# EVALUATION OF MUNICIPAL WITHDRAWALS FROM THE CONFINED AQUIFERS OF SOUTHEASTERN VIRGINIA

By Donna L. Richardson, Randell J. Laczniak, and Pixie A. Hamilton

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## CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who prefer metric (International System) units rather than the inch-pound units used in this report, the following conversion factors can be applied:

| Multiply inch-pound unit | By | To obtain metric unit |
|---|---|---|
| | Length | |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Flow | |
| 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."

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## ABSTRACT

A large quantity of ground water that is allocated for municipal use is not withdrawn from the confined aquifers of southeastern Virginia. Withdrawal at permitted municipal rates alone would increase the quantity of ground water withdrawn by 83 percent over 1986 rates. The withdrawal of the unused portion of permitted withdrawal could adversely affect municipalities and other ground-water users in southeastern Virginia.

A digital flow model of southeastern Virginia was used to evaluate the effects of permitted municipal withdrawal on 1986 ground-water flow conditions. Simulation of total permitted municipal withdrawal predicted as much as 265 feet of water-level decline in the middle Potomac aquifer. The predicted declines are in addition to declines caused by ground-water withdrawals through 1986. Results indicate that local dewatering would occur and that discharge to surface water would decrease about 66 million gallons per day. A simulation of 50 percent of the total permitted municipal withdrawal predicted less severe effects on 1986 ground-water flow conditions--maximum additional drawdown of 117 feet, no dewatering, and much less of a reduction in ground-water discharge to surface water.

Manuscript approved for publication December 9, 1988

## INTRODUCTION

The confined aquifers of southeastern Virginia historically have provided much of the water supply to area residents and industries. As a result, significant declines in water levels have occurred throughout these aquifers. The greatest measured decline, which now exceeds 175 feet, is near Franklin, Virginia. Historic declines, projected population growth, and the large quantity of water permitted but not withdrawn by municipal users have caused concern among local planning agencies about the future of the ground-water resource. The U.S. Geological Survey in cooperation with Southeastern Virginia Planning District Commission (SVPDC) evaluated the hydrologic effects of permitted municipal withdrawal on 1986 ground-water flow conditions. This evaluation was accomplished by using the digital flow model developed for southeastern Virginia by Hamilton and Larson (1988). This report presents the results of model simulations. Results are illustrated by maps of water levels (potentiometric surface), drawdown from simulated 1986 flow conditions, and distance between the potentiometric surface and top of the respective aquifer. The model is not designed to determine water-quality effects that may result from saltwater leakage from surface-water bodies or salty ground water; therefore, water quality is not addressed by this report. Although the ground-water system simulated by the model extends into the northern part of North Carolina, only results in Virginia are presented. Figure 1 shows the location and extent of the study and model areas.

## CONFINED-AQUIFER SYSTEM

The confined aquifers of southeastern Virginia are layered, sedimentary, coastal plain deposits of unconsolidated gravel, sand, and silt that dip and thicken eastward and range in age from Early Cretaceous to Pliocene. These aquifers are separated by intervening confining units of clay and silt. Previous studies by Meng and Harsh (1984) and Hamilton and Larson (1988) have delineated seven major confined aquifers in the area (fig. 2). Aquifers, rock units, and ages are, from youngest to oldest, (1) the Yorktown-Eastover aquifer in the Pliocene Yorktown Formation and the Miocene Eastover Formation; (2) the Chickahominy-Piney Point aquifer in the Eocene Chickahominy and Piney Point Formations, and younger deposits of Oligocene and Miocene age; (3) the Aquia aquifer in the Paleocene Aquia Formation; (4) the Virginia Beach aquifer in unnamed deposits of Early Paleocene and Late Cretaceous age; (5) the upper Potomac aquifer in the Potomac Formation of Late Cretaceous age; (6) the middle Potomac aquifer in the Potomac Formation of Early Cretaceous age; and (7) the lower Potomac aquifer in the Potomac Formation of Early Cretaceous age. The Potomac aquifers, which are the deepest and thickest of the confined aquifers, comprise about 70 percent of the total sediment thickness (Meng and Harsh, 1984) and supplied more than 80 percent of the total ground water withdrawn in southeastern Virginia during 1983 (Hamilton and Larson, 1988).

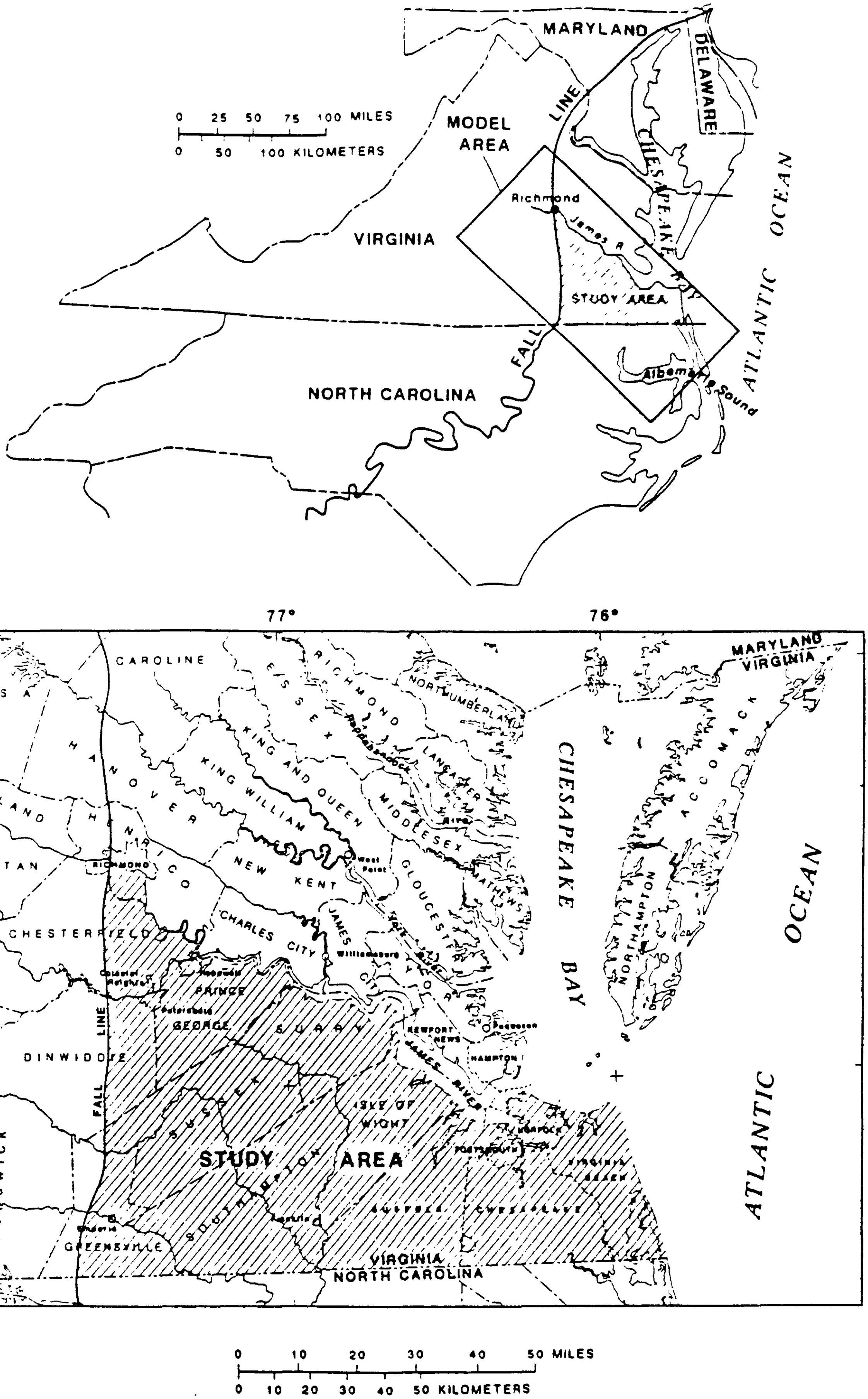


Figure 1.--Location and extent of study and model areas.

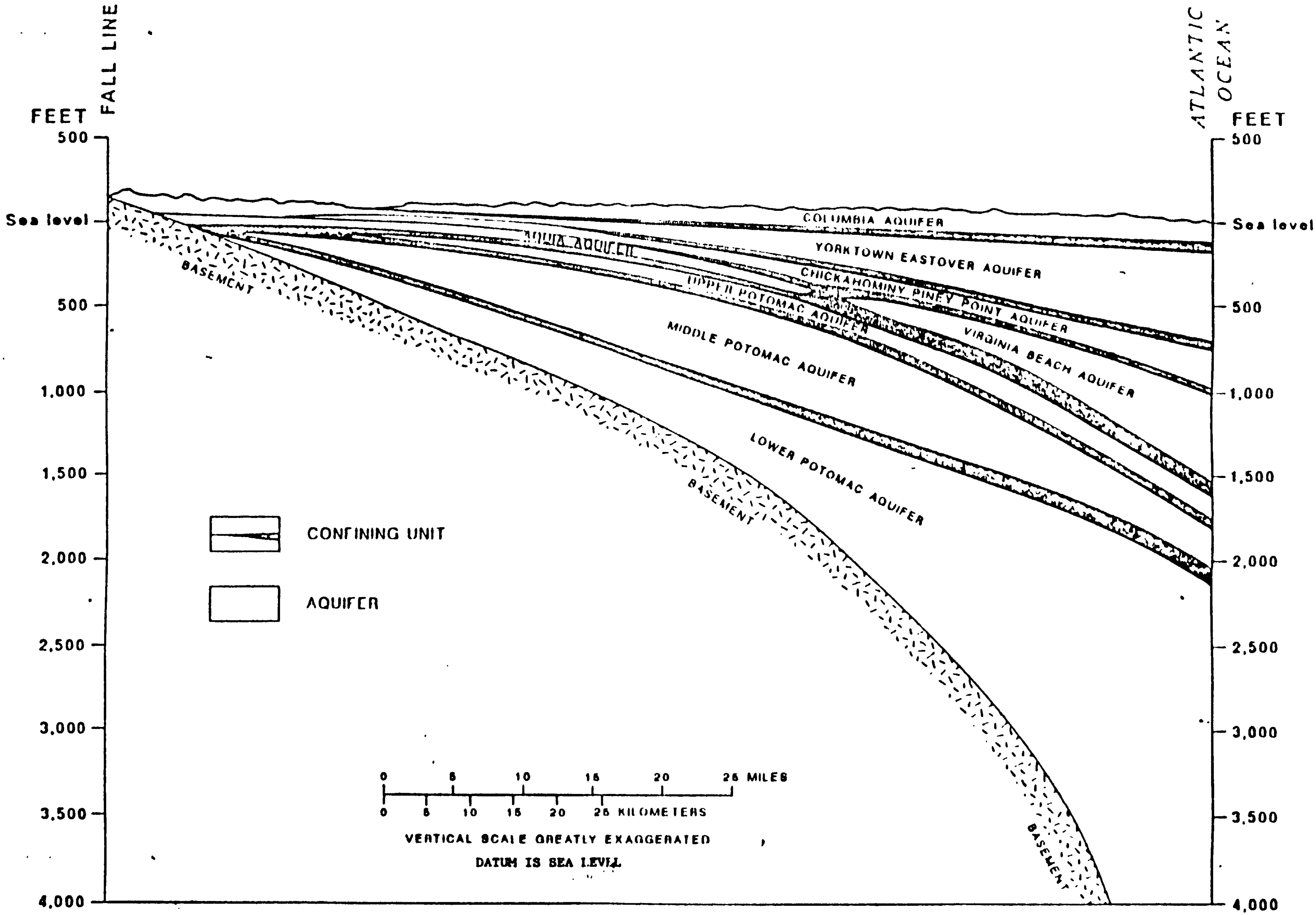


Figure 2. General depth of aquifers, confining units, and basement from the Fall Line through southeastern Virginia

## EVALUATION OF MUNICIPAL WITHDRAWALS

A digital flow model developed by Hamilton and Larson (1988) was used to simulate ground-water flow conditions in southeastern Virginia. Three simulations--1986 withdrawals, total permitted municipal withdrawals, and total permitted municipal withdrawals reduced by 50 percent--were used to evaluate ground water as a source for municipal water supply and to determine the effects of these withdrawals on 1986 water levels.

### Simulation of 1986 Withdrawals

A simulation of 1986 ground-water flow conditions was conducted to establish a base from which to compare ground-water flow conditions that would result from simulated increases in withdrawal. Current (1988) ground-water flow conditions would have been preferred for the analysis, but, because withdrawal data had been reported only through 1986 at the time of this investigation, simulation of more recent conditions was not possible. Although ground-water withdrawal data had been reported through 1986, data had been compiled only through 1983 prior to this investigation. The U.S. Geological Survey and the Virginia Water Control Board (VWCB) updated annual ground-water withdrawals from the Virginia Coastal Plain for the period 1984 through 1986. Average ground-water withdrawal during this period was about 88 Mgal/d (million gallons per day). This average rate is compared in figure 3 to prior average rates used in model simulations by Hamilton and Larson (1988). Estimated withdrawal from the model area for the 1986 calendar year was about 92 Mgal/d, of which about 88 Mgal/d were withdrawn from the Virginia part of the modeled area (table 1). Comparison of simulated 1986 water levels in the major aquifers (figs. 4-8) are in close agreement with water levels measured during 1983 by Hamilton and Larson (1988), because the change in pumpage from 1983 to 1986 was minimal.

### Simulation of Total Permitted Municipal Withdrawals

A simulation was conducted to estimate ground-water flow conditions that would result from municipal users withdrawing ground water at their present permitted rates. Although industrial use also is permitted and many users are currently withdrawing less water than their permits allow, permitted industrial use was not simulated because the primary purpose of this report is to examine the effects of permitted municipal pumpage on 1986 ground-water flow conditions. Permitted municipal ground-water use was compiled from information provided by the VWCB (fig. 9 and table 2). The simulation also included withdrawals increased for other users, including industry, because it is expected that their need for water will increase by the time municipalities reach their permitted rates. Withdrawal rates for other users were increased by the annual growth rate estimated for the region in which the user resides. Annual growth rates of 1.49 and 1.90 percent were applied to users north and south of the James River, respectively (Southeastern Virginia Planning District Commission, 1987). Local planners expect municipal users to need most of their permitted withdrawals by the year 1995. Thus, increases were compounded annually through and including 1995. Withdrawal by Union Camp Corporation,[1] the largest ground-water user in southeastern Virginia, was kept at the 1986 estimate of 33.2 Mgal/d (permitted rate, 43.316 Mgal/d) because the trend in this withdrawal indicates that pumpage

[1] Use of this firm name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

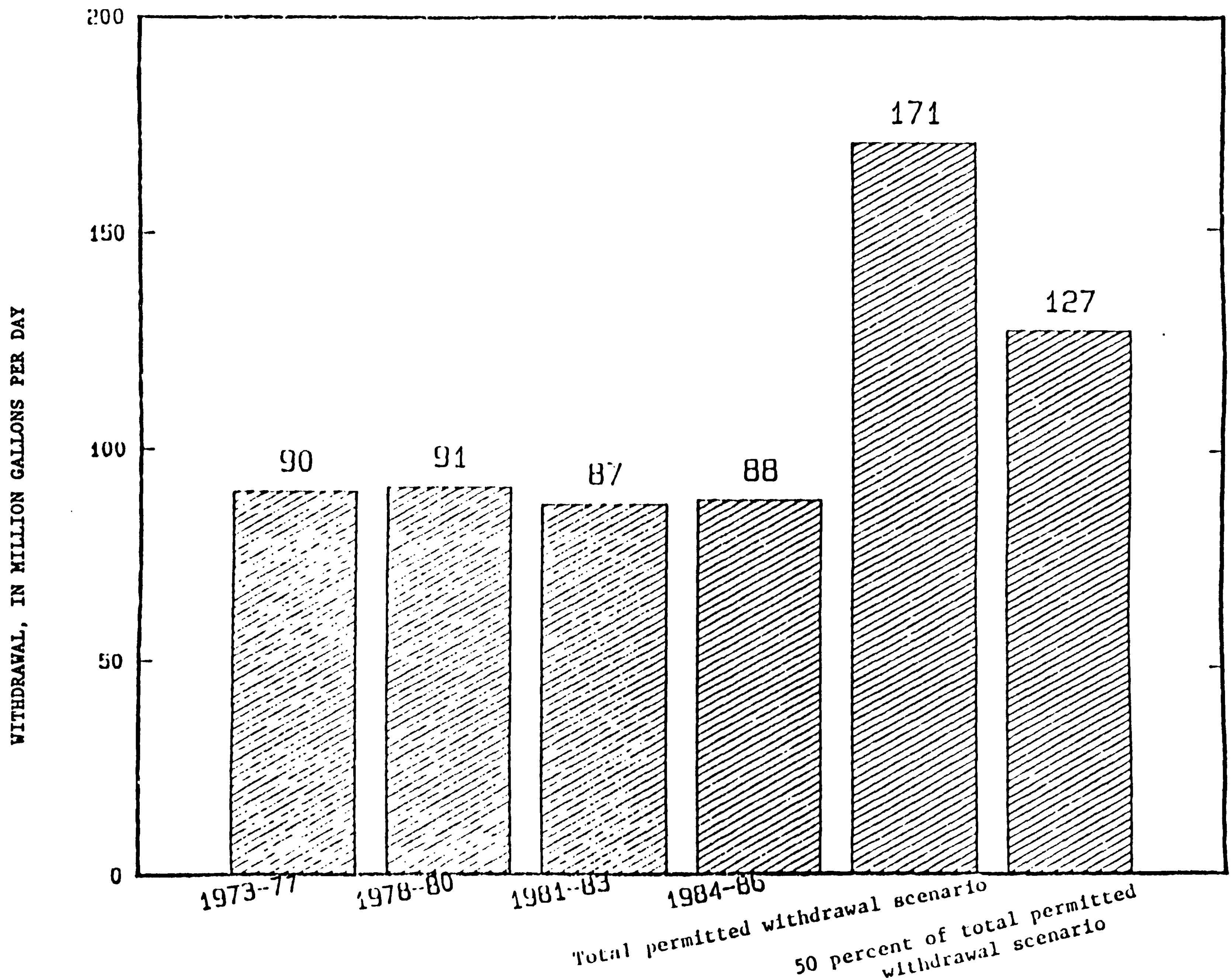


Figure 3. Ground-water withdrawal rates for simulated pumping periods

Table 1.-- Estimated ground-water withdrawal rates used in model simulations

[Rates are in millions gallons per day]

| | Withdrawal rates | | | |
|---|---|---|---|---|
| Period | Model area | Permitted municipal users | Virginia part of model | Change in withdrawal 1986 in Virginia |
| 1984-86 average | 88 | 12 | 84 | -- |
| 1986 | 92 | 15 | 88 | -- |
| Permitted municipal scenario | 171 | 88 | 167 | 79 |
| 50-percent permitted municipal scenario | 127 | 44 | 123 | 35 |

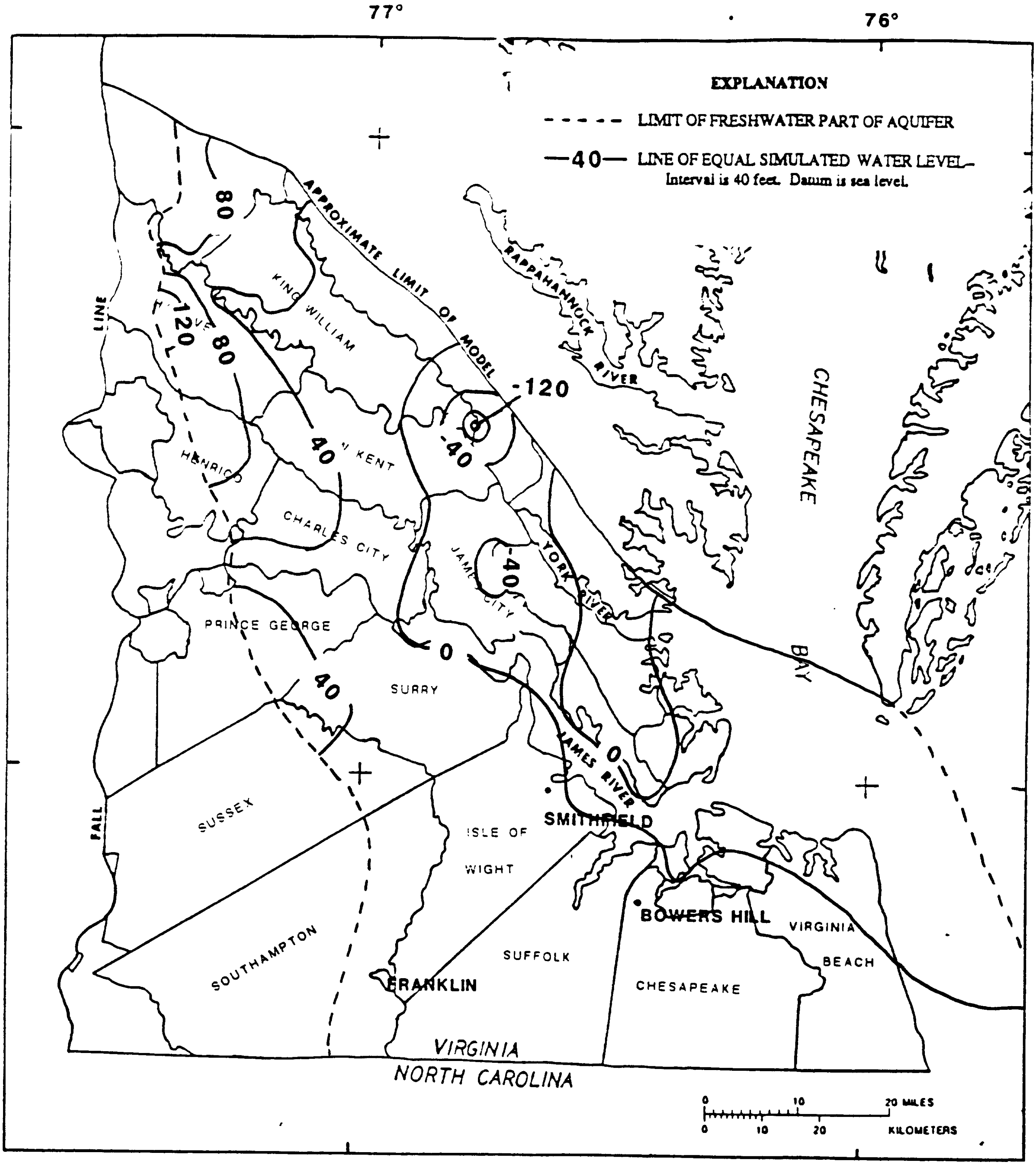


Figure 4. Simulated water levels for 1986 in Chickahominy-Piney Point aquifer

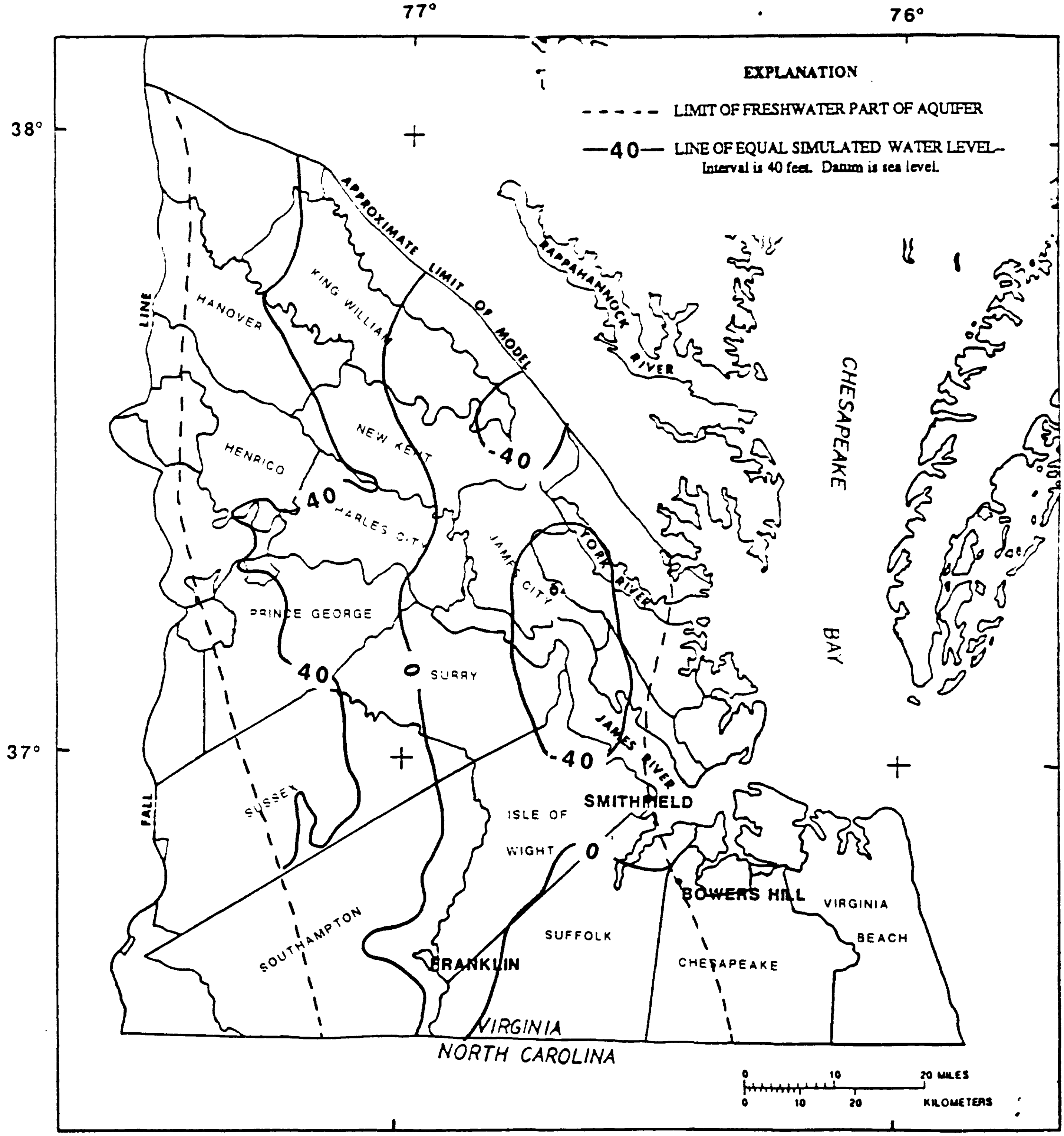


Figure 5. Simulated water levels for 1986 in Aquia aquifer

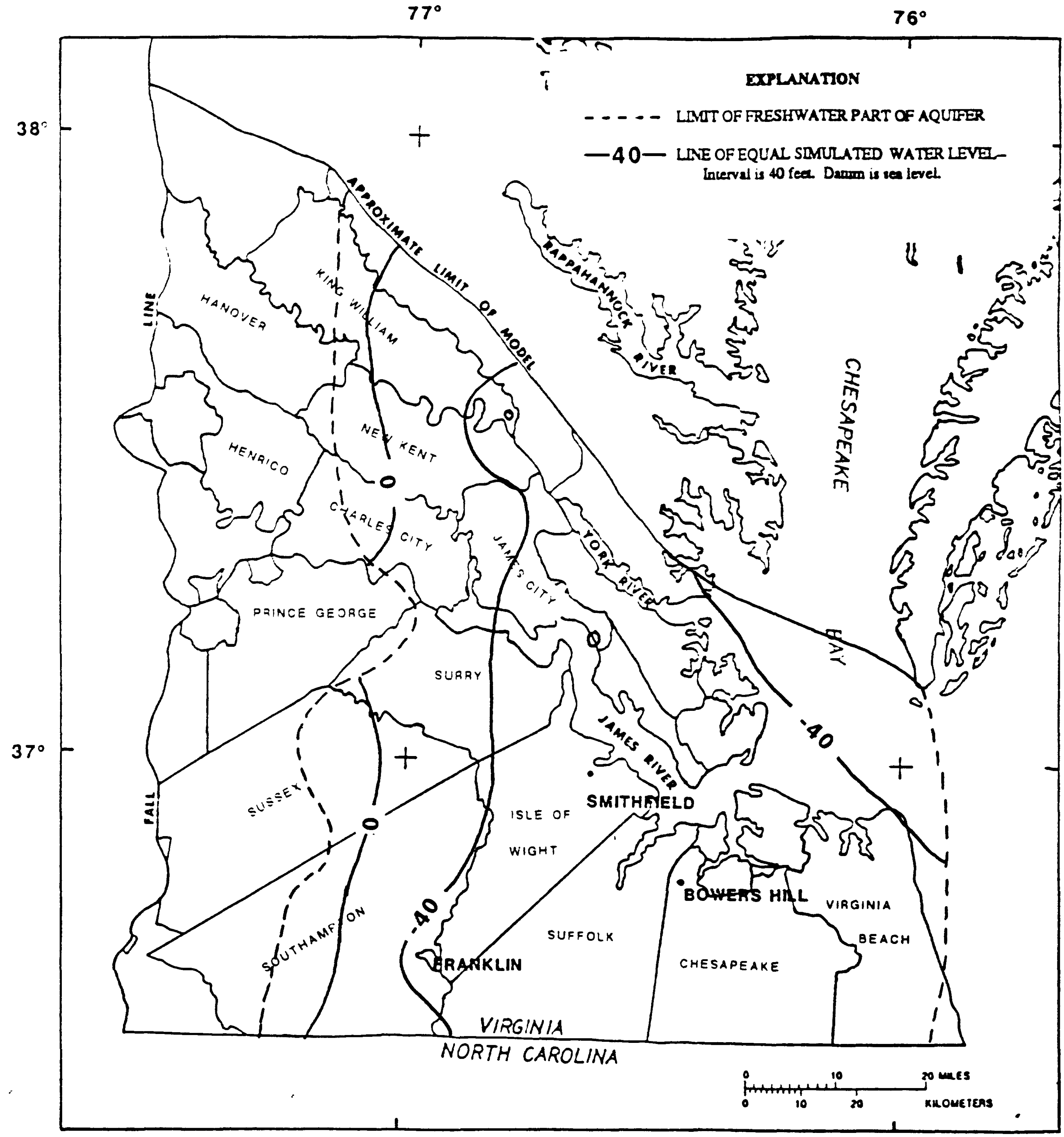


Figure 6. Simulated water levels for 1986 in upper Potomac aquifer

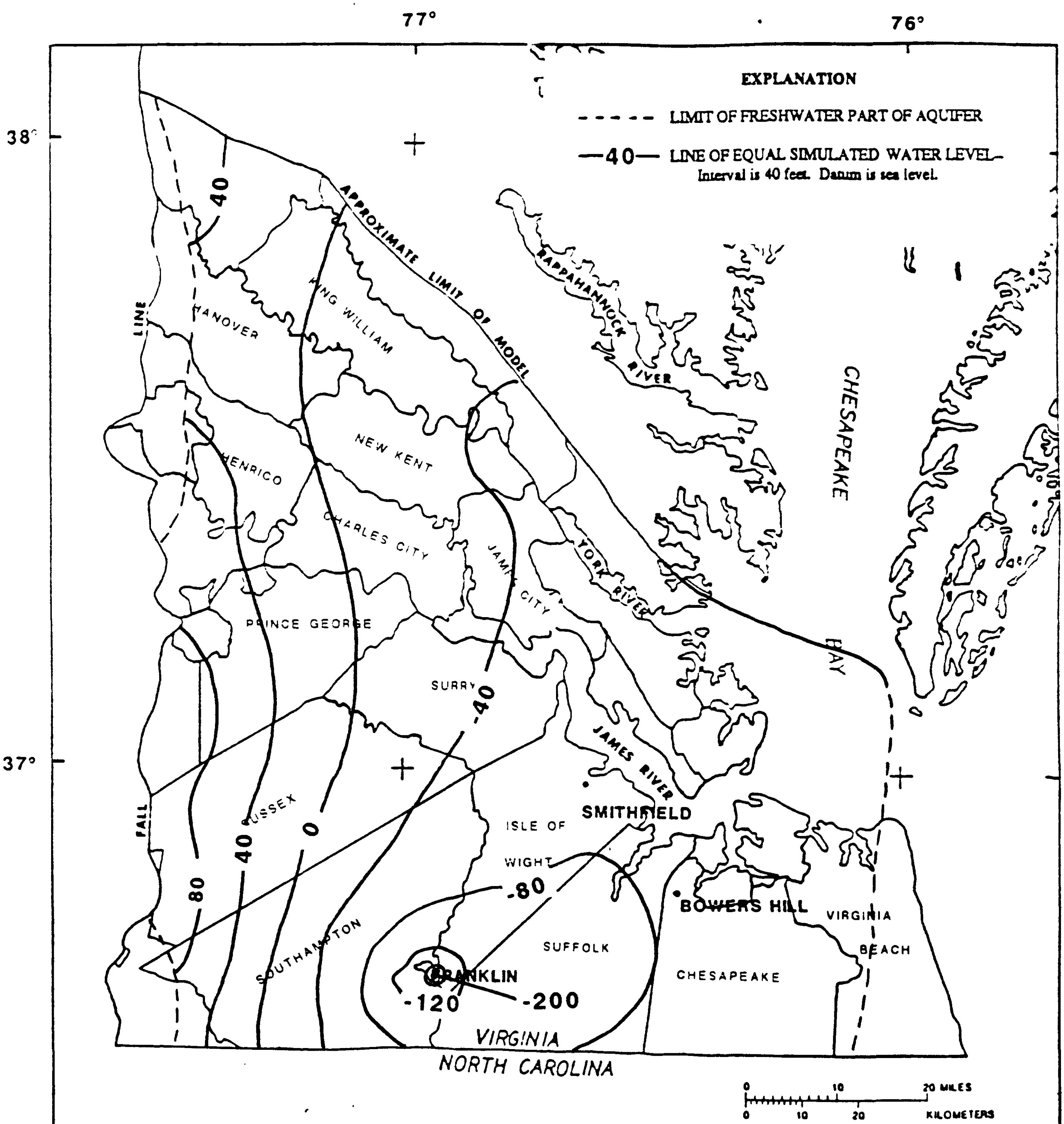


Figure 7. Simulated water levels for 1986 in middle Potomac aquifer

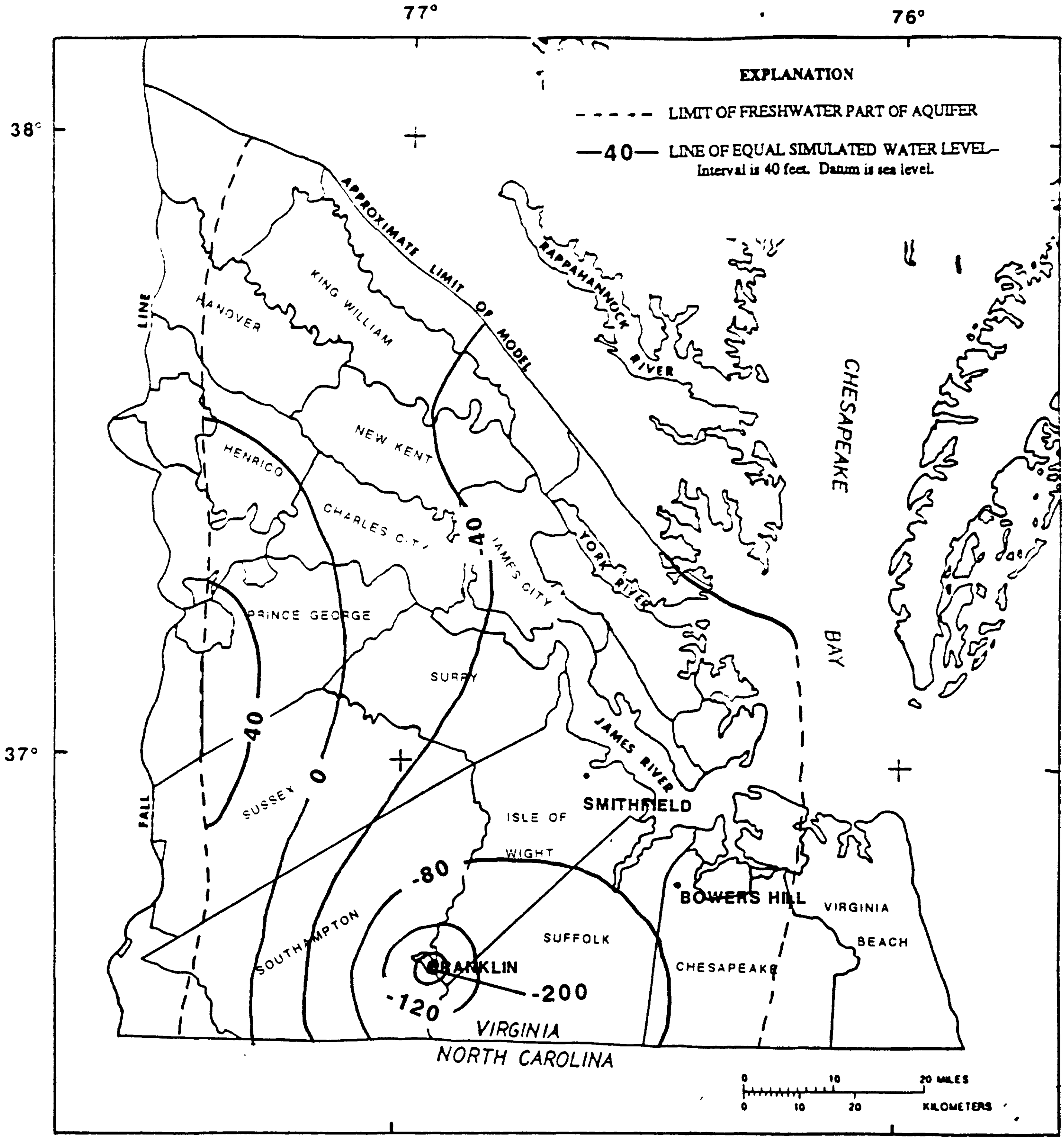


Figure 8. Simulated water levels for 1986 in lower Potomac aquifer

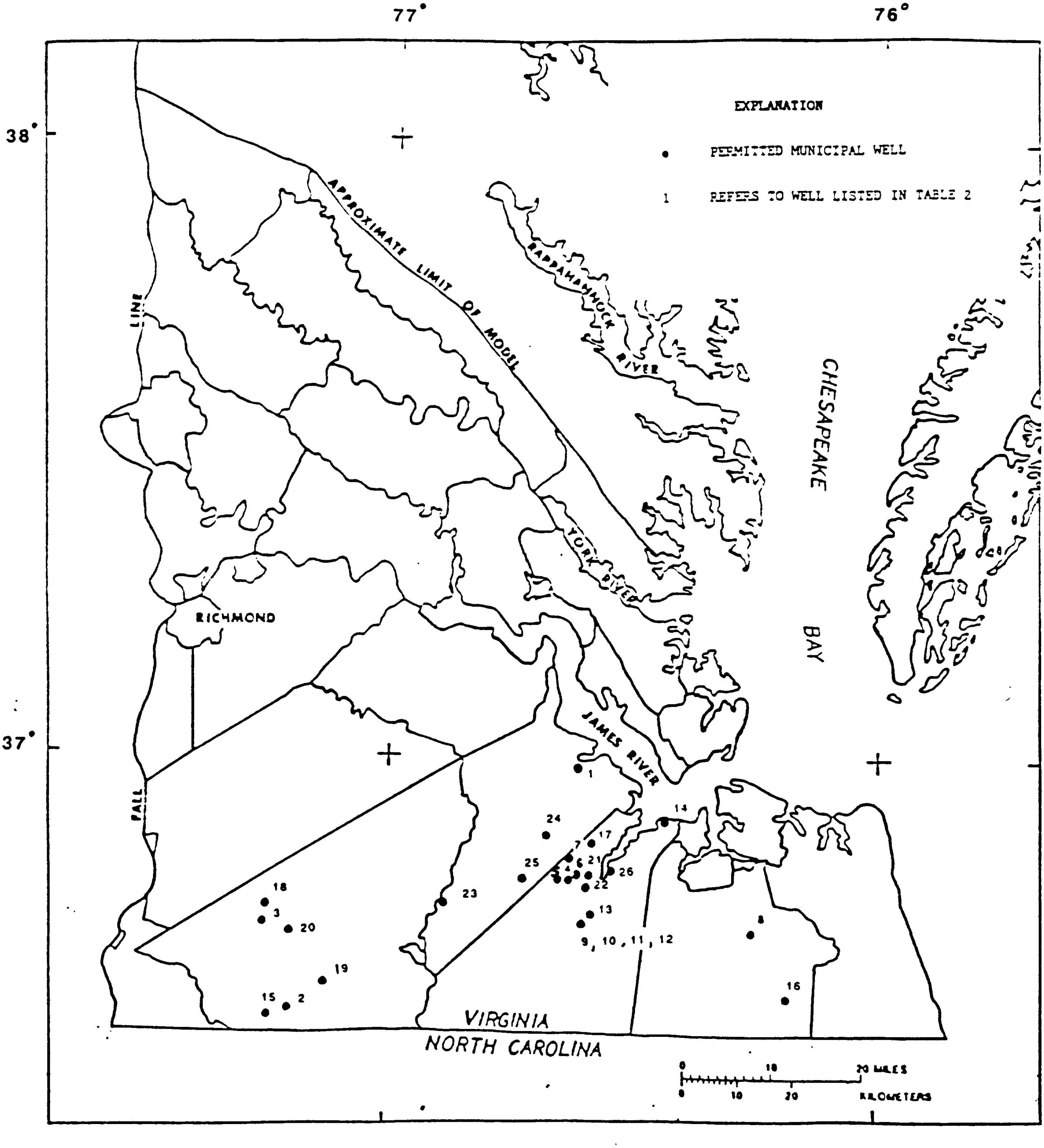


Figure 9. Locations of permitted municipal withdrawals

Table 2.-- Estimated municipal permitted withdrawal rates

[Mgal/d is million gallons per day]

| Name | Map number[a] | Permitted pumpage (Mgal/d) | Aquifers penetrated |
|---|---|---|---|
| Town of Smithfield | 1 | 0.710 | Upper Potomac |
| Town of Boykin | 2 | .250 | Middle Potomac |
| Southhampton Cor.Unit | 3 | .547 | Middle Potomac |
| Norfolk-well A | 4 | 4.320 | Upper and middle Potomac |
| Norfolk-well B | 5 | 3.888 | Upper and middle Potomac |
| Norfolk-well C | 6 | 3.888 | Upper and middle Potomac |
| Norfolk-well D | 7 | 3.888 | Upper, middle and lower Potomac |
| Ches. Civic Center | 8 | 14.914 | Yorktown-Eastover, upper and middle Potomac |
| Portsmouth-well A | 9 | 2.911 | Middle Potomac |
| Portsmouth-well B | 10 | 2.513 | Upper and middle Potomac |
| Portsmouth-well C | 11 | 3.300 | Upper and middle Potomac |
| Portsmouth-well D | 12 | 3.000 | Upper and middle Potomac |
| Portsmouth-well E | 13 | 4.000 | Middle Potomac |
| Tidewater Com. Col. | 14 | .435 | Yorktown-Eastover |
| Branchville | 15 | .659 | Lower Potomac |
| St. Brides Cor. Unit | 16 | .283 | Columbia and Yorktown-Eastover |
| City of Suffolk | 17 | 9.795 | Yorktown-Eastover, upper and middle Potomac |
| Capron Cor. Unit | 18 | .012 | Middle Potomac |
| Town of Newsons | 19 | .100 | Middle Potomac |
| Town of Capron | 20 | .288 | Middle Potomac |
| Va. Beach-well A | 21 | 4.039 | Middle Potomac |
| Va. Beach-well B | 22 | 4.039 | Middle Potomac |
| Va. Beach-well C | 23 | 4.039 | Middle and lower Potomac |
| Va. Beach-well D | 24 | 4.000 | Middle Potomac |
| Va. Beach-well E | 25 | 4.000 | Middle Potomac |
| Va. Beach Drivers | 26 | 8.064 | Upper and middle Potomac |

[a]Locations shown on figure 9.

has stabilized. Rates for the few ground-water users within the model area in North Carolina were kept at rates reported for 1980 because more recent data were unavailable.

Total ground-water withdrawals used in the simulation were about 171 Mgal/d (fig. 3 and table 1)--an increase of about 79 Mgal/d over the 1986 estimate of 92 Mgal/d. Permitted municipal use accounted for 73 Mgal/d or about 92 percent of the total increase, whereas compounded annual growth accounted for the remaining 6 Mgal/d. Permitted municipal use alone increased the quantity of ground-water withdrawn about 83 percent above 1986 withdrawals.

Simulated water-level distributions are shown for some of the major aquifers in figures 10-14. Distributions represent steady-state flow conditions that show the maximum effect of increased pumpage. A ground-water system has reached a steady-state flow condition or hydraulic equilibrium when recharge to the system equals discharge from the system. This condition implies that water levels remain constant over time and that the storage component of the ground-water budget is negligible. The simulated ground-water system responding to permitted municipal pumpage stresses reaches near steady-state conditions in 15 years. Simulated drawdowns (water-level declines from 1986) are shown in figures 15-19 and exceed 175 feet in the lower, middle, and upper Potomac aquifers and 100 and 70 feet in the Aquia and Chickahominy-Piney Point aquifers, respectively (table 3). The maximum simulated drawdown was 265 feet in the middle Potomac aquifer. The predicted declines are in addition to declines caused by ground-water withdrawals in 1986. In a linear confined system, overall water-level response is directly proportional to the change in stress. The magnitude of local decline, however, is dependent on the distribution of local stresses. Drawdown cones are centered around the town of Bowers Hill in the Potomac aquifers, the town of Smithfield in the Aquia aquifer, and Chesapeake Bay in the Chickahominy-Piney Point aquifer. Water-level declines are substantial given that historic pumpage already has resulted in measured water-level declines of greater than 175 feet.

The simulated 1986 water levels do not represent steady-state flow conditions; therefore, some of the simulated decline could be attributed to water levels adjusting to 1986 pumpage. A steady-state simulation using 1986 withdrawals was made in order to quantify the amount of simulated decline that is not due to the increase in permitted municipal pumpage. The 1986 steady-state simulation indicated that near steady-state conditions existed in the 1986 simulation; the difference in water levels predicted by the two simulations is minimal.

Distances between simulated water levels and the respective tops of the Chickahominy-Piney Point, Aquia, upper Potomac, and middle Potomac aquifers are shown in figures 20-23. Water levels that decline below the top of a confined aquifer cause unconfined conditions within the aquifer and can result in dewatering and associated irreversible changes within the aquifer. Dewatering can contribute to compaction of aquifer sediment and eventual decreases in aquifer yields. In general, simulated water levels are above the tops of their respective aquifers, except in the updip areas in the extreme western part of the model where aquifers thin and approach the surface. Distances greater than zero indicate that from a regional perspective dewatering would be minimal. However, because simulated water levels represent the average value over a model nodal block, actual drawdowns within and near wells would be greater than predicted and could result in local dewatering. In addition, aquifer tops often were interpreted from sparse data. Therefore, results should not be used to

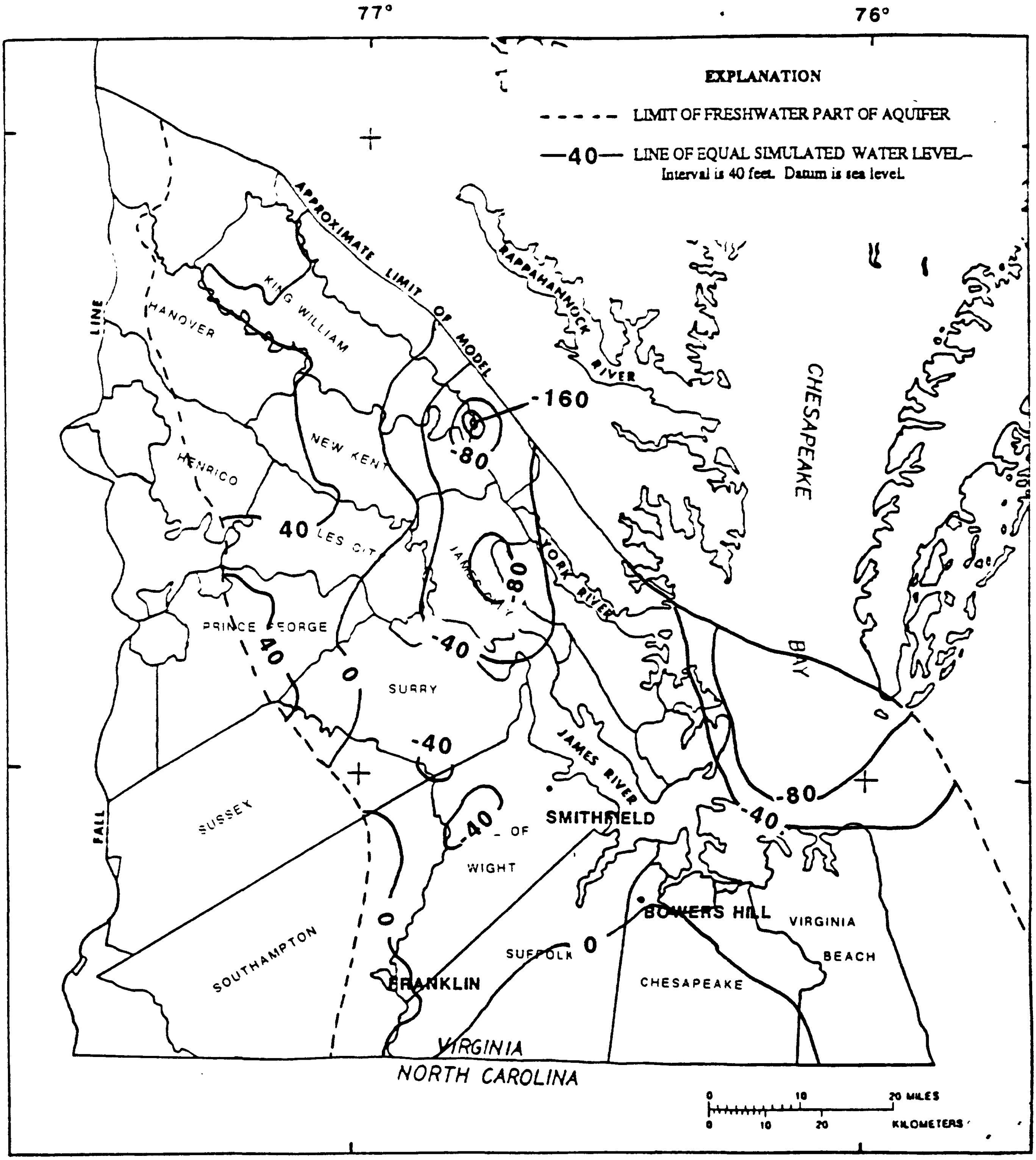


Figure 10. Simulated water levels for total permitted municipal withdrawal in Chickahominy-Piney Point aquifer

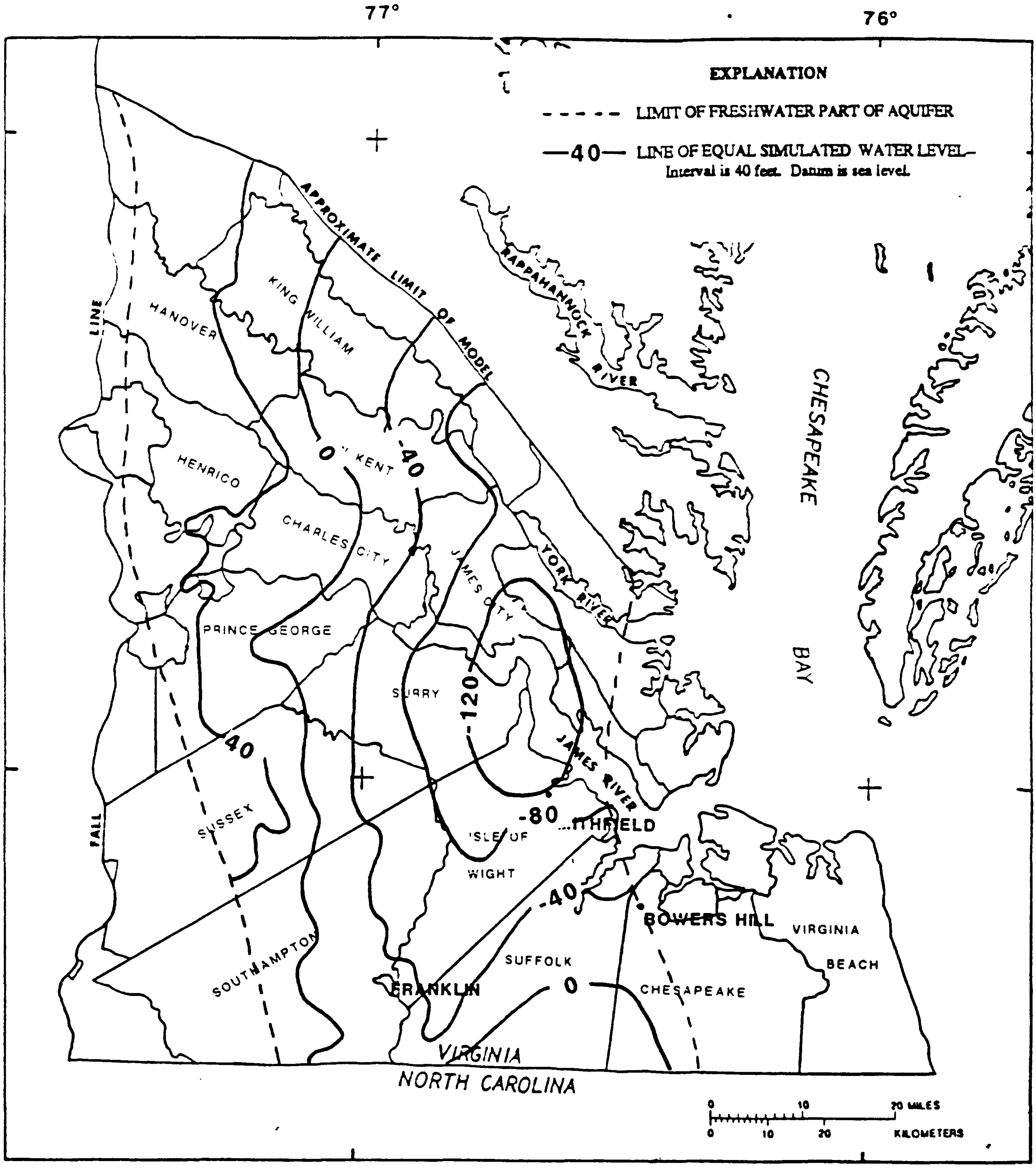


Figure 11. Simulated water levels for total permitted municipal withdrawal in Aquia aquifer

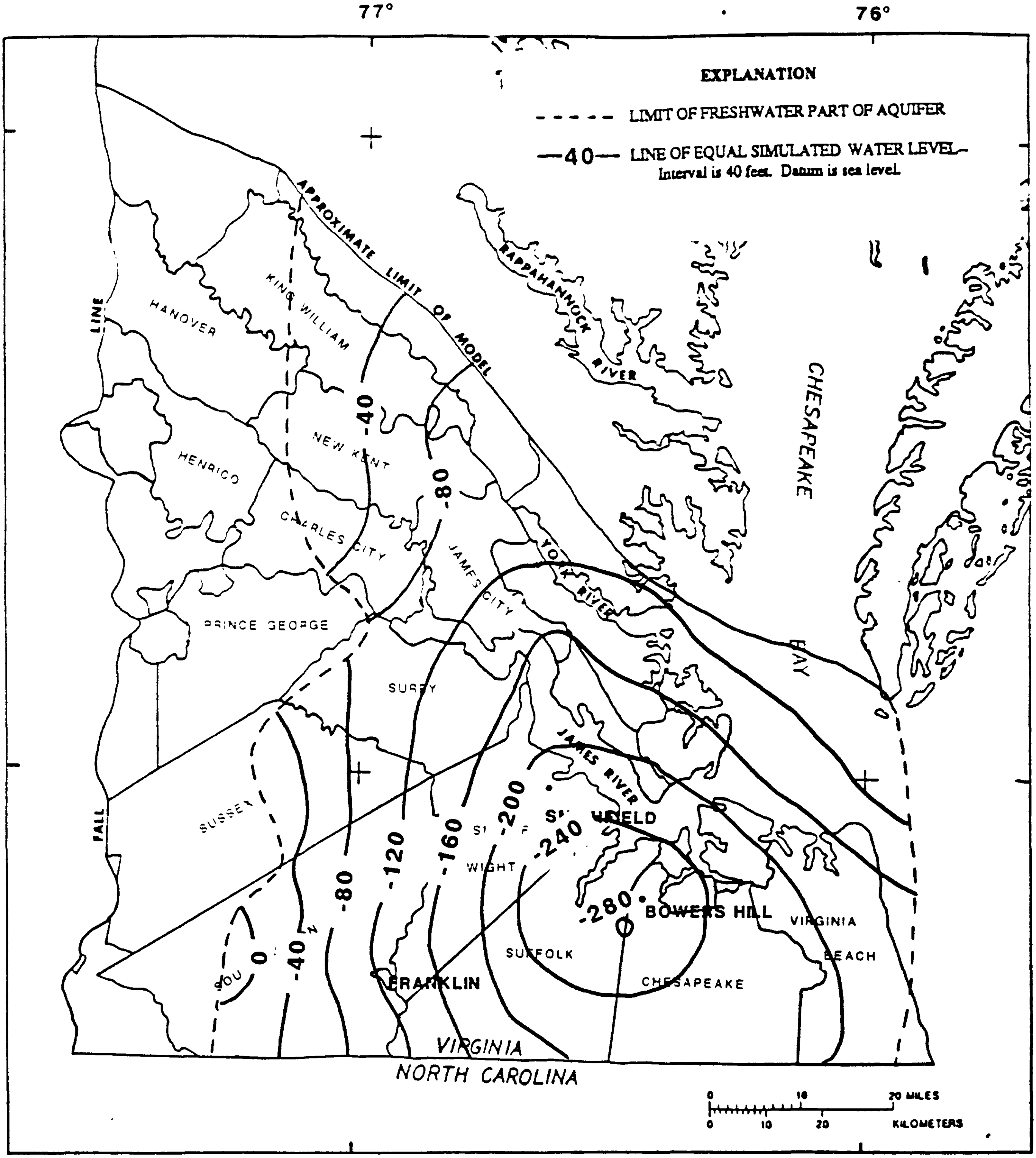


Figure 12. Simulated water levels for total permitted municipal withdrawal in upper Potomac aquifer

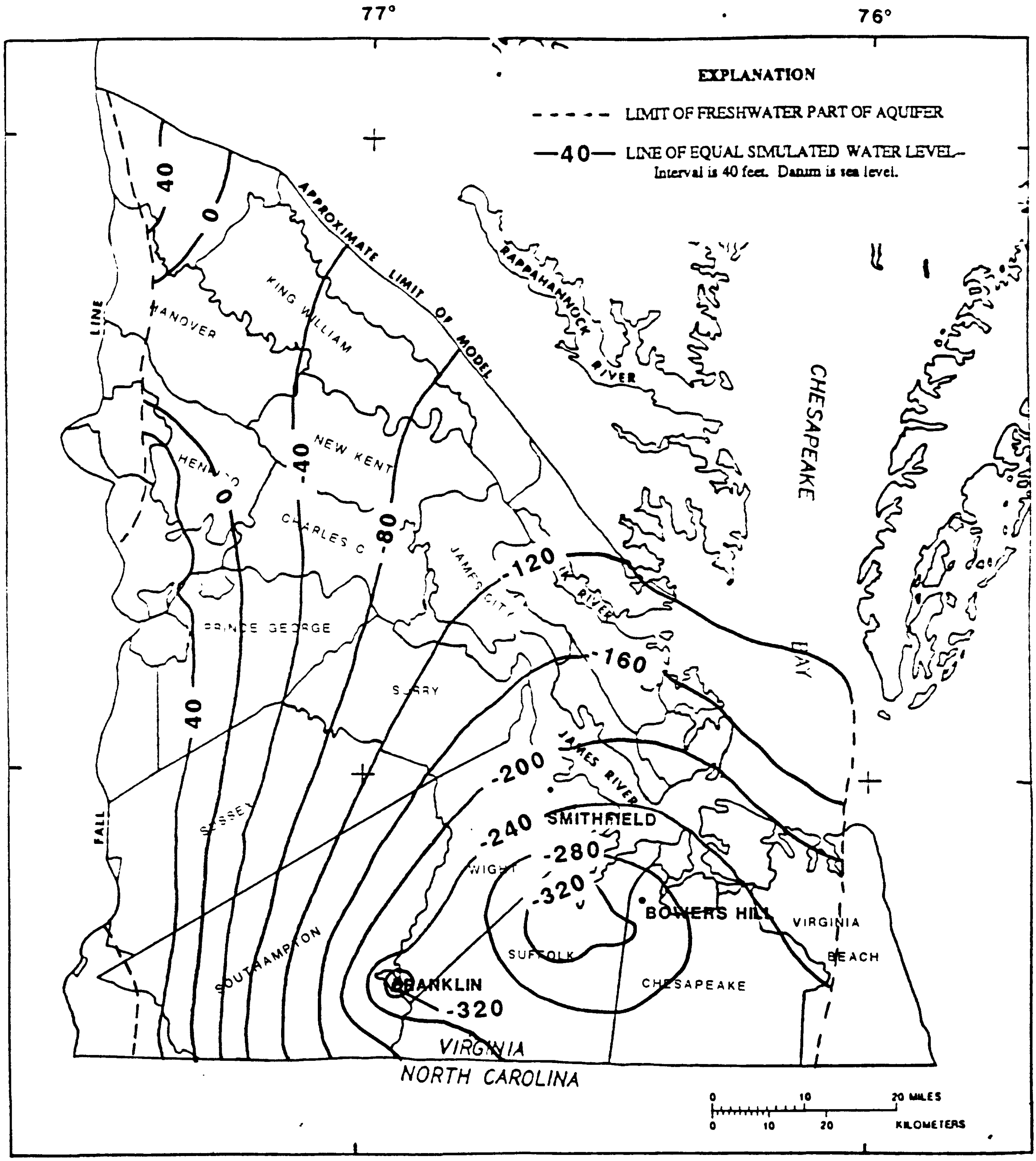


Figure 13. Simulated water levels for total permitted municipal withdrawal in middle Potomac aquifer

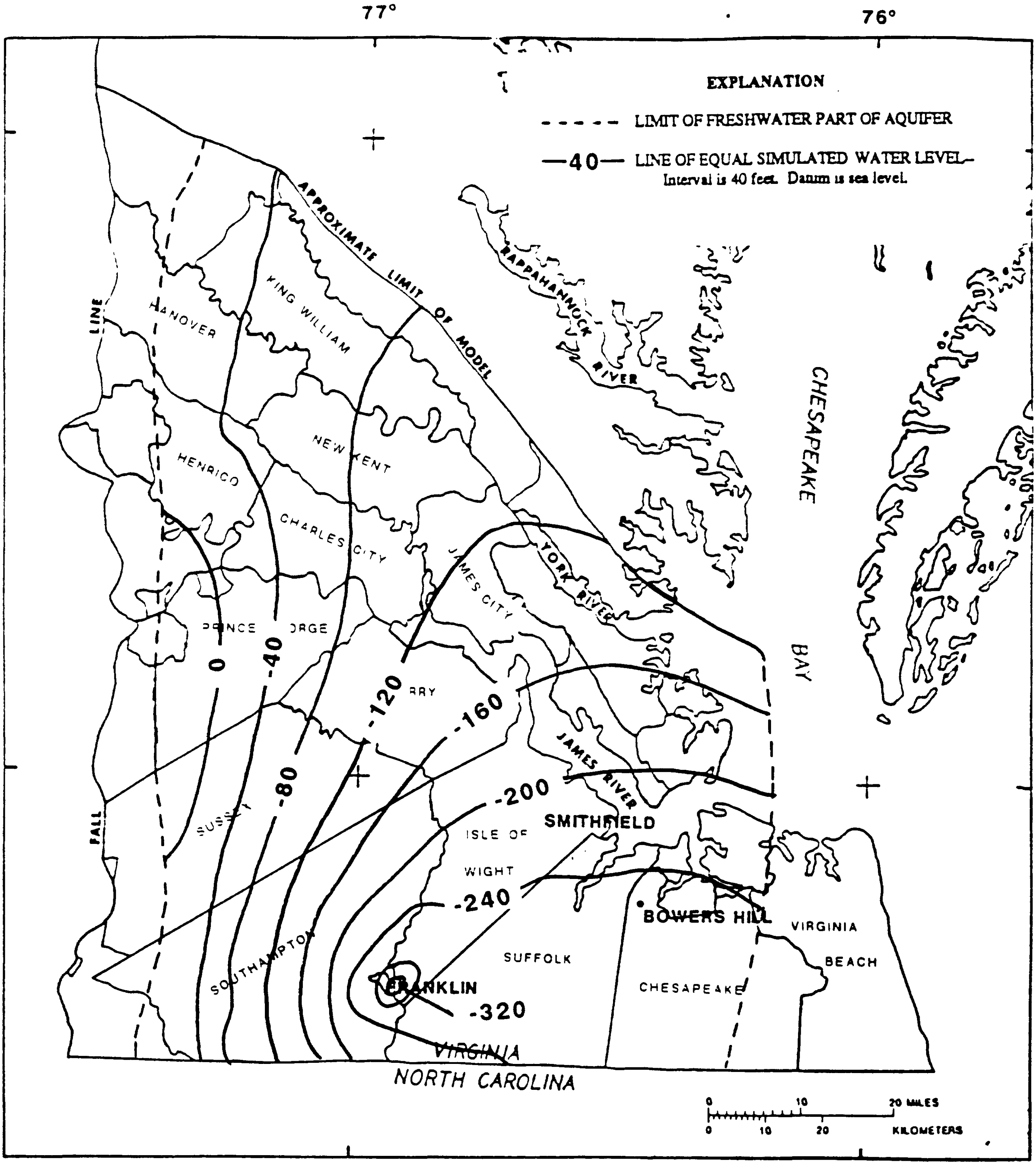


Figure 14. Simulated water levels for total permitted municipal withdrawal in lower Potomac aquifer

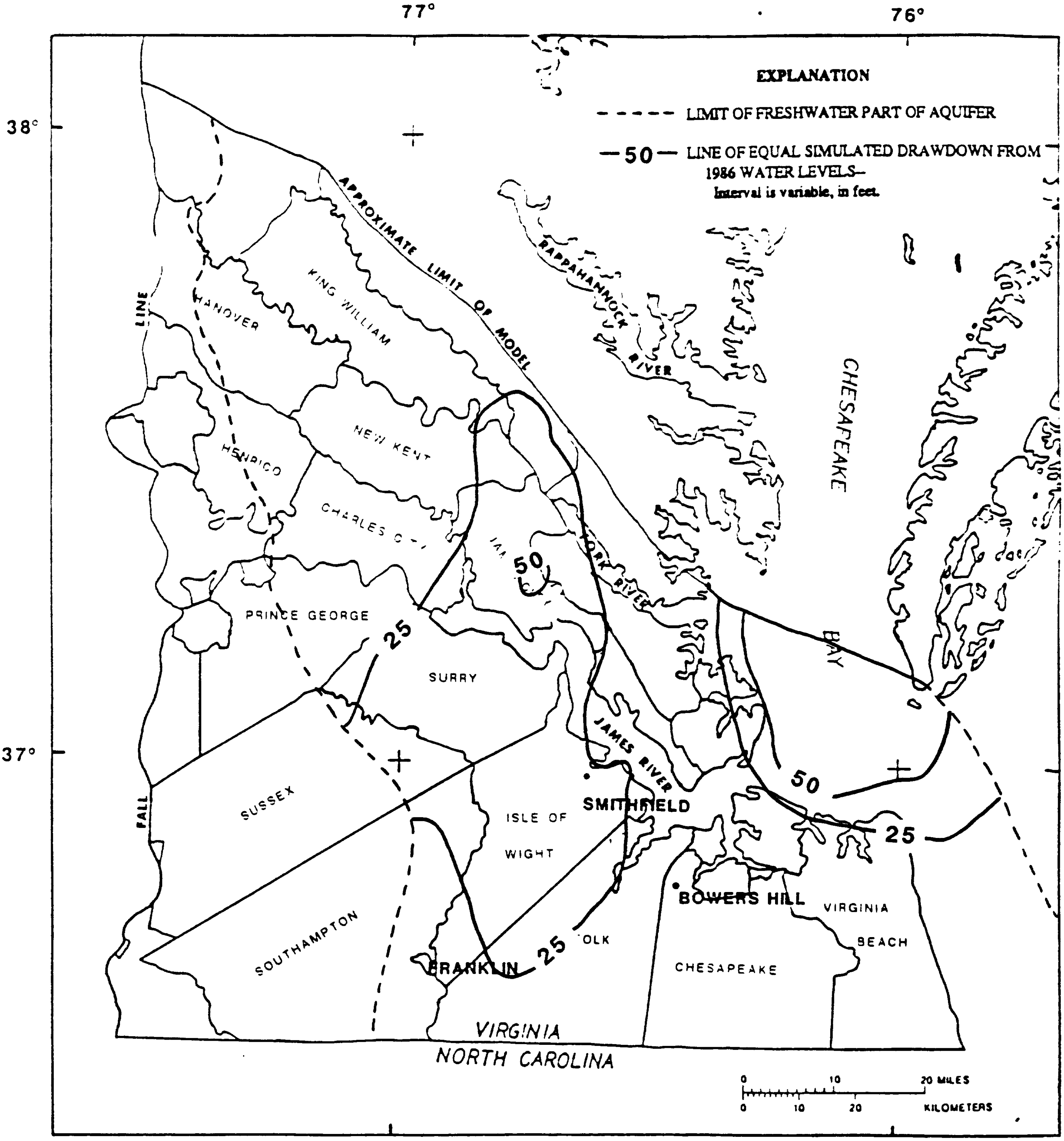


Figure 15. Simulated drawdown from 1986 for total permitted municipal withdrawal in Chickahominy-Piney Point aquifer

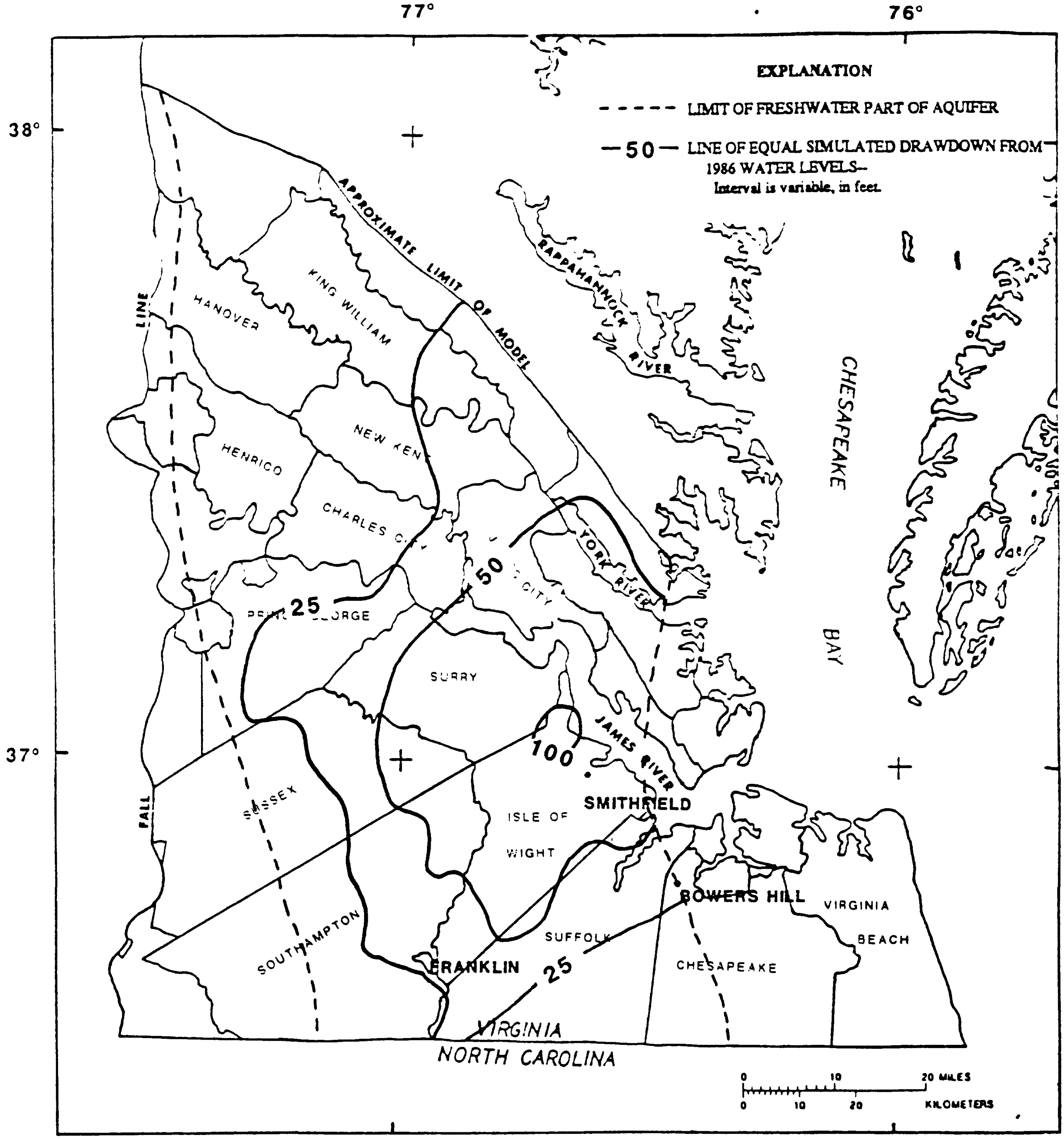


Figure 16. Simulated drawdown from 1986 for total permitted municipal withdrawal in Aquia aquifer

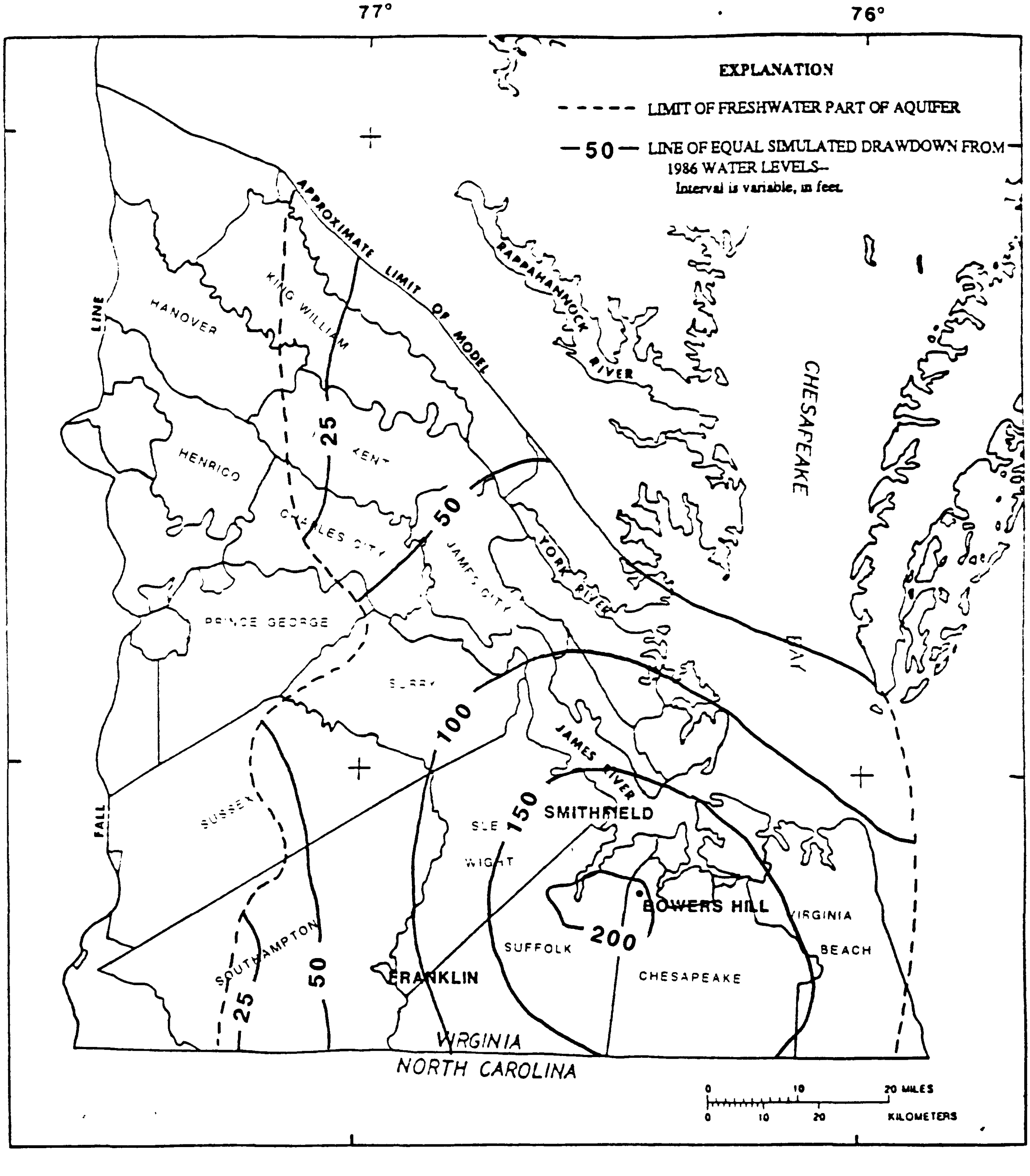


Figure 17. Simulated drawdown from 1986 for total permitted municipal withdrawal in upper Potomac aquifer

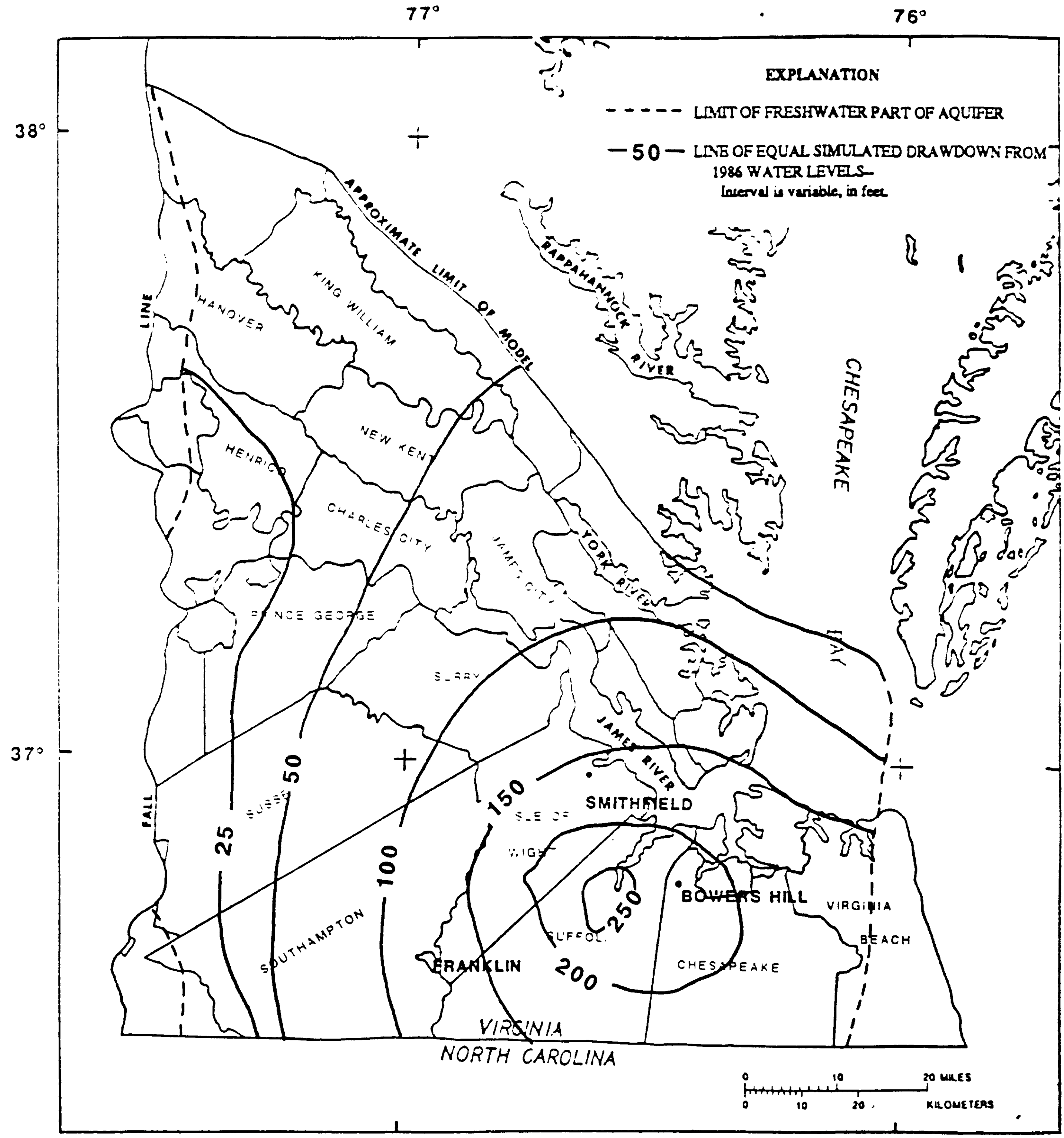


Figure 18. Simulated drawdown from 1986 for total permitted municipal withdrawal in middle Potomac aquifer

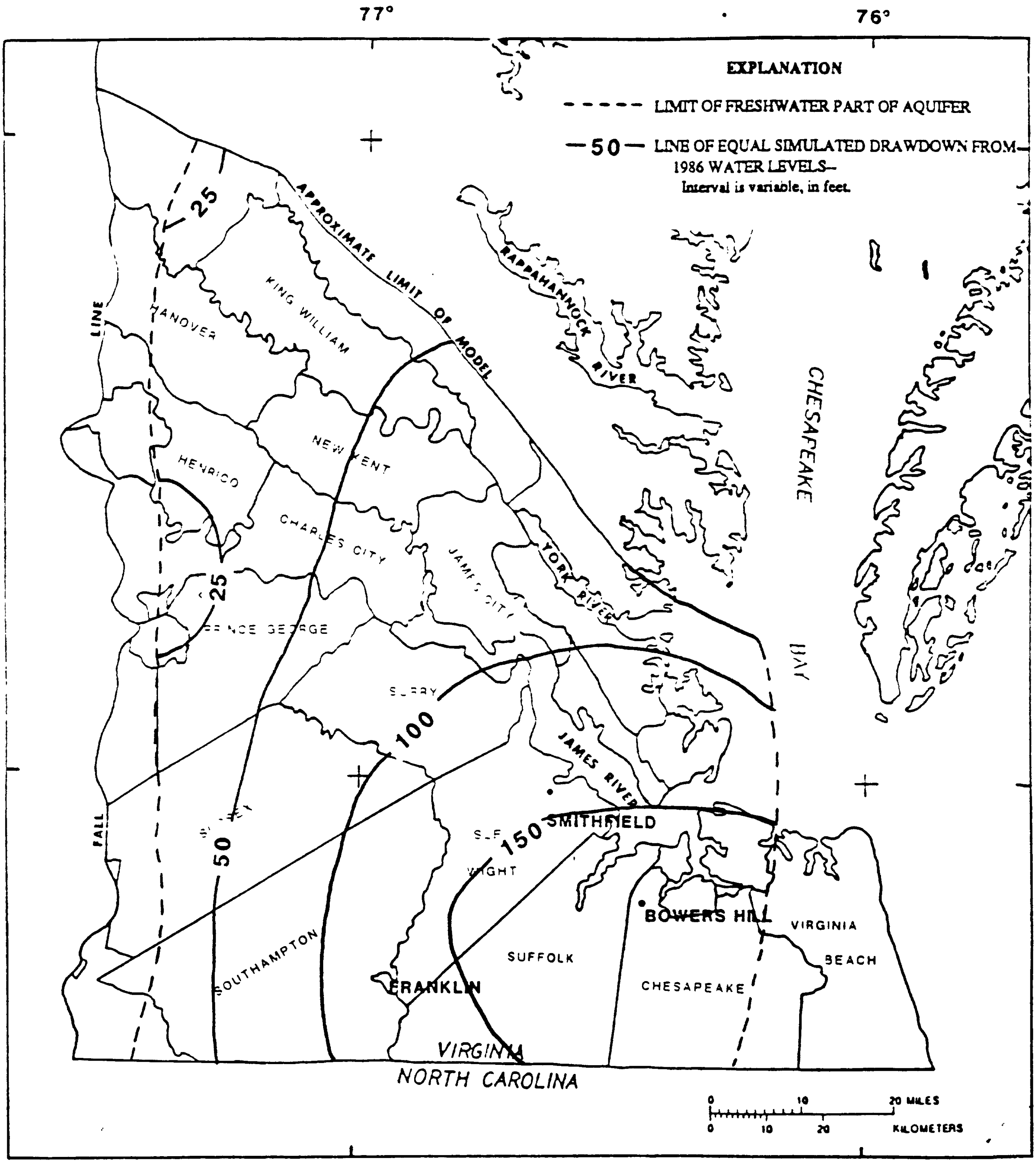


Figure 19. Simulated drawdown from 1986 for total permitted municipal withdrawal in lower Potomac aquifer

Table 3.-- Maximum simulated drawdown by aquifer

[Values in feet]

| Aquifer | Maximum drawdown: 100-percent municipal withdrawal | Maximum drawdown: 50-percent municipal withdrawal |
|---|---|---|
| Chickahominy-Piney Point | 75 | 39 |
| Aquia | 105 | 49 |
| Upper Potomac | 222 | 101 |
| Middle Potomac | 265 | 117 |
| Lower Potomac | 179 | 81 |

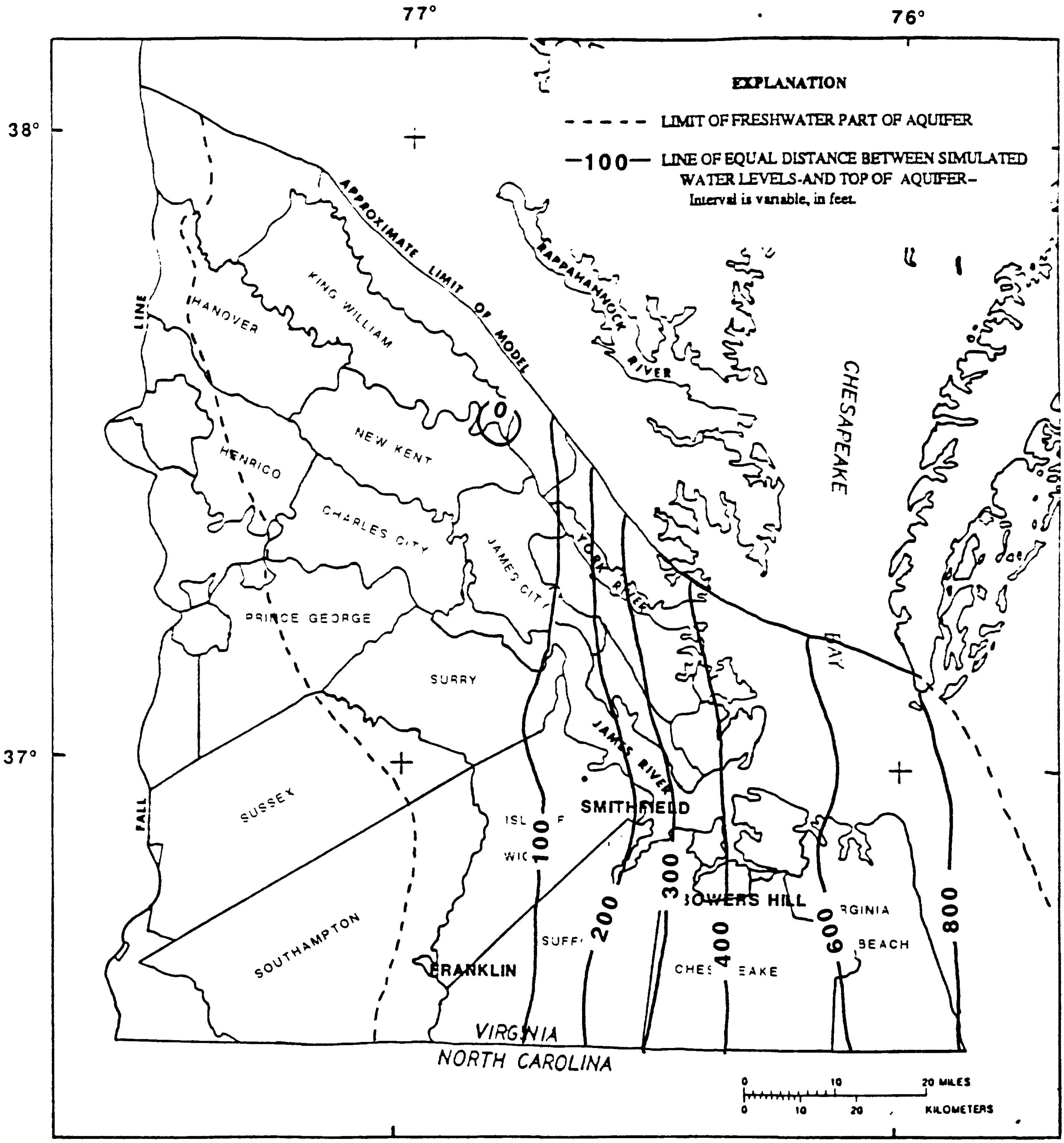


Figure 20. Distance from simulated water levels to top of aquifer for total permitted municipal withdrawal in Chickahominy-Piney Point aquifer

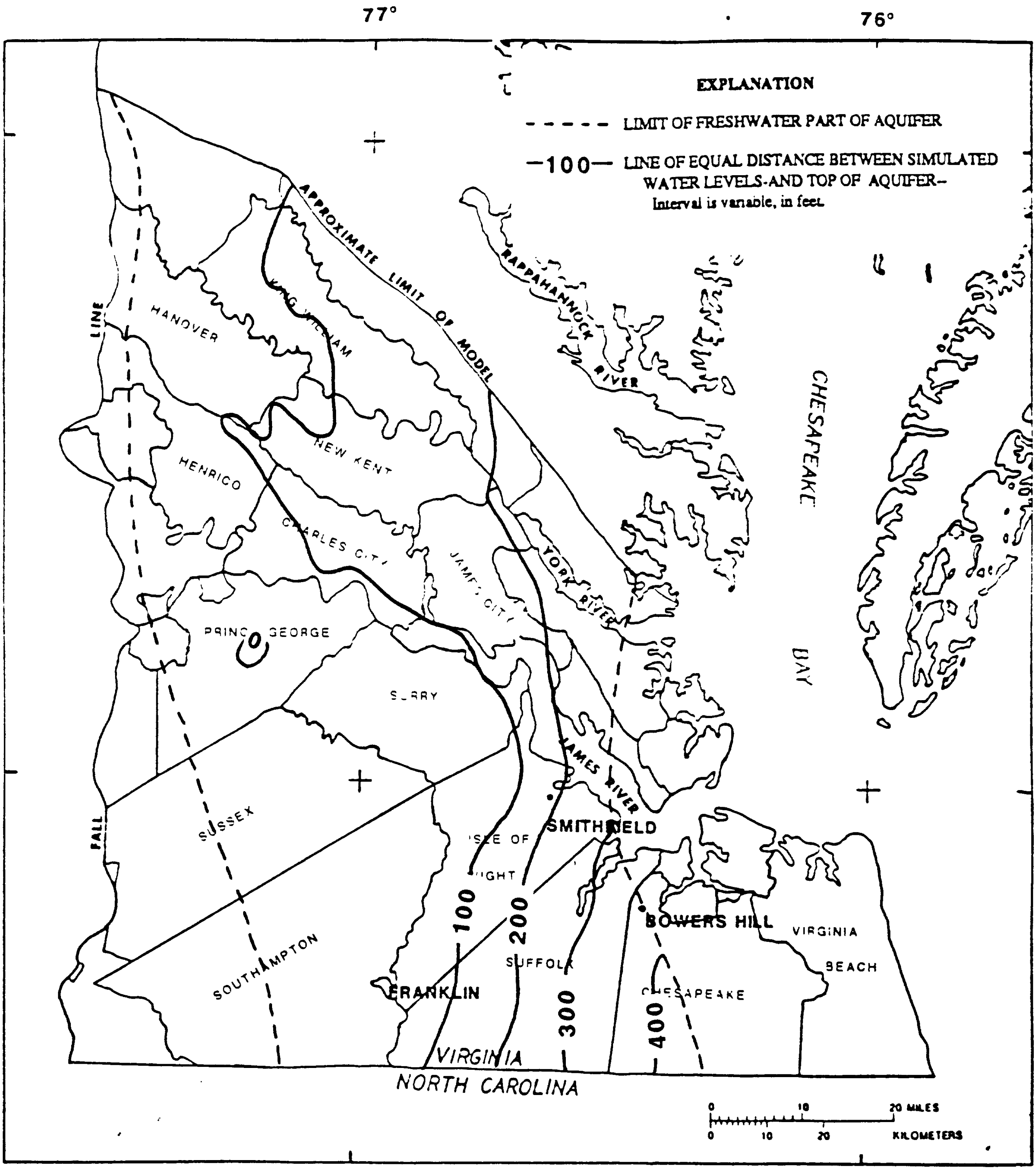


Figure 21. Distance from simulated water levels to top of aquifer for total permitted municipal withdrawal in Aquia aquifer

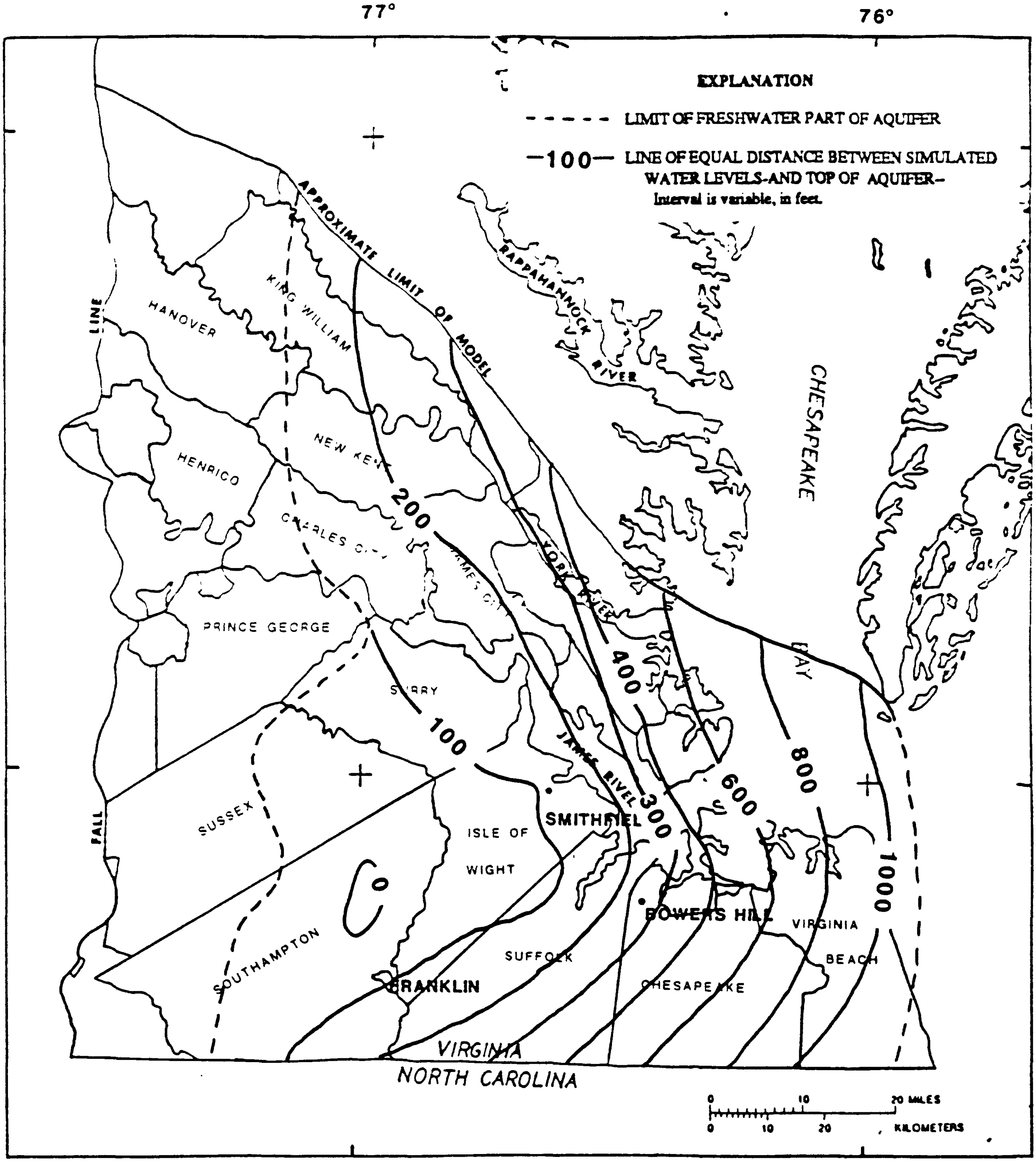


Figure 22. Distance from simulated water levels to top of aquifer for total permitted municipal withdrawal in upper Potomac aquifer

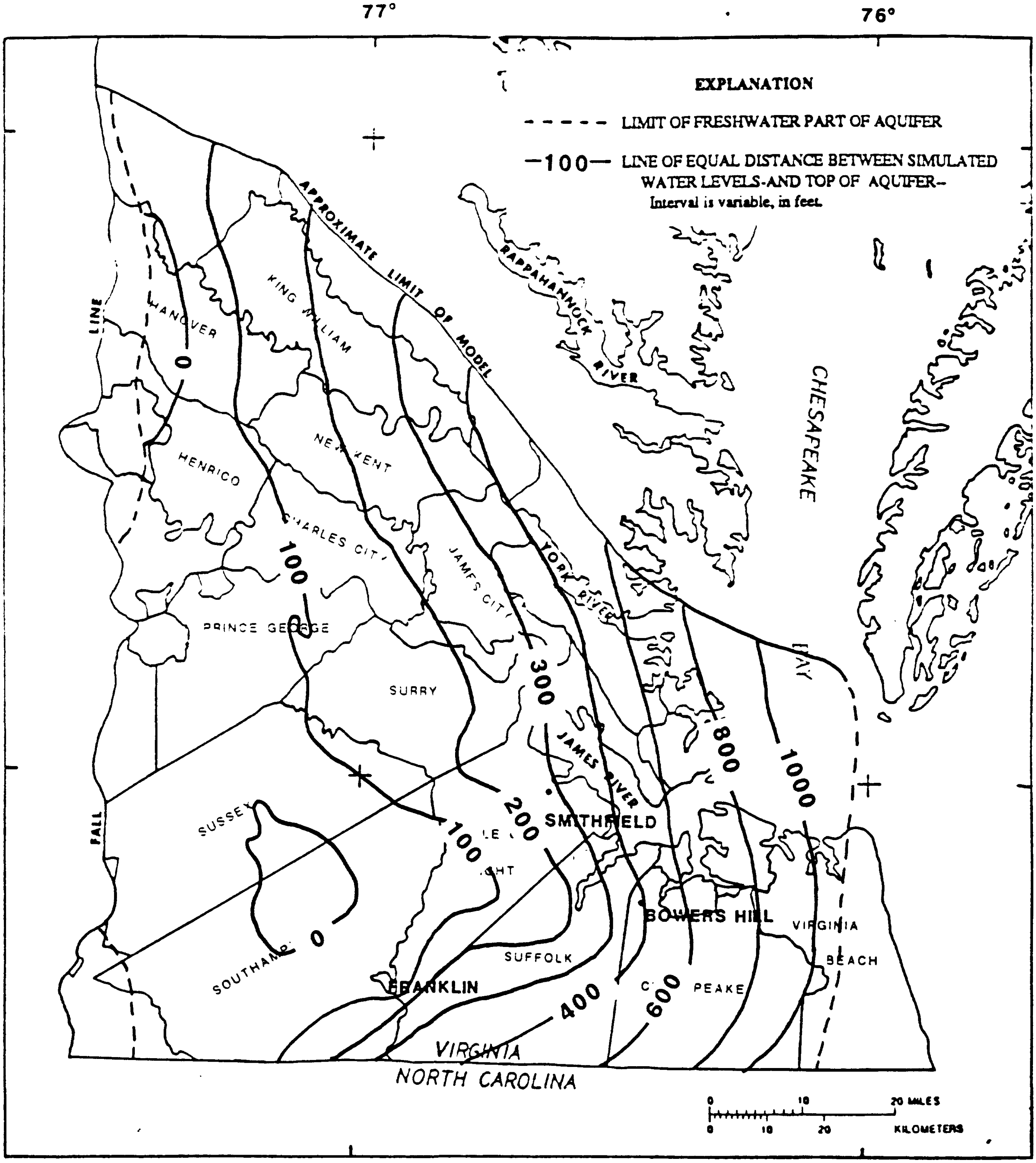


Figure 23. Distance from simulated water levels to top of aquifer for total permitted municipal withdrawal in middle Potomac aquifer

delineate specific areas of local dewatering but to indicate that dewatering could become a local problem under permitted municipal conditions.

The ground-water budget quantifies water entering and leaving the ground-water-flow system. Ground-water budgets for simulated conditions are compared in table 4. Sources of ground water are recharge from precipitation, recharge from surface water, and lateral inflow across the northern and southern model boundaries. Ground-water sinks are pumpage, discharge to surface water, and lateral outflow. The increase in pumpage of 83.6 Mgal/d from the 1986 simulation resulted in (1) a decrease of 66.2 Mgal/d in discharge to surface water, (2) an increase of 3.2 Mgal/d in induced recharge from surface water, (3) an increase of 14.3 Mgal/d in lateral inflow across the northern and southern model boundaries. Analysis of the budget flow components indicates that about 79 percent of the additional water withdrawn was replaced by decreased discharge to surface water. The water budget resulted in less than 0.03 percent error in mass balance (table 4).

## Simulation of 50 Percent of Total Permitted Municipal Withdrawals

A simulation was conducted to project ground-water flow conditions that would exist if municipal users withdrew ground water at 50 percent of their present permitted rates. Increases for non-municipal users were identical to those applied in the previous simulation. The amount of ground-water withdrawn in this scenario is not a 50 percent reduction in the amount of ground-water withdrawn in the total permitted municipal withdrawal scenario; the stress is not reduced uniformly in all wells throughout the model area. The total quantity of ground water withdrawn in this simulation was about 127 Mgal/d--an increase of about 35 Mgal/d from the 1986 estimate of 92 Mgal/d (table 1). Municipal users withdrawing ground water at 50 percent of their permitted rate accounted for 29 Mgal/d or about 82 percent of the total increase, while compounded annual growth accounted for the remaining 6 Mgal/d.

Simulated water-level distributions are shown for some of the major aquifers in figures 24-28. Drawdowns from 1986 water levels are shown in figures 29-33 and exceed 75 feet in the lower, middle, and upper Potomac aquifers and 45 and 35 feet in the Aquia and Chickahominy-Piney Point aquifers, respectively (table 3). The maximum simulated drawdown was in the middle Potomac aquifer at about 117 feet. Although much less extensive, drawdown cones are centered around the same areas as in the simulation of total permitted municipal withdrawal.

Distances between simulated water levels and the tops of respective aquifers are presented for the Chickahominy-Piney Point, Aquia, upper Potomac, and middle Potomac aquifers in figures 34-37. Water levels are well above aquifer tops throughout most of the model area. Projected water levels are below an aquifer top only in the northwestern-most part of the middle Potomac aquifer in the updip area of the aquifer. Because scenario results indicate large positive distances between water levels and aquifer tops, it is unlikely that any dewatering would occur.

The ground-water budget is compared to other simulated components of the water budget in table 4. The increase in pumpage of 39.6 Mgal/d from the 1986 simulation resulted in (1) a decrease of 31.2 Mgal/d in discharge to surface water, (2) an increase of 1.4 Mgal/d in recharge from surface water, (3) an increase of 7.1 Mgal/d in lateral inflow across the northern and southern

Table 4.-- Simulated ground-water budgets

[Modeled values, million gallons per day shown are not intended to imply accuracy to precision shown]

| Simulation | Sources | | | |
|---|---|---|---|---|
| | Recharge from precipitation | Recharge from surface water | Lateral inflow | Storage |
| 1984-86 | 4780.8 | 0.8 | 12.3 | 0.6 |
| Total permitted municipal withdrawal | 4780.8 | 4.0 | 26.6 | 0.0 |
| 50 percent of total permitted municipal withdrawal | 4780.8 | 2.2 | 19.4 | 0.0 |

| Simulation | Sinks | | | |
|---|---|---|---|---|
| | Pumpage | Discharge to surface water | Lateral outflow | Storage |
| 1984-86 | 87.3 | 4702.6 | 5.5 | 0.4 |
| Total permitted municipal withdrawal | 170.9 | 4636.4 | 5.4 | 0.0 |
| 50 percent of total permitted municipal withdrawal | 126.9 | 4671.4 | 5.3 | 0.0 |

FOOTNOTE: The small error between sources and discharges is due to numerical truncation in digital simulation.

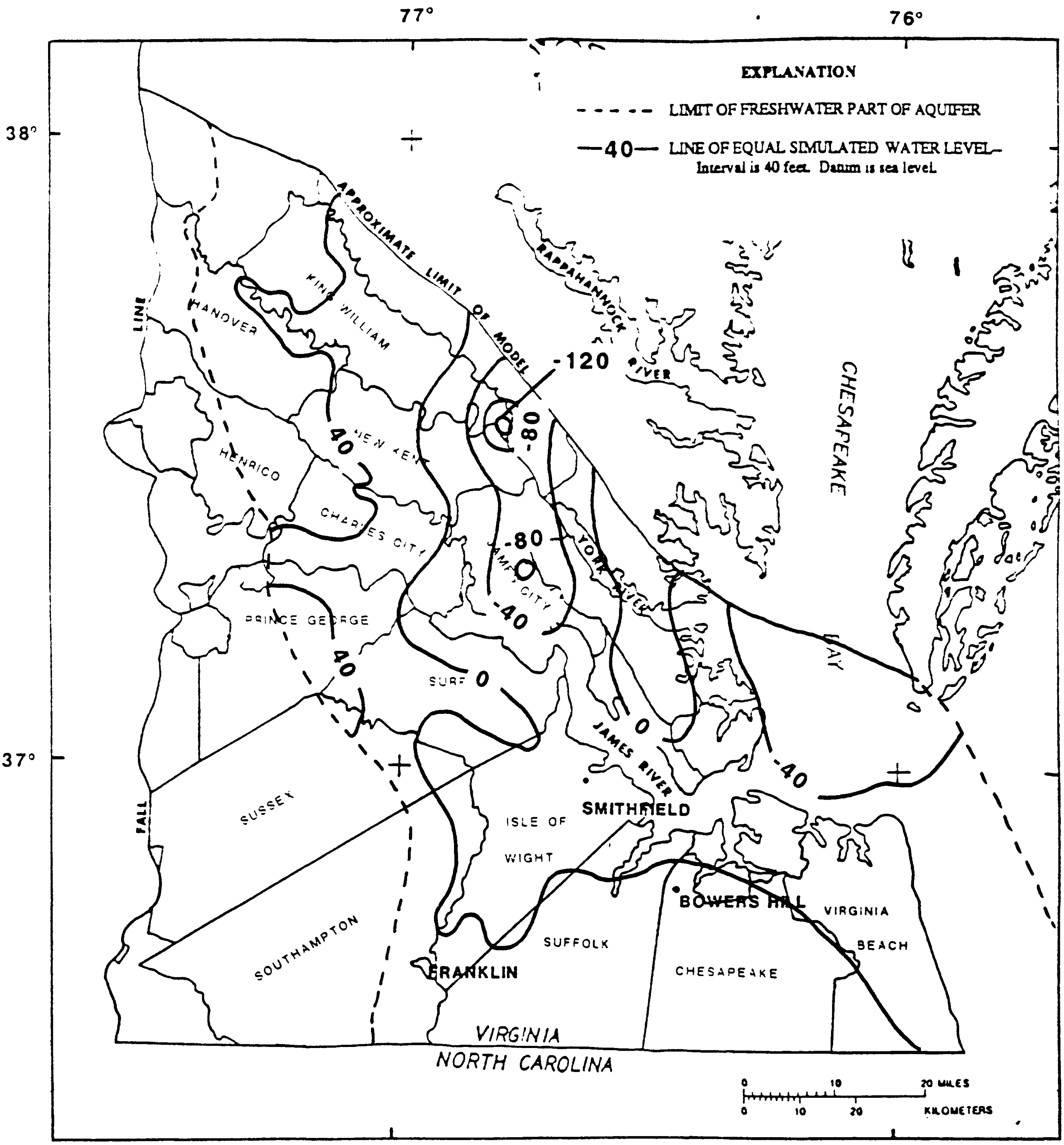


Figure 24. Simulated water levels for 50 percent of total permitted municipal withdrawal in Chickahominy-Piney Point aquifer

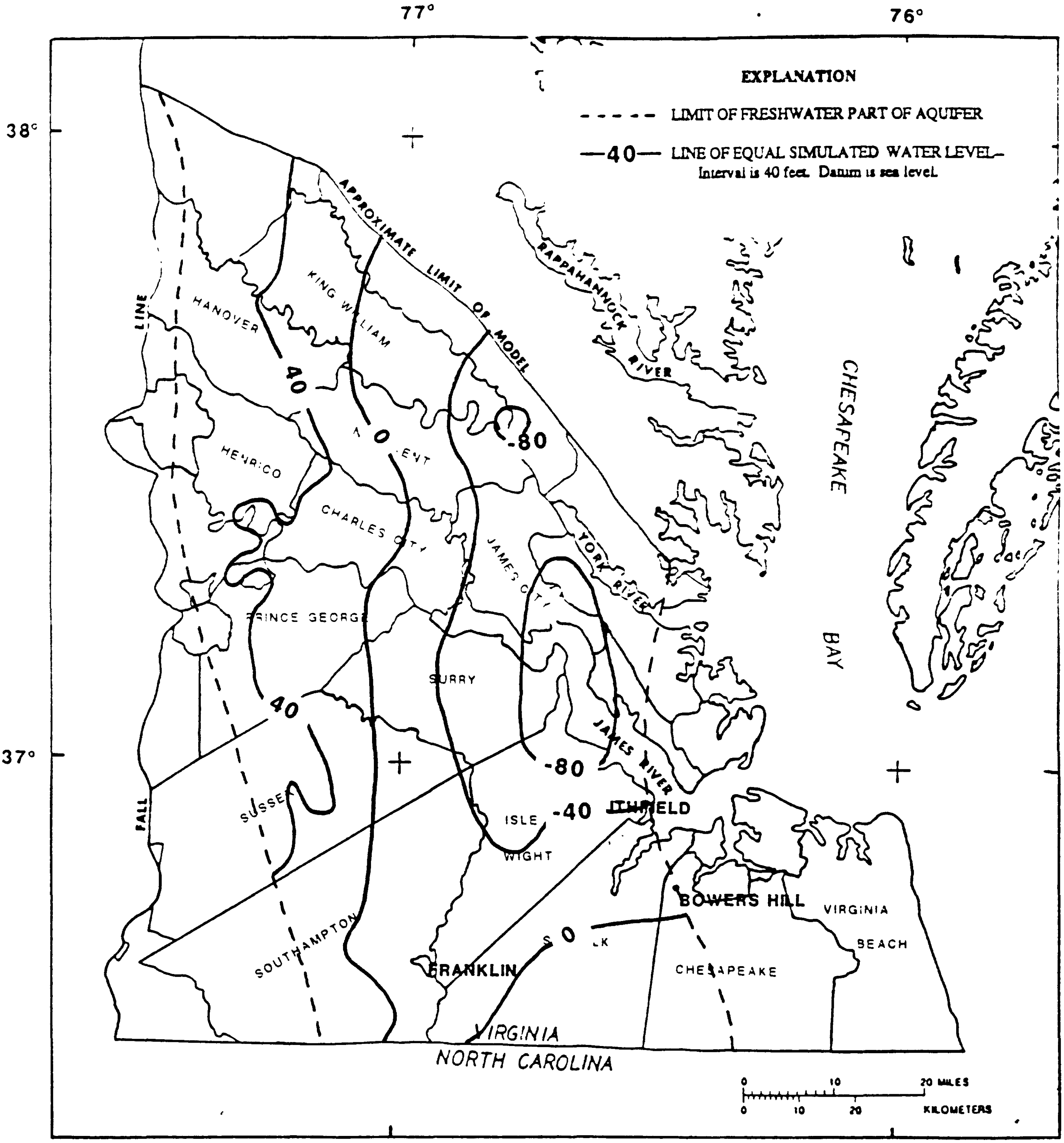


Figure 25. Simulated water levels for 50 percent of total permitted municipal withdrawal in Aquia aquifer

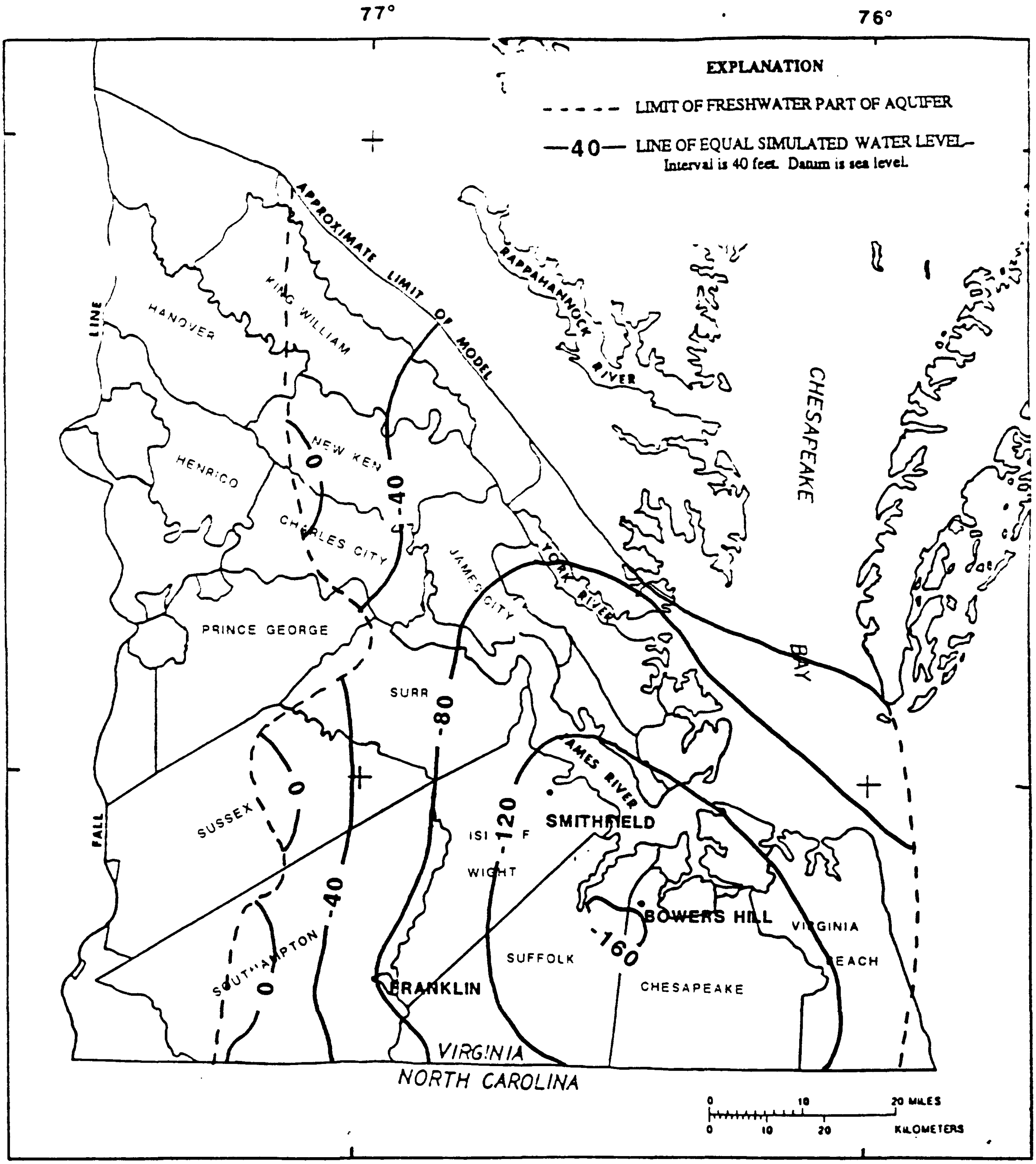


Figure 26. Simulated water levels for 50 percent of total permitted municipal withdrawal in upper Potomac aquifer

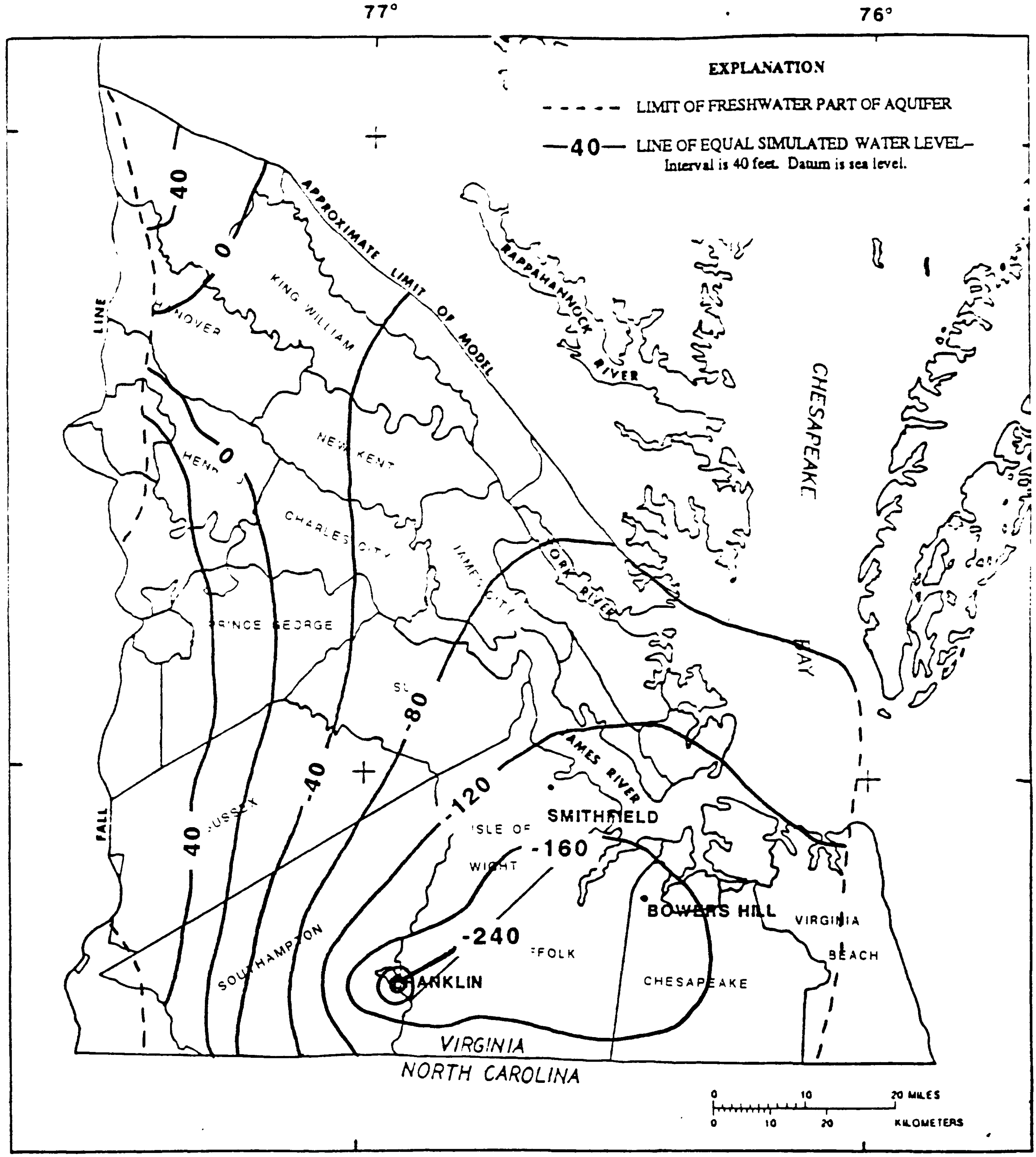


Figure 27. Simulated water levels for 50 percent of total permitted municipal withdrawal in middle Potomac aquifer

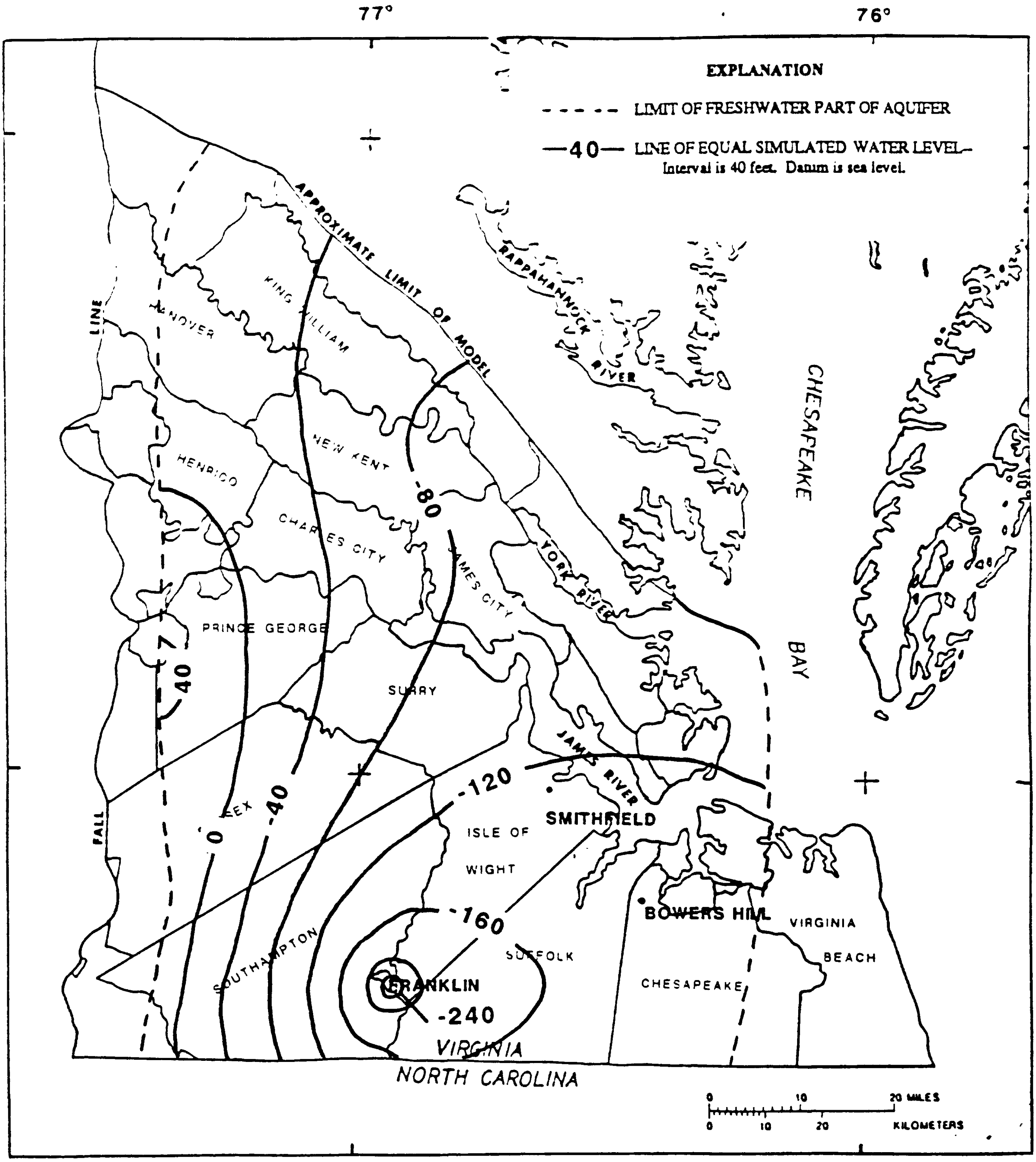


Figure 28. Simulated water levels for 50 percent of total permitted municipal withdrawal in lower Potomac aquifer

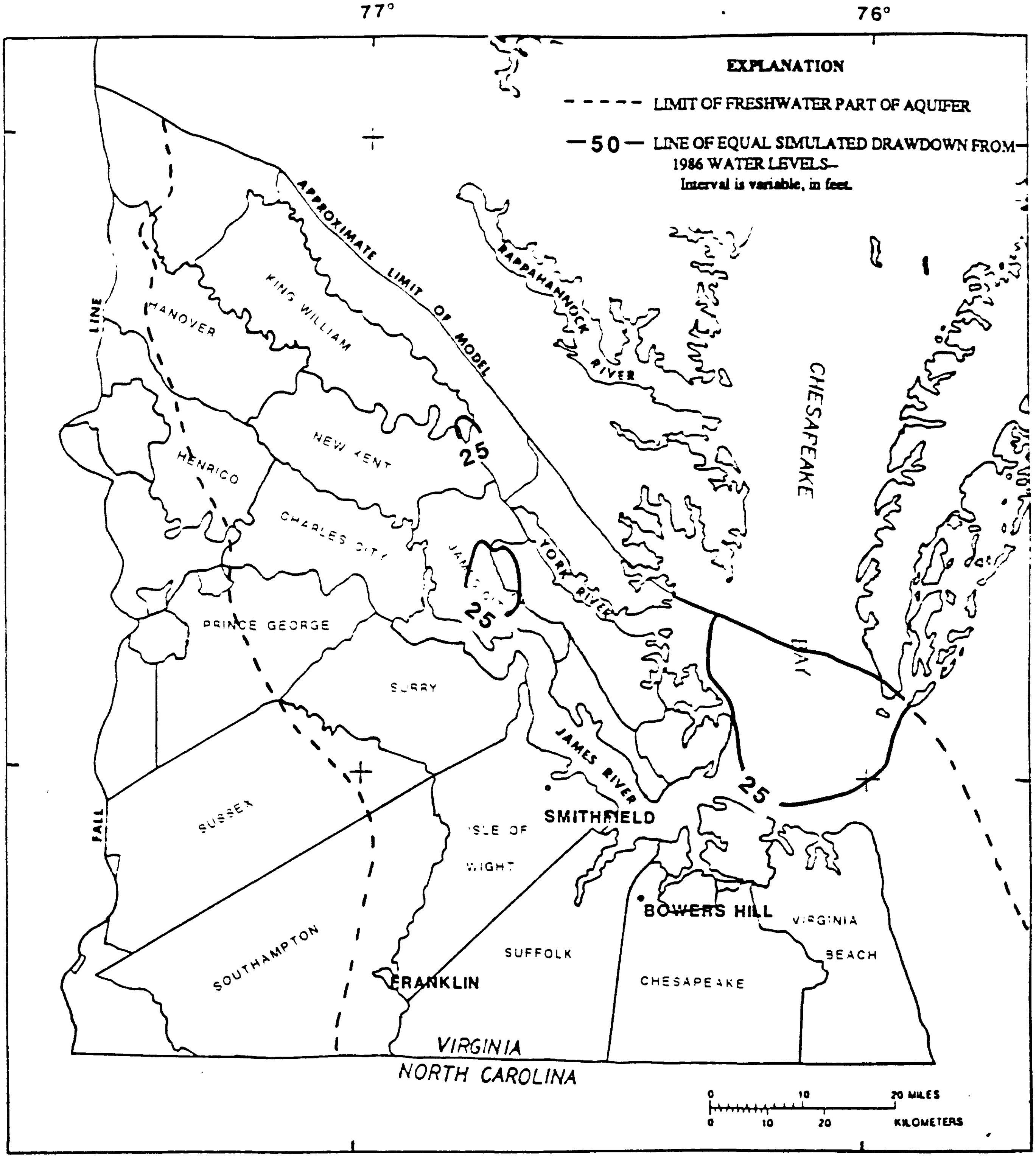


Figure 29. Simulated drawdown from 1986 for 50 percent of total permitted municipal withdrawal in Chickahominy-Piney Point aquifer

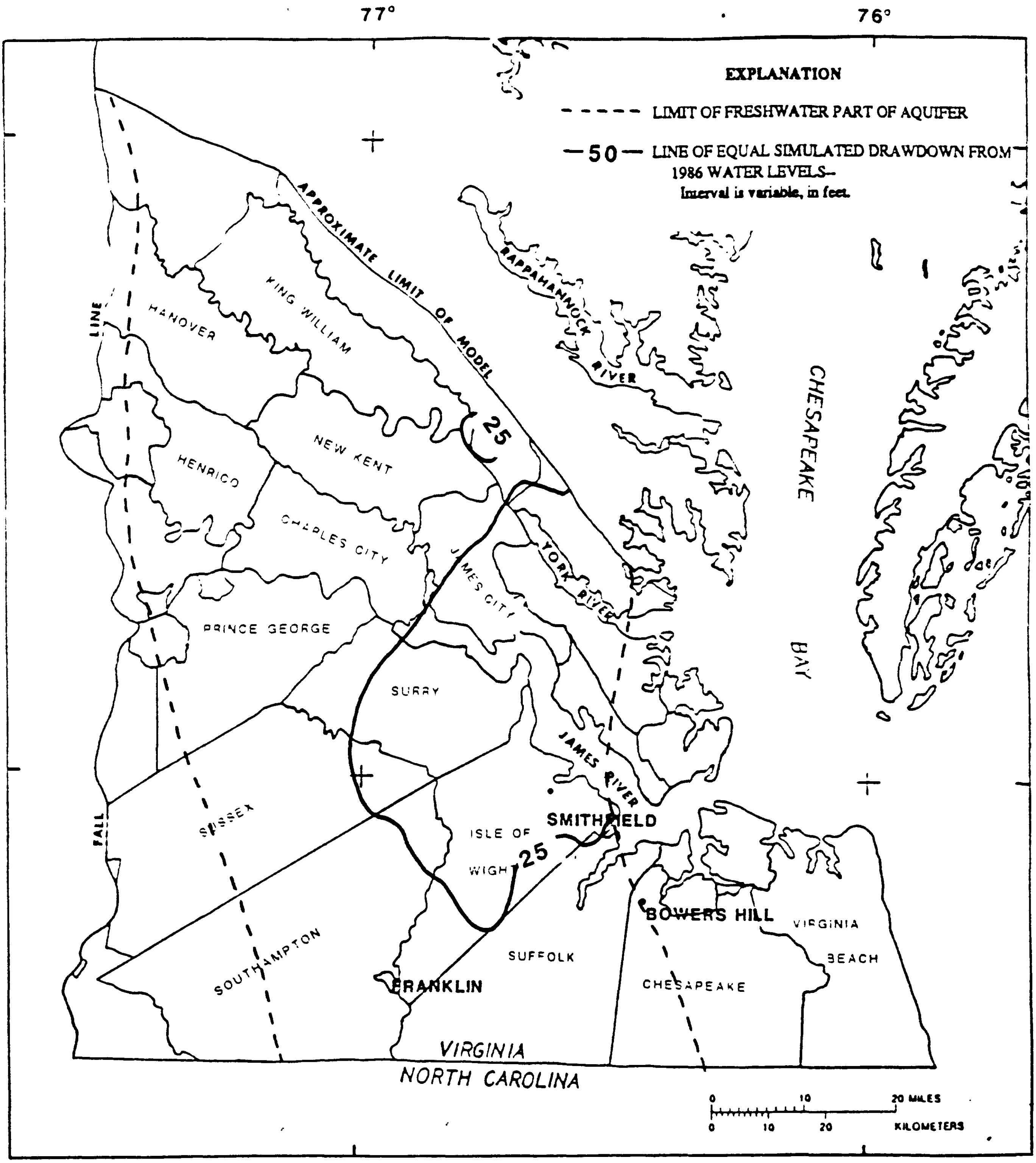


Figure 30. Simulated drawdown from 1986 for 50 percent of total permitted municipal withdrawal in Aquia aquifer

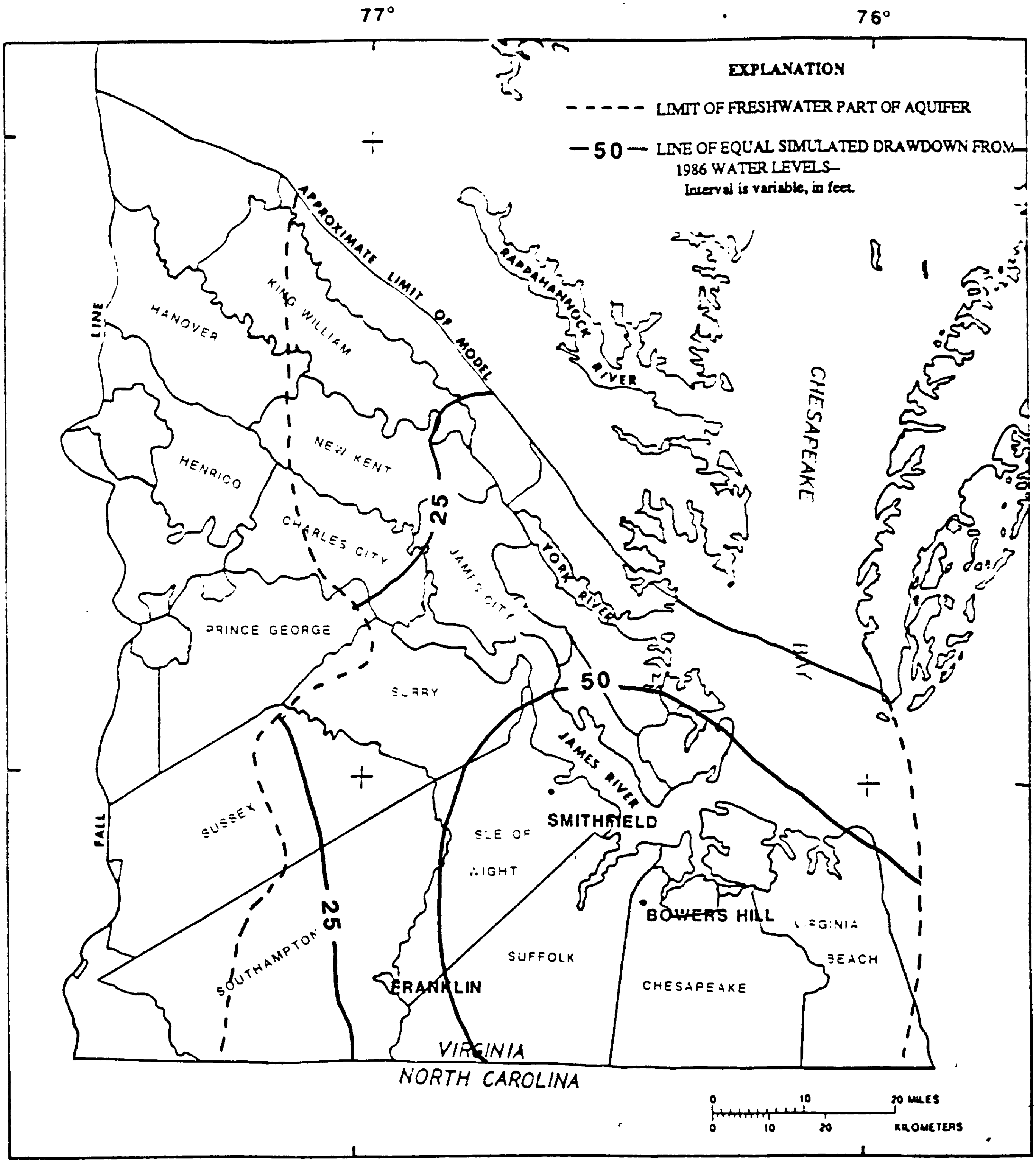


Figure 31. Simulated drawdown from 1986 for 50 percent of total permitted municipal withdrawal in upper Potomac aquifer

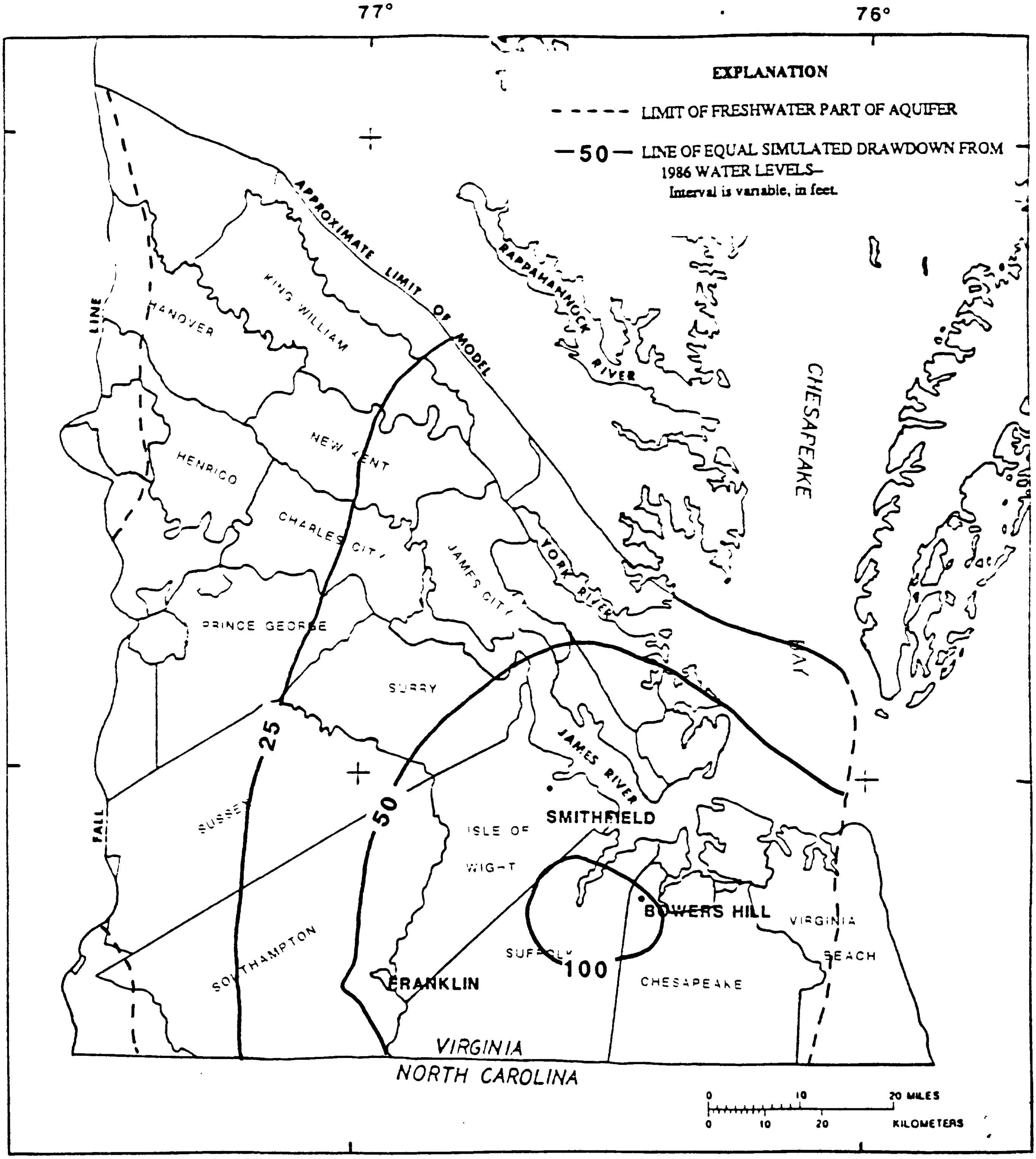


Figure 32. Simulated drawdown from 1986 for 50 percent of total permitted municipal withdrawal in middle Potomac aquifer

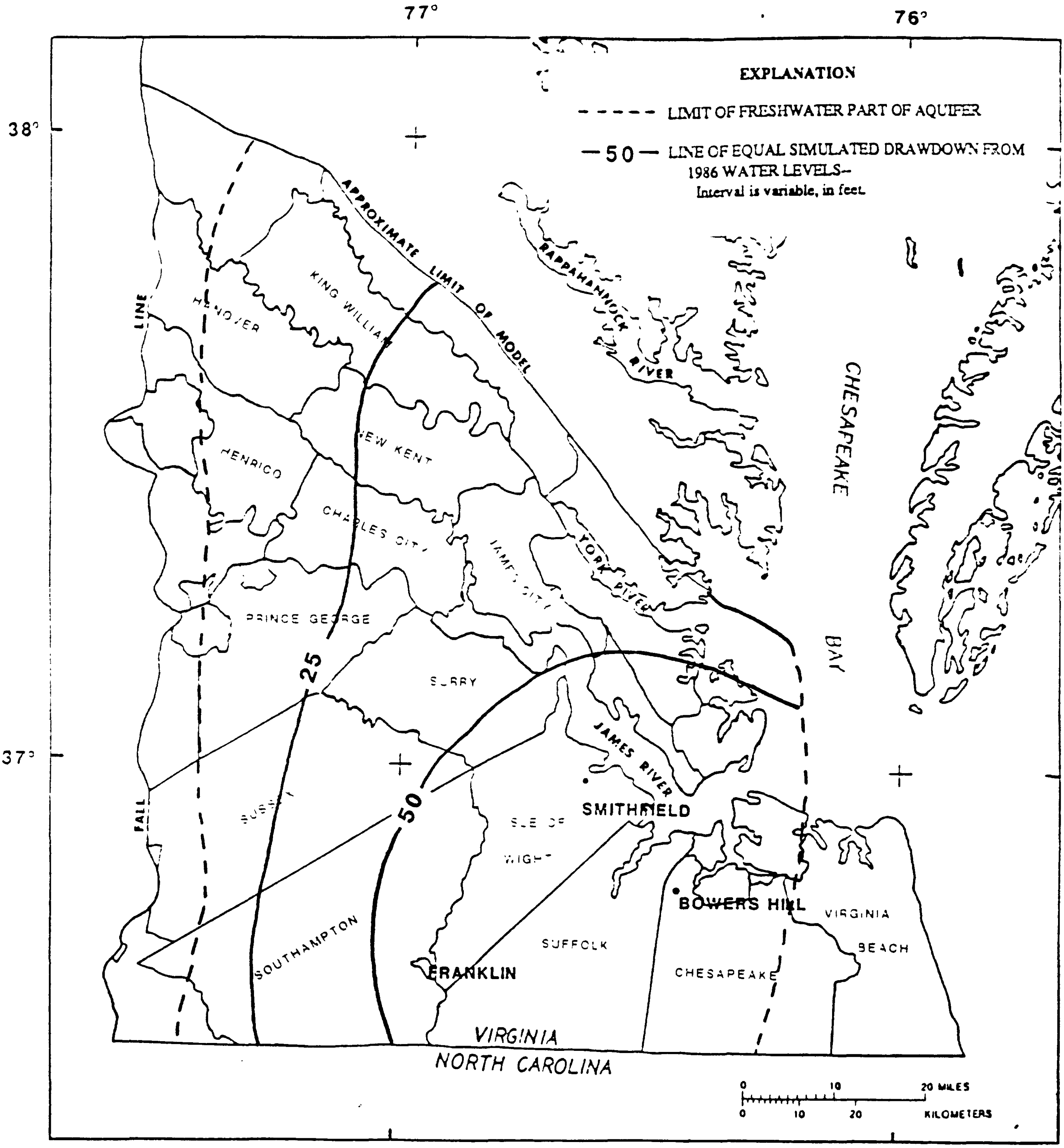


Figure 33. Simulated drawdown from 1986 for 50 percent of total permitted municipal withdrawal in lower Potomac aquifer

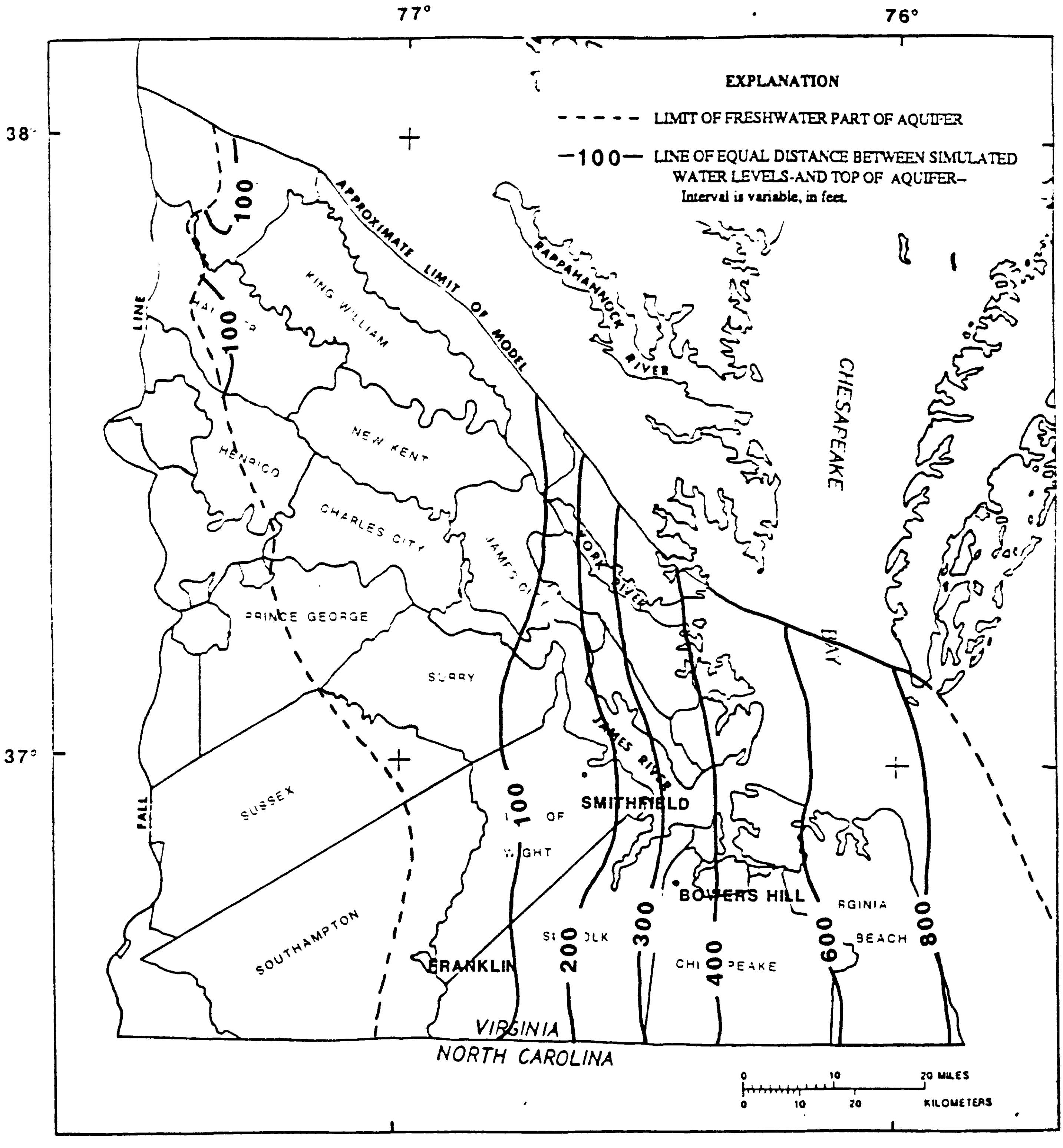


Figure 34. Distance from simulated water levels to top of aquifer for 50 percent of total permitted municipal withdrawal in Chickahominy-Piney Point aquifer

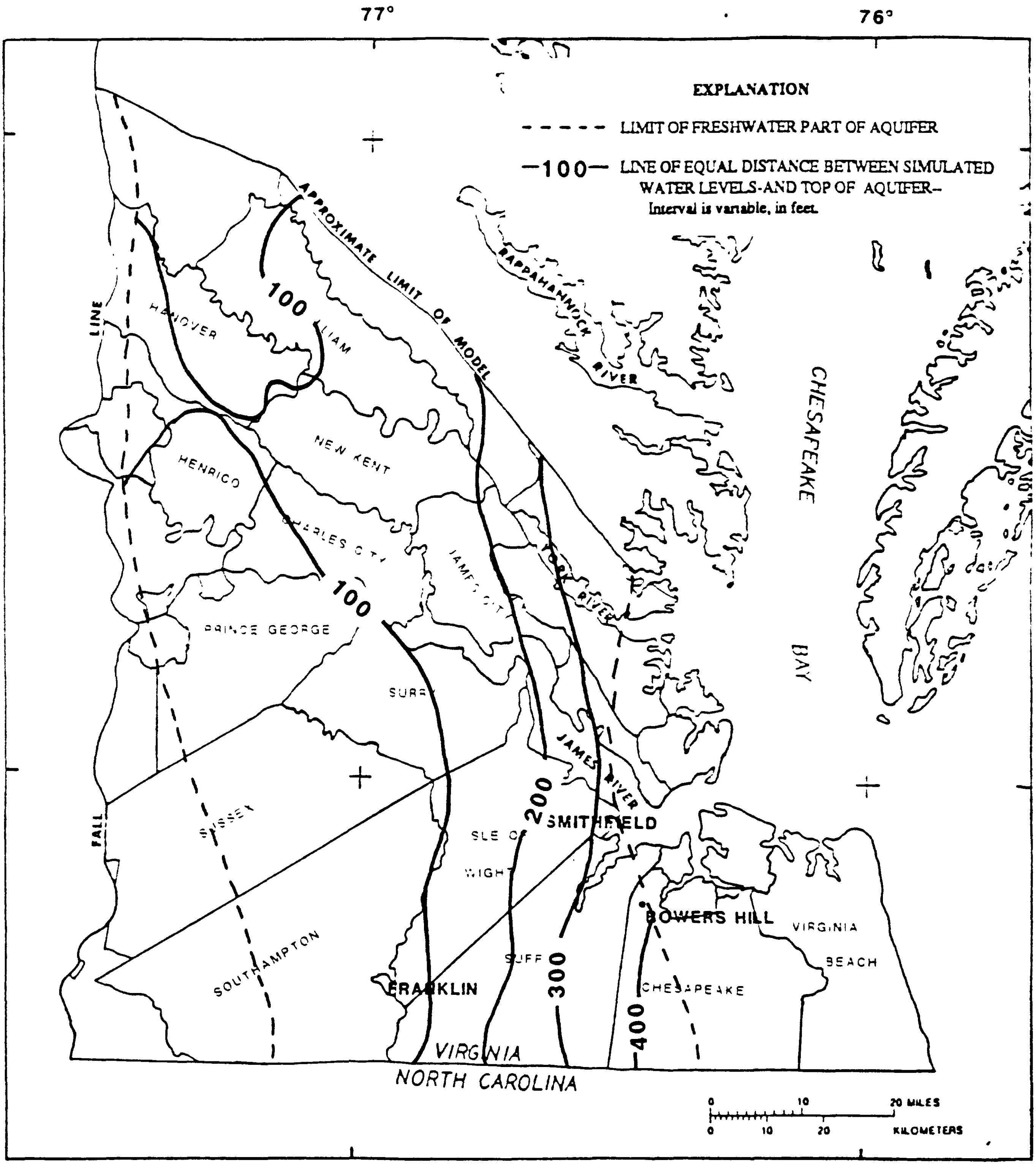


Figure 35. Distance from simulated water levels to top of aquifer for 50 percent of total permitted municipal withdrawal in Aquia aquifer

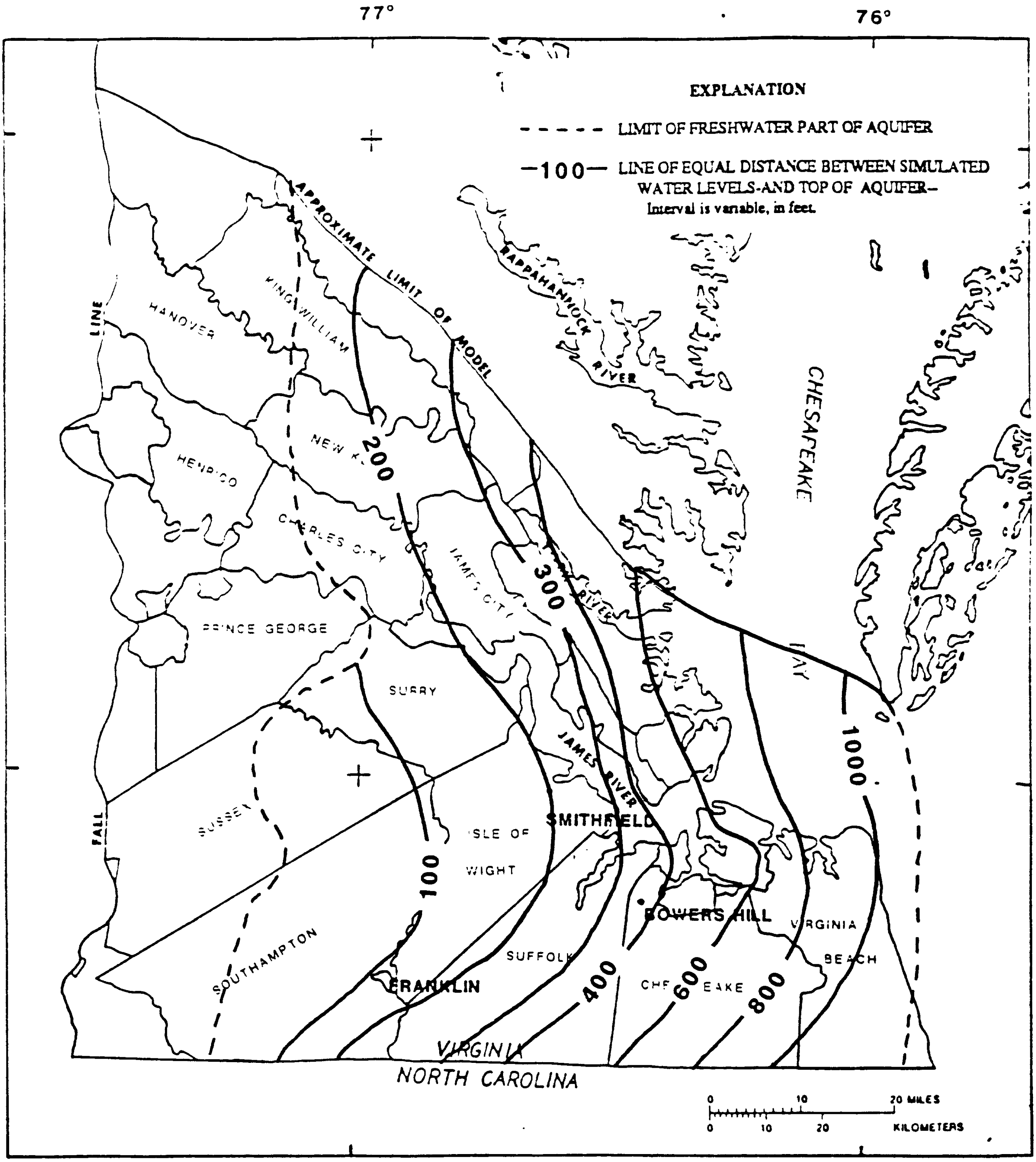


Figure 36. Distance from simulated water levels to top of aquifer for 50 percent of total permitted municipal withdrawal in upper Potomac aquifer

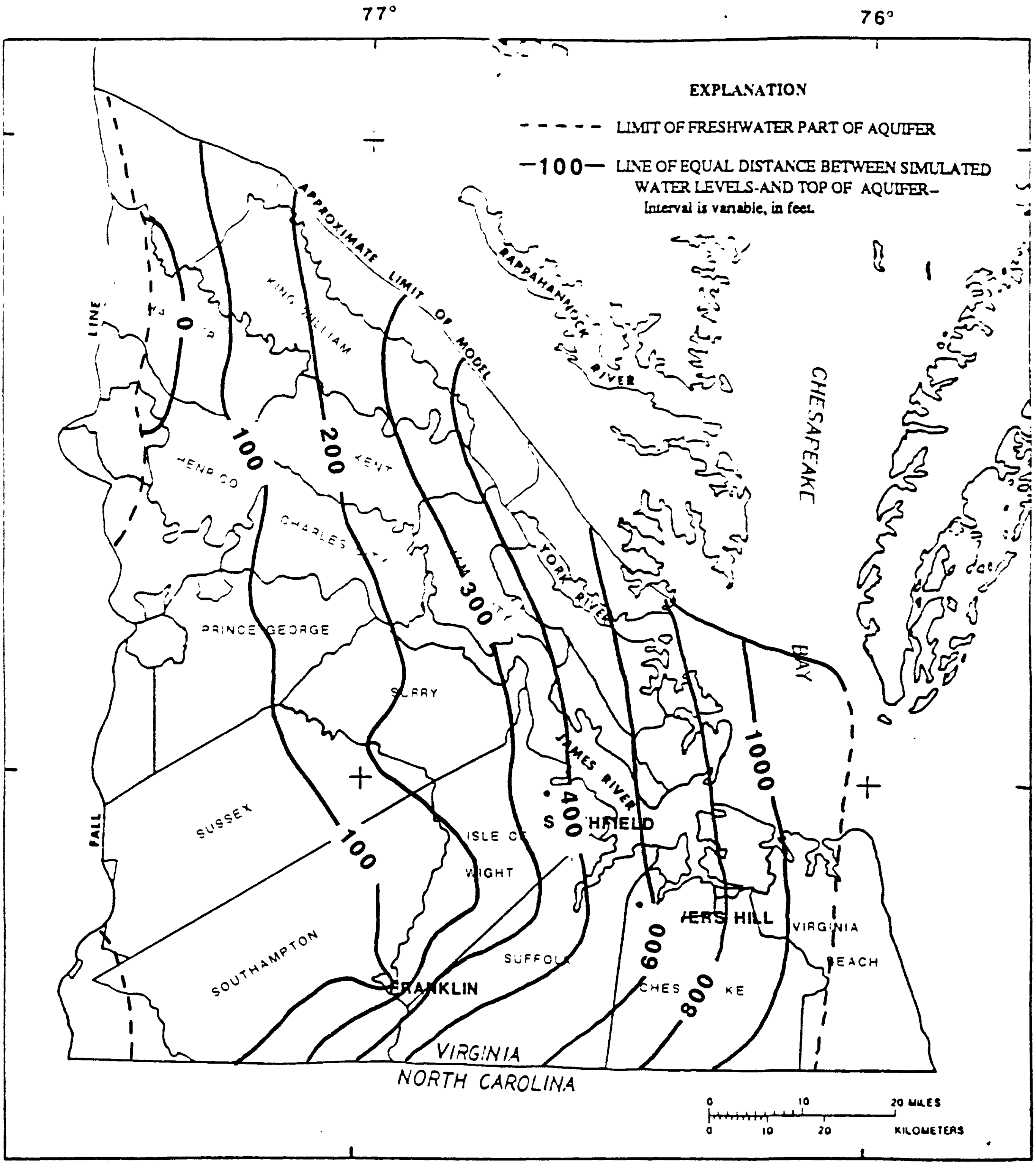


Figure 37. Distance from simulated water levels to top of aquifer for 50 percent of total permitted municipal withdrawal in middle Potomac aquifer

model boundaries, and (4) a decrease of 0.2 Mgal/d in lateral outflow across the northern and southern model boundaries. As in the previous simulation, the major part (about 79 percent) of the additional water withdrawn is replaced by decreased discharge to surface water, but the quantity of the decrease is 47 percent less. The water budget resulted in less than 0.03 percent error in mass balance (table 4).

## MODEL LIMITATIONS

Interpretations of model results are limited by the assumptions inherent in the development of the model. The limitations of this model relate to (1) the scale of the model, (2) the types of boundary conditions selected to simulate lateral model limits, (3) the confining characteristics of the aquifers, and (4) the assumption of average climatic conditions.

This analysis is intended to provide a regional perspective on the effects of permitted municipal pumpage from the confined aquifers of southeastern Virginia. The model consists of a three-dimensional grid of model blocks (1.75 miles per side) that is comprised of 92 rows by 52 columns by 9 layers. Each block is assigned values representative of average aquifer characteristics; the continuous physical properties of the porous medium (the ability to store and transmit water) are assumed to be uniform within each block. The simulation of well interference, water levels, and surface-water losses and gains on a local scale requires a detailed analysis by a more refined model--one with finer grid spacing to improve definition of physical and hydrologic characteristics.

Boundaries along the northern and southern lateral limits of the model were simulated by fluxes that approximate water moving into and out of the modeled area. Fluxes were calculated using head (water-level) gradients computed from a regional model of the Virginia Coastal Plain (Harsh and Laczniak, 1986). Lateral boundary fluxes for the Virginia Coastal Plain model were computed from head gradients simulated by a regional model of the Northern Atlantic Coastal Plain (Leahy and Martin, 1986). The regional Northern Atlantic Coastal Plain model only simulated water levels up through 1980. Thus, lateral fluxes for the Virginia Coastal Plain model after 1980 were kept at rates computed for 1980. This assumption is considered valid as long as simulated withdrawals do not affect water levels along these boundaries. Because southeastern Virginia is located centrally within the area simulated by the model, it is unlikely that withdrawals would significantly affect ground-water flow conditions along these boundaries.

The model also assumes that a stationary seaward no-flow condition exists at the estimated 10,000-milligram-per-liter-chloride concentration (Meisler, 1986). Thus, density changes caused by variations in salinity and the movement of the freshwater-saltwater interface which may result from water level declines are not accounted for. This assumption could produce erroneous results where drawdowns caused by pumpage propagate seaward to intercept this boundary.

Aquifers are assumed to remain confined throughout the simulation. If water levels decline below the top of their respective aquifer, unconfined conditions would be induced. Under unconfined conditions the transmissivity of an aquifer decreases proportionally with water-level decline and comparatively more water is contributed from storage for an equivalent decline in water level. Thus, for simulations in which water levels drop below the top of their respective aquifers, model results could be in error. The decline of simulated water levels below the top of a respective aquifer would indicate that the aquifer has undergone a change to unconfined conditions.

Ground-water recharge is represented in the model by an average areal rate; therefore, the model assumes average climatic conditions. Variations in natural discharge caused by a long-term drought or wet period would have an effect on the predicted water levels. No simulations were conducted to estimate the maximum effect these variations in climate may have upon water-level changes. Model limitations are discussed in more detail in Hamilton and Larson (1988).

## SUMMARY AND CONCLUSIONS

Ground water is an important resource of southeastern Virginia, and its withdrawal has created severe declines in water levels. The maximum measured historic decline exceeds 175 feet near Franklin, Virginia. A large quantity of water that has been permitted to municipalities throughout southeastern Virginia is not being withdrawn. The additional effects of withdrawing this unused portion of presently permitted ground water concerns local planners. A digital flow model simulating (1) 1986 withdrawal, (2) total permitted municipal withdrawal, and (3) 50 percent of the total permitted municipal withdrawal was used to determine the effects of permitted municipal withdrawal on 1986 ground-water flow conditions. The simulations of permitted municipal withdrawals include withdrawals increased by industrial and nonpermitted muncipal users.

Withdrawal data reported for 1986 were used to simulate ground-water flow conditions. This simulation established a base to which projected flow conditions could be compared. Estimated withdrawal from the model area in 1986 was about 92 Mgal/d. Simulated water levels agreed with water levels measured during this same period.

A simulation was used to examine changes in the 1986 ground-water flow system that would result from increasing municipal withdrawals to presently permitted rates. Other rates of use were increased by the annual growth rate estimated for the region in which the user resides. Total permitted ground-water use in the modeled area is about 171 Mgal/d, which is about 79 Mgal/d greater than the 1986 estimated use. Simulated drawdowns exceeded 175 feet in the Potomac aquifers. A maximum drawdown of 265 feet is projected in the middle Potomac aquifer. Drawdowns represent additional water-level decline from the already low 1986 water levels. Simulations indicate that local dewatering would occur, especially in the western part of the model area where the confined aquifers are thin and are near land surface. The simulated ground-water budget predicts that 79 percent (66.2 Mgal/d) of the additional water withdrawn (83.6 Mgal/d) would be replaced by decreased discharge to surface water.

Effects of withdrawing 50 percent of the total municipal withdrawal were simulated. Total ground-water use in this simulation is about 127 Mgal/d, which is an increase of about 35 Mgal/d from the 1986 estimate. Predicted drawdown exceeds 75 feet in the Potomac aquifers. As in the previous simulation, these declines are in addition to the water-level declines as of 1986. The maximum decline projected is 117 feet in the middle Potomac aquifer. Water levels are well above the tops of aquifers throughout virtually all of the model area, indicating that dewatering of aquifers is unlikely for municipal withdrawal at

50 percent of permitted rates. The ground-water budget predicts that discharge to surface water would decrease by about 31 Mgal/d, compared to 66.2 Mgal/d predicted in the simulation of total permitted municipal withdrawal.

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