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

REPORT OF INVESTIGATIONS NO. 54

SIMULATED HYDROLOGIC EFFECTS OF THE DEVELOPMENT OF THE PATAPSCO AQUIFER SYSTEM IN GLEN BURNIE, ANNE ARUNDEL COUNTY, MARYLAND

by

Grufron Achmad

Prepared in cooperation with the
United States Department of the Interior
Geological Survey
and the
Anne Arundel County Department of Utilities

1991

CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who prefer to use metric (International System) units, rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound units	*by*	*To obtain metric units*
inch (in.)	25.40	millimeter (mm)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
inch per year per square mile [(in/yr)/mi^2]	9.811	millimeter per year per square kilometer [(mm/yr)/km^2]
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot (ft^2)	0.09290	square meter (m^2)
foot squared per second (ft^2/s)	0.09290	meter squared per second (m^2/s)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.589	square kilometer (km^2)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons (Mgal)	3,785	cubic meter (m^3)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

Chemical concentration and water temperature in this report are expressed in metric units. Chemical concentration is given in milligrams per liter (mg/L) or in micrograms per liter (μg/L). One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations of less than about 7,000 mg/L, the numerical value is about the same as for concentration in parts per million. Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (μS/cm). Water temperature is expressed in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\ °C + 32$$

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CONTENTS

	Page
Abstract	1
Introduction	3
Purpose and scope	3
Previous investigations	3
Location of study area and general features	4
Acknowledgments	4
Patapsco aquifer system in Glen Burnie area	4
Hydrogeologic setting	4
Direction of ground-water flow	8
Natural recharge	10
Recharge calculated from ground-water stage	10
Recharge calculated from base flow	11
Natural discharge	12
Ground-water runoff to streams	12
Evapotranspiration	12
Hydrologic properties	14
Lower Patapsco aquifer	14
Confining unit overlying lower Patapsco aquifer	15
Upper Patapsco aquifer	15
Stream system	17
Pumpage	18
Water quality	19
Simulated hydrologic effects of development	19
Description of the flow model	19
Framework of the conceptual model	19
Assumptions and limitations	22
Boundary conditions	22
Upper Patapsco aquifer lateral boundary	22
Stream boundary	24
Uppermost boundary	24
Lower Patapsco aquifer lateral boundary	24
Model calibration	25
Initial water-level conditions	25
Steady-state model	25
Transient model	27
Ground-water-supply potential	38
Rationale for pumpage increases	38
Sawmill well field	40
Dorsey Road well field	41
Hammonds Ferry well field	41
Glendale well field	43
Harundale well field	43
Crain Highway well field	44
Phillips Drive well field	44
Elvaton well field	44
Quarterfield well field	46
Pumpage scenarios	49
Scenario 1	50
Scenario 2	50
Scenario 3	61
Scenario 4	61
Scenario 5	61
Scenario 6	61

CONTENTS—Continued

	Page
Scenario 7	61
Scenario 8	64
Summary and conclusions	72
Selected references	73
Appendix	75
Records of selected wells in the Glen Burnie area	75

ILLUSTRATIONS

Figure		Page
1.	Maps showing (A) location of study area, and (B) traces of hydrogeologic sections and location of selected well fields	5
2.	Map showing location of selected wells, data-collection sites, well fields, and 5-minute quadrangle grid for Anne Arundel County	6
3-4.	Hydrogeologic sections	
	3. A-A′, from well Ac 11 to well Ce 117	8
	4. B-B′, from well Bc 163 to well BA-Gf 11, and C-C′, from well Bd 158 to well Bd 156	9
5.	Diagrammatic section showing generalized steady-state ground-water flow along the (A) general strike and (B) general dip directions	10
6.	Graphs showing method of preparing base-flow recession curve of Sawmill Creek at Glen Burnie using streamflow hydrographs recorded during 1983-85	13
7.	Graph showing rating curve comparing ground-water levels measured in well Ad 104 and base flow of Sawmill Creek at Glen Burnie for 1984-85	14
8.	Graph showing daily discharge and base flow of Sawmill Creek at Glen Burnie for 1984-85	15
9.	Map showing transmissivity of the lower Patapsco aquifer	16
10.	Diagram showing method of calculating initial transmissivity and hydraulic conductivity of the upper Patapsco aquifer	17
11.	Graph showing total annual ground-water withdrawals from Glen Burnie well fields in the Sawmill Creek and Marley Creek basins, 1945-85	18
12.	Map showing finite-difference grid and boundary conditions for the Patapsco aquifers used in the model	23
13.	Graphs showing (A) water levels in wells Ad 88 and Bd 91 and (B) historical pumpage of the Glen Burnie well fields, 1960-70	26
14-15.	Maps showing comparison of simulated 1965 potentiometric surface and pre-1965 measured water levels used in the steady-state model calibration for the:	
	14. Upper Patapsco aquifer	29
	15. Lower Patapsco aquifer	30
16-18.	Graphs showing comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the:	
	16. Sawmill well field	33
	17. Dorsey Road well field	34
	18. Dorsey Road and Thelma Avenue well fields, and the State Highway Garage observation well	35
19.	Graphs showing comparison of measured water levels in wells and simulated water levels in cells tapping the upper Patapsco aquifer in the Hammonds Ferry observation wells	37
20-26.	Graphs showing comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the:	
	20. Hammonds Ferry observation wells	38
	21. Glendale well field and Bicycle Path Greenway observation well	40
	22. Harundale well field	41
	23. Vocational Technical School observation well, and Crain Highway and Phillips Drive well fields	42
	24. Elvaton well field and Rippling Woods School observation well	43
	25. Quarterfield well field and Queenstown Park observation well	44
	26. Curtis Bay observation well	45

ILLUSTRATIONS—Continued

Figure — Page

27-28. Graphs showing comparison of measured water levels in wells and simulated water levels in cells tapping the upper Patapsco aquifer in the:
- 27. Queenstown Park and Woodside School observation wells 45
- 28. Sawmill well field (Central Avenue) 46

29-30. Maps showing comparison of simulated 1985 potentiometric surface and water levels used in the transient model calibration for the:
- 29. Upper Patapsco aquifer 47
- 30. Lower Patapsco aquifer 48

31. Graphs showing comparison of base flows of Sawmill Creek at Glen Burnie derived from measured stream stage and computed by simulation of transient ground-water flow, 1984-85 49

32-34. Graphs showing hydrographs of simulated water-levels in the lower Patapsco aquifer and effects of pumpage scenarios totaling 11.57 to 16.12 million gallons per day for:
- 32. Cells (38, 35) and (46, 21) near wells Ad 1 (Sawmill) and Bd 95 (Dorsey Road) 53
- 33. Cells (13, 56) and (45, 45) near wells Ad 10 (Curtis Bay) and Bd 103 (Glendale) 54
- 34. Cells (54, 46) and (63, 38) near wells Bd 37 (Harundale) and Bd 107 (Elvaton) 55

35. Graph showing simulated base flows of Sawmill Creek at Glen Burnie using pumpages totaling 11.57 to 16.12 million gallons per day 56

36-37. Maps showing simulated potentiometric surface for year 2000 using pumpage of 11.57 million gallons per day for the:
- 36. Upper Patapsco aquifer 57
- 37. Lower Patapsco aquifer 58

38-39. Maps showing simulated potentiometric surface for year 2000 using pumpage of 11.57 million gallons per day plus 0.98 million gallons per day from the Dorsey Road, Sawmill, and Harundale well fields for the:
- 38. Upper Patapsco aquifer 59
- 39. Lower Patapsco aquifer 60

40-41. Maps showing simulated potentiometric surface for year 2000 using pumpage of 11.57 million gallons per day plus 0.96 million gallons per day from the Crain Highway and Quarterfield well fields for the:
- 40. Upper Patapsco aquifer 62
- 41. Lower Patapsco aquifer 63

42-43. Maps showing simulated potentiometric surface for year 2000 using pumpage of 11.57 million gallons per day plus 4.55 million gallons per day from all the Glen Burnie well fields, except the Glendale and Thelma Avenue well fields, for the:
- 42. Upper Patapsco aquifer 66
- 43. Lower Patapsco aquifer 67

44-46. Graphs showing hydrographs of simulated water-levels in the lower Patapsco aquifer and effects of pumpage scenarios totaling 11.57 to 16.12 million gallons per day with hypothetical 2-year (1989-90) drought for:
- 44. Cells (38, 35) and (46, 21) near wells Ad 1 (Sawmill) and Bd 95 (Dorsey Road) 68
- 45. Cells (13, 56) and (45, 45) near wells Ad 10 (Curtis Bay) and Bd 103 (Glendale) 69
- 46. Cells (54, 46) and (63, 38) near wells Bd 37 (Harundale) and Bd 107 (Elvaton) 70

47. Graph showing simulated base flows of Sawmill Creek at Glen Burnie using pumpages totaling 11.57 to 16.12 million gallons per day with hypothetical 2-year (1989-90) drought 71

48. Map showing location of selected 5-minute quadrangles 82

MAPS SHOWING WELL LOCATIONS

- Quadrangle AA-Ac 83
- Quadrangle AA-Ad 84
- Quadrangle AA-Ae 85
- Quadrangle AA-Bc 86
- Quadrangle AA-Bd 87
- Quadrangle AA-Be 88
- Quadrangle AA-Ce 89
- Quadrangle BA-Gf 90

TABLES

Table | Page

1. Generalized stratigraphy and hydrologic characteristics of geologic formations in the Glen Burnie area, Anne Arundel County 7
2. Flow-duration analysis of Sawmill Creek at Glen Burnie for 1944-52 11
3. Chemical analyses for major dissolved constituents in ground water from the Patapsco aquifers, 1983-85 20
4. Chemical analyses for major dissolved constituents in stream water from the Sawmill Creek and Marley Creek gaging stations, May and November 1984 21
5. Comparison of measured and simulated water levels used for the steady-state model calibration 28
6. Flow components for 1965 steady-state model simulation and steady-state simulation with no pumpage 31
7. Comparison of measured and simulated 1985 water levels used for the transient model calibration 32
8. Flow components for 1965, 1983, and 1985 transient-model simulations 36
9. Pumpages, water levels, and drawdowns in the Glen Burnie area well fields and observation wells, 1965-85 39
10. Simulated pumpage scenarios, simulated areal water level in cells, and simulated base flows of the Sawmill Creek basin at Glen Burnie for the year 2000 51
11. Measured water levels, available drawdowns, and simulated drawdowns in the lower Patapsco aquifer for eight pumpage scenarios, 1985-2000 52
12. Flow components for the year 2005 for pumpage scenarios of continuing 1985 pumpage and 1985 pumpage plus 4.55 million gallons per day 64
13. Comparison of simulated areal water levels for selected cells showing the effects of a hypothetical drought condition, where recharge is simulated at 60 percent of the long-term average value 65
14. Records of selected wells in the Glen Burnie area 76

SIMULATED HYDROLOGIC EFFECTS OF THE DEVELOPMENT OF THE PATAPSCO AQUIFER SYSTEM IN GLEN BURNIE, ANNE ARUNDEL COUNTY, MARYLAND

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ABSTRACT

The lower Patapsco aquifer is an important source of ground water in the Glen Burnie area of Anne Arundel County, Maryland, an area of increasing population growth. The ground-water withdrawal rate from the lower Patapsco aquifer increased from 3.80 million gallons per day (Mgal/d) in 1965 to about 9.70 Mgal/d in 1985. Water-level measurements in the area indicate a decline in areal water levels of 6 to 29 feet in the lower Patapsco aquifer during the twenty years. The amount of drawdown in the upper Patapsco aquifer during 1965-85 is estimated to be about 5 to 10 feet. For the period 1944-52 the average base flow for Sawmill Creek basin, derived from streamflow hydrographs measured at a Glen Burnie gaging station, was 7.4 cubic feet per second. The stream gage was reestablished in 1984-85 and appreciably lower base flows were observed (3.4 to 0.28 cubic feet per second).

The Patapsco aquifer system attains a thickness of about 250 feet in the Glen Burnie area. In the vicinity of Sawmill and Marley Creeks, the upper Patapsco aquifer is under unconfined conditions and is separated from the lower Patapsco aquifer by a clayey confining unit. Water in the upper Patapsco aquifer flows from the northern and western recharge areas toward Sawmill and Marley Creeks and the Curtis Bay tributaries. Vertical leakage occurs from the upper Patapsco aquifer downward to the lower Patapsco aquifer in the northwestern recharge areas, and from the lower Patapsco aquifer upward to the upper Patapsco aquifer near the areas of tidal surface water of the Chesapeake Bay tributaries.

In order to assess the ground-water resources of the Glen Burnie area, a ground-water-flow model of the Patapsco aquifer system was constructed. The model area encompasses about 40 square miles, which include the drainage basins of Sawmill Creek and Marley Creek. The hydrologic properties of the aquifer system were acquired from an earlier study and were reevaluated and combined with other hydrologic and climatological data obtained during this investigation. In the model, transmissivity values of the lower Patapsco aquifer range from 1,500 to 6,000 feet squared per day, with the high values being assigned to the southeastern downdip areas where aquifer tests indicate high transmissivity and the aquifer tends to be relatively thick. The upper Patapsco aquifer was assumed to be homogeneous and its average hydraulic conductivity was estimated to be 33 feet per day. The confining-unit leakance ranged from 10^{-8} second^{-1} in the model area to 10^{-6} second^{-1} in the areas of tidal surface water where the confining unit consists of more sandy material. A long-term average recharge rate of 20.5 inches per year was used throughout most of the simulation period, with the exception of 1984-85, which was assigned a recharge rate of 14.4 inches per year. The lower recharge rate reflects a precipitation deficiency of about 9.6 inches per year in the Glen Burnie area during June 1984 to May 1985. Average precipitation for 1955-85 was 41.5 inches per year. The steady-state simulation indicates that the effective ground-water evapotranspiration rate for the Sawmill Creek and Marley Creek basins was 4.59 inches per year.

The model was calibrated under steady-state and transient conditions by matching the simulated water levels and stream base flows with those measured in the field. Ninety percent of the water levels match with differences of less than 12 feet; the maximum difference is 14 feet and the mean difference is 6 feet. Eighty-five percent of the base flows match with differences less than 0.46 cubic foot per second, and the maximum difference is 0.6 cubic foot per second. The calibrated model was subsequently used to simulate hydrologic effects of increased pumpages on ground-water levels and stream base flows.

An evaluation of the ground-water-supply potential of the Patapsco aquifer system was made by using the results of the model simulations. The following three constraints on additional pumpage were considered: (1) The possibility of dewatering Sawmill Creek at Glen Burnie due to the effects of additional pumpage on stream base flow; (2) the possibility of saltwater intrusion due to ground-water levels declining below sea level in the vicinity of areas of tidal surface water; and (3) the possibility of dewatering the aquifer in a well field due to excessive drawdown from pumping wells.

Simulations that increase pumpage by 0.98, 1.95, 2.93, and 3.58 Mgal/d over the 1985 maximum of 11.57 Mgal/d indicate that the base flow of Sawmill Creek at Glen Burnie would be reduced to 0.67, 0.40, 0.08, and 0.001 cubic feet per second,

respectively. A simulation of an increase in pumpage of 4.55 Mgal/d over the 1985 maximum (11.57 Mgal/d) suggests that areal ground-water levels in the Glendale and Harundale areas would be lowered to about sea level, a condition that could lead to saltwater intrusion from the Chesapeake Bay and Curtis Bay tributaries. In all the scenarios, simulated drawdown expressed as a cell average does not cause water levels to decline below the top of the aquifer, which suggests that the water-yielding capacity of the aquifer is not exceeded. At the operational level, however, several scenarios simulating an additional pumpage of 0.32 to 0.97 Mgal/d at the Dorsey Road well field produced drawdowns that cause water levels to decline below the top of the aquifers in at least one pumping well (Bd 95). Likewise, the simulated water level in a hypothetical pumping well at the Thelma Avenue well field declined 5 feet below the top of the aquifer when pumpage is increased from 0.006 to 0.91 Mgal/d. Both of these cases suggest that additional wells, adequately spaced to minimize interference effects, would be needed to increase production at these well fields. In general, allocating additional pumpage to well fields in the southwestern part of the model area would reduce the adverse effects of the conditions cited above.

The simulation of a hypothetical 2-year drought, assuming 60 percent of the long-term average recharge, demonstrates that even with pumpage held to the 1985 maximum (11.57 Mgal/d), water-level declines are sufficient to dewater Sawmill Creek at Glen Burnie. The effects of the drought, however, are temporary and reversible once average recharge conditions are reimposed.

INTRODUCTION

The unconsolidated Patapsco Formation of Lower Cretaceous age crops out in the Glen Burnie area of Anne Arundel County, Maryland. The Patapsco Formation is a multilayer aquifer system. In the vicinity of the Sawmill Creek and Marley Creek drainage basins, the upper Patapsco aquifer is unconfined and is separated from the lower Patapsco aquifer by a clayey confining unit. The streams derive most of their water from the unconfined aquifer. Several brackish tributaries of the Chesapeake Bay extend deep into the basin and are natural discharge areas for the aquifer system. Local precipitation, percolating through the sandy outcrop area, is the principal source of recharge to the aquifer system. The lower Patapsco aquifer is an important source of ground water for the Glen Burnie area.

Pumpage from the lower Patapsco aquifer increased from 3.80 Mgal/d (million gallons per day) in 1965 to about 9.70 Mgal/d in 1985. Water-level measurements made during this study indicate that water levels in the lower Patapsco aquifer declined by 6 to 29 ft (feet). The 1965-85 drawdown in the upper Patapsco aquifer was estimated to be about 5 to 10 ft. Growth in population and industry in northern Anne Arundel County has increased demands for adequate water supplies. A consensus exists that drawdown of the potentiometric surfaces might be considered excessive if it significantly decreased streamflow or induced saltwater intrusion from the Chesapeake Bay or its tributaries. A study of the aquifer system was therefore needed to determine how the lowering of the potentiometric surface is related to these two different effects. In addition, a better understanding of the water-supply potential of recharge areas is needed. To address these issues, the Maryland Geological Survey, in cooperation with the U.S. Geological Survey and the Anne Arundel County Department of Utilities, began a study of the Glen Burnie area in 1983.

PURPOSE AND SCOPE

The purpose of this report is to describe the hydrologic effects that development (pumpage) of the Patapsco aquifer system will have on ground-water levels and streamflow and to evaluate the potential of the aquifer system to provide additional water to the Glen Burnie area. The drainage basin of Sawmill and Marley Creeks was chosen for study because it includes the recharge areas of the aquifer system and is a natural stream basin that can be treated as an autonomous hydrologic unit.

A previous model of the Potomac aquifer system (Mack and Achmad, 1986) did not allow stream-aquifer interactions and employed grid elements of 1 mi (mile) on each side. In this study the Patapsco aquifer system was simulated using a digital ground-water flow model that includes stream-aquifer interactions and calculates base flow for stream reaches. A finer grid-element network (500 by 500 ft) was used, allowing a better definition of the area between data points and a better discretization of modeled stream cells. The ground-water flow model was used to estimate the potential effects that increased well pumpage in existing well fields would have on ground-water levels, stream base flows, and possible saltwater intrusion.

During the investigation, a discontinued stream-gaging station was reactivated and two new stations were installed to continuously measure streamflows. Periodic streamflow measurements in the basin were conducted at 16 sites along stream channels during 1984 and 1985. Twelve observation wells ranging in depth from 11 to 300 ft were drilled to continuously measure water levels. More than 50 shallow wells (up to 80 ft deep) were inventoried and an additional 300 well records were studied for water-level data and other hydrologic information. Records of selected wells are shown in table 14 at the end of this report. Precipitation and weather data were obtained from the nearby National Oceanic and Atmospheric Administration (NOAA) weather station at Baltimore-Washington International Airport (BWI), and ground-water withdrawal records were obtained from the Anne Arundel County Department of Utilities and the Maryland Water Resources Administration.

Data from the above sources provided the information used to construct and calibrate the digital model for steady-state and transient conditions. Future pumpage scenarios were selected to meet county needs. Most simulations of future pumpage were made assuming long-term average recharge conditions, but, in some cases, a 2-year drought period was simulated.

PREVIOUS INVESTIGATIONS

Brookhart (1949) described the first stream-gaging station built on Sawmill Creek at Glen Burnie. Cushing, Kantrowitz, and Taylor (1973) reported the base flow for Sawmill Creek at Glen Burnie for 1944-52. The geologic characteristics of the Patapsco Formation have been studied by numerous investigators. Notable are the reports by Hansen (1968), who used geophysical logs to illustrate the change in lithology, and Glaser (1969), who described the origin and petrology of the formation. Water-yielding properties of the Patapsco aquifer system in Glen Burnie have been described by Otton (1955), Mack (1962), Hansen (1972), Mack and Achmad (1986), and Vroblesky and Fleck (in press). Chloride distributions in the Baltimore industrial area have been reported by Bennett and Meyer (1952), and Chapelle (1985). Information and knowledge obtained during the preparation of the digital models for the Potomac aquifers (Mack and Achmad,

1986) and the Cattail Creek stream-aquifer system (Willey and Achmad, 1986) were used in the development of this study.

LOCATION OF STUDY AREA AND GENERAL FEATURES

Glen Burnie is located in northern Anne Arundel County, which is about 5 mi south of Baltimore City and about 3 mi southeast of BWI (fig. 1). The study area, which is centered at Glen Burnie, is bordered on the north by a line extending from the intersection of Howard County and Baltimore County in the west to Curtis Bay in the east; on the west by Stoney Run; on the south by the upper reaches of the Severn and Magothy Rivers; and on the east by Marley Neck (fig. 2). The study area encompasses about 62.5 mi^2 (square miles), including the drainage basins of Sawmill Creek and Marley Creek, and the well fields of interest in this study. Sawmill and Marley Creeks begin as separate streams at their headwaters, merge downstream into one stream, and subsequently discharge into Curtis Bay.

Land-surface altitudes range from several feet above sea level at the shoreline in the Curtis Bay area, to 160 ft on the western divide of the basin at Stewart Corner. The altitude of the land surface in the northeastern part of the basin is about 50 ft or less.

The climate is humid with warm summers and mild winters. Rainfall distribution is rather uniform throughout the year, with the greatest intensity in the summer and early fall months. Moisture deficiency for crops occurs occasionally during the growing season, but severe droughts are rare.

ACKNOWLEDGMENTS

Most of the basic hydrologic data used for this study were collected by personnel of the U.S. Geological Survey and the Maryland Geological Survey. The author wishes to thank Seymour Bayuk and personnel from the Anne Arundel County Department of Utilities for their assistance during the project.

PATAPSCO AQUIFER SYSTEM IN THE GLEN BURNIE AREA

HYDROGEOLOGIC SETTING

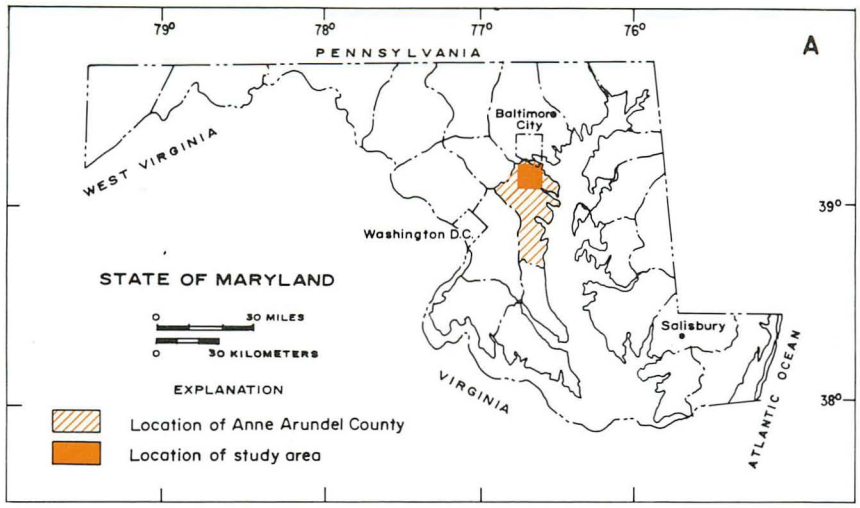
The unconsolidated sedimentary deposits underlying the Glen Burnie area are part of the Atlantic Coastal Plain physiographic province, a southeastward-thickening wedge of sediments that extends from the eastern edge of the Piedmont (Fall Line) to the Atlantic Ocean. During crustal movements along the continental margin, the area northwest of the Fall Line was uplifted, producing a seaward slope on the crystalline bedrock "basement." The sediment that eroded from the uplifted area now constitutes the Coastal Plain of Maryland (Glaser, 1969; Cushing, Kantrowitz, and Taylor, 1973).

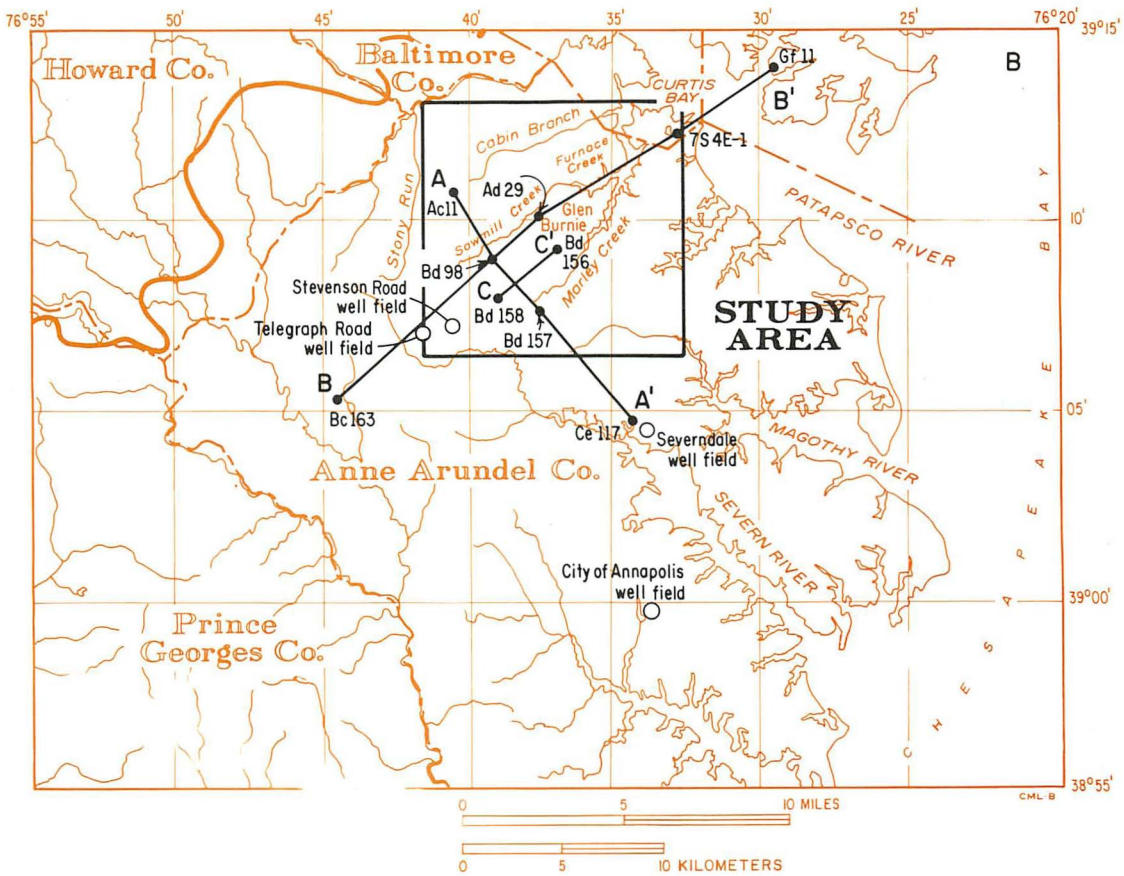
The Potomac Group is the basal unit in the Coastal Plain of Maryland and overlies with angular unconformity a basement of largely saprolitized Precambrian (?) and Lower Paleozoic (?) metamorphic and igneous rocks. In the Glen Burnie area, the Potomac Group sediments include, in ascending order, the Patuxent Formation, the Arundel Clay, and the Patapsco Formation (Mack and Achmad, 1986). Large and abrupt variations of lithology are typical of the Potomac Group. Clay-silt beds in the Patuxent and Patapsco Formations are generally developed as lenticular bodies and exhibit little lateral continuity; they are interbedded with sand and gravel.

The Patuxent Formation in the Glen Burnie area includes medium to coarse sand and gravel interbedded with relatively thin, pale-gray clay. The Arundel Clay, overlying the Patuxent Formation, is usually a dark-gray to maroon, tough, massive clay containing abundant lignite and siderite. The Patapsco Formation includes yellowish sand, fine- to medium-grain size, interstratified with massive to laminated, variegated (gray, brown, and red) silty clay. In general, the Patapsco sediments are similar to the Patuxent sediments and differentiation of the two units based on lithologic properties is difficult (Glaser, 1969).

The Patapsco Formation crops out in the Glen Burnie area where it overlies the Arundel Clay. The Arundel-Patapsco contact in this area is often marked by limonite-cemented sand layers. In the flood plains of the streams as well as in the tidal marsh area along the Chesapeake Bay estuaries, the Patapsco Formation is partially overlain by alluvial sediments of Holocene and Pleistocene age. The alluvium consists of interbedded sand, silty clay, and subordinate gravel. In tidal marsh areas, organic mud is common in the alluvium (Glaser, 1976).

The subsurface contacts between the formations of the Potomac Group in the Glen Burnie area were determined using gamma-ray and lithologic logs for the following Anne Arundel County wells: Ac 11, Ad 29, Bc 163, Bd 98, Ce 117; Baltimore County well Gf 11; and Baltimore City well 7S4E-1 (Mack and Achmad, 1986). Subdivision of the Patapsco Formation into an upper and lower part was later





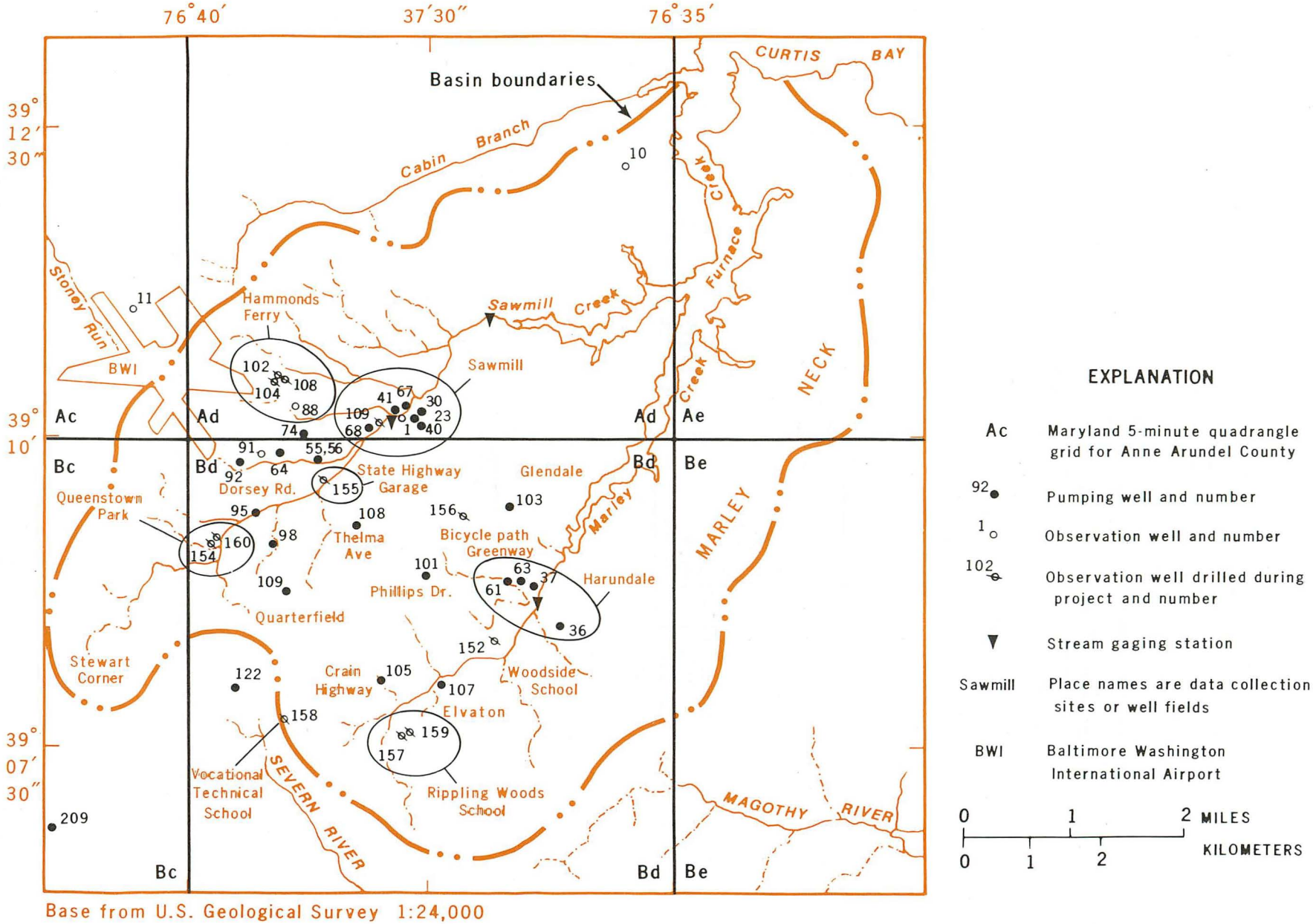
A●——●A' Trace of hydrogeologic section shown in figure 3 or 4.

●Bd 156 Control well and number.

○ Severndale well field Well field.

Fall Line

Figure 1. — (A) Location of study area, and (B) traces of hydrogeologic sections and location of selected well fields.



Base from U.S. Geological Survey 1:24,000

Figure 2. — Location of selected wells, data-collection sites, well fields, and 5-minute quadrangle grid for Anne Arundel County.

confirmed by gamma-ray logs of Anne Arundel County wells Bd 156, Bd 157, and Bd 158 (figs. 3 and 4). The generalized stratigraphy of the area is shown in table 1. Additional information on the lithology, age, and thickness of the Potomac Group formations can be found in Glaser (1969), Hansen (1972), Chapelle (1985), and Mack and Achmad (1986).

The Patapsco aquifer system in Anne Arundel County consists of an upper and lower aquifer separated by a confining unit of variable thickness (Mack and Achmad, 1986). In the Glen Burnie area, the Patapsco aquifer system is about 250 ft thick. The lower part of the Patapsco aquifer system (the confining unit and lower Patapsco aquifer) is about 150 ft thick (table 1). The lower Patapsco aquifer overlies the Arundel Clay and is the principal source of ground water for large public-supply wells in the area. County well fields pumping from the lower Patapsco aquifer include Sawmill, Dorsey Road, Glendale, Harundale, Phillips Drive, Thelma Avenue, Crain Highway, Elvaton, and Quarterfield (fig. 2).

The confining unit overlying the lower Patapsco aquifer consists of clayey layers of relatively low vertical hydraulic conductivity. The confining unit near the areas of tidal surface water of the bay tributaries contains more sandy material than the confining unit in the western part of the area. For example, drill cuttings obtained from well Bd 156 are more sandy than those from well Bd 158. In figure 4 (section C-C′), the confining unit in well Bd 156 occurs between 76 to 110 ft below land surface and in well Bd 158 the confining unit occurs between 94 to 130 ft below land surface. The time required to drill through these clay layers was 55 minutes for well Bd 156 and 171 minutes for well Bd 158, another indication that the clay layer in well Bd 156 is sandier than in well Bd 158.

Table 1. — Generalized stratigraphy and hydrologic characteristics of geologic formations in the Glen Burnie area, Anne Arundel County

[Modified from Mack and Achmad, 1986]

System	Series	Stratigraphic unit			Average thickness (feet)	Hydrologic character	General lithology
Quaternary	Holocene and Pleistocene	Alluvium and terrace deposits			0-5	Permeable bed underlying Chesapeake Bay estuaries	Mostly sand and silty clay, some gravel
Cretaceous	Lower Cretaceous	Potomac Group	Patapsco Formation	Upper part	100	Aquifer	Sand, fine to medium, brownish yellow color
				Lower part	150	Confining unit	Clay, tough, variegated color
						Aquifer	Sand, fine to medium, brownish yellow color
			Arundel Clay		150	Confining unit	Clay, red, brown, and gray; contains some ironstone nodules and plant remains
			Patuxent Formation		250	Aquifer	Sand, gray and yellow, with interbedded clay; kaolinized feldspar and lignite common. Locally clay layers predominate
Lower Paleozoic (?) to Precambrian (?)		Basement complex			Unknown	Confining unit	May be gneiss, granite, gabbro, metagabbro, quartz diorite, or schist

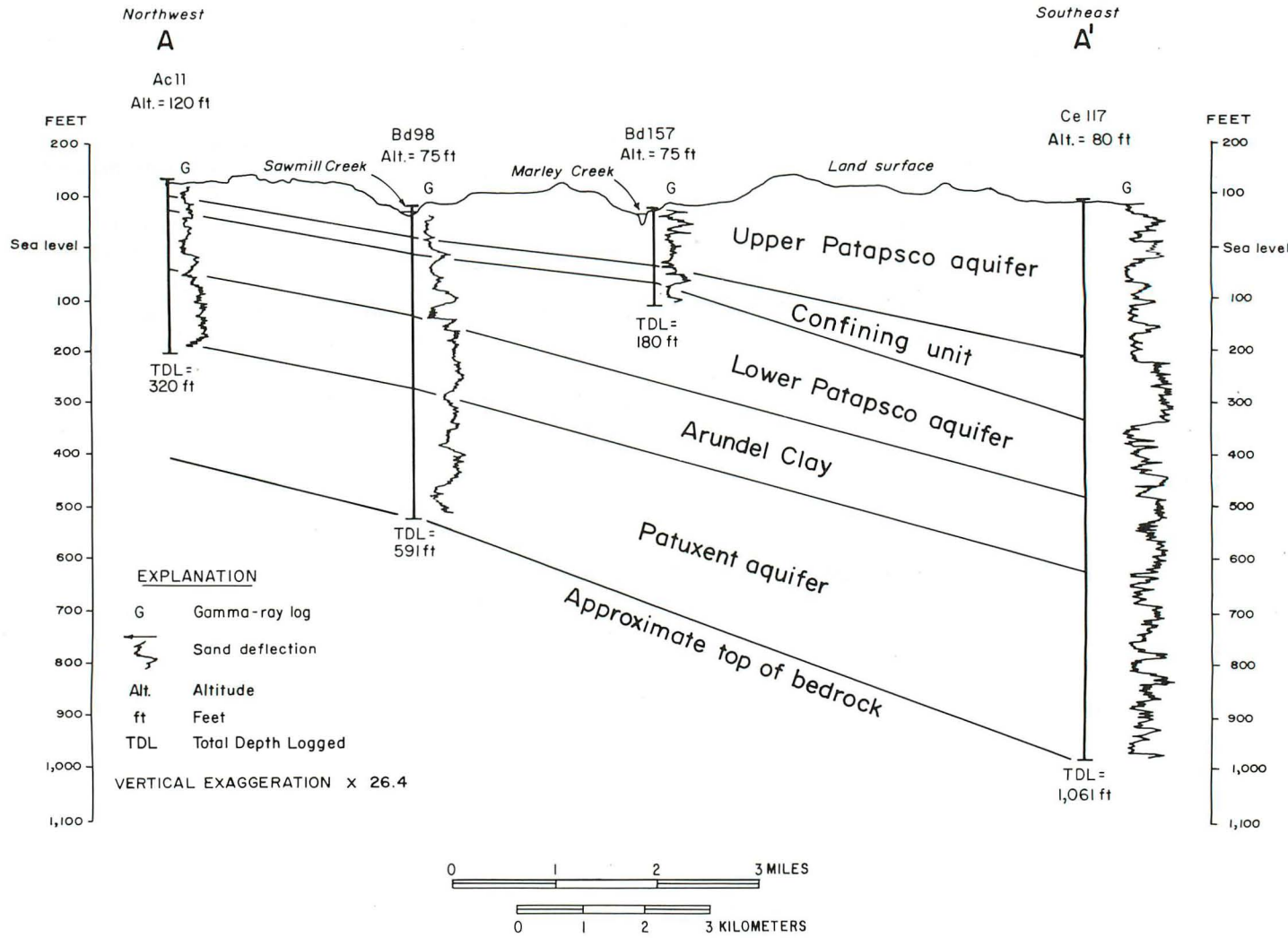


Figure 3. — Hydrogeologic section A-A′, from well Ac 11 to well Ce 117.

In the Glen Burnie area, the uppermost confining unit of the Patapsco aquifer system is missing. The upper part of the aquifer system (the upper Patapsco aquifer) is therefore under unconfined (water-table) conditions. The average thickness of the upper Patapsco aquifer is about 100 ft in the Glen Burnie area. Records indicate that until about 1950, wells of about 48 in. (inches) in diameter were dug into the shallow water-table aquifer. These wells were susceptible to falling water levels and have been abandoned.

DIRECTION OF GROUND-WATER FLOW

The land-surface and water-table altitudes in the western part of the study area are relatively higher than those in the eastern part. Thus, ground water flows from the western part of the study area northeastward toward Curtis Bay (figs. 2 and 5). In the western part of the study area, water levels in the unconfined aquifer are higher than water levels in the confined aquifer so that some of the ground water in the unconfined aquifer flows through the confining unit into the confined aquifer. Farther downstream on the northeastern side of the study area, water levels in the confined aquifer are higher than the water table, and ground water in the lower Patapsco aquifer flows upward into the water-table aquifer and subsequently discharges into the Chesapeake Bay tributaries.

As the lower Patapsco aquifer was developed and more ground water was withdrawn, flow patterns were locally distorted around the well fields. However, ground-water levels measured in 1985 in the Glen Burnie area indicate that the general direction of ground-water flow is still from recharge areas in the northwestern, western, and southwestern parts of the model area toward tidewater discharge areas in the

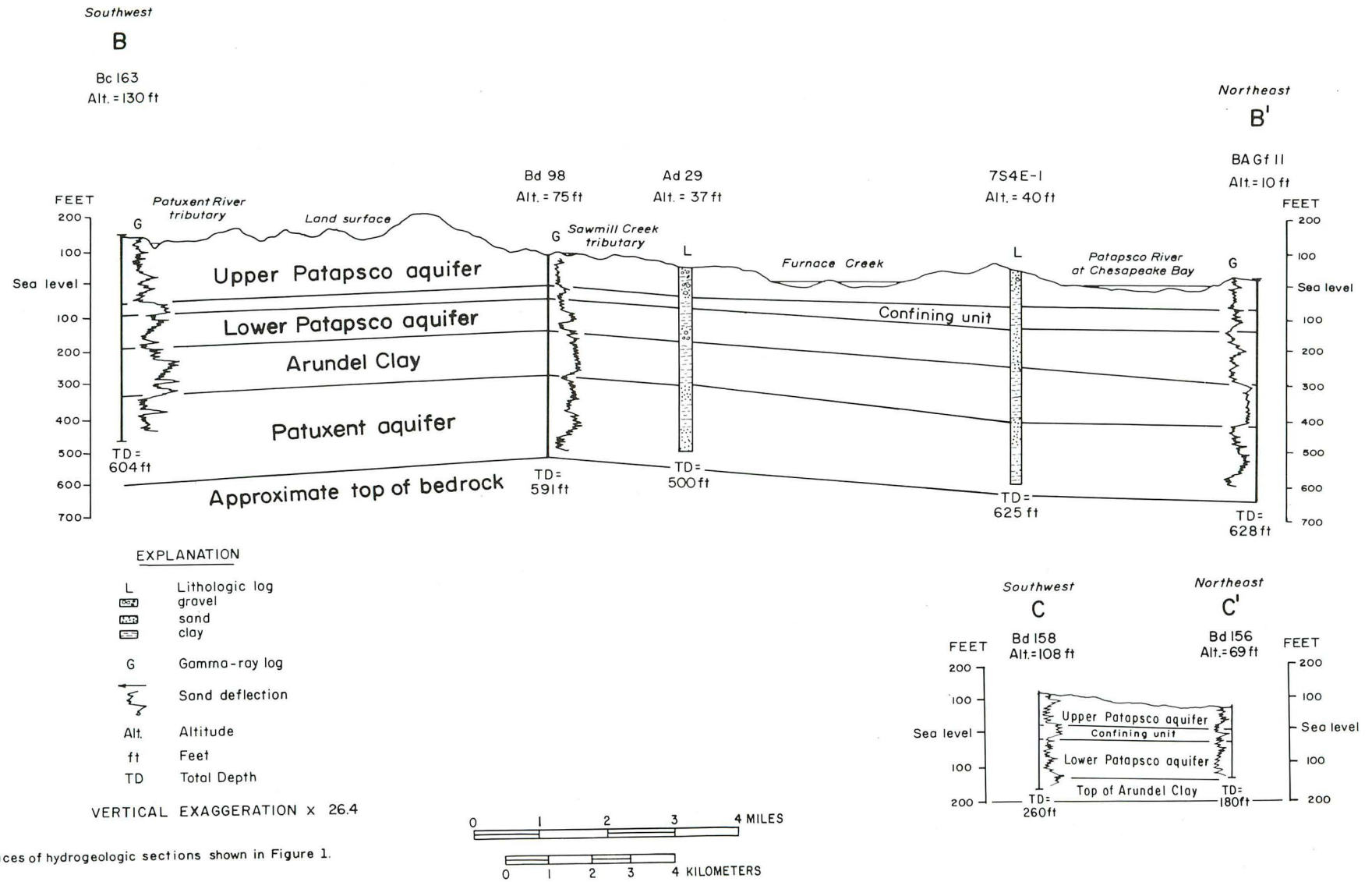


Figure 4. — Hydrogeologic sections B-B′, from well Bc 163 to well BA-Gf 11, and C-C′, from well Bd 158 to well Bd 156.

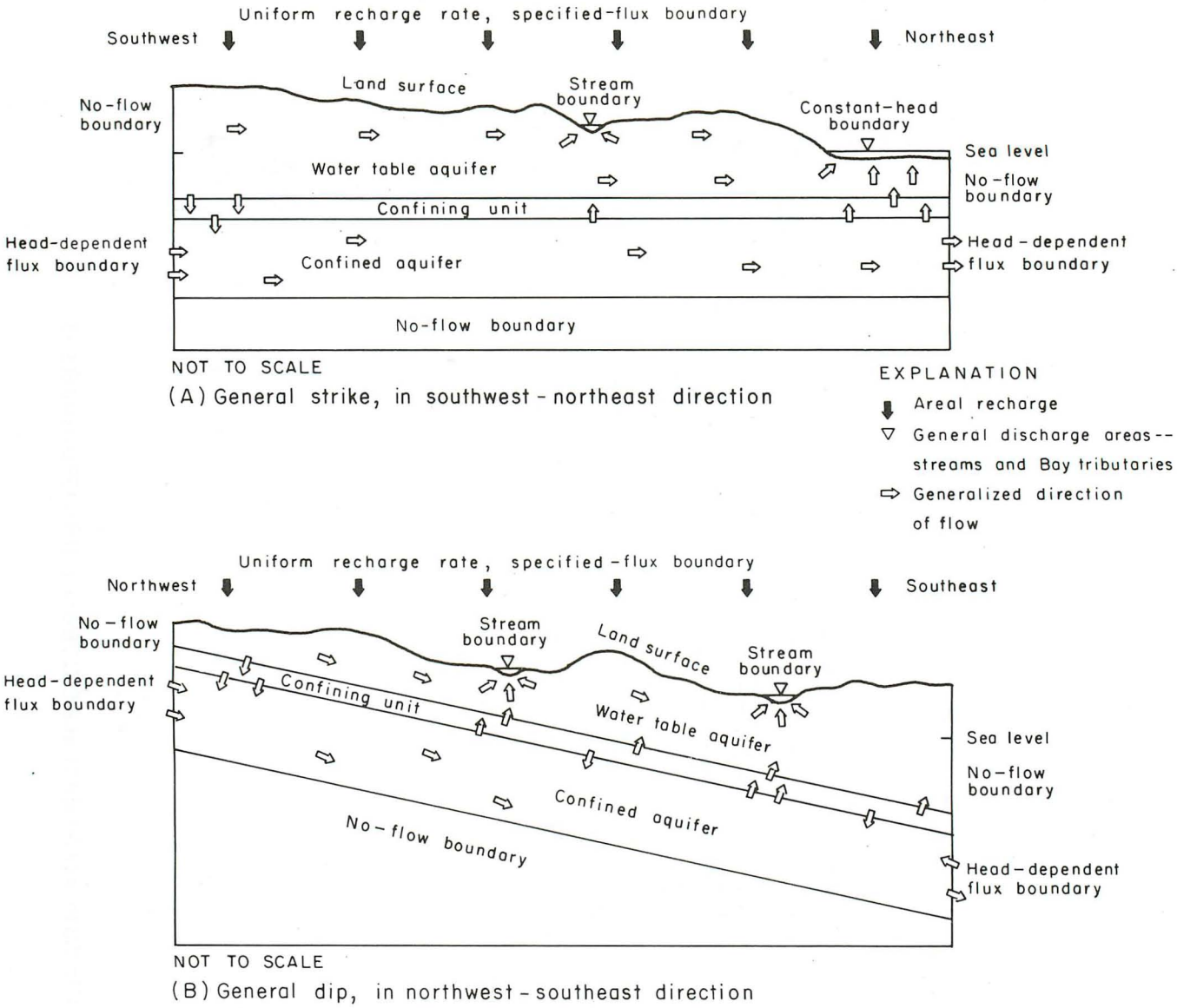


Figure 5. — Generalized steady-state ground-water flow along the (A) general strike and (B) general dip directions.

northeastern part of the model area. It is possible, however, that further increases in pumpage could reverse the ground-water flow direction; this problem will be addressed further in the section on "Ground-Water-Supply Potential."

NATURAL RECHARGE

Two methods were used to estimate ground-water recharge to the drainage basin under study. The first method was based on cumulative rises of ground-water stage in the Sawmill Creek basin after each rainfall, and the second method was based on base-flow hydrograph separation for Sawmill Creek at the Glen Burnie gaging station.

Recharge Calculated from Ground-Water Stage

The amount of precipitation that reaches the water table can be estimated from the rise in ground-water level after each rainfall. Rasmussen and Andreasen (1959, p. 93-96) reported that the amount of ground-water recharge calculated solely from the rise in ground-water level fell short of the total recharge by the amount of ground-water discharge during a precipitation event. The amount of ground-water discharge that occurs during a precipitation event can be estimated by using a ground-water hydrograph to project the recession prior to the date of the peak stage. The yearly ground-water recharge can be calculated as the summation of monthly differences between peak and recession stages

multiplied by specific yield (Meinzer and Stearns, 1929, p. 129-140).

The ground-water recharge for the Sawmill Creek basin for June 1984 to May 1985 was calculated using this method. The water level of well Ad 104 used in the calculation is considered representative of the average ground-water stage of the drainage basin. The well is located near an upstream section of a branch of Sawmill Creek at Hammonds Ferry Road where the effects of urbanization were assumed minimal. The specific yield was estimated using a method of convergent approximations, which is a trial-and-error method that alternately calculates evapotranspiration and ground-water recharge by using the hydrologic budget equation. The method was described in detail by Rasmussen and Andreasen (1959, p. 86-96). The winter months were chosen for applying this method to the Sawmill Creek basin because conditions for computing specific yield are best when evapotranspiration and soil-moisture change are small. A specific yield of 0.11 was obtained from the calculation, which is consistent with the specific yield (0.11 to 0.15) calculated for the Beaverdam Branch basin near Houston, Delaware, (Johnston, 1976, p. 27), the specific yield (0.11) calculated for the Beaverdam Creek basin near Salisbury, Maryland (Rasmussen and Andreasen, 1959, p. 86), and specific yields (0.10 to 0.15) used for the Patapsco aquifer in the Baltimore industrial area (Chapelle, 1985, p. 18) and in northern Anne Arundel County (Mack and Achmad, 1986, p. 42). Using a specific yield of 0.11, recharge for the basin was calculated to be 16.3 in/yr (inches per year) for June 1984 to May 1985.

The NOAA records for the BWI station show that the average precipitation for June 1984 to May 1985 was 31.9 in/yr, and 41.5 in/yr for 1955-85 (National Oceanic and Atmospheric Administration, 1984 and 1985). Assuming a linear relation exists between precipitation and ground-water recharge, average ground-water recharge for 1955-85 was calculated to be $41.5/31.9 \times 16.3 = 21.2$ in/yr.

Recharge Calculated from Base Flow

Stream base flow is ground-water runoff from an underlying aquifer. The total amount of recharge to a study area can be calculated as a summation of ground-water runoff plus ground-water evapotranspiration, assuming that leakage to and from deeper aquifers balance each other. Thus, for a long-term average condition with no change in storage, total ground-water recharge can be considered equal to long-term average ground-water runoff plus ground-water evapotranspiration. In the case of a stream drainage basin, total ground-water recharge would be equal to stream base flow plus ground-water evapotranspiration.

An earlier study on ground water in the Delmarva Peninsula by Cushing, Kantrowitz, and Taylor (1973, p. 35) indicated that the average base flow derived from streamflow-hydrograph separation coincides with the value obtained from the 50-percent flow-duration point. Table 2 shows that out of 2,922 observations of measured streamflow for 1944-52 at the Glen Burnie gaging station, the stream-stage mean daily values ranged from 3.6 to 66.0 ft^3/s (cubic feet per second) and the 50th percentile daily value was 7.4 ft^3/s. Cushing, Kantrowitz, and Taylor (1973) estimated base flow for the Sawmill Creek drainage basin area at Glen Burnie to be 1.48 $(ft^3/s)/mi^2$ (cubic feet per second per square mile); base flow for the entire 5.0-mi^2 drainage-basin area at Glen Burnie is 7.4 ft^3/s, or 20.1 in/yr. Thus, the total ground-water-recharge rate calculated using this method was 20.1 in/yr plus ground-water evapotranspiration.

The two values of the long-term average ground-water recharge for the Sawmill Creek drainage basin, derived using different methods, are in reasonably close agreement, which strengthens confidence in their accuracy. Additionally, they are within the range of values obtained for small study areas in other Coastal Plain localities. For example, Johnston

Table 2. — Flow-duration analysis of Sawmill Creek at Glen Burnie for 1944-52

[Analysis based on mean daily values; ft^3/s = cubic feet per second]

Lower class limit of flow (ft^3/s)	Frequency (number of days)	Cumulative frequency (number of days)	Percent cumulative frequency
0.0	0	2,922	100.00
3.6	3	2,922	100.00
3.9	3	2,919	99.90
4.3	26	2,916	99.79
4.7	130	2,890	98.80
5.1	205	2,760	94.46
5.6	302	2,555	87.44
6.1	402	2,253	77.10
6.7	315	1,851	63.35
7.3	389	1,530	52.57
8.0	305	1,147	39.25
8.7	242	842	28.52
9.5	78	600	20.53
10.0	79	522	17.86
11.0	117	443	15.16
12.0	151	326	11.16
14.0	47	175	5.99
15.0	37	128	4.39
16.0	32	91	3.11
18.0	10	59	2.02
19.0	12	49	1.68
21.0	10	37	1.27
23.0	7	27	0.92
25.0	2	20	0.68
27.0	6	18	0.62
30.0	3	12	0.41
33.0	3	9	0.31
39.0	1	6	0.21
42.0	1	5	0.17
51.0	2	4	0.14
66.0	2	2	0.07

95th percentile = 5.1 ft^3/s
75th percentile = 6.2 ft^3/s
50th percentile = 7.4 ft^3/s
25th percentile = 9.1 ft^3/s
5th percentile = 14.6 ft^3/s

(1976, p. 23) reported values of ground-water recharge for several small drainage basins in Delaware ranging from 15 to 16 in/yr (calculated by using the base-flow-separation method), to 14 to 26 in/yr (calculated by using the average decline rate of the water table based on the Theis method) (Theis, 1937, p. 566). Rasmussen and Andreasen (1959, p. 94) reported ground-water recharge values for the Beaverdam Creek study area near Salisbury, Maryland, to range from 15 to 27 in/yr.

NATURAL DISCHARGE

Ground-Water Runoff to Streams

Sawmill Creek generally acts as a drain and derives a large part of its water from the unconfined aquifer. The Sawmill Creek gaging station at Glen Burnie was constructed in 1943 and continuously recorded stream discharge to 1952 when it was discontinued. The station was reestablished in 1983 and continuously measured discharge to the present (1990). Several methods are available to separate the streamflow hydrographs into ground-water runoff or base flow, the part that sustains the streamflow, and surface runoff, the part that collects in the stream channel. A method described by Riggs (1963) was used in this investigation to make the hydrograph separation for sections of the hydrographs with an extended recession period. The method basically consists of constructing a master base-flow recession curve and overlaying it on the streamflow hydrographs to make the separation. First, a streamflow-discharge measurement taken after 5 days without rain is plotted against a discharge measurement taken after 15 days without rain; secondly, a discharge measurement taken after 10 days without rain is plotted against a discharge measurement taken after 20 days without rain, and so on if measurements are available. It was assumed that the stream was at base flow 5 days after cessation of rainfall. Plotted on log-log paper, an average curve was drawn through these points. From this plot, points representing recession of the base flow were obtained and a plot of base flow against time of recession, the master base-flow recession curve, was constructed on semilog paper (fig. 6).

For sections of the streamflow hydrograph with shorter recession periods, where the Riggs (1963) method is not applicable, a rating curve of ground-water level versus base flow was used for hydrograph separation. The rating curve was constructed using the ground-water level of well Ad 104 for periods when it was obvious from the precipitation records of the BWI weather station and streamflow hydrographs of the Glen Burnie gaging station that only base flow was present in the stream. Rorabaugh (1960, p. 315) indicates that after sufficient time has elapsed, all but the first term in the ground-water-level recession equation become very small and may be neglected. The ground-water-level recession, therefore, plots as a straight line on a semilog plot after a critical period elapses. The plot in figure 7 was made disregarding the critical time period and this partly explains the scatter of the data points. Although the curves used in both methods are approximate, they provide a realistic basis for hydrograph separation. The streamflow hydrograph for June 1984 to May 1985 shown in figure 8 was separated using both methods. The resulting base flow ranges from 3.4 to 0.28 ft^3/s.

Evapotranspiration

The potential evapotranspiration rate used in this study was calculated by the Thornthwaite and Mather (1957) method. Its seasonal variation was based on seasonal fluctuations of air temperature, type of soil, and type of vegetation growing in the region. Using monthly average air-temperature data from the BWI station, evapotranspiration values for 1955-85 and 1984-85 were calculated to be 29 and 27 in/yr, respectively. These values are for the total evapotranspiration and are comparable to the total evapotranspiration (23 and 26 in/yr) used by Johnston (1976). Ground-water evapotranspiration is that portion of water which is removed from the saturated zone through the roots of plants and is a fraction of the total evapotranspiration. Ground-water evapotranspiration under stabilized conditions is usually calculated indirectly as what is left of recharge after base flow is subtracted. Earlier studies accepted values for ground-water evapotranspiration that gave the best estimate of base flow, which ranged from 40 percent (Willey and Achmad, 1986) to 50 to 70 percent of the total evapotranspiration (McGreevy and Sloto, 1980). For the Sawmill Creek and Marley Creek basins, the ground-water evapotranspiration that gave the best estimate of base flow was a maximum of 18 in/yr, or about 65 percent of the total evapotranspiration.

However, Ripple, Rubin, and van Hylckama (1972) indicated that the rate of ground-water evapotranspiration varies with depth to the water table. They found that to a certain depth, the evapotranspiration rate was at a maximum and then gradually decreased to zero. In the Sawmill and Marley Creeks basin, it was assumed that ground-water evapotranspiration decreases linearly with depth (McDonald and Harbaugh, 1984, p. 137, fig. 42). Ground-water evapotranspiration was calculated using an equation similar to the equation used to calculate a head-dependent flux boundary (Franke, Reilly, and Bennett, 1984, p. 9). Field documentation for these changes was difficult to obtain. However, by assuming that the roots of plants in the area do not reach deeper than 8 ft (Wilson and Wiser, 1974, p. 271), the extinction-depth interval was set uniformly at 3 to 8 ft (Willey and Achmad, 1986). Using the extinction-depth interval of 3 to 8 ft and a maximum ground-water evapotranspiration

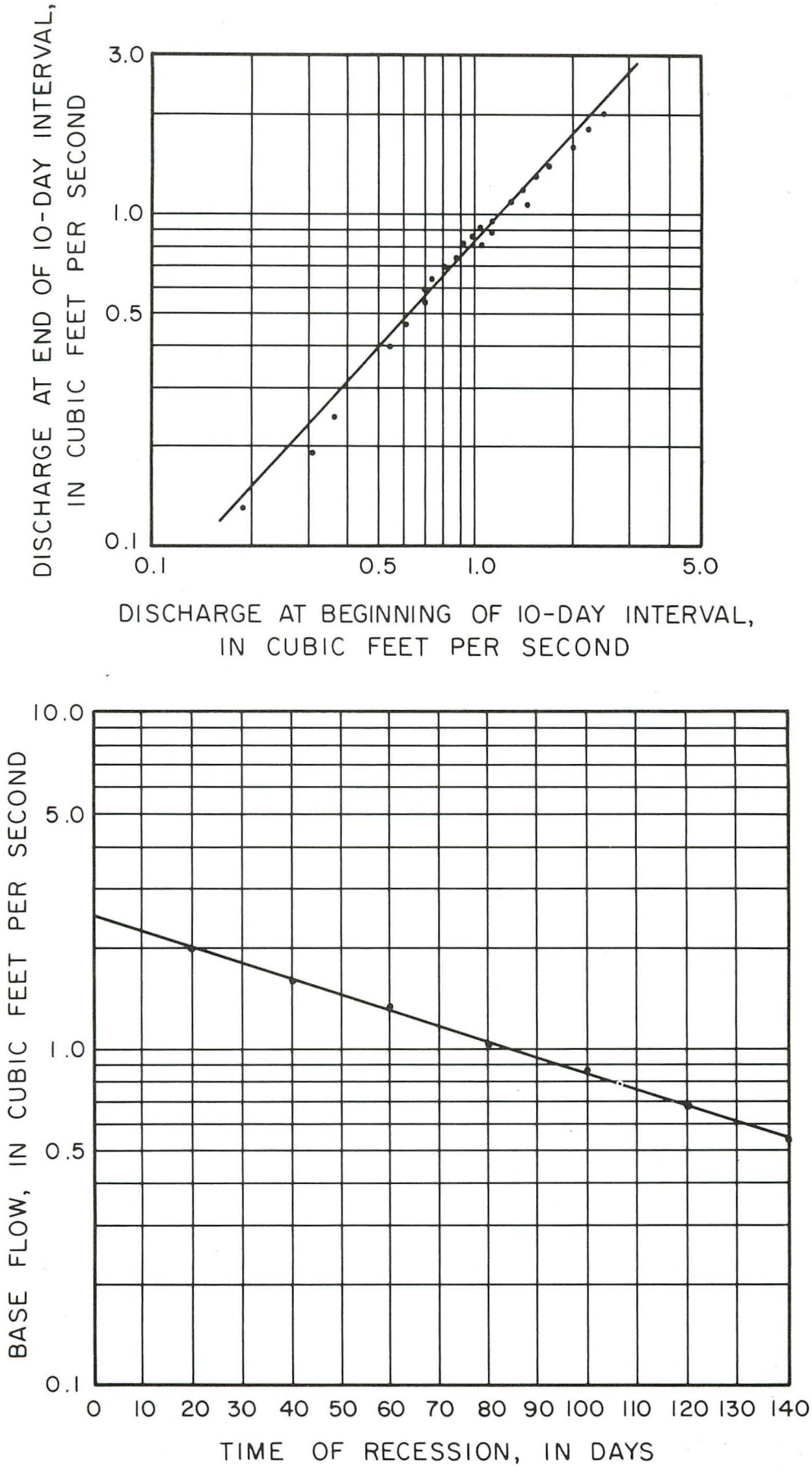


Figure 6. — Method of preparing base-flow recession curve of Sawmill Creek at Glen Burnie using streamflow hydrographs recorded during 1983-85.

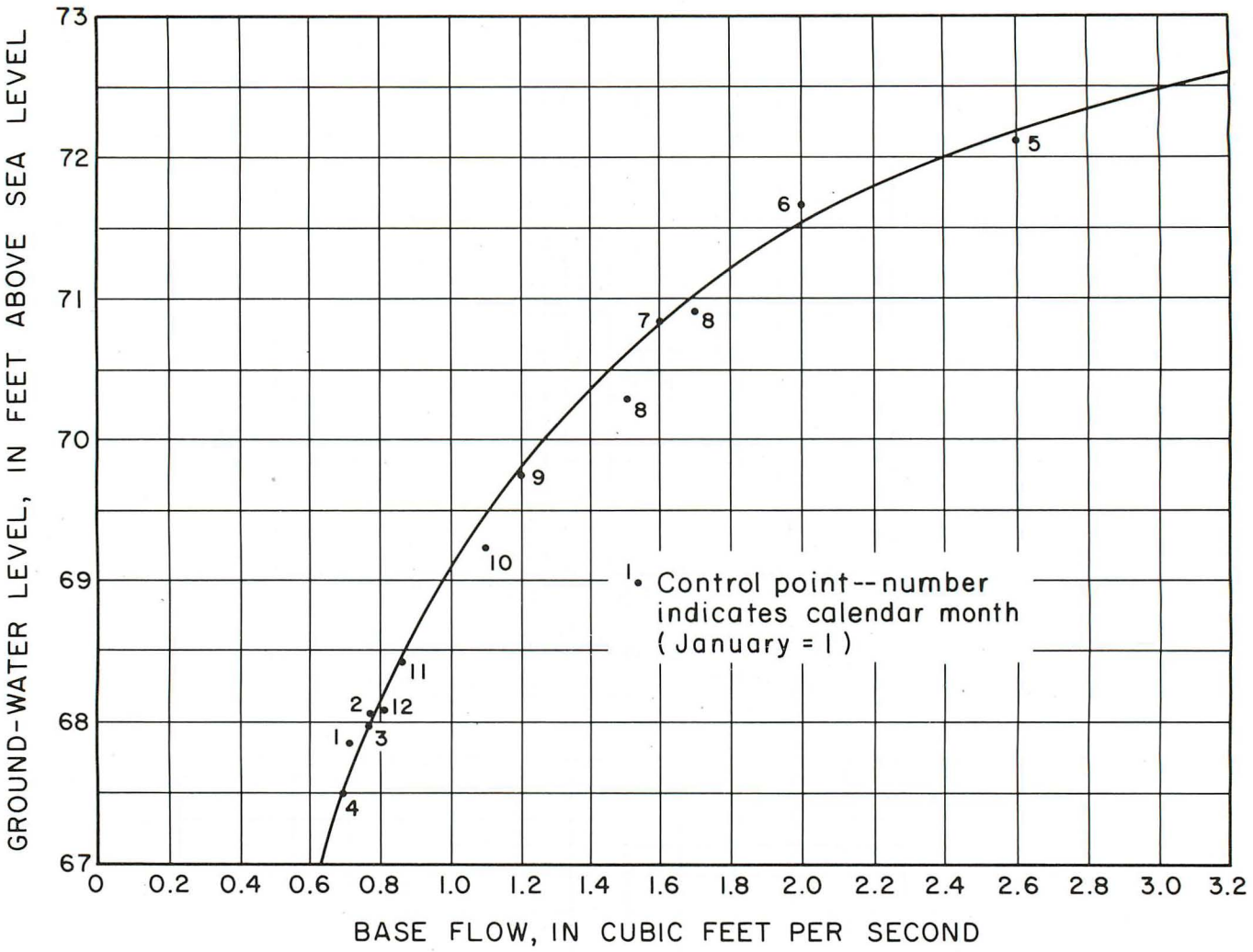


Figure 7. — Rating curve comparing ground-water levels measured in well Ad 104 and base flow of Sawmill Creek at Glen Burnie for 1984-85.

rate of 18 in/yr, the effective ground-water evapotranspiration for the Sawmill Creek and Marley Creek basins was calculated to be 4.59 in/yr, which is in the range of the ground-water evapotranspiration (3 in/yr) used by Johnston (1976) for several small Coastal Plain basins in Delaware, and the ground-water evapotranspiration (9.72 in/yr) used by Rasmussen and Andreasen (1959) for the Beaverdam Creek basin near Salisbury, Maryland.

HYDROLOGIC PROPERTIES

The hydrologic properties used in this study were derived from earlier studies (Brookhart, 1949; Mack, 1962; Mack and Achmad, 1986) and updated using hydrologic information obtained from wells drilled during the investigation. In the process of calibrating the flow model, values of the hydrologic properties at some locations in the model area were adjusted.

Lower Patapsco Aquifer

The confined lower Patapsco aquifer has an aggregate sand thickness of 100 to 150 ft and is capable of well yields ranging from 0.5 to 2 Mgal/d. Mack and Achmad (1986, p. 39) reported transmissivity values ranging from 1,000 to 6,000 ft^2/d (feet squared per day). Transmissivity values obtained from aquifer tests conducted at Bicycle Path Greenway ranged from 3,700 to 4,400 ft^2/d, and from 4,100 to 6,400 ft^2/d at the Vocational Technical School. These values closely match transmissivities for the respective areas reported earlier. In this study, the lower Patapsco aquifer is areally divided into several zones of transmissivity ranging from 1,500 to

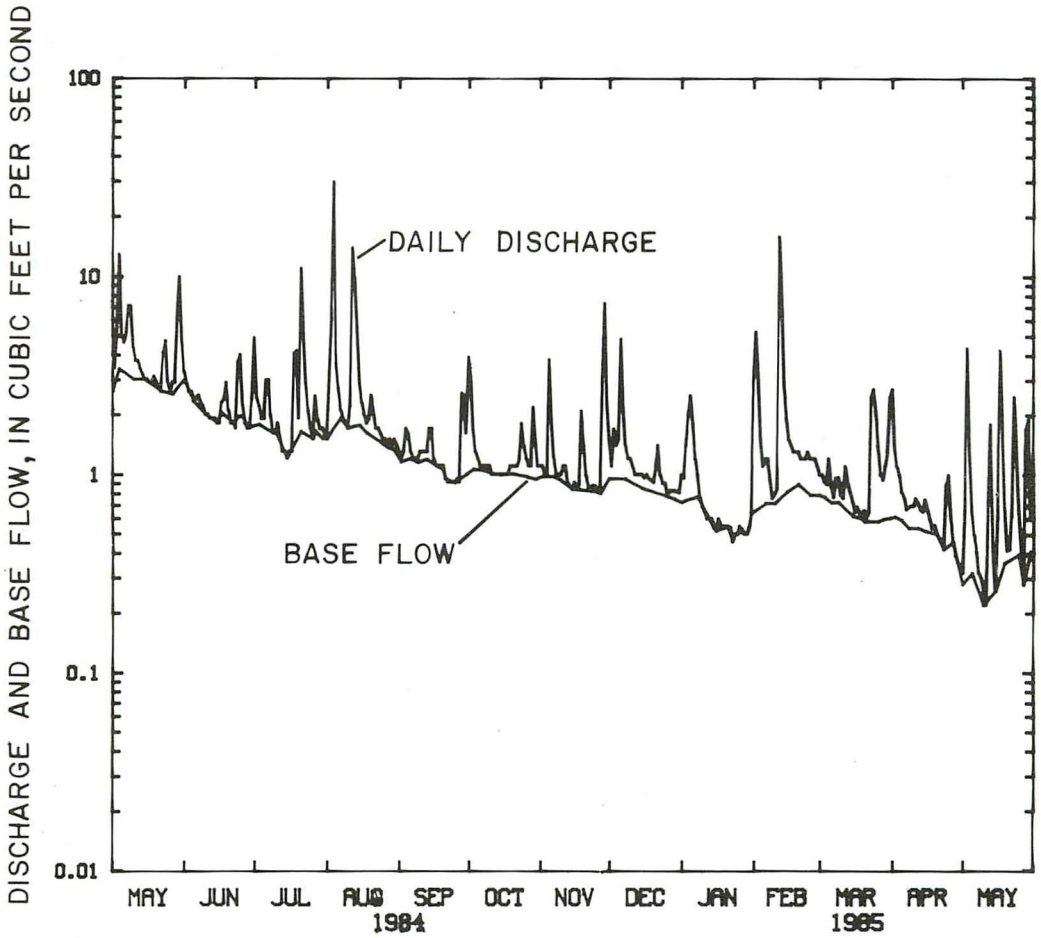


Figure 8. — Daily discharge and base flow of Sawmill Creek at Glen Burnie for 1984-85.

6,000 ft²/d (fig. 9), based on the transmissivity values used in the earlier model and results of aquifer tests.

Storage coefficients from aquifer-test results reported by earlier investigators were in the range of 10^{-5} (Brookhart, 1949; Mack, 1962; Mack and Achmad, 1986), and a value of 0.2×10^{-5} was used in this study. The storage coefficient of the lower Patapsco aquifer was assumed to be uniform.

Confining Unit Overlying Lower Patapsco Aquifer

The confining unit separating the lower Patapsco aquifer from the upper Patapsco aquifer consists of clayey layers of varying thickness and sand content and has a low vertical hydraulic conductivity. The confining unit covers an area extending from Washington, D.C., to Baltimore City, and includes parts of Prince George's, Baltimore, and Anne Arundel Counties. In this extended area (2,500 mi²), the confining unit ranges in thickness from 25 to 200 ft and in an earlier study was assigned an average vertical leakance (defined as conductivity divided by thickness) of 10^{-9} s^{-1} (second^{-1}) (Mack and Achmad, 1986). In contrast, the confining unit in the Glen Burnie area (40 mi²) is thinner, ranging from 30 to 35 ft thick (fig. 4) and is therefore assigned a leakance of 10^{-8} s^{-1}. Areally, the confining unit becomes more sandy toward the northeastern boundary of the model area. It is therefore more permeable in these areas and is assigned a leakance of 10^{-6} s^{-1}.

Upper Patapsco Aquifer

The unconfined upper Patapsco aquifer is thin in the northwestern part of the study area and thickens to the southeast. The transmissivity of an aquifer is the product of hydraulic conductivity and saturated thickness. Based on the results of aquifer tests conducted using wells Bd 152 and Bd 160, the hydraulic conductivity of the upper Patapsco aquifer ranges from 36 to 90 ft/d (feet per day), which is similar to values (40 to 120 ft/d) reported by earlier investigators for the Sawmill, Harundale, and Dorsey Road well fields (Brookhart, 1949; Mack, 1962; Hansen, 1972).

Initially, transmissivities for other locations in the study area were calculated using a relation (based on Darcy's law)

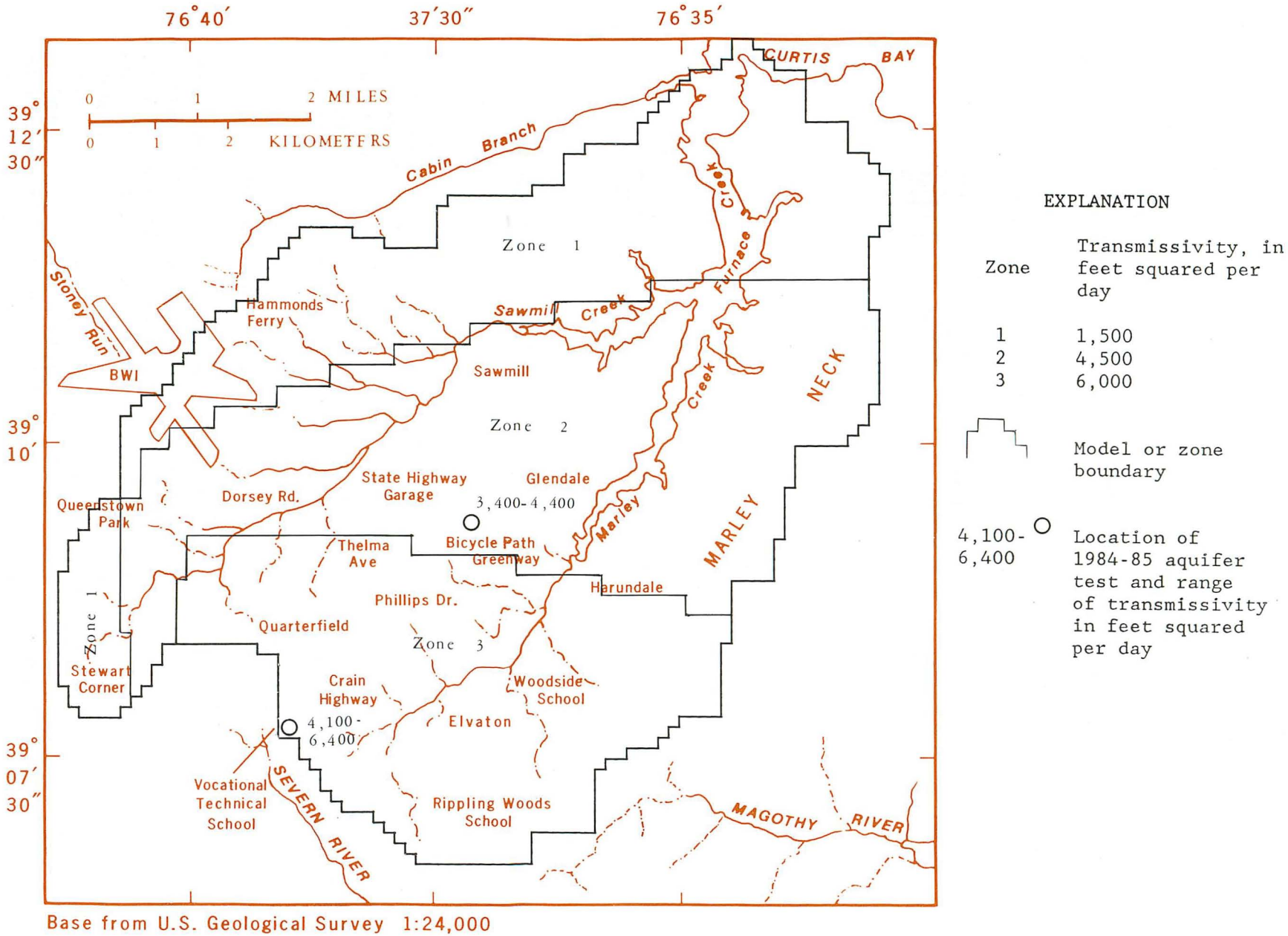


Figure 9. — Transmissivity of the lower Patapsco aquifer.

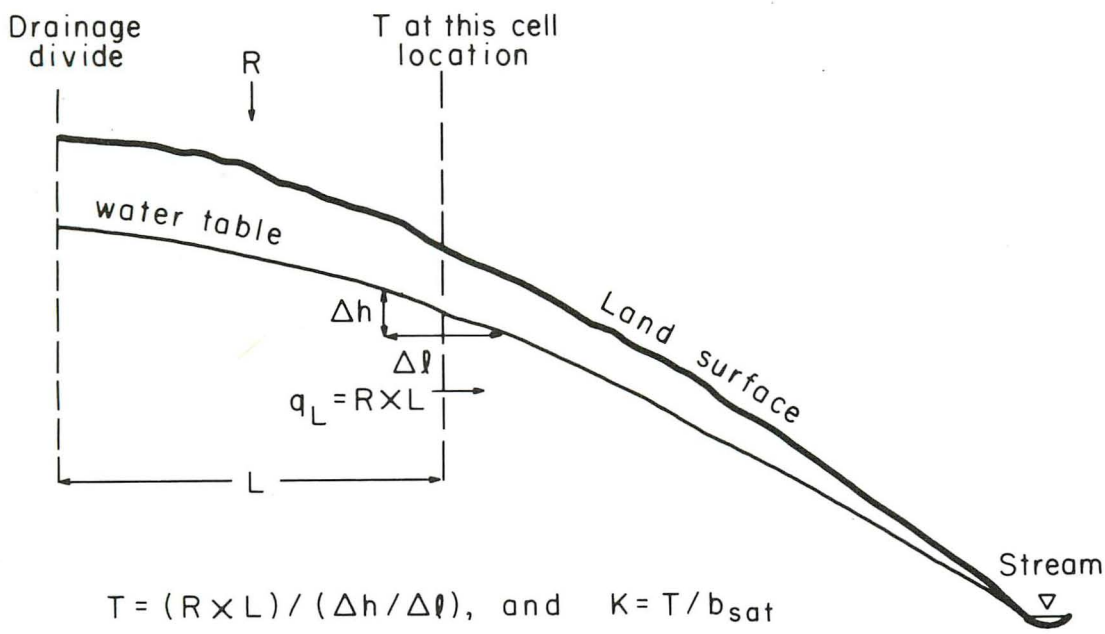
between the ground-water flow gradient ($\Delta h/\Delta l$), recharge rate (R), transmissivity (T), and distance to the drainage divide (L) (Jacob, 1945). The entire study area was divided into cross sections constructed along flow lines that stretch from the flow divide to a stream. Under steady-state conditions, along each flow line the transmissivity in a cell was calculated as:

$$T = (R \times L)/(\Delta h/\Delta l)$$

(McGreevy and Sloto, 1980, p. 12-14; Willey and Achmad, 1986, p. 17-20). Figure 10 shows the method used in generating the initial transmissivity and hydraulic conductivity. Conductivity (K) for each cell was calculated by dividing the transmissivity (T) by the saturated thickness (b_{sat}) in the cell. The hydraulic conductivities obtained range from 8 ft/d for cells on the flow divide, to 145 ft/d for cells representing the Chesapeake Bay tributaries, with an average value of 33 ft/d. The bay tributaries and some of the non-tidal stream reaches are covered with alluvium of high permeability (Glaser, 1976); however, these deposits are thin (about 5 ft) compared to the 100-ft-thick upper Patapsco aquifer (table 1). It is unlikely that the alluvium could have caused the relatively high average hydraulic conductivity, calculated by Jacob's method, for the water-table aquifer in the streams and bay tributaries. Thus, the upper Patapsco aquifer was assumed homogeneous and was assigned an average hydraulic conductivity of 33 ft/d. No specific yield value was reported for the upper Patapsco aquifer; it was estimated to be 0.11 using a convergent approximations method (Rasmussen and Andreasen, 1959).

Stream System

The amount of flow through the stream-bottom material differs from location to location depending upon differences between the water table, the stream stage, and the hydraulic conductivity of the stream-bottom material. There are no field measurements of hydraulic conductivity for the Sawmill



$T = (R \times L)/(\Delta h/\Delta l)$, and $K = T/b_{sat}$

where,

T = Initial transmissivity at a specific cell location
R = Uniform recharge rate
L = Distance from divide
$\Delta h/\Delta l$ = Average head gradient between adjacent cells
K = Hydraulic conductivity
b_{sat} = Saturated thickness
q_L = Ground-water recharge along L

Figure 10. — Method of calculating initial transmissivity and hydraulic conductivity of the upper Patapsco aquifer.

Creek bottom material. Based on values used by other investigators (Willey and Achmad, 1986, p. 17), the value for stream-bottom vertical hydraulic conductivity (K_v) was assumed to be about 1 ft/d, with a streambed thickness (b) of 1 ft. The value of streambed conductance (C) (where $C = K_v WL/b$) ranges from 60 to 2,592 ft^2/d, or 0.0007 to 0.03 ft^2/s (foot squared per second), depending on the length (L) and width (W) of the stream reach.

PUMPAGE

In the Glen Burnie area, most of the ground water for public supply is withdrawn from wells screened in the lower Patapsco aquifer. The location of the well fields is shown in figure 2. The Sawmill well field is the oldest public-supply well field; it was pumped at about 33,000 gallons per day (gal/d) in 1933. Gradually, as the demand for water increased, additional wells had to be drilled. In 1955, the Sawmill well field pumpage was 0.7 Mgal/d. The Harundale well field was developed in 1948, and in 1955 it was pumped at 0.7 Mgal/d. The Dorsey Road well field was developed in 1955 and was pumped at 0.5 Mgal/d by 1958. Several individual wells were drilled in other locations to meet local demands. The following production wells were completed in 1969: Glendale, Phillips Drive, Elvaton, and Crain Highway. Pumping from the Thelma Avenue and Quarterfield well fields started in 1971. In 1985, the Stevenson Road and Telegraph Road well fields were added to the public-supply system; these well fields are located on the outskirts of the Glen Burnie area, outside of the Sawmill Creek and Marley Creek basins.

Total pumpage and the pattern of aquifer usage have changed with increased demand. Early demands were for relatively small quantities of ground water that could be obtained from shallower wells. As demand for water increased, wells were drilled deeper to get higher yields and to avoid possible contamination. In 1945, total pumpage from the Glen Burnie well fields was about 0.18 Mgal/d; in 1985, total pumpage was about 9.70 Mgal/d (fig. 11). The total 1985 pumpage from the Stevenson Road and Telegraph Road wells was 1.8 Mgal/d.

Increased pumpage from the Glen Burnie area well fields has affected the flow characteristics of Sawmill Creek. Average base flow measured at the Glen Burnie gaging station at Sawmill Creek for 1944-52 was 7.4 ft^3/s. Base flow es-

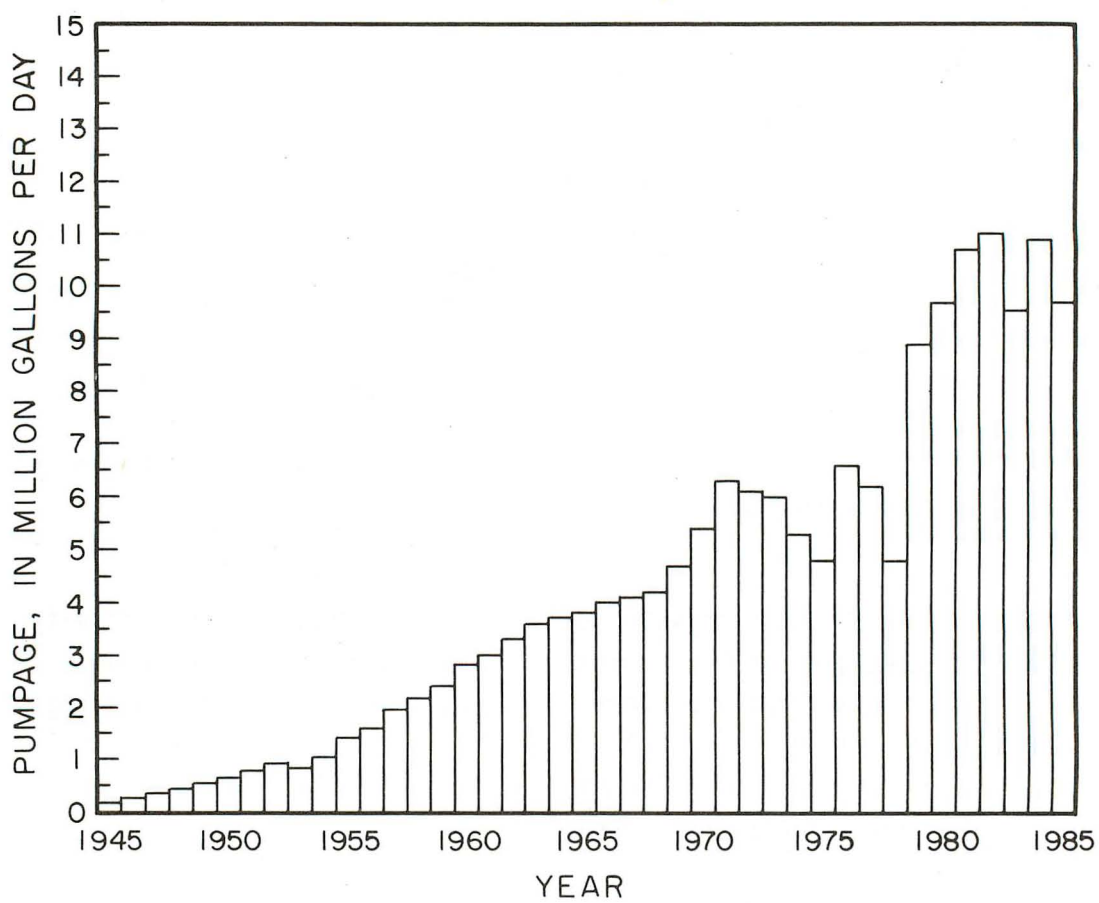


Figure 11. — Total annual ground-water withdrawals from the Glen Burnie well fields in the Sawmill Creek and Marley Creek basins, from 1945 to 1985.

timated from river-stage records was 3.2 ft^3/s in May 1984, 1.0 ft^3/s in October 1984, and 0.5 ft^3/s in May 1985 (fig. 7). Although water year 1984-85 had a precipitation deficiency of 9.6 in/yr (31.9 versus 41.5 in/yr), the decrease in average base flow since 1952 is caused, at least in part, by increased pumpage.

Pumpage data were obtained from water-use records filed at the Anne Arundel County Department of Utilities and the Maryland Water Resources Administration. Several of the pumpages were reported as well-field totals rather than by individual wells, which are located hundreds to thousands of feet apart. In these cases, the pumping rate used in the model analysis for simulating each individual well was approximated in proportion to the capacity of the pump used in the well, keeping the total simulated well-field pumpage the same as the total recorded pumpage.

WATER QUALITY

Water samples were collected from nine wells drilled during the investigation and from several locations along Sawmill and Marley Creeks. These samples were sent to the U.S. Geological Survey laboratory in Denver, Colorado, for chemical analysis of the major dissolved constituents (tables 3 and 4). The ground-water samples were collected from wells screened in the upper and lower Patapsco aquifers shortly after being drilled in 1983-85.

Table 3 shows that concentrations of major ions in ground water from the upper and lower Patapsco aquifers are generally similar. The pH values of the ground water are acidic, ranging from 4.5 to 5.9. Chloride concentrations in seven of the nine wells range from 1.6 to 7.0 mg/L (milligrams per liter). In two of the wells, Bd 156 and Bd 159, chloride concentrations are 26.0 and 21.0 mg/L, respectively. The higher chloride concentration could have come from dissolved road salt that drained into the water-table aquifer. The nitrate plus nitrite (as N) concentrations range from 0.58 to 5.40 mg/L, but the lowest value is an exception; the remaining eight wells had values of 2.6 mg/L or higher. Bachman (1984, p. 33) suggests that the natural level of nitrate in ground water is generally less than 1 mg/L (as N). Iron concentrations range from 13 to 170 μg/L (micrograms per liter) and are well below the recommended secondary drinking-water limit of 300 μg/L; manganese concentrations are generally below the recommended secondary drinking-water limit of 50 μg/L, except in well Bd 156 which is 54 μg/L (U.S. Environmental Protection Agency, 1986).

During the spring and fall of 1984, surface-water samples were collected from several locations along Sawmill and Marley Creeks. Chemical analyses for major dissolved constituents are shown in table 4. These limited data suggest that dissolved-solids concentrations in stream water in the study area is typically higher than the concentrations found in the shallow ground-water system. Since it was beyond the scope of this investigation, no attempt was made to study the distribution and transport of chemical constituents.

SIMULATED HYDROLOGIC EFFECTS OF DEVELOPMENT

Digital modeling provides a means for simulating flow of ground water in an aquifer system. A ground-water flow model integrates the various components of the flow system by taking into account the interaction between the aquifer's hydraulic properties, geometry, boundary conditions, recharge, discharge, and ground-water withdrawals. In this study, the U.S. Geological Survey modular ground-water flow model (McDonald and Harbaugh, 1984) was used to simulate the aquifer system of the Sawmill Creek and Marley Creek basins. A quasi-three-dimensional method was used to solve a set of partial-differential equations that describe the head distribution in the aquifer system. The derivation assumed nonsteady-state, three-dimensional flow of a homogeneous fluid in a nonhomogeneous aquifer system with leakage across a confining unit.

DESCRIPTION OF THE FLOW MODEL

Framework of the Conceptual Model

The Patapsco aquifer system in the Sawmill Creek and Marley Creek drainage basins was modeled as a two-aquifer, saturated ground-water flow system with a leaky confining unit separating the aquifers. The total area studied was about 62.5 mi^2, which was divided into an 84-column by 83-row grid of uniformly spaced cells. The cells were 500 ft long on each side. The area modeled was about 40 mi^2, including the drainage basins of Sawmill Creek and Marley Creek. The boundary conditions assigned to the model were selected to approximate the natural hydrologic boundaries. The 1965

Table 3. — Chemical analyses for major dissolved constituents in ground water from the Patapsco aquifers, 1983-85

[mg/L = milligrams per liter; µg/L = micrograms per liter;
µS/cm = microsiemens per centimeter at 25 degrees Celsius;
°C = degrees Celsius]

Well number	Date sampled	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, lab (mg/L as CaCO3)	Sulfate, dissolved (mg/L as SO4)	Chloride, dissolved (mg/L as Cl)	Nitrate plus nitrite, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (mg/L as Mn)	Dissolved solids (mg/L)	Screened interval (feet below land surface)
Ad 102	12-09-83	43	5.9	17	2.7	1.2	2.4	1.3	--	0.7	5.0	2.60	0.01	15	13	--	80-90
Bd 152[a/]	09-13-84	56	5.5	18	2.1	1.5	3.3	1.5	3.0	1.0	6.0	3.10	.01	75	40	26	84-94
Bd 154	09-24-84	23	5.1	18	1.1	1.5	.3	1.3	3.0	1.2	2.2	.58	.01	55	10	17	167-177
Bd 155	10-09-84	56	5.9	17	3.2	1.1	2.6	1.0	3.0	.2	4.4	3.50	< .01	46	13	22	145-155
Bd 156	10-23-84	125	5.6	15	4.1	2.8	12.0	2.5	3.0	.7	26.0	3.80	< .01	150	54	58	160-170
Bd 157	10-31-84	32	5.8	15	2.0	.7	2.3	.7	3.0	.4	2.8	5.20	.09	170	19	19	165-175
Bd 158	01-25-85	42	4.9	15	2.4	1.2	4.2	1.5	2.0	.3	7.0	2.60	.02	23	13	20	174-184
Bd 159[a/]	01-24-85	135	5.2	14	7.2	3.6	9.7	2.2	4.0	1.0	21.0	5.40	< .01	13	42	55	89-99
Bd 160[a/]	03-28-85	81	4.5	14	4.5	1.9	4.6	1.4	2.0	.3	1.6	5.10	< .01	60	30	23	88-98

[a/] Screened in the upper Patapsco aquifer.

Table 4. — Chemical analyses for major dissolved constituents in stream water from the Sawmill Creek and Marley Creek gaging stations, May and November 1984

[mg/L = milligrams per liter; µg/L = micrograms per liter; µS/cm = microsiemens per centimeter at 25 degrees Celsius; ft³/s = cubic feet per second; °C = degrees Celsius]

Date sampled	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity lab (mg/L as CaCO3)	Sulfate, dissolved (mg/L as SO4)	Chloride, dissolved (mg/L as Cl)	Nitrate plus nitrite, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Dissolved solids (mg/L)	Streamflow, instantaneous (ft^3/s)
Sawmill Creek at Glen Burnie																
05-22-84	128	6.6	20	9.1	2.0	8.9	2.4	12	22	16	0.43	<0.01	310	37	72	2.60
11-27-84	151	6.8	3	10.0	2.6	12.0	3.7	11	27	17	.97	< .01	260	46	85	.85
Sawmill Creek at Crain Highway																
05-22-84	194	6.6	21	17.0	3.4	13.0	2.5	32	19	23	1.60	< .01	300	56	100	5.50
11-27-84	193	6.5	10	15.0	3.7	14.0	2.8	23	21	23	2.10	< .01	190	58	100	3.00
Marley Creek at Harundale																
05-22-84	174	7.1	25	13.0	2.1	14.0	2.0	25	17	24	0.91	< .01	230	48	93	3.90
11-27-84	165	6.7	5	11.0	2.4	15.0	2.1	18	16	25	1.20	< .01	270	30	90	2.40

flow condition was chosen as the initial condition because it reflected a relatively stabilized condition.

In the model, the underlying Arundel Clay was assumed to be a no-flow boundary forming the lowermost external boundary of the flow system. The Patuxent aquifer was excluded from the model because the flux exchange across the relatively tight and thick Arundel Clay was calculated to be minimal and was assumed to be negligible in this model. For example, a 20-ft head difference across the Arundel Clay [vertical hydraulic conductivity of 5.9×10^{-7} ft/d (Mack and Achmad, 1986, p. 37)] applied over a 5-mi^2 area of influence of the Patuxent well field at Dorsey Road would cause an exchange of flux in the lower Patapsco aquifer of about 82 gal/d, or 0.6 Mgal over 20 years. Also, the simulated flow in the Patuxent aquifer would primarily depend upon artificial boundary conditions that would be difficult to verify because of a scarcity of data in the area studied.

The lower Patapsco aquifer was modeled as a confined aquifer that could discharge to or receive recharge from the upper Patapsco aquifer through leakage across the confining unit. The lower Patapsco aquifer also could discharge to or receive recharge from the lateral boundaries. The mostly clayey deposits between the upper and lower Patapsco aquifers were modeled as a leaky confining unit. The magnitude and direction of flow across the confining unit depends upon the difference in head between the aquifers and the vertical hydraulic conductivity and thickness of the confining unit. The upper Patapsco aquifer was modeled as an unconfined aquifer receiving recharge from precipitation. A uniform recharge rate was imposed over the entire basin simulating ground-water recharge to the system. Creeks were modeled as partially penetrating streams that act as drains in the unconfined aquifer. The areas of tidal freshwater of the bay tributaries were modeled as constant-head boundaries of the water-table aquifer.

Assumptions and Limitations

Because the conceptual model is an approximation of the aquifer system, simplifying assumptions must be made to facilitate a mathematical simulation of the system. The following assumptions concern the application of Darcy's law, the numerical approximations to mathematical solutions, and the simplification of the ground-water equation of motion:

1. The physical properties of the system do not change with time.
2. Change in ground-water storage will occur instantaneously with change in hydraulic head.
3. Ground-water flow is horizontal in the aquifer and vertical in the confining unit. No head change is calculated for the confining unit, but its hydrologic properties are used to estimate the flow moving across it.
4. Recharge is uniform over the basin area.
5. Stream stages are fixed for each stream cell and remain unchanged for the entire simulation period.
6. Ground-water evapotranspiration is calculated as a function of potential evapotranspiration; it decreases with increasing depths and ceases at some maximum depth.
7. The areal extent of the study area has limitations. The grid size must be small enough to give proper definition to the stream in a cell so that stream leakage will better simulate base flow. On the other hand, the areal extent must be large enough to incorporate regional hydrology.

Boundary Conditions

The flow model constructed for this study is enclosed by boundary surfaces that define the external geometry of the modeled flow system. The model boundaries were located to correspond as nearly as possible with the natural hydrologic boundaries. The boundary conditions assigned to the model were specified based on flow characteristics at each boundary surface (fig. 12). The terminology and description of the boundary conditions mentioned in this report follow definitions described by Franke, Reilly, and Bennett (1984).

Upper Patapsco aquifer lateral boundary

The periphery of the model grid was drawn to coincide with the boundary of the Sawmill Creek and Marley Creek drainage basins. The upper Patapsco aquifer thins toward the northwest and is apparently discontinuous near the northwestern border of the model; the northwestern border was assigned no-flow conditions. The northeastern limit of the model coincides with the areas of tidal surface water, which are discharge areas for the system. Assuming that the water table below the tidal areas remains constant, the northeastern boundary nodes were assigned constant-head boundary conditions. The southeastern boundary of the model was located coincident with the topographic divide along Marley Neck, and the southwestern limit of the model coincides with the topographic divide between Sawmill Creek and Stoney Run. It is assumed that the topographic divide closely approximates the ground-water divide. Because it was assumed that there is no exchange of flux across the divide, no-flow conditions were assigned to the southeastern and southwestern boundaries.

A topographically defined ground-water divide may be assumed to be a no-flow boundary if the unconfined aquifer is unstressed. In the model, the unconfined upper Patapsco aquifer was not directly stressed by pumping. The effects of pumping on the confined lower Patapsco aquifer were transmitted to the unconfined aquifer through leakage across the confining unit. The result was a lowering of the water table in cells directly above the pumping cells. Because the pumping cells were located in the central part of the model grid, the boundary cells of the unconfined aquifer were little affected by pumping.

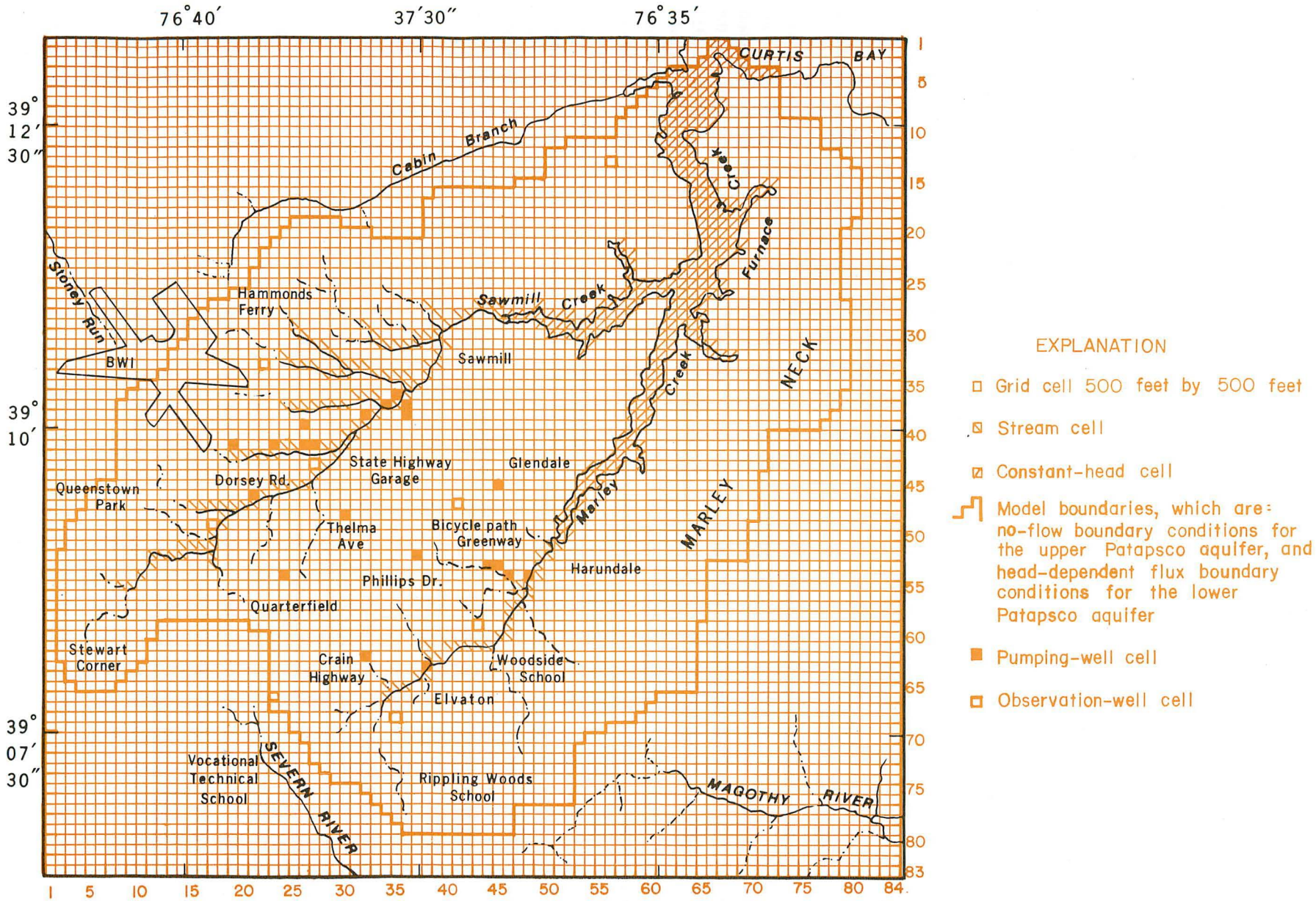


Figure 12. — Finite-difference grid and boundary conditions for the Patapsco aquifers used in the model.

Stream boundary

Model cells that include the stream network were assigned head-dependent flux boundary conditions simulating the stream-aquifer interaction. A head-dependent flux boundary calculates flux (q) across the streambed as a product between the conductance (C) of the streambed material and the head difference between the stream stage (HR) and the water table (h) [$q = -C(HR - h)$ (McDonald and Harbaugh, 1984, p. 209-219)]. Conductance is calculated as $K(WL/b)$, where K is the vertical hydraulic conductivity, b is the thickness of the streambed material, and L and W are the length and width, respectively, of the stream reach in the stream cell. The water table is usually higher than the stream stage so that the calculated stream leakage is base flow. When the water table drops below the stream stage, the calculated stream leakage is inflow to the aquifer. When the water table drops below the bottom of the streambed, the stream leakage is calculated as a constant flux, and the amount of inflow into the aquifer is constant regardless of how far the water table has dropped below the streambed.

Uppermost boundary

The aquifer system receives recharge from precipitation, which in the model is designed as a specified-flux boundary condition (fig. 5). Uniform fluxes are transferred across the areal boundary surface of the unconfined aquifer cells. Three different ground-water recharge rates were used at specific periods during the simulation—namely, a long-term average, a 1984-85 short-term average, and a hypothetical 2-year drought recharge rate.

Lower Patapsco aquifer lateral boundary

The model boundary of the upper Patapsco aquifer was projected vertically downward truncating the lower Patapsco aquifer at locations where the boundary cells are not necessarily the natural boundaries. Thus, the boundary cells of the lower Patapsco aquifer are assigned head-dependent flux boundary conditions because the head distribution in the vicinity of the model boundary is readily obtainable and the amount of flux flowing across the boundary can be adjusted by changing the conductance of the boundary cells during calibration of the model. The head-dependent flux boundary condition calculates a flux equal to the head difference between the specified head, representing the natural boundary, and the water level at the boundary cell, multiplied by the average conductance of the lower Patapsco aquifer between the boundary cell and the site of the specified head (McDonald and Harbaugh, 1984, p. 343-346).

The specified head and conductance used in the calculation of boundary flux were chosen to estimate the natural boundary conditions. For example, the lower Patapsco aquifer crops out about 0.75 mi northwest of the model area. Assuming that water levels in the outcrop area remain constant, flux across the western and northwestern lateral boundary cells was calculated using the 1965 steady-state head distribution for the entire simulation period. Conductance of the western and northwestern boundary cells was calculated as

$$C = T_B(W/L),$$

or

$$C = 189 \text{ ft}^2/\text{d } (0.0021 \text{ ft}^2/\text{s});$$

where

T_B = transmissivity of the boundary material,
W = width of the cell, and
L = distance to the specified head.

In this calculation, transmissivity of the boundary material (T_B) is assumed to be the same as in the adjacent model cells (1,500 ft^2/d). Similarly, for the northeastern and eastern lateral boundary cells, specific heads were chosen at locations about 2 to 2.5 mi away where the lower Patapsco aquifer discharges into the Chesapeake Bay estuaries. Water levels in the discharge area were assumed to remain constant throughout the simulation period. Conductance for the eastern boundary cells was calculated to be 60 to 189 ft^2/d, or 0.0007 to 0.0022 ft^2/s, assuming that transmissivity of the boundary material is the same as in the adjacent model cells (1,500 or 4,500 ft^2/d).

To the south, the lower Patapsco aquifer extends far beyond the model boundary. Specified heads were chosen at a location about 3 mi away where they were assumed to remain constant. Conductance of the boundary material for the southern boundary was calculated to be 189 ft^2/d or 0.0022 ft^2/s, assuming that the transmissivity of the adjacent model cells (6,000 ft^2/d) applies to the boundary material extending 3 mi from the model area. For the steady-state simulation, specified heads for the southern boundary cells were obtained from the 1965 steady-state water-level distribution. For the transient simulation, boundary cells influenced by pumping from the surrounding area were stressed with outflow fluxes.

Outflow fluxes for the boundary cells influenced by nearby pumpage were estimated by multiplying head differences due to nearby pumpage across a 500-ft-grid length by the conductance of the boundary cell. The Theis nonsteady, radial-flow equation calculates drawdown (s_r) at a distance (r) from the center of a well pumping at a rate (Q) after time (t) as

$$s_r = \frac{Q}{4\pi T}\left[-0.5772 - \ln (r^2S)/(4Tt)\right]$$

(Lohman, 1972, p. 19).

In this equation, T and S are transmissivity and storage coefficient of the aquifer material between the pumping center and the model boundary, and r is taken to be the distance between the location of a nearby pumping center and the influenced boundary. The head difference across the 500-ft boundary cell influenced by nearby pumpage was calculated using the Theis equation for radius r and r+(500 ft) as $(s_r - s_{(r+500)})$. The outflow flux (q) across the boundary is calculated as

$$q = C\,(s_r - s_{(r+500)}),$$

where

C is the conductance of material in the vicinity of the boundary cell.

The boundary cells influenced by pumpages at the Severndale, Annapolis, Telegraph Road, and Stevenson Road well fields (fig. 1) extend from cell row 62, column 2 at the western boundary to cell row 52, column 69 at the eastern boundary of the model. Pumpage from the Patapsco aquifer began at the Severndale and Annapolis well fields in 1975 and at the Telegraph Road and Stevenson Road well fields in 1985. Starting with 1975, boundary cells influenced by the Severndale and Annapolis pumpages were treated as pumping cells with a total outflow flux of 0.30 Mgal/d. Likewise, starting with 1985, boundary cells influenced by pumping at the Telegraph Road and Stevenson Road well fields were treated as pumping cells with a total outflow flux of 0.95 Mgal/d. These pumpages are not shown in figure 11, but appear in the flow components of the mass balances (see section on "Transient Model").

Some caution is necessary in applying constant-head and specified-head boundary conditions because these boundaries, in the case of recharging conditions, can provide unlimited sources of water to the system and cause inaccurate simulations. Therefore, after the water levels and base flows were calibrated, the flow components of the mass balance were examined to determine whether the solution was reasonable.

MODEL CALIBRATION

The model was conceptualized based on the hydrogeology of the ground-water flow system. Before the model could be used for estimating the effects of development, it was tested for accuracy and consistency of performance under steady-state and transient-flow conditions. Model calibration is a complex process of trial and error in which hydrologic properties derived from well-field data and earlier studies must initially be used. Commonly, however, in order to match simulated ground-water levels and base flows with values obtained from field observations, some adjustments must be made, particularly in areas of the model where hydrologic properties are uncertain or lacking. The steady-state and transient calibrations are discussed separately for the sake of clarity, but in the process of model calibration, they are inseparable. By satisfying these two calibration conditions, the model reasonably represents the actual ground-water flow conditions of the Patapsco aquifer system in the Glen Burnie area.

Several simulations were made to determine the sensitivity of the model to the hydrologic properties being tested. Simulating higher transmissivity values produced a more even head distribution in the aquifers and less drawdown at pumped cells. Also, under steady-state conditions, head distributions in the two aquifers had a tendency to be more similar when the leakance of the confining unit was high. Sensitivity tests such as these were run to ensure that adjustments of the hydrologic properties were reasonable.

Initial Water-Level Conditions

Water levels used to calibrate the steady-state model should represent a stabilized condition. A period in which there is no pumping is an ideal steady-state period to simulate. However, because of the scarcity of water-level and hydrologic data for the prepumping period, a specific period during the development of the Patapsco aquifer system in the Glen Burnie area was chosen for the steady-state model calibration.

During 1960-70, the Patapsco aquifer system in the Glen Burnie area was pumped at rates ranging from 2.8 to 5.4 Mgal/d, a relatively slow pace that gradually increased by about 0.25 Mgal/d each year (fig. 13). Data show that water levels in well Ad 88 (Hammonds Ferry) during 1960-66 declined at a relatively slow rate and water levels in well Bd 91 (Dorsey Road) during 1965-70 declined even more slowly. The ground-water flow conditions during 1965 represented the least disturbed conditions for 1960-70 and, therefore, were used to calibrate the steady-state model. The simulated 1965 water levels obtained from the steady-state calibration were used as initial water levels for the transient simulations.

Steady-State Model

At the start of a simulation, the aquifer system should be under equilibrium conditions; otherwise, the results at the end of the simulation will include the effects of presimulation stress as well as stress imposed during the simulation. The steady-state model of the basin was intended to represent such initial equilibrium conditions. Under steady-state conditions, recharge is equal to discharge and water levels remain unchanged with respect to time. In the model constructed for this study, sources of inflow include natural ground-water recharge, interaquifer leakage, boundary inflow across confined aquifer boundaries, and stream leakage into the aquifer from some of the upstream reaches. Natural ground-water recharge is the part of the precipitation that percolates into and recharges the unconfined aquifer. Sinks or outflows include natural discharge into the bay tributaries and the stream reaches, evapotranspiration, and outflow through the boundary of the confined aquifer.

Some of the values assigned to the hydrologic properties were obtained from sources that were considered more reliable than others. A value from a less-reliable source was subjected to more adjustments during the process of calibration. For instance, transmissivity values used for the lower Patapsco aquifer were obtained from an earlier model covering a larger area of Anne Arundel County and calibrated for the same 1965 head distribution. Thus, the lower Patapsco transmissivity was consistent with the general hydrologic condition established by the earlier model (Mack and Achmad, 1986) and was the least adjusted. The steady-state

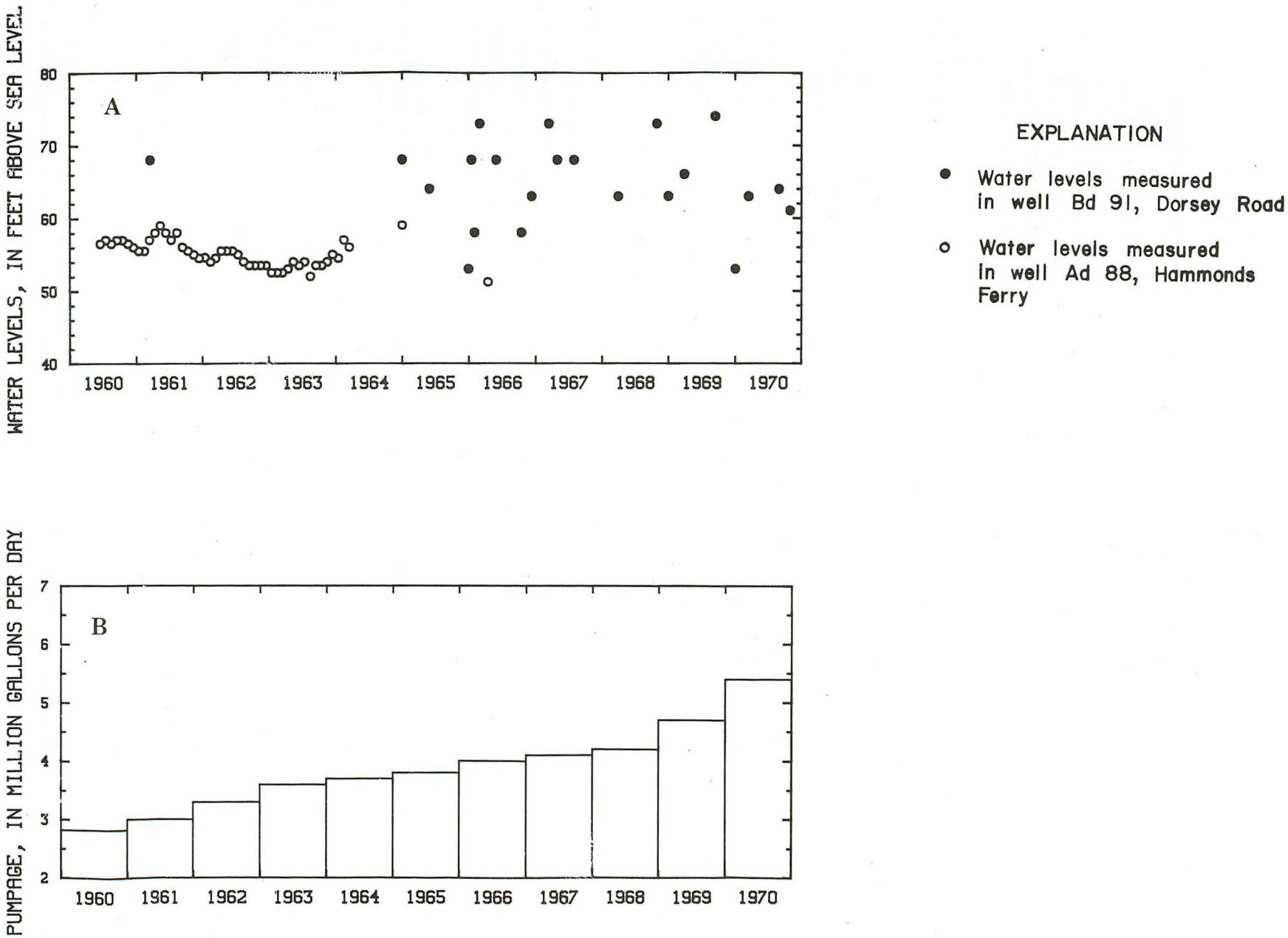


Figure 13. — (A) Water levels in wells Ad 88 and Bd 91 and (B) historical pumpage of the Glen Burnie well fields, 1960-70.

model calibration was primarily used to adjust the unconfined aquifer transmissivity and the stream-network characteristics.

Initial estimates of the upper Patapsco aquifer hydraulic conductivity, derived using Jacob's methods (see section on "Hydrologic Properties"), ranged from 8 ft/d for model cells on the flow divide, to 145 ft/d for cells representing the bay tributaries, with an average value of 33 ft/d. The higher hydraulic conductivity of the stream and bay cells was difficult to verify; the upper Patapsco was, therefore, assumed homogeneous with an average hydraulic conductivity of 33 ft/d. A simulation using an average hydraulic conductivity of 33 ft/d produced simulated water levels and base flows comparable with measured values.

The initial values assigned to the vertical hydraulic conductivity of the stream bottom in the model was 1 ft/d. The stream bottom in the model was assumed to be 1 ft thick. Sensitivity analysis indicated that the simulated stream leakage is relatively less sensitive to conductance of the stream cell than to the water levels of the unconfined aquifer at the stream cell location. During calibration, the vertical conductance of some stream cells in Sawmill Creek near Dorsey Road was increased because it appears that the streambeds are sandier. The vertical conductance of the stream cells obtained from model calibration ranged from 60 to 2,592 ft^2/d, or 0.0007 to 0.03 ft^2/s.

The calibration was considered satisfactory when the average difference between the simulated water levels and measured water levels was 10 ft or less. A rigorous calibration was not possible because the available water-level measurements pre-dated 1965. The measured water levels were based on a topographic map with a 20-ft contour interval; since these altitudes are accurate to only one-half the contour interval, the calibration criterion was set at 10 ft. Water-level comparisons are tabulated in table 5. Statistical analysis of the absolute value of the head differences in table 5 showed an average difference of 6 ft, a maximum difference of 13 ft, and a 90th-percentile difference of less than 11 ft. The resulting steady-state head distributions are compared to pre-1965 water levels of selected wells in figures 14 and 15.

The average base flow for the Sawmill Creek basin at Glen Burnie for 1944-52 was calculated to be 7.4 ft^3/s. The steady-state simulation for 1965 yields a base flow of 6.2 ft^3/s when the actual 1965 pumpage of 3.8 Mgal/d is used, and yields a base flow of 7.35 ft^3/s when the actual 1952 pumpage of 0.9 Mgal/d is used. The comparison was considered satisfactory because the difference was apparently caused by the differences in pumpage during the two periods. Base flow is very sensitive to head change in the water-table aquifer at the stream cell location. A slight head change results in a large base-flow difference.

After the water levels and base flows were matched, the flow components of steady-state simulation were examined to determine whether the solution was reasonable and within the hydrologic constraints specified for the model. For instance, the constant-head component was maintained as an outflow flux, keeping brackish water in the areas of tidal surface water from intruding into the water-table aquifer. Independent values for lateral boundary fluxes were difficult to obtain, so simulated values could only be evaluated in comparison to the other flow components. To find out whether the boundary fluxes across the lateral boundary cells of the lower Patapsco aquifer were reasonable, the head-dependent boundary component was compared to other flow components of the lower Patapsco aquifer simulated for steady-state conditions.

The flow components resulting from the final steady-state simulation are listed in table 6. The water table receives 30.18 Mgal/d of ground-water recharge, and 0.05 Mgal/d inflow from the upstream reaches of Sawmill Creek near Queenstown Park. The water table discharges 23.15 Mgal/d (68 percent of the total inflow) into the streams and tidal areas, and 6.76 Mgal/d is lost to evapotranspiration. As will be shown in the transient model, the areas of tidal surface water remain discharge areas for the entire simulation period. No flux crosses the lateral boundary of the water-table aquifer because no-flow boundary conditions were assigned there.

Ground-water inflow into the confined lower Patapsco aquifer comes from leakage through the western part of the model area, at which location the water table is about 10 ft higher than in the confined aquifer. In the eastern part of the model area, water levels in the confined aquifer are relatively higher than in the water table, resulting in an upward leakage outflow. The net leakage influx from the water table to the confined aquifer is 0.27 Mgal/d. Across the western lateral boundary of the lower Patapsco aquifer, the total amount of ground water that flows into the aquifer as an underflow from its outcrop area is 3.71 Mgal/d. Across the northeastern lateral boundary of the confined aquifer, the amount of ground water that flows out into the bay tributaries is 0.21 Mgal/d. Comparing the steady-state simulations with 3.8 Mgal/d pumpage and zero pumpage indicates that the 3.8 Mgal/d pumpage is derived from a 0.94-Mgal/d decrease in constant-head outflow across the areas of tidal surface water, a 0.26-Mgal/d decrease in evapotranspiration, a 0.22-Mgal/d decrease in stream base flow, a 0.14-Mgal/d decrease in outflow across the lateral boundary of the confined aquifer, and a 2.24-Mgal/d increase in inflow across the lateral boundary of the confined aquifer. The value of fluxes across each boundary cell of the confined lower Patapsco aquifer ranges from 0 to 0.01 ft^3/s, which was considered reasonable.

Transient Model

The transient model is an extension of the steady-state model wherein subsequent stresses are superimposed and the dimension of time and aquifer storage are considered. To ensure that the transient model would reasonably simulate future conditions, it was necessary that it first accurately simulate as much hydrologic history as possible.

Using the hydrologic properties derived from the calibrated steady-state simulation and simulated 1965 ground-water lev-

Table 5. — Comparison of measured and simulated water levels used for the steady-state model calibration

[--, information not available]

Well number	Well field or owner or location	Cell (row, column; location in figure 12)	Depth of top of screen (feet)	Patapsco aquifer: 1 = upper 2 = lower	Water level, in feet above sea level: Measured (year measured in parentheses)	Simulated (average for cell)	Measured minus simulated
Ad 27	Tracey, S. S.	(30, 48)	73	1	9 (1946)	13	-4
Ad 30	Sawmill	(36, 37)	13	1	26 (1948)	39	-13
Ad 46	BWI	(39, 21)	29	1	88 (1955)	81	7
Ad 48	BWI	(36, 22)	37	1	87 (1956)	80	7
Ad 64	Tebby, Ch.	(30, 38)	38	1	17 (1955)	26	-9
Ad 66	Kiefer & Braun	(27, 43)	10	1	18 (1957)	14	4
Ad 77	BWI	(38, 20)	31	1	96 (1958)	85	11
Bc 59	--	(49, 4)	26	1	124 (1955)	114	10
Bc 61	Toles, Mr.	(49, 10)	31	1	117 (1955)	105	12
Bc 62	Toles, Mr.	(51, 13)	18	1	90 (1955)	97	-7
Bc 63	Owens, H.	(57, 11)	38	1	102 (1955)	109	-7
Bc 66	Hasson, C.	(54, 3)	34	1	123 (1956)	118	5
Bd 9	Scherer, J. A.	(49, 31)	29	1	61 (1946)	66	-5
Bd 11	Steven, J. C.	(67, 23)	25	1	83 (1946)	80	3
Bd 46	Maynor, C. V.	(41, 16)	18	1	94 (1955)	93	1
Bd 47	Haney, L.	(42, 24)	22	1	58 (1955)	66	-8
Bd 53	Chappel	(56, 24)	62	1	88 (1955)	82	6
Bd 58	--	(40, 29)	30	1	37 (1956)	48	11
Bd 74	Moose Lodge	(60, 33)	70	1	55 (1957)	67	-12
Ad 10	Curtis Bay	(13, 56)	108	2	15 (1953)	16	-1
Ad 40	Sawmill #4	(38, 36)	80	2	27 (1947)	35	-8
Ad 41	Sawmill #5	(37, 34)	126	2	35 (1947)	36	-1
Ad 61	Highland Furniture	(37, 39)	104	2	25 (1953)	35	-10
Ad 69	Two Guys Dept. Store	(37, 41)	97	2	23 (1957)	33	-10
Ad 72	Two Guys Dept. Store	(38, 41)	110	2	28 (1957)	34	-6
Ad 74	Dorsey Road #4	(39, 26)	171	2	57 (1957)	57	0
Ad 88	Hammonds Ferry	(36, 25)	159	2	56 (1964)	61	-5
Bc 15	Wagner, H. E.	(51, 4)	118	2	100 (1930)	105	-5
Bc 58	Williamson, R.	(43, 13)	76	2	88 (1954)	87	1
Bd 2	Md. Training Sch.	(45, 19)	91	2	85 (1932)	74	11
Bd 5	Della, H.	(44, 58)	136	2	15 (1946)	20	-5
Bd 22	Glen Theatre	(40, 37)	110	2	37 (1941)	39	-2
Bd 33	Phillips, W. C.	(79, 36)	87	2	62 (1949)	63	-1
Bd 35	Phillsbury, L.	(46, 48)	120	2	30 (1948)	30	0
Bd 36	Harundale #1	(55, 48)	98	2	27 (1951)	32	-5
Bd 40	Fisher, J.	(58, 32)	203	2	50 (1949)	61	-11
Bd 55	Dorsey Road #1	(41, 26)	111	2	59 (1955)	56	3
Bd 56	Dorsey Road #3	(41, 27)	133	2	63 (1956)	55	8
Bd 59	Dasch, J.	(56, 41)	77	2	37 (1954)	46	-9
Bd 61	Harundale	(53, 45)	186	2	29 (1955)	31	-2
Bd 64	Dorsey Road #11	(41, 23)	161	2	62 (1957)	63	-1
Bd 73	Pioneer Restaurant	(63, 31)	90	2	51 (1960)	64	-13
Bd 75	G. B. Coach Lines	(56, 33)	120	2	53 (1955)	59	-6
Bd 78	Sunnyside School	(55, 22)	121	2	66 (1955)	75	-9
Bd 84	Brookwood Farm	(62, 53)	85	2	34 (1960)	45	-11
Bd 88	Warfield, C.	(60, 26)	208	2	79 (1949)	69	10
Bd 91	Dorsey Road	(41, 21)	155	2	64 (1961)	68	-4
Bd 92	Dorsey Road	(41, 19)	132	2	63 (1961)	70	-7
Bd 112	Myers Plant Farm	(60, 23)	156	2	70 (1963)	71	-1

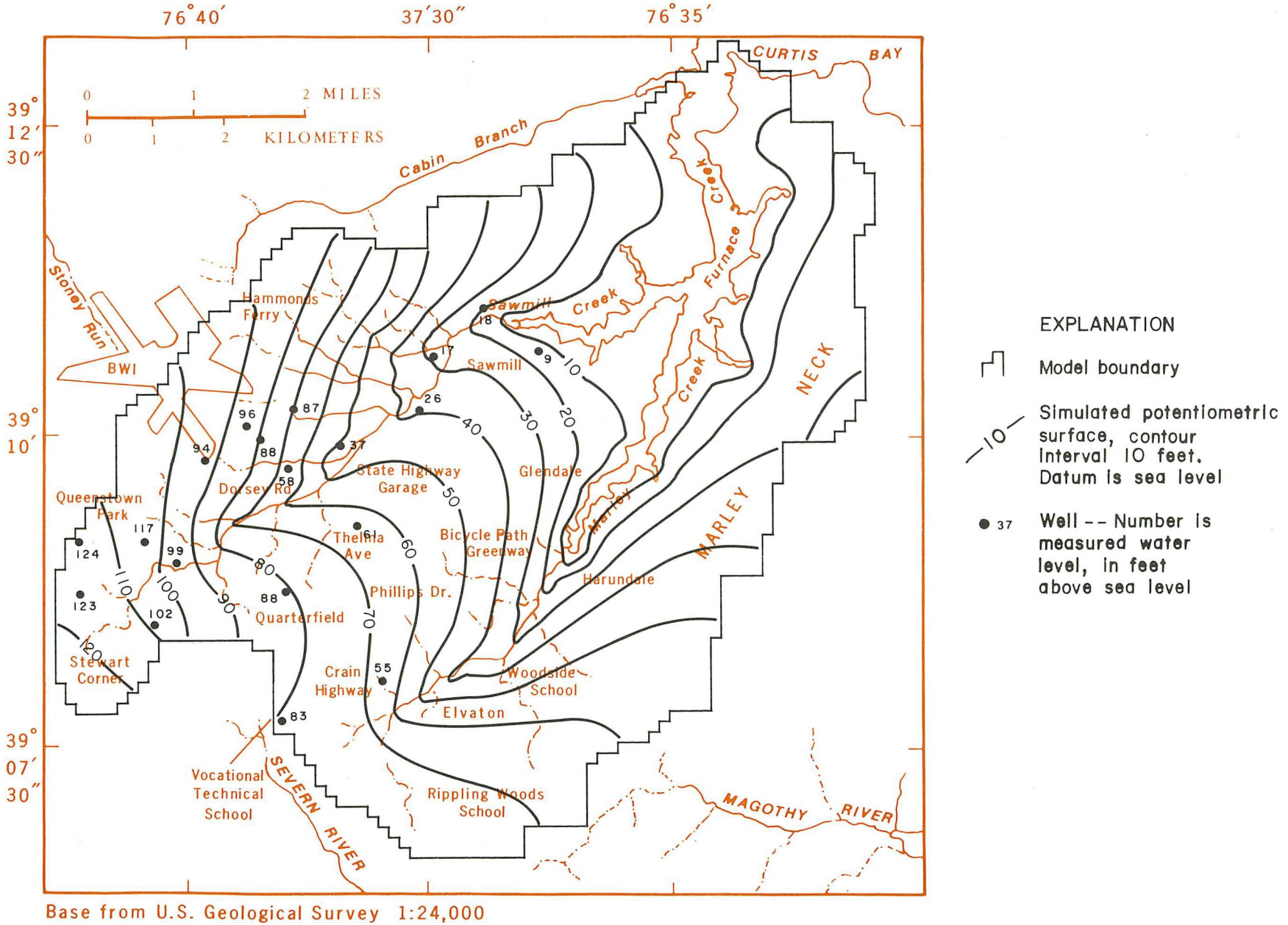


Figure 14. — Comparison of simulated 1965 potentiometric surface and pre-1965 measured water levels for the upper Patapsco aquifer used in the steady-state model calibration.

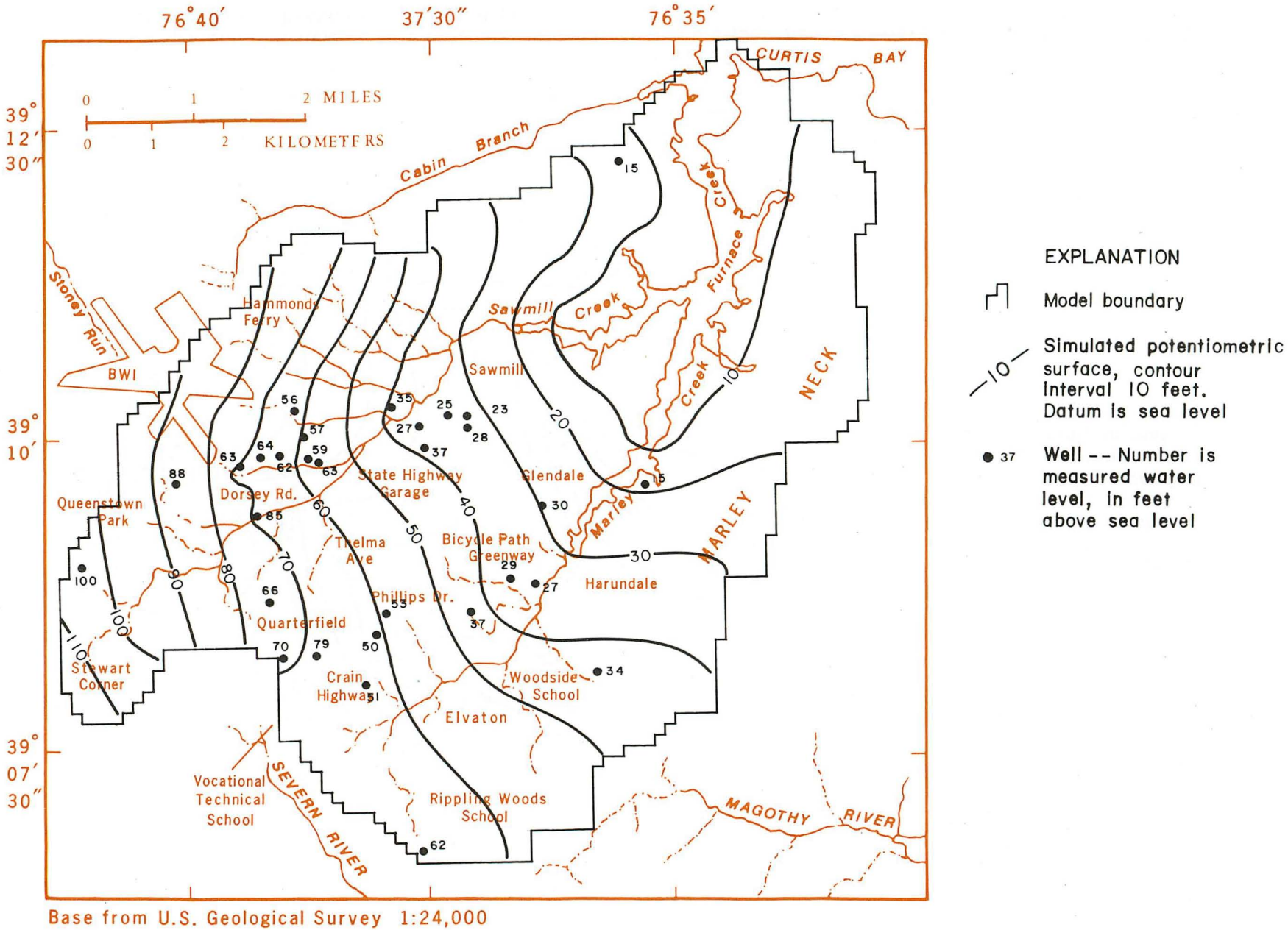


Figure 15. — Comparison of simulated 1965 potentiometric surface and pre-1965 measured water levels for the lower Patapsco aquifer used in the steady-state model calibration.

Table 6. — Flow components for 1965 steady-state model simulation and steady-state simulation with no pumpage

[in/yr = inches per year; Mgal/d = million gallons per day]

Components	Flow rate			
	1965		No pumpage	
	in/yr	Mgal/d	in/yr	Mgal/d
Inflow:				
Recharge	20.50	30.18	20.50	30.18
Constant-head boundary	0	0	0	0
Stream leakage	.03	.05	.03	.04
Head-dependent boundary	2.52	3.71	.99	1.47
Totals[a]	23.05	33.94	21.52	31.69
Outflow:				
Constant-head boundary	7.10	10.45	7.74	11.39
Pumpage	2.59	3.80	0	0
Ground-water evapotranspiration	4.59	6.76	4.72	7.02
Stream leakage	8.63	12.70	8.72	12.92
Head-dependent boundary	.14	.21	.23	.35
Totals[a]	23.05	33.92	21.41	31.68

[a] Discrepancies in the totals are due to rounding.

els as initial water-level conditions, the aquifer system was stressed under transient conditions with pumpage from the Glen Burnie well fields from 1965 to 1985. The transient simulation was divided into two periods—the 1965-84 simulation period which uses a long-term average recharge, and the 1984-85 simulation period which uses a specified recharge value. The 1965-84 period was simulated in yearly stress periods with time steps ranging in size from 1 to 3 months, and the 1984-85 period was simulated in monthly stress periods with an average time-step size of about 10 days. There were more data available for 1984-85, enabling monthly stress-period simulations.

In the early stages of calibration, the transient model was simulated using a long-term recharge rate of 22.95 in/yr, calculated as the average recharge rate of $(21.20 + (20.10 + 4.59))/2$ in/yr (see section on "Natural Recharge"); a 1984-85 recharge rate of 16.3 in/yr; and a confining-unit leakance of 10^{-9} s^{-1} (Mack and Achmad, 1986). Two problems that arose were: (1) both the simulated water levels of the upper Patapsco aquifer and the simulated base flows of Sawmill Creek at Glen Burnie for 1984-85 were too high, and (2) computed water levels of the lower Patapsco aquifer were 20 to 40 ft lower than they should have been. Any adjustment made to correct the first problem had an effect on the second problem. From the sensitivity analyses of the hydrologic properties, it was found that calculated base flow was more sensitive to changes in the water table than to changes in the vertical hydraulic conductivity of the riverbed, and that water levels in the confined aquifer were more sensitive to the vertical hydraulic conductivity of the confining unit than to hydraulic conductivity of the lateral boundary cells. The sensitivity analyses were made using values within ranges of normal practice. In the first problem, high base flow was caused by high water levels in the upper Patapsco aquifer, which leads to the suspicion that the recharge rate was too high. After some trials, the first problem was corrected by lowering the long-term average recharge to 20.5 in/yr and the 1984-85 annual recharge to 14.4 in/yr. These values were within the range of recharge values used by previous investigators. Other modifications, such as changing the vertical hydraulic conductivity of the riverbed material, were tried but not pursued. For example, decreasing the hydraulic conductivity of the riverbed reduces the base flow, but water levels of the unconfined aquifer remain high. Alternatively, increasing the hydraulic conductivity of the riverbed decreases the water level, but the base flow becomes higher, which does not correct the first problem.

In the case of the second problem, a few options were tried. The lower Patapsco aquifer water levels could be raised by allowing more water to flow into the aquifer by adding more inflow through the lateral boundary of the lower Patapsco aquifer. An additional lateral boundary flux could be simulated by either increasing head differences across the model boundaries or by increasing the boundary-cell conductance in the model. However, no substantial evidence could support these measures and they were therefore abandoned. Another option was to simulate an increase in vertical leakage through the confining unit by increasing the confining-unit leakance in the model. After several trials, it was found that a confining-unit leakance ranging from 10^{-8} to 10^{-6} s^{-1} gave the best water-level and base-flow comparisons. These values reflect the comparatively thin and sandy nature of the confining unit in the Glen Burnie area.

The actual calibration process was more complicated than just described. Each time changes were made in the hydrologic properties during transient calibration, the steady-state simulation was repeated to determine whether the steady-state calibration was still valid. If so, the new steady-state water levels were used to initiate the subsequent transient simulations. Similar to the steady-state calibration, the transient model was considered calibrated when the average difference between the simulated and measured water levels was less than 10 ft.

The final water-level comparisons for the transient calibration are tabulated in table 7. Statistically, the average difference is 6 ft, the 90th-percentile difference is 12 ft or less, and the maximum difference is 14 ft. Water-level hydrographs comparing historical and simulated 1965-85 water levels are shown in figures 16 to 28. The simulated 1985

Table 7. — Comparison of measured and simulated 1985 water levels used for the transient model calibration

[--, information not available]

Well number	Well field or owner or location	Cell, (row, column; location in figure 12)	Depth of top of screen (feet)	Patapsco aquifer: 1 = upper 2 = lower	Water level, in feet above sea level: Measured (year measured in parentheses)	Simulated (average for cell)	Measured minus simulated
Ad 101	Reclamation area	(28, 53)	17	1	2 (1980)	2	0
Ad 103	Cromwell	(33, 25)	57	1	63 (1984)	69	-6
Ad 104	Hammonds Ferry	(33, 23)	18	1	72 (1984)	74	-2
Ad 108	Hammonds Ferry	(33, 23)	6	1	71 (1984)	74	-3
Ad 109	Central Ave.	(38, 32)	36	1	27 (1984)	35	-8
Bc 220	Lewis, A.	(55, 10)	80	1	102 (1984)	103	-1
Bc 221	Mathew, W.	(51, 14)	16	1	98 (1985)	90	8
Bc 222	Mitchell, R.	(49, 13)	14	1	91 (1984)	91	0
Bd 124	Carter, F.	(56, 56)	50	1	42 (1984)	38	4
Bd 127	Anne Arundel County	(49, 32)	15	1	55 (1984)	54	1
Bd 133	Jones, W.	(51, 22)	26	1	76 (1984)	70	6
Bd 134	--	(49, 22)	63	1	69 (1984)	67	2
Bd 138	--	(48, 60)	15	1	38 (1985)	28	10
Bd 152	Woodside School	(59, 43)	90	1	24 (1984)	33	-9
Bd 160	Queenstown Park	(49, 17)	105	1	71 (1985)	63	8
Ad 40	Sawmill #4	(38, 36)	80	2	14 (1981)	24	-10
Ad 41	Sawmill #5	(37, 34)	126	2	18 (1984)	26	-8
Ad 68	Sawmill #7	(38, 32)	140	2	25 (1984)	32	-7
Ad 102	Hammonds Ferry	(33, 23)	80	2	66 (1983)	74	-8
Ae 37	Methodist Church	(33, 78)	96	2	29 (1981)	18	11
Bd 36	Harundale #1	(55, 48)	98	2	16 (1979)	22	-6
Bd 37	Harundale #2	(54, 46)	90	2	14 (1979)	20	-6
Bd 55	Dorsey Road #1	(41, 26)	111	2	38 (1985)	24	14
Bd 64	Dorsey Road #11	(41, 23)	161	2	36 (1985)	32	4
Bd 91	Dorsey Road	(41, 21)	155	2	36 (1984)	39	-3
Bd 92	Dorsey Road	(41, 19)	132	2	34 (1984)	31	3
Bd 95	Dorsey Road #15	(46, 21)	150	2	17 (1984)	29	-12
Bd 101	Phillips Drive	(52, 37)	172	2	24 (1985)	32	-8
Bd 103	Glendale	(45, 45)	176	2	7 (1981)	12	-5
Bd 105	Crain Highway	(62, 32)	197	2	49 (1985)	35	14
Bd 108	Thelma Ave.	(48, 30)	175	2	33 (1985)	35	-2
Bd 109	Quarterfield	(54, 25)	260	2	61 (1985)	48	13
Bd 136	Arco Gas	(58, 18)	85	2	65 (1984)	69	-4
Bd 154	Queenstown Park	(49, 17)	170	2	66 (1984)	65	1
Bd 155	St. Highway Garage	(43, 27)	145	2	36 (1984)	34	2
Bd 156	Bicycle Path	(47, 41)	160	2	17 (1984)	27	-10
Bd 157	Rippling Woods Sch.	(68, 35)	167	2	35 (1984)	47	-12
Bd 158	Vocat. Tech. School	(67, 23)	174	2	57 (1984)	55	2

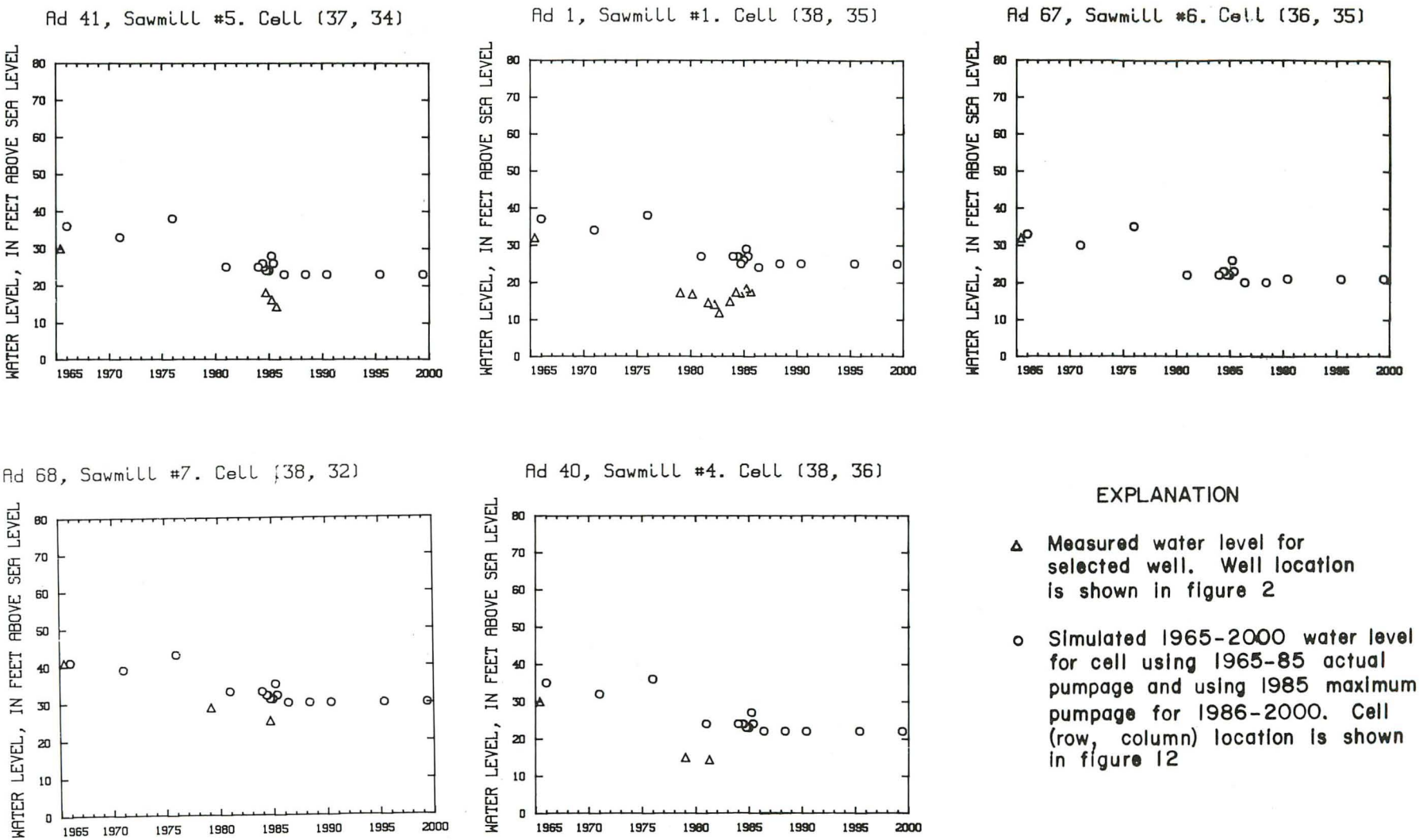


Figure 16. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Sawmill well field.

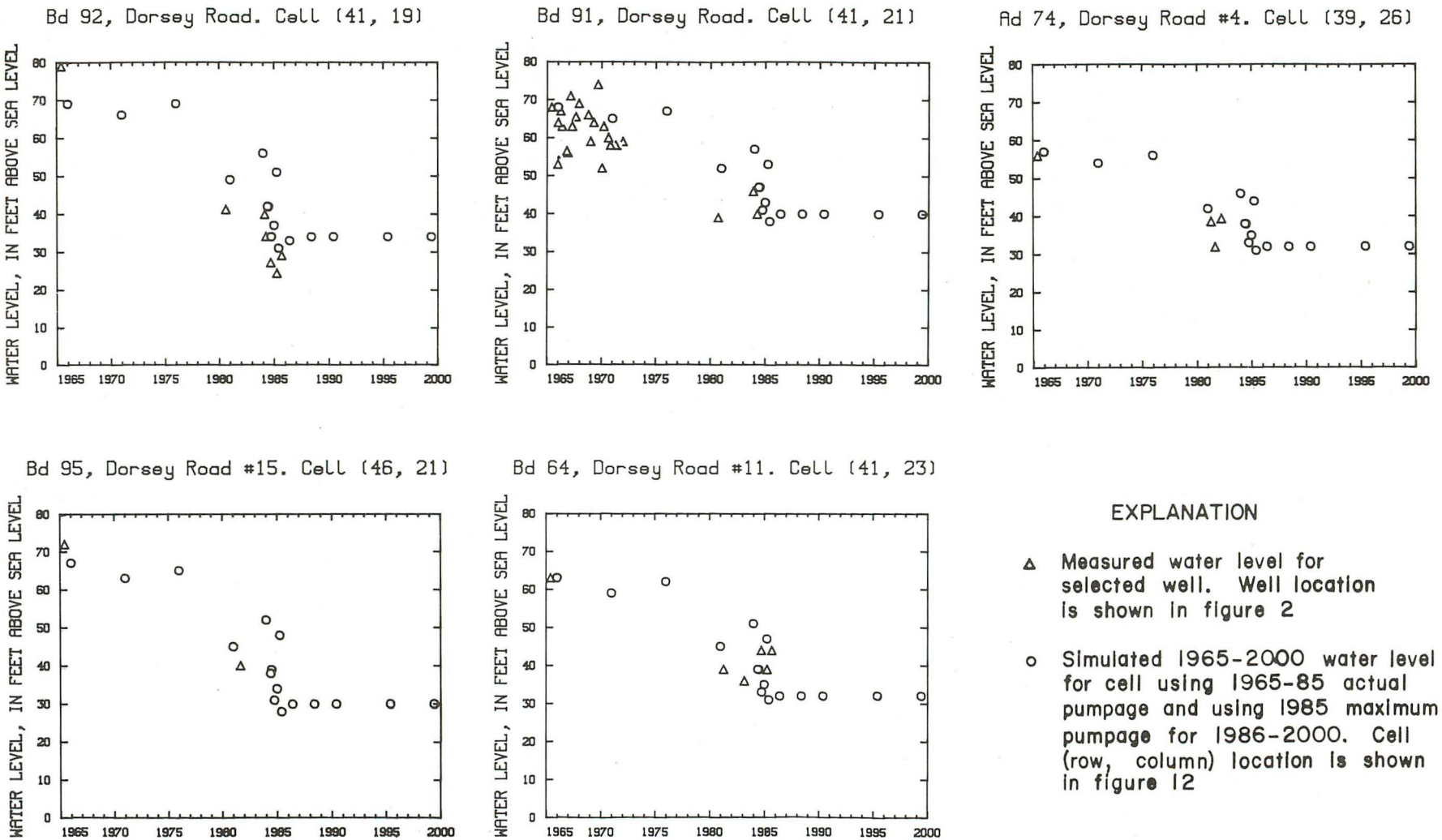


Figure 17. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Dorsey Road well field.

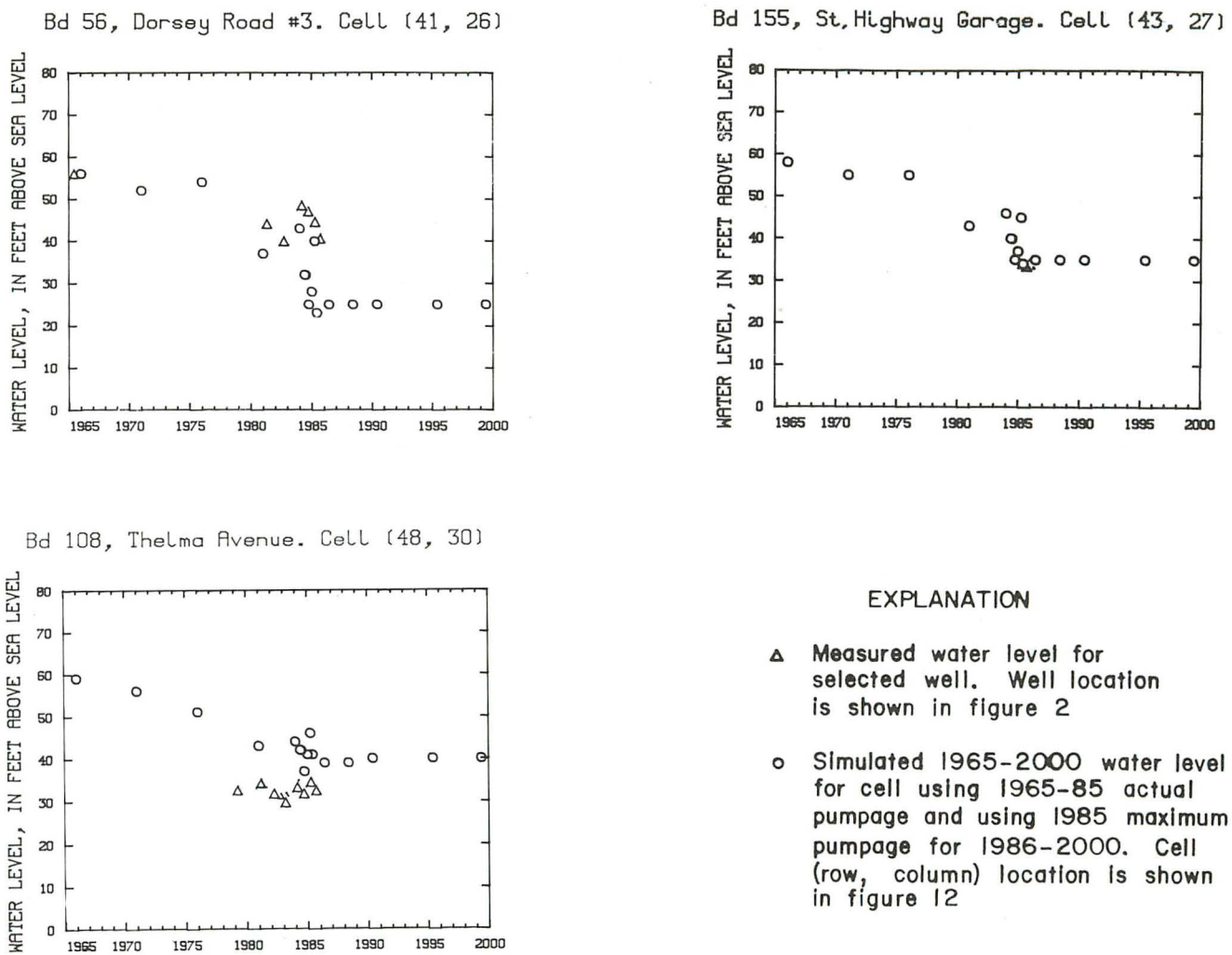


Figure 18. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Dorsey Road and Thelma Avenue well fields, and the State Highway Garage observation well.

potentiometric surfaces for the upper and lower Patapsco aquifers are compared to measured water levels of selected wells in figures 29 and 30. The simulated water levels of the lower Patapsco aquifer match reasonably close with measured water levels in the Dorsey Road (fig. 17), State Highway Garage (fig. 18), Hammonds Ferry (fig. 20), Crain Highway (fig. 23), Vocational Technical School (fig. 23), and Curtis Bay (fig. 26) wells.

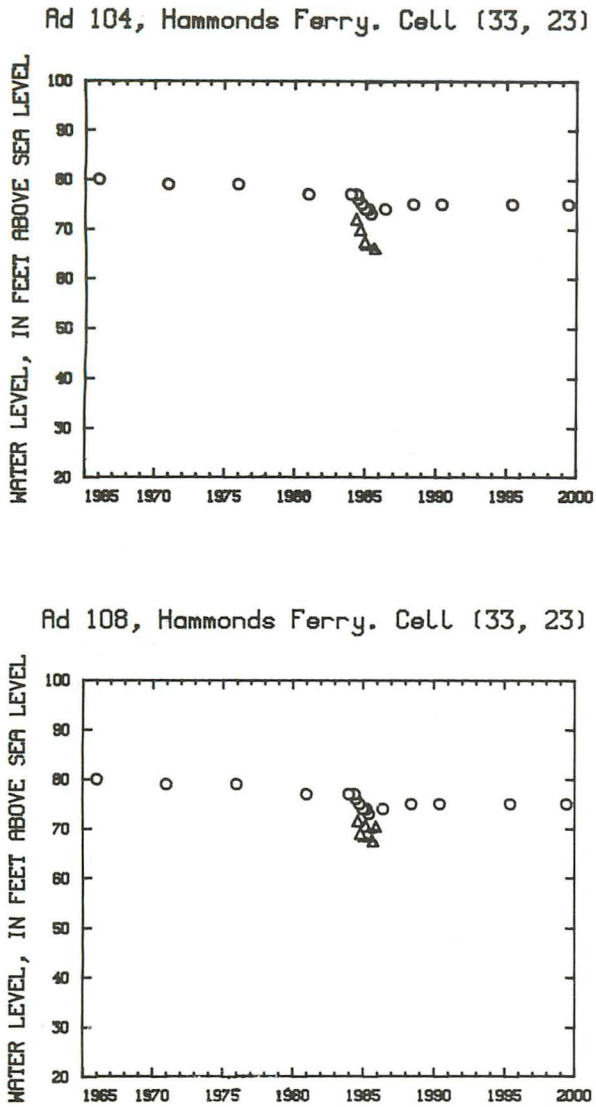
In more than one-half of the cases the simulated water levels are higher than the measured water levels for 1985, suggesting that dewatering of Sawmill Creek or saltwater intrusion into the aquifer might occur at lower pumping rates than calculated by the model. Because most of the areal water levels were measured in pumped wells that had not fully recovered, this possibility is lessened.

Table 8. — Flow components for 1965, 1983, and 1985 transient-model simulations

[in/yr = inches per year; Mgal/d = million gallons per day]

Components		Flow rate for last time step in year: 1965 in/yr	1965 Mgal/d	1983 in/yr	1983 Mgal/d	1985 in/yr	1985 Mgal/d
Inflow:	Storage[a]	0.41	0.60	0.05	0.12	2.75	4.03
	Recharge	20.50[b]	30.18	20.50[b]	30.18	14.40[c]	21.18
	Constant-head boundary	0	0	0	0	0	0
	Stream leakage (upstream reaches)	.21	.31	.51	.75	1.03	1.52
	Head-dependent boundary	.56	.82	1.16	1.71	1.54	2.26
	Totals[d]	21.68	31.91	22.22	32.76	19.72	28.99
Outflow:	Storage[e]	0.44	0.64	0.14	0.20	0	0
	Constant-head boundary	8.58	12.66	8.19	12.09	7.45	10.95
	Pumpage	2.59	3.80	6.69	9.85	7.46	10.95
	Ground-water evapotranspiration	2.37	3.49	1.70	2.50	1.06	1.55
	Stream leakage	7.05	10.38	5.11	7.53	3.54	5.12
	Head-dependent boundary	.66	.98	.40	.58	.24	.36
	Totals[d]	21.69	31.95	22.23	32.75	19.75	28.93

a/ Gain of storage in cells where water levels rise.
b/ Long-term average recharge rate of 20.5 in/yr.
c/ 1984-1985 average recharge rate of 14.4 in/yr.
d/ Discrepancies in the totals are due to rounding.
e/ Loss of storage in cells where water levels decline.



EXPLANATION

△ Measured water level for selected well. Well location is shown in figure 2

o Simulated 1965-2000 water level for cell using 1965-85 actual pumpage and using 1985 maximum pumpage for 1986-2000. Cell (row, column) location is shown in figure 12

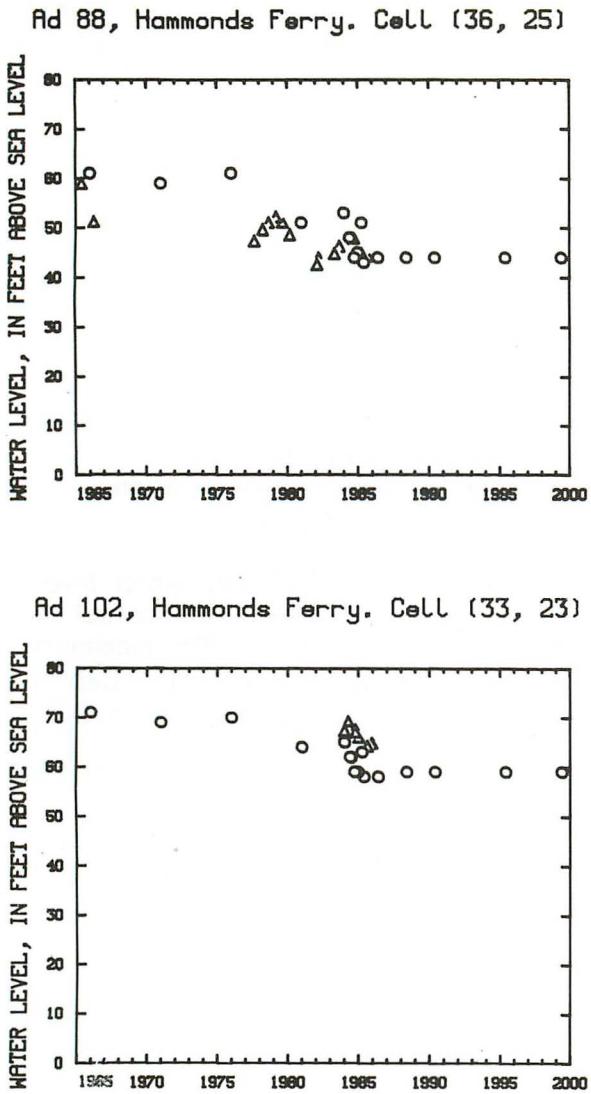
Figure 19. — Comparison of measured water levels in wells and simulated water levels in cells tapping the upper Patapsco aquifer in the Hammonds Ferry observation wells.

Stream base flow simulated for 1984-85 and base flow derived from the streamflow measured at the Glen Burnie gaging station are plotted in figure 31. Eighty-five percent of the base flows match with differences of less than 0.46 ft^3/s; the maximum difference is 0.6 ft^3/s.

A better match for water levels could be obtained by fine-tuning the hydrologic properties cell by cell. However, it was not done because of a sparsity of data.

An examination of the mass balance of the flow components helps explain the ground-water flow system of the Patapsco aquifers in its recharge area. In the mass balance, pumpage includes the boundary fluxes simulating pumpages from a nearby well field that in 1985 reached 1.25 Mgal/d. The flow components for 1965, 1983, and 1985 (tabulated in table 8) indicate that during 1965-85, as pumpage was increased from 3.80 Mgal/d (1965) to 10.95 Mgal/d (1985), stream base flow decreased from 10.38 Mgal/d (1965) to 5.12 Mgal/d (1985), and discharge into the areas of tidal surface water decreased from 12.66 Mgal/d (1965) to 10.95 Mgal/d (1985). The aquifers received a recharge of 30.18 Mgal/d (20.50 in/yr) during 1965-83 and a recharge of 21.18 Mgal/d (14.40 in/yr) during 1984-85.

The flux exchanges can also be used to explain the sources of additional pumpage. For example, between 1965 and 1983, pumpage increased by about 6.0 Mgal/d. The sources of this increase are (1) interception of outflow ground-water fluxes from stream base flow, interruption of outflow ground-water fluxes from tidal water areas, decrease in loss to evapotranspiration, and interception of ground-water fluxes across confined-aquifer lateral boundaries (totaling about 4.8 Mgal/d);



EXPLANATION

△ Measured water level for selected well. Well location is shown in figure 2

o Simulated 1965-2000 water level for cell using 1965-85 actual pumpage and using 1985 maximum pumpage for 1986-2000. Cell (row, column) location is shown in figure 12

Figure 20. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Hammonds Ferry observation wells.

and (2) increase in inflow ground-water fluxes from stream leakage at the upstream reaches, confined-aquifer lateral boundary fluxes, and a net decrease in aquifer storage (totaling about 1.2 Mgal/d). The maximum potential evapotranspiration rate was 18 in/yr. However, because evapotranspiration is head dependent, the model calculated the average ground-water evapotranspiration for the entire basin to be 2.37 in/yr for 1965 and 1.27 in/yr for 1985.

GROUND-WATER-SUPPLY POTENTIAL

Rationale for Pumpage Increases

The ground-water-supply potential of the Patapsco aquifer system in the Glen Burnie area was assessed by analyzing the effects of increased pumpage on water levels and stream base flows during 1965-85, and by using the calibrated model to simulate the effects of future pumping scenarios in the existing well fields. Table 9 shows how much both areal water levels in the vicinity of the well fields and water levels in the pumping wells declined due to additional pumpage during 1965-85. Water levels measured in a pumping well are lower when the pump is activated than when the pump is turned off; the difference ranges from 20 to 70 ft.

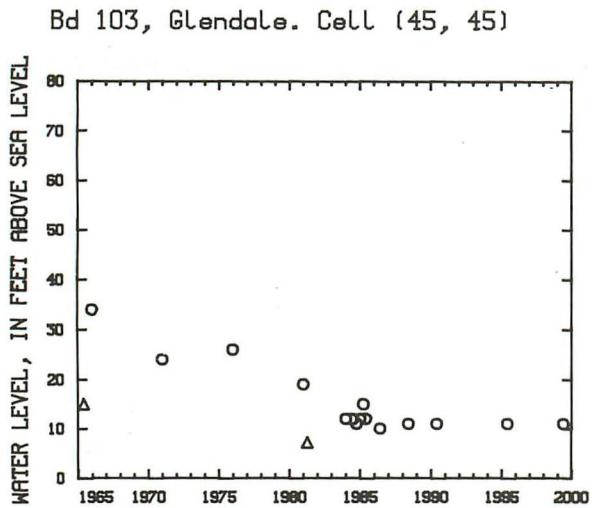
In general, water levels in the upper Patapsco aquifer were less affected than water levels in the lower Patapsco aquifer. This is expected because all the pumpages occurred in the confined lower Patapsco aquifer. A series of 1965-85 drawdowns ranging from 9 to 17 ft in the Sawmill well field, 10 to 29 ft in the Dorsey Road well field, and 6 to 17 ft in Harundale well field were observed in the lower Patapsco aquifer. The 1965-85 drawdown in the upper Patapsco aquifer was estimated to be about 5 to 10 ft (tables 5 and 7).

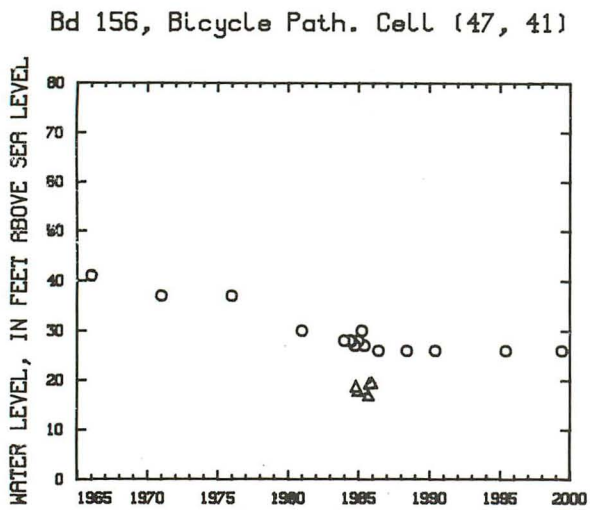
Table 9. — Pumpages, water levels, and drawdowns in the Glen Burnie area well fields and observation wells, 1965-85

[Mgal/d = million gallons per day; - = data not available; all water levels are expressed in feet above or below (-) sea level; all drawdowns are in feet]

Well field or location	Total well-field pumpage in Mgal/d: 1965	1985 average	1985 maximum	Increased pumpage (Mgal/d)	Pumping well: Well number	Water level[a] (year measured in parentheses)	Draw-down	Pump	Observation well: Well number	Water level[a] (year measured in parentheses)	Draw-down
Sawmill	1.20	1.41	1.74	0.21	Ad 40	27(1947), 14(1981)	13	Off	Ad 1	27(1926), 18(1985)	9
					Ad 40	- -7(1981)	-	On	Ad 109[b]	- 27(1984)	-
					Ad 41	35(1947), 18(1984)	17	Off			
					Ad 41	-52(1980), -52(1983)	0	On			
					Ad 67	- -72(1982)	-	On			
					Ad 68	- 25(1984)	-	Off			
Dorsey Road	1.20	3.67	4.38	2.47	Bd 55	59(1955), 38(1985)	21	Off	Bd 91	64(1961), 36(1984)	28
					Bd 56	- -54(1983)	-	On			
					Bd 92	63(1961), 34(1984)	29	Off			
					Bd 95	-66(1979), -76(1982)	10	On			
					Bd 64	- -21(1983)	-	On			
Glendale	-	.75	.80	.75	Bd 103	15(1969), 7(1981)	8	Off		-	
					Bd 103	- -63(1983)	-	On			
Harundale	1.42	1.18	1.42	-.24[c]	Bd 36	27(1951), 16(1979)	11	Off		-	
					Bd 37	31(1949), 14(1979)	17	Off			
					Bd 37	-19(1979), -25(1983)	6	On			
					Bd 61	29(1955), -	-	Off			
Phillips Drive	-	.46	.67	.46	Bd 101	37(1969), 24(1985)	13	Off		-	
					Bd 101	- -31(1981)	-	On			
Thelma Avenue	-	0	0	0	Bd 108	41(1971), 33(1985)	8	Off		-	
					Bd 108	- -53(1980)	-	On			
Crain Highway	-	.91	1.00	.91	Bd 105	60(1969), 49(1985)	11	Off		-	
					Bd 105	- 13(1983)	-	On			
Elvaton	-	.55	.70	.55	Bd 107	-24(1979), -34(1980)	10	On		-	
					Bd 107	24(1960), 17(1985)	7	Off			
Quarter-field	-	.73	.85	.73	Bd 109	67(1971), 61(1985)	6	Off		-	
					Bd 109	- -16(1983)	-	On			
Hammonds Ferry Road	no pumpage					-			Ad 88	56(1964), 44(1985)	12
									Ad 102[b]	- 66(1983)	-
									Ad 104[b]	- 72(1984)	-
									Ad 108[b]	- 71(1984)	-
Woodside School	no pumpage					-			Bd 152[b]	- 24(1984)	-
Bicycle Path Greenway	no pumpage					-			Bd 156	- 17(1984)	-
Curtis Bay	no pumpage					-			Ad 10	15(1953), 14(1979)	1
Rippling Woods	no pumpage					-			Bd 157	- 35(1984)	-
Queenstown Park	no pumpage					-			Bd 154	- 66(1984)	-
									Bd 160[b]	- 71(1985)	-
Vocational Technical School	no pumpage					-			Bd 158	- 57(1984)	-
State Highway Garage	no pumpage					-			Bd 155	- 36(1984)	-

[a] Water level of the lower Patapsco aquifer, except if otherwise noted, in feet above or below (-) sea level.
[b] Well screened in the upper Patapsco aquifer.
[c] Decreased pumpage.





EXPLANATION

△ Measured water level for selected well. Well location is shown in figure 2

○ Simulated 1965-2000 water level for cell using 1965-85 actual pumpage and using 1985 maximum pumpage for 1986-2000. Cell (row, column) location is shown in figure 12

Figure 21. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Glendale well field and Bicycle Path Greenway observation well.

Figures 29 and 30 indicate that 1985 areal water levels were still above sea level. This suggests that the Glen Burnie area well fields could sustain increased pumpage over 1985 levels before the Patapsco aquifer system would be endangered by saltwater encroachment from the bay tributaries, the only natural source of salty water in the area. Consequently, eight scenarios of different combinations of increased pumpage at the various well fields were simulated using the calibrated model. The increase in pumpage to be simulated at each well field was determined by analyzing the observed drawdown effects during 1965-85. In well fields where additional drawdown was considered to be available in 1985, pumpage increases were incorporated into the scenarios; where water levels were already near the top of the aquifer in 1985, no additional pumpage was incorporated. The following sections describe the rationale for determining the simulated pumpage increases used at each well field in the eight scenarios.

Sawmill well field

In the Sawmill well field between 1965 and 1985 the lower Patapsco aquifer pumpage was increased by 0.21 Mgal/d and the areal water levels declined an average of 9 ft (well Ad 1) to 17 ft (well Ad 41). In the lower Patapsco aquifer the areal water levels ranged from 14 ft above sea level in well Ad 40 during 1981 to 25 ft above sea level in well Ad 68 during 1984. In the upper Patapsco aquifer the water level was 27 ft above sea level in well Ad 109 during 1984. These water levels indicate that there is no immediate danger of saltwater intrusion. In contrast, the water levels in the lower Patapsco aquifer were 7 ft below sea level during 1981 in pumping well Ad 40, 52 ft below sea level during 1983 in well Ad 41, and 72 ft below sea level during 1982 in well Ad 67. Because the altitude of the top of the lower Patapsco

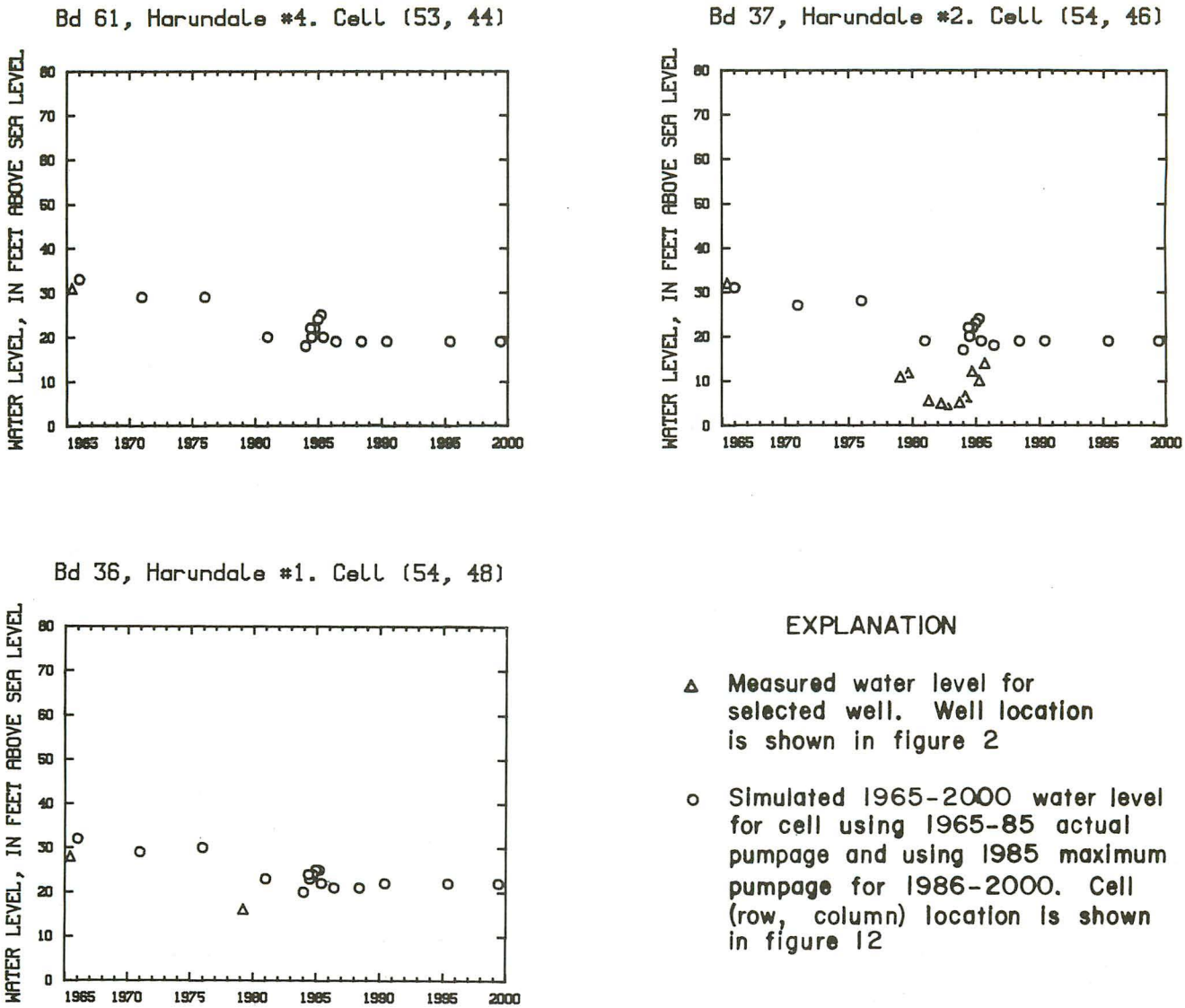


Figure 22. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Harundale well field.

aquifer is approximately 80 ft below sea level, pumpage in the model scenarios was only moderately increased to avoid dewatering the aquifer in the vicinity of the pumping wells.

Dorsey Road well field

Wells in the Dorsey Road well field are scattered throughout an area of 0.5 to 0.75 mi^2 and pump from both the lower Patapsco and Patuxent aquifers. In 1985, the amount of ground water pumped from the lower Patapsco aquifer from this well field was 3.67 Mgal/d, which makes it the most productive well field in the Glen Burnie area. Pumpage increased by 2.47 Mgal/d over 1965 rates, contributing to drawdowns of 10 ft (well Bd 95) to 29 ft (well Bd 92) in the lower Patapsco aquifer in the well-field area. The areal water level in the lower Patapsco aquifer in 1985 was about 38 ft above sea level (well Bd 55). There should be no immediate danger of saltwater intrusion in this well field as long as the areal water levels are not reduced below sea level. In the pumped wells, water levels are mostly lower than sea level. The water levels were 21 ft below sea level during 1983 in pumping well Bd 64, 54 ft below sea level during 1983 in well Bd 56, and 76 ft below sea level during 1982 in well Bd 95. Because the altitude of the top of the lower Patapsco aquifer is approximately 80 ft below sea level, pumpage in these wells in the model scenarios was only increased by a moderate amount in order not to dewater the aquifer in the vicinity of the pumping wells.

Hammonds Ferry well field

No production wells are located at the Hammonds Ferry well field. Three observation wells are aligned in a north-

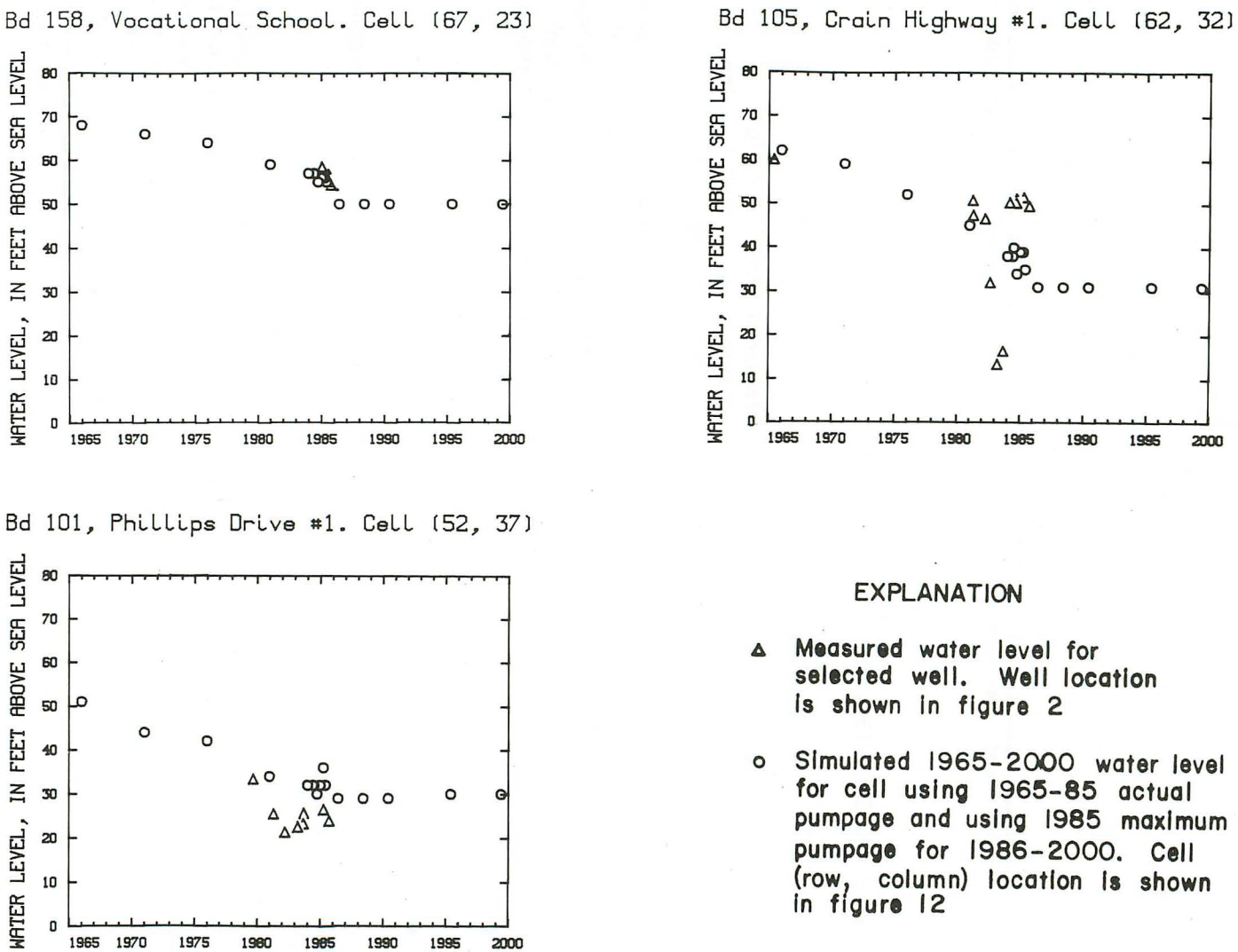
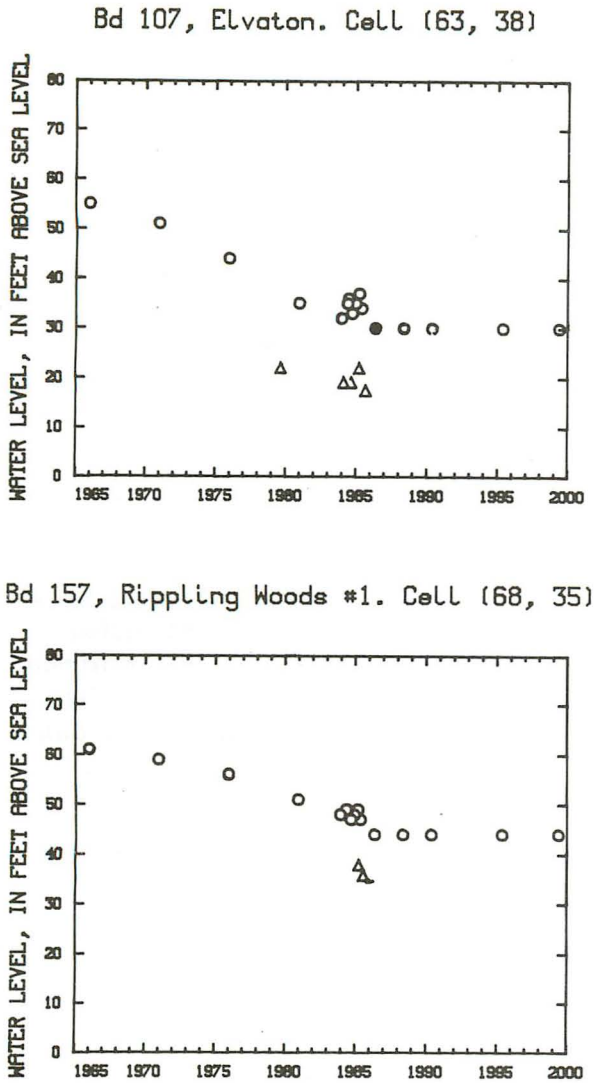


Figure 23. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Vocational Technical School observation well, and Crain Highway, and Phillips Drive well fields.



EXPLANATION

△ Measured water level for selected well. Well location is shown in figure 2

o Simulated 1965-2000 water level for cell using 1965-85 actual pumpage and using 1985 maximum pumpage for 1986-2000. Cell (row, column) location is shown in figure 12

Figure 24. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Elvaton well field and Rippling Woods School observation well.

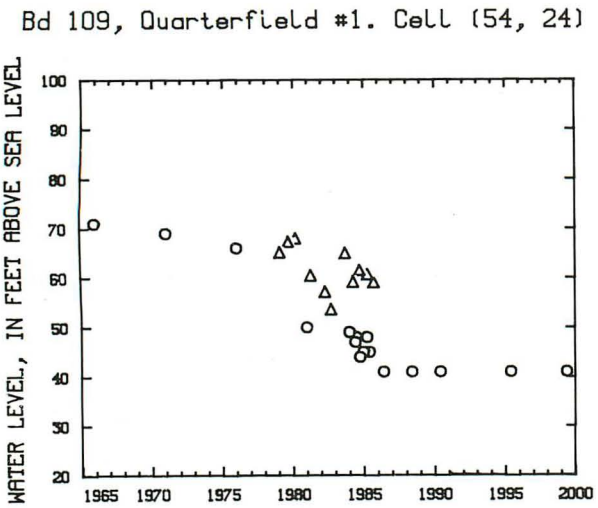
south direction for a distance of 0.75-mi. Water levels are affected by pumping from the Dorsey Road well field, which is 1 mi south of the Hammonds Ferry well field, and the Sawmill well field, which is 1 mi east. The areal water levels were about 44 ft above sea level in well Ad 88 during 1985 in the lower Patapsco aquifer and about 71 ft above sea level in well Ad 104 during 1984 in the upper Patapsco aquifer. Because of its updip location, the lower Patapsco aquifer is thinner and closer to land surface in this area; consequently, no pumpage was assigned to this well field.

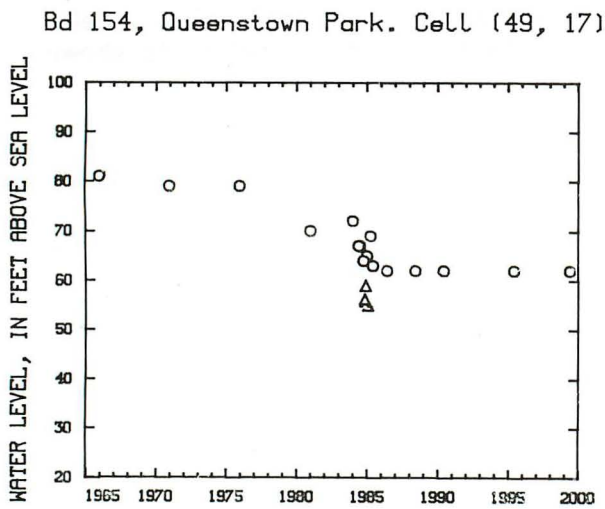
Glendale well field

In the Glendale well field, the 0.75-Mgal/d increase in pumpage during 1965-85 contributed about 8 ft of drawdown in the lower Patapsco aquifer. The areal water level in the lower Patapsco aquifer was 7 ft above sea level (well Bd 103, 1981), suggesting no imminent danger of saltwater intrusion. The water level in pumping well Bd 103 was 63 ft below sea level (1983). Because this well-field location is relatively close to areas of tidal surface water, pumpage was not increased in the model scenarios in this well field.

Harundale well field

Records indicate that pumpage at the Harundale well field in 1985 was 0.24 Mgal/d less than in 1965. However, the areal water levels in the lower Patapsco aquifer were lowered to 14 ft above sea level in well Bd 37 during 1979 and 16 ft above sea level in well Bd 36 during 1979. The 11- to 17-ft drawdowns are the result of increased pumpage from the updip well fields. Presently (1985) there probably is no immediate danger of saltwater intrusion, although the water level in pumping well Bd 37 was 25 ft below sea level (1983).





EXPLANATION

△ Measured water level for selected well. Well location is shown in figure 2

o Simulated 1965-2000 water level for cell using 1965-85 actual pumpage and using 1985 maximum pumpage for 1986-2000. Cell (row, column) location is shown in figure 12

Figure 25. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Quarterfield well field and Queenstown Park observation well.

The altitude of the top of the lower Patapsco aquifer is 70 ft below sea level. Considering the proximity of this well field to areas of tidal surface water, only minimal increases in pumpage were included in the model scenarios.

Crain Highway well field

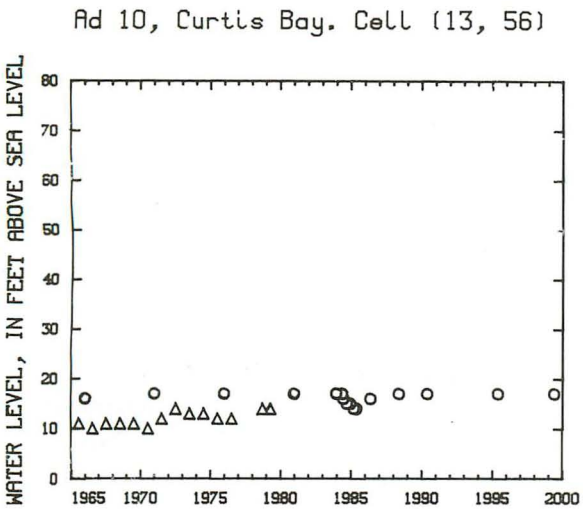
In 1985, about 0.91 Mgal/d was pumped from the lower Patapsco aquifer in the Crain Highway well field. The areal water level in 1985 was 49 ft above sea level (well Bd 105). The water level in pumping well Bd 105 was 13 ft above sea level (1983). The altitude of the top of the lower Patapsco aquifer is 90 ft below sea level. Of all the Glen Burnie area well fields, Crain Highway is farthest inland from areas of tidal surface water. Therefore, pumpage was increased in the model scenarios in this well field.

Phillips Drive well field

The amount of ground water pumped from the Phillips Drive well field in 1985 was about 0.46 Mgal/d, contributing to the 13-ft drawdown in well Bd 101. The areal water level in 1985 was 24 ft above sea level (well Bd 101). The water level in pumping well Bd 101 was 31 ft below sea level (1981). Because the altitude of the top of the lower Patapsco aquifer is 140 ft below sea level and its location is farther away from areas of tidal surface water, pumpage was increased in this well field in the model scenarios.

Elvaton well field

In 1985, pumpage from the Elvaton well field was 0.55 Mgal/d, causing a 7- to 10-ft drawdown in well Bd 107 which contributed to the lowering of the areal water level to 17 ft above sea level (well Bd 107). The water level in pumped

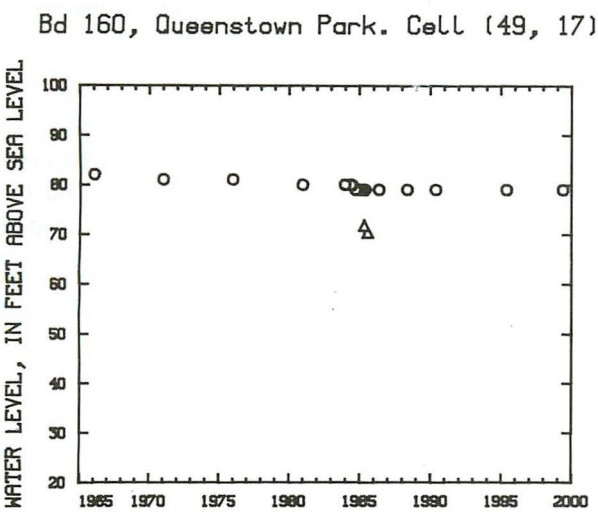


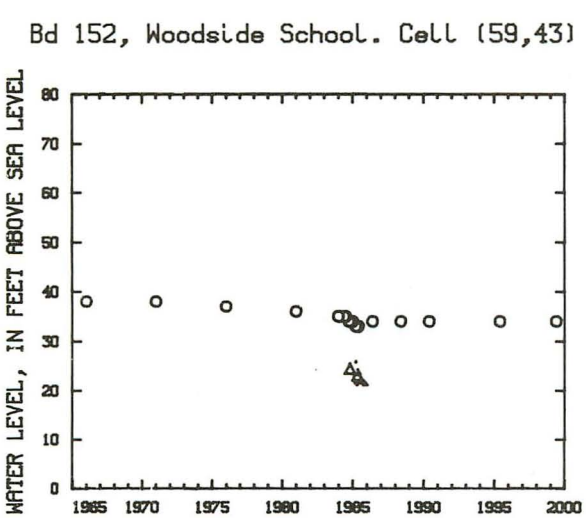
EXPLANATION

△ Measured water level for selected well. Well location is shown in figure 2

○ Simulated 1965-2000 water level for cell using 1965-85 actual pumpage and using 1985 maximum pumpage for 1986-2000. Cell (row, column) location is shown in figure 12

Figure 26. — Comparison of measured water levels in wells and simulated water levels in cells tapping the lower Patapsco aquifer in the Curtis Bay observation well.



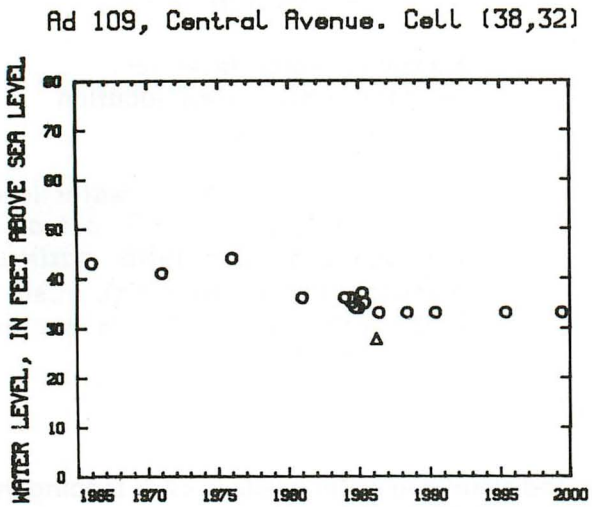


EXPLANATION

△ Measured water level for selected well. Well location is shown in figure 2

○ Simulated 1965-2000 water level for cell using 1965-85 actual pumpage and using 1985 maximum pumpage for 1986-2000. Cell (row, column) location is shown in figure 12

Figure 27. — Comparison of measured water levels in wells and simulated water levels in cells tapping the upper Patapsco aquifer in the Queenstown Park and Woodside School observation wells.



EXPLANATION

△ Measured water level for selected well. Well location is shown in figure 2

○ Simulated 1965-2000 water level for cell using 1965-85 actual pumpage and using 1985 maximum pumpage for 1986-2000. Cell (row, column) location is shown in figure 12

Figure 28. — Comparison of measured water levels in wells and simulated water levels in cells tapping the upper Patapsco aquifer in the Sawmill well field (Central Avenue).

well Bd 107 was 34 ft below sea level (1980). The altitude of the top of the lower Patapsco aquifer is 160 ft below sea level. Considering its location away from areas of tidal surface water, pumpage was increased in the model scenarios in this well field.

Quarterfield well field

In 1985 a ground-water withdrawal of 0.73 Mgal/d caused a 6-ft drawdown (well Bd 109) in the Quarterfield well field and contributed to the decline of the areal water level to 61 ft above sea level. The water level in pumping well Bd 109 was 16 ft below sea level (1983). The altitude of the top of the lower Patapsco aquifer is 140 ft below sea level. Considering its location away from areas of tidal surface water, pumpage was increased in the model scenarios in this well field.

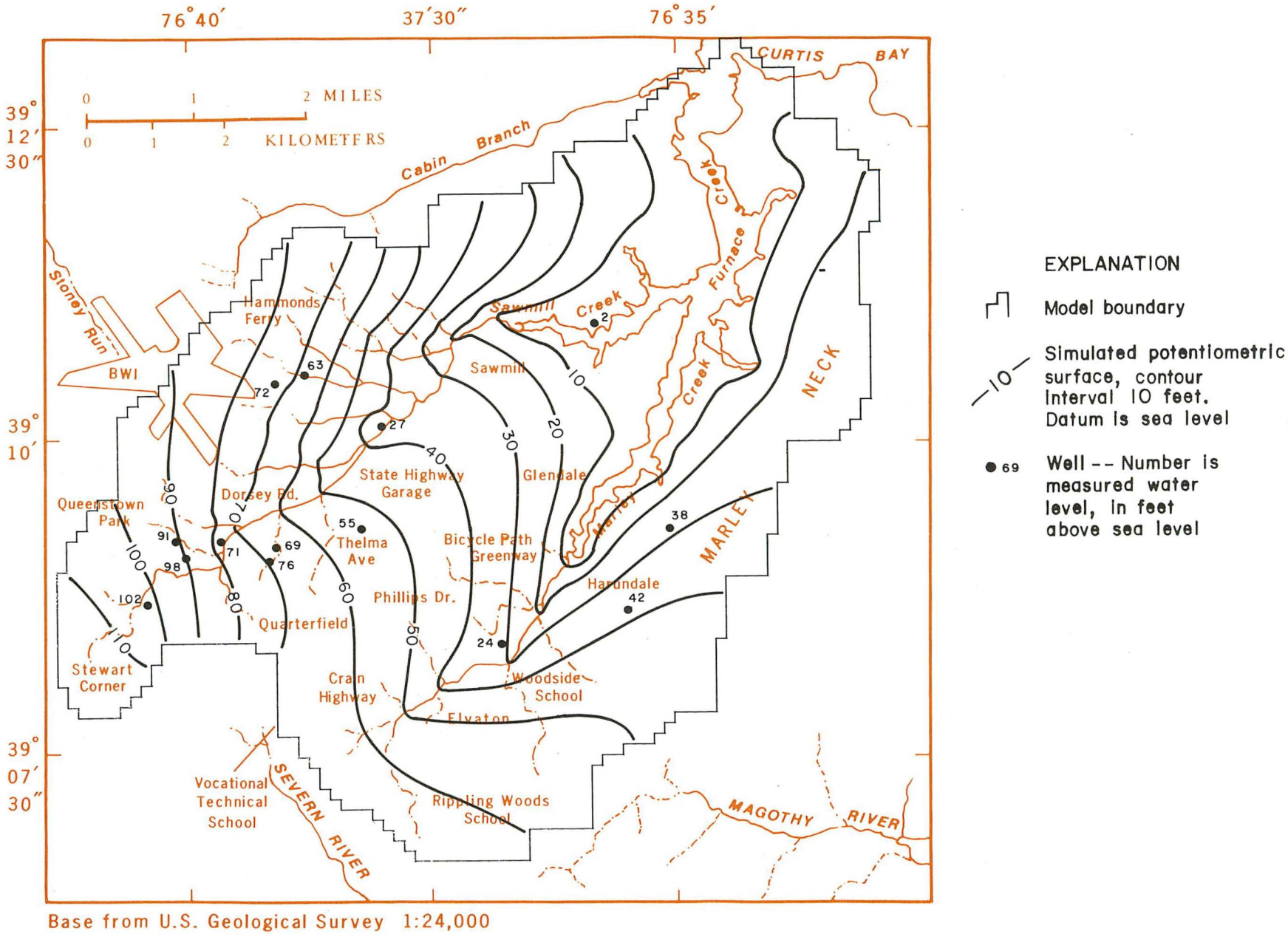


Figure 29. — Comparison of simulated 1985 potentiometric surface and water levels for the upper Patapsco aquifer used in the transient model calibration.

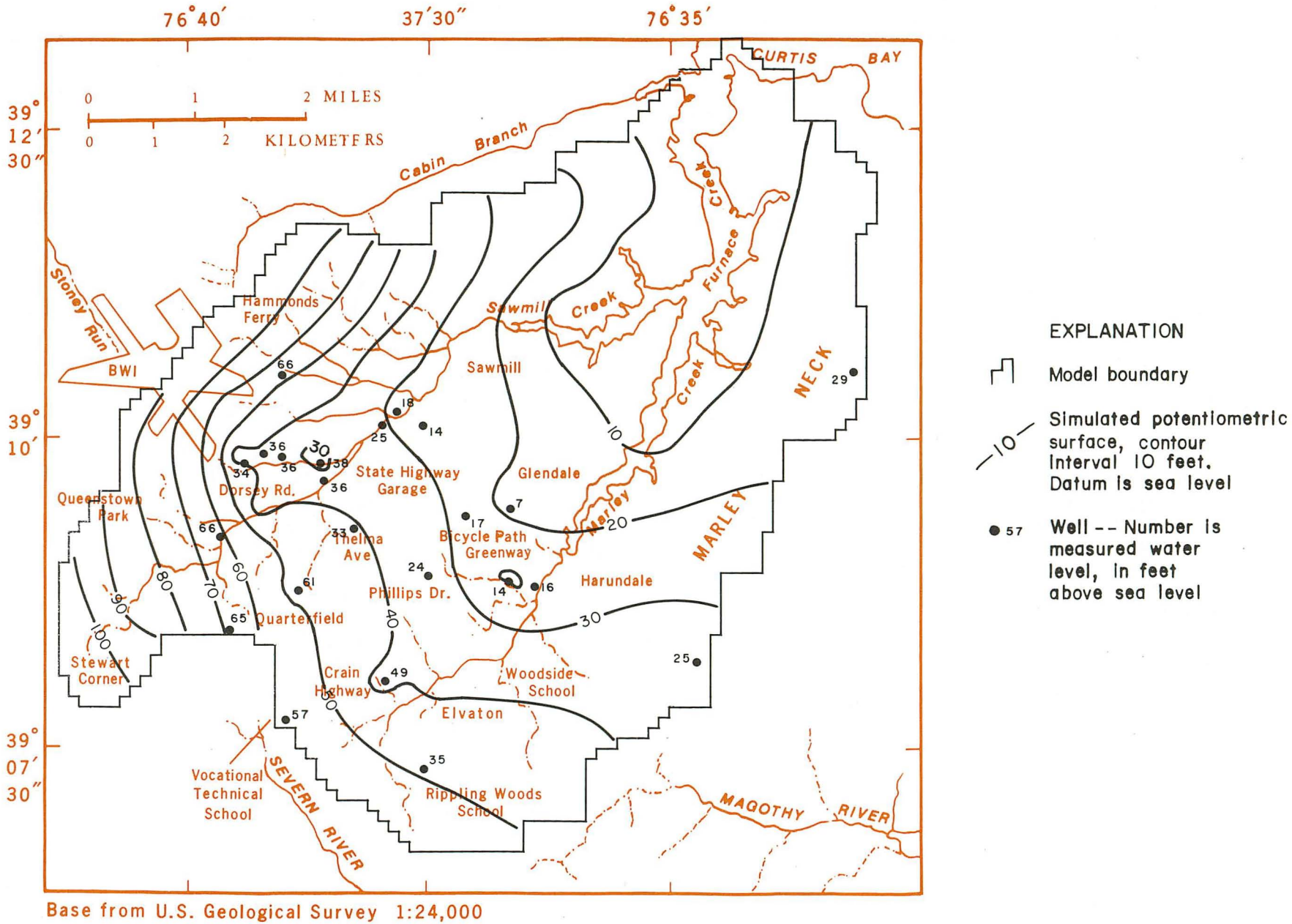


Figure 30. — Comparison of simulated 1985 potentiometric surface and water levels for the lower Patapsco aquifer used in the transient model calibration.

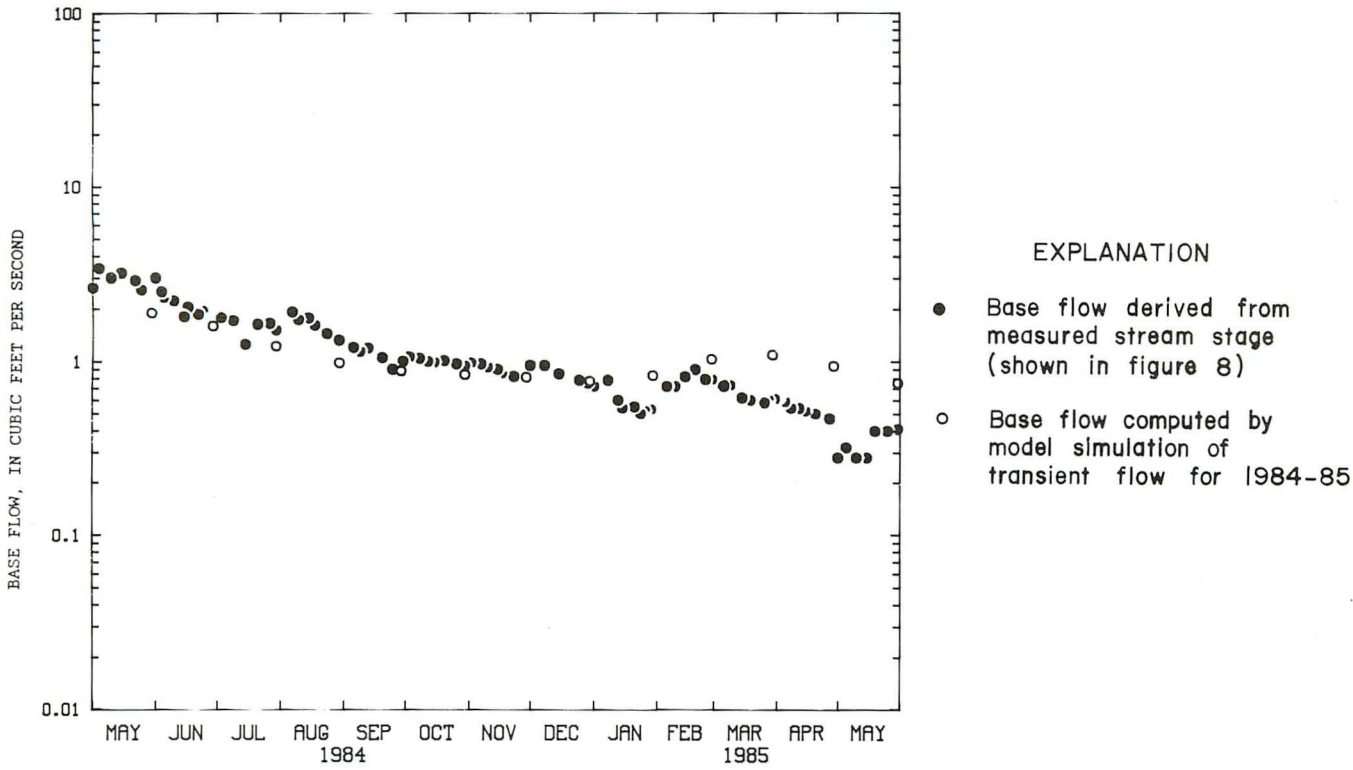


Figure 31. — Comparison of base flows of Sawmill Creek at Glen Burnie derived from measured stream stage and computed by simulation of transient ground-water flow, 1984-85.

Pumpage Scenarios

The calibrated model was used to assess the potential of the Patapsco aquifer system to supply future freshwater demands in the Glen Burnie area. Although the model is not an exact representation of reality, the various computed scenarios are considered reasonable and should provide useful insights into what may actually occur in response to increased pumpage.

The assessment procedure consisted of increasing pumpage at the existing well fields and analyzing the subsequent results with respect to the amount of drawdown, the potential for saltwater intrusion, and the base flow of Sawmill Creek at Glen Burnie. The questions that were considered include:

1. *How far will the water level be lowered as a result of additional pumpage?*
   If the simulated areal water level for the confined aquifer declined below the top of the aquifer, the pumpage was considered to be excessive.
   If the water table in a location near areas of tidal surface water declined below sea level, a potential for saltwater intrusion was indicated.

2. *Is there a reversal of flow direction at the constant-head boundary cells defining areas of tidal surface water?*
   If this should happen, saltwater intrusion of the unconfined aquifer could occur.

3. *How much did the pumpage reduce stream base flow?*
   Excess pumpage could dewater the streams.

Two recharge conditions that were assumed in simulating the future pumping scenarios were:

(1) Long-term average recharge rate of 20.5 in/yr for 1965-84, average recharge rate of 14.4 in/yr for 1984-85, and long-term average recharge rate of 20.5 in/yr for 1986-2005.

(2) Same recharge conditions as were previously mentioned, except for 1989-90, a 2-year hypothetical drought was simulated. During drought conditions, the recharge rate was assumed to be 60 percent of the long-term average recharge, which amounts to 12.3 in/yr.

The simulations of future scenarios were arranged as follows:

Scenario 1. A pumpage of 11.57 Mgal/d was used for 1986-2005. The simulated rate of 11.57 Mgal/d rep-

resents the reported maximum pumpage rate in 1985.

Scenario 2. Starting with 1986, pumpage for the Sawmill, Dorsey Road, and Harundale well fields was increased by a total of 0.98 Mgal/d over 11.57 Mgal/d.

Scenario 3. Starting with 1986, pumpage for the Quarterfield and Crain Highway well fields was increased by an additional total of 0.96 Mgal/d over 11.57 Mgal/d.

Scenario 4. Pumpage was increased by a total of 1.95 Mgal/d over 11.57 Mgal/d pumpages as scenarios 2 and 3 were combined.

Scenario 5. Pumpage was increased by 2.93 Mgal/d over 11.57 Mgal/d pumpage and was distributed among the existing well fields, with the exception of the Glendale well field.

Scenarios 6-8. Pumpage was further increased by an additional 3.58 Mgal/d (scenario 6) and 4.55 Mgal/d (scenario 7) over 11.57 Mgal/d. Scenario 8 is the same as scenario 7, except that the additional pumpage was withdrawn from five well fields farther away from the streams and areas of tidal surface water.

In all the simulations, water levels stabilized about the year 2000 and those water levels were used in the illustrations and tables describing the pumpage scenarios. The amount of pumpage, the simulated areal water levels in selected cells, and stream base flow at the Glen Burnie stream-gaging station are tabulated in table 10. Areal water-level hydrographs for selected cells are plotted in figures 32 to 34. These cells are located near pumping wells with the lowest areal water levels (for example, cell row 46, column 21 near well Bd 95), or close to areas of tidal surface water (for example, cell row 45, column 45 near well Bd 103). The hydrographs display, therefore, a worst-case situation for each scenario at specific well-field locations. Some of the hydrographs obtained from simulating scenario 1 indicate that water levels recover immediately after 1985. The recovery is in response to simulating the recurrence of the long-term recharge rate of 20.5 in/yr beginning in 1986, succeeding the 1984-85 recharge rate of 14.4 in/yr.

Additional drawdowns simulating water levels in pumped wells were calculated using Thiem's equation which assumes that (1) the flow around the well is laminar, (2) there is no well loss (100-percent well efficiency), (3) the well has an effective radius of 1 ft, (4) the well is screened for the entire thickness of the aquifer, and (5) the aquifer is homogeneous, isotropic, and infinite in areal extent. These assumptions are idealized conditions that are not met in the field, often resulting in simulated water levels that are higher than those measured. Table 11 lists simulated water levels and available drawdowns in hypothetical pumped wells in cells obtained by simulating pumpage scenarios. Available drawdown is defined as the arithmetic difference between water levels obtained from the 1985 calibration and the altitude of the top of the lower Patapsco aquifer or the top of the screen in the upper Patapsco aquifer.

Simulated base flows of Sawmill Creek at the Glen Burnie gaging station are shown in figure 35 for different pumpage scenarios. The simulated base flow for scenario 1 recovers immediately after 1985, in response to the recurrence of the long-term recharge rate of 20.5 in/yr beginning in 1986. The 1984-85 recharge rate is 14.4 in/yr.

Scenario 1

In scenario 1, the 1985 maximum pumpage of 11.57 Mgal/d was used from 1986 to 2005. The areal water levels in the Patapsco aquifers for the year 2000 are still above sea level and the water levels in the pumping wells are still above the altitude of the top of the aquifer (table 10, figs. 36 and 37); therefore, additional scenarios were simulated stressing the system with increased pumpage. Figure 36 indicates that the potentiometric surface in the upper Patapsco aquifer for the year 2000 would change only slightly from 1985. Although figure 37 shows cones of depression in the lower Patapsco potentiometric surface surrounding several well fields, the areal water levels in the Glen Burnie area are above sea level, indicating that there is no immediate danger of saltwater intrusion into the Glen Burnie well fields from areas of tidal surface water of the bay tributaries. The simulated base flow of Sawmill Creek at Glen Burnie shows a slight recovery after the 1984-85 decline and then stabilizes at 0.98 ft^3/s (fig. 35).

Scenario 2

In scenario 2, pumpages from the Sawmill, Dorsey Road, and Harundale well fields were increased by about 0.98 Mgal/d over scenario 1 (table 10). Table 11 shows that the areal water levels in the lower Patapsco aquifer in the Dorsey Road, Sawmill, and Harundale well fields for the year 2000 are reduced by 0 to 7 ft from the 1985 water levels; the upper Patapsco water level in the Sawmill well field is reduced by about 4 ft. The areal water level in the lower Patapsco aquifer in the Glendale well field for the year 2000 was lowered by 3 ft from the 1985 water level, even though no additional pumpage was simulated at this field. The potentiometric surfaces in the Patapsco aquifers for 2000 are plotted in figures 38 and 39. Figure 38 shows that there is less than a 5-ft decline in the water level of the upper Patapsco aquifer in scenario 2 as compared to scenario 1. Figure 39 shows that the cones of depression in the lower Patapsco aquifer expand

(Text continued on p. 61.)

Table 10. — Simulated pumpage scenarios, simulated areal water level in cells, and simulated base flows of the Sawmill Creek basin at Glen Burnie for the year 2000

[-, no pumpage simulated at this location; Mgal/d, million gallons per day; ft³/s, cubic feet per second]

Well field or location	Well number	Cell near well, (row, column; location in figure 12)	Simulated pumpage from the lower Patapsco aquifer, in million gallons per day: Pumpage scenarios 1	2	3	4	5	6	7	8	Selected cell, (row, column; location in figure 12)	Simulated areal water level of the lower Patapsco aquifer, except where otherwise noted, in feet above sea level: Pumpage scenarios 1	2	3	4	5	6	7	8
Sawmill	Ad 23	(37, 36)	0.19	0.26	0.19	0.26	0.32	0.32	0.39	0.19	(38, 35)	25	21	24	20	16	16	12	20
	Ad 40	(38, 36)	.25	.32	.25	.32	.38	.38	.45	.25	(37, 34)	23	19	22	19	14	14	9	19
	Ad 41	(37, 34)	.36	.43	.36	.43	.49	.49	.56	.36	(38, 32)	33	31	33	30	27	27	24	30
	Ad 67	(36, 35)	.48	.55	.48	.55	.61	.61	.67	.48									
	Ad 68	(38, 32)	.46	.52	.46	.52	.59	.59	.65	.47									
Subtotal pumpage			1.74	2.08	1.74	2.08	2.39	2.39	2.72	1.75									
Dorsey Road	Ad 74	(39, 26)	.28	.35	.28	.35	.48	.48	.67	.28	(41, 23)	30	27	28	25	23	23	21	23
	Bd 55	(41, 27)	.18	.23	.17	.23	.43	.43	.55	.17	(46, 21)	32	29	31	27	25	24	21	26
	Bd 56	(41, 26)	.78	.84	.78	.84	.85	.85	.85	.78									
	Bd 64	(41, 23)	.52	.59	.52	.59	.59	.59	.59	.53									
	Bd 92	(41, 19)	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29									
	Bd 95	(46, 21)	1.34	1.41	1.34	1.41	1.41	1.41	1.41	1.34									
Subtotal pumpage			4.39	4.71	4.38	4.71	5.05	5.05	5.36	4.39									
Hammonds Ferry	Ad 88	(36, 25)[a]	-	-	-	-	-	-	-	-	(36, 25)[a]	44	41	43	40	37	37	34	39
	Ad 104	(33, 23)[a]	-	-	-	-	-	-	-	-	(33, 23)[a]	75	74	74	74	73	73	72	73
Glendale	Bd 103	(45, 45)	.80	.80	.80	.80	.80	.80	.80	.80	(45, 45)	11	9	10	8	7	5	3	4
Harundale	Bd 36	(54, 48)	.35	.42	.35	.42	.42	.58	.65	.35	(54, 46)	19	16	18	13	13	6	2	19
	Bd 37	(54, 46)	.35	.42	.35	.42	.42	.58	.65	.35									
	Bd 61	(53, 44)	.36	.42	.36	.42	.42	.58	.71	.36									
	Bd 63	(53, 45)	.36	.48	.36	.48	.48	.65	.71	.36									
Subtotal pumpage			1.42	1.74	1.42	1.74	1.74	2.39	2.72	1.42									
Phillips Drive	Bd 101	(52, 37)	[b].67	[b].67	[b].67	[b].67	[b].87	[b].87	[b].87	1.58	(52, 37)	30	28	27	25	22	20	18	1
Thelma Avenue	Bd 105	(48, 30)	[b].00	[b].00	[b].00	[b].00	[b].00	[b].00	[b].00	.91	(48, 30)	40	38	37	35	32	31	30	15
Crain Highway	Bd 105	(62, 32)	1.00	1.00	1.32	1.32	1.32	1.32	1.32	1.90	(62, 32)	31	30	24	23	21	20	19	5
Elvaton	Bd 107	(63, 38)	.70	.70	.70	.70	.83	.83	.83	1.60	(63, 38)	30	29	28	27	24	22	21	6
Quarterfield	Bd 109	(54, 24)	.85	.85	1.50	1.50	1.50	1.50	1.50	1.77	(54, 24)	41	40	30	29	27	26	25	17
Woodside School	Bd 152[a]	(59, 43)	-	-	-	-	-	-	-	-	(59, 43)[a]	34	33	33	33	32	32	31	30
Bicycle Path Greenway	Bd 156	(47, 41)	-	-	-	-	-	-	-	-	(47, 41)	26	24	25	23	21	19	16	16
Curtis Bay	Ad 10	(13, 56)	-	-	-	-	-	-	-	-	(13, 56)	17	17	17	17	17	17	17	17
Rippling Woods School	Bd 157	(68, 35)	-	-	-	-	-	-	-	-	(68, 35)	44	44	42	41	40	39	38	31
Queenstown Park	Bd 160[a]	(49, 17)	-	-	-	-	-	-	-	-	(49, 17)[a]	79	79	79	79	79	79	78	78
Vocational Technical School	Bd 158	(67, 23)	-	-	-	-	-	-	-	-	(67, 23)	50	49	47	46	45	44	44	38
Pumpage over scenario 1 (Mgal/d)			-	0.98	0.96	1.95	2.93	3.58	4.55	4.55									
Total pumpage (Mgal/d)			11.57	12.55	12.53	13.52	14.50	15.15	16.12	16.12									
Base flow of Sawmill Creek at Glen Burnie (ft^3/s)			.98	.67	.72	.40	.08	.001	dry	dry									

[a] Well screened in the upper Patapsco aquifer.

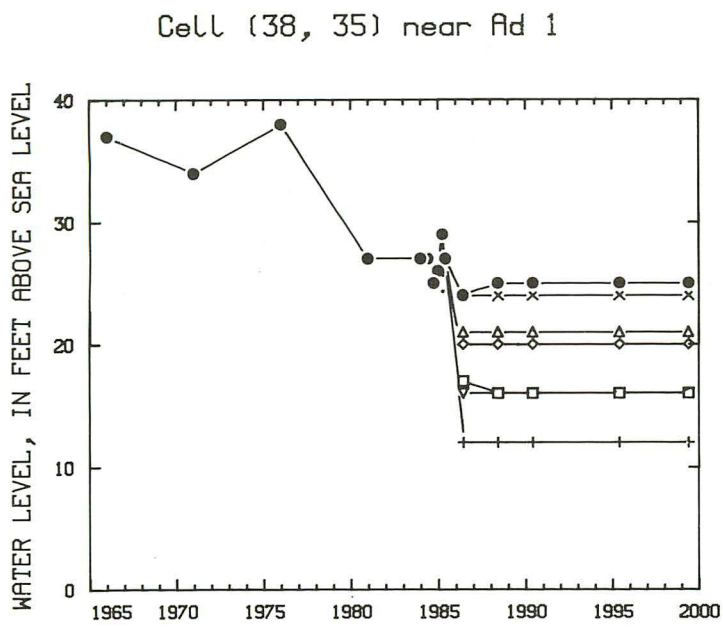
[b] Simulated pumpage is 0.006 Mgal/d.

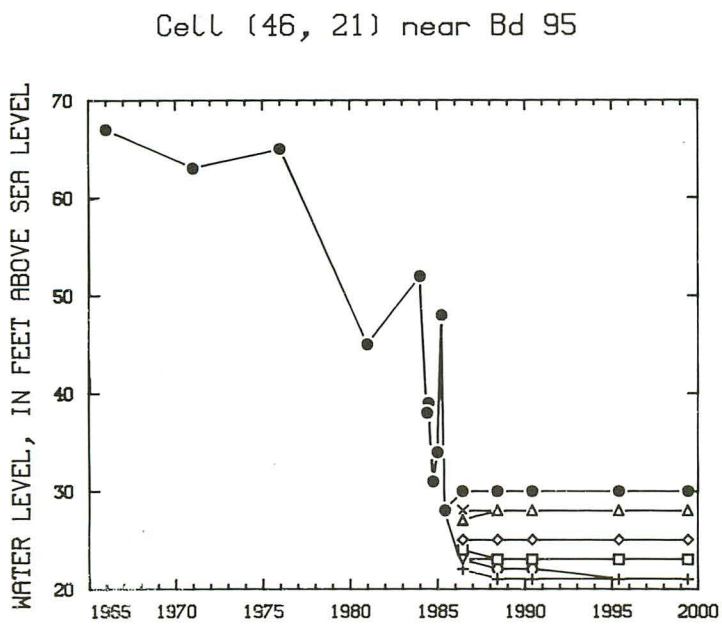
Table 11. — Measured water levels, available drawdowns, and simulated drawdowns in the lower Patapsco aquifer for eight pumpage scenarios, 1985-2000

[-, no measured water level at this location; ft = feet]

Well field or location	Well number	Altitude of the top of the aquifer, in feet above or below (-) sea level	Water levels and available drawdowns, in feet, for the lower Patapsco aquifer: Pumping well: Water level,[a] year measured in parentheses	Pumping well: Available drawdown	Cell area, 500 ft by 500 ft: Cell, (row, column; location in figure 12)	Cell area, 500 ft by 500 ft: Water level from the 1985 calibration	Cell area, 500 ft by 500 ft: Available drawdown	Simulated drawdowns (1985-2000), in feet, for cell areas and hypothetical wells in the lower Patapsco aquifer: Scenarios 1: Cell area	1: Hypothetical well	2: Cell area	2: Hypothetical well	3: Cell area	3: Hypothetical well	4: Cell area	4: Hypothetical well	5: Cell area	5: Hypothetical well	6: Cell area	6: Hypothetical well	7: Cell area	7: Hypothetical well	8: Cell area	8: Hypothetical well
Sawmill	Ad 1	-80	-	-	(38, 35)	27	107	2	-	6	-	3	-	7	-	11	-	11	-	15	-	7	-
	Ad 41	-80	-52 (1983)	28	(37, 34)	26	106	3	3	7	11	4	4	7	11	12	20	12	20	17	28	7	11
	Ad 109[b]	[c] +5	-	-	(38, 32)	35	30	[b]2	-	[b]4	-	[b]2	-	[b]5	-	[b]8	-	[b]8	-	[b]11	-	[b]5	-
Dorsey Road	Bd 64	-85	-21 (1983)	64	(41, 23)	32	117	2	2	5	8	4	4	7	10	9	12	9	12	11	14	9	9
	Bd 95	-80	-76 (1982)	4	(46, 21)	29	109	*3	*3	0	5	*2	*2	2	7	4	9	5	10	8	13	3	3
Hammonds Ferry	Ad 88	-40	-	-	(36, 25)	43	83	1	-	2	-	0	-	3	-	6	-	6	-	9	-	4	-
Glendale	Bd 103	-100	-63 (1983)	37	(45, 45)	12	112	1	1	3	3	2	2	4	4	5	5	7	7	9	9	8	8
Harundale	Bd 37	-70	-25 (1983)	45	(54, 46)	20	90	1	1	4	6	2	2	7	9	7	9	14	20	18	27	1	1
Phillips Drive	Bd 101	-140	-31 (1981)	109	(52, 37)	32	172	2	2	4	4	5	5	7	7	10	17	12	19	14	21	31	70
Thelma Avenue	Bd 108	-120	-53 (1980)	67	(48, 30)	35	155	*5	*5	*3	*3	*2	*2	0	0	3	3	4	4	5	5	20	72
Crain Highway	Bd 105	-90	13 (1983)	103	(62, 32)	35	125	4	4	5	5	11	24	12	25	14	27	15	28	16	29	30	69
Elvaton	Bd 107	-160	-34 (1980)	126	(63, 38)	34	194	4	4	5	5	6	6	7	7	10	13	12	15	13	16	28	69
Quarterfield	Bd 109	-140	-16 (1983)	124	(54, 24)	48	188	7	7	8	8	18	44	19	45	21	37	22	38	23	49	31	70
Woodside School	Bd 152[b]	[c] -45	-	-	(59, 43)	33	78	[b]*1	-	[b]0	-	[b]0	-	[b]0	-	[b]1	-	[b]1	-	[b]2	-	[b]3	-
Bicycle Path Greenway	Bd 156	-80	-	-	(47, 41)	27	107	1	-	3	-	2	-	4	-	6	-	8	-	11	-	11	-
Curtis Bay	Ad 10	-2	-	-	(13, 56)	14	16	*3	-	*3	-	*3	-	*3	-	*3	-	*3	-	*3	-	*3	-
Rippling Woods School	Bd 157	-75	-	-	(68, 35)	47	122	3	-	3	-	5	-	6	-	7	-	8	-	9	-	16	-
Queenstown Park	Bd 160[b]	[c] +0	-	-	(49, 17)	79	79	[b]0	-	[b]0	-	[b]0	-	[b]0	-	[b]0	-	[b]0	-	[b]1	-	[b]1	-
Vocational Technical School	Bd 158	-70	-	-	(67, 23)	55	125	5	-	6	-	8	-	9	-	10	-	11	-	11	-	17	-

[a] Sea-level datum.
[b] Upper Patapsco well (water-table condition).
[c] Altitude of the top of the screen in the well.
* Water-level recovery.



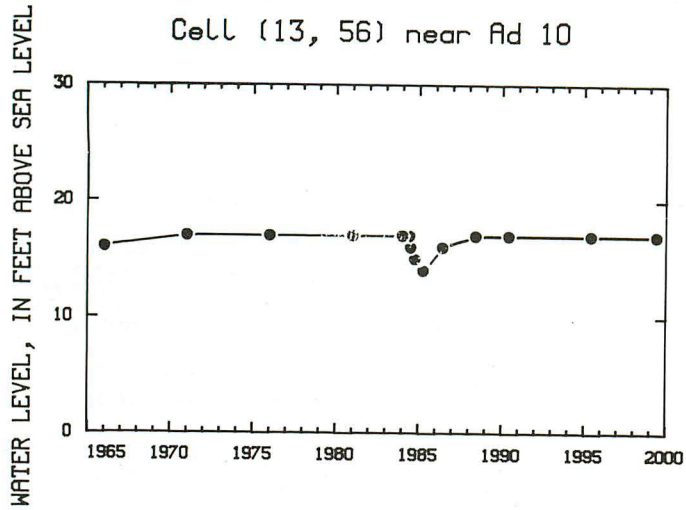


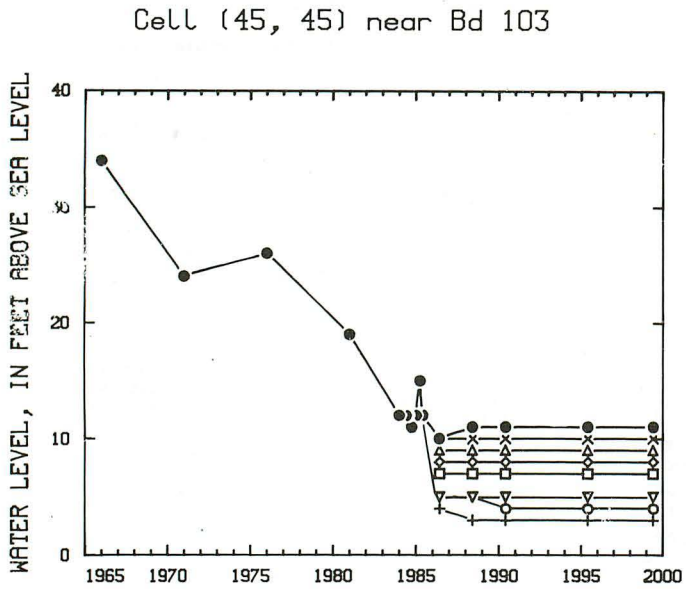
EXPLANATION

Scenario	Symbol	Pumpage added to 1985 rate of 11.57 Mgal/d	Well fields where the additional pumpage was assigned	Total pumpage, in million gallons per day (Mgal/d)
1	●	0.00	--	11.57
2	Δ	.98	Sawmill, Dorsey Road, and Harundale	12.55
3	x	.96	Crain Highway and Quarterfield	12.53
4	◇	1.95	Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield	13.52
5	□	2.93	All Glen Burnie well fields, except Glendale and Thelma Avenue	14.50
6	∇	3.58	All Glen Burnie well fields, except Glendale and Thelma Avenue	15.15
7	+	4.55	All Glen Burnie well fields, except Glendale and Thelma Avenue	16.12
8	○	4.55	Phillips Drive, Elvaton, Crain Highway, Thelma Avenue, and Quarterfield	16.12

Note: Where symbols coincide, only one symbol is shown on the plot. Table 10 lists water levels, base flows, and pumpage distributions for each scenario in year 2000.

Figure 32. — Hydrographs of simulated water-levels in the lower Patapsco aquifer and effects of pumpage scenarios totaling 11.57 to 16.12 million gallons per day for cells (38, 35) and (46, 21) near wells Ad 1 (Sawmill) and Bd 95 (Dorsey Road).



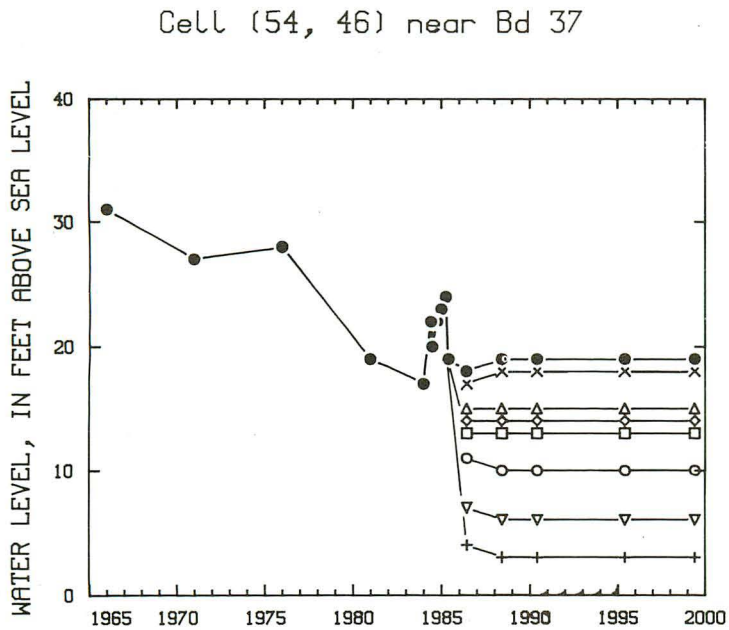


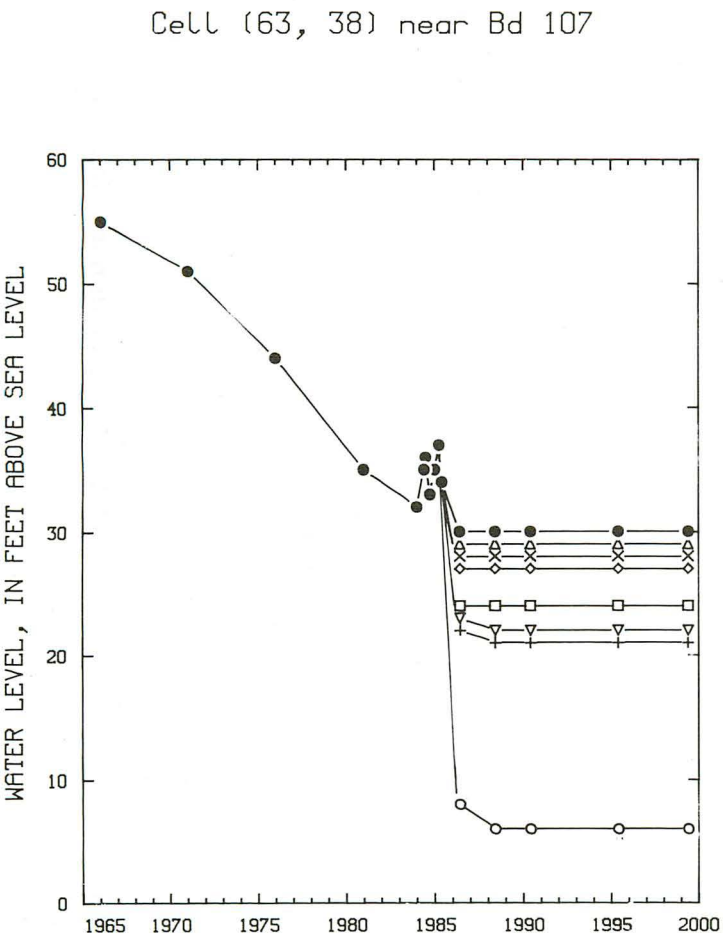
EXPLANATION

Scenario	Symbol	Pumpage added to 1985 rate of 11.57 Mgal/d	Well fields where the additional pumpage was assigned	Total pumpage, in million gallons per day (Mgal/d)
1	●	0.00	--	11.57
2	△	.98	Sawmill, Dorsey Road, and Harundale	12.55
3	x	.96	Crain Highway and Quarterfield	12.53
4	◇	1.95	Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield	13.52
5	□	2.93	All Glen Burnie well fields, except Glendale and Thelma Avenue	14.50
6	▽	3.58	All Glen Burnie well fields, except Glendale and Thelma Avenue	15.15
7	+	4.55	All Glen Burnie well fields, except Glendale and Thelma Avenue	16.12
8	○	4.55	Phillips Drive, Elvaton, Crain Highway, Thelma Avenue, and Quarterfield	16.12

Note: Where symbols coincide, only one symbol is shown on the plot. Table 10 lists water levels, base flows, and pumpage distributions for each scenario in year 2000.

Figure 33. — Hydrographs of simulated water-levels in the lower Patapsco aquifer and effects of pumpage scenarios totaling 11.57 to 16.12 million gallons per day for cells (13, 56) and (45, 45) near wells Ad 10 (Curtis Bay) and Bd 103 (Glendale).



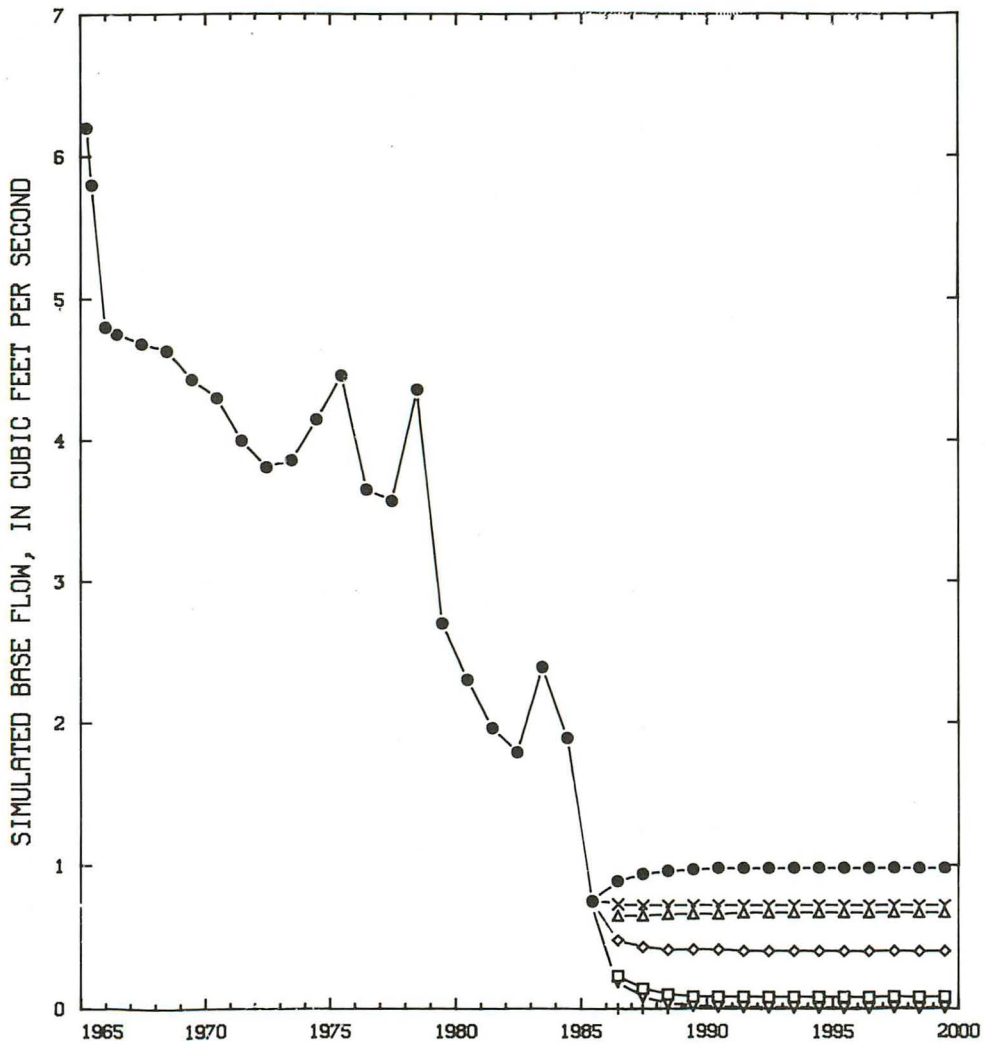


EXPLANATION

Scenario	Symbol	Pumpage added to 1985 rate of 11.57 Mgal/d	Well fields where the additional pumpage was assigned	Total pumpage, in million gallons per day (Mgal/d)
1	●	0.00	--	11.57
2	Δ	.98	Sawmill, Dorsey Road, and Harundale	12.55
3	x	.96	Crain Highway and Quarterfield	12.53
4	◇	1.95	Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield	13.52
5	□	2.93	All Glen Burnie well fields, except Glendale and Thelma Avenue	14.50
6	▽	3.58	All Glen Burnie well fields, except Glendale and Thelma Avenue	15.15
7	+	4.55	All Glen Burnie well fields, except Glendale and Thelma Avenue	16.12
8	○	4.55	Phillips Drive, Elvaton, Crain Highway, Thelma Avenue, and Quarterfield	16.12

Note: Where symbols coincide, only one symbol is shown on the plot. Table 10 lists water levels, base flows, and pumpage distributions for each scenario in year 2000.

Figure 34. — Hydrographs of simulated water-levels in the lower Patapsco aquifer and effects of pumpage scenarios totaling 11.57 to 16.12 million gallons per day for cells (54, 46) and (63, 38) near wells Bd 37 (Harundale) and Bd 107 (Elvaton).



EXPLANATION

Scenario	Symbol	Pumpage added to 1985 rate of 11.57 Mgal/d	Well fields where the additional pumpage was assigned	Total pumpage, in million gallons per day (Mgal/d)
1	●	0.00	--	11.57
2	△	.98	Sawmill, Dorsey Road, and Harundale	12.55
3	x	.96	Crain Highway and Quarterfield	12.53
4	◇	1.95	Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield	13.52
5	□	2.93	All Glen Burnie well fields, except Glendale and Thelma Avenue	14.50
6	▽	3.58	All Glen Burnie well fields, except Glendale and Thelma Avenue	15.15
7	+	4.55	All Glen Burnie well fields, except Glendale and Thelma Avenue	16.12
8	○	4.55	Phillips Drive, Elvaton, Crain Highway, Thelma Avenue, and Quarterfield	16.12

Note: Where symbols coincide, only one symbol is shown on the plot. Table 10 lists water levels, base flows, and pumpage distributions for each scenario in year 2000.

Figure 35. — Simulated base flows of Sawmill Creek at Glen Burnie using pumpages totaling 11.57 to 16.12 million gallons per day.

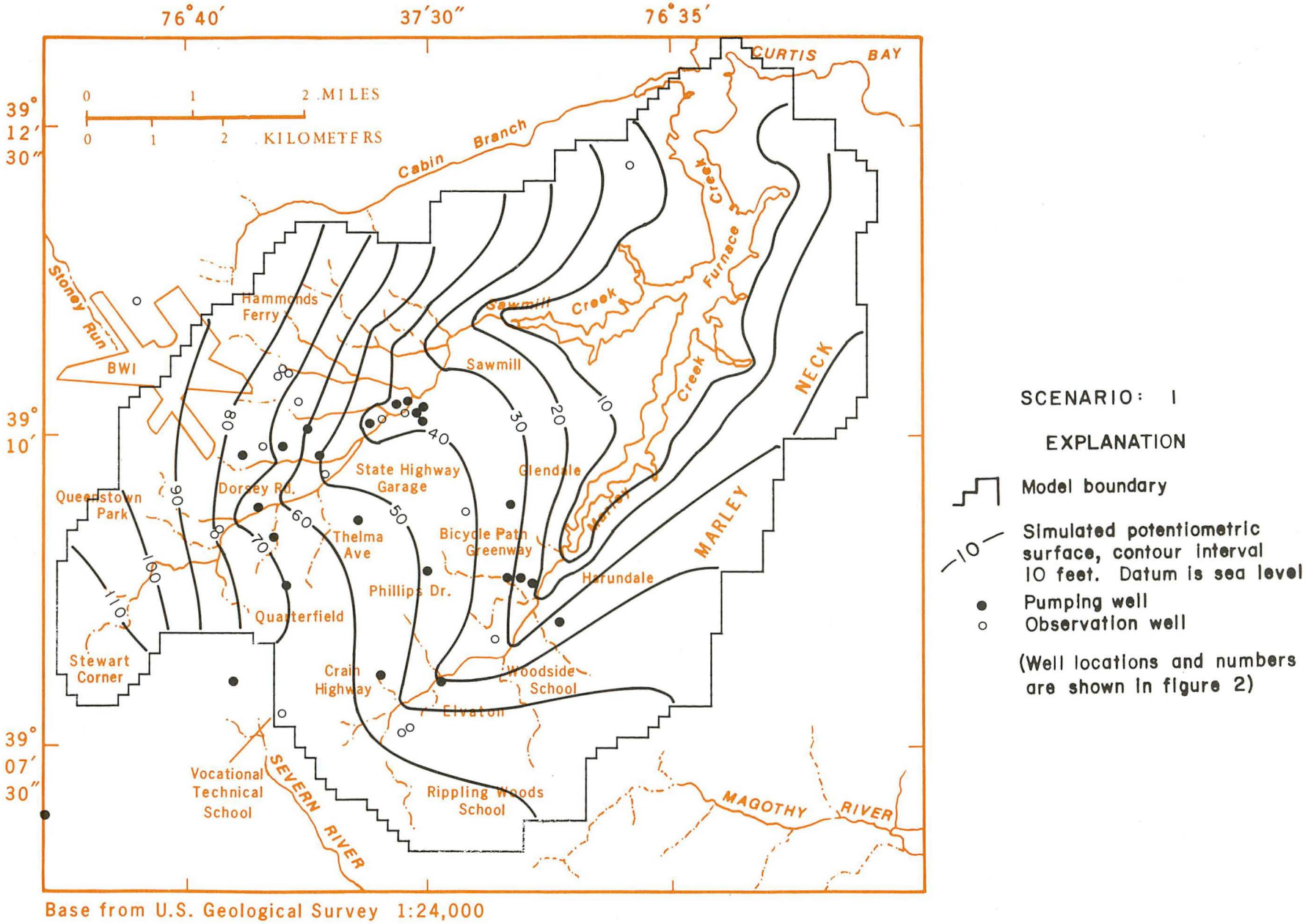


Figure 36. — Simulated potentiometric surface for the upper Patapsco aquifer for year 2000 using pumpage of 11.57 million gallons per day.

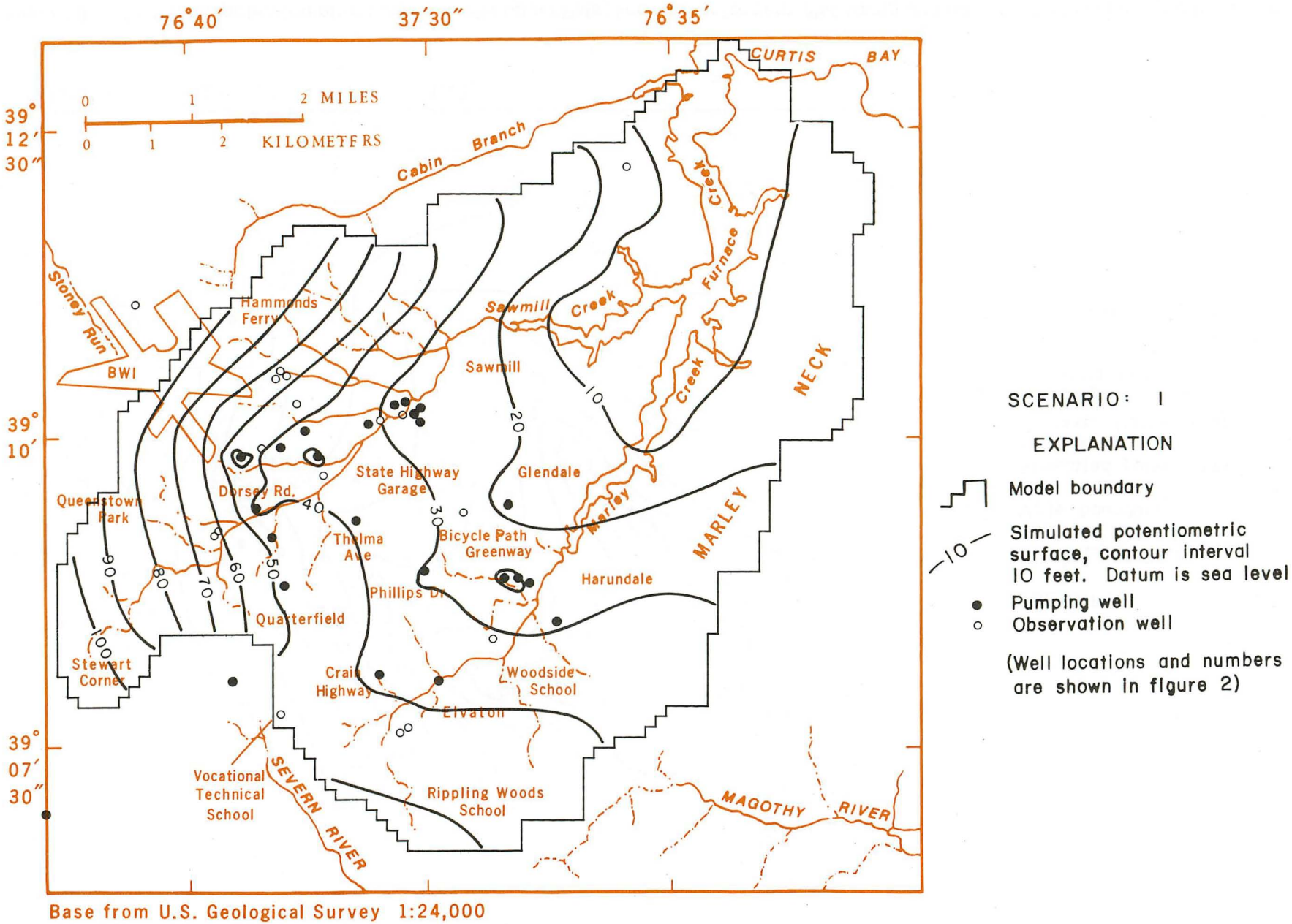


Figure 37. — Simulated potentiometric surface for the lower Patapsco aquifer for year 2000 using pumpage of 11.57 million gallons per day.

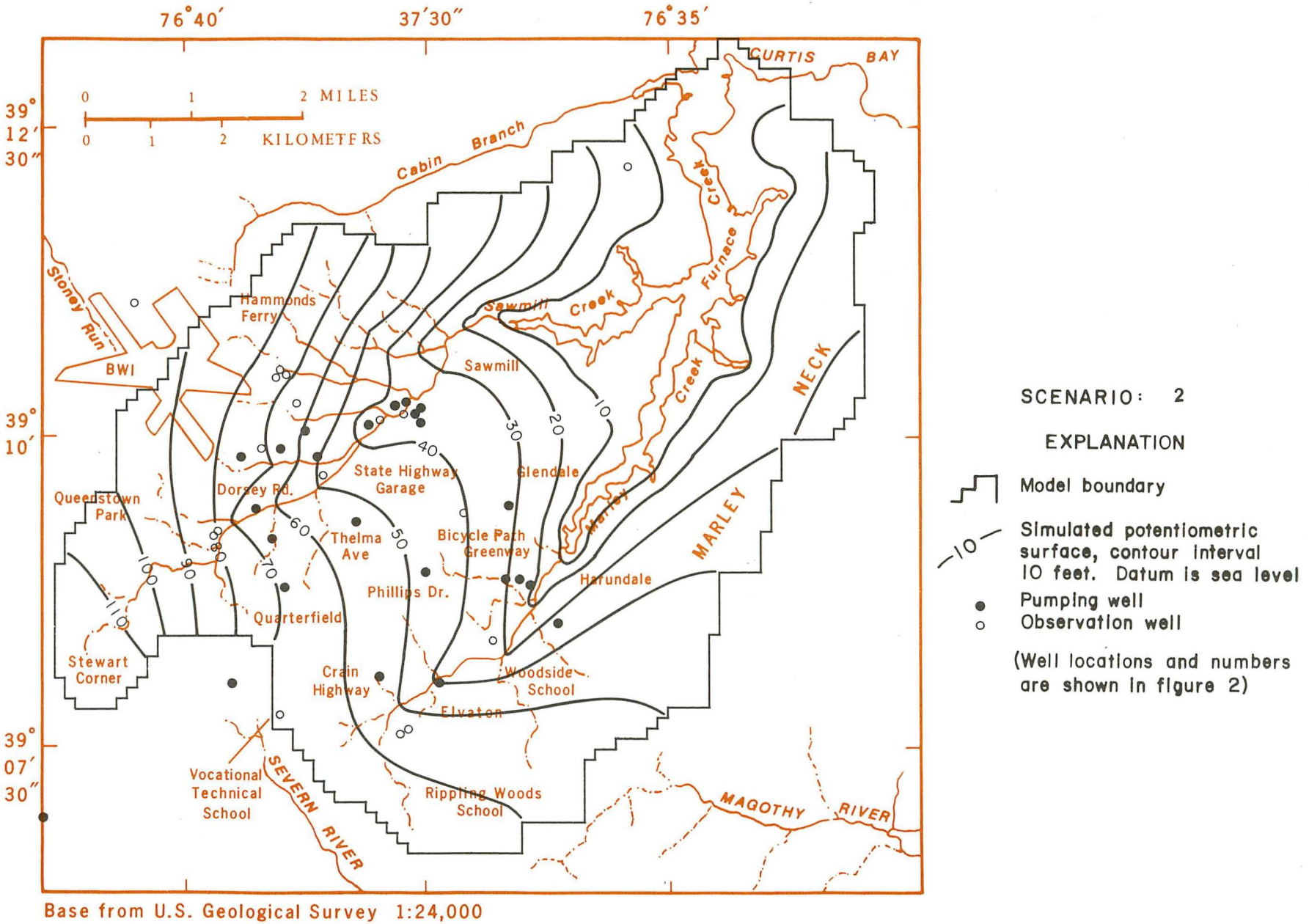
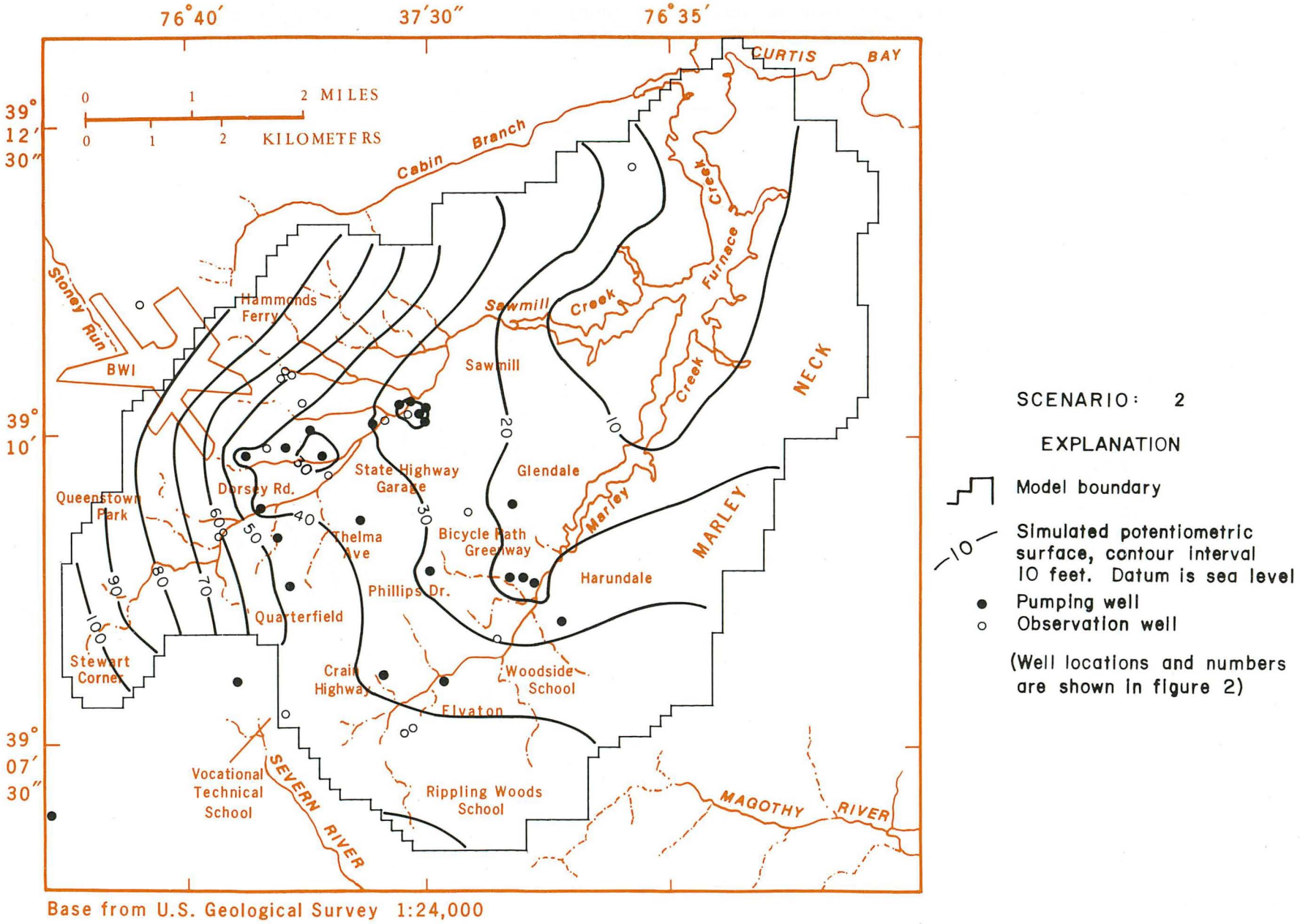


Figure 38. — Simulated potentiometric surface for the upper Patapsco aquifer for year 2000 using pumpage of 11.57 million gallons per day plus 0.98 million gallons per day from the Dorsey Road, Sawmill, and Harundale well fields.



Base from U.S. Geological Survey 1:24,000

Figure 39. — Simulated potentiometric surface for the lower Patapsco aquifer for year 2000 using pumpage of 11.57 million gallons per day plus 0.98 million gallons per day from the Dorsey Road, Sawmill, and Harundale well fields.

relatively more in the Sawmill, Dorsey Road, and Harundale well fields than in the other well fields.

Simulated water levels in hypothetical pumping wells are still above the altitude of the top of the aquifer, except for a hypothetical well in row 46 column 21 (location shown in fig. 12) near pumping well Bd 95 in the Dorsey Road well field. Simulating a pumpage of 1.41 Mgal/d from the Dorsey Road well field causes the water level in the hypothetical well to decline 8 ft, which exceeds the 4-ft available drawdown. This is an operational rather than a resource problem, because a shallower pumping level could be achieved by distributing the increased pumpage to more wells. The simulated 1985 areal water level in the same cell is 29 ft above sea level, which makes the available drawdown for the same cell area 109 ft (table 11). The unusually deep pumping level measured in well Bd 95 may be related to well construction or maintenance.

No immediate danger of saltwater intrusion from the bay tributaries into the Glen Burnie well fields is apparent because the areal water levels in the Glen Burnie area are above sea level. The simulated base flow of Sawmill Creek at the Glen Burnie gaging station is reduced to 0.67 ft^3/s.

Scenario 3

Scenario 3 was simulated to observe differences in drawdown and stream base flow when an 0.96-Mgal/d increase from scenario 1 is pumped from the Crain Highway and Quarterfield well fields, sites that are farther away from Sawmill Creek and the bay tributaries. Table 11 shows that the simulated 1985-2000 areal water-level declines in the lower Patapsco aquifer are 11 ft at the Crain Highway well field and 18 ft at the Quarterfield well field. However, the simulated 1985-2000 areal water-level decline in the lower Patapsco aquifer at the Harundale well field is only 2 ft; at the Dorsey Road well field, areal water level is lowered by about 4 ft; at the Sawmill well field the lower Patapsco areal water level is lowered by 4 ft or less and the upper Patapsco areal water level is lowered by 2 ft. At the Glendale well field the water-level decline is 2 ft, which is 1 ft less than in scenario 2.

Scenario 3 suggests that allocating additional pumpage to well fields in the southwestern part of the model area reduces both the hydrologic stress on the Dorsey Road well field and the possibility of saltwater intrusion from the areas of tidal surface water. Lower Patapsco water levels plotted for the year 2000 in figure 41 indicate deepening cones of depression in the Crain Highway and Quarterfield well fields. However, simulated water levels in the hypothetical pumping wells are still above the altitude of the top of the aquifer; therefore, the available drawdown is not exceeded (table 10). Because the ground-water levels in the Glen Burnie area are above sea level, there is no immediate danger of saltwater intrusion from the bay tributaries into the well fields. The simulated base flow of Sawmill Creek at the Glen Burnie gaging station rises to 0.72 ft^3/s, which is slightly higher than in scenario 2 (0.67 ft^3/s).

Scenario 4

Scenario 4 combines the increased pumpages of scenarios 2 and 3. A total increase of 1.95 Mgal/d above scenario 1 pumpage was withdrawn from the Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield well fields. Table 11 shows that the simulated 1985-2000 drawdowns in the lower Patapsco aquifer are 2 to 7 ft at the Dorsey Road, Sawmill, and Harundale well fields, and 12 and 19 ft at the Crain Highway and Quarterfield well fields, respectively. Simulated water levels in pumping wells are all above the altitude of the top of the aquifer, except for well Bd 95 as discussed in scenario 2. The areal water levels in the Glen Burnie well fields are above sea level, indicating that there is no immediate danger of saltwater intrusion from the bay tributaries. The simulated base flow of Sawmill Creek at the Glen Burnie gaging station is reduced to a low 0.40 ft^3/s in the year 2000.

Scenario 5

In scenario 5, the additional pumpage reached 2.93 Mgal/d above scenario 1. Simulated areal water levels in the lower Patapsco aquifer in the Hammonds Ferry, Dorsey Road, and Sawmill well fields are lowered by 6 to 12 ft, and simulated areal water levels in the upper Patapsco aquifer in the Sawmill well field are lowered by 8 ft. Simulated water levels in the pumping wells are above the altitude of the top of the aquifer, with the exception of well Bd 95, which was previously discussed in scenario 2. The areal water levels in the Glen Burnie well fields are above sea level, showing that there is no immediate danger of saltwater intrusion from the bay tributaries. The simulated base flow of Sawmill Creek at Glen Burnie is 0.08 ft^3/s, which is relatively low.

Scenario 6

In scenario 6, pumpage in the Harundale well field was increased by 0.65 Mgal/d above scenario 5 and the pumpages in the rest of the well fields were kept the same as in scenario 5. Simulated areal water levels for the year 2000 remain the same as in scenario 5 in the Sawmill well field, which is 3 mi northeast from the Harundale well field. In the Dorsey Road well field, the 1985-2000 drawdown is 1 ft more than the drawdown in scenario 5. In the Harundale well field, the 1985-2000 drawdown is 14 ft in the cell area and 20 ft in the hypothetical pumping well. In the Glendale well field, which is 0.75 mi north of Harundale, an additional drawdown of 2 ft lower than in scenario 5 occurs in the cell area and in the hypothetical well, making the aquifers more vulnerable to saltwater intrusion than in scenario 5. Simulated base flow of Sawmill Creek at Glen Burnie is 0.001 ft^3/s, which could be considered a dewatered condition.

Scenario 7

In scenario 7, additional pumpages of 4.55 Mgal/d over scenario 1 were imposed on all the well fields, except those at Glendale and Thelma Avenue. Simulated areal water levels

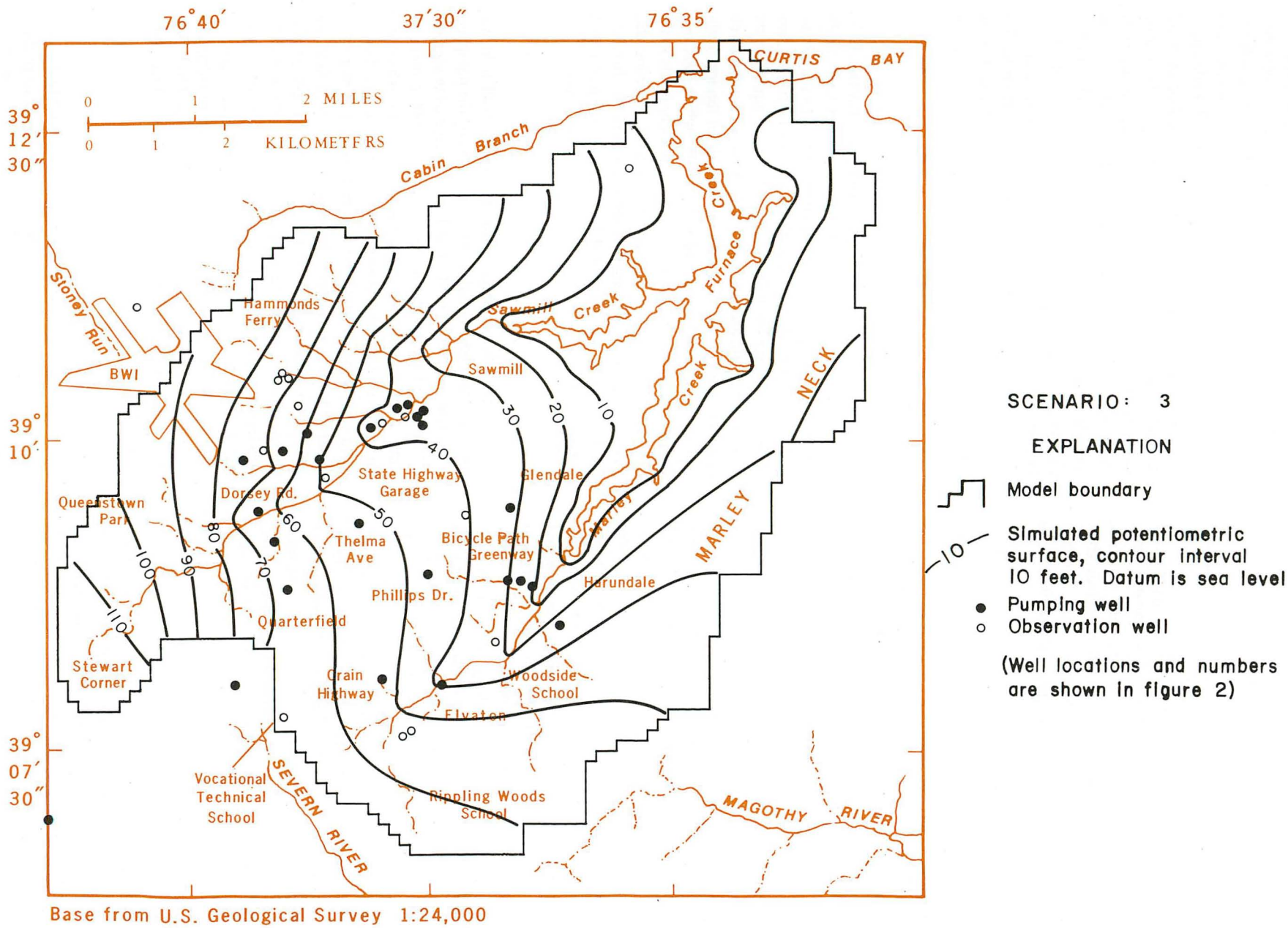


Figure 40. — Simulated potentiometric surface for the upper Patapsco aquifer for year 2000 using pumpage of 11.57 million gallons per day plus 0.96 million gallons per day from the Crain Highway and Quarterfield well fields.

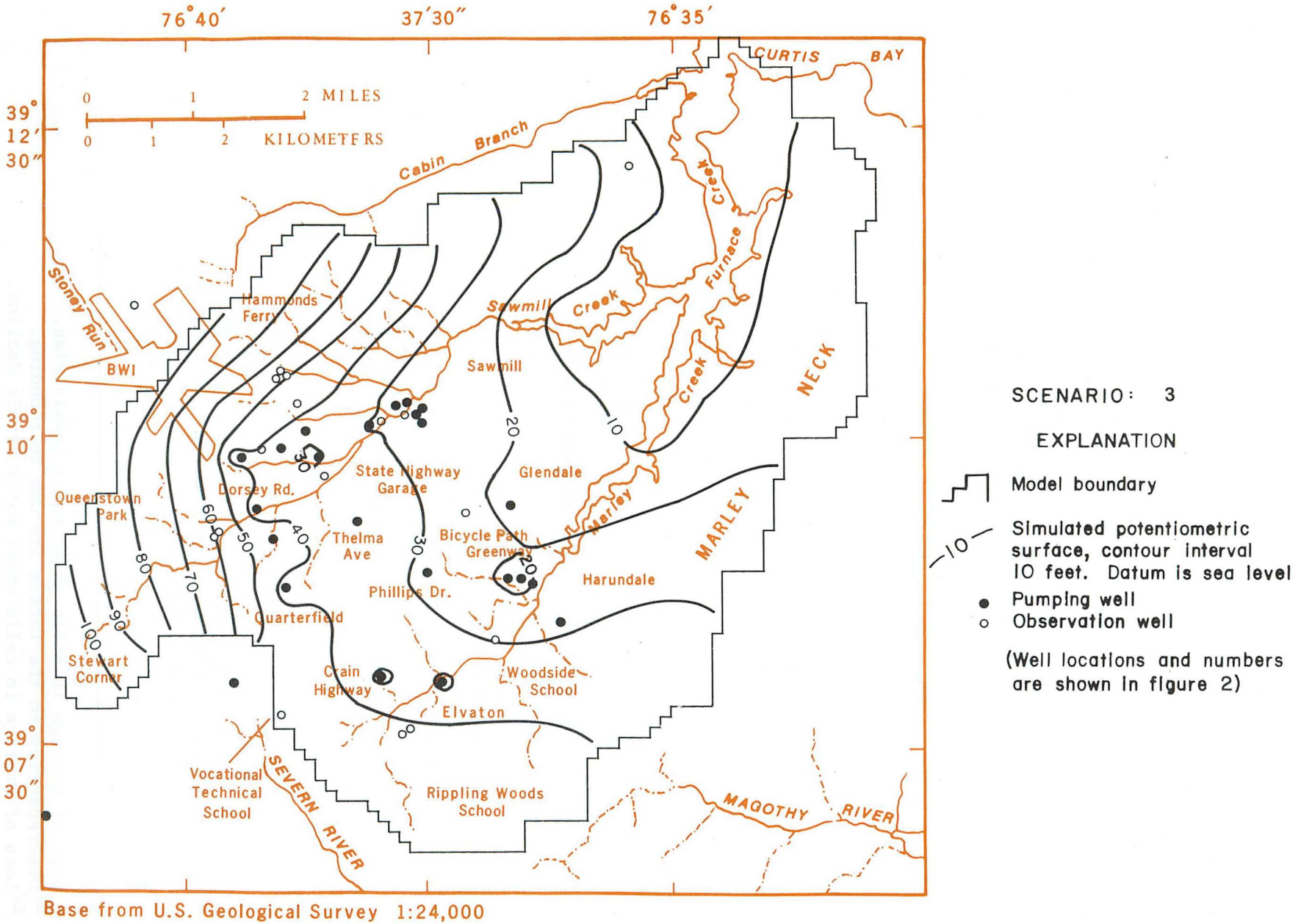


Figure 41. — Simulated potentiometric surface for the lower Patapsco aquifer for year 2000 using pumpage of 11.57 million gallons per day plus 0.96 million gallons per day from the Crain Highway and Quarterfield well fields.

for the year 2000 in the Harundale and Glendale well fields drop to 2 and 3 ft above sea level, respectively (table 11), posing an increased danger of saltwater intrusion from the bay tributaries. Potentiometric surfaces for the year 2000 are plotted in figures 42 (upper Patapsco) and 43 (lower Patapsco). Simulated drawdowns in the pumping wells are less than available drawdown, except for well Bd 95 which was previously discussed in scenario 2, and for a hypothetical pumping well in row 37, column 34 which is located in the Sawmill well field where the additional 28 ft of drawdown equals the 28 ft of available drawdown in pumping well Ad 41. In scenario 7, the simulated base flow of Sawmill Creek at Glen Burnie is zero. Because of the increased danger of saltwater intrusion, it is advisable to allocate the additional pumpage of this scenario to the southern and southwestern well fields described in scenario 8.

Scenario 8

Scenario 8, like scenario 7, was simulated adding a pumpage of 4.55 Mgal/d over scenario 1 pumpage, only this time the pumpages were withdrawn from the Phillips Drive, Thelma Avenue, Crain Highway, Elvaton, and Quarterfield well fields. As would be expected, areal water levels for the year 2000 in the lower Patapsco aquifer at the Glendale and Harundale well fields decline less than in scenario 7, stabilizing at 4 and 19 ft above sea level, respectively (table 10). These results demonstrate that the distribution of the additional pumpages to well fields farther away from the bay tributaries would probably reduce the likelihood of saltwater intrusion. In scenario 8, a hypothetical well pumped at 0.91 Mgal/d in row 48, column 30 located in the Thelma Avenue well field would produce an additional drawdown of 72 ft, which exceeds the available drawdown at that site (67 ft).

Table 12. — Flow components for the year 2005 for pumpage scenarios of continuing 1985 pumpage and 1985 pumpage plus 4.55 million gallons per day

[Mgal/d = million gallons per day]

Components		Scenario 1 pumpage of 11.57 Mgal/d Mgal/d	Scenario 1 pumpage plus 4.55 Mgal/d Mgal/d
Inflow:	Storage[a]	0	0
	Recharge	30.18	30.18
	Constant-head boundary	.00	.00
	Stream leakage (upstream reaches)	1.40	2.21
	Head-dependent boundary	2.52	3.25
	Totals[b]	34.10	35.64
Outflow:	Storage[c]	0	0
	Constant-head boundary	11.94	11.24
	Pumpage	12.86	17.41
	Ground-water evapotranspiration	2.33	1.97
	Stream leakage	6.49	4.78
	Head-dependent boundary	.47	.34
	Totals	34.09	35.74

[a] Gain of storage in cells where water levels rise.
[b] Discrepancies in the totals are due to rounding.
[c] Loss of storage in cells where water levels decline.

This possible operational problem could be avoided by distributing the simulated pumpage to two production wells rather than to one. In scenario 8, the simulated base flow of Sawmill Creek at Glen Burnie is zero.

The flow components for the scenario 1 pumpage (11.57 Mgal/d) and for the 4.55 Mgal/d additional pumpage through the year 2005 are tabulated in table 12. Comparison of flow components for 1985 indicates that of the 4.55 Mgal/d additional pumpage, 2.89 Mgal/d is obtained from intercepting ground-water fluxes that flowed out of the basin, and 1.54 Mgal/d is derived as inflows from lateral boundaries and stream leakage. The discrepancy in the totals is caused by rounding.

The effects of drought conditions on water levels and base flows were demonstrated by repeating the above pumpage scenarios using a 2-year hypothetical drought condition for 1989-90 that assumed a recharge rate 60 percent of the long-term average recharge. The impact of the drought can be clearly seen from the simulated well hydrographs in figures 44-46 and simulated water levels in table 13. In various pumpage scenarios, water levels are reduced in the range of 4 to 6 ft as a result of the drought. Figures 44-46 also show that after the long-term average recharge conditions are restored, water levels recover in about 4 to 5 years. The effects of a drought on base flows of Sawmill Creek at Glen Burnie is demonstrated in figure 47. It shows that the simulated drought of 1989-90 superimposed on 1985 pumping conditions causes Sawmill Creek to dewater within a few months. However, after the simulated drought ended, base flows recover in 4 to 5 years, as do ground-water levels.

(Text continued on p. 72.)

Table 13. — Comparison of simulated areal water levels for selected cells showing the effects of a hypothetical drought condition, where recharge is simulated at 60 percent of the long-term average value

Selected cell, (row, column; location in figure 12)	Nearby well (location in figure 2)	Simulated 1990 water levels of the lower Patapsco aquifer, in feet above and below (-) sea level (drought condition in parentheses)							
		Pumpage scenarios							
		1	2	3	4	5	6	7	8
(38, 35)	Ad 1, Sawmill	25 (21)	21 (17)	24 (20)	20 (16)	16 (12)	16 (12)	12 (7)	20 (15)
(46, 21)	Bd 95, Dorsey Road	32 (27)	29 (24)	31 (25)	27 (21)	25 (20)	24 (19)	21 (16)	26 (21)
(45, 45)	Bd 103, Glendale	11 (6)	9 (4)	10 (5)	8 (3)	7 (2)	5 (0)	3 (-2)	4 (-1)
(54, 46)	Bd 37, Harundale	19 (14)	16 (11)	18 (13)	13 (8)	13 (8)	6 (1)	2 (-3)	10 (5)
(63, 38)	Bd 107, Elvaton	30 (25)	29 (24)	28 (23)	27 (22)	24 (19)	22 (17)	21 (16)	16 (11)
(13, 56)	Ad 10, Curtis Bay	17 (13)	17 (13)	17 (13)	17 (13)	17 (13)	17 (13)	17 (13)	17 (13)

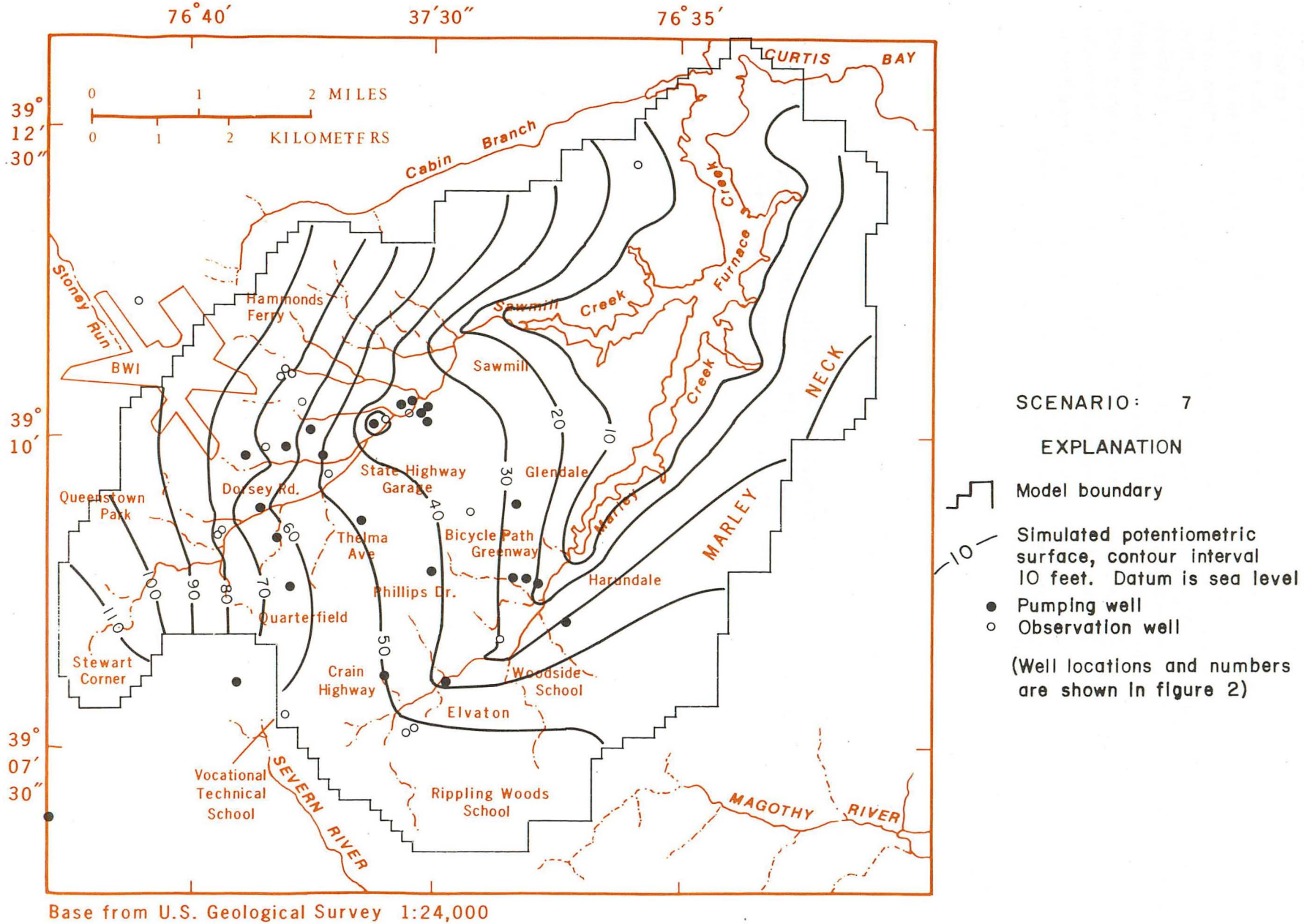


Figure 42. — Simulated potentiometric surface for the upper Patapsco aquifer for year 2000 using pumpage of 11.57 million gallons per day plus 4.55 million gallons per day from all the Glen Burnie well fields, except the Glendale and Thelma Avenue well fields.

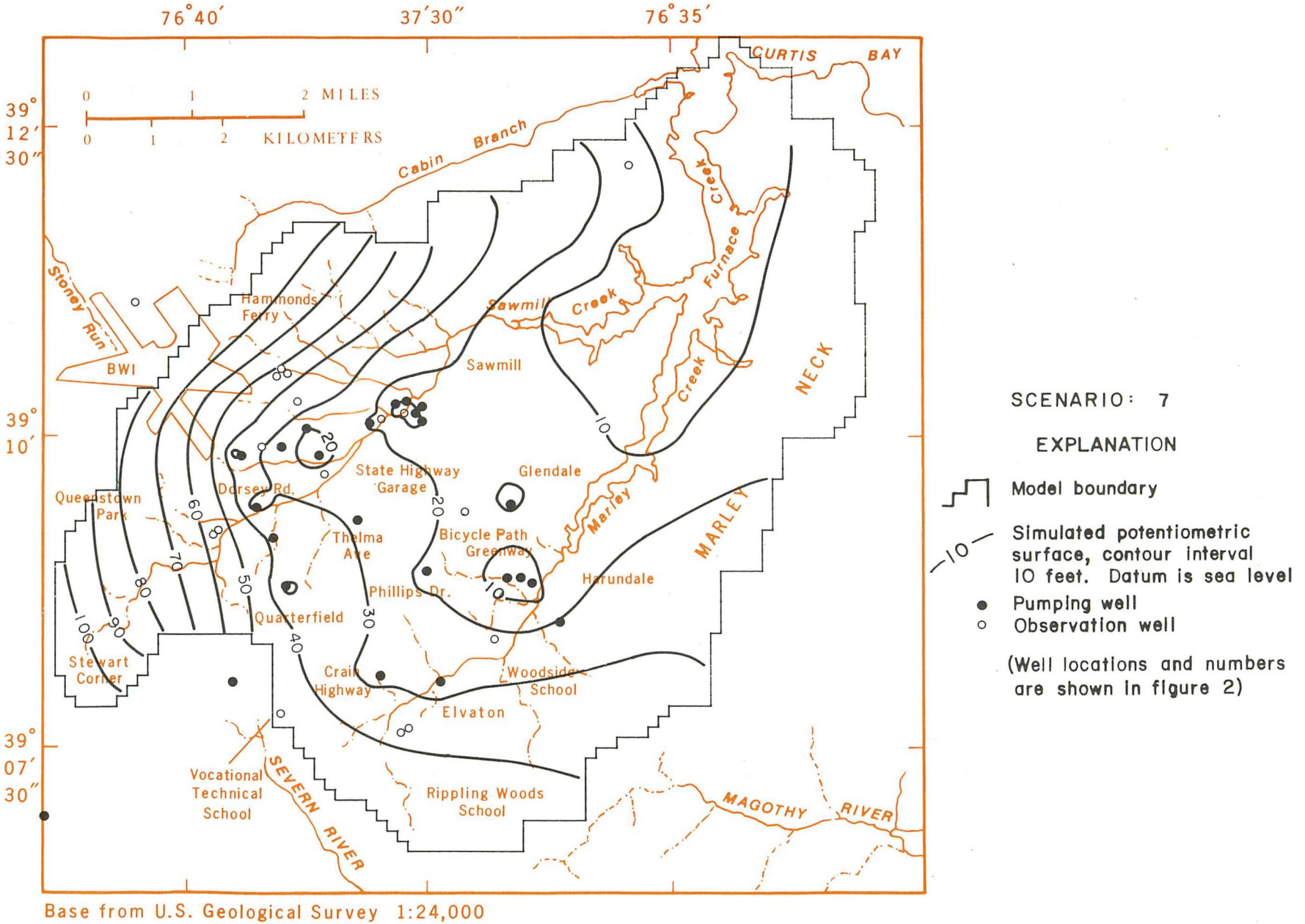
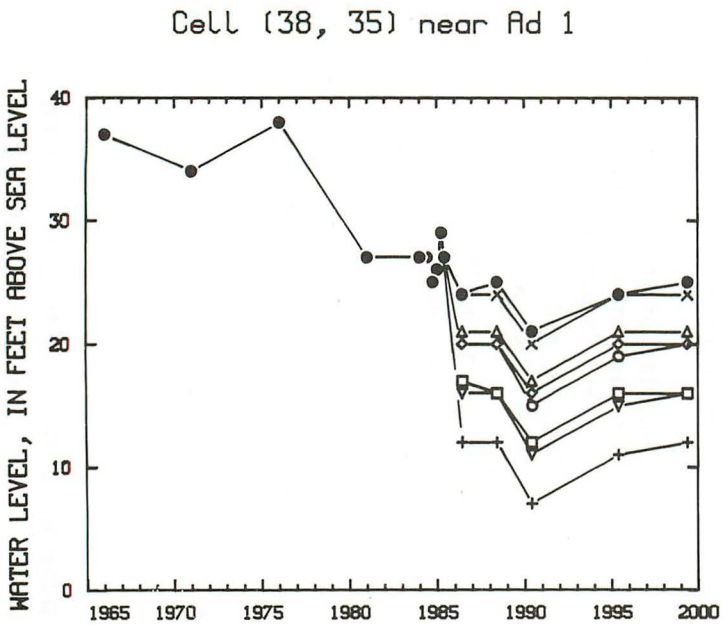
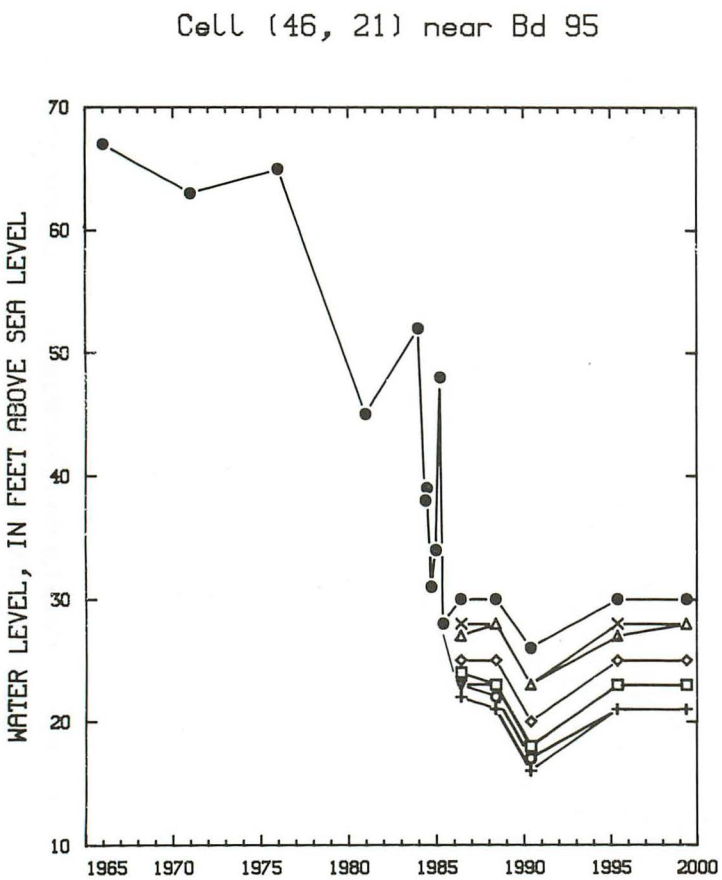


Figure 43. — Simulated potentiometric surface for the lower Patapsco aquifer for year 2000 using pumpage of 11.57 million gallons per day plus 4.55 million gallons per day from all the Glen Burnie well fields, except the Glendale and Thelma Avenue well fields.



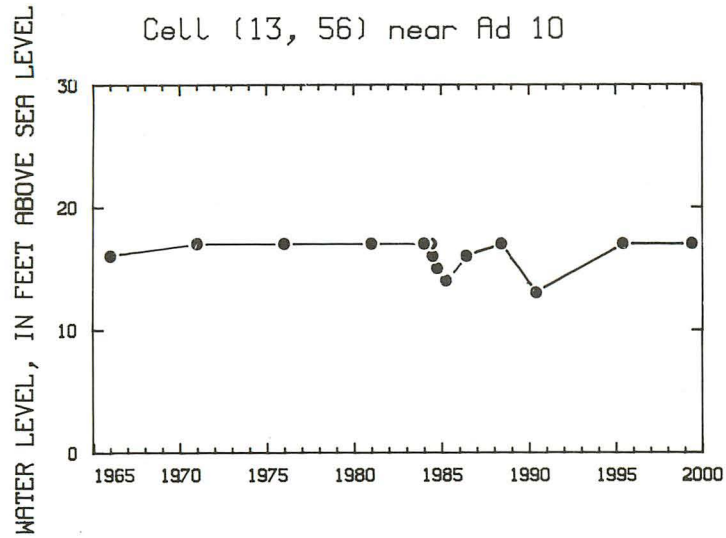


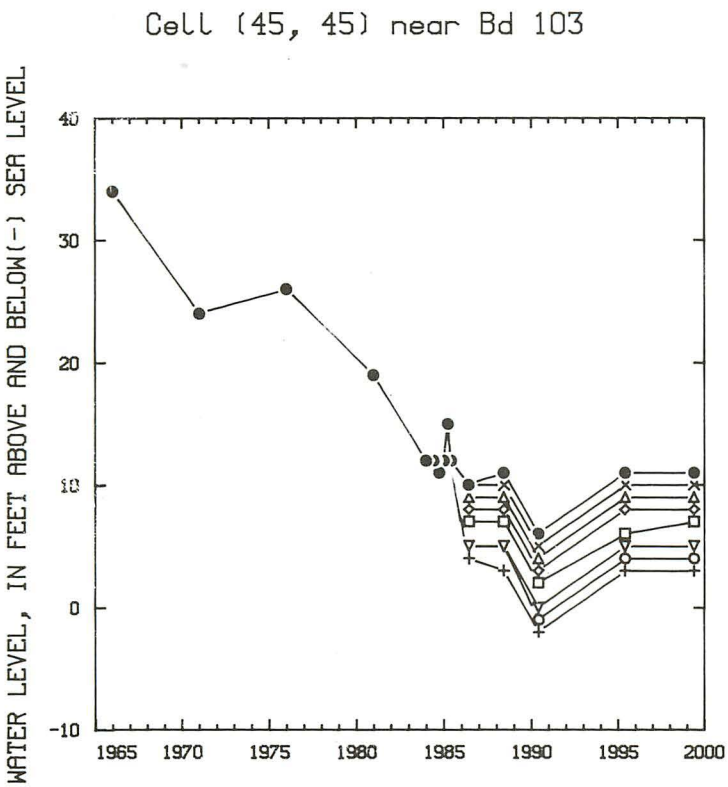
EXPLANATION

Scenario	Symbol	Pumpage added to 1985 rate of 11.57 Mgal/d	Well fields where the additional pumpage was assigned	Total pumpage, in million gallons per day (Mgal/d)
1	●	0.00	--	11.57
2	Δ	.98	Sawmill, Dorsey Road, and Harundale	12.55
3	x	.96	Crain Highway and Quarterfield	12.53
4	◇	1.95	Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield	13.52
5	□	2.93	All Glen Burnie well fields, except Glendale and Thelma Avenue	14.50
6	∇	3.58	All Glen Burnie well fields, except Glendale and Thelma Avenue	15.15
7	+	4.55	All Glen Burnie well fields, except Glendale and Thelma Avenue	16.12
8	O	4.55	Phillips Drive, Elvaton, Crain Highway, Thelma Avenue, and Quarterfield	16.12

Note: Where symbols coincide, only one symbol is shown on the plot. Table 10 lists water levels, base flows, and pumpage distributions for each scenario in year 2000.

Figure 44. — Hydrographs of simulated water-levels in the lower Patapsco aquifer and effects of pumpage scenarios totaling 11.57 to 16.12 million gallons per day with hypothetical 2-year (1989-90) drought for cells (38, 35) and (46, 21) near wells Ad 1 (Sawmill) and Bd 95 (Dorsey Road).



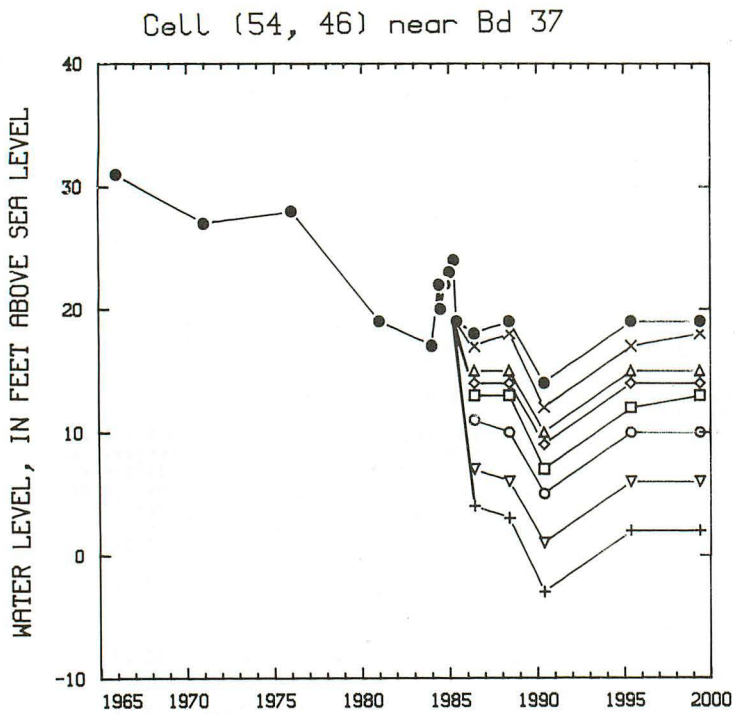


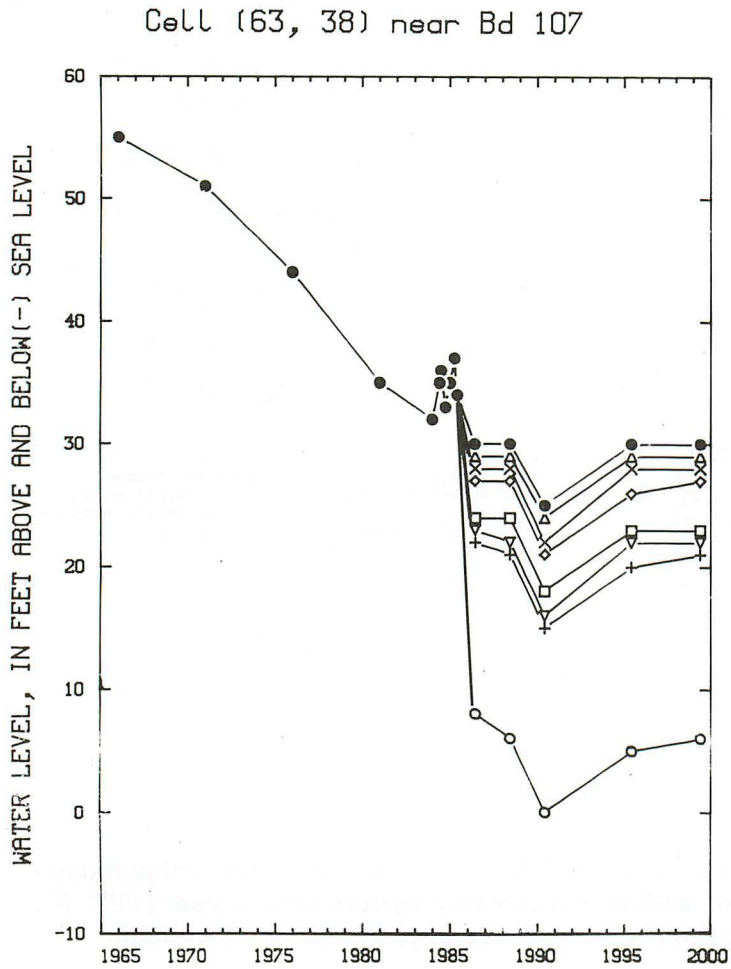
EXPLANATION

Scenario	Symbol	Pumpage added to 1985 rate of 11.57 Mgal/d	Well fields where the additional pumpage was assigned	Total pumpage, in million gallons per day (Mgal/d)
1	●	0.00	--	11.57
2	Δ	.98	Sawmill, Dorsey Road, and Harundale	12.55
3	x	.96	Crain Highway and Quarterfield	12.53
4	◇	1.95	Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield	13.52
5	□	2.93	All Glen Burnie well fields, except Glendale and Thelma Avenue	14.50
6	▽	3.58	All Glen Burnie well fields, except Glendale and Thelma Avenue	15.15
7	+	4.55	All Glen Burnie well fields, except Glendale and Thelma Avenue	16.12
8	○	4.55	Phillips Drive, Elvaton, Crain Highway, Thelma Avenue, and Quarterfield	16.12

Note: Where symbols coincide, only one symbol is shown on the plot. Table 10 lists water levels, base flows, and pumpage distributions for each scenario in year 2000.

Figure 45. — Hydrographs of simulated water-levels in the lower Patapsco aquifer and effects of pumpage scenarios totaling 11.57 to 16.12 million gallons per day with hypothetical 2-year (1989-90) drought for cells (13, 56) and (45, 45) near wells Ad 10 (Curtis Bay) and Bd 103 (Glendale).



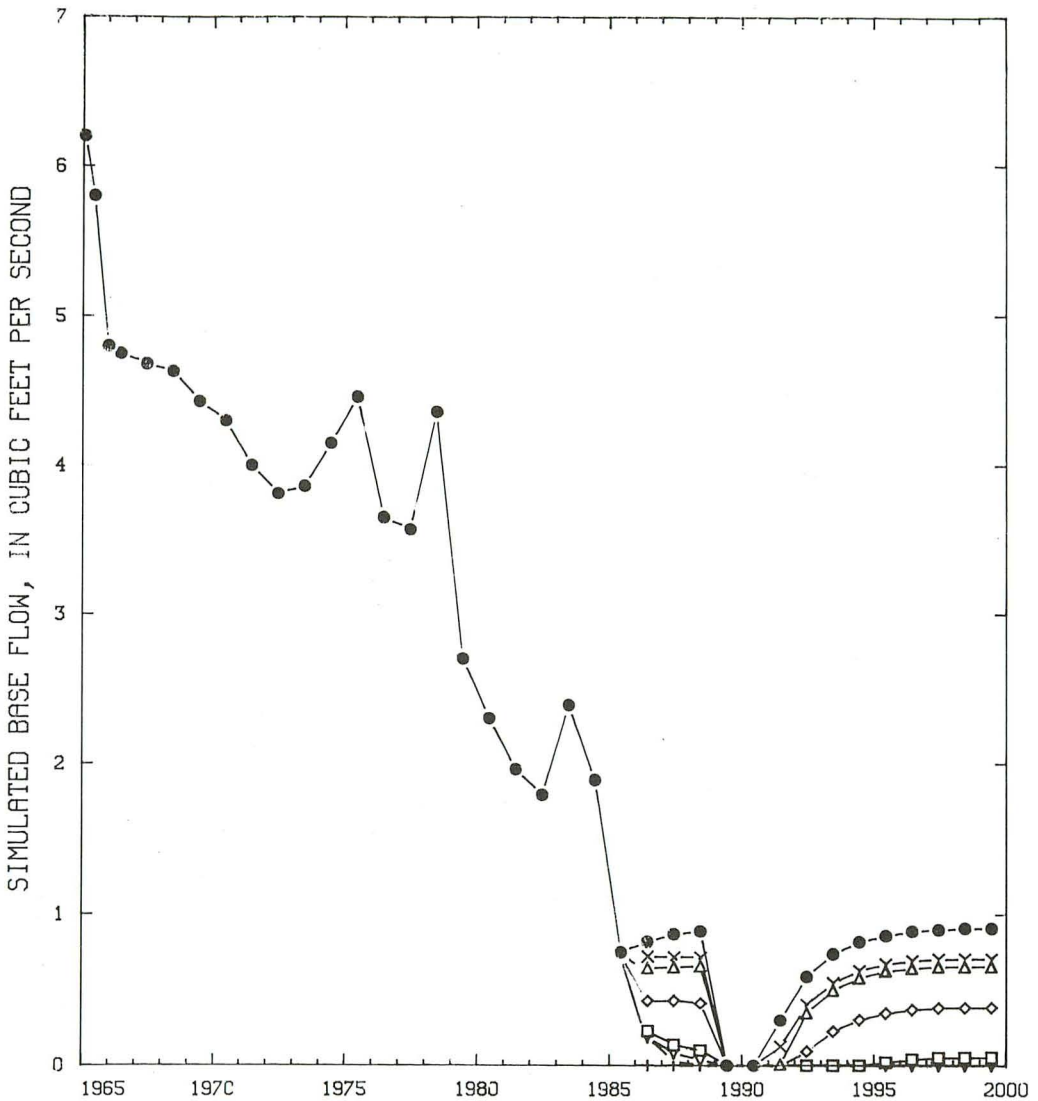


EXPLANATION

Scenario	Symbol	Pumpage added to 1985 rate of 11.57 Mgal/d	Well fields where the additional pumpage was assigned	Total pumpage, in million gallons per day (Mgal/d)
1	●	0.00	--	11.57
2	Δ	.98	Sawmill, Dorsey Road, and Harundale	12.55
3	x	.96	Crain Highway and Quarterfield	12.53
4	◇	1.95	Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield	13.52
5	□	2.93	All Glen Burnie well fields, except Glendale and Thelma Avenue	14.50
6	▽	3.58	All Glen Burnie well fields, except Glendale and Thelma Avenue	15.15
7	+	4.55	All Glen Burnie well fields, except Glendale and Thelma Avenue	16.12
8	O	4.55	Phillips Drive, Elvaton, Crain Highway, Thelma Avenue, and Quarterfield	16.12

Note: Where symbols coincide, only one symbol is shown on the plot. Table 10 lists water levels, base flows, and pumpage distributions for each scenario in year 2000.

Figure 46. — Hydrographs of simulated water-levels in the lower Patapsco aquifer and effects of pumpage scenarios totaling 11.57 to 16.12 million gallons per day with hypothetical 2-year (1989-90) drought for cells (54, 46) and (63, 38) near wells Bd 37 (Harundale) and Bd 107 (Elvaton).



EXPLANATION

Scenario	Symbol	Pumpage added to 1985 rate of 11.57 Mgal/d	Well fields where the additional pumpage was assigned	Total pumpage, in million gallons per day (Mgal/d)
1	●	0.00	--	11.57
2	Δ	.98	Sawmill, Dorsey Road, and Harundale	12.55
3	x	.96	Crain Highway and Quarterfield	12.53
4	◇	1.95	Sawmill, Dorsey Road, Harundale, Crain Highway, and Quarterfield	13.52
5	□	2.93	All Glen Burnie well fields, except Glendale and Thelma Avenue	14.50
6	▽	3.58	All Glen Burnie well fields, except Glendale and Thelma Avenue	15.15
7	+	4.55	All Glen Burnie well fields, except Glendale and Thelma Avenue	16.12
8	O	4.55	Phillips Drive, Elvaton, Crain Highway, Thelma Avenue, and Quarterfield	16.12

Note: Where symbols coincide, only one symbol is shown on the plot. Table 10 lists water levels, base flows, and pumpage distributions for each scenario in year 2000.

Figure 47. — Simulated base flows of Sawmill Creek at Glen Burnie using pumpages totaling 11.57 to 16.12 million gallons per day with hypothetical 2-year (1989-90) drought.

SUMMARY AND CONCLUSIONS

The Patapsco aquifer system attains a thickness of about 250 ft in the Glen Burnie area of Anne Arundel County, Maryland. In the vicinity of Sawmill and Marley Creeks, the upper Patapsco aquifer is under unconfined conditions and is separated from the lower Patapsco aquifer by a clayey confining unit. Water in the upper Patapsco aquifer flows from northern and western recharge areas toward Sawmill and Marley Creeks and the tidal tributaries of Curtis Bay, which function as discharge areas. Vertical leakage occurs from the upper Patapsco aquifer downward to the lower Patapsco aquifer in the northwestern recharge areas and from the lower Patapsco aquifer upward to the upper Patapsco aquifer in the northeastern discharge areas.

A ground-water flow model of the Patapsco aquifer system in the Glen Burnie area was constructed. The model was designed using boundary conditions that approximate the ground-water flow regime. The model was calibrated for steady-state and transient conditions to approximate historical water levels and stream base flows. Hydrologic properties in the model were adjusted during calibration but only within reasonable limits. The steady-state calibration was repeated each time adjustments of hydrologic properties were made during the transient calibration until the transient calibration was finalized. During the process of calibration, the hydrologic property adjusted the most was the confining-unit leakance, because it was the least known model input. Aquifer hydraulic conductivity, transmissivity, recharge rates, storage coefficients, and evapotranspiration rates were adjusted the least, if at all, because these values were based on more reliable field data. The steady-state model reproduces the 1965 or older water levels of 49 selected wells with an average difference of 6 ft, a maximum difference of 13 ft, and a 90th percentile of 11 ft or less. The transient model reproduces the 1985 water levels of 38 selected wells within an average difference of 6 ft, a maximum difference of 14 ft, and a 90th percentile of 12 ft or less, and reproduces the base flow of Sawmill Creek at Glen Burnie with a difference of no more than 0.6 ft^3/s. Comparison of water-level hydrographs for 33 wells indicates that the transient model simulates water levels mostly higher, some very close, and a few lower than the observed water levels.

In the calibrated model, the upper Patapsco aquifer is assumed to be homogeneous with a uniform hydraulic conductivity of 33 ft/d. In the model, transmissivity of the lower Patapsco aquifer ranges from 1,500 to 6,000 ft^2/d, which closely matches the transmissivities reported earlier for the area. In the model, vertical leakance of the clayey confining layers ranges from 10^{-8} to 10^{-6} s^{-1}. The higher value tends to occur in the vicinity of the bay tributaries where the clayey layers appear to be more sandy. The long-term average recharge rate used in the model is 20.5 in/yr, except for the period 1984-85, which was assigned a value of 14.4 in/yr. The lower rate reflects a precipitation deficiency during June 1984 to May 1985. The steady-state simulation indicates that the effective ground-water evapotranspiration rate for the Sawmill Creek basin is 4.59 in/yr.

Although the model of the aquifer system was based on a sound hydrologic framework, it is not an exact representation of reality. However, the relative effects of the various computed scenarios are reasonable and should provide useful insights into what may actually occur in response to increased pumpage.

The calibrated model was used to determine the hydrologic effects of increasing water use by simulating future pumping scenarios to the year 2005. In these scenarios, pumpages from the existing well fields were gradually increased and the resulting areal water levels, water levels in hypothetical pumping wells, and stream base flows were examined. In all the scenarios, water levels reach equilibrium by the year 2000. Simulating 11.57 Mgal/d (scenario 1) to the year 2005 shows that average annual base flow of Sawmill Creek at Glen Burnie decreases to and stabilizes at 0.98 ft^3/s. Areal water levels of the Patapsco aquifer system in 2000 are above sea level and the fluxes into the areas of tidal surface water of the bay tributaries are outflow fluxes, which indicated discharging conditions.

Areal water levels remain above sea level when pumpages are increased above scenario 1 pumpage by (1) 0.98 Mgal/d from the Sawmill, Dorsey Road, and Harundale well fields, (2) 0.96 Mgal/d from the Quarterfield and Crain Highway well fields, and (3) 1.95 Mgal/d from the combined Sawmill, Dorsey Road, Harundale, Quarterfield, and Crain Highway well fields, and the simulated base flow of Sawmill Creek at Glen Burnie decreases to 0.67, 0.72, and 0.40 ft^3/s, respectively. Simulated water levels in the hypothetical pumping wells are above the altitude of the top of the aquifer, except for one hypothetical pumping well in the Dorsey Road well field where the water level in several scenarios declines below the top of the aquifer.

The model suggests that increasing pumpage at the existing well fields by 2.93, 3.58, and 4.55 Mgal/d above scenario 1 pumpage (11.57 Mgal/d) would lower areal water levels in the upper Patapsco aquifer such that simulated base flow in Sawmill Creek would be reduced to 0.08 ft^3/s, 0.001 ft^3/s, and zero, respectively. When an additional pumpage of about 4.55 Mgal/d was imposed upon the existing well fields, water levels in the aquifer system near the areas of tidal surface water would approach sea level, creating the potential for saltwater intrusion. Shifting the additional 4.55 Mgal/d to well fields farther inland (Crain Highway, Quarterfield, Elvaton, Phillips Drive, and Thelma Avenue) would produce relatively higher areal water levels in the aquifer system near the areas of tidal surface water, but would still leave the system near the Glendale well field vulnerable to saltwater intrusion.

A hypothetical 2-year drought (1989-90) was simulated,

assuming 60 percent of the long-term average recharge. Under these conditions, Sawmill Creek at Glen Burnie would be dewatered even when pumpage was held to 11.57 Mgal/d (scenario 1). The effects of the drought, however, would be temporary and reversible once average recharge conditions were reimposed.

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APPENDIX

RECORDS OF SELECTED WELLS IN THE GLEN BURNIE AREA

Well-Numbering System

The well numbers listed in this report follow a system used by the Maryland Geological Survey. The wells are numbered according to a grid system in which each county is divided into 5-minute quadrangles of latitude and longitude identified by a two-letter code. The first letter of the quadrangle code identifies a 5-minute segment of latitude and the second letter identifies a 5-minute segment of longitude. The latitude letter code is written in uppercase and the longitude letter code in lowercase. Inventoried wells in each quadrangle are then numbered sequentially. The location of the quadrangles cited in this report are shown in figure 48. The quadrangle code is preceded by two uppercase letters identifying the county where the quadrangle is located. The county code for Anne Arundel County is AA and for Baltimore County is BA. Because nearly all the wells cited in this report are located in Anne Arundel County, the AA code is usually omitted. In the table of well records, the wells are designated with their county codes. Baltimore City well 7S4E-1 is located on quadrangle map AA-Ae.

Well-field site names, designated for convenient reference, are shown in figure 2. Several wells associated with a well-field name are enclosed. More accurate well locations are shown on the quadrangle maps of figure 48.

Table 14. — Records of selected wells in the Glen Burnie area

[ft = feet; gal/min = gallon per minute; (gal/min)/ft = gallon per minute per foot; -- = data not available; AA DU = Anne Arundel County Department of Utilities; USGS = U.S. Geological Survey]

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Depth of well (ft)
Anne Arundel County						
AA Ac 11	AA-00-2445	BWI Airport	Washington Well	1948	136	320
AA Ac 15	AA-00-5218	Goodard, Stanley	Layne-Atlantic	1950	180	273
AA Ac 34	AA-03-3523	Liskey Aluminum Inc	Layne-Atlantic	1959	120	288
AA Ad 1	--	AA DU, Sawmill #1	Layne-Atlantic	1926	45	65
AA Ad 10	--	US Army, Curtis Bay	--	1918	45	108
AA Ad 12	--	Phelps, Royland M.	--	1879	60	32
AA Ad 23	--	AA DU, Sawmill #3	Layne-Atlantic	1945	45	78
AA Ad 26	--	Martin, Thomas	McCarthy	1945	2	63
AA Ad 27	--	Tracey, S. S.	Craig	1916	30	73
AA Ad 29	--	AA DU, Sawmill	Layne-Atlantic	1947	37	500
AA Ad 30	--	AA DU, Sawmill	USGS	1948	35	13
AA Ad 40	AA-00-1629	AA DU, Sawmill #4	Layne-Atlantic	1947	55	102
AA Ad 41	AA-00-1630	AA DU, Sawmill #5	Layne-Atlantic	1947	45	153
AA Ad 46	--	BWI Airport	--	--	110	29
AA Ad 48	--	BWI Airport	--	--	120	37
AA Ad 57	AA-02-0776	Lang, Fred B.	H. A. Gropp	1955	25	75
AA Ad 61	AA-01-2284	Highland Furniture	Layne-Atlantic	1953	45	109
AA Ad 62	AA-01-2285	Highland Furniture	Layne-Atlantic	1953	45	123
AA Ad 63	AA-01-8253	Gas & Oil Products	J. H. Brown	1955	40	70
AA Ad 64	AA-01-7691	Tebby, Charles	G. E. Crouse	1955	40	38
AA Ad 66	--	Kiefer & Braun	Owner	1938	20	10
AA Ad 67	AA-01-3957	AA DU, Sawmill #6	Layne-Atlantic	1953	40	151
AA Ad 68	AA-01-3958	AA DU, Sawmill #7	Layne-Atlantic	1953	50	160
AA Ad 69	AA-02-7725	Two Guys Dept. Store	H. H. Bunker	1957	55	119
AA Ad 72	AA-02-7723	Two Guys Dept. Store	H. H. Bunker	1957	60	122
AA Ad 74	AA-02-8580	AA DU, Dorsey Road #4	Layne-Atlantic	1957	90	186
AA Ad 75	AA-02-7835	AA DU, Hammonds Ferry Rd.	Layne-Atlantic	1957	75	535
AA Ad 77	--	BWI Airport	--	--	110	31
AA Ad 82	AA-01-9573	Brown, Gilbert C.	Walter Frank	1955	70	63
AA Ad 88	AA-03-9818	AA DU, Hammonds Ferry Rd.	Layne-Atlantic	1960	70	164
AA Ad 90	AA-04-0298	AA DU, Hammonds Ferry Rd.	Layne-Atlantic	1960	79	453
AA Ad 91	AA-03-9973	Ritchie Farmers Market	Layne-Atlantic	1960	85	146
AA Ad 94	AA-02-6010	Matlack Inc.	Shannahan	1957	38	214
AA Ad 96	AA-67-1279	USS Agri/Chemicals Div.	Walter Frank	1967	15	370
AA Ad 101	AA-74-1856	AA Reclamation Area	H. H. Bunker	1980	10	32
AA Ad 102	AA-81-2641	USGS, Hammonds Ferry Rd.	Walter Frank	1983	77	108
AA Ad 103	AA-73-3378	Cromwell	J. H. Brown	1974	75	67
AA Ad 104	AA-81-2760	USGS, Hammonds Ferry Rd.	Ken Feheley	1984	77	28
AA Ad 108	AA-81-3475	USGS, Hammonds Ferry Rd.	Ken Feheley	1984	78	12
AA Ad 109	AA-81-4890	USGS, Central Avenue	Ken Feheley	1985	36	46
AA Ae 2	--	Coop Fertilizer	Owner	1936	10	23
AA Ae 3	--	Coop Fertilizer	Owner	1936	10	65
AA Ae 10	--	US Army Ordnance Depot	--	1917	16	76
AA Ae 22	--	Zamostny's Amoco Station	Dietz	1937	50	150
AA Ae 24	--	Ciordano Bros	--	1936	2	84
AA Ae 28	AA-00-0066	Clark, Harry M.	W. H. Eiler	1946	10	238
AA Ae 32	AA-00-2603	Miami Rubber Co.	Layne-Atlantic	1948	10	113
AA Ae 34	AA-01-4685	AA Board of Education	H. H. Bunker	1954	50	212
AA Ae 37	AA-73-5969	Solley Methodist Church	Walter Frank	1976	55	101
AA Ae 41	--	Martin, Delma	--	1949	40	9
AA Bc 15	--	Wagner, H. E.	--	1930	170	118
AA Bc 51	--	Moore, T. K.	H. H. Bunker	--	180	96
AA Bc 58	AA-01-6941	Williamson, Robert	Shannahan	1954	120	87
AA Bc 59	--	--	--	--	150	26
AA Bc 60	--	--	--	--	165	30

Diameter (inches) casing	Diameter (inches) screen	Depth to top of screen (feet)	Length of screen (feet)	Principal aquifer	Water Level (feet below land surface) Static	Water Level (feet below land surface) Pumping	Date water level measured	Yield (gal/min)	Hours pumped	Specific capacity [(gal/min)/ft]	Use of water	Well number
6	--	312	8	Patuxent	90	175	4/23/1948	60	12	0.70	U	AA Ac 11
4	2	261	5	Patuxent	180	--	9/00/1952	10	8	--	H	AA Ac 15
6	6	283	5	Patuxent	74	162	2/09/1959	275	6	3.12	U	AA Ac 34
18	12	43	20	Patapsco	18	--	9/00/1926	220	--	--	U	AA Ad 1
8	--	--	--	Patapsco	36	--	8/00/1944	50	--	--	U	AA Ad 10
48	--	--	--	Patapsco	26	--	3/00/1946	--	--	--	H	AA Ad 12
18	8	63	10	Patapsco	--	--	0/00/1945	150	--	--	P	AA Ad 23
2	--	--	--	Patapsco	2	--	1/00/1946	--	--	--	H	AA Ad 26
4	--	--	--	Patapsco	21	--	1/00/1946	--	--	--	H	AA Ad 27
3	--	395	45	Patuxent	11	--	6/00/1948	--	--	--	U	AA Bd 29
4	--	--	--	Patapsco	9	--	6/00/1948	--	--	--	U	AA Ad 30
20	10	80	22	Patapsco	28	62	4/09/1947	292	24	8.59	P	AA Ad 40
8	8	126	20	Patapsco	10	68	6/00/1947	250	--	4.31	P	AA Ad 41
48	--	--	--	Patapsco	22	--	3/00/1955	--	--	--	H	AA Ad 46
--	--	--	--	Patapsco	33	--	4/00/1956	--	--	--	U	AA Ad 48
4	2	70	5	Patapsco	21	27	9/27/1955	50	3	8.33	H	AA Ad 57
6	6	104	5	Patapsco	20	49	5/00/1953	80	3	2.76	A	AA Ad 61
6	--	97	5	Patapsco	21	50	5/21/1953	151	3	5.21	--	AA Ad 62
2	--	65	5	Patapsco	19	--	3/17/1955	12	3	--	C	AA Ad 63
4	--	--	--	Patapsco	23	25	2/10/1955	5	2	2.50	H	AA Ad 64
6	--	--	--	Patapsco	2	--	5/00/1957	--	--	--	U	AA Ad 66
20	8	131	20	Patapsco	12	120	11/18/1953	487	--	4.51	P	AA Ad 67
20	10	140	20	Patapsco	16	128	12/11/1953	400	--	3.57	P	AA Ad 68
8	8	97	22	Patapsco	32	62	7/22/1957	270	8	9.00	C	AA Ad 69
8	6	110	12	Patapsco	32	100	8/05/1957	165	24	2.43	--	AA Ad 72
12	10	171	15	Patapsco	33	157	10/00/1957	375	8	3.02	P	AA Ad 74
--	--	--	--		--	--	--	--	--	--	U	AA Ad 75
--	--	--	--	Patapsco	14	--	9/00/1958	--	--	--	U	AA Ad 77
2	2	59	4	Patapsco	21	28	6/28/1955	6	6	0.86	H	AA Ad 82
6	2	159	5	Patapsco	17	--	10/00/1960	--	--	--	U	AA Ad 88
6	6	438	15	Patuxent	34	113	10/00/1960	315	8	3.80	U	AA Ad 90
8	8	136	10	Patapsco	27	137	10/08/1960	289	8	2.63	U	AA Ad 91
6	4	198	15	Patuxent	34	65	5/00/1957	75	10	2.42	C	AA Ad 94
6	4	355	15	Patuxent	20	45	6/00/1967	400	25	16.00	N	AA Ad 96
4	4	17	15	Patapsco	8	12	5/16/1980	15	1	3.75	U	AA Ad 101
6	4	80	10	Patapsco	11	--	12/09/1983	60	--	--	U	AA Ad 102
4	3	57	10	Patapsco	12	--	3/00/1984	--	--	--	H	AA Ad 103
4	4	18	10	Patapsco	5	12	5/09/1984	20	--	2.86	U	AA Ad 104
6	4	6	5	Patapsco	7	10	8/15/1984	3	1	1.00	U	AA Ad 108
4	4	36	10	Patapsco	9	40	11/00/1985	15	3	0.48	U	AA Ad 109
48	--	--	--	Patapsco	14	--	8/00/1943	9	--	--	U	AA Ae 2
6	--	--	--	Patapsco	7	--	8/00/1943	--	--	--	U	AA Ae 3
10	--	--	--	Patapsco	13	30	0/00/1918	35	--	2.06	U	AA Ae 10
6	--	146	--	Patapsco	60	--	1/14/1946	--	--	--	H	AA Ae 22
4	--	--	--	Patapsco	--	--	--	2	--	--	H	AA Ae 24
2	--	--	--	Patapsco	19	21	7/12/1946	6	16	3.00	H	AA Ae 28
5	3	106	5	Patapsco	12	--	5/10/1948	15	5	--	N	AA Ae 32
6	4	207	5	Patapsco	50	63	4/19/1954	60	--	4.62	T	AA Ae 34
4	2	96	5	Patapsco	26	36	5/28/1976	18	2	1.80	T	AA Ae 37
36	--	--	--	Patapsco	3	--	5/01/1984	--	--	--	U	AA Ae 41
6	--	112	--	Patapsco	70	--	0/00/1930	5	--	--	H	AA Bc 15
4	--	--	--	Patapsco	85	--	12/00/1951	--	--	--	H	AA Bc 51
4	2	76	10	Patapsco	32	55	11/02/1954	5	--	0.22	H	AA Bc 58
36	--	--	--	Patapsco	26	--	3/00/1955	--	--	--	--	AA Bc 59
--	--	--	--	Patapsco	27	--	3/00/1955	--	--	--	H	AA Bc 60

Water-Use Codes

A = Air conditioning
C = Commercial
H = Domestic
I = Irrigation
N = Industrial
P = Public supply
T = Institutional
U = Unused

Table 14. — Records of selected wells in the Glen Burnie area—Continued

[ft = feet; gal/min = gallon per minute; (gal/min)/ft = gallon per minute per foot; -- = data not available; AA DU = Anne Arundel County Department of Utilities; USGS = U.S. Geological Survey]

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Depth of well (ft)
Anne Arundel County--Continued						
AA Bc 61	--	Toles, Mr.	--	--	145	31
AA Bc 62	--	Toles, Mr.	--	--	105	18
AA Bc 63	--	Owens, Harry	--	--	140	38
AA Bc 64	--	Johns, McGinnis	--	--	180	32
AA Bc 65	--	Bohle, Edward	H. H. Bunker	1954	140	72
AA Bc 66	--	Hasson, Charles	--	1951	150	34
AA Bc 104	AA-02-0170	Tyler, Dorothy M.	Layne-Atlantic	1955	175	45
AA Bc 112	--	Stewart, Carl H.	--	--	150	33
AA Bc 161	AA-65-0777	AA DU	H. A. Gropp	1965	80	458
AA Bc 163	AA-68-0667	US Army, Fort Meade	Shannahan	1968	130	604
AA Bc 205	AA-73-6839	Davco Food Corporation	H. H. Bunker	1977	160	90
AA Bc 206	AA-74-1126	Griffin, P. J.	Slater	1979	120	107
AA Bc 209	AA-81-0366	AA DU, Telegraph Rd.	A. C. Schultes	1982	126	295
AA Bc 213	--	Baden	--	--	140	17
AA Bc 214	--	Osmen	--	--	185	22
AA Bc 218	--	--	--	--	145	26
AA Bc 220	AA-74-0849	Lewis, Annie	D. Wolford	1979	130	87
AA Bc 221	--	Mathews, Winston	--	--	110	16
AA Bc 222	--	Mitchel, Robert	--	--	105	14
AA Bc 223	--	Hayes, Florence	--	--	105	--
AA Bc 224	--	Hollins	--	--	150	13
AA Bd 2	--	Md. Training School	Shannahan	1932	90	91
AA Bd 3	--	Palberg, John	John Novak	1941	60	147
AA Bd 5	--	Della, Howard	John Novak	1945	40	136
AA Bd 7	--	Furman, George B.	--	--	20	80
AA Bd 9	--	Scherer, John A.	--	--	70	29
AA Bd 11	--	Stevenson, J. C.	--	1927	100	25
AA Bd 22	--	New Glen Theatre	H. H. Bunker	1941	45	110
AA Bd 23	AA-00-2803	AA DU, Harundale	Layne-Atlantic	1948	30	617
AA Bd 33	AA-00-3608	Phillips, W. C.	H. A. Gropp	1949	110	113
AA Bd 34	AA-00-2458	Green, Albert	G. E. Crouse	1948	85	64
AA Bd 35	AA-00-2812	Pillsbury, Louis	G. E. Crouse	1948	80	120
AA Bd 36	AA-00-2803	AA DU, Harundale #1	Layne-Atlantic	1948	30	123
AA Bd 37	--	AA DU, Harundale #2	Layne-Atlantic	1949	38	115
AA Bd 38	AA-00-8315	Alberts	H. H. Bunker	1950	132	141
AA Bd 40	--	Fisher, James	G. E. Crouse	1949	80	203
AA Bd 46	--	Maynor, C. V.	--	1954	110	20
AA Bd 47	--	Haney, L.	--	--	80	22
AA Bd 48	--	Dicus, S.	--	--	60	20
AA Bd 53	--	Chappell, S.	Owner	--	150	62
AA Bd 55	AA-02-1548	AA DU, Dorsey Road #1	Layne-Atlantic	1955	70	131
AA Bd 56	AA-02-1550	AA DU, Dorsey Road #3	Layne-Atlantic	1956	70	153
AA Bd 58	--	--	--	--	65	30
AA Bd 59	AA-01-7337	Dasch, John	Layne-Atlantic	1954	60	82
AA Bd 60	AA-01-9686	AA DU	Layne-Atlantic	1955	40	236
AA Bd 61	AA-01-9874	AA DU, Harundale #4	Layne-Atlantic	1955	42	206
AA Bd 63	AA-02-0188	AA DU, Harundale	Layne-Atlantic	1955	28	180
AA Bd 64	AA-02-8059	AA DU, Dorsey Road #11	Layne-Atlantic	1957	75	181
AA Bd 73	AA-02-4386	Pioneer Restaurant	W. Gilleland	1956	95	110
AA Bd 74	AA-02-9245	Moose Lodge No 1456	J. K. Hewitt	1957	95	82
AA Bd 75	AA-01-7547	Glen Burnie Coach Lines	Layne-Atlantic	1955	100	125
AA Bd 76	AA-03-3956	Howard Johnson Rest.	J. H. Brown	1959	80	146
AA Bd 78	AA-02-0137	Sunnyside School	Layne-Atlantic	1955	136	126
AA Bd 79	--	Scherer, John	--	--	125	29
AA Bd 82	--	Jones, L. N.	--	--	130	52

Diameter (inches) casing	Diameter (inches) screen	Depth to top of screen (feet)	Length of screen (feet)	Principal aquifer	Water Level (feet below land surface) Static	Water Level (feet below land surface) Pumping	Date water level measured	Yield (gal/min)	Hours pumped	Specific capacity [(gal/min)/ft]	Use of water	Well number
--	--	--	--	Patapsco	28	--	3/00/1955	--	--	--	H	AA Bc 61
36	--	--	--	Patapsco	15	--	3/00/1955	--	--	--	H	AA Bc 62
36	--	--	--	Patapsco	38	--	3/01/1955	--	--	--	H	AA Bc 63
48	--	--	--	Patapsco	30	--	3/00/1955	--	--	--	H	AA Bc 64
4	--	--	--	Patapsco	40	--	3/00/1955	--	--	--	H	AA Bc 65
36	--	--	--	Patapsco	27	--	4/00/1956	--	--	--	H	AA Bc 66
4	2	40	5	Patapsco	27	32	4/00/1960	9	3	1.80	H	AA Bc 104
--	--	--	--	Patapsco	13	--	4/00/1960	--	--	--	U	AA Bc 112
6	--	230	15	Patapsco	1	110	4/00/1965	250	24	2.30	U	AA Bc 161
4	2	542	20	Patuxent	70	107	2/00/1968	58	4	1.57	T	AA Bc 163
4	2	85	5	Patapsco	40	60	2/04/1977	20	2	1.00	C	AA Bc 205
4	2	100	7	Patapsco	60	70	11/18/1979	15	4	1.50	H	AA Bc 206
6	6	275	20	Patapsco	67	120	5/27/1982	277	27	5.23	U	AA Bc 209
48	--	--	--	Patapsco	8	--	2/10/1984	--	--	--	H	AA Bc 213
4	--	--	--	Patapsco	17	--	2/00/1984	--	--	--	U	AA Bc 214
60	--	--	--	Patapsco	24	--	2/00/1984	--	--	--	U	AA Bc 218
4	3	80	7	Patapsco	32	87	8/06/1979	15	2	0.27	H	AA Bc 220
40	--	--	--	Patapsco	6	--	4/00/1984	--	--	--	U	AA Bc 221
40	--	--	--	Patapsco	14	--	4/00/1984	--	--	--	U	AA Bc 222
40	--	--	--	Patapsco	--	--	--	--	--	--	U	AA Bc 223
40	--	--	--	Patapsco	2	--	4/00/1984	--	--	--	U	AA Bc 224
10	--	--	--	Patapsco	5	22	1/01/1932	78	--	4.59	U	AA Bd 2
4	--	--	--	Patapsco	48	62	12/16/1941	6	--	0.43	H	AA Bd 3
4	--	--	--	Patapsco	25	55	1/00/1946	10	--	0.33	--	AA Bd 5
--	--	--	--	Patapsco	flows	--	0/00/1945	20	--	--	H	AA Bd 7
4	--	--	--	Patapsco	9	--	3/00/1946	--	--	--	H	AA Bd 9
48	--	--	--	Patapsco	17	--	3/00/1946	--	--	--	H	AA Bd 11
6	--	100	10	Patapsco	8	28	0/00/1941	100	--	5.00	A	AA Bd 22
4	--	--	--	Patuxent	--	--	--	16	8	--	U	AA Bd 23
4	2	87	5	Patapsco	48	--	2/04/1949	10	--	--	H	AA Bd 33
4	--	--	--	Patapsco	24	--	5/10/1948	5	4	--	H	AA Bd 34
4	--	--	--	Patapsco	50	50	6/29/1948	5	2	--	H	AA Bd 35
20	10	98	25	Patapsco	3	70	6/00/1948	439	--	6.50	--	AA Bd 36
20	--	90	25	Patapsco	7	67	1/01/1949	450	48	6.72	P	AA Bd 37
4	2	--	--	Patapsco	111	--	9/00/1951	--	--	--	H	AA Bd 38
4	--	--	--	Patapsco	30	--	12/00/1951	--	--	--	H	AA Bd 40
2	--	18	3	Patapsco	16	--	3/00/1955	--	--	--	H	AA Bd 46
--	--	--	--	Patapsco	22	--	3/00/1955	--	--	--	U	AA Bd 47
40	--	--	--	Patapsco	18	--	3/00/1955	--	--	--	H	AA Bd 48
36	--	--	--	Patapsco	62	--	3/00/1955	--	--	--	H	AA Bd 53
10	10	111	20	Patapsco	11	52	12/00/1955	450	8	11.00	P	AA Bd 55
10	10	133	20	Patapsco	7	118	2/00/1956	350	4	3.15	P	AA Bd 56
48	--	--	--	Patapsco	28	--	11/00/1956	--	--	--	U	AA Bd 58
4	2	77	5	Patapsco	23	31	4/30/1957	20	3	2.50	H	AA Bd 59
--	--	--	--	Patapsco	--	--	--	--	--	--	U	AA Bd 60
10	8	186	20	Patapsco	13	45	8/00/1955	500	5	15.50	P	AA Bd 61
10	8	160	20	Patapsco	0	110	9/00/1955	500	5	4.50	P	AA Bd 63
12	10	161	20	Patapsco	13	170	9/00/1957	375	8	2.39	--	AA Bd 64
4	--	90	6	Patapsco	44	73	1/06/1956	8	5	0.28	C	AA Bd 73
4	2	70	12	Patapsco	40	65	11/00/1957	--	--	--	C	AA Bd 74
6	4	120	5	Patapsco	47	53	1/00/1955	50	3	8.31	H	AA Bd 75
4	--	138	7	Patapsco	42	--	9/00/1959	30	4	--	C	AA Bd 76
6	6	121	5	Patapsco	70	80	8/00/1955	30	3	3.00	--	AA Bd 78
4	--	--	--	Patapsco	14	--	4/00/1960	--	--	--	U	AA Bd 79
--	--	--	--	Patapsco	49	--	5/00/1960	--	--	--	H	AA Bd 82

Water-Use Codes

A = Air conditioning
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T = Institutional
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Table 14. — Records of selected wells in the Glen Burnie area—Continued

[ft = feet; gal/min = gallon per minute; (gal/min)/ft = gallon per minute per foot; -- = data not available; AA DU = Anne Arundel County Department of Utilities; USGS = U.S. Geological Survey]

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Depth of well (ft)
Anne Arundel County--Continued						
AA Bd 83	--	Walker, M.	--	--	130	37
AA Bd 84	AA-03-8721	Brookwood Farms	H. H. Bunker	1960	60	95
AA Bd 88	--	Warfield, Clayton	Layne-Atlantic	1949	145	228
AA Bd 91	AA-04-2029	AA DU, Dorsey Road	Layne-Atlantic	1961	79	160
AA Bd 92	AA-04-2472	AA DU, Dorsey Road	Layne-Atlantic	--	85	157
AA Bd 95	AA-05-0489	AA DU, Dorsey Road #15	Layne-Atlantic	1963	70	178
AA Bd 98	AA-05-7226	AA DU, Dorsey Road #17	H. A. Gropp	1964	75	625
AA Bd 101	AA-69-0071	AA DU, Phillips #1	Layne-Atlantic	1969	55	212
AA Bd 103	AA-69-0054	AA DU, Glendale #1	Layne-Atlantic	1969	80	221
AA Bd 105	AA-69-0128	AA DU, Crain Hwy #1	Layne-Atlantic	1969	90	237
AA Bd 107	AA-69-0195	AA DU, Elvaton #1	Layne-Atlantic	1969	20	240
AA Bd 108	AA-71-0554	AA DU, Thelma Ave. #1	Layne-Atlantic	1971	70	205
AA Bd 109	AA-71-0553	AA DU, Quarterfield #1	Layne-Atlantic	1971	190	300
AA Bd 112	AA-05-0761	Myers Plant Farm	Layne-Atlantic	1963	160	161
AA Bd 116	AA-81-0993	AA DU	Layne-Atlantic	1983	90	365
AA Bd 121	AA-81-0368	AA DU, Stevenson Rd.	A. C. Schultes	1982	110	346
AA Bd 122	AA-81-0369	AA DU, Stevenson Rd.	A. C. Schultes	1982	110	349
AA Bd 123	AA-81-0388	Smith, Phillip	J. Branham	1982	65	90
AA Bd 124	AA-73-4524	Carter, Fred	J. H. Brown	1975	70	60
AA Bd 127	--	AA DU	--	--	70	15
AA Bd 129	--	Rowe	--	--	85	23
AA Bd 130	--	Truckson, William	--	--	120	42
AA Bd 131	--	--	--	--	90	23
AA Bd 132	--	--	--	--	105	36
AA Bd 133	--	Jones, Wilbur	--	--	100	26
AA Bd 134	AA-73-2785	--	John Branham	1974	90	70
AA Bd 135	--	--	--	--	90	19
AA Bd 136	--	Arco Gas Station	--	--	130	85
AA Bd 138	--	Hall, V.	--	1984	40	15
AA Bd 142	--	Jarmer	--	--	80	--
AA Bd 152	AA-81-3463	USGS, Woodside School	East Coast Dr.	1984	53	97
AA Bd 154	AA-81-3461	USGS, Queenstown Park	East Coast Dr.	1984	88	180
AA Bd 155	AA-81-3460	USGS, State Hwy. Garage	East Coast Dr.	1984	57	159
AA Bd 156	AA-81-3462	USGS, Bicycle Path	East Coast Dr.	1984	69	173
AA Bd 157	AA-81-3464	USGS, Rippling Woods Sch.	East Coast Dr.	1984	75	178
AA Bd 158	AA-81-3465	USGS, Vocational Technic.	East Coast Dr.	1984	108	187
AA Bd 159	--	USGS, Rippling Woods Sch.	East Coast Dr.	1984	75	--
AA Bd 160	AA-81-3461	USGS, Queenstown Park	East Coast Dr.	1985	88	118
AA Be 11	AA-00-0153	Katoski, Andres	W. H. Eiler	1945	50	96
AA Be 29	--	Wolfe's Tavern	--	--	100	53
AA Be 48	AA-00-0019	Reiser, John Jr.	W. H. Eiler	1946	23	254
AA Be 99	AA-02-9805	Freetown Elem School	H. H. Bunker	1958	80	131
AA Be 110	--	Swett, Albert	--	--	70	--
AA Ce 117	AA-73--0172	AA DU, Severndale	Delmarva	1972	80	922
Baltimore County						
BA Gf 11	--	Bethlehem Steel Corp.	Shannahan	1941	10	645
Baltimore City						
7S4E 1	BC-01-7129	Glidden Corp.	Shannahan	1954	40	638

Diameter (inches) casing	Diameter (inches) screen	Depth to top of screen (feet)	Length of screen (feet)	Principal aquifer	Water Level (feet below land surface) Static	Water Level (feet below land surface) Pumping	Date water level measured	Yield (gal/min)	Hours pumped	Specific capacity [(gal/min)/ft]	Use of water	Well number
36	--	--	--	Patapsco	32	--	5/00/1960	--	--	--	H	AA Bd 83
6	6	85	10	Patapsco	26	60	5/00/1960	50	5	1.47	C	AA Bd 84
8	6	208	20	Patapsco	66	--	11/00/1949	350	--	--	I	AA Bd 88
6	2	155	5	Patapsco	15	--	3/00/1961	--	--	--	--	AA Bd 91
10	10	132	25	Patapsco	22	120	5/00/1961	200	24	2.04	--	AA Bd 92
10	10	150	20	Patapsco	19	142	2/00/1963	350	24	2.85	--	AA Bd 95
10	10	552	39	Patuxent	58	205	8/00/1964	907	8	6.17	P	AA Bd 98
10	10	172	40	Patapsco	20	83	4/01/1969	608	24	9.65	P	AA Bd 101
10	--	176	35	Patapsco	67	152	5/01/1969	554	24	6.52	P	AA Bd 103
10	--	197	40	Patapsco	32	70	6/00/1969	554	24	14.58	P	AA Bd 105
10	10	185	35	Patapsco	flows	64	7/00/1969	650	24	10.16	P	AA Bd 107
10	10	175	30	Patapsco	30	158	5/00/1971	325	24	2.54	P	AA Bd 108
10	--	260	40	Patapsco	125	164	7/00/1971	326	24	8.36	P	AA Bd 109
6	--	156	5	Patapsco	90	156	3/00/1963	200	5	3.03	I	AA Bd 112
10	10	356	13	Patapsco	80	--	9/00/1981	--	--	--	H	AA Bd 116
6	6	326	20	Patapsco	63	142	5/05/1982	266	24	3.37	P	AA Bd 121
2	2	329	20	Patapsco	61	--	6/23/1982	--	--	--	U	AA Bd 122
4	2	80	10	Patapsco	20	45	4/29/1982	25	2	1.00	H	AA Bd 123
4	2	50	10	Patapsco	29	60	6/04/1975	20	4	0.65	U	AA Bd 124
40	--	--	--	Patapsco	0	--	3/23/1984	--	--	--	U	AA Bd 127
4	--	--	--	Patapsco	0	--	4/12/1984	--	--	--	U	AA Bd 129
40	--	--	--	Patapsco	27	--	4/12/1984	--	--	--	U	AA Bd 130
40	--	--	--	Patapsco	0	--	4/18/1984	--	--	--	U	AA Bd 131
40	--	--	--	Patapsco	21	--	4/18/1984	--	--	--	U	AA Bd 132
40	--	--	--	Patapsco	24	--	4/17/1984	--	--	--	H	AA Bd 133
4	2	63	7	Patapsco	21	32	4/17/1984	18	2	1.64	H	AA Bd 134
40	--	--	--	Patapsco	0	--	4/00/1984	--	--	--	U	AA Bd 135
4	--	--	--	Patapsco	65	--	4/00/1984	--	--	--	U	AA Bd 136
36	--	--	--	Patapsco	2	--	4/00/1984	--	--	--	H	AA Bd 138
40	--	--	--	Patapsco	2	--	5/00/1984	--	--	--	H	AA Bd 142
6	4	90	10	Patapsco	29	47	4/18/1985	30	4	2.00	U	AA Bd 152
6	4	105	10	Patapsco	22	38	4/20/1985	60	4	3.00	U	AA Bd 154
6	4	145	10	Patapsco	21	47	10/09/1984	60	--	2.31	U	AA Bd 155
6	4	160	10	Patapsco	52	132	10/23/1984	75	4	0.82	U	AA Bd 156
6	4	167	10	Patapsco	41	104	10/31/1984	75	4	1.47	U	AA Bd 157
6	4	174	10	Patapsco	51	140	11/01/1984	55	--	0.60	U	AA Bd 158
6	4	89	10	Patapsco	40	52	1/24/1985	33	4	2.75	U	AA Bd 159
6	4	105	10	Patapsco	17	38	3/20/1985	60	4	3.00	U	AA Bd 160
4	--	--	--	Patapsco	39	43	12/00/1945	8	--	2.00	C	AA Be 11
4	--	--	--	Patapsco	23	--	2/00/1946	--	--	--	U	AA Be 29
3	--	--	--	Patapsco	18	24	4/00/1946	8	12	1.33	H	AA Be 48
6	6	121	10	Patapsco	55	115	1/00/1958	50	24	0.83	U	AA Be 99
41	--	--	--	Patapsco	5	--	4/00/1984	--	--	--	--	AA Be 110
6	6	836	50	Patuxent	62	180	8/00/1972	500	24	4.20	U	AA Ce 117
14	--	423	--	Patuxent	--	--	--	--	--	--	C	BA Gf 11
2	2	565	10	Patuxent	100	--	10/00/1954	8	4	--	U	7S4E 1

Water-Use Codes

A = Air conditioning
C = Commercial
H = Domestic
I = Irrigation
N = Industrial
P = Public supply
T = Institutional
U = Unused

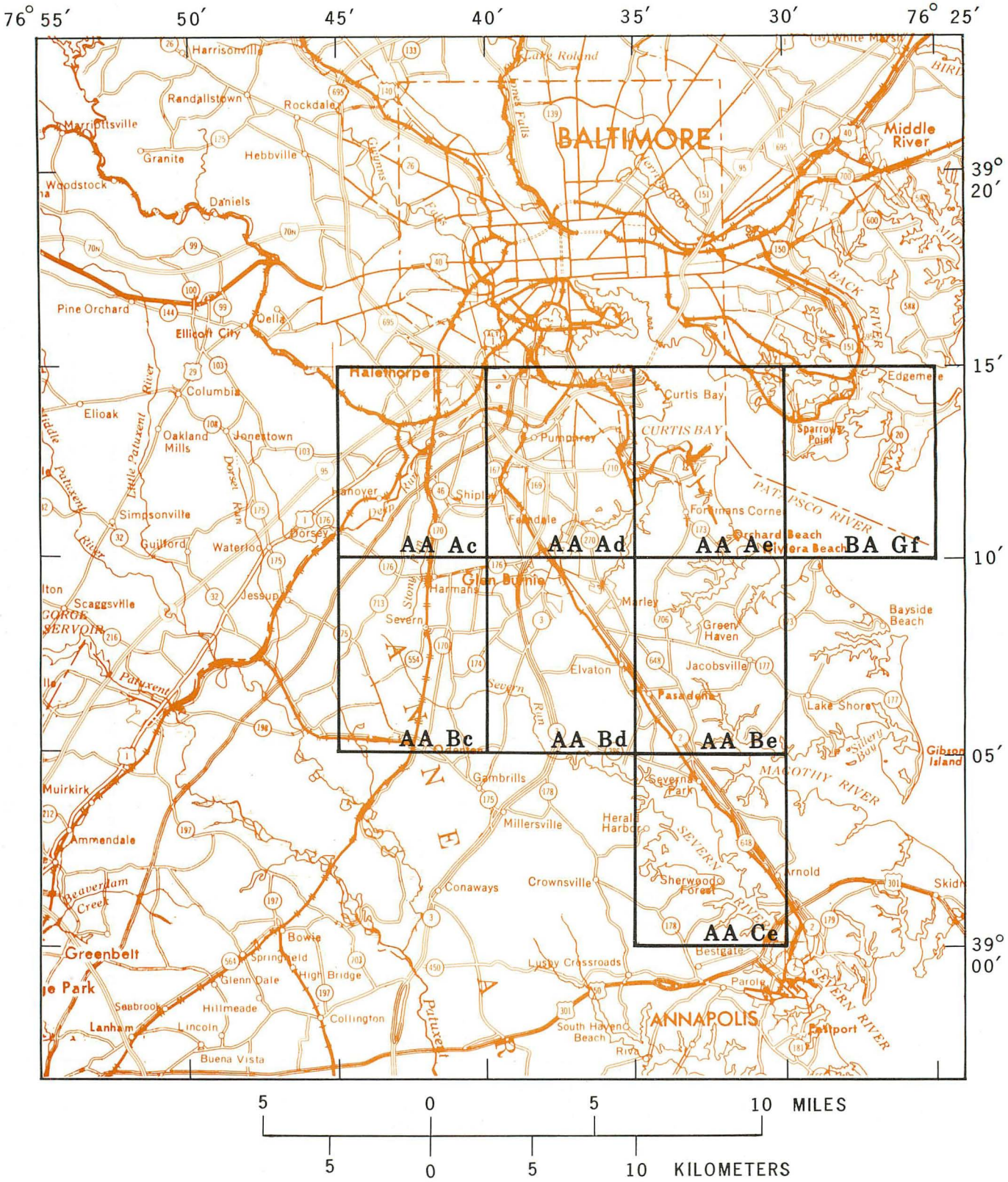
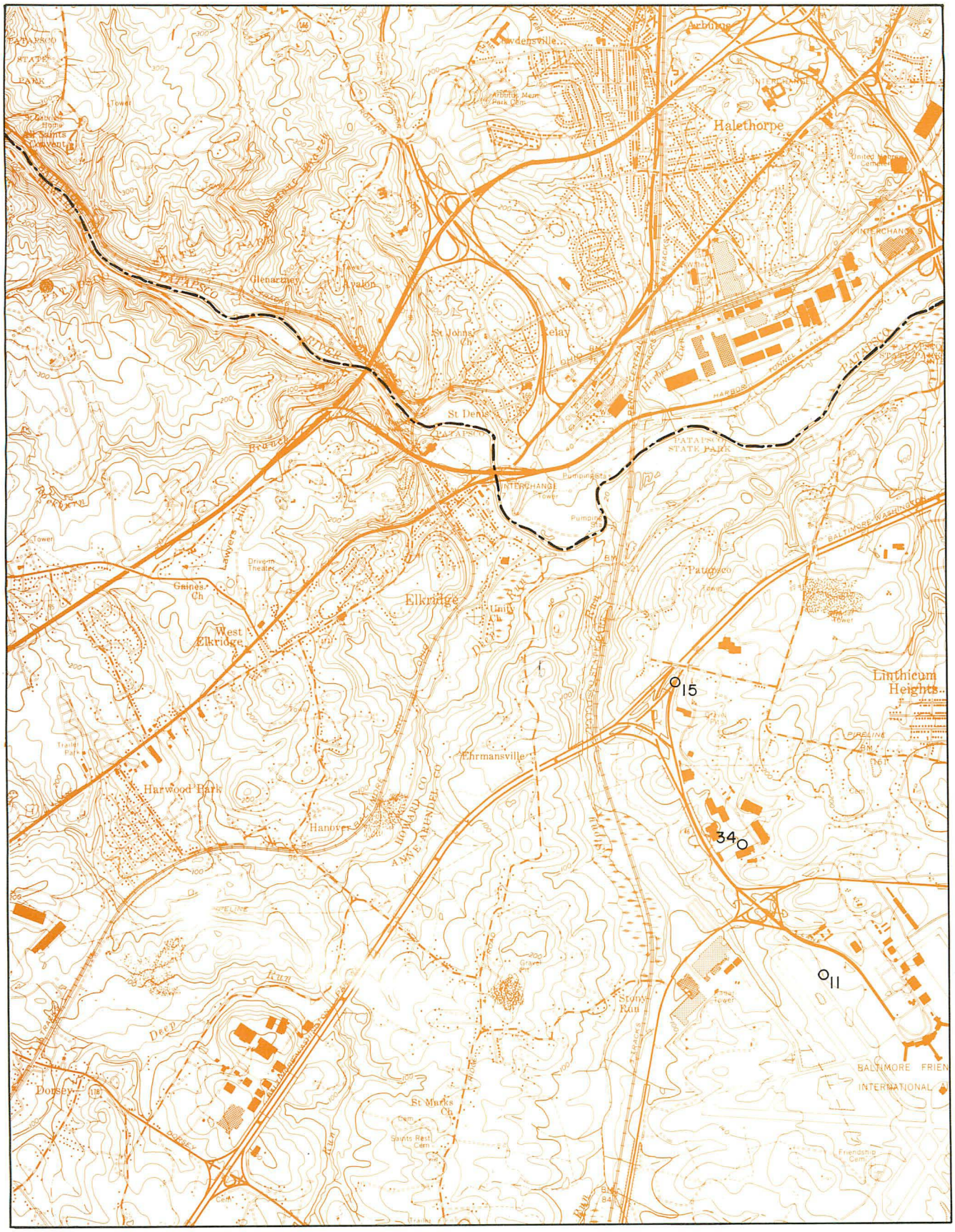


Figure 48. — Location of selected 5-minute quadrangles.



Quadrangle AA Ac

N

1 MILE 0

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Quadrangle AA Ad

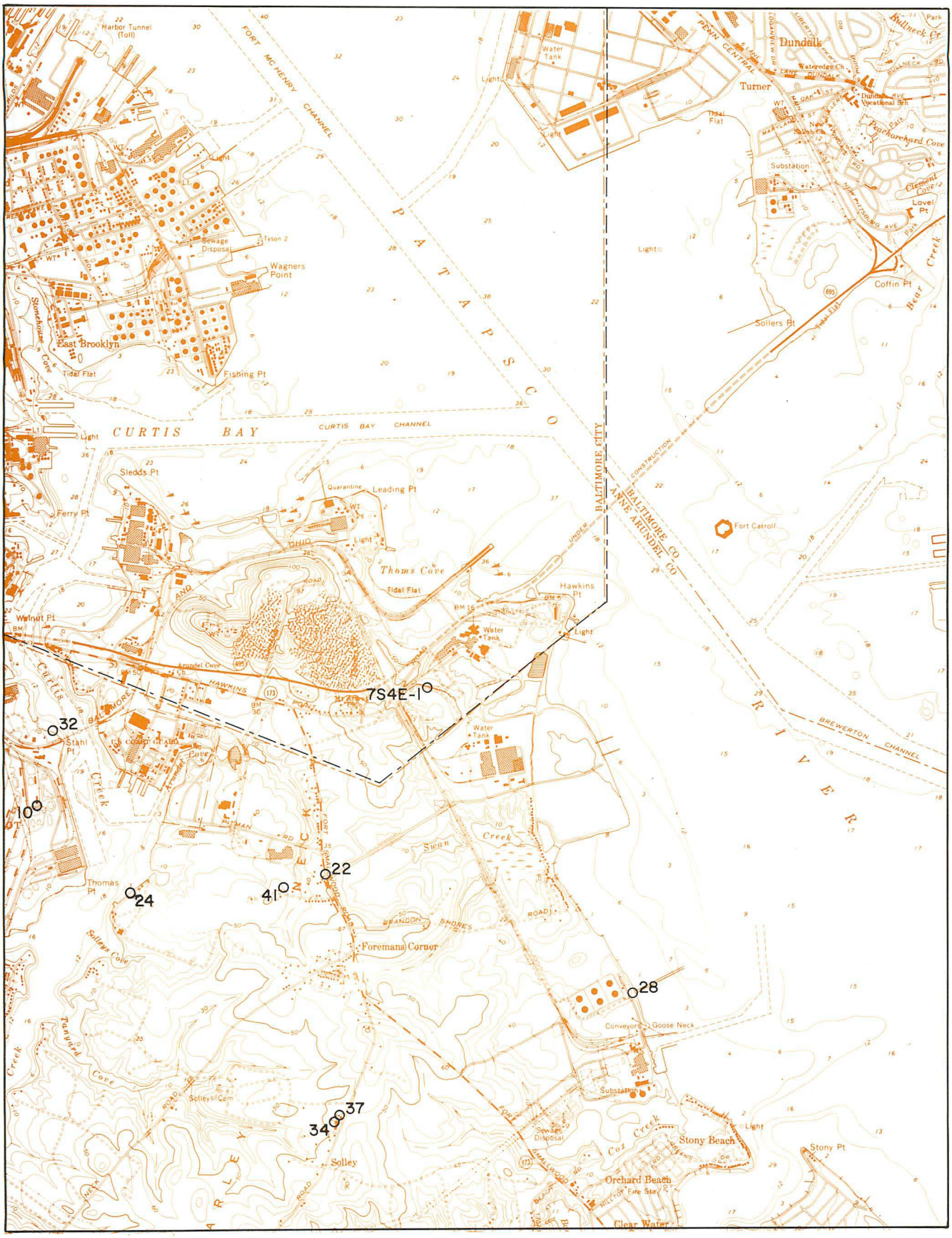
N

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETRE

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



Quadrangle AA Ae

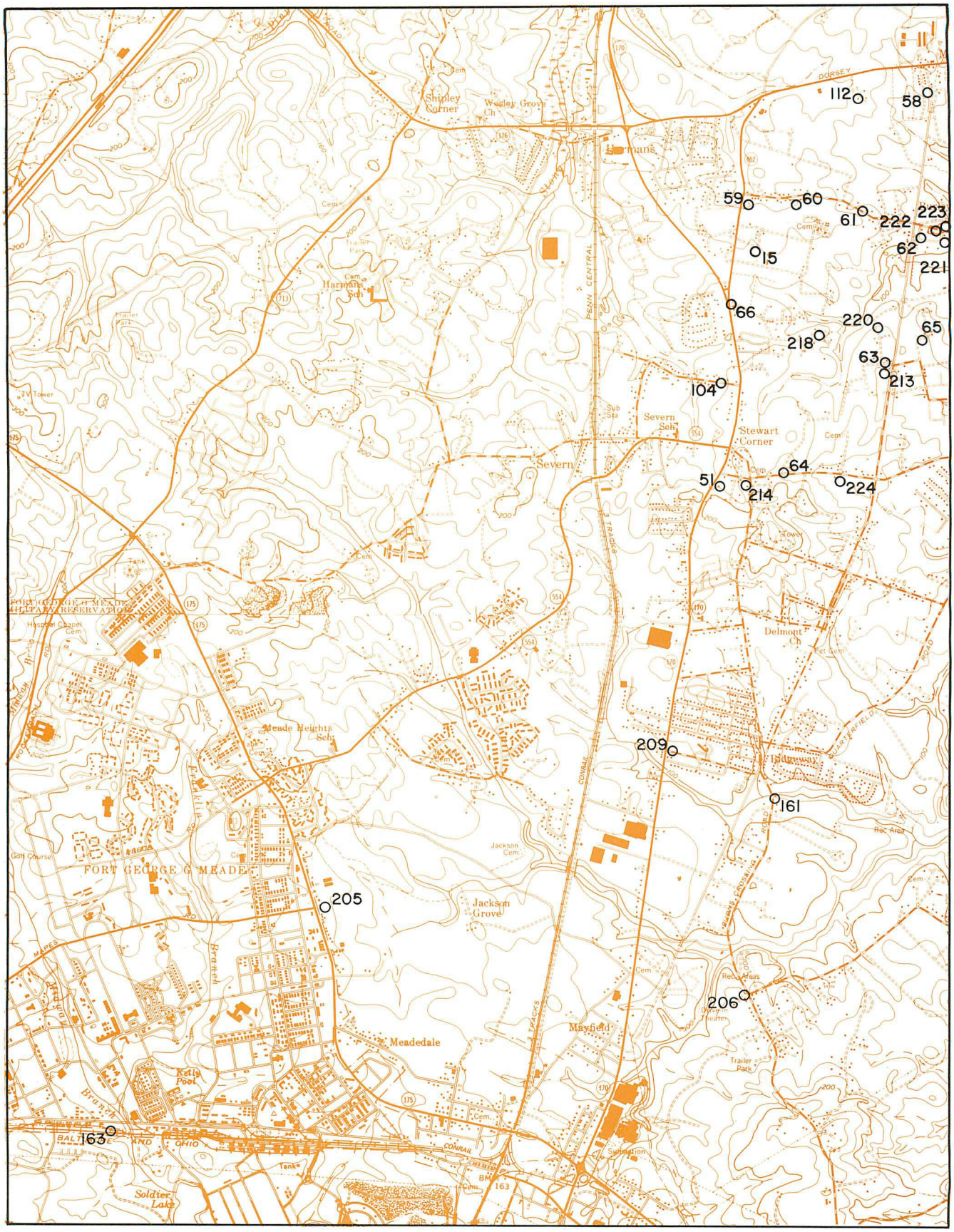
N

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETRE

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

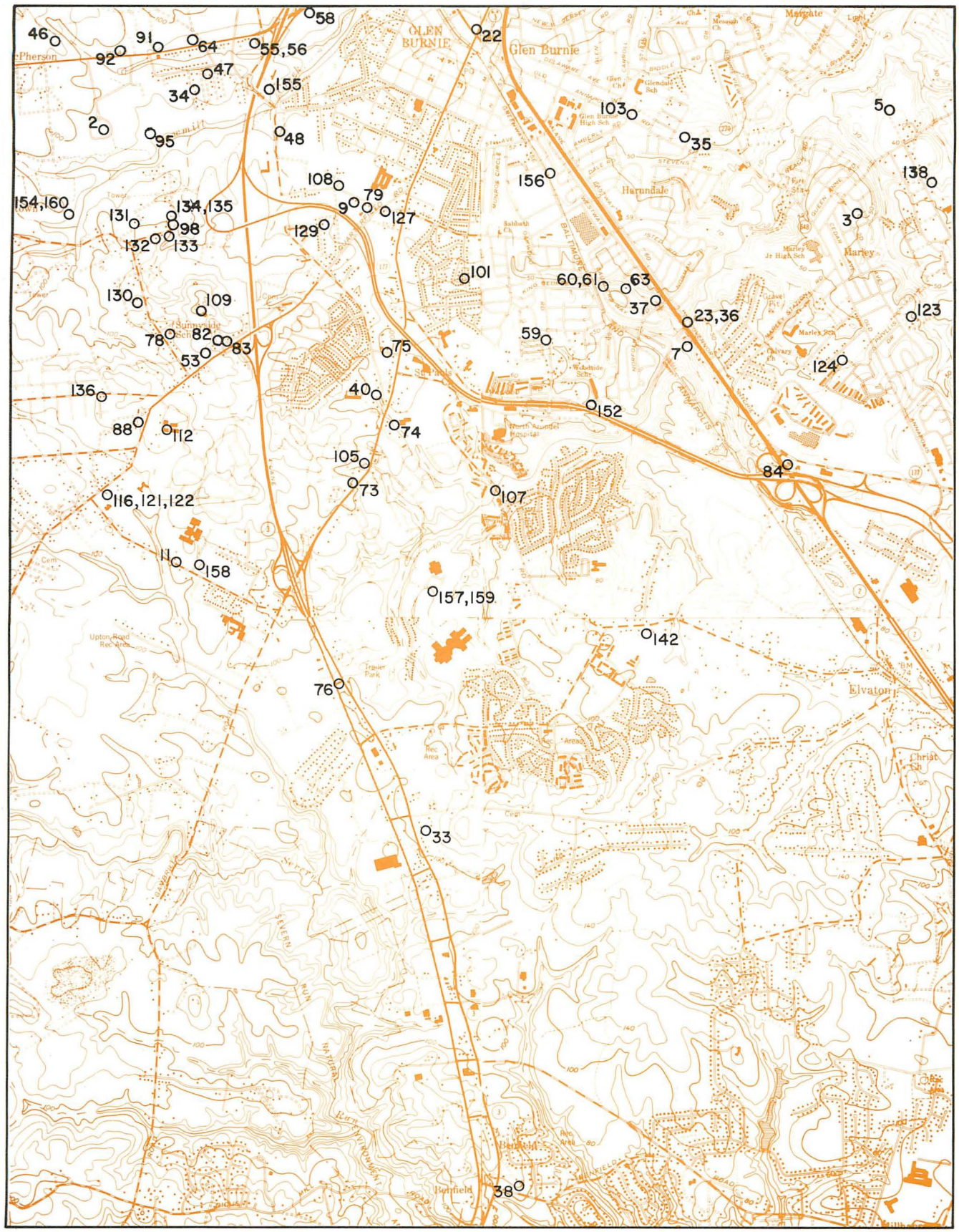


Quadrangle AA Bc

N

MILE 0 ½ 1
FEET 1000 0 1000 2000 3000 4000 5000 6000 7000
KILOMETER .5 0 1

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



Quadrangle AA Bd

N

1 MILE 0 1
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
.5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Quadrangle AA Be

N

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETRE

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Quadrangle AA Ce

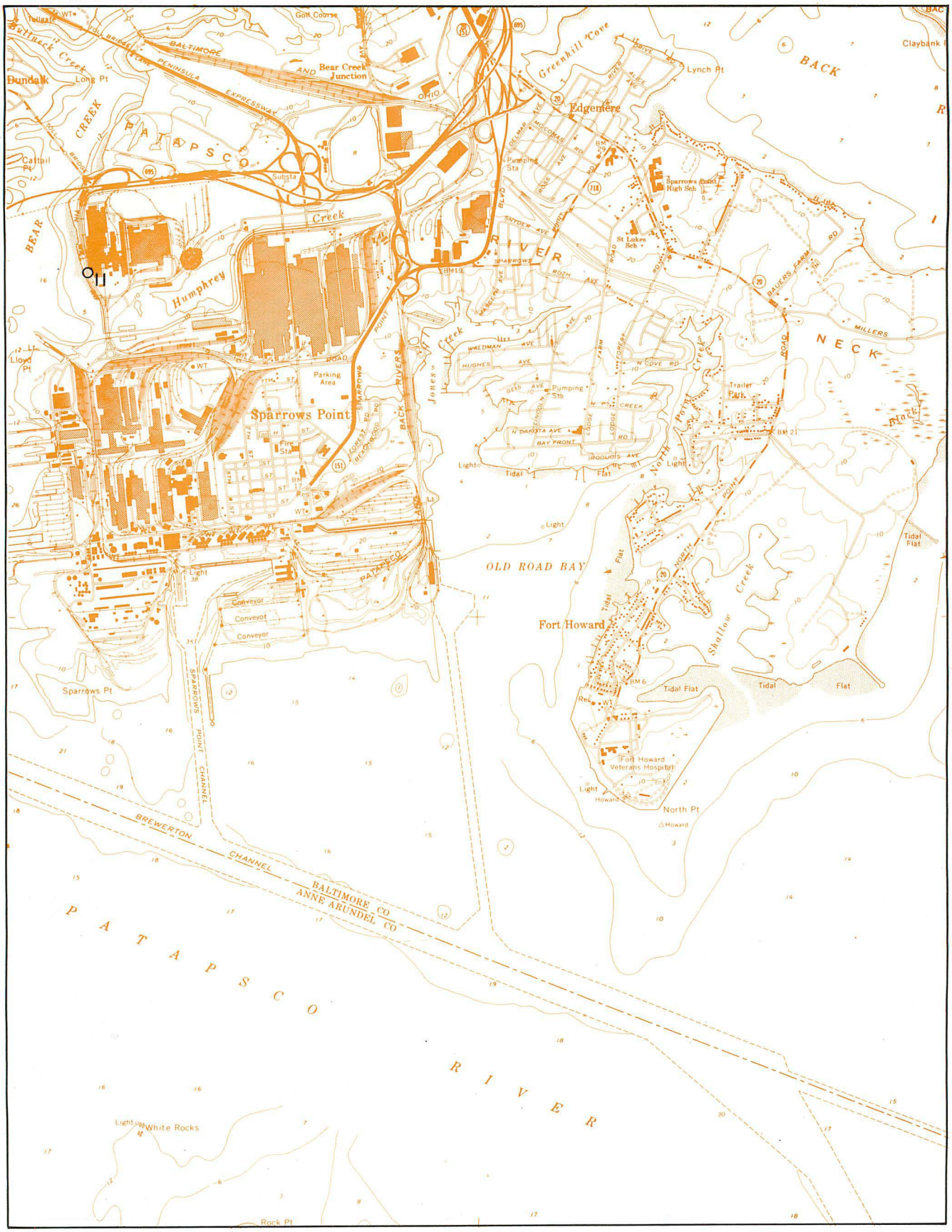
N

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



Quadrangle BA Gf

N

1 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETRE

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