',4X,'5',4X,'6',4X,'7',4X,'8',4X,'9',3X,'10
     1',3X,'11',3X,'12',3X,'13',3X,'14',3X,'15',3X,'16',3X,'17',3X,'18',
     23X,'19',3X,'20',3X,'21',3X,'22',3X,'23',3X,'24',3X,'25',3X,'26')
 1500 FORMAT('0',8X,'27',3X,'28',3X,'29',3X,'30',3X,'31',3X,'32',3X,'33'
     1,3X,'34',3X,'35',3X,'36',3X,'37',3X,'38',3X,'39',3X,'40',3X,'41',3
     2X,'42',3X,'43',3X,'44',3X,'45',3X,'46',3X,'47',3X,'48',3X,'49',3X,
     3'50')
 1600 FORMAT('0',8X,'51',3X,'52',3X,'53',3X,'54',3X,'55',3X,'56',3X,'57'
     1,3X,'58',3X,'59',3X,'60',3X,'61',3X,'62',3X,'63',3X,'64',3X,'65',3
     2X,'66',3X,'67',3X,'68',3X,'69',3X,'70',3X,'71',3X,'72',3X,'73',3X,
     3'74')
 1700 FORMAT('0',3X,'75',3X,'76',3X,'77',3X,'78',3X,'79',3X,'80',3X,'81'
     1,3X,'82',3X,'83',3X,'84',3X,'85',3X,'86',3X,'87',3X,'88',3X,'89',3
     2X,'90',3X,'91',3X,'92',3X,'93',3X,'94',3X,'95',3X,'96')
      END

      SUBROUTINE SOLVE(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FAC
     1T,EL,FL,GL,V,XI,TEST3,QRE,RCG,RCL,RHSS,HB)
C     -----------------------------------------------------------------
C     SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
C     -----------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8PHI,RHO,B,D,F,H,Z,SU,RHOP,W,WMIN,RHO1,RHO2,RHO3,XPART,YPART
     1,ZPART,DMIN1,WMAX,XT,YT,ZT,DABS,DMAX1,DEN,TXM,TYM,TZM
      REAL *8E,AL,BL,CL,A,C,G,WU,TU,U,DL,RES,SUPH,GLXI,ZPHI
C
      DIMENSION PHI(1), STRT(1), OLD(1), T(1), S(1), TR(1), TC(1), TK(1)
     1, WELL(1), DELX(1), DELY(1), DELZ(1), FACT(KO,3), RHOP(20), TEST3(
     21),EL(1),FL(1),GL(1),V(1),XI(1),QRE(1),RCG(1),RCL(1),RHSS(1),HB(1)
C
      COMMON /INTEGR/ IO,JO,KO,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK,IEQN,KK
     3K,KKKK,IR,ISTAT,MLTCHK,ISBOUT,IJKMAP,IVHMAP,IZTOZ,ITABLE,
     4LAYDDN,ISLEAK,IOCTAP,IWLWD,IPPOUT
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      RETURN
C     .................................................................
C     *********************
      ENTRY ITER
```

```
C     *********************
C     ---COMPUTE AND PRINT ITERATION PARAMETERS---
      WRITE (6,240)
      WMIN=1.D0
      DELT=1.
      P2=LENGTH-1
      NIJ=I0*J0
      NT=I0*J0*K0
      XT=3.141593**2/(2.*J2*J2)
      YT=3.141593**2/(2.*I2*I2)
      ZT=3.141593**2/(2.*K0*K0)
      RHO1=0.D0
      RHO2=0.D0
      RHO3=0.D0
      DO 40 K=1,K0
      DO 40 I=2,I1
      DO 40 J=2,J1
      N=I+(J-1)*I0+(K-1)*NIJ
      IF(T(N).EQ.0.) GO TO 40
      D=TR(N-I0)/DELX(J)
      F=TR(N)/DELX(J)
      B=TC(N-1)/DELY(I)
      H=TC(N)/DELY(I)
      SU=0.D0
      Z=0.D0
C
C     CORRECTION IN MANNER OF ITERATION PARAMETER COMPUTATION.
C
      IF(K.EQ.1) GO TO 5
      IF(T(N-NIJ).EQ.0) GO TO 5
      Z=TK(N-NIJ)
      IF(IEQN.EQ.ICHK(11)) Z=Z/DELZ(K)
    5 IF(K.EQ.K0) GO TO 10
      IF(T(N+NIJ).EQ.0) GO TO 10
      SU=TK(N)
      IF(IEQN.EQ.ICHK(11)) SU=SU/DELZ(K)
   10 CONTINUE
      TXM=DMAX1(D,F)
      TYM=DMAX1(B,H)
      TZM=DMAX1(SU,Z)
      DEN=DMIN1(D,F)
      IF (DEN.EQ.0.D0) DEN=TXM
      IF (DEN.EQ.0.D0) GO TO 20
      RHO1=DMAX1(RHO1,TYM/DEN)
   20 DEN=DMIN1(B,H)
      IF (DEN.EQ.0.D0) DEN=TYM
      IF (DEN.EQ.0.D0) GO TO 30
      RHO2=DMAX1(RHO2,TXM/DEN)
   30 DEN=DMIN1(SU,Z)
      IF (DEN.EQ.0.D0) DEN=TZM
      IF (DEN.EQ.0.D0) GO TO 40
      RHO3=DMAX1(RHO3,TXM/DEN)
   40 CONTINUE
      XPART=XT/(1.D0+RHO1)
      YPART=YT/(1.D0+RHO2)
```

```
      ZPART=ZT/(1.D0+RHO3)
      WMIN=DMIN1(WMIN,XPART,YPART,ZPART)
      WMAX=1.D0-WMIN
      PJ=-1.
      DO 50 I=1,LENGTH
      PJ=PJ+1.
   50 RHOP(I)=1.D0-(1.D0-WMAX)**(PJ/P2)
      WRITE (6,230) LENGTH,(RHOP(J),J=1,LENGTH)
      RETURN
C     ...................................................................
C
C     ---INITIALIZE DATA FOR A NEW ITERATION---
   60 IT=IT+1
      IF (IT.LE.ITMAX) GO TO 70
      WRITE (6,220)
      CALL OUTPUT
   70 IF (MOD(IT,LENGTH)) 80,80,90
C     *********************
      ENTRY NEWITA
C     *********************
   80 NTH=0
   90 NTH=NTH+1
      W=RHOP(NTH)
      TEST3(IT+1)=0.
      TEST=0.0
      BIG=0.
      DO 100 I=1,NT
      EL(I)=0.
      FL(I)=0.
      GL(I)=0.
      V(I)=0.
  100 XI(I)=0.
C
C     ---COMPUTE TRANSMISSIVITY AND T COEFFICIENTS FOR UPPER
C     HYDROLOGIC UNIT WHEN IT IS UNCONFINED---
      IF (IWATER.NE.ICHK(6)) GO TO 110
      CALL TRANS(0)
C
C     ---CHOOSE SIP NORMAL OR REVERSE ALGORITHM---
  110 IF (MOD(IT,2)) 120,120,170
  120 DO 150 K=1,KO
      DO 150 I=2,I1
      DO 150 J=2,J1
      N=I+(J-1)*IO+(K-1)*NIJ
      NIA=N+1
      NIB=N-1
      NJA=N+IO
      NJB=N-IO
      NKA=N+NIJ
      NKB=N-NIJ
C
C     ---SKIP COMPUTATIONS IF NODE OUTSIDE MODEL---
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 150
C
C     ---COMPUTE COEFFICIENTS---
```

```
      D=TR(NJB)/DELX(J)                                                 SP31300
      F=TR(N)/DELX(J)                                                   SP31310
      B=TC(NIB)/DELY(I)                                                 SP31320
      H=TC(N)/DELY(I)                                                   SP31330
      SU=0.D0                                                           SP31340
      Z=0.D0                                                            SP31350
      IF(K.EQ.1) GO TO 124                                              SP31361
      Z=TK(NKB)                                                         SP31362
      IF(IEQN.EQ.ICHK(11)) Z=Z/DELZ(K)                                  SP31363
  124 IF(K.EQ.KO) GO TO 125                                             SP31371
      SU=TK(N)                                                          SP31372
      IF(IEQN.EQ.ICHK(11))SU=SU/DELZ(K)                                 SP31373
  125 RHO=S(N)/DELT                                                     SP31380
      QR=0.                                                             SP31390
      IF (K.NE.KO) GO TO 130                                            SP31400
      IF (IQRE.EQ.ICHK(7)) QR=QRE(I+(J-1)*IO)                           SP31410
C                                                                       SP31420
C     ---SIP NORMAL ALGORITHM---                                        SP31430
C     ---FORWARD SUBSTITUTE, COMPUTING INTERMEDIATE VECTOR V---         SP31440
C                                                                         ***
C     ALL FOLLOWING CHANGES IN SOLVE SUBROUTINE                           ***
C     FOR HEAD DEPENDENT STREAM OPTION.                                   ***
C                                                                         ***
  130 IF(PHI(N).GE.RHSS(N)) E=-B-D-F-H-SU-Z-RHO-RCG(N)                    ***
      IF(PHI(N).LT.RHSS(N)) E=-B-D-F-H-SU-Z-RHO-RCL(N)                    ***
      BL=B/(1.+W*(EL(NIB)+GL(NIB)))                                     SP31460
      CL=D/(1.+W*(FL(NJB)+GL(NJB)))                                     SP31470
      C=BL*EL(NIB)                                                      SP31480
      G=CL*FL(NJB)                                                      SP31490
      WU=CL*GL(NJB)                                                     SP31500
      U=BL*GL(NIB)                                                      SP31510
      IF (K.EQ.1) GO TO 140                                             SP31520
      AL=Z/(1.+W*(EL(NKB)+FL(NKB)))                                     SP31530
      A=AL*EL(NKB)                                                      SP31540
      TU=AL*FL(NKB)                                                     SP31550
      DL=E+W*(A+C+G+WU+TU+U)-CL*EL(NJB)-BL*FL(NIB)-AL*GL(NKB)           SP31560
      EL(N)=(F-W*(A+C))/DL                                              SP31570
      FL(N)=(H-W*(G+TU))/DL                                             SP31580
      GL(N)=(SU-W*(WU+U))/DL                                            SP31590
      SUPH=0.D0                                                         SP31600
      IF (K.NE.KO) SUPH=SU*PHI(NKA)                                     SP31610
      IF(PHI(N).GE.RHSS(N)) RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJ  ***
     1A)-H*PHI(NIA)-SUPH-Z*PHI(NKB)-WELL(N)-RHO*OLD(N)-QR-RCG(N)*RHSS(N)  ***
      IF(PHI(N).LT.RHSS(N)) RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJ  ***
     1A)-H*PHI(NIA)-SUPH-Z*PHI(NKB)-WELL(N)-RHO*OLD(N)-QR-RCL(N)*RHSS(N)  ***
      IF(PHI(N).LT.HB(N)) RES=RES+RCL(N)*HB(N)-RCL(N)*PHI(N)              ***
      V(N)=(RES-AL*V(NKB)-BL*V(NIB)-CL*V(NJB))/DL                       SP31640
      GO TO 150                                                         SP31650
  140 DL=E+W*(C+G+WU+U)-CL*EL(NJB)-BL*FL(NIB)                           SP31660
      EL(N)=(F-W*C)/DL                                                  SP31670
      FL(N)=(H-W*G)/DL                                                  SP31680
      GL(N)=(SU-W*(WU+U))/DL                                            SP31690
      SUPH=0.D0                                                         SP31700
      IF (K.NE.KO) SUPH=SU*PHI(NKA)                                     SP31710
      IF(PHI(N).GE.RHSS(N)) RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJ  ***
```

```
     1A)-H*PHI(NIA)-SUPH-WELL(N)-RHO*OLD(N)-QR-RCG(N)*RHSS(N)           ***
      IF(PHI(N).LT.RHSS(N)) RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJ ***
     1A)-H*PHI(NIA)-SUPH-WELL(N)-RHO*OLD(N)-QR-RCL(N)*RHSS(N)           ***
      IF(PHI(N).LT.HB(N)) RES=RES+RCL(N)*HB(N)-RCL(N)*PHI(N)             ***
      V(N)=(RES-BL*V(NIB)-CL*V(NJB))/DL                                 SP31740
  150 CONTINUE                                                          SP31750
C                                                                       SP31760
C     ---BACK SUBSTITUTE FOR VECTOR XI---                               SP31770
      DO 160 K=1,KO                                                     SP31780
      K3=KO-K+1                                                         SP31790
      DO 160 I=1,I2                                                     SP31800
      I3=IO-I                                                           SP31810
      DO 160 J=1,J2                                                     SP31820
      J3=JO-J                                                           SP31830
      N=I3+(J3-1)*IO+(K3-1)*NIJ+I-I                                     SP31840
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 160                           SP31850
      GLXI=0.DO                                                         SP31860
      IF (K3.NE.KO) GLXI=GL(N)*XI(N+NIJ)                                SP31870
      XI(N)=V(N)-EL(N)*XI(N+IO)-FL(N)*XI(N+1)-GLXI                      SP31880
C                                                                       SP31890
C     ---COMPARE MAGNITUDE OF CHANGE WITH CLOSURE CRITERIA---           SP31900
      TCHK=ABS(XI(N))                                                   SP31910
      IF (TCHK.GT.BIG) BIG=TCHK                                         SP31920
      PHI(N)=PHI(N)+XI(N)                                               SP31930
  160 CONTINUE                                                          SP31940
      IF (BIG.GT.ERR) TEST=1.                                           SP31950
      TEST3(IT+1)=BIG                                                   SP31960
      IF (TEST.EQ.0.) RETURN                                            SP31970
      GO TO 60                                                          SP31980
C     ..................................................................SP31990
  170 DO 200 KK=1,KO                                                    SP32000
      K=KO-KK+1                                                         SP32010
      DO 200 II=1,I2                                                    SP32020
      I=IO-II                                                           SP32030
      DO 200 J=2,J1                                                     SP32040
      N=I+(J-1)*IO+(K-1)*NIJ                                            SP32050
      NIA=N+1                                                           SP32060
      NIB=N-1                                                           SP32070
      NJA=N+IO                                                          SP32080
      NJB=N-IO                                                          SP32090
      NKA=N+NIJ                                                         SP32100
      NKB=N-NIJ                                                         SP32110
C                                                                       SP32120
C     ---SKIP COMPUTATIONS IF NODE OUTSIDE AQUIFER---                   SP32130
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 200                           SP32140
C                                                                       SP32150
C     ---COMPUTE COEFFICIENTS---                                        SP32160
      D=TR(NJB)/DELX(J)                                                 SP32170
      F=TR(N)/DELX(J)                                                   SP32180
      B=TC(NIB)/DELY(I)                                                 SP32190
      H=TC(N)/DELY(I)                                                   SP32200
      SU=0.DO                                                           SP32210
      Z=0.DO                                                            SP32220
      IF(K.EQ.1) GO TO 174                                              SP32231
      Z=TK(NKB)                                                         SP32232
```

```
      IF(IEQN.EQ.ICHK(11)) Z=Z/DELZ(K)                                    SP32233
  174 IF(K.EQ.KO) GO TO 175                                               SP32241
      SU=TK(N)                                                            SP32242
      IF(IEQN.EQ.ICHK(11))SU=SU/DELZ(K)                                   SP32243
  175 RHO=S(N)/DELT                                                       SP32250
      QR=0.                                                               SP32260
      IF (K.NE.KO) GO TO 180                                              SP32270
      IF (IQRE.EQ.ICHK(7)) QR=QRE(I+(J-1)*IO)                             SP32280
C                                                                         SP32290
C     ---SIP REVERSE ALGORITHM---                                         SP32300
C     ---FORWARD SUBSTITUTE, COMPUTING INTERMEDIATE VECTOR V---           SP32310
  180 IF(PHI(N).GE.RHSS(N)) E=-B-D-F-H-SU-Z-RHO-RCG(N)                      ***
      IF(PHI(N).LT.RHSS(N)) E=-B-D-F-H-SU-Z-RHO-RCL(N)                      ***
      BL=H/(1.+W*(EL(NIA)+GL(NIA)))                                       SP32330
      CL=D/(1.+W*(FL(NJB)+GL(NJB)))                                       SP32340
      C=BL*EL(NIA)                                                        SP32350
      G=CL*FL(NJB)                                                        SP32360
      WU=CL*GL(NJB)                                                       SP32370
      U=BL*GL(NIA)                                                        SP32380
      IF (K.EQ.KO) GO TO 190                                              SP32390
      AL=SU/(1.+W*(EL(NKA)+FL(NKA)))                                      SP32400
      A=AL*EL(NKA)                                                        SP32410
      TU=AL*FL(NKA)                                                       SP32420
      DL=E+W*(C+G+A+WU+TU+U)-AL*GL(NKA)-BL*FL(NIA)-CL*EL(NJB)             SP32430
      EL(N)=(F-W*(C+A))/DL                                                SP32440
      FL(N)=(B-W*(G+TU))/DL                                               SP32450
      GL(N)=(Z-W*(WU+U))/DL                                               SP32460
      ZPHI=0.DO                                                           SP32470
      IF (K.NE.1) ZPHI=Z*PHI(NKB)                                         SP32480
      IF(PHI(N).GE.RHSS(N)) RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJ   ***
     1A)-H*PHI(NIA)-SU*PHI(NKA)-ZPHI-WELL(N)-RHO*OLD(N)-QR-RCG(N)*RHSS(N   ***
     2)                                                                    ***
      IF(PHI(N).LT.RHSS(N)) RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJ   ***
     1A)-H*PHI(NIA)-SU*PHI(NKA)-ZPHI-WELL(N)-RHO*OLD(N)-QR-RCL(N)*RHSS(N   ***
     2)                                                                    ***
      IF(PHI(N).LT.HB(N)) RES=RES+RCL(N)*HB(N)-RCL(N)*PHI(N)               ***
      V(N)=(RES-AL*V(NKA)-BL*V(NIA)-CL*V(NJB))/DL                         SP32510
      GO TO 200                                                           SP32520
  190 DL=E+W*(C+G+WU+U)-BL*FL(NIA)-CL*EL(NJB)                             SP32530
      EL(N)=(F-W*C)/DL                                                    SP32540
      FL(N)=(B-W*G)/DL                                                    SP32550
      GL(N)=(Z-W*(WU+U))/DL                                               SP32560
      ZPHI=0.DO                                                           SP32570
      IF (K.NE.1) ZPHI=Z*PHI(NKB)                                         SP32580
      IF(PHI(N).GE.RHSS(N)) RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJ   ***
     1A)-H*PHI(NIA)-ZPHI-WELL(N)-RHO*OLD(N)-QR-RCG(N)*RHSS(N)              ***
      IF(PHI(N).LT.RHSS(N)) RES=-B*PHI(NIB)-D*PHI(NJB)-E*PHI(N)-F*PHI(NJ   ***
     1A)-H*PHI(NIA)-ZPHI-WELL(N)-RHO*OLD(N)-QR-RCL(N)*RHSS(N)              ***
      IF(PHI(N).LT.HB(N)) RES=RES+RCL(N)*HB(N)-RCL(N)*PHI(N)               ***
      V(N)=(RES-BL*V(NIA)-CL*V(NJB))/DL                                   SP32610
  200 CONTINUE                                                            SP32620
C                                                                         SP32630
C     ---BACK SUBSTITUTE FOR VECTOR XI---                                 SP32640
      DO 210 K=1,KO                                                       SP32650
      DO 210 I=2,I1                                                       SP32660
```

```
      DO 210 J=1,J2
      J3=J0-J
      N=I+(J3-1)*I0+(K-1)*NIJ
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 210
      GLXI=0.D0
      IF (K.NE.1) GLXI=GL(N)*XI(N-NIJ)
      XI(N)=V(N)-EL(N)*XI(N+I0)-FL(N)*XI(N-1)-GLXI
C
C     ---COMPARE MAGNITUDE OF CHANGE WITH CLOSURE CRITERIA---
      TCHK=ABS(XI(N))
      IF (TCHK.GT.BIG) BIG=TCHK
      PHI(N)=PHI(N)+XI(N)
  210 CONTINUE
      IF (BIG.GT.ERR) TEST=1.
      TEST3(IT+1)=BIG
      IF (TEST.EQ.0.) RETURN
      GO TO 60
C     ..............................................................
C
C     ---FORMATS---
C
C
C
  220 FORMAT ('0EXCEEDED PERMITTED NUMBER OF ITERATIONS'/' ',39('*'))
  230 FORMAT (///1H0,I5,22H ITERATION PARAMETERS:,6E15.7/(/28X,6E15.7/))
  240 FORMAT ('-',44X,'SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE'/45X,
     143('_'))
      END

      SUBROUTINE COEF(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FACT
     1,PERM,BOTTOM,QRE,IZN,KXU,KYU,KZU,BZU,SZU,KXL,KYL,KZL,BZL,SZL,
     2 PMULT,NZNS)
C     --------------------------------------------------------------
C     COMPUTE COEFFICIENTS
C     --------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL *8PHI
      REAL KXU,KYU,KZU,KXL,KYL,KZL
C
      DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), OLD(I0,J0,K0), T(I0,J0,K0
     1), S(I0,J0,K0), TR(I0,J0,K0), TC(I0,J0,K0), TK(IK,JK,K5), WELL(I0,
     2J0,K0), DELX(J0), DELY(I0), DELZ(K0), FACT(K0,3), PERM(IP,JP), BOT
     3TOM(IP,JP),QRE(IQ,JQ),PMULT(25,5),PKXU(84,98),PKYU(84,98),PKZU(84,
     498)
      DIMENSION IZN(I0,J0),KXU(1),KYU(1),KZU(1),BZU(1),SZU(1),
     1 KXL(1),KYL(1),KZL(1),BZL(1),SZL(1)
C
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,N
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK,IEQN,KK
     3K,KKKK,IR,ISTAT,MLTCHK,ISBOUT,IJKMAP,IVHMAP,IZTOZ,ITABLE,
     4LAYDDN,ISLEAK,IOCTAP,IWLWD,IPPOUT
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
```

```
      RETURN                                                                COF 200
      ENTRY INPUT                                                            ***
      DO 100 I=1,I0                                                          ***
      DO 100 J=1,J0                                                          ***
      PKXU(I,J)=0.                                                           ***
      PKYU(I,J)=0.                                                           ***
  100 PKZU(I,J)=0.                                                           ***
C                                                                            ***
C     READ AQUIFER ZONATION AND VALUES FOR EACH ZONE                         ***
C                                                                            ***
      WRITE(6,9005)                                                          ***
      DO 9000 I=1,I0                                                         ***
      READ 9010,(IZN(I,J),J=1,J0)                                            ***
 9000 PRINT 9020,I,(IZN(I,J),J=1,J0)                                         ***
 9005 FORMAT('0','ZONATION SCHEME')                                          ***
 9010 FORMAT(40I2)                                                           ***
 9020 FORMAT(/,1X,I2,2X,3(/40I3))                                            ***
      WRITE(6,9035)                                                          ***
      DO 9030 K=1,NZNS                                                       ***
      READ 9010,N                                                            ***
      READ 9040,KXL(N),KYL(N),KZL(N),BZL(N),SZL(N)                           ***
      READ 9040,KXU(N),KYU(N),KZU(N),BZU(N),SZU(N)                           ***
      PRINT 9050,N,KXL(N),KYL(N),KZL(N),BZL(N),SZL(N)                        ***
 9030 PRINT 9060,N,KXU(N),KYU(N),KZU(N),BZU(N),SZU(N)                        ***
C                                                                            ***
C     MODIFICATION OF HYDRAULIC CONDUCTIVITY BASED                           ***
C     ON TOPOGRAPHIC SETTING.                                                ***
C                                                                            ***
      DO 9031 I=1,NZNS                                                       ***
 9031 READ(5,9070) (PMULT(I,J),J=1,5)                                        ***
      WRITE(6,9075)                                                          ***
      WRITE(6,9080)                                                          ***
      WRITE(6,9083)                                                          ***
      DO 9032 I=1,NZNS                                                       ***
 9032 WRITE(6,9085) I,(PMULT(I,J),J=1,5)                                     ***
      DO 9033 I=2,I1                                                         ***
      DO 9033 J=2,J1                                                         ***
      DO 9034 LLL=1,NZNS                                                     ***
      IF(IZN(I,J).EQ.0) GO TO 9033                                           ***
      IF(IZN(I,J).EQ.LLL) GO TO 9036                                         ***
      GO TO 9034                                                             ***
 9036 IF(PERM(I,J).EQ.0.) GO TO 9034                                         ***
      IF(PERM(I,J).EQ.1.) GO TO 9037                                         ***
      GO TO 9038                                                             ***
 9037 PKXU(I,J)=PMULT(LLL,1)*KXU(LLL)                                        ***
      PKYU(I,J)=PMULT(LLL,1)*KYU(LLL)                                        ***
      PKZU(I,J)=PMULT(LLL,1)*KZU(LLL)                                        ***
      GO TO 9033                                                             ***
 9038 IF(PERM(I,J).EQ.2.) GO TO 9039                                         ***
      GO TO 9041                                                             ***
 9039 PKXU(I,J)=PMULT(LLL,2)*KXU(LLL)                                        ***
      PKYU(I,J)=PMULT(LLL,2)*KYU(LLL)                                        ***
      PKZU(I,J)=PMULT(LLL,2)*KZU(LLL)                                        ***
      GO TO 9033                                                             ***
 9041 IF(PERM(I,J).EQ.3.) GO TO 9042                                         ***
```

```
      GO TO 9043                                                          ***
 9042 PKXU(I,J)=PMULT(LLL,3)*KXU(LLL)                                     ***
      PKYU(I,J)=PMULT(LLL,3)*KYU(LLL)                                     ***
      PKZU(I,J)=PMULT(LLL,3)*KZU(LLL)                                     ***
      GO TO 9033                                                          ***
 9043 IF(PERM(I,J).EQ.4.) GO TO 9044                                      ***
      GO TO 9045                                                          ***
 9044 PKXU(I,J)=PMULT(LLL,4)*KXU(LLL)                                     ***
      PKYU(I,J)=PMULT(LLL,4)*KYU(LLL)                                     ***
      PKZU(I,J)=PMULT(LLL,4)*KZU(LLL)                                     ***
      GO TO 9033                                                          ***
 9045 IF(PERM(I,J).EQ.5.) GO TO 9046                                      ***
 9046 PKXU(I,J)=PMULT(LLL,5)*KXU(LLL)                                     ***
      PKYU(I,J)=PMULT(LLL,5)*KYU(LLL)                                     ***
      PKZU(I,J)=PMULT(LLL,5)*KZU(LLL)                                     ***
      GO TO 9033                                                          ***
 9034 CONTINUE                                                            ***
 9033 CONTINUE                                                            ***
      IF(MLTCHK.EQ.0) GO TO 9048                                          ***
      WRITE(6,9090)                                                       ***
      WRITE(6,9095) (PKXU(10,J),J=1,J0)                                   ***
      WRITE(6,9095) (PKYU(10,J),J=1,J0)                                   ***
      WRITE(6,9095) (PKZU(10,J),J=1,J0)                                   ***
 9090 FORMAT('1',1X,'PRINTOUT OF PKXU,PKYU,PKZU, VALUES FOR ROW 10')      ***
 9095 FORMAT('0',4X,10E11.3/(5X,10E11.3))                                 ***
 9048 CONTINUE                                                            ***
 9035 FORMAT('1',3X,'LAYER',4X,'ZONE',6X,'KX',9X,'KY',9X,'KZ',5X,'THICKN  ***
     1ESS',3X,'STORAGE')                                                  ***
 9040 FORMAT(8F10.0)                                                      ***
 9050 FORMAT(/,5X,'1',5X,I4,2X,7(1X,1PE10.3))                             ***
 9060 FORMAT(/,5X,'2',5X,I4,2X,7(1X,1PE10.3))                             ***
 9070 FORMAT(5F5.1)                                                       ***
 9075 FORMAT('1',10X,'PERMEABILITY MULTIPLIERS')                          ***
 9080 FORMAT('0',16X,'AVERAGE BLOCK TOPOGRAPHY')                          ***
 9083 FORMAT('0',4X,'ZONE',6X,'1',6X,'2',6X,'3',6X,'4',6X,'5')            ***
 9085 FORMAT('0',5X,I2,6X,F3.1,4X,F3.1,4X,F3.1,4X,F3.1,4X,F3.1)          ***
      RETURN                                                              ***
C     ...................................................................COF 210
C     ---COMPUTE TRANSMISSIVITY FOR UPPER HYDROLOGIC UNIT WHEN           COF 220
C     IT IS UNCONFINED---                                                COF 230
C     *********************                                              COF 240
      ENTRY TRANS                                                         ***
C     *********************                                              COF 260
      DO 10 J=2,J1                                                        ***
      DO 10 I=2,I1                                                       COF 270
      N=IZN(I,J)                                                          ***
      IF(N.LE.0) GO TO 10                                                 ***
      THICK=PHI(I,J,K0)-BOTTOM(I,J)                                       ***
      IF(THICK.GT.0.) GO TO 5                                             ***
      IF(T(I,J,K0).EQ.0.) GO TO 10                                        ***
      IF (WELL(I,J,K0).LT.0.) WRITE (6,60) I,J,K0                        COF 320
      IF (WELL(I,J,K0).GE.0.) WRITE (6,70) I,J,K0                        COF 330
      T(I,J,K0)=0.                                                       COF 350
      TR(I,J-1,K0)=0.                                                    COF 360
      TR(I,J,K0)=0.                                                      COF 370
```

```
      TC(I,J,KO)=0.                                                     COF 380
      TC(I-1,J,KO)=0.                                                   COF 390
      IF (KO.NE.1) TK(I,J,K1)=0.                                        COF 400
      PHI(I,J,KO)=BOTTOM(I,J)                                           ***
      S(I,J,1)=S(I,J,2)                                                 ***
      GO TO 10                                                          ***
    5 CONTINUE                                                          ***
C                                                                       ***
C     COMPUTATIONS OF TR AND TC MODIFIED TO INCORPORATE                 ***
C     REVISED HYDRAULIC CONDUCTIVITY.                                   ***
C                                                                       ***
C     I+1 OR TC DIRECTION                                               ***
C                                                                       ***
      N1=IZN(I+1,J)                                                     ***
      IF(N1.LE.0) GO TO 6                                               ***
      IF(PKYU(I+1,J).LE.0.) GO TO 6                                     ***
      THICK1=PHI(I+1,J,KO)-BOTTOM(I+1,J)                                ***
      IF(THICK1.LE.0.) GO TO 6                                          ***
      T1=THICK*PKYU(I,J)                                                ***
      T2=THICK1*PKYU(I+1,J)                                             ***
      IF(T1.EQ.0..AND.T2.EQ.0.) GO TO 6                                 ***
      TC(I,J,2)=2.*T1*T2/(T1*DELY(I+1)+T2*DELY(I))                      ***
C                                                                       ***
C     J+1 OR TR DIRECTION                                               ***
C                                                                       ***
    6 N1=IZN(I,J+1)                                                     ***
      IF(N1.LE.0) GO TO 10                                              ***
      IF(PKXU(I,J+1).LE.0.) GO TO 10                                    ***
      THICK1=PHI(I,J+1,KO)-BOTTOM(I,J+1)                                ***
      IF(THICK1.LE.0.) GO TO 10                                         ***
      T1=THICK*PKXU(I,J)                                                ***
      T2=THICK1*PKXU(I,J+1)                                             ***
      IF(T1.EQ.0..AND.T2.EQ.0.) GO TO 10                                ***
      TR(I,J,2)=2.*T1*T2/(T1*DELX(J+1)+T2*DELX(J))                      ***
   10 CONTINUE                                                          COF 420
      RETURN                                                            ***
C     ---COMPUTE T COEFFICIENTS---                                      COF 480
C     *********************                                             COF 490
      ENTRY TCOF                                                        COF 500
C     *********************                                             COF 510
      DO 8000 J=1,JO                                                    ***
      DO 8000 I=1,IO                                                    ***
      N=IZN(I,J)                                                        ***
      T(I,J,1)=0.                                                       ***
      T(I,J,2)=0.                                                       ***
      IF(N.LE.0) GO TO 8000                                             ***
      T(I,J,1)=KXL(N)*BZL(N)                                            ***
      T(I,J,2)=PKXU(I,J)*BZU(N)                                         ***
      IF(S(I,J,1).GE.0.) S(I,J,1)=SZL(N)                                ***
      IF(S(I,J,2).GE.0.) S(I,J,2)=SZU(N)                                ***
 8000 CONTINUE                                                          ***
C                                                                       ***
C     COMPUTE TR, TC, AND TK COEFFICIENTS                               ***
C                                                                       ***
      DO 8010 J=1,J1                                                    ***
```

```
      DO 8010 I=1,I1                                                    ***
      N=IZN(I,J)                                                        ***
      IF(N.LE.0) GO TO 8010                                             ***
      T1=T(I,J,1)                                                       ***
      T2=T(I,J+1,1)                                                     ***
      IF(T1.EQ.0..AND.T2.EQ.0.) GO TO 20                                ***
      TR(I,J,1)=2.*T1*T2/(T1*DELX(J+1)+T2*DELX(J))                      ***
   20 T1=T(I,J,2)                                                       ***
      T2=T(I,J+1,2)                                                     ***
      IF(T1.EQ.0..AND.T2.EQ.0.) GO TO 25                                ***
      TR(I,J,2)=2.*T1*T2/(T1*DELX(J+1)+T2*DELX(J))                      ***
   25 N1=IZN(I+1,J)                                                     ***
      IF(N1.LE.0) GO TO 40                                              ***
      IF(PKYU(I+1,J).LE.0.) GO TO 40                                    ***
      T1=KYL(N)*BZL(N)                                                  ***
      T2=KYL(N1)*BZL(N1)                                                ***
      IF(T1.EQ.0..AND.T2.EQ.0.) GO TO 30                                ***
      TC(I,J,1)=2.*T1*T2/(T1*DELY(I+1)+T2*DELY(I))                      ***
   30 T1=PKYU(I,J)*BZU(N)                                               ***
      T2=PKYU(I+1,J)*BZU(N)                                             ***
      IF(T1.EQ.0..AND.T2.EQ.0.) GO TO 40                                ***
      TC(I,J,2)=2.*T1*T2/(T1*DELY(I+1)+T2*DELY(I))                      ***
   40 IF(KZL(N).EQ.0..AND.PKZU(I,J).EQ.0.) GO TO 8010                   ***
 8005 TK(I,J,1)=2.*KZL(N)*PKZU(I,J)/(KZL(N)*BZU(N)+PKZU(I,J)*BZL(N))    ***
 8010 CONTINUE                                                          ***
      RETURN                                                            COF
C                                                                       COF
C                                                                       COF
   60 FORMAT ('-',20('*'),'WELL',2I3,' IN LAYER',I3,' GOES DRY',20('*'))COF
   70 FORMAT ('-',20('*'),'NODE',2I3,' IN LAYER',I3,' GOES DRY',20('*'))COF
      END                                                               COF

      SUBROUTINE CHECKI(PHI,STRT,OLD,T,S,TR,TC,TK,WELL,DELX,DELY,DELZ,FACHK
     1CT,JFLO,FLOW,QRE,RCG,RCL,RHSS,HB,IZN,NZNS)                        ***
C     ------------------------------------------------------------------CHK
C     COMPUTE A VOLUMETRIC BALANCE                                      CHK
C     ------------------------------------------------------------------CHK
C                                                                       CHK
C     SPECIFICATIONS:                                                   CHK
      REAL *8PHI                                                        CHK
C                                                                       CHK
      DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), OLD(I0,J0,K0), T(I0,J0,KOCHK
     1), S(I0,J0,K0), TR(I0,J0,K0), TC(I0,J0,K0), TK(IK,JK,K5), WELL(I0,CHK
     2J0,K0), DELX(J0), DELY(I0), DELZ(K0), FACT(K0,3), JFLO(NCH,3), FLOCHK
     3W(NCH),QRE(IQ,JQ),RCG(I0,J0,K0),RCL(I0,J0,K0),RHSS(I0,J0,K0),     ***
     4HB(I0,J0,K0)                                                      ***
      DIMENSION IZN(I0,J0),ZINSUM(25),ZOUTSM(25)                        ***
      DIMENSION RESID(2,25),ARESID(2,25),NCOUNT(2,25),XMAX(2,25),XMIN(2,***
     125),RESID2(2,25)                                                  ***
      DIMENSION VFDOWN(25),VFUP(25)                                     ***
      DIMENSION STORAG(2,25),RECHQ(25),X1STOT(25),X2STOT(25),           ***
     1X1DTOT(25),X2DTOT(25),SDDIFF(25),PCDIFF(25),BDYQ(2,25)            ***
      DIMENSION STRLK (84,98),OCT1(84,98),OCT2(84,98)                   ***
C                                                                       CHK
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,NCHK
```

```
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK,IEQN,KK
     3K,KKKK,IR,ISTAT,MLTCHK,ISBOUT,IJKMAP,IVHMAP,IZTOZ,ITABLE,
     4LAYDDN,ISLEAK,IOCTAP,IWLWD,IPPOUT
      COMMON /SPARAM/ TMAX,CDLT,DELT,ERR,TEST,SUM,SUMP,QR
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      COMMON /CK/ ETFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT
      RETURN
C     ..................................................................
C     ********************
      ENTRY CHECK
C     ********************
C     ---INITIALIZE VARIABLES---
      PUMP=0.
      STOR=0.
      FLUXS=0.0
      CHD1=0.0
      CHD2=0.0
      QREFLX=0.
      CFLUX=0.
      FLUX=0.
      ETFLUX=0.
      FLXN=0.0
      II=0
C
C     HEAD DEPENDENT STREAM OPTION ADDITIONS.
C
      RFLOUT=0.
      RFLIN=0.
      KKK=KKK+1
      KKKK=KKKK+1
C     ..................................................................
C
C     ---COMPUTE RATES,STORAGE AND PUMPAGE FOR THIS STEP---
      IF(IR.NE.1) GO TO 5
      IF(KKK.NE.NUMT.AND.KKKK.NE.KTH) GO TO 5
      IF(ISBOUT.NE.1) GO TO 3
      WRITE(6,300)
      WRITE(6,305)
    3 KKKK=0
      KKK=0
C
C     STREAM/AQUIFER FLOW OUTPUT BY ZONE OPTION.
C
    5 DO 1 I=1,NZNS
      ZINSUM(I)=0.
    1 ZOUTSM(I)=0.
C
C     OPTION TO WRITE DRAWDOWN AND STREAM/AQUIFER FLOW
C     ON FILE FOR EACH GRID BLOCK.
C
      IF(ISLEAK.NE.1) GO TO 8
      DO 6 I=1,IO
      DO 6 J=1,JO
    6 STRLK(I,J)=0.
```

```
    8 MMM=2                                                              ***
      IF(LAYDDN.NE.1) GO TO 18                                           ***
      DO 7 I=1,IO                                                        ***
      DO 7 J=1,JO                                                        ***
      IF(IZN(I,J).EQ.0) GO TO 7                                          ***
      DRAW1=STRT(I,J,1)-PHI(I,J,1)                                       ***
      DRAW2=STRT(I,J,2)-PHI(I,J,2)                                       ***
      WRITE(11,2050)I,J,IZN(I,J),DRAW1,DRAW2                             ***
    7 CONTINUE                                                           ***
C                                                                        ***
C     OPTION TO WRITE DRAWDOWN DATA FOR FINAL TIME STEP                  ***
C     ON FILE FOR ALL PUMPING PERIODS IN TRANSIENT RUN.                  ***
C                                                                        ***
   18 IF(IPPOUT.NE.1) GO TO 9                                            ***
      IF(KT.NE.NUMT) GO TO 9                                             ***
      DO 19 I=1,IO                                                       ***
      DO 19 J=1,JO                                                       ***
      IF(IZN(I,J).EQ.0) GO TO 19                                         ***
      DRAW2=STRT(I,J,2)-PHI(I,J,2)                                       ***
      WRITE(15,2070) KP,IZN(I,J),DRAW2                                   ***
   19 CONTINUE                                                           ***
C                                                                        ***
C     OPTION TO WRITE TRANSIENT HEAD CHANGE ON FILE.                     ***
C                                                                        ***
    9 IF(IOCTAP.EQ.0) GO TO 16                                           ***
      IF(IOCTAP.EQ.1) NF=13                                              ***
      IF(IOCTAP.EQ.2) NF=14                                              ***
      IF(KP.NE.4.OR.KT.NE.NUMT)  GO TO 14                                ***
      DO 13 I=1,IO                                                       ***
      DO 13 J=1,JO                                                       ***
      IF(IZN(I,J).EQ.0) GO TO 13                                         ***
      OCT1(I,J)=PHI(I,J,1)                                               ***
      OCT2(I,J)=PHI(I,J,2)                                               ***
   13 CONTINUE                                                           ***
   14 IF(KP.NE.10.OR.KT.NE.NUMT)  GO TO 16                               ***
      DO 15 I=1,IO                                                       ***
      DO 15 J=1,JO                                                       ***
      IF(IZN(I,J).EQ.0) GO TO 15                                         ***
      DRAW1=PHI(I,J,1)-OCT1(I,J)                                         ***
      DRAW2=PHI(I,J,2)-OCT2(I,J)                                         ***
      WRITE(NF,2050) I,J,IZN(I,J),DRAW1,DRAW2                            ***
   15 CONTINUE                                                           ***
   16 DO 220 K=1,KO                                                      ***
      DO 220 I=2,I1                                                      CHK 420
      DO 220 J=2,J1                                                      CHK 430
      IF (T(I,J,K).EQ.0.) GO TO 220                                      CHK 440
      AREA=DELX(J)*DELY(I)                                               CHK 450
      VOLUME=AREA*DELZ(K)                                                CHK 455
      IF (S(I,J,K).GE.0.) GO TO 180                                      CHK 460
C                                                                        CHK 470
C     ---COMPUTE FLOW RATES TO AND FROM CONSTANT HEAD BOUNDARIES---       CHK 480
      II=II+1                                                            CHK 490
      FLOW(II)=0.                                                        CHK 500
      JFLO(II,1)=K                                                       CHK 510
      JFLO(II,2)=I                                                       CHK 520
```

```
      JFLO(II,3)=J                                                       CHK 530
      IF (S(I,J-1,K).LT.0..OR.T(I,J-1,K).EQ.0.) GO TO 30                 CHK 540
      X=(PHI(I,J,K)-PHI(I,J-1,K))*TR(I,J-1,K)*DELY(I)                    CHK 550
      IF(IEQN.EQ.ICHK(11)) X=X*DELZ(K)                                   CHK 555
      FLOW(II)=FLOW(II)+X                                                CHK 560
      IF (X) 10,30,20                                                    CHK 570
   10 CHD1=CHD1+X                                                        CHK 580
      GO TO 30                                                           CHK 590
   20 CHD2=CHD2+X                                                        CHK 600
   30 IF (S(I,J+1,K).LT.0..OR.T(I,J+1,K).EQ.0.) GO TO 60                 CHK 610
      X=(PHI(I,J,K)-PHI(I,J+1,K))*DELY(I)*TR(I,J,K)                      CHK 620
      IF(IEQN.EQ.ICHK(11)) X=X*DELZ(K)                                   CHK 625
      FLOW(II)=FLOW(II)+X                                                CHK 630
      IF (X) 40,60,50                                                    CHK 640
   40 CHD1=CHD1+X                                                        CHK 650
      GO TO 60                                                           CHK 660
   50 CHD2=CHD2+X                                                        CHK 670
   60 IF (K.EQ.1) GO TO 90                                               CHK 680
      IF (S(I,J,K-1).LT.0..OR.T(I,J,K-1).EQ.0.) GO TO 90                 CHK 690
      X=(PHI(I,J,K)-PHI(I,J,K-1))*TK(I,J,K-1)*AREA                       CHK 700
      FLOW(II)=FLOW(II)+X                                                CHK 720
      IF (X) 70,90,80                                                    CHK 730
   70 CHD1=CHD1+X                                                        CHK 740
      GO TO 90                                                           CHK 750
   80 CHD2=CHD2+X                                                        CHK 760
   90 IF (K.EQ.KO) GO TO 120                                             CHK 770
      IF (S(I,J,K+1).LT.0..OR.T(I,J,K+1).EQ.0.) GO TO 120                CHK 780
      X=(PHI(I,J,K)-PHI(I,J,K+1))*TK(I,J,K)*AREA                         CHK 790
      FLOW(II)=FLOW(II)+X                                                CHK 800
      IF (X) 100,120,110                                                 CHK 810
  100 CHD1=CHD1+X                                                        CHK 820
      GO TO 120                                                          CHK 830
  110 CHD2=CHD2+X                                                        CHK 840
  120 IF (S(I-1,J,K).LT.0..OR.T(I-1,J,K).EQ.0.) GO TO 150                CHK 850
      X=(PHI(I,J,K)-PHI(I-1,J,K))*TC(I-1,J,K)*DELX(J)                    CHK 860
      IF(IEQN.EQ.ICHK(11)) X=X*DELZ(K)                                   CHK 865
      FLOW(II)=FLOW(II)+X                                                CHK 870
      IF (X) 130,150,140                                                 CHK 880
  130 CHD1=CHD1+X                                                        CHK 890
      GO TO 150                                                          CHK 900
  140 CHD2=CHD2+X                                                        CHK 910
  150 IF (S(I+1,J,K).LT.0..OR.T(I+1,J,K).EQ.0.) GO TO 220                CHK 920
      X=(PHI(I,J,K)-PHI(I+1,J,K))*TC(I,J,K)*DELX(J)                      CHK 930
      IF(IEQN.EQ.ICHK(11)) X=X*DELZ(K)                                   CHK 935
      FLOW(II)=FLOW(II)+X                                                CHK 940
      IF (X) 160,220,170                                                 CHK 950
  160 CHD1=CHD1+X                                                        CHK 960
      GO TO 220                                                          CHK 970
  170 CHD2=CHD2+X                                                        CHK 980
      GO TO 220                                                          CHK 990
C                                                                        CHK1000
C       ---CHECK FOR EQUATION BEING SOLVED---                            CHK1001
  180 IF(IEQN.EQ.ICHK(11)) GO TO 211                                     CHK1002
C                                                                        CHK1003
C     ---EQUATION 4---                                                   CHK1004
```

```
C      ---RECHARGE AND WELLS---                                          CHK1010
       IF (K.EQ.KO.AND.IQRE.EQ.ICHK(7)) QREFLX=QREFLX+QRE(I,J)*AREA      CHK1020
       IF (WELL(I,J,K)) 190,210,200                                      CHK1030
  190  PUMP=PUMP+WELL(I,J,K)*AREA                                        CHK1040
       GO TO 210                                                         CHK1050
  200  CFLUX=CFLUX+WELL(I,J,K)*AREA                                      CHK1060
C                                                                        CHK1070
C      ---COMPUTE VOLUME FROM STORAGE---                                 CHK1080
  210  STOR=STOR+S(I,J,K)*(OLD(I,J,K)-PHI(I,J,K))*AREA                   CHK1090
C                                                                           ***
C      HEAD DEPENDENT STREAM OPTION.                                        ***
C                                                                           ***
       HDD=PHI(I,J,K)                                                       ***
       IF(HDD.LT.HB(I,J,K)) HDD=HB(I,J,K)                                   ***
       IF(HDD.GE.RHSS(I,J,K)) XRNET=(RHSS(I,J,K)-HDD)*RCG(I,J,K)*AREA       ***
       IF(HDD.LT.RHSS(I,J,K)) XRNET=(RHSS(I,J,K)-HDD)*RCL(I,J,K)*AREA       ***
       IF(K.EQ.2) STRLK(I,J)=XRNET                                          ***
       FLUXS=FLUXS+XRNET                                                    ***
       IF(XRNET.LT.0.) RFLOUT=RFLOUT-XRNET                                  ***
       IF(XRNET.GT.0.) RFLIN=RFLIN+XRNET                                    ***
C                                                                           ***
C      STREAM/AQUIFER FLOW OUTPUT BY ZONE.                                  ***
C                                                                           ***
       IF(XRNET.EQ.0.) GO TO 219                                            ***
       IF(XRNET.LT.0.) GO TO 217                                            ***
       DO 215 NNN=1,NZNS                                                    ***
       IF(IZN(I,J).EQ.NNN) ZINSUM(NNN)=ZINSUM(NNN)+XRNET                    ***
  215  IF(IZN(I,J).EQ.NNN) GO TO 219                                        ***
  217  DO 218 NNN=1,NZNS                                                    ***
       IF(IZN(I,J).EQ.NNN) ZOUTSM(NNN)=ZOUTSM(NNN)-XRNET                    ***
  218  IF(IZN(I,J).EQ.NNN) GO TO 219                                        ***
C                                                                           ***
C      HEAD DEPENDENT STREAM OPTION.                                        ***
C                                                                           ***
  219  IF(XRNET.LT.0.) FLXN=FLXN-XRNET                                      ***
       IF(KKK.NE.NUMT.AND.KKKK.NE.0) GO TO 220                              ***
       IF(XRNET.EQ.0.) GO TO 220                                            ***
       IF(ISBOUT.NE.1) GO TO 220                                            ***
       MMM=MMM+1                                                            ***
       IF((MOD(MMM,2)).NE.0) WRITE(6,310) I,J,K,XRNET                       ***
       IF((MOD(MMM,2)).EQ.0) WRITE(6,311) I,J,K,XRNET                       ***
C                                                                           ***
C      OPTION TO WRITE ON FILE STREAM/AQUIFER FLOW                          ***
C      IN WELL CARD FORMAT.                                                 ***
C                                                                           ***
       IF(IWLWD.NE.1) GO TO 220                                             ***
       IF(XRNET.LT.0.) WRITE(15,2060)K,I,J,XRNET                            ***
       GO TO 220                                                         CHK1091
C                                                                        CHK1092
C      ---EQUATION 3---                                                  CHK1093
C      ---RECHARGE AND WELLS---                                          CHK1094
  211  IF (K.EQ.KO.AND.IQRE.EQ.ICHK(7)) QREFLX=QREFLX+QRE(I,J)*VOLUME    CHK1095
       IF (WELL(I,J,K)) 212,214,213                                      CHK1096
  212  PUMP=PUMP+WELL(I,J,K)*VOLUME                                      CHK1097
       GO TO 214                                                         CHK1098
```

```
  213 CFLUX=CFLUX+WELL(I,J,K)*VOLUME                                   CHK1099
C                                                                      CHK1100
C     ---COMPUTE VOLUME FROM STORAGE---                                CHK1101
  214 STOR=STOR+S(I,J,K)*(OLD(I,J,K)-PHI(I,J,K))*VOLUME                CHK1102
C                                                                          ***
C     HEAD DEPENDENT STREAM OPTION.                                        ***
C                                                                          ***
      HDD=PHI(I,J,K)                                                       ***
      IF(HDD.LT.HB(I,J,K)) HDD=HB(I,J,K)                                   ***
      XRNET=(RHSS(I,J,K)-HDD)*RCG(I,J,K)*VOLUME                            ***
      FLUXS=FLUXS+XRNET                                                    ***
      IF(XRNET.LT.0.) RFLOUT=RFLOUT-XRNET                                  ***
      IF(XRNET.GT.0.) RFLIN=RFLIN+XRNET                                    ***
      IF(XRNET.LT.0.) FLXN=FLXN-XRNET                                      ***
      IF(KKK.NE.NUMT.AND.KKKK.NE.0) GO TO 220                              ***
      IF(XRNET.EQ.0.) GO TO 220                                            ***
      WRITE(6,310) I,J,K,XRNET                                             ***
  220 CONTINUE                                                         CHK1103
C     ...........................................................CHK1110
      IF(IR.NE.1) GO TO 225                                                ***
      IF(KKK.NE.NUMT.AND.KKKK.NE.0) GO TO 225                              ***
C                                                                          ***
C     STREAM/AQUIFER FLOW OUTPUT BY ZONE.                                  ***
C                                                                          ***
      WRITE(6,315)                                                         ***
      WRITE(6,316)                                                         ***
      DO 222 LL=1,NZNS                                                     ***
  222 WRITE(6,317) LL,ZINSUM(LL),ZOUTSM(LL)                                ***
C                                                                          ***
C     HEAD DEPENDENT STREAM OPTION.                                        ***
C                                                                          ***
      WRITE(6,320)                                                         ***
      WRITE(6,325)                                                         ***
      WRITE(6,330) RFLIN,RFLOUT                                            ***
C                                                                      CHK1120
C     ---COMPUTE CUMULATIVE VOLUMES, TOTALS, AND DIFFERENCES---        CHK1130
C                                                                          ***
C     WRITE STREAM/AQUIFER FLOW ON FILE                                    ***
C     FOR EACH GRID BLOCK.                                                 ***
C                                                                          ***
      IF(ISLEAK.NE.1) GO TO 225                                            ***
      DO 224 I=1,IO                                                        ***
  224 WRITE(12,2040) (STRLK(I,J), J=1,JO)                                  ***
  225 FLXPT=0.                                                             ***
      STORT=STORT+STOR                                                 CHK1150
      STOR=STOR/DELT                                                   CHK1160
      FLUXT=FLUXT+FLUXS*DELT                                               ***
      FLXNT=FLXNT+FLXN*DELT                                                ***
      FLXPT=FLUXT+FLXNT                                                    ***
      QRET=QRET+QREFLX*DELT                                            CHK1170
      CHDT=CHDT-CHD1*DELT                                              CHK1180
      CHST=CHST+CHD2*DELT                                              CHK1190
      PUMPT=PUMPT-PUMP*DELT                                            CHK1200
      CFLUXT=CFLUXT+CFLUX*DELT                                         CHK1210
      TOTL1=STORT+QRET+CFLUXT+CHST+FLXPT                               CHK1220
```

```
      TOTL2=CHDT+PUMPT+ETFLXT+FLXNT                                     CHK1230
      SUMR=QREFLX+CFLUX+CHD2+CHD1+PUMP+ETFLUX+FLUXS+STOR                CHK1240
      DIFF=TOTL2-TOTL1                                                  CHK1250
      PERCNT=0.0                                                        CHK1260
C                                                                         ***
C     OPTION TO COMPUTE STATISTICS ON ZONE RESIDUALS.                     ***
C                                                                         ***
      IF(ISTAT.EQ.0) GO TO 241                                            ***
      DO 232 I=1,KO                                                       ***
      DO 232 J=1,NZNS                                                     ***
      RESID(I,J)=0.                                                       ***
      ARESID(I,J)=0.                                                      ***
      NCOUNT(I,J)=0                                                       ***
      XMAX(I,J)=0.                                                        ***
      XMIN(I,J)=0.                                                        ***
  232 RESID2(I,J)=0.                                                      ***
      DO 238 K=1,KO                                                       ***
      DO 236 I=2,I1                                                       ***
      DO 236 J=2,J1                                                       ***
      IF(IZN(I,J).EQ.0) GO TO 236                                         ***
      DO 234 NNN=1,NZNS                                                   ***
      IF(IZN(I,J).EQ.NNN) GO TO 233                                       ***
      GO TO 234                                                           ***
  233 RESID(K,NNN)=RESID(K,NNN)+(STRT(I,J,K)-PHI(I,J,K))                  ***
      WW=STRT(I,J,K)-PHI(I,J,K)                                           ***
      ARESID(K,NNN)=ARESID(K,NNN)+ABS(WW)                                 ***
      NCOUNT(K,NNN)=NCOUNT(K,NNN)+1                                       ***
      XMAX(K,NNN)=AMAX1(XMAX(K,NNN),WW)                                   ***
      XMIN(K,NNN)=AMIN1(XMIN(K,NNN),WW)                                   ***
      RESID2(K,NNN)=RESID2(K,NNN)+(STRT(I,J,K)-PHI(I,J,K))**2             ***
      GO TO 236                                                           ***
  234 CONTINUE                                                            ***
  236 CONTINUE                                                            ***
  238 CONTINUE                                                            ***
      WRITE(6,332)                                                        ***
      WRITE(6,334)                                                        ***
      DO 239 K=1,KO                                                       ***
      DO 239 NNN=1,NZNS                                                   ***
      XMEAN=RESID(K,NNN)/NCOUNT(K,NNN)                                    ***
      AMEAN=ARESID(K,NNN)/NCOUNT(K,NNN)                                   ***
      SDMEAN=SQRT((NCOUNT(K,NNN)*RESID2(K,NNN)-RESID(K,NNN)**2)/(NCOUNT(  ***
     1K,NNN)*(NCOUNT(K,NNN)-1)))                                          ***
  239 WRITE(6,336) K,NNN,NCOUNT(K,NNN),XMEAN,AMEAN,SDMEAN,XMAX(K,NNN),XM  ***
     1IN(K,NNN)                                                           ***
  241 IF(TOTL2.EQ.0.) GO TO 230                                           ***
      PERCNT=DIFF/TOTL2*100.                                            CHK1280
  230 RETURN                                                            CHK1290
C     ..................................................................CHK1300
C                                                                       CHK1310
C     ---PRINT RESULTS---                                               CHK1320
C     ************************                                          CHK1330
      ENTRY CWRITE                                                      CHK1340
C     ************************                                          CHK1350
C                                                                       CHK1360
      WRITE (6,260) STOR,QREFLX,STORT,CFLUX,QRET,PUMP,CFLUXT,ETFLUX,CHSTCHK1370
```

```
     1,FLXPT,CHD2,TOTL1,CHD1,FLUX,FLUXS,ETFLXT,CHDT,SUMR,PUMPT,FLXNT,TOTCHK1380
     2L2,DIFF,PERCNT                                                    CHK1390
      IF (NCH.EQ.0) GO TO 240                                           CHK1400
      WRITE (6,270)                                                     CHK1410
      WRITE (6,280) ((JFLO(I,J),J=1,3),FLOW(I),I=1,NCH)                 CHK1420
C                                                                       CHK1430
C     ---COMPUTE VERTICAL FLOW---                                       CHK1440
  240 X=0.                                                              CHK1450
      Y=0.                                                              CHK1460
      IF (KO.EQ.1) RETURN                                               CHK1470
      DO 250 I=2,I1                                                     CHK1480
      DO 250 J=2,J1                                                     CHK1490
      X=X+(PHI(I,J,1)-PHI(I,J,2))*TK(I,J,1)*DELX(J)*DELY(I)             CHK1500
  250 Y=Y+(PHI(I,J,K1)-PHI(I,J,K0))*TK(I,J,K1)*DELX(J)*DELY(I)          CHK1520
      WRITE (6,290) Y,X                                                 CHK1540
C                                                                         ***
C     COMPUTE VERTICAL FLOW TOTALS BETWEEN LAYERS FOR EACH ZONE.          ***
C                                                                         ***
      DO 394 I=1,NZNS                                                     ***
      VFUP(I)=0.                                                          ***
  394 VFDOWN(I)=0.                                                        ***
      DO 400 I=2,I1                                                       ***
      DO 400 J=2,J1                                                       ***
      IF(IZN(I,J).EQ.0) GO TO 400                                         ***
      DO 398 NNN=1,NZNS                                                   ***
      IF(IZN(I,J).EQ.NNN) GO TO 396                                       ***
      GO TO 398                                                           ***
  396 XYZ=PHI(I,J,2)-PHI(I,J,1)                                           ***
      IF(XYZ.GE.0.) VFDOWN(NNN)=VFDOWN(NNN)+XYZ*TK(I,J,1)*DELX(J)*DELY(I  ***
     1)                                                                   ***
      IF(XYZ.LT.0.) VFUP(NNN)=VFUP(NNN)-XYZ*TK(I,J,1)*DELX(J)*DELY(I)     ***
      GO TO 400                                                           ***
  398 CONTINUE                                                            ***
  400 CONTINUE                                                            ***
      WRITE(6,386)                                                        ***
      WRITE(6,387)                                                        ***
      DO 390 I=1,NZNS                                                     ***
  390 WRITE(6,388) I,VFDOWN(I),VFUP(I)                                    ***
C                                                                         ***
C     OPTION TO COMPUTE ZONE TO ZONE LATERAL FLOW TOTALS.                 ***
C                                                                         ***
      IF(IZTOZ.NE.1) GO TO 560                                            ***
      DO 550 K=1,KO                                                       ***
      WRITE(6,1000) K                                                     ***
      DO 540 IMM=1,NZNS                                                   ***
      DO 530 JMM=1,NZNS                                                   ***
      IF(IMM.EQ.JMM) GO TO 530                                            ***
      QQPOS=0.                                                            ***
      QQNEG=0.                                                            ***
      KPOS=0                                                              ***
      KNEG=0                                                              ***
      DO 510 I=2,I1                                                       ***
      DO 510 J=2,J1                                                       ***
      IF(IZN(I,J).NE.IMM) GO TO 510                                       ***
      IF(IZN(I+1,J).NE.JMM) GO TO 500                                     ***
```

```
      QQ=TC(I,J,K)*(PHI(I,J,K)-PHI(I+1,J,K))*DELX(J)                 ***
      IF(QQ.GE.0.) QQPOS=QQPOS+QQ                                     ***
      IF(QQ.GE.0.) KPOS=KPOS+1                                        ***
      IF(QQ.LT.0.) QQNEG=QQNEG-QQ                                     ***
      IF(QQ.LT.0.) KNEG=KNEG+1                                        ***
  500 IF(IZN(I,J+1).NE.JMM) GO TO 510                                 ***
      QQ=TR(I,J,K)*(PHI(I,J,K)-PHI(I,J+1,K))*DELY(I)                 ***
      IF(QQ.GE.0.) QQPOS=QQPOS+QQ                                     ***
      IF(QQ.GE.0.) KPOS=KPOS+1                                        ***
      IF(QQ.LT.0.) QQNEG=QQNEG-QQ                                     ***
      IF(QQ.LT.0.) KNEG=KNEG+1                                        ***
  510 CONTINUE                                                        ***
      IF(QQPOS.EQ.0.) GO TO 520                                       ***
      IF(KPOS.EQ.0) GO TO 520                                         ***
      YPOSAV=QQPOS/KPOS                                               ***
      WRITE(6,1100) QQPOS,IMM,JMM,KPOS,YPOSAV                         ***
  520 IF(QQNEG.EQ.0.) GO TO 530                                       ***
      IF(KNEG.EQ.0) GO TO 530                                         ***
      YNEGAV=QQNEG/KNEG                                               ***
      WRITE(6,1100) QQNEG,JMM,IMM,KNEG,YNEGAV                         ***
  530 CONTINUE                                                        ***
  540 CONTINUE                                                        ***
  550 CONTINUE                                                        ***
C                                                                     ***
C     OPTION TO COMPUTE MASS BALANCE FOR EACH ZONE.                   ***
C                                                                     ***
  560 IF(ITABLE.NE.1) RETURN                                          ***
C                                                                     ***
C     CONSTANT HEAD.                                                  ***
C                                                                     ***
      DO 1200 I=1,2                                                   ***
      DO 1200 J=1,NZNS                                                ***
      RESID(I,J)=0.                                                   ***
 1200 ARESID(I,J)=0.                                                  ***
      DO 1360 NNNN=1,NZNS                                             ***
      XNGSUM=0.                                                       ***
      POSSUM=0.                                                       ***
      XNSUM=0.                                                        ***
      PSUM=0.                                                         ***
      DO 1350 I=2,I1                                                  ***
      DO 1350 J=2,J1                                                  ***
      IF(IZN(I,J).NE.NNNN) GO TO 1350                                 ***
      IF(S(I,J,2).LT.0.) GO TO 1320                                   ***
      IF(S(I+1,J,2).GE.0..OR.T(I+1,J,2).EQ.0.) GO TO 1230             ***
      X=(PHI(I,J,2)-PHI(I+1,J,2))*TC(I,J,2)*DELX(J)                  ***
      IF(X) 1210,1230,1220                                            ***
 1210 XNGSUM=XNGSUM-X                                                 ***
      GO TO 1230                                                      ***
 1220 POSSUM=POSSUM+X                                                 ***
 1230 IF(S(I-1,J,2).GE.0..OR.T(I-1,J,2).EQ.0.) GO TO 1260             ***
      X=(PHI(I,J,2)-PHI(I-1,J,2))*TC(I-1,J,2)*DELX(J)                ***
      IF(X) 1240,1260,1250                                            ***
 1240 XNGSUM=XNGSUM-X                                                 ***
      GO TO 1260                                                      ***
 1250 POSSUM=POSSUM+X                                                 ***
```

```
 1260 IF(S(I,J+1,2).GE.0..OR.T(I,J+1,2).EQ.0.) GO TO 1290                  ***
      X=(PHI(I,J,2)-PHI(I,J+1,2))*TR(I,J,2)*DELY(I)                        ***
      IF(X) 1270,1290,1280                                                 ***
 1270 XNGSUM=XNGSUM-X                                                      ***
      GO TO 1290                                                           ***
 1280 POSSUM=POSSUM+X                                                      ***
 1290 IF(S(I,J-1,2).GE.0..OR.T(I,J-1,2).EQ.0.) GO TO 1350                  ***
      X=(PHI(I,J,2)-PHI(I,J-1,2))*TR(I,J-1,2)*DELY(I)                      ***
      IF(X) 1300,1350,1310                                                 ***
 1300 XNGSUM=XNGSUM-X                                                      ***
      GO TO 1350                                                           ***
 1310 POSSUM=POSSUM+X                                                      ***
      GO TO 1350                                                           ***
 1320 X=(PHI(I,J,2)-PHI(I,J,1))*TK(I,J,1)*DELX(J)*DELY(I)                  ***
      IF(X) 1330,1350,1340                                                 ***
 1330 XNSUM=XNSUM-X                                                        ***
      GO TO 1350                                                           ***
 1340 PSUM=PSUM+X                                                          ***
 1350 CONTINUE                                                             ***
      RESID(1,NNNN)=POSSUM                                                 ***
      RESID(2,NNNN)=XNGSUM                                                 ***
      ARESID(1,NNNN)=PSUM                                                  ***
      ARESID(2,NNNN)=XNSUM                                                 ***
 1360 CONTINUE                                                             ***
C                                                                          ***
C     LATERAL FLOW.                                                        ***
C                                                                          ***
      DO 1370 I=1,2                                                        ***
      DO 1370 J=1,NZNS                                                     ***
      XMAX(I,J)=0.                                                         ***
 1370 XMIN(I,J)=0.                                                         ***
      DO 1510 K=1,KO                                                       ***
      DO 1500 NN=1,NZNS                                                    ***
      QQPOS=0.                                                             ***
      QQNEG=0.                                                             ***
      DO 1490 I=2,I1                                                       ***
      DO 1490 J=2,J1                                                       ***
      IF(IZN(I,J).NE.NN) GO TO 1490                                        ***
      IF(IZN(I,J).EQ.0) GO TO 1490                                         ***
      IF(S(I+1,J,K).LT.0..OR.T(I+1,J,K).EQ.0..OR.IZN(I+1,J).EQ.NN) GO TO   ***
     1 1400                                                                ***
      X=TC(I,J,K)*(PHI(I,J,K)-PHI(I+1,J,K))*DELX(J)                        ***
      IF(X) 1380,1400,1390                                                 ***
 1380 QQNEG=QQNEG-X                                                        ***
      GO TO 1400                                                           ***
 1390 QQPOS=QQPOS+X                                                        ***
 1400 IF(S(I-1,J,K).LT.0..OR.T(I-1,J,K).EQ.0..OR.IZN(I-1,J).EQ.NN) GO TO   ***
     1 1430                                                                ***
      X=TC(I-1,J,K)*(PHI(I,J,K)-PHI(I-1,J,K))*DELX(J)                      ***
      IF(X) 1410,1430,1420                                                 ***
 1410 QQNEG=QQNEG-X                                                        ***
      GO TO 1430                                                           ***
 1420 QQPOS=QQPOS+X                                                        ***
 1430 IF(S(I,J+1,K).LT.0..OR.T(I,J+1,K).EQ.0..OR.IZN(I,J+1).EQ.NN) GO TO   ***
     1 1460                                                                ***
```

```
      X=TR(I,J,K)*(PHI(I,J,K)-PHI(I,J+1,K))*DELY(I)                     ***
      IF(X) 1440,1460,1450                                              ***
 1440 QQNEG=QQNEG-X                                                     ***
      GO TO 1460                                                        ***
 1450 QQPOS=QQPOS+X                                                     ***
 1460 IF(S(I,J-1,K).LT.0..OR.T(I,J-1,K).EQ.0..OR.IZN(I,J-1).EQ.NN) GO TO ***
     1 1490                                                             ***
      X=TR(I,J-1,K)*(PHI(I,J,K)-PHI(I,J-1,K))*DELY(I)                   ***
      IF(X) 1470,1490,1480                                              ***
 1470 QQNEG=QQNEG-X                                                     ***
      GO TO 1490                                                        ***
 1480 QQPOS=QQPOS+X                                                     ***
 1490 CONTINUE                                                          ***
      XMAX(K,NN)=QQPOS                                                  ***
      XMIN(K,NN)=QQNEG                                                  ***
 1500 CONTINUE                                                          ***
 1510 CONTINUE                                                          ***
C                                                                       ***
C     WELLS.                                                            ***
C                                                                       ***
      DO 1515 I=1,2                                                     ***
      DO 1515 J=1,NZNS                                                  ***
      BDYQ(I,J)=0.                                                      ***
 1515 RESID2(I,J)=0.                                                    ***
      DO 1560 K=1,KO                                                    ***
      DO 1550 NNN=1,NZNS                                                ***
      QNEG=0.                                                           ***
      QPOS=0.                                                           ***
      DO 1540 I=2,I1                                                    ***
      DO 1540 J=2,J1                                                    ***
      IF(IZN(I,J).NE.NNN) GO TO 1540                                    ***
      X=WELL(I,J,K)*DELX(J)*DELY(I)                                     ***
      IF(X) 1520,1540,1530                                              ***
 1520 QNEG=QNEG-X                                                       ***
      GO TO 1540                                                        ***
 1530 QPOS=QPOS+X                                                       ***
 1540 CONTINUE                                                          ***
      BDYQ(K,NNN)=QPOS                                                  ***
      RESID2(K,NNN)=QNEG                                                ***
 1550 CONTINUE                                                          ***
 1560 CONTINUE                                                          ***
C                                                                       ***
C     RECHARGE.                                                         ***
C                                                                       ***
      DO 1580 NN=1,NZNS                                                 ***
      RECHQ(NN)=0.                                                      ***
      DO 1570 I=2,I1                                                    ***
      DO 1570 J=2,J1                                                    ***
      IF(IZN(I,J).NE.NN) GO TO 1570                                     ***
      RECHQ(NN)=RECHQ(NN)+QRE(I,J)*DELX(J)*DELY(I)                      ***
 1570 CONTINUE                                                          ***
 1580 CONTINUE                                                          ***
C                                                                       ***
C     STORAGE.                                                          ***
C                                                                       ***
```

```
      DO 1590 I=1,2                                                      ***
      DO 1590 J=1,NZNS                                                   ***
 1590 STORAG(I,J)=0.                                                     ***
      DO 1620 K=1,K0                                                     ***
      DO 1610 NNN=1,NZNS                                                 ***
      DO 1600 I=2,I1                                                     ***
      DO 1600 J=2,J1                                                     ***
      IF(S(I,J,K).LT.0.) GO TO 1600                                      ***
      IF(DELT.LE.0.0) GO TO 1600                                         ***
      IF(IZN(I,J).NE.NNN) GO TO 1600                                     ***
      STORAG(K,NNN)=STORAG(K,NNN)+S(I,J,K)*(OLD(I,J,K)-PHI(I,J,K))*DELX( ***
     1J)*DELY(I)/DELT                                                    ***
 1600 CONTINUE                                                           ***
 1610 CONTINUE                                                           ***
 1620 CONTINUE                                                           ***
C                                                                        ***
C     TOTALS.                                                            ***
C                                                                        ***
      DO 1630 N=1,NZNS                                                   ***
      X1STOT(N)=STORAG(1,N)+ARESID(1,N)+XMIN(1,N)+BDYQ(1,N)              ***
      X2STOT(N)=STORAG(2,N)+RECHQ(N)+ZINSUM(N)+RESID(2,N)+XMIN(2,N)+BDYQ ***
     1(2,N)                                                              ***
      X1DTOT(N)=RESID2(1,N)+ARESID(2,N)+XMAX(1,N)                        ***
      X2DTOT(N)=RESID2(2,N)+ZOUTSM(N)+RESID(1,N)+XMAX(2,N)               ***
      SDDIFF(N)=(X1STOT(N)+X2STOT(N))-(X1DTOT(N)+X2DTOT(N))              ***
      IF(X1STOT(N).NE.0.0.OR.X2STOT(N).NE.0.0) GO TO 1625                ***
      IF(X1DTOT(N).EQ.0.0.AND.X2DTOT(N).EQ.0.0) GO TO 1630               ***
 1625 PCDIFF(N)=2.*SDDIFF(N)*100./(X1STOT(N)+X2STOT(N)+X1DTOT(N)+X2DTOT( ***
     1N))                                                                ***
 1630 CONTINUE                                                           ***
      DO 1640 N=1,NZNS                                                   ***
      WRITE(6,1700) N                                                    ***
      WRITE(6,1710)                                                      ***
      WRITE(6,1720)                                                      ***
      WRITE(6,1730)                                                      ***
      WRITE(6,1740)                                                      ***
      WRITE(6,1760)                                                      ***
      WRITE(6,1770)                                                      ***
      WRITE(6,1780)                                                      ***
      WRITE(6,1790)                                                      ***
      WRITE(6,1800) STORAG(1,N),STORAG(2,N)                              ***
      WRITE(6,1810) RECHQ(N)                                             ***
      WRITE(6,1820) ZINSUM(N)                                            ***
      WRITE(6,1830) ARESID(1,N),RESID(2,N)                               ***
      WRITE(6,1840) XMIN(1,N),XMIN(2,N)                                  ***
      WRITE(6,1850) BDYQ(1,N),BDYQ(2,N)                                  ***
      WRITE(6,1860)                                                      ***
      WRITE(6,1870) X1STOT(N),X2STOT(N)                                  ***
      WRITE(6,1880)                                                      ***
      WRITE(6,1890)                                                      ***
      WRITE(6,1900) RESID2(1,N),RESID2(2,N)                              ***
      WRITE(6,1910) ZOUTSM(N)                                            ***
      WRITE(6,1920) ARESID(2,N),RESID(1,N)                               ***
      WRITE(6,1930) XMAX(1,N),XMAX(2,N)                                  ***
      WRITE(6,1940)                                                      ***
```

```
      WRITE(6,1950) X1DTOT(N),X2DTOT(N)                                 ***
      WRITE(6,1960)                                                     ***
      WRITE(6,1970)                                                     ***
      WRITE(6,1980) SDDIFF(N)                                           ***
      WRITE(6,1990) PCDIFF(N)                                           ***
      WRITE(6,2000)                                                     ***
      WRITE(6,2010)                                                     ***
      WRITE(6,2020) VFUP(N)                                             ***
      WRITE(6,2030) VFDOWN(N)                                           ***
 1640 CONTINUE                                                          ***
      RETURN                                                            CHK1550
C                                                                       CHK1560
C     ---FORMATS---                                                     CHK1570
C                                                                       CHK1580
C     ------------------------------------------------------------------CHK1590
C                                                                       CHK1600
C                                                                       CHK1610
C                                                                       CHK1620
  260 FORMAT ('0',10X,'CUMULATIVE MASS BALANCE:',16X,'L**3',23X,'RATES FCHK1630
     1OR THIS TIME STEP:',16X,'L**3/T'/11X,24('-'),43X,25('-')//20X,'SOUCHK1640
     2RCES:',69X,'STORAGE =',F20.4/20X,8('-'),68X,'RECHARGE =',F20.4/27XCHK1650
     3,'STORAGE =',F20.2,35X,'CONSTANT FLUX =',F20.4/26X,'RECHARGE =',F2CHK1660
     40.2,41X,'PUMPING =',F20.4/21X,'CONSTANT FLUX =',F20.2,30X,'EVAPOTRCHK1670
     5ANSPIRATION =',F20.4/21X,'CONSTANT HEAD =',F20.2,34X,'CONSTANT HEACHK1680
     6D:'/27X,'LEAKAGE =',F20.2,46X,'IN =',F20.4/21X,'TOTAL SOURCES =',FCHK1690
     720.2,45X,'OUT =',F20.4/96X,'LEAKAGE:'/20X,'DISCHARGES:',45X,'FROM CHK1700
     8PREVIOUS PUMPING PERIOD =',F20.4/20X,11('-'),68X,'TOTAL =',F20.4/1CHK1710
     96X,'EVAPOTRANSPIRATION =',F20.2/21X,'CONSTANT HEAD =',F20.2,36X,'SCHK1720
     $UM OF RATES =',F20.4/19X'QUANTITY PUMPED =',F20.2/27X,'LEAKAGE =',CHK1730
     $F20.2/19X,'TOTAL DISCHARGE =',F20.2//17X,'DISCHARGE-SOURCES =',F20CHK1740
     $.2/15X,'PER CENT DIFFERENCE =',F20.2//)                           CHK1750
  270 FORMAT ('0FLOW RATES TO CONSTANT HEAD NODES:'/' ',34('-')//' ',3(9CHK1760
     1X,'K',4X,'I',4X,'J',5X,'RATE (L**3/T)')/' ',3(9X,'-',4X,'-',4X,'-'CHK1770
     2,5X,13('-'))/)                                                    CHK1780
  280 FORMAT (/(1X,3(I10,2I5,G18.7)))                                   CHK1790
  290 FORMAT ('0FLOW TO TOP LAYER =',G15.7,'   FLOW TO BOTTOM LAYER =',GCHK1800
     115.7,'       POSITIVE UPWARD')                                    CHK1810
  300 FORMAT('1',2X,              'RATE IN CFS OF STREAM FLOW IN EACH BLO  ***
     1CK FOR THIS STEP ( OUT OF AQUIFER (-) )')                         ***
  305 FORMAT('0',5X,'I',5X,'J',5X,'K',8X,'STREAM',8X,25X,'I',           ***
     15X,'J',5X,'K',8X,'STREAM')                                        ***
  310 FORMAT(' ',4X,I2,4X,I2,5X,I1,6X,E10.4)                            ***
  311 FORMAT('+',72X,I2,4X,I2,5X,I1,6X,E10.4)                           ***
  315 FORMAT('1',2X,'TOTAL RATES,IN CFS,OF STREAM - AQUIFER FLOW BY ZONE ***
     1')                                                                ***
  316 FORMAT('0',12X,'ZONE',5X,'STREAMS INTO AQUIFER',5X,'AQUIFER INTO S ***
     1TREAMS')                                                          ***
  317 FORMAT('0',13X,I2,12X,E10.3,16X,E10.3)                            ***
  320 FORMAT('0',2X,              'TOTAL RATE,IN CFS,OF STREAM FLOW IN MO ***
     1DEL AREA FOR THIS STEP')                                          ***
  325 FORMAT('0',5X,'STREAMS INTO AQUIFER',5X,'AQUIFER INTO STREAMS')   ***
  330 FORMAT(' ',10X,E10.4,15X,E10.4)                                   ***
  332 FORMAT('1',2X,'BASIC STATISTICS RELATING TO RESIDUALS AT ALL BLOCK ***
     1S')                                                               ***
  334 FORMAT('0',2X,'LAYER',2X,'ZONE',2X,'BLOCKS',4X,'MEAN',4X,'MEAN(ABS ***
```

```
     1)',2X,'ST.DEV.(MEAN)',2X,'MAX.DD',3X,'MAX.BU')                        ***
  336 FORMAT('0',4X,I1,5X,I2,4X,I4,5X,F5.1,5X,F5.1,8X,F5.1,7X,F6.1,4X,F6    ***
     1.1)                                                                    ***
  386 FORMAT('1',4X,'TOTAL VERTICAL FLOW RATES BY ZONE (CFS)')               ***
  387 FORMAT('0',14X,'ZONE',8X,'DOWN',10X,'UP')                              ***
  388 FORMAT('0',15X,I2,5X,E10.3,3X,E10.3)                                   ***
 1000 FORMAT('1',10X,'FLOW BETWEEN ZONES IN LAYER',3X,I2)                    ***
 1100 FORMAT('0',6X,F10.2,2X,'CFS FROM ZONE',2X,I2,2X,'INTO ZONE',2X,I2,     ***
     12X,'OVER',2X,I3,2X,'BLOCK BOUNDARIES (',2X,F10.2,2X,'CFS PER BOUND     ***
     2ARY  )')                                                               ***
 1700 FORMAT('1',12X,'ZONE',2X,I2)                                           ***
 1710 FORMAT(' ',11X,'----------')                                           ***
 1720 FORMAT('0',11X,'MASS BALANCE')                                         ***
 1730 FORMAT(' ',13X,'(IN CFS)')                                             ***
 1740 FORMAT(' ',10X,'--------------')                                       ***
 1760 FORMAT('0',34X,'LAYER  1',5X,'LAYER  2')                               ***
 1770 FORMAT(' ',33X,'----------',3X,'----------')                           ***
 1780 FORMAT('0',9X,'SOURCES')                                               ***
 1790 FORMAT(' ',8X,'---------')                                             ***
 1800 FORMAT(' ',19X,'STORAGE    = ',F11.3,2X,F11.3)                         ***
 1810 FORMAT('0',18X,'RECHARGE    = ',13X,     F11.3)                        ***
 1820 FORMAT('0',19X,'STREAMS    = ',13X,F11.3)                              ***
 1830 FORMAT('0',21X,'RIVER    = ',F11.3,2X,F11.3)                           ***
 1840 FORMAT('0',17X,'UNDERFLOW    = ',F11.3,2X,F11.3)                       ***
 1850 FORMAT('0',18X,'BOUNDARY    = ',F11.3,2X,F11.3)                        ***
 1860 FORMAT(' ',16X,'------------------------------------------')          ***
 1870 FORMAT(' ',21X,'TOTAL    = ',F11.3,2X,F11.3)                           ***
 1880 FORMAT('0',9X,'DISCHARGES')                                            ***
 1890 FORMAT(' ',8X,'------------')                                          ***
 1900 FORMAT(' ',19X,'PUMPING    = ',F11.3,2X,F11.3)                         ***
 1910 FORMAT('0',19X,'STREAMS    = ',13X,F11.3)                              ***
 1920 FORMAT('0',21X,'RIVER    = ',F11.3,2X,F11.3)                           ***
 1930 FORMAT('0',17X,'UNDERFLOW    = ',F11.3,2X,F11.3)                       ***
 1940 FORMAT(' ',15X,'-------------------------------------------')         ***
 1950 FORMAT(' ',21X,'TOTAL    = ',F11.3,2X,F11.3)                           ***
 1960 FORMAT('0',9X,'BALANCE')                                               ***
 1970 FORMAT(' ',8X,'---------')                                             ***
 1980 FORMAT(' ',15X,'TOTAL SOURCES  -  TOTAL DISCHARGES    = ',F11.3)       ***
 1990 FORMAT('0',31X,'PERCENT DIFFERENCE    = ',F11.3)                       ***
 2000 FORMAT('0',9X,'VERTICAL FLOW')                                         ***
 2010 FORMAT(' ',8X,'---------------')                                       ***
 2020 FORMAT(' ',15X,'FROM LAYER 1 TO LAYER 2    = ',F11.3)                  ***
 2030 FORMAT('0',15X,'FROM LAYER 2 TO LAYER 1    = ',F11.3)                  ***
 2040 FORMAT(8E10.4)                                                         ***
 2050 FORMAT(3I5,2F10.1)                                                     ***
 2060 FORMAT(3I10,F10.2)                                                     ***
 2070 FORMAT(2I5,F10.2)                                                      ***
      END                                                                CHK1820

      SUBROUTINE PRNTAI(PHI,STRT,T,S,WELL,DELX,DELY)                     PRN
C     -----------------------------------------------------------------PRN
C     PRINT MAPS OF DRAWDOWN AND HYDRAULIC HEAD                          PRN
C     -----------------------------------------------------------------PRN
C                                                                        PRN
C     SPECIFICATIONS:                                                    PRN
```

```
      REAL *8PHI,Z,XLABEL,YLABEL,TITLE,XN1,MESUR
      REAL *4K
C
      DIMENSION PHI(I0,J0,K0), STRT(I0,J0,K0), S(I0,J0,K0), WELL(I0,J0,K
     10), DELX(J0), DELY(I0), T(I0,J0,K0)
C
      COMMON /INTEGR/ I0,J0,K0,I1,J1,K1,I,J,K,NPER,KTH,ITMAX,LENGTH,KP,NP
     1WEL,NUMT,IFINAL,IT,KT,IHEAD,IDRAW,IFLO,IERR,I2,J2,K2,IMAX,ITMX1,NC
     2H,IDK1,IDK2,IWATER,IQRE,IP,JP,IQ,JQ,IK,JK,K5,IPU1,IPU2,ITK,IEQN,KK  ***
     3K,KKKK,IR,ISTAT,MLTCHK,ISBOUT,IJKMAP,IVHMAP,IZTOZ,ITABLE,           ***
     4LAYDDN,ISLEAK,IOCTAP,IWLWD,IPPOUT                                   ***
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(6),XN1,MESUR,PRNT(122),BLANK
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100),
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2
      RETURN
C     ..........................................................................
C
C     ---INITIALIZE VARIABLES FOR PLOT---
C     ********************
      ENTRY MAP
C     ********************
      YDIM=0.
      WIDTH=0.
      DO 10 J=2,J1
   10 WIDTH=WIDTH+DELX(J)
      DO 20 I=2,I1
   20 YDIM=YDIM+DELY(I)
   30 XSF=DINCH*XSCALE
      YSF=DINCH*YSCALE
      NYD=YDIM/YSF
      IF (NYD*YSF.LE.YDIM-DELY(I1)/2.) NYD=NYD+1
      IF (NYD.LE.12) GO TO 40
      DINCH=YDIM/(12.*YSCALE)
      WRITE (6,330) DINCH
      IF (YSCALE.LT.1.0) WRITE (6,340)
      GO TO 30
   40 NXD=WIDTH/XSF
      IF (NXD*XSF.LE.WIDTH-DELX(J1)/2.) NXD=NXD+1
      N4=NXD*N1+1
      N5=NXD+1
      N6=NYD+1
      N8=N2*NYD+1
      NA(1)=N4/2-1
      NA(2)=N4/2
      NA(3)=N4/2+3
      NC=(N3-N8-10)/2
      ND=NC+N8
      NE=MAX0(N5,N6)
      VF1(3)=DIGIT(ND)
      VF2(3)=DIGIT(ND)
      VF3(3)=DIGIT(NC)
      XLABEL(3)=MESUR
      YLABEL(6)=MESUR
      DO 60 I=1,NE
      NNX=N5-I
```

```
      NNY=I-1
      IF (NNY.GE.N6) GO TO 50
      YN(I)=YSF*NNY/YSCALE
   50 IF (NNX.LT.0) GO TO 60
      XN(I)=XSF*NNX/YSCALE
   60 CONTINUE
      RETURN
C     ..........................................................................
C
C     ********************
      ENTRY PRNTA(NG,LA)
C     ********************
C     ---VARIABLES INITIALIZED EACH TIME A PLOT IS REQUESTED---
      DIST=WIDTH-DELX(J1)/2.
      JJ=J1
      LL=1
      Z=NXD*XSF
      IF (NG.EQ.1) WRITE (6,300) (TITLE(I),I=1,3),LA
      IF (NG.EQ.2) WRITE (6,300) (TITLE(I),I=4,6),LA
      DO 290 I=1,N4
C
C     ---LOCATE X AXES---
      IF (I.EQ.1.OR.I.EQ.N4) GO TO 70
      PRNT(1)=SYM(12)
      PRNT(N8)=SYM(12)
      IF ((I-1)/N1*N1.NE.I-1) GO TO 90
      PRNT(1)=SYM(14)
      PRNT(N8)=SYM(14)
      GO TO 90
C
C     ---LOCATE Y AXES---
   70 DO 80 J=1,N8
      IF ((J-1)/N2*N2.EQ.J-1) PRNT(J)=SYM(14)
   80 IF ((J-1)/N2*N2.NE.J-1) PRNT(J)=SYM(13)
C
C     ---COMPUTE LOCATION OF NODES AND DETERMINE APPROPRIATE SYMBOL---
   90 IF (DIST.LT.0..OR.DIST.LT.Z-XN1*XSF) GO TO 240
      YLEN=DELY(2)/2.
      DO 220 L=2,I1
      J=YLEN*N2/YSF+1.5
      IF (T(L,JJ,LA).EQ.0.) GO TO 160
      IF (S(L,JJ,LA).LT.0.) GO TO 210
      INDX3=0
      GO TO (100,110), NG
  100 K=(STRT(L,JJ,LA)-PHI(L,JJ,LA))*FACT1
C     -TO CYCLE SYMBOLS FOR DRAWDOWN, REMOVE C FROM COL. 1 OF NEXT CARD-
C     K=AMOD(K,10.)
      GO TO 120
  110 K=PHI(L,JJ,LA)*FACT2
  120 IF (K) 130,160,140
  130 IF (J-2.GT.0) PRNT(J-2)=SYM(13)
      N=-K+.5
      IF (N.LT.100) GO TO 150
      GO TO 190
  140 N=K+.5
```

```
      IF (N.LT.100) GO TO 150                                           PRN1150
      IF (N.GT.999) GO TO 190                                           PRN1160
      INDX3=N/100                                                       PRN1170
      IF (J-2.GT.0) PRNT(J-2)=SYM(INDX3)                                PRN1180
      N=N-INDX3*100                                                     PRN1190
  150 INDX1=MOD(N,10)                                                   PRN1200
      IF (INDX1.EQ.0) INDX1=10                                          PRN1210
C     -TO CYCLE SYMBOLS FOR DRAWDOWN, REMOVE C FROM COL. 1 OF NEXT CARD-PRN1220
C     IF (NG.EQ.1) GO TO 170                                            PRN1230
      INDX2=N/10                                                        PRN1240
      IF (INDX2.GT.0) GO TO 180                                         PRN1250
      INDX2=10                                                          PRN1260
      IF (INDX3.EQ.0) INDX2=15                                          PRN1270
      GO TO 180                                                         PRN1280
  160 INDX1=15                                                          PRN1290
  170 INDX2=15                                                          PRN1300
  180 IF (J-1.GT.0) PRNT(J-1)=SYM(INDX2)                                PRN1310
      PRNT(J)=SYM(INDX1)                                                PRN1320
      GO TO 220                                                         PRN1330
  190 DO 200 II=1,3                                                     PRN1340
      JI=J-3+II                                                         PRN1350
  200 IF (JI.GT.0) PRNT(JI)=SYM(11)                                     PRN1360
  210 IF (S(L,JJ,LA).LT.0.) PRNT(J)=SYM(16)                             PRN1370
  220 YLEN=YLEN+(DELY(L)+DELY(L+1))/2.                                  PRN1380
  230 DIST=DIST-(DELX(JJ)+DELX(JJ-1))/2.                                PRN1390
      JJ=JJ-1                                                           PRN1400
      IF (JJ.EQ.0) GO TO 240                                            PRN1410
      IF (DIST.GT.Z-XN1*XSF) GO TO 230                                  PRN1420
  240 CONTINUE                                                          PRN1430
C                                                                       PRN1440
C     ---PRINT AXES,LABELS, AND SYMBOLS---                              PRN1450
      IF (I-NA(LL).EQ.0) GO TO 260                                      PRN1460
      IF ((I-1)/N1*N1-(I-1)) 270,250,270                                PRN1470
  250 WRITE (6,VF1) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8),XN(1+(I-1)/6)    PRN1480
      GO TO 280                                                         PRN1490
  260 WRITE (6,VF2) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8),XLABEL(LL)       PRN1500
      LL=LL+1                                                           PRN1510
      GO TO 280                                                         PRN1520
  270 WRITE (6,VF2) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8)                  PRN1530
C                                                                       PRN1540
C     ---COMPUTE NEW VALUE FOR Z AND INITIALIZE PRNT---                 PRN1550
  280 Z=Z-2.*XN1*XSF                                                    PRN1560
      DO 290 J=1,N8                                                     PRN1570
  290 PRNT(J)=SYM(15)                                                   PRN1580
C                                                                       PRN1590
C     ---NUMBER AND LABEL Y AXIS AND PRINT LEGEND---                    PRN1600
      WRITE (6,VF3) (BLANK(J),J=1,NC),(YN(I),I=1,N6)                    PRN1610
      WRITE (6,320) (YLABEL(I),I=1,6)                                   PRN1620
      IF (NG.EQ.1) WRITE (6,310) FACT1                                  PRN1630
      IF (NG.EQ.2) WRITE (6,310) FACT2                                  PRN1640
      RETURN                                                            PRN1650
C                                                                       PRN1660
C     ---FORMATS---                                                     PRN1670
C                                                                       PRN1680
C     ------------------------------------------------------------------PRN1690
```

```
C
C
  300 FORMAT ('1',49X,3A8,'LAYER',I4//)
  310 FORMAT ('0EXPLANATION'/' ',11('-')//' R = CONSTANT HEAD BOUNDARY'/
     1' *** = VALUE EXCEEDED 3 FIGURES'/' MULTIPLICATION FACTOR =',F8.3)
  320 FORMAT ('0',39X,6A8)
  330 FORMAT ('0',25X,10('*'),' TO FIT MAP WITHIN 12 INCHES, DINCH REVIS
     1ED TO',G15.7,1X,10('*'))
  340 FORMAT ('0',45X,'NOTE: GENERALLY SCALE SHOULD BE > OR = 1.0')
      END

      BLOCK DATA
C     ----------
C
C     SPECIFICATIONS:
      REAL *8XLABEL,YLABEL,TITLE,XN1,MESUR
C
      COMMON /SARRAY/ ICHK(13),LEVEL1(9),LEVEL2(9)
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(6),XN1,MESUR,PRNT(122),BLANK
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100),
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2
C     ******************************************************************
C
      DATA ICHK/'DRAW','HEAD','MASS','DK1','DK2','WATE','RECH','PUN1','P
     1UN2','ITKR','EQN3',2*0/
      DATA SYM/'1','2','3','4','5','6','7','8','9','0','*','¢','-','+','
     1 ','R','W'/
      DATA PRNT/122*' '/,N1,N2,N3,XN1/6,10,133,.833333333D-1/,BLANK/60*'
     1 '/,NA(4)/1000/
      DATA XLABEL/' X DIS- ','TANCE IN',' MILES '/,YLABEL/'DISTANCE','
     1FROM OR','IGIN IN ','Y DIRECT','ION, IN ','MILES   '/,TITLE/'PLOT
     2OF ','DRAWDOWN',' ','PLOT OF ','HYDRAULI','C HEAD'/
      DATA DIGIT/'1','2','3','4','5','6','7','8','9','10','11','12','13'
     1,'14','15','16','17','18','19','20','21','22','23','24','25','26',
     2'27','28','29','30','31','32','33','34','35','36','37','38','39','
     340','41','42','43','44','45','46','47','48','49','50','51','52','5
     43','54','55','56','57','58','59','60','61','62','63','64','65','66
     5','67','68','69','70','71','72','73','74','75','76','77','78',' 79
     6','80','81','82','83','84','85','86','87','88','89','90','91','92'
     7,'93','94','95','96','97','98','99','100','101','102','103',' 104'
     8,'105','106','107','108','109','110','111','112','113','114','115'
     9,'116','117','118','119','120','121','122'/
      DATA VF1/'(1H ',',',','    ','A1,F','10.2',')'/
      DATA VF2/'(1H ',',',','    ','A1,1','X,A8',')'/
      DATA VF3/'(1H0',',',','    ','A1,F','3.1,','12F1','0.2)'/
C     ******************************************************************
      END
```

ATTACHMENT B

Instructions for use of model program

The following is a list of data input instructions for the model program used in this investigation. It is a modified version of the original instructions in Trescott, (1975).

DATA INPUT INSTRUCTIONS

REGIONAL GROUND-WATER FLOW MODEL OF LOWER SUSQUEHANNA RIVER BASIN

(Modified from Original 3-D Model (Trescott, 1975)

by J.M. Gerhart and G.J. Lazorchick in 1980 and 1981)

Group I: Title, Simulation Options, and Problem Dimensions

This group of cards, which is read by the main program, contains data required to dimension the model. To specify an option on card 5, punch the characters underlined in the definition. For an option not used, that section of card 5 can be left blank.

Note: Default typing of variables applies for all data input.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
1	1-80	20A4	HEADING	Any title the user wishes to print on one line at the start of output.
2	1-52	13A4	HEADING	
3	1-10	I10	IO	Number of rows
	11-20	I10	JO	Number of columns
	21-30	I10	KO	Number of layers (specify 2)
	31-40	I10	ITMAX	Maximum number of iterations per time step
	41-50	I10	NCH	Number of constant-head blocks
	51-60	I10	NZNS	Number of hydrogeologic units
	61-65	I5	IR	IR=1 if head-dependent stream output desired; blank otherwise

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
	66-70	I5	ISTAT	ISTAT=1 if residual statistics desired; blank otherwise
	71-75	I5	MLTCHK	MLTCHK=1 if spot check of hydraulic conductivity modification for topography desired; blank otherwise
4	1-5	I5	ISBOUT	ISBOUT=1 if block-by-block printout of stream-aquifer flow desired; blank otherwise
	6-10	I5	IJKMAP	IJKMAP=1 if maps of head change from STRT desired; blank otherwise

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
5	21-23	A3	IDK2	DK2 to write computed head, elapsed time, and mass balance parameters on unit 4 (disk)
	26-29	A4	IWATER	WATE if the upper layer is unconfined (must specify)
	31-34	A4	IQRE	RECH for a constant recharge that may be a function of space
	36-39	A4	IPU1	PUN1 to read initial head, elapsed time, and mass balance parameters from cards
	41-44	A4	IPU2	PUN2 to punch computed head, elapsed time, and mass balance parameters on cards

Group II: Scalar parameters

The parameters required in every problem are underlined. The other parameters are required as noted; when not required, their location on the card can be left blank. The G format is used to read E, F and I format data. Minimize mistakes by always right-justifying data in the field. If F format data do not contain significant figures to the right of the decimal point, the decimal point can be omitted.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
1	1-10	I10	NPER	Number of pumping periods for the simulation
	11-20	I10	KTH	Number of time steps between printouts

Note: To print only the results for the final time step in a pumping period, make KTH greater than the expected number of time steps. The program always prints the results for the final time step.

	21-30	G10.0	ERR	Error criterion for closure (L)

Note: When the head change in all blocks on subsequent iterations is less than this value (for example, 0.01 foot), the program has converged to a solution for the time step.

	31-40	I10	LENGTH	Number of iteration parameters (5 for SIP)

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
4	1-20	G20.10	QRET	
	21-40	G20.10	CHST	
	41-60	G20.10	CHDT	
	61-80	G20.10	FLUXT	
5	1-20	G20.10	STORT	
	21-40	G20.10	ETFLXT	
	41-60	G20.10	FLXNT	

Group III: Array Data

Each of the following data sets (except data sets 1, 11, 12, 13) consists of a parameter card and, if the data set contains variable data, a set of data cards. If the data set requires data for each layer, a parameter card and data cards (for layers with variable data) are required for each layer. Each parameter card contains at least five variables:

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
	1-10	G10.0	FAC	If IVAR=0, FAC is the value assigned to every element of the matrix for this layer. If IVAR=1, FAC is the multiplication for the following set of data cards for this layer.
	11-20	G10.0	IVAR	=0 if no data cards are to be read for this layer. =1 if data cards for this layer follow.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
	21-30	G10.0	IPRN	=0 if input data for this layer are to be printed; =1 if input data for the layer are not to be printed.
	61-70	G10.0	IRECS	=0 if the matrix is being read from cards or if each element is being set equal to FAC. =1 if the matrix is to be read from disk (unit 2)
	71-80	G10.0	IRECD	=0 if the matrix is not to be stored on disk. =1 if the matrix being read from cards or set equal to FAC is to be stored on disk (unit 2) for later retrieval.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
4	11-15	I5	IVHMAP	IVHMAP=1 if map of head difference between layers desired; blank otherwise
	16-20	I5	IZTOZ	IZTOZ=1 if printout of unit-to-unit flow desired; blank otherwise
	21-25	I5	ITABLE	ITABLE=1 if mass balance for each unit desired; blank otherwise
	26-30	I5	LAYDDN	LAYDDN=1 if head change from STRT in both layers to be written on file 11; blank otherwise
	31-35	I5	ISLEAK	ISLEAK=1 if stream-aquifer flow in each block to be written on file 12; blank otherwise
	36-40	I5	IOCTAP	IOCTAP=1 or 2 if head change between pumping periods 4 and 10 to be written on files 13 or 14; blank otherwise
	41-45	I5	IWLWD	IWLWD=1 if rates of discharge in each stream block to be written on file 15 in format of well cards; blank otherwise

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
	46-50	I5	IPPOUT	IPPOUT=1 if head, head changes from STRT, and rates of stream discharge at end of each pumping period of transient simulation to be written on file 15; blank otherwise
5	1-4	A4	IDRAW	DRAW to print drawdown
	6-9	A4	IHEAD	HEAD to print hydraulic head
	11-14	A4	IFLOW	MASS to compute a mass balance
	16-18	A3	IDK1	DK1 to read initial head, elapsed time, and mass balance parameters from unit 4 on disk

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
2	1-10	G10.0	XSCALE	Factor to convert model length unit to unit used in X direction on maps (e.g. to convert from feet to miles, XSCALE= 5280) For no maps, card 2 is blank
	11-20	G10.0	YSCALE	Factor to convert model length unit to unit used in Y direction on maps
	21-30	G10.0	DINCH	Number of map units per inch
	31-40	G10.0	FACT1	Factor to adjust value of drawdown printed*(1/FACT1=contour interval)
	41-49	9I1	LEVEL1(I)	Layers for which drawdown maps are to be printed. List the layers starting in column 41; the first zero entry terminates the printing of drawdown maps (up to 9 layers)
	51-60	G10.0	FACT2	Factor to adjust value of head printed*
	61-69	9I1	LEVEL2(I)	Layers for which head maps are to be printed. List layers starting in column 61; the first zero entry terminates the printing of head maps.
	71-78	A8	MESUR	Name of map length unit

*Value of drawdown or head	FACT 1 or FACT 2	Printed value
	0.01	1
	0.1	5
52.57	1.0	53
	10.0	526
	100.0	***

Note: On the following three cards (3, 4, 5) are parameters in which elapsed time and cumulative volumes for mass balance are stored. For the start of a simulation insert three blank cards. For continuation of a previous run using cards as input, replace the three blank cards with the first three cards of punched output from the previous run. Using data from disk for input, leave the three blank cards in the data deck.

3	1-20	G20.10	SUM
	21-40	G20.10	SUMP
	41-60	G20.10	PUMPT
	61-80	G20.10	CFLUXT

When data cards are included, start each row on a new card. To prepare a set of data cards for an array that is a function of space, the general procedure is to overlay the finite-difference grid on a contoured map of the parameter and record the average value of the parameter for each finite-difference block on coding forms according to the appropriate format. In general, record only significant digits and no decimal points (except for data set 2); use the multiplication factor to convert the data to their appropriate values. For example, if DELX ranges from 1000 to 15000 feet, coded values should range from 1-15; the multiplication factor (FAC) would be 1000.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
1	1-80	8F10.4	PHI(I,J,K)	Head values for continuation of a previous run(L)(for all layers)

Note: For a new simulation this data set is omitted. Do not include a parameter card with this data set.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
2	1-80	8F10.4	STRT(I,J,K)	Starting head matrix(L) (for all layers)
3	1-80	20F4.0	S(I,J,K)	Location of constant-head blocks (for all layers)

Note: This matrix is only used to locate constant-head blocks. Code a negative number at constant-head blocks. At these blocks, T must be greater than zero.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
4	1-80	40F2.0	PERM(I,J)	Topographic setting (1=hilltop to 5=valley bottom)(only once for all layers)
5	1-80	20F4.0	BOTTOM(I,J)	Elevation of bottom of upper layer (L)

Note: Data set 5 is required only for simulating unconfined conditions in the upper layer. Omit if not used.

6	1-80	20F4.0	QRE(I,J)	Recharge rate in upper layer (L/T)

Note: Omit data set 6 if not used.

7	1-80	8E10.3	RCG(I,J,K)	Stream leakage coefficient for gaining stream conditions (1/T) (for all layers)
8	1-80	8E10.3	RCL(I,J,K)	Stream leakage coefficient for losing stream conditions(1/T) (for all layers)

NOTE: Both RCG and RCL should be divided by grid block area before entry.

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITIONS
9	1-80	20F4.0	RHSS(I,J,K)	Elevation of constant stream stage(L)(for all layers)
10	1-80	20F4.0	HB(I,J,K)	Elevation of stream infiltration cutoff(L)(for all layers)
11	1-80	40I2	IZN(I,J)	Hydrogeologic unit numbers(only once for all layers)(no parameter card)

Note: If any of data sets 7-11 are not used, insert a blank parameter card for each layer for each unused data set.

12 This data set is for hydrogeologic unit properties. There are 3 cards per unit, so 3(NZNS) cards needed. Each unit has the following 3 cards:

Card 1	1-2	I2	N	Hydrogeologic unit number
Card 2	1-10	F10.0	KXL(N)	Hydraulic conductivity in the x-direction in lower layer (L/T)
	11-20	F10.0	KYL(N)	Hydraulic conductivity in the y-direction in lower layer (L/T)
	21-30	F10.0	KZL(N)	Hydraulic conductivity in the z-direction in lower layer (L/T)
	31-40	F10.0	BZL(N)	Thickness of lower layer (L)
	41-50	F10.0	SZL(N)	Storage coefficient in lower layer (dimensionless)

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITIONS
Card 3	1-10	F10.0	KXU(N)	Hydraulic conductivity in the x-direction in upper layer (L/T)
	11-20	F10.0	KYU(N)	Hydraulic conductivity in the y-direction in upper layer (L/T)
	21-30	F10.0	KZU(N)	Hydraulic conductivity in the z-direction in upper layer (L/T)
	31-40	F10.0	BZU(N)	Initial saturated thickness of upper layer (L)
	41-50	F10.0	SZU(N)	Specific yield in upper layer (dimensionless)

DATA SET	COLUMNS	FORMAT	VARIABLE	DEFINITION
13	This data set is for multipliers to modify unit hydraulic conductivities according to topographic position. There is one card per unit, so NZNS cards needed. Each card should be set up as follows:			
	1-5	F5.0	PMULT(I,1)	Multiplier for hilltop setting
	6-10	F5.0	PMULT(I,2)	Multiplier for upper-slope setting
	11-15	F5.0	PMULT(I,3)	Multiplier for middle-slope setting
	16-20	F5.0	PMULT(I,4)	Multiplier for lower-slope setting
	21-25	F5.0	PMULT(I,5)	Multiplier for valley-bottom setting
14	1-80	8G10.0	DELX(J)	Grid spacing in x-direction(L)
15	1-80	8G10.0	DELY(I)	Grid spacing in y-direction(L)
16	1-80	8G10.0	DELZ(K)	Grid spacing in z-direction(L) (must be 1)

Group IV: Parameters that change with the pumping period

The program has two options for the simulation period:

1. To simulate a given number of time steps, set TMAX to a value larger than the expected simulation period. The program will use NUMT, CDLT, and DELT as CODED. If NUMT is greater than 50 change the dimension of ITTO in subroutine STEP to the appropriate size.

2. To simulate a given pumping period, set NUMT larger than the number required for the simulation period (for example, 50). The program will compute the exact DELT (which will be $\leq$ DELT coded) and NUMT to arrive exactly at TMAX on the last time step.

Card 1 is required for every problem.

CARD	COLUMNS	FORMAT	VARIABLE	DEFINITION
1	1-10	G10.0	KP	Number of the pumping period
	11-20	G10.0	KPM1	Number of the previous pumping period

Note: KPM1 is currently not used

	21-30	G10.0	NWEL	Number of wells for this pumping period
	31-40	G10.0	TMAX	Number of days in this pumping period
	41-50	G10.0	NUMT	Number of time steps
	51-60	G10.0	CDLT	Multiplying factor for DELT

Note: 1.5 is commonly used

	61-70	G10.0	DELT	Initial time step in hours

The following well cards are read only for the first pumping period but will automatically be used in all subsequent pumping periods.

	1-10	G10.0	K	Layer in which well is located
	11-20	G10.0	I	Row location of well
	21-30	G10.0	J	Column location of well
	31-40	G10.0	WELL(I,J,K)	Pumping rate (L^3/T), negative for a pumping well

For each additional pumping period, the following set of data is needed:

Card 1	Same as card 1, Group IV
Card 2	Card with multiplier for following recharge matrix (E10.3)
DATA SET	Recharge matrix for pumping period (20F4.0)

ATTACHMENT C

Water-level measurement data from observation-well network

The following table contains the results of water-level measurements in 320 wells (plate 2) in the model area in October 1980, April 1981, and October 1981. Differences between the three measurements are also included, as well as the hydrogeologic unit and topographic setting for each well.

Local number: Number used to identify well for U.S. Geological Survey well-schedule file.

Topographic setting: 1, hilltop; 2, upper-slope; 3, middle-slope; 4, lower-slope; 5, valley-bottom.

Change in water level: Negative change indicates a decline in water level.

ATTACHMENT C

Local number	Hydrogeologic unit	Topographic setting	Date: October 1980 Day	October 1980 Depth below land surface, in feet	April 1981 Day	April 1981 Depth below land surface, in feet	October 1981 Day	October 1981 Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	April 1981 to October 1981	October 1980 to October 1981
					Adams County						
110	5	4	28	17.10	22	12.20	20	15.95	4.90	-3.75	1.15
146	13	4	29	13.09	22	12.00	20	12.95	1.09	-.95	.14
481	5	4	30	25.89	21	15.21	19	25.74	10.68	-10.53	.15
568	8	4	28	20.51	21	14.80	19	21.20	5.71	-6.40	-.69
569	7	5	28	14.21	21	12.29	19	14.94	1.83	-2.65	-.82
570	5	5	28	20.62	21	19.70	19	21.70	.92	-2.00	-1.08
571	8	4	29	44.46	22	38.96	20	45.32	5.50	-6.36	-.86
572	13	4	28	5.05	21	1.84	19	6.59	3.21	-4.75	-1.54
573	5	4	30	30.09	20	15.30	19	31.08	14.79	-15.78	-.99
574	5	5	30	15.19	20	5.22	20	16.32	9.97	-11.10	-1.13
575	5	5	28	21.48	20	18.45	20	21.31	3.03	-2.86	.17
576	5	2	30	28.26	21	23.94	19	29.22	4.32	-5.28	-.96
577	13	2	28	55.46	20	48.88	21	55.95	6.58	-7.07	-.49
578	5	2	29	20.22	22	11.12	21	21.09	9.10	-9.97	-.87
579	5	1	28	34.16	22	24.50	21	32.16	9.66	-9.68	-.02
582	5	1	30	42.42	20	36.75	19	43.30	5.67	-6.55	-.88
583	5	4	30	32.02	20	29.81	19	31.48	2.21	-1.67	.54
584	13	2	30	14.14	20	9.32	19	14.19	4.82	-4.87	-.05
585	5	4	30	26.77	21	17.85	21	24.60	8.92	-6.75	2.17
586	13	3	30	32.28	20	16.43	19	27.62	15.85	-11.19	4.66
					Berks County						
698	1	4	28	17.19	23	12.16	19	16.80	5.03	-4.64	0.39
1282	1	3	29	50.84	23	46.43	20	50.90	4.41	-4.47	-.06
1284	18	3	29	53.35	23	42.99	19	50.45	10.36	-7.46	2.90
1285	21	1	28	31.56	23	26.90	19	31.10	4.66	-4.20	.46
1286	1	4	28	7.31	23	1.75	19	5.23	5.56	-3.48	2.08

ATTACHMENT C--continued

Hydrogeologic unit	Topographic setting	October 1980: Day	October 1980: Depth below land surface, in feet	April 1981: Day	April 1981: Depth below land surface, in feet	October 1981: Day	October 1981: Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	Change in water level, in feet: April 1981 to October 1981	Change in water level, in feet: October 1980 to October 1981
Cecil County										
10	3	28	27.07	20	24.84	19	29.98	2.23	-5.14	-2.91
10	1	28	28.90	21	29.65	19	30.66	-0.75	-1.01	-1.76
10	1	28	15.66	20	4.78	20	12.97	10.88	-8.19	2.69
10	2	28	27.34	20	24.07	19	26.33	3.27	-2.26	1.01
10	2	28	49.20	20	54.11	19	54.10	-4.91	.01	-4.90
10	4	28	18.27	20	17.11	19	19.34	1.16	-2.23	-1.07
Chester County										
16	4	29	7.05	22	6.42	23	7.06	0.63	-0.64	-0.01
10	2	28	62.32	20	67.97	19	65.67	-5.65	2.30	-3.35
10	1	28	25.22	20	12.17	19	20.92	13.05	-8.75	4.30
10	3	29	31.98	20	34.74	19	36.35	-2.76	-1.61	-4.37
10	1	28	42.26	20	45.59	19	46.56	-3.33	-.97	-4.30
Cumberland County										
4	2	30	34.70	23	29.43	20	38.48	5.27	-9.05	-3.78
4	3	30	31.92	23	33.58	20	32.06	-1.66	1.52	-.14
4	2	29	57.99	21	48.10	20	67.84	9.89	-19.74	-9.85
4	2	30	33.33	23	31.34	20	35.29	1.99	-3.95	-1.96
4	3	29	39.43	20	26.01	20	40.15	13.42	-14.14	-.72
4	2	30	60.94	22	53.06	20	62.71	7.88	-9.66	-1.78
4	5	29	16.33	21	11.97	20	18.49	4.36	-6.52	-2.16
4	1	29	94.52	21	95.15	20	115.99	-.63	-20.84	-21.47
4	2	29	80.69	21	75.59	19	90.78	5.10	-15.19	-10.09
4	1	29	153.87	21	159.07	19	174.10	-5.20	-15.03	-20.23
4	1	30	59.90	21	59.15	20	61.48	.75	-2.33	-1.58
4	1	28	62.89	20	50.10	19	64.20	12.79	-14.10	-1.31
4	3	29	50.03	21	51.46	19	68.70	-1.43	-17.24	-18.67
4	3	30	91.06	21	62.92	20	92.23	28.14	-29.31	-1.17
4	1	30	38.96	23	36.13	20	39.20	2.83	-3.07	-.24
1	2	28	34.54	20	30.27	19	35.30	4.27	-5.03	-.76
1	3	28	20.39	20	19.28	19	21.43	1.11	-2.15	-1.04
1	1	29	40.66	21	32.70	20	40.05	7.96	-7.35	.61
1	4	29	9.52	22	7.47	20	9.81	2.05	-2.34	-.29
1	4	29	20.07	20	18.05	19	20.80	2.02	-2.75	-.73

Local number	Hydrogeologic unit	Topographic setting	Date: October 1980 — Day	October 1980 — Depth below land surface, in feet	April 1981 — Day	April 1981 — Depth below land surface, in feet	October 1981 — Day	October 1981 — Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	April 1981 to October 1981	October 1980 to October 1981
Cumberland County											
819	1	1	29	33.94	21	31.04	20	33.32	2.90	-2.28	0.62
820	1	1	29	32 30	21	26 18	20	29.98	6.12	-3.80	2.32
821	21	1	30	29.03	22	20.84	21	32.48	8.19	-11.64	-3.45
823	1	3	30	27.22	22	25.54	21	27.41	1.68	-1.87	-.19
824	12	3	30	78.57	22	78.90	21	83.09	-.33	-4.19	-4.52
825	1	2	28	29.67	20	23.45	19	31.00	6.22	-7.55	-1.33
827	4	5	30	11.82	22	10.60	20	12.19	1.22	-1.59	-.37
828	4	1	30	49.80	23	46.46	20	51.75	3.34	-5.29	-1.95
830	1	4	28	11.38	20	11.37	19	15.52	.01	-4.15	-4.14
831	21	4	31	14.44	21	12.35	21	14.97	2.09	-2.62	-.53
832	4	2	29	65.00	21	62.06	20	68.49	2.94	-6.43	-3.49
833	4	2	30	41.13	21	26.27	20	43.81	14.86	-17.54	-2.68
834	4	1	28	94.39	20	81.64	19	96.37	12.75	-14.73	-1.98
835	1	4	28	12.25	20	8.13	19	12.25	4.12	-4.12	0.0
836	12	2	28	12.03	20	9.53	19	10.71	2.50	-1.18	1.32
837	1	2	29	15.04	22	11.49	20	15.04	3.55	-3.55	0.0
Dauphin County											
350	1	5	29	5.89	22	4.40	20	5.96	1.49	-1.56	-0.07
522	5	2	29	61.86	22	72.71	20	75.12	-10.85	-2.41	-13.26
538	13	3	29	72.35	22	62.34	20	64.73	10.01	-2.39	7.62
579	21	4	30	13.78	23	7.58	20	14.63	6.20	-7.05	-.85
580	21	1	29	60.34	22	52.25	20	55.22	8.09	-2.97	5.12
581	21	2	29	14.89	22	17.24	21	19.34	-2.35	-2.10	-4.45
582	5	3	28	29.10	21	21.38	20	28.82	7.72	-7.44	.28
583	21	1	28	19.50	22	13.87	21	18.53	5.63	-4.66	.97
584	20	2	28	46.42	22	49.02	20	47.08	-2.60	1.94	-.66
586	5	3	28	85.49	21	80.85	20	80.73	4.64	.12	4.76
587	5	2	29	50.37	22	38.61	20	41.19	11.76	-2.58	9.18
588	20	2	29	122.16	22	115.57	20	105.93	6.59	9.64	16.23
589	20	4	28	46.45	22	47.10	21	65.91	-.65	-18.81	-19.46
590	1	3	29	40.40	23	41.73	20	38.93	-1.33	2.80	1.47
591	1	3	29	28.74	22	26.75	21	28.97	1.99	-2.22	-.23

Local number	Hydrogeologic unit	Topographic setting	October 1980 Day	October 1980 Depth below land surface, in feet	April 1981 Day	April 1981 Depth below land surface, in feet	October 1981 Day	October 1981 Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	Change in water level, in feet: April 1981 to October 1981	Change in water level, in feet: October 1980 to October 1981
						Franklin					
498	1	4	28	5.64	20	2.79	19	5.90	2.85	-3.11	-0.26
528	1	4	28	11.10	20	7.61	19	12.31	3.49	-4.70	-1.21
592	1	2	28	39.61	20	34.68	19	40.82	4.93	-5.60	-.67
606	1	4	28	9.81	20	5.94	19	9.76	3.87	-3.82	.05
624	1	3	28	11.87	20	8.53	19	12.18	3.34	-3.65	-.31
666	4	2	28	77.65	20	79.32	19	89.43	-1.67	-10.11	-11.78
						Harford					
AA23	11	3	31	45.24	22	47.85	20	48.86	-2.61	-1.01	-3.62
AB12	11	1	31	54.91	21	58.42	20	59.46	-3.51	-1.04	-4.55
AC49	11	4	29	36.52	21	39.28	20	42.17	-2.76	-2.89	-5.65
AC55	11	4	29	21.49	21	22.09	20	23.19	-.60	-1.10	-1.70
AD13	10	3	29	54.17	21	54.83	19	57.85	-.66	-3.02	-3.68
AD14	11	2	31	44.89	21	49.64	19	51.58	-4.75	-1.94	-6.69
BA87	11	2	30	32.01	22	32.60	20	33.10	-.59	-.50	-1.09
BC26	11	2	29	23.84	20	23.56	19	25.39	.28	-1.83	-1.55
BC29	11	3	29	56.67	20	57.10	19	57.49	-.43	-.39	-.82
BD67	11	3	29	22.03	20	25.54	20	28.19	-3.51	-2.65	-6.16
BD81	11	2	29	47.58	20	52.00	19	54.97	-4.42	-2.97	-7.39
BE39	11	2	29	43.67	21	44.80	19	47.58	-1.13	-2.78	-3.91
BE40	10	3	29	3.84	20	3.81	20	2.55	.03	1.26	1.29
BF13	10	4	29	18.95	21	12.84	19	21.60	6.11	-8.76	-2.65
F169	10	4	29	19.93	21	9.93	19	17.25	10.00	-7.32	2.68
						Lancaster					
236	5	2	28	21.27	21	13.37	20	18.81	7.90	-5.44	2.46
249	5	3	28	13.71	21	9.15	20	13.52	4.56	-4.37	.19
400	5	2	28	16.73	21	16.15	20	16.85	.58	-.70	-.12
503	19	4	30	31.70	21	32.12	20	40.00	-.42	-7.88	-8.30
514	16	4	29	33.37	22	33.16	20	33.41	.21	-.25	-.04
521	17	4	30	9.88	22	7.56	19	10.89	2.32	-3.33	-1.01
538	17	3	30	67.91	22	70.72	19	73.00	-2.81	-2.28	-5.09
564	17	1	30	48.97	21	50.66	21	51.64	-1.69	-.98	-2.67
691	9	3	30	34.78	22	34.96	19	37.10	-.18	-2.14	-2.32
725	9	4	29	20.40	20	15.76	19	19.34	4.64	-3.58	1.06
797	9	2	29	22.52	20	20.51	19	23.46	2.01	-2.95	-.94

			Date								
			October 1980		April 1981		October 1981		Change in water level, in feet		
Local number	Hydrogeologic unit	Topographic setting	Day	Depth below land surface, in feet	Day	Depth below land surface, in feet	Day	Depth below land surface, in feet	October 1980 to April 1981	April 1981 to October 1981	October 1980 to October 1981
					Lancaster						
920	9	3	29	27.25	20	26.10	19	27.18	1.15	-1.08	0.07
938	9	4	29	48.01	20	46.31	19	48.32	1.70	-1.92	-.22
1036	9	4	30	21.44	21	19.05	20	22.50	2.39	-3.45	-1.06
1063	9	1	28	46.43	21	46.49	19	51.33	-.06	-4.84	-4.90
1075	9	2	28	57.19	21	55.16	19	59.81	2.03	-4.65	-2.62
1107	9	2	30	42.36	21	38.23	20	44.57	4.13	-6.34	-2.21
1321	13	4	29	9.24	22	8.40	22	9.70	.84	-1.30	-.46
1411	3	3	28	30.02	20	29.77	20	32.10	.25	-2.33	-2.08
1412	10	1	28	90.80	20	95.75	19	97.72	-4.95	-1.97	-6.92
1413	10	2	28	62.52	20	69.19	19	72.63	-6.67	-3.44	-10.11
1414	3	3	28	44.41	20	49.73	20	48.94	-5.32	.79	-4.53
1415	10	1	29	68.82	20	72.04	20	73.05	-3.22	-1.01	-4.23
1416	10	2	29	61.15	20	62.46	20	64.18	-1.31	-1.72	-3.03
1417	10	2	29	42.02	20	48.20	20	51.51	-6.18	-3.31	-9.49
1418	10	4	30	30.15	21	29.80	21	31.55	.35	-1.75	-1.40
1419	10	1	30	65.41	21	75.00	21	69.15	-9.59	5.85	-3.74
1420	10	3	29	26.41	21	27.03	21	27.10	-.62	-.07	-.69
1421	10	3	29	50.59	21	50.99	21	52.80	-.40	-1.81	-2.21
1422	10	2	30	44.94	21	51.30	21	53.01	-6.36	-1.71	-8.07
1423	10	1	30	73.16	21	49.79	21	59.87	23.37	-10.08	13.29
1425	17	3	29	33.00	22	37.40	20	41.58	-4.40	-4.18	-8.58
1426	17	2	29	20.94	22	20.70	20	24.11	.24	-3.41	-3.17
1427	17	3	29	32.15	22	34.28	21	35.86	-2.13	-1.58	-3.71
1428	10	4	29	19.27	22	22.68	20	20.20	-3.41	2.48	-.93
1429	16	1	29	32.83	21	31.02	20	32.83	1.81	-1.81	0.0
1430	17	3	29	27.02	22	20.32	20	27.09	6.70	-6.77	-.07
1431	9	2	28	59.64	20	61.67	21	62.93	-2.03	-1.26	-3.29
1432	10	3	29	78.30	22	80.32	21	82.30	-2.02	-1.98	-4.00
1434	16	3	29	32.50	21	34.33	20	32.29	-1.83	2.04	.21
1435	17	2	30	26.12	20	24.98	19	26.56	1.14	-1.58	-.44
1436	9	4	29	52.96	20	37.65	19	49.33	15.31	-11.68	3.63
1437	9	4	30	39.98	20	33.70	19	38.01	6.28	-4.31	1.97

Local number	Hydrogeologic unit	Topographic setting	October 1980 Day	October 1980 Depth below land surface, in feet	April 1981 Day	April 1981 Depth below land surface, in feet	October 1981 Day	October 1981 Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	Change in water level, in feet: April 1981 to October 1981	Change in water level, in feet: October 1980 to October 1981
Lancaster											
1438	15	1	30	26.79	20	19.85	19	24.46	6.94	-4.61	2.33
1439	5	3	30	11.15	21	6.99	20	11.25	4.16	-4.26	-.10
1440	15	1	29	19.86	20	16.19	20	20.48	3.67	-4.29	-.62
1441	13	2	29	58.37	21	55.87	22	58.53	2.50	-2.66	-.16
1442	9	3	29	31.36	21	42.59	22	43.65	-11.23	-1.06	-12.29
1444	9	3	29	19.92	20	20.36	21	21.76	-.44	-1.40	-1.84
1445	9	3	28	79.46	20	80.15	20	84.33	-.69	-4.18	-4.87
1446	9	3	30	68.34	22	62.56	22	70.73	5.78	-8.17	-2.39
1449	9	4	30	10.68	22	9.88	22	9.90	.80	-.02	.78
1450	15	1	30	34.47	22	34.85	22	36.67	-.38	-1.82	-2.20
1452	19	4	29	12.90	23	9.75	20	12.81	3.15	-3.06	.09
1453	9	2	28	26.84	20	31.64	20	32.87	-4.80	-1.23	-6.03
1454	9	2	30	27.94	21	28.15	20	30.65	-.21	-2.50	-2.71
1455	9	3	29	53.60	21	55.29	20	61.07	-1.69	-5.78	-7.47
1457	9	3	28	16.36	20	15.53	20	18.38	.83	-2.85	-2.02
1458	9	2	30	41.73	21	45.17	20	47.58	-3.44	-2.41	-5.85
1459	9	2	30	26.40	21	26.10	20	26.63	.30	-.53	-.23
1460	9	2	28	60.55	20	63.87	20	67.45	-3.32	-3.58	-6.90
1461	9	1	30	49.75	21	41.74	20	53.87	8.01	-12.13	-4.12
1462	9	3	29	69.79	21	63.85	22	69.82	5.94	-5.97	-.03
1463	6	4	29	4.46	21	3.00	22	4.97	1.46	-1.97	-.51
1464	19	3	29	22.61	21	14.91	22	22.97	7.70	-8.06	-.36
1465	19	2	29	79.57	22	73.35	22	86.82	6.22	-13.47	-7.25
1466	13	3	29	78.40	21	70.99	22	76.17	7.41	-5.18	2.23
1467	3	2	29	51.34	20	55.20	21	56.29	-3.86	-1.09	-4.95
1468	9	4	28	25.60	20	26.10	20	26.92	-.50	-.82	-1.32
1469	1	3	29	45.58	21	44.19	22	46.57	1.39	-2.38	-.99
1470	10	2	28	48.07	20	53.72	19	56.07	-5.70	-2.35	-8.05
1471	10	2	29	51.85	20	55.46	20	56.05	-3.61	-.59	-4.20
1473	16	2	29	36.22	22	38.49	20	39.80	-2.27	-1.31	-3.58
1475	10	2	30	46.83	21	45.52	21	46.64	1.31	-1.12	.19
1476	16	3	29	19.50	21	19.00	20	20.14	.50	-1.14	-.64

			Date						Change in water level, in feet		
			October 1980		April 1981		October 1981				
Local number	Hydrogeologic unit	Topographic setting	Day	Depth below land surface, in feet	Day	Depth below land surface, in feet	Day	Depth below land surface, in feet	October 1980 to April 1981	April 1981 to October 1981	October 1980 to October 1981
1477	10	2	29	60.34	21	66.43	20	69.33	-6.09	-2.90	-8.99
1478	10	3	28	27.89	20	29.45	19	31.29	-1.56	-1.84	-3.40
1479	3	3	28	19.89	20	22.69	20	24.22	-2.80	-1.53	-4.33
1480	19	5	29	15.94	23	12.24	20	15.79	3.70	-3.55	.15
1481	19	4	29	19.85	23	14.45	19	20.35	5.40	-5.90	-.50
1482	9	5	30	17.80	23	15.88	22	18.86	1.92	-2.98	-1.06
1483	16	1	31	50.84	23	52.21	22	50.21	-1.37	2.00	.63
1485	9	3	31	29.71	23	33.40	22	30.24	-3.69	3.16	-.53
1487	3	3	28	28.02	20	27.47	21	30.60	.55	-3.13	-2.58
1488	9	3	28	68.26	20	68.36	21	68.83	-.10	-.47	-.57
1489	15	1	30	38.69	21	33.95	20	38.61	4.74	-4.66	.08
1490	15	2	28	20.80	21	15.38	19	20.24	5.42	-4.86	.56
1491	17	3	29	54.81	21	55.05	20	55.99	-.24	-.94	-1.18
1493	9	3	28	20.25	22	17.10	22	21.42	3.15	-4.32	-1.17
1495	9	4	30	26.48	22	25.43	22	27.16	1.05	-1.73	-.68
1496	9	3	30	59.48	22	56.76	22	58.52	2.72	-1.76	.96
1497	15	2	29	32.96	20	30.01	20	33.44	2.95	-3.43	-.48
1498	15	2	29	30.41	20	23.62	19	29.20	6.79	-5.58	1.21
1499	13	2	30	64.92	21	42.99	20	61.83	21.93	-18.84	3.09
1500	9	3	29	28.33	20	25.52	19	30.47	2.81	-4.95	-2.14
1502	13	4	29	7.00	21	5.63	22	7.52	1.37	-1.89	-.52
1503	16	4	29	26.11	21	29.16	20	31.23	-3.05	-2.07	-5.12
1504	16	1	30	82.46	22	87.20	20	88.38	-4.74	-1.18	-5.92
1505	9	3	31	91.20	23	95.31	22	97.11	-4.11	-1.80	-5.91
1506	15	3	28	26.82	21	18.17	20	27.34	8.65	-9.17	-.52
1507	9	4	31	13.62	23	13.29	22	13.67	.33	-.38	-.05
1622	13	3	28	47.38	21	40.72	22	49.70	6.66	-8.98	-2.32
Lebanon											
173	2	3	29	63.57	24	64.81	21	68.71	-1.24	-3.90	-5.14
270	21	1	30	40.51	22	34.66	14	41.29	5.85	-6.63	-.78
488	2	3	31	73.42	22	77.32	21	76.67	-3.90	.65	-3.25
522	2	2	29	36.16	24	35.25	20	35.15	.91	.10	1.01
615	2	4	29	31.14	24	27.86	20	33.15	3.28	-5.29	-2.01

Local number	Hydrogeologic unit	Topographic setting	October 1980 Day	October 1980 Depth below land surface, in feet	April 1981 Day	April 1981 Depth below land surface, in feet	October 1981 Day	October 1981 Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	April 1981 to October 1981	October 1980 to October 1981
						Lebanon					
661	2	3	30	75.75	21	87.47	21	89.86	-11.72	-2.39	-14.11
727	1	5	28	10.68	23	7.64	19	11.01	3.04	-3.37	-.33
825	19	2	30	80.97	21	64.70	20	83.46	16.27	-18.76	-2.49
845	5	4	28	19.93	21	16.07	20	19.70	3.86	-3.63	.23
856	2	5	30	14.21	24	13.89	21	17.09	.32	-3.20	-2.88
857	2	2	29	41.61	24	42.50	21	48.10	-.89	-5.60	-6.49
858	2	3	30	61.50	22	59.45	21	73.74	2.05	-14.29	-12.24
859	19	3	29	24.60	23	16.12	20	23.78	8.48	-7.66	.82
861	6	4	29	21.78	23	18.47	20	21.67	3.31	-3.20	.11
862	21	2	28	51.36	23	48.18	19	51.52	3.18	-3.34	-.16
863	1	3	30	50.09	24	41.69	21	48.09	8.40	-6.40	2.00
864	1	3	28	20.42	24	18.80	21	20.80	1.62	-2.00	-.38
865	21	3	28	8.80	24	2.20	21	8.58	6.60	-6.38	.22
866	21	2	28	8.91	24	3.92	21	9.14	4.99	-5.22	-.23
867	21	1	31	14.79	22	7.65	19	14.37	7.14	-6.72	.42
868	21	4	30	29.86	22	26.49	19	29.45	3.37	-2.96	.41
869	21	2	31	24.74	22	18.89	19	26.01	5.85	-7.12	-1.27
870	1	4	31	16.53	22	10.55	19	18.32	5.98	-7.77	-1.79
871	21	3	29	26.79	22	21.88	21	27.94	4.91	-6.06	-1.15
873	21	2	29	18.60	22	8.51	21	20.25	10.09	-11.74	-1.65
874	19	3	30	23.55	24	20.10	21	23.33	3.45	-3.23	.22
875	2	2	30	65.02	22	63.72	21	67.05	1.30	-3.33	-2.03
876	21	1	28	19.07	24	15.18	22	20.78	3.89	-5.60	-1.71
877	1	3	30	21.60	24	18.10	21	23.08	3.50	-4.98	-1.48
878	21	2	30	21.61	22	19.05	19	22.66	2.56	-3.61	-1.05
879	6	1	29	75.78	24	69.33	21	76.17	6.45	-6.84	-.39
						York					
180	5	3	29	27.72	22	22.81	20	28.01	4.91	-5.20	-0.29
268	10	4	30	31.70	22	26.92	21	33.15	4.78	-6.23	-1.45
324	8	3	28	23.93	21	17.48	20	25.64	6.45	-8.16	-1.71
327	8	4	28	13.31	22	7.18	20	13.02	6.13	-5.84	.29
347	14	4	28	39.33	21	37.36	20	40.59	1.97	-3.23	-1.26

Local number	Hydrogeologic unit	Topographic setting	October 1980 Day	October 1980 Depth below land surface, in feet	April 1981 Day	April 1981 Depth below land surface, in feet	October 1981 Day	October 1981 Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	April 1981 to October 1981	October 1980 to October 1981
York											
407	10	2	31	54.54	22	57.82	21	57.82	-2.67	-.61	-3.28
446	10	3	28	65.02	21	68.38	20	70.73	-3.36	-2.35	-5.71
478	10	1	30	47.74	21	39.19	21	46.57	8.55	-7.38	1.17
499	10	2	30	30.15	22	30.76	20	31.26	-.61	-.50	-1.11
506	10	1	30	68.75	21	67.51	21	67.94	1.24	-.43	.81
514	10	3	31	56.16	21	59.67	20	61.06	-3.51	-1.39	-4.90
516	10	1	31	73.85	21	77.78	20	78.58	-3.93	-.80	-4.73
543	10	3	31	44.84	22	46.42	20	45.41	-1.58	1.01	-.57
559	13	3	29	43.49	21	40.58	19	46.74	2.91	-6.16	-3.25
604	10	3	31	8.83	22	6.42	22	10.25	2.41	-3.83	-1.42
614	10	4	31	15.34	22	12.30	22	15.79	3.04	-3.49	-.45
622	10	3	29	27.19	21	26.39	20	27.80	.80	-1.41	-.61
628	10	5	28	33.44	21	30.75	20	44.30	2.69	-13.55	-0.86
642	17	4	29	45.64	22	45.44	21	46.47	.20	-1.03	-.83
666	7	5	31	18.35	20	17.19	21	18.64	1.16	-1.45	-.29
714	8	4	29	35.88	22	31.13	21	37.15	4.75	-6.02	-1.27
788	8	3	30	37.96	20	34.68	21	38.92	3.28	-4.24	-.96
906	5	2	28	72.34	21	71.51	19	72.30	.83	-.79	.04
968	19	2	28	33.89	21	33.06	19	34.29	.83	-1.23	-.40
1001	13	3	29	28.63	21	23.62	19	28.73	5.01	-5.11	-.10
1050	10	2	31	45.55	22	49.87	20	50.69	-4.32	-.82	-5.14
1051	10	2	31	50.62	22	53.21	21	54.08	-2.59	-.87	-3.46
1052	10	3	28	38.31	21	38.04	20	39.26	.27	-1.22	-.95
1053	10	2	28	73.39	21	76.92	20	78.30	-3.53	-1.38	-4.91
1054	10	2	28	67.41	21	62.58	20	65.06	4.83	-2.48	2.35
1055	10	3	29	66.80	22	56.81	21	66.31	9.99	-9.50	.49
1056	10	2	29	38.63	22	28.03	21	39.00	10.60	-10.97	-.37
1057	10	3	29	68.80	22	47.04	21	64.86	21.76	-17.82	3.94
1058	20	4	30	67.41	21	66.64	19	68.47	.77	-1.83	-1.06
1059	5	3	30	71.01	21	63.65	19	67.70	7.36	-4.05	3.31
1061	13	3	31	30.23	23	23.69	22	32.69	6.54	-9.00	-2.46
1062	5	4	28	21.35	22	15.91	19	24.05	5.44	-8.14	-2.70

Local number	Hydrogeologic unit	Topographic setting	October 1980 Day	October 1980 Depth below land surface, in feet	April 1981 Day	April 1981 Depth below land surface, in feet	October 1981 Day	October 1981 Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	April 1981 to October 1981	October 1980 to October 1981
York											
1063	13	4	28	31.80	22	28.84	19	32.38	2.96	-3.54	-0.58
1064	5	2	30	69.85	20	55.45	21	71.60	14.40	-16.15	-1.75
1065	5	3	28	31.81	21	26.35	19	32.72	5.46	-6.37	-.91
1066	5	2	28	53.36	21	50.04	14	54.53	3.32	-4.49	-1.17
1067	5	3	29	39.56	22	34.55	21	37.95	5.01	-3.40	1.61
1068	8	3	29	14.28	22	9.80	21	13.27	4.48	-3.47	1.01
1069	5	3	29	20.01	22	14.77	21	18.69	5.24	-3.92	1.32
1070	5	3	29	41.94	22	34.64	21	40.23	7.30	-5.59	1.71
1072	5	3	29	84.02	21	70.88	19	73.74	13.14	-2.86	10.28
1076	10	3	30	25.57	22	22.24	21	25.63	3.33	-3.39	-.06
1077	10	3	28	45.71	21	41.65	20	46.13	4.06	-4.48	-.42
1078	10	2	28	75.41	21	48.32	20	64.49	27.09	-16.17	10.92
1079	8	2	28	48.81	22	42.12	20	50.35	6.69	-8.23	-1.54
1081	10	3	30	32.09	22	24.96	21	34.92	7.13	-9.96	-2.83
1082	8	3	30	56.25	20	44.62	22	51.91	11.63	-7.29	-4.34
1083	10	3	30	20.48	20	17.97	22	20.26	2.15	-2.29	.22
1084	8	4	30	67.76	20	61.58	22	70.15	6.18	-8.57	-2.39
1085	5	4	31	27.68	20	16.98	22	25.59	10.70	-8.61	2.09
1086	14	2	31	59.94	20	57.48	22	60.25	2.46	-2.77	-.39
1087	8	3	31	18.30	21	17.46	22	18.45	.84	-.99	-.15
1088	5	3	31	41.94	20	32.15	22	43.63	9.79	-11.48	-1.69
1090	8	1	31	43.88	23	38.15	21	44.28	5.73	-6.13	-.40
1091	13	3	30	36.74	20	33.70	21	36.78	3.04	-3.08	-.04
1093	13	4	30	20.66	21	18.75	19	21.24	2.41	-2.99	-.58
1094	5	2	28	38.36	22	29.34	21	45.82	9.02	-16.48	-7.46
1095	14	5	28	16.77	22	15.61	20	17.44	1.16	-1.83	-.67
1096	8	3	28	32.45	22	29.56	20	32.13	2.89	-2.57	.32
1097	10	4	30	30.16	21	30.18	21	30.41	-.02	-.23	-.25
1098	7	3	31	13.70	20	9.28	22	14.45	4.42	-5.17	-.75

Local number	Hydrogeologic unit	Topographic setting	October 1980 Day	October 1980 Depth below land surface, in feet	April 1981 Day	April 1981 Depth below land surface, in feet	October 1981 Day	October 1981 Depth below land surface, in feet	Change in water level, in feet: October 1980 to April 1981	April 1981 to October 1981	October 1980 to October 1981
						York					
1099	18	3	28	70.82	23	69.38	19	72.94	1.44	-3.56	-2.12
1100	18	3	28	34.83	22	29.18	19	36.15	5.65	-6.97	-1.32
1101	8	3	28	31.20	21	27.00	20	33.98	4.20	-6.89	-2.69
1102	10	3	31	59.77	22	58.45	21	58.80	1.32	-.35	.97
1103	19	1	28	85.32	22	84.79	19	82.74	.53	2.05	2.58
1104	8	2	31	62.31	23	53.29	21	62.52	9.02	-9.23	-.21
1105	10	2	29	71.82	21	46.56	20	61.88	25.26	-15.32	9.94
1106	10	2	28	80.85	21	79.83	20	88.38	1.02	-8.55	-7.53
1107	10	2	28	44.99	21	42.64	20	36.93	2.35	5.71	8.06
1108	10	3	28	44.10	21	46.64	20	47.72	-2.54	-1.08	-3.62
1112	10	2	28	39.93	21	27.98	20	39.85	11.95	-11.87	.08
1113	8	3	29	62.53	22	61.00	21	63.37	1.53	-2.37	-.84
1115	7	3	30	42.84	20	37.07	21	36.24	5.77	.83	6.60
1116	10	2	31	67.82	22	52.00	22	55.38	15.82	-3.38	12.44