Department of Natural Resources

MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO 28

DIGITAL SIMULATION AND PREDICTION OF WATER LEVELS IN THE MAGOTHY AQUIFER IN SOUTHERN MARYLAND

by
Frederick K. Mack
and
Richard J. Mandle

Prepared in cooperation with
Geological Survey
United States Department of the Interior
Anne Arundel County Office of Planning and Zoning
Planning Commission of Calvert County
Prince Georges County
Department of Program Planning and Economic Development
and
Charles County Department of Public Works

1977

CONVERSION OF MEASUREMENT UNITS

The following factors may be used by those readers who wish to convert the English units published in this report to metric (SI) units.

English Unit	Multiply By	Metric Unit
feet (ft)	0.3048	meters (m)
feet per day (ft/d)	0.3048	meters per day (m/d)
feet per second (ft/s)	30.48	centimeters per second (cm/s)
feet squared per day (ft^2/d)	0.0929	meters squared per day (m^2/d)
gallons (gal)	3.785	liters (L)
gallons per day (gal/d)	3.785	liters per day (L/d)
million gallons (Mgal)	3785	cubic meters (m^3)
million gallons per day (Mgal/d)	3785	cubic meters per day (m^3/d)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)

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DIGITAL SIMULATION AND PREDICTION OF WATER LEVELS IN THE MAGOTHY AQUIFER IN SOUTHERN MARYLAND

by
F. K. Mack and R. J. Mandle*

ABSTRACT

A digital model was developed of the Magothy aquifer, an important source of water in an 800-square mile area of the Coastal Plain of Maryland. The model was developed as part of a program to furnish planners with information on the availability of water from areas in which demands for water are increasing in response to rapid increases in population.

Data obtained by test drilling, development of an observation well network, and searches of unpublished and published pumpage and water-level data were used to develop a calibrated digital model of the aquifer. The digital model is based on a computer program which uses the finite-difference method of approximating the ground-water flow equation and, with appropriate initial and boundary conditions, solves the resulting simultaneous algebraic equations using the iterative alternating-direction implicit procedure (IADIP). The model was calibrated by adjusting various hydrologic parameters until computed water-level declines caused by historical pumpage compared favorably with water-level declines measured in several observation wells. The model provides a method for evaluating the impact pumping rates would have on water levels in the aquifer.

Stressing the model with pumping from hypothetical well fields designed to utilize the most favorable hydrologic factors—high transmissivity and greatest available drawdown—indicated that the projected average daily demands for water for the year 2000 could not be met by pumpage solely from the Magothy. However, because the transmissivity and the amount of available drawdown vary considerably within the project area, there is a great difference in the amount of water available from one part of the area to another. Southern Anne Arundel and northern Calvert Counties have adequate quantities of water available from the Magothy, while Prince Georges and Charles Counties would have to seek additional supplies of water, possibly from deeper aquifers, by the year 2000.

At the Chalk Point power-generation plant in southern Prince Georges County., where the expected rate of pumping from the Magothy aquifer by year 2000 is 0.83 million gallons per day, the model predicts a relatively steepsided cone of depression having drawdowns of about 50 feet at a distance of 1 mile away, and less than 5 feet of drawdown at a distance of 10 miles away.

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* U.S. Geological Survey

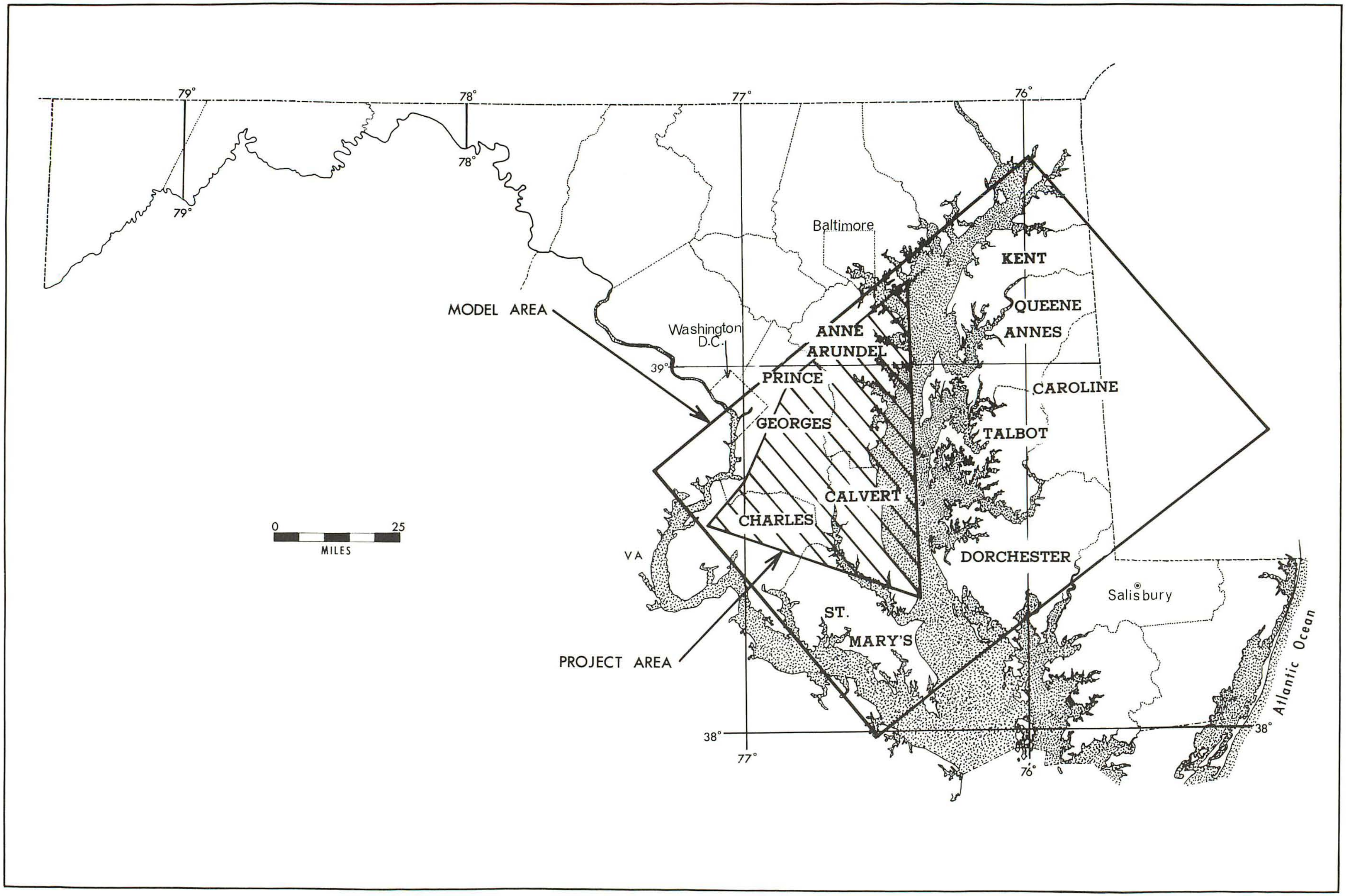

Figure 1.—The Magothy project area in southern Maryland.

INTRODUCTION

Purpose and Scope of Investigation

The Coastal Plain sediments underlying Anne Arundel, Prince Georges, Calvert, and Charles Counties include several sandy aquifers that supply much of the water for the area. One of these unconsolidated sands, the Magothy aquifer, of Cretaceous age, is the principal source of water in the Annapolis area of Anne Arundel County, the Waldorf area of Charles County, and parts of Prince Georges County. Ground-water levels in the Magothy have declined throughout the area in the last 20 years in response to increased development.

Demands for water in southern Maryland are increasing and are expected to continue to increase through the year 2000 as a result of increases in population and commercial development. In order to be sure that adequate water is available in the future, planners need information regarding the location of aquifers and especially the quantities of water that may be derived from them. This study was made to assist in the evaluation of the availability of water from the Magothy aquifer and to provide a tool useful in the development of the aquifer.

The digital modeling technique was selected to make the evaluation because it considers available quantitative information regarding the complex geologic and hydrologic relationships between the Magothy aquifer and the masses of fine-grained Coastal Plain sediments confining it. This study, which resulted in the development of a single-layered model, is an essential step in the eventual development of a multilayered model of the Coastal Plain sediments in southern Maryland. This report on the Magothy aquifer in southern Maryland presents the data and rationale used to develop the model as well as the conclusions resulting from model predictions.

Management of the Magothy aquifer would ultimately have to be based on considerations of factors controlling the amount of water the aquifer will yield and factors such as the potential hazard of aquifer contamination by intrusion of saline water from Chesapeake Bay. This model of the Magothy aquifer addresses only the aquifer yield aspects of the management problem. Model predictions for parts of the aquifer near Severn, South, and Magothy Rivers need to be tempered with further evaluation with regard to the hazard of saltwater intrusion. Several aspects of the saltwater hazard have been discussed by Mack (1974). As more information becomes available, conceptions of the hydrology of the system may be modified, resulting in further refinement of the model.

Location and Extent of Study Area

The project area (fig. 1) includes the southern two thirds of Anne Arundel County, the southeastern half of Prince Georges County, the northeastern third of Charles County, and northern Calvert County. It includes about 800 mi^2, with its center about 20 mi east of Washington D.C., and 30 mi south of Baltimore, Md. Annapolis and Bowie are the largest municipalities within the area.

The area of the model was made considerably larger than the area of the project, as seen in figure 1, in order to simulate the lateral extent and distant boundaries of the aquifer. The modeled area includes parts of Anne Arundel, Prince Georges, Charles, and Calvert Counties in southern Maryland, and Kent, Queen Anne's, Talbot, and Caroline Counties on Maryland's Eastern Shore.

Previous Investigations

Aspects of the geologic and water-yielding characteristics of the Magothy aquifer have been studied and published by many earlier hydrologists. The status of development of water supplies from the Magothy and other aquifers in southern Maryland before the turn of the century was described by Darton (1896). Wells tapping the aquifers 22 years later were tabulated and described by Clark, Mathews, and Berry (1918). Several studies published as part of the series of Bulletins of the Maryland Geological Survey were concerned with water resources of individual counties of the area. Ground-water resources of Anne Arundel County were described by Brookhart (1949) and Mack (1962). Similar studies in Prince Georges County were described by Meyer (1952) and Mack (1966). Overbeck (1948), Slaughter and Laughlin (1966), and Slaughter and Otton (1968) described the ground-water resources of Charles County. Another report by Overbeck (1951) described the ground-water resources of Calvert County. Ferguson (1953) described the ground-water resources of St. Mary's County. Multi-county studies of southern Maryland were done by Darton (1951), Otton (1955), Hansen (1968), Weigle, Webb, and Gardner (1970), and Glaser (1969, 1971).

The extensive list of references included in each of these publications will lead researchers to the work of others whose contributions enriched the background upon which this current report is based.

In developing the digital model of the Magothy aquifer, the authors referred to the techniques developed by Pinder and Bredehoeft (1968), and Bredehoeft and Pinder (1970, 1973). Frequent reference was also made to two recently completed models; one for the Piceance basin of Colorado

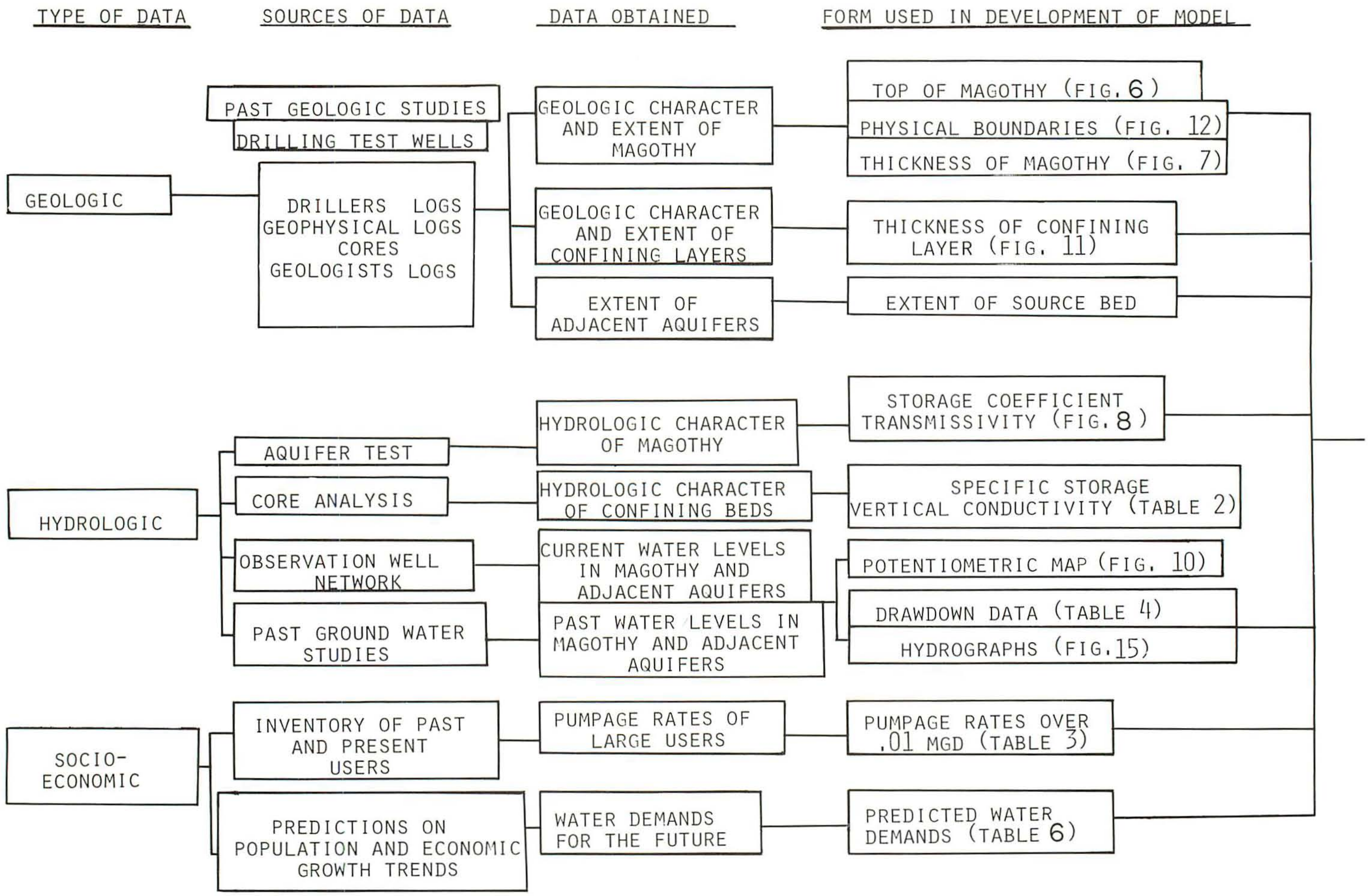

Figure 2.—Sources and types of data obtained and the format for utilizing the data in the development and stressing of the model by pumping.

(Weeks and others, 1974), and one for the Odessa-Lind area of Washington State (Luzier and Skrivan, 1975).

Experience and data obtained during the preparation of digital and electric-analog models of the Magothy aquifer in the Annapolis area (Mack, 1974) were used as a starting point in the development of this model. Additional data collected during the course of the present study required some changes from earlier assumptions and thus necessitated corresponding changes in the model.

Acknowledgments

Assistance with this project was rendered by well drillers, well owners, and Federal, State, county, and city agencies. Personnel of the Maryland Geological Survey and the Maryland Water Resources Administration provided support for much of the fieldwork, including semiannual measurements of the observation-well network, pumping tests, geophysical logging, and other test drilling activities. Harry Hansen of the Maryland Geological Survey participated in early planning of the project and provided helpful comments and criticisms during its several stages of development. Funds for establishing the cluster of observation wells at Chalk Point were furnished by the Maryland Power Plant Siting Program.

METHOD OF STUDY

The availability of water from the Magothy aquifer was evaluated by means of a digital model. Project activities progressed through the following phases to produce the digital model:

1. Acquisition of data for the Magothy aquifer and adjacent formations. This entailed the gathering of many types of information from many different sources as may be seen in figure 2.

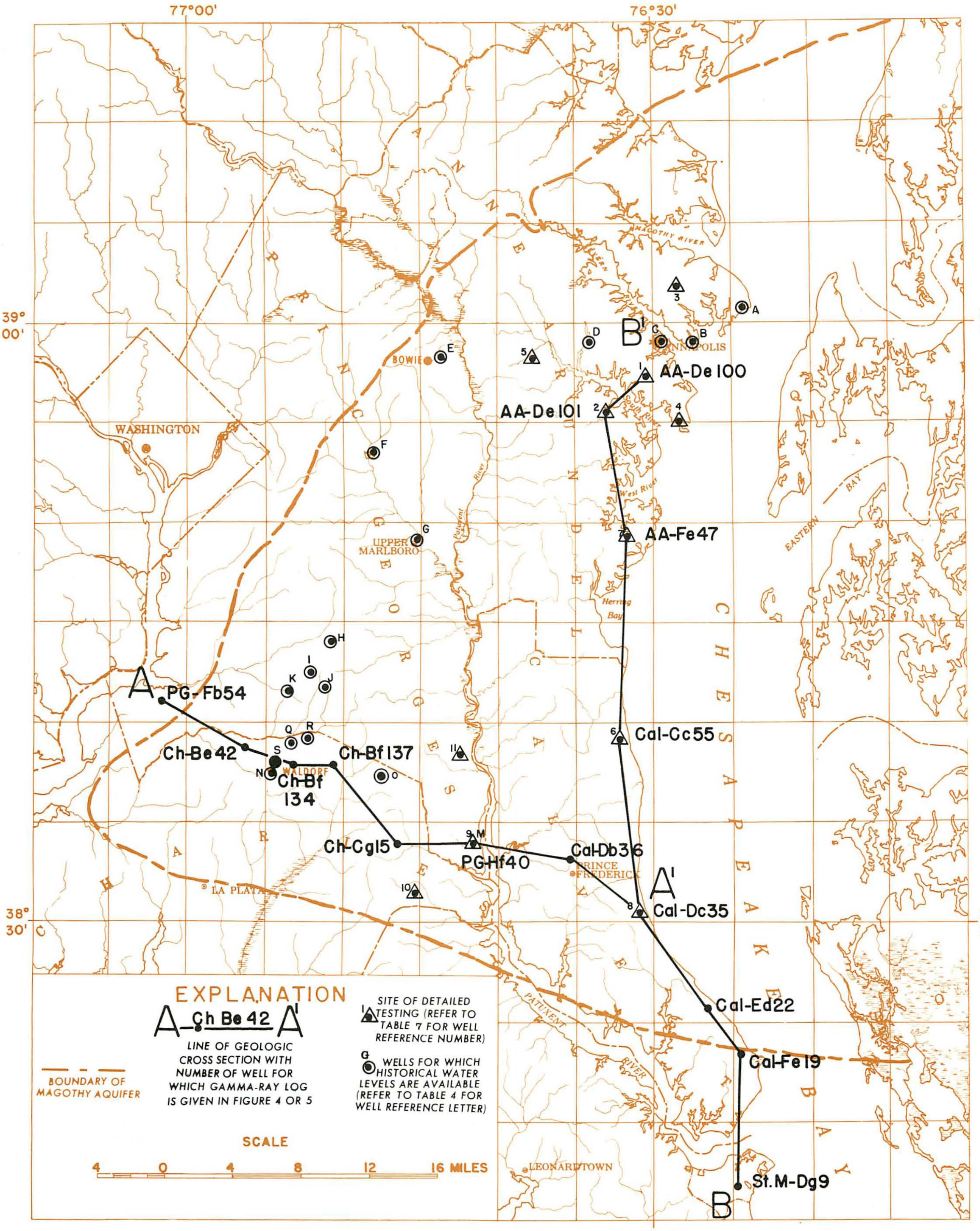

Figure 3.—Sites of detailed test work and points used for calibrating the model.

2. Development of a conceptual model of the geologic framework and hydrologic system of the Magothy aquifer from existing hydrogeologic knowledge, new data obtained by test drilling, and newly developed observation well networks.
3. Translation of the data from the conceptual model to a computer-manipulatable mathematical simulation of the real aquifer - the digital model.
4. Calibration of the model by adjusting it until its computed drawdowns matched historical relationships between pumpage and water-level decline.
5. Trial runs to predict water-level declines due to conceivable hypothetical well-field configurations of the future.

Later sections of this report elaborate on these phases.

The two-dimensional model used in this report solves the nonsteady ground-water flow equation:

$$\frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right)=S\frac{\partial h}{\partial t}+W(x,y,t)+L(x,y,t) \qquad (1)$$

where

T=transmissivity (L^2/T),
h=hydraulic head (L),
S=storage coefficient (dimensionless),
x, y=space coordinates (L),
$W(x, y, t)$=source term (L^3/T),
$L(x, y, t)$=leakage term (L^3/T), and
t=time (T).

Inclusion of the source term, W (x, y, t), allows the model to determine water-level fluctuations (h) in response to pumping. Because the Magothy is a confined aquifer, leakage from adjacent beds must also be considered. The leakage term, L (x, y, t), is composed of two parts—steady and transient leakage. Steady leakage is controlled by the vertical conductivity (K′) and thickness of the confining layer (d′) and the hydraulic gradient (h′-h) across this confining layer.

$$\text{Steady leakage}=\frac{K'}{d'}(h'_{i,j}-h_{i,j,o}) \qquad (2)$$

Transient leakage is the result of water released from storage in the confining layer as a result of head declines in the confined aquifer. It is important only if the confining layers are thick or during initial development of the aquifer.

$$\text{Transient leakage}=(h_{i,j,o}-h_{i,j,k})\frac{K'}{d'_{i,j}\sqrt{\pi K't_k/2d'^2_{i,j}Ss}}\left\{1+2\sum_{n=1}^{\infty}\exp\left[\frac{n^2}{K't_k/2d'^2_{i,j}Ss}\right]\right\}$$

where

$h_{i,j,o}$ =initial head in confined aquifer (L),
$h_{i,j,k}$ =head at time k (T),
$h_{i,j}$ =head in source layer "above" confining layer (L),
K'=vertical conductivity of confining layer (L/T),
$d'_{i,j}$=thickness of confining layer (L),
t =elapsed time (T),
Ss =specific storage of confining layer (L^{-1}) and
n=iteration index (0).

From equations 1, 2, and 3, it can be seen that specific hydrogeologic data are needed. These are: transmissivity and storage coefficient of the aquifer; vertical conductivity, thickness and specific storage of the confining layer; and water levels in the Magothy aquifer and adjacent aquifers. Also needed are historical drawdowns and pumping rates for calibration of the model and projected pumping rates for prediction with the model. Methods of collection and analysis of these data are shown in figure 2.

Tests to determine the coefficient of transmissivity of the aquifer were made by pumping wells for known periods of time at known rates of discharge and, where possible, observing the following effects: (1) The hydraulic interference occurring in the aquifer determined by measuring water levels in one or more observation wells; (2) the rate at which the water level in the pumped well recovered when pumping stopped; and (3) the drawdown in the pumped well. Data obtained from these tests were analyzed by the methods developed by Theis (1935) and Cooper and Jacob (1946).

HYDROGEOLOGIC SETTING

First steps in the study of the Magothy aquifer entailed refinement of earlier concepts of the geologic framework of the southern Maryland area and of the hydrologic system functioning within the geologic framework. Geologic and hydrologic data from earlier studies were compiled, and new data

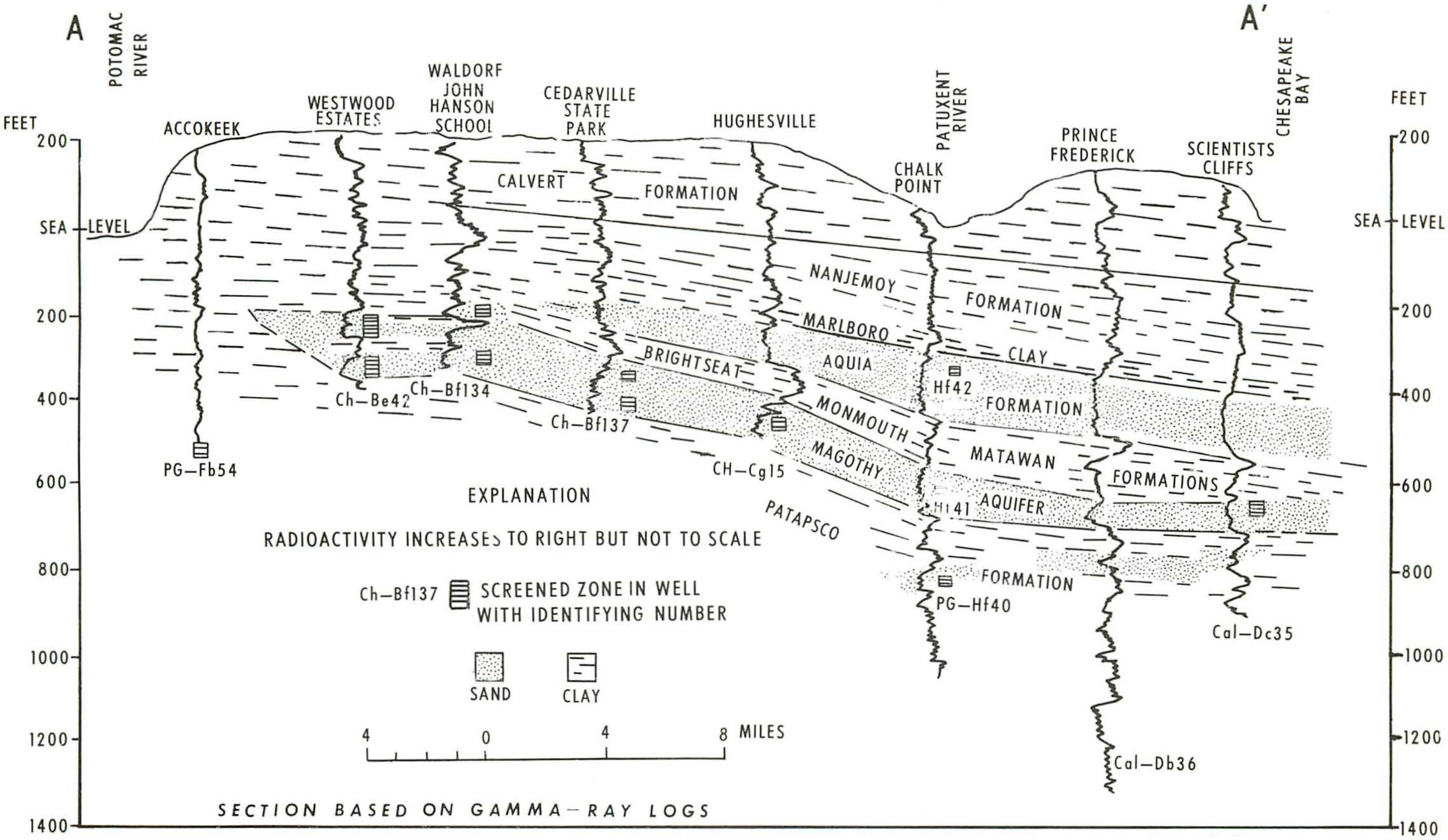

Figure 4.—Geologic section A-A′ across southern Maryland

were collected by test drilling, geophysical logging, laboratory studies, aquifer tests, and an observation-well network. Detailed testing was done in the field at six sites (See figs. 20-25; Hansen, 1978). Observation wells and test sites are shown on figures 3 and 10. The data were used to prepare potentiometric maps, geologic sections, and maps of transmissivity.

The project area is underlain by a wedge-shaped mass of unconsolidated sedimentary deposits, the Coastal Plain sediments. That wedge overlies much older consolidated sedimentary rocks in some places and igneous or metamorphic crystalline rocks in other places. The eroded surface of the basement complex dips gently toward the southeast.

Each lithologic type of sediment plays a special role in the functioning of the hydrologic system. Clean sand layers of sufficient thickness can yield large quantities of water to individual wells and thus are important in developing large water supplies. Clay layers cannot readily yield significant quantities of water to individual wells, but they strongly influence the movement of water within the hydrologic system by impeding vertical flow between aquifers. Clay layers also serve as sources of recharge by furnishing water stored within them. Their effectiveness depends on their thickness, hydraulic conductivity, and lateral extent.

Figures 4 and 5 show that the sand and clay layers are both correlatable and variable from point to point as they slope gently toward the southeast. Little information is available regarding the unconsolidated deposits at depths greater than 1,000 ft in the project area. Table 1 summarizes the thickness and character of the geologic units. (Note that the Miocene Calvert Formation, which is shown as a confining layer in figures 4 and 5, is not differentiated from the Nanjemoy Formation in table 1 or figures 20 to 25).

The term "Magothy aquifer," as used in this report, includes those layers of light-gray sand, interbedded with relatively thin layers of clay, that occur in the geologic section above the tough reddish clay layers of the Patapsco Formation and below the rather tough dark-gray to black layers of clayey silt and sand of the Matawan Formation (figs. 4 and 5).

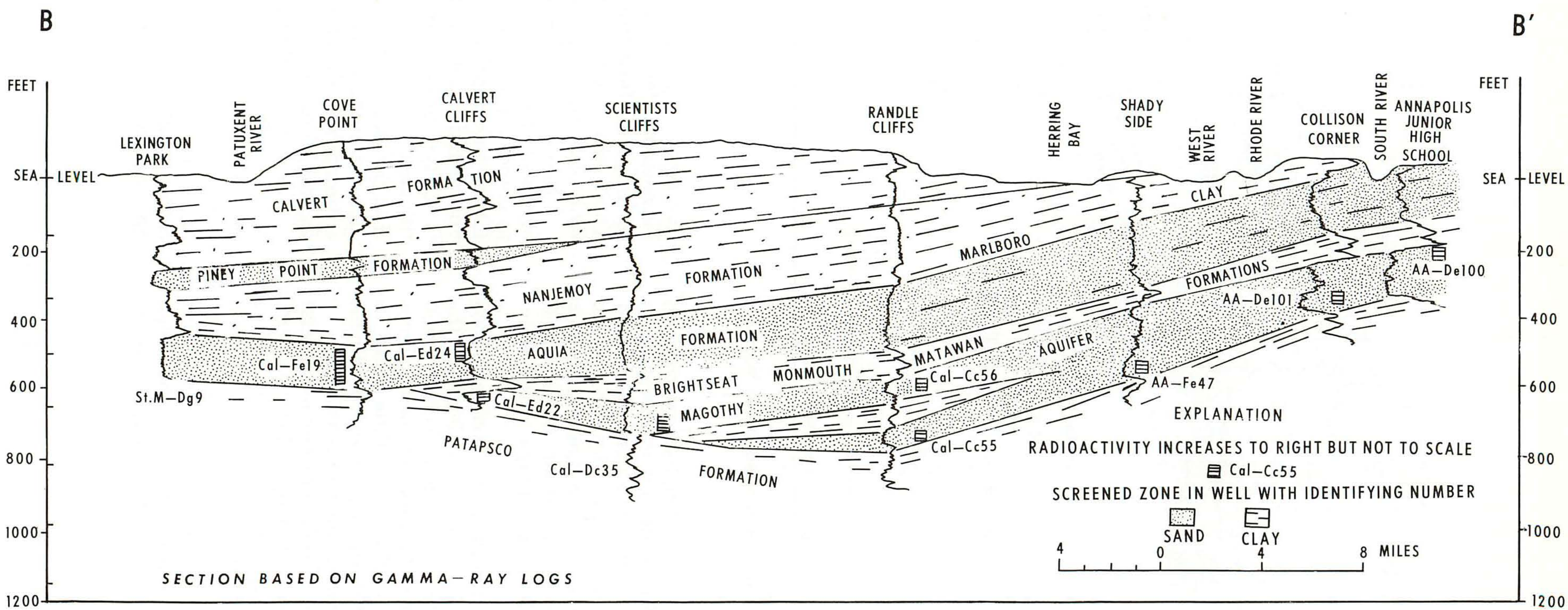

Figure 5.—Geologic section B-B′ across southern Maryland.

Table 1.—Stratigraphy, hydrologic and lithologic characteristics of geologic formations in the southern Maryland area.

System	Series	Group	Formation	Average thickness (feet)	Lithology	Hydrologic character	General character
Quaternary	Holocene and Pleistocene		Unconsolidated deposits	30		Confining bed in most places. Poor aquifer in some places.	Sand, gravel, silt, and clay.
Tertiary	Eooene	Pamunkey	Nanjemoy	80		Confining bed	Sand, with clayey layers, glauconitic.
			Marlboro Clay 1/	30		Confining bed	Clay, plastic, pale-red
	Paleocene		Aquia	100		Aquifer	Glauconitic, greenish to brown sand with indurated or "rock" layers in middle and basal parts.
			Brightseat	40		Confining bed in most places. Poor aquifer in some places.	Sand, silt, and clay, olive gray to black, glauconitic.
Cretaceous	Upper Cretaceous		Monmouth	90		Poor aquifer in places	Sand, silty to fine, with some glauconite.
			Matawan	30		Confining bed	Silt and fine sand, clayey, dark gray to black, glauconitic.
			Magothy	175		Aquifer	Sand, light gray to white, with interbedded thin layers of organic black clay. Contains pyrite and lignite. Lower part composed of interbedded layers of sand and white to light gray clay. Layers of coarse sand and gravel near the base.
		Potomac	Patapsco	500		Confining bed Aquifer Confining bed Aquifer Confining bed Aquifer	Sand layers interbedded with thick clay layers. Color variegated but chiefly hues of red and yellow.
	Lower Cretaceous		Arundel Clay	250 ?		Confining bed	Clay, red brown, and gray, contains some ironstone nodules and plant remains.
			Patuxent	250 ?		Aquifer ? Confining bed Aquifer ?	Sand, gray and yellow, with interbedded clay; kaolinized feldspar and lignite common. Locally clay layers predominate.
Cambrian or Pre-cambrian	Lower Cambrian or Precambrian		Basement Complex	Unknown		Confining bed	Probably gneiss, granite, gabbro, metagabbro, quartz diorite and granitized schist.

1/ The term Marlboro Clay is used in this report in accordance with usage proposed by Glaser (1971). The term does not conform to the stratigraphic nomenclature of the U.S. Geological Survey.

The term "Magothy aquifer," therefore, includes some of the layers of fine to coarse sand and light-gray clay considered to be the Raritan Formation in earlier publications (Clark, 1916; Brookhart, 1949; Otton, 1955), and presently considered to be upper sands of the Patapsco Formation by Glaser (1976).

The Magothy aquifer occurs as a sand layer within the Coastal Plain deposits of Maryland. Most of its outcrop area is in the Anne Arundel County part of the project area. (See fig. 6.) The southwestern boundary of the aquifer lies between La Plata and Waldorf in Charles County. (See fig. 6.)

Maps of the top and the thickness of the Magothy aquifer are presented in figures 6 and 7. Values for the control points used to prepare these maps were picked from drillers' logs, geophysical logs, and studies of cores and cuttings from wells.

The availability of water from the Magothy aquifer varies from site to site because of variation in transmissivity, available drawdown , and recharge. Transmissivity is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is the product of the thickness and hydraulic conductivity of the aquifer. Figure 8, a map of the transmissivity of the Magothy, is based on values from pumping tests made at 30 sites. Higher yielding wells can generally be developed in areas of high transmissivity, such as central Anne Arundel County.

The amount that the hydraulic head of an aquifer can be lowered—the available drawdown—limits the availability of water from the aquifer by (1) limiting the quantity of water that is taken from storage and (2) limiting the hydraulic gradient that can be established between points of withdrawal and sources of recharge.

Figure 9 shows the available drawdown in the artesian part of the aquifer. The values of available drawdown represent the vertical distance, in feet, between the potentiometric surface of the Magothy in 1975 (fig. 10) and the top of the aquifer (fig. 6). (The data shown in fig. 9 are based on computer manipulation of gridded data rather than on actual superposition of figs. 6 and 10.) To some degree, the greater available drawdown in the southern and eastern parts of the project area compensates for lower transmissivity in these areas and permits relatively high yields per well.

Recharge from precipitation on the outcrop area, where water-table conditions exist, occurs at rates limited by the extent of the outcrop areas, rate of precipitation, soil saturation, and the hydraulic conductivity of the aquifer. The fact that streams carry water away from the outcrop area indicates that additional water may be induced to move downgradient within the aquifer under the stress of pumping. This is the basis for the constant-head boundary in the outcrop area, which will be discussed in the description of the model.

Recharge also occurs by leakage from adjacent beds where the aquifer is confined. The quantity of water recharging or discharging by leakage is controlled by the thickness, hydraulic conductivity and lateral extent of the confining layers, and the hydraulic gradient between the adjacent beds and the Magothy aquifer.

Confining beds overlying the Magothy aquifer in the project area are dark-gray to dark-green, laterally extensive silt and clay of the Brightseat-Monmouth-Matawan Formations. They impede the movement of water between the overlying Aquia Formation and the Magothy. Thickness of this confining layer is variable, as shown in cross sections A-A′ and B-B′ in figures 4 and 5. Some laboratory determinations of the vertical hydraulic conductivities of core samples of these overlying confining beds are shown in table 2.

The underlying confining beds consist of tough red clays of the Patapsco Formation throughout much of the area. Too little data are available to map the thickness of these clay layers, but they are known to range from a few feet in some areas to over 100 ft in others. Clay beds in the Patapsco Formation are probably lenticular and do not necessarily have the lateral continuity that would restrict vertical movement to or from deeper aquifers. Core samples were taken from these confining beds at several test sites. Laboratory values obtained for the vertical hydraulic conductivity of these samples are listed in table 2.

The thickness of the confining layer used in the model is shown in figure 11. It is recognized, however, that leakage occurs through both adjacent confining beds.

DESCRIPTION OF THE MAGOTHY AQUIFER MODEL

A digital model is a mathematical representation of a physical flow system. Several generalizations and assumptions concerning the aquifer system must be made in order to conform with the idealized mathematical model. The Magothy aquifer is modeled as being confined throughout its extent, even in areas where it is actually unconfined. The mathematical model is two-dimensional, that is, all flow in the aquifer is assumed to be in the horizontal plane. Within each block in the grid system, the aquifer is assumed to be isotropic and homogeneous. Heterogeneity, however, may exist from block to block.

Flow in the confining bed is assumed to be vertical, but can be either into or out of the aquifer,

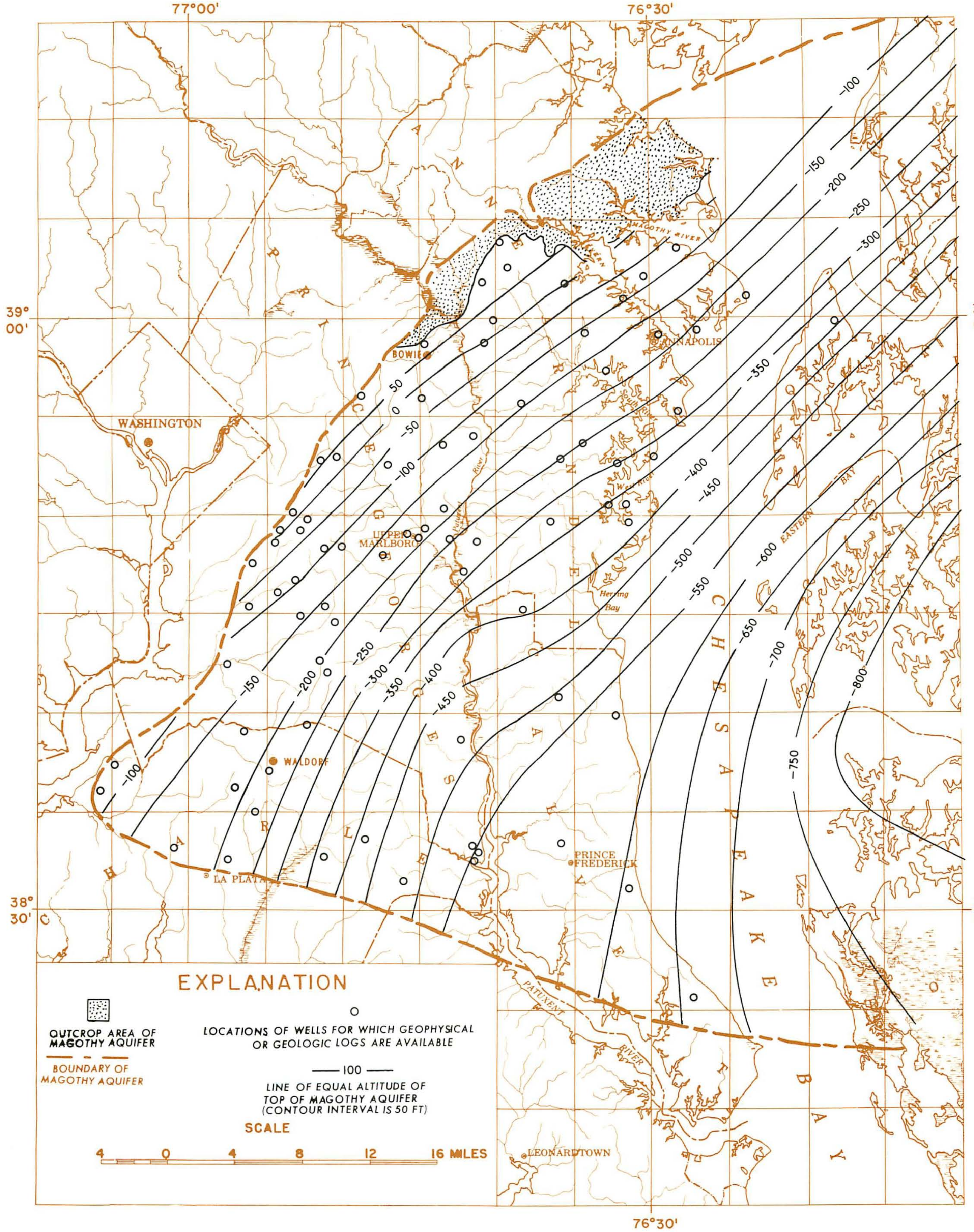

Figure 6.—Outcrop area and altitude of the top of the Magothy aquifer.

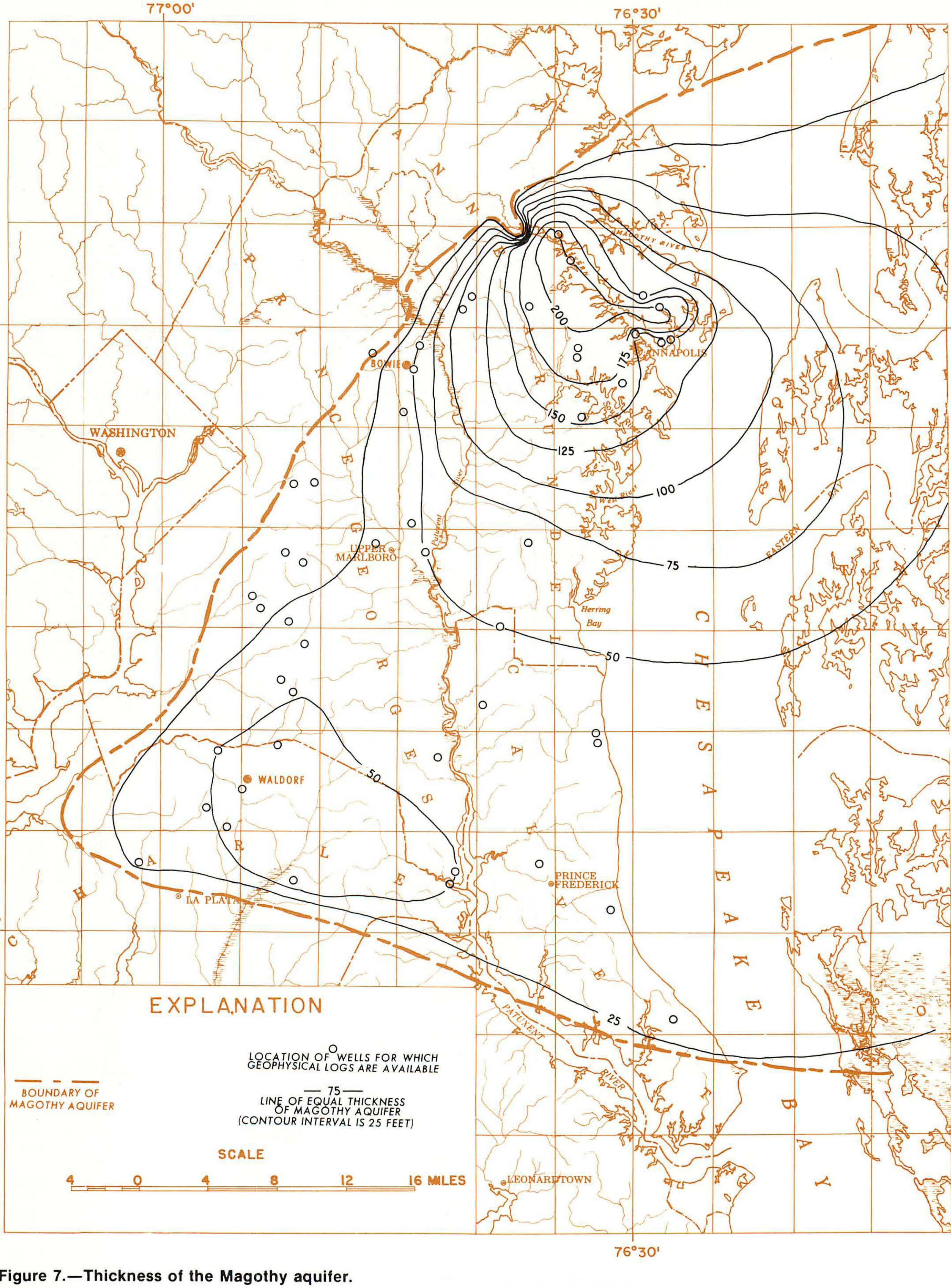

Figure 7.—Thickness of the Magothy aquifer.

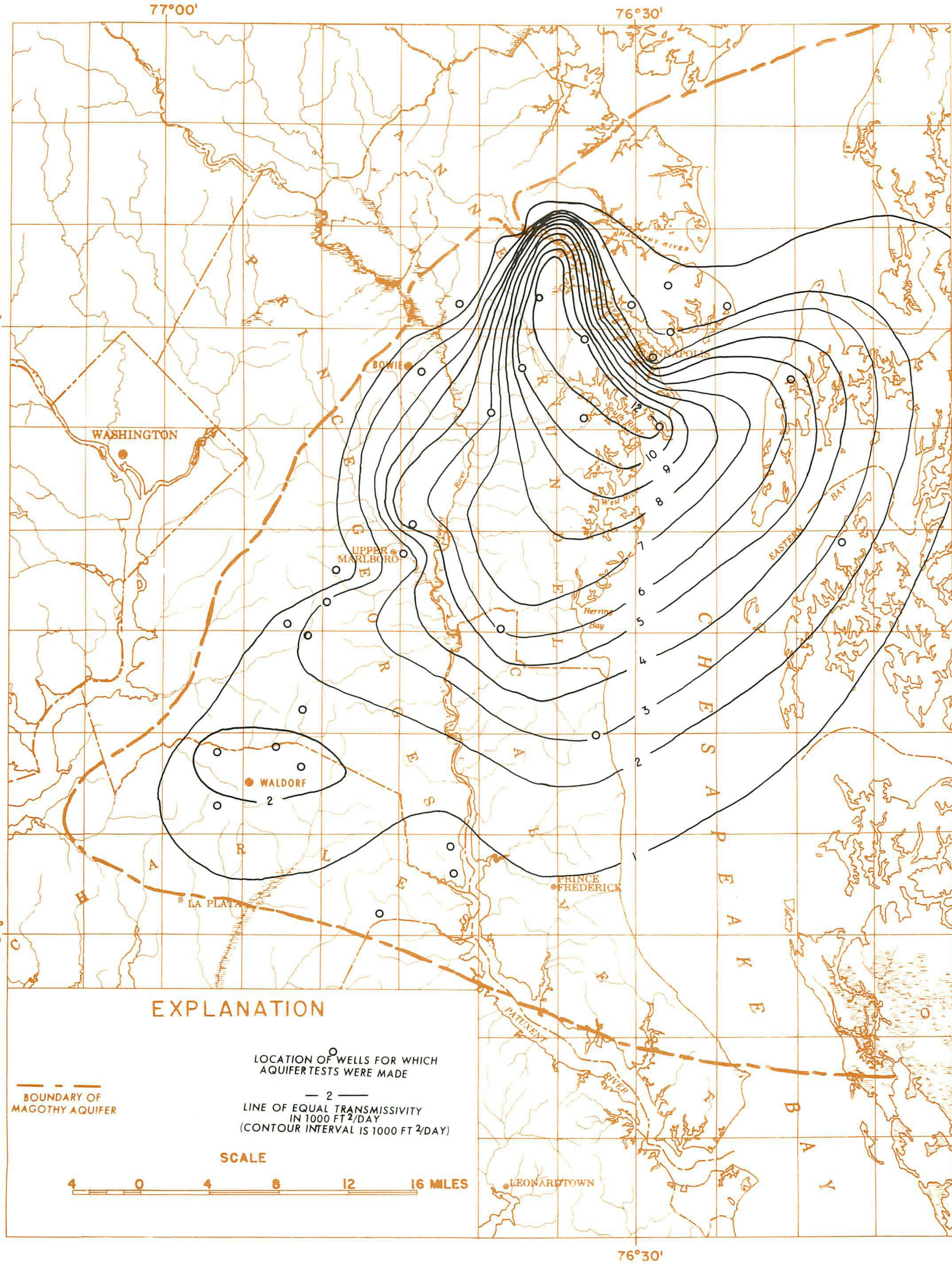

Figure 8.—The transmissivity of the Magothy aquifer.

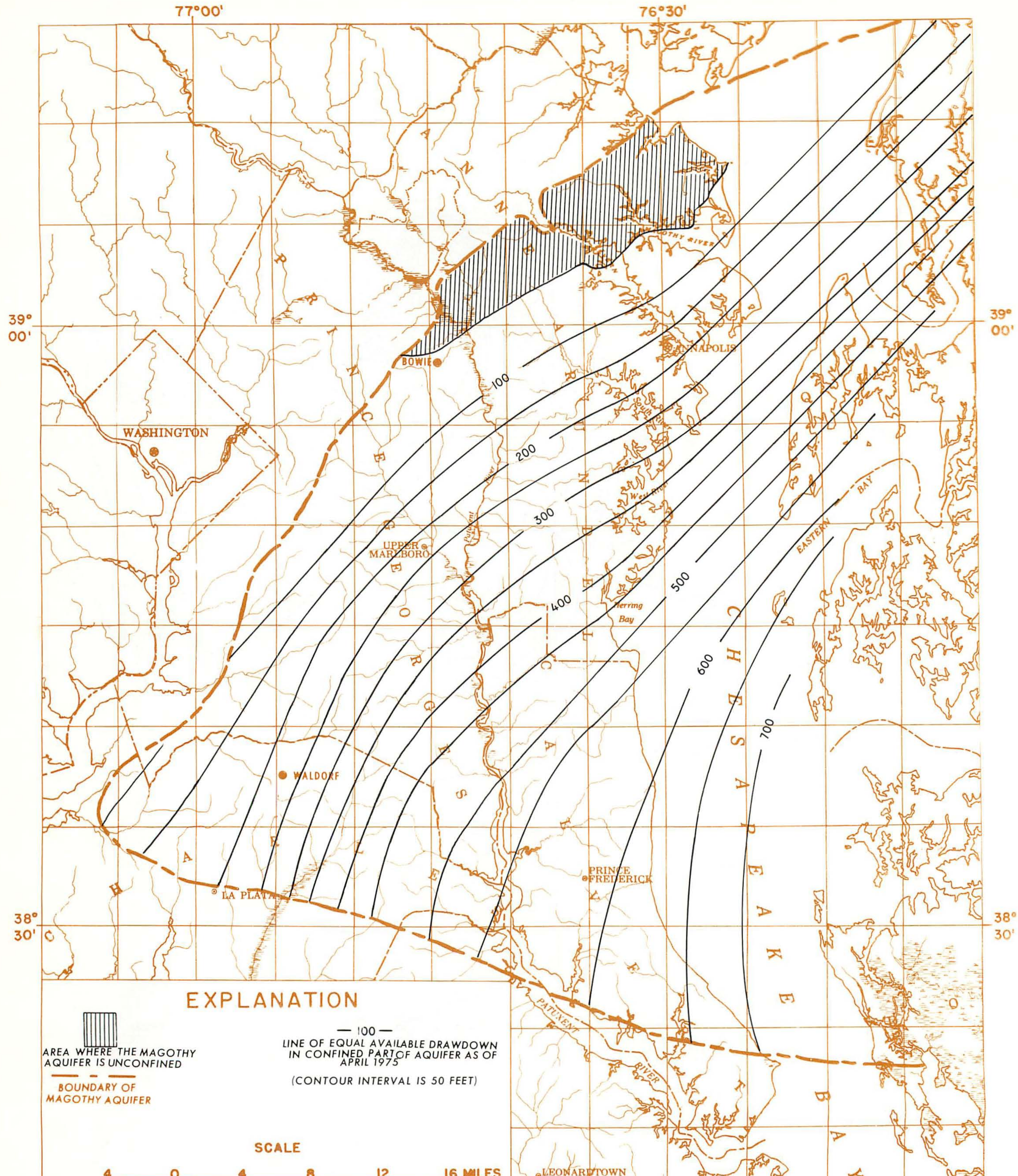

Figure 9.—Available drawdown for the Magothy aquifer in 1975.

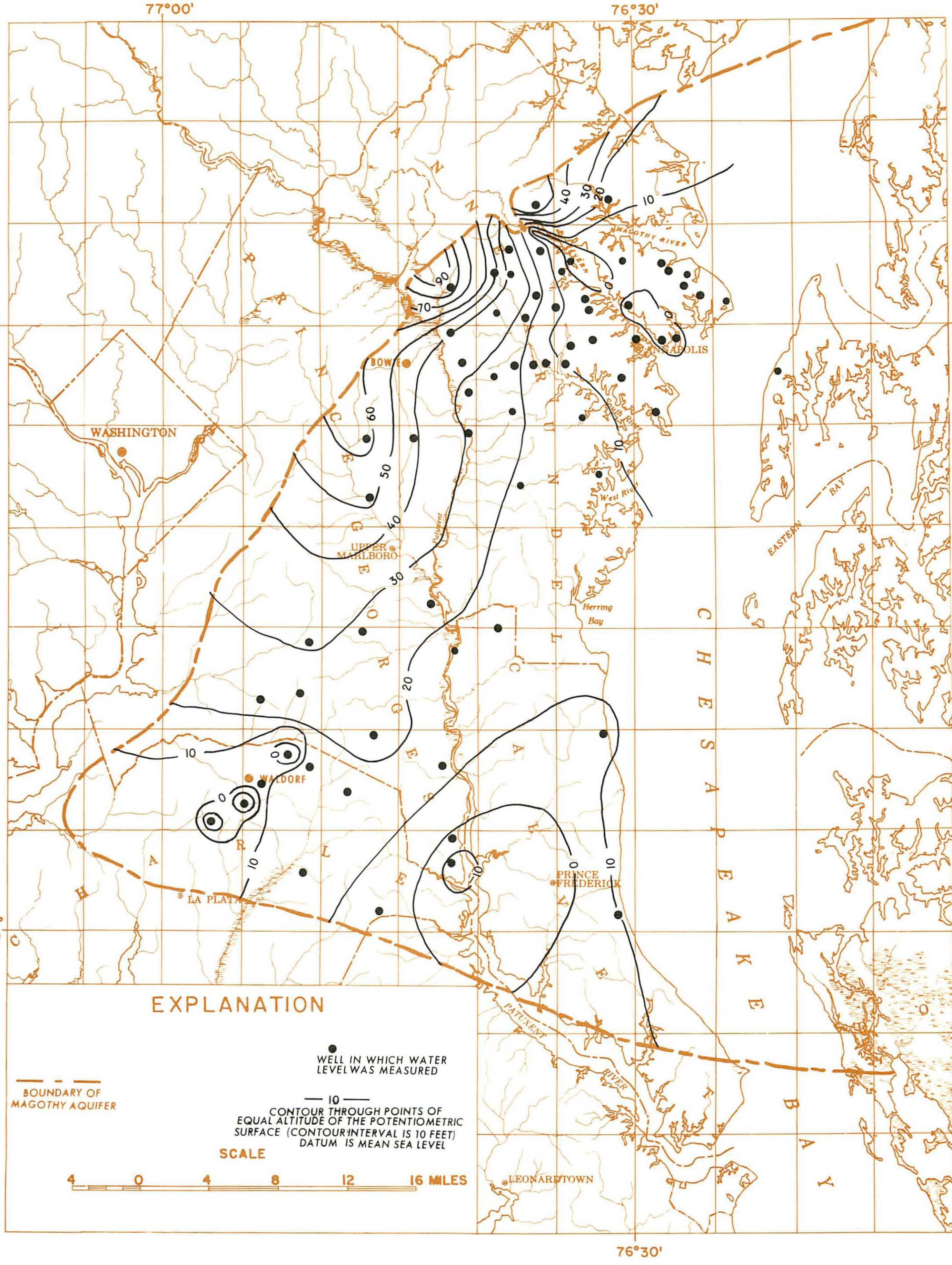

Figure 10.—The potentiometric surface of the Magothy aquifer in April 1975.

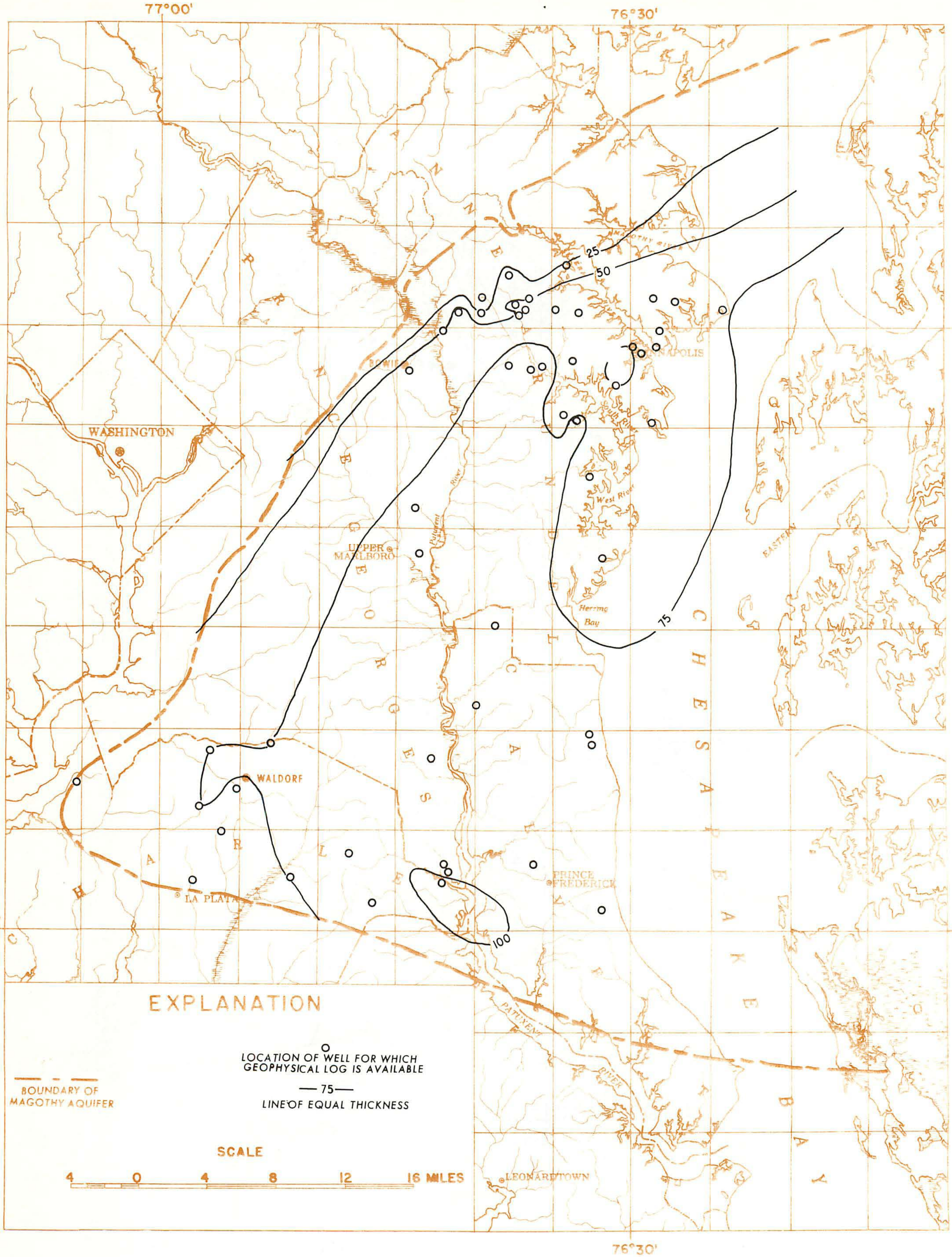

Figure 11.—Thickness of the overlying confining bed used in the model.

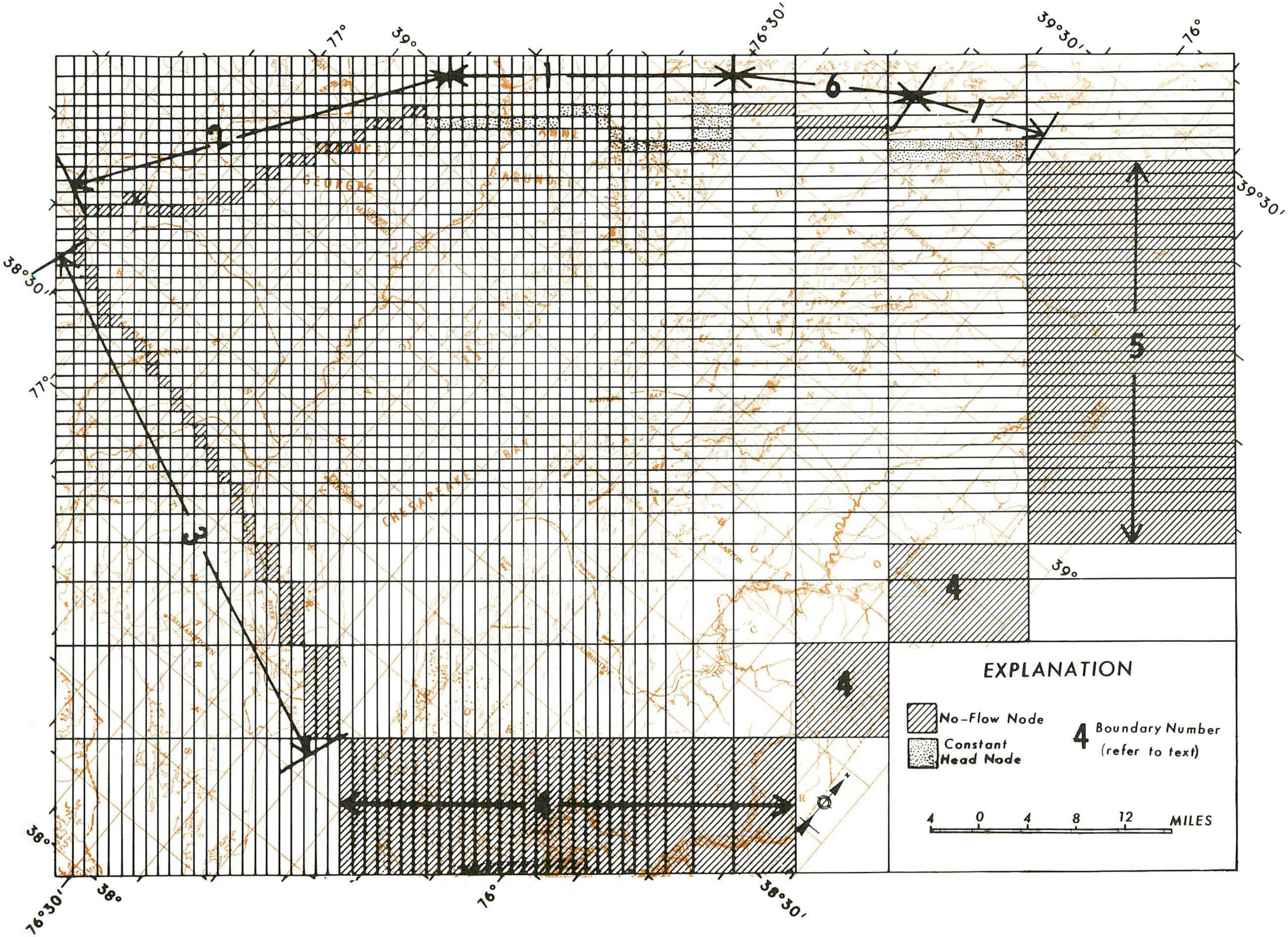

Figure 12.—Area, grid spacing, and boundaries used in the digital model.

Table 2.—Values for vertical hydraulic conductivity (K′) of confining layers determined by laboratory methods.

Well No.	Depth of sample (ft)	Formation	Vertical hydraulic conductivity (K')				Percent clay size or finer (0.001 mm)	Median-grain size Grain size at 50% of volume by weight (mm)	Determinations by
			Values from consolidation tests		Values from constant flow tests				
			cm/s	ft/d	cm/s	ft/d			
AA-									
Cf 101	144	Matawan	1.1×10^{-7}	3.11×10^{-4}	1.5×10^{-6}	4.26×10^{-3}	28.1	0.047	Michael Sorey, USGS
	171	Matawan	2.0×10^{-8}	5.68×10^{-5}	5.0×10^{-8}	1.42×10^{-4}	44.0	.0135	Do.
De 100	214	Matawan	1.7×10^{-7}	4.83×10^{-4}	1.3×10^{-6}	3.68×10^{-3}	18.0	.2	Roger Wolff, USGS
	228	Matawan	-	-	9.0×10^{-9}	2.56×10^{-5}	-	-	Hydrologic Lab. Denver, Colorado
	242	Matawan	4.1×10^{-8}	1.16×10^{-4}	7.3×10^{-8}	2.07×10^{-4}	54.2	.0013	Roger Wolff, USGS
	432	Patapsco	3.8×10^{-9}	1.08×10^{-5}	2.6×10^{-9}	7.36×10^{-6}	63.8	.0019	Do.
De 116	12	Marlboro	-	-	1.2×10^{-8}	3.41×10^{-5}	-	-	Do.
De 104	24	Marlboro	-	-	-	-	60.0	.0028	Do.
De 125	215	Patapsco	(1/)	(1/)	(1/)	(1/)	28.6	.030	Hydrologic Lab. Denver, Colorado
Fe 47	443	Magothy	2.5×10^{-9}	7.2×10^{-6}	(1/)	(1/)	94.6	.001	Do.
CAL-									
Cc 55	1,017	Patapsco	5.2×10^{-10}	1.47×10^{-6}	(1/)	(1/)	58.3	.0023	Do.
PG-									
Hf 40	1,095	Patapsco	2.1×10^{-10}	5.9×10^{-7}	(1/)	(1/)	77.9	.001	Do.
Hf 41	571	Patapsco	9.5×10^{-10}	2.7×10^{-6}	(1/)	(1/)	80.2	.001	Do.

1/ Values have not yet been received.

depending on the hydraulic gradient. Only one confining bed is simulated by the model—the effects of leakage from above and below the Magothy are incorporated into one leakage calculation. The outcrop area of the Magothy was modeled by using a constant head boundary along the inner edge of the outcrop area. Water levels in the source bed—the aquifer "above" the confining bed—are kept constant. This is one of several questionable assumptions, but it is inherent in two-dimensional modeling.

A value of 0.0003 was used for the storage coefficient of the confined part of the Magothy. The value used for specific storage of the confining bed was 0.00005.

To place the hydrogeologic data in a form compatible with the model, a map of the aquifer is overlain by a finite-difference grid that divides the area of interest into small rectangles or blocks. Each block's location is defined in the model by using i, j matrix notation; every block has a node at the center and is assigned aquifer and confining-bed hydraulic properties averaged over the area of the block.

In order to obtain detail in the project area and broad coverage in outlying areas, a uniform grid spacing of 1 mi was used for the project area, and a grid spacing expanded by a ratio of 1:1.5 was used for the areas of the model outside the project area. The total grid consists of 41 rows and 55 columns, or 2,255 blocks, describing an area of 6,224 mi^2.

Boundaries used in the model are based on assumptions developed from information currently available about the geology of the Magothy aquifer. The accuracy of these assumptions is uncertain in the Annapolis area because pumpage from the Magothy has probably been too low for drawdowns to include identifiable effects of the boundaries.

Boundaries used in the model are of two types: Constant head (infinite storage) and zero flow (transmissivity equal to zero). Figure 12 shows where each of these boundary types was used in the model to represent present concepts of the real boundary conditions.

Boundary 1 simulates the outcrop areas of the Magothy aquifer, where water-table conditions exist. It is assumed that recharge is sufficient to keep head values constant in these areas.

Boundary 2 represents the line along which the Magothy aquifer is terminated in the updip direction as a result of a thinning of water-bearing sands and overlap by younger fine-grained sediments. Boundary 3 represents the line along which the Magothy sands pinch out at the southwest extremity of the formation (figs. 4 and 5). To simulate boundaries 2 and 3 in the model, values of transmissivity were set equal to zero at those nodes in which the aquifer is absent, thus preventing any flow across the boundary.

Boundaries 4 and 5 are artificial boundaries located far enough away from the project area to have little effect on drawdowns. These distant boundaries were treated as zero-flow boundaries.

Boundary 6 represents the updip termination of the Magothy aquifer under the Chesapeake Bay. It is approximated by a zero-flow boundary rather than a constant-head boundary because the fine-grained bay-bottom sediments retard the vertical movement of water into the aquifer in this area.

Because the object of the study was to evaluate the response of water levels in the Magothy aquifer to increased pumping rates, the model was designed to calculate head changes (drawdown) resulting from changes in pumpage. To do this, the initial water levels in the aquifer and the source bed were defined as being identical flat surfaces. The aquifer was then in equilibrium with all boundaries and responded only to changes in pumping rates. Drawdowns computed by the model in this manner can be converted to head by subtracting the drawdown from the real aquifer head that existed at the beginning of the simulation.

The computer program used to solve the finite-difference equations was written by Trescott (1973) and it employs the iterative-alternating direction implicit procedure (IADIP) as its solution scheme. In brief, this scheme first solves simultaneously for the hydraulic head along each row while using adjacent row values from the previous iteration; then the hydraulic head is solved simultaneously along each column while adjacent column values are obtained from the first half of the iteration. For each time step, this procedure is repeated until the difference in computed head at all nodes between successive iterations is less than a predetermined error criterion. Details of this method may be found in Remson and others (1971) and Bredehoeft and Pinder (1970).

Details of the calibration and prediction phases of the modeling activity are discussed in detail in subsequent sections of the report.

Calibration

Although the model was developed to predict future drawdowns, predictions were not made until the model was able to reproduce the past history of the aquifer. This process is called "calibration" and is shown graphically on figure 13. Figure 14 shows the location of the well fields tapping the Magothy, and table 3 shows the pumping history of the well fields. The calibration period was 1950-75. This period was broken down into five pumping periods, and the model was stressed with pumping at an

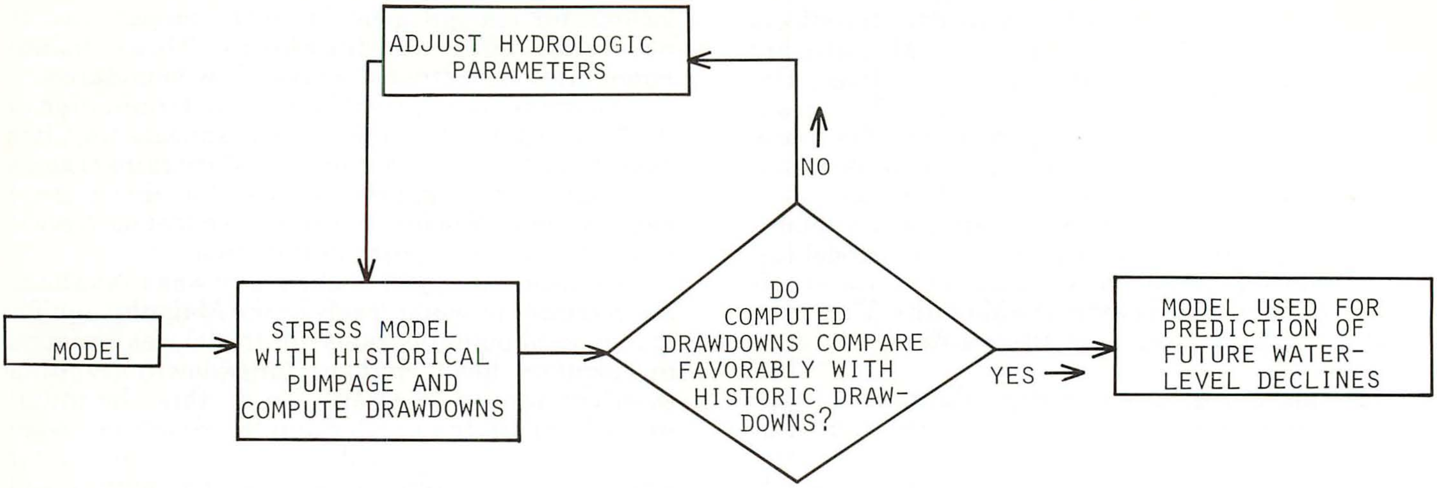

Figure 13.—The procedure used to calibrate the digital model.

average rate over a 5-year period. Drawdowns computed by the model were, therefore, changes in head from 1950 to 1975. These drawdowns were then compared with actual drawdown that had been observed at specific observation wells or other calibration points. (See table 4.) When the comparison of the computed and actual drawdown was poor, adjustments were made in the model and new drawdown values were computed. Most adjustments were made in the vertical hydraulic conductivity of the confining layer because there was less confidence in data for that parameter than in the others. Adjustment of the vertical conductivity compensates for the errors in other hydrologic parameters. The adjusting process was continued until there was an acceptable comparison between computed and real drawdowns at all available calibration points. The "goodness of fit" criteria was to match observed drawdown values within natural fluctuations of the water levels, which may vary as much as 5 ft annually. The values used for vertical conductivity of the confining layer ranged from $2x10^{-8}$ to $2x10^{-10}$ ft/s.

Ideally, there would be enough calibration points to develop a map showing historical drawdown in each finite-difference block. The model could then be adjusted until it computed a similar drawdown map when stressed with the same pumpage. Most of the calibration points, however, are located along a line extending westward from Annapolis and then southwestward toward La Plata (fig. 3). A large degree of confidence in the model is localized along thisline. A reasonable degree of confidence in the model may be extended to a considerably larger percentage of the project area because of the calibration point in southeastern Prince Georges County. The reliable data for that site provide a much broader spread to the calibration data and permit a higher degree of confidence.

Confidence in the calibration for the Annapolis area is tempered by the realization that pumping rates to date have been barely high enough for the effects of boundaries to be identified as factors affecting drawdowns in observation wells. Thus, the boundaries may be virtually uncalibrated. Recalibration after significant but intermediate increases in pumping rates would provide a stronger basis for predicting water-level declines at even higher pumping rates in the Annapolis area.

Two of the points used in the calibration of this model, wells PG-De 21 and PG-Fd 40, are especially valuable because they have been measured several times a year since 1958 and 1955, respectively (See fig. 15). Computed values of drawdown reflect the declining trends of water levels shown in both hydrographs. The lack of an exact fit probably reflects some inherent errors in the model and the fact that the computed drawdowns based on 5-year average pumping rates must be expected to deviate somewhat from drawdowns caused by constantly fluctuating pumping rates.

Predictions

The calibrated model was used to provide computed estimates of drawdown that would be

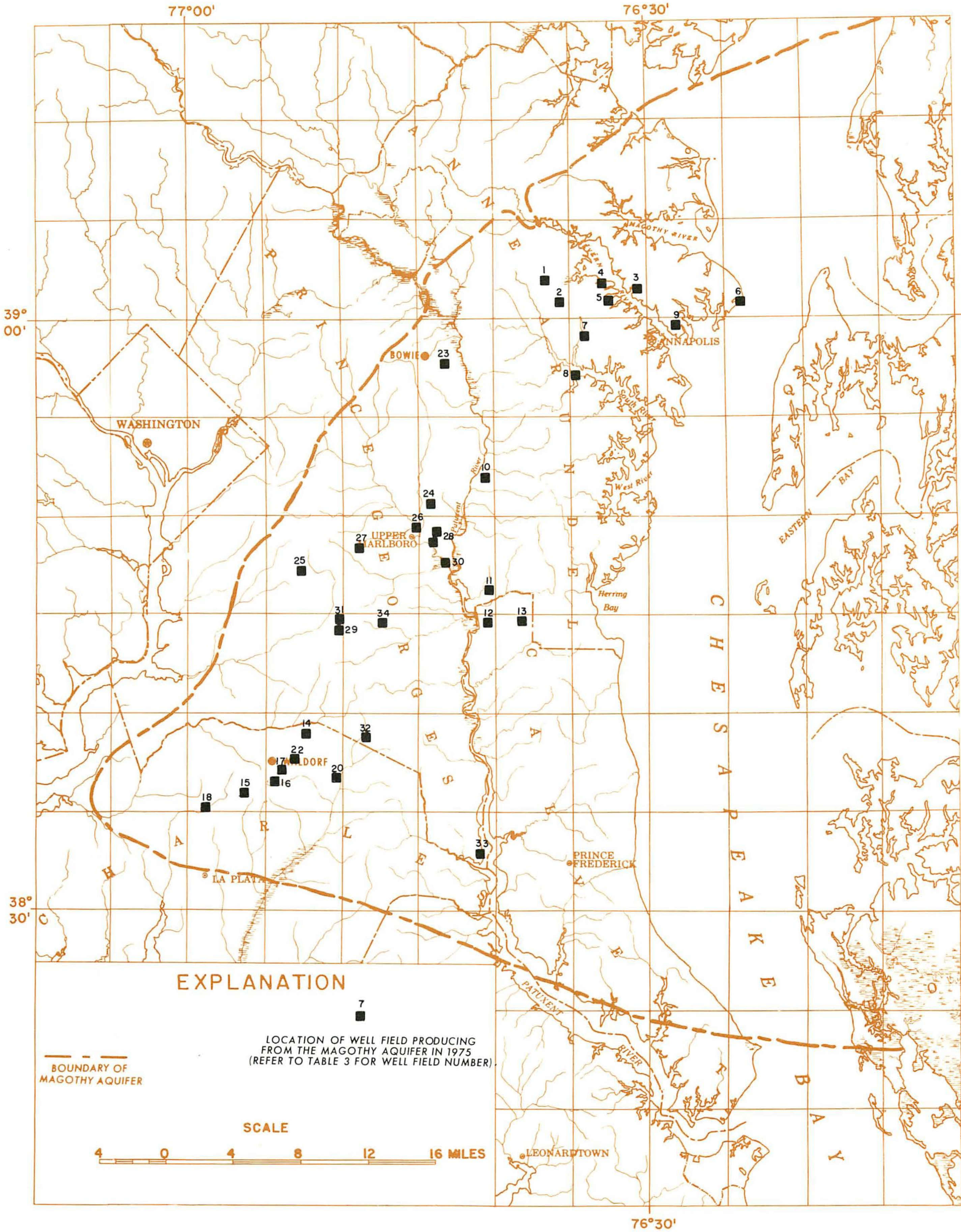

Figure 14.—Well fields with appropriation permits for more than 10,000 gal/d from the Magothy aquifer, 1975.

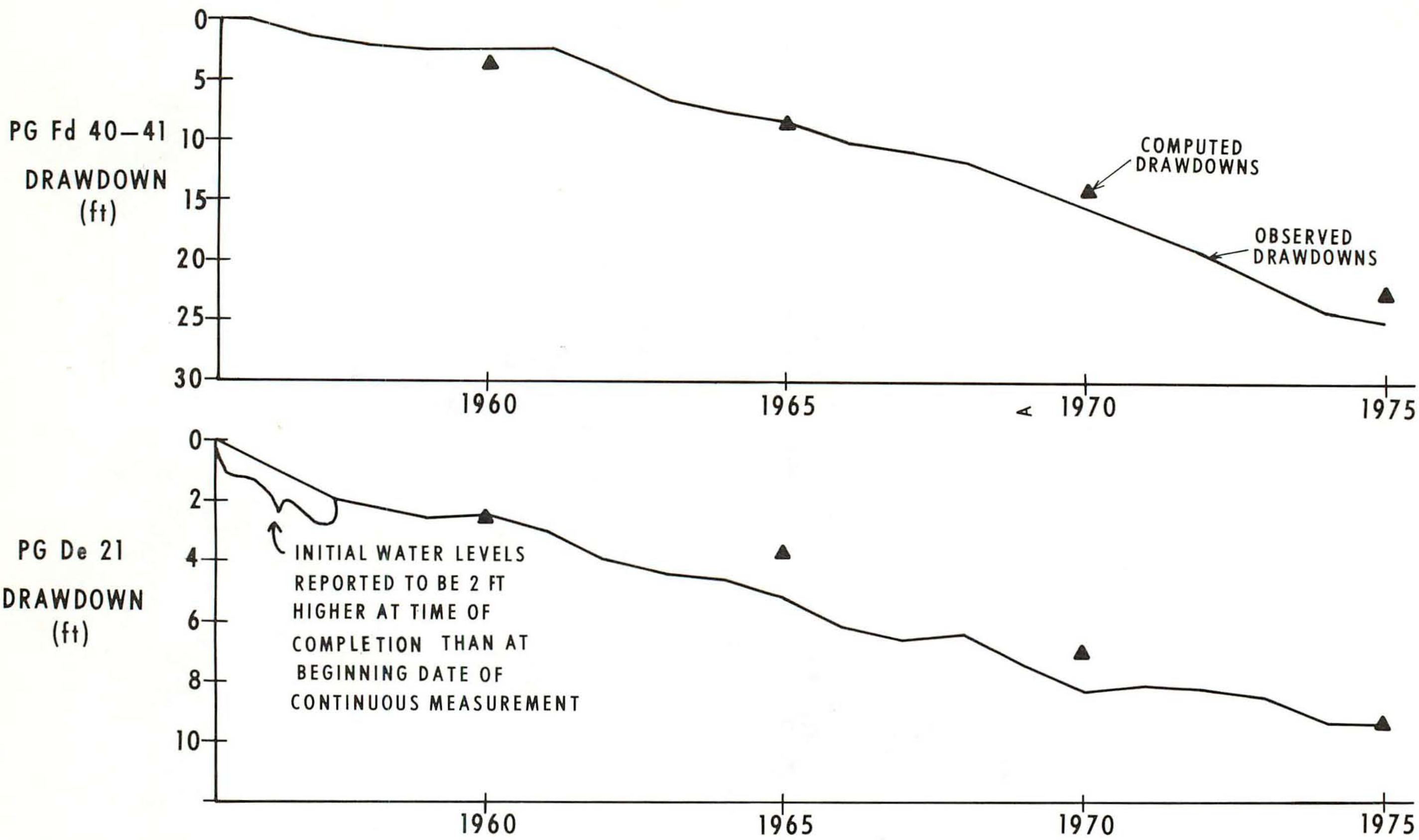

Figure 15.—Historical and computed water-level declines in two observation wells.

expected as the result of various development schemes. For each scheme, steady-state drawdowns were computed and compared with the actual available drawdown shown in figure 9. Five significant tests made by this procedure are described below. The model, of course, may be used to evaluate other well configurations, pumping periods, and pumping rates and, as shown by an example in this report, may be used to isolate the pumping effect of a single well field.

The schemes tested by the model and described below were designed to estimate the role the Magothy will be able to play as a source of water supply for various parts of the project area in the future. The tests are summarized in table 5. Projected population data furnished by planning agencies of the individual counties were used to estimate future water demands by assuming a water-use value of 100 gal/d per person. Table 6 shows the predicted population and water requirements of the subareas, and figure 16 shows the location of the subareas.

Test 1 was made to see if the future water requirements of individual subareas could be obtained from wells developed in the Magothy aquifer within each subarea. It showed that pumping hypothetical wells located at the centers of the subareas, at rates of predicted use, would cause only moderate drawdown in Calvert and much of Anne Arundel Counties, but would cause excessive drawdown in most subareas of Charles and Prince Georges Counties. Not only would water levels be drawn down below the top of the aquifer, but parts of the aquifer would be completely dewatered. In showing areas with excessive drawdown, the model indicated that the Magothy aquifer can supply only a part of the future water needs of some subareas.

Test 2 was made to see if the future water requirements of individual counties could be obtained from wells developed in the Magothy, if well sites were selected on the basis of the most favorable hydrologic factors within each county. The test showed

Table 3.—Well fields with appropriation permits for more than 10,000 gal/d, and pumpage in millions of gallons per day from the Magothy aquifer, 1950-75.

Well No.	Name of well field	1950-1954	1955-1959	1960-1964	1965-1969	1970-1974	1975
	Anne Arundel County						
1	Crownsville State Hospital	0.335	0.333	0.375	0.396	0.382	0.382
2	Summerhill Trailer Park	-	-	.009	.009	.009	.010
3	Pines-On-Severn	.018	.030	.029	.070	.180	.187
4	Sherwood Forest	-	-	-	.034	.048	.042
5	Epping Forest	-	-	.029	.029	.036	.032
6	Sandy Point State Park	.008	.009	.009	.009	.009	.009
7	City of Annapolis	2.231	2.231	2.691	2.839	2.792	3.031
8	Sylvan Shores	-	.043	.043	.043	.045	.034
9	USN Ship R&D Center	.178	.191	.193	.185	.174	.159
10	Maryland Manor	-	-	-	-	.053	.054
11	J. W. Crosby	-	-	-	-	.039	.039
	Calvert County						
12	Shores of Calvert	-	-	-	-	.015	.039
13	Cavalier Water Association	-	-	-	-	.042	.042
	Charles County						
14	Charles Co. Sanitary Dist. - (North well)	-	-	.083	.150	.227	.375
15	do. (South well)	-	-	.077	.207	.238	.275
16	do. (St. Charles City well)	-	-	-	-	.238	.256
17	Star Dust Motel	-	-	.019	.019	.019	.019
18	Oak Hill Estates	-	-	-	.012	.012	.012
20	Bellwood Water Association	-	-	-	.017	.017	.017
22	Charles Co. Sand and Gravel	-	-	.020	.020	.020	.020
	Prince Georges County						
23	City of Bowie	-	-	.163	.180	.282	.164
24	Marlboro Meadows	-	-	-	.131	.131	.131
25	Lone Star Industries	-	-	.017	.017	.017	.017
26	NE Marlboro Water System	.013	.013	.013	.013	.010	.012
27	W. Sauerwein	.011	.011	.011	.011	.011	.011
28	Safeway Stores & United Leaf Tobacco Corp.	-	.001	.011	.011	.012	.012
29	Boys Village of Maryland	.020	.020	.020	.020	.020	.020
30	Upper Marlboro Sew. Trt. Plt.	-	-	-	.104	.104	.104
31	Cheltenham-USN	.065	.065	.065	.065	.065	.065
32	Cedarville Trailer Park	-	-	.058	.058	.058	.058
33	Chalk Point-PEPCO	-	-	.240	.342	.487	.749
34	Brandywine Country Club	-	-	-	-	.070	.070

Table 4.—Computed drawdowns compared with declines in water level measured in observation wells.

Symbol used on map (fig. 3)	Location	USGS number	Water level 1975 (ft)	Earliest water level and date (ft)	Measured drawdown (ft)	Computed drawdown (ft)
A	Sandy Point State Park	AA-Cg8	+2.38 (04-04-75)	+7.1 (05-14-51)	4.8	7
B	USN Radio Station, Annapolis	AA-Df20	+2.44 (04-14-75)	+11.46 (01-12-51)	9	14
C	USN Academy, Annapolis	AA-Df9, 79	+2.87 (04-14-75)	+16.79 (02-20-34)	14	19
D	City of Annapolis	AA-De1	-10.5 (04-04-75) -12.5 (03-20-75) -17.5 (03-19-75)	+20.81 (06-21-51)	30-37	32
E	City of Bowie	PG-Cf33	+54.35 (11-23-76)	+60.30 (07-26-61)	5.9	7
F	Md. Tobacco Experimental Farm, Upper Marlboro	PG-De21	+50.63 (04-11-75)	+57.42 (05-29-58)	7-10	13
G	Prince Georges County Courthouse, Upper Marlboro	PG-Ee30	-	+53 (1893)	-	13
H	Boys Village, Cheltenham	PG-Fd39	+30.18 (04-05-75)	+48.1 (05-07-49)	18	20
I	Gwynn Park	PG-Fd24	+27.9 (04-07-76)	+55.0 (05-05-49)	27.1	25
J	Brandywine Elem. School	PG-Fd32	+24.7 (04 - 75)	+50 (11-30-50)	25	26
K	Brandywine Estates	PG-Fd40, 41	+25.71 (04-05-75)	+54 (02-06-61)	28	30
M	Chalk Point	PG-Hf23, 41	-8.77 (04-11-75)	+28 (05-16-62)	37	39
N	So. Md. Novelty, Waldorf	CH-Bf128	-4.28 (05-12-76)	+45.79 (09-26-62)	50	50
O	Malcomb School	CH-Bg10	+23.19 (05-06-74)	1/ +49 (05-03-55)	26	23
	Waldorf Elem. School	CH-Bf98	+2.4 (07-14-75)	1/ +45 (02-28-55)	42.6	42
Q	Martha Washington Motel	CH-Bf101	-3 (11-19-76)	1/ +38 (03-27-53)	41	37
R	NIKE Site	CH-Bf96	+3 (07-27-76)	1/ +50 (08-29-56)	47	33

1/ Reported by driller.

Table 5.—Summary of model predictions to determine the availability of water from the Magothy aquifer in southern Maryland.*

Test No.	Query	Anne Arundel County	Calvert County	Charles County	Prince Georges County	Total
1	Could wells developed in the center of the subareas produce the amount of water needed in that subarea in the year 2000? (See table 6)	YES	YES	NO	NO	--
2	Could wells developed in the best hydrogeologic areas of each county produce the amount of water needed in that county in the year 2000? (See table 6)	YES	YES	NO	NO	--
3	What pumping rate could be maintained from Charles and Prince Georges Counties if wells in Anne Arundel and Calvert Counties were pumped at the rate predicted for the year 2000?	25	4.2	4.5	7.8	41.6
4	What pumping rates could be maintained if pumping rates in Anne Arundel and Calvert Counties were increased in an attempt to supply the deficits of Prince Georges and Charles Counties?	37.9	19.4	4.5	7.8	69.6
5	How much drawdown would be caused by pumping 0.83 Mgal/d from the Magothy at Chalk Point?		(See figure 20)			

1/ The hazard of saltwater contamination was not considered by these tests.

*All values are in millions of gallons per day

Table 6.—Predicted population and water-supply requirements for the part of southern Maryland underlain by the Magothy aquifer.

Planning subareas 1/	1980		1990		2000	
	Population	Water demand 2/ (Mgal/d)	Population	Water demand 2/ (Mgal/d)	Population	Water demand 2/ (Mgal/d)
Anne Arundel Co. 3/	-	11.03	-	17.44	-	24.97
Severna Park/Arnold	14,700	1.47	25,100	2.51	36,700	3.67
Whitehall	4,900	.49	8,500	.85	11,900	1.19
North Basin	43,600	4.36	51,600	5.16	55,400	5.54
Bay Ridge	25,100	2.51	42,800	4.28	61,200	6.12
SE3	7,900	.79	20,900	2.09	39,400	3.94
SE1	12,000	1.20	19,300	1.93	30,600	3.06
SE2	1,200	.12	2,600	.26	4,600	.46
SE4	1,400	.14	3,600	.36	9,900	.99
Calvert County 4/	-	2.29	-	3.18	-	4.22
Planning Area A	3,100	.31	4,800	.48	7,350	.74
Planning Area B	8,700	.87	11,600	1.16	15,700	1.57
Planning Area C	12,000	1.20	17,100	1.71	23,000	2.30
Charles County 5/	-	4.01	-	7.80	-	11.84
Section 4	6,700	.67	14,700	1.47	35,200	3.52
Section 7	2,200	.22	11,900	1.19	20,500	2.05
Section 8	20,700	2.07	33,500	3.35	39,800	3.98
Section 10	8,100	.81	13,700	1.37	16,500	1.65
Section 12	2,400	.24	4,200	.42	6,400	.64
Prince Georges County 6/	-	25.25	-	39.06	-	48.36
Greater Western	104,026	10.40	184,258	18.42	230,196	23.02
Greater Piscataway	106,600	10.66	138,600	13.86	174,000	17.40
Belair I	24,400	2.44	24,400	2.44	24,400	2.44
Belair II	3,600	.36	3,600	.36	3,600	.36
Patuxent II	4,600	.46	22,300	2.23	26,300	2.63
Mattawoman	3,800	.38	10,500	1.05	15,500	1.55
Southeastern	5,300	.53	7,000	.70	9,600	.96
Total Project Area	-	42.58	-	67.48	-	89.39

1/ Population values for some subareas that are only partially underlain by the Magothy aquifer have been adjusted accordingly. (See figure 17 for locations of these subareas.)
2/ Water requirements were obtained by multiplying population figures by 100 gallons.
3/ Population data modified from Greiner Environmental Systems, Inc., 1973.
4/ Population data modified from Calvert County Planning Office, 1975.
5/ Population data modified from Johnson and Williams, 1969.
6/ Population data modified from Maryland National Capital Parks and Planning Commission, 1976.

that the required pumping rates for Prince Georges and Charles Counties would cause excessive drawdown, whereas pumping rates for Anne Arundel and Calvert Counties would not utilize all available drawdown. The need to estimate the quantity of water that would be available from Charles and Prince Georges Counties then became apparent.

Test 3 was made to estimate the quantity of water available from the Magothy in Charles and Prince Georges Counties. It consisted of a series of trial runs in which (1) pumping rates of wells in Charles and Prince Georges Counties were adjusted downward from the predicted rates of demand until drawdowns were no longer excessive, and (2) pumping rates in Anne Arundel and Calvert Counties were held at rates required to satisfy their predicted demands. Under these conditions, it was found that pumpage from the Magothy in Prince Georges County would be limited to 7.8 Mgal/d and that from Charles County to 4.5 Mgal/d. Figure 17 shows the drawdowns that would be expected at these pumping rates.

Test 4 was made to estimate the quantity of water available from the Magothy aquifer in the total project area. It consisted of a series of test runs in which pumping rates in Anne Arundel and Calvert Counties were increased beyond predicted demands in order to utilize additional available drawdown. Pumping rates and well-field patterns determined by test 3 for wells in Charles and Prince Georges Counties were used in test 4. The resulting drawdowns shown in figure 18 indicate that relatively small areas of excessive drawdown would be developed in the updip parts of the aquifer by pumping a total of 69.6 Mgal/d from the Magothy aquifer.

Drawdown in Anne Arundel County shown in figure 18 is similar to that predicted by an earlier model (Mack, 1974, fig. 19). However, the pumping rate used for the county (37.9 Mgal/d) was considerably lower than that used in the earlier model (58.4 Mgal/d). Differences in the predictions of quantities of water available result from a modification of boundary conditions and the inclusion of other pumping centers in the present model.

Test 5 demonstrated that the model has the capability of isolating the pumping effect of a specific well field. This feature of the model was used to indicate the probable effect that pumping from the Magothy aquifer at Chalk Point will have on water levels in southern Maryland. Figure 19 shows that hypothetical wells pumped at a rate of 0.83 Mgal/d* until the year 2000 would create a cone of depression with drawdowns of about 50 ft at a distance of 1 mile, but less than 5 ft at 10 miles.

SUMMARY AND CONCLUSIONS

The Magothy aquifer, one of several water-bearing formations in southern Maryland, is capable of supplying many millions of gallons of water per day to wells in optimum locations. Parts of the aquifer have high transmissivities in areas of greatest available drawdown and, thus, have the best potential for high yields. The model of the aquifer developed during this study provides a means for estimating the drawdown that would be caused by withdrawing water from hypothetical well fields.

Stressing the model at pumping rates required to satisfy the projected demand expected by the year 2000 (90 Mgal/d) indicated that drawdowns would be excessive in parts of the area. Transmissivities and available drawdowns are adequate in the Calvert and Anne Arundel County areas to supply the water requirements of those parts of the counties underlain by the Magothy. Well fields yielding more than a total of 4.5 Mgal/d from the Magothy in northern Charles County and 7.8 Mgal/d in Prince Georges County (areas of low transmissivity and proximity to no-flow boundaries) would cause excessive drawdown. To supply the predicted water needs of the year 2000, additional water would have to be obtained from deeper aquifers or imported from other areas.

One computer run with the model (test 4, fig. 18) suggested that pumping at a total of about 70 Mgal/d from wells located in the best hydrogeological areas of each county would create cones of depression in Charles, Calvert, and Anne Arundel Counties of about 250, 275, and 225 ft, respectively.

The problem of possible contamination of the aquifer by saltwater from Chesapeake Bay, although not a factor of great concern to most of the project area, needs to be considered and evaluated before much additional development of the aquifer is allowed in the vicinity of the Severn, Magothy, and South Rivers. The reader is referred to an earlier report (Mack, 1974) for a discussion of the present understanding of the problem.

The observation-well network and potentiometric maps prepared in this study will provide a better distribution of calibration points for future versions of the model. Using these data as a reference base for the comparison of future computed and observed drawdowns, it should be possible to develop higher degrees of confidence in the model or updated versions of it.

(Continued on p. 32)

*The Potomac Electric Power Company has received an appropriation permit from the Maryland Water Resources Administration for the use of 0.83 Mgal/d from the Magothy aquifer at Chalk Point in Prince George's County.

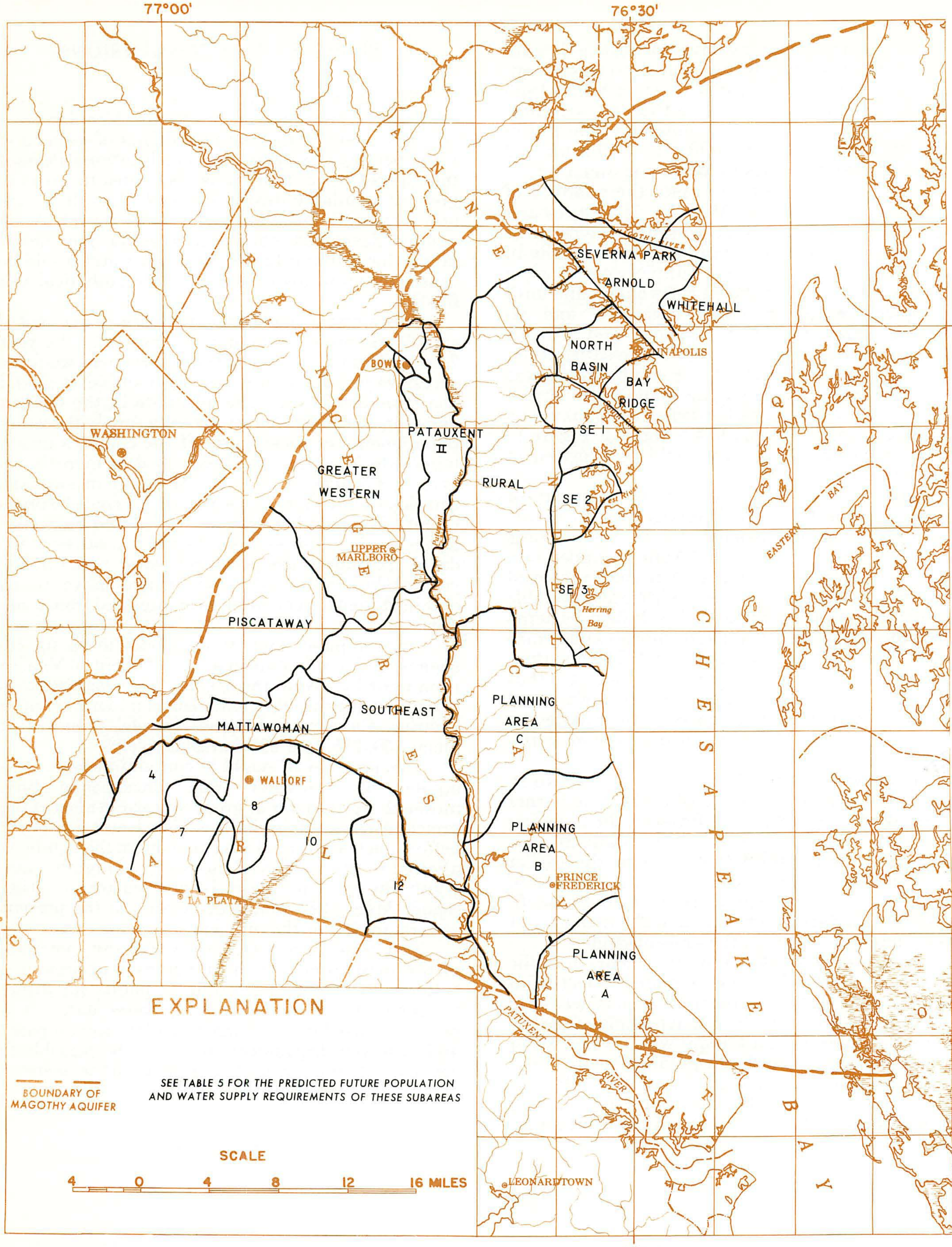

Figure 16.—Subareas of counties used for distributing projected population growth and water demands.

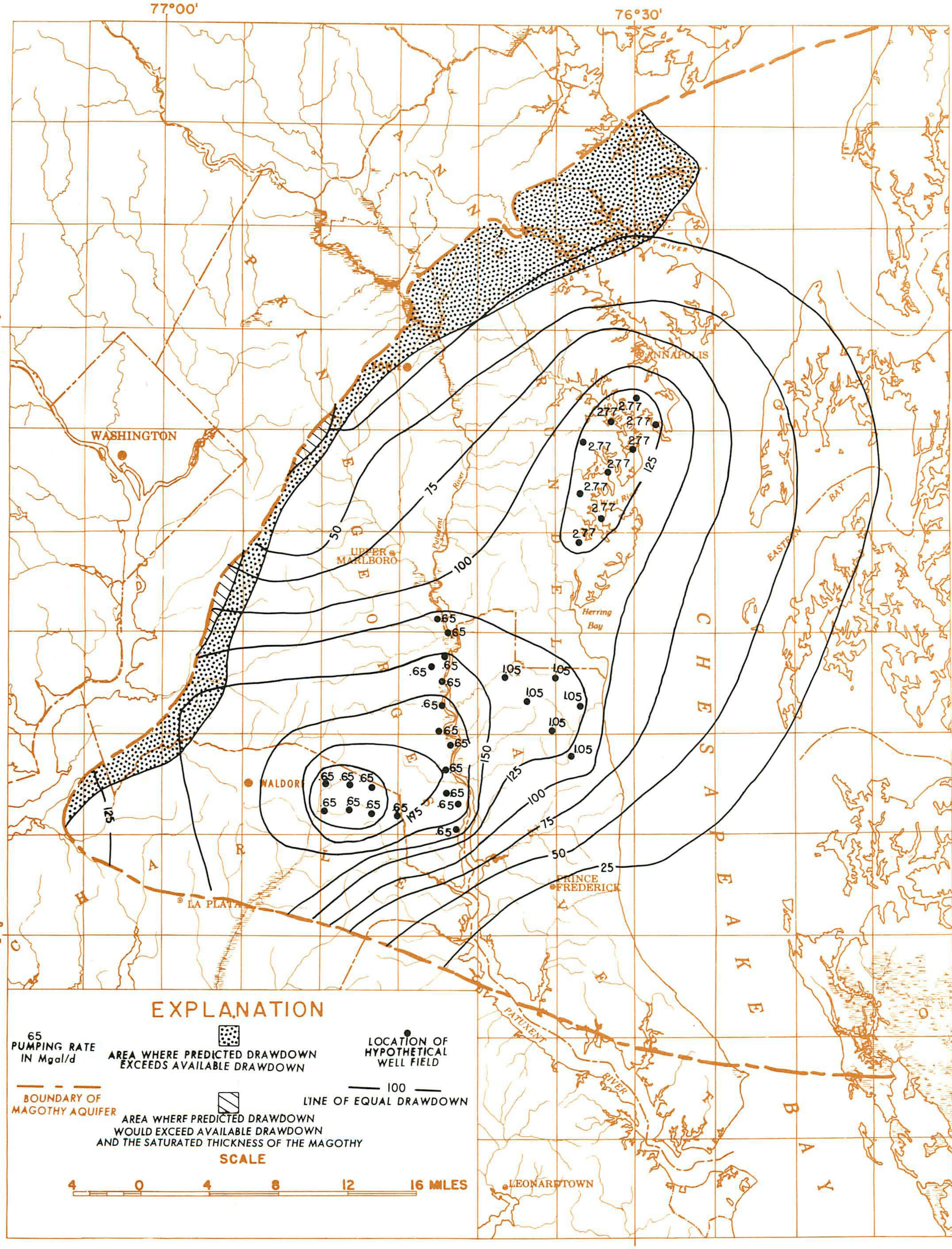

Figure 17.—Predicted drawdowns resulting from pumping a total of 41.6 Mgal/d from the best hydrogeologic areas in each county. (Test 3)

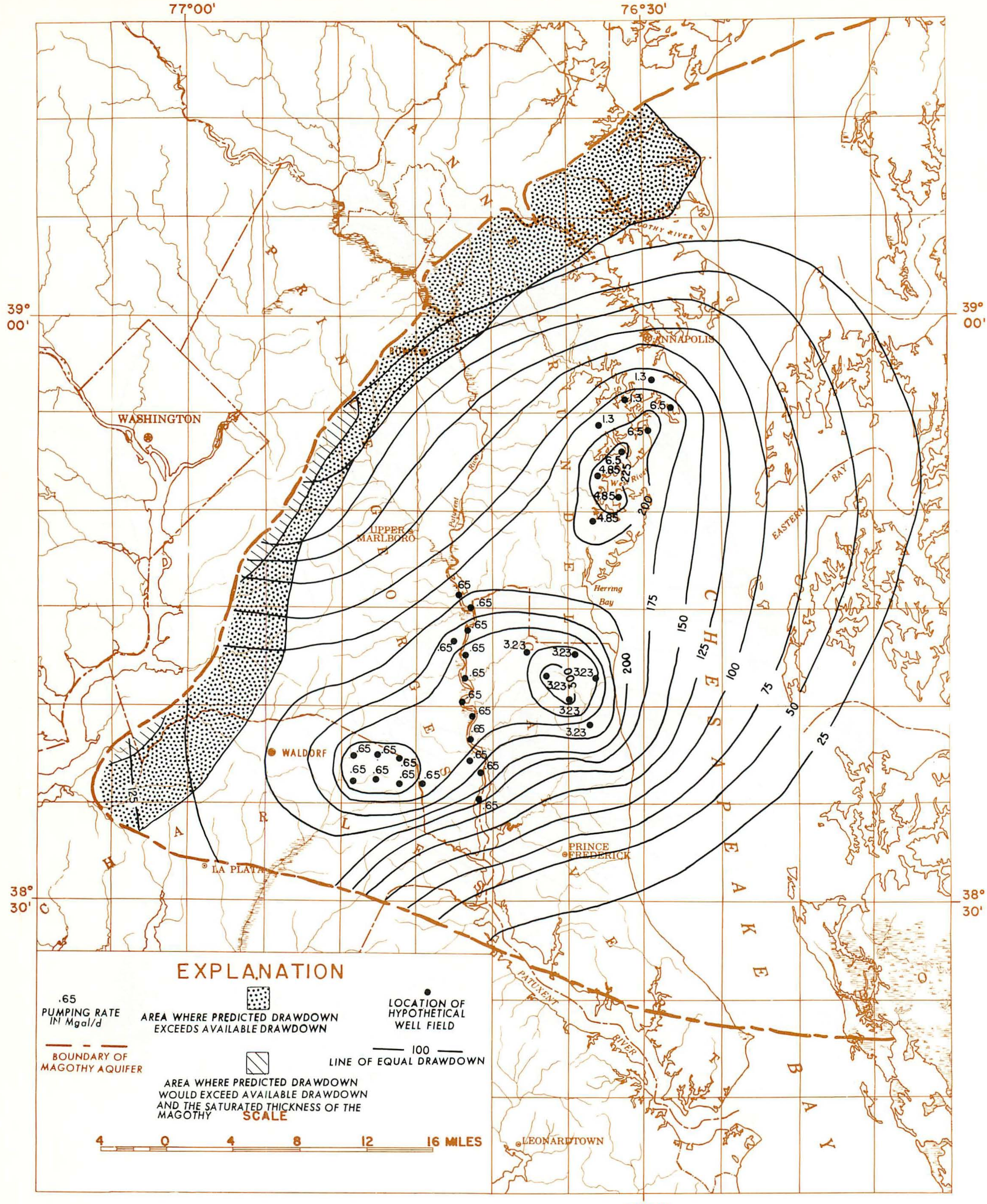

Figure 18.—Predicted drawdowns resulting from pumping a total of 69.6 Mgal/d from the best hydrogeologic areas in each county. (Test 4)

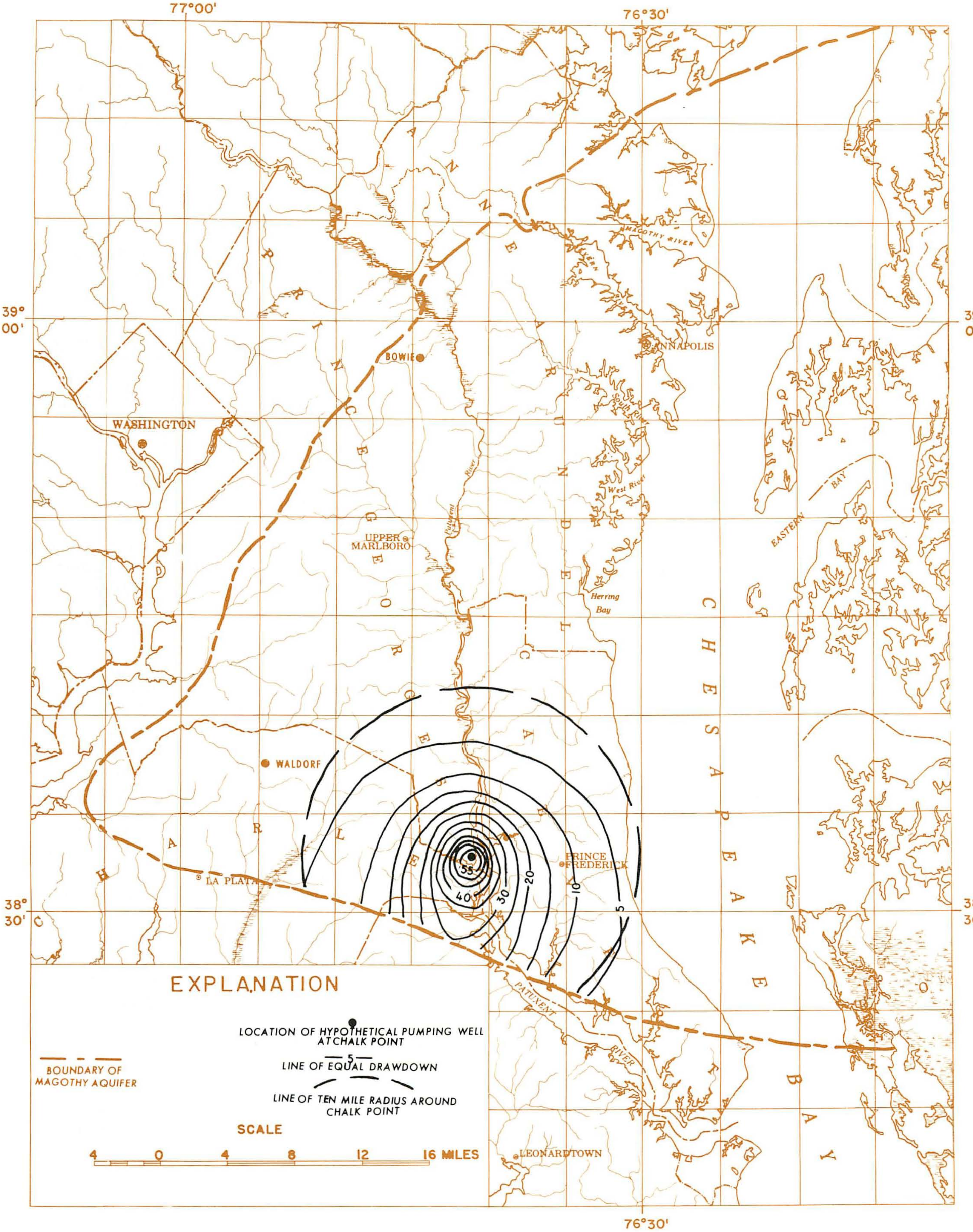

Figure 19.—Predicted drawdown resulting from pumping 0.83 Mgal/d from the Magothy aquifer at Chalk Point.

Predictions made with this model were based on the assumption that water levels in adjacent formations will remain constant as the Magothy is pumped. Because other aquifers will probably be pumped, water levels in them will doubtless decline, leakage from them will decrease, and the quantity of water available from the Magothy will be decreased accordingly. A multi-layer model capable of transmitting head changes across individual confining beds is needed to simulate a leaky aquifer system of this type (Trescott, 1975; Achmad, in prep.).

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[1]The name of this agency was changed to the Maryland Geological Survey in June 1964.

DATA FOR SELECTED TEST SITES

Table 7.—Data available at test sites.

Test site No.	Location	Owner of property	Altitude of land surface (ft)	Depth of probe hole (ft)	Geophysical logs: Resistivity	Geophysical logs: Self potential	Geophysical logs: Gamma ray	Geophysical logs: Caliper	Core samples: Split spoon: Number of cores taken	Core samples: Stationary piston sampler: Depth sampled (feet below land surface)	Number of sands tested by pumping	Permanent observation wells: Well number	Permanent observation wells: Positions of screens relative to sea level
1	Annapolis Junior High School	Anne Arundel County Board of Education	41	436	X	X	X	X	0	177 214 347	0	AA-De 99 AA-De 107	-55 to -65 -215 to -242
2	Collison Corner	Maryland State Roads Commission	50	534	X	X	X	X	36	23 282 358	3	AA-De 101 AA-De 102 AA-De 103	-360 to -400 -20 to -46 -248 to -288
3	Broadneck Road & Jones Station Road	Anne Arundel County Dept. of Recreation	94	410	X	X	X	X	18	144 172 231	1	AA-Cf 98 AA-Cf 99 AA-Cf 100	+3 to -7 -116 to -126 -222 to -232
4	Thomas Point	U. S. Coast Guard	6	510					15	0	1	AA-Df 84	-294 to -304
5	South side of right-of-way of Rt. 50, 0.5 mile east of Rutland Road	Maryland State Roads Commission	106	505	X	X	X	X	16	0	1	AA-Dd 41 AA-Dd 42	-254 to -266 -84 to -94 -119 to -129 -159 to -169
6	Randle Cliff	U. S. Navy Research Laboratory	96	1,017	X	X	X	X	-	550 600 643 649 1,017	2	CAL-Cc 18 CAL-Cc 41 CAL-Cc 55 CAL-Cc 56	-358 to -372 -426 to -446 -762 to -772 -608 to -628
7	Shady Side	Anne Arundel County Dept. of Public Works	7	698	X	X	X	-	-	434	-	AA-Fe 46 AA-Fe 47	-578 to -588
8	Chalk Point	Potomac Electric Power Company	28	1,095	X	X	X	X	6	570 1,095	3	PG-Hf 40 PG-Hf 41 PG-Hf 42	-832 to -842 -620 to -630 -339 to -349
9	Magruder Landing	National Capital Park and Planning Commission	34	586	X	X	X	X	-	-	1	PG-Gf 35	-508 to -518
10	Hughesville Camp Winona	National Capital Girl Scout Council	154	1,030	X	X	X	-	-	600 650	1	CH-Cg 18	-543 to -553
11	Scientists Cliffs	Scientists Cliffs Association	91	1,000	X	X	X	X	5	649	-	CAL-Dc 35	-639 to -669

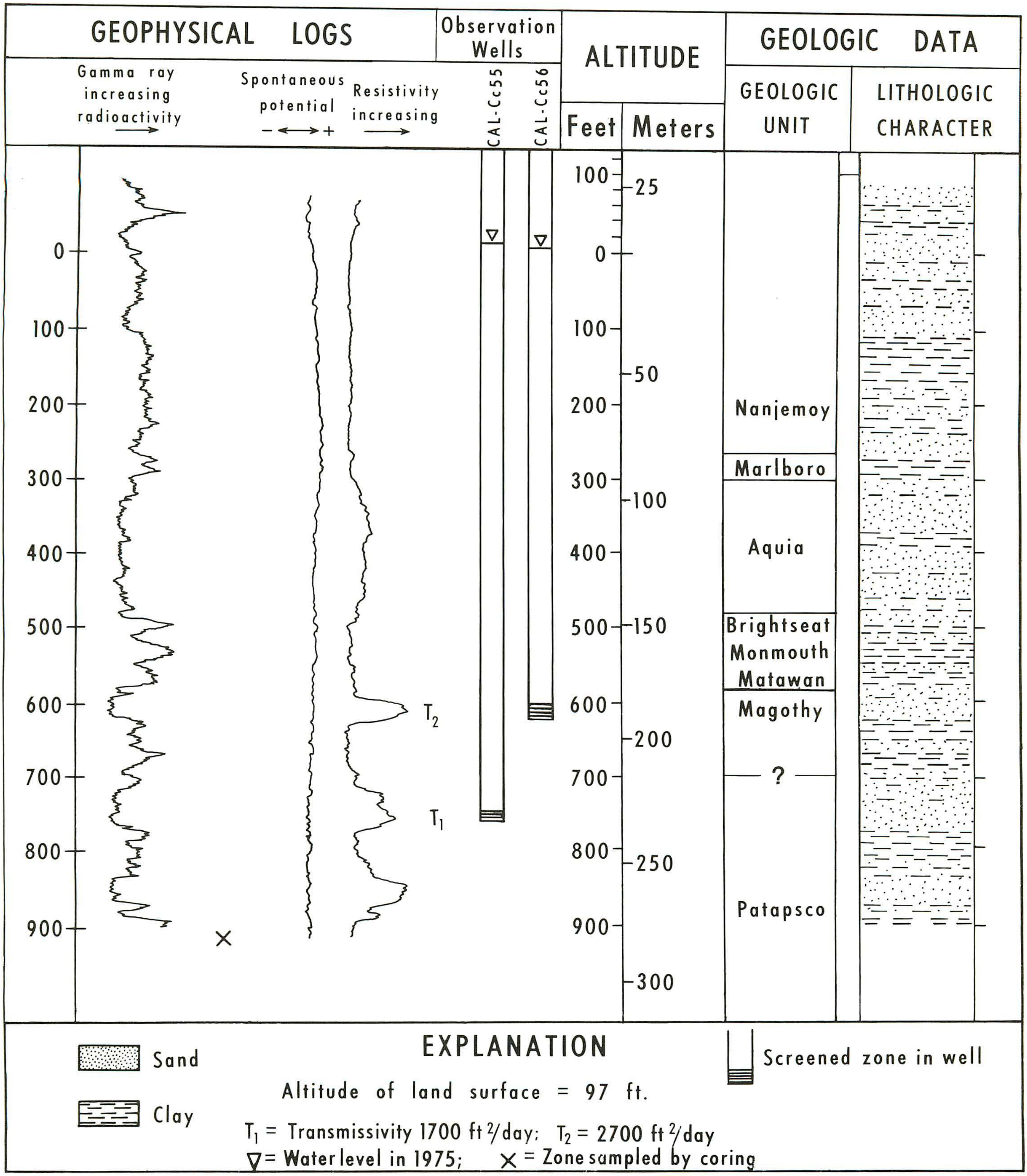

Figure 20.—Test site 6 at Randle Cliff, Calvert County.

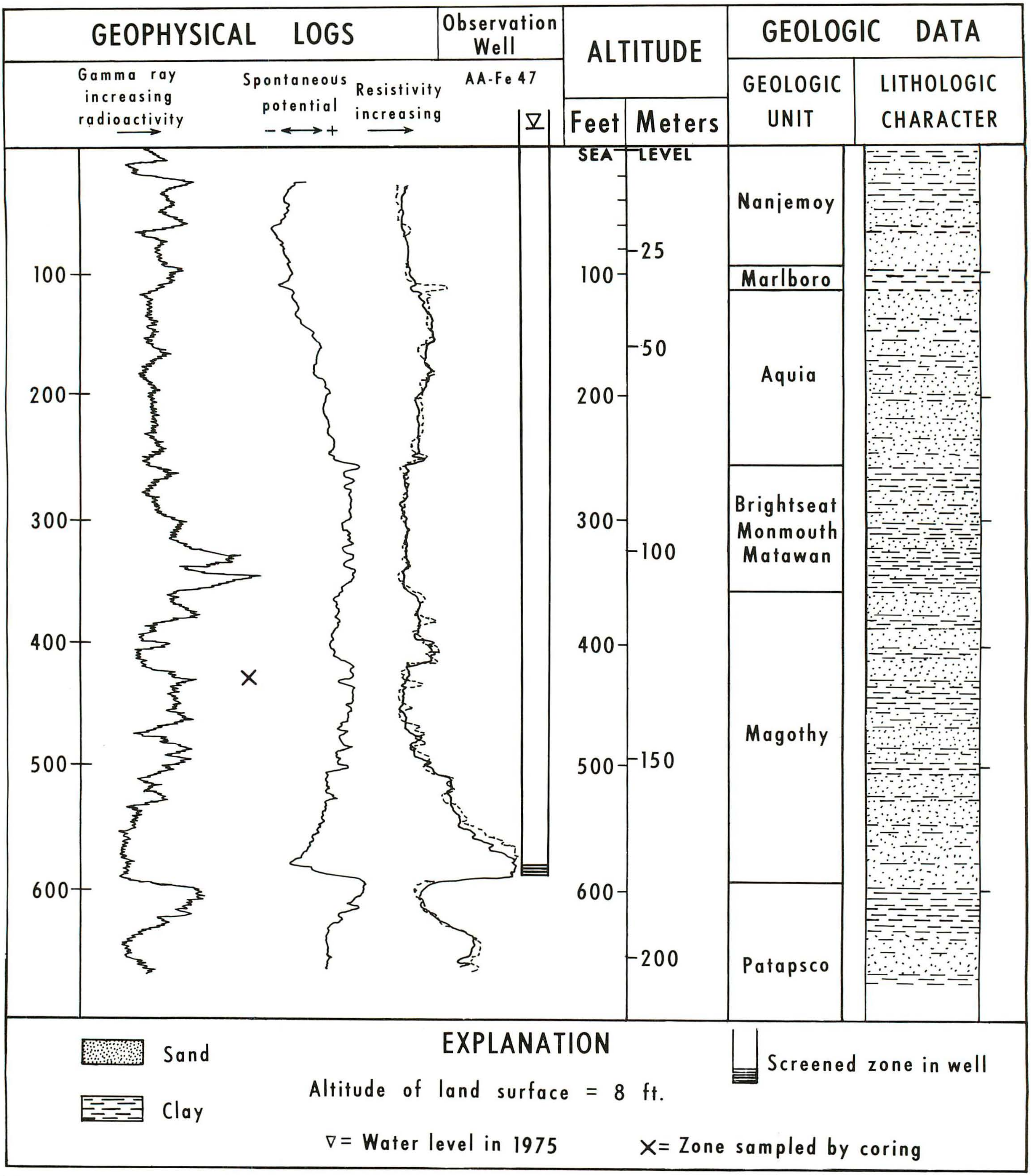

Figure 21.—Test site 7 at Shady Side, Anne Arundel County.

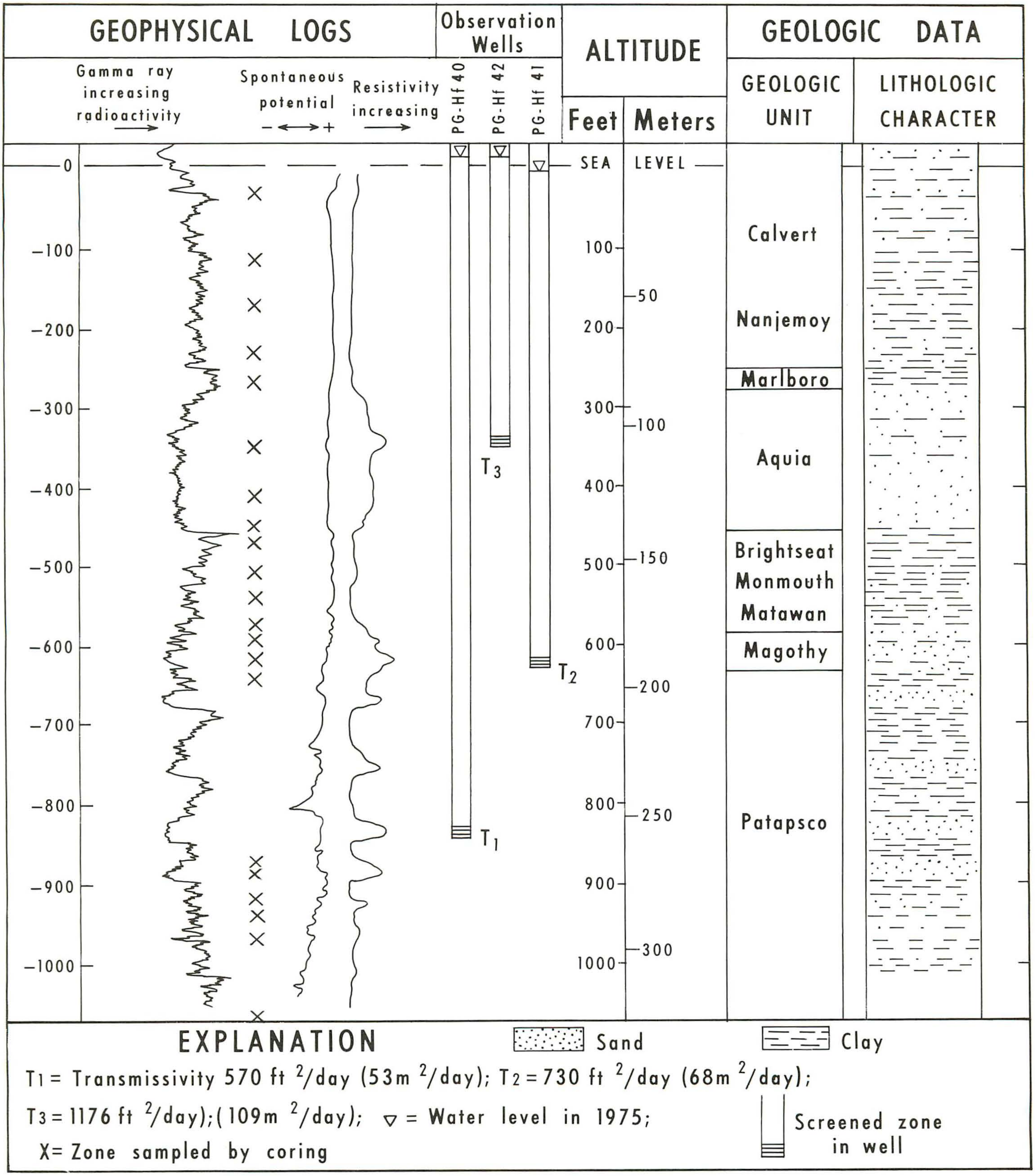

Figure 22.—Test side 8 at Chalk Point, Prince George's County.

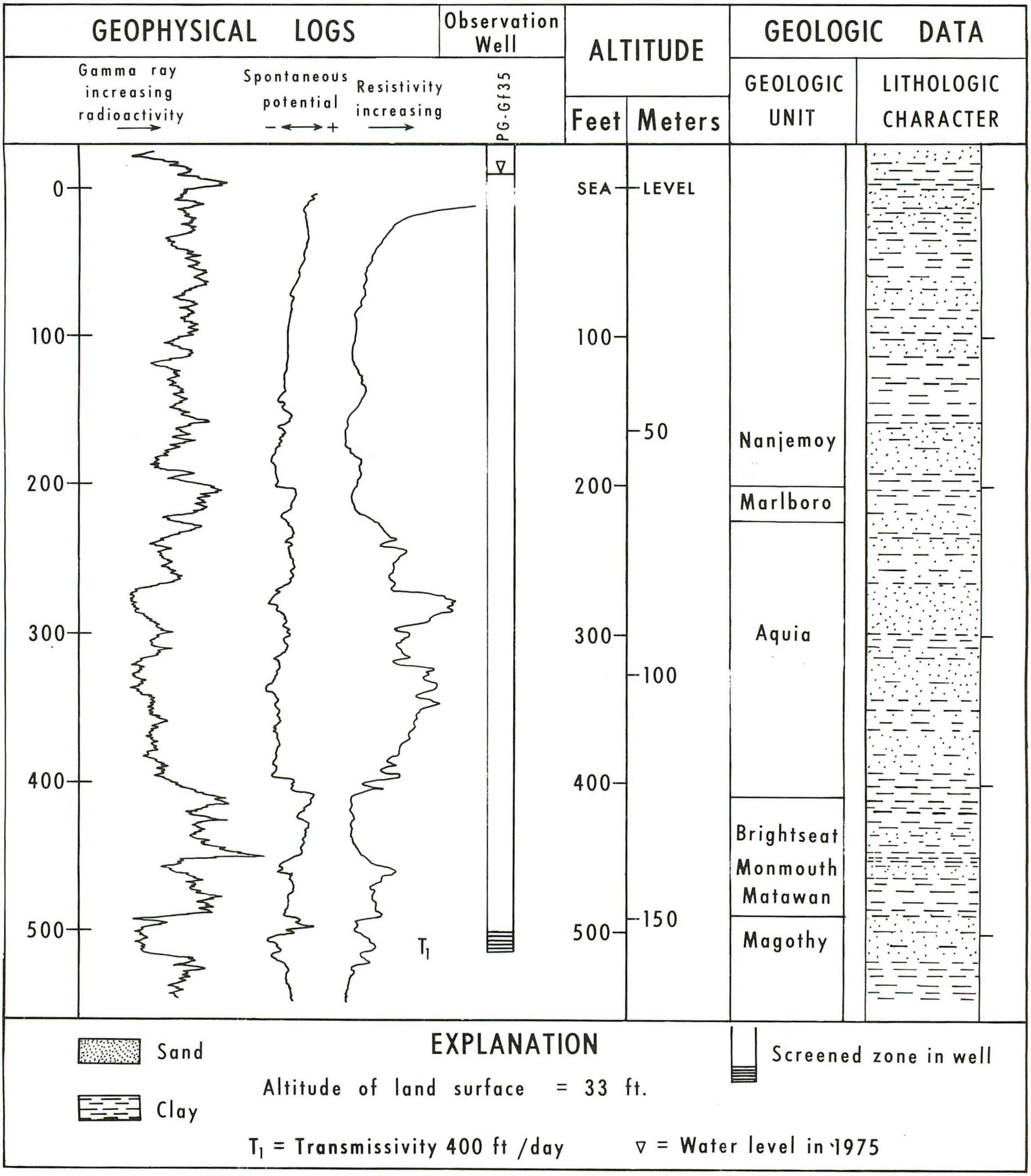

Figure 23.—Test site 9 at Magruder Landing, Prince George's County.

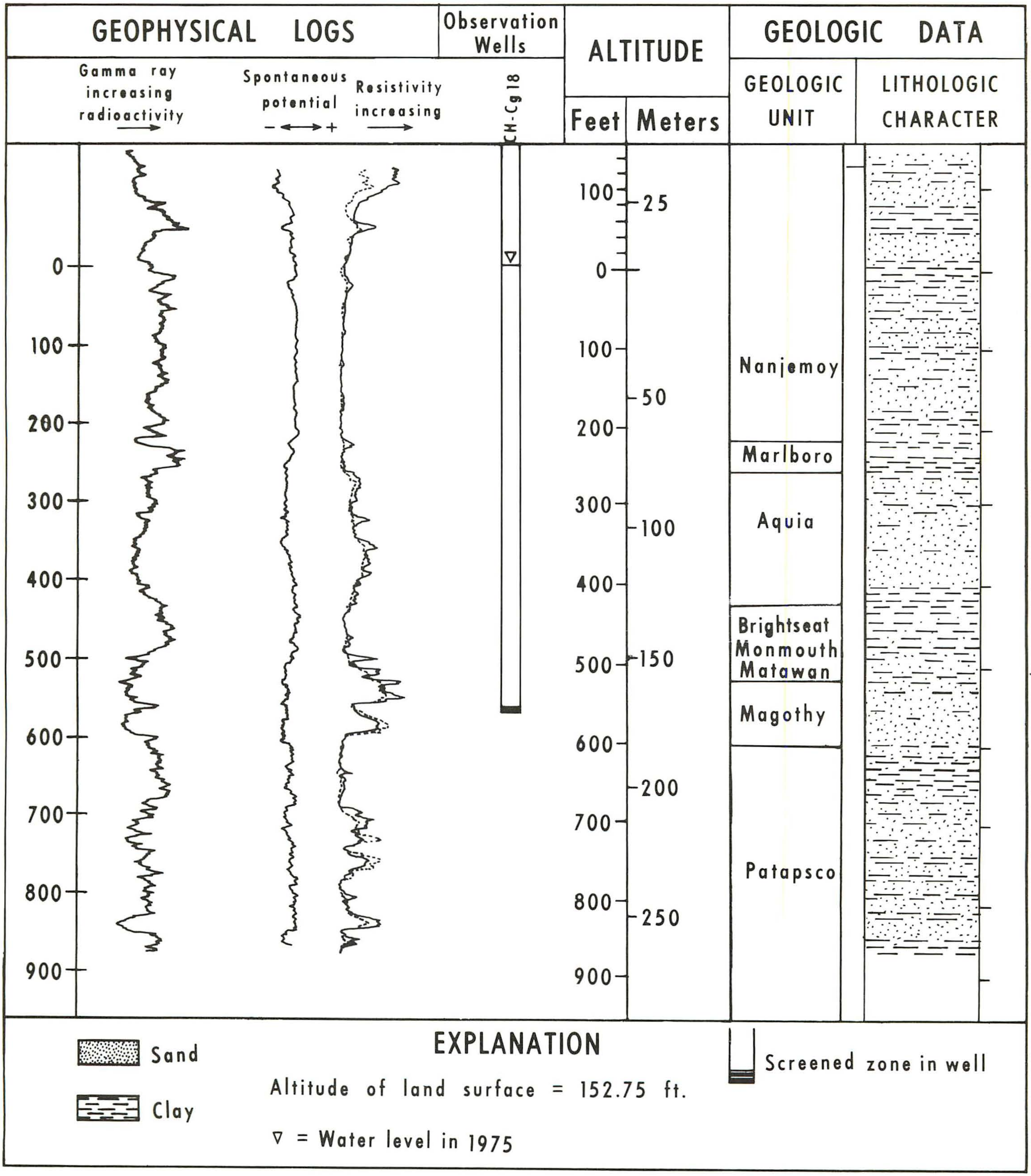

Figure 24.—Test site 10 at Camp Winona, Charles County.

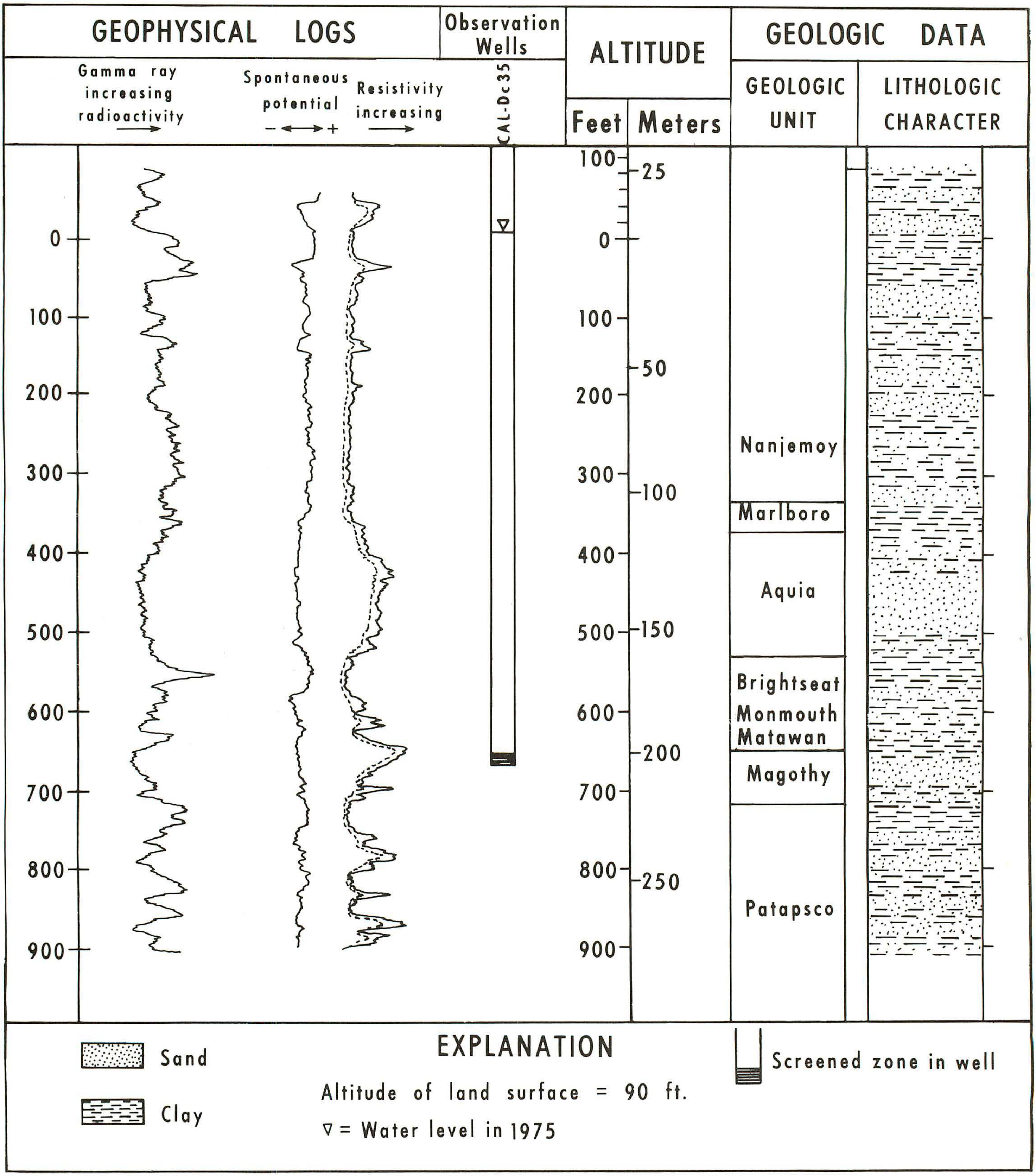

Figure 25.—Test site 11 at Scientists Cliffs, Calvert County.

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