Department of Natural Resources
Resource Assessment Service
MARYLAND GEOLOGICAL SURVEY
Richard Ortt, Director

OPEN-FILE REPORT NO. 17-02-01

EFFECTS OF PROJECTED (2086) GROUNDWATER WITHDRAWALS ON MANAGEMENT WATER LEVELS AND DOMESTIC WELLS IN ANNE ARUNDEL COUNTY, MARYLAND

by

David C. Andreasen

Prepared in cooperation with the
Anne Arundel County Department of Public Works

DNR Publication No. 12-071917-10

2017

CONTENTS

ILLUSTRATIONS

TABLES

EFFECTS OF PROJECTED (2086) GROUNDWATER WITHDRAWALS ON MANAGEMENT WATER LEVELS AND DOMESTIC WELLS IN ANNE ARUNDEL COUNTY, MARYLAND

by

David C. Andreasen

KEY RESULTS

Well fields operated by Anne Arundel County Department of Public Works withdrew ~34 million gallons per day (average day) in 2016. That amount is projected to increase to ~67 million gallons per day (average day) by 2086 at build-out. Current permitted groundwater allocations for Anne Arundel County Department of Public Works total ~51 million gallons per day (average day) from the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems. The projected withdrawals will require additional allocations totaling ~16 million gallons per day (average day). Total average-day build-out withdrawals will increase by 2.7, 12.1, and 1.4 million gallons per day over current permitted allocations in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems respectively. To determine if the increased withdrawals are sustainable (do not fall below the 80-percent management level) and to assess the potential effects on water levels and domestic-well operation, a groundwater-flow model simulation was run. The model is a revised version of a previously developed model used for water-supply planning in Anne Arundel County. The model was updated and re-calibrated using more recent water-level and pumpage data. Model simulations indicate that projected withdrawals will not cause water levels to fall below the 80-percent management level in all well fields with the exception of the Upper Patapsco aquifer system at Severndale. Sufficient supply capacity is available in the Lower Patapsco aquifer system at Severndale, however, to shift the Upper Patapsco withdrawals (0.4 million gallons per day by 2086) to the Lower Patapsco. Simulated water levels by 2086 are as low as approximately 100, 170, and 228 feet below sea level in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems respectively. Drawdown from current water levels is as great as ~80, 130, and 200 feet in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems respectively. Seasonal variations in withdrawals at build-out have a negligible effect on water levels. The simulated drawdown at the projected build-out amount does not adversely affect domestic-well operation. Simulated water levels remain above well screens and casing-diameter reductions (telescoping wells) in the 3,154 domestic wells estimated to be screened in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems. Of the total number of domestic wells only ~3 percent are telescoping. Simulated water levels remain at least 20 ft above well screens and casing-diameter reductions in all but six wells.

INTRODUCTION

Anne Arundel County Department of Public Works (AADPW) relies almost entirely on groundwater for its municipal water supply. In 2016, approximately 34 million gallons per day (Mgal/d) was pumped from three aquifer systems tapped by AADPW production wells, providing drinking water to ~144,000 homes (population of ~400,000) and ~2,100 businesses (Edward Cope, Anne Arundel County Department of Public Works, written commun., 2017). A relatively small amount (average of ~0.44 Mgal/d) was imported from the surface-water-sourced Baltimore City water system in 2016. Projected groundwater withdrawals may increase to ~67 million gallons per day from the Patapsco (Upper and Lower) and Patuxent aquifer systems at build-out (Malcolm Pirnie, Water Division of Arcadis, 2016). In 2007, a groundwater-flow modeling study by the Maryland Geological Survey (Andreasen, 2007) indicated that projected (2044) withdrawals contained in the 2003 Comprehensive Water Strategic Plan (O'Brien and Gere, Inc., 2003) would not cause groundwater levels to exceed management levels in the Patapsco (Upper and Lower) and Patuxent aquifer systems if managed (optimized) correctly. However, with the advent of revised water-use projections an updated assessment of potential impacts to the resource was needed. Additionally, the 2007 study did not evaluate the potential impacts to private domestic wells (i.e. water levels declining below pump intakes or below the depth to which pumps can be lowered in telescoping wells).

OBJECTIVE AND SCOPE OF WORK

The purpose of the study is to assess the potential effects of projected increases in groundwater withdrawals from the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems from AADPW public supply wells on water levels related to the 80-percent management levels, and on the operation of domestic wells in areas currently not served by public water in north-central Anne Arundel County. Projected withdrawals were assessed using a revised version of the 2007 groundwater-flow (MODFLOW) model (Andreasen, 2007).

LOCATION OF STUDY AREA

The study area includes AADPW well fields in central and northern portions of Anne Arundel County (fig. 1). The current major well fields include Arnold, Broad Creek, Crofton Meadows, Dorsey Road, and Severndale. AADPW also operates individual wells in the Lower Patapsco aquifer system at Stevenson Road, Telegraph Road, and Elvaton as well as independent well fields at Herald Harbor (Lower Patapsco aquifer system), Gibson Island (Upper Patapsco aquifer system), and Rose Haven (Aquia aquifer). The Rose Haven well field is in the Aquia aquifer and not included in this study. To simulate groundwater flow in the Magothy, Upper Patapsco, Lower Patapsco, and Patuxent aquifers, a larger area was included in the groundwater-flow model to account for flow into and out of the area interest. The model area includes Anne Arundel County and portions of Baltimore, Calvert, Howard, Kent, Prince George's, Queen Anne's, and Talbot Counties and Baltimore City.

AVAILABLE DRAWDOWN

Groundwater withdrawals in confined (artesian) aquifers of Maryland's coastal plain are managed such that groundwater levels are maintained above a prescribed management level. The management level is defined as 80 percent of the difference between the top of the aquifer and the pre-pumping water level. The 80-percent management level, acting as a buffer against de-watering of the aquifer, constrains groundwater withdrawals, ultimately defining the water-supply capacity of the aquifer. Assessing whether withdrawals have exceeded aquifer-supply capacity as defined by the management level requires sustained monitoring and assessment of groundwater levels at both regional and local scales. For this study, the amount of available drawdown remaining (difference between the current water level and the 80-percent management level) in 2015 in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems was determined based on potentiometric surface maps from Staley and others (2016) using aquifer top elevation from the GIS-based Maryland Coastal Plain Aquifer Information System (MCPAIS) (Andreasen and others, 2013) and model-simulated pre-pumping water levels from Andreasen (2007) (figs. 2-4).

Available drawdown remaining in 2015 in the Upper Patapsco aquifer system in Anne Arundel County ranged from zero near the outcrop area of the aquifer to ~500 ft in the southern-most part of the county (fig. 2). At the Arnold, Broad Creek, Gibson Island, and Severndale well fields, the

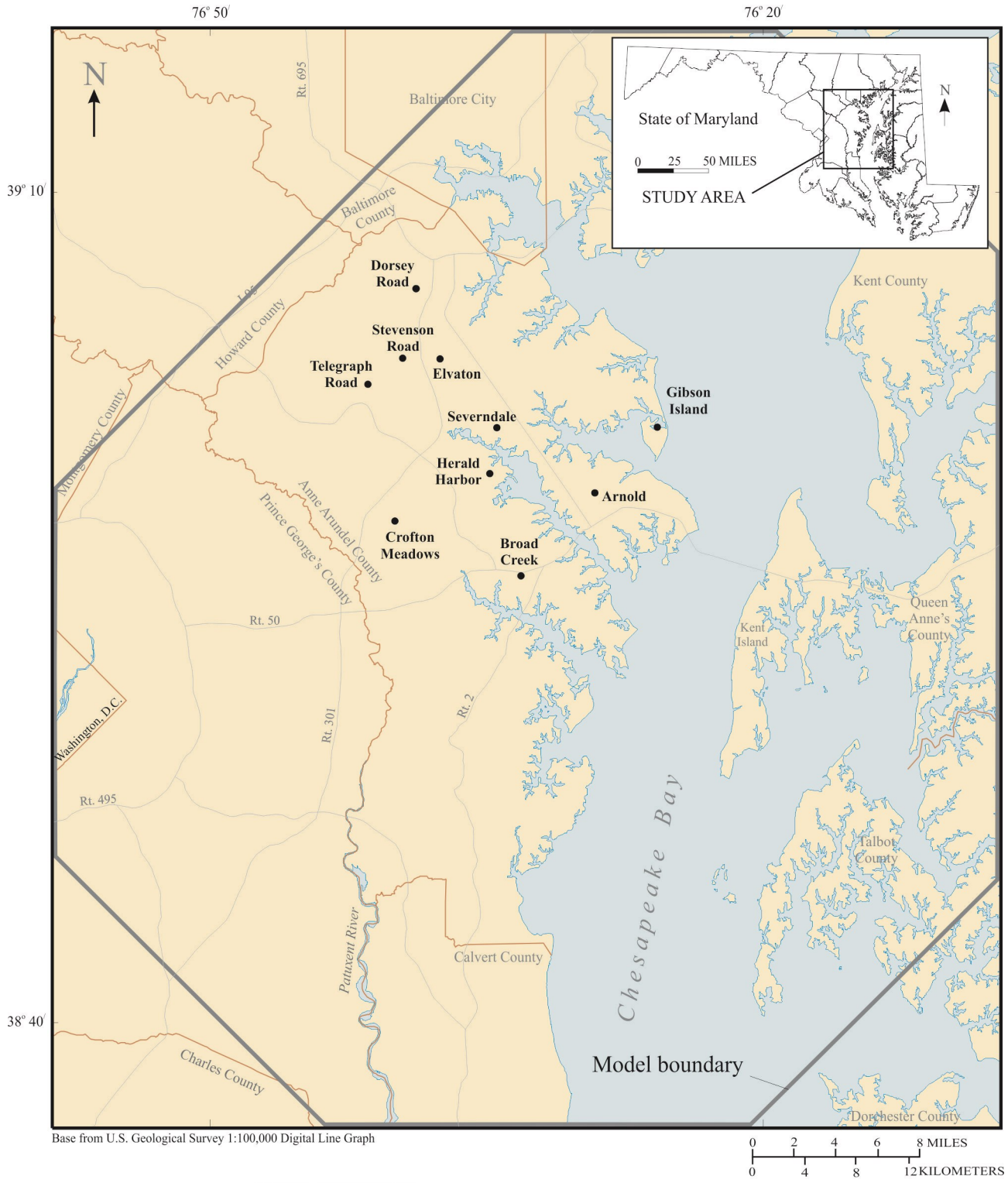

Figure 1. Location of study area.

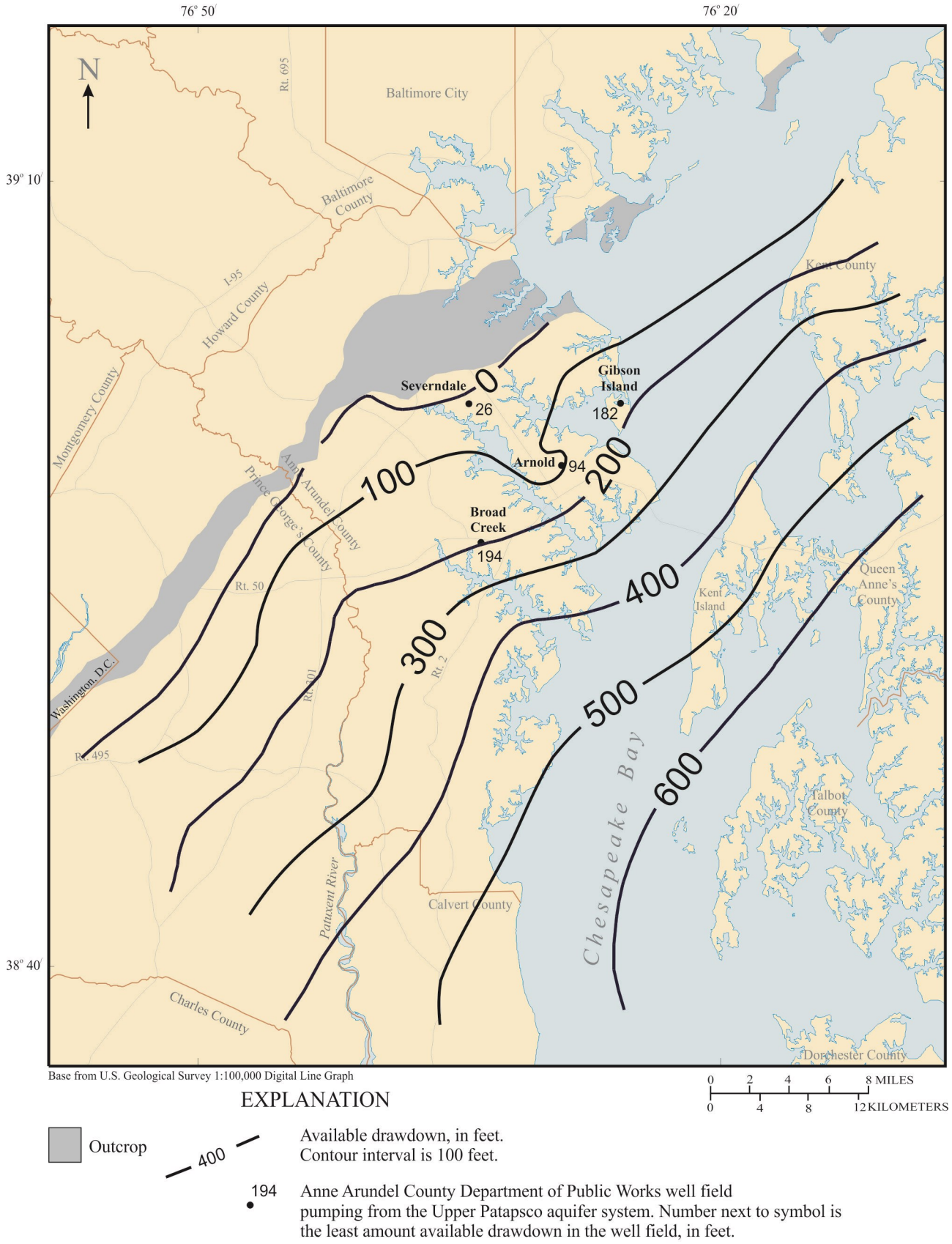

Figure 2. Approximate available drawdown remaining in 2015 in the Upper Patapsco aquifer system.

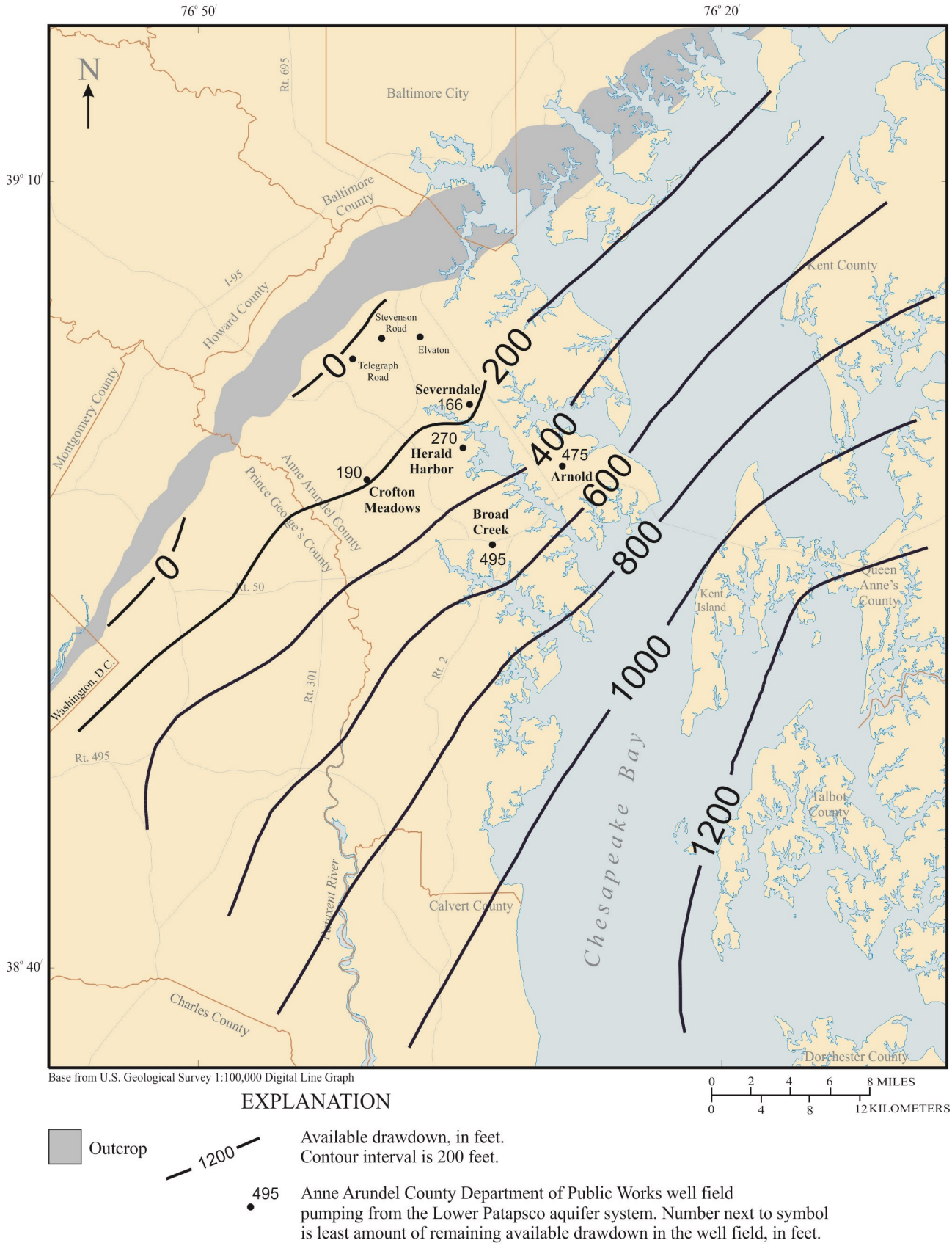

Figure 3. Approximate available drawdown remaining in 2015 in the Lower Patapsco aquifer system.

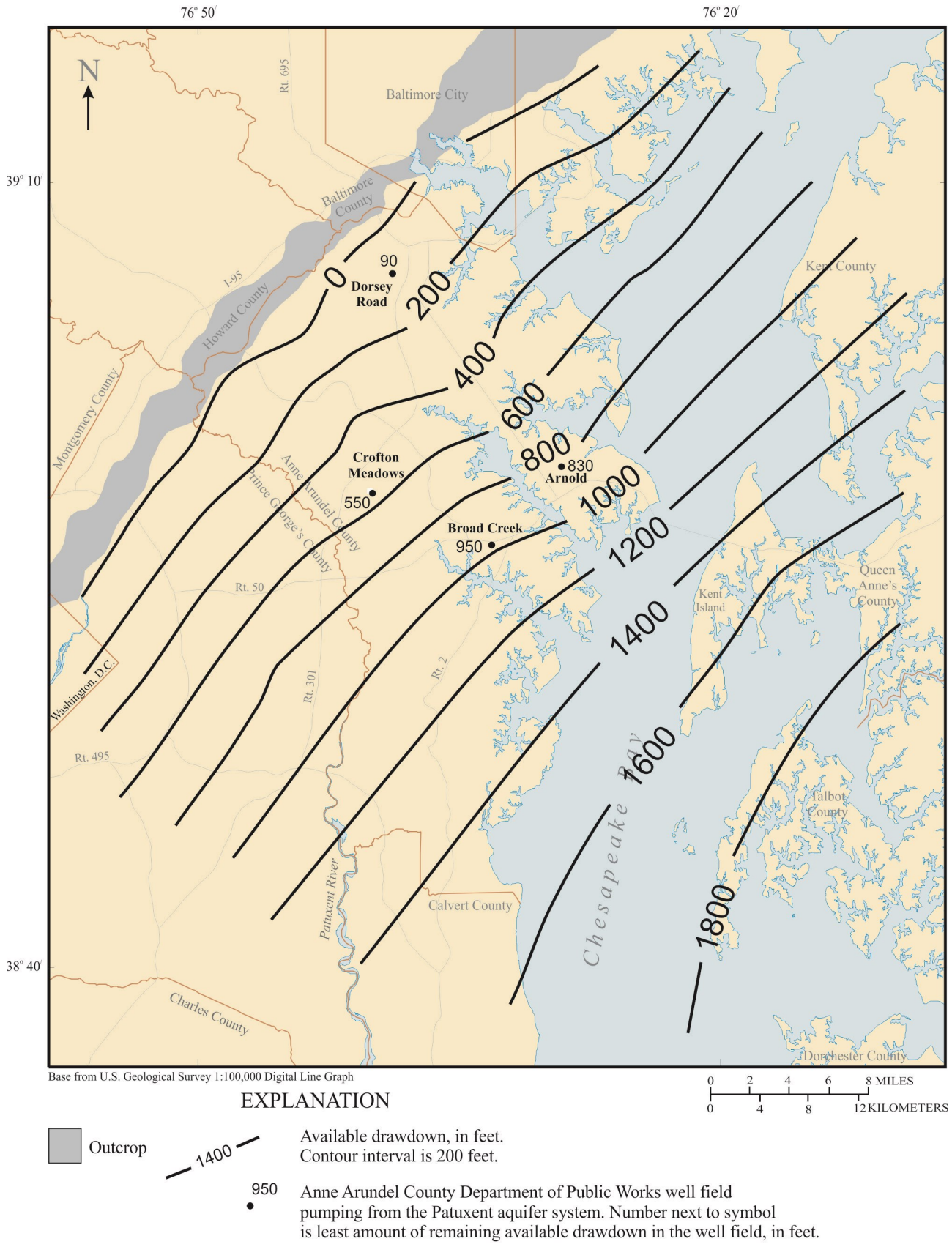

Figure 4. Approximate available drawdown remaining in 2015 in the Patuxent aquifer system.

available drawdown remaining was approximately 94, 194, 182, and 26 ft respectively.

Available drawdown remaining in 2015 in the Lower Patapsco aquifer system in Anne Arundel County ranged from zero near the outcrop area of the aquifer to ~1,000 ft in the southern-most part of the county (fig. 3). At the Arnold, Broad Creek, Crofton Meadows, Herald Harbor, and Severndale well fields, the available drawdown remaining was approximately 475, 495, 190, 270, and 166 ft respectively. Available drawdown remaining at the three independent wells (Telegraph Road, Stevenson Road, and Elvaton) was all less than ~100 ft.

Available drawdown remaining in 2015 in the Patuxent aquifer system in Anne Arundel County ranged from zero near the outcrop area to ~1,500 ft in the southern-most part of the county (fig. 4). At the Arnold, Broad Creek, Crofton Meadows, and Dorsey Road well fields, the available drawdown remaining was approximately 830, 950, 550, and 90 ft respectively.

In all three aquifer systems, there is a relatively narrow band parallel to the aquifer outcrops where water levels are below management levels. In these areas the top of the aquifers are relatively shallow, therefore even relatively minor amounts of drawdown can cause water levels to fall below the management level. The resolution of both water levels and layer elevations limit the accuracy in those shallow areas near aquifer outcrops.

GROUNDWATER-FLOW MODEL

The potential effects of projected withdrawals from the Anne Arundel County Department of Public Works well fields were evaluated using a groundwater-flow model (MODFLOW) previously constructed by the Maryland Geological Survey (Andreasen, 2007). That model consisted of ~61,000 cells and six layers representing (from shallow to deep) the water table, Aquia, Magothy, Upper and Lower Patapsco, and Patuxent aquifer systems (figs. 5 and 6). The 2007 model was updated and re-calibrated, extending the simulation period from 1900-2002 to 1900-2015. The groundwater-flow model simulates flow in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems as well as the Magothy aquifer. The water-table aquifer, a portion of which includes the outcrop areas of the Magothy aquifer and Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems, is also represented in the model. The Aquia aquifer is represented in the model as a layer with specified (constant) heads. The groundwater-flow model was re-calibrated using more recent groundwater levels (2004 to 2015). The re-calibrated model was then used to evaluate the effects of future withdrawals from Anne Arundel County's well fields on water levels.

Model Revisions

Prior to re-calibration, several revisions were made to input arrays and time discretization of the original model. Changes made to the model are described below.

Time Discretization

The transient model simulation period of the 2007 model was expanded from 1900-2002 to 1900-2015 by adding 13 one-year stress periods (two time steps per year) (tab. 1). The additional simulation period required updates to all time-dependant arrays including specified (constant) heads and general-head boundaries. The additional stress periods also allowed for input of 2002-2015 well withdrawals.

Table 1. Time discretization used in the transient (1900 – 2015) groundwater-flow model.

Stress period	Period	Duration of stress period, years
1	1900 - 1919	20
2	1920 - 1929	10
3	1930 - 1939	10
4	1940 - 1949	10
5	1950 - 1959	10
6	1960 - 1969	10
7 - 52	1970 - 2015	1

Specified (Constant) Heads

The Aquia aquifer (model layer 2) is represented by specified (constant) heads at select time intervals. For the model period 1900-2002 heads were specified for stress periods 1 (1900-1919), 4 (1940-1949), 17 (1980), 22 (1985), 27 (1990), 32 (1995), and 39 (2002) (Andreasen, 2007). Heads for those periods are held constant until the subsequent specified-head stress period. With the extension of the simulation period to 2015, specified heads were assigned to stress periods 44 (2007), 48 (2011) and 52 (2015). Heads were derived from published potentiometric-surface maps (Curtin and others,

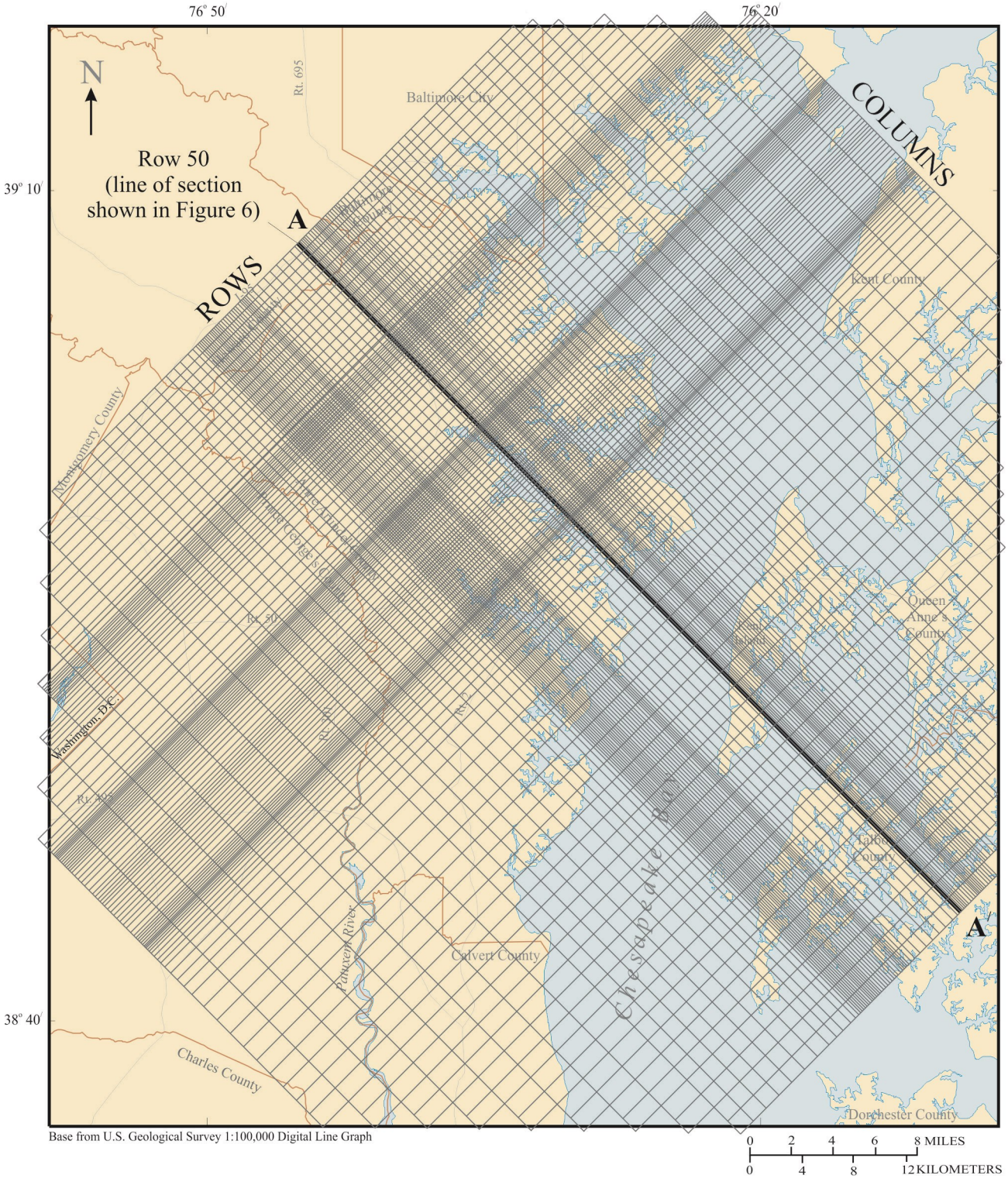

Figure 5. Finite-difference model grid.

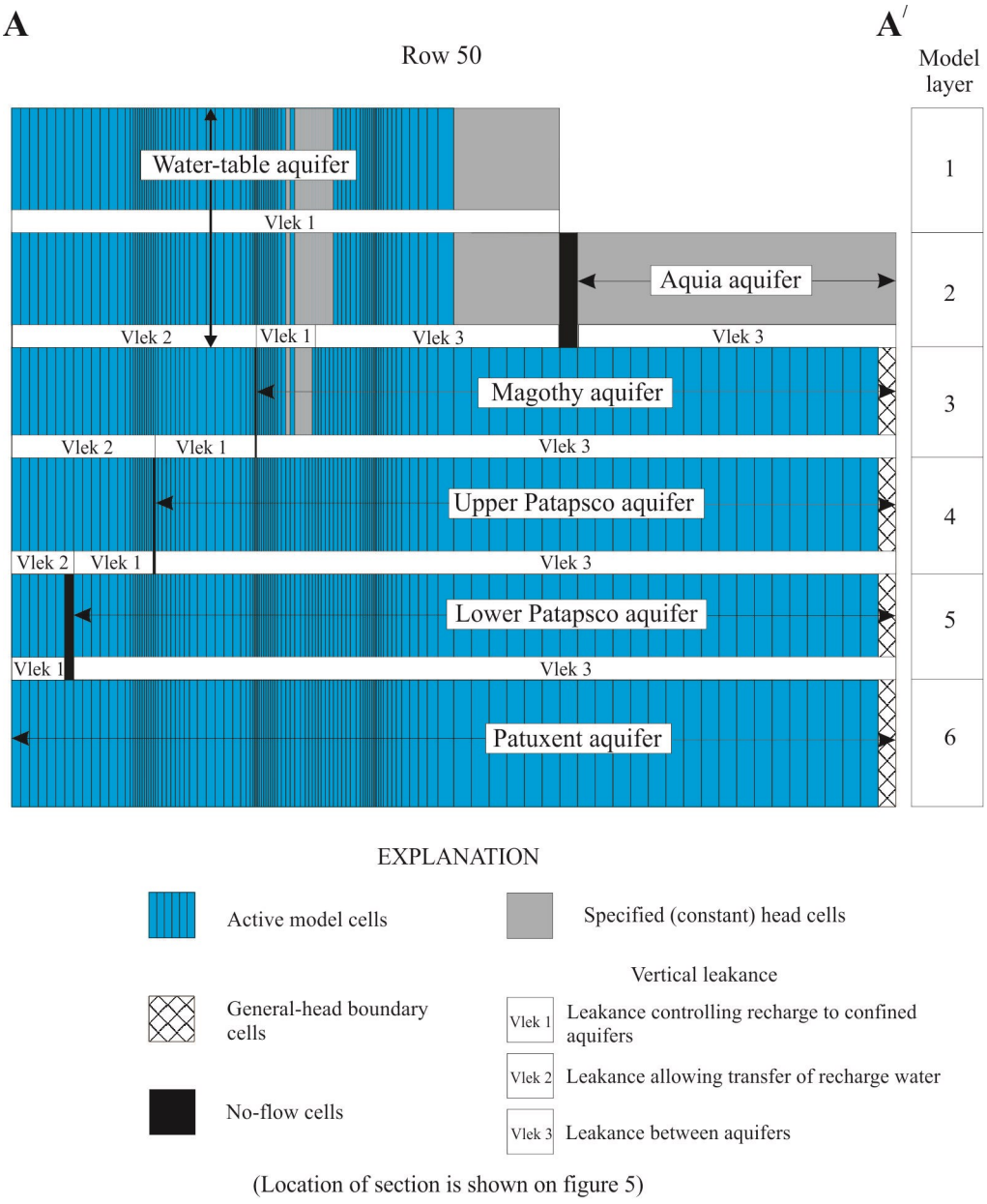

Figure 6. Cross section along model row 50 showing model layers and boundaries.

2009; Curtin and others, 2012; Staley and others, 2016).

General-Head Boundaries

The Magothy aquifer, Upper and Lower Patapsco aquifer systems, and Patuxent aquifer system model boundaries (with the exception of the no-flow boundary at the up-dip [northwest] extent of the aquifers) are represented as general heads (Andreasen, 2007). For the model period 1900-2002 general heads were assigned for stress periods 1 (1900-1919), 4 (1940-1949), 17 (1980), 22 (1985), 27 (1990), 32 (1995), and 39 (2002) (Andreasen, 2007). With the extension of the simulation period to 2015, general heads were assigned for stress periods 44 (2007), 48 (2011) and 52 (2015). Heads were derived from published potentiometric surface maps (Curtin and others, 2009; Curtin and others, 2012; Staley and others, 2016).

Pumpage

Pumpage in the model was updated for the additional stress periods 40-52 (2003-2015) (app. A). The pumpage represents annual-average withdrawals for appropriated use greater than 10,000 gallons per day, and includes pumping wells in the 2002 model (19 of which are now inactive) and several new permitted users. Total pumpage in the model increased from ~46 Mgal/d in 2002 to ~50 Mgal/d in 2015 (an increase of ~7 percent over the 13-year period). Pumpage from the AADPW wells increased from ~26 Mgal/d in 2002 to ~30 Mgal/d in 2015. The total number of appropriated users within the model area withdrawing water in 2002 and 2015 were similar at 74 and 75 respectively.

Model Re-calibration

To assess the calibration of the revised model and to aid in re-calibration, measured water levels at observation wells used in the original model were updated to 2015. A total of 50 wells were used to re-calibrate the model (tab. 2 and fig. 7). Model calibration was assessed by examining trends in simulated head change versus observed head over the simulation period as well as by a quantitative analysis of simulated versus observed head match at the end of the simulation period (2015). Since some of the original observation wells had no head data for 2015, not all of the original wells were included in the analysis. One observation well (AA Cf 166) screened in the Patuxent aquifer system and drilled since the original model was constructed was added to the set of calibration points.

Overall, a good match was attained between simulated and observed heads. The root-mean-square-error (RMSE) and correlation coefficient was 10.5 ft and 0.97 respectively, and the median of the absolute difference between simulated and observed heads was 4.1, 5.1, 8.7, and 13.2 ft for the Magothy aquifer, Upper and Lower Patapsco aquifer systems, and Patuxent aquifer system respectively. Some adjustments to model input were required to improve calibration in the Lower Patapsco and Patuxent aquifer systems in some areas. Based on a sensitivity analysis performed on the original model (Andreasen, 2007, p. 45) which showed that the model was most sensitive to changes in transmissivity and vertical leakance, only those two parameters were adjusted.

To improve the match between simulated and observed heads in the Patuxent aquifer system, the transmissivity array for the Patuxent aquifer system in the original model (Andreasen, 2007, fig. 5) was revised using transmissivity values from a compilation of aquifer hydraulic properties from the MCPAIS (Andreasen and others, 2013, fig. 45). The transmissivity values, averaged in locations with multiple values, were interpolated by kriging to create the new array (fig. 8). The resulting transmissivity values are generally lower than the original array in west-central Anne Arundel, southern Prince George's, northern Calvert, and northern Charles Counties, and on the Eastern Shore south of southern Kent County. The transmissivity values are higher in southern Baltimore County east of Baltimore City and are approximately the same in all other areas.

Vertical leakance representing flux across the Arundel Clay confining unit (between the Lower Patapsco and Patuxent aquifer systems) was adjusted in a relatively small area surrounding the Crofton Meadows well field in west-central Anne Arundel County. In that area vertical leakance was lowered from 2.0×10^{-4} to 1.0×10^{-6} ft^{-1}. A portion of that area was also increased from 3.0×10^{-8} to 1.0×10^{-6} ft^{-1}. In the same area of west-central Anne Arundel County, vertical leakance between the Upper Patapsco and Lower Patapsco aquifer systems was lowered from 2.0×10^{-5} to 6.0×10^{-7} ft^{-1}.

Adjustments made through the calibration process resulted in an improved match between simulated and observed heads (figs. 9-11). Aside from attaining a good match with water-level trends, the RMSE between simulated and observed heads at

Table 2. Comparison of observed and simulated water levels (2015).

Well number	Model cell (row, column, layer)	Observed water level, feet related to sea level	Simulated water level, feet related to sea level	Difference between observed and simulated water level, feet
Magothy aquifer				
AA Cc 117	84,44,3	46.13	46.50	0.37
AA Cd 78	59,49,3	38.04	36.29	1.75
AA Cf 99	35,87,3	-23.23	-32.68	9.45
AA Dd 42	88,69,3	-0.10	2.15	2.25
AA De 103	85,93,3	-15.00	-16.61	1.61
AA Df 79	54,92,3	-23.48	-27.29	3.81
AA Ed 39	96,93,3	-9.68	-6.34	3.34
AA Fe 47	95,100,3	-18.29	-23.29	5.00
CA Bb 10	103,105,3	-38.56	-43.01	4.45
CA Bb 23	102,99,3	-23.24	-28.31	5.07
CA Cc 56	102,108,3	-40.49	-45.36	4.87
KE Cb 97	2,95,3	4.32	-6.07	10.39
PG Cf 33	96,47,3	45.87	51.51	5.64
PG De 21	102,67,3	30.79	24.98	5.81
PG Fe 30	106,91,3	-29.48	-13.97	15.51
PG Gf 35	106,102,3	-40.55	-44.70	4.15
QA Ea 27	28,100,3	-21.62	-24.31	2.69
Median of the absolute difference between simulated and observed heads				4.45
Upper Patapsco aquifer system				
AA Bd 159	46,33,4	38.21	51.13	12.92
AA Ce 120	54,58,4	5.45	-2.13	7.58
AA Cf 118	40,81,4	-49[1]	-48.40	0.6
AA De 128	86,92,4	-16.35	-19.63	3.28
AA De 95	63,81,4	-33.22	-31.73	1.49
AA Df 19	45,94,4	-24.20	-31.03	6.83
AA Ec12	100,90,4	-5.13	-4.36	0.77
KE Cb 36	1,91,4	-5.45	-9.73	4.28
KE Db 40	5,95,4	-10.41	-15.54	5.13
PG De 33	102,58,4	52.08	35.76	16.32
QA Eb 111	19,102,4	-22.11	-29.69	7.58
Median of the absolute difference between simulated and observed heads				5.13
Lower Patapsco aquifer system				
AA Ad 102	33,13,5	68.14	61.70	6.44
AA Ad 109	31,20,5	40.45	50.52	10.07
AA Bd 157	46,33,5	36.24	34.36	1.88
AA Cc 40	76,29,5	86.50	71.74	14.76
AA Cc 89	92,42,5	-13.74	-0.66	13.08
AA Ce 94	48,50,5	-77.24	-72.92	4.32
AA Ce 124	54,58,5	-23.14	-23.56	0.42
AA Cf 137	39,80,5	-83.92	-70.47	13.45
AA Cg 23	24,94,5	-42.04	-29.86	12.18
PG Be 14	95,18,5	105.47	107.36	1.89
PG Ed 34	105,56,5	-7.95	16.17	24.12
QA Eb 112	19,102,5	-31.79	-31.86	0.07
Median of the absolute difference between simulated and observed heads				8.25
Patuxent aquifer system				
AA Ad 29	28,21,6	-46.61	-49.02	2.41
AA Cb 1	93,23,6	20.75	17.28	3.47
AA Cc 102	92,42,6	-37.80	-34.99	2.81
AA Ce 117	48,50,6	-26.71	-18.97	7.74
AA Cf 166	35,86,6	-91.00	-90.35	0.65
AA Cg 22	24,94,6	-38.06	-38.31	0.25
AA De 203	63,80,6	-40.45	-33.80	6.65
BA Gf 11	11,33,6	-4.70	0.15	4.85
PG Cf 66	97,43,6	-11.35	-8.11	3.24
QA Eb 110	19,102,6	-9.32	--23.82	14.50
Median of the absolute difference between simulated and observed heads				3.36

[1] Interpolated from hydrograph

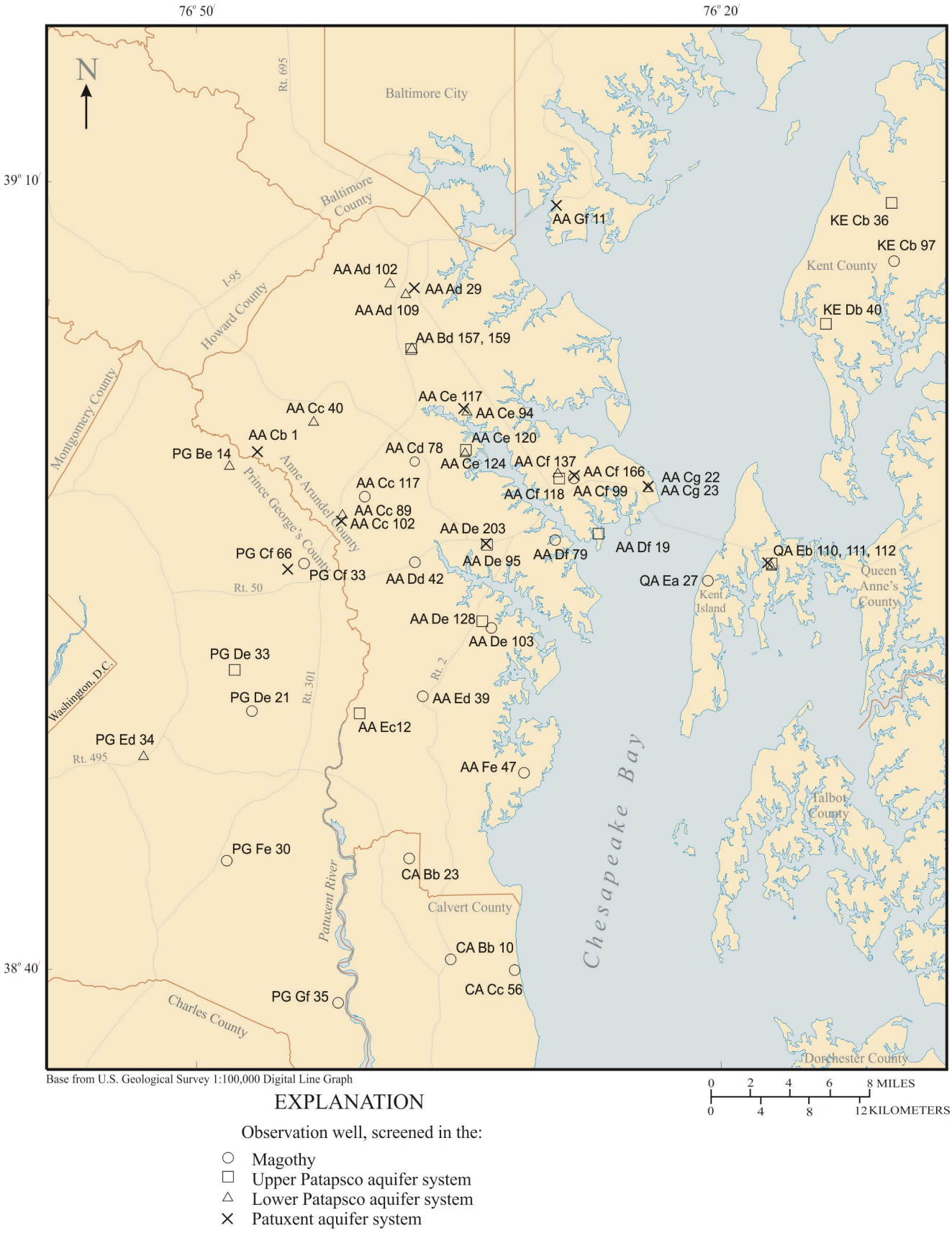

Figure 7. Locations of wells with long-term water-level record used in model re-calibration.

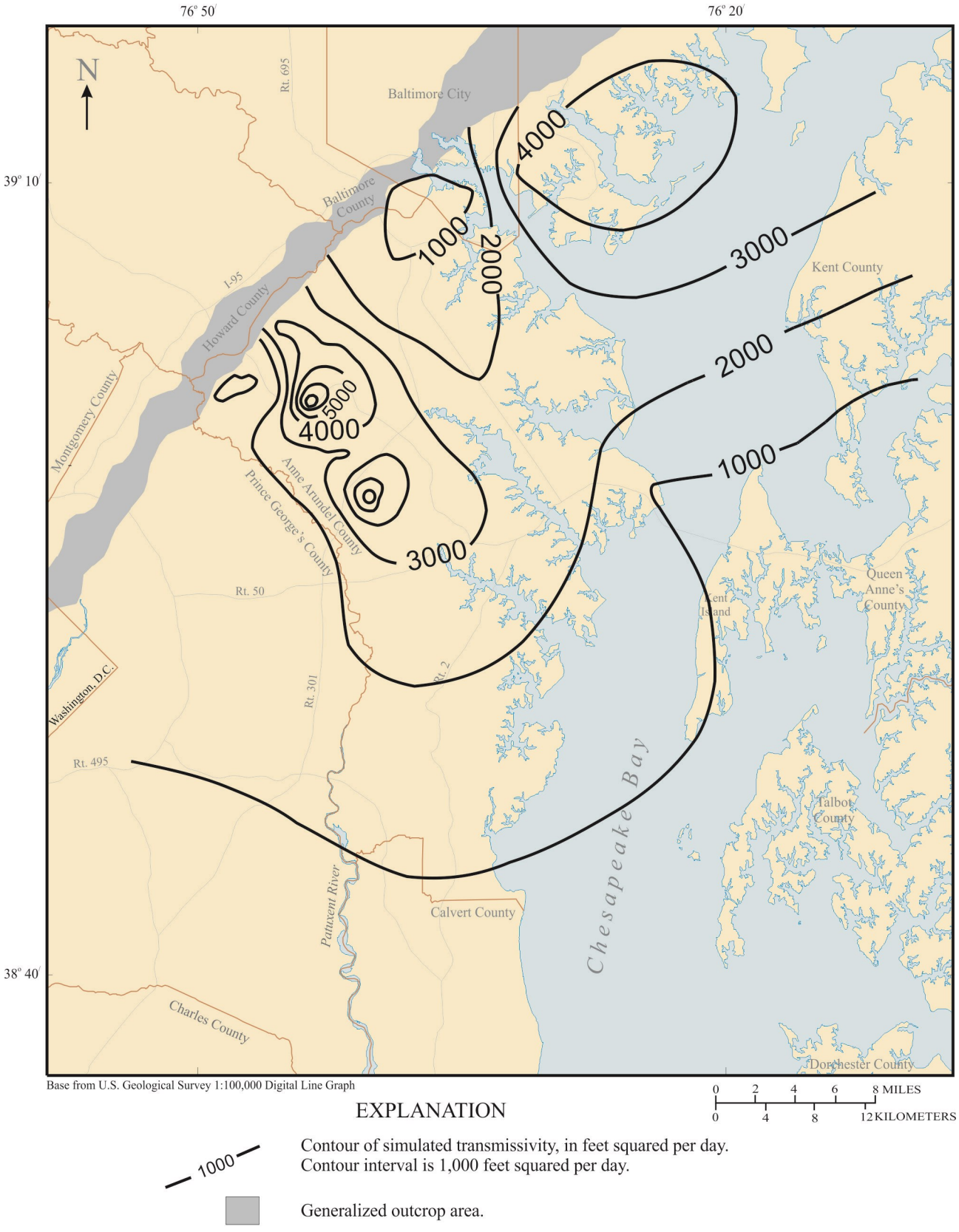

Figure 8. Simulated transmissivity of the Patuxent aquifer system.

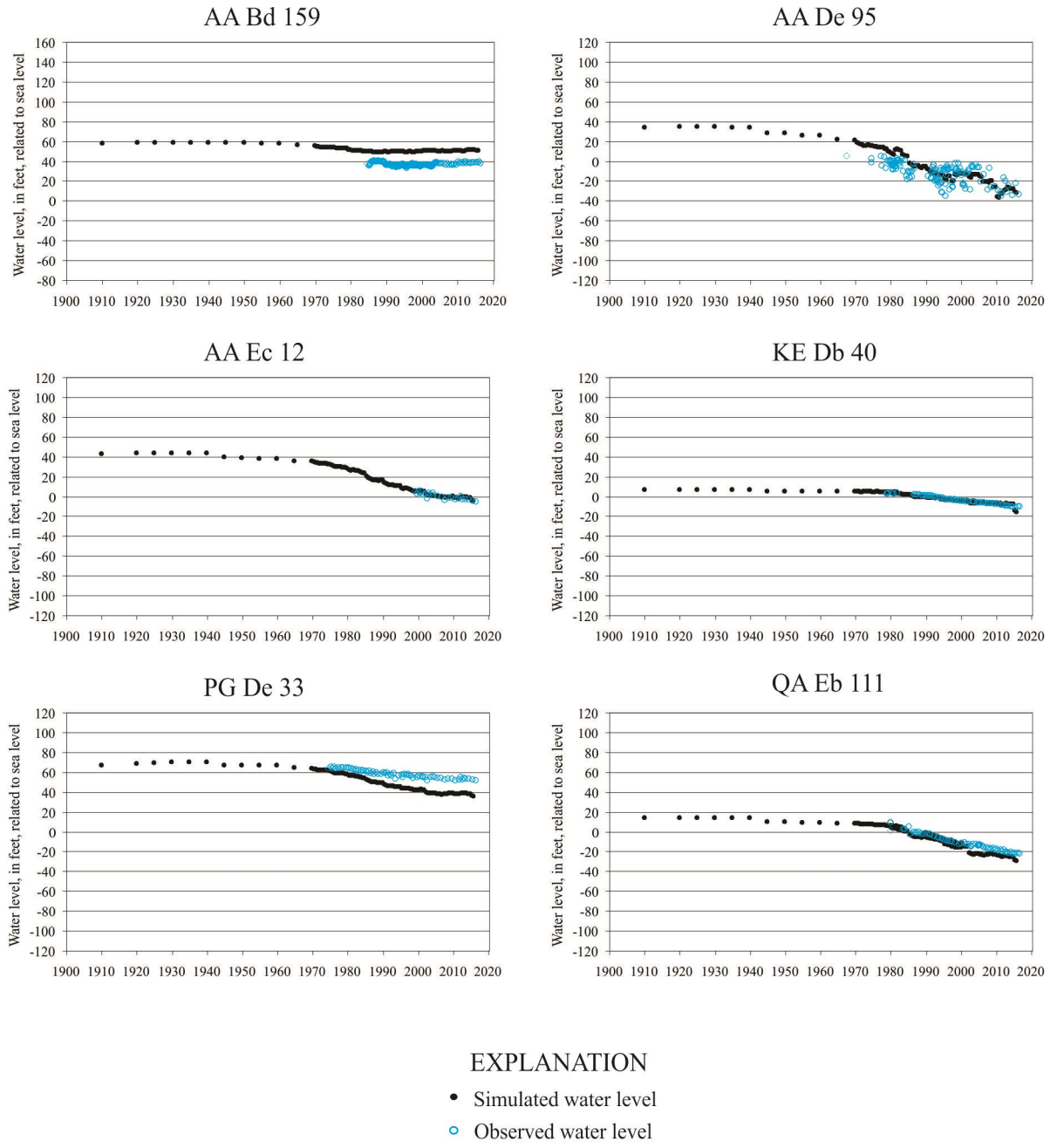

Figure 9. Hydrographs of observed and simulated water levels in wells screened in the Upper Patapsco aquifer system, 1900-2015.

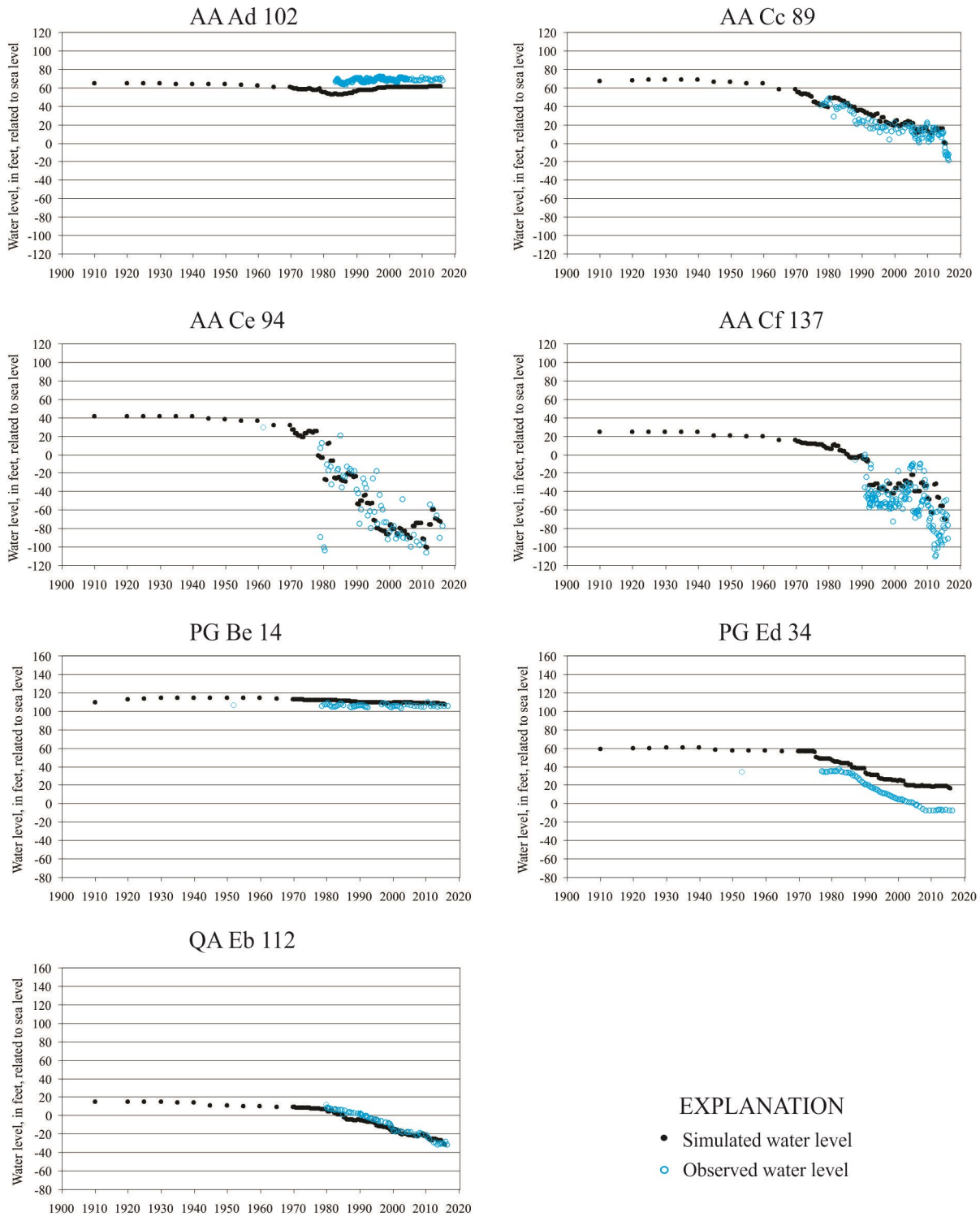

Figure 10. Hydrographs of observed and simulated water levels in wells screened in the Lower Patapsco aquifer system, 1900-2015.

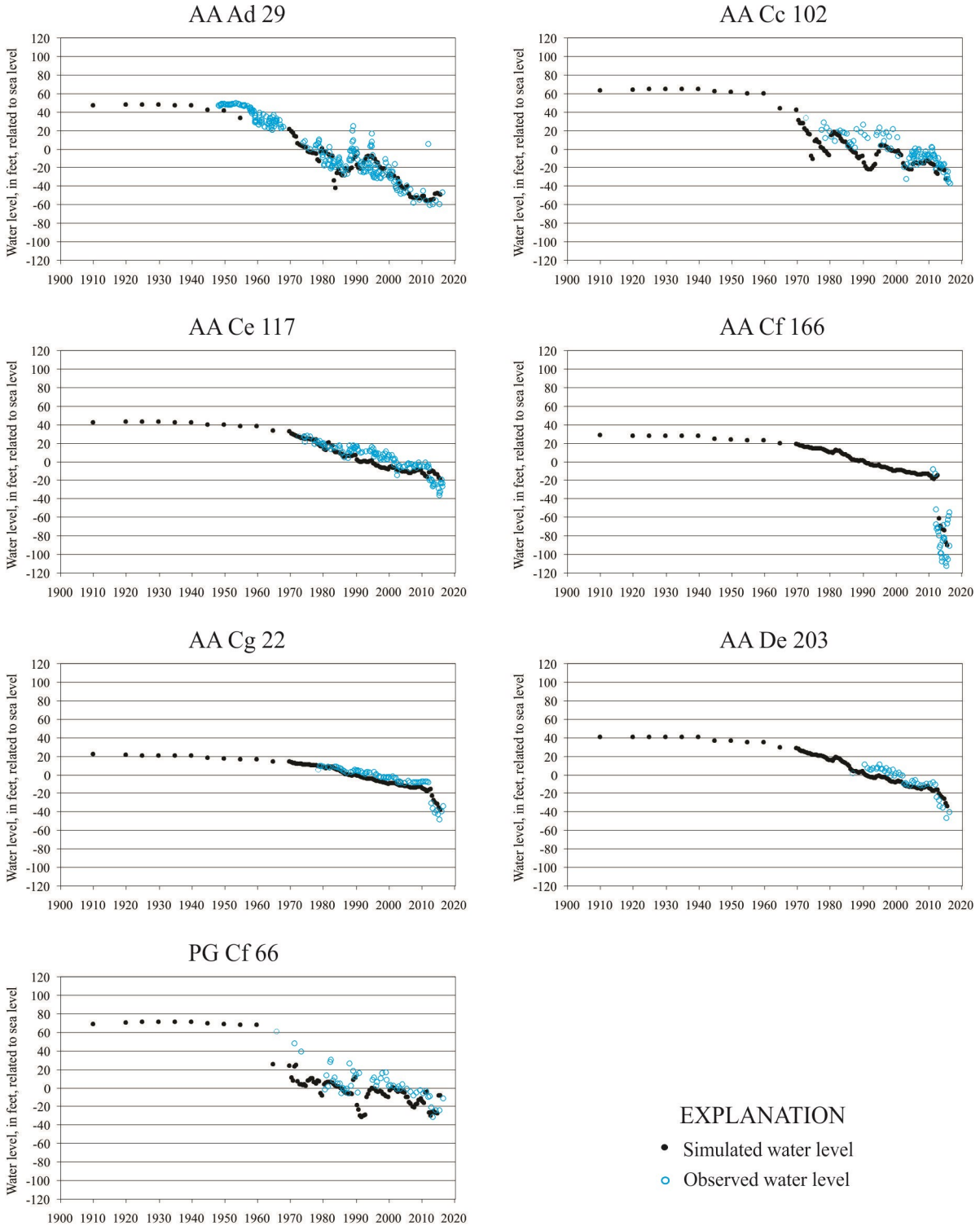

Figure 11. Hydrographs of observed and simulated water levels in wells screened in the Patuxent aquifer system, 1900-2015.

the 50 observation points was minimized for the ending stress period (2015). The resulting RMSE was 8.02 ft. The correlation coefficient was 0.98, which is considered a good fit. The median of the absolute difference between simulated and observed heads was 4.45, 5.13, 8.25, and 3.36 ft for the Magothy aquifer, Upper and Lower Patapsco aquifer systems, and Patuxent aquifer system respectively (tab. 2).

PREDICTIVE MODEL SIMULATIONS

Effects of Build-Out Withdrawal Rates (2086)

The potential effects of future withdrawals on groundwater levels, 80-percent management levels, and domestic-well operation in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems were evaluated using a predictive groundwater-flow model simulation. The calibrated transient (1900-2015) flow model was altered to simulate conditions for the period 2017 to 2086 (70-year period). The model consists of five stress periods ranging in duration from 3 to 52 years; the number of time steps ranged from 1 to 4 years in duration (tab. 3). The time discretization was designed to align with the projected changes in withdrawals from the AADPW well fields (tab. 4). The last stress period (stress period 5 representing 2035 to 2086) equals build-out for the projected withdrawals. Over the simulation period, withdrawals from wells other than those operated by the AADPW were increased incrementally to the permitted average-day appropriation amount (app. B). In a few instances, recent withdrawals (2015) were greater than the permitted average-day appropriation amount (app. A). In those cases, withdrawals declined over the simulation period. General-head boundary heads in the Magothy, Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems were lowered at rates consistent with regional water-level trends observed over the past ~10 years. A similar lowering in time-dependant specified heads was made in the Aquia aquifer (model layer 2).

Average-day groundwater withdrawals from AADPW well fields tapping the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems are projected to increase to a total build-out amount of ~67 Mgal/d by 2086, an approximate two-fold increase (~34 Mgal/d) over 2016 withdrawals (Malcolm Pirnie, Water Division of Arcadis, 2016) (tab. 4). Total average-day withdrawals at Broad Creek, Arnold, and Crofton Meadows will increase by 0.9, 1.5, and 2.7 Mgal/d respectively, over the current average appropriated amount. At Severndale, total average-day withdrawals decrease by 2.45 Mgal/d over the current average appropriated amount. The most significant changes in future withdrawals are the discontinuation of pumping from the Dorsey well field (Patuxent aquifer system), and the addition of two new well fields (Crownsville and Millersville) that pump from both the Lower Patapsco and Patuxent aquifer systems. The majority of the total projected increase in withdrawals occurs at the new well fields (combined total of 20 Mgal/d). Total average-day build-out withdrawals increase by 4.7, 18.3, and 9.8 Mgal/d over 2016 withdrawals, and by 2.7, 12.1, and 1.4 Mgal/d over current permitted allocations from the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems respectively.

To simulate the potential effects of the projected withdrawals on groundwater levels, average-day withdrawals from the AADPW well fields were increased incrementally to build-out amounts over five stress periods. Total well-field withdrawals were apportioned to aquifers pumped within the well field (Malcolm Pirnie, Water Division of Arcadis, 2016), and then distributed evenly to the existing production wells (tab. 5). At Arnold and Crofton

Table 3. Time discretization used in the predictive (2017 – 2086) groundwater-flow model.

Stress period	Period	Duration of stress period, years	Time steps (duration, years)
1	2017 – 2019	3	3 (1)
2	2020 – 2024	5	5 (1)
3	2025 – 2029	5	5 (1)
4	2030 – 2034	5	5 (1)
5	2035 – 2086	52	13 (4)

Table 4. Projected withdrawals from Anne Arundel County Department of Public Works well fields by aquifer.

Well field	Groundwater Appropriation Permit	Aquifer system	Average-day withdrawals, million gallons per day			
			Permitted appropriation (current)	2016 (Reported)	2086 (Build-out)	Change from permitted amount
Broad Creek	AA1968G006	Upper Patapsco	1.4	0.7	2.7	+ 1.3
	AA1986G070	Lower Patapsco	3.6	2.4	3.3	- 0.3
	AA2014G003	Patuxent	1.0	0	0.9	- 0.1
		Total	**6.0**	**3.1**	**6.9**	**+ 0.9**
Arnold	AA1982G036	Upper Patapsco	3.5	2.7	4.9	+ 1.4
	AA1987G069	Lower Patapsco	8.0	5.2	9.8	+ 1.8
	AA2005G020	Patuxent	4.5	2.4	2.8	- 1.7
		Total	**16.0**	**10.3**	**17.5**	**+ 1.5**
Severndale	AA1953G108	Upper Patapsco	0.45	0	0.4	- 0.05
	AA1953G008	Lower Patapsco	7.0	5.8	4.6	- 2.4
		Total	**7.45**	**5.8**	**5.0**	**- 2.45**
Telegraph Road	AA1981G026	Lower Patapsco	1.0	0.41	0	- 1.0
Stevenson Road	AA1981G025		0.83	0.7	0	- 0.83
Herald Harbor	AA1982G031		0.16	0.14	0.3	+ 0.14
Gibson Island	AA1971G034	Upper Patapsco	0.12	0.074	0.2	+ 0.08
Dorsey Road	AA1969G019	Patuxent	4.8	1.8	0	- 4.8
		Total	**4.8**	**1.8**	**0**	**- 4.8**
Crofton Meadows	AA1972G105	Lower Patapsco	6.8	6.5	11.5	+ 4.7
	AA1972G005	Patuxent	8.0	5.7	6.0	- 2.0
		Total	**14.8**	**12.2**	**17.5**	**+ 2.7**
Crownsville	No current permit	Lower Patapsco	0	0	5.0	5.0
	No current permit	Patuxent	0	0	5.0	5.0
		Total	**0**	**0**	**10.0**	**+ 10.0**
Millersville	No current permit	Lower Patapsco	0	0	5.0	5.0
	No current permit	Patuxent	0	0	5.0	5.0
		Total	**0**	**0**	**10.0**	**+ 10.0**
		Grand total	**51.2**	**34.5**	**67.4**	**+ 16.2**
Upper Patapsco aquifer system			**5.5**	**3.5**	**8.2**	**+ 2.7**
Lower Patapsco aquifer system			**27.4**	**21.2**	**39.5**	**+ 12.1**
Patuxent aquifer system			**18.3**	**9.9**	**19.7**	**+ 1.4**

Table 5. Projected withdrawals from Anne Arundel County Department of Public Works well fields assigned to individual production wells.

Well field	Well	Aquifer system	Model cell (row, column, layer)	Average-day withdrawal demand in stress period, Mgal/d				
				1[1] 2017-2019	2 2020-2024	3 2025-2029	4 2030-2034	5 2035-2086 "Build-out"
Broad Creek	AA De 96	Upper Patapsco	62,81,4	0.233	0.4	0.57	0.73	0.9
	AA De 97		64,80,4	0.233	0.4	0.57	0.73	0.9
	AA De 136		66,77,4	0.233	0.4	0.57	0.73	0.9
	AA De 177	Lower Patapsco	63,80,5	1.2	1.3	1.4	1.5	1.65
	AA De 208		65,84,5	1.2	1.3	1.4	1.5	1.65
	AA De 234	Patuxent	66,76,6	0	0.11	0.22	0.34	0.45
	AA De 235		64,83,6	0	0.11	0.22	0.34	0.45
			Total	**3.1**	**4.0**	**5.0**	**5.95**	**6.9**
Arnold	AA Cf 118	Upper Patapsco	39,80,4	0.54	0.65	0.76	0.87	0.98
	AA Cf 119		40,80,4	0.54	0.65	0.76	0.87	0.98
	AA Cf 120		40,81,4	0.54	0.65	0.76	0.87	0.98
	AA Cf 155		41,83,4	0.54	0.65	0.76	0.87	0.98
	AA Cf 170		35,82,4	0.54	0.65	0.76	0.87	0.98
	AA Cf 142	Lower Patapsco	40,80,5	1.73	1.9	2.1	2.3	2.45
	AA Cf 150		41,83,5	1.73	1.9	2.1	2.3	2.45
	AA Cf 168		35,82,5	1.73	1.9	2.1	2.3	2.45
	Hypothetical well 1		42,81,5	0	0.61	1.2	1.8	2.45
	AA Cf 169	Patuxent	35,82,6	1.2	1.25	1.3	1.35	1.4
	AA Cf 171		41,83,6	1.2	1.25	1.3	1.35	1.4
			Total	**10.3**	**12.1**	**13.9**	**15.7**	**17.5**
Severndale	AA Ce 96	Upper Patapsco	48,50,4	0	0.1	0.2	0.3	0.4
	AA Ce 131,152	Lower Patapsco	48,50,5	2.32	2.2	2.08	1.96	1.84
	AA Ce 121		50,50,5	1.16	1.1	1.04	0.98	0.92
	AA Ce 122		48,49,5	1.16	1.1	1.04	0.98	0.92
	AA Ce 139		46,52,5	1.16	1.1	1.04	0.98	0.92
			Total	**5.8**	**5.6**	**5.4**	**5.2**	**5.0**
Telegraph Road	AA Bc 215	Lower Patapsco	56,23,5	0.41	0	0	0	0
Stevenson Road	AA Bd 121		52,26,5	0.7	0	0	0	0
Herald Harbor	AA Ce 123, 124		54,58,5	0.14	0.18	0.22	0.26	0.3
Gibson Island	AA Cf 123, 172	Upper Patapsco	19,80,4	0.074	0.10	0.14	0.17	0.2
Dorsey Road	AA Ad 111	Patuxent	34,15,6	0.297	0.31	0.32	0.33	0
	AA Bd 161		36,18,6	0.297	0.31	0.32	0.33	0
	AA Bd 177,178		40,15,6	0.593	0.62	0.64	0.67	0
	AA Bd 188		44,17,6	0.297	0.31	0.32	0.33	0
	AA Bd 189		44,21,6	0.297	0.31	0.32	0.33	0
			Total	**1.8**	**1.86**	**1.93**	**2.0**	**0**
Crofton Meadows	AA Cc 128	Lower Patapsco	84,43,5	1.3	1.38	1.47	1.56	1.64
	AA Cc 129		85,44,5	1.3	1.38	1.47	1.56	1.64
	AA Cc 140		83,46,5	1.3	1.38	1.47	1.56	1.64
	AA Cc 152		81,41,5	1.3	1.38	1.47	1.56	1.64
	AA Cd 106		81,49,5	1.3	1.38	1.47	1.56	1.64
	Hypothetical well 1		80,42,5	0	0.41	0.82	1.23	1.64
	Hypothetical well 2		87,54,5	0	0.41	0.82	1.23	1.64
	AA Cc 103	Patuxent	86,43,6	0.95	0.96	0.97	0.98	1.0
	AA Cc 105		85,43,6	0.95	0.96	0.97	0.98	1.0
	AA Cc 107		88,43,6	0.95	0.96	0.97	0.98	1.0
	AA Cc 138		83,46,6	0.95	0.96	0.97	0.98	1.0
	AA Cc 151		81,41,6	0.95	0.96	0.97	0.98	1.0
	AA Cd 107		81,49,6	0.95	0.96	0.97	0.98	1.0
			Total	**12.2**	**13.5**	**14.8**	**16.1**	**17.5**
Crownsville	Hypothetical well 1	Lower Patapsco	69,64,5	0	0	0	0	1.67
	Hypothetical well 3		69,65,5	0	0	0	0	1.67
	Hypothetical well 5		70,64,5	0	0	0	0	1.67
	Hypothetical well 2	Patuxent	69,64,6	0	0	0	0	1.67
	Hypothetical well 4		69,65,6	0	0	0	0	1.67
	Hypothetical well 6		70,64,6	0	0	0	0	1.67
			Total	**0**	**0**	**0**	**0**	**10.0**
Millersville	Hypothetical well 1	Lower Patapsco	52,36,5	0	0	0	0	1.67
	Hypothetical well 3		53,37,5	0	0	0	0	1.67
	Hypothetical well 5		52,37,5	0	0	0	0	1.67
	Hypothetical well 2	Patuxent	52,36,6	0	0	0	0	1.67
	Hypothetical well 4		53,37,6	0	0	0	0	1.67
	Hypothetical well 6		52,37,6	0	0	0	0	1.67
			Total	**0**	**0**	**0**	**0**	**10.0**
			Grand total	**34.4**	**37.3**	**41.4**	**45.4**	**67.4**

1 – Based on reported withdrawals for 2016

Meadows, additional Lower Patapsco production wells were added to the simulation to meet the projected demand. At the two new well fields at Crownsville and Millersville, projected withdrawals were divided evenly between the Lower Patapsco and Patuxent aquifer systems.

Simulated heads at the end of the simulation period (2086) in the Upper Patapsco aquifer system show a large cone of depression with heads greater than 80 ft below sea level centered around the Broad Creek well field (fig. 12). The cone of depression is a result of the projected increase in withdrawals from the Broad Creek, City of Annapolis, and U.S. Naval Academy well fields. The deepest heads occur at the Broad Creek and City of Annapolis well fields at ~100 ft below sea level. The projected withdrawals result in a shift of the cone of depression mapped in 2015 surrounding the Arnold well (Staley and others, 2016) to the Broad Creek well field, and a deepening of heads by as much as ~80 ft.

Simulated heads at the end of the simulation period (2086) in the Lower Patapsco aquifer system show large cones of depression centered around the Arnold, Broad Creek, Crofton Meadows, and Crownsville (hypothetical) well fields with heads 170, 135, 172, and 154 ft below sea level respectively (fig. 13). The deepest heads occur at the Arnold and Crofton Meadows well fields at ~170 ft below sea level. The projected withdrawals result in an expansion of the cone of depression mapped in 2015 surrounding the Arnold, Broad Creek, and Severndale well fields (Staley and others, 2016) to include the Crofton Meadows and Crownsville (hypothetical) well fields, and a deepening of heads by as much as ~130 ft. Withdrawals from the Millersville (hypothetical) well field result in a relatively small cone of depression with heads ~70 ft below sea level.

Simulated heads at the end of the simulation period (2086) in the Patuxent aquifer system show large cones of depression centered around the Arnold, Broad Creek, Crofton Meadows, Crownsville (hypothetical), and Millersville (hypothetical) well fields with heads 177, 140, 187, 228, and 145 ft below sea level respectively (fig. 14). The projected withdrawals result in a significant expansion of the cone of depression mapped in 2015 surrounding the Arnold and Crofton Meadows well fields (Staley and others, 2016) to include the Broad Creek, Crownsville (hypothetical), and Millersville (hypothetical) well fields, and a deepening of heads by as much as ~200 ft. Simulated heads at the Dorsey Road well field recover by ~160 ft as a result of cessation of withdrawals in 2035 (tab. 5).

The simulated available drawdown remaining at projected build-out (2086) ranges from zero to ~500 ft in the Upper Patapsco aquifer system in Anne Arundel County (fig. 15). At the Arnold, Broad Creek, and Gibson Island well fields, available drawdown remaining is approximately 70, 109, and 152 ft respectively. The management level is exceeded by 15 ft at the Severndale well field and, similar to the available drawdown remaining in 2015 discussed earlier in the report, is exceeded in a relatively narrow band paralleling the outcrop area of Upper Patapsco aquifer system (fig. 2). Sufficient supply capacity is available, however, for the Upper Patapsco withdrawals (0.4 Mgal/d by 2086) to be shifted to the Lower Patapsco aquifer system.

The simulated available drawdown remaining at projected build-out (2086) ranges from zero to ~1,000 ft in the Lower Patapsco aquifer system in Anne Arundel County (fig. 16). The least amount of available drawdown remaining, approximately 60 and 80 ft, occurs at the Crofton Meadows and Millersville well fields respectively. At the Arnold, Broad Creek, Crownsville, Herald Harbor, and Severndale well fields, available drawdown remaining is approximately 365, 430, 260, 220, and 145 ft respectively. Similar to the available drawdown remaining in 2015 discussed earlier in the report, the management level is exceeded in a relatively narrow band paralleling the outcrop area of the Lower Patapsco aquifer system (fig. 3).

The simulated available drawdown remaining at projected build-out (2086) ranges from zero to ~1,500 ft in the Patuxent aquifer system in Anne Arundel County (fig. 17). At the Arnold, Broad Creek, Crofton Meadows, Crownsville (hypothetical), and Millersville (hypothetical) well fields, available drawdown remaining is approximately 775, 850, 410, 600 and 250 ft respectively. Similar to the available drawdown remaining in 2015 discussed earlier in the report, the management level is exceeded in a relatively narrow band paralleling the outcrop area of the Patuxent aquifer system (fig. 4).

Large groundwater withdrawals near outcrop areas of confined aquifers can potentially result in a lowering of the water table and reduction of baseflow to streams in the outcrop ("recharge") areas. In the 2007 study, simulated baseflow was reduced between 4 and 9 percent from 2002 to the end of the simulation period (2044), a period over

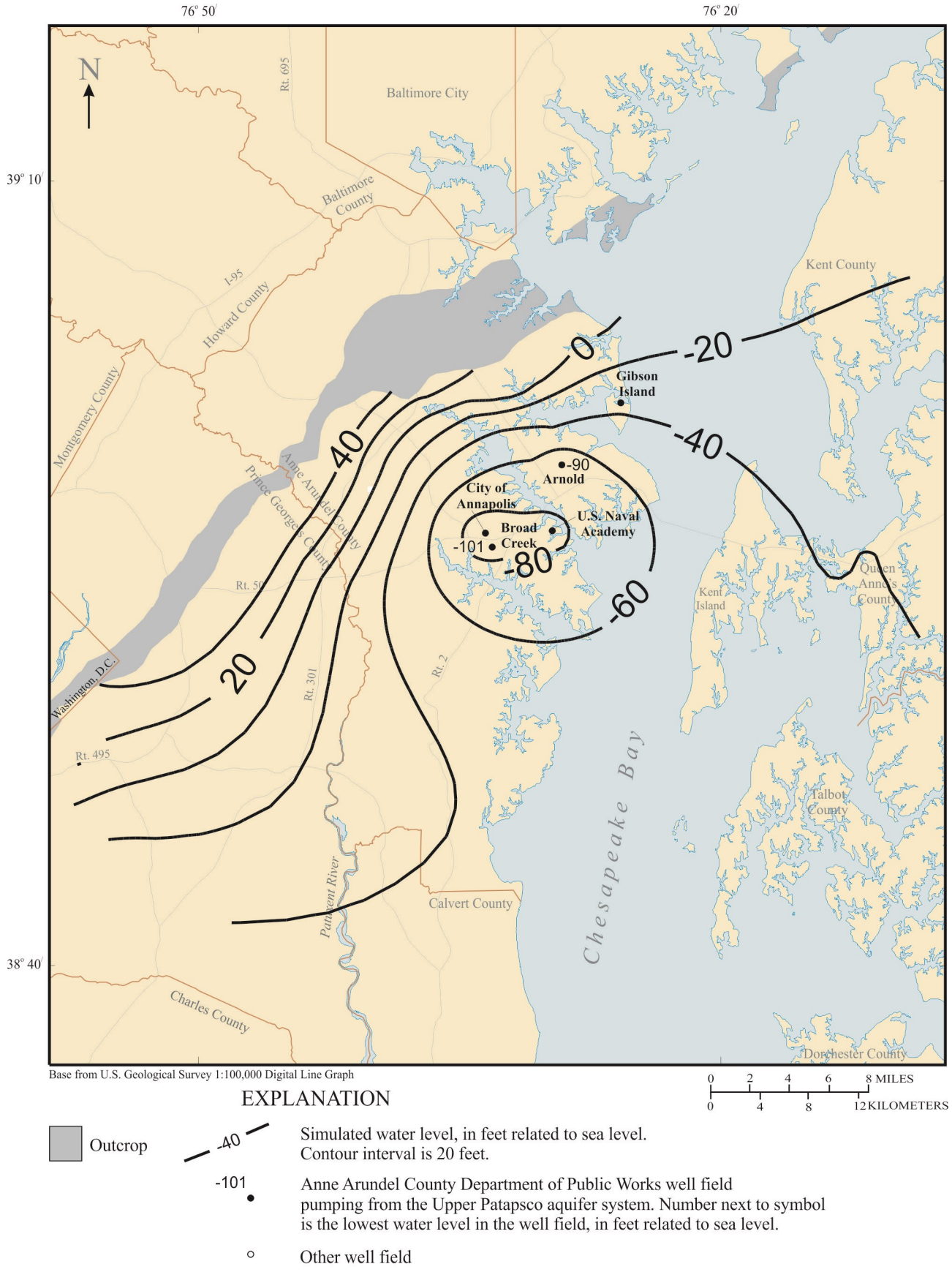

Figure 12. Simulated water levels at projected build-out (2086) in the Upper Patapsco aquifer system.

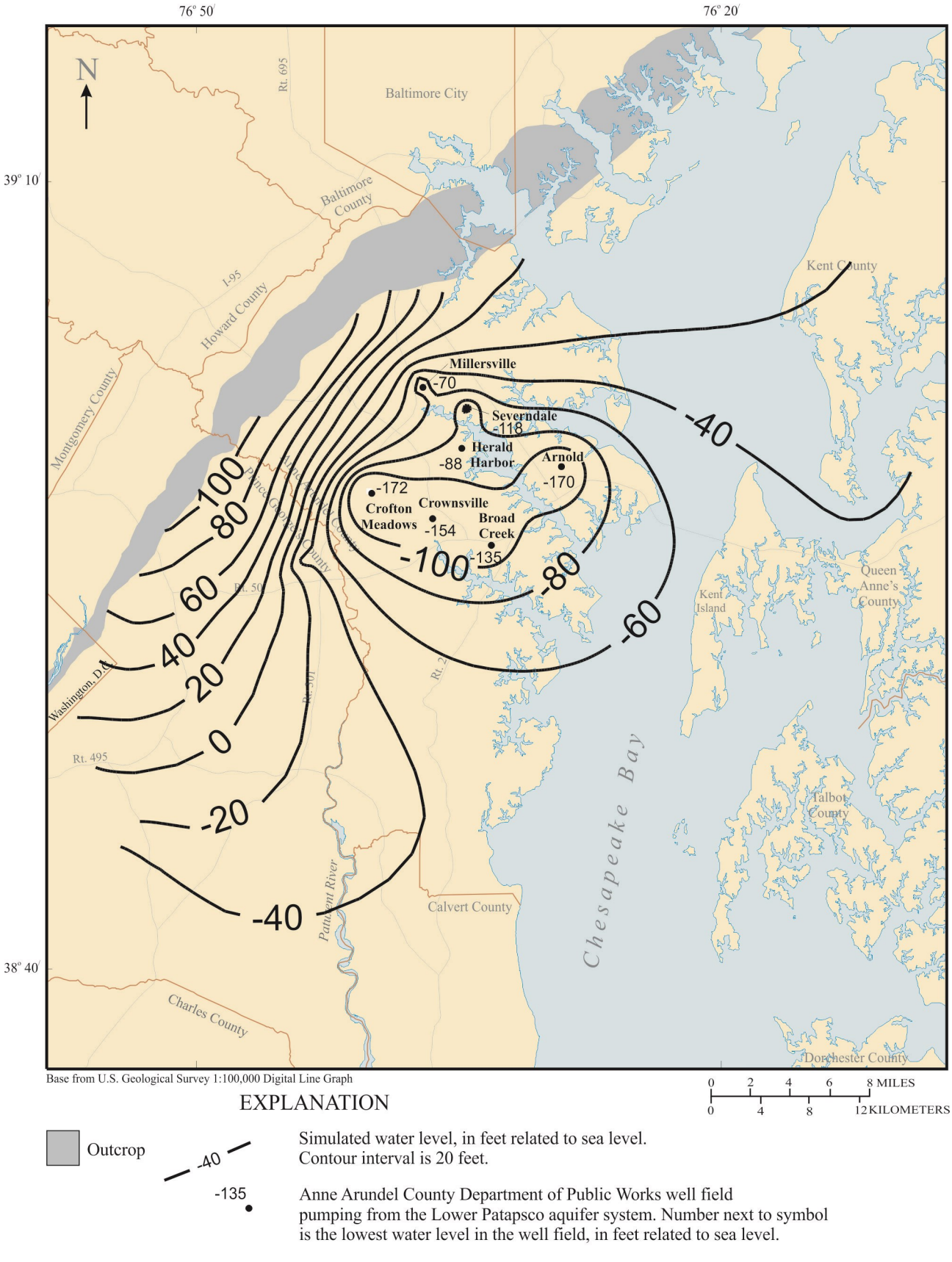

Figure 13. Simulated water levels at projected build-out (2086) in the Lower Patapsco aquifer system.

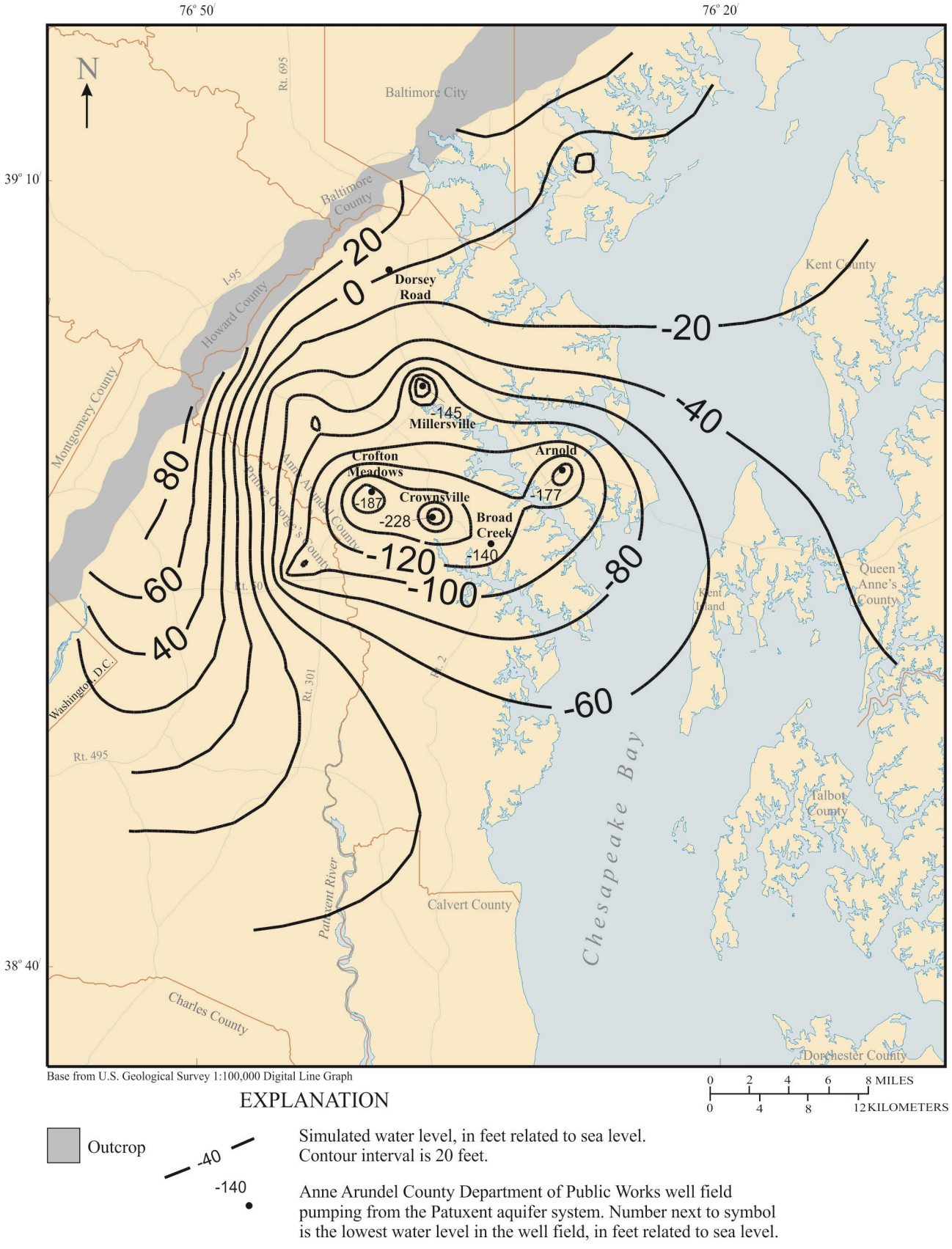

Figure 14. Simulated water levels at projected build-out (2086) in the Patuxent aquifer system.

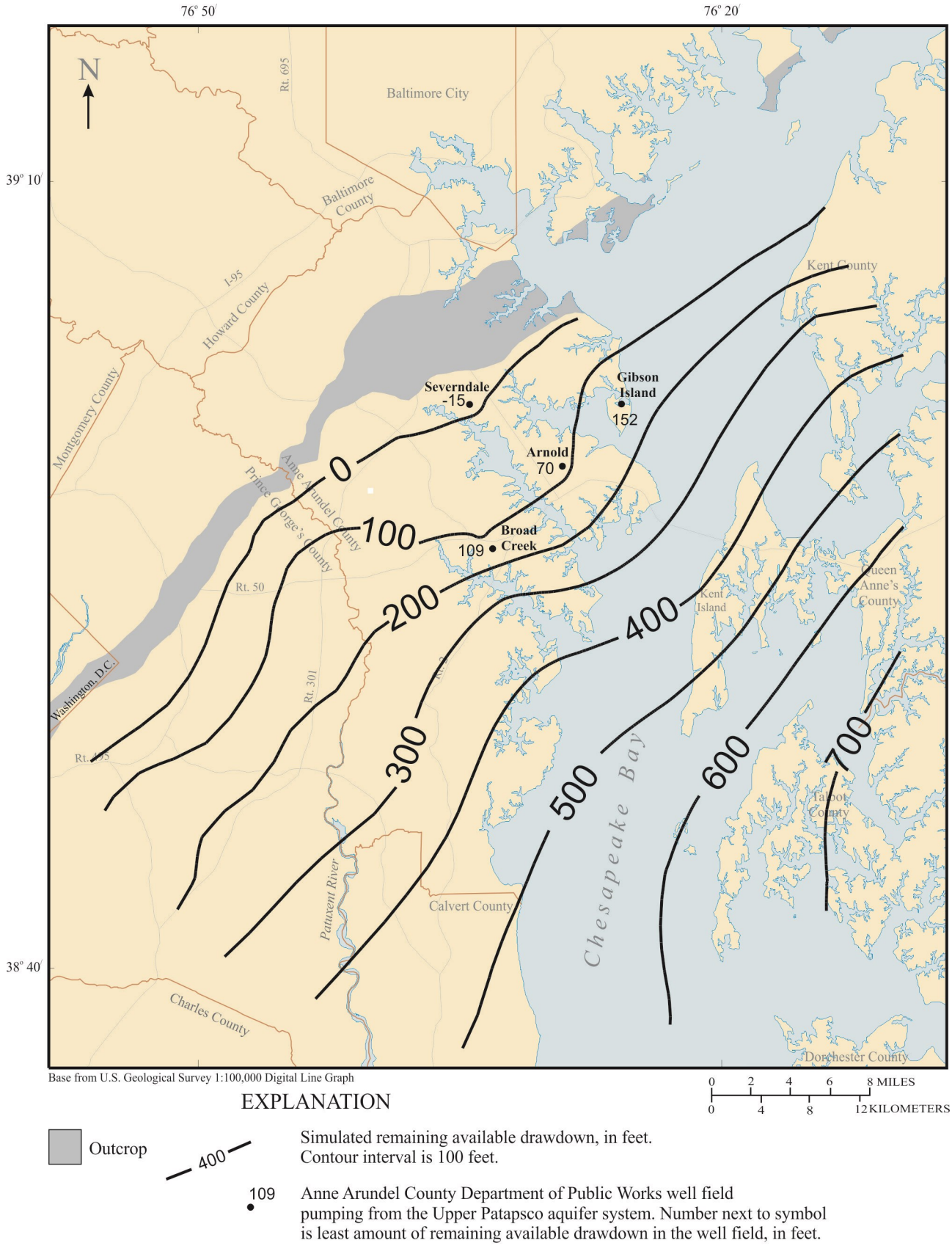

Figure 15. Simulated available drawdown remaining at projected build-out (2086) in the Upper Patapsco aquifer system.

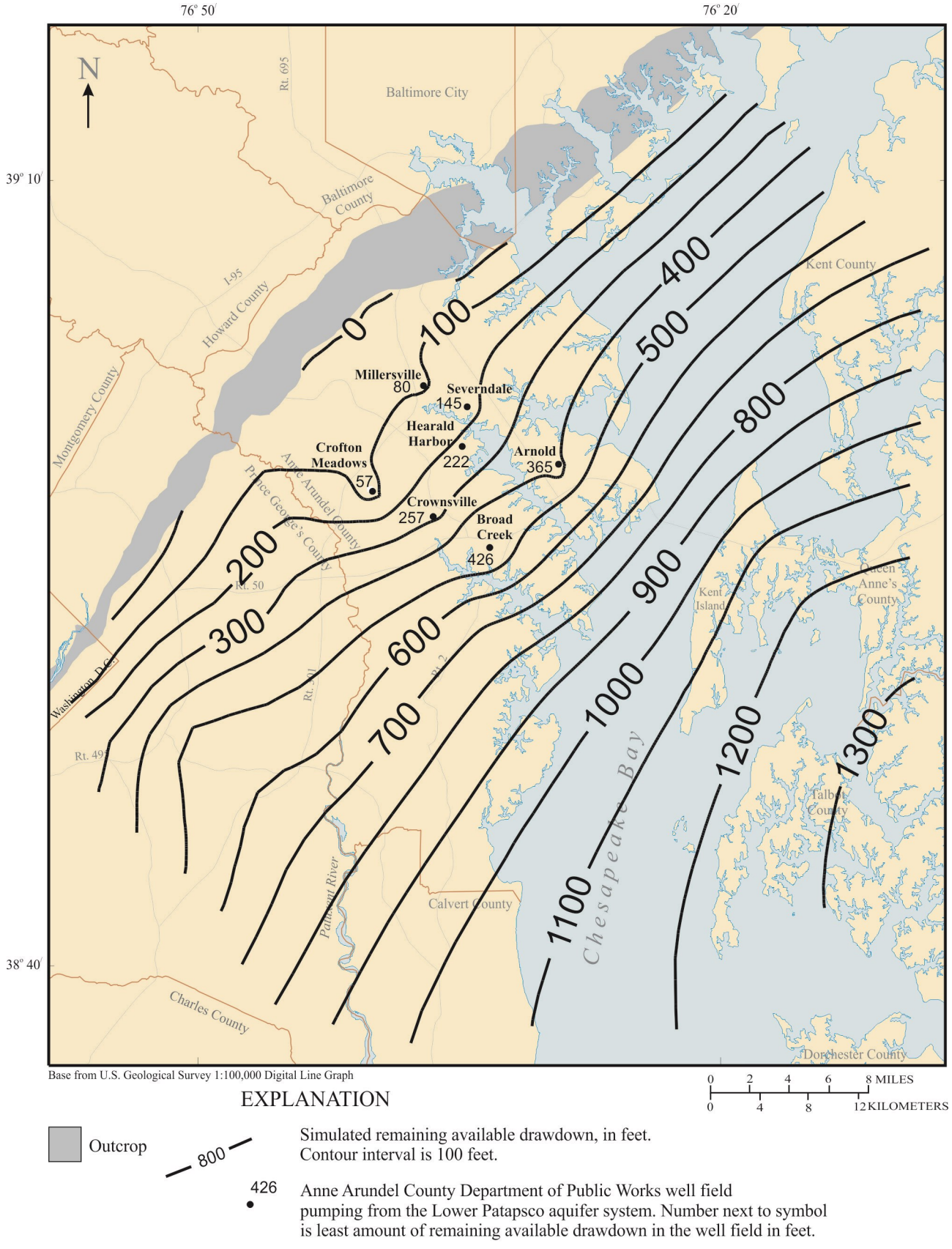

Figure 16. Simulated available drawdown remaining at projected build-out (2086) in the Lower Patapsco aquifer system.

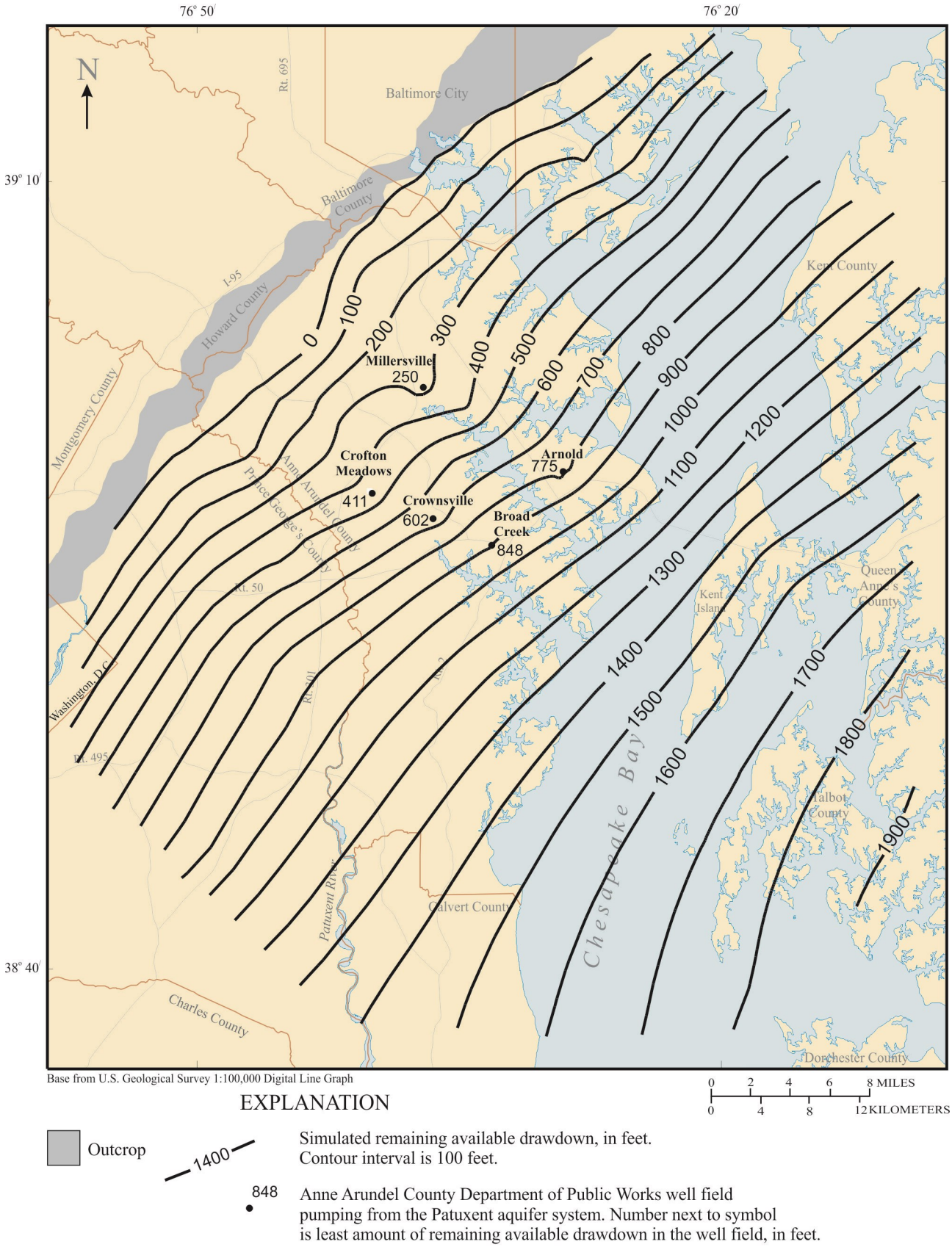

Figure 17. Simulated available drawdown remaining at projected build-out (2086) in the Patuxent aquifer system.

which withdrawals from the Upper and Lower Patapsco and Patuxent aquifer systems increased from ~26 to ~67 Mgal/day from the AADPW wells, and total withdrawals in the model area (including the Magothy aquifer) increased from ~46 to ~109 Mgal/d. Over the period simulated in this study (2015-2086), withdrawals from the Upper and Lower Patapsco and Patuxent aquifer systems increased from ~34 to ~67 Mgal/d from the AADPW wells, and total withdrawals in the model area (including the Magothy aquifer) increased from ~50 to ~92 Mgal/d. Given that the total rate of withdrawals simulated in this study are less than those simulated in the 2007 study it can be inferred that the potential reduction in stream baseflow in the outcrop areas would be less than the 4 – 9 percent range.

Effects of Seasonal Variations in Withdrawals

The potential effects of seasonal variation in withdrawals on groundwater levels were evaluated by model simulation. Specifically, the final year simulated (2086) in the previous build-out simulation was expanded to include 12 month-long stress periods in order to represent the seasonal pumpage variation (fig. 18). All simulated annual average withdrawals in that year were decreased by a factor of 0.9 for the first three months (January-March), increased by a factor of 1.1 for 6 months (April-September), and then decreased again by a factor of 0.9 (October-December). The applied factors (and time periods) are based on the monthly deviation from annual average withdrawals reported at Anne Arundel County's three largest well fields (Arnold, Broad Creek, and Crofton Meadows) averaged over the period 2014-2015 (fig. 18). Results of the model simulation show water levels in the Upper and Lower Patapsco and Patuxent aquifer systems after six months of the higher seasonal rates (September) less than 20 ft deeper than under annual average simulated withdrawals. The simulated heads recover to within ~10 ft or less of the heads simulated under the average simulated withdrawals by the end of the year (December) after withdrawal rates lessen.

EFFECTS OF SIMULATED DRAWDOWN ON DOMESTIC-WELL OPERATION

Drawdown from large-scale withdrawals can potentially effect the operation of domestic wells by lowering water levels below pump intakes or below the maximum depth to which a pump can be lowered in the well (top of well screen or reduction in well-casing casing diameter). To help identify potential conflicts with domestic wells, an analysis was made to determine if simulated drawdown resulting from projected AADPW withdrawals will impact well operation of domestic wells screened in the confined portion of Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems in areas currently not served by public water by in north-central Anne Arundel County. Well operation will fail if water levels fall below pump intakes. If the pump can be lowered then the failure is temporary (remedied by lowering the pump), however, if the pump can't be lowered due to a reduction in casing diameter ("telescoping" wells) then the failure is permanent, provided the water level does not recover. Pump settings in wells without restrictions in casing diameter would be limited to the top of the well screen. Well regulations in Maryland do not allow setting pumps adjacent to well screens. In the set of wells considered here, less than ~3 percent of domestic wells are telescoping, with reductions in well-casing diameter from four to two inches above the well screen. Therefore, in most of the wells the limiting factor in pump placement is the top of the well screen.

Domestic wells screened in the confined portion of the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems were identified from the database of permitted wells maintained by the Maryland Department of the Environment (MDE) (see app. C for methodology used to identify screened aquifer). This analysis provides only a gross approximation of wells screened in the target aquifers because of the uncertainty in well locations and elevations, and accuracy and resolution of aquifer-layer elevations. No attempt was made to verify well locations in the field. A total of 3,154 wells were identified as being screened in the Upper Patapsco (2,373 wells), Lower Patapsco (645 wells), and Patuxent aquifer (136 wells) systems respectively (figs. 19-21).

Simulated water levels in the Upper Patapsco, Lower Patapsco and Patuxent aquifer systems at build-out rates (2086) discussed previously were compared to elevation of well screens and casing-reduction elevation. The results indicate that simulated water levels do not fall below either well-casing diameter reductions or well screens in all but three wells. Domestic-well operation therefore is

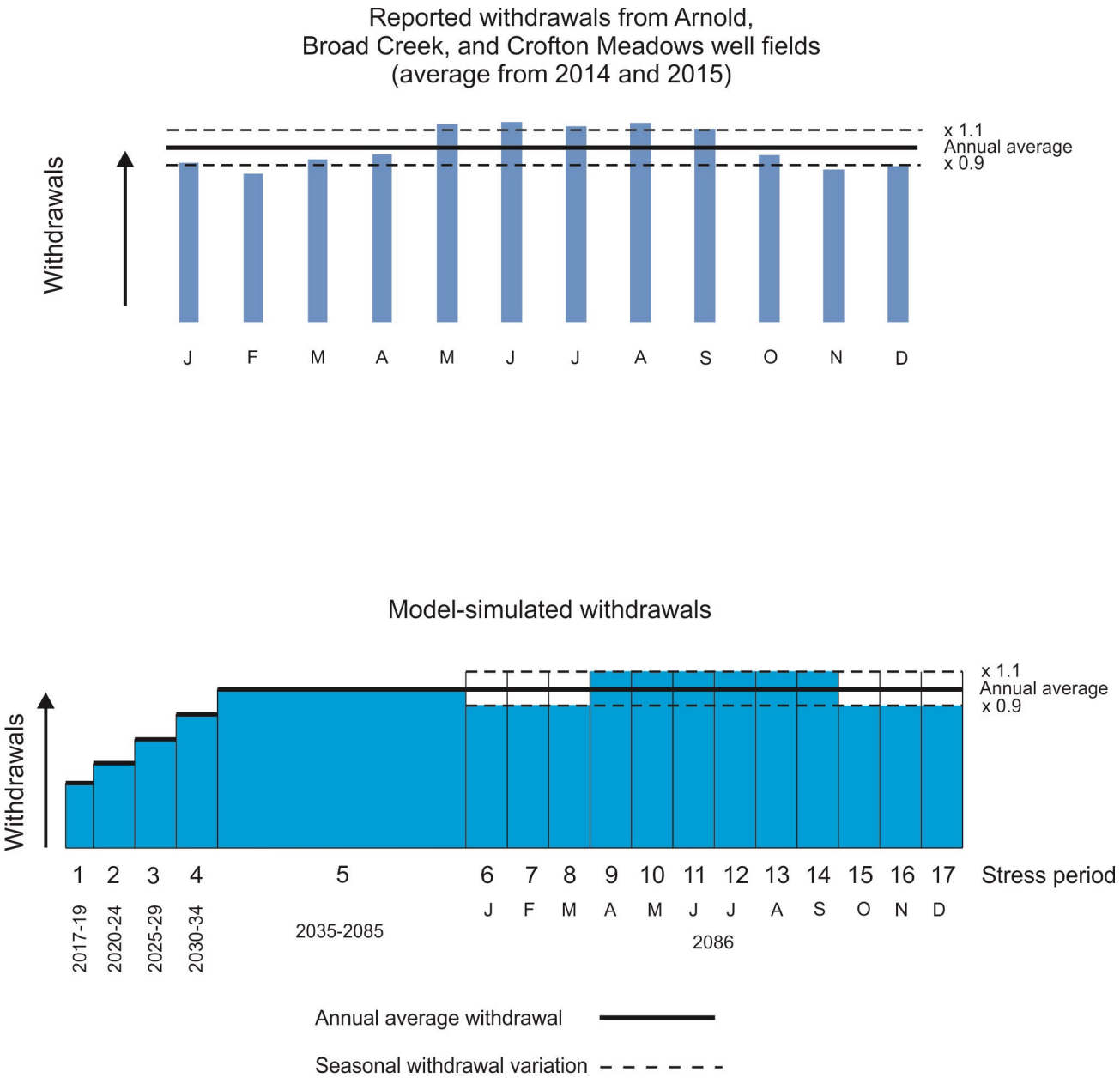

Figure 18. Reported and model-simulated seasonal withdrawal variation.

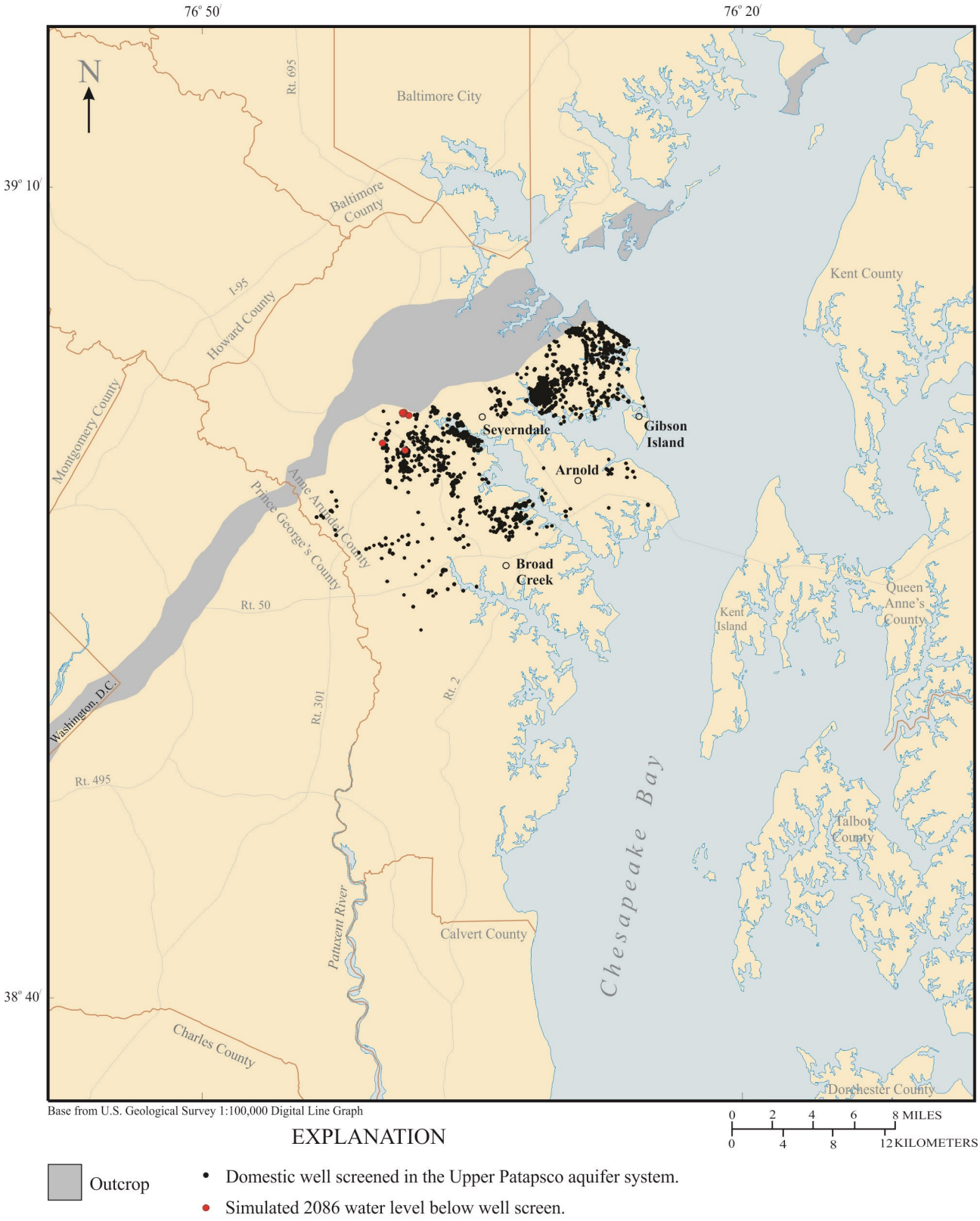

Figure 19. Domestic wells screened in the Upper Patapsco aquifer system.

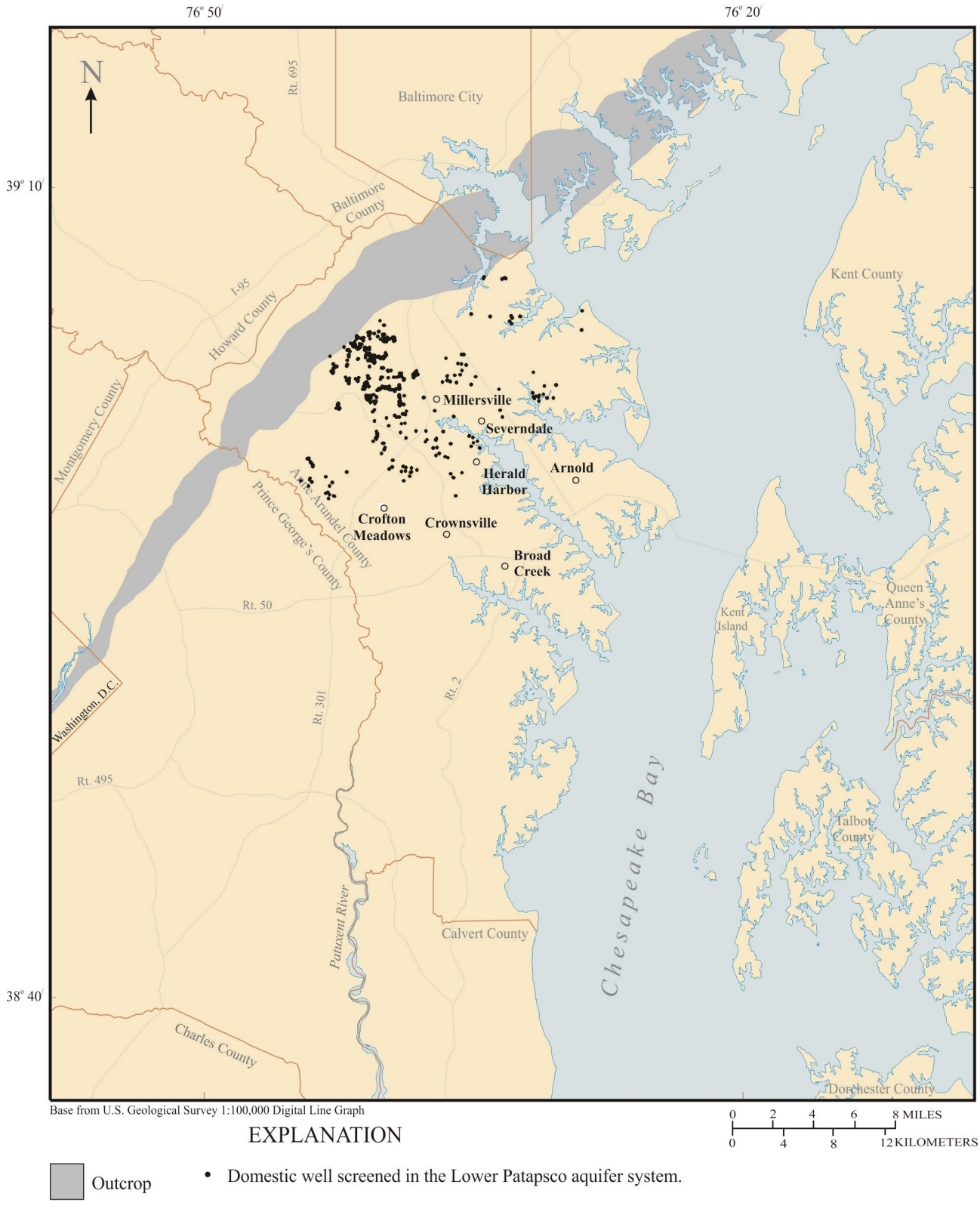

Figure 20. Domestic wells screened in the Lower Patapsco aquifer system.

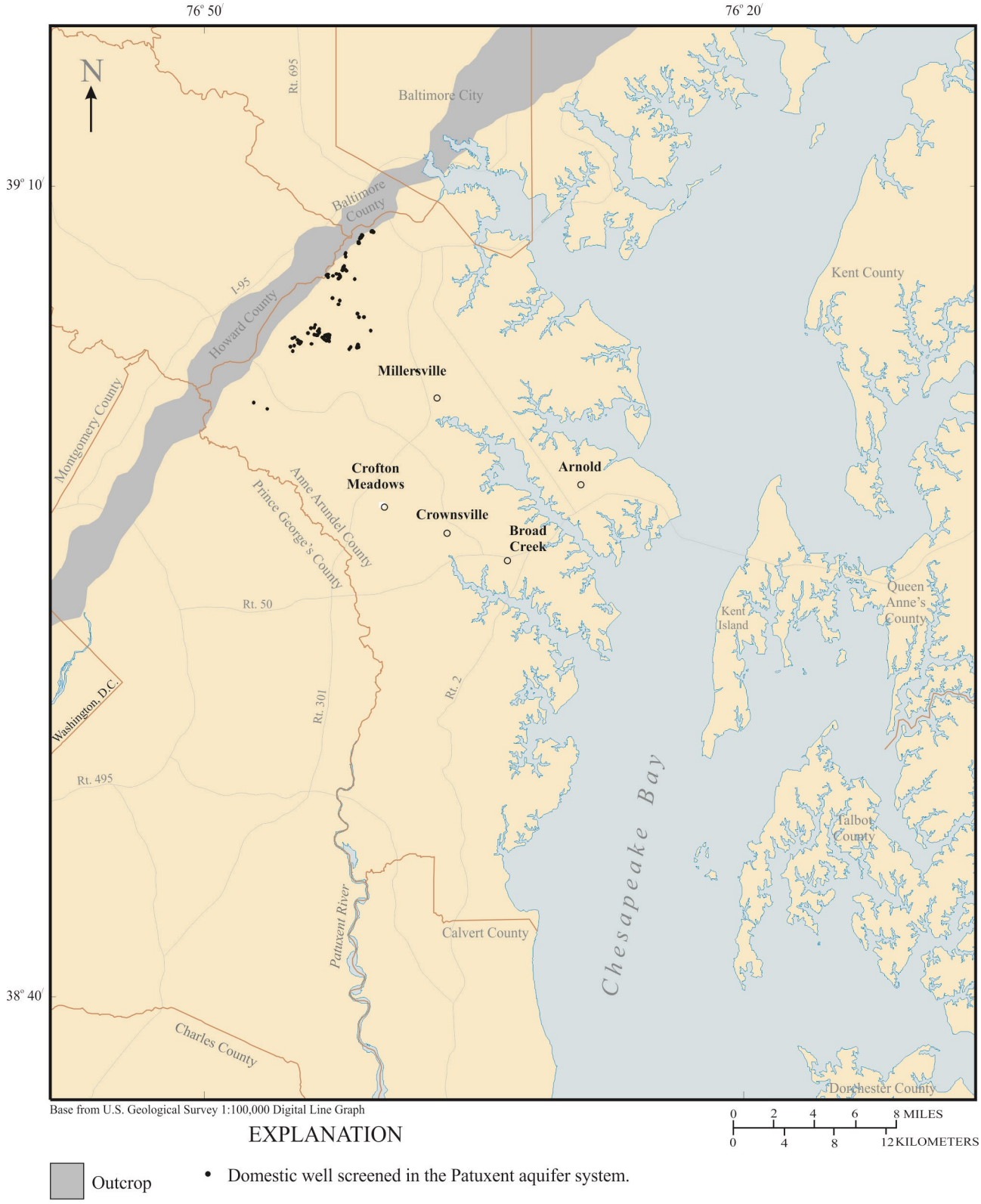

Figure 21. Domestic wells screened in the Patuxent aquifer system.

generally not adversely affected by projected increased withdrawals from Anne Arundel County Department of Public Works well fields. Simulated water levels remain at least 20 ft above well screens and casing-diameter reductions (telescoping wells) in all but six wells (fig. 19). The same outcome applies when seasonal variations in withdrawals are simulated as discussed earlier in the report.

SUMMARY

Anne Arundel County Department of Public Works withdrawals from the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems are projected to increase from a current amount of ~34 to ~67 Mgal/d at build-out (2086). This study was undertaken to assess the potential effects of the increased withdrawals on water levels, the 80-percent management level, and domestic-well operation using an updated and re-calibrated groundwater-flow model. Anne Arundel County currently operates major well fields at Arnold, Broad Creek, Crofton Meadows, Dorsey Road and Severndale, as wells as individual wells at Stevenson Road, Telegraph Road, and Elvaton, and independent well fields at Herald Harbor, Gibson Island, and Rose Haven. The Rose Haven well field is in the Aquia aquifer and not included in this study.

Currently there is sufficient available drawdown in Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems in Anne Arundel County to support withdrawals. Available drawdown remaining in 2015 in the Upper Patapsco aquifer system ranged from zero near the outcrop area of the aquifer to ~500 ft; at the Arnold, Broad Creek, Gibson Island, and Severndale well fields, the available drawdown remaining was approximately 94, 194, 182, and 26 ft respectively. Available drawdown remaining in 2015 in the Lower Patapsco aquifer system ranged from zero near the outcrop area of the aquifer to ~1,000 ft; at the Arnold, Broad Creek, Crofton Meadows, Herald Harbor and Severndale well fields, the available drawdown remaining was approximately 475, 495, 190, 270, and 166 ft respectively. Available drawdown remaining at the three independent wells (Telegraph Road, Stevenson Road, and Elvaton) was all less than ~100 ft. Available drawdown remaining in 2015 in the Patuxent aquifer system ranged from zero near the outcrop area to ~1,500 ft; at the Arnold, Broad Creek, Crofton Meadows, and Dorsey Road well fields, the available drawdown remaining was approximately 830, 950, 550, and 90 ft respectively.

The groundwater-flow model (MODFLOW) developed by Andreasen (2007) was updated and re-calibrated using more recent data. Revisions to the model included the expansion of the simulation period from 1900-2002 to 1900-2015, assignment of specified (constant) heads in layer 2 (Aquia aquifer) and general heads along model boundaries in layers 3 (Magothy aquifer), 4 (Upper Patapsco aquifer system), 5 (Lower Patapsco aquifer system), and 6 (Patuxent aquifer system), and input of new pumpage data. The model was re-calibrated by adjusting transmissivity of the Patuxent aquifer based on more recently compiled data, and vertical leakance between the Lower Patapsco and Patuxent aquifer systems. The RMSE of the calibrated model was 8.02 ft, which a slight improvement over the original model (RMSE of 9.34 ft.

To assess the effects of the projected withdrawals, the calibrated groundwater-flow model was altered to simulate conditions for the period 2017 to 2086 (70-year period). Total average-day withdrawals simulated in the model at Broad Creek, Arnold, and Crofton Meadows increase by 0.9, 1.5, and 2.7 Mgal/d respectively, over the current average appropriated amount. Withdrawals decrease by 2.45 Mgal/d at Severndale and decrease to zero at Dorsey Road. The majority of the total projected withdrawals are from two new well fields (Crownsville and Millersville) tapping both the Lower Patapsco and Patuxent aquifer systems. Rates at those well fields total 20 Mgal/d divided evenly between aquifers. Total average-day build-out withdrawals increase by 2.7, 12.1, and 1.4 Mgal/d over current permitted allocations in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems respectively.

Results of the model simulation show water levels as deep as 100, 170, and 228 feet below sea level in the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems respectively. Water levels are above the 80-percent management level in all well fields with the exception of the Upper Patapsco aquifer system at Severndale. Sufficient supply capacity is available in the Lower Patapsco aquifer system at Severndale, however, to shift the Upper Patapsco withdrawals (0.4 Mgal/d by 2086) to the Lower Patapsco. Seasonal variations in withdrawals at build-out have a negligible effect on water levels. Simulated water levels do not fall below either well-casing diameter reductions or well screens in

domestic wells, which indicates that well operations will not be adversely affected.

ACKNOWLEDGEMENTS

This study was funded through a cooperative agreement between the Anne Arundel County Department of Public Works and the Maryland Geological Survey. John Grace of the Maryland Department of the Environment, Water Supply Program, was instrumental in initiating the study. The report was reviewed by Jeff Raffensperger of the U.S. Geological Survey and Marianna Eberle of the Maryland Department of the Environment Waster-Supply Program. Laura Layton and Edward Cope of the Anne Arundel County Department of Public Works provided guidance and helpful information throughout the study. Andrew Staley of the Maryland Geological Survey provided editorial review and assistance in preparation of illustrations.

REFERENCES

Andreasen, D.C., 2007, Optimization of ground-water withdrawals in Anne Arundel County, Maryland, from the Upper Patapsco, Lower Patapsco, and Patuxent aquifers projected through 2044: Maryland Geological Survey Report of Investigations No. 77, 107 p. [http://www.mgs.md.gov/publications/report_pages/RI_77.html, accessed 5/5/2017]

Andreasen, D.C., Staley, A.W., and Achmad, Grufron, 2013, Maryland Coastal Plain aquifer information system: Hydrogeologic framework: Maryland Geological Survey Open-File Report No. 12-02-20, 121 p. [http://www.mgs.md.gov/publications/report_pages/OFR_12-02-20.html, accessed 5/5/2017]

Curtin, S.E., Andreasen, D.C., and Staley, A.W., 2009, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 2007: U.S. Geological Survey Open-File Report 2009 –1080, 1 map sheet [https://pubs.usgs.gov/of/2009/1080/pdf/OFR2009-1080.pdf, accessed 5/5/2017]

Curtin, S.E., Andreasen, D.C., and Staley, A.W., 2012, Potentiometric surface and water-level difference maps of selected confined aquifers of Southern Maryland and Maryland's Eastern Shore, 1975–2011: U.S. Geological Survey Scientific Investigations Report 2012–5165, 36 p. [https://pubs.usgs.gov/sir/2012/5165/, accessed 5/5/2017]

Malcolm Pirnie, Water Division of Arcadis, 2016, Comprehensive water strategic plan, Final report: Arlington, Virginia, 144 p.

O'Brien and Gere, Inc., 2003, Comprehensive Water Strategic Plan for Anne Arundel County:Landover, Maryland, 77 p.

Staley, A.W., Andreasen, D.C., and Curtin, S.E., 2016, Potentiometric surface and water-level difference maps of selected confined aquifers in Southern Maryland and Maryland's Eastern Shore, 1975-2015: Maryland Geological Survey Open-File Report 16-02-02, 30 p. [http://www.mgs.md.gov/publications/report_pages/OFR_16-02-02.html, accessed 5/5/2017]

Appendix A. Appropriated withdrawals in the Magothy, and Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems in the model area, 2003-2015.

List of abbreviations

AA DPW – Anne Arundel County Department of Public Works
GAP – Groundwater Appropriation Permit
Kmg – Magothy aquifer
Ukpt – Upper Patapsco aquifer system
Lkpt – Lower Patapsco aquifer system
Kpx – Patuxent aquifer system
(e) – estimated pumpage
CA Co. – Calvert County
QA Co. – Queen Anne's County
GC – golf course

Appendix A. Appropriated withdrawals in the Magothy, and Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems in the study area, 2003-2015.

GAP	Owner	Aquifer	Average annual appropriation, gallons per day	Production wells	Model cell (row, col,layer)	2003	2004
AA1932G003	U.S. Naval Academy	Ukpt	1,750,000	AA Df 12, 13	54,92,4	318,608	313,483
				AA Df 80,83,160	54,91,4	477,913	470,224
				AA Df 101	53,91,4	159,304	156,741
					Total	955,825	940,448
AA1947G003	Laurel Racing Association	Kpx	43,000	AA Bb 22	92,6,6	4,340	14,945
AA1949G004	Sandy Point State Park	Kmg	29,000	AA Cg 6, 8	24,94,3	13,217	13,351
AA1953G008	AA DPW, Severndale	Lkpt	7,000,000	AA Ce 131, 132	48,50,5	2,409,762	2,475,888
				AA Ce 121	50,50,5	1,204,881	1,237,944
				AA Ce 122	48,49,5	1,204,881	1,237,944
				AA Ce 139	46,52,5	1,204,881	1,237,944
					Total	6,024,405	6,189,721
AA1953G108	AA DPW, Severndale	Ukpt	450,000	AA Ce 96	48,50,4	8,175	313,194
AA1953G208	AA DPW, Severndale	Kpx	1,600,000	AA Ce 149	46,52,6	0	0
AA1954G001	Crownsville State Hospital	Kmg	215,000	AA Cd 11	60,60,3	29,757	22,687
				AA Cd 43, 72	62,60,3	59,513	45,373
				AA Cd 50	61,60,3	29,757	22,687
					Total	119,026	90,746
AA1956G002	Sylvan Shores	Kmg	currently inactive	AA De 69, 122	80,86,3	116,394	64,254
AA1960G021	Landsman Mobile Home Park	Kmg	20,000	AA Cd 93	63,67,3	13,876	15,441
AA1960G024	U.S. Department of Defense	Kpx	currently inactive	AA Bb 50, 54,70	76,9,6	8,003	6,243
				AA Bb 75	77,10,6	2,668	2,081
					Total	10,670	8,324
AA1962G030	Chemetals Corporation	Kpx	122,000	AA Ae 35, 36	18,29,6	41,195	20,459
AA1963G008	Holiday Mobile Estates	Kpx	125,000	AA Bc 177	58,9,6	96,975	104,617
AA1963G029	Sherwood Forest Water Co.	Kmg	100,000	AA Ce 98	55,71,3	80,632	74,441
AA1965G032	Maryland Manor Mobile Estates	Kmg	74,000	AA Ec 6, 7, 8	100,89,3	29,992	0
AA1966G027	Northrop Grumman Corp.	Ukpt	40,000	AA Cg 18, 19	27,95,4	0	21,164
AA1966G028	Epping Forest	Kmg	42,000	AA Ce 99, 119	54,75,3	27,373	27,556(e)
AA1966G048	Crofton Country Club	Kmg	60,000	AA Cc 62	89,39,3	0	26,015(e)
AA1968G006	AA DPW, Broad Creek	Ukpt	1,400,000	AA De 96	62,81,4	124,395	6,639
				AA De 97	64,80,4	124,395	6,639
				AA De 136	66,77,4	124,395	6,639
					Total	376,953	20,117
AA1968G011	Southern High School	Kmg	25,000	AA Ed 39, 41	96,93,3	16,474	1,222
AA1969G016	Pioneer City	Lkpt	480,000	AA Bc 169, 195	57,15,5	434,347	427,533
AA1969G019	AA DPW, Dorsey Road	Kpx	4,800,000	AA Ad 111	34,15,6	500,527	529,501
				AA Bd 161	36,18,6	500,527	529,501
				AA Bd 66, 177, 178	40,15,6	1,501,581	1,588,502
				AA Bd 188	44,17,6	500,527	529,501
				AA Bd 189	43,20,6	500,527	529,501
					Total	3,503,690	3,706,505

Appendix A. Continued.

GAP	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AA1932G003	341,795	306,773	320,481	299,539	313,640	323,632	352,816	412,694	359,586	326,052	322,841
	512,693	460,159	480,722	449,309	470,461	485,448	529,225	619,041	539,380	489,078	484,262
	170,898	153,386	160,241	149,770	156,820	161,816	176,408	206,347	179,793	163,026	161,421
	1,025,386	920,318	961,444	898,617	940,921	970,896	1,058,449	1,238,082	1,078,759	978,156	968,523
AA1947G003	948	18,924	6,165	12,717	96	23,556	15,033	32,540	7,403	0	0
AA1949G004	11,141	11,763	13,240	14,598	7,721	12,947	15,469	15,393	20,018	10,207	25,864
AA1953G008	2,570,025	2,614,482	2,260,096	2,206,192	2,214,796	2,621,450	2,823,840	2,249,172	1,786,709	2,014,803	1,981,629
	1,285,013	1,307,241	1,130,048	1,103,096	1,107,398	1,310,725	1,411,920	1,124,586	893,355	1,007,402	990,815
	1,285,013	1,307,241	1,130,048	1,103,096	1,107,398	1,310,725	1,411,920	1,124,586	893,355	1,007,402	990,815
	1,285,013	1,307,241	1,130,048	1,103,096	1,107,398	1,310,725	1,411,920	1,124,586	893,355	1,007,402	990,815
	6,425,063	6,536,205	5,650,241	5,515,481	5,536,989	6,553,625	7,059,600	5,622,929	4,466,773	5,037,008	4,954,073
AA1953G108	491,085	351,496	268,784	334,869	267,433	156,151	82,175	16,251	80,175	111,071	134,775
AA1953G208	0	0	0	0	0	0	3,542	0	0	0	0
AA1954G001	15,524	7,394	9,330	6,673	6,945	5,832	6,431	12,317	11,640	11,428	14,897
	31,049	14,789	18,660	13,346	13,891	11,664	12,861	24,634	23,281	22,856	29,794
	15,524	7,394	9,330	6,673	6,945	5,832	6,431	12,317	11,640	11,428	14,897
	62,098	29,578	37,321	26,693	27,781	23,329	25,723	49,268	46,561	45,711	59,587
AA1956G002	81,919	67,085	85,575	80,660	44,107	38,501	39,741(e)	0	0	0	0
AA1960G021	13,686	15,882	13,212	13,240	10,781	12,520	11,390	12,947	13,444	15,532	14,525
AA1960G024	4,814 (e)	1,907	0	0	0	0	920	2,362	1,406	2,967	0
	1,605 (e)	636	0	0	0	0	307	787	469	989	0
	6,418(e)	2,543	0	0	0	0	1,226	3,149	1,874	3,956	0
AA1962G030	28,575	37,991	20,476	14,778	21,798	21,262	11,765	3,964	10,123	6,983	9,612
AA1963G008	107,293	96,425	105,614	98,839	96,479	92,696	87,088	83,932	93,784	105,011	96,619
AA1963G029	81,169	79,647	97,052	70,343	69,476	67,934	70,637	74,094	68,206	64,207	61,583
AA1965G032	72,720(e)	61,765	64,919(e)	0	66,006	77,999	82,684	84,279	69,420	71,264	68,245
AA1966G027	21,282	24,093	24,958	19,770	19,634	20,156	17,198	16,239	17,844	14,453	13,518
AA1966G028	31,056	33,415	37,455	35,468	36,308	31,326	38,815	36,887	32,412	35,806	33,257
AA1966G048	37,693	36,784	32,290	34,886	33,252	48,132	19,332	61,049	49,084(e)	37,267	76,699
AA1968G006	9,810	151,374	38,000	13,843	64,887	453,832	364,969	360,875	281,099	289,253	231,849
	9,810	151,374	38,000	13,843	64,887	453,832	364,969	360,875	281,099	289,253	231,849
	9,810	151,374	38,000	13,843	64,887	453,832	364,969	360,875	281,099	289,253	231,849
	29,729	458,710	115,151	41,948	196,627	1,375,249	1,105,967	1,093,560	851,814	876,523	702,573
AA1968G011	1,626	2,006	22,884	16,293	14,044	14,199	12,607	20,852	19,725	9,202	12,880
AA1969G016	415,062	390,335	382,692	388,270	400,085	351,109	358,378	369,366	376,529	379,419	385,247
AA1969G019	502,124	599,713	607,555	607,456	618,197	591,508	632,476	632,393(e)	638,643	563,456	572,575
	502,124	599,713	607,555	607,456	618,197	591,508	632,476	632,393(e)	638,643	563,456	572,575
	1,506,372	1,799,139	1,822,664	1,822,369	1,854,591	1,774,525	1,897,427	1,897,180 (e)	1,915,929	1,690,368	1,717,724
	502,124	599,713	607,555	607,456	618,197	591,508	632,476	632,393(e)	638,643	563,456	572,575
	502,124	599,713	607,555	607,456	618,197	591,508	632,476	632,393(e)	638,643	563,456	572,575
	3,514,868	4,197,992	4,252,882	4,252,194	4,327,378	4,140,559	4,427,330	4,426,754 (e)	4,470,501	3,944,192	4,008,022

Appendix A. Continued.

GAP	Owner	Aquifer	Average annual appropriation, gallons per day	Production wells	Model cell (row, col,layer)	2003	2004
AA1969G021	U.S. Army, Ft. Meade	Kpx	3,300,000	AA Bb 68	79,13,6	386,561	397,573
				AA Bc 164	75,18,6	386,561	397,573
				AA Bc 234	73,23,6	386,561	397,573
				AA Cc 144	75,28,6	386,561	397,573
				AA Cc 120	73,26,6	386,561	397,573
				AA Cc 123	77,29,6	386,561	397,573
					Total	2,319,367	2,385,437
AA1970G012	International Paper Co.	Lkpt	currently inactive	AA Bc 171	62,30,5	853,894	425,958
AA1970G013	Chesapeake School Complex	Ukpt	41,000	AA Bf 50, 51	18,67,4	22,731	27,771
AA1970G041	U.S. Naval Academy Golf Course	Ukpt	85,000	AA Df 89	47,93,4	13,917	31,988
AA1970G046	Provinces Water Co.	Kpx	415,000	AA Bc 192, 193, 241	59,11,6	336,861	316,362
AA1970G112	International Paper Co.	Kpx	currently inactive	AA Bc 173	62,30,6	148,867	48,360
AA1971G034	AA DPW, Gibson Island	Ukpt	120,000	AA Cf 123, 172	19,80,4	78,767	84,847
AA1972G005	AA DPW, Crofton Meadows	Kpx	8,000,000	AA Cc 103	86,43,6	561,040	551,347
				AA Cc 105	85,43,6	561,038	551,345
				AA Cc 107	88,43,6	561,038	551,345
				AA Cc 138	83,46,6	561,038	551,345
				AA Cc 151	81,41,6	561,038	551,345
				AA Cd 107	81,49,6	561,038	551,345
					Total	3,366,244	3,308,082
AA1972G009	City of Annapolis	Kmg	2,000,000	AA De 2	64,75,3	335,113	331,560
				AA De 45	62,75,3	335,113	331,560
				AA De 46, 88	62,76,3	670,227	663,120
					Total	1,340,454	1,326,241
AA1972G105	AA DPW, Crofton Meadows	Lkpt	6,800,000	AA Cc 128	84,43,5	384,153	332,473
				AA Cc 129	85,44,5	384,153	332,473
				AA Cc 140	83,46,5	384,153	332,473
				AA Cd 106	81,49,5	384,153	332,473
				AA Cc 152	81,41,5	384,153	332,473
					Total	1,920,764	1,662,363
AA1972G209	City of Annapolis	Lkpt	1,650,000	AA De 94	62,76,5	1,351,383	1,202,007
				AA De 139	64,75,5	1,351,383	1,202,007
					Total	2,702,767	2,404,015
AA1972G309	City of Annapolis	Ukpt	1,850,000	AA De 219	62,76,4	89,416(e)	294,376
				AA De 220	64,75,4	89,416(e)	294,376
					Total	178,832(e)	588,752
AA1973G013	Patuxent Mobile Estates	Kmg	40,000	AA-74-1853, AA-94-0921	102,92,3	33,531	29,982
AA1973G025	Lake Village Apartments	Kpx	160,000	AA Bc 201, 202	56,13,6	93,290	89,885
AA1981G025	AA DPW, Stevenson Road	Lkpt	830,000	AA Bd 121	52,26,5	843,868	819,410
AA1981G026	AA DPW, Telegraph Road	Lkpt	1,000,000	AA Bc 215	56,23,5	670,110	429,399
AA1981G039	Millineum Convalescent Center	Kmg	currently inactive	AA De 216	78,91,3	2,770	1,466
AA1982G031	AA DPW, Herald Harbor	Lkpt	160,000	AA Ce 123, 124	54,58,5	129,619	130,301

Appendix A. Continued.

GAP	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AA1969G021	401,797	388,556	375,467	377,430	335,901	363,928	376,461	359,054	321,699	350,543	367,571
	401,797	388,556	375,467	377,430	335,901	363,928	376,461	359,054	321,699	350,543	367,571
	401,797	388,556	375,467	377,430	335,901	363,928	376,461	359,054	321,699	350,543	367,571
	401,797	388,556	375,467	377,430	335,901	363,928	376,461	359,054	321,699	350,543	367,571
	401,797	388,556	375,467	377,430	335,901	363,928	376,461	359,054	321,699	350,543	367,571
	401,797	388,556	375,467	377,430	335,901	363,928	376,461	359,054	321,699	350,543	367,571
	2,410,784	2,331,334	2,252,800	2,264,579	2,015,408	2,183,570	2,258,766	2,154,322	1,930,192	2,103,260	2,205,425
AA1970G012	307	0	9,242	8,184	0	0	0	0	0	0	0
AA1970G013	38,079	38,612	37,419	21,613	24,453	31,041	30,193	33,113	27,354	26,292	19,941
AA1970G041	52,131	61,711	76,186	52,676	50,127	65,982	33,058	42,163	33,841	46,414	37,183
AA1970G046	325,523	335,371	347,689	310,937	305,751	329,589	314,882	293,413	271,902	532,541	395,560
AA1970G112	0	0	0	0	0	0	0	0	0	0	0
AA1971G034	101,134	103,279	114,005	97,350	89,014	107,326	98,318	112,686	93,370	81,904	83,962
AA1972G005	396,555	354,443	320,181	362,350	338,404	353,006	392,889	549,146	411,154	442,361	646,760
	396,554	354,442	320,180	362,349	338,403	353,005	392,887	549,144	411,153	442,359	646,758
	396,554	354,442	320,180	362,349	338,403	353,005	392,887	549,144	411,153	442,359	646,758
	396,554	354,442	320,180	362,349	338,403	353,005	392,887	549,144	411,153	442,359	646,758
	396,554	354,442	320,180	362,349	338,403	353,005	392,887	549,144	411,153	442,359	646,758
	396,554	354,442	320,180	362,349	338,403	353,005	392,887	549,144	411,153	442,359	646,758
	2,379,332	2,126,660	1,921,085	2,174,104	2,030,427	2,118,036	2,357,334	3,294,877	2,466,926	2,654,164	3,880,562
AA1972G009	316,420	303,357	359,635	250,419	336,376	252,095	330,903	298,380	334,972	345,845	526,435
	316,420	303,357	359,635	250,419	336,376	252,095	330,903	298,380	334,972	345,845	526,435
	632,840	606,714	719,271	500,838	672,753	504,190	661,807	596,761	669,944	691,690	1,052,869
	1,265,680	1,213,429	1,438,542	1,001,676	1,345,505	1,008,379	1,323,614	1,193,521	1,339,888	1,383,380	2,105,738
AA1972G105	409,237	619,161	752,739	657,686	626,459	718,462	708,154	647,973	702,299	617,422	1,042,737
	409,237	619,161	752,739	657,686	626,459	718,462	708,154	647,973	702,299	617,422	1,042,737
	409,237	619,161	752,739	657,686	626,459	718,462	708,154	647,973	702,299	617,422	1,042,737
	409,237	619,161	752,739	657,686	626,459	718,462	708,154	647,973	702,299	617,422	1,042,737
	409,237	619,161	752,739	657,686	626,459	718,462	708,154	647,973	702,299	617,422	1,042,737
	2,046,186	3,095,803	3,763,696	3,288,432	3,132,293	3,592,312	3,540,770	3,239,863	3,511,496	3,087,110	5,213,685
AA1972G209	1,353,699	1,321,058	908,031	696,675	0	448,457	494,654	586,355	584,730	622,850	590,853
	1,353,699	1,321,058	908,031	696,675	0	448,457	494,654	586,355	584,730	622,850	590,853
	2,707,398	2,642,116	1,816,061	1,393,350	0	896,914	989,307	1,172,710	1,169,459	1,245,699	1,181,705
AA1972G309	340,429	454,592	636,333	807,087	1,298,088	1,095,723	741,509	716,382	554,456	548,033	503,044
	340,429	454,592	636,333	807,087	1,298,088	1,095,723	741,509	716,382	554,456	548,033	503,044
	680,859	909,185	1,272,665	1,614,175	2,596,177	2,191,446	1,483,019	1,432,763	1,108,912	1,096,066	1,006,087
AA1973G013	24,233	25,044	25,472	23,036	25,220	23,924	21,922	21,719	15,537	7,097	25,855
AA1973G025	85,293	77,225	76,882	69,030	67,797	65,904	73,427	64,224	54,630	56,721	56,899
AA1981G025	819,455	788,142	792,934	793,962	791,573	507,189	774,701	767,757	793,499	606,940	709,332
AA1981G026	952,381	864,784	792,789	824,254	844,449	803,819	789,893	785,057	821,953	1,025,814	428,921
AA1981G039	0	0	0	0	0	0	0	0	0	0	0
AA1982G031	150,482	152,515	146,595	134,016	138,153	150,871	137,701	164,320	128,419	133,104	123,019

Appendix A. Continued.

GAP	Owner	Aquifer	Average annual appropriation, gallons per day	Production wells	Model cell (row, col,layer)	2003	2004
AA1982G036	AA DPW, Arnold	Ukpt	3,500,000	AA Cf 118	39,80,4	289,200	256,373
				AA Cf 119	40,80,4	289,200	256,373
				AA Cf 120	40,81,4	289,200	256,373
				AA Cf 155	41,83,4	289,200	256,373
				AA Cf 170	35,82,4	289,200	256,373
					Total	1,446,000	1,281,866
AA1982G037	AA DPW, Harundale	Lkpt	currently inactive	AA Bd 36, 37	32,32,5	1,058,901	971,488
				AA Bd 63, 162	33,31,5	1,058,901	971,488
					Total	2,117,803	1,942,975
AA1982G039	AA DPW, Elvaton	Lkpt	860,000	AA Bd 107	42,32,5	331,630	516,380
AA1982G043	AA DPW, Glendale	Lkpt	currently inactive	AA Bd 103	28,28,5	127,288	814,872
AA1982G045	AA DPW, Quarterfield Road	Lkpt	currently inactive	AA Bd 109	45,24,5	0	0
AA1982G069	Campbell Sand and Gravel Co.	Lkpt	currently inactive	AA Cc 127	92,36,5	1,768	711
AA1983G060	Ridgeview Plaza	Kpx	18,000	AA Bc 237, 251	60,11,6	14,137	13,852
AA1984G070	Millennium Inorganic Chemicals, Inc.	Lkpt	14,500		15,31,5	11,384	10,130
AA1986G070	AA DPW, Broad Creek	Lkpt	3,600,000	AA De 177	63,80,5	956,500	1,169,542
				AA De 208	65,84,5	956,500	1,169,542
					Total	1,913,000	2,339,085
AA1987G051	Central Sod Farm	Kmg	40,000	AA-81-9201	36,93,3	0	0
AA1987G069	AA DPW, Arnold	Lkpt	8,000,000	AA Cf 142	40,80,5	539,754	616,731
				AA Cf 150	41,83,5	539,754	616,731
				AA Cf 168	35,82,5	539,754	616,731
					Total	1,619,279	1,850,210
AA1987G070	Eisenhower Golf Course	Ukpt/ Lkpt	15,000	AA Ce 136(Ukpt)	59,67,4	0	0
				AA Ce 137(Lkpt)	59,67,5	0	0
					Total	0	0
AA1988G044	Central Sod Farm	Kmg	currently inactive	AA Fe 54	97,99,3	0	0
AA1988G058	Shady Oaks Sod Farm	Kmg	200,000	AA Fe 55	96,98,3	0	0
AA1989G041	Old South County Golf Course	Ukpt	68,000	AA Fd 50, 51	101,95,4	5,479	24,413
AA1989G059	James Schillinger	Lkpt	32,000	AA Bd 175, 176	52,32,5	11,188	13,166
AA1989G094	Solley Road landfill	Ukpt	50,000		24,34,4	27,952	13,316
AA1990G024	Londontown Public House	Ukpt	10,000	AA-88-5488	72,92,4	0	0
AA1990G045	South River Colony Golf Course	Kmg	70,000	AA De 217	90,92,3	21,030	35,784
AA1990G054	Walden Golf Club	Kmg	59,000	AA Cd 130	81,47,3	60,291	3,159
AA1991G018	John Schillinger	Ukpt	17,000	AA Cd 131, 132	58,40,4	13,614	2,096
AA1992G022	Lyons Creek Mobile Home Park	Kmg	66,000	AA Fc 23	102,97,3	0	0
AA1992G031	Pumphrey farm	Lkpt	24,000	AA-81-2936	53,34,5	0	410
AA1996G122	Tierres nursery irrigation	Kmg	currently inactive		100,91,3	17,441	23,000
AA1997G030	Crofton Athletic Complex	Kmg	16,200	AA Dc 22, 23	91,56,3	112	13,110
AA1999G041	Maryland Manor Mobile Estates	Ukpt	16,000	AA Ec 12	100,89,4	31,902	71,132
AA2002G017	Compass Point Golf Course	Ukpt	108,500	AA-94-8264	18,54,4	36,268	31,950
AA2003G005	Turner Pit--groundwater remediation	Kmg	288,000		80,39,3	0	90,526
AA2005G015	Anne Arundel Manor Golf Course	Kmg	150,000		99,91,3	0	0

Appendix A. Continued.

GAP	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AA1982G036	493,136	105,739	207,347	329,732	489,204	679,046	791,085	617,830	752,440	696,751	585,021
	493,136	105,739	207,347	329,732	489,204	679,046	791,085	617,830	752,440	696,751	585,021
	493,136	105,739	207,347	329,732	489,204	679,046	791,085	617,830	752,440	696,751	585,021
	493,136	105,739	207,347	329,732	489,204	679,046	791,085	617,830	752,440	696,751	585,021
	493,136	105,739	207,347	329,732	489,204	679,046	791,085	617,830	752,440	696,751	585,021
	2,465,682	528,696	1,036,734	1,648,661	2,446,022	3,395,230	3,955,425	3,089,148	3,762,200	3,483,756	2,925,104
AA1982G037	900,548	963,293	930,656	946,188	985,466	906,315	682,723	165,372	172,462	232,230	0
	900,548	963,293	930,656	946,188	985,466	906,315	682,723	165,372	172,462	232,230	0
	1,801,096	1,926,586	1,861,312	1,892,376	1,970,932	1,812,630	1,365,447	330,744	344,923	464,460	0
AA1982G039	60,523	122,803	202,282	170,948	193,633	179,079	186,721	157,415	0	90,690	102,416
AA1982G043	1,048,888	1,035,677	787,392	732,901	618,409	0	0	0	0	0	0
AA1982G045	0	0	0	0	0	0	557,373	0	0	0	0
AA1982G069	10,105	18,919	6,148	0	0	0	0	0	0	0	0
AA1983G060	11,496	10,532	10,301	7,596	6,849	8,411	0	6,908	6,634	0	11,329
AA1984G070	14,513	15,970	14,781	14,030	13,445	10,658	6,782	12,021	12,425	15,637	12,646
AA1986G070	1,333,021	1,292,188	1,621,410	1,593,425	1,522,285 (e)	1,075,466	892,303	1,060,232	1,021,878	1,042,752	1,222,822
	1,333,021	1,292,188	1,621,410	1,593,425	1,522,285 (e)	1,075,466	892,303	1,060,232	1,021,878	1,042,752	1,222,822
	2,666,041	2,584,375	3,242,819	3,186,850	3,044,577 (e)	2,150,932	1,784,605	2,120,464	2,043,756	2,085,504	2,445,644
AA1987G051	0	17,162	18,755	15,399	9,144	25,951	10,642	10,104	8,310	7,196	4,776
AA1987G069	220,314	881,819	870,762	561,912	667,065	1,032,269	1,490,264	514,610	948,916	1,231,936	1,602,728
	220,314	881,819	870,762	561,912	667,065	1,032,269	1,490,264	514,610	948,916	1,231,936	1,602,728
	220,314	881,819	870,762	561,912	667,065	1,032,269	1,490,264	514,610	948,916	1,231,936	1,602,728
	660,948	2,645,482	2,612,312	1,685,751	2,001,216	3,096,838	4,470,836	1,543,844	2,846,775	3,695,844	4,808,232
AA1987G070	144	576	512	0	8,624	0	1,007	205	0	0	0
	144	576	512	0	8,624	0	1,007	205	0	0	0
	288	1,153	1,025	0	17,249	0	2,014	410	0	0	0
AA1988G044	0	0	0	0	0	0	0	0	0	0	0
AA1988G058	14,483	3,366	35,826	0	173	3,352	196	0	0	0	0
AA1989G041	39,900	39,023	39,933	38,795	35,385	63,898	31,219	73,255	10,852	56,277	67,503
AA1989G059	73,911	33,924	42,442	45,331	34,221	55,870	9,002	14,838	10,192	25,741	7,514
AA1989G094	16,576	16,827	15,407	16,708	31,237	34,841	20,629	36,847	32,890	28,625	28,497
AA1990G024	0	0	0	0	0	0	13,069	415	317	1,300	0
AA1990G045	69,179	79,383	82,926	49,628	37,243	45,425	50,587	64,502	34,936	38,239	42,548
AA1990G054	7,473	31,374	24,759	28,457	48,156	32,685	0	0	24,132	16	0
AA1991G018	4,521	2,989	4,359	6,071	1,759	1,517	877	721	571	200	489
AA1992G022	39,099	88,729	78,326	72,035	68,741	61,322	49,000	44,589	42,210(e)	41,205	44,825
AA1992G031	7,175	13,216	23,671	11,541	986	6,214	18,937	16,593	2,550	1,635	11,836
AA1996G122	10,011	0	0	0	0	0	0	0	0	0	0
AA1997G030	9,417(e)	18,700(e)	32,613	5,638	8,014	8,759(e)	8,458	9,434	5,218	5,628	232
AA1999G041	33,059	0	0	62,138	0	0	0	0	0	0	0
AA2002G017	12,174	48,387	81,584	17,172	28,597	41,139	37,376	46,835	52,310	57,876	58,533
AA2003G005	128,019	122,069	123,264	147,987	148,830	154,879	156,416	175,942	163,865	179,879	168,696
AA2005G015	0	0	0	0	0	53,175(e)	120,364	119,763	119,934(e)	117,176	0

Appendix A. Continued.

GAP	Owner	Aquifer	Average annual appropriation, gallons per day	Production wells	Model cell (row, col,layer)	2003	2004
AA2005G020	AA DPW, Arnold	Kpx	4,500,000	AA Cf 169	35,82,6	0	0
				AA Cf 171	41,83,6	0	0
					Total	0	0
BA1946G003	Bethlehem Steel Corporation	Kpx	currently inactive	BA Gf 3	11,33,6	304,295	167,707
				BA Gf 5, 8, 9	11,34,6	912,884	503,122
				BA Gf 32, 210	11,36,6	608,590	335,415
				BA Gf 35	10,35,6	304,295	167,707
				BA Gf 139	12,35,6	304,295	167,707
				BA Gf 211, 212	12,36,6	608,590	335,415
					Total	3,042,948	1,677,075
BA1956G006	Avesta Sheffield East, Inc.	Kpx	currently inactive	BA Fe 59, 64	8,11,6	25,657	17,289
				BA Fe 66	8,12,6	25,657	17,289
					Total	51,313	34,577
BA1969G020	American Yeast Corporation	Kpx	3,200,000	BA Ff 85, 90, 91	8,30,6	2,948,138	3,020,352
BA1970G006	Rocky Point Golf Course	Kpx	65,000	BA Fg 176	6,37,6	12,145	5,812
BA1975G012	Marshy Point Nursery	Lkpt	65,000	BA Eg 260	2,31,5	56,110	61,107
BC1960G001	SAF Corp.-Lesaffre Yeast	Kpx	currently inactive	3S5E-39, 40, 41, 42, 43	11,13,6	814,812	643,293
CA1970G004	CA Co., Cavalier Country	Kmg	36,000	CA Bb 23, 24	102,99,3	35,057	36,608
CA1972G001	Northern High School	Kmg	18,000	CA Bb 25	104,102	15,030	11,186
CA1972G002	CA Co., Shores of Calvert	Kmg	35,000	CA Bc 7, 8	103,98,3	27,218	27,287
CA1998G124	Swan Farm	Kmg	45,000		105,101	55	1,351
CA2002G010	Dunkirk Business Park	Kmg	32,000	CA-94-4579; CA-95-0067	103,100	0	0
KE1971G004	Town of Rock Hall	Kmg	230,000	KE Db 35, 55, 56, 57	5,95,3	176,918	183,003
PG1956G007	Boy's Village of Maryland	Kmg	65,000	PG Fd 5, 55, 67	107,89,3	43,964	34,722
PG1957G003	Glendale Golf Course	Kpt	50,000	PG-92-0625	98,34,5	0	28,675
PG1958G003	Patuxent Wildlife Research Center	Kpx	300,000	PG Be 8	95,12,6	19,049	22,591
				PG Be 23	94,25,6	19,049	22,591
				PG Be 24	95,26,6	19,049	22,591
				PG Be 28	95,20,6	19,049	22,591
				PG Be 29	94,15,6	19,049	22,591
				PG Be 30	95,28,6	19,049	22,591
					Total	114,296	135,552
PG1958G103	Patuxent Wildlife Research Center	Lkpt	200,000	PG Be 22	95,15,5	56,390	50,813
PG1961G008	City of Bowie	Kmg	200,000	PG Cf 33	96,47,3	129,858	109,168
				PG Cf 34	96,40,3	129,858	109,168
					Total	259,715	218,336
PG1961G108	City of Bowie	Lkpt	1,500,000	PG Cf 32, 76	96,47,5	340,939	380,115
				PG Cf 35, 77	96,45,5	340,939	380,115
				PG Cf 80	97,43,5	170,470	190,057
					Total	852,348	950,287

Appendix A. Continued.

GAP	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AA2005G020	0	0	0	0	0	0	0	0	1,374,893	1,369,281	1,662,561
	0	0	0	0	0	0	0	0	1,374,893	1,369,281	1,662,561
	0	0	0	0	0	0	0	0	2,749,786	2,738,562	3,325,123
BA1946G003	323,761	302,557	252,910	242,516	250,498	164,964	172,267	118,104	0	0	0
	971,284	907,670	758,731	727,547	751,495	494,891	516,802	354,312	0	0	0
	647,523	605,113	505,821	485,031	500,997	329,927	344,535	236,208	0	0	0
	323,761	302,557	252,910	242,516	250,498	164,964	172,267	118,104	0	0	0
	323,761	302,557	252,910	242,516	250,498	164,964	172,267	118,104	0	0	0
	647,523	605,113	505,821	485,031	500,997	329,927	344,535	236,208	0	0	0
	3,237,614	3,025,567	2,529,104	2,425,156	2,504,984	1,649,636	1,722,674	1,181,041	0	0	0
BA1956G006	15,531	314	0	0	0	0	0	0	0	0	0
	15,531	314	0	0	0	0	0	0	0	0	0
	31,061	628	0	0	0	0	0	0	0	0	0
BA1969G020	2,251,308	2,247,767	2,178,778	2,185,022	2,788,804	2,697,183	2,229,944	2,315,249	2,397,779	2,542,258	2,645,161
BA1970G006	32,179	26,497	33,952	21,949	38,433	87,340	53,723	78,240	56,159	49,658	56,690
BA1975G012	39,973	39,973	38,397	39,863	33,767	38,795	38,192	38,115	37,740	35,548	9,384
BC1960G001	855,916	0	0	0	0	0	0	0	0	0	0
CA1970G004	32,512	29,729	31,052	24,783	26,695	29,828	21,914	21,737	20,986	10,441	21,408
CA1972G001	10,435	11,636	12,136	10,070	10,476	12,684	22,115	12,025	10,357	13,144	9,434
CA1972G002	29,272	28,095	30,234	23,795	23,835	27,107	23,868	26,431	23,960	24,468	23,451
CA1998G124	548	4,419	29,617	2,945	2,655	1,403	21,699	1,562	1,580	1,551	1,468
CA2002G010	548	4,948	15,232	14,721	10,551	13,167	12,590	13,620	13,078	11,912	10,958
KE1971G004	167,532	154,605	183,537	171,306	162,285	82,643	185,241	92,826	198,641	170,066	79,089
PG1956G007	45,945	38,075	48,940	35,189	29,351	28,761	25,910	34,967	26,110	33,737	39,650
PG1957G003	14,408	29,097(e)	41,142	16,560	20,273	25,489	24,787	26,728	8,491	15,918	15,166
PG1958G003	17,759	23,401	9,953	13,195	23,648	24,111	20,868	11,883	20,102	21,935	23,050
	17,759	23,401	9,953	13,195	23,648	24,111	20,868	11,883	20,102	21,935	23,050
	17,759	23,401	9,953	13,195	23,648	24,111	20,868	11,883	20,102	21,935	23,050
	17,759	23,401	9,953	13,195	23,648	24,111	20,868	11,883	20,102	21,935	23,050
	17,759	23,401	9,953	13,195	23,648	24,111	20,868	11,883	20,102	21,935	23,050
	17,759	23,401	9,953	13,195	23,648	24,111	20,868	11,883	20,102	21,935	23,050
	106,558	140,410	59,723	79,170	141,893	144,671	125,212	71,300	120,617	131,614	138,306
PG1958G103	50,304	29,595	15,774	40,444	77,169	101,555	105,919	71,907	105,789	141,899	152,905
PG1961G008	98,499	86,577	142,200	77,452	89,716	102,796	32,460	19,950	14,476	20,996	80,728
	98,499	86,577	142,200	77,452	89,716	102,796	32,460	19,950	14,476	20,996	80,728
	196,997	173,153	284,400	154,904	179,433	205,592	64,921	39,900	28,952	41,993	161,455
PG1961G108	374,362	321,607	324,239	296,070	364,103	349,370	491,510	97,956	147,836	129,253	377,364
	374,362	321,607	324,239	296,070	364,103	349,370	491,510	97,956	147,836	129,253	377,364
	187,181	160,803	162,119	148,035	182,052	174,685	245,755	48,978	73,918	64,626	188,682
	935,904	804,016	810,597	740,175	910,258	873,425	1,228,775	244,890	369,590	323,132	943,409

Appendix A. Continued.

GAP	Owner	Aquifer	Average annual appropriation, gallons per day	Production wells	Model cell (row, col,layer)	2003	2004
PG1961G208	City of Bowie	Kpx	1,800,000	PG Cf 64	96,46,6	346,500	363,153
				PG Cf 66	97,43,6	346,500	363,153
					Total	693,000	726,306
PG1963G003	Marlboro Meadows	Kmg	currently inactive	PG Df 34	101,86,3	115,741	137,501
				PG Df 36	101,87,3	115,741	137,501
				PG Df 39	101,90,3	115,741	137,501
					Total	347,224	412,503
PG1970G002	Western Run Waste Water Plant	Kmg	currently inactive	PG Ef 37	103,93,3	1,678	0
PG1975G006	Marlboro Counrty Club	Kmg	currently inactive	PG Ef 19	102,92,3	39,041	1,989
PG1977G008	Bowie Golf and Country Club	Lkpt	20,000	PG Ce 44, 45	96,36,5	6,766	8,675
PG1977G012	Gardner Sand and Gravel	Kmg	currently inactive	PG Fe 35	107,95,3	51,814	41,538
PG1979G002	Andrews Air Force Base	Kmg	70,000	PG Ed 50	106,67,3	30,406	22,176
PG1987G003	Enterprise Golf Course	Ukpt	30,000	PG Ce 46	101,40,4	0	0
PG1990G012	Beltsville Agriculture Research Center	Kpx	750,000	PG Bd 17	99,9,6	78,586	79,869
				PG Bd 61	99,8,6	78,586	79,869
				PG Bd 62	98,10,6	78,586	79,869
					Total	235,759	239,607
PG1994G006	U.S. Food and Drug Admin.	Kpx	30,000	PG-92-0681	97,8,6	0	10,989
PG1995G019	Marlton Golf Course	Kmg	40,000	PG Ee 57	105,90,3	0	11,561
PG1996G105	Andrews Air Force Base	Ukpt	110,000		106,67,4	0	0
PG1998G006	Beechtree GC	Lkpt	95,000	PG Df 42	101,79,5	0	0
		Kpx		PG Df 42	101,79,6	0	0
					Total	0	0
PG1998G023	NASA	Kpx	257,000	PG-94-1408	100,21,6	174,105	186,032
PG2002G009	Oak Creek Golf Club	Kpx	200,000		101,65,6	0	0
QA1984G016	QA Co., Bridgepointe	Ukpt	100,000	QA Eb 169, 170	19,102,4	48,858	46,471
QA1985G009	QA Co., Blue Heron Golf Course	Kmg	45,000	QA Fa 77	46,102,3	0	0
QA1985G024	QA Co., Bayside Marina	Ukpt	144,000	QA Eb 162, 171	17,101,4	54,543	71,314
QA1989G024	QA Co., Stevensville	Ukpt	currently inactive	QA Eb 166, 167	20,100,4	452,837	0
QA1994G007	QA Co., Grasonville	Ukpt	100,000	QA Ec 91, 92	13,106,4	45,239	43,067
QA1997G050	QA Co., Stevensville	Lkpt	750,000	QA Eb 184	20,100,5	5,267	445,727

Appendix A. Continued.

GAP	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PG1961G208	458,156	557,405	612,612	553,178	485,832	531,642	335,327	704,070	637,336	658,058	287,595
	458,156	557,405	612,612	553,178	485,832	531,642	335,327	704,070	637,336	658,058	287,595
	916,312	1,114,811	1,225,225	1,106,355	971,663	1,063,285	670,655	1,408,139	1,274,671	1,316,115	575,189
PG1963G003	126,548	110,505	91,994	0	0	0	0	0	0	0	0
	126,548	110,505	91,994	0	0	0	0	0	0	0	0
	126,548	110,505	91,994	0	0	0	0	0	0	0	0
	379,645	331,515	275,984	0	0	0	0	0	0	0	0
PG1970G002	2,319	2,662	2,734	2,943	3,719	0	6,835	4,416	3,531(e)	0	0
PG1975G006	22,567(e)	0	34,384	35,612(e)	0	0	0	0	0	0	0
PG1977G008	14,637	20,160	2,641	12,393	11,323	20,712	14,913	20,931	14,084	10,494	18,227
PG1977G012	20,772	0	0	0	0	0	0	0	0	0	0
PG1979G002	18,341	16,456	53,233	25,084	16,007	48,516	29,853	37,828	30,173	25,580	39,877
PG1987G003	0	7,693	15,386	29,652	10,459	23,236	16,428	16,957	15,069	15,442	25,860
PG1990G012	85,753	109,327	165,152	131,767	138,013	170,535	230,831	206,114	256,276	216,540	153,668
	85,753	109,327	165,152	131,767	138,013	170,535	230,831	206,114	256,276	216,540	153,668
	85,753	109,327	165,152	131,767	138,013	170,535	230,831	206,114	256,276	216,540	153,668
	257,259	327,982	495,455	395,301	414,038	511,606	692,494	618,341	768,828	649,619	461,004
PG1994G006	29,473	41,685	9,314	830	1,417	17,401	33,783	9,598	18,253	9,465	3,044
PG1995G019	20,075	16,608	44,899	13,714	16,772	15,915	16,586	20,471	12,787	5,020	11,499
PG1996G105	0	0	0	0	0	69,981	65,008	79,650	76,606	65,233	95,093
PG1998G006	0	0	43,195	0	0	0	38,603	20,485	0	0	0
	0	0	43,195	0	0	0	38,603	20,485	0	0	0
	0	0	86,389	0	0	0	77,205	40,970	0	0	0
PG1998G023	156,159	195,266	156,027	203,287	176,937	210,408	218,778	169,880	205,622	194,000	223,205
PG2002G009	0	118,312	151,609	89,712	81,213	88,471	16,391	0	2,397	5,853	0
QA1984G016	47,647	65,764	82,636	75,593	77,842	58,634	9,145	32,964	24,537	21,386	12,898
QA1985G009	0	21,146(e)	34,154	14,049	39,649	37,414	22,159	44,044	25,959	20,061	63,978
QA1985G024	43,216	54,228	93,818	86,837	88,371	94,981	81,248	88,651	73,716	112,458	177,067
QA1989G024	0	0	0	0	0	0	0	0	0	0	0
QA1994G007	36,227	70,496	77,870	70,251	75,490	72,214	71,459	72,335	72,190	73,019	74,958
QA1997G050	471,811	500,134	498,005	444,178	498,371	596,774	684,853	663,194	731,392	668,852	642,384

Appendix B. Average appropriated withdrawals used in the predictive model from wells other than those operated by the Anne Arundel County Department of Public Works.

GAP	Owner	Aquifer	Production wells	Average appropriated withdrawal assigned to wells in model, gallons per day
AA1932G003	U.S. Naval Academy	Ukpt	AA Df 12, 13	583,333
			AA Df 80,83,160	875,000
			AA Df 101	291,667
AA1947G003	Laurel Racing Association	Kpx	AA Bb 22	43,000
AA1949G004	Sandy Point State Park	Kmg	AA Cg 6, 8	29,000
AA1954G001	Crownsville State Hospital	Kmg	AA Cd 11	53,750
			AA Cd 43, 72	107,500
			AA Cd 50	53,750
AA1960G021	Landsman Mobile Home Park	Kmg	AA Cd 93	20,000
AA1962G030	Chemetals Corporation	Kpx	AA Ae 35, 36	122,000
AA1963G008	Holiday Mobile Estates	Kpx	AA Bc 177	125,000
AA1963G029	Sherwood Forest Water Co.	Kmg	AA Ce 98	100,000
AA1965G032	Maryland Manor Mobile Estates	Kmg	AA Ec 6, 7, 8	74,000
AA1966G027	Northrop Grumman Corp.	Ukpt	AA Cg 18, 19	40,000
AA1966G028	Epping Forest	Kmg	AA Ce 99, 119	42,000
AA1966G048	Crofton Country Club	Kmg	AA Cc 62	60,000
AA1968G011	Southern High School	Kmg	AA Ed 39, 41	25,000
AA1969G016	Pioneer City	Lkpt	AA Bc 169, 195	480,000
AA1969G021	U.S. Army, Ft. Meade	Kpx	AA Bb 68	550,0000
			AA Bc 164	550,0000
			AA Bc 234	550,0000
			AA Cc 144	550,0000
			AA Cc 120	550,0000
			AA Cc 123	550,0000
AA1970G013	Chesapeake School Complex	Ukpt	AA Bf 50, 51	41,000
AA1970G041	U.S. Naval Academy Golf Course	Ukpt	AA Df 89	85,000
AA1970G046	Provinces Water Co.	Kpx	AA Bc 192, 193, 241	415,000
AA1972G009	City of Annapolis	Kmg	AA De 2	500,000
			AA De 45	500,000
			AA De 46, 88	1,000,000
AA1972G209	City of Annapolis	Lkpt	AA De 94	825,000
			AA De 139	825,000
AA1972G309	City of Annapolis	Ukpt	AA De 219	925,000
			AA De 220	925,000
AA1973G013	Patuxent Mobile Estates	Kmg		40,000
AA1973G025	Lake Village Apartments	Kpx	AA Bc 201, 202	160,000
AA1983G060	Ridgeview Plaza	Kpx	AA Bc 237, 251	18,000
AA1984G070	Millennium Inorganic Chemicals Inc	Lkpt		14,500
AA1987G051	Central Sod Farm	Kmg		40,000
AA1987G070	Eisenhower Golf Course	Lkpt	AA Ce 136 (Ukpt)	7,500
			AA Ce 137 (Lkpt)	7,500

Appendix B. Continued.

GAP	Owner	Aquifer	Production wells	Average appropriated withdrawal, gallons per day
AA1988G058	Shady Oaks Sod Farm	Kmg	AA Fe 55	200,000
AA1988G059	Shady Oaks Sod Farm	Kmg	AA-88-1348	150,000
AA1988G060	Shady Oaks Sod Farm	Kmg	AA-88-1347	50,000
AA1989G041	Old South County Golf Course	Ukpt	AA Fd 50, 51	68,000
AA1989G059	James Schillinger	Lkpt	AA Bd 175, 176	32,000
AA1989G094	Solley Road landfill	Ukpt		50,000
AA1990G024	Londontown Public House	Ukpt		10,000
AA1990G045	South River Colony Golf Course	Kmg	AA De 217	70,000
AA1990G054	Walden Golf Club	Kmg	AA Cd 130	59,000
AA1991G018	John Schillinger	Ukpt	AA Cd 131, 132	17,000
AA1992G022	Lyons Creek Mobile Home Park	Kmg	AA Fc 23	66,000
AA1992G031	Pumphrey farm	Lkpt		24,000
AA1997G030	Crofton Athletic Complex	Kmg	AA Dc 22, 23	16,200
AA1999G041	Maryland Manor Mobile Estates	Ukpt	AA Ec 12	16,000
AA2002G017	Compass Point Golf Course	Ukpt		108,500
AA2003G005	Turner Pit--groundwater remediation	Kmg		288,000
AA2005G015	Anne Arundel Manor Golf Course	Kmg		150,000
BA1969G020	American Yeast Corporation	Kpx	BA Ff 85, 90, 91	3,200,000
BA1970G006	Rocky Point Golf Course	Kpx	BA Fg 176	65,000
BA1975G012	Marshy Point Nursery	Lkpt	BA Eg 260	65,000
CA1970G004	CA Co., Cavalier Country	Kmg	CA Bb 23, 24	36,000
CA1972G001	Northern High School	Kmg	CA Bb 25	18,000
CA1972G002	CA Co., Shores of Calvert	Kmg	CA Bc 7, 8	35,000
CA1989G008	Shoppes at Apple Green	Kmg	CA-94-4998	21,000
CA1998G124	Swan Farm	Kmg		45,000
CA2002G010	Dunkirk Business Park	Kmg	CA-94-4579; CA-95-0067	32,000
KE1971G004	Town of Rock Hall	Kmg	KE Db 35, 55, 56, 57	230,000
PG1956G007	Boy's Village of Maryland	Kmg	PG Fd 5, 55, 67	65,000
PG1957G003	Glendale Golf Course	Kpt		50,000
PG1958G003	Patuxent Wildlife Research Center	Kpx	PG Be 8	50,000
			PG Be 23	50,000
			PG Be 24	50,000
			PG Be 28	50,000
			PG Be 29	50,000
			PG Be 30	50,000
PG1958G103	Patuxent Wildlife Research Center	Lkpt	PG Be 22	200,000
PG1961G008	City of Bowie	Kmg	PG Cf 33	100,000
			PG Cf 34	100,000
PG1961G108	City of Bowie	Lkpt	PG Cf 32 76	600,000
			PG Cf 35, 77	600,000
			PG Cf 80	300,000

Appendix B Continued.

GAP	Owner	Aquifer	Production wells	Average appropriated withdrawal, gallons per day
PG1961G208	City of Bowie	Kpx	PG Cf 64	900,000
			PG Cf 66	900,000
PG1977G008	Bowie Golf and Country Club	Lkpt	PG Ce 44, 45	20,000
PG1979G002	Andrews Air Force Base	Kmg	PG Ed 50	70,000
PG1987G003	Enterprise Golf Course	Ukpt	PG Ce 46	30,000
PG1990G012	Beltsville Agriculture Research Center	Kpx	PG Bd 17	250,000
			PG Bd 61	250,000
			PG Bd 62	250,000
PG1994G006	U.S. Food and Drug Admin.	Kpx		30,000
PG1995G019	Marlton Golf Course	Kmg	PG Ee 57	40,000
PG1996G105	Andrews Air Force Base	Ukpt		110,000
PG1998G006	Beechtree GC	Lkpt	PG Df 42	47,500
		Kpx	PG Df 42	47,500
PG1998G023	NASA	Kpx		257,000
PG2002G009	Oak Creek Golf Club	Kpx		200,000
QA1984G016	QA Co., Bridgepointe	Ukpt	QA Eb 169, 170	100,000
QA1985G009	QA Co., Blue Heron Golf Course	Kmg	QA Fa 77	45,000
QA1985G024	QA Co., Bayside Marina	Ukpt	QA Eb 162, 171	144,000
QA1994G007	QA Co., Grasonville	Ukpt	QA Ec 91, 92	100,000
QA1997G050	QA Co., Stevensville	Lkpt	QA Eb 184	750,000

Appendix C. Methodology used in identifying aquifer screened by permitted wells.

(1) Well data (address, construction date, total depth drilled, top and bottom of well screens, depth of casing, depth of initial pump installation, and indication of abandonment) were retrieved for domestic wells in Anne Arundel County from the MDE wells database (June 2016 version).

(2) Wells noted as abandoned were removed from the dataset.

(3) Well locations were plotted in an ESRI ArcMap GIS project using latitude and longitude coordinates derived from geocoded property addresses given in MDE wells database. Since the geocoding assigns a coordinate at or near the property-lot centroid, the accuracy of the well location is dependant on the lot size (i.e. smaller lot size would be more likely accurately represent the actual well location).

(4) Elevation of top and bottom surfaces (GIS rasters) of the Upper and Lower Patapsco and Patuxent aquifer systems from the Maryland Coastal Plain Aquifer Information System (MCPAIS)(Andreasen and others, 2013) were extracted for each well site. The aquifer layer rasters represent mean values at a gridded resolution of 2,500 by 2,500 ft.

(5) Well-screen depths from the MDE wells database were adjusted to elevation (mean sea level) using the 2011 Maryland iMap LIDAR digital elevation model (3-ft grid resolution). The well-screen elevations were then compared to aquifer-layer elevations from MCPAIS to make aquifer assignments.

Larry Hogan
Governor

Boyd K. Rutherford
Lt. Governor

Mark J. Belton
Secretary

Joanne Throwe
Deputy Secretary

A message to Maryland's citizens

The Maryland Department of Natural Resources (DNR) seeks to balance the preservation and enhancement of the living and physical resources of the state with prudent extraction and utilization policies that benefit the citizens of Maryland. This publication provides information that will increase your understanding of how DNR strives to reach that goal through the earth science assessments conducted by the Maryland Geological Survey.

MARYLAND DEPARTMENT OF NATURAL RESOURCES
Resource Assessment Service
Tawes State Office Building
580 Taylor Avenue
Annapolis, Maryland 21401
Toll free in Maryland: 1-877-620-8DNR
Out of State call: 1-410-260-8021
TTY users: Call via the Maryland Relay
Internet Address: www.dnr.Maryland.gov

MARYLAND GEOLOGICAL SURVEY
2300 St. Paul Street
Baltimore, Maryland 21218
Telephone Contact Information: 410-554-5500
Internet Address: www.mgs.md.gov

DNR Publication Number 12-071917-10

2017