Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 45

SIMULATION OF GROUND-WATER FLOW AND BASE FLOW IN WEATHERED CRYSTALLINE ROCK, UPPER CATTAIL CREEK, HOWARD COUNTY, MARYLAND

by

Richard E. Willey
and
Grufron Achmad

Prepared in cooperation with the
United States Department of the Interior
Geological Survey
and
Maryland Water Resources Administration

1986

CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.6093	kilometer (km)
	Area	
square mile (mi^2)	2.59	square kilometer (km^2)
acre	4047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
	Volume	
gallon (gal)	0.003785	cubic meter (m^3)
	Flow	
foot per day (ft/d)	3.281	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
million gallons per year (Mgal/yr)	0.00012	cubic meters per second (m^3/s)
	Transmissivity	
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)

The National Geodetic Vertical Datum of 1929 (NGVD of 1929): The geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level, is referred to as sea level in this report.

Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 45

SIMULATION OF GROUND-WATER FLOW AND BASE FLOW IN WEATHERED CRYSTALLINE ROCK, UPPER CATTAIL CREEK, HOWARD COUNTY, MARYLAND

by

Richard E. Willey
U.S. Geological Survey

and

Grufron Achmad
Maryland Geological Survey

Prepared in cooperation with the
United States Department of the Interior
Geological Survey
and
Maryland Water Resources Administration

1986

COMMISSION
OF THE
MARYLAND GEOLOGICAL SURVEY

M. Gordon Wolman, *Chairman* ..... Baltimore

S. James Campbell ..... Towson

James M. Coffroth ..... Frostburg

Richard W. Cooper ..... Salisbury

Robert W. Ridky ..... College Park

CONTENTS

	Page
Abstract	1
Introduction	3
Purpose and scope	3
Acknowledgments	3
Basin description	3
Physical setting	3
Cultural setting	6
Hydrologic system	6
Hydrologic budget	6
Streamflow	7
Wells in bedrock	7
Occurrence and movement of water in bedrock	9
Model description	14
Hydrologic parameters	14
Finite-difference grid	14
Boundary conditions	16
Land-surface altitude	16
Water-table altitude	16
Ground-water recharge	16
Stream-cell network	16
Ground-water evapotranspiration	17
Transmissivity	20
Steady-state calibration	20
Simulation of transient-flow conditions	23
Hydraulic conductivity	23
Specific yield	25
Transient-flow simulations	27
Predictive simulations	31
Development on 3-acre lots	32
Development on 1-acre lots	32
Development on 1/4-acre lots	43
Adjustment of stream-aquifer system to stress	43
Summary and conclusions	50
Selected references	51
Supplemental data	53

ILLUSTRATIONS

	Page
Figure 1. Map showing location of study area	4
2. Geologic map of study area	5
3. Bar graphs showing monthly precipitation, potential evapotranspiration, streamflow, and ground-water storage change, July 1979 to September 1980	7
4. Map showing streamflow measurement sites	8
5. Graph showing relationship of measured low flows to drainage area	9
6. Map showing location of inventoried wells	10
7. Idealized section showing bedrock fracturing in the Piedmont	11

ILLUSTRATIONS (Continued)

		Page
Figure 8.	Graph showing yield classification for inventoried wells	11
9.	Map showing yields of inventoried bedrock wells	12
10.	Map showing approximate water-level contours, spring 1980	13
11.	Map showing finite-difference grid	15
12.	Graph showing relationship of ground-water evapotranspiration rate to water-table depth as used in model	16
13.	Idealized cross-section showing method of estimating initial transmissivity values	17
14.	Map showing areal distribution of calibrated transmissivity values	18
15.	Graph showing frequency distribution of calibrated transmissivity values	20
16.	Graph showing relationship of simulated base flows to measured low flows, June 25, 1980	21
17.	Map showing areal distribution of differences between simulated and mapped water levels for final steady-state calibration	22
18.	Graph showing frequency distribution of differences between simulated and mapped water levels for final steady-state calibration	23
19.	Graph showing relationship of hydraulic conductivity to depth for selected areas underlain by the Wissahickon Formation	24
20.	Idealized cross-section showing distribution of hydraulic conductivity values used in transient-flow simulations	25
21.	Map showing areal distribution of calibrated hydraulic conductivity values (upper zone)	26
22.	Graph showing frequency distribution of calibrated hydraulic conductivity values (upper zone)	27
23.	Map showing areal distribution of specific-yield values used for transient-flow simulations	28
24.	Idealized cross-section showing distribution of specific-yield values used for final calibration of transient model	28
25.	Hydrographs showing simulated base flows of Cattail Creek compared with estimated base flows at streamflow site 11, July 1979 to September 1980	Pocket
26-28.	Hydrographs showing simulated water levels compared with observed water levels, July 1979 to September 1980, for	
	26. Cell B, well HO-BB 26	Pocket
	27. Cell A, well HO-AB 4	Pocket
	28. Cell C, well HO-BC 38	Pocket
29.	Graph showing relationship of simulated base flows, transient conditions, to measured low flows	29
30.	Graph showing comparison of simulated base flows and water levels for transient-flow and steady-state conditions on June 25, 1980	30
31.	Index maps and table showing hypothetical development schemes used for predictive simulations	Pocket
32.	Idealized cross-section showing effects of model no-flow boundary on water-table drawdown	32
33-45.	Maps and tables showing simulated changes in ground-water levels and base flows after 20 years of pumping:	
	33. Hypothetical development scheme Ia_1 (3-acre lots, on-lot wells and septic systems, 95-percent pumpage returned)	33

ILLUSTRATIONS (Continued)

Page

Figure 34. Hypothetical development scheme Ia_2 (3-acre lots, on-lot wells and septic systems, 90-percent pumpage returned) 34
35. Hypothetical development scheme Ia_3 (3-acre lots, on-lot wells and septic systems, 80-percent pumpage returned) 35
36. Hypothetical development scheme Ib (3-acre lots, on-lot wells, waste water sewered out of basin) ... 36
37. Hypothetical development scheme Ic (3-acre lots, 15 public-supply wells, on-lot septic systems, 90-percent pumpage returned) 37
38. Hypothetical development scheme Id (3-acre lots, 15 public-supply wells, waste water sewered out of basin) 38
39. Hypothetical development scheme IIa (1-acre lots, on-lot wells and septic systems, 90-percent pumpage returned) 39
40. Hypothetical development scheme IIb (1-acre lots, on-lot wells, waste water sewered out of basin) 40
41. Hypothetical development scheme IIc (1-acre lots, 15 public-supply wells, on-lot septic systems, 90-percent pumpage returned) 41
42. Hypothetical development scheme IId (1-acre lots, 15 public-supply wells, waste water sewered out of basin) 42
43. Hypothetical development scheme IIIa (1/4-acre lots or equivalent, 15 public-supply wells, waste water sewered out of basin) 44
44. Hypothetical development scheme IIIb (1/4-acre lots or equivalent, 15 public-supply wells, waste water sewered to five stream locations within basin) 45
45. Hypothetical development scheme IIIc (1/4-acre lots or equivalent, 15 public-supply wells, waste water sewered to 10 land-disposal sites within basin) 46

46. Idealized cross-section showing potential sources of water available for diversion to a pumping well under water-table conditions 47
47. Graph showing annual contributions to simulated ground-water pumpage by source (development scheme Ib) 48
48. Graph showing simulated reduction in long-term average base flow at station 11 using various estimates of specific yield 50
49. Graph showing comparison of simulated base flows at streamflow site 11 for developed (scheme Ib) and undeveloped basin, July 1979 to September 1980 ..... Pocket
50. Graph showing comparison of simulated water levels at cell B for developed (scheme Ib) and undeveloped basin, July 1979 to September 1980 ..... Pocket

ILLUSTRATIONS (Continued)

TABLES

		Page
Table 1.	Statistical summary of selected bedrock-well characteristics	9
2.	Selected values for vertical hydraulic conductivity in streambeds	17
3.	Reported transmissivity, hydraulic conductivity, and specific-yield values for selected areas underlain by crystalline rock	19
4.	Contributions to ground-water pumpage, by source, after 20 years of simulated pumping	49
5.	Simulated base flows and ground-water levels for undeveloped and developed basins, September 3, 1980	49
6.	Description of selected wells	54
7.	Drillers' logs of selected wells	59
8.	Water levels in observation wells	66

SIMULATION OF GROUND-WATER FLOW AND BASE FLOW IN WEATHERED CRYSTALLINE ROCK, UPPER CATTAIL CREEK, HOWARD COUNTY, MARYLAND

by

Richard E. Willey and Grufron Achmad

ABSTRACT

Population growth and changing land use patterns are increasing water-supply demands in the Maryland Piedmont. Local ground-water resources may be sufficient in much of the area to satisfy these demands; however, there is a need to quantify these resources and assess the potential impacts of ground-water withdrawals and waste-water returns. Digital-simulation modeling of the stream-aquifer system is one method of doing this.

The Trescott, Pinder, and Larson two-dimensional finite-difference model is used to simulate ground-water flow in an 8.4-square-mile area at the headwaters of Cattail Creek, located in Howard County, Maryland. The model is modified to revise the method of decreasing ground-water evapotranspiration with falling water levels and to allow systematic reduction of hydraulic conductivity and specific yield with depth. Most hydrologic parameters are initially approximated using published data from similar hydrogeologic settings. Ground-water levels and base flows from steady-state and transient-flow simulations agree well with values obtained in the field.

Predictive simulations are made to demonstrate the utility of modeling in assessing the potential effects of well pumpage and waste-water returns on the stream-aquifer system. Hypothetical development schemes examine various modes of water supply, waste-water disposal, and population distribution, while holding both total population and water use constant. Impacts to the modeled area are shown as changes in long-term average annual water levels and base flows. Individual subbasin changes vary greatly depending mainly on supply well location, location and manner of waste-water disposal, and subbasin hydrology. Collectively, base flows are reduced essentially by the amount of pumpage not returned as recharge. Base flow and water-level declines are greatest when all pumpage is sewered out of the basin. Predictive simulations with long-term average annual conditions underestimate impacts of development on ground-water resources during seasonal low-water periods and drought years.

INTRODUCTION

Dependable supply sources of high quality water are vital to the economic growth and physical well-being of an area. The Maryland Piedmont, which occupies parts or all of seven counties, is experiencing increasing demands for water due to population growth and changing patterns of land use. The crystalline-rock aquifers underlying the area provide water for all self-supplied domestic, business, and institutional needs and many small-scale public supplies.

Purpose and Scope

The purpose of this report is to demonstrate the utility of digital modeling in simulating natural ground-water flow in a stream-aquifer system in the upper Cattail Creek basin, and in estimating potential effects of well pumpage and waste-water returns on water levels and base flow to streams in the study area. Concepts and methods illustrated in this report should be helpful in the analysis of other stream-aquifer systems in the Maryland Piedmont.

The headwater area of Cattail Creek was chosen for study because it has relatively uniform geology, is essentially rural and undeveloped, and encompasses a small natural stream basin that can be treated as an autonomous hydrogeologic unit. During the investigation, 299 wells representing about 65 percent of the ground-water supply sources in the basin were inventoried. Water levels were measured at least once in 242 wells. A continuous recorder was maintained at one unused domestic well, and periodic measurements were made at two other wells. Precipitation and temperature data were gathered from records of nearby National Oceanic and Atmospheric Administration weather stations. Continuous surface-water discharge data were obtained at one gaging station where the stream flows out of the study area, and low flows were measured at 11 sites within the basin. Data from the above sources provide the information used to calibrate the digital model for steady-state and transient-flow conditions.

Acknowledgments

The authors wish to thank the many property owners for allowing water-level measurements to be made on their wells. Grateful acknowledgment is also made for the assistance of personnel from the Maryland Water Resources Administration, the Howard County Office of Planning and Zoning, the Howard County Public School System, and the Howard County Health Department for providing much of the data.

This report is the product of a study by the U.S. Geological Survey done in cooperation with the Maryland Geological Survey. The project was started under the direction of Larry J. Nutter, with most of the early fieldwork by Michael J. Smigaj. John J. Hilleary assisted in the later fieldwork. John R. Sobashinski measured the surface-water discharges. The manuscript was typed by Sheryl J. Protani and illustrations drafted by Jean G. Hyatt and Amy V. Todd.

BASIN DESCRIPTION

Physical Setting

The study area is located in western Howard County, about 24 mi north of Washington, D.C., and 19 mi west of Baltimore, Md. (fig. 1). It encompasses an 8.4-mi^2 area in the headwaters of Cattail Creek, a tributary of the Patuxent River. The stream basin lies within the Maryland Piedmont and is geologically uniform. The Wissahickon Formation, composed of intensely folded and cleaved schists and quartzites, underlies most of the stream basin (fig. 2). Two small lens-shaped areas in the eastern portion are underlain by ultramafic rocks or rocks of the Baltimore Gabbro Complex. A veneer of weathered bedrock (saprolite) varying in thickness covers nearly the entire basin.

The geology and lithologic descriptions shown in figure 2 are modified from Cleaves, Edwards, and Glaser, 1968; and Cloos and Broedel, 1940. The stratigraphic nomenclature used in this report is that of the Maryland Geological Survey and does not necessarily follow usage of the U.S. Geological Survey.

Topographic relief in the basin is about 290 ft. Altitude is nearly 480 ft where Cattail Creek flows out of the basin, and about 770 ft at the topographic high on a ridge that parallels the regional structure on the western edge of the basin. Central and eastern portions of the stream basin have an open, moderately rolling topography with broad valleys. In the upstream areas west of State Route 94, the land steepens and valleys are more deeply incised. Throughout

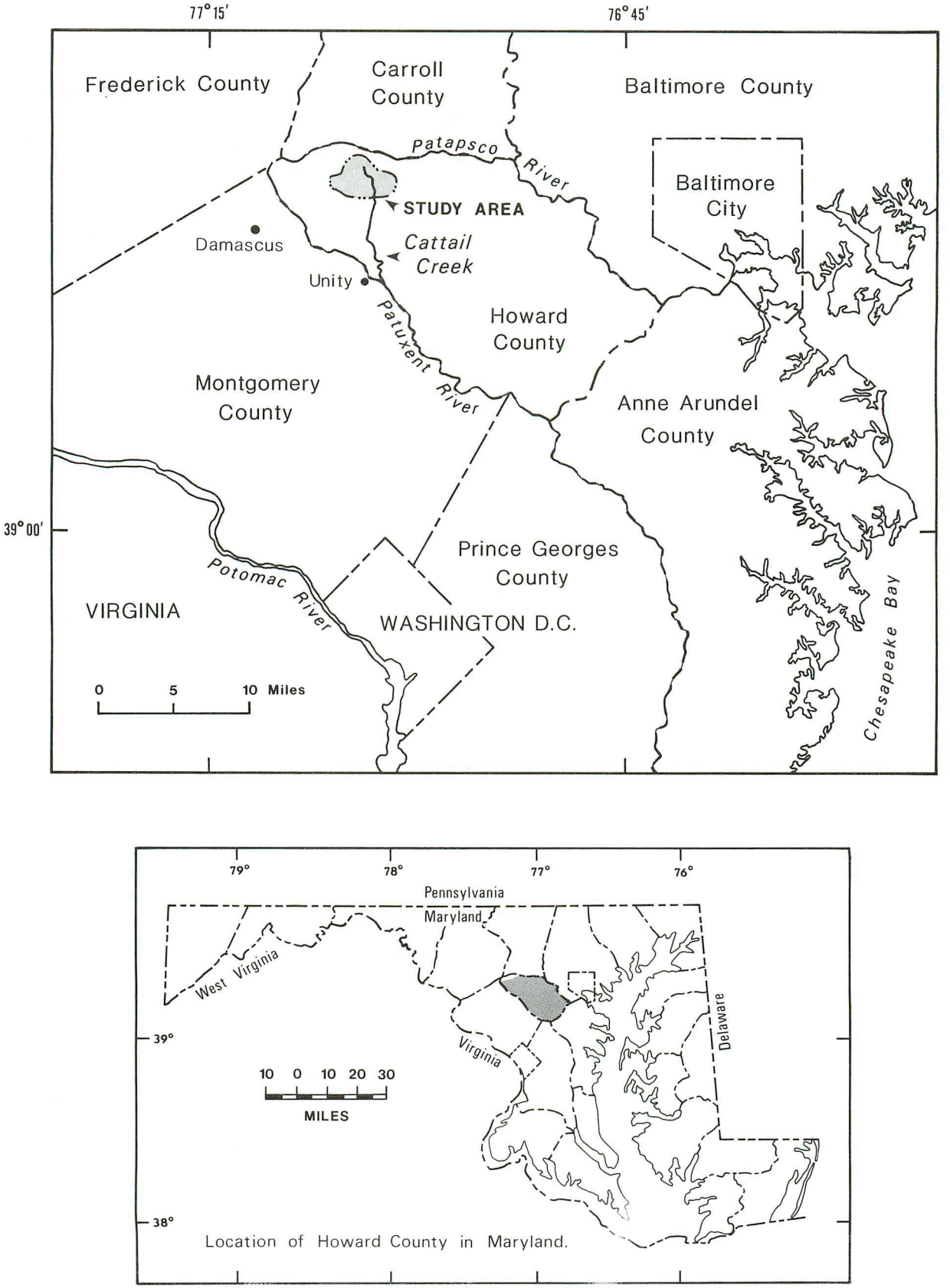
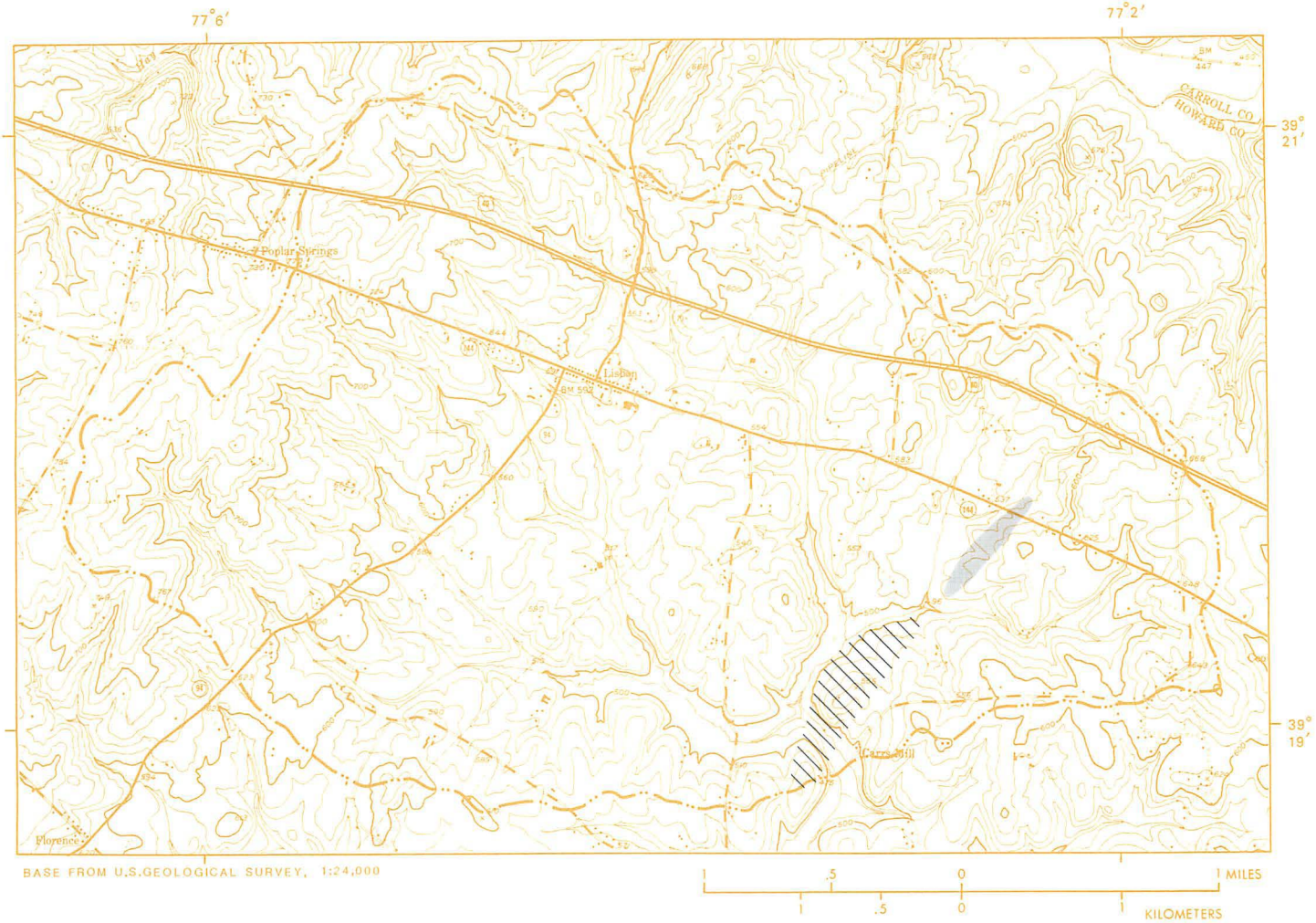


Figure 1. — Location of study area.



EXPLANATION

UPPER PRECAMBRIAN - LOWER PALEOZOIC

WISSAHICKON FORMATION (undivided)- Muscovite-chlorite-albite schist, muscovite-chlorite schist, chloritoid schist, and quartzite ; intensely folded and cleaved.

BALTIMORE GABBRO COMPLEX- Hypersthene gabbro with subordinate amounts of olivine gabbro, norite, anorthositic gabbro and pyroxenite.

ULTRAMAFIC ROCKS- Chiefly serpentinite with partly to completely altered dunite, peridotite, pyroxenite; and massive to schistose soapstone; talc-carbonate rock and altered gabbro locally common.

BASIN BOUNDARY

Geology and lithologic description modified from: Cleaves, Edwards, and Glaser, 1968; Cloos, and Broedel, 1940.

Figure 2. — Geologic map of study area.

the basin, distances between perennial streams and local-stream divides are usually less than 0.5 mi.

The climate is humid, semicontinental, generally with mild winters and very warm, moist summers. Average annual precipitation is approximately 43 inches per year (Crooks and others, 1967, sheet 2) and tends to be distributed evenly throughout the year (Matthews and Hershberger, 1968, p. 2).

Cultural Setting

Approximately 460 private residences lie within the study area. The village of Lisbon, consisting of two dozen houses, several businesses, churches, and an elementary school, is the focal point of the stream basin. A few small housing developments are scattered throughout the rest of the area. Total population is slightly more than 1,600. The most important land uses are dairy farming and growing forage crops for livestock. Most residents commute to work outside the basin. Prospects for residential and commercial growth seem to be good due to the area's proximity to Baltimore and Washington, D.C., and the location of an interchange for Interstate 70 within the basin.

The sole source of water for domestic and commercial use is on-site wells or springs. Total domestic water use, based on estimates of population and a daily per capita use of 75 gal, is about 120,000 gal/d. Nearly all water pumped is returned to the stream-aquifer system through on-site subsurface leaching pits or fields. Given the current regulations governing new residential development in the area (3-acre lots with single detached house), this manner of on-site self-sufficiency will probably continue to be the most economical way of satisfying water-supply and waste-disposal needs within the basin.

HYDROLOGIC SYSTEM

Hydrologic Budget

The choice of a natural stream basin as the unit of investigation simplifies the task of accounting for water. Water gains are derived from precipitation, and losses are by streamflow or evapotranspiration. Relatively little water is thought to be lost to intermediate or regional flow systems that lie deeper in the unweathered rock (Lawson, 1968, p. 822; McGreevy and Sloto, 1980, p. 3). The concept of water movement in a natural stream basin may be expressed in terms of a hydrologic budget and written in the following form:

Water gain to stream basin	=	Water loss from stream basin	+	changes in water storage within stream basin

or as

$$P = Q_T + E_T \pm \Delta S_T$$

where

P = precipitation;

Q_T = total streamflow (surface runoff + ground-water runoff);

E_T = total evapotranspiration [evaporation (direct, soil and ground water) + transpiration by plants (from soil water and ground water)]; and

ΔS_T = change in total water storage (ground water + soil moisture + surface water in streams and ponds + ice or snow on the ground).

Estimates of the major equation components are shown in figure 3 as monthly summaries for July 1979 to September 1980. Precipitation during the 15 months varied from less than 1 to almost 10 inches per month at a rain gage in Damascus, Md., located some 6 mi west of the study area. Records from this station indicate the total water gain for the period was about 63.2 in. Total evapotranspiration for the period (43.1 in.) is approximated using precipitation and temperature records from the Damascus weather station, and the concept of potential evapotranspiration (Thornthwaite and Mather, 1957) as the estimation technique. Potential evapotranspiration attains a seasonal high in the summer when temperatures and water use by plants reach a peak. It declines with falling temperatures in autumn, climbing again with rising temperatures and the advent of the spring growing season. Total streamflow (25.4 in.) was obtained from a continuous-record station located at the mouth of the basin. A 2-in. decline in ground-water storage for the basin was approximated using water-level data from observation well HO-BB 26, and an estimated specific yield of 0.025 for the well. The specific yield was obtained from cumulative positive changes in the water-level hydrograph and total recharge as determined from steady-state modeling. Both streamflow and ground-water storage show the effects of variations in precipitation and evapotranspiration. Total water losses for the basin during the period were about 66.5 in. Differences between total gains and losses vary from 1 to 43 percent for individual months and average 2.5 percent for the 15-month period. These differences are due mainly to precipitation values at Damascus that are not truly representative of conditions in the basin, and to changes in soil moisture that are ignored. Measurement of these elements within the basin would increase the accuracy of estimates.

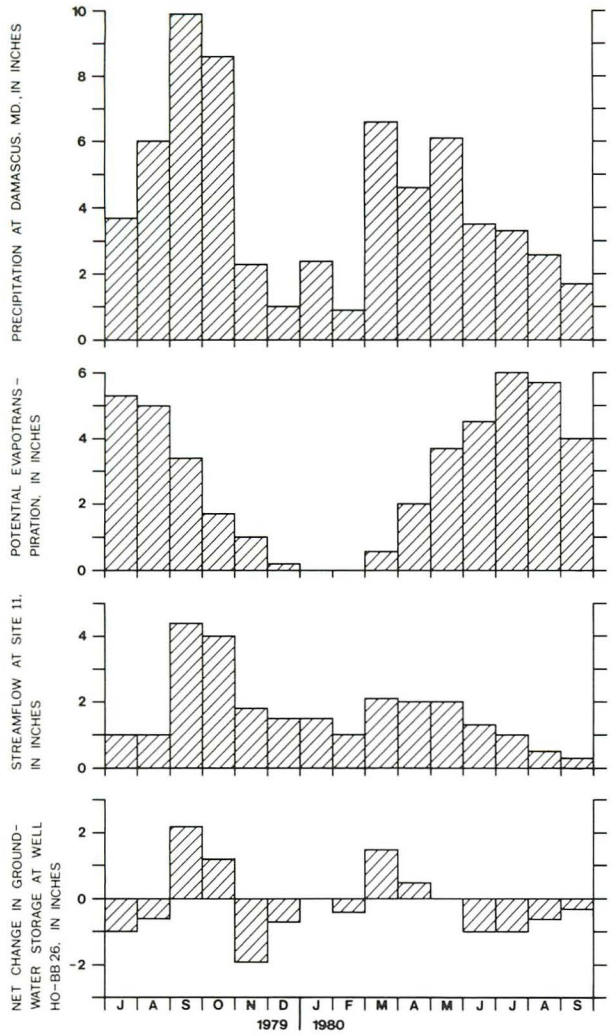


Figure 3. — Monthly precipitation, potential evapotranspiration, streamflow, and ground-water storage change, July 1979 to September 1980.

Streamflow

The basin boundary drawn along the topographic highs in figure 4 outlines the surface-water divide and approximates the underlying ground-water divide for the stream basin. Precipitation falling within this area may potentially contribute to streamflow as measured at the continuous-record station (site 11) at the mouth of the basin. Mean daily discharges for this site are published in U.S. Geological Survey Water-Data Report MD-DE-80-1 as station 01591350. For July 1979 to September 1980, these data provide a basis for the construction of a base-flow hydrograph to represent estimated ground-water flow contributions to total streamflow on a daily basis. Low-flow measurements were made at 11 additional sites to determine areal variability in base flow and as an internal check on ground-water runoff to streams within the basin. Data obtained during three different low-flow periods (fig. 5) show that base flows decrease with diminishing drainage area and as the summer progresses. Low-flow sites 7 and 8 have consistently higher discharges per unit area. This may be due in part to unweathered bedrock cropping out in the vicinity of these measurement sites, forcing proportionately more water into the stream channel at these locations. Stream-channel alterations at site 4, after the June 1980 measurement, necessitated the selection of a new site a short distance downstream. Subsequent discharge measurements were higher than expected, probably due to inflows from local drainage ditches; these measurements were not used in model calibration and are not shown. Stream discharge at site 5 on August 8, 1980, was negligible, and on September 3, 1980, the stream channel was dry; both have been omitted from the figure.

Several general statements can be made about the stream-aquifer system in the Cattail Creek basin on the basis of low-flow measurement data and field reconnaissance of the stream channels.

1. The stream network functions as a drain for the ground-water body and all stream-channel sections may be considered as gaining reaches.

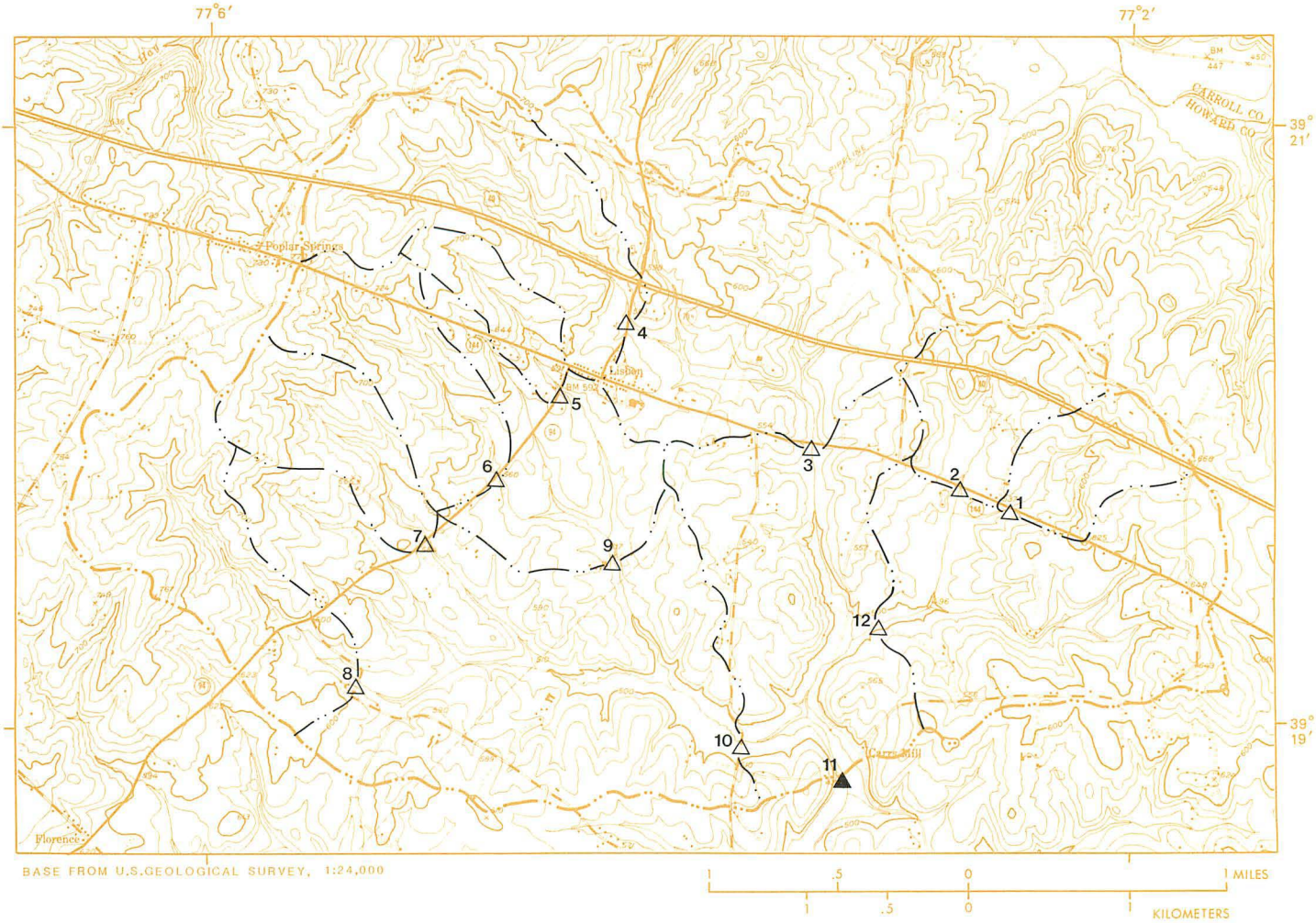
2. Ground-water runoff (base flow) nearly always constitutes a significant part of total streamflow. During low-flow periods, streamflow is entirely ground-water runoff.

3. Headwater reaches of a stream may go dry as local ground-water levels fall below the bottom of the channel.

4. Base flows do not appear to vary with stream orientation and the stream-aquifer system may be considered isotropic for the purposes of the model. Special conditions that may enhance base flows, as at sites 7 and 8, are localized and not considered indicative of an entire subbasin.

Wells in Bedrock

Locations of nearly 300 inventoried wells are shown in figure 6. Water levels were measured in the field at 242 wells. Wells were inventoried to obtain water-level information and to gain some insight into the aquifer characteristics of the area by examining data on yield, casing depth, total well depth, and lithology. Most information on the physical dimensions, yield, and lithology of each bedrock well was obtained from drillers' well-completion reports filed with the Maryland Water Resources Administration.



EXPLANATION

—··— Basin boundary

—··— Sub-basin boundary

11▲ Continuous record station

7△ Low-flow measurement site

SITE	DRAINAGE AREA (Square miles)	DISCHARGE MEASUREMENT (Cubic feet per second)		
		6-25-80	8-8-80	9-3-80
1	0.24	0.16	0.05	0.02
2	.34	.16	.08	.03
3	1.82	1.60	1.00	.66
4	.74	.59	1.04	.40
5	.18	.04	0	0
6	.44	.41	.18	.10
7	.34	.46	.23	.16
8	.73	.91	.63	.39
9	1.11	.73	.41	.24
10	3.90	2.95	2.22	1.41
11	8.38	6.65	3.95	2.85
12	1.66	1.14	.69	.43

Figure 4. — Streamflow measurement sites.

Table 1. — Statistical summary of selected bedrock-well characteristics

Well characteristics	Depth below land surface (ft)		Number of wells
	Range	Median	
Water-level depth	1 - 74	36	242
Well-casing depth	18 - 127	36.5	190
Finished well depth	33 - 368	145	197

Wells inventoried during the study are identified and can be located by using a numbering system adopted by the Maryland Geological Survey. Each identification number consists of two pairs of letters followed by a number (HO-AC 12). The first pair of letters designates the county (HO for Howard); the second pair of letters designates one of the 5-minute quadrangles into which the county has been divided — the first letter represents a 5-minute increment of latitude and the second letter represents a 5-minute increment of longitude. Within each 5-minute quadrangle, individual wells are numbered sequentially in the order they were inventoried. Data for selected wells are shown in tables 6 and 7 found at the end of the report.

Occurrence and Movement of Water in Bedrock

Work by other hydrologists (LeGrand, 1967; Davis and DeWiest, 1966; and Nutter and Otton, 1969) has led to a general understanding of the hydrogeology and bedrock well yields in areas underlain by crystalline-rock aquifers. The reader is referred to these authors for a more complete treatment of the subject, but a review of some of the more important aspects is provided here. Figure 7 is an idealized cross-section showing the occurrence and distribution of fractures in the Piedmont. In Maryland's humid environment, ground water is an almost constant source of supply for streamflow. Where water levels are in the saprolite (a rind of highly weathered materials overlying fresh bedrock), water occurrence and movement is between individual grains of material. However, saprolite frequently has insufficient saturated thickness or is too fine grained to yield appreciable quantities of water to screened or open-ended wells, so wells penetrating consolidated rock are utilized. These wells are cased into the consolidated bedrock where ground-water movement takes place within systems of fractures because the rock is virtually impermeable. Success or failure of a bedrock well to yield water depends on the well bore intersecting water-bearing fractures and the degree of connection these fractures have with a dependable source of recharge. These studies have also shown that fractures are more abundant in valleys and draws than at topographic highs, and the number of fractures and degree of openness decrease with depth. Decreases in the number and degree of openness

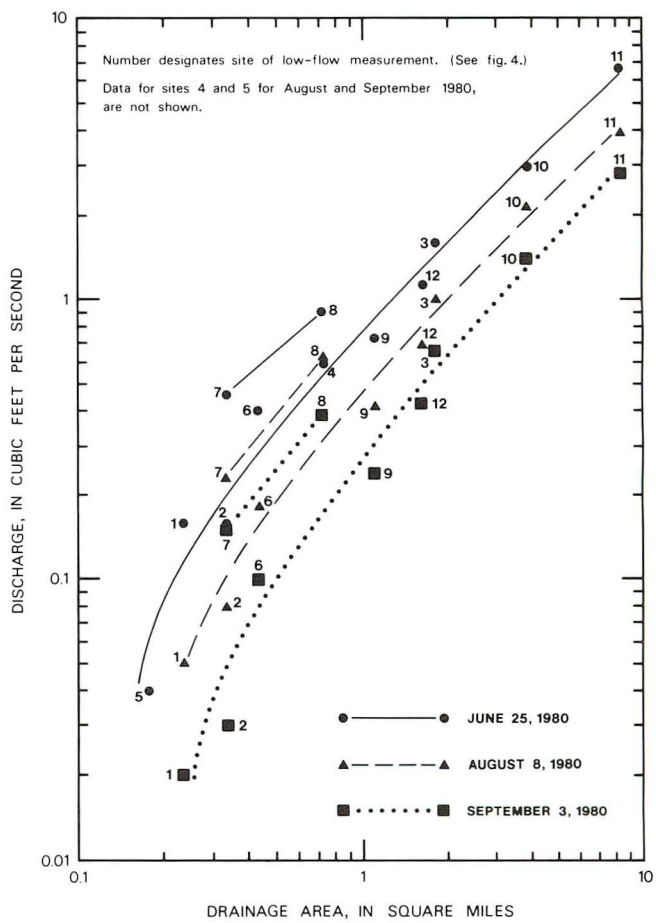
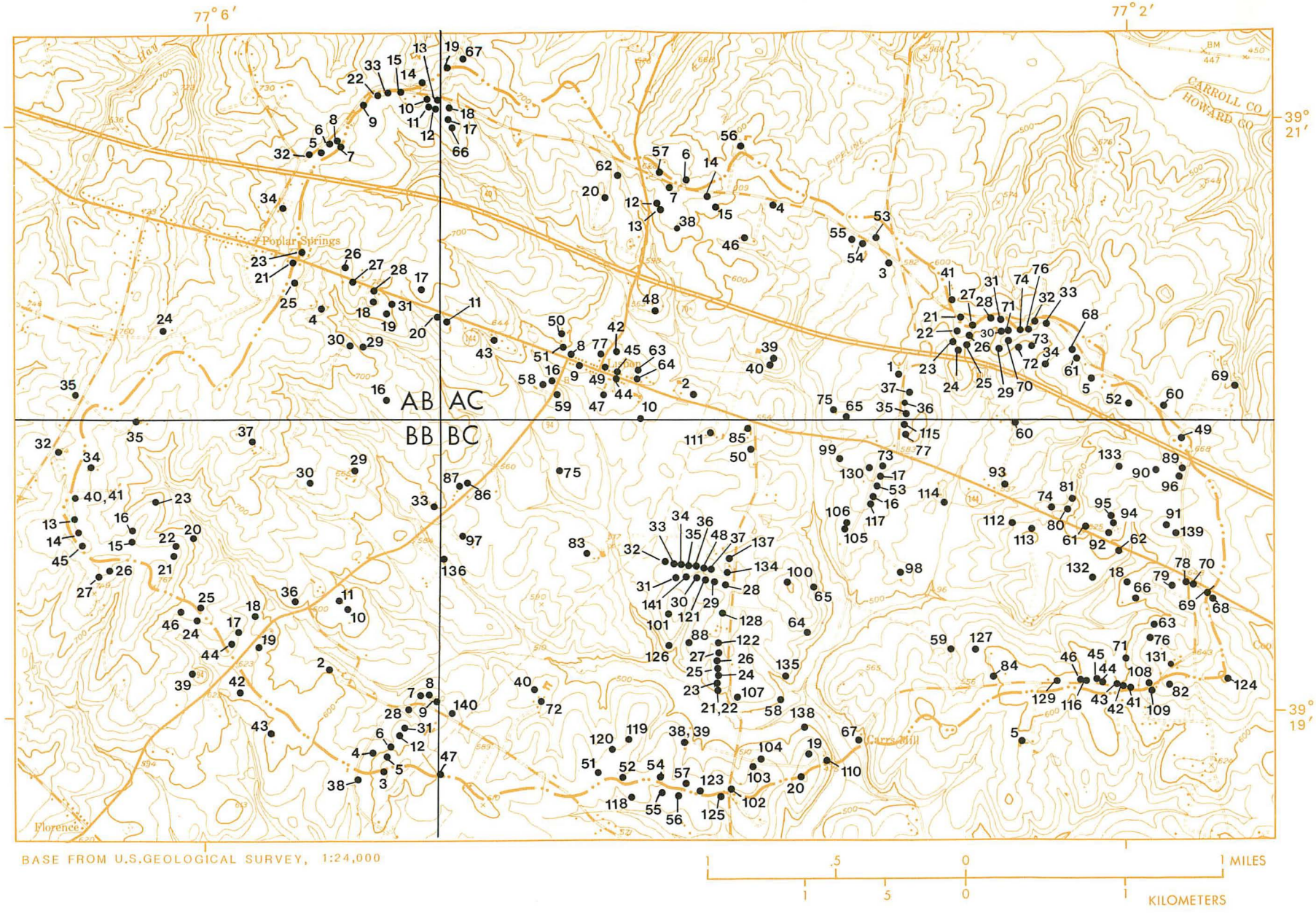


Figure 5. — Relationship of measured low flows to drainage area.



EXPLANATION

3 ● Well and number

Basin Boundary

Figure 6. — Location of inventoried wells.

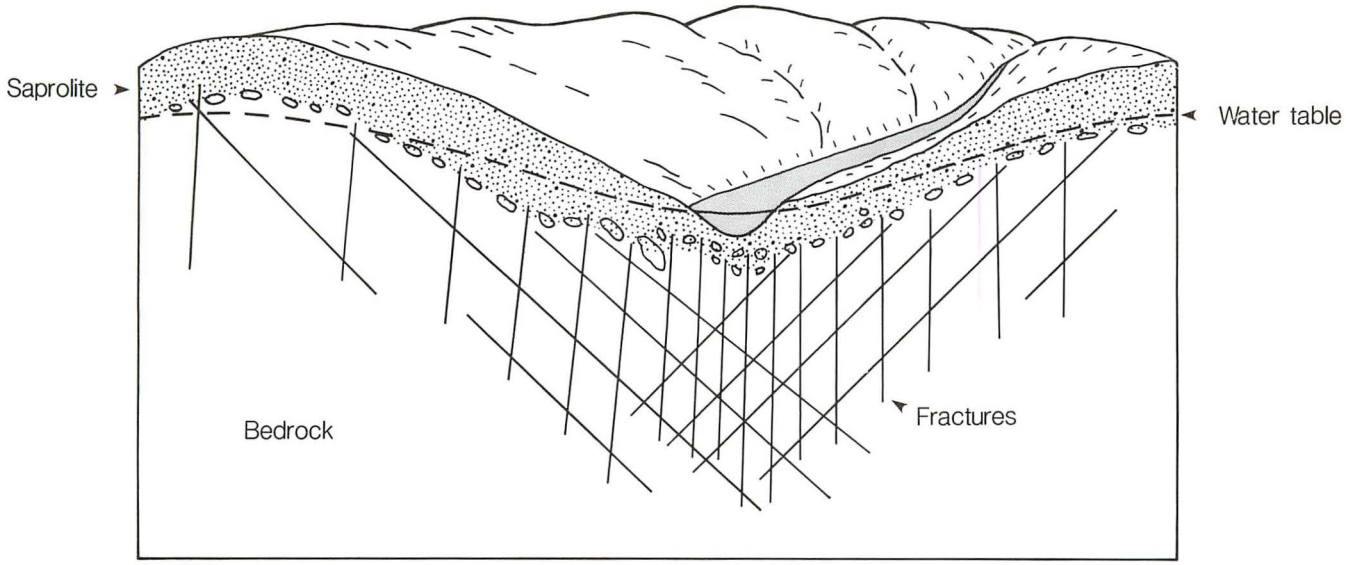


Figure 7. — Idealized section showing bedrock fracturing in the Piedmont. (Modified from Heath, 1978, fig. 6.)

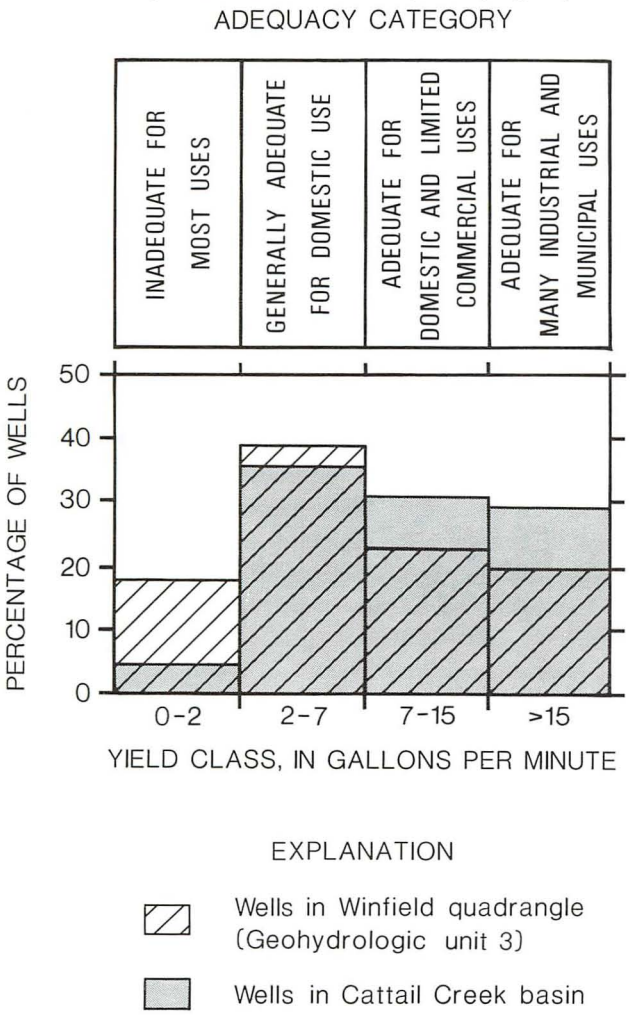
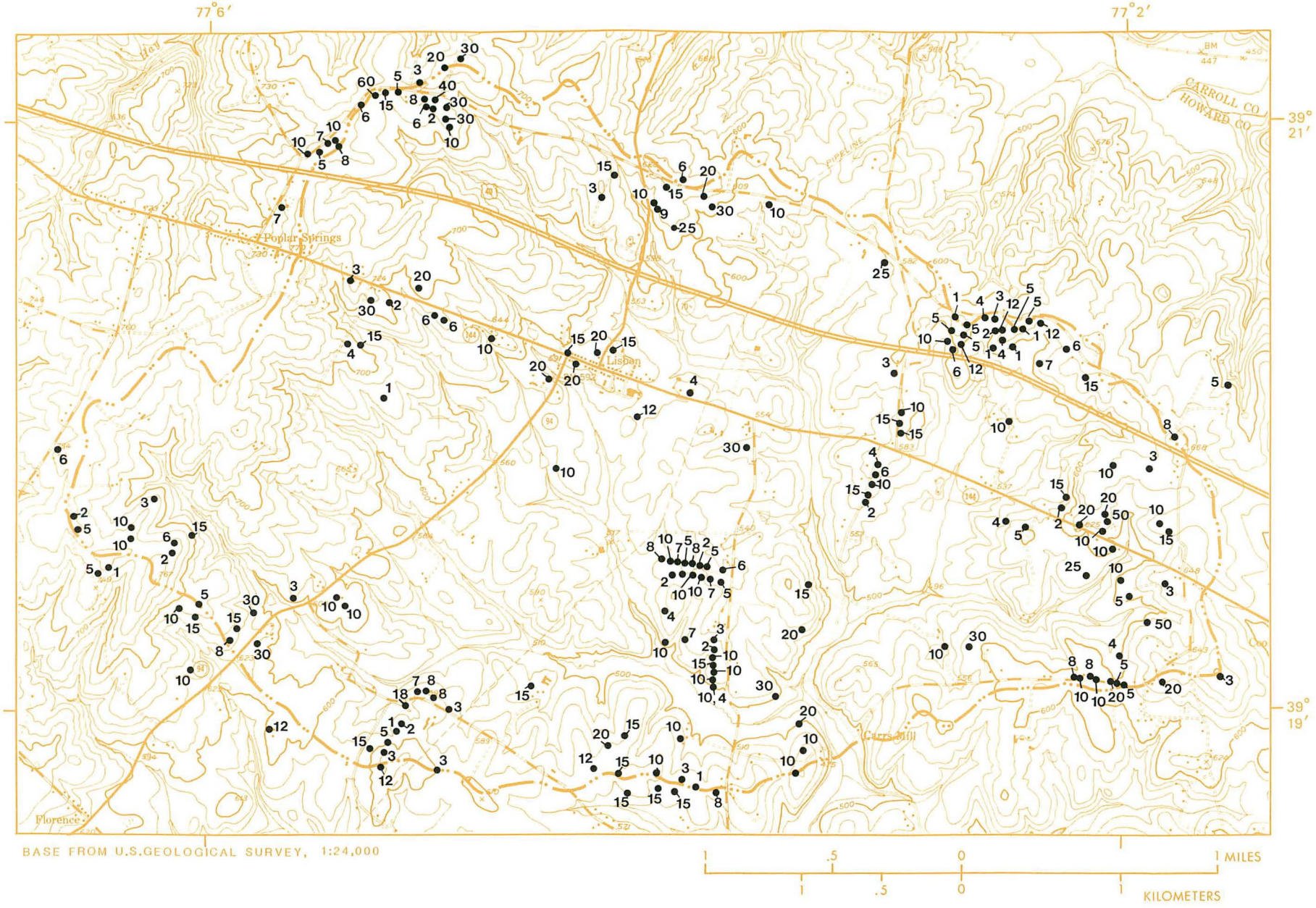


Figure 8. — Yield classification for inventoried wells. (Modified from Otton, 1980, map 3, fig. 4.)

of water-bearing fractures with depth produces a similar decline in the average bulk permeability and storage capabilities of the aquifer.

In the Cattail Creek basin, 75 percent of the wells are less than 200 ft deep. Values for median water-level and well-casing depths are 36 and 36.5 ft, respectively (table 1). The median well yield is 10 gal/min, and well yields are somewhat better than those reported for wells located in a geohydrologically comparable unit (fig. 8) in the Winfield, Md., quadrangle, which abuts the area on the north. While wells in valleys and draws frequently yield comparatively more water than wells in other topographic situations, little data for these locations are available in Cattail Creek since most development has been along topographic highs. Wells in the study area exhibit considerable variability in yield (fig. 9); differences by a factor of two or more are not uncommon in wells less than 500 ft apart.

Water levels measured April to July 1980 are used to construct an approximate water-level-contour map for spring 1980 (fig. 10). Nearly all wells examined were being used for domestic purposes and had been pumped at some time during the day of the measurement. Thus, true static water levels may be somewhat higher than reported and, while care was taken to minimize these problems, errors of as much as 10 ft are possible. These errors tend to be greater in low-yielding wells that recover slowly after pumping. Additional errors may be present because land-surface altitude estimates are based on a topographic map with a 20-ft contour interval, and large areas exist for which no water-level data are available.

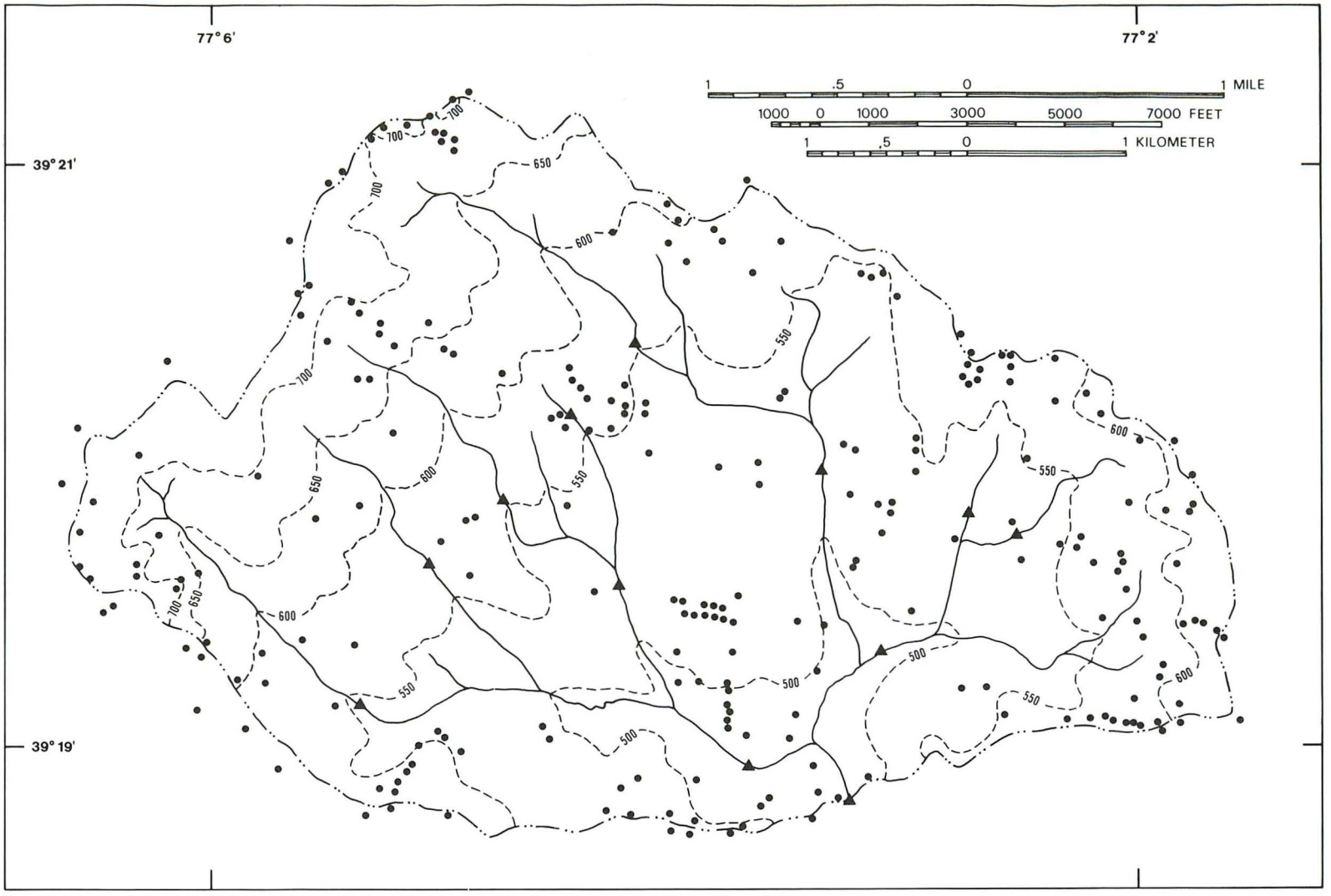


EXPLANATION

6● Well with reported yield in gallons per minute.

Basin boundary

Figure 9. — Yields of inventoried bedrock wells.



EXPLANATION

Basin boundary

Stream

700 Water-level contour -- Shows approximate altitude of potentiometric surface in feet above sea level, contour interval 50 feet. Altitudes are inferred from topography, streams, and water levels in wells measured in the spring of 1980.

● Well used for control

▲ Surface-water gaging site

Figure 10. — Approximate water-level contours, spring 1980.

MODEL DESCRIPTION

A two-dimensional finite-difference aquifer model (Trescott, Pinder, and Larson, 1976) is used to simulate the response of the ground-water system to imposed hydrologic stresses. These stresses are recharge to or discharge from the system. Sources include recharge from precipitation, releases from aquifer storage, and induced infiltration from streams. Discharges include evapotranspiration losses from the water table and leakage to streams. At present, all water used in the basin (120,000 gal/d) is pumped from on-site ground-water sources and an estimated 90 percent of this pumpage is returned to the water table via on-site disposal systems. The magnitude of this pumpage lost to the basin is so small (about 0.03 in/yr) that it was omitted from simulations of the present-day system. During the predictive phase of modeling, additional stresses imposed were discharges due to ground-water pumping and sources from pumpage returns.

Satisfactory simulations of ground-water-system stress responses require adequate estimates of certain hydrologic elements. These include transmissivity, hydraulic conductivity, specific-yield or storage coefficient, vertical hydraulic conductivity of the streambed, and boundary conditions. Utilizing data from the above elements, the digital model solves the two-dimensional flow equation for head distribution by the strongly implicit procedure of finite-difference approximation.

A conceptual model of the stream-aquifer system was first developed using hydrologic data from the area and drawing on information from studies completed in similar areas. This conceptual model involves some simplifying assumptions to facilitate mathematical simulation of the system; assumptions are as follows:

1. The basin is not experiencing any long-term adjustments due to natural or man-induced stresses, but is in dynamic equilibrium.

2. Ground-water flow in the aquifer system is nearly horizontal, and the aquifer is isotropic. While these assumptions appear to be valid based on available data, the existence of significant vertical-flow components could cause errors in predicted water levels.

3. The aquifer system, while irregular, is continuous throughout the basin. The aquifer may be divided into a finite number of rectangular cells in which the average aquifer properties remain constant in the horizontal plane, but diminish with depth in a prescribed manner. Aquifer properties may vary from cell to cell.

4. Recharge to the aquifer from precipitation is uniform over the basin; recharge from pumpage returns is uniform within specified cells and neither vary within a pumping period. Pumpage return is defined as that portion of water pumped from wells that is returned to the stream-aquifer system.

5. There is no inflow or outflow across the modeled basin boundary.

6. Stream stage (or discharge) remains constant within each pumping period.

7. Ground-water discharges are by ground-water evapotranspiration, leakage to streams (base flow), or by pumpage not returned to the stream-aquifer system (pumpage losses) within the stream basin.

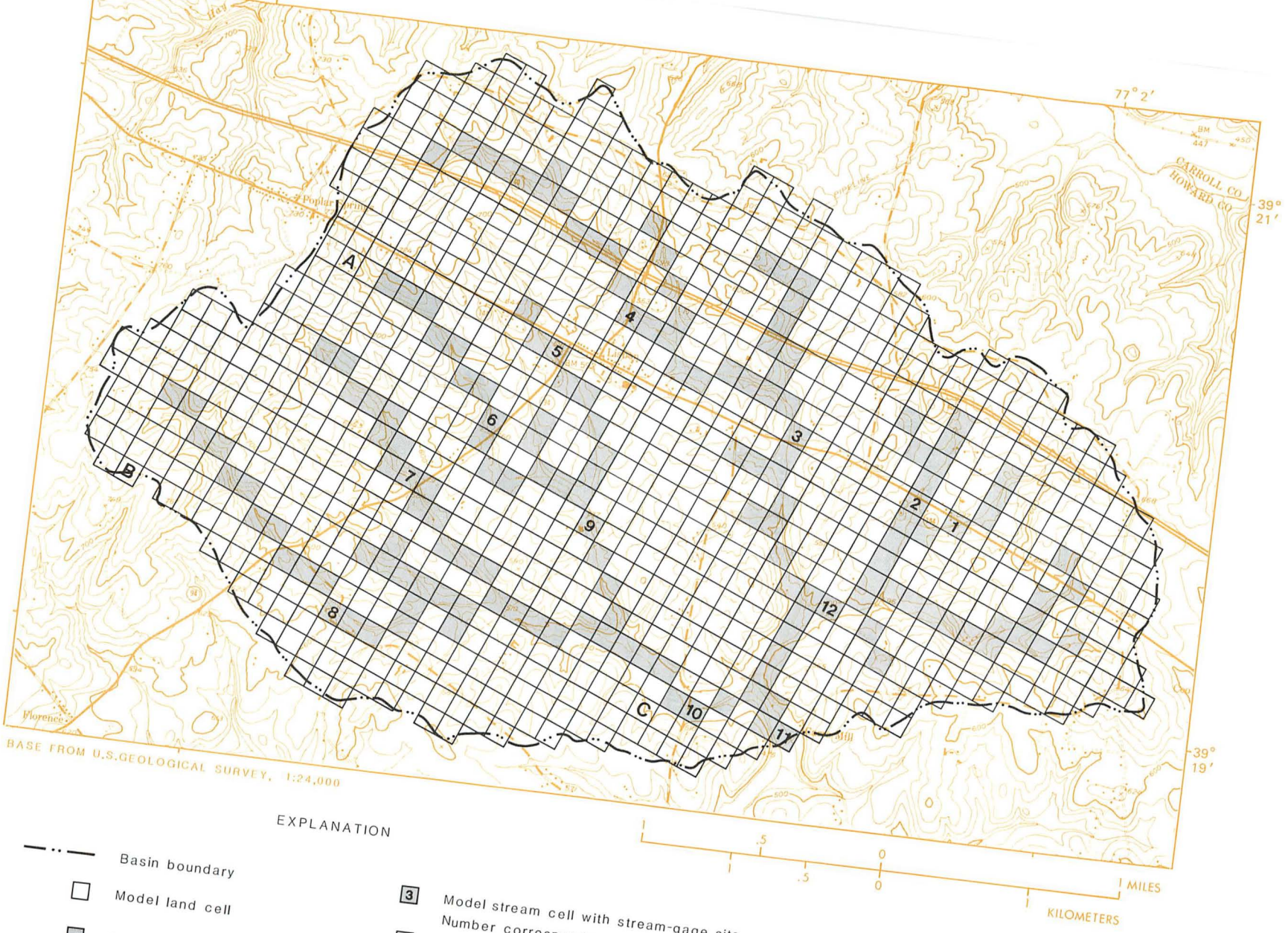
8. Ground-water evapotranspiration is a function of potential evapotranspiration and decreases with increasing depth to the water table.

These assumptions, although not representing actual conditions in the stream-aquifer system exactly, probably do not incur errors of sufficient magnitude to invalidate the model simulations.

HYDROLOGIC PARAMETERS

Finite-Difference Grid

Solution of finite-difference approximations of the ground-water flow equations by the digital model requires the basin area be divided into rectangular cells and that hydrologic characteristics values be specified for each cell. The stream basin is divided into a grid of cells each 500 ft on a side, as shown in figure 11. The choice of a smaller cell size would significantly increase the cost of each simulation, while a larger cell size would probably not adequately characterize the narrower areas between streams. Care was taken that the shape and total area of the 933-cell grid closely matched the basin delineated on the topographic map. This network of cells is referred to as a block-centered finite-difference grid with fixed spacing. Values for individual hydrologic characteristics assigned to each cell are average values for the cell.



EXPLANATION

Basin boundary

Model land cell

Model stream cell

3 Model stream cell with stream-gage site. Number corresponds to stream-gaging site.

A Model land cell with observation well. Letters identify the following local well numbers:

A = well HO AB 4

B = well HO BB 26

C = well HO BC 38

Figure 11. — Finite-difference grid.

Boundary Conditions

The periphery of the finite-difference grid closely approximates the basin boundary (fig. 11) and delimits the area contributing to base flow measured at surface-water site 11. Because the area outside this boundary does not contribute water to the basin, it is assigned zero transmissivity or hydraulic conductivity, thus simulating a no-flow boundary. Stream segments may act as discharge or recharge boundaries for the aquifer depending upon altitude differences between the water in the stream and the aquifer in the same cell.

Land-Surface Altitude

The average altitude of land surface for each land cell is used as the altitude of the cell (fig. 11). At stream cells, the land-surface altitude is set to equal the average stream altitude in the cell. The accuracy of these estimates is considered to be 10 ft, one-half the mapped contour interval.

Water-Table Altitude

The water-table altitude (head) for each land cell is obtained using the water-level contour map for April 1980 (fig. 10) and an overlay of the finite-difference grid. The accuracy of these values varies widely from cell to cell. Cells with field data are probably within 10 ft of the estimated value, but those cells with no water-level data (about 90 percent) may be in error by 20 ft or more. At stream cells, heads in the aquifer are set equal to the stream altitude.

Three cells contain observation wells (fig. 11) and are designated as follows:

Cell A = well HO-AB 4
Cell B = well HO-BB 26
Cell C = well HO-BC 38

For these three cells, the water-table altitude at the well is used as the average water-table altitude for the cell.

Ground-Water Recharge

The model assumes ground-water recharge from precipitation is distributed evenly throughout the stream basin and occurs simultaneously at a constant rate within each designated time period. During predictive simulations, recharge may be reduced or increased at selected locations depending on the development scheme being modeled.

For simulations of steady-state conditions, recharge is set to equal the sum of ground-water runoff (base flow) plus ground-water evapotranspiration. During simulations of transient conditions, recharge is periodic and the water-level rise in observation well HO-BB 26 is used to estimate the timing and magnitude of recharge for the entire basin. This method of estimation is similar to that of Rasmussen and Andreasen (1959, p. 94) and assumes that the amount of water gained in the basin during a recharge event equals the water-level rise in the well when multiplied by a factor representing specific yield (in this case, 0.025).

Stream-Cell Network

The modeled stream-cell network (fig. 11) approximates the stream network from the topographic map. Numbered stream-cell locations coincide with locations of streamflow measurement sites. Simulated base flow is calculated for these locations and compared with low-flow measurements.

Stream-channel areas are determined using topographic map lengths and widths obtained at low-flow sites. Channel area for each stream cell is expressed as a percentage of the total cell area.

Streams may discharge or recharge the ground-water aquifer depending on the relative heads in the stream and the aquifer. The quantity of water transferred depends for the most part on the difference in head values, stream-channel area, and the vertical-flow characteristics of a semiconfining layer used to represent the streambed in the model. In the field, restrictions to the movement of water between aquifer and stream vary from place to place. At some locations this may be a function of vertical-flow characteristics in the aquifer, and, at others, the existence of a true semiconfining layer. No field determinations were made of vertical hydraulic conductivity of materials, but table 2 shows a sample of values found in the literature. Calibration runs (simulating steady-state conditions)

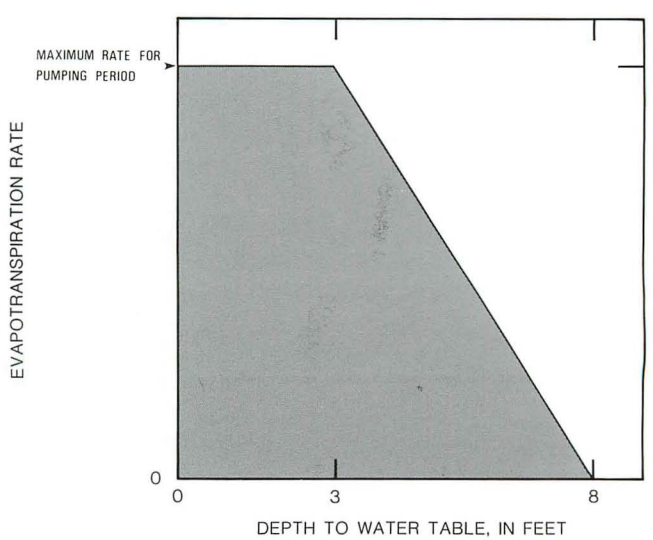


Figure 12. — Relationship of ground-water evapotranspiration rate to water-table depth as used in model. (Modified from McGreevy and Sloto, 1980, p. 19.)

Table 2. — Selected values for vertical hydraulic conductivity in streambeds

Vertical hydraulic conductivity (ft/d)	Remarks	Reference
0.99	Assuming a semiconfining layer 1 ft thick.	This report.
0.06- 5.2	Seepage loss measurements	Fidler, 1975, p. 11.
1.9	Field test average } Sand and gravel.	Haeni, 1978, p. 19.
.09- 3.9	Laboratory } Sand and gravel.	
2	Final value used in model	Haeni, 1978, p. 29.
.09-15.2	Variable head permeameter Field tests in various materials.	Rosenshein and others, 1968, p. 23.
3.4	Flood-plain sediments } Laboratory tests.	Kilpatrick, 1964, p. 332.
10.5 -31.5	Silty sands } Laboratory tests.	
10.5	Saprolite } Laboratory tests.	
5.3	When assuming a restrictive layer 1 ft thick.	McGreevy and Sloto, 1980, p. 18.

assuming a semiconfining layer thickness of 1 ft and a vertical hydraulic conductivity of 0.99 ft/d give leakage results that compare well with measured low-flow values while maintaining differences of 4 ft or less between the water table and the stream.

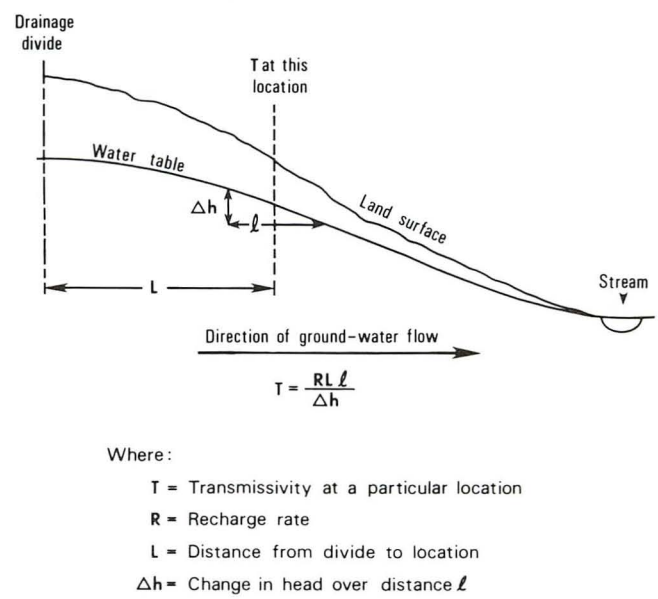
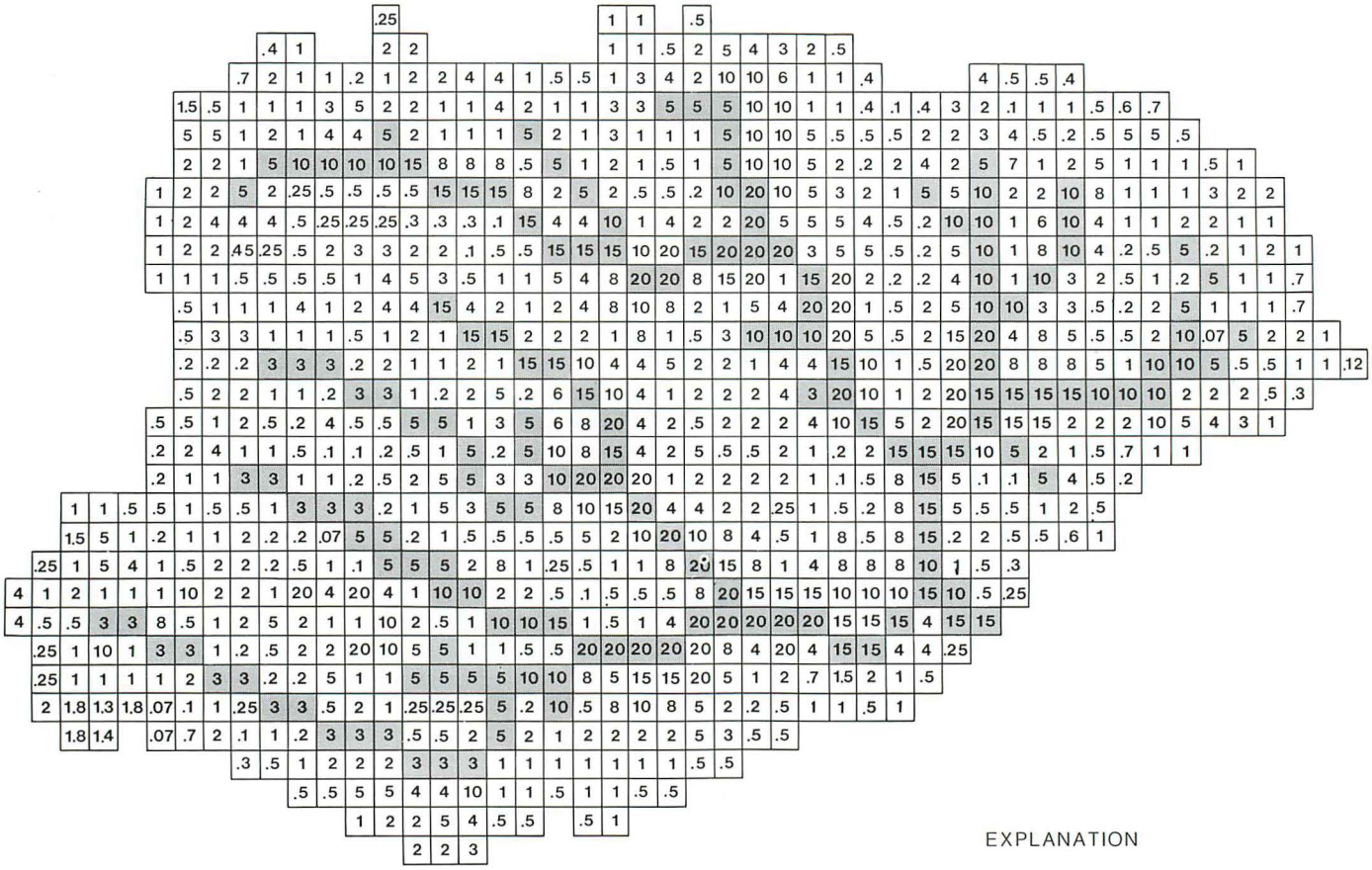


Figure 13. — Method of estimating initial transmissivity values. (Modified from McGreevy and Sloto, 1980, p. 13.)

Ground-Water Evapotranspiration

Ground-water evapotranspiration varies with the season and water-table depth, but field documentation of these changes is difficult to obtain. Estimates of daily variation in ground-water evapotranspiration were made by considering it as a function of daily potential evapotranspiration. First, the estimated average annual ground-water evapotranspiration rate of 12 in/yr (McGreevy and Sloto, 1980, p. 10) is divided by an average annual potential evapotranspiration rate of 29.45 in. at College Park, Md. (Thornthwaite and others, 1958, p. 41), yielding a 0.4 factor. The daily potential evapotranspiration rate was calculated for 1979 and 1980 using the method of Thornthwaite and Mather (1957). Daily potential evapotranspiration (PE)



EXPLANATION

3 Cell -- Number is transmissivity (rounded) in feet squared per day times 100 ($ft^2/day \times 10^2$)

Stream cell

Figure 14. — Areal distribution of calibrated transmissivity values.

Table 3. — Reported transmissivity, hydraulic conductivity, and specific-yield values for selected areas underlain by crystalline rock

Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Specific yield	Remarks	Reference
7 -2,000	0.05 - 19	0.0001-0.08	Final model values, see text for discussion	This report.
6.7-2,000	.11 -220	.0002- .001	Aquifer tests (Wissahickon Formation, Montgomery County)	Dames and Moore, 1978, v. 2-5, chap. 2.
-	<.001 - 5.7	-	Pressure tests, relatively sound bedrock. (Wissahickon Formation, Montgomery County)	Dames and Moore, 1978, v. 2, chap. 2, table 9,
-	.001 - 39.7	-	Rising and falling head tests, saprolite to relatively sound bedrock. (Wissahickon Formation, Montgomery County)	v. 3-5, chap. 2, table 10, v. 2-5, chap. 2, table 6.
-	1.6 - 12.4	-	Laboratory tests, saprolite cores; Wissahickon Formation, Baltimore County	Dingman and Ferguson, 1956, table 10.
37 - 744	-	-	Aquifer tests; crystalline rocks in Georgia Piedmont	Kilpatrick, 1964, p. 333.
-	.028 - .24	-	Constant and falling head tests, saprolite. (Wissahickon Formation, Montgomery County)	Law Engineering and Testing Co., 1973, v. 4, appendix B.
-	.003 - 2.84	-	Pressure tests relatively sound bedrock. (Wissahickon Formation, Montgomery County)	
68 - 130	-	.08	Water-table slope; base-flow measurements, Wissahickon Formation, York County, Pa.	Lloyd and Growitz, 1977, p. 29-30.
-	.4 - 12.6	-	Laboratory tests on soils representative of those in Cattail Creek basin.	Matthews and Hershberger, 1968, table 6.
4 -1,700	.22 - 9.5	.08	Final model values; basin underlain chiefly by gneissic rocks; Chester County, Pa.	McGreevy and Sloto, 1980, p. 12-18.
228 - 590	-	.003 - .12	Aquifer tests; Wissahickon Formation; Laytonsville, Md.	Nutter and Otton, 1969, table 8.
-	-	.08	Water-level fluctuation	Nutter and Otton, 1969, p. 28.
-	-	.075 - .10	Water-level fluctuation	Olmsted and Hely, 1962, p. 16-18.
-	.0013- 34.2	-	Specific capacities of 480 wells in schist in the United States.	Rasmussen, 1964, p. 324.
12 - 976	-	.0048- .017	Aquifer tests (Thick weathered materials overlying fractured rock; upper Potomac River basin.)	Trainer and Watkins, 1975, p. 41.
-	-	.007 - .014	Water-level fluctuation (Thick weathered materials overlying fractured rock; upper Potomac River basin.)	
6 - 50	-	-	Water-level recession (Thick weathered materials overlying fractured rock; upper Potomac River basin.)	

values multiplied by 0.4 provide an estimate of the maximum daily ground-water evapotranspiration rate. Variations in ground-water evapotranspiration with depth to water table are treated in a manner similar to that reported by McGreevy and Sloto (1980, p. 19), as shown in figure 12. Ground-water evapotranspiration remains at the maximum rate until the water table falls below 3 ft. It then decreases linearly until the water table reaches 8 ft, a critical depth for forested areas (Wilson and Wiser, 1974, p. 271), where it becomes zero.

Transmissivity

Initial transmissivities are estimated utilizing a method reported by McGreevy and Sloto (1980, p. 12-14). This method uses the water-level contour map with a 10-ft contour interval and Darcy's Law to calculate transmissivities at successive nodes (fig. 13) until values are obtained for the entire modeled area. These data provide the initial values for steady-state calibration. After each simulation, transmissivity values are revised, starting at the stream cells and working progressively upgradient, until a reasonable match of 10 ft or less is achieved between simulated and original estimates of water-table altitude. Care is taken that subbasin boundaries do not shift and appropriate base flows are maintained at all low-flow sites.

Calibrated transmissivity values vary from 7 to 2,000 ft^2/d, with most of the larger values being at or adjacent to the stream cells (fig. 14). A frequency-distribution diagram (fig. 15) shows that most transmissivities are between 100 and 1,000 ft^2/d. These values seem consistent with those reported for other areas underlain by crystalline rock (table 3).

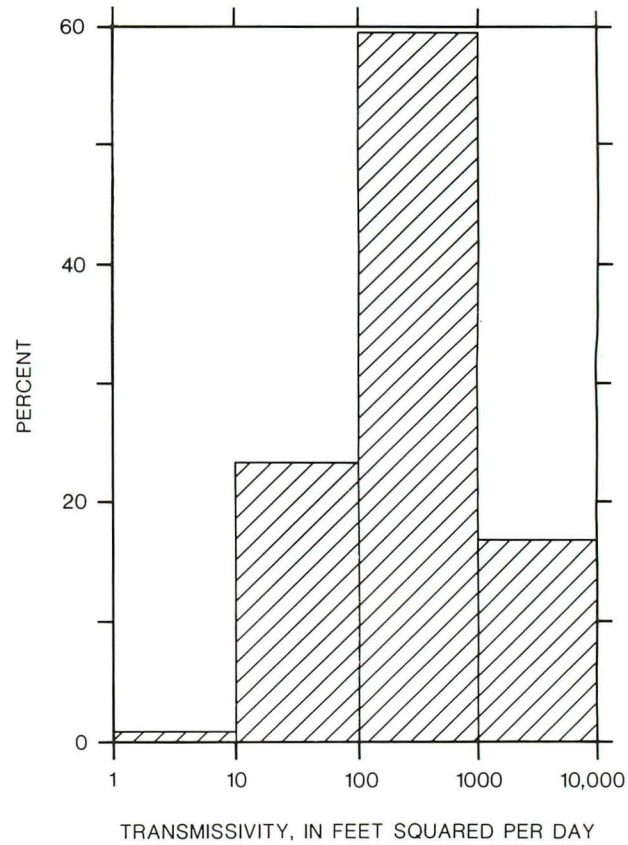


Figure 15. — Frequency distribution of calibrated transmissivity values.

STEADY-STATE CALIBRATION

A steady-state simulation of ground-water flow conditions on June 25, 1980, is used to calibrate transmissivity. Base flow on that day averaged 7.2 ft^3/s (11.64 in/yr) at site 11, and low-flow data are available at 11 other sites within the basin. The ground-water evapotranspiration rate is estimated to be 22.25 in/yr based on potential evapotranspiration for the previous 10 days. Recharge was set at 33.89 in/yr. Head values are considered comparable to those shown on the water-level contour map for spring 1980. Model calibration starts with the elements above and initial transmissivity values, then successive simulations are performed to adjust the transmissivity values. Final transmissivity values shown in figure 14 produced water-table altitudes and base flows that are comparable to field values.

Nine base-flow sites have simulated discharges within 25 percent of the measured values; the other three sites are within 50 percent (fig. 16). Distribution of residuals (differences) between the simulated water-table altitude and values interpolated from the original water-table map is shown in figure 17. There is no consistent pattern, positive or negative, high or low, among these residuals. Altitude differences range from 10 ft above to 11 ft below the original map values; about 73 percent of the cells are within 5 ft of the expected value (fig. 18).

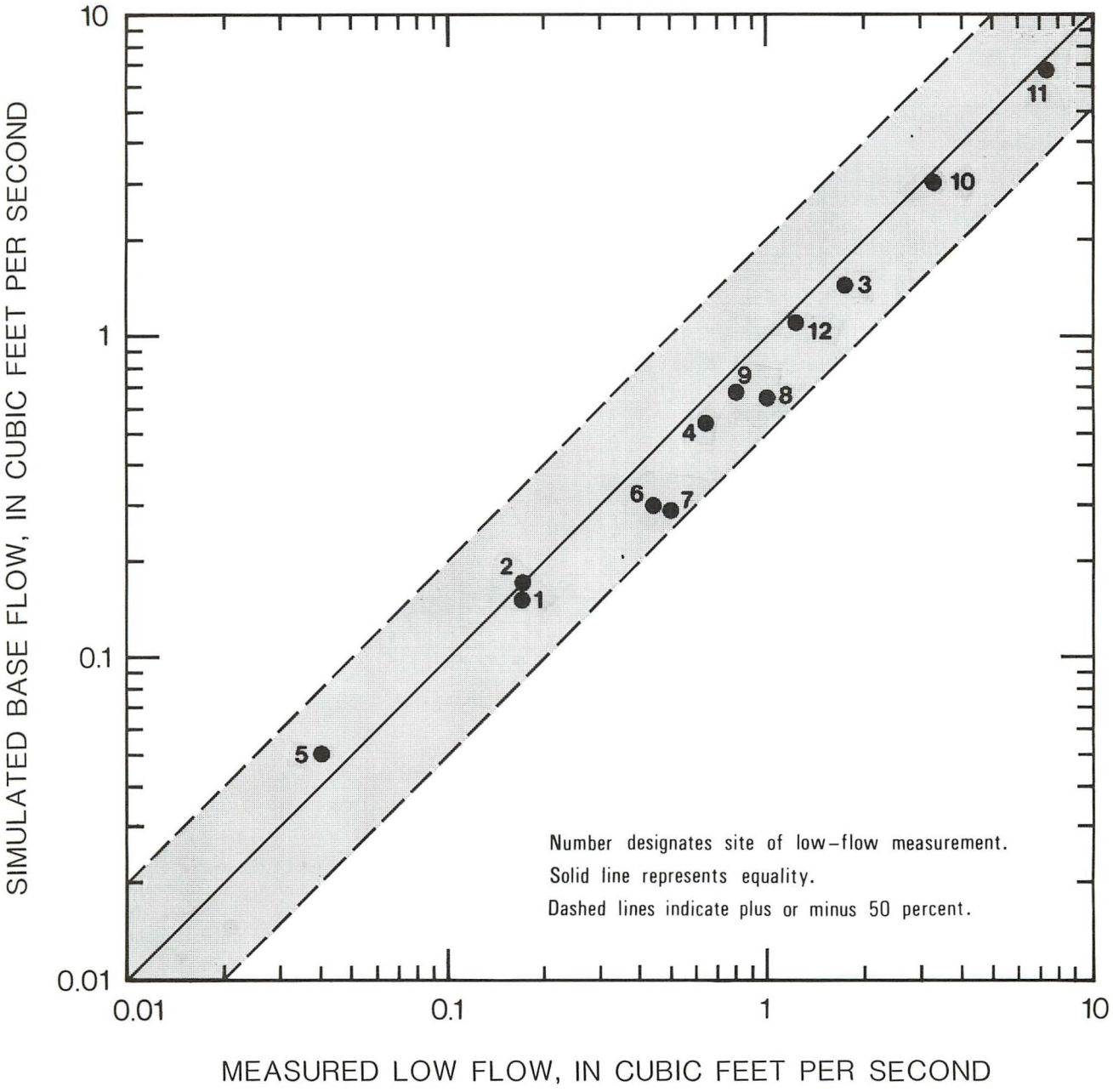
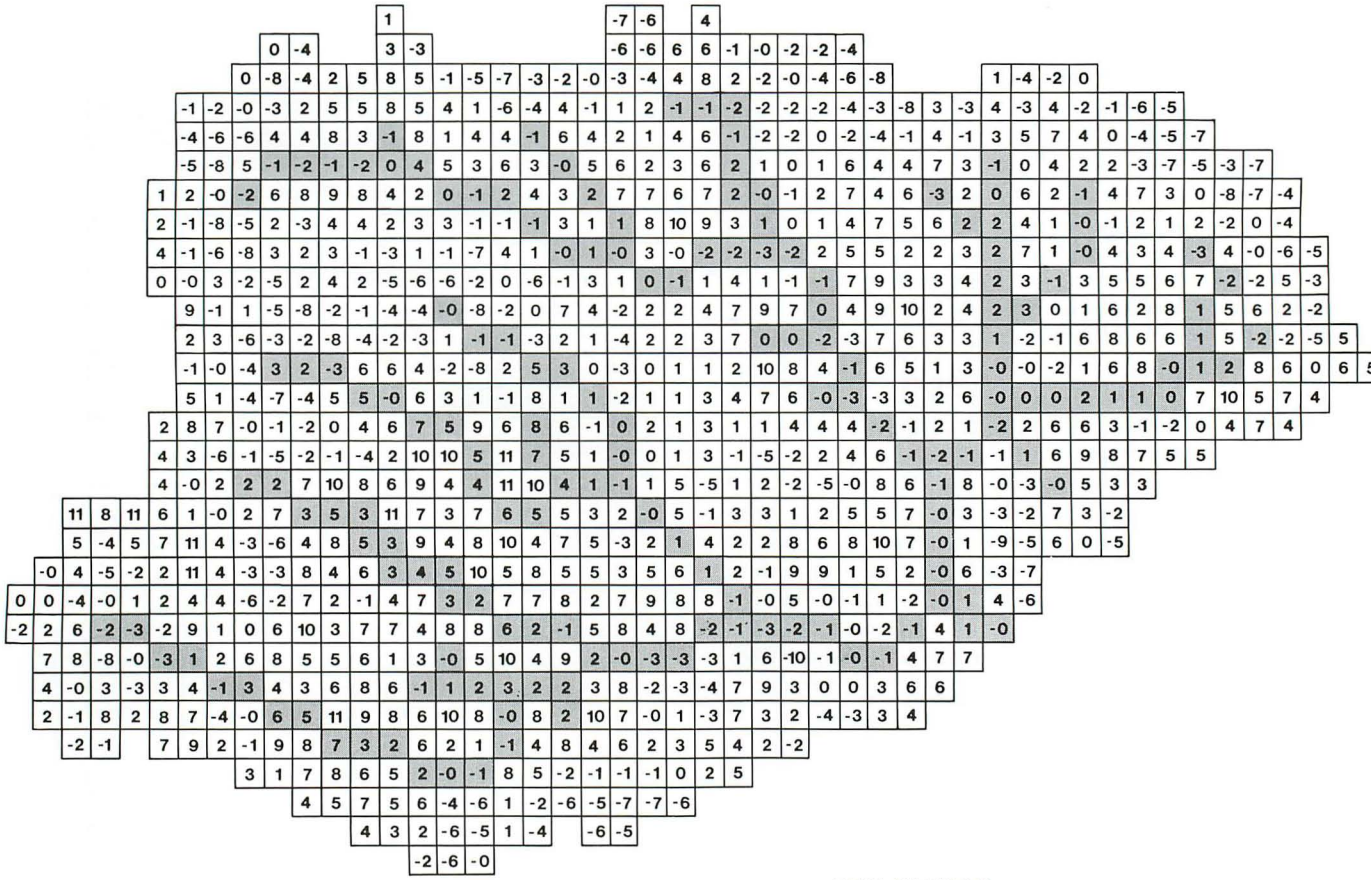


Figure 16. — Relationship of simulated base flows to measured low flows, June 25, 1980.



EXPLANATION

3 Cell -- Number is the difference in feet (rounded) between simulated water level and value interpolated from water level map for spring 1980 (figure 10). Minus sign indicates simulated water level is above interpolated value.

Stream cell

Figure 17. — Areal distribution of differences between simulated and mapped water levels for final steady-state calibration.

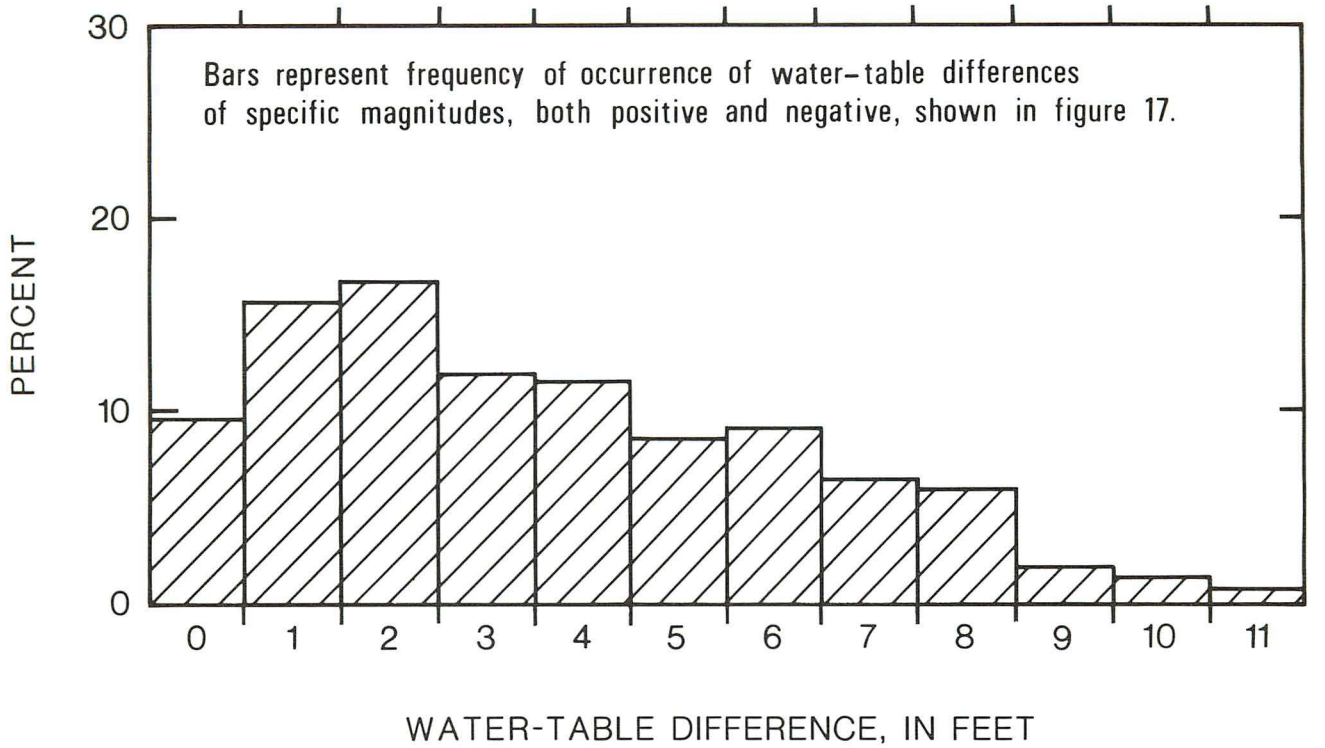


Figure 18. — Frequency distribution of differences between simulated and mapped water levels for final steady-state calibration.

SIMULATION OF TRANSIENT-FLOW CONDITIONS

In order to obtain a longer period of record for simulation of transient ground-water flow conditions, an earlier starting date with hydrologic conditions comparable to June 25, 1980, was chosen to initiate the transient run. On July 8, 1979, base flow at site 11 was the same, and the average estimated ground-water evapotranspiration for 10 days before July 8 was nearly the same (22.41 in/yr) as the value used in the steady-state calibration for June 25, 1980. No synoptic water-level data are available for July 8, 1979, but a measurement on July 3 for well HO-BB 26 shows only a 0.31-ft difference from the water level for June 25, 1980 (table 8). Water levels in the other two observation wells show less than a 1-ft difference from measured values for the end of June 1980. Head conditions for the two dates are therefore considered comparable. Base flow, ground-water evapotranspiration values for July 8, 1979, and the calibrated transmissivity values were used to initiate a new steady-state simulation allowing head values to readjust. Head values for individual cells changed less than 2 ft. This new steady-state simulation establishes starting conditions for simulating transient flow from July 1979 through September 1980.

Hydraulic Conductivity

Simulation of transient-flow conditions requires an estimation of hydraulic conductivity in water-table aquifers since the rise and fall of water levels produce changes in the saturated thickness, and thus changes in transmissivity. A technique also is needed to approximate the decrease in hydraulic conductivity with depth expected in this hydrogeologic setting. (See section on Wells in Consolidated Bedrock.)

Engineering studies (Dames and Moore, 1978; and Law Engineering and Testing Co., 1973) performed in Montgomery County provide some data on variations of hydraulic conductivity with depth for the Wissahickon

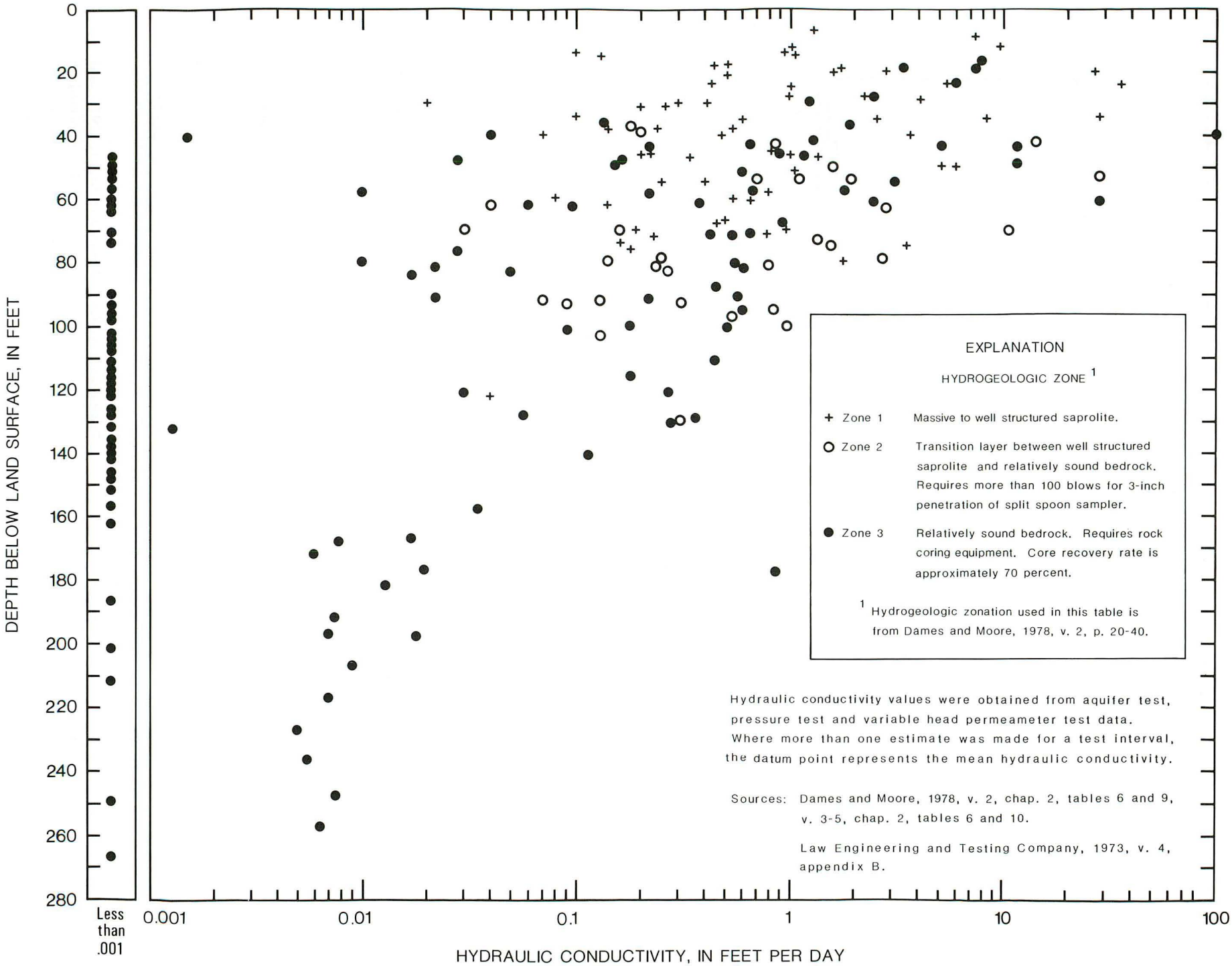


Figure 19. — Relationship of hydraulic conductivity to depth for selected areas underlain by the Wissahickon Formation.

Formation (fig. 19). Each data point represents the midpoint or average depth of an interval of test hole open to the aquifer. Hydraulic conductivities were determined using aquifer tests, variable-head permeameter tests, or pressure tests with packers for test intervals that varied in length from 10 ft to over 200 ft. Aquifer-test data for pumping wells and observation wells varied as much as one order of magnitude for a test interval. Variable-head permeameter test data ranged widely (two orders of magnitude) when several tests were run at each depth interval in the same holes, as did estimates of hydraulic conductivity using pressure tests. In all cases where more than one test was performed for a depth interval, the mean hydraulic conductivity value was used. Data from depth intervals that straddled more than one hydrogeologic zone showed no unique characteristics and are omitted here for clarity.

Hydraulic conductivities for each hydrogeologic zone show wide variations at all depths. Zones 1 and 2 do not show decreasing hydraulic conductivity with depth and may be only marginally superior to those for zone 3 at depths less than 150 ft. Zone 3 does show a decrease in hydraulic conductivity with depth. However, the data provide only a qualitative picture. Variation in testing methods, length of test intervals, and problems in interpreting data reported as less than 0.001 ft/d make precise quantitative estimates of the rate of decline difficult or impossible. For example, the decline in the number of values reported as less than 0.001 ft/d for depths greater than 160 ft is not due to an increase in hydraulic conductivity, but to a lengthening of the open hole being tested. This increased length improves the chance that some water-bearing fractures would be intercepted and the test successful.

Zones 1 and 2 would probably be cased off during installation of a permanent bedrock well because wells finished off in these zones often have problems of rock fragments sloughing into the open well bore. Zone 3 reflects conditions found in most bedrock wells below the casing.

In the Cattail Creek basin, the median depth of bedrock wells is 145 ft and the maximum reported depth is 368 ft. The maximum reported depth of casing is 127 ft. Both water-well and test-boring data imply a hydrogeologic change around 150 ft, and almost negligible water-yielding capability below 300 ft. The model simulates permeability changes found in the field by allowing a stepped reduction in hydraulic conductivity. Hydraulic conductivity calculations utilize the calibrated transmissivity value for each cell and saturated thickness of the upper 300 ft of material (fig. 20) under steady-state conditions. Hydraulic conductivity below 150 ft is set at one-tenth that of the saturated material above 150 ft. A minimum transmissivity value of 0.0001 ft^2/d is used to keep model nodes from "going dry." Once unit values for hydraulic conductivity have been obtained, the model recalculates transmissivity based on saturated thickness changes during each pumping period.

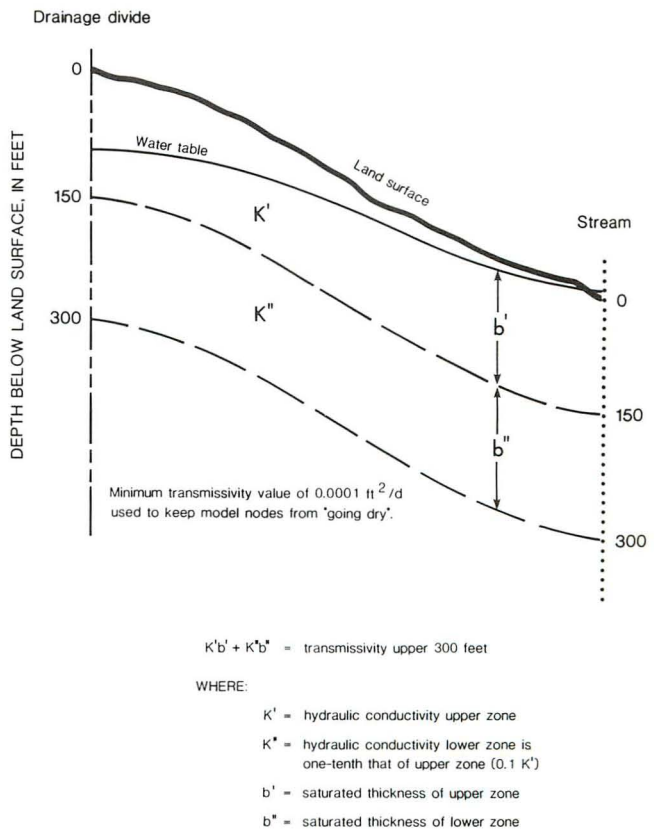


Figure 20. — Distribution of hydraulic conductivity values used in transient-flow simulations.

Areal distribution of hydraulic conductivities (upper zone) used for transient-flow simulations is shown in figure 21. Wide variations in values between many adjoining cells mirror the large lateral variations found in the Montgomery County hydraulic conductivity data (fig. 19) and in the well-yield data for the Cattail Creek basin (fig. 9). Hydraulic conductivities range from 0.05 to 19 ft/d, with over half the values between 0.1 and 10 ft/d (fig. 22).

Specific Yield

In a natural stream basin, water is never at rest. During precipitation, streamflow increases and the aquifer may be recharged. With cessation of precipitation, streamflow begins to decline; as time between precipitation events lengthens, proportionately more and more streamflow comes from the ground-water reservoir. Ground-water seepage (base flow) coming from drainable voids in the aquifer maintains streamflow during low-flow periods. Thus, for the model to adequately simulate transient-flow conditions, some estimate of the aquifer's ability to store

EXPLANATION

3 Cell -- Number is the average hydraulic conductivity in feet per day (rounded), for the interval between the water table and 150 feet in depth, calculated from calibrated transmissivity value.

Stream cell

Figure 21. — Areal distribution of calibrated hydraulic conductivity values (upper zone).

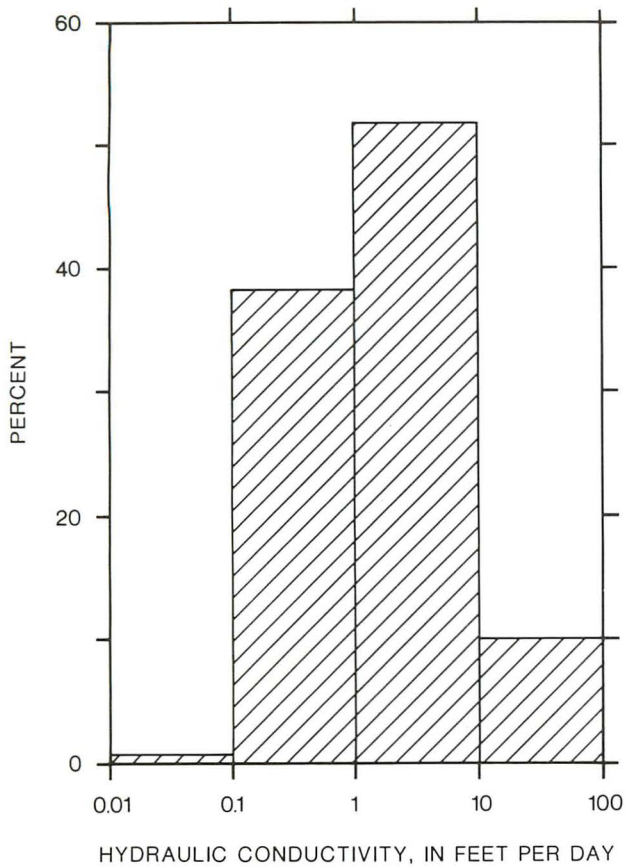


Figure 22. — Frequency distribution of calibrated hydraulic conductivity values (upper zone).

water (specific yield under water-table conditions) is needed. Specific-yield values in hydrogeologically similar areas range over three orders of magnitude (0.0002 - 0.12) as seen in table 3. This reflects variations in lithology, fracturing, and weathering occurring both laterally and vertically within a crystalline-rock aquifer. However, the lack of specific-yield data within the basin necessitated some broad generalizations of the system. The resulting model values should be considered approximate in both magnitude and distribution, but are consistent with the conceptualization of the system.

Initial transient-flow simulations using a specific yield of 0.08 for the entire basin produced a simulated base-flow hydrograph that closely matched the estimated base flows, and a poor match between simulated and observed water levels for well HO-BB 26. A specific yield of 0.025, the same as estimated for well HO-BB 26, produced the opposite — a good match for the water levels at that well and a poor one for base flows. Therefore, specific yield for the basin model is zoned horizontally (figs. 23 and 24) in order to simulate field data more closely. In lowland areas (specific yield 0.08) the water table is near land surface; seasonal water-table fluctuations take place in the saprolite or in highly weathered bedrock with proportionately more water-storage capabilities than less weathered bedrock (see fig. 7). In upland areas (specific yield 0.025) the zone of water-level fluctuation is deep, often in sound bedrock (65 percent of the reported water levels are below the end of casing) with a low storage capability.

Vertical zonation of specific yield (fig. 24) is set at the same depth intervals and decreases in a manner similar to that of hydraulic conductivity. Both aquifer characteristics decline with increasing depth for the same reasons; namely, due to the decrease in number and degree of openness of fractures. Specific-yield values for the lower zone do not become a factor in the model calculations until the water level falls into that zone. In the event water levels fall below 300 ft, a minimum specific-yield value of 0.0001 is assumed. Greatest water-level declines occurred during the predictive phase of modeling when the largest average drawdown for a cell was 40 ft and the largest drawdown at a well was 114 ft. Thus, at least for the modeled pumping conditions, water levels did not fall below the upper zone.

Transient-Flow Simulations

Transient-flow simulations are initiated using the steady-state simulation for July 8, 1979, hydraulic conductivities shown in figure 21, and specific yields in figure 23. Recharge is estimated from the positive changes in the water-level hydrograph for well HO-BB 26 and a specific yield of 0.025. Ground-water evapotranspiration is computed as a function (0.4 PE) of daily potential evapotranspiration. Simulation runs produced a series of base-flow and water-level hydrographs for comparison with observed data.

The final simulated base-flow hydrograph in figure 25 shows the correlation with estimated base flows (site 11) when the basin is zoned with respect to specific yield. Simulated and observed water levels are in reasonable agreement at all three observation wells (figs. 26-28). Wells HO-AB 4 and HO-BC 38 are in the 0.08 specific-yield zone.

Simulated base flows are in good agreement with measured low flows at nearly all sites as indicated in figure 29. All sites, except site 9, have simulated values that are within 50 percent of measured values for all three low-flow periods. Data scatter for the August 8 measurements is greater than that of June 25. This is not interpreted as a sign of deterioration of the model's ability to simulate the system with increasing time but, rather, a need for further calibration, especially during periods of very low flows.

The appropriateness of the transient-model starting conditions and the relative reproducibility of results at a

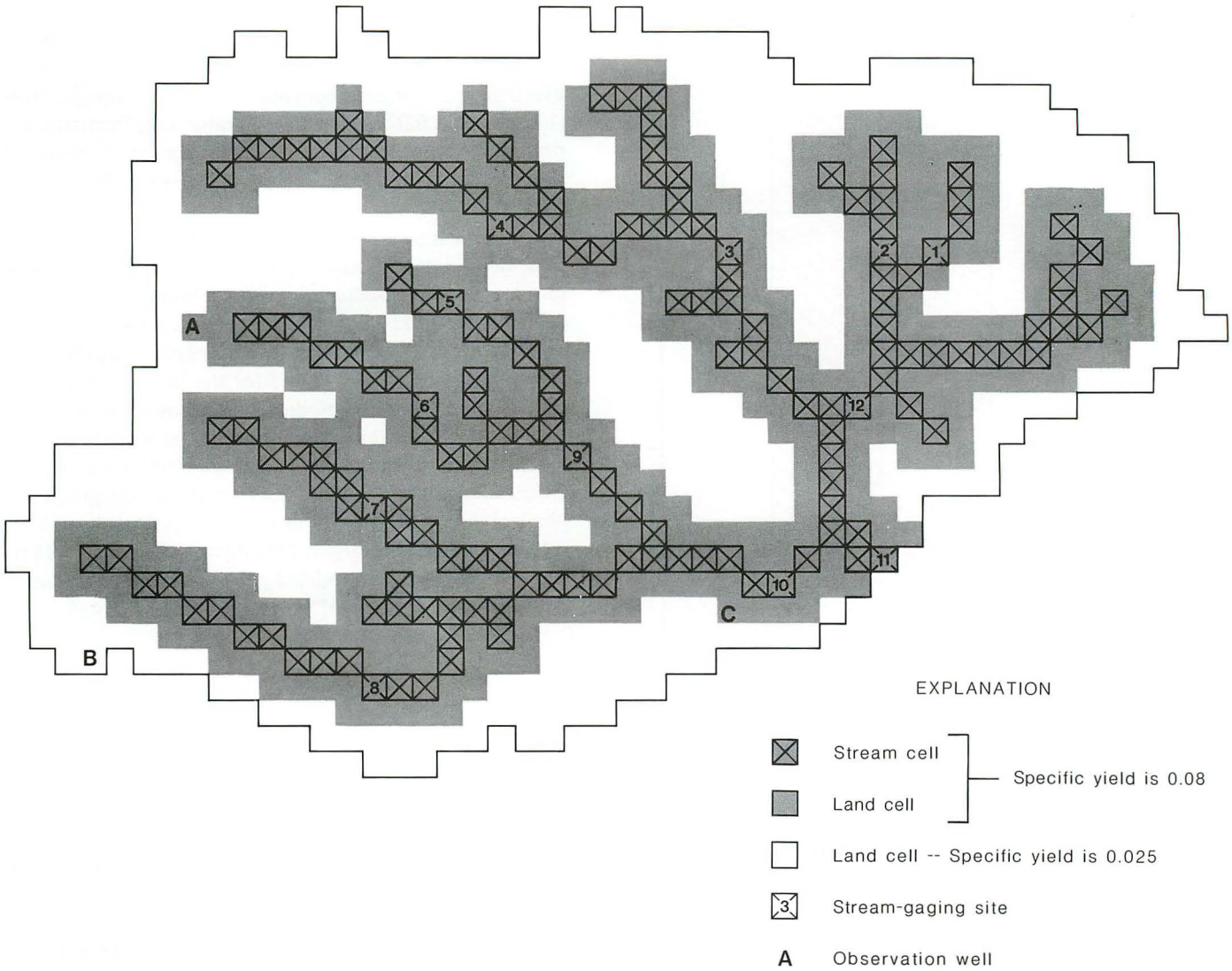


Figure 23. — Areal distribution of specific-yield values used for transient-flow simulations.

later time (fig. 30) is checked. Base flows for the 12 sites after nearly 12-months' transient-flow simulation are compared with those of the steady-state calibration model for the same date (July 25, 1980). The agreement between base flows is quite good (within 25 percent), as are values for the three observation wells (within 2.5 ft).

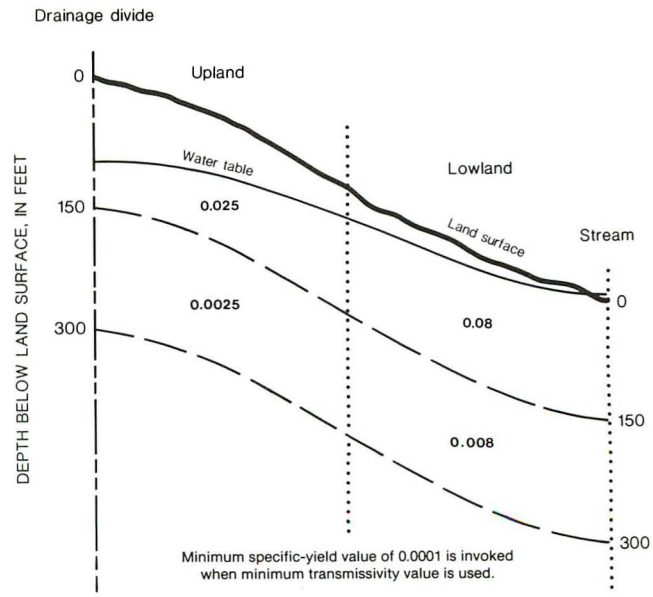


Figure 24. — Distribution of specific-yield values used for final calibration of transient model.

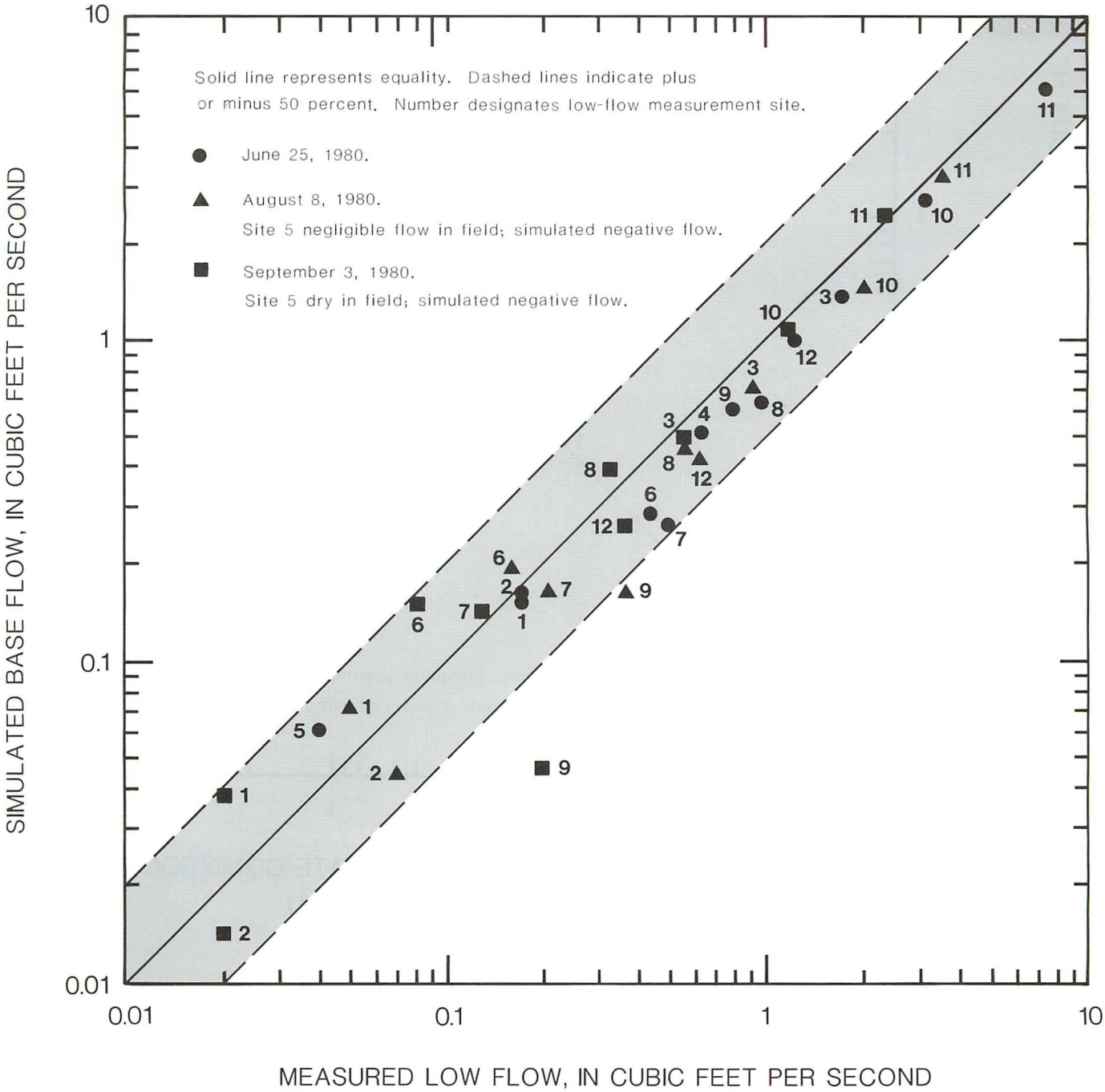
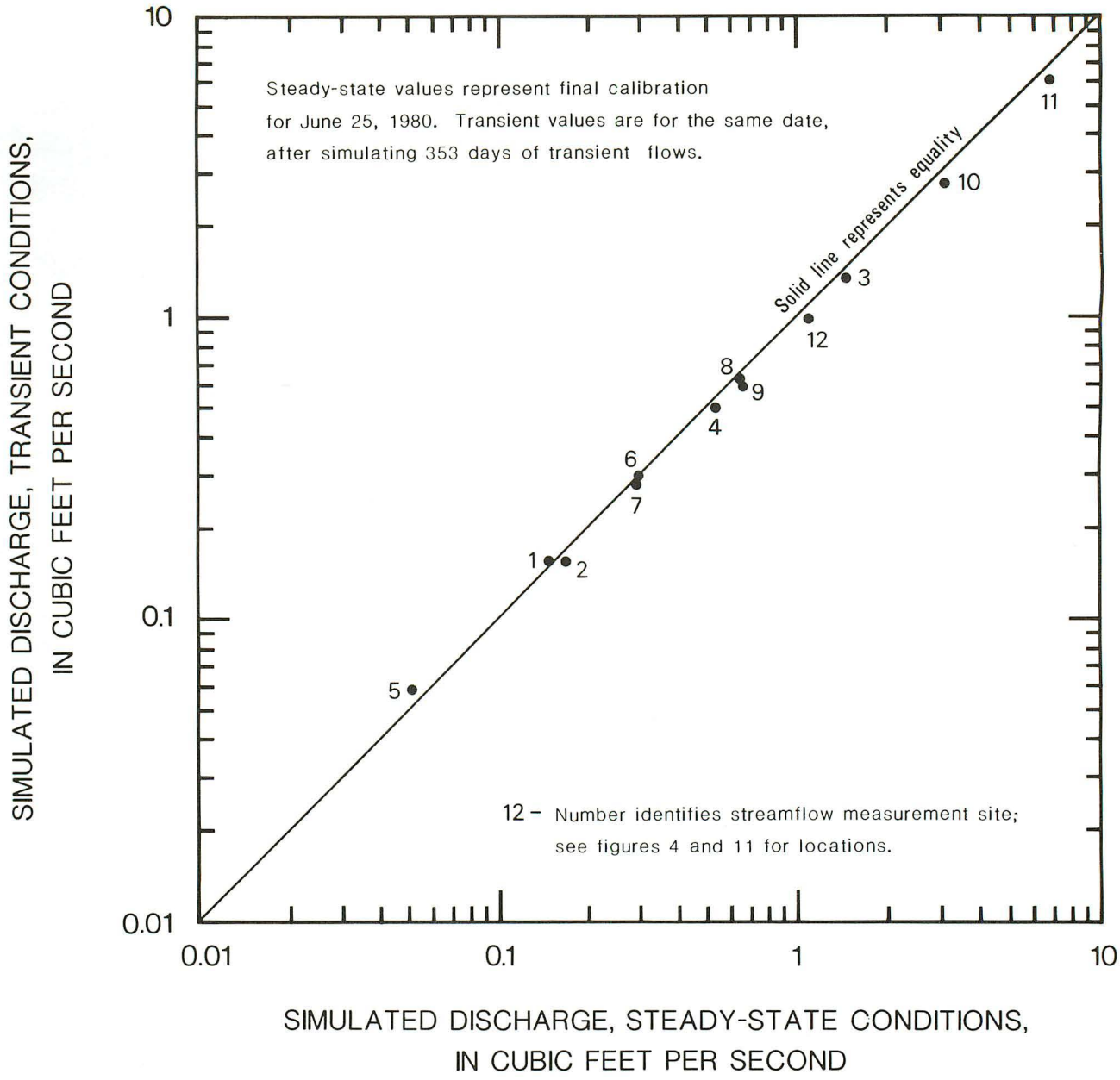


Figure 29. — Relationship of simulated base flows, transient conditions, to measured low flows.



CELL	SIMULATED WATER LEVEL ON JUNE 25, 1980	
	Steady-state	Transient
A	[1] 708.0	710.4
B	719.7	722.0
C	495.5	496.2

[1] Altitude of water level, in feet above sea level.

Figure 30. — Comparison of simulated base flows and water levels for transient-flow and steady-state conditions on June 25, 1980.

PREDICTIVE SIMULATIONS

Up to this point, the concern has been with quantifying those hydrogeologic parameters that most influence the occurrence and movement of ground water in the stream-aquifer system. With appropriate values for these parameters, the model has replicated within acceptable limits ground-water level and base-flow changes through time. This calibrated model can now be used to examine generalized hydrologic effects of various modes of water supply and waste-water disposal on the stream-aquifer system.

Previously, simulations assumed the basin is in a natural, undeveloped state. This is not quite the case. There are a number of farms, businesses, a school, and about 1,600 people residing within the stream-basin boundary. Current land use does have some effect on the natural stream-basin hydrology. While the magnitude of impact is not known, it is thought to be small and the stream basin is not undergoing any long-term adjustment due to man's activities. Values obtained by modeling the basin as it is today (and considered "undeveloped" for the reasons given in the section on Model Description) provide a base line with which one can compare simulations of a future "developed" basin.

Development schemes used in the predictive simulations are shown in figure 31. Population and water use for scheme I were determined by dividing the total land-cell area into 3-acre lots having a house and three occupants using 75 gallons per person per day. This gives a total population of 4,410, and a total basin water use of 330,750 gal/d. The same population and water use are used for schemes II and III. Details of development schemes and the physical setting are generalized and schemes ignore current land use so that each hypothetical development might represent a wide variety of hydrologic conditions within the basin. It is important to remember that the model examines only the effects of well pumpage and waste-water disposal on the quantity of water available in the stream-aquifer system.

Three schemes of possible population distribution are used. In development scheme I, the entire land-cell area is developed using 3-acre lots. Scheme II distributes the same population and housing on 1-acre lots in five separate areas covering only part of the basin. In scheme III, the same population is housed in single-family detached or attached houses, or in multi-unit buildings in five development areas having housing density equivalent to 1/4-acre lots. Development schemes I and II examine various mixes of on-lot water supply and disposal with public-supply wells and sewers. Scheme III looks at the effects of public-sewer discharges within the basin. The predictive model assumes all development occurs instantaneously at the start of the first year. The effects of development on the stream-aquifer system are followed for 20 years. Pumpages and returns are assigned to the appropriate cells and the effects are reported as changes in annual average water level for the entire cell relative to the long-term average.

In several of the development schemes, 15 public-supply wells are used to provide the total basin water use of 330,750 gal/d, which amounts to a discharge of about 15 gal/min per well. The public-supply wells are hypothetical wells with 100-percent efficiency and penetrate completely the water-bearing formation. Locations of the public-supply wells are selected to coincide mostly with nodes having relatively high transmissivity of 800 to 2,000 ft^2/d and vary depending on the development scheme. Simulated water-level changes in public-supply wells are obtained using the Thiem equation (Lohman, 1979, p. 11) to calculate drawdown for a well 1 ft in diameter, located at the center of the cell.

Suburban development produces water losses in the stream-aquifer system by the export of waste water from the area via sewers (100 percent of the water pumped is lost), by increases in evapotranspiration, or other consumptive uses. In the field, increased evapotranspiration losses come mostly from seasonal suburban water uses such as watering lawns and gardens, washing cars, and filling swimming pools. Increases in evapotranspiration may also occur when using on-site septic systems since waste water is introduced into the soil at depths closer to land surface than the original water table. Various estimates (5 to 20 percent) of the collective losses due to development are used to show differences in impact, but most development schemes with on-site disposal use a value of 10 percent, which is consistent with estimates by other authors (Pluhowski and Kantrowitz, 1964, p. 85). These collective losses are represented in the model by reducing the pumpage returned as recharge to the affected cells.

In this study, the ground-water divide is used to define the area contributing to base flow as measured at the downstream gage. Water-table fluctuations and slopes are comparable on both sides of the divide, and no-flow boundaries may be used as a convenient way of portraying the ground-water divide when modeling. This works well under natural stress conditions, but, with the imposition of man-made stresses, the boundary may shift.

Figure 32 illustrates a natural water table sloping away equally on both sides of a drainage divide. When the well is pumped, a cone of depression is created (line y). Some ground water (from aquifer storage and captured discharge) now moves from basin B across the drainage divide into basin A, and while the well is pumping, the drainage divide in effect shifts slightly into basin B. The

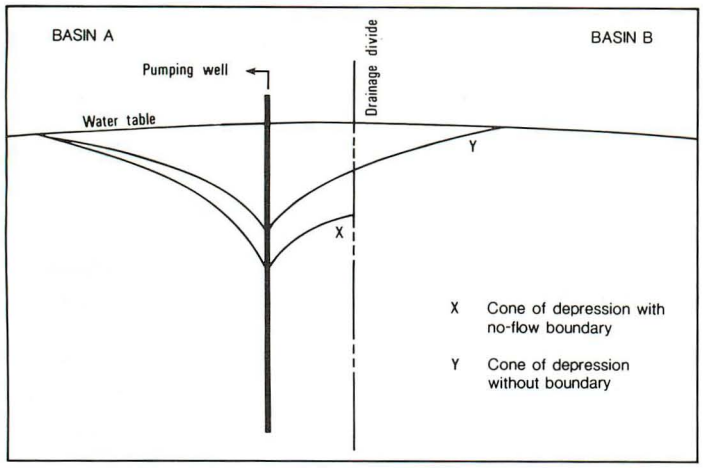


Figure 32. — Effects of model no-flow boundary on water-table drawdown.

model, in treating the divide as a no-flow boundary, prohibits ground-water flow from one basin to another. Now the pumping well can no longer derive some of its discharge from ground-water inflow from basin B, and, in compensation, a deeper cone of depression is established in basin A (line x). Thus, the model overestimates water-level changes (rise and fall) in the vicinity of no-flow boundaries. The maximum head changes (average for the cell) obtained for cells abutting a no-flow boundary during predictive modeling were a decline of 4.2 ft and a rise of 3.8 ft. These values are approximately double what they would be if a no-flow boundary was not assumed (Lohman, 1979, p. 57-61), and give a conservative estimate of aquifer capabilities along the no-flow boundary.

Before making predictive runs with the transient-flow model, a steady-state simulation using long-term average annual conditions is made. A long-term average base-flow value of 11 in/yr (median base flow for the Maryland Piedmont area, Richardson, 1982, p. 13) is assumed for the basin. The ground-water evapotranspiration rate is set at 12 in/yr (McGreevy and Sloto, 1980, p. 10). Recharge is then adjusted until the proper base flow is obtained. Since these values are less than those for steady-state simulations of conditions on June 25, 1980, water-table heads show a downward adjustment. Most head values change only a few feet; the maximum change is 12 ft.

Development on 3-Acre Lots

Hypothetical development schemes Ia_1-Id (figs. 33-38) assume the entire land area of the basin is subdivided into 3-acre lots. Water for domestic purposes is obtained either from on-lot wells or 15 public-supply wells. Waste-water disposal is by on-lot disposal systems or is removed from the basin by sewers. Pumpage returns to the stream-aquifer system are arbitrarily fixed at 95, 90, and 80 percent for on-lot disposal systems and zero for sewered basin.

Simulations show that after 20 years, base flows at site 11 are reduced by the amount of pumpage not returned as recharge to the stream-aquifer system. This is also true for developments on 1-acre and 1/4-acre lots. Pumpage returns of 90 percent and zero reduced base flows at site 11 by 1 and 7 percent, respectively. Changes in base flows within the basin depend on the magnitude of withdrawals and pumpage returns within each subbasin. The amount of water-level change at individual cells depends on the cell's net ground-water loss or gain, the average hydraulic conductivity, and specific yield.

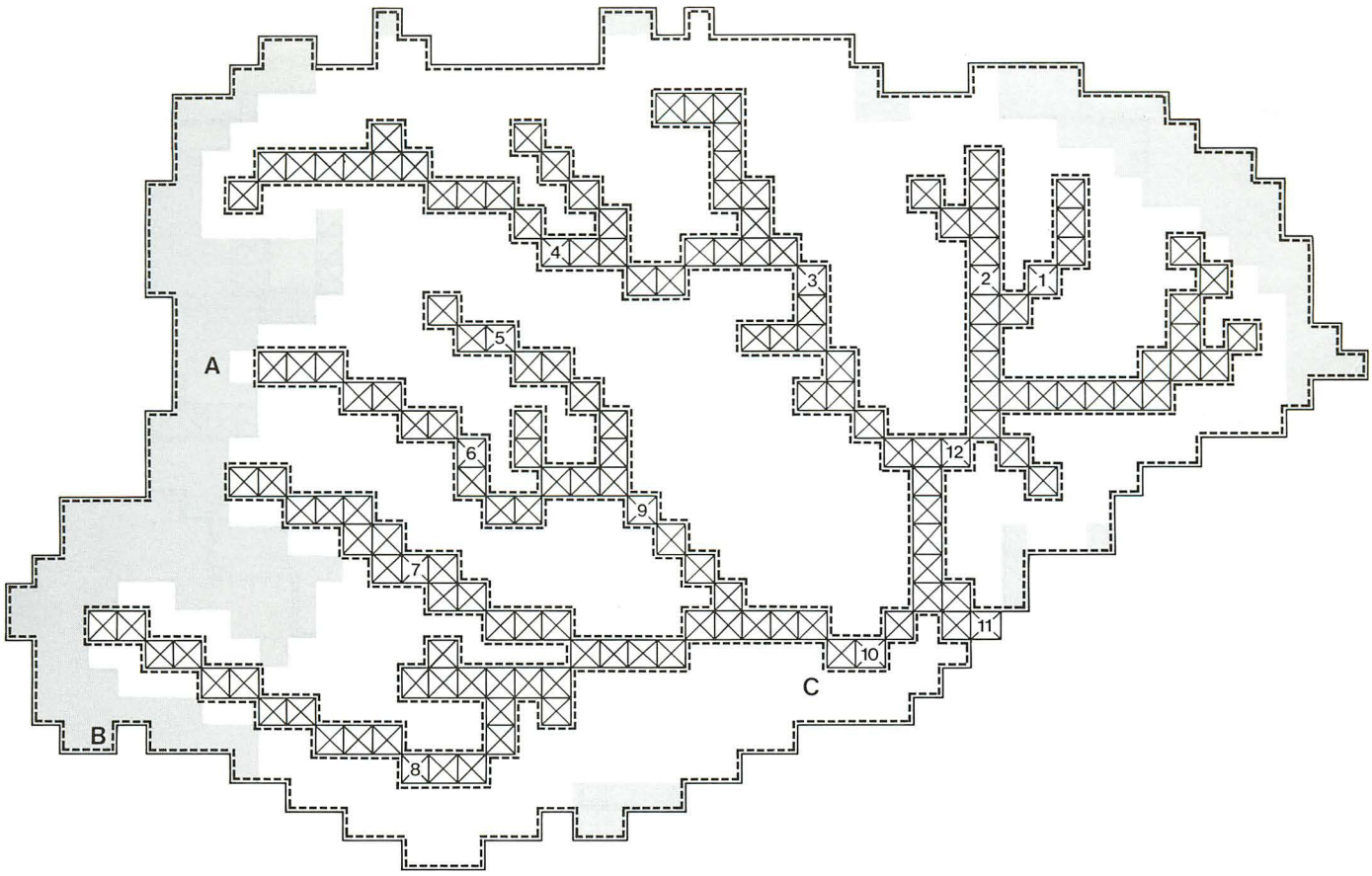
Development schemes Ia_1-Ia_3 (on-lot water supply and disposal) show that with decreasing pumpage returns, declines in both water levels and base flows become larger (figs. 33, 34, and 35). Basin adjustments to these water losses is usually accomplished in 5 years or less, at which point the basin attains a new state of dynamic equilibrium. Water-level declines of 0.1 ft or more appear first in areas along the basin boundary (fig. 33) due, in part, to the effects of a no-flow boundary. With decreasing pumpage returns, the affected area grows larger (figs. 34 and 35). When no pumpage is returned as recharge (scheme Ib — all waste water disposed of outside basin), nearly the entire model area shows water-level declines over 0.1 ft and substantial areas show declines of more than 1 ft (fig. 36).

In development schemes Ic and Id (figs. 37 and 38), all houses are supplied by public wells. When homeowners maintain on-lot disposal systems (scheme Ic), most of the area shows a water-level rise since there is a net gain in recharge for cells that are remote from the effects of pumping.

Water-level declines due to withdrawals by individual wells (waste water sewered out of basin; scheme Ib, fig. 36) occur over a much larger area than when 15 public-supply wells are used (scheme Id, fig. 38), but base-flow reduction at site 11 is essentially the same for both schemes. Patterns of water-level declines reflect transmissivities at or near the pumping well and proximity to a stream.

Development on 1-Acre Lots

Development schemes IIa-IId show impacts of different modes of water supply and waste-water disposal when five areas of the basin are subdivided into 1-acre lots (figs. 39-42). With on-lot wells and 90 percent of well pumpage returned (scheme IIa, fig. 39), water-level declines are small and occur within the limits of the hypothetical development. When none of the pumpage is returned, water levels decline further and the affected area becomes larger (scheme IIb, fig. 40). Substantial portions of the basin outside the development areas are now affected.



EXPLANATION

Area developed -- Basin divided into 3 acre lots with individual on lot wells and septic systems. Pumpage return is 95 percent.

Stream cell

Stream cell with simulated annual average base flow data.

A — Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

Changes in annual average ground-water level (average for the cell) are shown as follows:

0.1 - 1 foot decline (maximum decline is 0.4 foot)

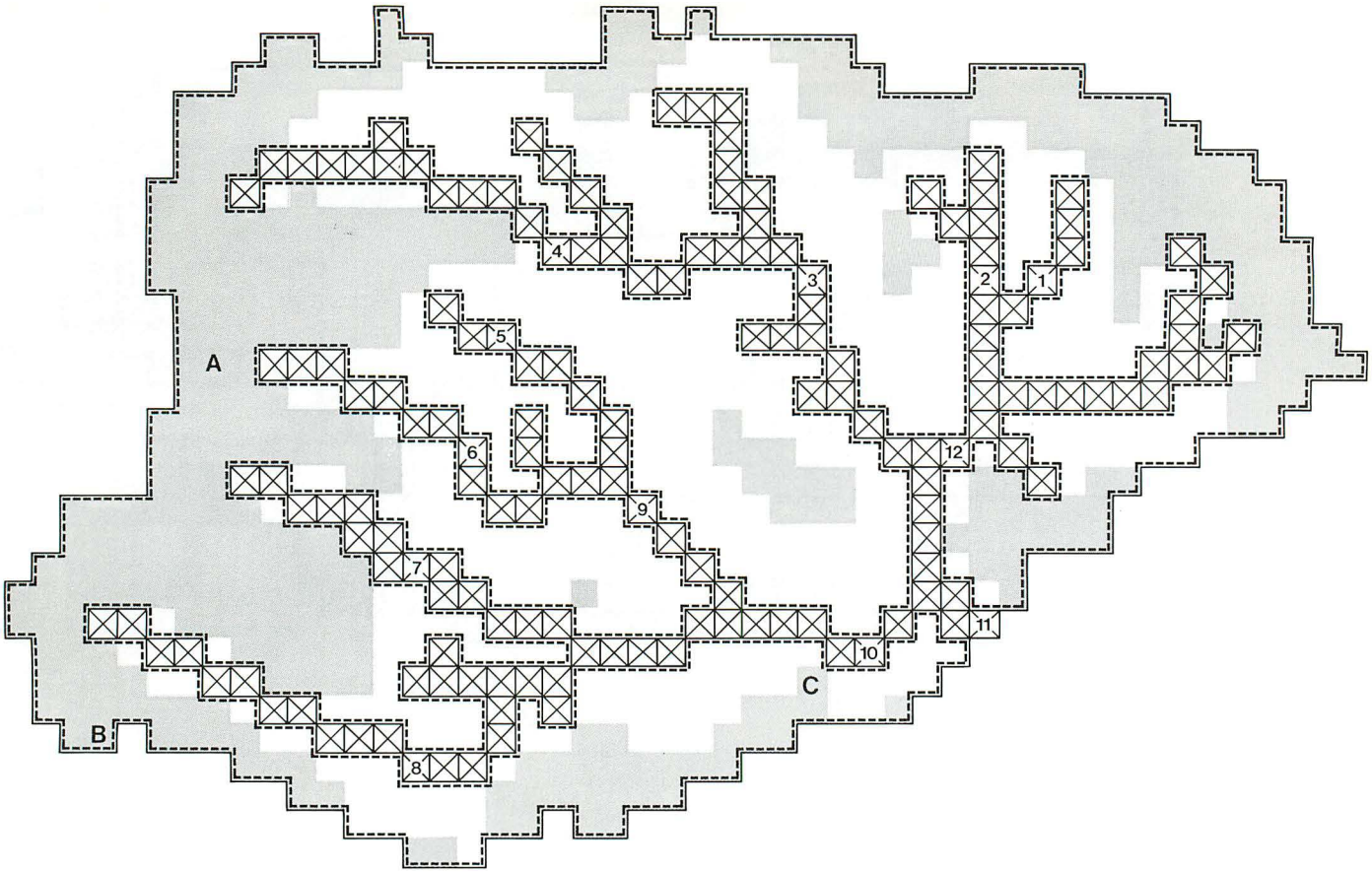
Less than 0.1 foot change

	Data site	Years since pumping began								Long-term average
		1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second	1	0.14	1/						0.14	0.14
	2	.17							.17	.17
	3	1.42							1.42	1.43
	4	.52							.52	.52
	5	.05							.05	.05
	6	.30							.30	.30
	7	.30	0.30	0.30	0.29				.29	.30
	8	.62							.62	.62
	9	.69							.69	.69
	10	3.09							3.09	3.10
	11	6.81	6.81	6.81	6.81	6.80			6.80	6.83
	12	1.10							1.10	1.10
Cumulative change in annual average water level, in feet	A	0.1							0.1	
	B	0.1							0.1	
	C	0.0							0.0	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 33. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme Ia_1 (3-acre lots, on-lot wells and septic systems, 95-percent pumpage returned).



EXPLANATION

Area developed -- Basin divided into 3 acre lots with individual on lot wells and septic systems. Pumpage return is 90 percent.

Stream cell

Stream cell with simulated annual average base flow data.

A — Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

Changes in annual average ground-water level (average for cell) are shown as follows:

0.1 - 1 foot decline (maximum decline is 0.4 foot)

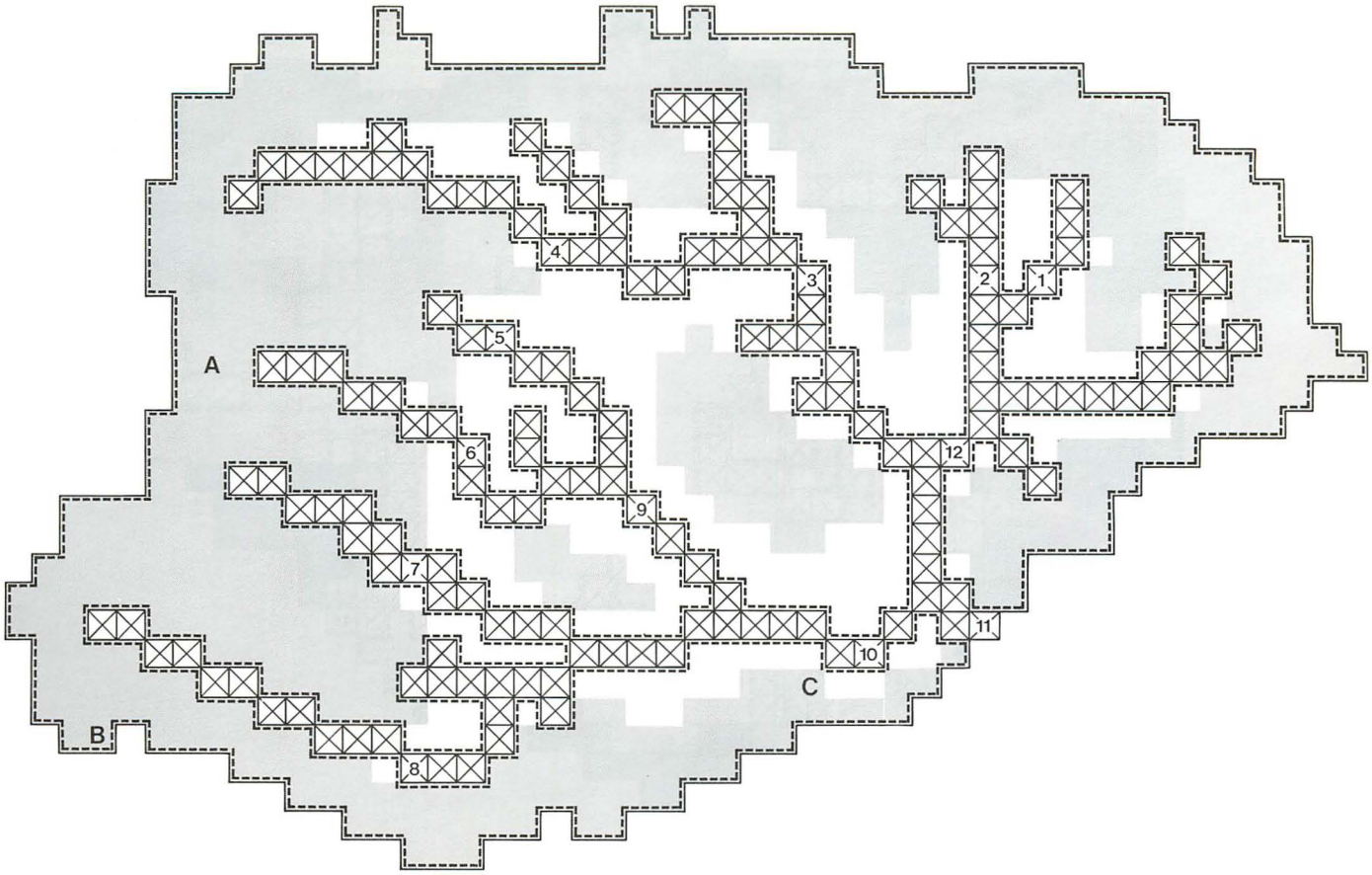
Less than 0.1 foot change

	Data site	Years since pumping began								Long-term average
		1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second	1	0.14	1/						0.14	0.14
	2	.17							.17	.17
	3	1.42							1.42	1.43
	4	.52							.52	.52
	5	.04							.04	.05
	6	.30							.30	.30
	7	.29							.29	.30
	8	.62							.62	.62
	9	.68							.68	.69
	10	3.08							3.08	3.10
	11	6.79	6.78						6.78	6.83
	12	1.10	1.10	1.09					1.09	1.10
Cumulative change in annual average water level, in feet	A	0.1	0.2	0.2	0.3				0.3	
	B	0.2	0.2	0.3					0.3	
	C	0.1							0.1	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 34. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme Ia_2 (3-acre lots, on-lot wells and septic systems, 90-percent pumpage returned).



EXPLANATION

Area developed -- Basin divided into 3 acre lots with individual on lot wells and septic systems. Pumpage return is 80 percent.

Stream cell

Stream cell with simulated annual average base flow data.

A — Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

Areas showing changes in annual average ground-water level (average for cell) are shown as follows:

0.1 - 1 foot decline (maximum decline is 0.8 foot)

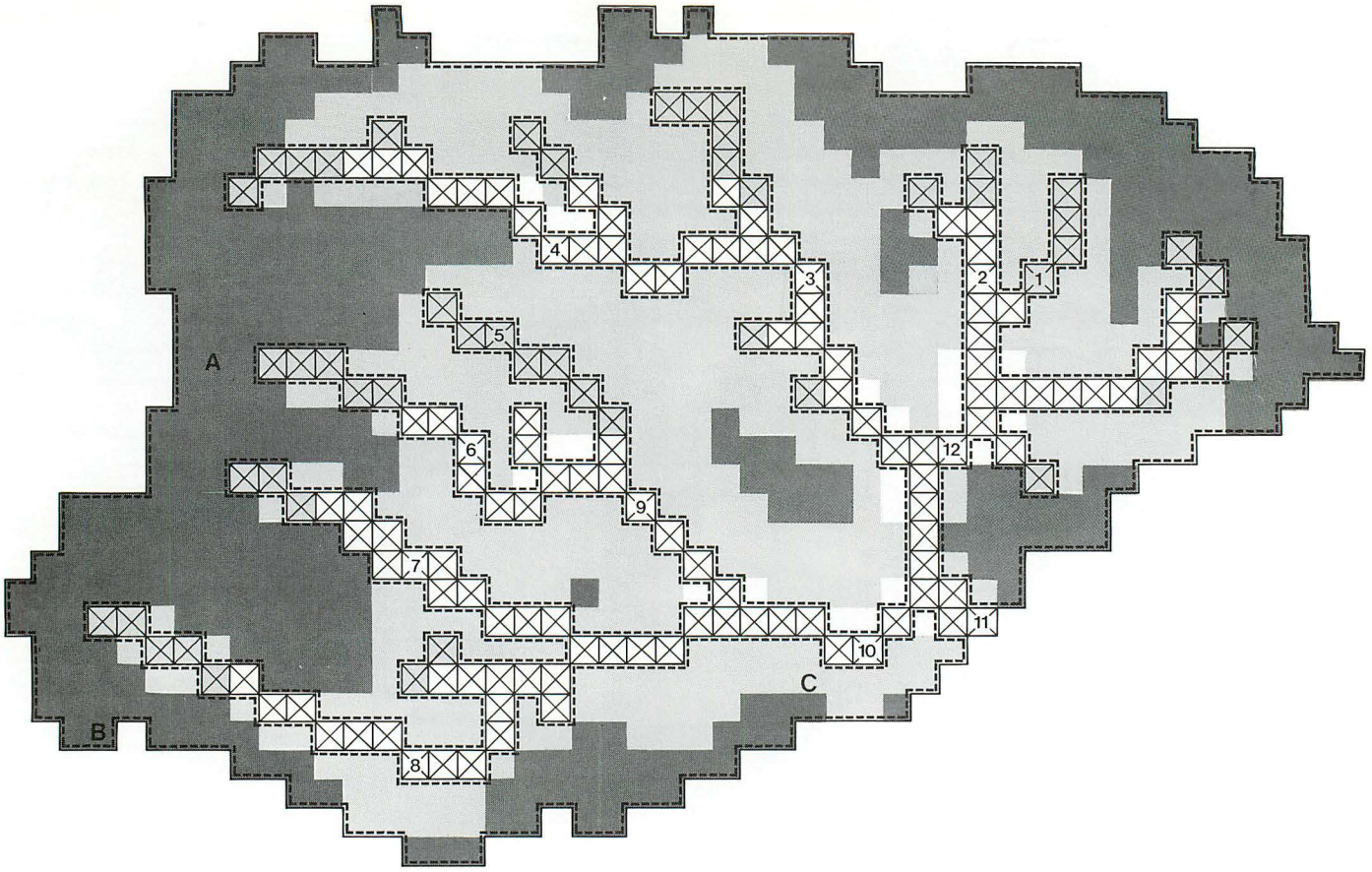
Less than 0.1 foot change

	Data site	Years since pumping began								Long-term average
		1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second	1	0.14	1/						0.14	0.14
	2	.17							.17	.17
	3	1.41	1.41	1.41	1.40				1.40	1.43
	4	.51							.51	.52
	5	.04							.04	.05
	6	.30							.30	.30
	7	.29							.29	.30
	8	.62	.61						.61	.62
	9	.68							.68	.69
	10	3.06	3.06	3.05					3.05	3.10
	11	6.75	6.74	6.73					6.73	6.83
	12	1.09	1.08						1.08	1.10
Cumulative change in annual average water level, in feet	A	0.2	0.4	0.5	0.5	0.5	0.6		0.6	
	B	0.4	0.5	0.6					0.6	
	C	0.1							0.1	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 35. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme Ia_3 (3-acre lots, on-lot wells and septic systems, 80-percent pumpage returned).



EXPLANATION

Area developed -- Basin divided into 3 acre lots with individual on lot wells and sewered out of basin. Pumpage return is zero.

Stream cell

3 Stream cell with simulated annual average base flow data.

A Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

Areas showing changes in annual average ground-water level (average for cell) are shown as follows:

1 - 10 foot decline (maximum decline is 4.2 feet)

0.1 - 1 foot decline

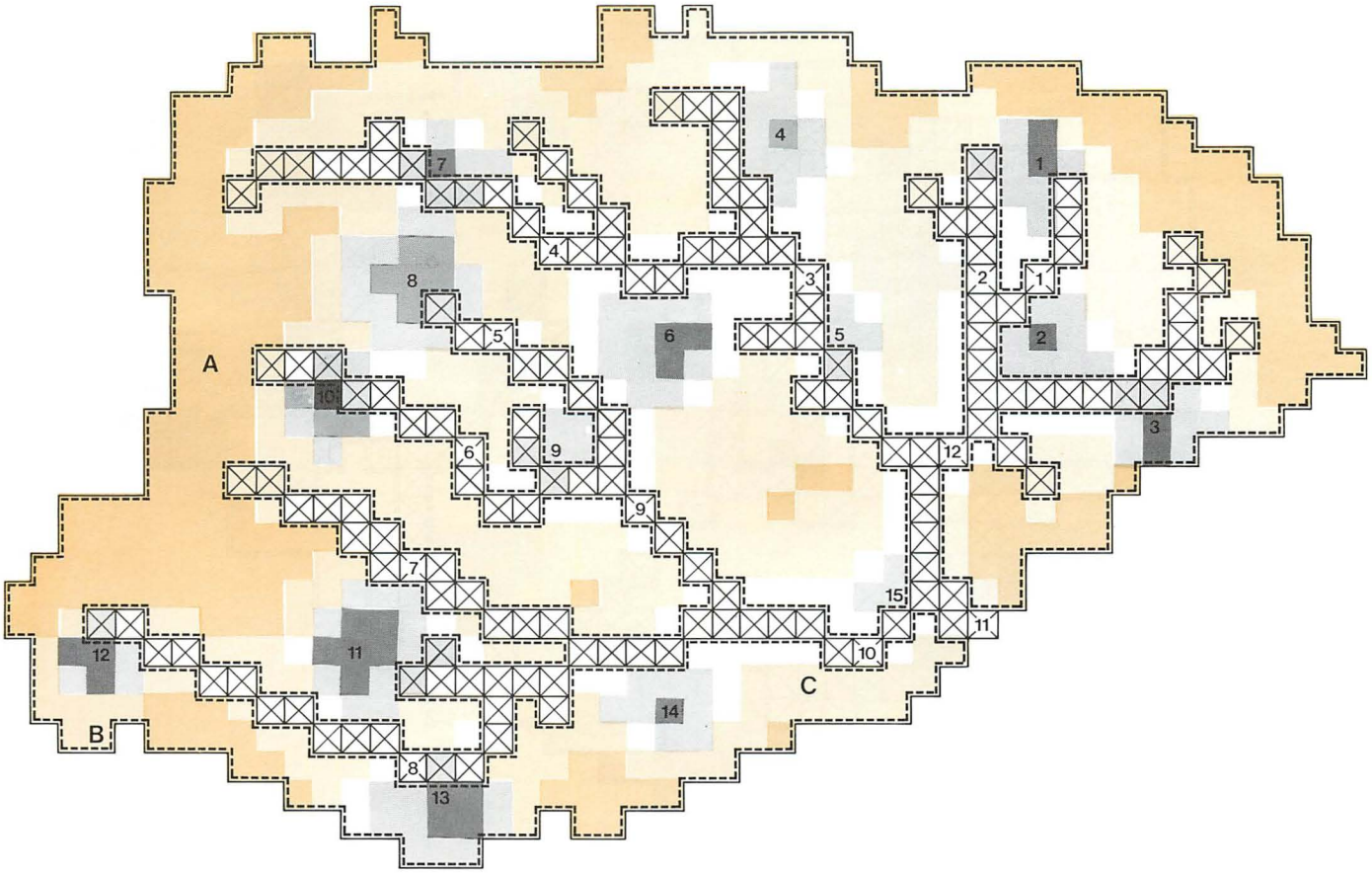
Less than 0.1 foot change

	Data site	Years since pumping began								Long-term average
		1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second	1	0.12	1/						0.12	0.14
	2	.15							.15	.17
	3	1.33	1.32	1.32	1.32	1.32	1.32	1.32	1.31	1.43
	4	.48	.48	.48	.47				.47	.52
	5	.04	.03						.03	.05
	6	.29	.28						.28	.30
	7	.28	.27						.27	.30
	8	.59	.58	.57					.57	.62
	9	.63	.62						.62	.69
	10	2.91	2.88	2.87	2.86				2.86	3.10
	11	6.43	6.36	6.34	6.34	6.33			6.33	6.83
	12	1.02	1.01	1.00					1.00	1.10
Cumulative change in annual average water level, in feet	A	1.3	2.3	2.7	2.9	3.0	3.0	3.1	3.1	
	B	2.0	2.8	3.1					3.3	
	C	0.6							0.6	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 36. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme Ib (3-acre lots, on-lot wells, waste water sewered out of basin).



EXPLANATION

Area developed -- Basin divided into 3 acre lots with 15 public supply wells and individual on lot septic systems. Pumpage return is 90 percent.

Stream cell

3 Stream cell with simulated annual average base flow data.

A Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

15 Cell with public supply well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

Changes in annual average ground-water level (average for the cell) are shown as follows:

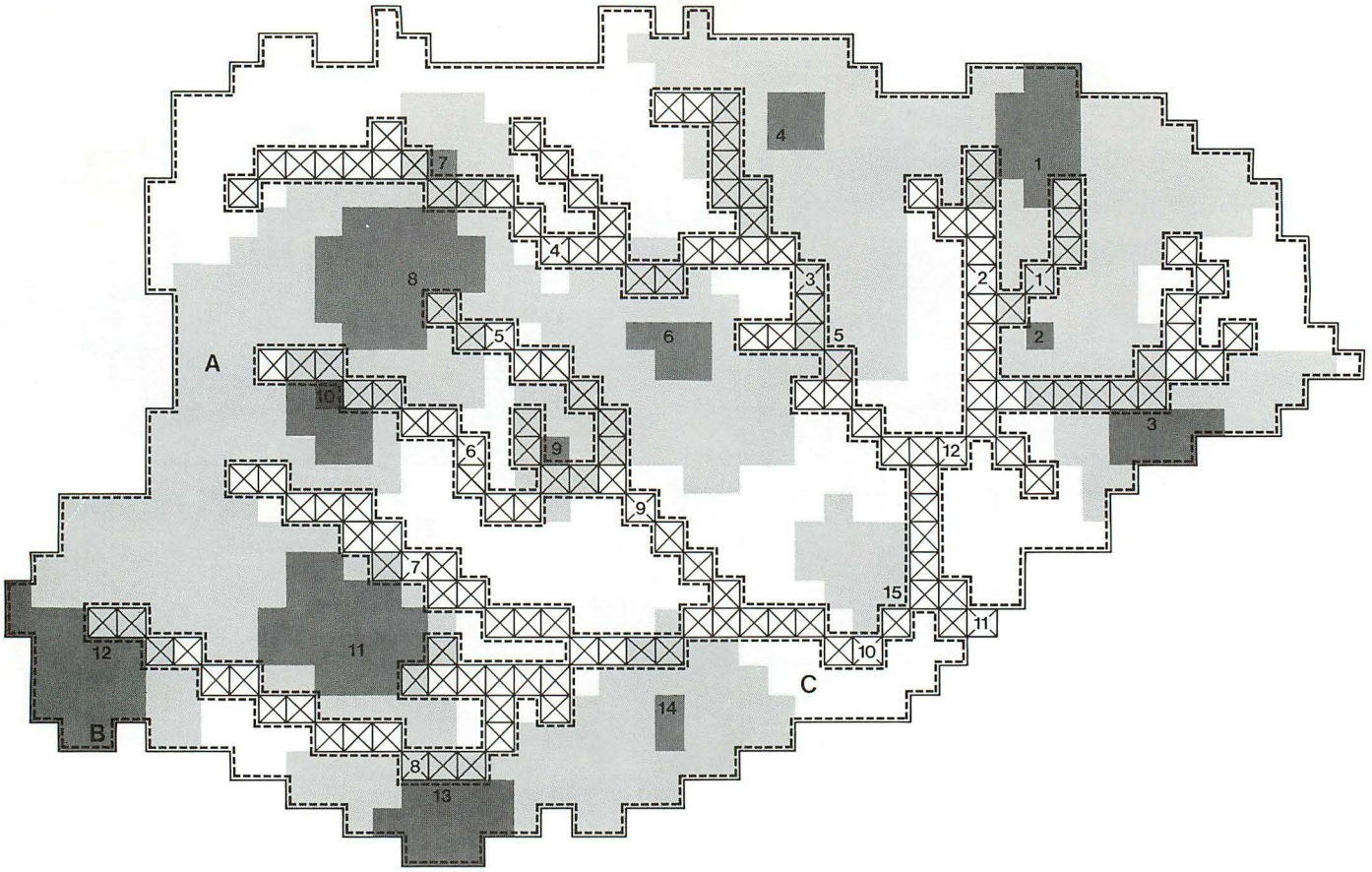
- More than 10 foot decline (maximum decline is 20.8 feet)
- 1-10 foot decline
- 0.1-1 foot decline
- Less than 0.1 foot change
- 0.1-1 foot rise
- More than 1 foot rise (maximum rise is 3.6 feet)

		Data site	Years since pumping began								Long-term average
			1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second		1	0.13	0.13	0.14	1/				0.14	0.14
		2	.17							.17	.17
		3	1.42	1.43						1.43	1.43
		4	.52	.52	.53					.53	.52
		5	.04							.04	.05
		6	.29							.29	.30
		7	.30	.31						.31	.30
		8	.61	.62						.62	.62
		9	.65							.65	.69
		10	3.06	3.06	3.07					3.07	3.10
		11	6.73	6.76	6.77					6.77	6.83
		12	1.08	1.09						1.09	1.10
Cumulative change in annual average water level, in feet	Observation well	A	+1.3	+2.0	+2.3	+2.4	+2.5	2/		+2.5	
		B	+0.5	+0.5	+0.5	+0.5	+0.6			+0.6	
		C	+0.5							+0.5	
	Public supply well	1	16.7	16.6						16.6	
		2	2.9							2.9	
		3	2.9							2.9	
		4	2.3							2.3	
		5	1.1							1.1	
		6	16.6							16.6	
		7	2.5							2.5	
		8	5.2							5.2	
		9	2.1							2.1	
		10	79.4	82.8	83.4	83.6				83.6	
		11	3.3	3.2						3.2	
		12	4.5	4.5	4.5	4.4				4.4	
		13	5.0							5.0	
		14	2.6							2.6	
		15	1.8							1.8	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.
2/ All water-level changes are declines unless prefixed by a plus (+) sign.

Figure 37. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme Ic (3-acre lots, 15 public-supply wells, on-lot septic systems, 90-percent pumpage returned).



EXPLANATION

- Area developed -- Basin divided into 3 acre lots with 15 public supply wells and sewered out of basin. Pumpage return is zero.
- Stream cell
- 3 Stream cell with simulated annual average base flow data.
- A Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.
- 15 Cell with public supply well located at its center. Data are simulated cumulative changes in annual average ground-water level for the cell.

Areas showing changes in annual average ground-water level (average for cell) are shown as follows:

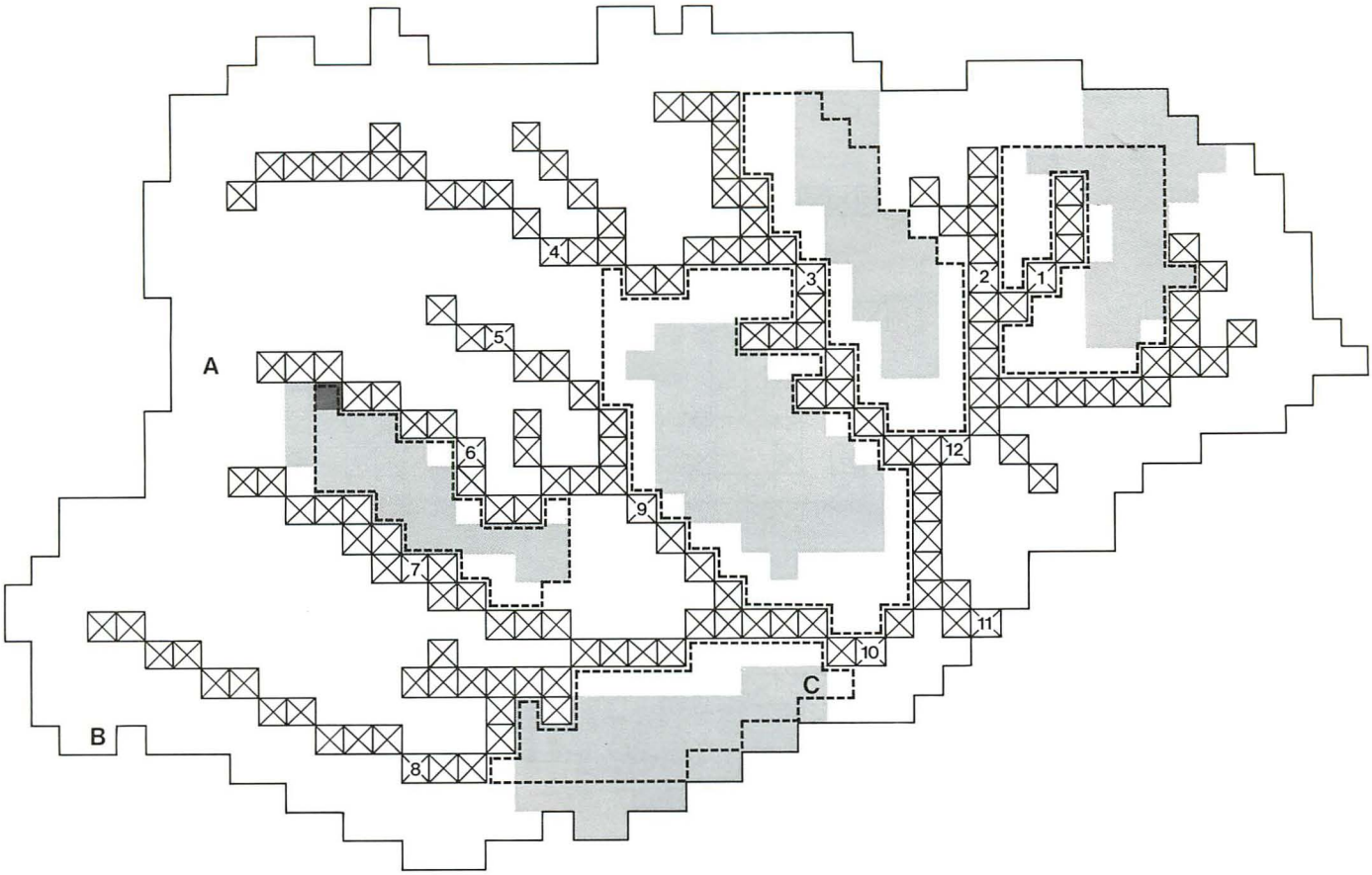
- More than 10 foot decline (maximum decline is 22 feet)
- 1 - 10 foot decline
- 0.1 - 1 foot decline
- Less than 0.1 foot change

		Data site	Years since pumping began								Long-term average
			1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second		1	0.12	1/						0.12	0.14
		2	.16	0.15						.15	.17
		3	1.34	1.33						1.33	1.43
		4	.49	.48						.48	.52
		5	.03	.02						.02	.05
		6	.28	.27						.27	.30
		7	.29	.29	0.28					.28	.30
		8	.58	.58	.57					.57	.62
		9	.60	.59						.59	.69
		10	2.89	2.86						2.86	3.10
		11	6.37	6.36	6.33	6.32				6.32	6.83
		12	1.01	1.00						1.00	1.10
Cumulative change in annual average water level, in feet	Observation well	A	.0	.1	.1	0.2				.2	
		B	1.3	2.0	2.3	2.4				2.4	
		C	.0							.0	
	Public supply well	1	17.3	17.5						17.5	
		2	3.1							3.1	
		3	3.2	3.3						3.3	
		4	2.8							2.8	
		5	1.2							1.2	
		6	17.0							17.0	
		7	2.6							2.6	
		8	6.1	6.3						6.3	
		9	2.2							2.2	
		10	80.2	84.1	84.9	85.1	85.2			85.2	
		11	4.0	4.2						4.2	
		12	5.2	5.4	5.5	5.6				5.6	
		13	5.5	5.6						5.6	
		14	3.0							3.0	
		15	1.9							1.9	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 38. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme Id (3-acre lots, 15 public-supply wells, waste water sewered out of basin).



EXPLANATION

Area developed -- Five areas in the basin divided into 1 acre lots with individual on lot wells and septic systems. Pumpage return is 90 percent.

Stream cell

Stream cell with simulated annual average base flow data.

A — Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

Areas showing changes in annual average ground-water level (average for cell) are shown as follows:

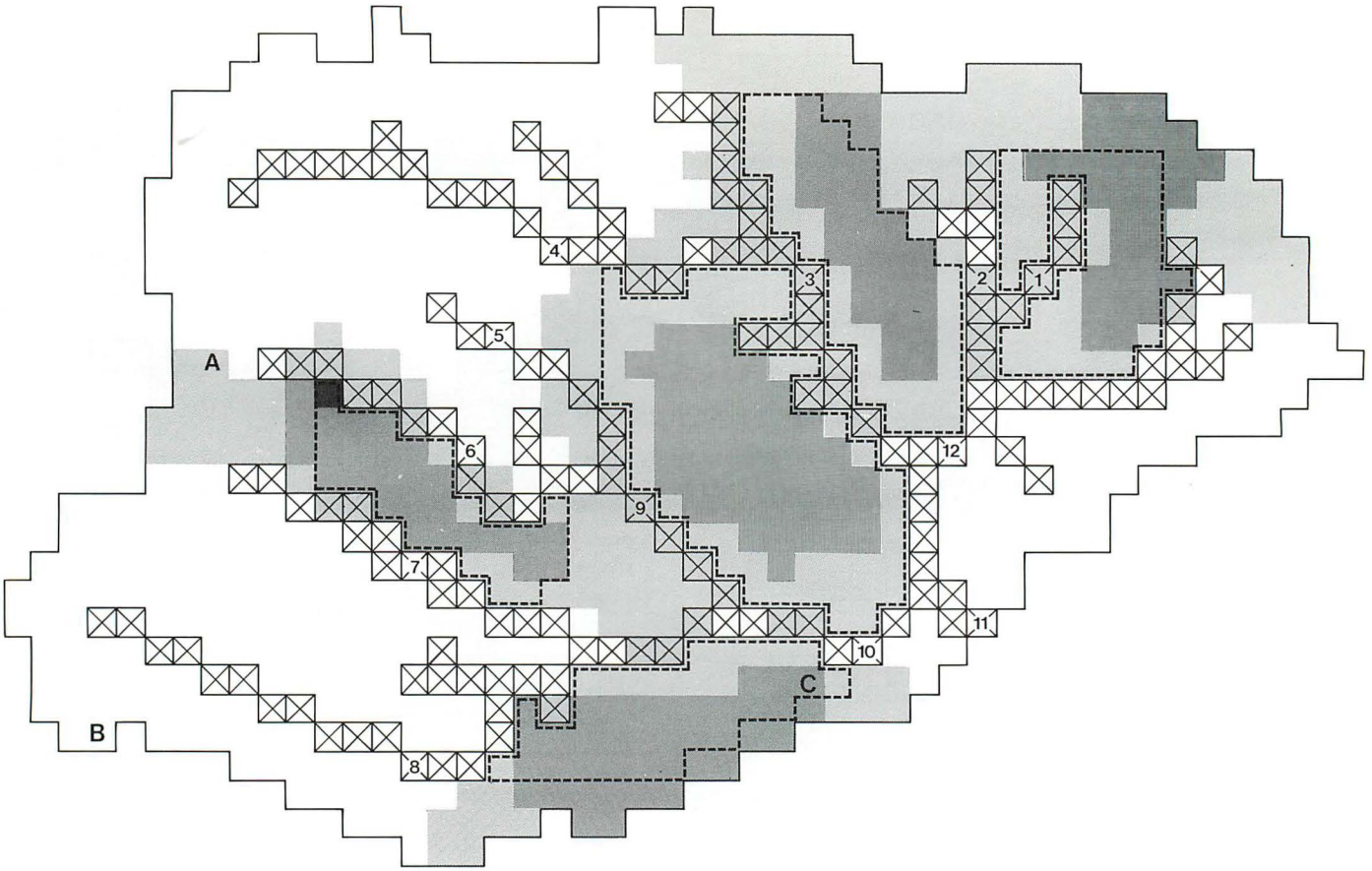
- 1 - 10 foot decline (maximum decline is 1.1 feet)
- 0.1 - 1 foot decline
- Less than 0.1 foot change

	Data site	Years since pumping began								Long-term average
		1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second	1	0.14	1/						0.14	0.14
	2	.17							.17	.17
	3	1.42							1.42	1.43
	4	.52							.52	.52
	5	.05							.05	.05
	6	.30							.30	.30
	7	.30							.30	.30
	8	.62							.62	.62
	9	.68							.68	.69
	10	3.08							3.08	3.10
	11	6.78							6.78	6.83
	12	1.09							1.09	1.10
Cumulative change in annual average water level, in feet	A	.0							.0	
	B	.0							.0	
	C	.1							.1	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 39. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme IIa (1-acre lots, on-lot wells and septic systems, 90-percent pumpage returned).



EXPLANATION

- Area developed -- Five areas in the basin divided into 1 acre lots with individual on lot wells and sewered out of basin. Pumpage return is zero.
- Stream cell
- 3 Stream cell with simulated annual average base flow data.
- A Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

Areas showing changes in annual average ground-water level (average for cell) are shown as follows:

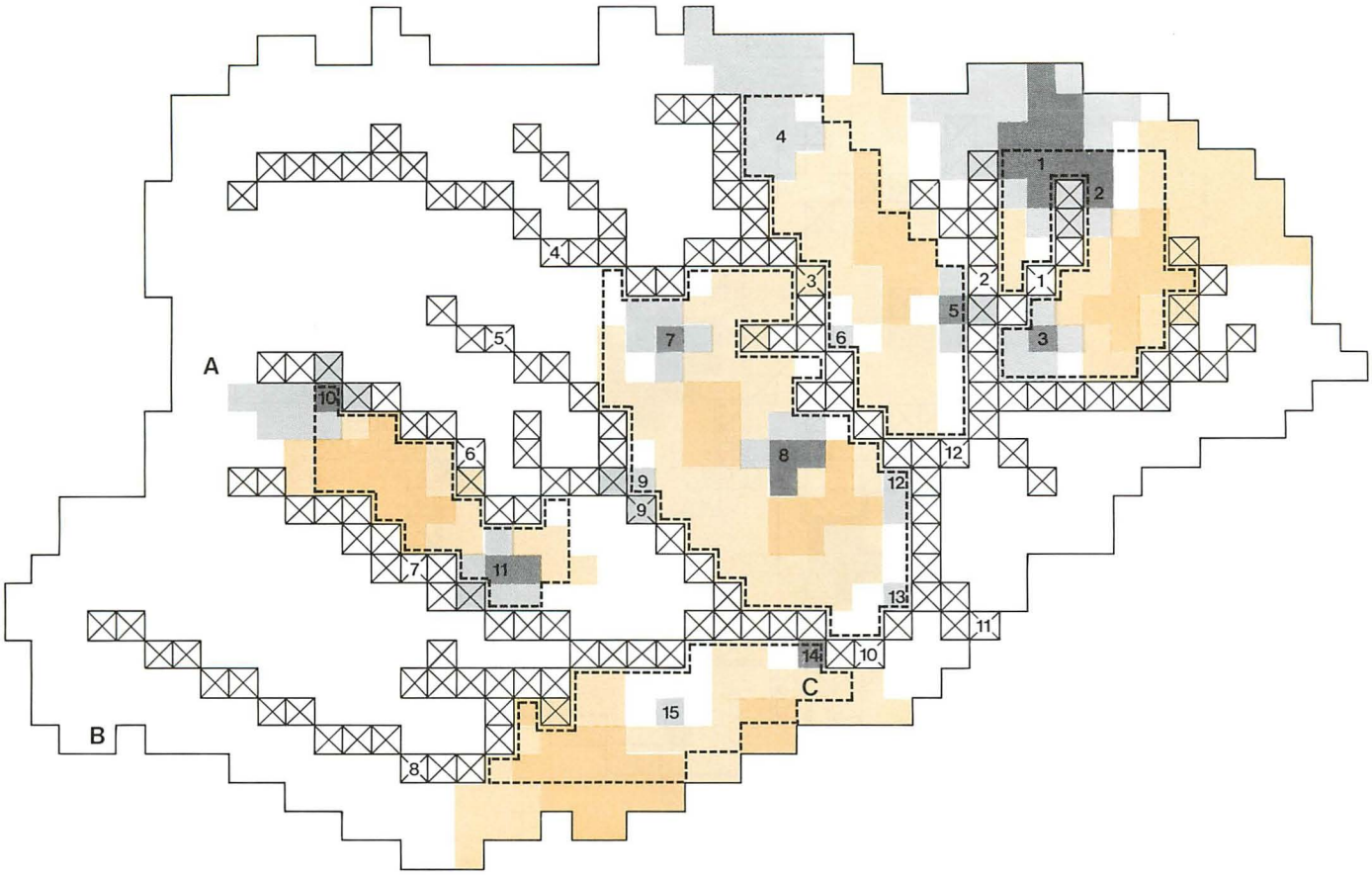
- More than 10 foot decline (maximum decline is 12.7 feet)
- 1 - 10 foot decline
- 0.1 - 1 foot decline
- Less than 0.1 foot change

	Data site	Years since pumping began								Long-term average
		1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second	1	0.11	0.10	1/					0.10	0.14
	2	.15							.15	.17
	3	1.36	1.35						1.35	1.43
	4	.52							.52	.52
	5	.05							.05	.05
	6	.28	.27						.27	.30
	7	.29	.28						.28	.30
	8	.62							.62	.62
	9	.62	.61						.61	.69
	10	2.89	2.87	2.86					2.86	3.10
	11	6.35	6.31	6.31	6.30				6.30	6.83
	12	1.00	.99						.99	1.10
Cumulative change in annual average water level, in feet	A	.0	.0	.1					.1	
	B	.0							.0	
	C	1.0	1.1						1.1	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 40. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme IIb (1-acre lots, on-lot wells, waste water sewered out of basin).



EXPLANATION

Area developed -- Five areas in the basin divided into 1 acre lots with 15 public supply wells and individual on lot septic systems. Pumpage return is 90 percent.

Stream cell

3 Stream cell with simulated annual average base flow data.

A Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

15 Cell with public supply well located at its center. Data are simulated cumulative changes in annual average ground-water level for the cell.

Changes in annual average ground-water level (average for cell) are shown as follows:

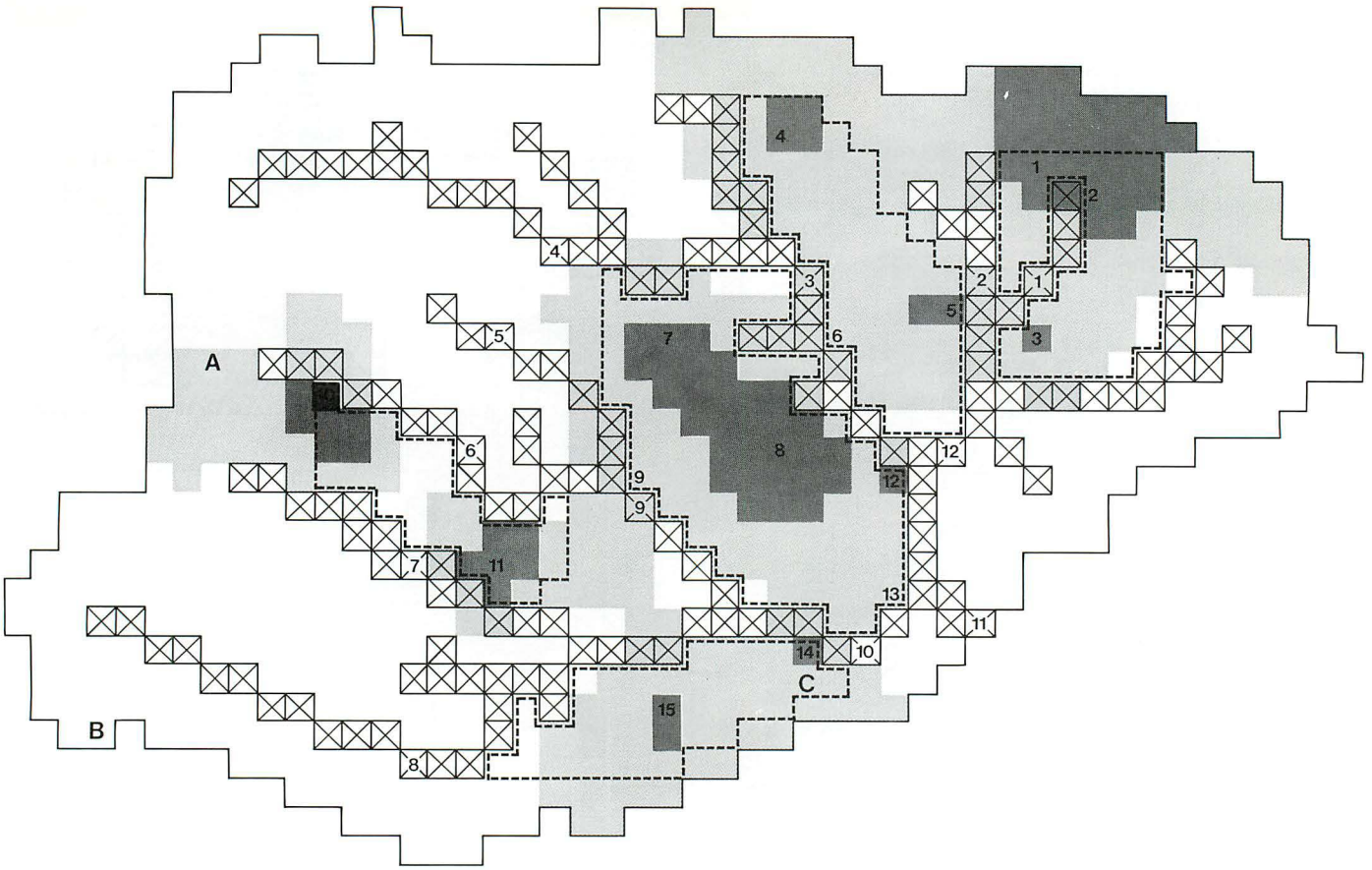
- 1 - 10 foot decline (maximum decline is 8.7 feet)
- 0.1 - 1 foot decline
- Less than 0.1 foot change
- 0.1 - 1 foot rise
- More than 1 foot rise (maximum rise is 4.3 feet)

		Data site	Years since pumping began								Long-term average
			1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second		1	0.12	1/						0.12	0.14
		2	.16							.16	.17
		3	1.43	1.44						1.44	1.43
		4	.52							.52	.52
		5	.05							.05	.05
		6	.30							.30	.30
		7	.30							.30	.30
		8	.62							.62	.62
		9	.68	.69						.69	.69
		10	3.11	3.12						3.12	3.10
		11	6.78	6.79						6.79	6.83
		12	1.07							1.07	1.10
Cumulative change in annual average water level, in feet	Observation well	A	2/ .0							.0	
		B	.0							.0	
		C	+.3							+.3	
	Public supply well	1	16.9	17.0						17.0	
		2	3.1							3.1	
		3	2.7							2.7	
		4	2.0							2.0	
		5	3.6							3.6	
		6	1.0							1.0	
		7	15.8							15.8	
		8	10.5							10.5	
		9	1.1							1.1	
		10	66.2	67.1	67.2	67.3				67.3	
		11	5.0							5.0	
		12	2.1							2.1	
		13	1.7							1.7	
		14	4.0							4.0	
		15	2.2	2.1						2.1	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.
2/ All water-level changes are declines unless prefixed by a plus (+) sign.

Figure 41. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme IIc (1-acre lots, 15 public-supply wells, on-lot septic systems, 90-percent pumpage returned).



EXPLANATION

Area developed -- Five areas in the basin divided into 1 acre lots with 15 public supply wells and sewered out of basin. Pumpage return is zero.

Stream cell

3 Stream cell with simulated annual average base flow data.

A Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

15 Cell with public supply well located at its center. Data are simulated cumulative changes in annual average ground-water level for the cell.

Changes in annual average ground-water level (average for cell) are shown as follows:

- More than 10 foot decline (maximum decline 22 feet)
- 1 - 10 foot decline
- 0.1 - 1 foot decline
- Less than 0.1 foot change

		Data site	Years since pumping began								Long-term average
			1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second		1	0.09	1/						0.09	0.14
		2	.15	0.14						.14	.17
		3	1.37							1.37	1.43
		4	.52							.52	.52
		5	.05							.05	.05
		6	.28	.27						.27	.30
		7	.29							.29	.30
		8	.62							.62	.62
		9	.62	.61						.61	.69
		10	2.92	2.91						2.91	3.10
		11	6.35	6.33	6.32					6.32	6.83
		12	.98	.97						.97	1.10
Cumulative change in annual average water level, in feet	Observation well	A	.0	.0	.1					.1	
		B	.0							.0	
		C	.6	.7						.7	
	Public supply well	1	17.7	17.9	18.0					18.0	
		2	3.9	4.0	4.1					4.1	
		3	3.1	3.2						3.2	
		4	2.8							2.8	
		5	4.0							4.0	
		6	1.3							1.3	
		7	17.1							17.1	
		8	13.3	13.5						13.5	
		9	1.4							1.4	
		10	80.2	84.0	84.9	85.1	85.1	85.2		85.2	
		11	5.8	5.9						5.9	
		12	2.2	2.3						2.3	
		13	1.9							1.9	
		14	4.3							4.3	
		15	3.0							3.0	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 42. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme IId (1-acre lots, 15 public-supply wells, waste water sewered out of basin).

With public-supply wells and private on-lot waste disposals (scheme IIc, fig. 41), some areas again show net ground-water gains as in scheme Ic (fig. 37). Areas showing water-level change are less extensive, reflecting more localized effects of water withdrawals and returns.

The pattern of water-level declines for development scheme IId (fig. 42) is nearly the same as scheme IIb (fig. 40). Areas showing a decline of 0.1 ft or more are less extensive for the development scheme using public-supply wells because most of the wells are located in areas having larger transmissivities.

Development on 1/4-Acre Lots

Development schemes IIIa-IIIc assume the same total basin population as for previous development schemes, but development takes place in a much smaller area (figs. 43-45). In each scheme, water is obtained from public-supply wells. Waste water is disposed of at different locations using public sewers. Scheme IIIa (fig. 43) shows the maximum impact occurs when all the waste water is exported from the basin. The proximity of the pumping wells to each other produces overlapping cones of depression and appreciable water-level declines within most of the developed and abutting undeveloped areas. Average cell water-level declines were greatest in the vicinity of wells 10 to 12 (10 ft or more). There was a drawdown of 114 ft at well 12.

In scheme IIIb (fig. 44), waste water for each developed area is treated and disposed of in a nearby stream. Water-level declines remain the same as in IIIa, but the average base flow for the basin is reduced only 1 percent, rather than 7 percent.

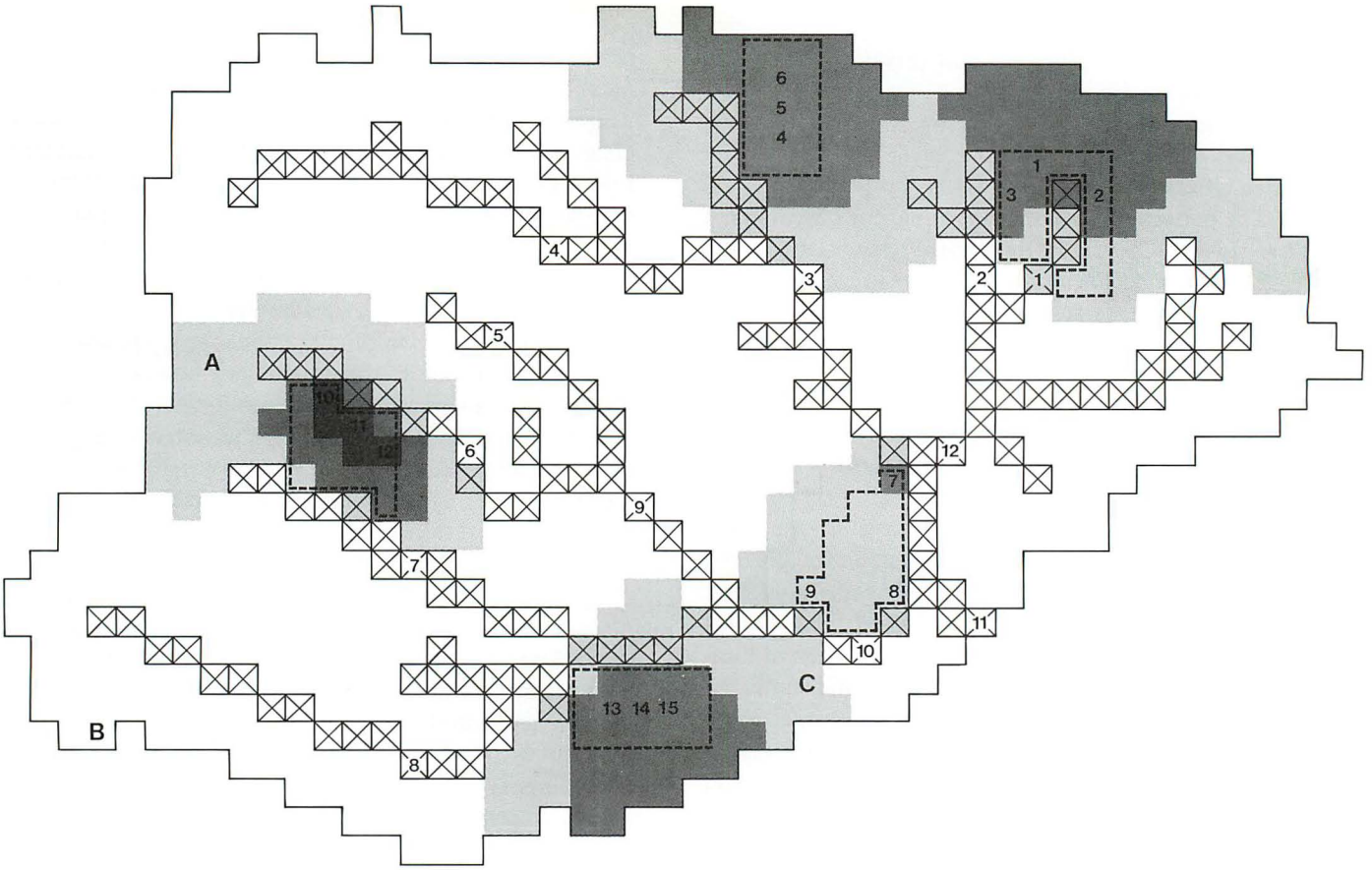
Scheme IIIc assumes land disposal of treated waste water at community facilities serving each development (fig. 45). With proper placement of these facilities, water recharged to the aquifer system can do much to ameliorate the impact of ground-water withdrawals; however, water-quality impacts could be significant. Water-level declines for cells in the vicinity of wells 1 through 9 were greatly reduced in this manner when compared with water-level declines for IIIb, while the location of disposal facilities in respect to wells 10 through 15 were not nearly as successful in reducing these declines. Recharge water from the development containing wells 10 through 12 produced about a 20-percent increase in the annual average base flow at streamflow site 7.

Adjustment of Stream-Aquifer System to Stress

Predictive simulations demonstrate generalized effects of ground-water withdrawals and pumpage returns on a previously unstressed stream basin. These effects are reported as changes in annual average ground-water levels and base flows over a 20-year period. By the 20th year, annual water-level changes are less than 0.1 ft, annual base-flow changes are less than 0.01 ft^3/s, and the basin has adjusted to a new dynamic equilibrium; therefore, no further simulations are made. During the period of adjustment, pumpage is derived from ground-water storage and natural ground-water discharge. Potential sources of water for pumping can perhaps best be seen in an idealized cross-section (fig. 46).

Prior to pumping, aquifer discharges are primarily by ground-water runoff to the stream (base flow) and ground-water evapotranspiration. Combined discharges are maintained by precipitation recharging the system and there is negligible long-term change in ground-water storage. With the introduction of pumping, the water table is lowered in the vicinity of the pumping well, creating a cone of depression. Initially, well discharge comes from dewatering this portion of the aquifer (change in storage) but, with time, increasing amounts come from the redirection (capture) of ground-water runoff that would have gone to the stream. This reduces base flow. In areas where the water table is close to land surface, lowering the water level by pumping diminishes the rate of ground-water evapotranspiration. The amount it is reduced may be termed "captured ground-water evapotranspiration." A final source of water occurs in valleys where the water table may be lowered sufficiently to cause water in the stream to leak back into the aquifer (induced stream infiltration). Annual contributions from these sources to simulated ground-water pumpage (development scheme Ib) are shown in figure 47. All sources, except change in ground-water storage, show an increasing contribution in the early years of pumping with very little gain after 5 years. Ground-water storage declines rapidly for the first 5 years and then at markedly decreasing rates for the remainder of the simulation period. True equilibrium conditions occur when there is no longer any change in storage, and ground-water pumpage is derived completely from captured ground-water runoff, captured evapotranspiration, and induced stream infiltration.

Table 4 shows the net contribution from sources previously discussed as a percentage of net ground-water pumpage over the 20-year simulation period. Variations in contributions from individual sources are due to differences in simulated stress patterns as produced by changes in pumping well locations and pumpage returns. In all cases, captured ground-water runoff contributes the largest amount to pumpage, producing reductions in base flow nearly equal to the reductions in pumpage returns. Simulations of three development schemes (Ic, IIc, IIIc) show the water table rises in portions of the model area to levels above those for the undeveloped basin. In these schemes, water is supplied by 15 public-supply wells and 90 percent of the pumpage is returned to the water table either uniformly over the entire development area, or at 10 land-disposal sites. A number of development cells which experience little or no effects of



EXPLANATION

Area developed -- Five areas in the basin divided into equivalent of 1/4 acre lots with 15 public supply wells and sewered out of basin. Pumpage return is zero.

Stream cell

3 Stream cell with simulated annual average base flow data.

A Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

15 Cell with public supply well located at its center. Data are simulated cumulative changes in annual average ground-water level for the cell.

Changes in annual average ground-water level (average for cell) are shown as follows:

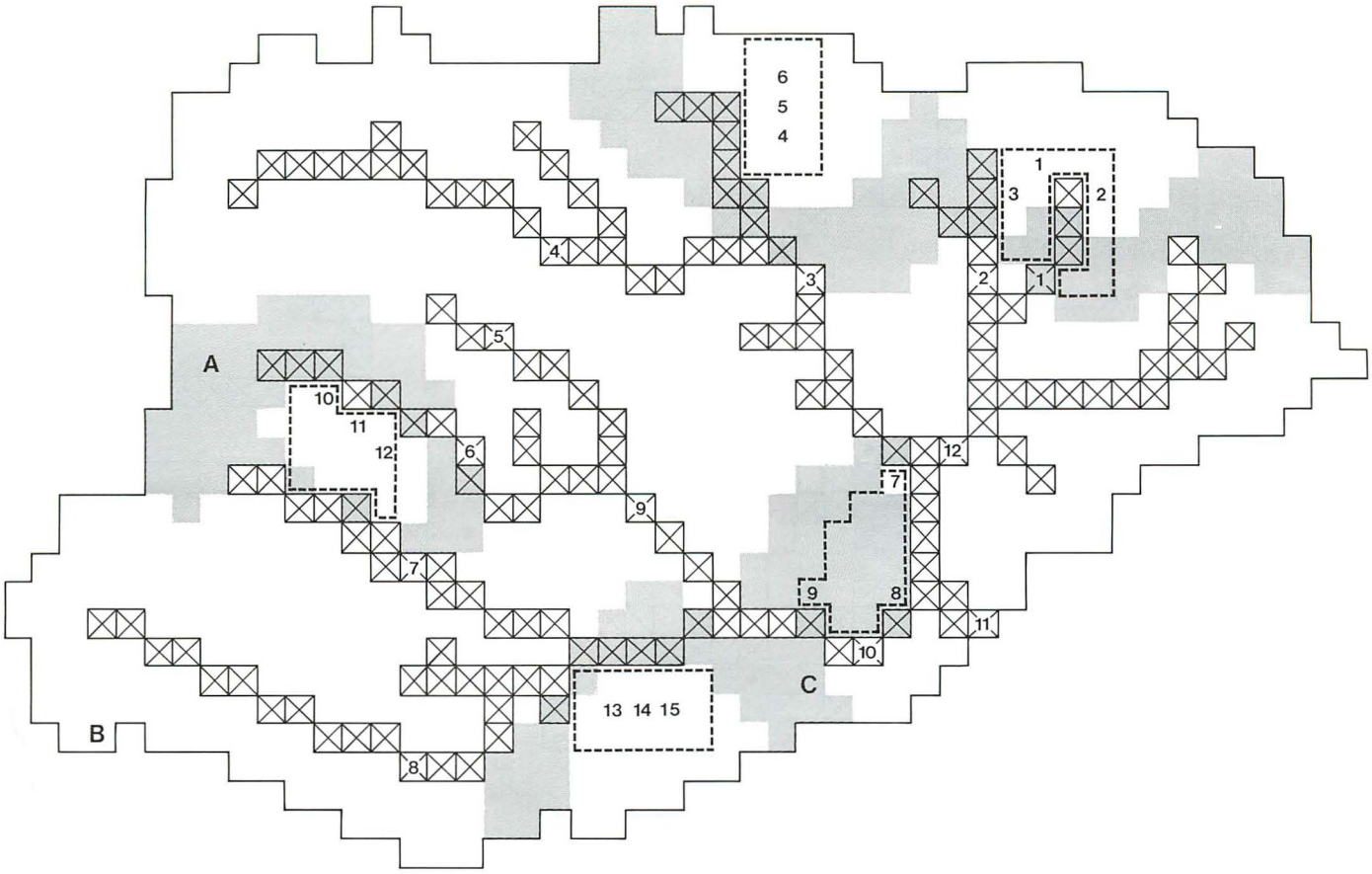
- More than 10 foot decline (maximum decline is 39.7 feet)
- 1 - 10 foot decline
- 0.1 - 1 foot decline
- Less than 0.1 foot change

		Data site	Years since pumping began								Long-term average
			1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second		1	0.09	0.09	0.08	1/				0.08	0.14
		2	.13							.13	.17
		3	1.34	1.33						1.33	1.43
		4	.52							.52	.52
		5	.05							.05	.05
		6	.25	.23	.23	0.22				.22	.30
		7	.29	.29	.29	.28				.28	.30
		8	.62							.62	.62
		9	.63	.61	.60					.60	.69
		10	2.91	2.88	2.87	2.86				2.86	3.10
		11	6.38	6.34	6.33	6.32				6.32	6.83
		12	1.01	1.00						1.00	1.10
Cumulative change in annual average water level, in feet	Observation well	A	.0	.1	.1	.2				.2	
		B	.0							.0	
		C	.1	.2						.2	
	Public supply well	1	18.5	18.8						18.8	
		2	4.0	4.2						4.2	
		3	10.1	10.2						10.2	
		4	4.8	4.9						4.9	
		5	5.8	5.9						5.9	
		6	7.1	7.3						7.3	
		7	2.2							2.2	
		8	2.0							2.0	
		9	1.5							1.5	
		10	81.9	87.4	89.0	89.5	89.7	89.8		89.8	
		11	38.6	42.4	43.7	44.1	44.3	44.4		44.4	
		12	93.8	105.6	110.5	112.6	113.4	114.1		114.1	
		13	5.3	5.4						5.4	
		14	4.7							4.7	
		15	4.5							4.5	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 43. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme IIIa (1/4-acre lots or equivalent, 15 public-supply wells, waste water sewered out of basin).



EXPLANATION

Area developed -- Five areas in the basin divided into equivalent of 1/4 acre lots with 15 public supply wells and treated domestic sewage discharged at 5 stream locations. Pumpage return is 90 percent.

Stream cell

Stream cell with simulated annual average base flow data.

A — Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

15 — Cell with public supply well located at its center. Data are simulated cumulative changes in annual average ground-water level for the cell.

Location of stream outfalls for treated domestic sewage.

Changes in annual average ground-water level (average for cell) are shown as follows:

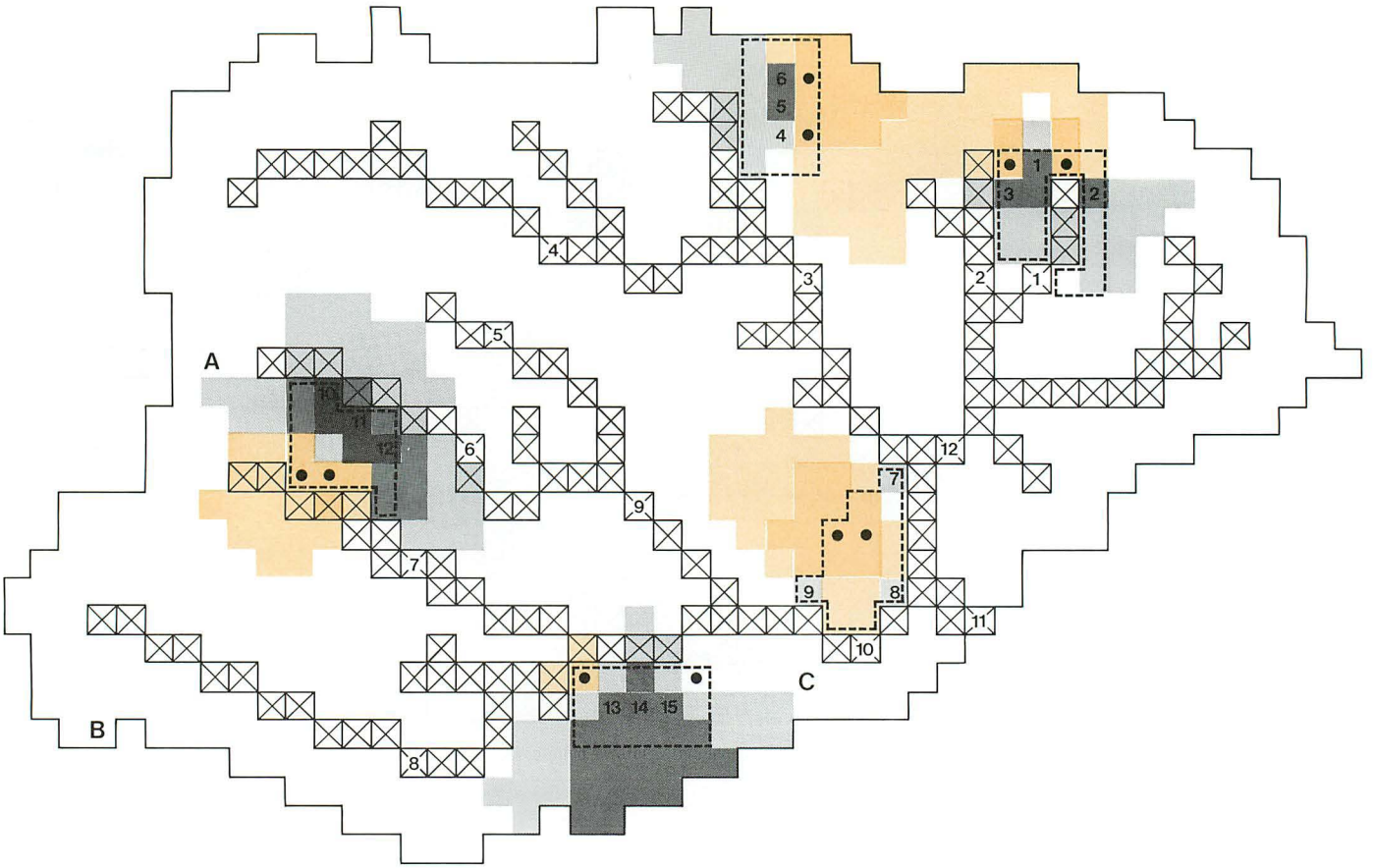
- More than 10 foot decline (maximum decline is 39.7 feet)
- 1 - 10 foot decline
- 0.1 - foot decline
- Less than 0.1 foot change

	Data site	Years since pumping began								Long-term average
		1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second	1	0.09	0.09	0.08	1/				0.08	0.14
	2	.13							.13	.17
	3	1.34	1.33						1.33	1.43
	4	.52							.52	.52
	5	.05							.05	.05
	6	.25	.23	.23	0.22				.22	.30
	7	.29	.29	.29	.28				.28	.30
	8	.62							.62	.62
	9	.72	.70	.69					.69	.69
	10	3.09	3.06	3.05	3.04				3.04	3.10
	11	6.84	6.80	6.79	6.78				6.78	6.83
	12	1.10	1.09						1.09	1.10
Cumulative change in annual average water level, in feet — Observation well	A	.0	.1	.1	.2				.2	
	B	.0							.0	
	C	.1	.2						.2	
Cumulative change in annual average water level, in feet — Public supply well	1	18.5	18.8						18.8	
	2	4.0	4.2						4.2	
	3	10.1	10.2						10.2	
	4	4.8	4.9						4.9	
	5	5.8	5.9						5.9	
	6	7.1	7.3						7.3	
	7	2.2							2.2	
	8	2.0							2.0	
	9	1.5							1.5	
	10	81.9	87.4	89.0	89.5	89.7	89.8		89.8	
	11	38.6	42.4	43.7	44.1	44.3	44.4		44.4	
	12	93.8	105.6	110.5	112.6	113.4	114.1		114.1	
	13	5.3	5.4						5.4	
	14	4.7							4.7	
	15	4.5							4.5	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 44. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme IIIb (1/4-acre lots or equivalent, 15 public-supply wells, waste water sewered to five stream locations within basin).



EXPLANATION

Area developed- - Five areas in the basin divided into equivalent of 1/4 acre lots with 15 public supply wells and domestic sewage recharged at10 land disposal sites. Pumpage return is 90 percent.

Stream cell

Stream cell with simulated annual average base flow data.

A — Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

15 — Cell with public supply well located at its center. Data are simulated cumulative changes in annual average ground-water level for the cell.

● Location of land disposal site for treated domestic sewage.

Changes in annual average ground-water level (average for cell) are shown as follows:

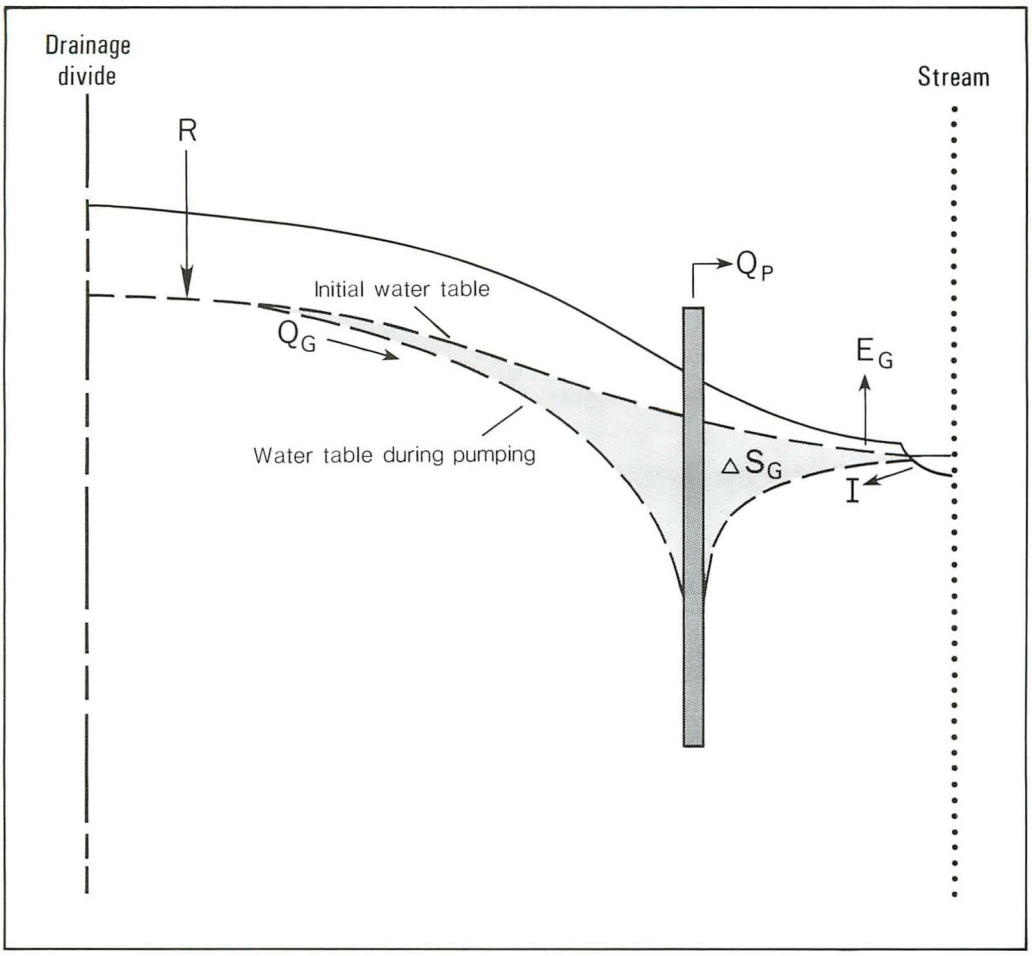
- More than 10 foot decline (maximum decline is 38.3 feet)
- 1-10 foot decline
- 0.1-1 foot decline
- Less than 0.1 foot change
- 0.1-1 foot rise
- More than 1 foot rise (maximum rise is 14.6 feet)

		Data site	Years since pumping began								Long-term average
			1	2	3	4	5	10	15	20	
Annual average base flow, in cubic feet per second		1	0.13	1/						0.13	0.14
		2	.17							.17	.17
		3	1.41	1.42						1.42	1.43
		4	.52							.52	.52
		5	.05							.05	.05
		6	.25	.23						.23	.30
		7	.37							.37	.30
		8	.62							.62	.62
		9	.63	.61						.61	.69
		10	3.12	3.10	3.09					3.09	3.10
		11	6.80	6.79	6.78					6.78	6.83
		12	1.09	1.10						1.10	1.10
Cumulative change in annual average water level, in feet	Observation well	A	.0	2/						.0	
		B	.0							.0	
		C	.0							.0	
	Public supply well	1	14.5	14.4						14.4	
		2	2.6							2.6	
		3	8.2	8.2	8.2	8.1				8.1	
		4	1.9							1.9	
		5	2.7	2.6						2.6	
		6	3.1	3.1	3.0					3.0	
		7	2.1							2.1	
		8	1.5							1.5	
		9	.9							.9	
		10	81.7	86.8	88.2	88.6	88.7	88.8		88.8	
		11	38.3	41.5	42.5	43.0	43.1	43.2		43.2	
		12	93.4	104.5	108.9	110.7	111.4	112.0		112.0	
		13	4.8							4.8	
		14	4.1							4.1	
		15	3.7	3.8						3.8	

SIMULATED BASE FLOW AND GROUND-WATER LEVEL CHANGES

1/ To emphasize time needed to stabilize, base flow and water-level change values are omitted once they become equal to those of year 20.

Figure 45. — Simulated changes in ground-water levels and base flows after 20 years of pumping. Hypothetical development scheme IIIc (1/4-acre lots or equivalent, 15 public-supply wells, waste water sewered to 10 land-disposal sites within basin).



EXPLANATION

R - Recharge to the water table. Recharge comes mainly from precipitation; minor amounts may come from waste-water disposal depending on the manner of disposal.

Q_P - Pumpage from a well.

ΔS_G - Change in ground-water storage. Water removed from storage by lowering of the water table around the pumping well (shaded area), contributes to ground-water pumpage.

Q_G - Ground-water runoff. Ground water moves downgradient from areas of recharge to areas of discharge. Much of this discharge occurs as base flow to streams. Ground-water discharge that is diverted to a pumping well is considered captured.

E_G - Ground-water evapotranspiration. Ground-water evapotranspiration decreases naturally with the lowering of a shallow water table. When this is due to the effects of pumping the amount of decrease may be termed captured ground-water evapotranspiration.

I - Induced stream infiltration. When natural water-table gradients toward the stream are reversed due to well pumpage, some of the streamflow may be induced into the aquifer and contribute to well discharge.

Figure 46. — Potential sources of water available for diversion to a pumping well under water-table conditions.

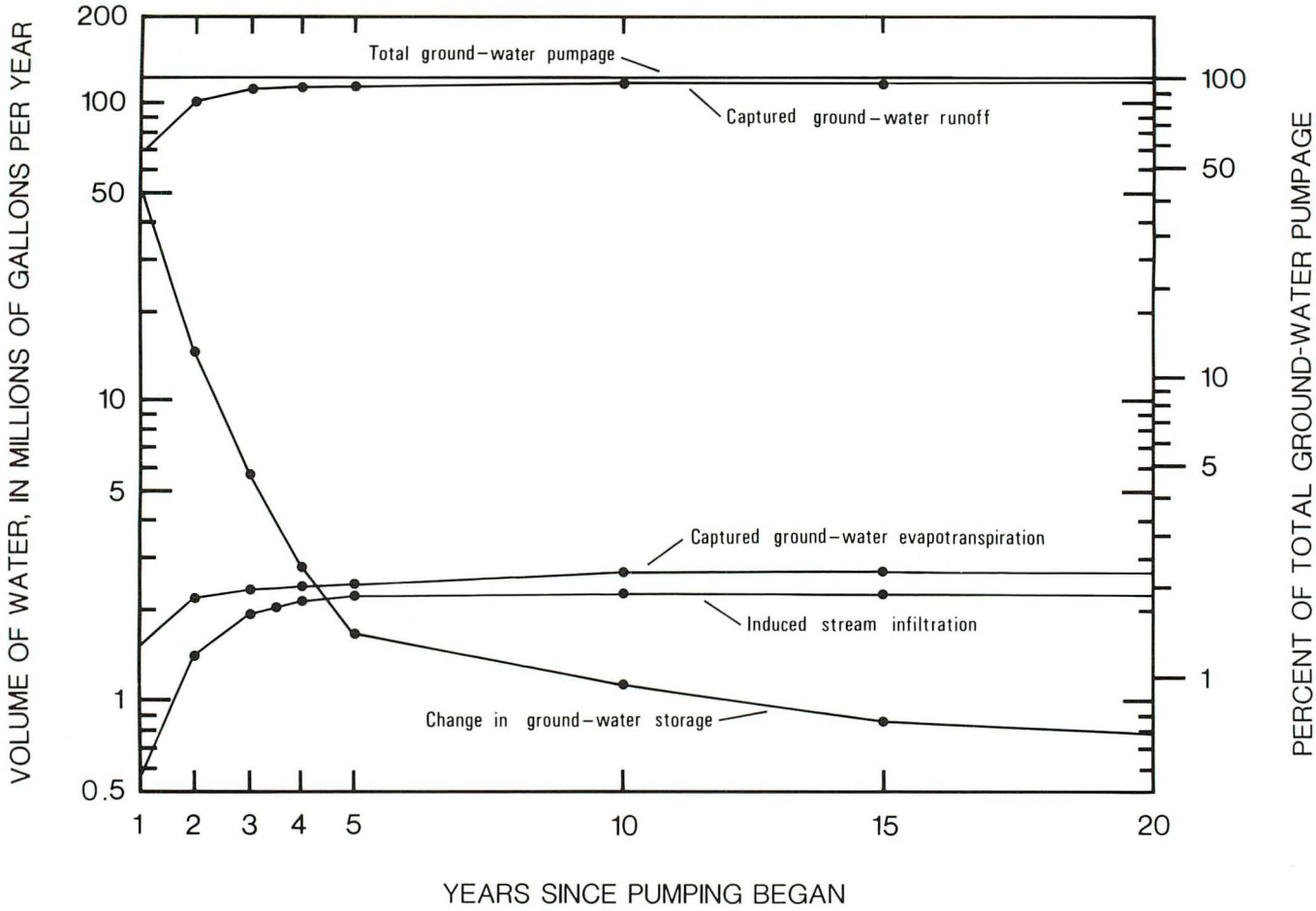


Figure 47. — Annual contributions to simulated ground-water pumpage by source (development scheme Ib).

well pumping show net gains in recharge. This produces local increases in ground-water storage and ground-water evapotranspiration.

Simulated times for the basin to reach equilibrium are influenced by the distribution of pumping stresses, patterns of pumpage returns, and by specific-yield estimates used in the model. Figure 48 shows that with increases in specific yield, the time required for the stream-aquifer system to reach a new equilibrium increases. This is because higher specific-yield estimates imply larger volumes of water are available in ground-water storage to satisfy pumpage requirements and base flows are reduced more gradually. Overestimation of the specific-yield term may seriously underestimate the short-term impacts of pumping. This is especially critical if the purpose of the model is to estimate the potential impacts of pumping during seasonal low-water periods or drought years.

Predictive simulations have heretofore been compared with average annual conditions. This is a convenient way to evaluate long-term impacts of pumping on the stream-aquifer system. However, average annual conditions are seldom duplicated in any one year, and within each year there are large seasonal variations in all components of the hydrologic budget. Insufficient data exist to adequately simulate seasonal conditions over a multi-year period, but some insight may be gained regarding short-term pumping impacts by examining simulations of the period July 1979 to September 1980.

Comparisons of simulated base flow (stream cell 11) and water-level (cell B) hydrographs for the developed (scheme Ib) and undeveloped stream basins are shown in figures 49 and 50, respectively. Both sets of hydrographs show increasing divergence of values with time between the developed and undeveloped basin. This reflects decreasing ground-water storage and base flow as the stream-aquifer system adjusts to the stress of pumping. Pumping rates are the same as used previously. Table 5 summarizes changes in simulated base flows and water-level altitudes at all data sites on September 3, 1980. Decreases in base flows are not uniform throughout the basin even though pumpage is

Table 4. — Contributions to ground-water pumpage, by source, after 20 years of simulated pumping

[Percentage totals may not equal 100 due to rounding]

Simulated development scheme	Percent pumpage returned	Supply wells	Contributions to pumpage after 20 years, in percent: Captured ground-water runoff	Change in ground-water storage	Captured ground-water evapotranspiration	Induced stream infiltration
Ia_1	95	domestic	96	2	3	-
Ia_2	90	domestic	95	3	3	-
Ia_3	80	domestic	94	3	3	-
Ib	0	domestic	92	4	2	2
Ic	90	public	88	(1)	(1)	12
Id	0	public	94	2	1	3
IIa	90	domestic	98	1	1	-
IIb	0	domestic	97	2	1	-
IIc	90	public	100	(1)	(1)	-
IId	0	public	97	1	1	-
IIIa	0	public	96	2	1	-
IIIb	90	public	96	2	1	-
IIIc	90	public	85	6	(1)	8

[1] Net ground-water storage or evapotranspiration increased during the period.

distributed evenly among all the land cells. Differences in base-flow reduction are attributed to variations in aquifer characteristics among the subbasins. Base flow for the basin declined 0.41 ft^3/s (site 11), which is less than the pumpage removed from the basin (0.51 ft^3/s). This indicates that significant quantities of water are still coming from storage.

Average annual base flow is a poor estimator of the impact of ground-water withdrawals on the stream-aquifer system during dry periods. Using development scheme Ib as an example, figure 36 shows that the average annual base flow (6.83 ft^3/s) after 20 years of pumping is reduced to 6.33 ft^3/s, a decline of 7 percent. In simulations of transient flows for July 1979 to September 1980, which ends during a typical annual low for streamflow and water levels, ground-water pumping reduces base flow at site 11 by 17 percent (table 5).

The impact of ground-water withdrawals during prolonged dry spells may be approximated by using the estimated low-flow value for 7 consecutive days with a 10-year recurrence interval ($7Q_{10}$). A value of 1.07 ft^3/s is obtained by correlation with the Patuxent River gaging station near Unity. Assuming streamflow during this period is sustained entirely by ground-water runoff, development conditions are those of scheme Ib, and pumpage is derived from captured ground-water runoff, then base flow (1.07 ft^3/s at site 11) would be reduced by 0.51 ft^3/s or 48 percent. Thus,

Table 5. — Simulated base flows and ground-water levels for undeveloped and developed basins, September 3, 1980

Base flow at stream cell	Simulated base flow, in cubic feet per second, for September 3, 1980: Undeveloped basin	Developed basin using scheme Ib
1	0.04	0.02
2	.01	no flow
3	.48	.39
4	.20	.17
5	no flow	no flow
6	.15	.13
7	.14	.12
8	.39	.36
9	.04	no flow
10	1.07	.88
11	2.40	1.99
12	.26	.18
Average water level at cell	**Simulated ground-water level, altitude in feet above sea level, for September 3, 1980**	
A	706.9	705.3
B	713.4	711.2
C	492.6	492.0

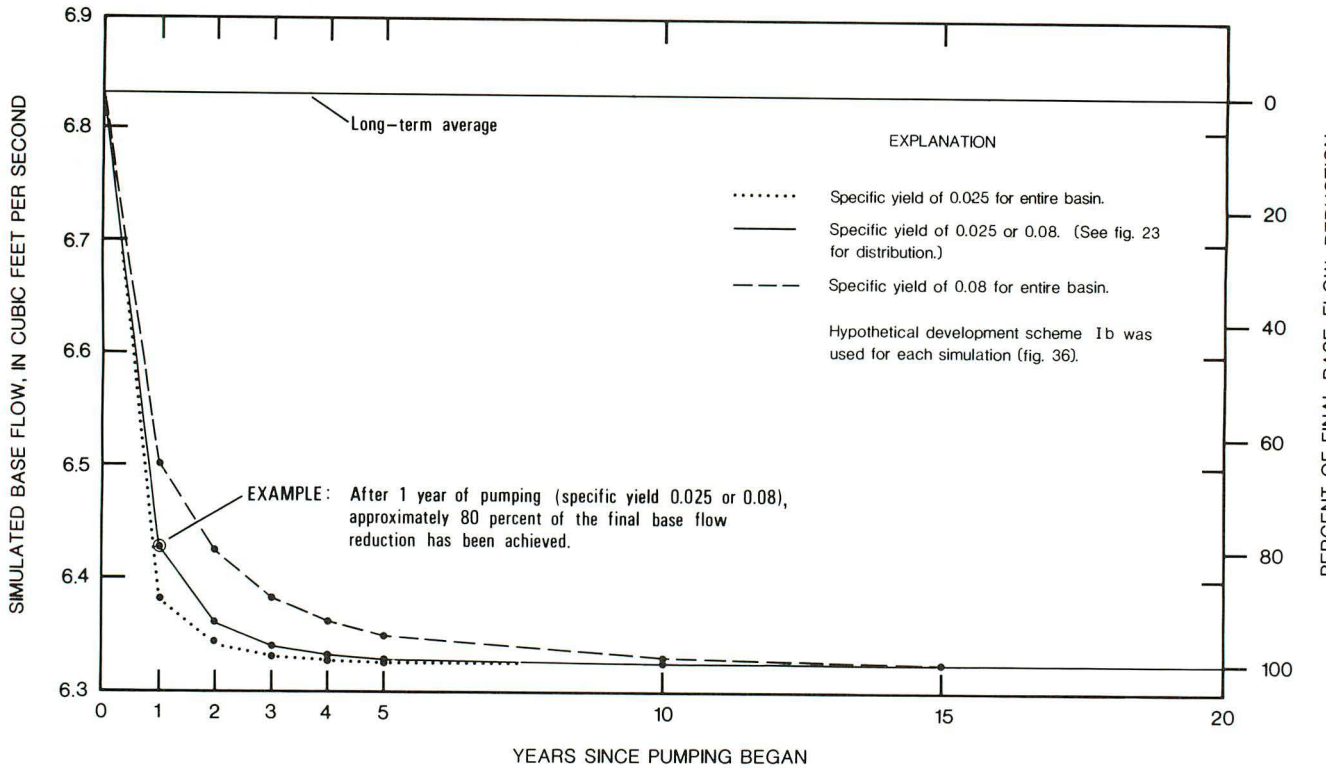


Figure 48. — Simulated reduction in long-term average base flow at station 11 using various estimates of specific yield.

base-flow reduction due to constant ground-water withdrawals from the stream-aquifer system becomes proportionately larger as natural streamflow diminishes.

SUMMARY AND CONCLUSIONS

The Cattail Creek stream basin is underlain by deeply weathered crystalline rock and is representative of ground-water flow conditions that occur throughout most of the Maryland Piedmont. The stream-aquifer system of the basin is simulated by a two-dimensional finite-difference model. Modeling methodologies described may be applied in similar hydrogeologic settings when characterizing stream-aquifer systems and assessing potential effects of ground-water withdrawals.

Modifications of the computer program included revising the method used to decrease ground-water evapotranspiration with falling water levels, and utilizing a method to systematically reduce hydraulic conductivity and specific yield with depth. Lack of field data for most hydrologic parameters necessitated their estimation using values from areas of similar hydrogeology. Simulated ground-water levels and base flows from steady-state and transient-flow models are in good agreement with estimated values. Model accuracy is commensurate with field-data accuracy and is in accord with the purpose and scope of the study.

Predictive simulations were run to demonstrate potential effects of ground-water withdrawals on the modeled stream-aquifer system under average annual conditions. All simulations have a fixed population of 4,410 and water use of 330,750 gal/d for the basin. Three hypothetical schemes of population distribution and development density are examined. In addition, various modes of ground-water supply and waste-water disposal show the effects of water withdrawals and returns both locally and for the entire basin. In all cases, captured ground-water runoff contributes most to well pumpage, with only minor amounts coming from ground-water storage, captured ground-water evapotranspiration, or induced stream infiltration. Reduction of base flow in streams, the major impact of well pumpage, is greatest for development schemes with waste water removed from the basin by sewers. Impacts on individual subbasins

vary greatly depending mainly on location of supply wells, location and amount of ground-water returns, and subbasin hydrology. Collectively, base flows are reduced by the amount of pumpage not returned as recharge within the basin.

Predictive simulations using long-term average annual conditions provide little information on the effects of pumping and waste-water returns during seasonal dry periods, or dry years when development would impact ground-water resources most. Export of waste-water by sewers produces a 7-percent decline in the average annual base flow, while simulation of an actual 15-month period shows a 17-percent decline in total base flow for September 3, 1980. These same losses produce a 48-percent decline in the estimated $7Q_{10}$ low flow.

SELECTED REFERENCES

Brown, R. H., 1963, The cone of depression and the area of diversion around a discharging well in an infinite strip aquifer subject to uniform recharge, *in* Shortcuts and special problems in aquifer tests: U.S. Geological Survey Water-Supply Paper 1545-C, p. 69-85.

Cleaves, E. T., Edwards, Jonathan, Jr., and Glaser, J. D., 1968, Geologic map of Maryland: Maryland Geological Survey, scale 1:250,000.

Cloos, Ernst, and Broedel, C. H., 1940, Geologic map of Howard County and adjacent parts of Montgomery and Baltimore Counties: Maryland Geological Survey, scale 1:62,500.

Crooks, J. W., O'Bryan, Deric, and others, 1967, Water resources of the Patuxent River basin, Maryland: U.S. Geological Survey Hydrologic Investigations Atlas HA-244, 5 maps.

Dames and Moore, 1978, Site selection and evaluation study for sanitary landfills, Montgomery County, Maryland: Consultant's report, v. 2-5, Chapter 2.

Davis, S. N., and DeWiest, R. J. M., 1966, Hydrogeology: New York, John Wiley, p. 318-333.

Dingman, R. J., and Ferguson, H. F., 1956, The ground-water resources of the Piedmont part, *in* The Water resources of Baltimore and Harford Counties: Maryland Department of Geology, Mines and Water Resources, Bulletin 17, p. 1-128.

Fidler, R. E., 1975, Digital model simulation of the glacial-outwash aquifer at Dayton, Ohio: U.S. Geological Survey Water-Resources Investigations 18-75, 30 p.

Haeni, F. P., 1978, Computer modeling of ground-water availability in the Pootatuck River Valley, Newtown, Connecticut: U.S. Geological Survey Water-Resources Investigations 78-77, 76 p.

Heath, R. C., 1978, Better utilization of ground water in the Piedmont and mountain region of the southeast, *in* Water conservation and alternative water supplies: Southeast Regional Conference; Georgia Institute of Technology, November 8-9, 1978, Proceedings, p. 145-160.

Heath, R. C., 1980, Basic elements of ground-water hydrology with reference to conditions in North Carolina: U.S. Geological Survey Water-Resources Investigations 80-44, 86 p.

Hopson, C. A., 1964, The crystalline rocks of Howard and Montgomery Counties, *in* The geology of Howard and Montgomery Counties: Maryland Geological Survey, p. 27-215.

Kilpatrick, F. A., 1964, Source of base flow to streams: International Association of Scientific Hydrology Publication 63, p. 329-339.

Law Engineering and Testing Company, 1973, Report of subsurface investigation, Montgomery County advanced wastewater treatment plant, Darnestown, Maryland, *in* Montgomery County regional advanced wastewater treatment plant project development report: Consultant's report by CH_2M Hill, Inc., for Washington Suburban Sanitary Commission, v. 4, appendix B.

Lawson, D. W., 1968, Groundwater flow systems in the crystalline rocks of the Okanagan Highland, British Columbia: Canadian Journal of Earth Sciences, v. 5, p. 813-824.

LeGrand, H. E., 1967, Ground water of the Piedmont and Blue Ridge Provinces in the Southeastern States: U.S. Geological Survey Circular 538, 11 p.

Lloyd, O. B., Jr., and Growitz, D. J., 1977, Ground-water resources of central and southern York County, Pennsylvania: Pennsylvania Topographic and Geologic Survey, Water Resources Report 42, 93 p.

Lohman, S. W., 1979, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 69 p.

Matthews, E. D., and Hershberger, M. F., 1968, Soil survey Howard County, Maryland: U.S. Department of Agriculture, Soil Conservation Service, 104 p.

McGreevy, L. J., and Sloto, R. A., 1980, Development of a digital model of ground-water flow in deeply weathered crystalline rock, Chester County, Pennsylvania: U.S. Geological Survey Water-Resources Investigations 80-2, 42 p.

Nutter, L. J., and Otton, E. G., 1969, Ground-water occurrence in the Maryland Piedmont: Maryland Geological Survey, Report of Investigations No. 10, 56 p.

Olmsted, F. H., and Hely, A. G., 1962, Relation between

ground water and surface water in Brandywine Creek basin, Pennsylvania: U.S. Geological Survey Professional Paper 417-A, 21 p.

Otton, E. G., 1980, Map 3. Availability of ground water, *in* Hydrogeologic atlas of the Winfield quadrangle: Maryland Geological Survey, Atlas No. 10, scale 1:24,000, 5 sheets.

Pluhowski, E. J., and Kantrowitz, I. H., 1964, Hydrology of the Babylon-Islip area Suffolk County, Long Island, New York: U.S. Geological Survey Water-Supply Paper 1768, 119 p.

Rasmussen, W. C., 1964, Permeability and storage of heterogeneous aquifers in the United States: International Association of Scientific Hydrology Publication 64, p. 317-325.

Rasmussen, W. C., and Andreasen, G. E., 1959, Hydrologic budget of Beaverdam Creek basin, Maryland: U.S. Geological Survey Water-Supply Paper 1472, 106 p.

Richardson, C. A., 1982, Ground water in the Piedmont upland of central Maryland: U.S. Geological Survey Water-Supply Paper 2077, 42 p.

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

Roen, J. B., and Froelich, A. J., 1976, Contour map of the base of saprolite, Howard County, Maryland: U.S. Geological Survey Miscellaneous Field Studies Map MF-772-A, scale 1:62,500.

_____ 1978, Thickness of overburden map, Howard County, Maryland: U.S. Geological Survey Miscellaneous Field Studies Map MF-772-B, scale 1:62,500.

Rosenshein, J. S., Gonthier, J. B., and Allen, W. B., 1968, Hydrologic characteristics and sustained yield of principal ground-water units Potowomut-Wickford area, Rhode Island: U.S. Geological Survey Water-Supply Paper 1775, 38 p.

Thornthwaite, C. W., and Mather, J. R., 1957, Instructions and tables for computing potential evapotranspiration and water balance: Drexel Institute of Technology, Publications in Climatology, v. 10, no. 3, 311 p.

Thornthwaite, C. W., Mather, J. R., and Carter, D. B., 1958, Three water balance maps of Eastern North America: Resources for the Future, Incorporated, 48 p., map scale 1:5,000,000.

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

U.S. Geological Survey, 1980, Water resources data, Maryland and Delaware, water year 1980: U.S. Geological Survey Water-Data Report MD-DE-80-1, p. 133-136.

Wilson, T. V., and Wiser, E. H., 1974, Groundwater-baseflow relationships and baseflow predictions from groundwater levels on Piedmont watersheds: American Society of Agricultural Engineering — 1974, Transactions, p. 269-279.

SUPPLEMENTAL DATA

Table 6. — Description of selected wells

LOCAL NUMBER	STATE PERMIT NUMBER	OWNER	DATE COMPLETED	ALTITUDE OF LAND SURFACE (FEET)	DEPTH OF WELL (FEET)	FINISH	DEPTH CASED	CASING DIAM-ETER (INCHES)	WATER LEVEL (FEET)	DATE WATER LEVEL MEASURED	DISCHARGE (GALLONS PER MINUTE)	DATE DISCHARGE MEASURED	PUMPING PERIOD (HOURS)	USE OF WATER	USE OF SITE
HO AB 4	--	PICKETT, MERHLE P	1900	720	33.20	X	--	6	12.63	05/13/1977	--	--	--	U	O
HO AB 5	HO-73-1521	FULP, WILLIAM G	07/13/1976	750	165.00	X	37	6	34.00	05/08/1980	5.0	07/13/1976	2.0	H	W
HO AB 6	HO-73-1677	PORTER, TIMOTHY W	10/07/1976	750	100.00	X	28	6	30.00	10/07/1976	7.0	10/07/1976	6.0	H	W
HO AB 7	HO-73-1501	WEBER, GERARD J	06/21/1976	760	145.00	X	23	6	40.00	06/21/1976	8.0	06/21/1976	2.0	H	W
HO AB 8	HO-73-1502	HARRELL, WILLIAM G	06/22/1976	755	145.00	X	38	6	34.80	04/15/1980	10	06/22/1976	2.0	H	W
HO AB 9	HO-73-2153	TURKEL, STEVEN C	07/01/1977	735	140.00	X	19	6	37.10	04/15/1980	6.0	07/01/1977	2.0	H	W
HO AB 10	HO-73-1845	CURTIN, THOMAS E	02/23/1977	748	140.00	X	19	6	41.70	04/09/1980	8.0	02/23/1977	2.0	H	W
HO AB 11	HO-73-2061	WALK, CHARLES R	06/29/1977	730	165.00	X	21	6	40.00	06/29/1977	6.0	06/29/1977	2.0	H	W
HO AB 12	HO-73-2062	WEBSTER, EDWARD P	06/29/1977	730	205.00	X	21	6	51.00	04/15/1980	2.0	06/29/1977	2.0	H	W
HO AB 13	HO-73-1844	MIERNICKI, ROBERT A	02/23/1977	730	120.00	X	19	6	45.70	04/09/1980	40	02/23/1977	2.0	H	W
HO AB 14	HO-73-1673	DIANGELO, MARION R	10/18/1976	745	200.00	X	21	6	53.98	04/22/1980	3.0	10/18/1976	2.0	H	W
HO AB 15	HO-73-2483	UNITED BLD	02/02/1978	740	165.00	X	61	6	43.30	04/09/1980	5.0	02/02/1978	2.0	H	W
HO AB 16	HO-73-2519	HILLIARD, THURBER G	02/06/1978	670	300.00	X	63	6	55.00	04/11/1980	1.0	02/06/1978	4.0	H	W
HO AB 17	HO-73-3442	HAMILTON, MARTIN C	10/18/1979	705	205.00	X	62	6	38.68	04/11/1980	20	10/18/1979	3.0	H	W
HO AB 18	HO-73-2610	MILLER, JESSE	04/10/1978	720	185.00	X	86	6	35.10	04/14/1980	30	04/10/1978	2.0	H	W
HO AB 19	--	PARKER, JAMES B	--	708	--	X	--	6	40.50	04/14/1980	--	--	--	H	W
HO AB 20	HO-73-0308	DORSEY, PHILLIP H	06/14/1973	680	140.00	X	21	6	39.93	04/14/1980	6.0	06/14/1973	1.0	H	W
HO AB 21	HO-73-1533	STURDEVANT, GEORGE	08/18/1976	770	180.00	X	21	6	18.87	04/18/1980	3.0	08/18/1976	2.0	H	W
HO AB 22	HO-73-2790	STYSLEY, MICHAEL T	06/16/1978	740	105.00	X	20	6	30.60	04/16/1980	60	06/16/1978	2.0	H	W
HO AB 23	--	HOOD, ROBERT SR.	--	775	--	X	--	6	23.08	04/21/1980	--	--	--	H	W
HO AB 24	--	STANCER, CHARLES A	--	730	--	X	--	6	12.36	04/23/1980	--	--	--	H	W
HO AB 25	--	PICKETT, CLARENCE E	--	765	--	X	--	6	41.56	04/24/1980	--	--	--	H	W
HO AB 26	--	BAKER, CHARLES JR.	--	730	--	X	--	6	33.77	04/28/1980	--	--	--	H	W
HO AB 27	--	LEMMON, LAURENCE F	--	742	80.00	--	--	--	50.40	04/28/1980	--	--	--	H	W
HO AB 28	--	BLAIR, VERNON E	--	720	--	X	--	6	42.00	04/28/1980	--	--	--	H	W
HO AB 29	HO-73-3601	MILLER, STANLEY	06/04/1980	690	225.00	X	78	6	35.87	06/09/1980	15	06/04/1980	6.0	H	W
HO AB 30	HO-73-2205	MITCHELL, ALLEN	08/25/1977	710	145.00	X	54	6	34.75	06/09/1980	4.0	08/25/1977	2.0	H	W
HO AB 31	HO-73-3194	PHEBUS, KENNETH D	04/02/1979	700	260.00	X	90	6	40.00	04/02/1979	2.0	04/02/1979	4.0	H	W
HO AB 32	HO-73-3240	WINTERS, EUGENE R	05/16/1979	750	170.00	X	56	6	40.00	05/16/1979	10	05/16/1979	1.0	H	W
HO AB 33	HO-73-2495	BAILE, ROBERT J	02/02/1978	740	105.00	X	19	6	30.00	02/02/1978	15	02/02/1978	2.0	H	W
HO AB 34	--	POPLAR SPRING METH CH	--	745	--	X	--	6	32.59	07/02/1980	--	--	--	T	W
HO AB 35	--	FREDERICKSEN, ALVIN H	--	760	--	X	--	6	25.95	07/11/1980	--	--	--	H	W
HO AC 1	HO-00-7704	WYATT, WILLIAM	1951	590	81.20	X	--	6	40.25	05/07/1952	3.0	05/07/1952	--	H	W
HO AC 2	HO-68-0254	MARKLEY, ALBERT	07/08/1968	570	160.00	X	28	6	35.00	07/08/1968	4.0	07/08/1968	0.5	H	W
HO AC 3	HO-73-0424	BRADLY, DONALD	09/06/1973	580	140.00	X	24	6	24.10	04/10/1980	25	09/06/1973	1.0	H	W
HO AC 4	HO-73-0687	STRADER, WARREN	07/15/1974	590	110.00	X	22	6	16.60	04/10/1980	10	07/15/1974	2.0	H	W
HO AC 5	HO-03-1849	TAYLOR, TOM A	09/12/1958	640	84.00	X	24	6	38.13	04/10/1980	15	09/12/1958	2.0	H	W
HO AC 6	HO-66-0252	SANNER, ROGER F	08/09/1966	630	140.00	X	40	6	40.00	08/09/1966	6.0	08/09/1966	0.5	H	W
HO AC 7	HO-73-0749	BOWENS, CAROL S	07/26/1974	635	125.00	X	45	6	39.76	04/15/1980	15	07/26/1974	1.0	H	W
HO AC 8	HO-73-1760	CHEAK, DEWITT	12/09/1976	590	100.00	X	50	6	20.81	04/08/1980	15	12/09/1976	--	H	W
HO AC 9	HO-73-0369	SMITH, EDGAR W JR	08/06/1973	590	100.00	X	25	6	13.70	04/08/1980	20	08/06/1973	1.0	H	W
HO AC 10	HO-73-1589	LISBON ELEM SCH	08/13/1976	550	368.00	X	82	6	16.81	04/08/1980	12	08/13/1976	6.0	T	W
HO AC 11	HO-73-0308	MILLER, STANLEY B	06/14/1973	680	140.00	X	21	6	51.50	04/14/1980	6.0	06/14/1973	1.0	H	W
HO AC 12	HO-73-0110	SHARPE, CHARLES M	12/30/1972	625	82.00	X	26	6	32.00	12/30/1972	10	12/30/1972	3.0	H	W
HO AC 13	HO-73-0202	MILLS, RAYMOND F	04/02/1973	625	85.00	X	51	6	35.79	05/05/1980	9.0	04/02/1973	2.5	H	W
HO AC 14	HO-73-0144	ROHDE, CARL D	03/26/1973	620	140.00	X	27	6	37.10	04/11/1980	20	03/26/1973	2.0	H	W
HO AC 15	HO-73-0143	MORRONE, JOSEPH A	05/07/1973	610	100.00	X	27	6	21.26	04/11/1980	30	05/07/1973	2.0	H	W
HO AC 16	HO-03-7495	LISBON VOL FIRE CO	01/07/1960	580	57.00	X	25	6	6.09	04/01/1980	20	01/07/1960	2.0	H	W
HO AC 17	HO-73-2060	BROWN, HARTS M	06/29/1977	720	105.00	X	23	6	53.35	04/15/1980	30	06/29/1977	2.0	H	W
HO AC 18	HO-73-1846	HARDESTY, DONALD H	02/23/1977	725	120.00	X	21	6	47.15	04/09/1980	30	02/23/1977	2.0	H	W
HO AC 19	HO-73-2137	CLARK, JIMMIE L	07/01/1977	750	120.00	X	21	6	46.83	04/28/1980	20	07/01/1977	2.0	H	W
HO AC 20	HO-73-2737	BURCHETT, JAMES M	06/15/1978	660	205.00	X	77	6	53.46	04/15/1980	3.0	06/16/1978	2.0	H	W
HO AC 21	HO-73-1833	GILROY, WILLIAM F	02/22/1977	620	300.00	X	21	6	43.95	04/21/1980	1.0	02/22/1977	2.0	H	W
HO AC 22	HO-73-1834	EVANS, ROBERT M	02/22/1977	610	160.00	X	21	6	40.78	04/21/1980	5.0	02/22/1977	2.0	H	W
HO AC 23	HO-73-2680	HILL, WILLIE JR	04/26/1978	600	145.00	X	72	6	32.98	06/22/1978	10	04/26/1978	2.0	H	W

EXPLANATION OF CODES

FINISH:	O —Open end	W—Walled	X —Open hole	
USE OF WATER:	C —Commercial	H —Domestic	T —Institution	U —Unused
USE OF SITE:	O —Observation	U —Unused	W—Withdrawal	

Table 6. — Description of selected wells, continued

LOCAL NUMBER	STATE PERMIT NUMBER	OWNER	DATE COMPLETED	ALTITUDE OF LAND SURFACE (FEET)	DEPTH OF WELL (FEET)	FINISH	DEPTH CASED	CASING DIAM-ETER (INCHES)	WATER LEVEL (FEET)	DATE WATER LEVEL MEASURED	DISCHARGE (GALLONS PER MINUTE)	DATE DISCHARGE MEASURED	PUMPING PERIOD (HOURS)	USE OF WATER	USE OF SITE
HO AC 24	HO-73-2681	PATTERSON, LARRY A	04/26/1978	600	145.00	X	50	6	32.22	04/21/1980	6.0	04/26/1978	2.0	H	W
HO AC 25	HO-73-2122	CORBIN, ARTHUR L	03/07/1978	620	120.00	X	52	6	34.10	04/10/1980	12	03/07/1978	2.0	H	W
HO AC 26	HO-73-1835	DONOVAN, CECILIA L	02/22/1977	630	140.00	X	21	6	38.76	04/10/1980	5.0	02/22/1977	2.0	H	W
HO AC 27	HO-73-1836	OLIPHANT, CHARLES A	02/22/1977	620	140.00	X	22	6	40.00	02/22/1977	5.0	02/22/1977	2.0	H	W
HO AC 28	HO-73-2049	EASH, DAVID D	05/27/1977	610	165.00	X	34	6	45.80	04/10/1980	4.0	05/27/1977	2.0	H	W
HO AC 29	HO-73-2132	POPE, FRANCIS X	11/23/1977	620	300.00	X	88	6	53.47	04/10/1980	1.0	11/23/1977	2.0	H	W
HO AC 30	HO-73-2683	ZACK, SUZAN M	04/24/1978	620	220.00	X	63	6	40.00	04/24/1978	2.0	04/24/1978	2.0	H	W
HO AC 31	HO-73-2125	DIXON, LORING J	10/14/1977	610	200.00	X	21	6	44.32	04/22/1980	3.0	10/14/1977	2.0	H	W
HO AC 32	HO-73-2128	DAY, HOWARD M	09/15/1977	630	140.00	X	21	6	40.00	09/15/1977	5.0	09/15/1977	2.0	H	W
HO AC 33	HO-73-2131	LONG, ROBERT D	03/07/1978	620	120.00	X	57	6	39.25	04/10/1980	12	03/07/1978	2.0	H	W
HO AC 34	HO-73-2134	JACJEREDON INC	11/23/1977	620	120.00	X	21	6	25.59	07/07/1980	7.0	11/23/1977	2.0	H	W
HO AC 35	HO-73-2038	NUGENT, JULIUS	06/08/1977	685	125.00	X	25	6	33.30	04/09/1980	10	06/08/1977	1.0	H	W
HO AC 36	--	DORSEY, JOSEPH M	--	580	--	X	--	6	37.30	04/09/1980	--	--	--	H	W
HO AC 37	--	BROWN, WILLIAM H	--	580	--	X	--	6	44.50	04/09/1980	--	--	--	H	W
HO AC 38	HO-73-0750	CLEMENT, THOMAS J	07/26/1974	615	125.00	X	74	6	28.00	04/09/1980	25	07/26/1974	1.0	H	W
HO AC 39	--	FREEMAN, CARL M	--	565	--	X	--	6	31.80	04/11/1980	--	--	--	H	W
HO AC 40	--	FREEMAN, CARL M	--	565	--	O	--	11	35.24	04/11/1980	--	--	--	H	U
HO AC 41	--	SCHULTE, WILLIAM A	--	610	--	X	--	6	30.40	04/21/1980	--	--	--	H	W
HO AC 42	HO-73-0372	LIBERTY BAPT CH	07/27/1973	585	102.00	X	30	6	33.05	04/12/1980	15	07/27/1973	2.0	H	W
HO AC 43	HO-73-2695	SWANN, WILLIAM L	04/14/1978	635	105.00	X	55	6	34.00	04/16/1980	10	04/14/1978	6.0	H	W
HO AC 44	--	ESWORTHY, ROBERT L	--	580	--	--	--	--	18.96	04/18/1980	--	--	--	H	W
HO AC 45	--	WARNER, FRANK L	--	580	--	X	--	6	17.85	04/18/1980	--	--	--	H	W
HO AC 46	--	FRANKLIN, HERMAN M	--	585	--	X	--	6	17.90	04/21/1980	--	--	--	H	W
HO AC 47	--	SIRK, JASPER L JR	--	575	--	X	--	6	24.74	04/23/1980	--	--	--	H	W
HO AC 48	--	SCLAR, REUBEN	--	585	--	X	--	6	35.65	04/23/1980	--	--	--	H	U
HO AC 49	--	CLARK, HOWARD W	--	590	--	--	--	--	27.26	04/23/1980	--	--	--	H	W
HO AC 50	--	HOWARD ASSOC.	--	610	--	X	--	6	20.50	04/24/1980	--	--	--	H	U
HO AC 51	--	HARLESS, MARION	--	600	--	W	--	--	23.00	04/24/1980	--	--	--	H	U
HO AC 52	--	BATES, ABRAHAM	--	630	--	X	--	6	35.00	04/28/1980	--	--	--	H	W
HO AC 53	--	WELSH, HAZEL L	--	575	--	X	--	6	30.69	04/28/1980	--	--	--	H	W
HO AC 54	--	BRADLEY, DONALD C	--	575	--	W	--	--	28.85	04/28/1982	--	--	--	H	W
HO AC 55	--	BRADLEY, DONALD C	--	575	--	X	--	6	31.54	04/28/1980	--	--	--	H	W
HO AC 56	--	SAUNDERS	--	625	--	W	--	--	38.70	04/28/1980	--	--	--	H	W
HO AC 57	--	WILSON, W F	--	645	--	X	--	6	44.55	04/28/1980	--	--	--	H	W
HO AC 58	--	HARLESS, MARION	--	590	--	X	--	6	19.47	04/29/1980	--	--	--	H	W
HO AC 59	--	WELLER, NORMAN	--	590	46.00	W	--	--	18.40	04/30/1980	--	--	--	H	W
HO AC 60	--	PUE, RIDGELY R	--	645	--	X	--	6	40.55	04/30/1980	--	--	--	H	W
HO AC 61	--	HARBIN, RUFUS	--	640	--	X	--	6	33.58	05/05/1980	--	--	--	H	W
HO AC 62	HO-73-0977	THOMEY, RONALD J	04/16/1975	640	158.00	X	81	6	29.58	05/05/1980	15	04/16/1975	7.0	H	W
HO AC 63	--	LUTHERAN METH, CHURCH	--	570	--	X	--	6	23.79	06/09/1980	--	--	--	T	W
HO AC 64	--	WHITTINGTON, WILLIAM A	--	565	--	X	--	6	17.10	06/09/1980	--	--	--	H	W
HO AC 65	--	CROSS, ETHEL	--	555	--	W	--	--	32.70	06/09/1980	--	--	--	H	U
HO AC 66	HO-73-3036	BOWLIN, JAMES G	01/29/1979	725	145.00	X	34	6	35.00	01/29/1979	10	01/29/1979	6.0	H	W
HO AC 67	HO-73-3484	SIMCO CORP	11/08/1979	750	105.00	X	21	6	54.60	07/11/1980	30	11/08/1979	2.0	H	W
HO AC 68	HO-73-2321	HARBIN, GEORGE	09/22/1977	630	245.00	X	52	6	45.00	09/22/1977	6.0	09/22/1977	2.0	H	W
HO AC 69	HO-73-0181	DOVE, WILBUR A	03/22/1973	600	100.00	X	19	6	40.00	03/22/1973	5.0	03/22/1973	2.0	H	W
HO AC 70	HO-73-2682	RYNARZEWSKI, ROBERT J	04/26/1978	625	140.00	X	72	6	40.00	04/26/1978	4.0	04/26/1978	2.0	H	W
HO AC 71	HO-73-2684	CREEL, DONALD J	04/24/1978	620	120.00	X	61	6	40.00	04/24/1978	12	04/24/1978	2.0	H	W
HO AC 72	HO-73-3186	SMITH BROS	04/02/1979	600	305.00	X	74	6	40.00	04/02/1979	1.0	04/02/1979	2.0	H	W
HO AC 73	--	--	--	595	--	X	--	--	15.49	07/11/1980	--	--	--	H	W
HO AC 74	HO-73-2127	BALL, HAROLD H. JR	10/20/1977	630	200.00	X	19	6	40.00	10/20/1977	5.0	10/20/1977	2.0	H	W
HO AC 75	--	CROSS, ETHEL	--	560	96.00	X	--	--	37.00	07/14/1980	--	--	--	H	W
HO AC 76	HO-73-2685	KASDA, WILLIAM J JR	04/26/1978	630	300.00	X	61	6	50.00	04/26/1978	1.0	04/26/1978	2.0	H	W
HO AC 77	HO-73-3616	MCINTOSH, PETER	07/10/1980	594	145.00	X	34	6	40.00	07/10/1980	20	07/10/1980	4.0	H	W
HO BB 2	--	WARFIELD, BERNARD D	1918	600	56.00	X	--	6	35.90	04/09/1980	--	--	--	H	W

Table 6. — Description of selected wells, continued

LOCAL NUMBER	STATE PERMIT NUMBER	OWNER	DATE COMPLETED	ALTITUDE OF LAND SURFACE (FEET)	DEPTH OF WELL (FEET)	FINISH	DEPTH CASED	CASING DIAM-ETER (INCHES)	WATER LEVEL (FEET)	DATE WATER LEVEL MEASURED	DISCHARGE (GALLONS PER MINUTE)	DATE DISCHARGE MEASURED	PUMPING PERIOD (HOURS)	USE OF WATER	USE OF SITE
HO BB 3	HO-72-0092	REED, CARL	11/05/1971	620	170.00	X	100	6	59.63	04/21/1980	12	11/05/1971	1.0	H	W
HO BB 4	HO-73-1320	DABBS, LAWRENCE W	02/25/1976	600	125.00	X	78	6	40.00	04/21/1980	15	02/25/1976	2.0	H	W
HO BB 5	HO-73-0859	HALL, JOSEPH W	10/28/1974	610	185.00	X	80	6	49.38	04/16/1980	3.0	10/28/1974	2.0	H	W
HO BB 6	HO-73-0012	LOBER, NELSON W	07/27/1972	595	120.00	X	20	6	33.50	04/21/1980	5.0	07/27/1972	1.0	H	W
HO BB 7	HO-73-0076	SEALING, LEROY	10/06/1972	580	140.00	X	30	6	30.00	10/06/1972	7.0	10/06/1972	2.0	H	W
HO BB 8	HO-73-1162	CLARK, EDWARD	10/20/1975	580	150.00	X	21	6	34.52	04/23/1980	8.0	10/20/1975	2.0	H	W
HO BB 9	HO-73-0465	ROESEMANN, HENRY	01/15/1974	580	180.00	X	74	6	33.60	04/21/1980	8.0	01/15/1974	2.0	H	W
HO BB 10	HO-71-0062	MORNINGSTAR, JAMES F	11/04/1970	610	200.00	X	36	6	40.32	04/15/1980	10	11/04/1970	1.0	H	W
HO BB 11	HO-05-6758	WARFIELD, DAVID R	04/01/1964	610	92.00	X	22	6	36.00	04/01/1964	10	04/01/1964	1.0	H	W
HO BB 12	HO-73-1707	MARSHECK, CHARLES W	11/06/1976	590	340.00	X	80	6	34.00	04/18/1980	1.0	11/06/1976	2.0	H	W
HO BB 13	HO-73-0165	GILMORE, DAVID L JR	02/19/1973	760	200.00	X	21	6	40.00	02/19/1973	2.0	02/19/1973	1.0	H	W
HO BB 14	HO-72-0237	KETTERMEN, OLEN W	06/20/1972	760	300.00	X	33	6	55.20	04/16/1980	5.0	06/20/1972	1.0	H	W
HO BB 15	HO-73-0666	MOODY, THOMAS	05/03/1974	740	150.00	X	21	6	40.96	04/11/1980	10	05/03/1974	2.0	H	W
HO BB 16	HO-73-0427	PATRICK, LOYD V	10/19/1973	750	150.00	X	21	6	22.80	04/11/1980	10	10/19/1973	2.0	H	W
HO BB 17	HO-73-0743	HOWARD, MELVIN C	01/15/1973	640	100.00	X	23	6	40.00	01/15/1973	15	01/15/1973	1.0	H	W
HO BB 18	HO-73-1888	MCFANN, CHARLES E	03/30/1977	615	125.00	X	21	6	30.92	04/11/1980	30	03/30/1977	2.0	H	W
HO BB 19	HO-73-0981	HOWES, WARREN G	04/22/1975	620	100.00	X	24	6	27.18	04/11/1980	30	04/22/1975	1.0	H	W
HO BB 20	HO-72-0166	BOONE, DAVID	03/28/1972	690	160.00	X	21	6	49.99	07/11/1980	15	03/28/1972	1.0	H	W
HO BB 21	HO-72-0161	OLES, THOMAS F	03/27/1972	750	350.00	X	21	6	37.05	04/20/1980	2.0	03/27/1972	1.0	H	W
HO BB 22	HO-73-0070	OLES, THOMAS F	11/06/1972	745	200.00	X	43	6	21.80	04/20/1980	6.0	11/06/1972	2.0	H	W
HO BB 23	HO-71-0178	BOWIE, CHARLES	08/13/1971	720	160.00	X	21	6	31.10	04/11/1980	3.0	08/13/1971	1.0	H	W
HO BB 24	HO-73-0339	PETRIDES, EARNEST	05/30/1973	680	160.00	X	46	6	38.30	04/20/1980	15	05/30/1973	1.0	H	W
HO BB 25	HO-73-0393	GIGLIOTTA, ANTHONY P	09/28/1973	685	175.00	X	26	6	47.90	07/07/1980	5.0	09/28/1973	6.0	H	W
HO BB 26	HO-73-0118	THOMAS, MELVIN P	03/28/1973	750	300.00	X	21	6	30.81	06/24/1980	1.0	03/28/1973	1.0	U	O
HO BB 27	HO-73-0493	THOMAS, MELVIN P	07/22/1974	750	145.00	X	22	6	23.18	04/01/1980	5.0	07/22/1974	1.0	H	W
HO BB 28	HO-73-2659	TEMPLEMAN, ROBERT E	04/28/1978	575	100.00	X	47	6	24.05	04/09/1980	18	04/28/1978	2.0	H	W
HO BB 29	--	STREAKER, J W	--	665	--	O	--	--	42.04	04/11/1980	--	--	--	H	W
HO BB 30	--	BARNES, WILLIAM E	--	665	--	X	--	6	35.26	04/18/1980	--	--	--	H	W
HO BB 31	HO-73-2865	GILROY, WILLIAM R	08/09/1978	585	265.00	X	48	6	28.55	04/18/1980	2.0	08/09/1978	5.0	H	W
HO BB 32	HO-73-2348	PIPPIN, LANDON D	10/20/1977	755	145.00	X	19	6	45.00	04/17/1980	6.0	10/20/1977	2.0	H	W
HO BB 33	--	BOWMAN, STANLEY E	--	600	--	X	--	6	34.25	04/18/1980	--	--	--	H	W
HO BB 34	--	PRENTICE, VERN C	--	760	--	X	--	6	26.37	04/18/1980	--	--	--	H	W
HO BB 35	--	MULLINIX, LESTER E	--	740	--	O	--	--	17.50	04/24/1980	--	--	--	H	U
HO BB 36	HO-73-0421	LUCE, LLEWELLYN A	09/18/1973	610	235.00	X	43	6	35.37	04/29/1980	3.0	09/18/1973	1.0	H	W
HO BB 37	--	BARNES, EDGAR J	--	765	--	X	--	6	73.77	07/09/1980	--	--	--	H	W
HO BB 38	--	SLAGLE, PAUL D	--	590	--	X	--	6	35.67	07/02/1980	--	--	--	H	W
HO BB 39	HO-73-0911	FLESHMAN, ALLEN D	12/30/1974	650	185.00	X	46	6	36.40	07/02/1980	10	12/30/1974	2.0	H	W
HO BB 40	--	ROBINSON, WILBUR B	--	760	--	X	--	6	29.50	07/02/1980	--	--	--	H	W
HO BB 41	--	ROBINSON, WILBUR B	--	760	--	X	--	6	28.80	07/02/1980	--	--	--	H	W
HO BB 42	--	TRAGESER, HERBERT W SR	--	605	--	X	--	6	29.40	07/07/1980	--	--	--	H	W
HO BB 43	HO-73-1523	LEONHARDT, KARL T	07/29/1976	605	125.00	X	19	6	44.60	07/07/1980	12	07/29/1976	2.0	H	W
HO BB 44	HO-73-1525	SWEADNER, NICHOLAS E	07/01/1976	645	125.00	X	19	6	42.80	07/07/1980	8.0	07/01/1976	2.0	H	W
HO BB 45	--	GIBSON, CLYDE F JR	--	765	--	X	--	6	52.87	07/11/1980	--	--	--	H	W
HO BB 46	HO-73-0392	STAEHLING, ROBERT J SR	09/24/1973	685	175.00	X	28	6	39.30	07/07/1980	10	09/24/1973	6.0	H	W
HO BC 16	HO-73-0806	HAWKESWORTH, ROGER W J	08/22/1974	565	125.00	X	41	6	47.16	04/07/1980	15	08/22/1974	6.0	H	W
HO BC 17	HO-73-0357	JAMKE, PETER J	07/11/1973	580	140.00	X	59	6	47.90	04/08/1980	6.0	07/11/1973	2.0	H	W
HO BC 18	HO-73-1302	FERGUSON, JAMES R	02/17/1976	605	80.00	X	22	6	40.78	04/08/1980	10	02/17/1976	2.0	H	W
HO BC 19	HO-72-0011	HIRKA, STEPHEN	07/20/1971	545	125.00	X	90	6	55.70	04/07/1980	10	07/20/1971	1.0	H	W
HO BC 20	HO-72-0020	REEDY, PAUL E	09/09/1971	560	120.00	X	20	6	63.76	04/07/1980	10	09/09/1971	1.0	H	W
HO BC 21	HO-73-0249	PARKER, JAMES T	05/16/1973	510	100.00	X	40	6	24.01	04/08/1980	10	05/16/1973	2.0	H	W
HO BC 22	HO-73-0478	PARKER, JAMES T	10/02/1973	510	140.00	X	62	6	--	--	4.0	10/02/1973	1.0	H	W
HO BC 23	HO-73-0496	HAYNES, JOHN	11/12/1973	525	140.00	X	65	6	38.71	04/08/1980	10	11/12/1973	2.0	H	W
HO BC 24	HO-73-0212	STEVENS, WILLIAM T	05/18/1973	530	160.00	X	39	6	54.00	04/08/1980	10	05/18/1973	2.0	H	W
HO BC 25	HO-73-0433	RUPSIS, THOMAS F	10/15/1973	535	200.00	X	38	6	50.20	04/16/1980	15	10/15/1973	6.0	H	W
HO BC 26	HO-73-0210	PETERS, JEROME G	05/17/1973	535	120.00	X	40	6	40.00	05/17/1973	10	05/17/1973	2.0	H	W

Table 6. — Description of selected wells, continued

LOCAL NUMBER	STATE PERMIT NUMBER	OWNER	DATE COMPLETED	ALTITUDE OF LAND SURFACE (FEET)	DEPTH OF WELL (FEET)	FINISH	DEPTH CASED	CASING DIAM-ETER (INCHES)	WATER LEVEL (FEET)	DATE WATER LEVEL MEASURED	DISCHARGE (GALLONS PER MINUTE)	DATE DISCHARGE MEASURED	PUMPING PERIOD (HOURS)	USE OF WATER	USE OF SITE
HO BC 27	HO-73-0211	KELLY, LAWRENCE K	05/17/1973	540	180.00	X	36	6	45.70	04/10/1980	2.0	05/17/1973	2.0	H	W
HO BC 28	HO-73-0654	GILLIS, HERMAN	04/30/1974	565	160.00	X	59	6	43.06	04/17/1980	5.0	04/30/1974	1.0	H	W
HO BC 29	HO-73-0463	PETERS, JAMES R	10/17/1973	565	125.00	X	39	6	44.29	04/10/1980	7.0	10/17/1973	2.0	H	W
HO BC 30	HO-73-0816	KINSLEY, HOMAN B	09/15/1974	565	80.00	X	37	6	33.64	07/18/1980	10	--	2.0	H	W
HO BC 31	HO-73-0706	KRAJEWSKI, THOMAS M	05/29/1974	555	340.00	X	104	6	35.02	04/10/1980	2.5	05/29/1974	7.0	H	W
HO BC 32	HO-73-0599	TAYLOR, ALAN R JR	03/26/1974	540	205.00	X	71	6	20.20	04/10/1980	8.0	03/26/1974	2.0	H	W
HO BC 33	HO-73-0815	DAVIS, DANIEL M	10/05/1974	565	90.00	X	37	6	26.78	04/23/1980	10	10/05/1974	2.0	H	W
HO BC 34	HO-73-0814	RODGERS, GENE C	09/16/1974	555	105.00	X	29	6	30.00	09/18/1974	7.0	09/18/1974	2.0	H	W
HO BC 35	HO-73-0740	HAIRFIELD, CARL F JR	08/16/1974	560	245.00	X	80	6	60.00	08/16/1974	5.0	08/16/1974	2.0	H	W
HO BC 36	HO-73-1540	KEENE, JOHN M	07/16/1976	565	150.00	X	40	6	37.61	04/17/1980	8.0	07/16/1976	6.0	H	W
HO BC 37	HO-73-1348	ZIMMERMAN, THEODORE H	05/17/1976	565	185.00	X	83	6	38.99	04/10/1980	5.0	05/17/1976	2.0	H	W
HO BC 38	--	PATRICK, BELDEN	1911	520	57.80	--	--	--	24.41	06/30/1980	--	--	--	U	O
HO BC 39	HO-03-3898	PATRICK, BELDEN	03/31/1959	520	79.00	X	42	6	22.55	04/01/1980	10	03/31/1974	1.5	H	W
HO BC 40	HO-73-0788	MULLINIX, GENE	08/07/1974	530	225.00	X	52	6	17.35	04/08/1980	15	08/07/1974	1.0	S	W
HO BC 41	HO-73-1622	EVANS, ROGER H	12/01/1976	605	150.00	X	36	6	34.85	04/07/1980	5.0	12/01/1976	6.0	H	W
HO BC 42	HO-73-1621	MARSHALL, WALTER C	12/02/1976	600	150.00	X	35	6	31.92	04/07/1980	5.0	12/02/1976	6.0	H	W
HO BC 43	HO-73-1620	SHIPLEY, WAYNE	10/16/1976	605	125.00	X	40	6	27.13	04/07/1980	20	10/16/1976	1.0	H	W
HO BC 44	HO-73-1594	BOETKER, JOHN K	08/30/1976	610	165.00	X	73	6	36.46	04/07/1980	10	08/30/1976	2.0	H	W
HO BC 45	HO-73-1619	BRIAN, MICHAEL J	10/15/1976	605	150.00	X	35	6	46.74	04/07/1980	8.0	10/15/1976	6.0	H	W
HO BC 46	HO-73-1542	INGRAM, EARL R	08/04/1976	605	150.00	X	46	6	40.00	08/04/1976	3.0	08/04/1976	6.0	H	W
HO BC 47	HO-73-0437	CUMBERLAND, WILLIAM T	01/15/1974	590	300.00	X	70	6	46.50	04/09/1980	3.0	01/15/1974	2.0	H	W
HO BC 48	HO-73-0006	WEST, WILLIAM E	07/14/1972	565	340.00	X	102	6	38.31	04/10/1980	2.0	07/14/1972	12.0	H	W
HO BC 49	HO-73-0857	BALL, EDWARD E	10/22/1974	665	180.00	X	96	6	51.15	04/15/1980	8.0	10/22/1974	1.0	H	W
HO BC 50	HO-73-1799	CLEMENT, LEONARD K	01/25/1977	530	105.00	X	61	6	0.55	04/21/1980	30	01/25/1977	2.0	H	W
HO BC 51	HO-73-0197	VINCENT, JOHN C	03/27/1973	570	140.00	X	21	6	45.60	04/16/1980	12	03/27/1973	1.0	H	W
HO BC 52	HO-73-0239	CAVALIERE, RALPH L	04/20/1973	570	82.00	X	23	6	40.19	04/09/1980	15	04/20/1973	3.0	H	W
HO BC 53	HO-73-0338	EMORY, ADDISON JR	08/23/1973	575	125.00	X	54	6	32.00	08/23/1973	10	08/23/1973	4.0	H	W
HO BC 54	HO-73-0636	KIERNAN, SHERWOOD C	04/19/1974	565	85.00	X	23	6	41.19	04/08/1980	10	04/19/1974	2.0	H	W
HO BC 55	HO-73-0382	HORNBERGER, EDWARD C	09/04/1973	550	100.00	X	23	6	34.70	04/08/1980	15	09/04/1973	1.0	H	W
HO BC 56	HO-73-0387	DIGNAN, RICHARD D	09/05/1973	550	100.00	X	23	6	40.00	04/08/1980	15	09/05/1973	1.0	H	W
HO BC 57	HO-73-1316	WEISS, WILLIAM W	05/17/1976	545	200.00	X	72	6	41.97	04/08/1980	3.0	05/17/1976	4.0	H	W
HO BC 58	HO-73-0206	MALINOWSKI, LEO J	07/05/1973	505	100.00	X	20	6	26.10	04/18/1980	30	07/05/1973	1.0	H	W
HO BC 59	HO-70-0036	DEBERNARDO, DAVID	11/ /1969	550	77.00	X	25	6	15.24	04/07/1980	10	11/ /1969	2.0	H	W
HO BC 60	HO-73-0384	GREEN, RICHARD W	09/11/1973	565	120.00	X	28	6	9.25	04/08/1980	10	09/11/1973	2.0	H	W
HO BC 61	HO-73-0011	FLETCHER, JOHN R	07/24/1972	630	100.00	X	74	6	51.70	04/07/1980	20	07/24/1972	1.0	H	W
HO BC 62	HO-73-0416	FERGUSON, JAMES R	11/17/1973	600	200.00	X	127	6	31.43	04/08/1980	10	11/17/1973	1.0	H	W
HO BC 63	HO-73-0804	ROSENBAUM, ERIK	09/26/1974	620	75.00	X	37	6	28.60	04/07/1980	50	09/26/1974	1.0	H	W
HO BC 64	HO-73-1557	CAHILL, EUGENE B	09/01/1976	550	125.00	X	24	6	54.33	04/07/1980	20	09/01/1976	2.0	H	W
HO BC 65	HO-70-0191	CAIN, HOWARD S	08/06/1970	545	120.00	X	24	6	46.00	04/07/1980	15	08/06/1970	1.0	H	W
HO BC 66	HO-73-0901	ROSENBAUM, PER	12/16/1974	610	140.00	X	71	6	40.10	07/11/1980	5.0	12/16/1974	1.0	H	W
HO BC 67	--	PELTON, RONALD W	--	492	57.30	X	--	6	11.19	04/01/1980	--	--	--	H	U
HO BC 68	--	C & P TELEPHONE	--	640	141.00	X	--	6	30.61	04/01/1980	5.0	03/30/1961	--	C	W
HO BC 69	--	STOPPENBACK, THEODORE	--	642	--	X	--	6	31.96	04/01/1980	--	--	--	H	U
HO BC 70	--	JONES, ROSCOE C	--	645	--	X	--	6	36.05	04/07/1980	--	--	--	H	U
HO BC 71	HO-73-2973	ALBERS, D W	09/21/1978	600	277.00	X	86	6	24.70	04/07/1980	4.0	09/21/1978	6.0	H	W
HO BC 72	--	MULLINIX, GENE	--	535	--	X	--	6	16.19	04/08/1980	--	--	--	H	W
HO BC 73	HO-73-1733	TAMAGNI, JACK	10/27/1976	590	200.00	X	123	6	53.10	04/08/1980	4.0	10/27/1976	1.0	H	W
HO BC 74	--	HARLESS, MARION	--	565	--	X	--	6	15.59	04/08/1980	--	--	--	H	W
HO BC 75	HO-73-2611	MACKEBEE, LESTER P	03/30/1978	565	160.00	X	46	6	34.81	04/09/1980	10	03/30/1978	2.0	H	W
HO BC 76	--	DORSEY, CHARLES A	--	635	--	X	--	6	35.80	04/09/1980	--	--	--	H	W
HO BC 77	HO-73-2040	SMITH, ROBERT L	06/07/1977	590	100.00	X	21	6	52.30	04/09/1980	15	06/07/1977	1.0	H	W
HO BC 78	--	PLEMMONS, FAUN L	--	650	--	X	--	6	37.92	04/11/1980	--	--	--	H	W
HO BC 79	HO-73-1757	LIVESAY, DAVID L	12/06/1976	645	140.00	X	21	6	44.78	04/11/1980	3.0	12/06/1976	4.0	H	W
HO BC 80	HO-73-3203	SPRINGLAKE RESEARCH	03/28/1979	570	265.00	X	101	6	34.52	04/11/1980	2.0	03/28/1979	6.0	H	W
HO BC 81	HO-73-2788	SPRINGLAKE RESEARCH	07/14/1978	575	85.00	X	54	6	20.40	04/11/1980	15	07/14/1978	2.0	H	W

Table 6. — Description of selected wells, continued

LOCAL NUMBER	STATE PERMIT NUMBER	OWNER	DATE COMPLETED	ALTITUDE OF LAND SURFACE (FEET)	DEPTH OF WELL (FEET)	FINISH	DEPTH CASED	CASING DIAM-ETER (INCHES)	WATER LEVEL (FEET)	DATE WATER LEVEL MEASURED	DISCHARGE (GALLONS PER MINUTE)	DATE DISCHARGE MEASURED	PUMPING PERIOD (HOURS)	USE OF WATER	USE OF SITE
HO BC 82	HO-73-0959	COOK, RAYMOND	04/10/1975	665	100.00	X	18	6	63.78	04/18/1980	20	04/10/1975	1.0	H	W
HO BC 83	--	BRENDLE, WILLIAM	--	545	--	X	--	--	32.80	04/18/1980	--	--	--	H	W
HO BC 84	--	AMOSS, EDGAR L	--	600	94.00	X	--	--	42.14	04/21/1980	--	--	--	H	W
HO BC 85	--	FREEMAN, CARL M	--	550	--	X	--	--	14.65	04/21/1980	--	--	--	H	W
HO BC 86	--	BOWMAN, LELAND	--	590	--	X	--	--	36.63	07/09/1980	--	--	--	H	W
HO BC 87	--	POTH, ROBERT G	--	590	--	X	--	--	35.51	07/09/1980	--	--	--	H	W
HO BC 88	HO-73-0623	THEIS, WILLIAM R	05/22/1974	545	105.00	X	32	6	42.60	04/17/1980	7.0	05/22/1974	2.0	H	W
HO BC 89	--	JACKSON, HARRIETT	--	660	--	X	--	--	56.60	04/17/1980	--	--	--	H	W
HO BC 90	HO-73-0867	PIRRUNG, HARRY G	10/30/1978	650	200.00	X	36	6	40.73	04/17/1978	3.0	10/30/1978	2.0	H	W
HO BC 91	HO-73-2867	GRIMES, H T	08/08/1978	645	145.00	X	68	6	31.33	04/17/1980	10	08/08/1978	2.0	H	W
HO BC 92	HO-73-3155	KETTERMAN, OLLEN	02/27/1979	620	185.00	X	69	6	40.97	04/17/1980	10	02/27/1979	8.0	H	W
HO BC 93	--	HARBIN, JOHN M	--	540	--	X	--	6	8.42	04/17/1980	--	--	--	H	W
HO BC 94	HO-73-3430	SMITH, MICHAEL L	09/19/1979	625	185.00	X	98	6	44.24	04/17/1980	50	09/19/1979	3.0	H	W
HO BC 95	--	HUBER, HARRY R	04/18/1979	625	145.00	X	102	6	42.53	04/17/1980	20	04/18/1979	8.0	H	W
HO BC 96	--	JACKSON, JOHN J	--	655	--	X	--	6	51.60	04/22/1980	--	--	--	H	W
HO BC 97	--	SNOUFFER, CHARLES	--	575	--	W	--	--	15.80	04/22/1980	--	--	--	H	W
HO BC 98	--	CHRISTOPHER, WILLIAM C	--	525	--	W	--	--	14.41	04/22/1980	--	--	--	H	U
HO BC 99	--	GIAMPOALI, VIRGINIA	--	565	185.00	X	--	6	55.49	07/11/1980	--	--	--	H	W
HO BC 100	--	TALLEY, RICHARD W	--	600	--	X	--	6	74.22	07/18/1980	--	--	--	H	W
HO BC 101	HO-73-2945	CORNETT, GENE D	09/05/1978	560	265.00	X	29	6	56.23	04/23/1980	4.0	09/05/1978	2.0	H	W
HO BC 102	--	RUTZ, DONALD	--	560	--	X	--	6	44.70	04/23/1980	--	--	--	H	W
HO BC 103	--	COLE, JOHN B	--	550	--	X	--	6	61.57	04/28/1980	--	--	--	H	W
HO BC 104	--	COLE, JOHN B	--	540	--	--	--	--	42.80	04/28/1980	--	--	--	H	U
HO BC 105	--	MYERS, DAVID H	--	545	--	X	--	6	39.51	04/28/1980	--	--	--	H	W
HO BC 106	--	ABEL, PHILIP R	--	550	--	X	--	6	41.88	04/28/1980	--	--	--	H	W
HO BC 107	--	HARRIDAY, HERBERT H	--	525	--	X	--	6	50.50	04/28/1980	--	--	--	H	W
HO BC 108	--	HACKETT, DOROTHY	--	640	--	X	--	6	45.94	04/28/1980	--	--	--	H	W
HO BC 109	--	DARSEY, JOHN W	--	640	--	--	--	--	54.90	04/28/1980	--	--	--	H	U
HO BC 110	--	OREM, WILMA H	--	515	--	X	--	6	48.60	05/05/1980	--	--	--	H	W
HO BC 111	--	FREEMAN, CARL M	--	585	--	X	--	6	57.15	06/09/1980	--	--	--	H	W
HO BC 112	HO-73-2251	WOLBERT, JAMES W	08/15/1977	565	225.00	X	48	6	44.90	06/09/1980	4.0	08/15/1977	2.0	H	W
HO BC 113	HO-73-0786	MOYERS, JOE W	08/16/1974	590	225.00	X	54	6	60.00	08/16/1974	5.0	08/16/1974	2.0	H	W
HO BC 115	HO-73-2039	BENNETT, IRIS J	06/07/1977	590	200.00	X	31	6	35.00	06/07/1977	15	06/07/1977	1.0	H	W
HO BC 116	HO-73-1822	HUNT, DENNIS H	03/08/1977	605	200.00	X	42	6	35.00	03/08/1977	10	03/08/1977	6.0	H	W
HO BC 117	HO-73-1528	KING, DAVID T	09/14/1976	560	350.00	X	109	6	51.00	09/14/1976	2.0	09/14/1976	1.0	H	W
HO BC 118	HO-73-2350	FITZGERALD, HERBERT JR	10/08/1977	560	150.00	X	40	6	50.00	10/08/1977	15	10/08/1977	5.0	H	W
HO BC 119	HO-73-1471	MOORE, HUBERT W	07/27/1976	565	125.00	X	36	6	32.90	07/09/1980	15	07/27/1976	2.0	H	W
HO BC 120	HO-73-3523	HEIGES, ALBERT E	01/30/1980	565	285.00	X	60	6	43.54	07/09/1980	20	01/30/1980	3.0	H	W
HO BC 121	HO-73-0154	AUSTIN, GERALD D	03/31/1973	560	93.00	X	50	6	36.47	07/18/1980	10	03/31/1973	3.0	H	W
HO BC 122	HO-73-0081	FREEMAN, MICHAEL G	10/09/1972	542	200.00	X	68	6	35.84	07/11/1980	3.0	10/09/1972	2.0	H	W
HO BC 123	HO-73-0104	ANDERSON, ROBERT	12/18/1972	550	300.00	X	31	6	60.00	12/18/1972	1.0	12/18/1972	2.0	H	W
HO BC 124	HO-73-2912	S P COMMUNICATIONS	07/31/1978	700	180.00	X	25	6	30.87	06/25/1980	3.0	07/31/1978	3.0	C	W
HO BC 125	HO-73-1361	FLEISHELL, JOHN R	06/23/1976	555	105.00	X	23	6	50.70	07/02/1980	8.0	06/23/1976	2.0	H	W
HO BC 126	HO-73-0506	CLEARY, THOMAS C	10/26/1973	525	80.00	X	20	6	29.87	07/02/1980	10	10/26/1973	2.0	H	W
HO BC 127	HO-73-2094	CONLON, JANE T	06/23/1977	590	145.00	X	99	6	51.63	07/02/1980	30	06/23/1977	2.0	H	W
HO BC 128	--	SMITH, LAWRENCE C	--	560	--	X	--	6	33.36	07/02/1980	--	--	--	H	W
HO BC 129	--	AMBERS, AUGUSTUS	--	605	--	X	--	6	51.99	07/02/1980	--	--	--	H	W
HO BC 130	--	CARVER, GARY P	--	585	--	X	--	6	55.75	07/02/1980	--	--	--	H	W
HO BC 131	--	DORSEY, PAUL A	--	660	--	X	--	6	40.90	07/02/1980	--	--	--	H	W
HO BC 132	HO-73-0822	SCOTT, WESLEY W	09/26/1974	585	100.00	X	63	6	30.77	07/07/1980	25	09/26/1974	2.0	H	W
HO BC 133	HO-73-0663	HIGGINS, PATRICK J	05/01/1974	645	150.00	X	98	6	49.32	07/07/1980	10	05/01/1974	6.0	H	W
HO BC 134	HO-05-1347	LISBON METH CHURCH PAR	04/25/1963	562	103.00	X	87	6	65.00	04/25/1963	6.0	04/25/1963	0.5	H	W
HO BC 135	--	ODELL, EARL D	--	520	--	X	--	6	31.10	07/09/1980	--	--	--	H	W
HO BC 136	--	SMITH, LEROY L	--	555	--	W	--	--	2.25	07/09/1980	--	--	--	H	W
HO BC 137	--	JORDAN, DAVID C JR	--	550	--	X	--	6	31.28	07/11/1980	--	--	--	H	W
HO BC 138	HO-73-2951	ROSSER, LUTHER H	09/20/1974	500	100.00	X	30	6	22.19	07/11/1980	20	09/20/1974	2.0	H	W
HO BC 139	HO-73-3429	FICHTER, GEORGE L	09/19/1979	645	145.00	X	84	6	30.00	09/19/1979	15	09/19/1979	4.0	H	W
HO BC 140	HO-73-2703	LEBLANC, DONALD J	05/08/1978	570	225.00	X	67	6	10.80	07/17/1980	3.0	05/08/1978	8.0	H	W
HO BC 141	--	SPRINGER, STEPHEN B	--	560	--	X	--	6	36.28	07/18/1980	--	--	--	H	U

Table 7. — Drillers' logs of selected wells

(Depths are in feet below land surface)

[Drillers' logs of water wells are a valuable source of information on the lithology, depth of weathering, and occurrence of water-bearing fractures. While the terminology is often colloquial in nature, it does provide the hydrogeologist with qualitative estimates of these parameters that would be difficult to duplicate without significant levels of funding.]

	Depth
HO-AB 5	
Shale, brown.....	0 - 35
Rock, blue; water bearing.....	35 - 165
HO-AB 6	
Dirt.....	0 - 10
Sandrock.....	10 - 100
HO-AB 7	
Shale, brown.....	0 - 20
Rock, blue.....	20 - 145
HO-AB 8	
Shale, brown.....	0 - 36
Rock, blue; water bearing.....	36 - 145
HO-AB 9	
Soil.....	0 - 2
Shale.....	2 - 8
Slate, brown; water bearing.....	8 - 70
Slate, blue.....	70 - 140
HO-AB 10	
Soil.....	0 - 2
Shale.....	2 - 12
Slate, brown.....	12 - 60
Slate, blue; water bearing.....	60 - 140
HO-AB 11	
Soil.....	0 - 3
Shale.....	3 - 10
Slate, brown.....	10 - 70
Slate, blue.....	70 - 165
HO-AB 12	
Soil.....	0 - 3
Shale.....	3 - 10
Slate, brown; water bearing.....	10 - 80
Slate, blue.....	80 - 205
HO-AB 13	
Soil.....	0 - 2
Shale.....	2 - 12
HO-AB 13 (Continued)	
Slate, brown; water bearing.....	12 - 120
HO-AB 14	
Soil.....	0 - 2
Shale.....	2 - 12
Slate, brown.....	12 - 50
Slate, blue; water bearing.....	50 - 200
HO-AB 15	
Soil.....	0 - 3
Shaley.....	3 - 20
Shale.....	20 - 53
Slate, brown; water bearing.....	53 - 75
Slate, green.....	75 - 120
Slate, blue.....	120 - 165
HO-AB 16	
Shale, brown.....	0 - 62
Rock, blue; water bearing.....	62 - 300
HO-AB 17	
Dirt.....	0 - 30
Slate; water bearing.....	30 - 205
HO-AB 18	
Soil.....	0 - 3
Shaley.....	3 - 30
Shale.....	30 - 70
Slate, brown; water bearing.....	70 - 100
Slate, blue.....	100 - 160
Slate, brown; water bearing.....	160 - 165
Slate, blue.....	165 - 185
HO-AB 20	
Soil.....	0 - 3
Shaley.....	3 - 15
Slate, brown; water bearing.....	15 - 40
Shaley.....	40 - 60
HO-AB 20 (Continued)	
Slate, brown water bearing.....	60 - 80
Slate, blue.....	80 - 140
HO-AB 21	
Soil.....	0 - 3
Shaley.....	3 - 10
Slate, brown; water bearing.....	10 - 75
Slate, blue.....	75 - 180
HO-AB 22	
Soil.....	0 - 3
Shale.....	3 - 12
Slate, brown.....	12 - 65
Slate, blue.....	65 - 105
HO-AB 29	
Sand, mica.....	0 - 76
Rock, mica; water bearing.....	76 - 225
HO-AB 30	
Soil.....	0 - 3
Shaley.....	3 - 20
Shale.....	20 - 45
Slate, brown; water bearing.....	45 - 90
Slate, blue.....	90 - 145
HO-AB 31	
Shale, brown.....	0 - 45
Sand.....	45 - 89
Rock, blue; water bearing.....	89 - 260
HO-AB 32	
Shale, brown.....	0 - 51
Slate, blue; water bearing.....	51 - 170
HO-AB 33	
Soil.....	0 - 3
Shale.....	3 - 12
Slate, brown; water bearing.....	12 - 55
Slate, blue.....	55 - 105
HO-AC 2	
Soil.....	0 - 3
Shaley.....	3 - 25
Slate, brown; (water at 60 ft).....	25 - 80
Slate, blue.....	80 - 160
HO-AC 3	
Soil.....	0 - 3
Shaley.....	3 - 10
Slate, brown; water bearing.....	10 - 125
Rock, gray.....	125 - 140
HO-AC 4	
Rock, shale.....	0 - 20
Rock, gray.....	20 - 110
HO-AC 5	
Soil.....	0 - 20
Sandstone/soapstone, soft.....	20 - 84
HO-AC 6	
Soil.....	0 - 3
Sandy.....	3 - 30
Slate, brown.....	30 - 80
Slate, blue.....	80 - 140
HO-AC 7	
Soil.....	0 - 2
Shale.....	2 - 30
Slate, brown.....	30 - 50
Slate, blue; water bearing.....	50 - 125
HO-AC 8	
Sand; water bearing.....	0 - 40
Sandstone, gray.....	40 - 100
HO-AC 9	
Soil.....	0 - 3
Slate, brown; water bearing.....	3 - 80
Slate, blue; water bearing.....	80 - 100

Table 7. — Drillers' logs of selected wells, continued

	Depth
HO-AC 10	
Dirt	0 - 8
Shale, brown, soft; water bearing	8 - 50
Clay, red	50 - 58
Shale, brown	58 - 72
Schist, blue	72 - 140
Schist, brown; water bearing	140 - 143
Schist/slate, blue	143 - 260
Schist, brown; water bearing	260 - 265
Schist, blue	265 - 368
HO-AC 11	
Soil	0 - 3
Shaley	3 - 15
Slate, brown; water bearing	15 - 40
Shaley	40 - 60
Slate, brown; water bearing	60 - 80
Slate, blue	80 - 140
HO-AC 12	
Shale	0 - 15
Rock, light gray; water bearing	15 - 40
Rock, dark gray; water bearing	40 - 82
HO-AC 13	
Slate, brown	0 - 49
Rock, blue	49 - 85
HO-AC 14	
Soil	0 - 3
Earth, brown	3 - 19
Shale, brown	19 - 22
Schist, white; water bearing	22 - 140
HO-AC 15	
Soil	0 - 2
Shale, brown	2 - 23
Schist, white; water bearing	23 - 100
HO-AC 16	
Clay	0 - 5
Sand and gravel	5 - 25
Rock	25 - 57
HO-AC 17	
Soil	0 - 3
Shale	3 - 10
Slate, brown; water bearing	10 - 70
Slate, blue	70 - 105
HO-AC 18	
Soil	0 - 2
Shale	2 - 12
Slate, brown; water bearing	12 - 120
HO-AC 19	
Soil	0 - 2
Shale	2 - 8
Slate, brown; water bearing	8 - 80
Slate, blue; water bearing	80 - 120
HO-AC 20	
Soil	0 - 3
Shaley	3 - 20
Shale	20 - 60
Slate, brown; water bearing	60 - 130
Slate, blue	130 - 205
HO-AC 21	
Soil	0 - 2
Shale	2 - 8
Slate, brown; water bearing	8 - 75
Slate, blue	75 - 300
HO-AC 22	
Soil	0 - 2
Shale	2 - 12
Slate, brown; water bearing	12 - 80
Slate, blue	80 - 160

	Depth
HO-AC 23	
Soil	0 - 3
Shaley	3 - 15
Shale	15 - 60
Slate, brown; water bearing	60 - 100
Slate, blue	100 - 145
HO-AC 24	
Soil	0 - 3
Shaley	3 - 15
Shale	15 - 40
Slate, brown; water bearing	40 - 80
Slate, blue	80 - 145
HO-AC 25	
Soil	0 - 2
Shale, brown	2 - 30
Slate, brown; water bearing	30 - 40
Mica	40 - 55
Slate, brown; water bearing	55 - 60
Slate, blue	60 - 80
Slate, brown; water bearing	80 - 90
Slate, blue	90 - 120
HO-AC 26	
Soil	0 - 2
Shale	2 - 12
Slate, brown; water bearing	12 - 60
Slate, blue	60 - 140
HO-AC 27	
Soil	0 - 2
Shale	2 - 12
Slate, brown; water bearing	12 - 80
Slate, blue	80 - 140
HO-AC 28	
Soil	0 - 3
Shale	3 - 25
Slate, brown; water bearing	25 - 90
Slate, blue	90 - 165
HO-AC 29	
Soil	0 - 3
Shaley	3 - 10
Slate, brown	10 - 84
Slate, blue	84 - 98
Slate, brown; water bearing	98 - 100
Slate, blue	100 - 140
Flint; water bearing	140 - 141
Slate, blue	141 - 150
Flint; water bearing	150 - 151
Slate, blue	151 - 183
Flint; water bearing	183 - 184
Slate, blue	184 - 300
HO-AC 30	
Soil	0 - 2
Shale, brown	2 - 20
Slate, brown; water bearing	20 - 70
Slate, blue	70 - 90
Slate, brown	90 - 110
Slate, blue	110 - 130
Slate, brown; water bearing	130 - 135
Slate, blue	135 - 210
Quartz	210 - 215
Slate, blue	215 - 220
HO-AC 31	
Soil	0 - 3
Shaley	3 - 8
Slate, brown; water bearing	8 - 85
Slate, blue	85 - 97
Slate, brown; water bearing	97 - 99
Slate, blue	99 - 142
Flint; water bearing	142 - 144
Slate, blue	144 - 200
HO-AC 32	
Soil	0 - 3
Shaley	3 - 8

Table 7. — Drillers' logs of selected wells, continued

	Depth
HO-AC 32 (Continued)	
Slate, brown; water bearing	8 - 90
Slate, blue	90 - 140
HO-AC 33	
Soil	0 - 2
Shale, brown	2 - 30
Slate, brown	30 - 40
Shale, brown; water bearing	40 - 48
Slate, brown	48 - 60
Slate, blue	60 - 70
Slate, brown; water bearing	70 - 75
Slate, blue	75 - 83
Slate, brown; water bearing	83 - 87
Slate, blue	87 - 120
HO-AC 34	
Soil	0 - 3
Shaley	3 - 8
Slate, brown; water bearing	8 - 90
Slate, blue	90 - 120
HO-AC 35	
No record	0 - 4
Sandstone, gray	4 - 125
HO-AC 38	
Soil	0 - 2
Shale	2 - 28
Slate, brown	28 - 70
Slate, blue; water bearing	70 - 125
HO-AC 42	
Shale, brown	0 - 30
Rock, flint	30 - 102
HO-AC 43	
Soil	0 - 2
Sandy	2 - 46
Sandstone; water bearing	46 - 60
Mica	60 - 65
HO-AC 43 (Continued)	
Sandstone; water bearing	65 - 70
Mica	70 - 105
HO-AC 62	
Dirt	0 - 5
Shale, brown	5 - 14
Clay and sand, red	14 - 20
Shale, brown; water bearing	20 - 50
Shale, brown	50 - 78
Shale, hard, brown; water bearing	78 - 85
Rock, hard, black; water bearing	85 - 95
Rock, hard, black and brown shale; water bearing	95 - 108
Schist, hard, blue	108 - 158
HO-AC 66	
Sand, mica	0 - 34
Rock, mica; water bearing	34 - 145
HO-AC 67	
Soil	0 - 2
Shale, brown	2 - 16
Slate, brown	16 - 25
Slate, blue	25 - 30
Slate, brown	30 - 40
Slate, blue	40 - 50
Slate, brown; water bearing; (trace water)	50 - 52
Slate, blue	52 - 55
Slate, brown	55 - 57
Slate, blue	57 - 60
Slate, brown	60 - 62
Slate, blue	62 - 82
Slate, blue; water bearing; (30 gal/min)	82 - 86
Slate, blue	86 - 95
Slate, blue, flint	95 - 105
HO-AC 68	
Shale, brown	0 - 50
Granite, gray; water bearing	50 - 245
HO-AC 69	
Soil	0 - 2
Shaley	2 - 14
Slate, brown; water bearing	14 - 60
Slate, blue	60 - 100
HO-AC 70	
Soil	0 - 2
Shale, brown	2 - 20
Slate, brown; water bearing	20 - 90
Slate, blue	90 - 110
Slate, brown	110 - 112
Slate, blue	112 - 117
Slate, brown	117 - 120
Slate, blue	120 - 140
HO-AC 71	
Soil	0 - 2
Shale, brown	2 - 20
Slate, brown; water bearing	20 - 65
Slate, blue	65 - 75
Slate, brown; water bearing	75 - 85
Slate, blue	85 - 120
HO-AC 72	
Soil	0 - 3
Shaley	3 - 25
Shale	25 - 60
Slate, brown; water bearing	60 - 145
Slate, blue	145 - 210
Slate, gray	210 - 235
Slate, blue	235 - 305
HO-AC 74	
Soil	0 - 3
Shaley	3 - 8
Slate, brown	8 - 110
Slate, blue	110 - 143
Flint	143 - 145
Slate, blue	145 - 200
HO-AC 76	
Soil	0 - 2
Shale, brown	2 - 30
Slate, brown; water bearing	30 - 80
Slate, blue	80 - 90
Slate, brown	90 - 92
Slate, blue	92 - 103
Slate, brown	103 - 110
Slate, blue	110 - 205
Quartz	205 - 208
Slate, blue	208 - 300
HO-AC 77	
Soil	0 - 2
Shale, brown	2 - 25
Slate, brown	25 - 40
Slate, blue	40 - 70
Slate, brown	70 - 75
Slate, blue	75 - 145
HO-BB 3	
Shale, soft, brown	0 - 95
Slate, green; water bearing	95 - 170
HO-BB 4	
Sand; water bearing	0 - 65
Sandstone, gray	65 - 125
HO-BB 5	
Shale, brown	0 - 76
Rock, blue; water bearing	76 - 185
HO-BB 6	
Soil	0 - 3
Shaley	3 - 15
Slate, brown; water bearing	15 - 80
Granite	80 - 120
HO-BB 7	
Soil	0 - 2
Shaley	2 - 26
Slate, brown; water bearing	26 - 84
Slate, blue	84 - 140

Table 7. — Drillers' logs of selected wells, continued

	Depth
HO-BB 8	
Shale, brown; water bearing	3 - 150
HO-BB 9	
Shale, brown	0 - 72
Rock, blue	72 - 180
HO-BB 10	
Soil, top	0 - 3
Shaley	3 - 30
Slate, brown; water bearing	30 - 85
Slate, blue	85 - 200
HO-BB 11	
Clay	0 - 4
Sand, gravel	4 - 22
Rock, shale	22 - 56
Rock, blue, slate	56 - 92
HO-BB 12	
Shale, brown	0 - 65
Rock, blue; water bearing	65 - 340
HO-BB 13	
Soil	0 - 3
Slate, brown; water bearing	3 - 100
Slate, blue	100 - 200
HO-BB 14	
Soil	0 - 3
Shaley	3 - 20
Slate, brown; water bearing	20 - 100
Slate, blue; water bearing	100 - 300
HO-BB 15	
Soil	0 - 4
Slate, blue; water bearing	4 - 150
HO-BB 16	
No record	0 - 3
Slate, green	3 - 150
HO-BB 17	
Soil	0 - 3
Shaley; water bearing	3 - 60
Slate, blue	60 - 100
HO-BB 18	
Soil	0 - 3
Shale	3 - 12
Slate, brown; water bearing	12 - 80
Slate, blue	80 - 125
HO-BB 19	
Soil	0 - 3
Slate, brown	3 - 20
Rock, gray; water bearing	20 - 100
HO-BB 20	
Soil	0 - 3
Slate, brown; water bearing	3 - 130
Slate, blue	130 - 160
HO-BB 21	
Soil	0 - 3
Slate, brown; water bearing	3 - 80
Slate, blue	80 - 220
Slate, brown; water bearing	220 - 225
Slate, blue	225 - 350
HO-BB 22	
Soil	0 - 2
Shaley	2 - 30
Slate, brown	30 - 90
Slate, blue	90 - 207
HO-BB 23	
Soil	0 - 3
Slate, brown; water bearing	3 - 60
Slate, blue	60 - 160
HO-BB 24	
Soil	0 - 3
Sandy	3 - 40
Slate, brown; water bearing	40 - 90
Slate, blue	90 - 160
HO-BB 25	
Soil, mica	0 - 30
Rock, mica; water bearing	30 - 175
HO-BB 26	
Soil	0 - 3
Shaley	3 - 15
Slate, brown; water bearing	15 - 65
Slate, blue	65 - 210
Slate, brown; water bearing	210 - 220
Slate, blue	220 - 300
HO-BB 27	
Soil	0 - 2
Shaley	2 - 30
Slate, brown	30 - 40
Slate, blue; water bearing	40 - 145
HO-BB 28	
Soil	0 - 2
Shale	2 - 10
Slate, brown	10 - 45
Bed, gravel	45 - 46
Slate, blue	46 - 55
Slate, brown; water bearing	55 - 59
Slate, blue	59 - 75
Slate, brown; water bearing	75 - 78
Slate, blue	78 - 100
HO-BB 31	
Slate, brown	0 - 47
Rock, blue; water bearing	47 - 265
HO-BB 32	
Soil	0 - 3
Shale	3 - 10
Slate, brown; water bearing	10 - 70
Slate, green	70 - 100
Slate, blue	100 - 145
HO-BB 36	
Dirt	0 - 15
Slate, water bearing	15 - 235
HO-BB 39	
Shale, brown	0 - 45
Rock, blue	45 - 185
HO-BB 43	
Soil	0 - 2
Shale	2 - 8
Slate, brown	8 - 40
Slate, blue; water bearing	40 - 185
HO-BB 44	
Soil	0 - 2
Shaley	2 - 8
Shale	8 - 12
Slate, brown	12 - 16
Slate, blue	16 - 70
Slate, brown; water bearing	70 - 85
Slate, blue	85 - 125
HO-BB 46	
Soil, mica	0 - 30
Rock, mica; water bearing	30 - 175
HO-BC 16	
Overburden	0 - 8
Shale, brown	8 - 39
Rock, gray; water bearing	39 - 125
HO-BC 17	
Sand	0 - 58
Granite, gray	58 - 140

Table 7. — Drillers' logs of selected wells, continued

	Depth
HO-BC 18	
Rock, shale	0 - 21
Rock, flint	21 - 80
HO-BC 19	
Soil	0 - 3
Sandy	3 - 85
Slate, brown; water bearing	85 - 100
Mica	100 - 125
HO-BC 20	
Soil	0 - 3
Slate, brown; water bearing	3 - 90
Rock, mica	90 - 120
HO-BC 21	
Soil	0 - 2
Shaley	2 - 38
Slate, brown; water bearing	38 - 140
HO-BC 22	
Mica, sand, clay; water bearing	0 - 59
Rock, gray; water bearing	59 - 140
HO-BC 23	
Sand	0 - 63
Rock, gray	63 - 140
HO-BC 24	
Soil	0 - 2
Shaley	2 - 35
Slate, brown; water bearing	35 - 120
Slate, blue	120 - 160
HO-BC 25	
Clay	0 - 20
Soil, mica	20 - 40
Rock, shale	40 - 70
Rock, mica; water bearing	70 - 200
HO-BC 26	
Soil	0 - 2
Shaley	2 - 35
Slate, brown; water bearing	35 - 90
Slate, blue	90 - 120
HO-BC 27	
Soil	0 - 2
Shaley	2 - 30
Slate, brown; water bearing	30 - 120
Slate, blue	120 - 180
HO-BC 28	
Soil	0 - 3
Sandy, shaley; water bearing	3 - 120
Rock, gray	120 - 160
HO-BC 29	
Sand	0 - 25
Sandstone	25 - 125
HO-BC 30	
Sand	0 - 35
Rock, gray	
HO-BC 31	
Mica, brown	0 - 12
Clay	12 - 17
Mica, brown	17 - 63
Mica, soft, brown; water bearing	63 - 66
Mica, soft, brown; water bearing	66 - 99
Mica, hard, brown	99 - 114
Slate, blue	114 - 120
Mica, brown; water bearing	120 - 121
Slate, blue	121 - 340
HO-BC 32	
Sand	0 - 69
Granite, gray	69 - 205
HO-BC 33	
Sand	0 - 35
Rock, blue; water bearing	35 - 90
HO-BC 34	
Sand	0 - 26
Granite, gray	26 - 105
HO-BC 35	
Sand	0 - 78
Rock, mica	78 - 245
HO-BC 36	
Clay	0 - 30
Sand, mica	30 - 40
Rock, mica; water bearing	40 - 150
HO-BC 37	
Shale, brown	0 - 80
Rock, blue; water bearing	80 - 185
HO-BC 40	
Soil	0 - 2
Shaley	2 - 40
Slate, brown	40 - 70
Slate, blue; water bearing	70 - 225
HO-BC 41	
Sand, mica	0 - 36
Rock, mica; water bearing	36 - 150
HO-BC 42	
Sand, mica	0 - 35
Rock, mica; water bearing	35 - 150
HO-BC 43	
Clay	0 - 20
Sand, mica	20 - 40
Rock, mica; water bearing	40 - 125
HO-BC 44	
Soil	0 - 2
Shaley	2 - 50
Shale	50 - 60
Slate, brown	60 - 80
Slate, blue; water bearing	80 - 165
HO-BC 45	
Clay	0 - 30
Rock, mica; water bearing	30 - 150
HO-BC 46	
Clay	0 - 20
Boulders	20 - 43
Rock, mica; water bearing	43 - 150
HO-BC 47	
Shale, brown	0 - 68
Rock, blue	68 - 300
HO-BC 48	
Dirt	0 - 5
Shale, soft, red; water bearing	5 - 95
Shale, hard, brown	95 - 108
Quartz; water bearing	108 - 109
Mica, blue	109 - 220
Quartz; water bearing	220 - 221
Mica, hard, blue	221 - 340
HO-BC 49	
Soil	0 - 3
Sandy	3 - 90
Rock, gray; water bearing	90 - 180
HO-BC 50	
Soil	0 - 3
Shaley	3 - 20
Shale	20 - 45
Slate, brown; water bearing	45 - 70
Slate, blue	70 - 105

Table 7. — Drillers' logs of selected wells, continued

	Depth
HO-BC 51	
Soil	0 - 3
Shale	3 - 15
Slate, brown; water bearing	15 - 115
Slate, blue	115 - 120
HO-BC 52	
Shale	0 - 21
Rock, gray	21 - 82
HO-BC 53	
Soil	0 - 8
Shale, brown	8 - 52
Rock, gray; water bearing	52 - 125
HO-BC 54	
Shale, brown	0 - 21
Rock, blue	21 - 85
HO-BC 55	
Soil	0 - 3
Slate, brown; water bearing	3 - 100
HO-BC 56	
Soil	0 - 3
Shaley	3 - 10
Slate, brown; water bearing	10 - 85
Rock, gray	85 - 100
HO-BC 57	
Sand	0 - 60
Sandstone, gray	60 - 200
HO-BC 58	
Soil	0 - 3
Slate, brown; water bearing	3 - 100
HO-BC 59	
Clay, shale	0 - 40
Rock, gray	40 - 77
HO-BC 60	
Clay, yellow	0 - 26
Granite, gray	26 - 120
HO-BC 61	
Soil	0 - 3
Slate	3 - 30
Shaley	30 - 60
Slate, brown	60 - 70
Granite; water bearing	70 - 200
HO-BC 62	
Soil	0 - 3
Sandy, shaley	3 - 125
Slate, blue; water bearing	125 - 200
HO-BC 63	
Sandstone, gray; water bearing	3 - 75
HO-BC 64	
Soil	0 - 2
Shale	2 - 18
Slate, brown; water bearing	18 - 80
Slate, blue	80 - 125
HO-BC 65	
Soil	0 - 3
Shaley	3 - 20
Slate, brown; water bearing	20 - 80
Slate, blue	80 - 120
HO-BC 66	
Sand; water bearing	0 - 60
Sandstone, brown	60 - 140
HO-BC 71	
Dirt	0 - 5
Shale/schist, soft, brown	5 - 36
Schist, blue	36 - 42
Schist, soft, brown	42 - 80
Schist, hard, black	80 - 91
Schist, brown; water bearing	91 - 94
Schist, black	94 - 118
HO-BC 71 (Continued)	
Schist, brown	118 - 119
Schist, black	119 - 130
Quartz	130 - 131
Granite, black	131 - 163
Sandstone; water bearing	163 - 164
Granite	164 - 277
HO-BC 73	
Shale, brown	0 - 38
Sandstone, brown	38 - 120
Slate, green; water bearing	120 - 200
HO-BC 75	
Soil	0 - 2
Shale	2 - 10
Slate, brown	10 - 45
Granite	45 - 50
Slate, brown; water bearing	50 - 80
Granite; water bearing	80 - 160
HO-BC 77	
No record	0 - 4
Sandstone, gray; water bearing	4 - 140
HO-BC 79	
No record	0 - 4
Granite, gray; water bearing	4 - 140
HO-BC 80	
Soil	0 - 2
Shale, brown	2 - 4
Clay, brown	4 - 25
Slate, brown	25 - 52
Clay, brown	52 - 55
Bed, gravel; water bearing	55 - 57
Clay, brown	57 - 60
Bed, gravel; water bearing	60 - 65
Clay, brown	65 - 74
HO-BC 80 (Continued)	
Bed, gravel; water bearing	74 - 76
Clay, brown	76 - 95
Bed, gravel; water bearing	95 - 100
Sandstone, gray	100 - 123
Sandstone, brown; water bearing	123 - 125
Sandstone, gray	125 - 140
Slate, blue	140 - 265
HO-BC 81	
Soil	0 - 3
Shaley	3 - 20
Shale	20 - 40
Slate, brown; water bearing	40 - 85
HO-BC 82	
Soil	0 - 3
Shaley	3 - 15
Slate, brown; water bearing	15 - 80
Rock, gray; water bearing	80 - 100
HO-BC 88	
Sand	0 - 32
Granite, gray	32 - 105
HO-BC 90	
Shale, brown	0 - 35
Granite, gray; water bearing	35 - 200
HO-BC 91	
Shale, brown	0 - 67
Rock, blue; water bearing	67 - 145
HO-BC 92	
Soil	0 - 2
Sandy	2 - 55
Sandstone; water bearing	55 - 70
Mica	70 - 80

Table 7. — Drillers' logs of selected wells, continued

	Depth
HO-BC 92 (Continued)	
Sandstone;	
water bearing.....	80 - 85
Mica.....	85 - 185
HO-BC 94	
Soil.....	0 - 2
Sandy;	
water bearing.....	2 - 89
Sandstone.....	89 - 93
Mica.....	93 - 100
Sandstone;	
water bearing.....	100 - 110
Mica.....	110 - 185
HO-BC 95	
Soil.....	0 - 2
Sandy;	
water bearing.....	2 - 92
Sandstone.....	92 - 100
Mica.....	100 - 105
Sandstone;	
water bearing.....	105 - 107
Mica.....	107 - 145
HO-BC 101	
Shale, brown.....	0 - 27
Rock, blue;	
water bearing.....	27 - 265
HO-BC 112	
Shale, brown.....	0 - 40
Rock, blue;	
water bearing.....	40 - 225
HO-BC 113	
Sand.....	0 - 52
Rock, mica;	
water bearing.....	52 - 225
HO-BC 115	
No record.....	0 - 4
Sandstone, gray;	
water bearing.....	4 - 200
HO-BC 116	
Soil, mica.....	0 - 40
HO-BC 116 (Continued)	
Rock, mica;	
water bearing.....	40 - 200
HO-BC 117	
Shale, brown.....	0 - 105
Slate, blue;	
water bearing.....	105 - 350
HO-BC 118	
Clay.....	0 - 3
Shale, brown.....	3 - 33
Slate, blue;	
water bearing.....	33 - 150
HO-BC 119	
Soil.....	0 - 2
Shale.....	2 - 20
Slate, brown.....	20 - 50
Slate, blue;	
water bearing.....	50 - 125
HO-BC 120	
Dirt.....	0 - 4
Slate;	
water bearing.....	4 - 285
HO-BC 121	
Shale, soft.....	0 - 40
Rock, light brown, soft; water bearing.....	40 - 70
Rock, light gray;	
water bearing.....	70 - 93
HO-BC 122	
Soil.....	0 - 2
Mud and sand.....	2 - 65
Rock, gray;	
water bearing.....	65 - 160
Mica.....	160 - 200
HO-BC 123	
Soil.....	0 - 2
Shaley.....	2 - 27
Slate, brown;	
water bearing.....	27 - 80
Slate, blue.....	80 - 300
HO-BC 124	
Soil.....	0 - 2
Clay.....	2 - 5
Sandstone;	
water bearing.....	5 - 35
Mica.....	35 - 180
HO-BC 125	
Shale, brown.....	0 - 20
Rock, blue;	
water bearing.....	20 - 105
HO-BC 126	
Rock, shale.....	0 - 20
Rock, flint.....	20 - 80
HO-BC 127	
Soil.....	0 - 3
Shaley.....	3 - 35
Shale.....	35 - 60
Sand.....	60 - 80
Slate, brown;	
water bearing.....	80 - 110
Slate, blue.....	110 - 145
HO-BC 132	
Soil.....	0 - 2
Shaley.....	2 - 10
Slate, brown;	
water bearing.....	10 - 100
HO-BC 133	
Clay;	
water bearing.....	0 - 100
Rock, hard, mica....	100 - 150
HO-BC 134	
Clay.....	0 - 89
Rock, gray.....	89 - 103
HO-BC 138	
Soil.....	0 - 2
Shaley.....	2 - 15
Slate, brown;	
water bearing.....	15 - 33
Slate, blue.....	33 - 38
Flint;	
water bearing.....	38 - 39
HO-BC 138 (Continued)	
Slate, blue.....	39 - 45
Slate, brown;	
water bearing.....	45 - 55
Slate, blue.....	55 - 100
HO-BC 139	
Soil.....	0 - 2
Sandy;	
water bearing.....	2 - 74
Sandstone.....	74 - 80
Mica.....	80 - 90
Sandstone;	
water bearing.....	90 - 95
Mica.....	95 - 145
HO-BC 140	
Soil, top.....	0 - 2
Shale, brown;	
water bearing.....	2 - 57
Slate, brown.....	57 - 70
Slate, blue.....	70 - 80
Slate, brown;	
water bearing.....	80 - 84
Slate, blue.....	84 - 225

Table 8. — Water levels in observation wells

HO AB 4. Unused domestic well in bedrock. Highest water level 6.50 ft below lsd (land surface datum). April 1,1980; lowest 16.14 ft below lsd, October 24,1977.

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
MAY 13, 1977	12.63	OCT 13, 1977	16.03	AUG 09, 1978	12.02	JAN 04, 1980	11.80
20	12.96	24	16.14	SEP 08	12.62	MAR 04	12.82
26	13.16	NOV 23	15.66	OCT 03	13.31	APR 01	6.50
JUN 14	13.64	DEC 12	14.35	27	13.86	MAY 01	11.64
JUL 01	14.02	28	10.73	DEC 05	14.34	JUN 02	10.99
07	14.19	JAN 11, 1978	11.10	JAN 19, 1979	11.54	30	11.57
14	14.35	FEB 23	10.72	MAR 06	8.35	JUL 28	12.50
22	14.55	MAR 31	9.40	23	10.09	AUG 27	14.20
27	14.87	APR 21	10.50	MAY 02	10.89	OCT 20	14.75
AUG 02	14.92	MAY 11	11.18	18	11.38	NOV 21	15.25
23	15.12	26	10.29	JUN 06	10.98	DEC 19	15.60
29	15.33	JUN 09	10.69	JUL 26	12.40	MAR 03, 1981	13.91
SEP 08	15.43	14	11.03	OCT 23	7.50		
21	15.68	JUL 17	11.40	NOV 15	9.72		

HO BB 26. Unused domestic well drilled in bedrock. Highest water level 11.46 ft below lsd, October 16,1979; lowest 42.46 ft below lsd, March 3,1981. Records are for the mean daily water level taken from a continuous recorder. Water levels may be affected by neaby pumping and changes in atmospheric pressure.

WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	---	36.40	37.59	34.91		---	24.83	27.29	30.14	30.27	33.50	35.42
2	---	36.46	37.61	34.03		---	24.90	27.45	30.10	30.43	33.56	35.44
3	---	36.51	37.63	31.53		---	25.11	27.43	29.97	30.62	33.69	35.46
4	---	36.53	37.59	30.55		---	25.10	27.49	29.79	---	33.81	35.55
5	---	36.58	37.62	30.13		---	25.15	27.72	29.49	---	33.87	35.60
6	---	36.64	37.70	29.84		---	25.27	27.86	29.22	---	33.91	33.73
7	---	36.68	37.70	29.65		---	25.50	28.02	28.97	---	34.00	28.53
8	---	36.76	37.66	29.48		---	25.41	28.15	28.77	---	34.06	28.07
9	---	36.81	37.62	28.86		---	25.15	28.25	28.59	---	34.18	28.34
10	---	36.87	37.67	28.47		---	25.65	28.32	28.47	---	34.20	28.48
11	---	36.92	37.66	28.49		---	25.77	28.45	28.42	---	34.24	28.54
12	---	36.96	37.59	28.39		---	25.57	28.60	28.60	---	34.34	28.78
13	---	37.01	37.48	28.11		---	25.53	28.69	28.80	---	34.45	28.99
14	---	37.02	37.41	28.17		---	25.37	28.89	28.93	---	34.50	29.00
15	---	37.07	37.32	28.97		---	25.34	29.05	28.95	---	34.54	29.15
16	---	37.13	37.24	29.05		---	25.49	29.22	28.93	---	34.62	29.60
17	---	37.15	37.17	28.95		---	25.63	29.37	28.90	---	34.68	29.83
18	---	37.17	37.12	29.13		---	25.71	29.35	29.01	---	34.67	29.89
19	---	37.24	37.08	29.45		---	25.80	29.38	29.27	---	34.70	29.87
20	---	37.29	37.01	---		---	25.94	29.47	29.44	---	34.79	30.12
21	---	37.31	36.93	---		---	26.03	29.55	29.44	---	34.85	30.30
22	---	37.34	37.03	---		---	26.14	29.73	29.39	---	34.91	30.25
23	36.04	37.34	37.04	---		24.52	26.29	29.78	29.49	---	34.96	30.10
24	36.12	37.33	36.93	---		24.42	26.39	29.73	29.67	---	34.98	29.39
25	36.13	37.41	36.82	---		24.58	26.43	29.73	29.88	---	35.03	28.39
26	36.13	37.46	36.76	---		24.71	26.39	29.82	30.07	32.95	35.13	27.92
27	36.22	37.47	36.58	---		24.84	26.45	29.91	30.12	33.06	35.15	27.82
28	36.27	37.50	36.33	---		24.85	26.78	29.90	30.10	33.17	35.19	27.85
29	36.33	37.54	35.98	---		24.66	27.01	29.92	30.14	33.24	35.23	27.81
30	36.41	37.55	35.61	---		24.70	27.11	30.03	30.18	33.34	35.28	27.92
31	36.39	---	25.27	---		24.70	---	30.14	---	33.43	35.35	---

Table 8. — Water levels in observation wells, continued

HO BB 26 (Continued)

WATER YEAR OCTOBER 1979 TO SEPTEMBER 1980

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	28.04	---	30.86	---	33.76	35.11	29.09	28.22	28.15	31.70	34.88	36.92
2	25.77	---	31.04	---	33.83	35.06	27.93	28.07	28.19	31.78	34.96	36.97
3	23.93	---	31.23	---	33.86	35.12	27.48	27.84	28.27	31.86	35.04	37.03
4	23.95	---	31.11	33.90	33.88	35.17	26.93	27.62	28.45	32.00	35.15	37.08
5	23.82	---	31.16	33.86	33.91	35.18	27.14	27.38	28.62	32.04	35.26	37.13
6	23.59	---	31.20	34.05	33.89	35.33	27.36	27.21	28.66	32.20	35.36	37.16
7	23.49	---	31.39	34.03	33.93	35.35	27.46	27.19	28.65	32.40	35.43	37.21
8	23.30	---	31.68	34.20	34.04	35.27	27.47	27.17	28.70	32.43	35.46	37.27
9	23.46	---	31.89	34.29	33.97	35.38	27.32	27.21	28.88	32.59	35.51	37.31
10	23.44	---	31.89	34.40	33.93	35.39	27.42	27.27	29.01	32.65	35.60	37.35
11	23.24	---	31.98	34.28	34.00	35.45	27.50	27.24	29.31	32.76	35.66	37.41
12	21.65	---	32.06	34.40	34.11	35.59	27.34	27.32	29.47	32.88	35.73	37.46
13	19.94	---	32.14	34.50	34.23	35.55	27.32	27.32	29.52	33.04	35.82	37.49
14	19.55	---	32.34	34.38	34.22	35.49	27.14	27.48	29.49	33.18	35.87	37.51
15	19.49	---	32.50	34.44	34.20	35.50	27.12	27.74	29.52	33.25	36.03	37.54
16	19.46	28.62	32.42	34.48	34.07	35.26	27.40	27.91	29.73	33.31	36.18	37.59
17	19.55	28.78	32.58	34.47	34.30	34.80	27.58	28.00	29.93	33.40	36.28	37.62
18	19.81	28.97	32.73	34.42	34.43	34.51	27.48	27.92	29.98	33.55	36.31	37.66
19	20.15	29.23	32.77	34.41	34.45	34.27	27.52	27.97	30.05	33.68	36.34	37.68
20	20.49	29.41	32.99	34.28	34.41	33.83	27.48	28.10	30.15	33.77	36.37	37.70
21	20.82	29.59	33.08	34.08	34.49	33.26	27.53	28.21	30.36	33.88	36.41	37.72
22	21.20	29.66	33.07	33.83	34.52	32.77	27.56	28.25	30.48	33.96	36.46	37.74
23	21.91	29.79	33.10	33.65	34.58	31.96	27.53	28.11	30.61	34.03	36.53	37.77
24	22.19	29.96	---	33.63	34.67	31.06	27.72	27.95	30.76	34.15	36.58	37.80
25	---	30.08	---	33.59	34.68	30.74	27.89	27.83	30.93	34.27	36.61	37.81
26	---	30.01	---	33.74	34.77	30.75	28.07	27.92	30.99	34.35	36.65	37.84
27	---	30.39	---	33.72	34.80	30.74	28.05	27.96	31.09	34.45	36.70	37.86
28	---	30.36	---	33.71	34.85	30.68	28.08	27.97	31.22	34.53	36.73	37.88
29	---	30.53	---	33.75	35.01	30.46	28.19	28.00	31.27	34.60	36.78	37.90
30	---	30.73	---	33.79	---	30.25	28.24	28.09	31.44	34.71	36.82	37.91
31	---	---	---	33.72	---	29.90	---	28.11	---	34.82	36.86	---

WATER YEAR OCTOBER 1980 TO SEPTEMBER 1981

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	37.93	38.56	39.10	---		---		---	37.15
2	37.94	38.58	39.11	---		---		---	37.13
3	37.96	38.60	39.14	---		42.46		---	37.09
4	37.98	38.62	39.14	---		42.44		---	37.06
5	38.02	38.63	39.15	---		42.34		---	37.06
6	38.04	38.65	39.15	---		41.86		---	36.95
7	38.06	38.67	39.16	39.75		40.42		---	36.95
8	38.07	38.70	39.16	---		39.31		---	36.93
9	38.09	38.72	39.18	---		39.16		---	36.80
10	38.12	38.75	39.21	---		39.02		---	36.81
11	38.13	38.77	39.22	---		38.82		---	36.87
12	38.15	---	39.23	---		38.64		---	36.87
13	38.18	---	39.24	---		38.58		---	36.81
14	38.20	---	39.26	---		38.50		---	36.77
15	38.23	---	39.27	---		38.40		---	36.74
16	38.25	---	39.27	39.93		38.35		---	36.66
17	38.27	---	39.29	---		---		---	36.58
18	38.29	---	39.30	---		---		---	36.56
19	38.31	---	39.33	---		---		---	---
20	38.33	---	39.34	---		---		37.08	---
21	38.35	39.01	---	40.42		---		37.06	---
22	38.38	39.01	---	40.48		---		37.04	---
23	38.40	39.01	---	40.56		---		37.08	---
24	38.41	39.02	---	40.66		---		37.07	---
25	38.40	39.03	---	40.74		---		37.06	---
26	38.43	39.05	---	40.82		---		37.05	---
27	38.45	39.05	---	40.90		---		37.05	---
28	38.47	39.05	---	40.98		---		36.98	---
29	38.50	39.06	---	---		---		37.00	---
30	38.52	39.09	---	---		---		37.02	---
31	38.54	---	---	---		---		37.05	---

Table 8. — Water levels in observation wells, continued

HO BC 38. Unused domestic well in bedrock. Highest water level 18.14 below lsd, January 4,1980; lowest 28.24 ft below lsd, January 7,1981. Water levels affected by nearby pumping.

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
MAR 03, 1977	26.38	JUL 27, 1977	26.75	MAY 26, 1978	23.34	JUL 26, 1979	24.26
10	26.38	AUG 02	27.07	JUN 09	23.70	OCT 23	22.40
25	25.62	23	27.01	14	23.80	NOV 15	22.81
APR 11	24.90	29	27.08	JUL 17	23.60	JAN 04, 1980	18.14
26	25.28	SEP 08	27.74	AUG 09	23.21	MAR 04	25.08
MAY 03	25.36	21	27.70	SEP 08	24.15	APR 01	23.70
09	25.45	OCT 13	27.59	OCT 03	24.76	MAY 01	25.67
13	25.39	24	27.54	27	25.65	JUN 02	26.88
20	24.82	NOV 23	26.50	DEC 05	25.37	30	24.41
26	26.01	DEC 12	26.20	JAN 19, 1979	24.16	JUL 28	26.27
JUN 14	26.23	28	24.54	MAR 06	23.24	AUG 27	27.40
JUL 01	26.50	FEB 23, 1978	24.45	23	23.20	OCT 20	27.60
07	26.62	MAR 31	23.12	MAY 02	23.33	NOV 21	27.53
14	26.84	APR 21	23.17	18	23.53	JAN 07, 1981	28.24
22	26.75	MAY 11	23.91	JUN 06	22.89	MAR 03	27.07

MARYLAND GEOLOGICAL SURVEY
2300 St. Paul Street
Baltimore, Maryland 21218

Selected Reports of Investigations:

3. Water resources of the Salisbury area, Maryland, by D.H. Boggess and S.G. Heidel, 1968, 69 p. 3.00
5. Chemical quality reconnaissance of water of Maryland streams, by J.D. Thomas, 1966, 61 p. 2.00
6. Revision of stratigraphic nomenclature—Glenarm Series of the Appalachian Piedmont, by D.L. Southwick and G.W. Fisher, 1967, 19 p. 1.50
9. Chemical and physical character of municipal water supplies in Maryland, by J.D. Thomas and S.G. Heidel, 1969, 52 p. 1.00
10. Ground-water occurrence in the Maryland Piedmont, by L.J. Nutter and E.G. Otton, 1969, 56 p. 2.50
13. Extent of brackish water in the tidal rivers of Maryland, by W.E. Webb and S.G. Heidel, 1970, 46 p. 1.50
14. Geologic and hydrologic factors bearing on subsurface storage of liquid wastes in Maryland, by E.G. Otton, 1970, 39 p. 2.75
17. Water resources of Dorchester and Talbot Counties, Maryland: With special emphasis on the ground-water potential of the Cambridge and Easton areas, by F.K. Mack, W.E. Webb, and R.A. Gardner, 1971, 107 p. 5.25
18. Solid-waste disposal in the geohydrologic environment of Maryland, by E.G. Otton, 1972, 59 p. 3.00
19. Hydrogeology of the carbonate rocks, Frederick and Hagerstown Valleys, Maryland, by L.J. Nutter, 1973, 70 p. 3.50
20. Hydrogeology of the formation and neutralization of acid waters draining from underground mines of western Maryland, by E.F. Hollyday and S.W. McKenzie, 1973, 50 p. 2.25
23. Stratigraphy, sedimentology, and Cambro-Ordovician paleogeography of the Frederick Valley, Maryland, by J. Reinhardt, 1974, 74 p. . . . . *
25. Petrologic and chemical investigation of chemical weathering in mafic rocks, eastern Piedmont of Maryland, by E.T. Cleaves, 1974, 28 p. 2.25
26. Hydrogeology of the Triassic rocks of Maryland, by L.J. Nutter, 1975, 37 p. 2.50
27. The geology of the crystalline rocks near Baltimore bearing on the evolution of the eastern Maryland Piedmont, by W.P. Crowley, 1976, 40 p. . . . . *
28. Digital simulation and prediction of water levels in the Magothy aquifer in Southern Maryland, by F.K. Mack and R.J. Mandle, 1977, 42 p. 3.00
31. Simulated changes in water level in the Piney Point aquifer in Maryland, by J.F. Williams III, 1979, 50 p. 6.25
32. Geological interpretations of aeromagnetic maps of the crystalline rocks of the central Appalachians, northern Virginia to New Jersey, by G.W. Fisher, M.W. Higgins, and I. Zietz, 1979, 43 p. 6.25
33. A quasi three-dimensional finite-difference ground-water flow model with a field application, by G. Achmad and J.M. Weigle, 1979, 22 p. with appendix 6.50
34. The availability of ground water in western Montgomery County, Maryland, by E.G. Otton, 1981, 76 p. 5.75
35. Characteristics of streamflow in Maryland, by D.H. Carpenter, 1983, 238 p. 12.50
37. Geohydrology of the fresh-water aquifer system in the vicinity of Ocean City, Maryland, with a section on simulated water-level changes, by J.M. Weigle and G. Achmad, 1982, 56 p. 10.00
38. Hydrogeology, digital simulation, and geochemistry of the Aquia and Piney Point-Nanjemoy aquifer system in Southern Maryland, by F.H. Chapelle and D.D. Drummond, 1982, 100 p. 14.50
41. First report on the hydrologic effects of underground coal mining in southern Garrett County, Maryland, by M.T. Duigon and M.J. Smigaj, 1985, 99 p 6.75
43. Hydrogeology, digital solute-transport simulation, and geochemistry of the Lower Cretaceous aquifer system near Baltimore, Maryland, by F.H. Chapelle, 1985, 120 p. 13.50
45. Simulation of ground-water flow and base flow in weathered crystalline rock, upper Cattail Creek, Howard County, Maryland, by R.E. Willey and G. Achmad, 1986, 68 p. 8.50

---

* out-of-print

05/28/86—43241

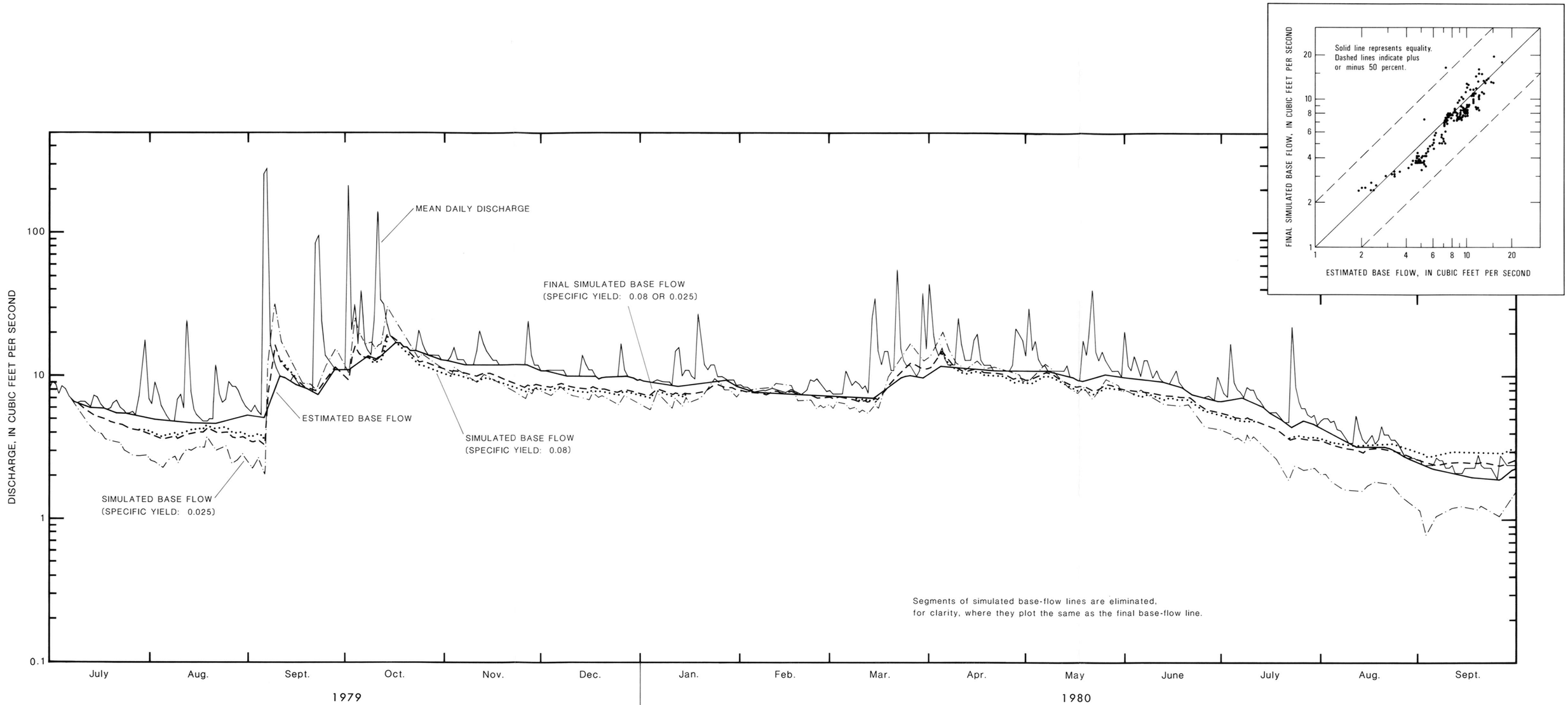


Figure 25. — Simulated base flows of Cattail Creek compared with estimated base flows at streamflow site 11, July 1979 to September 1980.

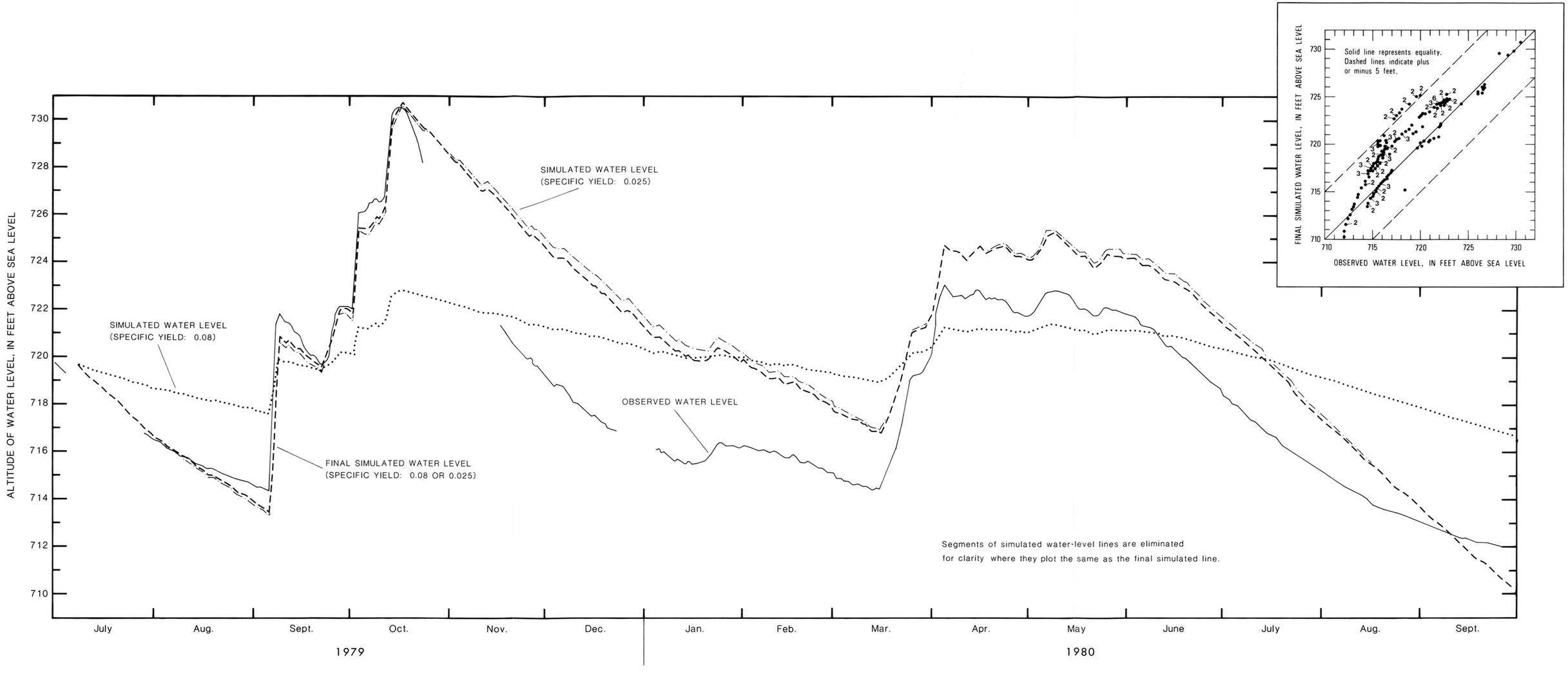


Figure 26. — Simulated water levels, cell B, compared with observed water levels for well HO-BB 26, July 1979 to September 1980.

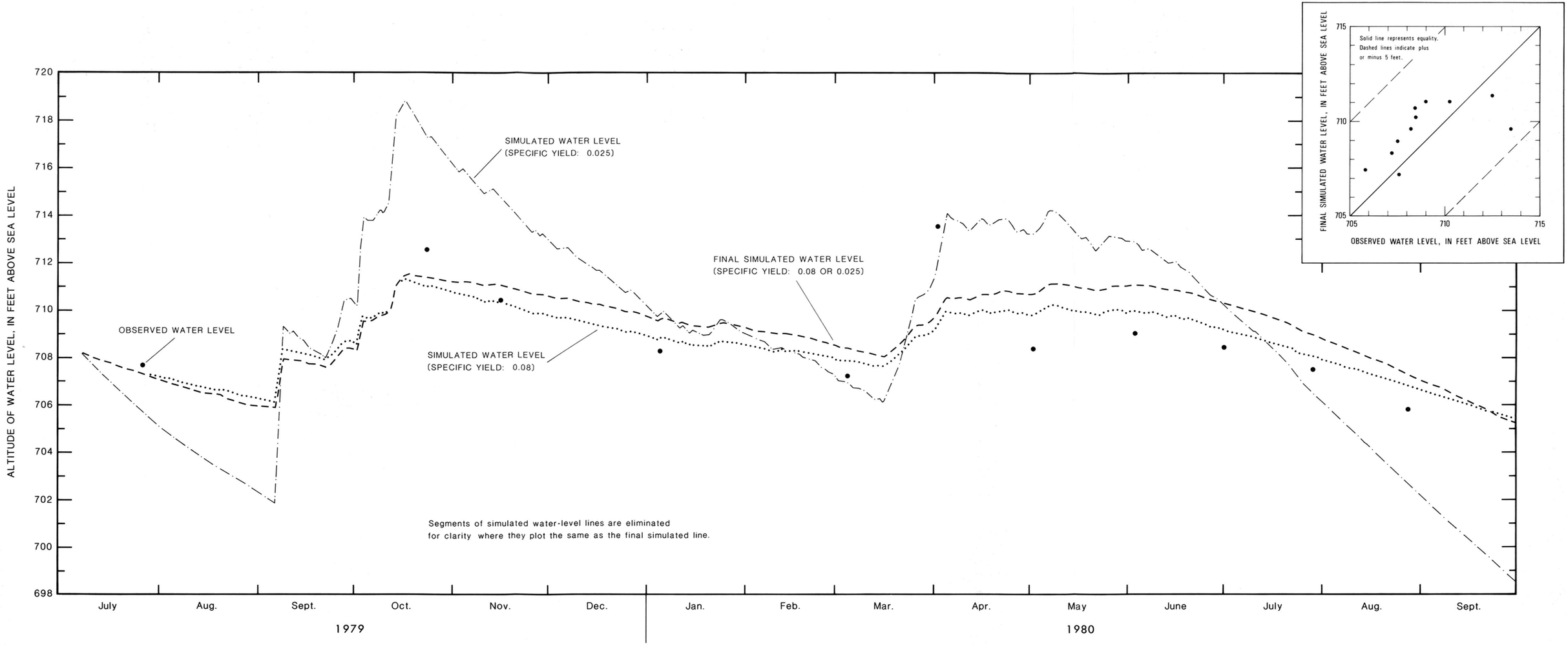


Figure 27. — Simulated water levels, cell A, compared with observed water levels for well HO-AB 4, July 1979 to September 1980.

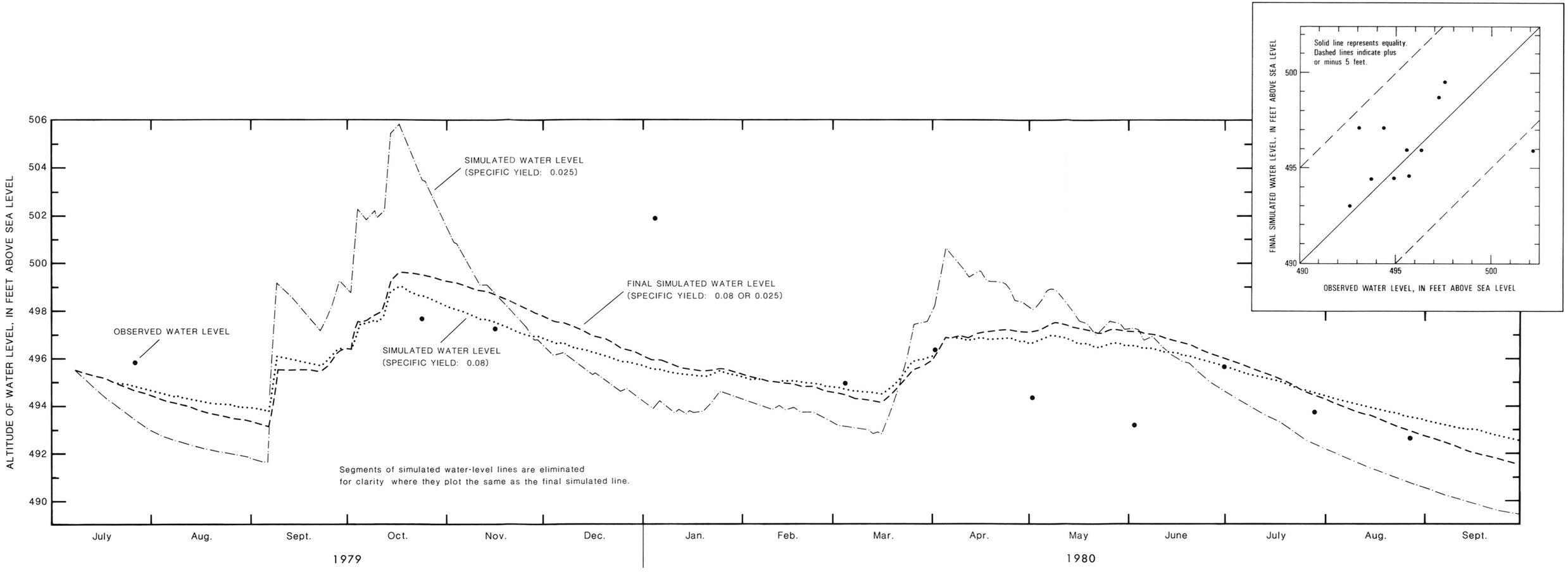
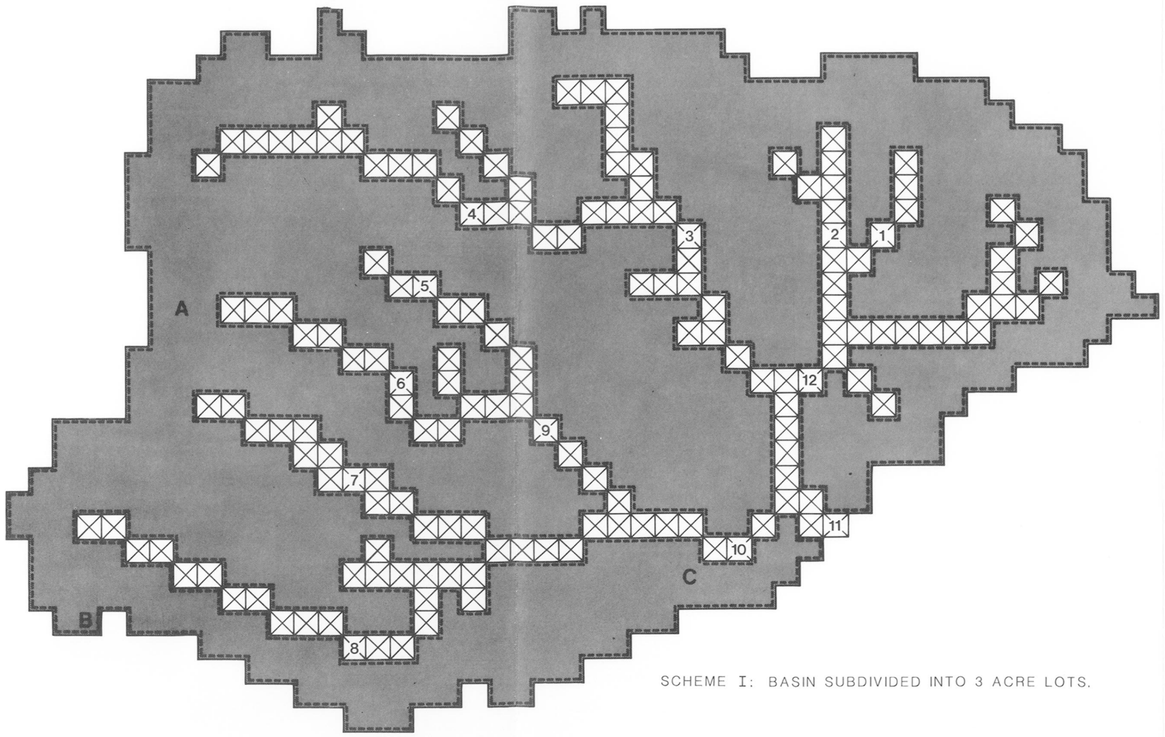
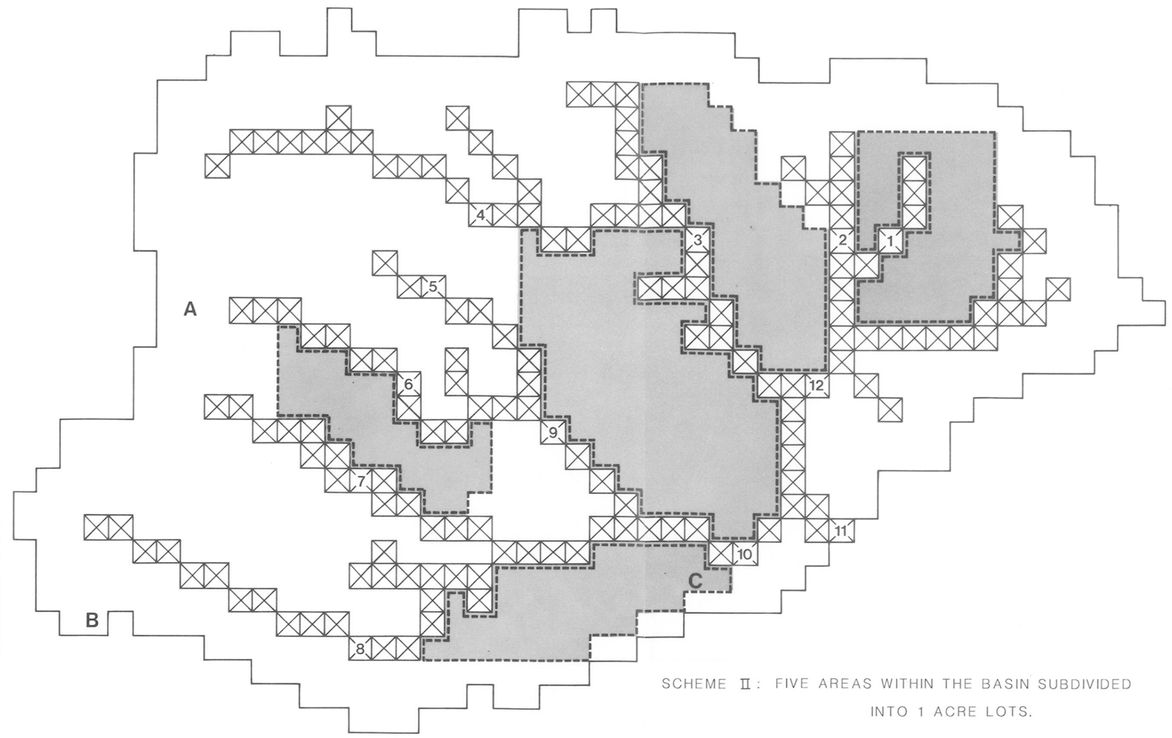


Figure 28. — Simulated water levels, cell C, compared with observed water levels for well HO-BC 38, July 1979 to September 1980.



SCHEME I: BASIN SUBDIVIDED INTO 3 ACRE LOTS.



SCHEME II: FIVE AREAS WITHIN THE BASIN SUBDIVIDED INTO 1 ACRE LOTS.

EXPLANATION

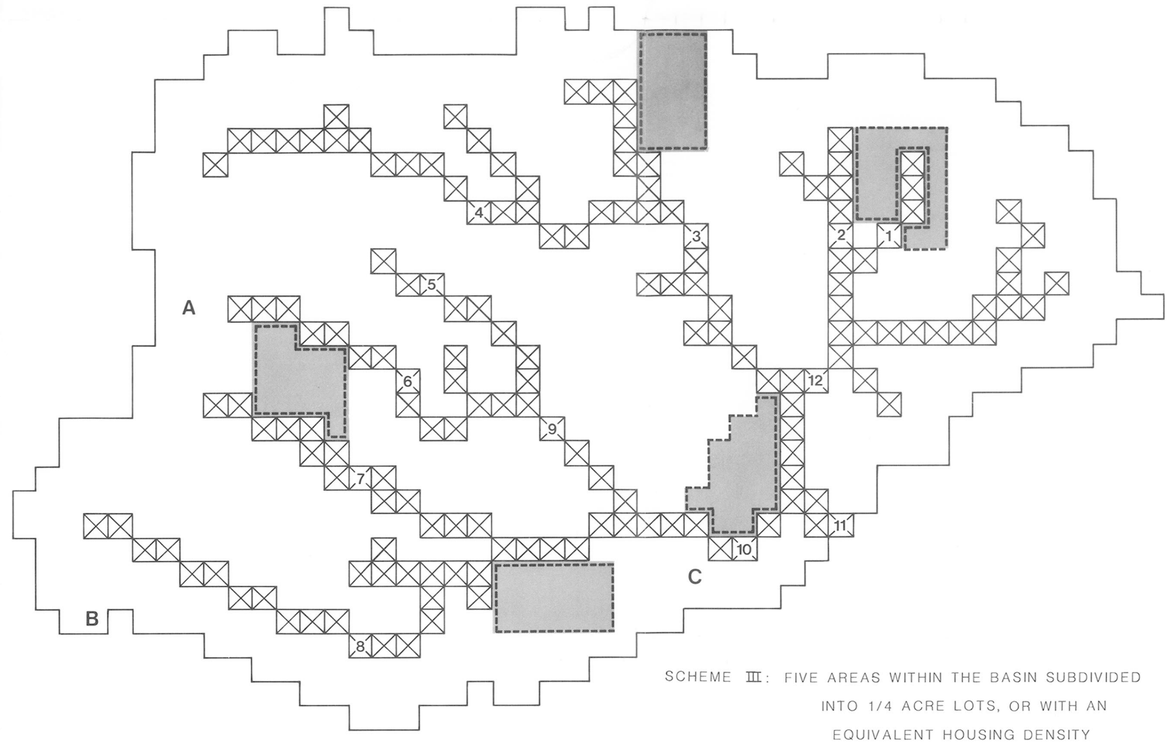
Area developed

Stream cell

3 Stream cell with simulated annual average base flow data.

A Cell with observation well located at its center. Data are simulated cumulative changes in annual average ground-water level for the well.

LOT SIZE	SCHEME	WATER SUPPLY		WASTE-WATER DISPOSAL				PERCENT PUMPAGE RETURNED TO BASIN			
				On each lot	Treated sewer discharge						
		On-lot well	Public wells		Out of basin	To basin streams	On basin land	95	90	80	None
3-ACRE	Ia 1	●		●				●			
	Ia 2	●		●					●		
	Ia 3	●		●						●	
	Ib	●			●						●
	Ic		●	●					●		
	Id		●		●						●
1-ACRE	IIa	●		●					●		
	IIb	●			●						●
	IIc		●	●					●		
	IId		●		●						●
1/4-ACRE	IIIa		●		●						●
	IIIb		●			●			●		
	IIIc		●				●		●		



SCHEME III: FIVE AREAS WITHIN THE BASIN SUBDIVIDED INTO 1/4 ACRE LOTS, OR WITH AN EQUIVALENT HOUSING DENSITY

Figure 31. — Hypothetical development schemes used for predictive simulations.

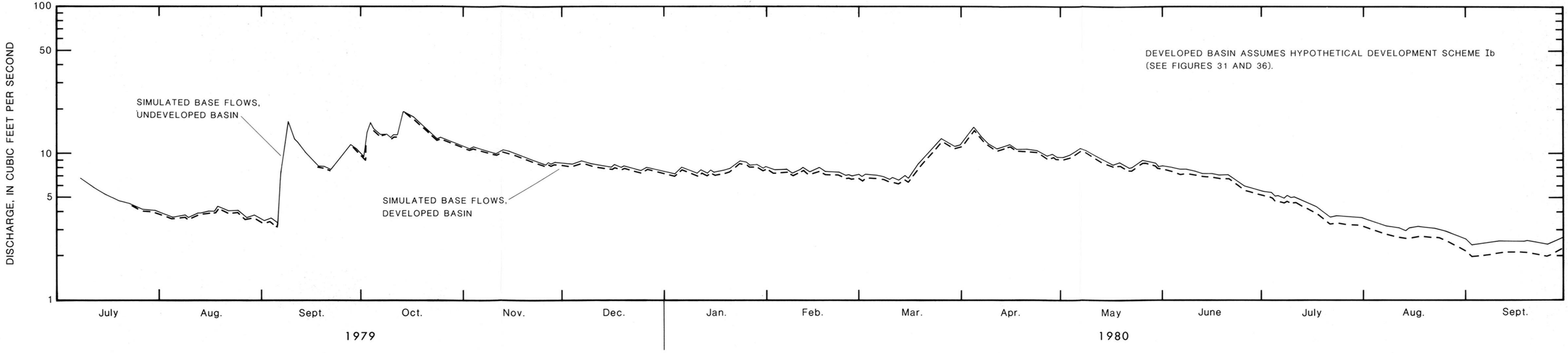


Figure 49. — Comparison of simulated base flows at streamflow site 11 for developed (scheme Ib) and undeveloped basin, July 1979 to September 1980.

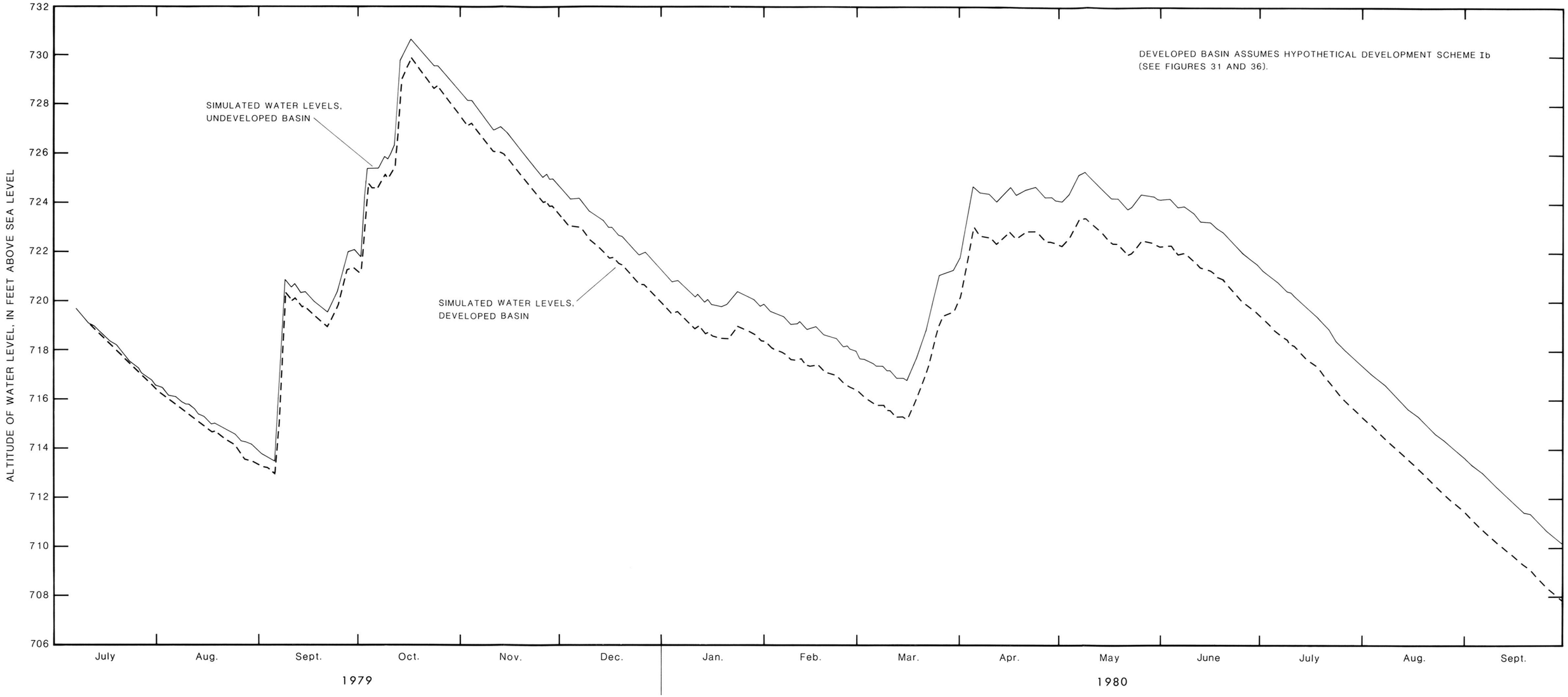


Figure 50. — Comparison of simulated water levels at cell B for developed (scheme Ib) and undeveloped basin, July 1979 to September 1980.