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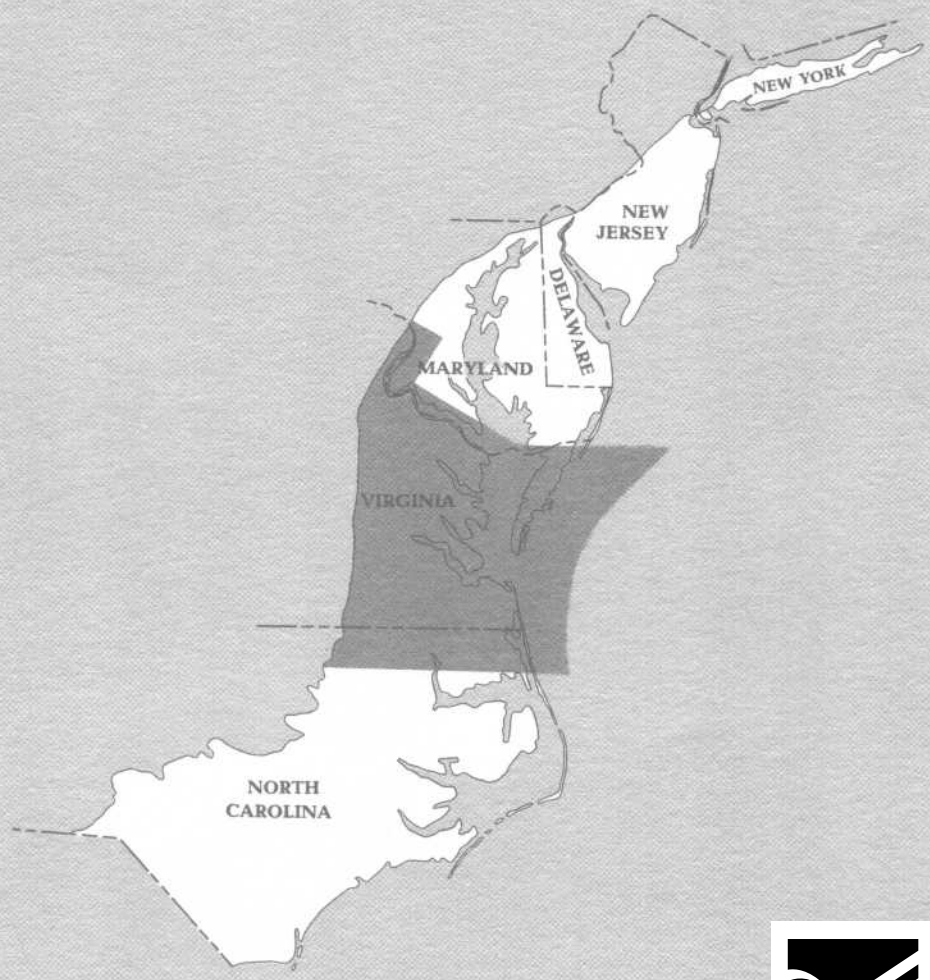
CONCEPTUALIZATION AND ANALYSIS OF GROUND-WATER FLOW SYSTEM IN THE COASTAL PLAIN OF VIRGINIA AND ADJACENT PARTS OF MARYLAND AND NORTH CAROLINA

REGIONAL AQUIFER-SYSTEM ANALYSIS



U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1404—F

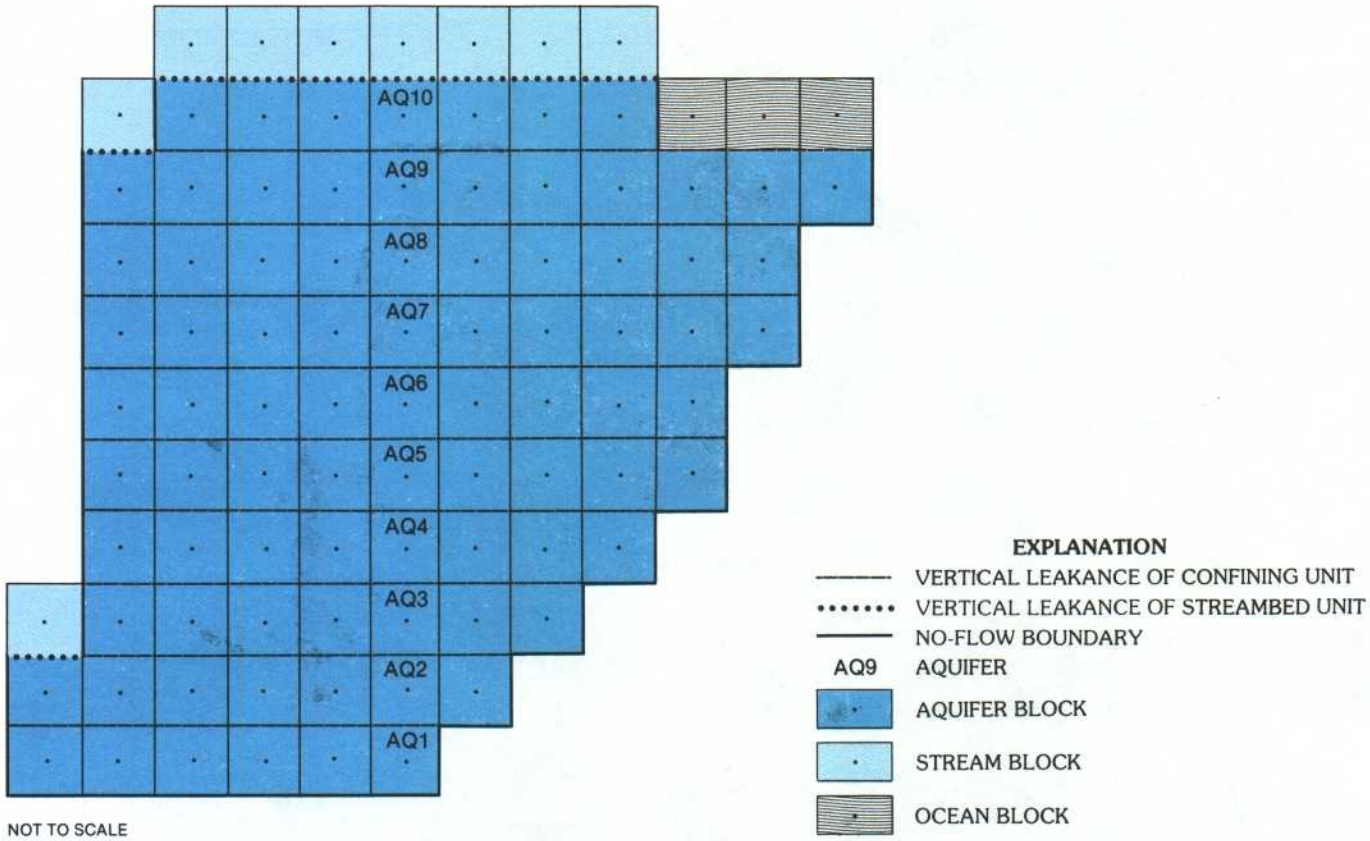


FIGURE 12.—Cross section of finite-difference grid and boundary conditions.

for all confined aquifers. This value is slightly lower than those given in table 3, but it is assumed reasonable because most values in table 3 were determined from standard nonleaky methods. This value is in close agreement with that estimated by Hopkins (U.S. Geological Survey, written commun., 1984) from compaction-recorder data and determined by model calibration (Cosner, 1975; Chapelle and Drummond, 1983). A value of 0.15 was used to simulate storage for the unconfined (water-table) parts of aquifers.

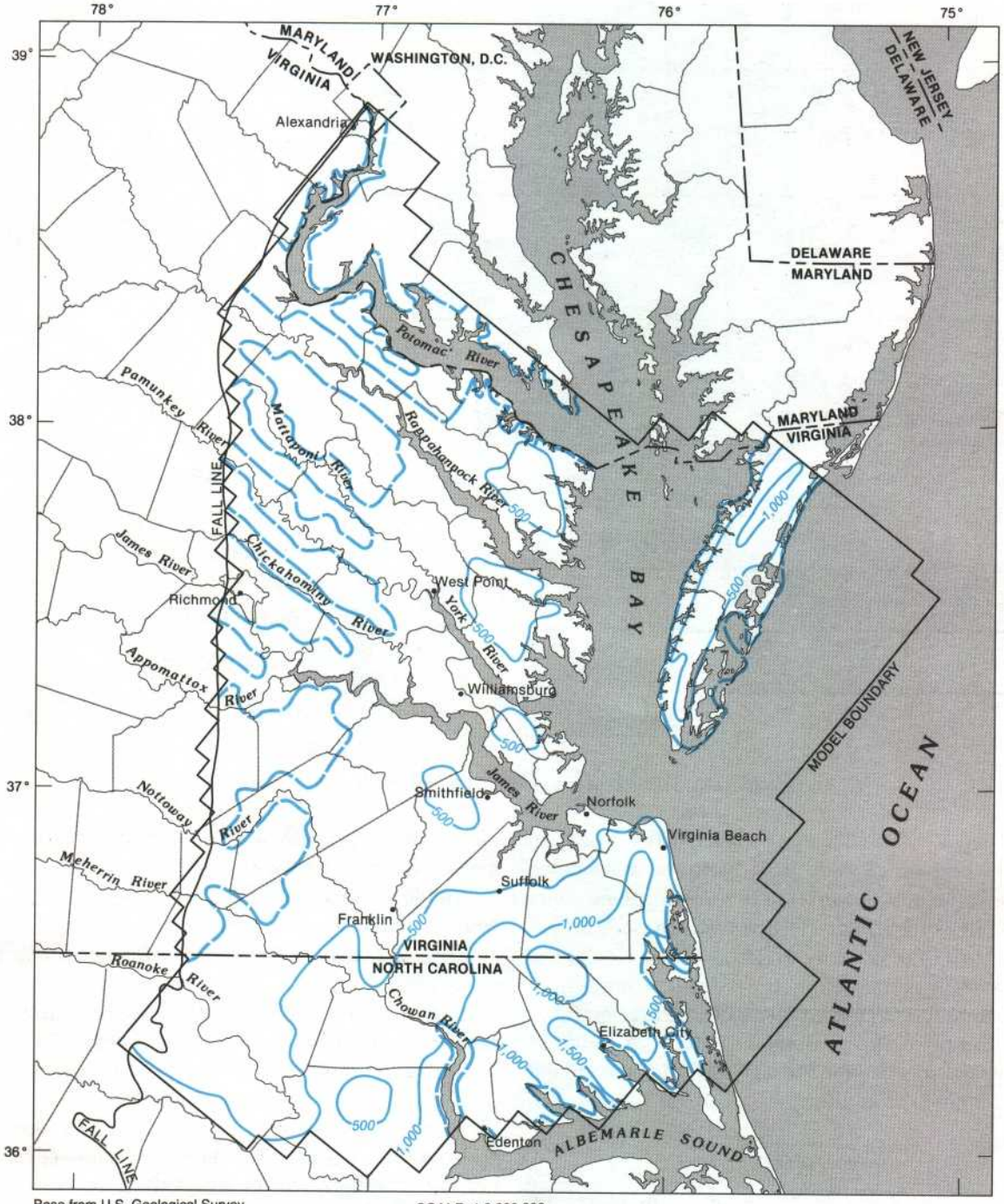
VERTICAL LEAKANCE

Vertical leakance controls the vertical flow of ground water through confining units. It defines the degree of hydraulic connection between aquifers and is dependent on the physical properties of the sediment that makes up the confining unit. Vertical leakance is defined as the average vertical hydraulic conductivity of the confining unit sediment divided by its thickness.

In the model, vertical leakance controls the degree of hydraulic connection between two vertically adjacent, or sequential, aquifer blocks and represents the intervening confining unit (fig. 22*A*). Confining unit thicknesses for blocks were estimated from confining unit thickness maps reported by Meng and Harsh (1988). Vertical hydraulic conductivities of confining units, estimated from laboratory cores, are given in table 6. The range of vertical leakance for each confining unit is given in table 7.

Aquifers and confining units are not continuous over the entire study area (Meng and Harsh, 1988). In some areas, the confining unit between two sequential aquifers pinches out or is not present (fig. 22*B*). In the model, high vertical leakance values were used to represent the hydraulic connection between two sequential aquifers not separated by a confining unit. Vertical leakance between two such blocks was assumed to be four orders of magnitude greater than the vertical hydraulic conductivity of the missing confining unit. A value of this magnitude is considered more representative of the vertical leakance of aquifer material.

In some areas, two nonsequential aquifers are connected hydraulically through a single confining unit, because the overlying sequential hydrologic units are missing (fig. 22*C*); blocks representing the missing aquifers are eliminated from the ground-water flow system



Base from U.S. Geological Survey
State base maps, 1:1,000,000

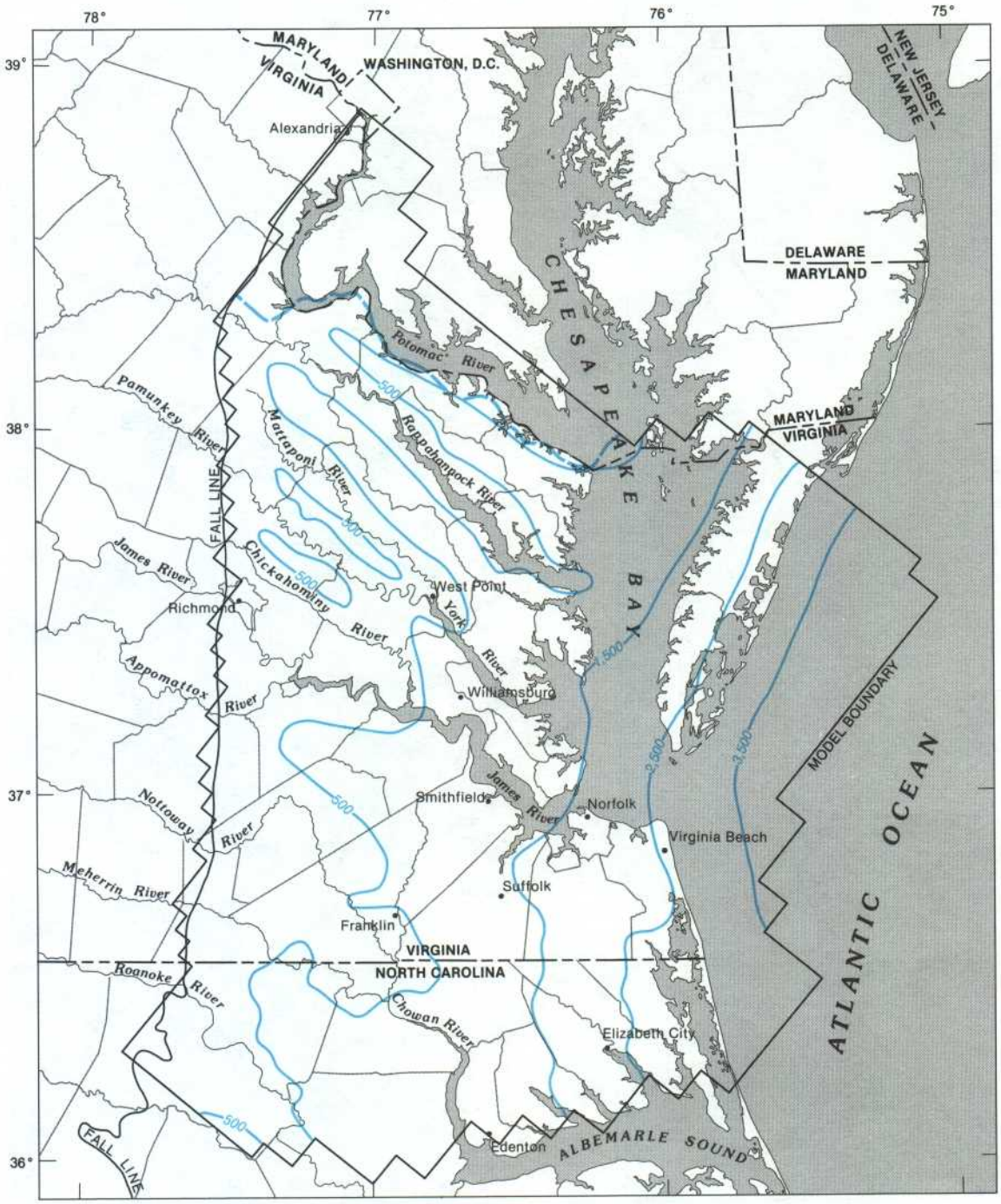
SCALE 1:2,000,000
0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS

EXPLANATION

—500— LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval is 500 feet squared per day

APPROXIMATE LIMIT OF COLUMBIA AQUIFER

FIGURE 13.—Transmissivity of the Columbia aquifer used in model simulations.



Base from U.S. Geological Survey
State base maps, 1:1,000,000

SCALE 1:2,000,000

0 10 20 30 40 50 MILES

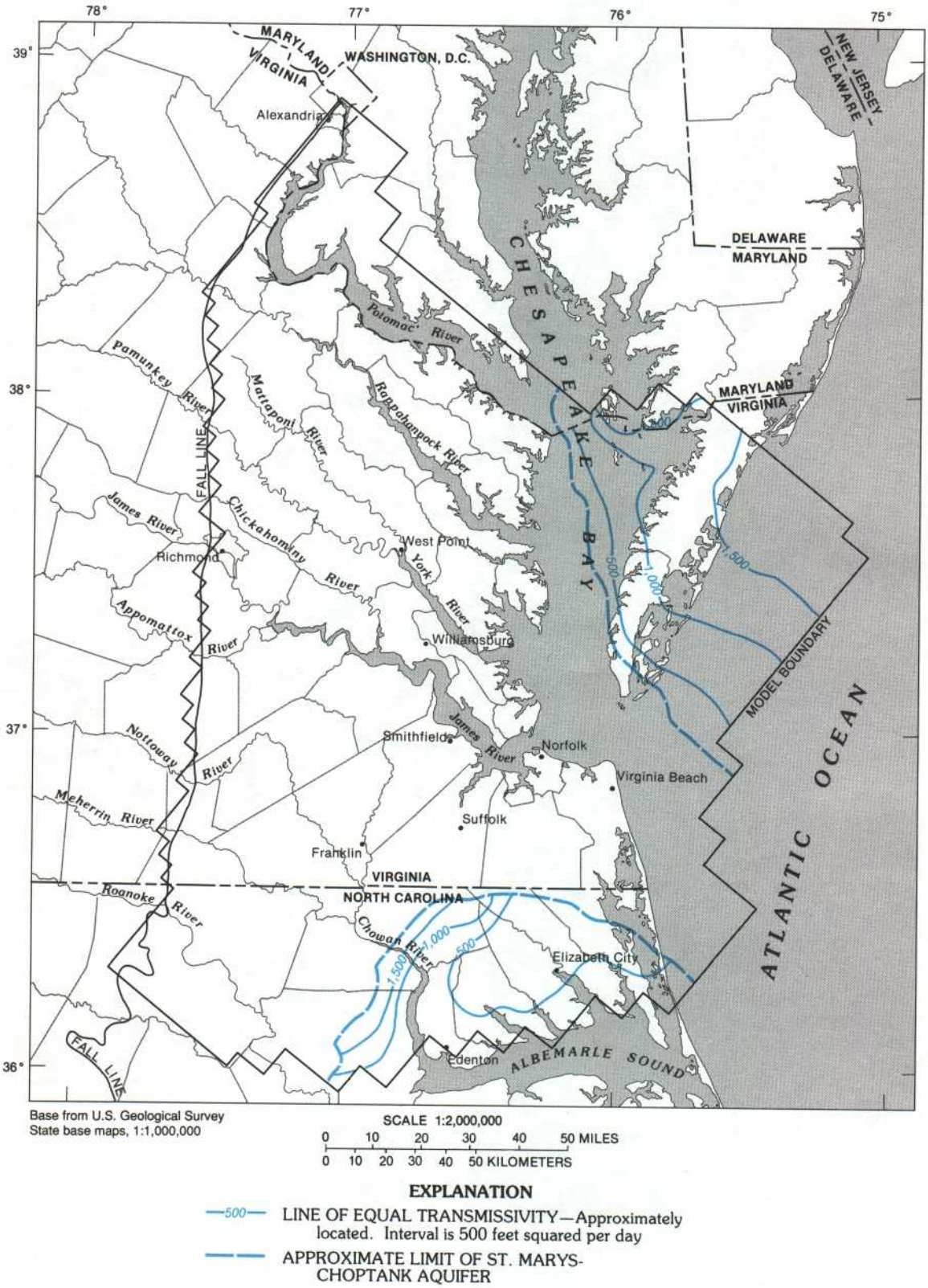
0 10 20 30 40 50 KILOMETERS

EXPLANATION

—500— LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval, in feet squared per day, is variable

— — APPROXIMATE LIMIT OF YORKTOWN-EASTOVER AQUIFER

FIGURE 14.—Transmissivity of the Yorktown-Eastover aquifer used in model simulations.



Base from U.S. Geological Survey
State base maps, 1:1,000,000

SCALE 1:2,000,000

0 10 20 30 40 50 MILES

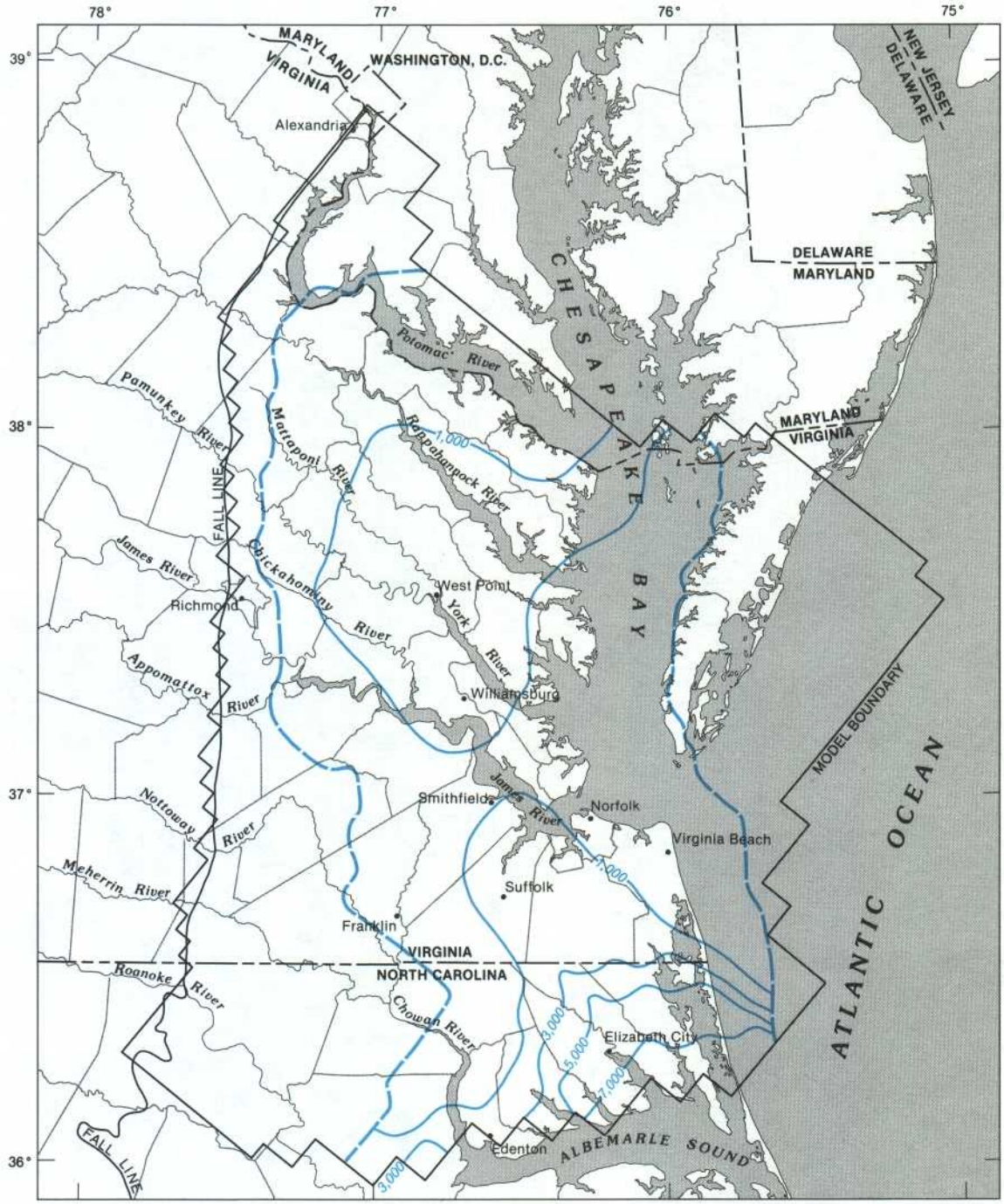
0 10 20 30 40 50 KILOMETERS

EXPLANATION

—500— LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval is 500 feet squared per day

— — APPROXIMATE LIMIT OF ST. MARYS-CHOPTANK AQUIFER

FIGURE 15.—Transmissivity of the St. Marys-Choptank aquifer used in model simulations.



Base from U.S. Geological Survey
State base maps, 1:1,000,000

SCALE 1:2,000,000

0 10 20 30 40 50 MILES

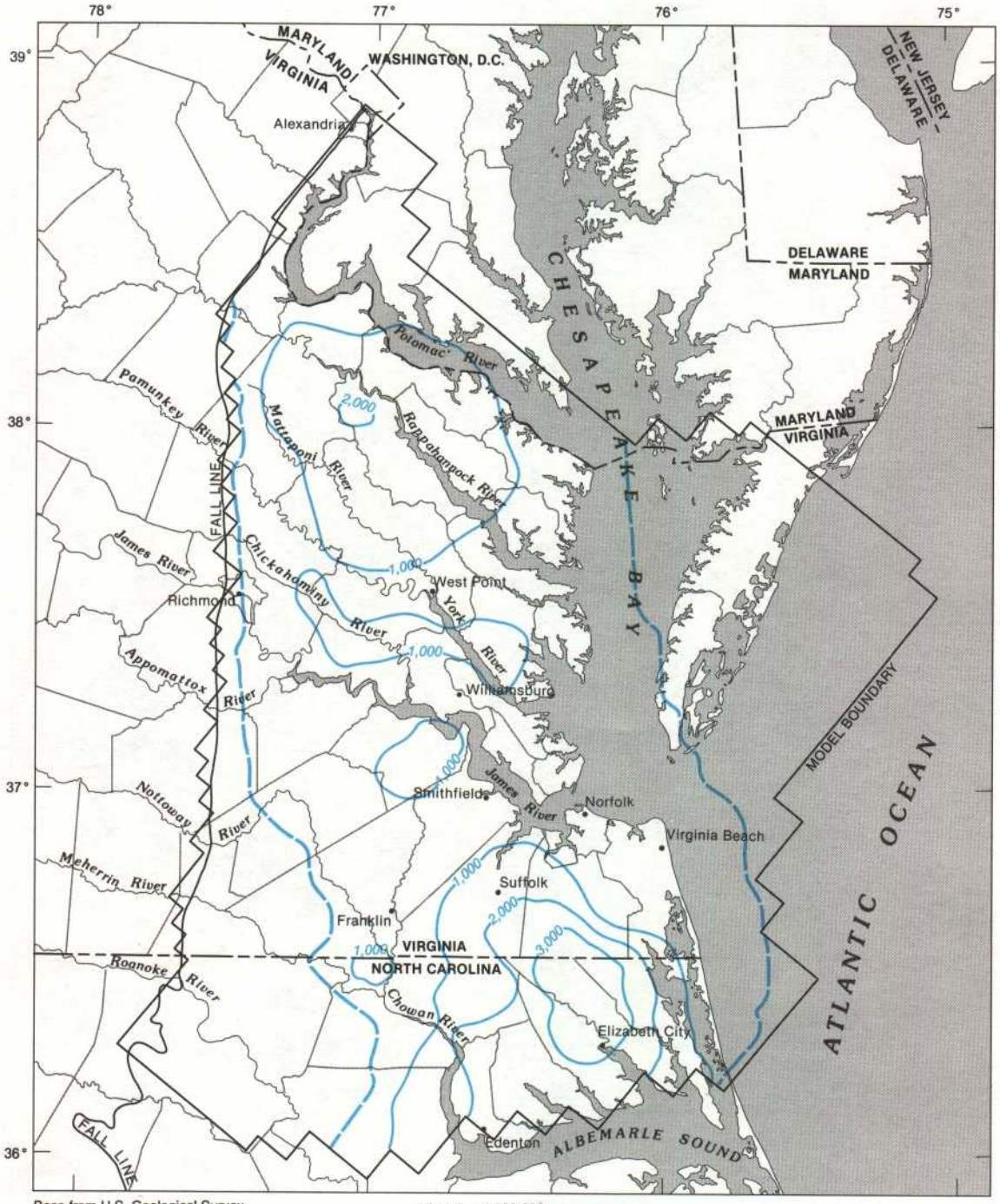
0 10 20 30 40 50 KILOMETERS

EXPLANATION

—1,000— LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval is 2,000 feet squared per day

— — APPROXIMATE LIMIT OF CHICKAHOMINY-PINEY POINT AQUIFER

FIGURE 16.—Transmissivity of the Chickahominy-Piney Point aquifer used in model simulations.



Base from U.S. Geological Survey
State base maps, 1:1,000,000

SCALE 1:2,000,000

0 10 20 30 40 50 MILES

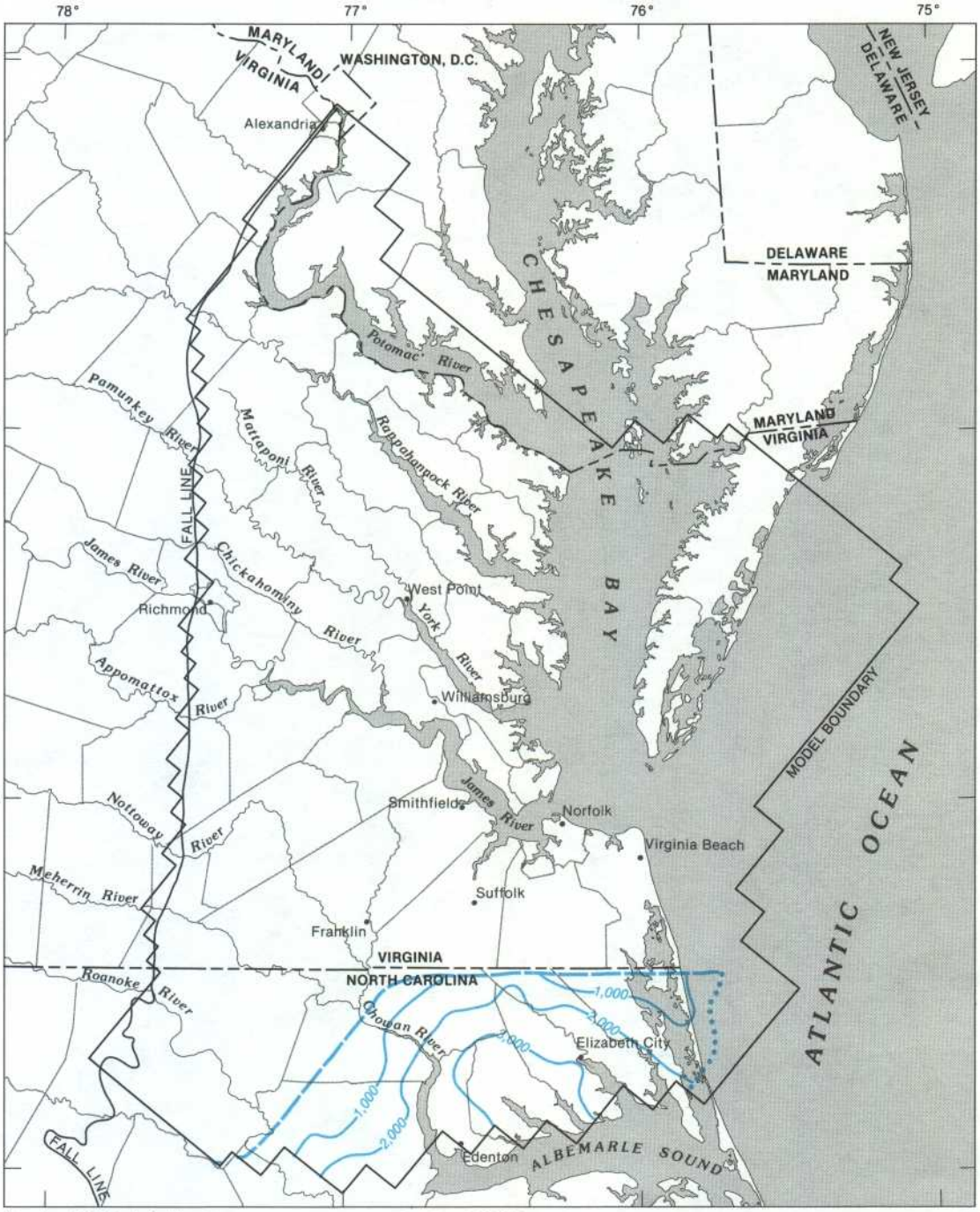
0 10 20 30 40 50 KILOMETERS

EXPLANATION

—1,000— LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval is 1,000 feet squared per day

— — APPROXIMATE LIMIT OF AQUIA AQUIFER

FIGURE 17.—Transmissivity of the Aquia aquifer used in model simulations.



Base from U.S. Geological Survey
State base maps, 1:1,000,000

SCALE 1:2,000,000
0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS

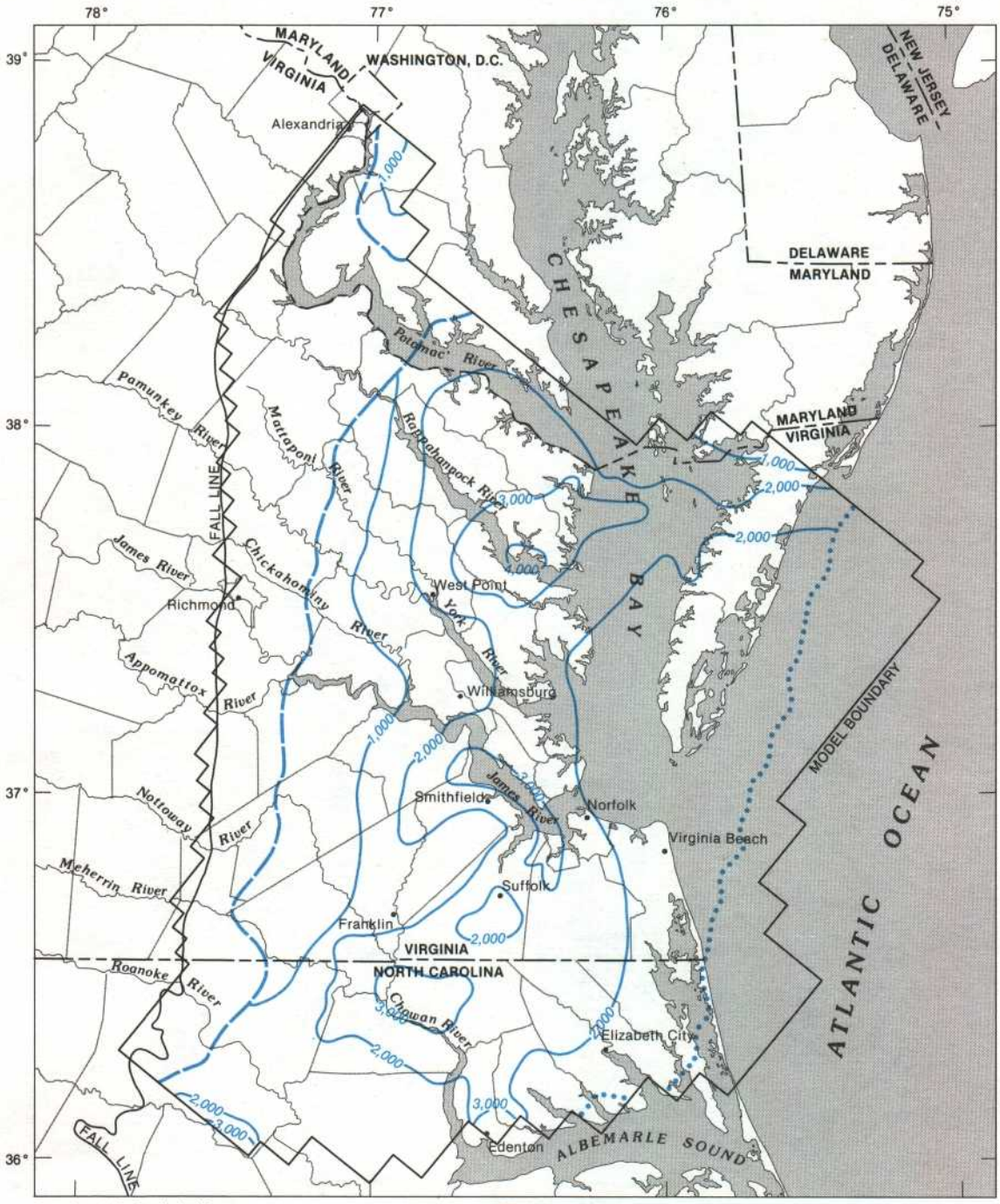
EXPLANATION

—1,000— LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval is 1,000 feet squared per day

APPROXIMATE LIMIT OF AQUIFER 4

ESTIMATED SEAWARD LIMIT OF FRESHWATER SYSTEM—Less than 10,000 milligrams per liter chloride

FIGURE 18.—Transmissivity of aquifer 4 used in model simulations.



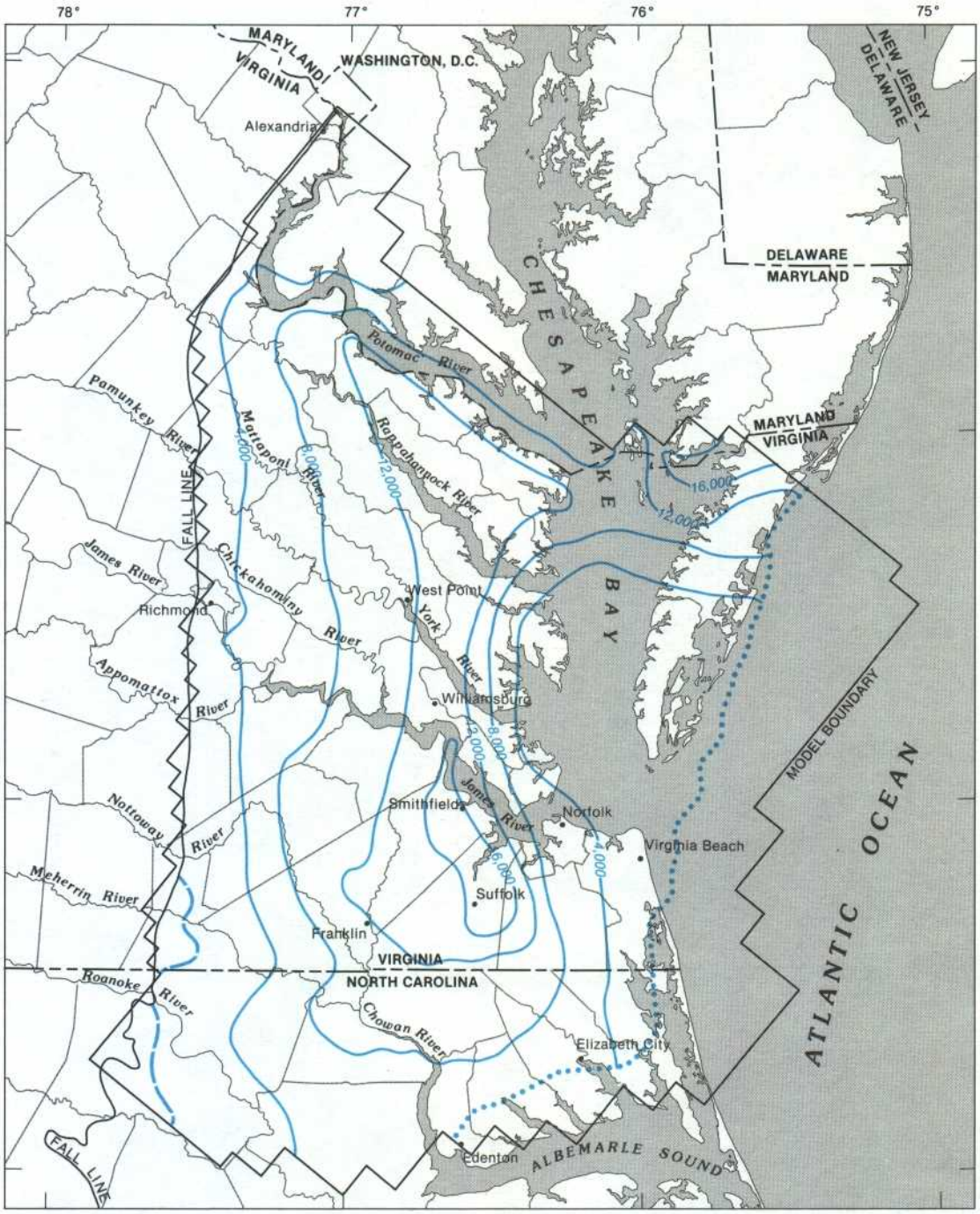
EXPLANATION

—1,000— LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval is 1,000 feet squared per day

— — APPROXIMATE LIMIT OF BRIGHTSEAT-UPPER POTOMAC AQUIFER

····· ESTIMATED SEAWARD LIMIT OF FRESHWATER SYSTEM—Less than 10,000 miligrams per liter chloride

FIGURE 19.—Transmissivity of the Brightseat-upper Potomac aquifer used in model simulations.



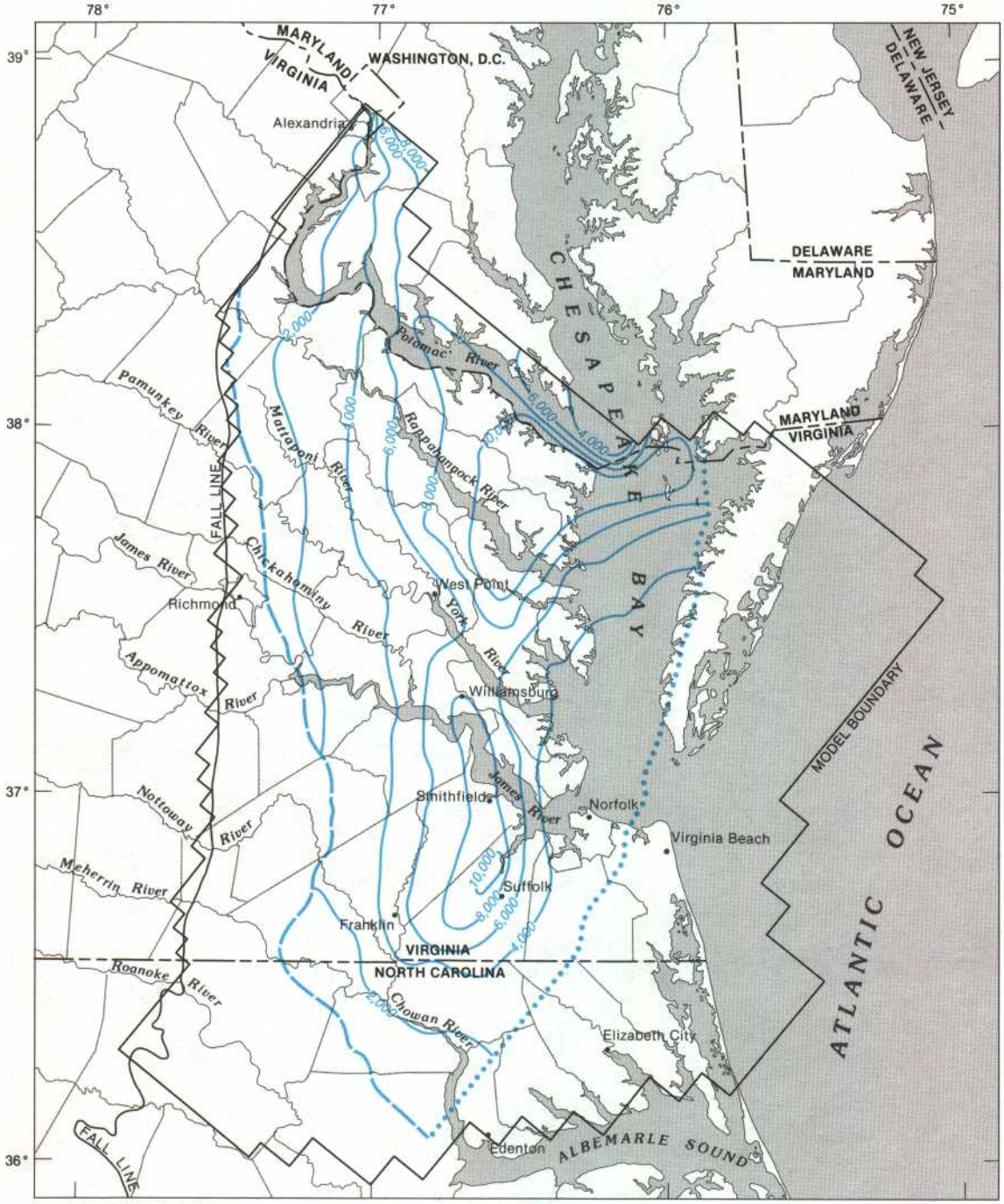
EXPLANATION

–12,000– LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval is 4,000 feet squared per day

APPROXIMATE LIMIT OF MIDDLE POTOMAC AQUIFER

ESTIMATED SEAWARD LIMIT OF FRESHWATER SYSTEM—Less than 10,000 milligrams per liter chloride

FIGURE 20.—Transmissivity of the middle Potomac aquifer used in model simulations.



Base from U.S. Geological Survey
State base maps, 1:1,000,000

SCALE 1:2,000,000
0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS

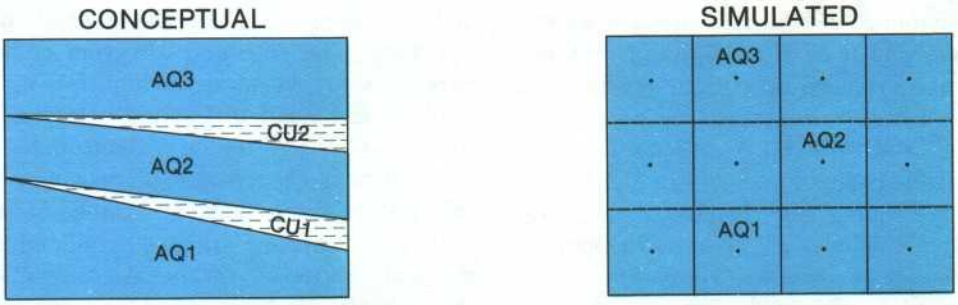
EXPLANATION

—2,000— LINE OF EQUAL TRANSMISSIVITY—Approximately located. Interval is 2,000 feet squared per day

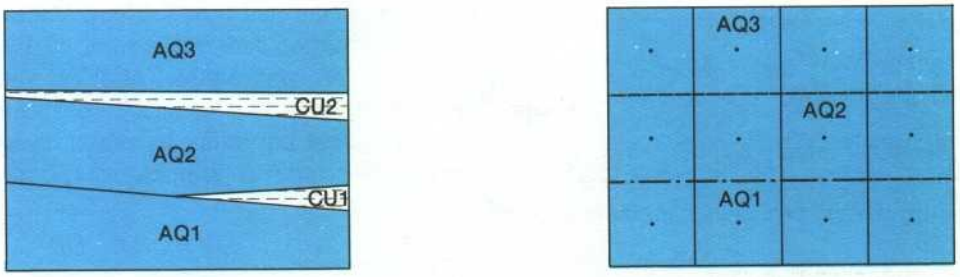
APPROXIMATE LIMIT OF LOWER POTOMAC AQUIFER

ESTIMATED SEAWARD LIMIT OF FRESHWATER SYSTEM—Less than 10,000 milligrams per liter chloride

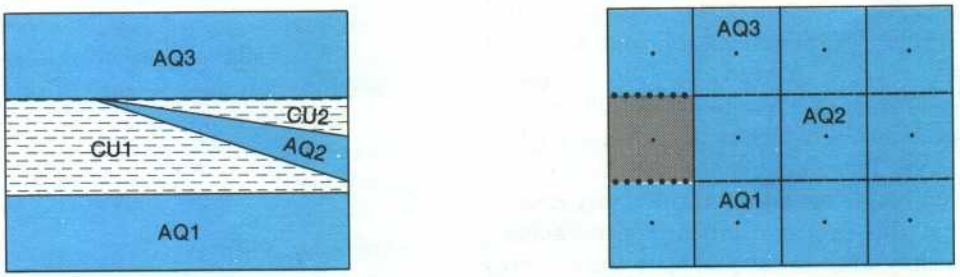
FIGURE 21.—Transmissivity of the lower Potomac aquifer used in model simulations.



A. Vertical leakance between two sequential aquifers seperated by a confining unit.



B. Vertical leakance between two sequential aquifers in direct contact.



C. Vertical leakance between two nonsequential aquifers separated by a confining unit.

EXPLANATION

------ VERTICAL LEAKANCE OF CONFINING UNIT BETWEEN TWO SEQUENTIAL AQUIFERS

—·— VERTICAL LEAKANCE OF AQUIFER MATERIALS WHERE CONFINING UNIT BETWEEN AQUIFERS IS MISSING. TWO ADJACENT AQUIFERS ARE IN DIRECT CONTACT

····· VERTICAL LEAKANCE BETWEEN TWO NON-SEQUENTIAL AQUIFERS WHERE THE SEQUENTIAL AQUIFER AND (OR) THE CONFINING UNIT ARE MISSING

CU2 CONFINING UNIT

AQ2 AQUIFER

AQUIFER BLOCK

INACTIVE BLOCK (Horizontal transmissivity is assumed to be zero)

FIGURE 22.—Schematic diagrams of the conceptual and simulated aquifer contacts.

by assigning a zero transmissivity. To allow vertical flow between two nonsequential blocks, leakance values are needed to connect the nonsequential aquifers. Leakance values for missing confining units were computed by multiplying the leakance value calculated for the existing confining unit by the number of simulated confining units between the nonsequential aquifers. This procedure allowed vertical flow between the nonsequential aquifer blocks and simulated the true vertical leakage between aquifers.

In areas where confining unit material was eroded and replaced by more permeable stream deposits, vertical

leakance was increased one or two orders of magnitude (Chapelle and Drummond, 1983). An increase of two orders of magnitude was used if a confining unit was completely eroded and replaced by stream deposits. An order-of-magnitude increase was used for a confining unit partially eroded and replaced by stream deposits. The degree of hydraulic connection between the stream and the aquifer underlying the confining unit was increased with this procedure. Figures 23 through 30 show the vertical leakance used for simulation of the confining units present in the study area. In general, vertical leakance decreases toward the east as confining units thicken.

Ground-Water Recharge

Recharge entering the water-table aquifer was estimated by the following equation:

$$QRE = P - OF - ET \tag{1}$$

where

QRE = rate of ground-water recharge, in inches per year;
P = precipitation, in inches per year;
OF = overland flow, in inches per year; and
ET = evapotranspiration, in inches per year.

Average annual precipitation in the study area is about 43 inches per year (in/yr) (National Oceanic and Atmospheric Administration, 1980). A study by Cushing and others (1973, p. 35) shows that average overland flow on the Eastern Shore Peninsula, which is part of the study area, is about 6.5 in/yr. This value is assumed to represent the average hydrologic condition in the study area. About 50 percent of the average annual precipitation (21.5 in/yr) in the study area is estimated to be evaporated and transpired by vegetation (Geraghty and Miller, 1978b; Harsh, 1980). Hence, the average rate of areal recharge to the water-table aquifer system is about 15 in/yr. This value was assigned to blocks representative of the water-table aquifer. The water-table aquifer includes the Columbia aquifer and those parts of underlying aquifers that crop out. A digital-flow-model study in the Coastal Plain of central and southern Delaware (Johnston, 1977) shows that 14 in/yr is a good estimate of the long-term recharge rate for the water-table aquifer in the Coastal Plain of Delaware. Undoubtedly, ground-water recharge rates vary spatially throughout the model area; however, data are insufficient to define these local variations. The recharge rate was assumed constant during all model simulations.

Streambed Leakance

Streambed leakance, as used in this report, controls the movement of water between streams and the water-table aquifer. It is defined as the ratio of the vertical hydraulic conductivity of the streambed sediment to its thickness. The rate and direction of flow through the streambed are calculated by multiplying streambed leakance by the head difference between the water-table aquifer and stage in the stream and the area through which flow is occurring. This assumes that the aquifer material adjacent to the streambed is fully saturated.

Few quantitative data are available that define the physical properties of the streambed sediment. However, an alternative method was developed to calculate streambed leakance in order to simulate flow between the water-table aquifer and streams. This method calculates streambed leakance from the simulated flow to the underlying confined flow system, the estimated ground-water recharge, and the estimated hydraulic gradient between the water-table aquifer and streams. The method equates two equations describing stream base flow. The first equation, based on conservation of mass for steady-state, prepumping conditions, is of the form

$$BF = QRE - DP \tag{2}$$

where

BF = base flow per unit area, in feet per second;
QRE = volumetric rate per unit area of ground-water recharge to water-table aquifer, in feet per second; and
DP = deep percolation or volumetric rate per unit area of flow into (positive) or out of (negative) underlying confined aquifer system, in feet per second.

The second equation, based on Darcy's law, states

$$BF = \frac{K'}{M}(h_a - h_s) = SL\,(h_a - h_s) \tag{3}$$

where

BF = base flow per unit area, in feet per second;
K' = vertical hydraulic conductivity of streambed, in feet per second;
M = thickness of streambed, in feet;
h_a = altitude of water table, in feet;
h_s = elevation of stream stage, in feet; and
SL = streambed leakance, in seconds^{-1}.

Equating the two expressions for base flow results in the following expression:

$$SL = \frac{QRE - DP}{(h_a - h_s)} \tag{4}$$

The method requires calculation of deep percolation (DP), the volumetric rate of water per unit area moving between the confined flow system and the water-table aquifer. Block values of deep percolation were computed