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Robert L. Ehrlich, Jr.
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OPEN-FILE REPORT NO. 2003-02-16

DELINEATION OF ZONES OF TRANSPORT FOR PUBLIC-SUPPLY WELLS IN ST. MARY'S COUNTY, MARYLAND

by

Grufron Achmad and T. Brandon Fewster

Prepared by Maryland Geological Survey
Emery T. Cleaves, Director
in cooperation with the
St. Mary's County Metropolitan Commission
and Maryland Department of the Environment
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DELINEATION OF ZONES OF TRANSPORT FOR PUBLIC-SUPPLY WELLS IN ST. MARY'S COUNTY, MARYLAND

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KEY RESULTS

Ground-water flow models designated as the Western area model and the Lexington Park area model were developed to simulate particle pathlines that delineate zones of transport for 102 water-supply wells, withdrawing from the confined Aquia and Piney Point-Nanjemoy aquifers in St. Mary's County, Maryland. Zones of transport, defined as the area surrounding a pumping well that is bounded by an isochrone contour through which a contaminant may travel and reach a pumping well, can be used to develop well-head protection areas surrounding public water-supply wells. These areas help to focus the search for improperly abandoned wells that could potentially provide a pathway for contamination from the land surface to the confined aquifer. Withdrawals by major users (typically greater than 10,000 gallons per day) were simulated using the annual average rates allocated by ground-water appropriation permit. These withdrawals totaled 4.776 million gallons per day from the Aquia aquifer and 0.517 million gallons per day from the Piney Point-Nanjemoy aquifer. Pumpage by self-supplied domestic and minor users was estimated at 1.18 million gallons per day for the Aquia aquifer and 3.34 million gallons per day for the Piney Point-Nanjemoy aquifer. Zones of transport were delineated for public water-supply wells operated by the St. Mary's County Metropolitan Commission, Leonardtown Board of Commissioners, Patuxent Naval Air Test Center, and other selected ground-water users. Key results of the study include:

Aquia aquifer

The Aquia aquifer is the principal source of ground water for public suppliers in St. Mary's County. Zones of transport were delineated for 88 water-supply wells, 13 of which pumped at simulated rates greater than 100,000 gallons per day. Withdrawals from those wells created large cones of depression in the Lexington Park, Leonardtown, and Country Lakes areas, which influenced regional ground-water flow in St. Mary's County. The 20-year zones of transport associated with these sites extended outward radially in mostly circular or ellipsoidal patterns to distances ranging from 1,150 feet to 2,350 feet from the pumping wells. The remaining users, simulated at lower rates, generated zones of transport that were relatively small and elongated in the up-gradient direction. The shape of these zones is strongly influenced by the regional ground-water gradient and extend approximately 300 feet to 800 feet from the pumping wells.

Piney Point-Nanjemoy aquifer

Zones of transport were delineated for nine St. Mary's County Metropolitan Commission wells and five Patuxent Naval Air Test Center wells pumping from the Piney Point-Nanjemoy aquifer. Three St. Mary's County Metropolitan Commission wells (Great Mills, Hills Mobile Home Park, and Town Creek #6A) and one Patuxent Naval Air Test Center well (building #532) were simulated using pumpage greater than 100,000 gallons per day. These large withdrawals created local cones of depression and generated particle pathlines that propagated outward in a radial direction. The 20-year zones of transport extended 1,500 feet to 1,800 feet from the pumping wells. The remaining public water-supply wells were simulated at lower rates and created smaller cones of depression. The lower rates of withdrawal generated particle pathlines that were generally elongated in an up-gradient direction. Their pathlines track the regional flow pattern. Twenty (20)-year pathlines extended approximately 500 feet to 1,000 feet from the pumping wells.

INTRODUCTION

St. Mary's County, located in southern Maryland (fig. 1), is experiencing significant population growth. The population centers in the northern part of the county are within commuting distance of Washington, D.C. Growth in the southern part of the county occurs in the Lexington Park area, which is adjacent to the Patuxent Naval Air Test Center (PNATC). The demand for public water supply has increased along with population growth. The St. Mary's County Metropolitan Commission (MetCom), the primary supplier of ground water for residential and commercial use, operates 58 production wells of which nine wells are screened in the Piney Point-Nanjemoy aquifer, 49 wells are screened in the Aquia aquifer, and two wells are screened in the Upper Patapsco aquifer. Other major ground-water users of the Aquia and Piney Point-Nanjemoy aquifers in St. Mary's County are the PNATC operating 25 wells and the Leonardtown Board of Commissioners operating four wells. Fifteen wells are operated by other users.

In St. Mary's County, the Piney Point-Nanjemoy and Aquia aquifers occur under thick confining beds that retard vertical ground-water flow. The Piney Point-Nanjemoy aquifer occurs approximately 50 feet (ft) to 300 ft below sea level and is overlain by a confining bed that separates it from the surficial water-table aquifer. The aquifer thins toward the northwest and is not a significant source of water supply in northern St. Mary's County. The Aquia aquifer occurs approximately 230 ft to 450 ft below sea level in the county. It outcrops from western Charles County through central Prince George's and Anne Arundel Counties.

A previous report (Achmad and Hansen, 1997) issued by the Maryland Geological Survey (MGS) simulated 1995 pumpage under steady-state conditions and determined that ground water would require thousands of years to travel from the Aquia outcrop areas to wells pumping in Lexington Park. Furthermore, the estimated average age of five Aquia water samples from St. Mary's County, dated using the carbon-14 method, ranged from 15,500 years (uncorrected) to 8,500 years (corrected for 'dead' carbon from matrix dissolution) (Mignery, 1994, tab. 2; Achmad and Hansen, 1997, p. 76). As a consequence, the potential for salt-water intrusion from the Chesapeake Bay or for intrusion of other contaminants is unlikely, unless direct recharge occurs through old, uncased, ungrouted, or improperly abandoned wells (Achmad and Hansen, 1997, p. 76). Delineating zones of transport for public-supply wells will help public water suppliers prioritize efforts to locate potential contaminant pathways, like improperly abandoned wells.

PURPOSE AND SCOPE

The purpose of this report is to present the results of a ground-water modeling study to determine zones of transport for public water-supply wells withdrawing ground water from the Piney Point-Nanjemoy and Aquia aquifers in St. Mary's County. The study focused on delineating the source areas likely to contribute ground water to public water-supply wells operated by MetCom when using withdrawal rates based on annual average Ground-Water Appropriation Permits (GAP) issued by the Maryland Department of the Environment (MDE) through year 2000. A propriety program, Visual MODFLOW (Guiger and Franz, 2000), was used in this study. The program applied the U.S. Geological Survey's (USGS) modular three-dimensional finite-difference ground-water flow model (MODFLOW) (McDonald and Harbaugh, 1988) and particle-tracking post-processor (MODPATH) (Pollock, 1994) to backtrack particle pathlines from production wells for time periods of 1 year, 10 years, and 20 years. The endpoints of these pathlines delineate the extent of the source areas and define the zone of transport for the production wells for the respective time periods. For the purposes of this report the 20-year zone of transport surrounding a production well is its well-head protection area.

PREVIOUS STUDIES

Earlier studies by the MGS (Chapelle and Drummond, 1983; Achmad and Hansen, 1997) addressed the hydrogeology, ground-water flow, and water-supply potential of the Piney Point-Nanjemoy and Aquia aquifers in St. Mary's and Calvert Counties. Table 1 describes the hydrogeologic framework of the Coastal Plain aquifers in St. Mary's and Calvert Counties. Achmad and Hansen (1997) applied the USGS's MODFLOW code to evaluate the historic lowering of ground-water levels with increasing ground-water pumpage from the Piney Point-Nanjemoy and Aquia aquifers. Achmad

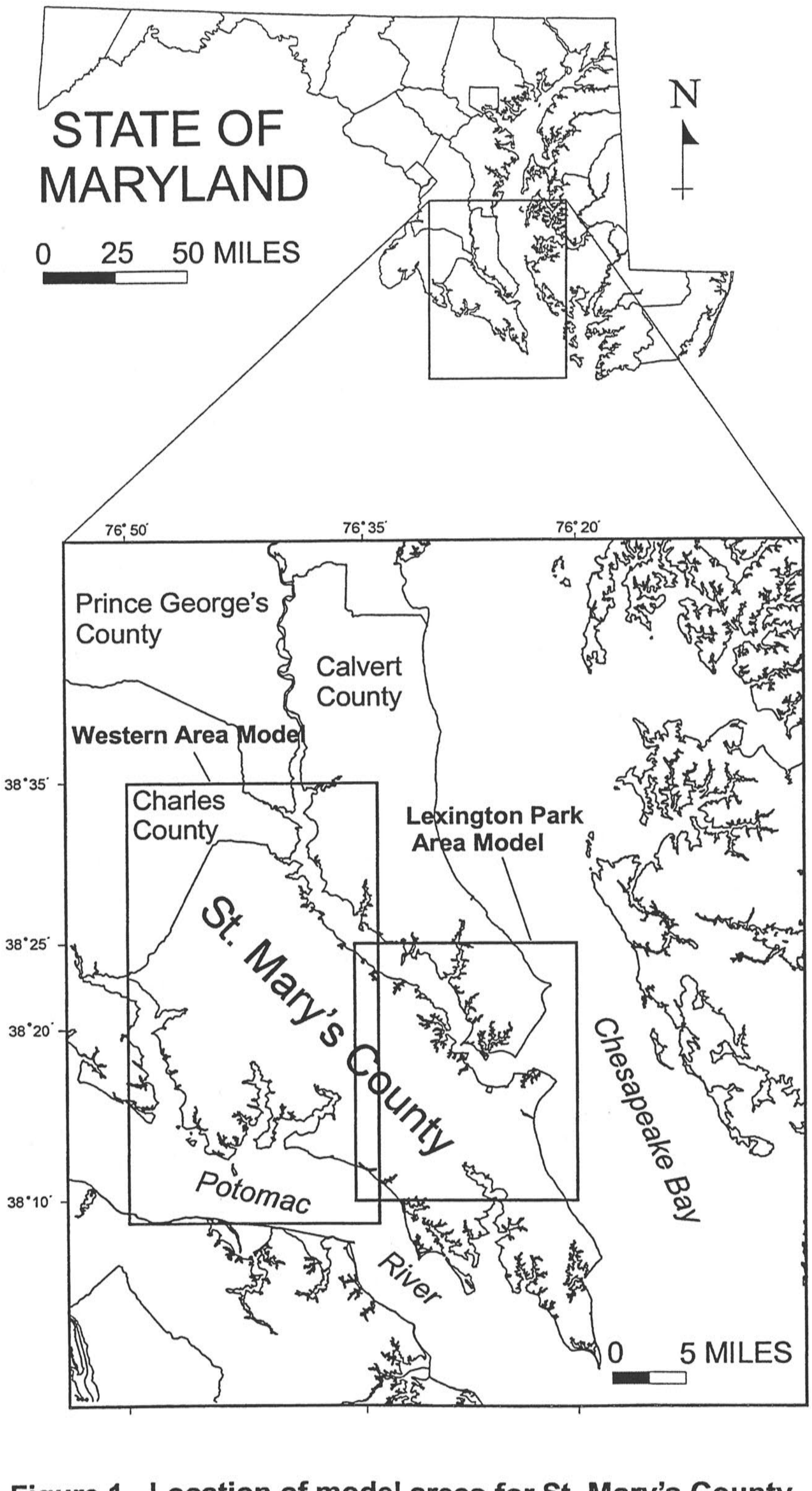


Figure 1 . Location of model areas for St. Mary's County Western area model and Lexington Park area model.

Table 1. Generalized descriptions of Tertiary hydrogeologic units underlying Calvert and St. Mary's Counties, Maryland, and their approximate correlation with geologic units (from Achmad and Hansen, 1997, tab. 2; modified after Weigle and Webb, 1970; Weigle, Webb, and Gardner, 1970; Chapelle and Drummond, 1983; and Hansen and Wilson, 1984)

Hydrogeologic Unit	Approximate thickness (ft.)	Water-bearing characteristics	Lithologic description	Geologic unit	Series	System
SURFICIAL AQUIFER (undivided)	0-140	Yields limited quantities of water to large-diameter wells. Has potential for larger yields along southern shores of St. Mary's County, but may be susceptible to salt-water intrusion.	Complexly stratified tan, brown, and gray clay, silt, medium to coarse sand, and gravel. Underlies near-shore areas below 80± feet above sea level.	Lowland Deposits[1]	Holocene to Pleistocene	Quaternary
	0-85	Limited saturated thickness. Yields moderate amounts of water to large-diameter wells. Commonly, streams have cut downward through the deposits permitting the deposits to drain rapidly.	Complexly stratified tan or orange clay, silt, and sand mixture in upper loam member, and sand and gravel in lower gravel member. Underlies dissected southeastward-sloping upland surfaces. Between 80± and 200± feet above sea level.	Upland Deposits[2]	Pliocene	Tertiary
UPPER CONFINING BED	60-270	Generally functions as a confining bed.	Olive gray, greenish brown, and light gray clays, sandy clays, and fine sands; fossiliferous. Lower beds may be diatomaceous.	Chesapeake Group (undivided)	Miocene	
PINEY POINT AQUIFER	0-130	Primary source of water in southern Calvert and St. Mary's Counties where the Piney Point aquifer is hydraulically connected to the upper sandy portion of the Nanjemoy Formation.	Light gray to yellowish green, fine sand. May include phosphatic pebbles and shell clasts at basal contact.			
			Dusky brown to olive green clayey sand. Slightly glauconitic; fossiliferous. (Areal extent uncertain).	Unnamed[3]	Oligocene (?)	
			Light gray to brownish-yellow, slightly glauconitic, medium to coarse sand; interbedded layers of shell and sand, locally cemented.	Piney Point[4] Fm.	Eocene	
NANJEMOY AQUIFER	0-30	Secondary source of water in northern Calvert and St. Mary's Counties where the Piney Point aquifer is absent.	Sand, silt, and clay; blackish-green to gray; glauconitic; the upper portion of formation is sandy; the lower portion is predominantly silt and clay.	Nanjemoy Fm.		
MIDDLE CONFINING BED	70-200	Generally functions as a confining bed.	Pink, red, or gray plastic clay.	Marlboro Clay	Paleocene	
AQUIA AQUIFER	0-205	Primary source of water in Calvert County and St. Mary's County north of Kitts Point.	Green to yellowish brown, medium grained, clayey, glauconitic sand with locally cemented shell beds.	Aquia Fm.		
LOWER CONFINING BED	20-105	Generally functions as a confining bed.	Gray to grayish black, micaceous, slightly glauconitic clay, silt, and fine sand. (Areal extent unknown).	Brightseat Fm.		
			Upper and Lower Cretaceous Units (undifferentiated)			

[1] On the St. Mary's County geologic map the Lowland Deposits have been subdivided by McCartan (1989) into several geologic units including Holocene Deposits (undivided), Kent Island Formation (upper Pleistocene), Maryland Point Formation (upper Pleistocene), Omar Formation (upper Pleistocene) and Chicamuxen Church Formation (middle to lower Pleistocene).

[2] On the St. Mary's County geologic map the Upland Deposits have been subdivided by McCartan (1989) into several geologic units including Park Hall Formation (upper Pliocene), Upland Gravel 4 (upper Pliocene), and Upland Gravel 3 (lower to upper Pliocene).

[3] Ward (1985) has assigned very late Oligocene to very early Miocene (?) beds in Maryland to the Old Church Formation.

[4] Olsson, Miller, and Ungrady (1980) have argued that the Piney Point Formation includes Oligocene beds.

and Hansen (1997) also presented 200-year zones of transport for five major well fields in St. Mary's and Calvert Counties using reported pumpage for 1995 (Achmad and Hansen, 1997, p. 76-77).

An update (Achmad and Hansen, 2001) of the 1997 model applied the USGS's MODFLOW 2000 program (Harbaugh, Banta, Hill, and McDonald, 2000) to simulate changes in Aquia water levels through 2025 using revised water-use projections.

METHOD OF STUDY

This study involved the collection and evaluation of hydrogeologic and pumpage data from the Piney Point-Nanjemoy and Aquia aquifers in St. Mary's County, the development of two local ground-water flow models (the Western area model and the Lexington Park area model) based on the updated 2001 regional model, and the simulation of particle pathlines to determine zones of transport that may be used to delineate well-head protection areas for production wells.

The hydrogeologic frameworks of the two local models were derived from the hydrogeology of the southern Maryland Coastal Plain aquifers described in MGS Report of Investigation Number 64 (Achmad and Hansen, 1997, p. 6-25). Table 1 is a generalized description of the hydrogeologic units. The locations of production wells were updated and georeferenced using latitude and longitude coordinates obtained from MetCom and USGS's Ground Water Site Inventory database (app. 1 and pl. 1). Well pumpage data reported for year 2000 were obtained from MetCom, MDE, and USGS. For an accurate accounting of production wells operated by MetCom, MetCom's Water Operations Staff was consulted to determine well status and pumpage during the year 2000. For wells operated by PNATC, USGS staff was consulted (C. Klohe, written comm., 2001) (Klohe and Feehley, 2001), and for wells operated by Leonardtown, MDE and town staff were consulted. The allocated pumpage rates effective for 2000 were assembled from the GAPs issued by MDE. Year 2000 withdrawals by self-supplied domestic and minor users were based on earlier estimates from Achmad and Hansen (1997; 2001), supplemented by data compiled by Judith Wheeler (written comm., 2001) for the 5-year national water-use survey (Judith Wheeler, written comm., 2002).

The Visual MODFLOW program, which provides pre-processing, post-processing, and visualization capabilities for MODFLOW and MODPATH, was used to develop the two local models. The local models were verified by comparing simulated water levels with the results of the 2001 regional model. Zones of transport were delineated for 1-year, 10-year, and 20-year intervals for MetCom public water-supply wells and other major ground-water users located in St. Mary's County.

NOMENCLATURE

The following terms used in this report to describe areas surrounding pumping wells were proposed by the U.S. Environmental Protection Agency (USEPA) (1987, p. 20-21; Kreitler and Senger, 1991, p. 167-168):

> *Zone of Contribution*—The area surrounding a pumping well that encompasses all areas or features that supply ground-water recharge to the well.
>
> *Zone of Transport*—The area surrounding a pumping well, bounded by an isochrone and/or isoconcentration contour, through which a contaminant may travel and reach the well.
>
> *Well-head Protection Area*—The surface or subsurface area surrounding a water well or well field, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or well field.

Zones of contribution are generally associated with unconfined aquifers that receive recharge from the water table. Zones of transport are generally associated with confined aquifers that are fully saturated, such as the Piney Point-Nanjemoy and Aquia aquifers in St. Mary's County. Well-head protection areas in this report are represented in plan view by particle pathlines depicting 20-year zones of transport surrounding public-supply wells pumping at their permitted annual average rate of withdrawal. Because the Aquia and Piney Point-Nanjemoy aquifers are confined, a contaminant released in the well-head protection area must travel through either the annular space of a poorly grouted well or an improperly abandoned well.

ACKNOWLEDGMENTS

Steven King, Director, and Larry Petty, Director of Special Projects of MetCom, helped initiate the

study by recognizing the importance of protecting county public water-supply wells from potential contaminants.

Partial funding was provided by the USEPA under provisions of the Federal Clean Water Act. The grant was administered by MDE (Source Protection and Administration Division of the Public Drinking Water Program), John Grace, Chief.

Gary Reynolds and Marshall Fenwick of MetCom supplied MetCom pumpage records and detailed reviews of the current status, operational usage, and location of MetCom public water-supply wells.

The authors would also like to thank the following individuals for their contributions: Nancy Reilman of MDE for assistance with determining existing GAPs and wells associated with the permits for St. Mary's and Calvert Counties; Clay Supensky and Warren Cherry of the Maryland State Highway Administration and Barbara Cooper of the MGS for assistance with developing customized base maps; Judith Wheeler of the USGS for supplying allocated pumpage rates and reported pumpage data for appropriation permit holders in St. Mary's, Calvert, Prince George's, and Charles Counties; Cheryl Klohe and Stephen Curtin of the USGS for well location, status, and pumpage data for PNATC; Harry Hansen and David Andreasen of the MGS for technical reviews of the manuscript; and Donajean Appel and Claire Richardson of the MGS for editorial review and report preparation.

SIMULATION OF GROUND-WATER FLOW

CONCEPTUAL DESIGN

The southern Maryland regional ground-water flow model described in Achmad and Hansen (1997, p. 32; 2001, p. 3) was based upon a hydrogeologic framework consisting of three layers. These layers listed, in sequence from top to bottom, are: 1) the unconfined, surficial aquifer and underlying upper confining bed, 2) the confined Piney Point-Nanjemoy aquifer and underlying middle confining bed, and 3) the confined Aquia aquifer and underlying lower confining bed (tab. 1). The regional model was a quasi-three dimensional model with vertical flow between aquifers represented by a leakance term.

In this report the pre-/post-processor, Visual MODFLOW (Guiger and Franz, 2000), is used to simulate the ground-water flow and particle tracking in the Piney Point-Nanjemoy and Aquia aquifers. Since Visual MODFLOW requires the explicit input of layer thickness and vertical and horizontal hydraulic conductivity for both aquifer and confining bed, the three-layer hydrogeologic framework of the regional model was restructured into a five-layer hydrogeologic framework that includes the following layers, listed in sequence from top to bottom: 1) the unconfined surficial aquifer, 2) the upper confining bed, 3) the confined Piney Point-Nanjemoy aquifer, 4) the middle confining bed, and 5) the confined Aquia aquifer.

MODEL AREA AND GRID

In order to achieve the resolution necessary to represent the ground-water flow lines adequately, it was determined that a cell size limited to 400 ft x 400 ft or less was required (Heitjema, Kelson, and de Lange, 2001). Construction of finer finite-difference grids for the local models provided greater resolution of water levels than could be achieved by the existing regional model. In this report particle pathlines used to delineate zones of transport are displayed on 1:24,000 scale maps (1 in. = 2,000 ft). Because of Visual MODFLOW's limitation on the maximum number of columns and rows, it was necessary to divide the regional model into two separate local area models, the Western area and Lexington Park area models.

The Western area ground-water flow model is primarily located in the northwestern part of St. Mary's County and includes the eastern part of Charles County, the southern part of Prince George's County, and a relatively small section of central Calvert County (fig.1). The model area covers about 318 square miles and encompasses public water-supply systems located in Charlotte Hall, Rolling Acres, and King-Kennedy Estates in the north and Wicomico Shores, Mount Pleasant, Breton Bay Estates, and Leonardtown in the south (fig. 1, pls. 1, 2, 3). The Western area model was divided into 400 ft by 400 ft cell nodes forming a finite-difference grid of 240 columns and 380 rows.

The Lexington Park area ground-water flow model is centered on the Lexington Park area of St. Mary's County. The model area extends north to Hollywood Shores, south to St. Mary's City, west to Hollywood, and east to PNATC. The model area includes southern Calvert County (fig. 1, pl. 3). The model area incorporates the majority of MetCom production wells withdrawing from the Aquia aquifer and all of MetCom's production wells withdrawing from the Piney Point-Nanjemoy aquifer. The majority of the MetCom pumpage from the Aquia aquifer occurs in the immediate vicinity of Lexington Park and several of the production wells are located in close proximity to one another. The Lexington Park area model was constructed utilizing a variable-sized grid. A finer grid pattern was used in the Lexington Park area to ensure that production wells were individually modeled and that adequate resolution of water levels was provided as an output for MODPATH to use in the calculation of particle pathlines. A coarser grid pattern toward the model's lateral boundaries ensured the total grid array did not exceed Visual MODFLOW limitations. The finest discretization, located in the central part of the model, measured 264 ft x 264 ft. At the furthermost boundary, the grid measured 792 ft x 1,056 ft. The model grid consisted of an array of 225 columns and 240 rows.

Pumpage for self-supplied domestic and minor users, and steady-state head in areas coincident with the local model boundaries were transferred from the regional model to the local model in the regridding process. A Fortran program and spreadsheet were developed to transfer the data from the coarser regional model cells to the finer local model cells.

BOUNDARY CONDITIONS

The unconfined surficial aquifer and surface-water bodies (model layer 1) were assigned a

constant-head boundary condition as in the regional model. In order to maintain the predominantly vertical flow across the confining layers of the regional model, the lateral boundaries of the confining layers (model layers 2 and 4) in the local models were assigned no-flow boundary conditions. The lateral boundaries of the Piney Point-Nanjemoy and Aquia aquifers, model layers 3 and 5 respectively, were assigned general-head boundary (GHB) conditions (McDonald and Harbaugh, 1988, p. 11-1 to 11-4). The heads input to the GHB nodes were derived from the regional model steady-state simulation using GAP annual average withdrawal rates. The local models' boundaries maintain the ground-water inflows and outflows of the regional model.

HYDROLOGIC PROPERTIES

The hydraulic properties for the aquifers and confining beds used in the local models were derived in part from the values used in the regional model (Achmad and Hansen, 1997, tab. 4, p. 34). Visual MODFLOW required the input of lateral (x- and y-direction component) and vertical (z-direction component) hydraulic conductivities for each layer. Aquifer hydraulic conductivity values for the local models were obtained by dividing the regional model's transmissivity by the aquifer thickness. Vertical hydraulic conductivity of the aquifers was calculated as 1/10 of the lateral hydraulic conductivity value. In the regional model, each confining layer was assigned a vertical hydraulic conductivity value. For the local models, lateral hydraulic conductivity values of the confining layers were calculated by multiplying the vertical hydraulic conductivity values by a factor of ten.

Hydraulic properties used in the local models are summarized in table 2. In the local models the surficial aquifer (layer 1) is designated a constant-head boundary and properties unassigned. For the upper confining bed (model layer 2), lateral hydraulic conductivity was assigned a value of 0.004 feet per day (ft/d); porosity was assigned an average value of 40 percent; and thickness was assigned a range from 150 ft to 270 ft (Achmad and Hansen, 1997, fig. 3, p. 11). The Piney Point-Nanjemoy aquifer (model layer 3) was given lateral hydraulic conductivity values ranging from 0.0001 ft/d to 5.0 ft/d. The low end of the range permitted the Western area model to more directly allow vertical ground-water flow from the surficial aquifer to the Aquia aquifer in the areas west and north of Leonardtown where the Piney Point-Nanjemoy aquifer pinches out. Thickness of the Piney Point-Nanjemoy aquifer ranged from less than 1 ft to 150 ft (Achmad and Hansen, 1997, fig. 4, p. 14). An average porosity of 40 percent was assumed. For the middle confining bed (model layer 4), lateral hydraulic conductivity was assigned a value of 0.005 ft/d, porosity was assigned an average value of 40 percent, and thickness was assigned a range from 100 ft to 200 ft (Achmad and Hansen, 1997, fig. 6, p. 18). The Aquia aquifer (model layer 5) was given lateral hydraulic conductivity values ranging from 2.5 ft/d to 11.7 ft/d. The higher hydraulic conductivity values occurred in the vicinity of Lexington Park. Thickness of the Aquia aquifer ranged from 120 ft to 175 ft (Achmad and Hansen, 1997, fig. 8, p. 22), and porosity had an assigned average value of 40 percent. The hydrologic units dip in a southeast to easterly direction at an angle of approximately 1 degree or less. Deeper strata generally dip more steeply than the shallower strata.

PUMPAGE

Ground-water withdrawals from the Piney Point-Nanjemoy and Aquia aquifers are attributed to withdrawals made by major users and self-supplied domestic and minor users. Major users withdraw greater than 10,000 gallons per day (gpd). Domestic users are primarily homeowners located in areas not served by public water- supply systems and minor users are all other users pumping less than 10,000 gpd.

The GAP issued by MDE requires water-supply systems withdrawing greater than 10,000 gpd to report pumpage records. These systems may consist of a single well or multiple production wells. For GAPs with a single well, the pumpage assigned to the well in the model is the GAP annual average withdrawal rate. For GAPs with multiple wells, pumpage was assigned evenly to the wells or was distributed based on the GAP annual average withdrawal rate apportioned using the reported year 2000 pumpage for each well. The year 2000 GAP annual average withdrawal rate by major users in the two local model areas totaled 0.517 million gallons per day (Mgal/d) from the Piney Point-Nanjemoy aquifer and 4.776 Mgal/d from the Aquia aquifer (app. B and C).

Pumpage amounts and distribution for self-supplied domestic and minor users for the two local models were derived from the regional model. The year 2000 estimated aggregate pumpage by self-

Table 2. Aquifer and confining bed hydraulic conductivity, porosity, and thickness in the Western area model and Lexington Park area model

[ft/d, feet per day; ft, feet; no values are specified for storage or specific yield because the simulation assumes steady-state conditions.]

Layer	Aquifer/confining layer	Lateral hydraulic conductivity[1] (ft/d)	Average porosity (percent)[4]	Thickness (ft)	Depth to top of layer (-) below sea level (ft)
1	Water table[2]	(75)	(40)	(30-50)	+150 to +40 above sea level
2	Upper confining bed	0.004	40	150-270	+100 above sea level to -50
3	Piney Point-Nanjemoy aquifer	0.0001-5.0[3]	40	1-150	-50 to -200
4	Middle confining bed	0.005	40	100-200	-50 to -370
5	Aquia aquifer	2.5-11.7	40	120-175	-230 to -450

[1] The vertical hydraulic conductivity is automatically calculated in model as 1/10 of the lateral value.
[2] No values assigned in model because water table is modeled as a constant head.
[3] At locations where the Piney Point-Nanjemoy aquifer pinches out conductivity of 0.001 ft/day and layer thickness of 1 ft were assigned to facilitate a conduit for vertical flow from the water table through the upper and middle confining beds to the Aquia aquifer.
[4] Value assigned in model. Average porosity values reported by Morris and Johnson (1967, p. D20-D21) are 39 to 43 percent for sand and 42 to 46 percent for silt/clay.

supplied domestic and minor users from the Piney Point-Nanjemoy and Aquia aquifers in St. Mary's County were 3.34 Mgal/d and 1.18 Mgal/d (Judith Wheeler, written comm., 2002), respectively. Because the local models used a finer grid than the regional model, the year 2000 domestic pumpage assigned to each cell of the regional model was divided by the number of new cells formed in the regridding process. Pumpage for the local models was then evenly distributed to the newly formed cells. Redistributed domestic pumpage was not assigned to those newly formed cells overlying surface-water bodies.

MODEL VERIFICATION

The local area models are derived in part from the larger regional model and use the same hydraulic properties. As independent ground-water flow models, however, they incorporate several aspects not found in the original model: horizontal flow in confining beds versus quasi-three dimensional flow in the regional model, finer grid discretization, aquifer transmissivity calculated from horizontal hydraulic conductivities and layer thickness opposed to specified transmissivity, use of five model layers versus three model layers, and location and type changes to the boundary conditions. A verification process was followed to evaluate the accuracy of the local area models in duplicating water level of the previously calibrated regional model. Initially, the local area and regional models were run under steady-state conditions using the same GAP annual average withdrawal rates. Simulated water levels for pumping nodes from the local models were compared with those of the regional model. Additionally, potentiometric surfaces of the local models were visually compared and matched with those of the regional model.

A comparison of 41 simulated water levels for the Western area model is shown in table 3. A graphical representation and best-fit linear regression of the simulated water levels is illustrated in figure 2. The linear regression indicates a mean absolute error of 8.66 ft and a coefficient of determination (r^2) of 0.90. The slope of the linear regression line is 1.16, while it is 1.00 for a perfect match. Differences in simulated head of pumping wells between the two models were most likely caused by differences in the respective sizes of the pumping cells in the two models.

In the Lexington Park area model, simulated water levels for 66 production wells were used for comparison with the regional model. In order to reduce the effects of differing cell sizes between the models, simulated water levels of both models were adjusted for additional drawdown in the pumping

Table 3. Comparison of simulated water levels of the regional model and Western area model

[SM, St. Mary's County; CA, Calvert County; ft, feet]

Well	Regional model water-level (ft)	Western area model water-level (ft)	Difference Western-Regional (ft)
SM Ab 6	-47	-35.1	11.9
SM Ab 7	-47	-35.1	11.9
SM Ab 9	-47	-33.1	13.9
SM Bb 26	-55	-43.2	11.8
SM Bb 28	-55	-43.5	11.5
SM Bb 29	-53	-40.3	12.7
SM Bb 30	-52	-39.5	12.5
SM Bc 32	-55	-43.2	11.8
SM Bc 33	-49	-46.0	3.0
SM Bc 35	-49	-43.5	5.5
SM Bc 36	-35	-37.8	-2.8
SM Ca 9	-55	-41.8	13.2
SM Cb 18	-61	-59.4	1.6
SM Cb 29	-72	-68.2	3.8
SM Cb 30	-60	-50.2	9.8
SM Cc 15	-55	-42.6	12.4
SM Cc 16	-55	-42.5	12.5
SM Cc 19	-65	-51.9	13.1
SM Cc 27	-62	-50.5	11.5
SM Cc 30	-63	-52.8	10.2
SM Db 45	-32	-32.7	-0.7
SM Dc [1]	-85	-86.6	-1.6
SM Dc 58	-58	-60.2	-2.2
SM Dc 60	-43	-39.7	3.3
SM Dc 62	-72	-85.5	-13.5
SM Dd 39	-115	-111.2	3.8
SM Dd 30	-117	-136.5	-19.5
SM Dd 41	-87	-91.2	-4.2
SM Dd 45	-87	-91.6	-4.6
SM Dd 47	-74	-81.3	-7.3
SM Dd 64	-85	-86.5	-1.5
SM Dd 65	-110	-118.1	-8.1
SM Dd 70	-100	-87.9	12.1
SM Dd 73	-78	-86.7	-8.7
SM Ed 17	-73	-82.3	-9.3
CA Db 26	-54	-52.4	1.6
CA Db 40	-48	-43.8	4.2
CA Db 41	-60	-75.6	-15.6
CA Db 45	-49	-54.6	-5.6
CA Db 64	-53	-49.4	3.6
CA Db 88	-55	-52.9	2.1

[1] No well number, well not inventoried

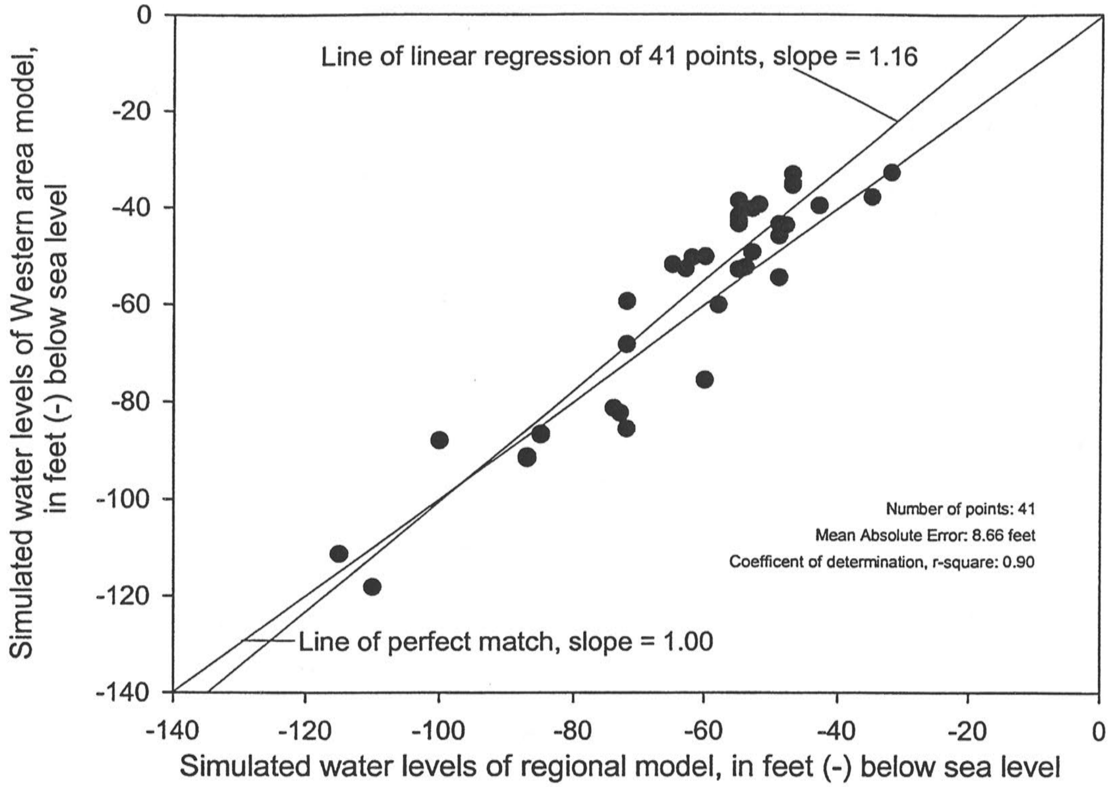


Figure 2. Regression analysis comparing simulated water levels of the Western area model and regional model.

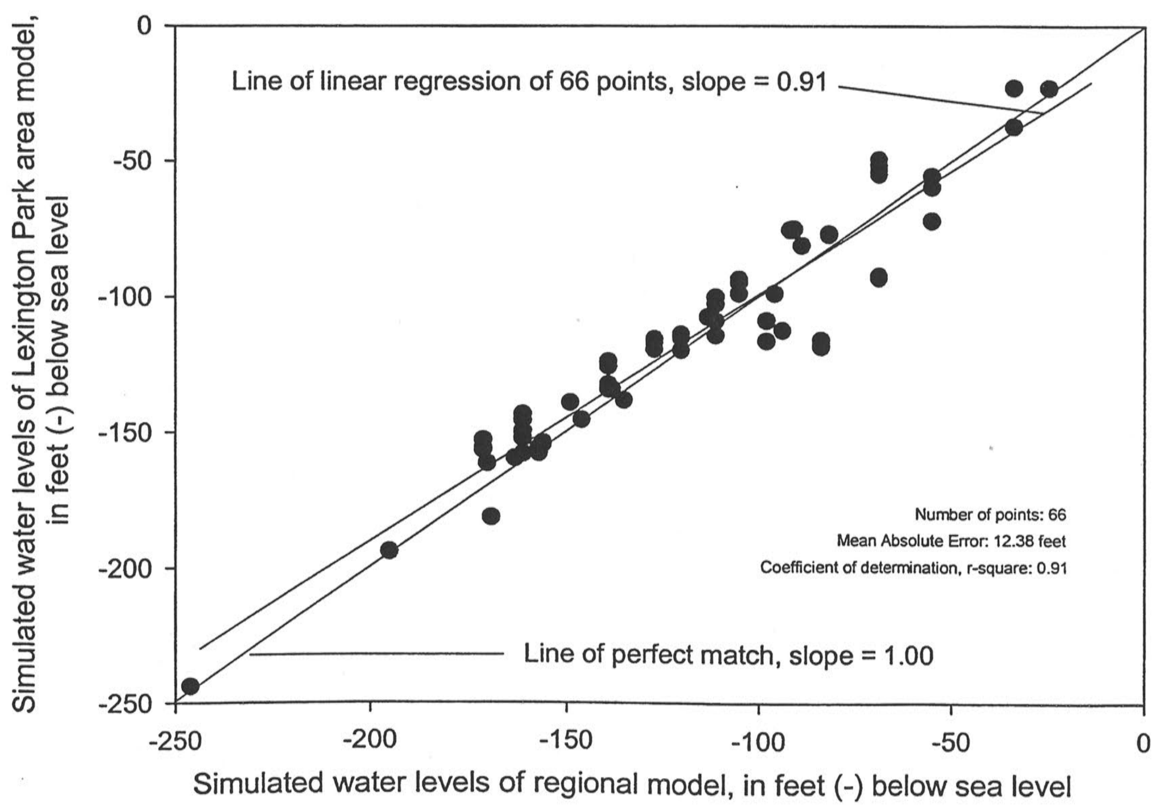


Figure 3. Regression analysis comparing simulated water levels of the Lexington Park area model and regional model.

center by applying the Theim equation (Anderson and Woessner, 1992, p. 147-148; Achmad and Hansen, 2001, p. 6). This comparison is shown in table 4 and graphically illustrated in figure 3. A regression analysis of the adjusted simulated water levels indicated a mean absolute error of 12.38 ft, a coefficient of determination (r^2) of 0.91 and a regression line slope of 0.91.

A statistical comparison of the water levels simulated by the regional model and the two local models show that they differ within acceptable limits and have similar trends.

MASS BALANCE

At the end of the steady-state simulation, a mass balance was calculated to analyze the ground-water fluxes of the Western area and the Lexington Park area models. The mass balance indicated that the local models received inflow to the Piney Point-Nanjemoy and Aquia aquifers from vertical leakage through overlying layers at a rate of 8.611 Mgal/d (62 percent) and from lateral inflow through GHB nodes at a rate of 5.286 Mgal/d (38 percent). The outflow component of the models totaled 0.163 Mgal/d (1 percent) from the constant-head nodes assigned to major surface-water bodies, 2.173 Mgal/d (16 percent) from lateral flow through GHB nodes and 11.561 Mgal/d (83 percent) from the aggregate pumpage of the major users and the self-supplied domestic and minor users.

The outflow component of pumpage (11.561 Mgal/d) simulated in the local models included withdrawals from St. Mary's County (9.853 Mgal/d) and Calvert County (1.708 Mgal/d). The St. Mary's County portion of the total consisted of 5.293 Mgal/d by major ground-water users (exceeding 10,000 gal/d) and 4.56 Mgal/d by self-supplied domestic and minor users.

SIMULATED WATER LEVELS

The GAP annual average rates used in the model simulations differ from the actual reported pumpage for year 2000. Consequently, simulated water levels do not depict the reported water levels for year 2000 (Curtin, Andreasen, and Wheeler, 2002). In the Western area model, simulated Aquia water levels range from 30 ft below mean sea level (msl) to more than 110 ft below msl with a cone of depression forming towards the east (pl. 2). The MetCom well field at Country Lakes, the South Star Sand and Gravel Mine water-supply well, and the Leonardtown well field simulated GAP annual average withdrawal rates from the Aquia aquifer greater than 100,000 gpd. The Country Lakes-Beverly Estates well field, simulated at an GAP annual average withdrawal rate of 140,000 gpd, lowered water levels to approximately 50 ft below msl. The South Star Sand and Gravel Mine water-supply well simulated at 119,000 gpd lowered the water level to about 75 ft below msl. The Leonardtown well field simulated at an annual average withdrawal rate of 525,000 gpd deepened the cone of depression in the area to approximately 115 ft below msl. Simulated Aquia water levels in the vicinity of pumping wells with lower pumpage rates ranged from 40 ft below msl in the north at Charlotte Hall to approximately 87 ft below msl in the south at Holland Forest. The simulated potentiometric gradient in the northern portion of the Western area model averages about 3.3 ft per mile (ft/mi) and in the southern portion averages about 17.6 ft/mi (pl. 2).

In the Lexington Park area model simulated heads and flow lines for the Aquia aquifer show a cone of depression in the area of Lexington Park (fig. 4). Significant GAP withdrawals in the Lexington Park area model are derived from MetCom's Lexington Park and Cedar Cove systems, PNATC, and Chesapeake Ranch Estates (in Calvert County). MetCom Lexington Park system wells located at Pegg Road, Bank Square, Colony Square, and Essex Drive simulated a combined withdrawal rate of 922,851 gpd. Pumpage for all wells associated with the Lexington Park system totaled 1,450,000 gpd. These wells created a significant cone of depression that influenced the ground-water flow lines around the Lexington Park area. Maximum depth of the simulated heads measures approximately 172 ft below msl near the intersection of Pegg Road and Route 235, and 159 ft below msl near Bank Square. GAP wells located at Chesapeake Ranch Estates pumped a combined 900,000 gpd and created a second cone of depression near Solomons Island (in Calvert County). This cone had a maximum depth of approximately 155 ft below msl. At the -110 ft msl contour, the two cones of depression merged to create a regional cone of depression that influenced the direction of ground-water flow toward the Lexington Park area.

Simulated heads and flow lines for the Piney Point-Nanjemoy aquifer also show a cone of depression in the area of Lexington Park (fig. 5). Significant withdrawals are derived from MetCom

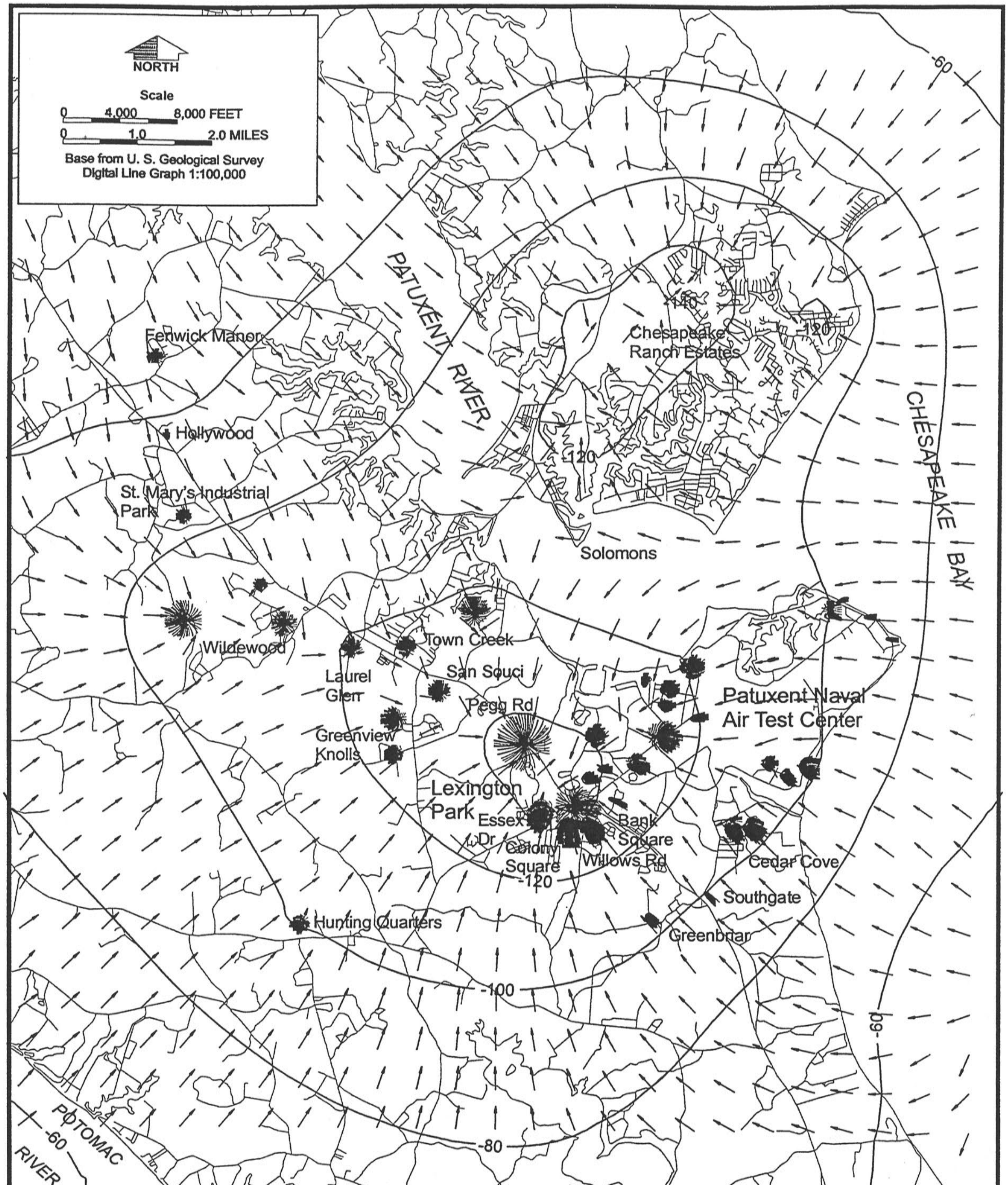
Table 4. Comparison of simulated water levels of the regional model and Lexington Park area model after adjustment using the Thiem equation

[ft, feet; SM, St. Mary's County; CA, Calvert County]

Well	Adjusted water levels applying the Thiem equation (ft)		Water level difference (ft)
	Regional Model	Lexington Park Model	
	St. Mary's County		
SM Ce 30	-96	-98.9	-3
SM Ce 34	-82	-76.8	5
SM Ce 35	-82	-77.2	5
SM Ce 36	-34	-23.0	11
SM Ce 37	-34	-37.3	-3
SM Ce 38	-96	-98.8	-3
SM Ce 43	-89	-81.1	8
SM De 36	-195	-193.9	1
SM De 55	-135	-138.1	-3
SM Df 1	-161	-145.6	15
SM Df 3	-161	-151.9	9
SM Df 4	-161	-143.4	18
SM Df 5	-161	-149.5	11
SM Df 7	-139	-134.0	5
SM Df 8	-55	-55.6	-1
SM Df 9	-55	-59.6	-5
SM Df 10	-139	-132.3	7
SM Df 12	-139	-123.8	15
SM Df 14	-55	-71.9	-17
SM Df 22	-157	-157.7	-1
SM Df 42	-156	-154.4	2
SM Df 43	-139	-125.6	13
SM Df 49	-98	-116.4	-18
SM Df 50	-98	-108.9	-11
SM Df 53	-69	-93.0	-24
SM Df 54	-69	-53.7	15
SM Df 60	-69	-92.3	-23
SM Df 61	-161	-152.3	9
SM Df 62	-246	-243.8	2
SM Df 67	-69	-49.5	20
SM Df 68	-69	-51.7	17
SM Df 69	-69	-54.9	14
SM Df 70	-94	-112.4	-18
SM Df 73	-149	-139.1	10
SM Df 76	-157	-155.7	1
SM Df 78	-156	-153.8	2
SM Df 80	-127	-116.9	10
SM Df 89	-171	-156.5	14
SM Df 90	-146	-145.4	1
SM Df 92	-170	-161.4	9

Table 4. Comparison of simulated water levels of the regional model and Lexington Park area model after adjustment using the Thiem equation—Continued

Well	Adjusted water levels applying the Thiem equation (ft)		Water level difference (ft)
	Regional Model	Lexington Park Model	
	St. Mary's County—Continued		
SM Dg 1	-120	-119.7	0
SM Dg 2	-120	-115.2	5
SM Dg 3	-120	-113.8	6
SM Dg 5	-111	-100.1	11
SM Dg 6	-111	-108.8	2
SM Dg 10	-127	-119.3	8
SM Dg 13	-127	-115.5	12
SM Ee 49	-113	-107.4	6
SM Ef 3	-84	-116.0	-32
SM Ef 65	-84	-118.3	-34
SM Ef 66	-84	-117.9	-34
SM Ef 69	-91	-75.0	16
SM Ef 81	-92	-75.4	17
SM Ef 82	-111	-102.8	8
SM Ef 83	-91	-75.4	16
SM Ef 90	-111	-114.2	-3
SM Eg 29	-25	-23.1	2
	Calvert County		
CA Fd 1	-138	-134.1	4
CA Fd 68	-171	-152.8	18
CA Fd 69	-171	-155.7	15
CA Fd 70	-169	-181.3	-12
CA Fe 18	-161	-157.9	3
CA Fe 19	-105	-94.8	10
CA Fe 20	-105	-93.6	11
CA Fe 21	-105	-98.9	6
CA Fe 30	-163	-159.5	4



EXPLANATION

-20 — Water level contour of Aquia aquifer, in feet related to sea level - contour interval is 20 feet.

Ground-water flow lines of the Aquia aquifer

20-year particle pathlines for Aquia production wells operated by St. Mary's County Metropolitan Commission and Patuxent Naval Air Test Center

Figure 4. Simulated potentiometric surface, ground-water flow direction, and particle pathlines delineating 20-year zones of transport in the Aquia aquifer using withdrawal rates based on annual average ground-water appropriation permits for year 2000 in the Lexington Park area model.

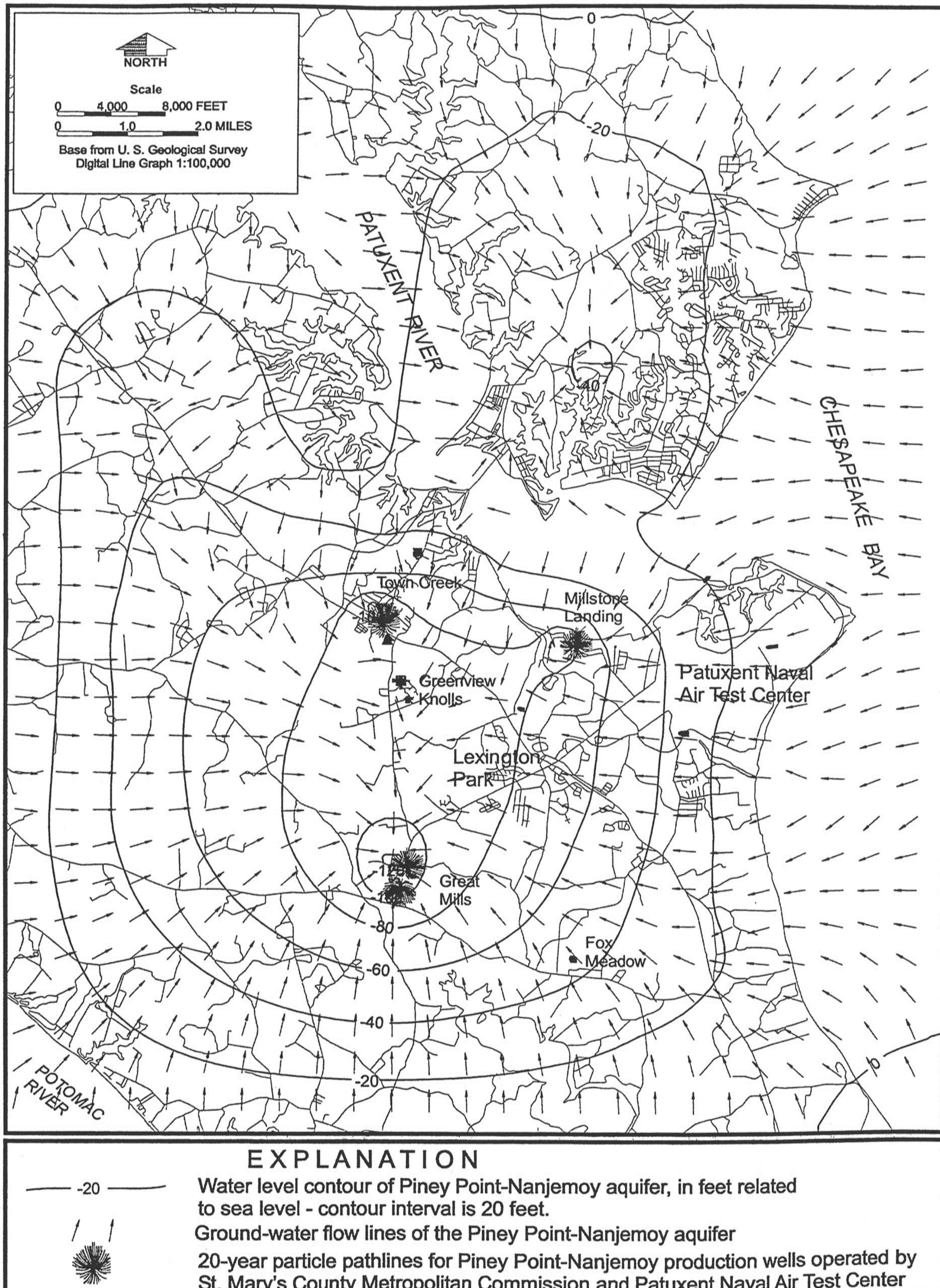


Figure 5. Simulated potentiometric surface, ground-water flow direction, and particle pathlines delineating 20-year zones of transport in the Piney Point-Nanjemoy aquifer using withdrawal rates based on annual average ground-water appropriation permits for year 2000 in the Lexington Park area model.

wells located at Great Mills, Hills Mobile Home Park (Hills MHP), and Town Creek #6A and from PNATC's well located at building #532. These wells were simulated at annual average GAP withdrawal rates of 150,810 gpd, 150,000 gpd, 182,377 gpd, and 127,684 gpd, respectively[1]. Maximum depth of the simulated heads in the Piney Point-Nanjemoy aquifer measured approximately 147 ft below msl near Great Mills. An additional cone of depression measuring approximately 40 ft below msl was located at Solomons Island in Calvert County.

[1] It should be noted actual pumpage rates for Metcom's Hills MHP and PNATC's building 532 were significantly less than simulated. Delineated zones of transport for these wells may not be appropriate if future usage does not approximate simulated pumpage rates.

SIMULATION OF PARTICLE TRACKING

For this study, Visual MODFLOW was used to apply the USGS ground-water flow program MODFLOW and particle-tracking program MODPATH. MODPATH calculates three-dimensional particle trajectories using the assumption that the components of velocity in each of the three directions of flow within the finite-difference cell of the MODFLOW model vary linearly with the flow rates calculated by MODFLOW at each face of the cell (Pollock, 1994). Since MODPATH is a post-processor to MODFLOW, its accuracy is dependent on the accuracy of the ground-water flow model.

Discretization of the modeled area determines the accuracy of the particle pathlines calculated by MODPATH. Numerous studies have indicated that only when the model-cell size was made sufficiently small would ground-water flow rates, particle traces and the associated travel time be accurately calculated (Moltyaner and others, 1993; Pollock, 1988). A characteristic leakage length (Lambda), defined as the square root of aquifer transmissivity times the resistance of the confining bed (Haitjema, Kelson, and de Lange, 2001, p. 937), was used to estimate the appropriate grid size for the local area models. Using aquifer and confining bed parameters representative of the area, a Lambda value[2] of 4,000 ft was estimated. Ideally, cell sizes should be 0.1 Lambda (or 400 ft) (Haitjema, Kelson, and de Lange, 2001, p. 935). The grid dimensions for both the Western area model (400 ft x 400 ft) and central part of the Lexington Park area model (264 ft x 264 ft) are within this limit.

The vertical dimensions of the aquifers and confining beds are used by MODPATH when calculating the position and velocity of the hypothetical particles at discrete points in the flow system. The hypothetical particles may be released at different depths along the well screen, in different patterns, and different quantities. The option selected was to release 40 particles from the middle of the pumping cell in a circle with a radius equal in length to one half the side of the pumping cell (an average of 200 ft.). The circular arrangement of particle sources better depicted the areal extent of the pathline trajectories.

Particle pathlines and endpoints are influenced by decisions made during model set-up in addition to simulated withdrawal rates and time of travel. In MODFLOW, a pumping well is simulated by a single cell with a specified discharge rate. The withdrawal occurs over the entire cell and the cell's head is an averaged head over the entire area of the cell. The size of the pumping cell will influence the degree to which the averaged head is able to approximate the observed head and, thus, the gradient in the area adjacent to the pumping well. Smaller cell sizes better approximate simulated heads and, therefore, pathlines, by providing greater resolution of the gradient. However, smaller cell sizes do not necessarily infer a better understanding of the hydrogeologic conditions. Higher simulated withdrawal rates increase the gradient and the travel distances of particles over a specified period of time. However, the increase in distance will not be linear since the gradient is steeper closer to the well than it is at further distance.

The particle-tracking program MODPATH simulates the pathlines and endpoints of particles released in the ground-water flow model. Particle pathlines, and, consequently, endpoints, are affected by several factors. In addition to the considerations previously mentioned, MODPATH must determine when to terminate a particle's travel. MODPATH accomplishes this determination by classifying a model cell as either a strong or weak sink. In a strong sink, the volume of water discharging from the model equals the volume entering the cell. In a weak sink, the volume of water discharging from the cell is less than the volume entering or passing through the cell. For a weak sink, the particle may: 1) pass through the cell, 2) stop when it enters the cell, or 3) stop when the volume discharged exceeds a certain percentage of the cell's inflow. The default value for the latter option is 5 percent (Guiger and Franz, 2000) and was the value accepted for this study.

BACKTRACKING PARTICLE PATHLINES FROM PRODUCTION WELLS

Particle-tracking techniques calculate pathlines of hypothetical water particles in a ground-water flow system either forward in the direction of the ground-water flow or backward in the direction

[2] Lambda = square root (Aquifer transmissivity x confining bed thickness divided by confining bed vertical hydraulic conductivity) (Haitjema, Kelson, and de Lange, 2001). Using a minimum value for aquifer transmissivity of about 640 ft squared per day, an average confining bed thickness of 100 ft, and a minimum confining bed conductivity of 0.004 ft/d, Lambda is 4,000 ft and 1/10 Lambda is 400 ft.

opposing the ground-water flow. The backward-tracking technique assumes water particles are released in the pumping cell of the model and tracked backwards in the direction opposing ground-water flow to either the source of water in the water table or to the location of particles at some period of time before entering the well. The area surrounding a pumping well that encompasses all areas or features that supply ground-water recharge to the well is the Zone of Contribution and the area surrounding a pumping well bounded by an isochrone contour, through which a contaminant may travel and reach the well, is the Zone of Transport. A Wellhead Protection Area is the surface or subsurface area surrounding a water well or well field through which contaminants are reasonably likely to move toward and reach a public-supply well or well field. Backward-tracking techniques, therefore, provide an efficient means of delineating the source of recharge and time of travel to localized points of discharge, such as production wells or well fields (Pollock, 1994, p. 2-15).

DELINEATION OF ZONES OF TRANSPORT

Zones of transport for production wells were affected by the rates of pumpage. Stand-alone wells pumped at a relatively large rate created large cones of depression in the immediate vicinity of the wells. The zones of transport associated with these wells were generally concentric in shape and propagated greater distances. Clusters of wells pumped at higher rates created larger cones of depression and zones of transport that showed interference of ground-water flow lines with adjacent wells. In contrast, wells pumped at lower rates generally exhibited localized and less identifiable cones of depression. Zones of transport for these wells propagated shorter distances and were elongated in shape in the up-gradient direction of the regional flow lines. The elongation of zones of transport were more pronounced in areas of high potentiometric gradient.

Particle pathlines were backward tracked for time intervals of 1 year, 10 years, and 20 years. Corresponding time-related zones of transport were delineated for production wells in St. Mary's County active during year 2000 and screened in either the Piney Point-Nanjemoy or Aquia aquifer. Zones of transport for specified periods of time were estimated from MODPATH's endpoints. Visual MODFLOW, however, terminates particle paths at the nearest cell face for the specified ending time (20 years), imparting a step-like pattern. The zones of transport displayed in figures 6 to 33 include the endpoints farthest from the pumping well and, therefore, may slightly exaggerate the extent of the zones. Because the 20-year endpoints are confined to the pumped aquifer, the zones of transport are presented in plan-view.

An overview is provided by plate 3, which is a composite map of particle pathlines (scale 1:100,000) representing 20-year zones of transport for production wells in the Western area and Lexington Park area models. One-year, 10-year, and 20-year zones of transport for individual production wells and well fields are also shown on more detailed base maps (scale 1:24,000) for the Western area model (figs. 6-20) and the Lexington Park area model (figs. 21-33). For the purposes of this report, the 20-year zone of transport surrounding a pumping well is considered its well-head protection area.

Aquia Aquifer

The Aquia aquifer is the principal source of ground-water in St. Mary's County. A total of 88 public water-supply wells, 13 with simulated pumpage rates greater than 100,000 gpd, withdraw from the Aquia aquifer. Major cones of depression have formed in the Lexington Park and Leonardtown areas, which influence regional ground-water flow in St. Mary's County. The 20-year zones of transport for the higher capacity wells extend radially outward in generally concentric patterns to distances ranging from 1,150 ft to 2,350 ft. Where production wells are located in close proximity to one another, well interference distorts the particle pathlines creating zones of transport that are mirror images of one another. Wells simulated at lower withdrawal rates generated zones of transport that are comparatively small and elongated in the up-gradient direction. The shapes of these zones of transport indicate that they are chiefly influenced by prevailing ground-water flow patterns (fig. 4, pl. 3). These 20-year zones of transport extend approximately 400 ft to 1,000 ft from the pumping wells.

Charlotte Hall, Rolling Acres, Laurel Ridge, and Hearts Desire

MetCom operates public water-supply wells at McKays Plaza, Charlotte Hall (CH#1 and CH#1R) at a combined, simulated GAP annual average of 57,200 gpd. The 1-year, 10-year, and 20-year zones

of transport for a well at McKays Plaza, simulated at an allocated withdrawal rate of 14,500 gpd, have maximum radial distances of about 450 ft, 650 ft, and 850 ft, respectively (fig. 6). Charlotte Hall wells (CH#1R and CH#1) were simulated in two adjacent cell nodes at allocated withdrawal rates of 23,600 gpd and 19,100 gpd. The zones of transport for CH#1 and CH#2 are elliptical in shape and mimic a mirror image, reflecting interference between closely spaced wells (fig. 6). Their 1-year, 10-year, and 20-year zones of transport are approximately the same and at a maximum extend about 400 ft, 600 ft, and 1,000 ft, respectively, from the well. Effects of well interference also are evident at Charlotte Hall Veterans Home where wells CHVH#1 and CHVH#2 pump at a combined GAP annual average rate of 70,000 gpd with 35,000 gpd allocated to each well. Their zones of transport are mirror images with elongated elliptical shapes. The 1-year, 10-year, and 20-year zones of transport measured at their maximum extend about 400 ft, 750 ft, and 1,150 ft from the well.

At the Wentworth Nursery well field two supply wells are pumped at a combined GAP annual average of 15,000 gpd. The wells were simulated in two adjacent cell nodes at an allocated withdrawal rate of 7,500 gpd each. The 1-year, 10-year, and 20-year zones of transport measured at their maximum extend about 300 ft, 500 ft, and 800 ft from the wells (fig. 6). The elongated up-gradient direction of the zones of transport was influenced by the generally north-south direction of regional ground-water flow (pl. 2).

MetCom operates two wells at Rolling Acres Subdivision that were simulated at a GAP annual average of 59,200 gpd and two wells at Laurel Ridge Subdivision simulated at a GAP annual average of 61,300 gpd. The two wells at both subdivisions were pumped alternately throughout the year and simulated as a single cell node. The 1-year, 10-year, and 20-year zones of transport for both well fields were similar in sizes and have maximum radial distances of about 600 ft, 800 ft, and 1,200 ft, respectively (fig. 7).

The 1-year, 10-year, and 20-year zones of transport for the MetCom public-supply wells at Hearts Desire Subdivision simulated at GAP annual average of 5,300 gpd have maximum radial distances of about 400 ft, 500 ft, and 700 ft, respectively (fig. 8). The influence of the regional ground-water flow gradient on the zones of transport is minor, because it is comparatively low in the northern part of the Western area model (3.3 ft/mi).

Persimmon Hills, Birch Manor, King-Kennedy Estates, Country Lakes, and Wicomico Shores

MetCom operates eight public-supply wells located in the middle portion of the Western area model, including Persimmon Hills, Birch Manor, King-Kennedy Estates, Country Lakes (pl. 2). The 1-year, 10-year, and 20-year zones of transport for the public-supply well at Persimmon Hills Subdivision simulated at GAP annual average of 39,700 gpd have radial distances of about 450 ft, 600 ft, and 800 ft, respectively (fig. 9). MetCom operates two wells at Birch Manor Subdivision with a combined GAP annual average of 30,000 gpd. The supply wells were simulated as two adjacent cell nodes pumped at an allocated rate of 15,000 gpd each. The zones of transport for the production wells were mirror images of the same size. The 1-year, 10-year, and 20-year zones of transport at the two sites, measured from the well, extend a maximum distance of 400 ft, 700 ft, and 1,000 ft, respectively (fig. 9).

MetCom operates two wells (KK#1 and KK#2R) at the King-Kennedy Estates with a combined GAP annual average of 31,000 gpd. The KK#1 well simulated an allocated withdrawal rate of 5,862 gpd, while the KK#2R well simulated an allocated withdrawal rate of 25,138 gpd. The 1-year, 10-year, and 20-year zones of transport for KK#1 were elliptical in shape extending at maximum about 550 ft, 700 ft, and 1,100 ft, respectively from the well (fig. 10). The circular 1-year, 10-year, and 20-year zones of transport for KK#2R were slightly eccentric in shape with maximum distances from the wells of about 500 ft, 700 ft, and 950 ft, respectively (fig. 10). The southeast-northwest up-gradient direction of the elongated zones of transport for KK#1 was caused by the prevailing northwest-southeast direction of regional ground-water flow (pl. 2) and interference from KK#2R.

MetCom operates three public-supply wells at Country Lakes and Beverly Estates with a combined GAP annual average of 240,000 gpd. The wells were simulated at allocated rates of 48,00 gpd for well CL#1B, 45,000 gpd for well CL#2 , and 147,000 gpd for well CL#3, which produced zones of transport of different sizes and shapes related to magnitude of the withdrawal and distance between the wells. The 1-year, 10-year, and 20-year zones of transport for CL#2 Tower well, a stand-alone well, has a maximum radial distance of about 500 ft, 750 ft, and 1,300 ft, respectively. The zones of transport for CL#3 were relatively dominant and interfered with the zones of transport of CL#1B, which was

simulated at a relatively lower allocated withdrawal rate (fig. 11). The 1-year, 10-year, and 20-year zones of transport for CL#1B and CL#3 extend at their maximum about 550 ft, 700 ft, and 1,250 ft and 550 ft, 1,050 ft, and 1,600 ft, respectively from the well.

Well SM Ca 9 is operated by the St. Mary's County Department of Recreation and Parks. It supplies the golf course in Wicomico Shores and was simulated at a GAP annual average of 60,300 gpd. The maximum radial distances for 1-year, 10-year, and 20-year zones of transport are 500 ft, 850 ft ,and 1,150 ft, respectively (fig. 12). MetCom wells SM Ca 5 and SM Ca 10, also located in Wicomico Shores, were not included in the model simulation because they withdraw from the Upper Patapsco aquifer.

Holland Forest, Mulberry South, Wilderness Run, Saint Clements Shores , and Breton Bay

In the southern part of the Western area model MetCom well fields at Holland Forest and Mulberry South consist of pairs of closely located wells. The production wells are normally pumped in an alternating manner and are simulated in the model as a single pumping node. Both Holland Forest (7,100 gpd) and Mulberry South (5,700 gpd) have comparatively low GAP annual average withdrawal rates. Their zones of transport are elongated in the up-gradient direction because the potentiometric gradient is comparatively high in the southern part of the Western area model (about 17.6 ft/mi). The 1-year, 10-year, and 20-year zones of transport form elongated ellipses that extend for both wells a maximum distance of about 400 ft, 550 ft, and 900 ft, respectively, for Holland Forest (fig. 13), and 400 ft, 700 ft, 1,050 ft, respectively, for Mulberry South (fig. 14).

Zones of transport were simulated for MetCom production wells at Wilderness Run, Saint Clements Shores, and Breton Bay at GAP annual average pumpage rates of 25,000 gpd, 55,000 gpd, and 85,000 gpd, respectively. The size of the zones of transport reflect their rates of withdrawal. The maximum radius of the 1-year, 10-year, and 20-year zones of transport measured from the wells at Wilderness Run, Saint Clements Shores, and Breton Bay are, respectively, about 500 ft, 650 ft, and 950 ft (fig. 15); 500 ft, 950 ft, and 1,200 ft (fig. 16); and 700 ft, 1,000 ft, and 1,400 ft (fig. 17).

Leonardtown, Vocational Technical Center, Maryland Rock Industries Plant, Tekstar Industries, Mount Pleasant, Bushwood Bottling Company, South Star Sand and Gravel Mine, and Chopticon High School

Four production wells with a combined GAP annual average of 525,000 gpd are operated at Leonardtown (figs. 13, 14). Two of the wells at Fenwick Road (LT#1 and LT#4) were simulated as pumping from one cell node at 261,994 gpd. The maximum radius of the 1-year, 10-year, and 20-year zones of transport are about 600 ft, 1,200 ft, and 2,200 ft, respectively (fig. 14). The other two production wells at Leonardtown are located adjacent to one another in the St. Mary's County Government Center. Wells LT#2 and LT#3 simulated at withdrawal rates of 137,103 gpd and 125,903 gpd respectively, produced elliptical 1-year, 10-year, and 20-year zones of transport that extend from the wells about 700 ft, 1,200 ft, and 1,750 ft and about 500 ft, 900 ft, and 1,150 ft at their maximum (fig. 13). The zones of transport for wells LT#2 and LT#3 showed the effects of well interference in addition to regional ground-water flow.

Two water-supply wells at the Vocational Technical Center with a GAP annual average of 30,000 gpd simulated pumping from two adjacent cell nodes at an allocated rate of 15,000 gpd each. The zones of transport are mirror images of each other. The 1-year, 10-year, and 20-year zones of transport at their maximum extend about 400 ft, 650 ft, and 900 ft, respectively (fig. 14). Maryland Rock Industries operate one supply well simulated at a GAP annual average of 40,000 gpd. At their maximum the 1-year, 10-year, and 20-year zones of transport extend from the well about 500 ft, 850 ft, and 1,200 ft, respectively (fig. 17). The low rate of withdrawal (7,500 gpd) at the Tekstar Industries site produced elliptical zones of transport extended in the up-gradient direction of regional ground-water flow (pl. 2). The 1-year, 10-year, and 20-year zones of transport extend about 400 ft, 600 ft, and 1,050 ft, respectively, at their maximum from the well (fig. 13).

The 1-year, 10-year, and 20-year zones of transport for the production wells at Mount Pleasant simulated at a GAP annual average of 13,000 gpd and Bushwood Water Bottling Company simulated at a GAP annual average of 10,000 gpd were almost

identical with a radial distance of about 500 ft, 600 ft, and 900 ft, respectively (fig. 18). The 1-year, 10-year, and 20-year zones of transport for the wells at South Star Sand and Gravel Mine simulated at a GAP annual average of 119,000 gpd and Chapticon High School simulated at a GAP annual average of 20,300 gpd were eccentric circles. At their maximum the zones of transport extended about 700 ft, 11,000 ft, and 14,000 ft (fig. 19) and about 400 ft, 600 ft, and 800 ft, respectively (fig. 20).

Fenwick Manor and Hollywood

MetCom operates public-water supply wells #1 and #2R at Fenwick Manor. These wells are essentially co-located with alternating on/off cycles. Combined annual average pumpage is 25,000 gpd. Zones of transport for the 1-year, 10-year, and 20-year periods extend radially about 400 ft, 500 ft, and 700 ft from the well, respectively. The zones are centered on the wells and slightly elongated toward the north (fig. 21). The well located at Hollywood has a GAP annual average rate of 7,500 gpd. The zones of transport for the 1-year, 10-year, and 20-year periods measured approximately 400, 600, and 700 ft, respectively, from the well in an elongated pattern toward the north (fig. 21).

St. Mary's Industrial Park and Wildewood

The Saint Mary's Industrial Park well has a GAP annual average rate of 34,000 gpd. Zones of transport for the 1-year, 10-year, and 20-year periods measured approximately 600, 850, and 1,100 ft, respectively, from the well in an ellipsoid pattern toward the north-northwest (fig. 22). The Wildewood Subdivision is served by three public water-supply wells. The permitted annual average withdrawal rate is 350,000 gpd. The modeled pumpage rates for wells #1, #2, and #3 are approximately 97,000 gpd, 25,000 gpd, and 228,000 gpd, respectively. Zones of transport for the 1-year, 10-year, and 20-year periods vary in size, dependent upon the pumpage amounts, and reach a maximum radial distance of approximately 600, 1200, and 1600 feet, respectively, for well #3 (fig. 22). The shape of the zones of transport for wells #1 and #3 is nearly concentric, while for well #2 the shape is slightly ellipsoidal.

Esperanza Farms, Town Creek, Laurel Glen, San Souci, Greenview Knolls, and Tubman Douglas

In the Town Creek area, MetCom operates wells located at Esperanza Farms, Town Creek #6B, and Laurel Glen (fig. 23). These wells were simulated at GAP annual average rates of 138,400 gpd, 60,047 gpd, and 55,300 gpd, respectively. The zones of transport for Esperanza Farms extend radially to a maximum of 500 ft, 1,000 ft, and 1,400 ft, respectively for time periods of 1, 10, and 20 years. The zones were concentric in shape indicating that pumpage at Esperanza Farms was the dominant influence on ground-water flow in that area. For Town Creek #6B and Laurel Glen, zones measured about 400 ft, 800 ft, and 1,100 ft, respectively, for the same time periods. These wells' zones of transport were slightly elliptical in a northwest direction, indicating that they were influenced by their relatively lower pumpage rates and their proximity to other higher pumpage wells in the Lexington Park area. South of Town Creek, MetCom operates wells at San Souci, Greenview Knolls #3, and Tubman Douglas (fig. 24). These wells were pumped at GAP annual average rates of 71,133 gpd, 80,000 gpd, and 50,000 gpd, respectively. For time periods of 1, 10, and 20 years, the maximum radius of the zones of transport measured approximately: 400 ft, 800 ft, and 1,200 ft, respectively, for San Souci; 500 ft, 1,000 ft, and 1,400 ft, respectively, for Greenview Knolls #3; and 400 ft, 800 ft, and 1,300 ft, respectively, for Tubman Douglas. Zones of transport were slightly elliptical in the up-gradient direction indicating that some well interference occurred from pumpage in the Lexington Park area.

Pegg Road, Bank Square, Willows Road, Colony Square, and Essex Drive

In the immediate vicinity of Lexington Park, near the intersection of Routes 235 and 246, MetCom operates wells at Pegg Road, Bank Square, Willows Road, Colony Square, and Essex Drive (fig. 25). These wells were simulated at apportioned GAP annual average rates of 450,675 gpd, 225,065 gpd, 96,239 gpd, 114,768 gpd, and 132,343 gpd, respectively. Combined, these withdrawals total approximately 1.019 Mgal/d and constitute the highest pumpage rate in the Aquia

aquifer by MetCom. The maximum radius of the zones of transport for Pegg Road measured about 700 ft, 1,600 ft, and 2,350 ft, respectively, for 1-year, 10-year, and 20-year intervals. These zones were concentric in shape. Zones of transport for the remaining four wells had a maximum radial distance of about 550 ft, 1,500 ft, and 2,300 ft. The shape of these zones varied from elongated for Essex Drive to mirror images of each other for Colony Square and Willows Road. The shape of the zone of transport for Bank Square was roughly a mirror image of the combined pattern for Colony Square and Willows Road. The shapes of these zones of transport show extensive well interference with one another. However, the combined pumpage from these wells approximate one large withdrawal with a composite 20-year zone of transport measuring about 6,000 ft across in an east-west direction and about 5,000 ft across in a north-south direction.

Hunting Quarters, Greenbriar, Southgate, and Cedar Cove

MetCom also operates several smaller public water-supply systems with wells located at Hunting Quarters #1 and #2, Greenbriar #2, Southgate, and Cedar Cove #1 and #2 (figs. 26-28). Since Hunting Quarters #1 and #2 are co-located and operate with alternating on/off cycles, the wells were simulated as one withdrawal at the GAP annual average rate of 40,800 gpd. The remaining wells were simulated at their apportioned GAP annual average rates of 26,500 gpd, 13, 600 gpd, 73,262 gpd, and 86,738 gpd, respectively. For 1-year, 10-year, and 20-year periods, the maximum radius of the zones of transport for Hunting Quarters measured about 500 ft, 800 ft, and 1,100 ft, respectively (fig. 26). The shape of the zones of transport were slightly elliptical. For 1-year, 10-year, and 20-year periods, the maximum radius of the zones of transport for Greenbriar #2 and Southgate measured about 450 ft, 900 ft, and 1,600 ft; and 600 ft, 900 ft, and 1,250 ft, respectively (fig. 27). The shape of the zones of transport were elliptical showing some influence from the Aquia production wells in Lexington Park. For 1-year, 10-year, and 20-year periods, the maximum radius of the zones of transport for Cedar Cove #1 and #2 measured approximately 500 ft, 1,200 ft, and 1,800 ft, respectively (fig. 28). The shape of the zones were elliptical due to pumping at neighboring PNATC, but also showed some well interference with one another.

Patuxent Naval Air Test Center

At PNATC, the U.S. Navy operates 20 production wells screened in the Aquia aquifer (app. C, permit SM 74GAP018) (figs. 29-31). Wells located at buildings #529 and #590 (fig. 29) had the largest withdrawals and were simulated at apportioned GAP annual average rates of 148,356 gpd and 102,619 gpd, respectively. The maximum radius of the zones of transport measured 550 ft, 1,300 ft, and 1,900 ft, respectively, for the well at building #529 (fig. 29) and 500 ft, 1,000 ft, and 1,500 ft, respectively, for the well at building #590 (fig. 30) at the 1-year, 10-year, and 20-year intervals. The shapes of the zones of transport were concentric with some elongation of the pathlines in the direction of the regional ground-water flow. The remaining production wells at PNATC had zones of transport that ranged from 200-400 ft, 600-1,400 ft, and 600-2,000 ft at the 1-year, 10-year, and 20-year intervals, respectively. The shapes of the zones of transport were elongated with the pathlines paralleling regional ground-water flow lines in the direction of the Pegg Road and Bank Square area (fig. 4).

Piney Point-Nanjemoy Aquifer

In the Piney Point-Nanjemoy aquifer, zones of transport were delineated for nine MetCom wells (figs. 26, 27, 32, and 33) and five PNATC wells (figs. 29-31). The largest withdrawals were derived from MetCom's wells located at Great Mills (fig. 26), Hills MHP (fig. 20), and Town Creek #6A (figs. 32 and 33) and from PNATC's well located at building #532 (fig. 29). These wells were simulated at pumpage rates ranging from about 128,000 gpd to 182,000 gpd. Individually, the wells created local cones of depression, and when combined, they created a larger cone of depression centered in the Lexington Park area. Particle pathlines for these wells spread out radially and at the 20-year period extended to distances of 1,500 to 1,800 ft from each pumping well. The remaining production wells screened in the Piney Point-Nanjemoy aquifer pumped ground-water at significantly lower rates. Their zones of transport were smaller in diameter, influenced by regional ground-water flow, and elongated in the up-gradient direction of the regional flow lines (fig. 5). At the 20-year period , particle pathlines for these wells extended approximately 500 to 1,000 ft upgradient along the regional ground-water flow lines.

Town Creek, Hickory Hills, and Greenview Knolls

In the Town Creek area, MetCom operated public water-supply wells at Town Creek (TC #3 and #6A), Hickory Hills, and Greenview Knolls (GK #1 and #2) (figs. 32 and 33). The simulated apportioned GAP annual average rates were 17,623 gpd, and 182,377 gpd, respectively, for Town Creek #3 and #6A; 10,521 gpd for Hickory Hills (reported as part of the Lexington Park system); and 3,000 gpd and 17,000 gpd, respectively for Greenview Knolls (#1 and #2). The maximum distance from the well of the zones of transport for TC #3 measures approximately 400 ft, 650 ft, and 900 ft at the 1-year, 10-year, and 20-year intervals, respectively (fig. 32). The maximum distance from the well of zones of transport for TC #6A measured about 500 ft, 1,400 ft, and 1,800 ft at the 1-year, 10-year and 20-year intervals, respectively (figs. 32, 33). The shape of the zone of transport for TC #6A was concentric with pathlines radiating outward in all directions. At the 20-year interval, some well interference exists between TC #6A and Hickory Hills. At Hickory Hills, the maximum distance from the well of the zones of transport measured 600 ft, 700 ft, and 1,000 ft at the 1-year, 10-year, and 20-year intervals, respectively (figs. 32, 33). Particle pathlines were somewhat elongated due to its proximity to TC #6A. At Greenview Knolls #1, the maximum radius of the zones of transport measured about 200 ft, 400 ft, and 500 ft at the 1-year, 10-year, and 20-year intervals, respectively (fig. 33). Elongated pathlines in a northwest and southeast direction indicate that particle travel is influenced by pumpage at Greenview Knolls #2. At Greenview Knolls #2, the maximum radius of the zones of transport measured 400 ft, 550 ft, and 700 ft at the 1-year, 10-year, and 20-year intervals, respectively (fig. 33). Despite the relatively low pumpage rate, the concentric shape of the pathlines may have been caused by an induced ground-water divide located between TC #6A and the pumpage at Great Mills and Hills MHP.

Great Mills and Hills Mobile Home Park

Apportioned GAP annual average rates for MetCom wells located at Hills MHP and Great Mills (fig. 26) were 150,000 gpd and 150,810 gpd, respectively (reported as part of the Lexington Park system). The maximum distance from the well of the zones of transport measured about 600 ft, 1,250 ft, and 1,800 ft for Great Mills and about 550 ft, 1,000 ft, and 1,650 ft for Hills MHP at the 1-year, 10-year, and 20-year intervals, respectively. The shape of the zones were roughly concentric mirror-images, indicating well interference. The combined pumpage of these two wells influenced ground-water flow lines in the Lexington Park area and their combined 20-year zones of transport covered an area measuring approximately 5,000 ft in the north-south direction and 3,000 ft in the east-west direction.

Fox Meadow

At the intersection of Hermanville Road and Route 5, MetCom operates wells at Fox Meadow (FM #1 and #2) (fig. 27). Since these wells are co-located and operate with alternating on/off cycles, they were simulated as one withdrawal. The simulated GAP annual average rate was 7,100 gpd. The maximum distance from the well of the zones of transport measured about 400 ft, 500 ft, and 600 ft for both wells at the 1-year, 10-year, and 20-year intervals, respectively. Shapes of the zones of transport were slightly elongated and primarily captured ambient ground-water flow.

Patuxent Naval Air Test Center

At PNATC, the U. S. Navy operates five production wells (buildings #532, #536, #596, #1633, and #2100) screened in the Piney Point-Nanjemoy aquifer (figs. 29-31). These wells were simulated at apportioned GAP annual average rates of 127,684 gpd, 1,514 gpd, 7,929 gpd, 2,070 gpd, and 802 gpd, respectively. The well at building #532 had the highest pumpage rate and its zones of transport were concentric in shape. The maximum radius of the zones of transport for well #532 measured about 500 ft, 1,200 ft, and 1,500 ft (fig. 29). The remaining wells had much lower pumpage rates and the maximum distance from the wells of

their zones of transport measured approximately 200 ft, 400 ft, and 600 ft (figs. 29-31). The shapes of these zones of transport were elongated in the direction of the regional ground-water flow lines.

Maps showing particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia and Piney Point-Nanjemoy production wells are shown on pages 27-54 (figs. 6 to 33).

Text continued on page 55.

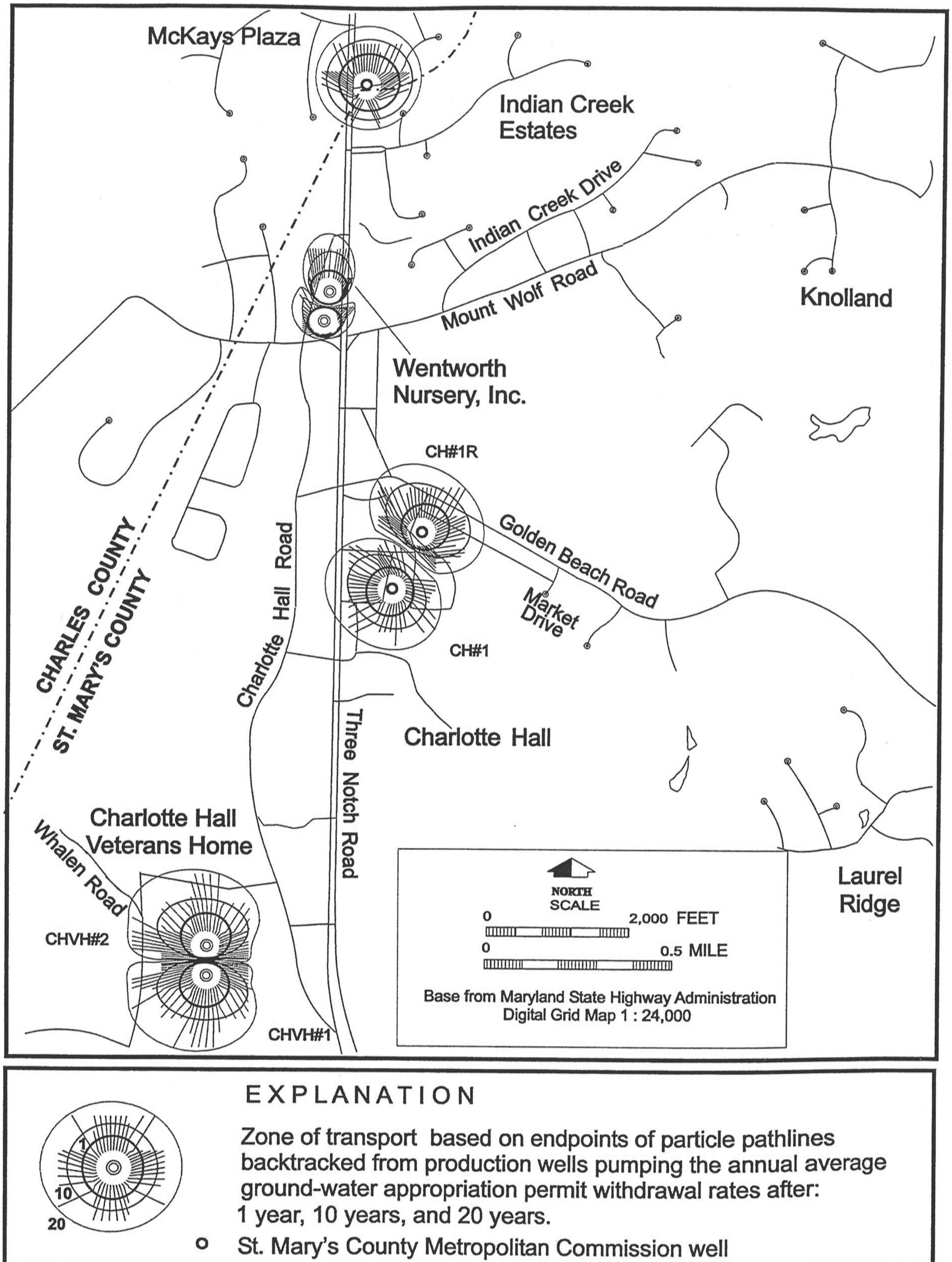
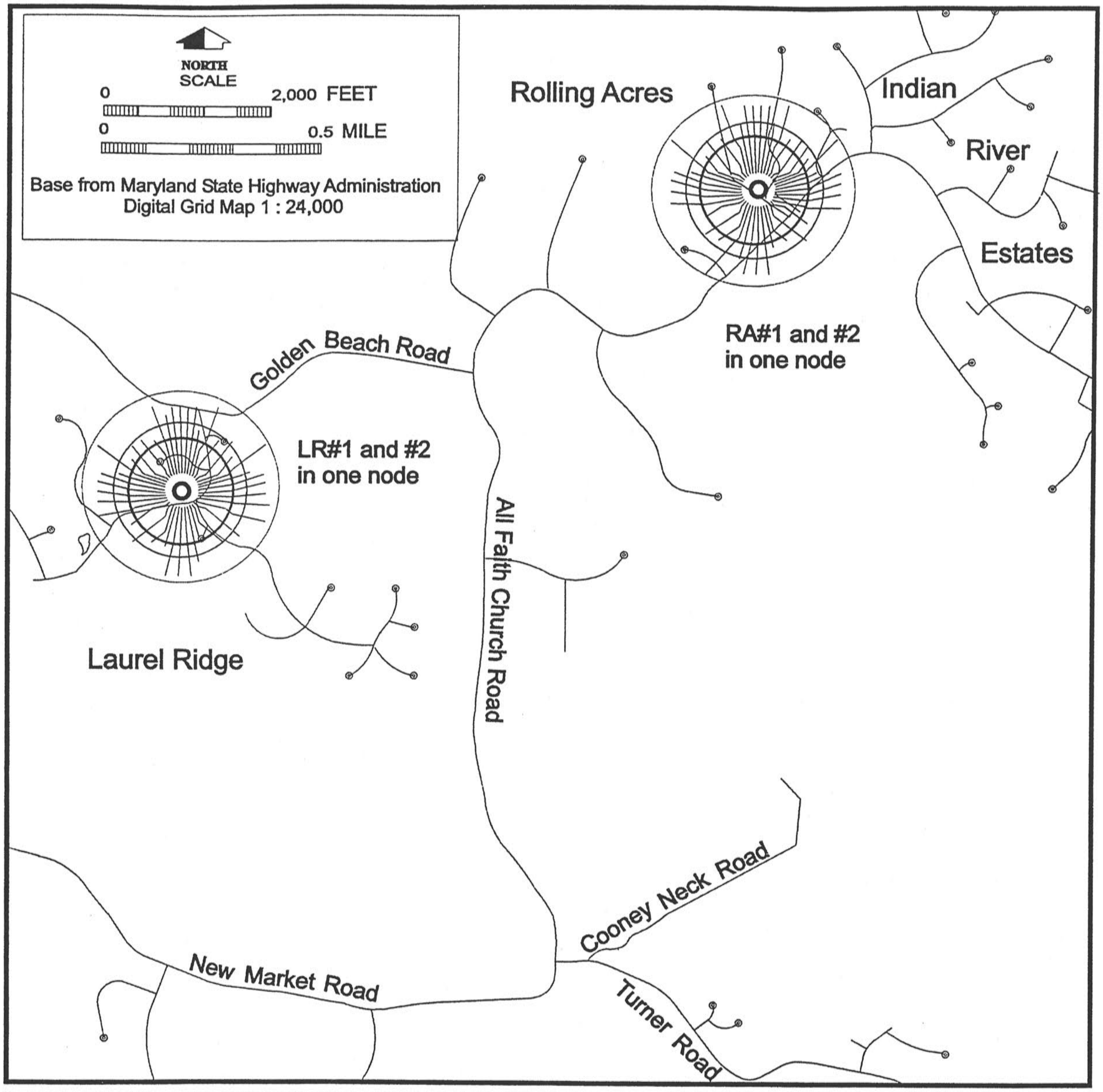


Figure 6. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at McKays Plaza, Wentworth Nursery, Charlotte Hall (CH#1R and CH#1), and Charlotte Hall Veterans Home (CHVH#1 and CHVH#2).



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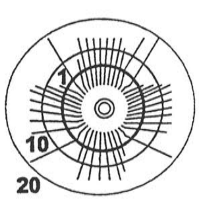
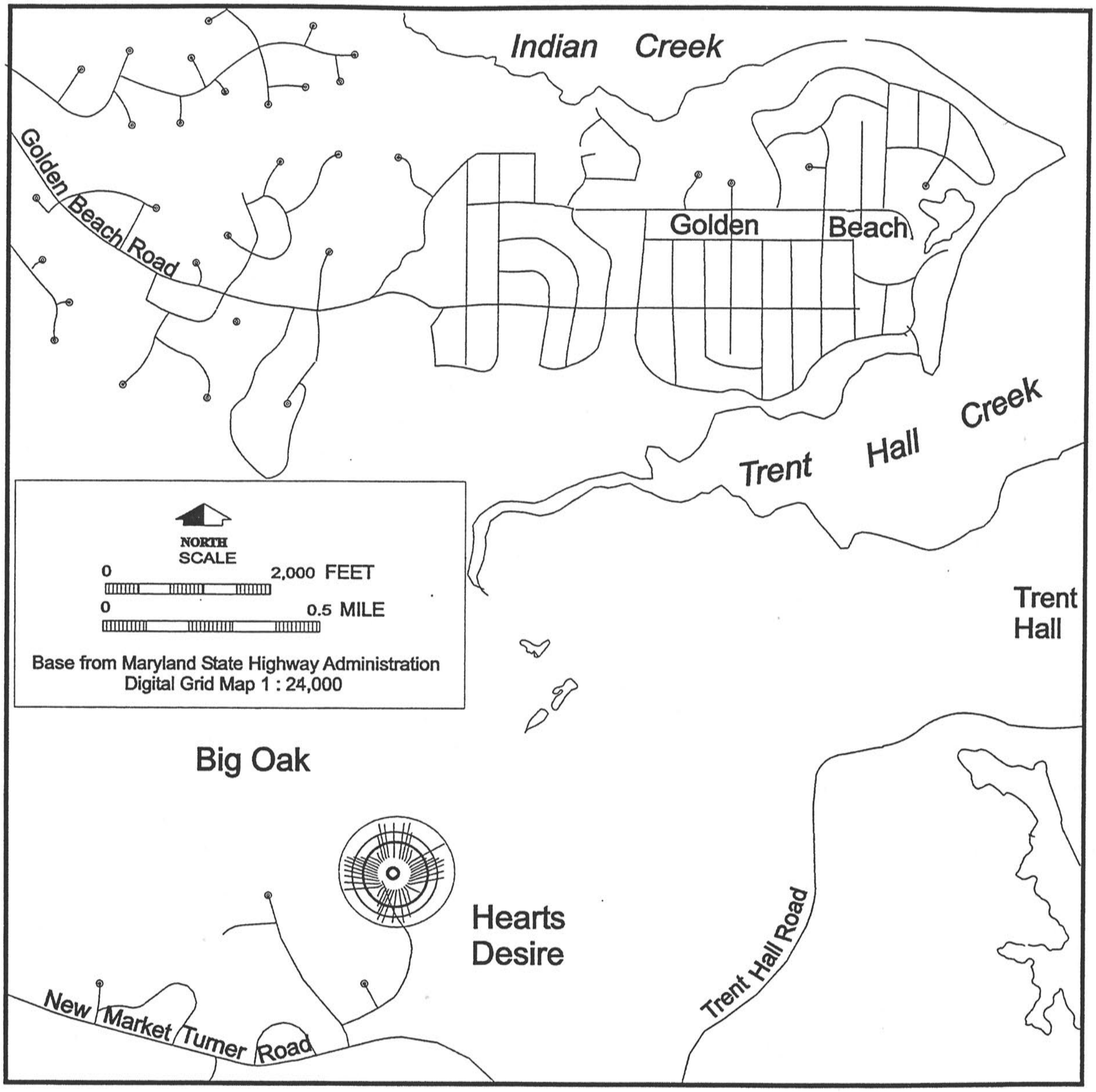
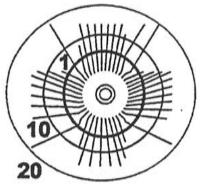


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

o St. Mary's County Metropolitan Commission well

Figure 7. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Rolling Acres Subdivision (RA#1 and #2R) and Laurel Ridge Subdivision (LR#1 and #2).





EXPLANATION

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

o St. Mary's County Metropolitan Commission well

Figure 8. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production well at Hearts Desire Subdivision.

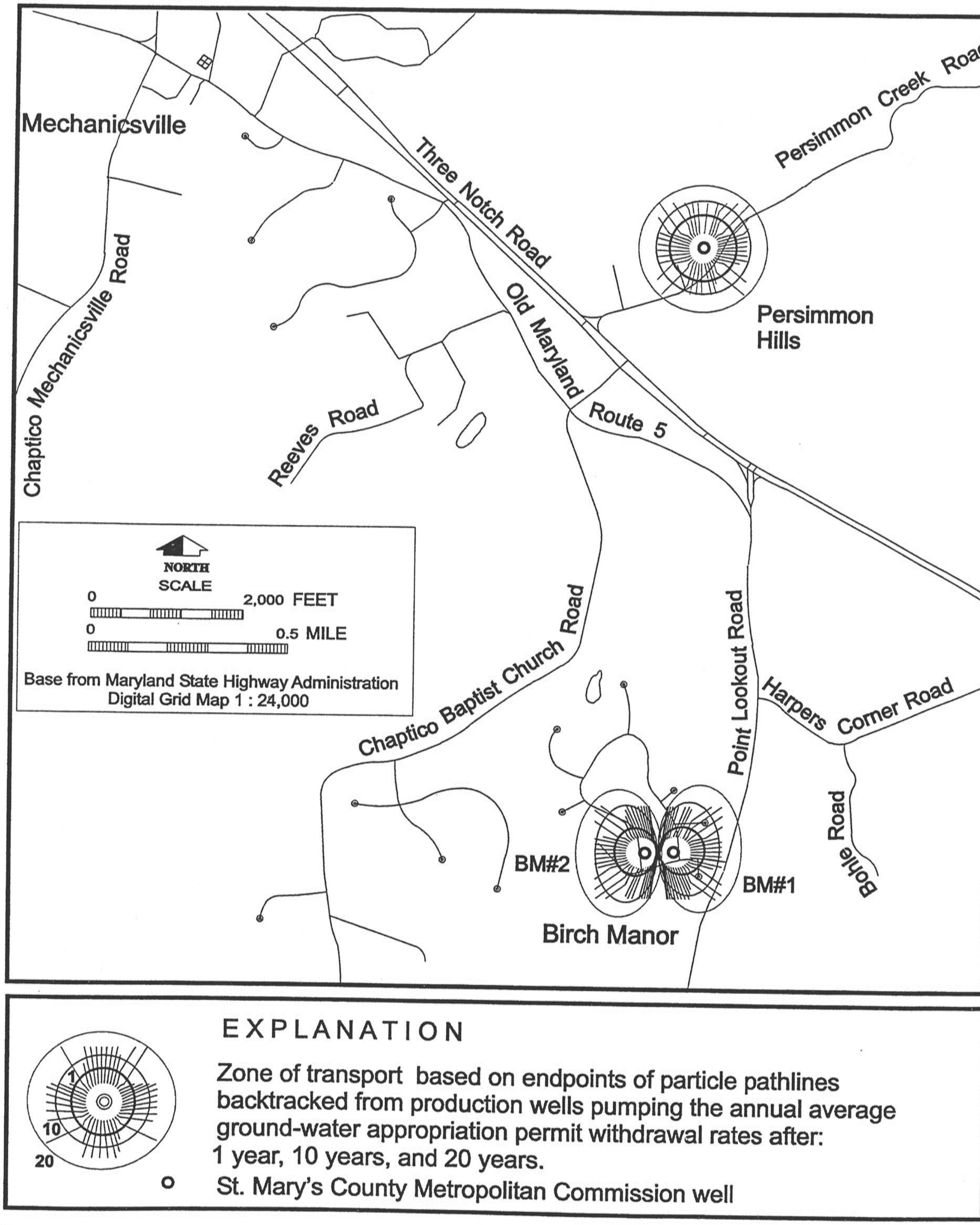


Figure 9. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Persimmon Hills Subdivision and Birch Manor Subdivision (BM#1 and BM#2).

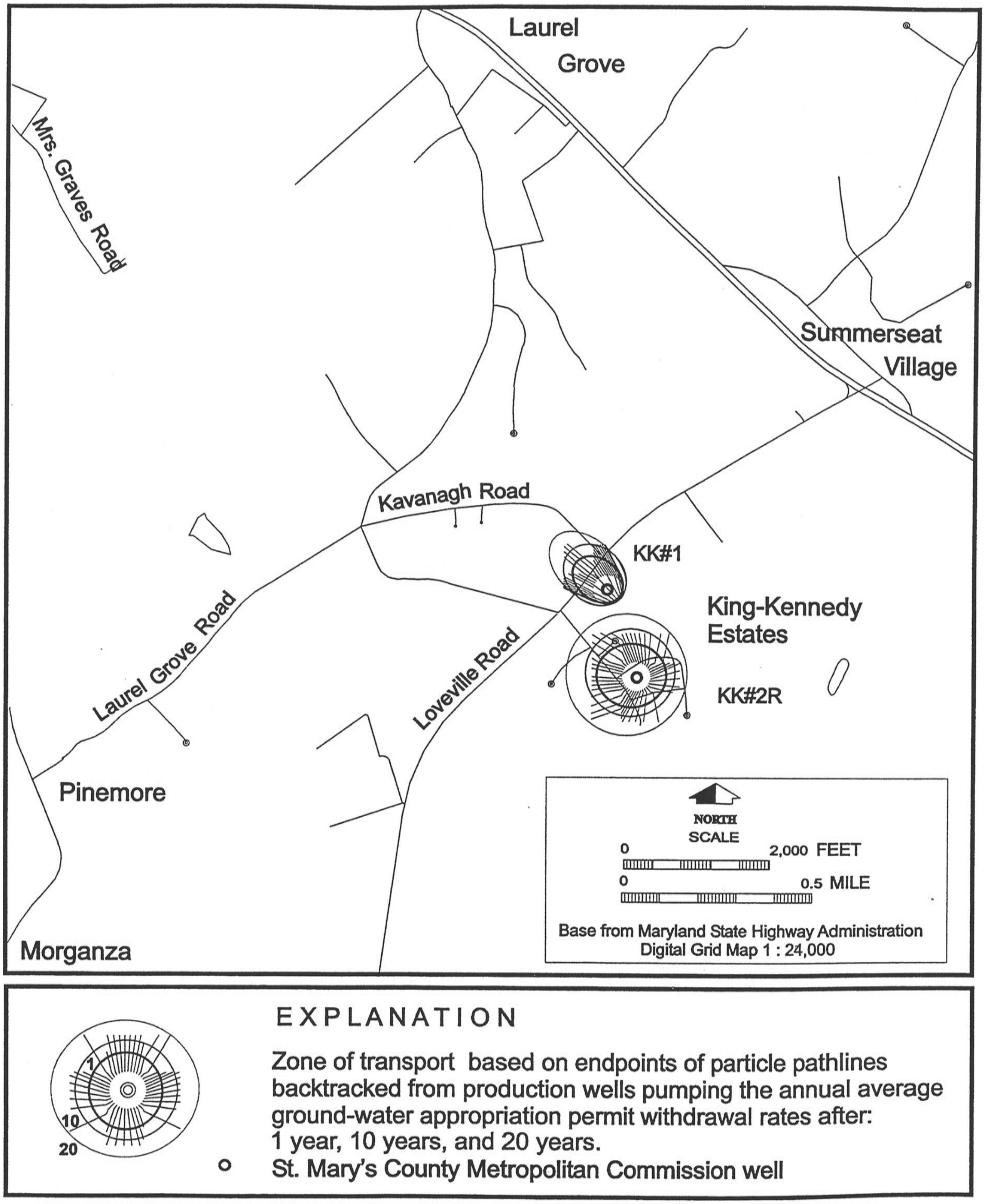
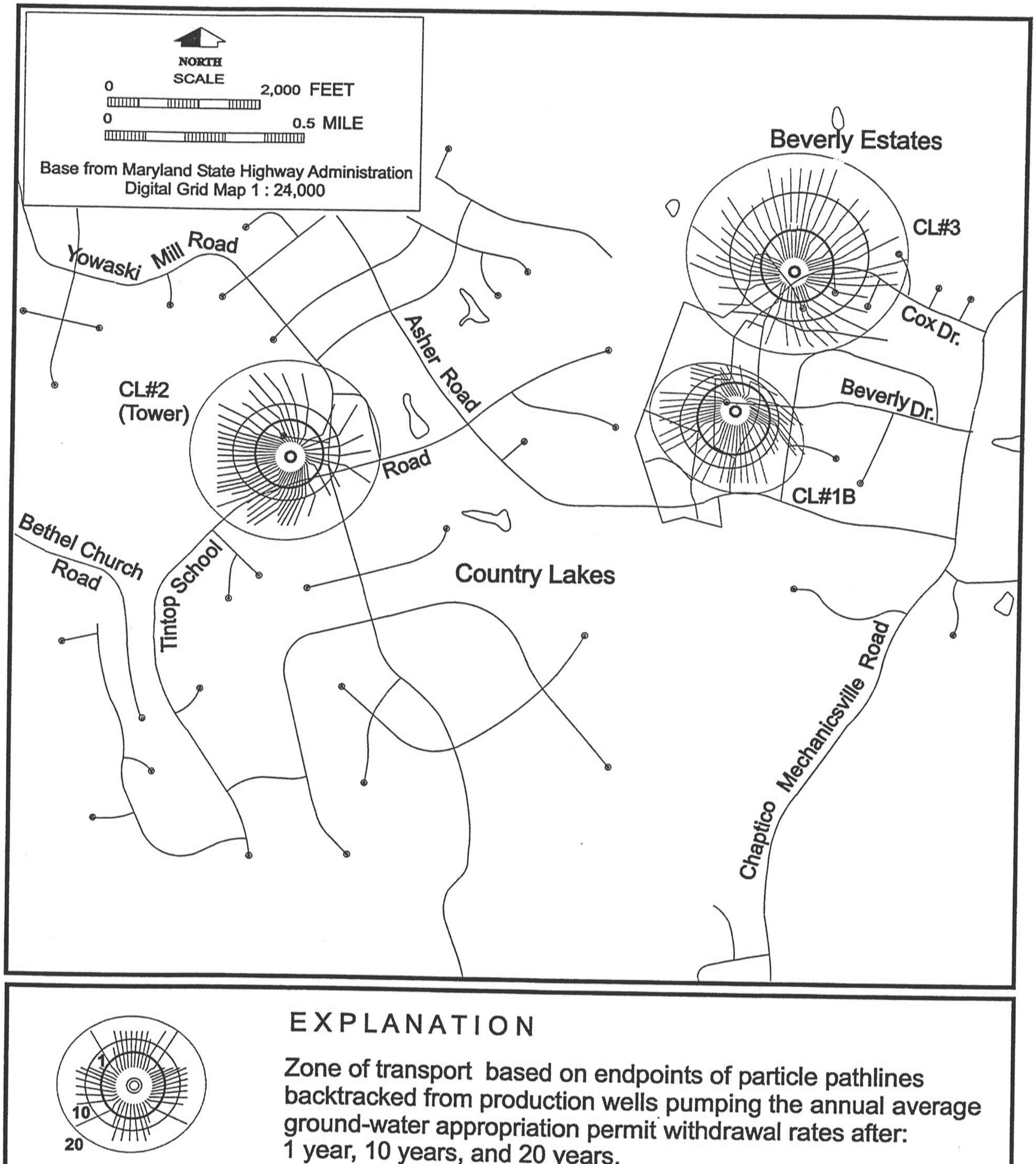


Figure 10. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at King-Kennedy Estates (KK#1 and KK#2R).

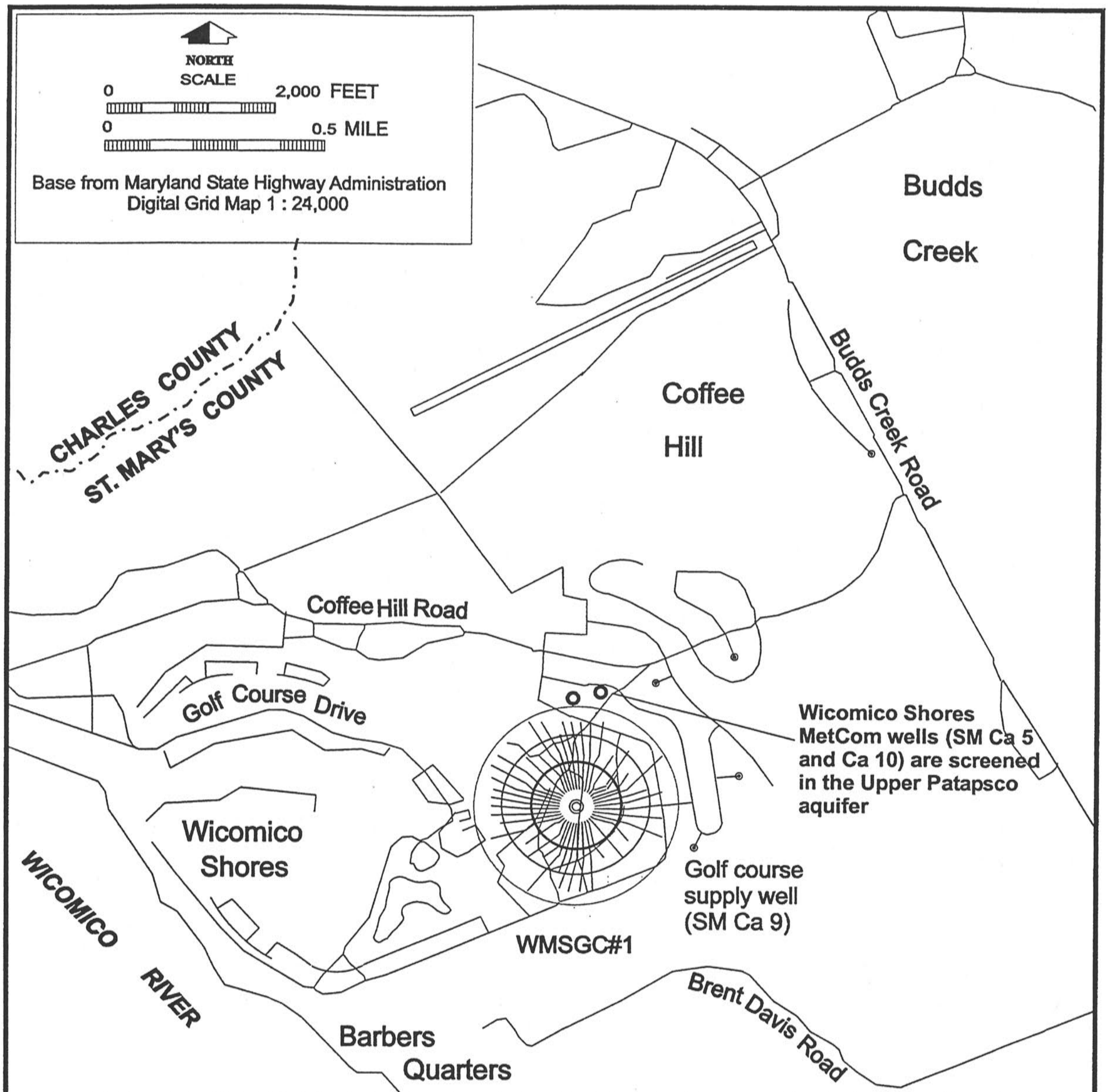


EXPLANATION

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

o St. Mary's County Metropolitan Commission well

Figure 11. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Country Lakes and Beverly Estates (CL#1B, CL#2, and CL#3).



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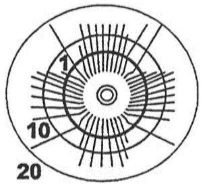
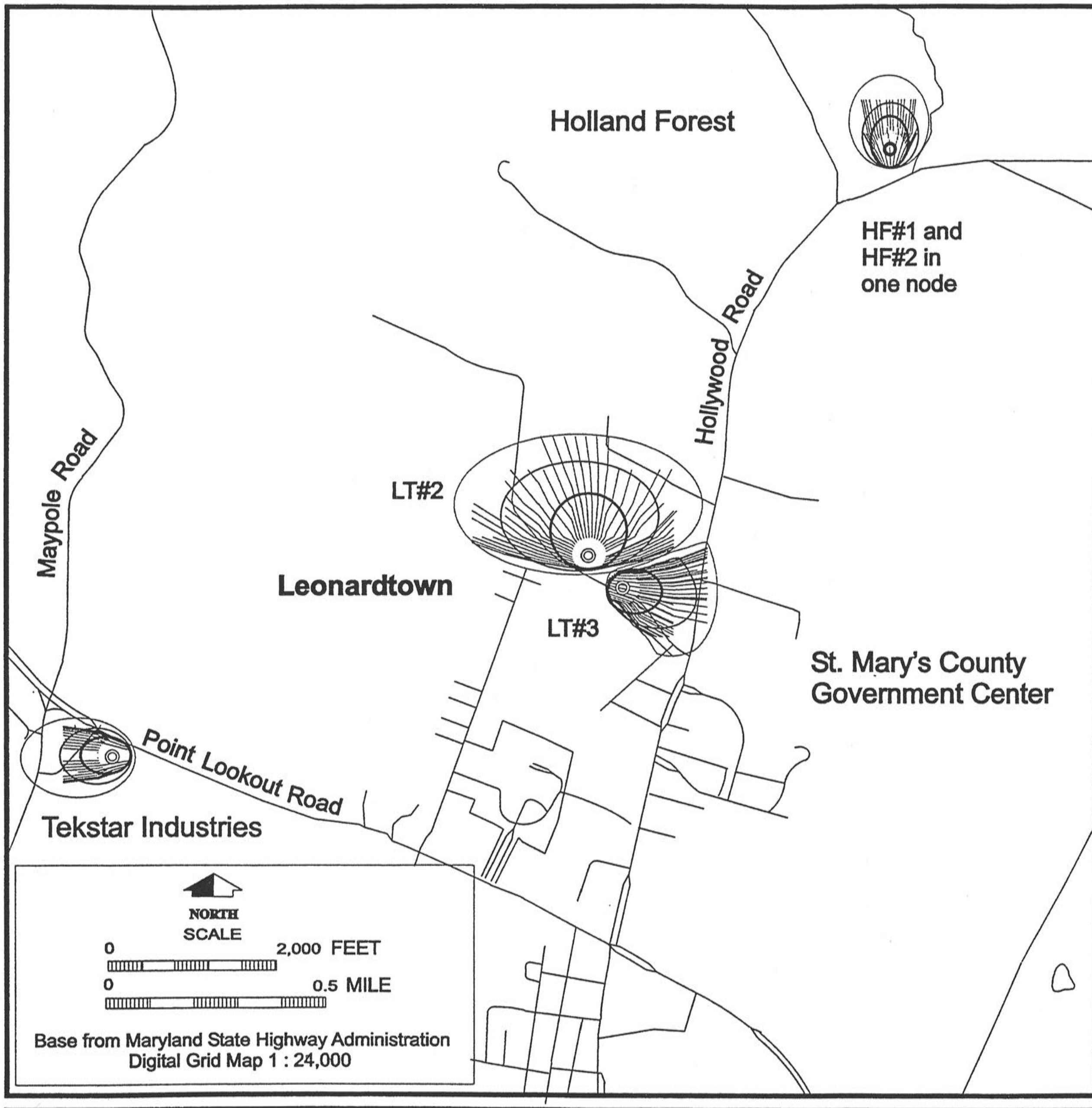


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

o St. Mary's County Metropolitan Commission well. Wells SM Ca 5 and Ca 10 are screened in the Upper Patapsco aquifer.

Figure 12. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production well at Wicomico Shores Golf Course (WMSGC#1).



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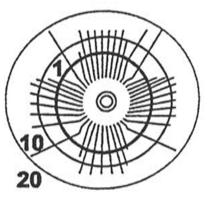
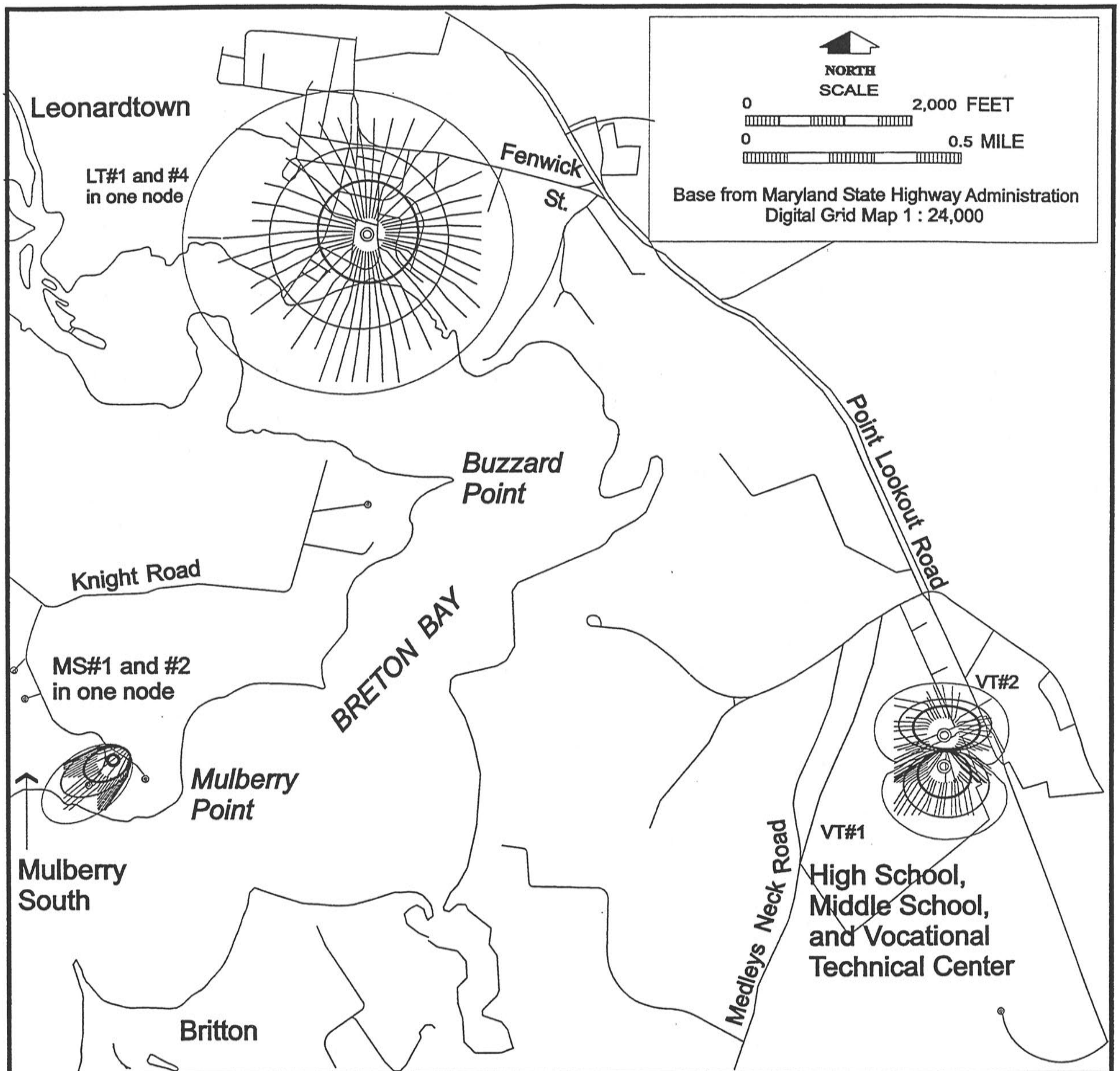


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

o St. Mary's County Metropolitan Commission well

Figure 13. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Holland Forest (HF#1 and #2), City of Leonardtown (LT#2 and LT#3), and Tekstar Industries.



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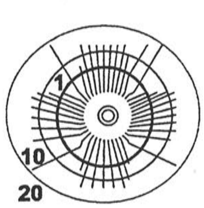


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

o St. Mary's County Metropolitan Commission well

Figure 14. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at City of Leonardtown (LT#1 and #4), Vocational Technical Center (VT#1 and VT#2), and Mulberry South (MS#1 and #2).

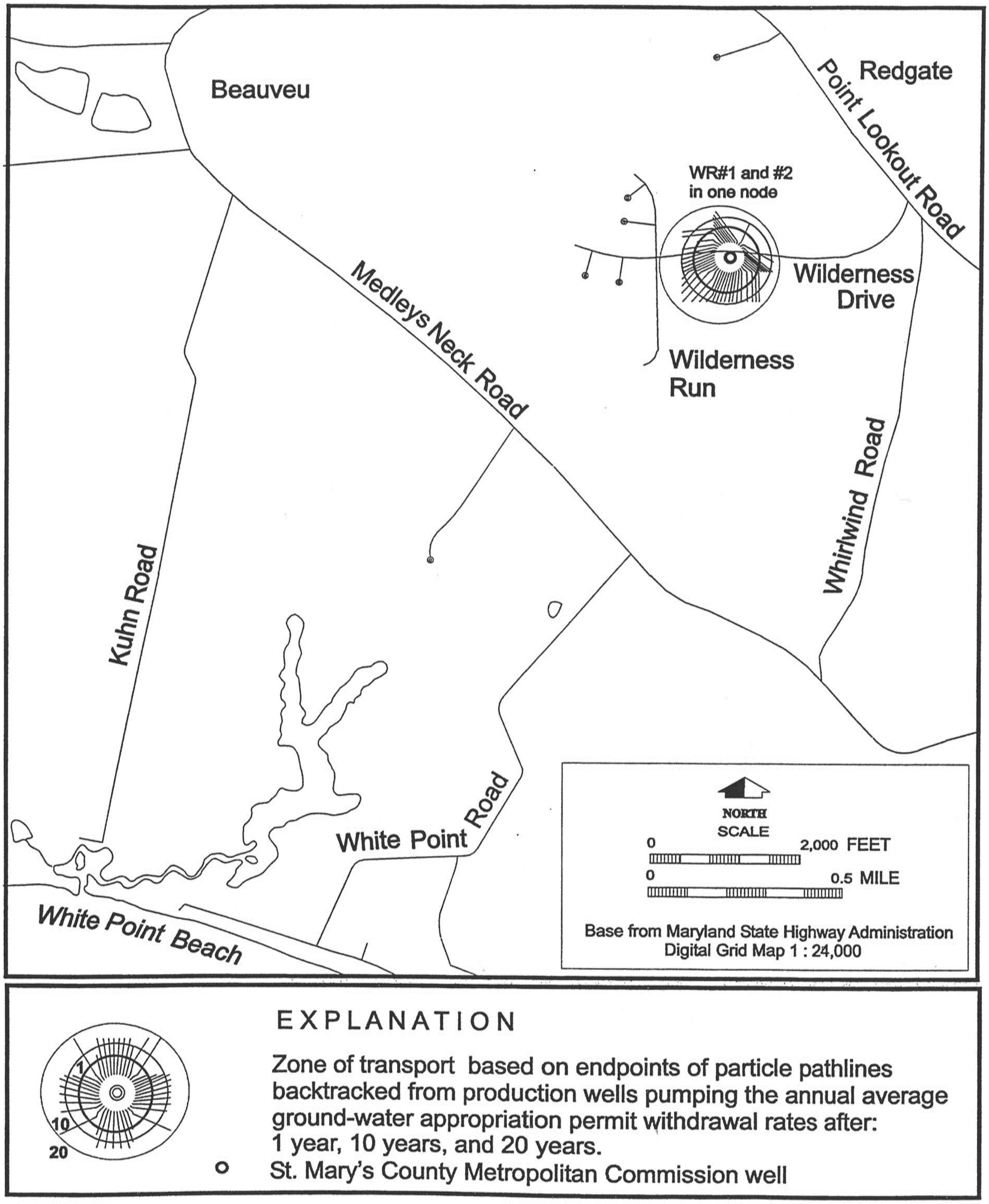
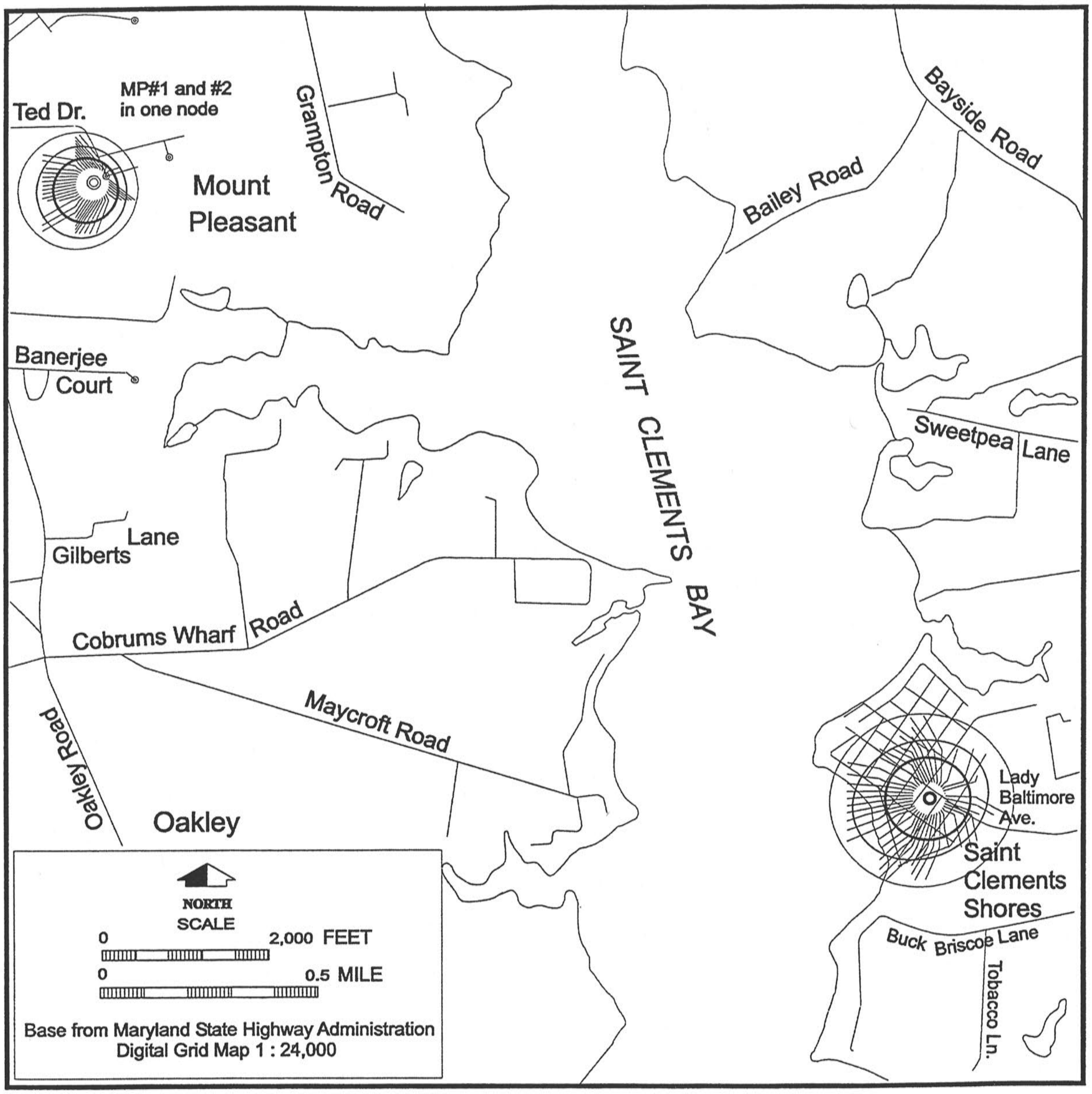


Figure 15. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Wilderness Run Subdivision (WR#1 and #2).



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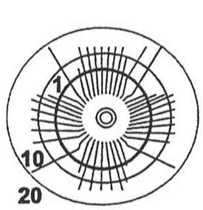
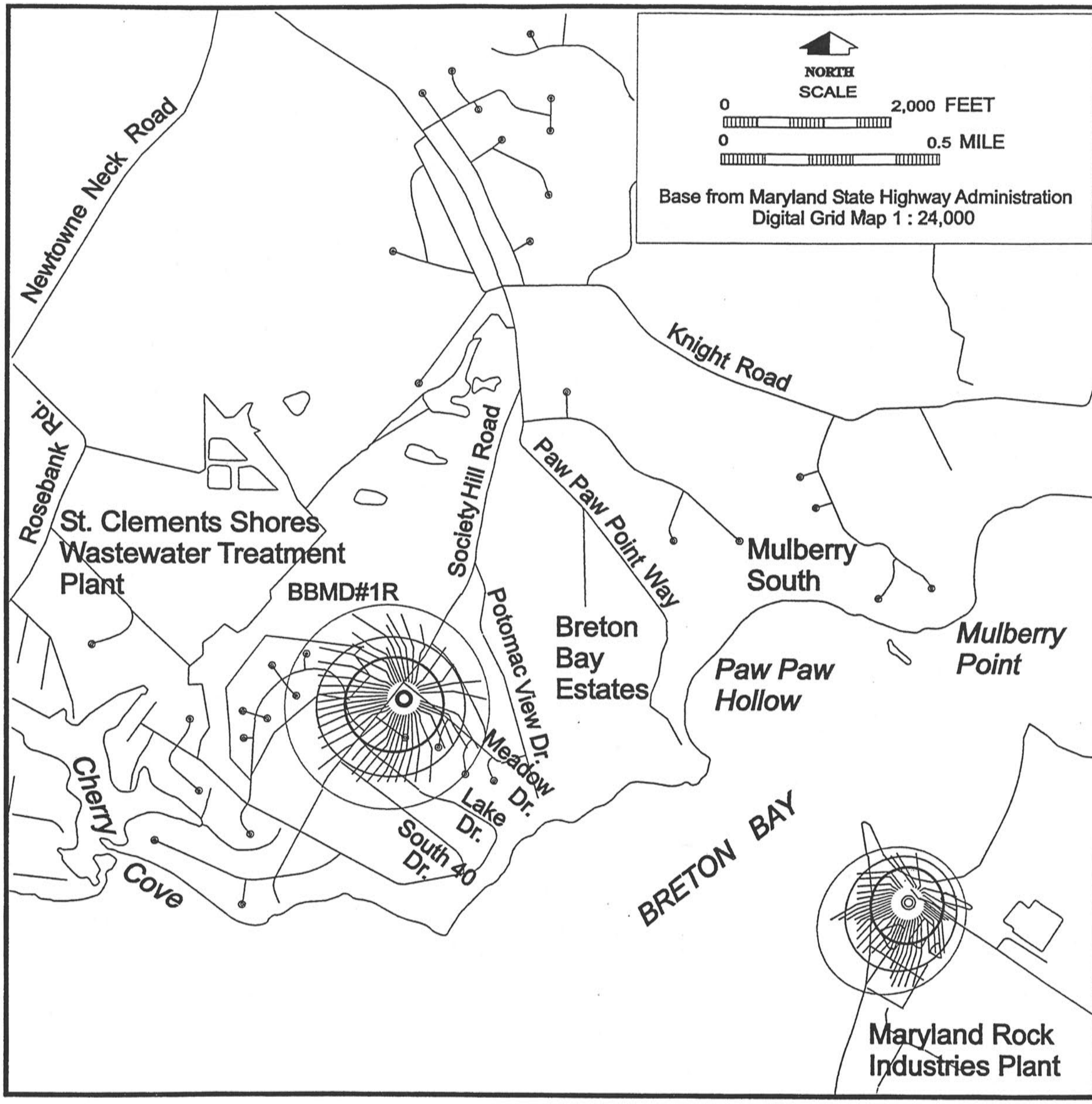
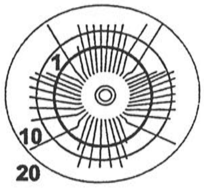


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

o St. Mary's County Metropolitan Commission well

Figure 16. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Saint Clements Shores and Mount Pleasant (MP#1 and #2).



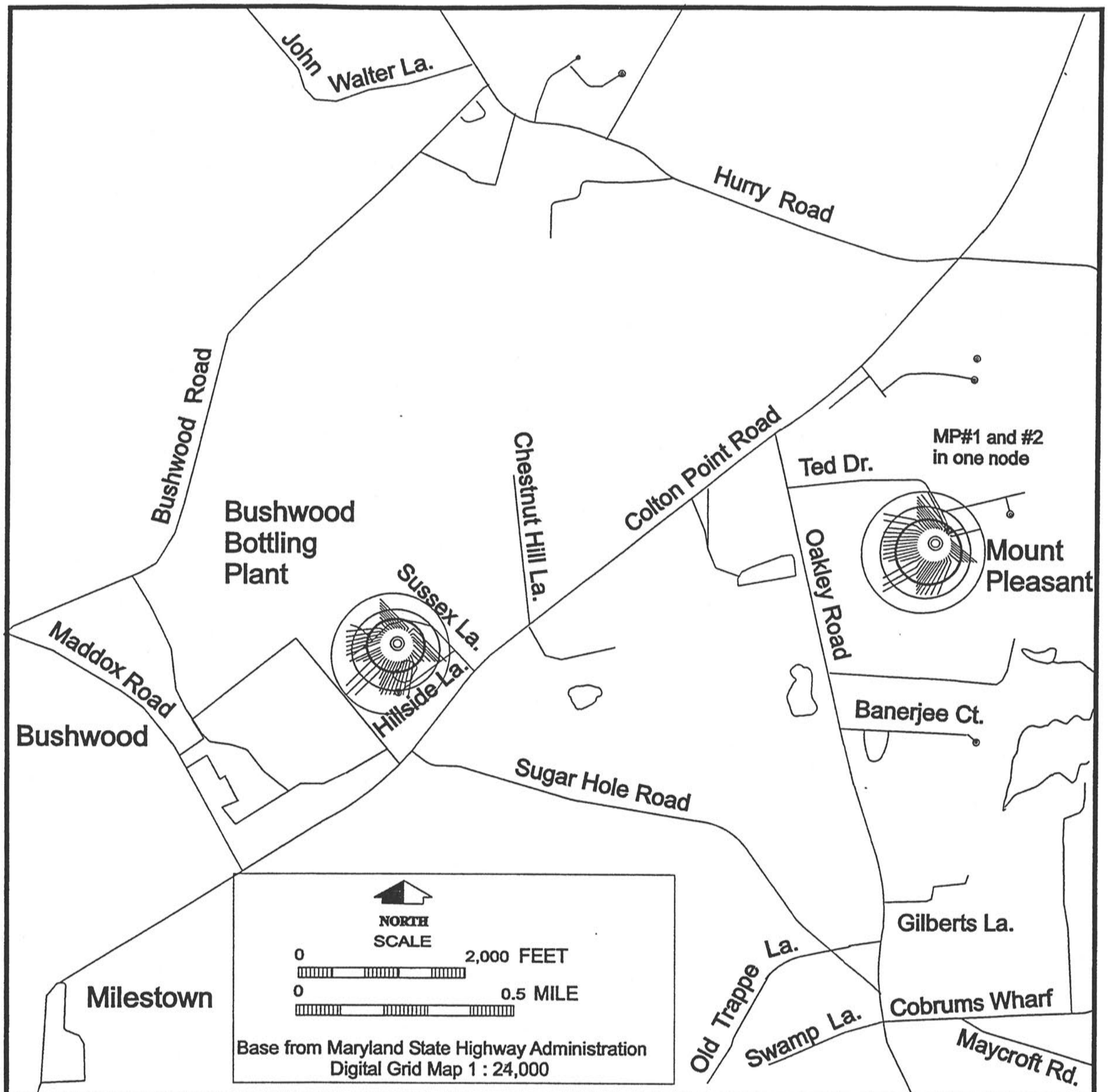


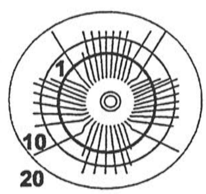
EXPLANATION

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

o St. Mary's County Metropolitan Commission well

Figure 17. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Breton Bay Estates at Meadow Drive (BBMD#1R) and Maryland Rock Industries Plant.

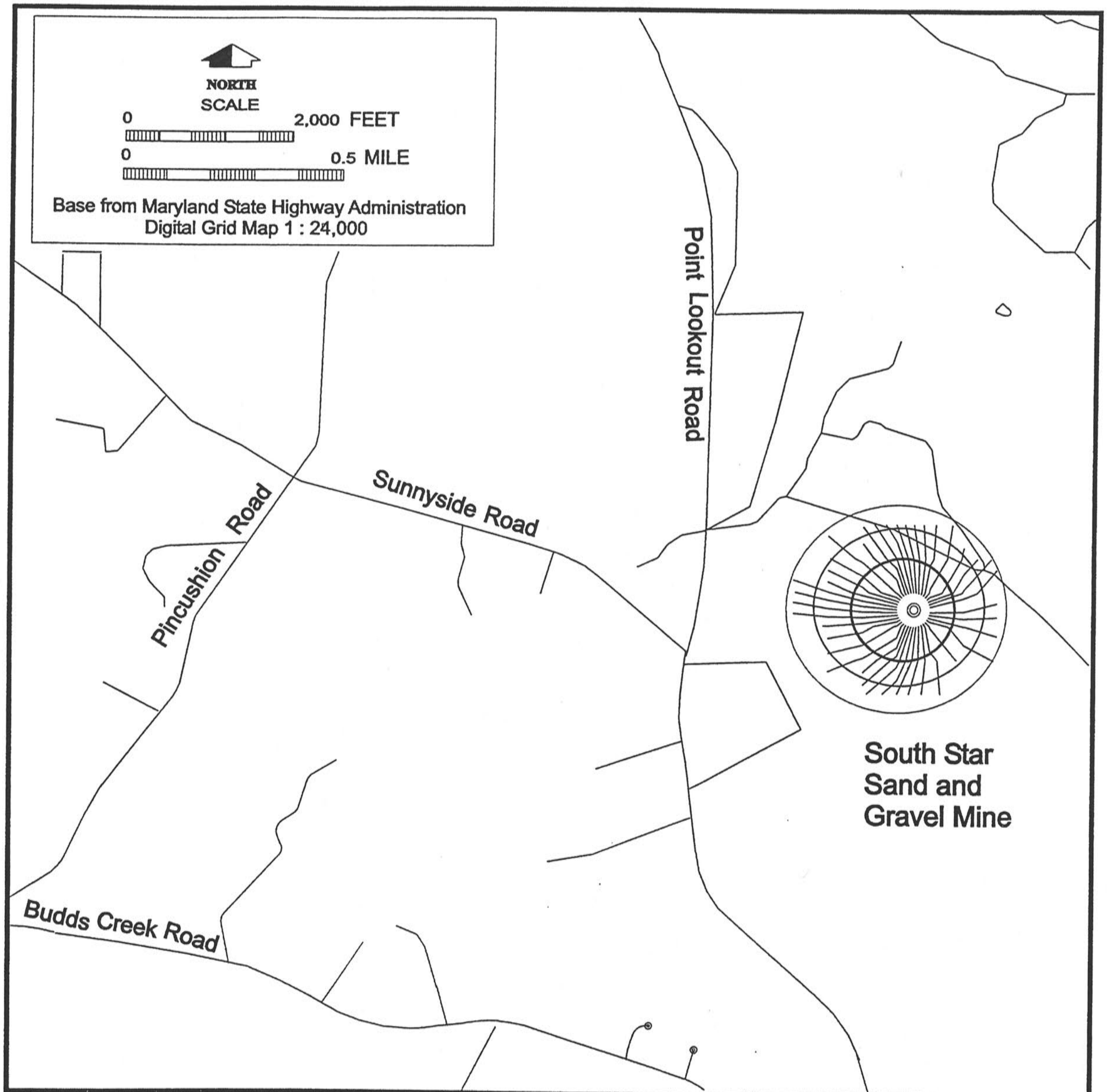


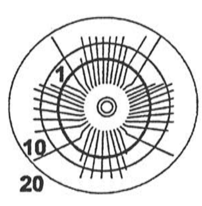


EXPLANATION

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 18. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Bushwood Bottling Plant and Mount Pleasant (MP#1 and #2).

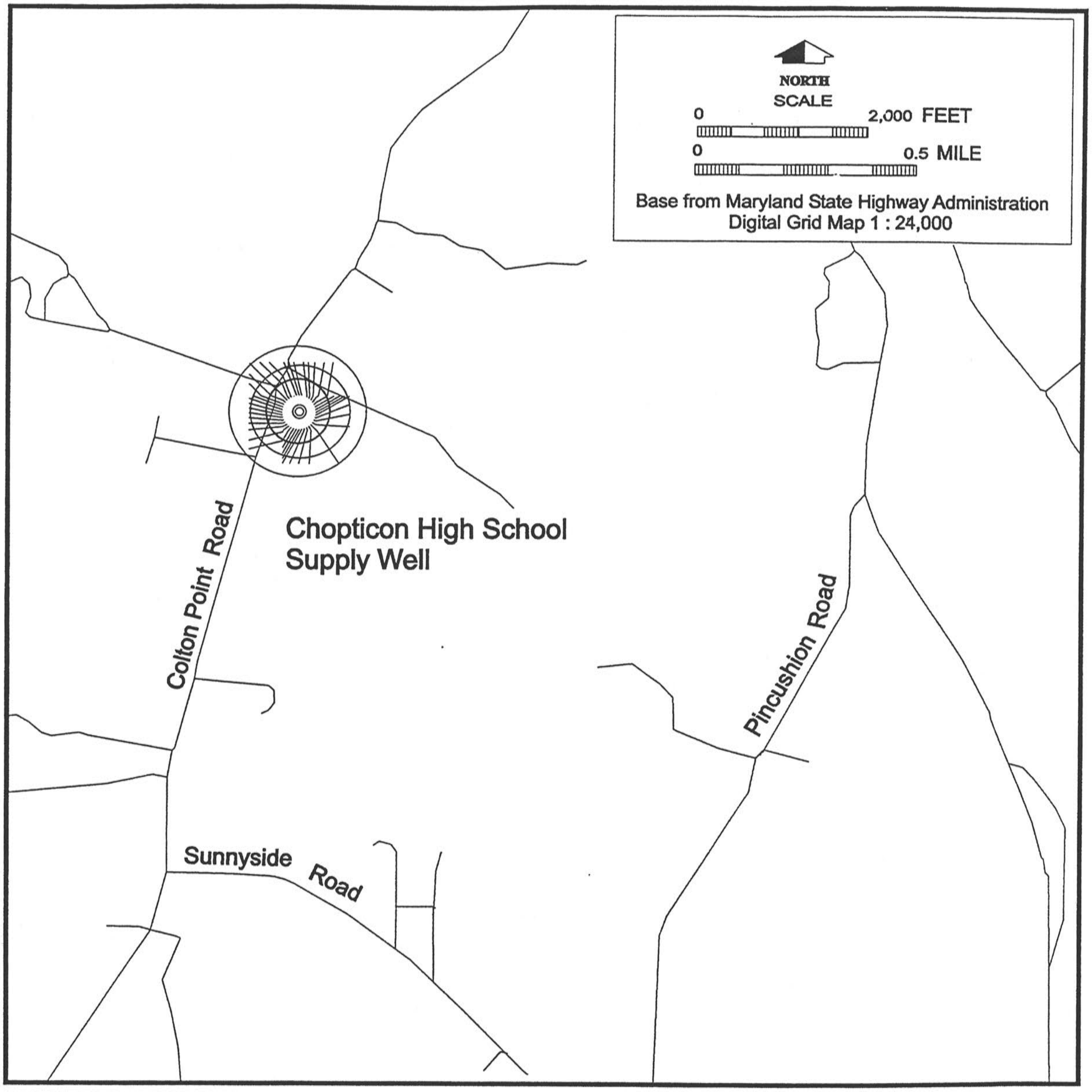




EXPLANATION

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 19. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production well at South Star Sand and Gravel Mine.



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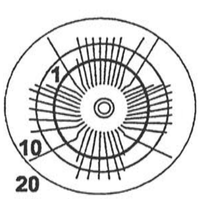
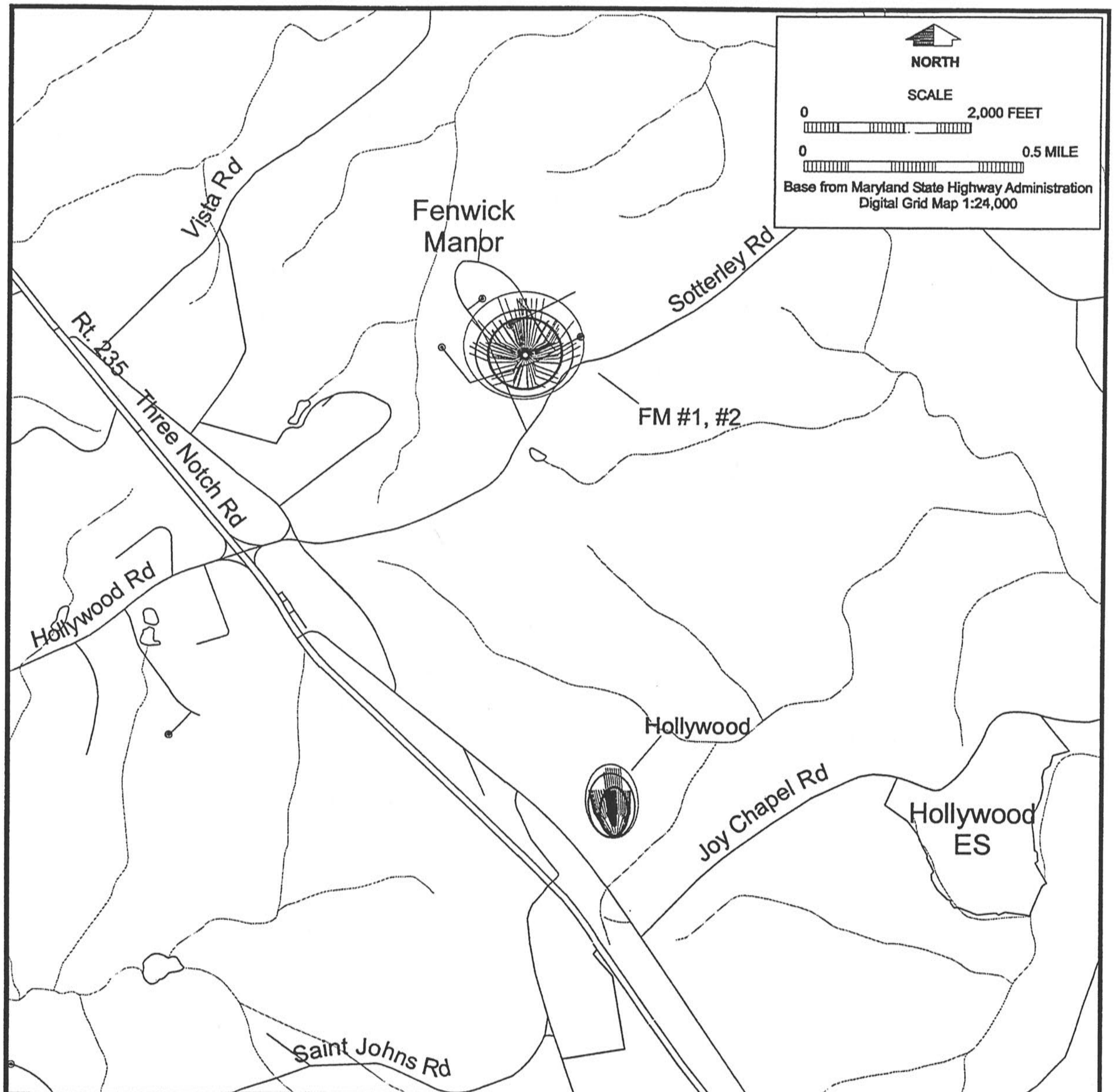


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 20. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production well at Chopticon High School.



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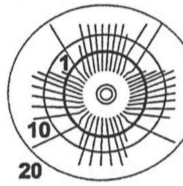
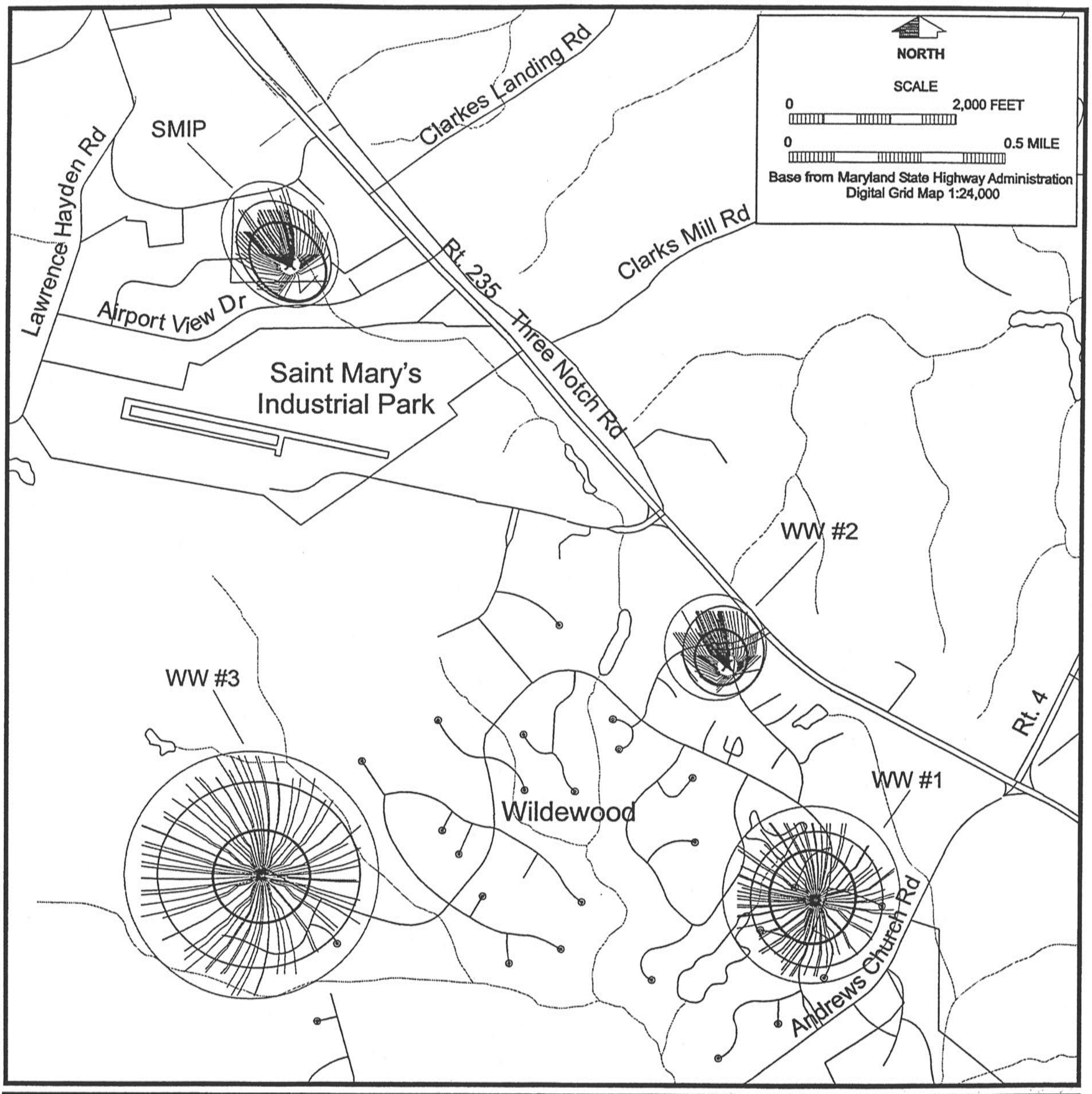


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 21. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Hollywood and Fenwick Manor (FM#1 and #2).



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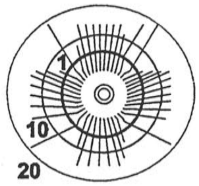
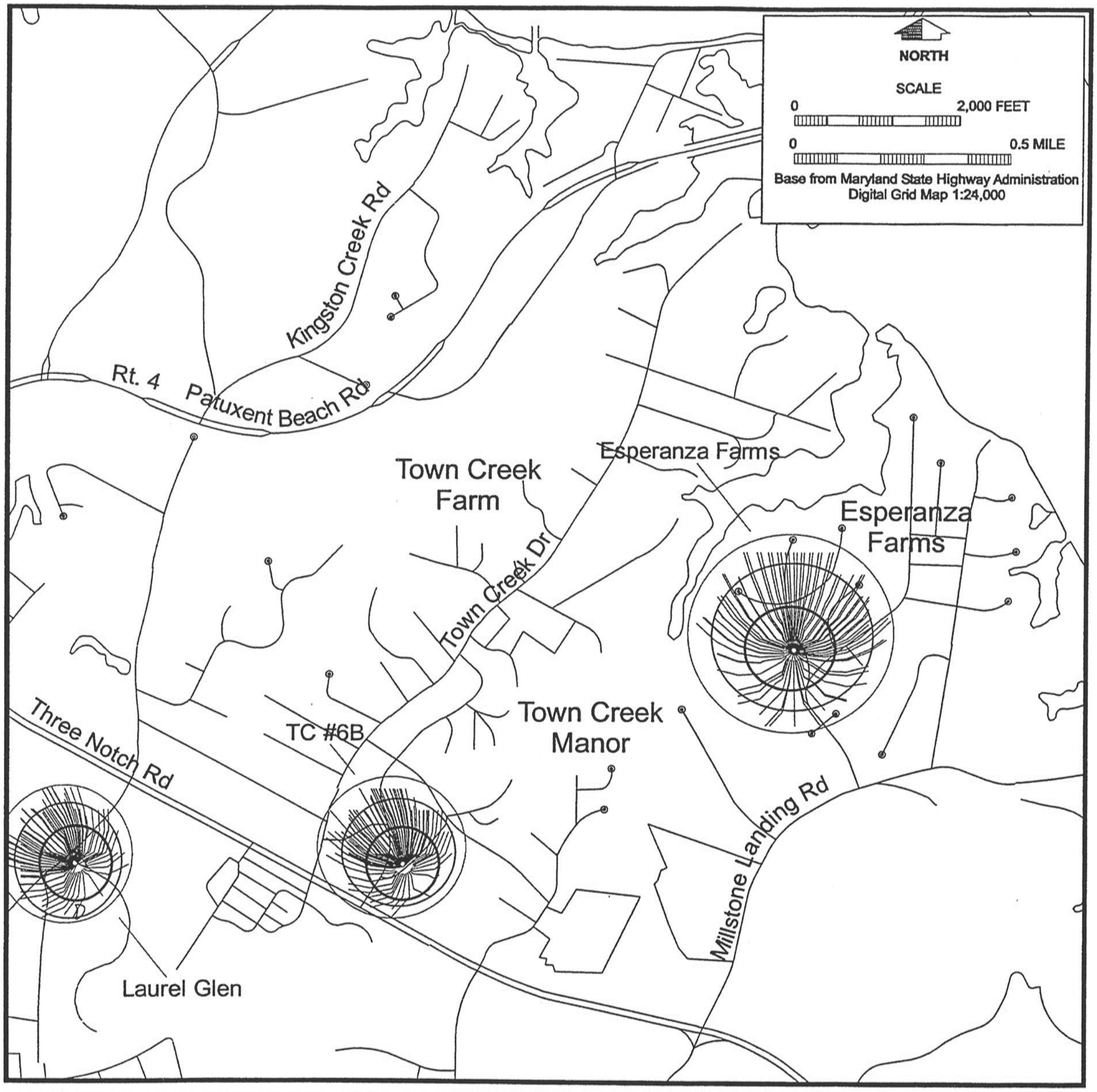
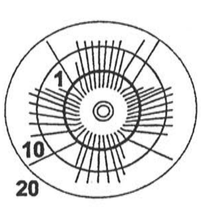


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 22. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at St. Mary's Industrial Park (SMIP) and Wildewood Subdivision (WW #1, #2, and #3).

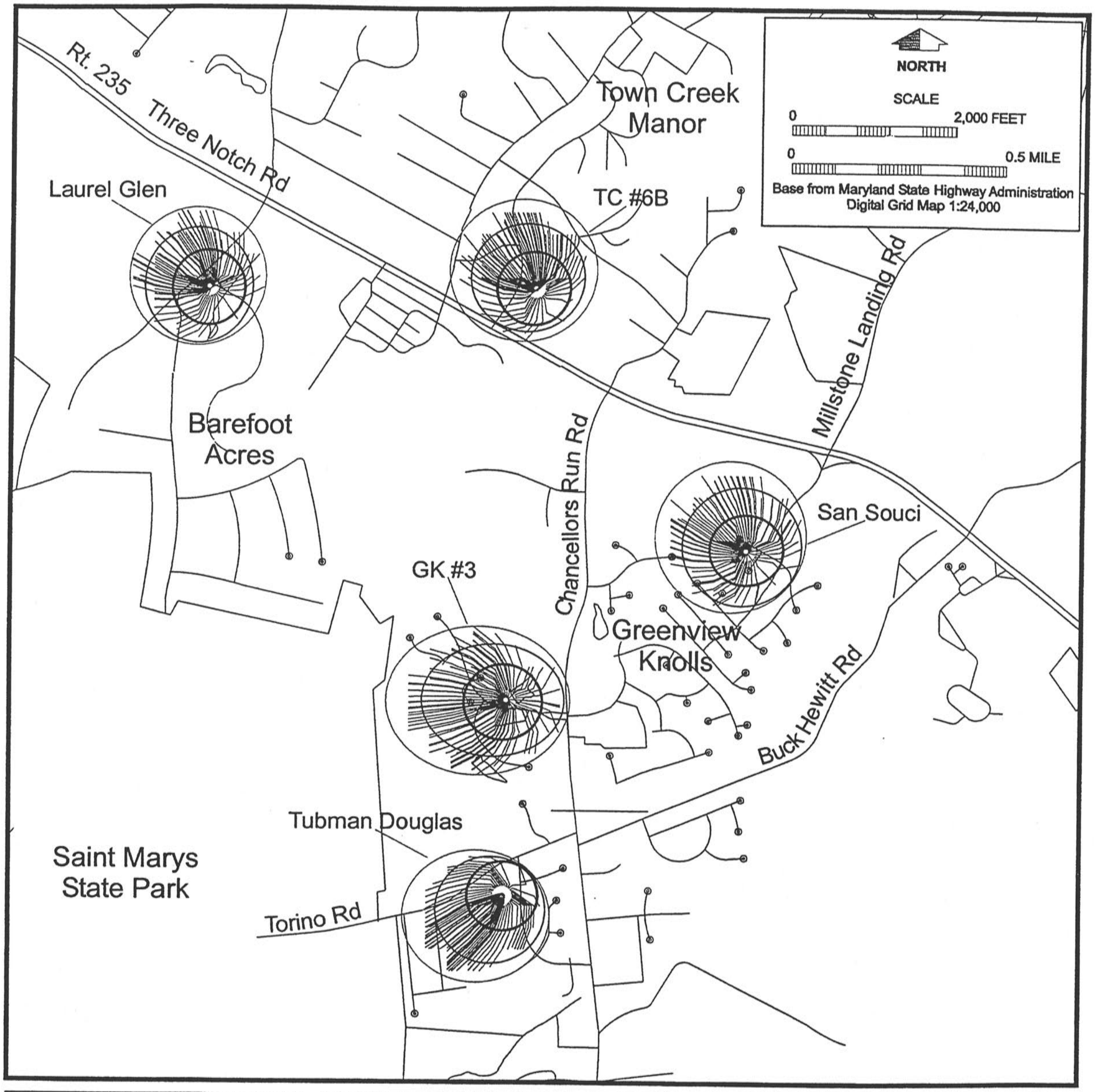




EXPLANATION

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 23. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Laurel Glen, Town Creek (TC #6B), and Esperanza Farms.



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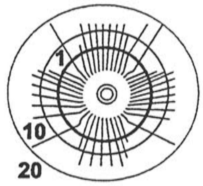
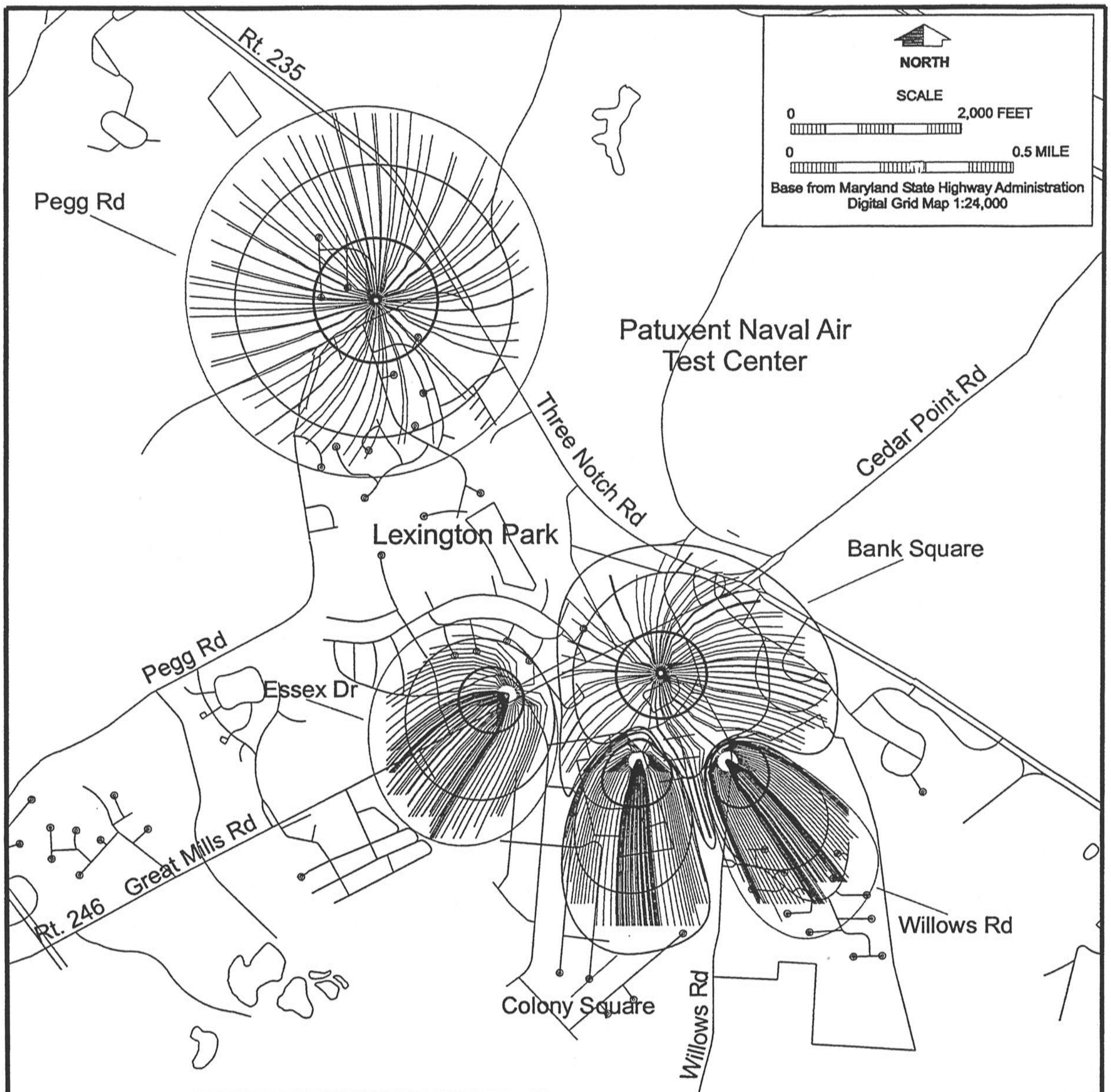
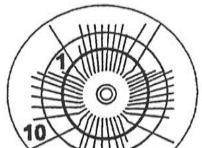


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 24. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Laurel Glen, Town Creek (TC #6B), San Souci, Greenview Knolls (GK #3), and Tubman Douglas.

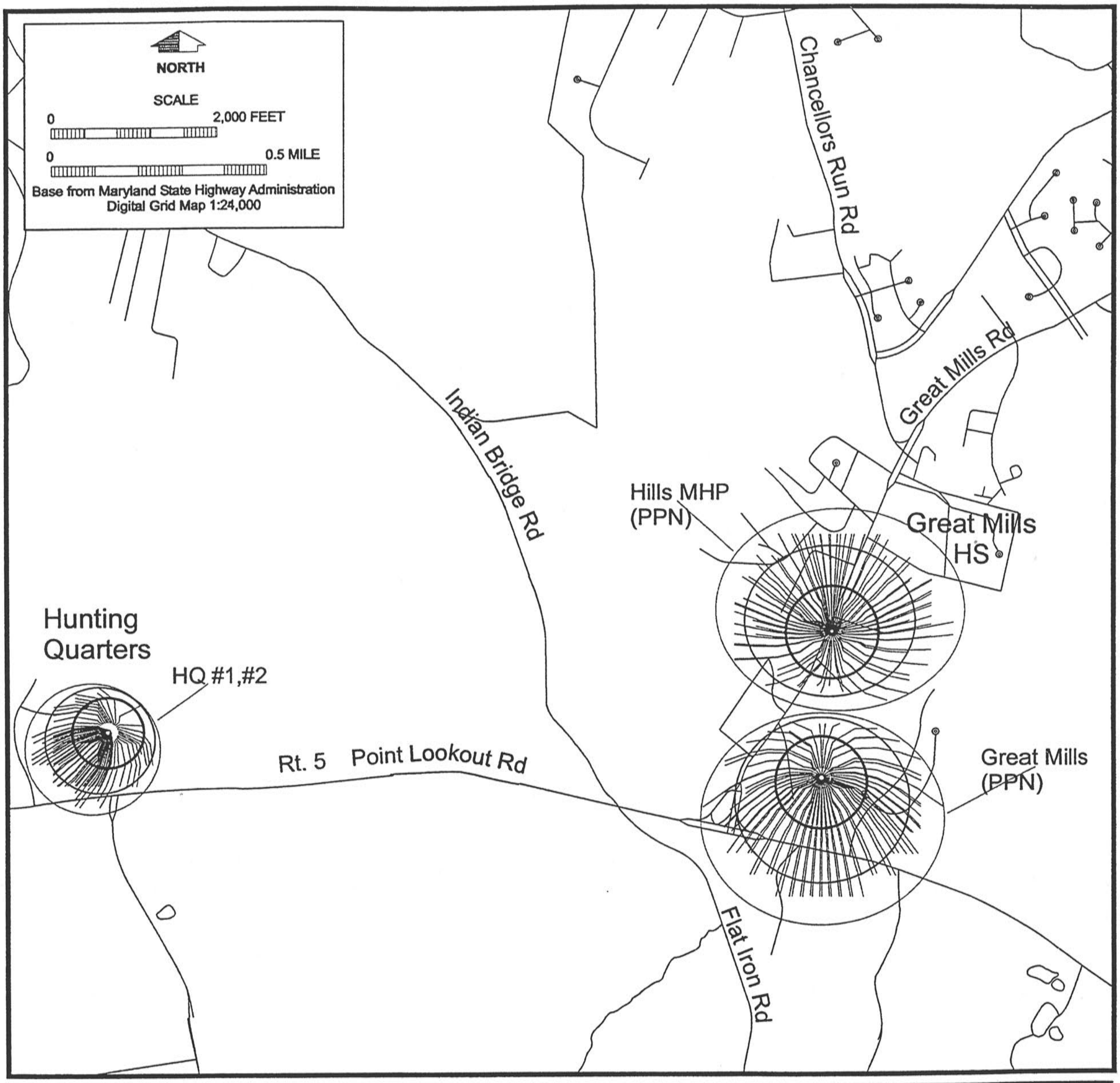


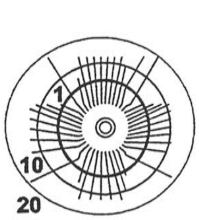


EXPLANATION

Zone of Transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 25. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Pegg Road, Bank Square, Essex Drive, Colony Square, and Willows Road.

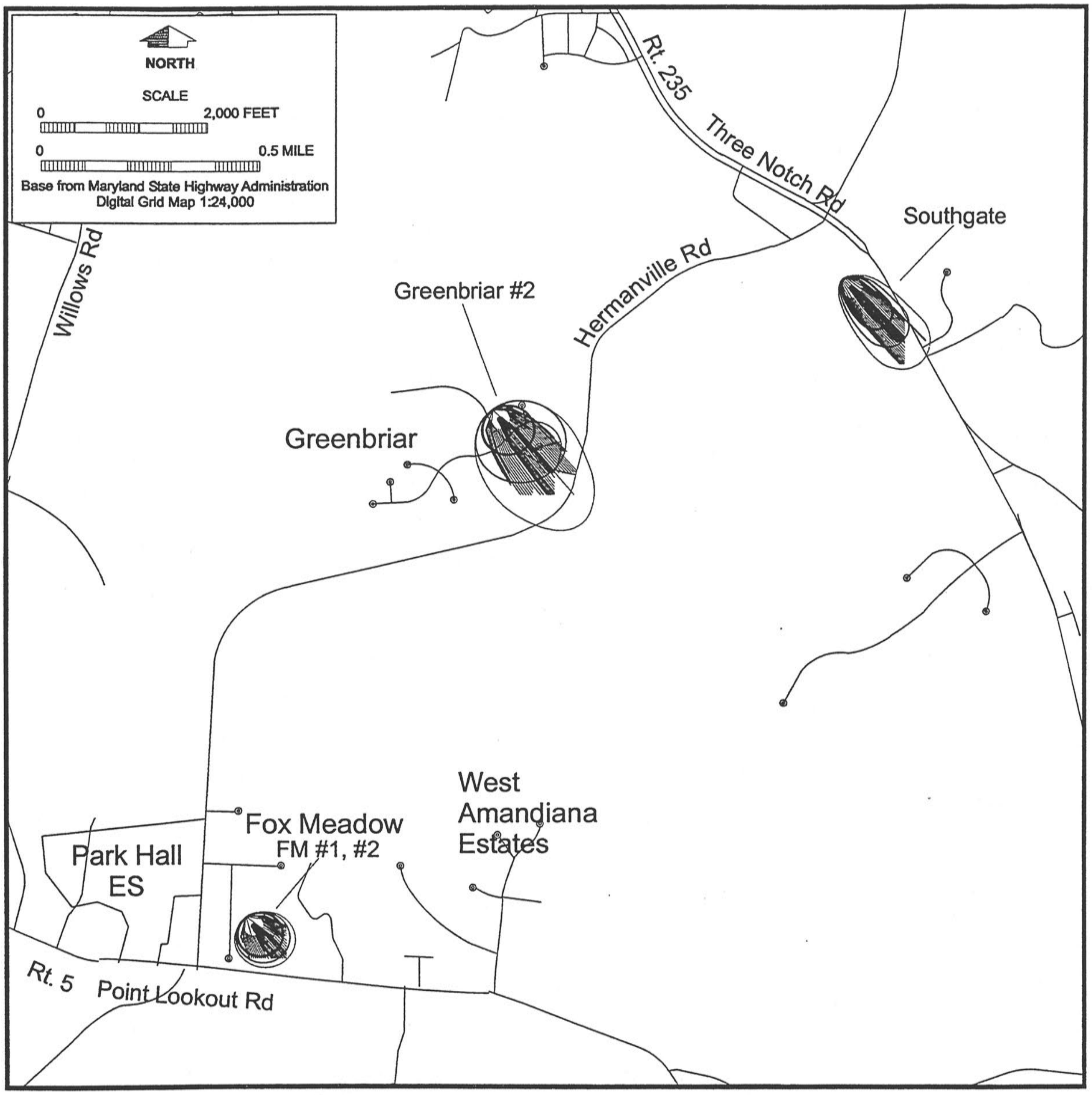




EXPLANATION

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 26. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Hunting Quarters (HQ #1 and #2) and Piney Point-Nanjemoy (PPN) production wells at Great Mills and Hills Mobile Home Park (MHP).



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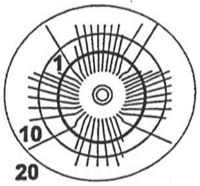
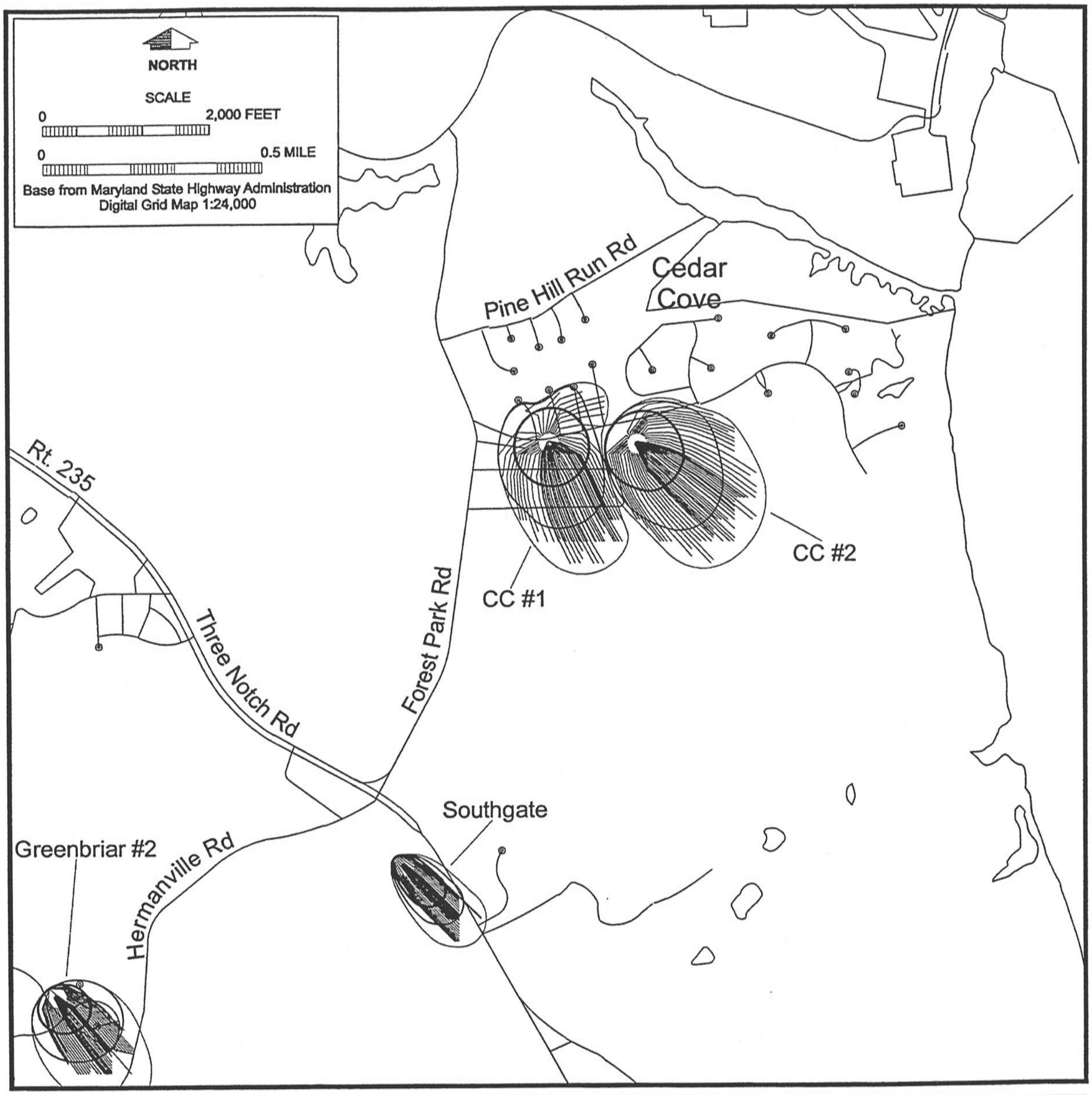


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 27. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Greenbriar #2, Southgate Center Townhouses and Piney Point-Nanjemoy production well at Fox Meadow (FM #1 and #2).



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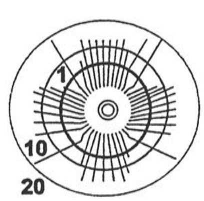
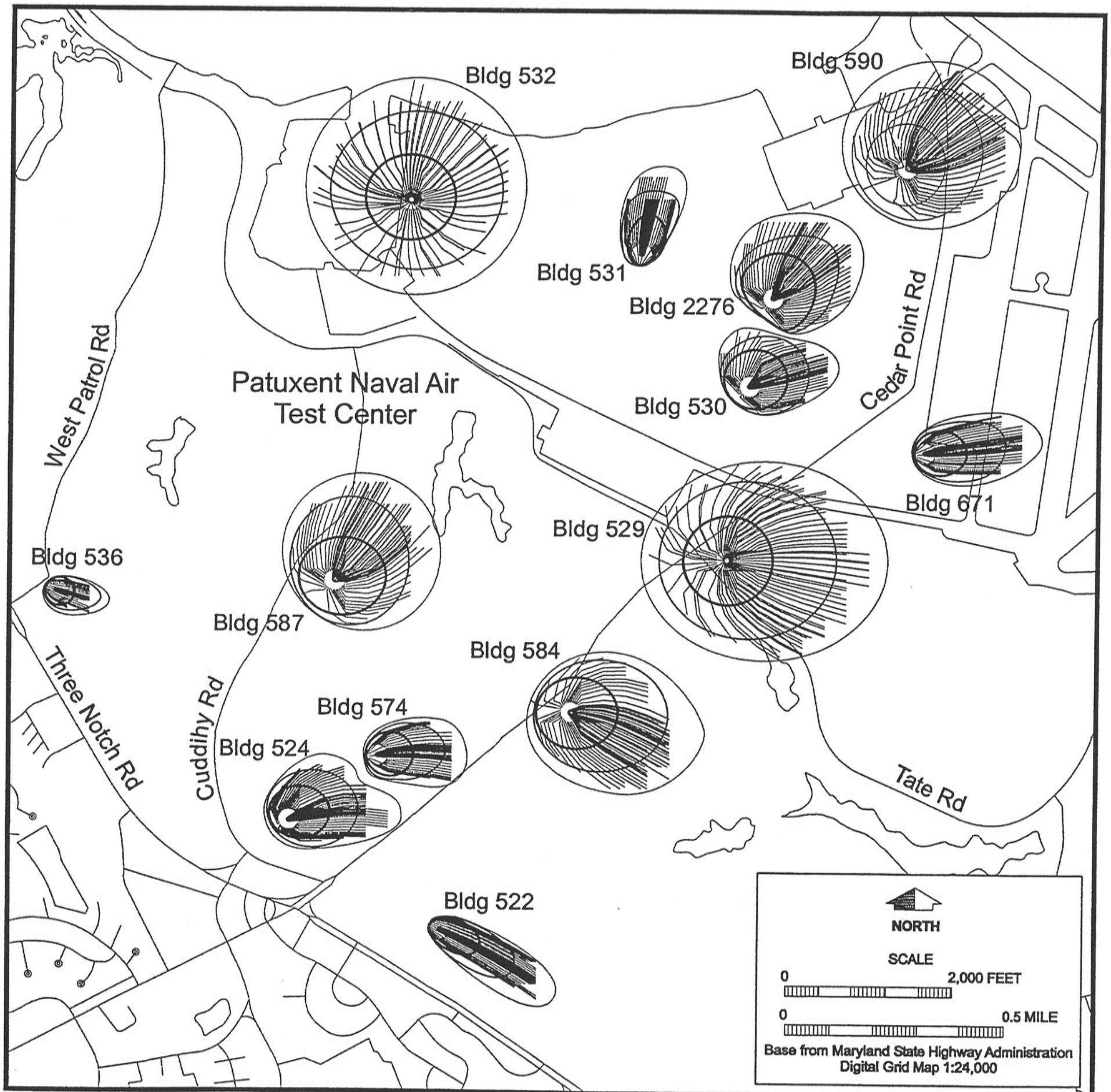
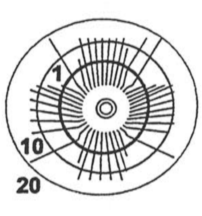


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 28. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Greenbriar #2, Southgate Center Townhouses, and Cedar Cove (CC #1 and #2).

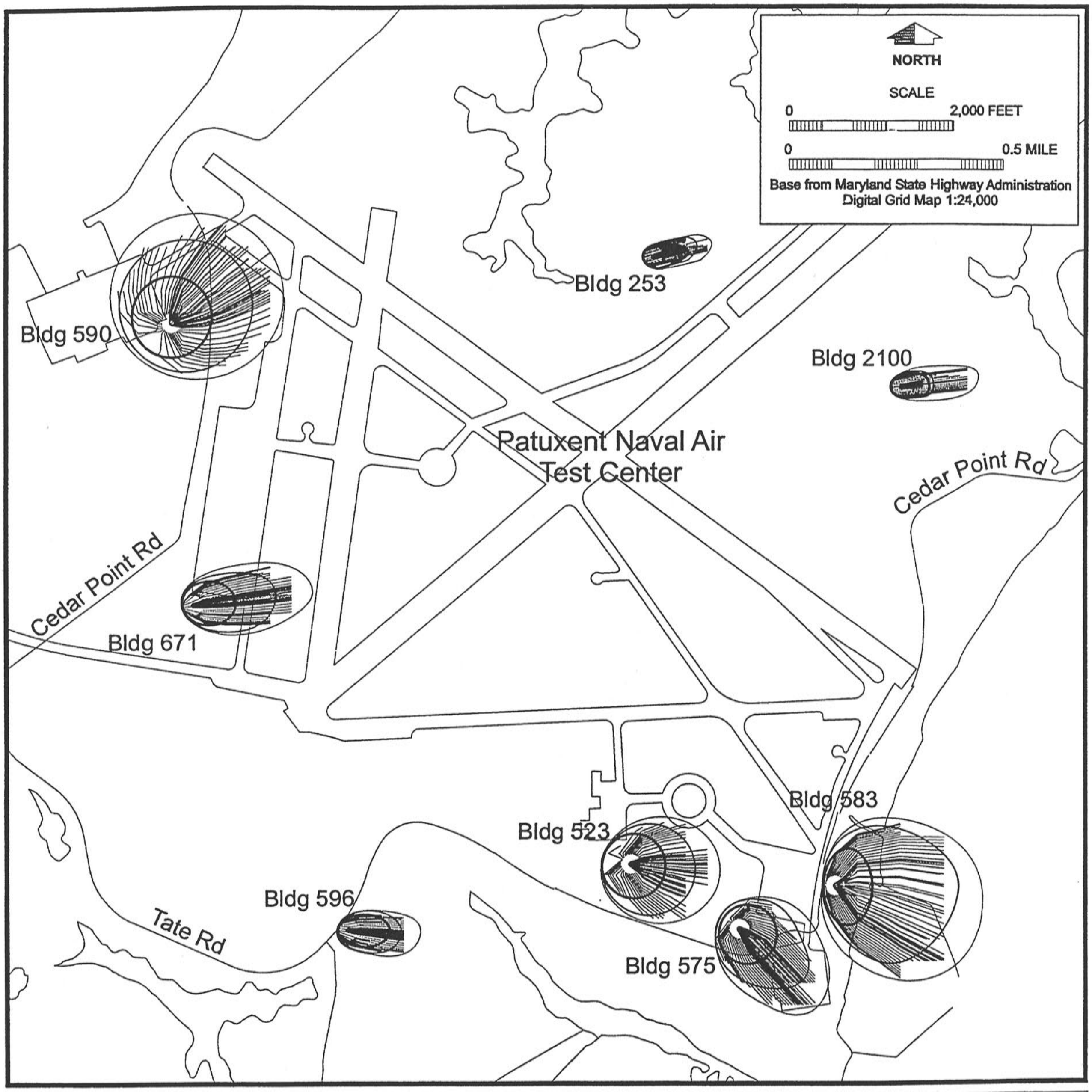




EXPLANATION

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 29. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Patuxent Naval Air Test Center building numbers 590, 531, 2276, 530, 671, 587, 529, 524, 574, 584, 522, and Piney Point-Nanjemoy production wells at building numbers 532 and 536.



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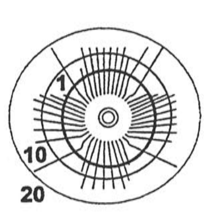
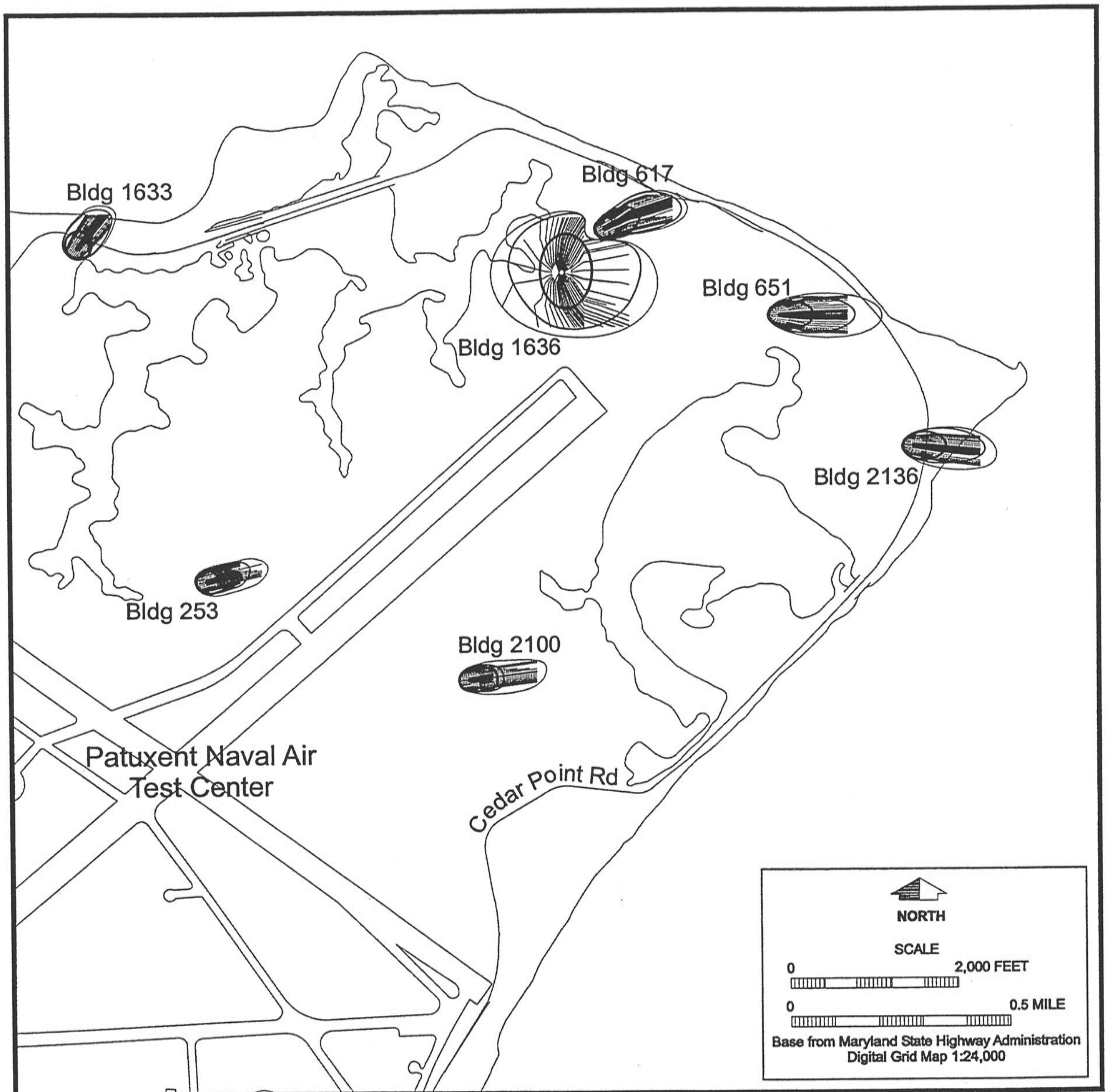


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 30. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Patuxent Naval Air Test Center building numbers 590, 671, 523, 575, 583, 253, and Piney Point-Nanjemoy production wells at building numbers 596 and 2100.



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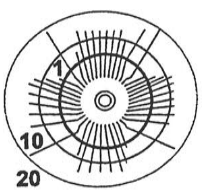
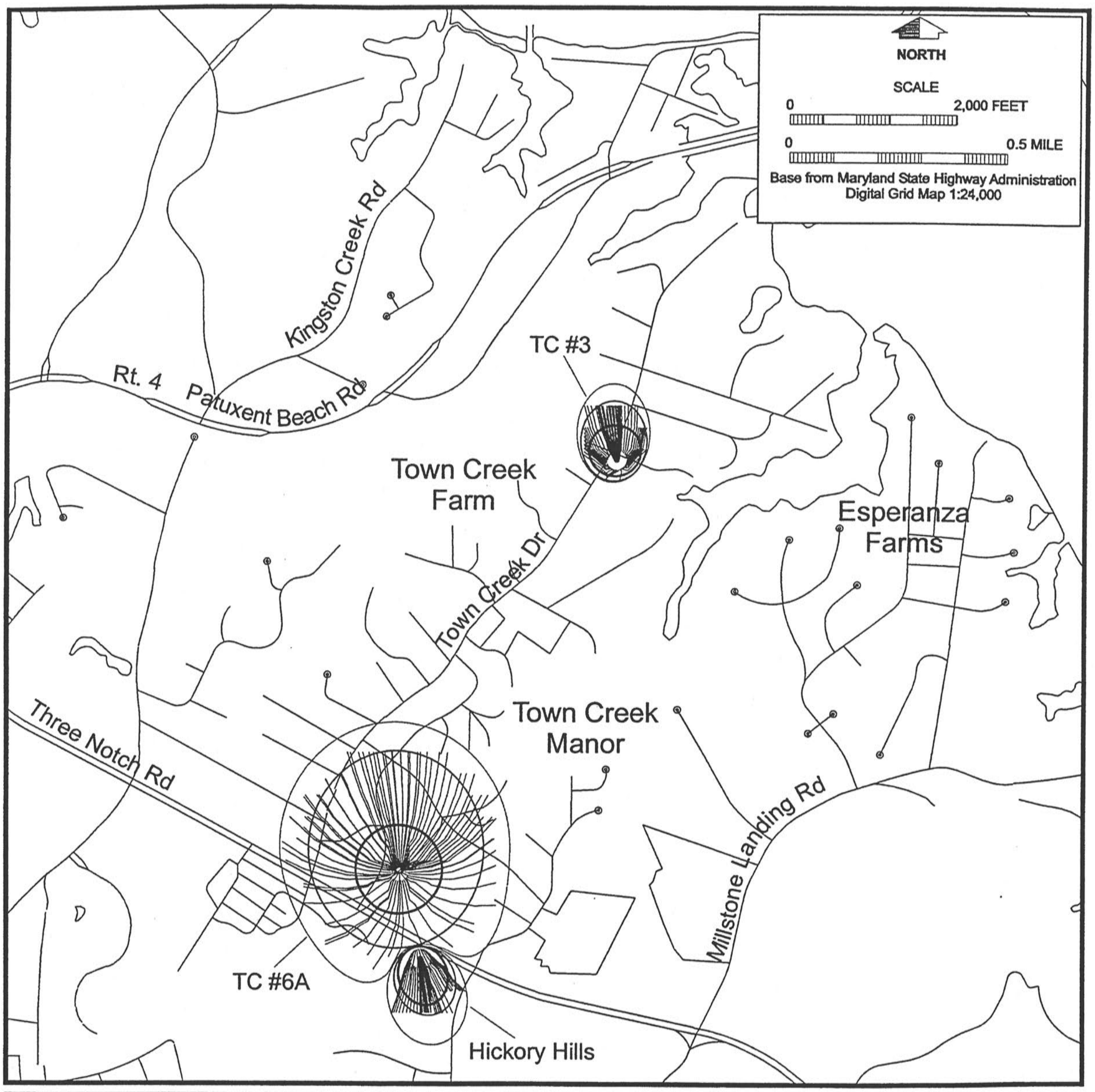


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 31. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Aquia production wells at Patuxent Naval Air Test Center building numbers 253, 2100, 1636, 617, 651, 2136, and Piney Point-Nanjemoy production well at bulding number 1633.



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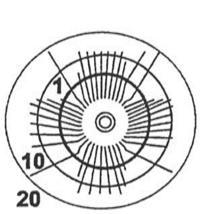
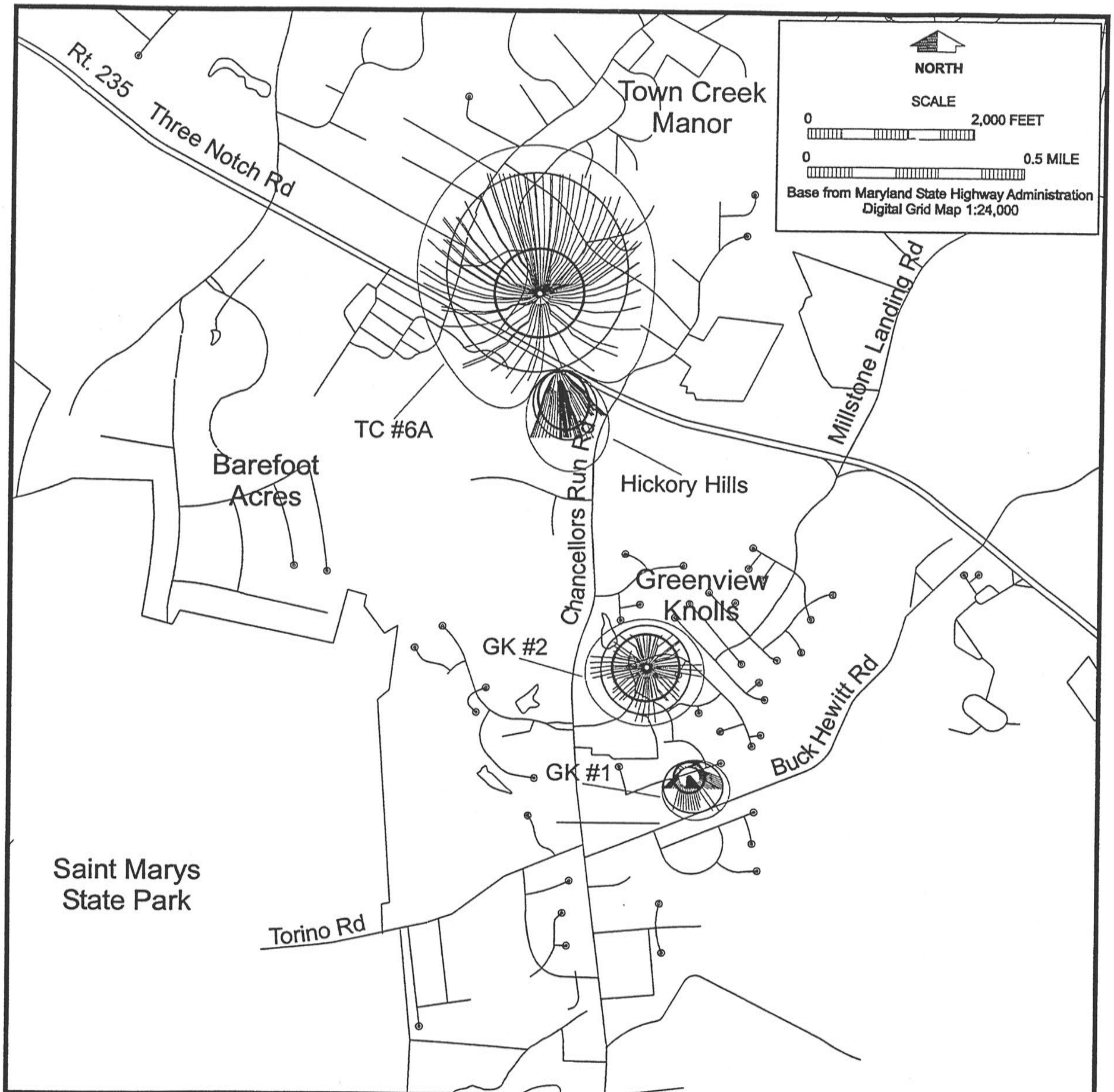


Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 32. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Piney Point-Nanjemoy production wells at Town Creek (TC #3 and TC #6A) and Hickory Hills.



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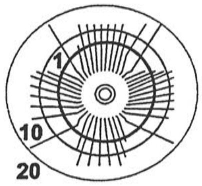

Zone of transport based on endpoints of particle pathlines backtracked from production wells pumping the annual average ground-water appropriation permit withdrawal rates after: 1 year, 10 years, and 20 years.

Figure 33. Particle pathlines and delineation of 1-year, 10-year, and 20-year zones of transport for Piney Point-Nanjemoy production wells at Town Creek (TC #6A), Hickory Hills, and Greenview Knolls (GK #1 and GK #2).

SUMMARY

Two local ground-water flow models in St. Mary's County, the Western area model and the Lexington Park area model, were developed from an existing southern Maryland regional model (Achmad and Hansen, 1997; 2001). The local models updated well locations and used a finer grid for pumping cells (400 ft x 400 ft and 264 ft x 264 ft, respectively). The models were used for the simulation of particle pathlines to determine zones of transport and delineate well-head protection areas for production wells pumped at the annual average GAP withdrawal rates from the Aquia and Piney Point-Nanjemoy aquifers. As derivatives of the larger regional model, the local models were verified by comparison of water levels with the regional model simulating steady-state flow conditions. The slope of the regression lines matching water levels ranged from 1.16 (Western area model) to 0.91 (Lexington Park area model) with mean absolute errors of 8.7 ft to 12.4 ft, respectively.

Because the annual average GAP withdrawal rates for year 2000 used in the simulation differ from the reported pumpage for year 2000, the simulated water levels do not depict the reported water levels for year 2000. In the Western area model, major withdrawals in the Aquia aquifer with significant GAP pumpage (greater than 100,000 gpd) are located at Leonardtown and Country Lakes. The Leonardtown well field is located in the area of the Western model most affected by the large pumpage in the vicinity of Lexington Park. It was simulated at an annual average withdrawal rate of 525,000 gpd. This withdrawal caused water levels to deepen near the center of the cone of depression in the Leonardtown area to approximately 115 ft below msl. The Country Lakes-Beverly Estates well field was simulated at a GAP annual average withdrawal rate of 140,000 gpd. Simulated water levels in this area were approximately 50 ft below msl. Simulated Aquia water levels in the vicinity of pumping wells with lower GAP pumpage rates ranged from 40 ft below msl at Charlotte Hall to approximately 85 ft below msl at Holland Forest.

In the Lexington Park area model the simulated potentiometric surface of the Aquia aquifer showed a cone of depression of approximately 172 ft below msl near the intersection of Pegg Road and Route 235, and 159 ft below msl near Bank Square. The combined GAP annual average withdrawal rate at Pegg Road, Bank Square, Colony Square, and Essex Drive is 922,851 gpd. In adjacent Calvert County a cone of depression of approximately 155 ft below msl formed in the Solomons Island-Chesapeake Ranch Estates area, with a combined GAP annual average withdrawal rate of 900,000 gpd. These two cones merged to create a regional cone of depression that influenced the direction of ground-water flow toward the Lexington Park area.

In the Lexington Park area model, the simulated potentiometric surface for the Piney Point-Nanjemoy aquifer showed a cone of depression of approximately 147 ft below msl near Great Mills. The cone of depression resulted from significant GAP annual average withdrawals from MetCom wells located at Great Mills (150,810 gpd), Hills MHP (150,000 gpd), and Town Creek #6A (182,377 gpd), and from the PNATC's well located at building #532 (127,684 gpd).

Zones of transport for 88 Aquia wells, 13 exceeding 100,000 gpd, were simulated:

At McKays Plaza-Charlotte Hall, Laurel Ridge, Rolling Acres, and Hearts Desire, the 1-, 10-, and 20-year zones of transport ranged in radial distance from about 450 ft, 600 ft, and 850 ft at McKays Plaza-Charlotte Hall (GAP annual average of 57,200 gpd) to about 600 ft, 800 ft, and 1,200 ft at Rolling Acres (GAP annual average of 59,200 gpd).

At Wicomico Shores, Country Lakes, Persimmon Hills, Birch Manor, and King- Kennedy Estates, the 1-, 10-, and 20-year zones of transport in radial distance ranged from about 450 ft, 600 ft, and 800 ft at Persimmon Hills Subdivision (GAP annual average of 39,700 gpd) to about 550 ft, 1,050 ft, and 1,600 ft at Country Lakes (GAP annual average of 240,000 gpd).

At Holland Forest, Saint Clements Shores, Breton Bay, Mulberry South, and Wilderness Run, the 1-, 10-, and 20-year zones of transport at their maximum distance from the wells ranged from about 400 ft, 700 ft, and 1,050 ft at Mulberry South (GAP annual average of 5,700 gpd) to about 700 ft, 1,000 ft, and 1,400 ft at Breton Bay (GAP annual average of 85,000 gpd).

At Leonardtown, Vocational Technical Center, Maryland Rock Industries Plant, Tekstar Industries, Mount Pleasant, Bushwood Bottling Company, South Star Sand and Gravel Mine, and Chopticon High School, the 1-, 10-, and 20-year zones of transport measured radially from the well ranged from about 500 ft, 600 ft, and 900 ft at Mount Pleasant (GAP annual average of 13,000 gpd) to about 600 ft, 1,200 ft, and 2,200 ft at Leonardtown (GAP annual average of 525,000 gpd for four production wells).

At Fenwick Manor (annual average pumpage is 25,000 gpd) and Hollywood (GAP annual average of 7,500 gpd), the 1-, 10-, and 20-year zones of transport of both extend radially approximately 400 ft, 500 ft, and 700 ft; the Hollywood zones are, however, narrow and elongated.

At Saint Mary's Industrial Park (GAP annual average of 34,000 gpd) and Wildewood Subdivision (GAP annual average of 350,000 gpd), the 1-, 10-, and 20-year zones of transport extend radially from the well approximately 600 ft, 850 ft, and 1,100 ft and 600 ft, 1,200 ft, and 1,600 ft, respectively.

At Esperanza Farms, Town Creek, Laurel Glen, San Souci, Greenview Knolls, and Tubman Douglas, the 1-, 10-, and 20-year zones of transport extend radially for distances ranging from about 400 ft, 800 ft, and 1,300 ft at Tubman Douglas (GAP annual average of 50,000 gpd) to about 500 ft, 1,000 ft, and 1,400 ft at Greenview Knolls (GAP annual average rates of 80,000 gpd).

In the immediate vicinity of Lexington Park at Pegg Road (apportioned GAP annual average of 450,675 gpd), Bank Square (apportioned GAP annual average of 225,065 gpd), Willows Road (apportioned GAP annual average of 96,239 gpd), Colony Square (apportioned GAP annual average of 114,768 gpd), and Essex Drive (apportioned GAP annual average of 132,343 gpd), the 1-year, 10-year, and 20-year zones of transport extend radially approximately 700 ft, 1,600 ft, and 2,350 ft at Pegg Road and 550 ft, 1,500 ft, and 2,300 ft at Essex Drive, Colony Square and Willows Road. The combined withdrawals totaled approximately 1.019 Mgal/d, which constituted the highest pumpage rate in the Aquia aquifer by MetCom. The withdrawal created a composite 20-year zone of transport measuring 6,000 ft across in an east-west direction and 5,000 ft across in a north-south direction.

At Hunting Quarters, Greenbriar, Southgate, and Cedar Cove, the 1-, 10-, and 20-year zones of transport measured radially ranged from about 450 ft, 900 ft, and 1,600 ft at Greenbriar #2 (apportioned GAP annual average of 26,500 gpd) to about 500 ft, 1,200 ft, and 1,800 ft at Cedar Cove #1 (apportioned GAP annual average of 73,262 gpd).

At PNATC, the two largest 1-, 10-, and 20-year zones of transport measured radially ranged from about 550 ft, 1,300 ft, and 1,900 ft at building #529 (apportioned GAP annual average of 148,356 gpd) to about 500 ft, 1,000 ft, and 1,500 ft at building #590 (apportioned GAP annual average of 102,619 gpd).

Zones of transport were delineated for nine Piney Point-Nanjemoy wells operated by MetCom and five Piney Point-Nanjemoy wells operated by PNATC.

In the Town Creek area, the 1-year, 10-year, and 20-year zones of transport at TC #3 (apportioned annual average GAP withdrawals of 17,623 gpd) measured approximately 400 ft, 650 ft, and 900 ft, respectively. The 1-year, 10-year, and 20-year zones of transport at TC #6A (apportioned annual average GAP withdrawal of 182,377 gpd) measured approximately 500 ft, 1,400 ft, and 1,800 ft, respectively.

At Hills MHP and Great Mills (GAP annual average withdrawals of 150,000 gpd and 150,810 gpd) the 1-year, 10-year, and 20-year zones of transport measured about 600 ft, 1,250 ft, and 1,800 ft and 550 ft, 1,000 ft, and 1,650 ft, respectively.

At Fox Meadow (GAP annual average of 7,100 gpd) the 1-year, 10-year, and 20-year zones of transport measured about 400 ft, 500 ft, and 600 ft, respectively. Shapes of the zones of transport were elongated and primarily captured ambient ground-water flow.

At PNATC, the Piney Point-Nanjemoy wells at buildings #532, #536, #596, #1633, and #2100 simulated apportioned GAP annual average rates of 127,684 gpd, 1,514 gpd, 7,929 gpd, 2,070 gpd, and 802 gpd. For the 1-year, 10-year, and 20-year zones of transport, the well at building #532 measured radially at approximately 500 ft, 1,200 ft, and 1,500 ft, and the remaining lower pumpage wells extended at their maximum measured approximately 200 ft, 400 ft, and 600 ft from the well.

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APPENDIXES

Appendix A. Selected well records (updated from Achmad and Hansen, 1997, app. A)

[Depths stated in feet (ft) below land surface; +, water level above land surface datum (lsd); M, measured; (R), replacement well; -, data not available; gpm, gallons per minute; gpm/ft, gallons per minute per foot]

Well number	State permit number	Owner	Driller	Approximate altitude of land surface surface (ft)	Date well reported completed	Depth Hole (ft)	Depth well (ft)	Diameter of well screen (inches)
CA Db 21	CA-00-9750	Calvert Memorial Hospital	Washington Pump & Well Co.	130	04-29-52	540	540	5.5
CA Db 26	CA-04-2924	Calvert Middle School	Shannahan Artesian Well Co.	150	06-15-61	581	576	5
CA Db 41	CA-69-0164	Calvert County Commissioners	Shannahan Artesian Well Co.	151.3	12-02-69	595	588	4
CA Db 44	CA-73-0631	Calvert County Commissioners	Shannahan Artesian Well Co.	140	09-03-74	589	589	5
CA Db 45	CA-70-0097	Calvert County Board of Education, Calvert High School & Career Center	Shannahan Artesian Well Co.	140	04-30-70	572	572	4
CA Db 46	CA-73-2879	Calvert County Commissioners, Calvert Memorial Hospital	C.Z. Enterprises, Inc.	140	11-15-79	617	540	6
CA Db 64	CA-73-2670	Calvert County Commissioners	Calvert Well Drilling Co.	150	05-20-78	551	542	4
CA Db 88	CA-88-1903	Calvert County Commissioners	C.Z. Enterprises, Inc.	60	05-16-91	560	549	4
CA Fd 1	None	U.S. Navy: Patuxent Naval Air Test Center, Solomons Annex	Washington Pump & Well Co.	21	1942	500	500	-
CA Fd 38	CA-04-4077	Chesapeake Ranch Water Co.	Patuxent Pump & Well, Inc.	85	09-12-61	355	355	5.25
CA Fd 39	CA-04-4076	Chesapeake Ranch Water Co.	Patuxent Pump & Well, Inc.	105.1	03-24-62	626	626	5.25
CA Fd 68	CA-81-1193	Calvert County Commissioners	Sydnor Hydrodynamics, Inc.	90.4	06-14-85	640	620	12
CA Fd 69	CA-81-1194	Calvert County Commissioners	Sydnor Hydrodynamics, Inc.	21	01-03-85	618	546	12
CA Fd 70	CA-81-1754	Chesapeake Ranch Water Co.	Sydnor Hydrodynamics, Inc.	108.5	11-25-85	660	640	8
CA Fd 86	CA-88-3340	Chesapeake Ranch Water Co.	A.C. Schultes of Maryland, Inc.	110	06-21-93	687	687	8
CA Fe 18	CA-04-6865	Chesapeake Ranch Water Co.	Patuxent Pump & Well, Inc.	120.2	06-22-62	657	657	5.25
CA Fe 19	CA-73-0440	Columbia LNG Corp.	Layne-Atlantic Co.	113.4	10-17-74	829	700	8
CA Fe 20	CA-73-0439	Columbia LNG Corp.	Layne-Atlantic Co.	114.5	10-17-74	752	703	8
CA Fe 21	CA-73-0082	Columbia LNG Corp.	Shannahan Artesian Well Co.	129.0	11-29-72	664	658	4
CA Fe 30	CA-88-0667	Chesapeake Ranch Water Co.	Sydnor Hydrodynamics, Inc.	118.8	07-26-89	717	688	8
CH Ce 51	CH-81-0828	La Plata, Town of	Layne-Atlantic Co.	150	11-02-84	1,509	1,340	12

Appendix A.—Continued

Screen settings (ft)	Aquifer	Pumping test data: Depth to static water level (ft)	Date reported	Yield (gpm)	Draw down (ft)	Specific capacity (gpm/ft)	Duration of test (hour)	Remarks	Well number
526-540	Aquia	135	04-29-52	75	75	1.0	12	-	CA Db 21
533-570	Aquia	133	06-15-61	75	75	1.0	4	-	CA Db 26
560-588	Aquia	147	12-02-69	33	35	0.9	8	Calvert Village. Owner's well #1.	CA Db 41
532-589	Aquia	161	09-03-74	82	50	1.6	8	Calvert Village. Owner's well #2.	CA Db 44
533-572	Aquia	140	04-30-70	32	30	1.1	8	-	CA Db 45
500-540	Aquia	148	11-15-79	254	144	1.8	12	Gravel pack 400-540 ft.	CA Db 46
512-542	Aquia	150	05-20-78	40	42	1.0	8	Woodridge.	CA Db 64
509-549	Aquia	171	05-16-91	125	66	1.9	24	Barstow Jail. Gravel pack 420-549 ft.	CA Db 88
477-500	Aquia	10	1942	125	151	0.8	-	Naval Recreation Center. Formerly Mine Warfare Test Station well #1.	CA Fd 1
325-355	Piney Point-Nanjemoy	101	09-12-61	100	89	1.1	8	Chesapeake Ranch Estates. Owner's well #1.	CA Fd 38
596-626	Aquia	95	03-24-62	125	105	1.2	8	Chesapeake Ranch Estates. Owner's well #3.	CA Fd 39
542-574 580-618	Aquia	126	06-12-85	503	202	2.5	26	Solomons. Owner's well #1. Gravel pack 384-620 ft.	CA Fd 68
452-460 466-504 512-536	Aquia	62	12-26-84	503	209	2.4	24	Solomons. Owner's well #2. Gravel pack 300-555 ft.	CA Fd 69
580-640	Aquia	149	11-05-85	460	151	3.0	24	Chesapeake Ranch Estates. Owner's well #2A. Gravel pack 500-650 ft.	CA Fd 70
604-684	Aquia	189	06-21-93	351	159	2.21	24	Aquia production well. Test well was CA Fd 71.	CA Fd 86
627-657	Aquia	128	06-22-62	100	160	0.6	12		CA Fe 18
580-700	Aquia	139.5	10-17-74	351	112	3.1	48	Owner's well #3. Gravel pack 470-700 ft.	CA Fe 19
593-703	Aquia	134.2	10-17-74	351	139.4	2.5	8	Owner's well #2. Gravel pack 595-703 ft.	CA Fe 20
648-658	Aquia	146	11-29-72	9	54	0.2	10	Owner's well #1.	CA Fe 21
578-678	Aquia	177	07-26-89	400	120	3.3	27	Owner's well #3B. Gravel pack 500-706 ft.	CA Fe 30
1,250-1,340	Lower Patapsco	182	11-02-84	450	188	2.4	24	Owner's well #9. Production well at Clark's Run.	CH Ce 51

Appendix A. Selected well records (updated from Achmad and Hansen, 1997, app. A)—Continued

Well number	State permit number	Owner	Driller	Approx-imate altitude of land surface surface (ft)	Date well reported completed	Depth Hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM Ab 6	SM-81-0366	Wentworth Nursery, Inc.	Patuxent Pump & Well, Inc.	180	08-05-83	540	540	2
SM Ab 7	SM-81-3899	Wentworth Nursery, Inc.	Calvert Well Drilling Co.	180	01-24-89	540	530	2
SM Ab 8	SM-81-2529	Wentworth Nursery, Inc.	Calvert Well Drilling Co.	180	11-11-87	275	275	2
SM Ab 9	SM-81-0084	St. Mary's County Metropolitan Commission	J. J. Payne & Sons, Inc.	160	10-29-82	535	535	2
SM Bb 26	SM-81-0091	Charlotte Hall Veterans Home	Shannahan Artesian Well Co.	170	05-20-83	559	559	5
SM Bb 27	SM-81-0295	Charlotte Hall Veterans Home	East Coast Well & Pump, Inc.	165	10-12-85	1,001.5	-	-
SM Bb 28	SM-81-1042	Charlotte Hall Veterans Home	East Coast Well & Pump, Inc.	160	05-20-85	1002	601	5
SM Bb 29	SM-88-0632	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	170	07-25-90	505	505	4
SM Bb 30	SM-88-1932	St. Mary's County Metropolitan Commission	Wooster Drilling Co.	160	11-21-94	572	572	4
SM Bc 30	SM-73-2502	St. Mary's County Metropolitan Commission	Robert M. Leatherbury	125	08-10-78	560	560	4
SM Bc 32	SM-88-0467	St. Mary's County Metropolitan Commission	Wooster Drilling Co.	138	07-06-90	610	610	4
SM Bc 33	SM-88-0012	St. Mary's County Metropolitan Commission	Branham Contractors, Inc.	160	05-30-90	560	560	4
SM Bc 34	SM-81-1243	St. Mary's County Metropolitan Commission	Branham Contractors, Inc.	160	07-18-86	597	542	4
SM Bc 35	SM-94-0716	St. Mary's County Metropolitan Commission	A.C. Schultes & Sons, Inc.	120	06-28-97	480	465	6
SM Bc 36	SM-88-1131	St. Mary's County Metropolitan Commission	Watson & Johnon Well Drilling, Inc.	130	03-24-93	555	555	4
SM Ca 5	SM-73-0438	Wicomico Shores Yacht & Country Club	Sydnor Hydrodynamics, Inc.	140	07-23-73	908	650	6
SM Ca 9	SM-88-1167	St. Mary's County Recreation & Parks Department	Watson & Johnson Well Drilling, Inc.	25	06-19-91	335	335	2
SM Ca 10	SM-93-0818	St. Mary's County Metropolitan Commission	Sydnor Hydrodynamics, Inc.	145	07-19-96	770	687	8
SM Cb 18	SM-73-1874	St. Mary's County Metropolitan Commission	Robert M. Leatherbury	75	06-07-76	380	380	2

Appendix A.—Continued

Screen settings (ft)	Aquifer	Pumping test data						Remarks	Well number
		Depth to static water level (ft)	Date reported	Yield (gpm)	Draw down (ft)	Specific capacity (gpm/ft)	Duration of test (hour)		
510-540	Aquia	180	08-05-83	40	47	0.9	4	-	SM Ab 6
520-530	Aquia	195	01-24-89	55	45	1.2	7	-	SM Ab 7
265-275	Nanjemoy	62	11-11-87	30	29	1.0	5	-	SM Ab 8
510-535	Aquia	167	10-29-82	30	23	1.3	6	McKays Plaza	SM Ab 9
435-559	Aquia	171	05-20-83	240	79	3.0	24	Owner's well #1.	SM Bb 26
-	-	-	-	-	-	-	-	Hole abandoned and plugged.	SM Bb 27
474-596	Aquia	185	05-20-85	320	168	1.9	24	Owner's well #2.	SM Bb 28
475-505	Aquia	160	07-25-90	170	30	5.67	4	Charlotte Hall 1. Owner's well #1.	SM Bb 29
446-466 490-540	Aquia	194	11-21-94	187	99	1.89	24	Charlotte Hall 2. Owner's well #1.	SM Bb 30
540-560	Aquia	146	08-10-78	80	62	1.3	72	Rolling Acres. Owner's well #1.	SM Bc 30
472-492 504-524 530-580	Aquia	189	07-06-90	156	100	1.6	24	Persimmon Hills Subdivision. Gravel pack 463-610 ft.	SM Bc 32
508-540 540-560	Aquia	175	05-30-90	100	85	1.2	20	Laurel Ridge Subdivision. Owner's well #2. Gravel pack 490-560 ft.	SM Bc 33
502-542	Aquia	168	07-18-86	100	67	1.5	24	Laurel Ridge Subdivision. Owner's well #1. Originally drilled as a test well. Gravel pack 490-550 ft.	SM Bc 34
425-465	Aquia							Rolling Acres. Owner's well #2. Replaced SM Bc 31 which was destroyed early 1997.	SM Bc 35
515-555	Aquia	165	03-24-93	165	63	2.62	12	Hearts Desire Subdivision	SM Bc 36
578-588 608-628 636-642 646-650	Upper Patapsco	134 143.56M	07-23-73 08-29-78	200	45	4.4	24	Gravel pack 100-655 ft.	SM Ca 5
321-335	Aquia	35	06-19-91	29	19	1.5	4	Wicomico Shores Golf Course. Gravel pack 305-335 ft.	SM Ca 9
579-594 632-637 667-683	Upper Patapsco	189	07-19-96	235	137	1.72	24	-	SM Ca 10
350-380	Aquia	55 57.9	06-07-76 04-13-79	100	115	0.9	35	Country Lakes Subdivision. Owner's well #1B.	SM Cb 18

Well number	State permit number	Owner	Driller	Approx-imate altitude of land surface surface (ft)	Date well reported completed	Depth hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM Cb 19	SM-73-1873	St. Mary's County Metropolitan Commission	Robert M. Leatherbury	80	06-07-76	380	380	4
SM Cb 29	SM-88-0167	St. Mary's County Metropolitan Commission	Wooster Drilling Co.	58	07-27-90	531	531	4
SM Cb 30	SM-81-0484	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	165	03-20-85	515	515	4
SM Cc 15	SM-73-1431	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	155	07-22-75	545	545	5
SM Cc 16	SM-73-1959	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	155	02-03-77	555	555	3
SM Cc 18	SM-71-0064	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	142	08-28-70	482	482	2
SM Cc 19	SM-73-0699	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	130	05-02-74	560	560	5
SM Cc 27	SM-92-0571	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	135	08-19-94	495	495	2
SM Cc 30	SM-94-1371	St. Mary's Public Schools, Chopticon High School	Sydnor Hydrodynamics, Inc.	-	04-07-98	476	450	8
SM Ce 34	SM-73-1926	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	120	06-17-76	615	595	4
SM Ce 38	SM-73-2030	Internat'l Assn. of Machinists	Patuxent Pump & Well, Inc.	15.9	08-10-76	470	470	2
SM Ce 43	SM-88-2161	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	88	11-23-92	595	595	4
SM Ce 45	SM-93-0043	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	120	10-25-94	620	611	2
SM Dc 58	SM-69-0338	St. Mary's County Metropolitan Commission	Shannahan Artesian Well Co.	13.5	09-16-69	410	398	6
SM Dc 59	SM-72-0199	Mt. Pleasant Water Co.	J. J. Payne & Sons, Inc.	40.9	05-17-72	340	340	2
SM Dc 60	SM-72-0200	Mt. Pleasant Water Co.	J. J. Payne & Sons, Inc.	50	06-15-72	340	340	2
SM Dc 62	SM-92-0537	St. Mary's County Metropolitan Commission	A.C. Schultes & Sons, Inc.	33	06-30-94	530	475	8
SM Dc	-	South Star Limited Partnership, sand and gravel mines	-	-	-	-	-	-
SM Dd 30	SM-05-7480	Commissioners of Leonardtown	Patuxent Pump & Well, Inc.	25	06-09-64	388	388	7.25
SM Dd 39	SM-67-0053	Commissioners of Leonardtown	Patuxent Pump & Well, Inc.	107.5	09-03-66	510	510	6
SM Dd 41	SM-67-0257	St. Mary's Vocational Technical Center	Columbia Pump & Well Co.	115	07-03-67	502	502	8

Appendix A.—Continued

Screen settings (ft)	Aquifer	Pumping test data						Remarks	Well number
		Depth to static water level (ft)	Date reported	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)	Duration of test (hour)		
350-380	Aquia	65	06-07-76	155	115	1.4	35	Country Lakes Subdivision. Owner's well #1. Not used in 2000	SM Cb 19
364-394 411-481	Aquia	119	07-27-90	340	145	2.34	24	Country Lakes Subdivision. Owner's well #3	SM Cb 29
475-515	Aquia	178	03-20-85	220	47	4.7	13	Country Lakes Subdivision. Owner's well #2 (Tower).	SM Cb 30
515-545	Aquia	151	07-22-75	50	68	0.7	4	Birch Manor Subdivision. Owner's well #1.	SM Cc 15
525-555	Aquia	154	02-03-77	60	51	1.2	6	Birch Manor Subdivision. Owner's well #2.	SM Cc 16
467-482	Aquia	135	08-28-70	40	35	1.1	4	Loveville Acres. Not used in 2000.	SM Cc 18
540-560	Aquia	126	05-02-74	100	124	0.8	6	King-Kennedy Estates. Owner's well #1. Formerly owned by SATAV Corp.	SM Cc 19
465-495	Aquia	175	08-19-94	80	41	2.0	3	King-Kennedy Estates. Owner's well #2R. Gravel pack 455-495 ft.	SM Cc 27
415-450	Aquia	162	04-07-98	106	69	1.5	24	Well not inventoried. Replacement for well SM 05-7689.	SM Cc 30
574-595	Aquia	113	06-17-76	60	87	0.7	6	Fenwick Manor. Owner's well #1.	SM Ce 34
450-470	Aquia	34	08-10-76	40	116	0.3	4	Placid Harbor Education Center.	SM Ce 38
555-595	Aquia	162	11-23-92	225	148	1.5	6	Hollywood. Owner's well #2.	SM Ce 43
581-611	Aquia	180	10-25-94	100	31	3.2	6	Fenwick Manor. Owner's well #2R. Replaces SM Ce 35 (SM-73-1872).	SM Ce 45
347-398	Aquia	24.5	09-16-69	90	60.5	1.5	16	St. Clement Shores. Owner's well #S3.	SM Dc 58
316-340	Aquia	42	05-17-72	40	20	2.0	4	Owner's well #1.	SM Dc 59
316-340	Aquia	42	06-15-72	40	18	2.2	4	Owner's well #2.	SM Dc 60
380-475	Aquia	81	06-30-94	350	140	2.5	24	Breton Bay Estates. Society Hill Road-Meadow Drive. Owner's well #1R.	SM Dc 62
-	Aquia	-	-	-	-	-	-	Well not inventoried.	SM Dc
358-388	Aquia (?)	25	06-09-64	250	93	2.7	8	Owner's well #1.	SM Dd 30
480-510	Aquia	120	09-03-66	300	100	3.0	12	Owner's well #2. Gravel pack 480-510 ft.	SM Dd 39
485-502	Aquia	127	07-03-67	70	93	0.8	8	Owner's well #2.	SM Dd 41

Appendix A. Selected well records (updated from Achmad and Hansen, 1997, app. A)—Continued

Well number	State permit number	Owner	Driller	Approx-imate altitude of land surface surface (ft)	Date well reported completed	Depth Hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM Dd 44	SM-69-0337	St. Mary's County Metropolitan Commission	Shannahan Artesian Well Co.	31	10-08-69	459	459	5
SM Dd 45	SM-73-1756	St. Mary's Technical Center	Shannahan Artesian Well Co.	113	03-11-76	540	536	6
SM Dd 47	SM-73-2269	Maryland Rock Industries	Patuxent Pump & Well, Inc.	10	03-29-77	440	440	4
SM Dd 48	SM-73-2271	Maryland Rock Industries	Patuxent Pump & Well, Inc.	10	03-18-77	440	440	2
SM Dd 64	SM-01-8951	Tekstar Industries	Joseph J. Payne	10	05-07-55	357	357	-
SM Dd 65	SM-81-1397	Commissioners of Leonardtown	Sydnor Hydrodynamics, Inc.	107.5	07-30-86	522	520	8
SM Dd 66	SM-81-3372	Commissioners of Leonardtown	Sydnor Hydrodynamics, Inc.	35	08-01-88	549	502	8
SM Dd 69	SM-92-0699	St. Mary's County Metropolitan Commission	Van's Constructions Company, Inc.	125	11-04-94	569	545	6
SM Dd 70	SM-92-0701	St. Mary's County Metropolitan Commission	Van's Constructions Company, Inc.	125	09-06-94	550	545	-
SM Dd 73	SM-81-3893	St. Mary's County Metropolitan Commission	J. J. Payne & Sons, Inc.	20	06-13-89	395	395	2
SM Dd 74	SM-81-3894	St. Mary's County Metropolitan Commission	J. J. Payne & Sons, Inc.	20	06-17-89	395	395	2
SM De 36	SM-73-1957	St. Mary's County Metropolitan Commission	A.C. Schultes & Sons, Inc.	130	06-08-76	643	620	6
SM De 50	SM-81-0060	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	130	10-05-82	610	585	5
SM De 51	SM-94-1981	Portobello Development, Inc.	A.C. Schultes & Sons, Inc.	130	01-08-99	983	960	6
SM De 52	SM-94-2702	Portobello Development, Inc.	A.C. Schultes & Sons, Inc.	110	11-11-99	983	955	6
SM De 53	SM-88-0305	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	140	01-02-90	610	610	4
SM De 55	SM-93-0272	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	120	10-15-95	605	605	5

Appendix A.—Continued

Screen settings (ft)	Aquifer	Pumping test data: Depth to static water level (ft)	Date reported	Yield (gpm)	Draw down (ft)	Specific capacity (gpm/ft)	Duration of test (hour)	Remarks	Well number
374-397 417-459	Aquia	42	10-08-69	110	37	3.0	10	Society Hill. Called Breton Bay on driller's permit. Owner's well #2. Formerly owned by Cherry Cove Water Company.	SM Dd 44
490-536	Aquia	135	03-11-76	56	22	2.6	12	Owner's well #1.	SM Dd 45
379-399 420-440	Aquia	29	03-29-77	120	71	1.7	4	Breton Bay Plant..	SM Dd 47
404-434	Aquia	30	03-18-77	30	30	1.0	3	Breton Bay Plant. Observation well.	SM Dd 48
-	Aquia	5	05-07-55	15	21	0.7	5	Leonardtown Laundry.	SM Dd 64
445-515	Aquia	149	07-25-86	300	142	2.1	24	Owner's well #3. Greenbrier well. Gravel pack 370-525 (?) ft.	SM Dd 65
384-414 432-482	Aquia	87	07-28-88	460	111	4.1	24	Owner's well #4. Gravel pack 300-549 ft.	SM Dd 66
450-505 520-545	Aquia	168	11-04-94	100	69	1.45	24	Holland Forest. Owner's well #1.	SM Dd 69
	Aquia	172	09-06-94	105	80	1.31	24	Holland Forest. Owner's well #2.	SM Dd 70
375-395	Aquia	62	06-13-89	35	15	2.33	5	Mulberry South. Owner's well #1.	SM Dd 73
375-395	Aquia	62	06-17-89	30	15	2	6	Mulberry South. Owner's well #2.	SM Dd 74
548-574 594-620	Aquia	167	06-08-76	200	54	3.7	12	Wildewood Subdivision & Technology Park. Owner's well #1. Gravel pack 548-620 ft.	SM De 36
560-585	Aquia	160	10-05-82	100	68	1.5	7	Wildewood Subdivision & Technology Park. Owner's well #2.	SM De 50
797-802 812-822 840-855 860-883 890-955	Upper Patapsco	171	10-08-99	402	28	14.36	24	First Colony Development. Patapsco. Owner's well First Colony #1.	SM De 51
782-792 816-831 845-865 882-917 925-955	Upper Patapsco	149	11-11-99	300	25	12	24	First Colony Development Patapsco. Owner's well First Colony #2.	SM De 52
580-610	Aquia	210	01-02-90	100	64	1.56	3	St. Marys Industrial Park. Owner's well #1R.	SM De 53
555-605	Aquia	225	10-15-95	300	58	5.17	8	Laurel Glen Subdivision	SM De 55

Well number	State permit number	Owner	Driller	Approximate altitude of land surface surface (ft)	Date well reported completed	Depth Hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM De 56	SM-94-0001	St. Mary's County Metropolitan Commission	A.C. Schultes & Sons, Inc.	130	09-11-96	703	659	8
SM Df 1	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	94	1943	587	587	8
SM Df 4	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	80	1944	547	547	7.5
SM Df 6	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	115	1942	357	357	4
SM Df 8	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	46	1942	286	282	4
SM Df 9	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	47	1943	285	285	6
SM Df 10	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	46	1943	534	534	6
SM Df 13	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	20	1944	490	490	6
SM Df 14	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	18	1943	262	262	8
SM Df 39	None	U.S. Navy: Patuxent Naval Air Test Center	-	45	1943	-	284	-
SM Df 42	SM-00-6688	St. Mary's County Metropolitan Commission	Washington Pump & Well Co.	86.5	07-26-51	570	570	5.5
SM Df 49	SM-05-5243	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	120	04-18-64	380	380	4.5
SM Df 50	SM-04-5141	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	105	11-18-61	365	365	5
SM Df 53	SM-03-4292	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	110	05-18-59	350	350	5.5
SM Df 60	SM-67-0256	St. Mary's County Metropolitan Commission	Shannahan Artesian Well Co.	100	07-15-67	358	358	4
SM Df 61	SM-05-5823	U.S. Navy: Patuxent Naval Air Test Center	Patuxent Pump & Well, Inc.	120	03-03-64	600	600	6
SM Df 62	SM-73-0635	St. Mary's County Metropolitan Commission	Frederick C. Lehmann	104	02-07-74	708	630	5
SM Df 67	SM-01-0607	St. Mary's County Metropolitan Commission	Washington Pump & Well Co.	30	12-08-52	274	274	5.5
SM Df 69	SM-02-2161	St. Mary's County Metropolitan Commission	Washington Pump & Well Co.	80	04-03-56	321	321	-
SM Df 73	SM-73-0768	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	100	04-10-74	620	620	5

Appendix A.—Continued

Screen settings (ft)	Aquifer	Pumping test data: Depth to static water level (ft)	Date reported	Yield (gpm)	Draw down (ft)	Specific capacity (gpm/ft)	Duration of test (hour)	Remarks	Well number
556-656	Aquia	226	09-11-96	306	245	1.25	24	Wildewood Subdivision & Technology Park. Owner's well #3R.	SM De 56
567-587	Aquia	123.50	06-01-43	225	53	4.2	-	Owner's well #1A. Building #522.	SM Df 1
527-547	Aquia	96.30	05- -44	300	152	2.0	-	Unused and replaced by well SM Df 95.	SM Df 4
347-357	Piney Point-Nanjemoy	125	1942	25	45	0.6	-	Owner's well #1R. Building #536.	SM Df 6
272-282	Piney Point-Nanjemoy	40	1942	25	40	0.6	-	Owner's well #1M.	SM Df 8
270-285	Piney Point-Nanjemoy	33	06-01-43	191	63	3.0	-	Replaced by SM Df 97.	SM Df 9
514-534	Aquia	45	06-07-43	225	98	2.3	-	Owner's well #3B. Building #531.	SM Df 10
470-490	Aquia	35	06-20-44	-	-	-	-	Owner's well #2P.	SM Df 13
247-262	Piney Point-Nanjemoy	35	05-31-43	170	165	1.0	-	Owner's well #1P. Building #532.	SM Df 14
-	Piney Point-Nanjemoy	34.10	09-06-50	-	-	-	-	Owner's well #1S. Data incomplete. Building #596.	SM Df 39
550-570	Aquia	130	07-26-51	210	58	3.6	12	Lexington Park. Colony Square well. Originally Patuxent Water Co.'s well #2.	SM Df 42
360-380	Piney Point-Nanjemoy	126	04-18-64	125	124	1.0	6	Owner's well Town Creek #6A.	SM Df 49
350-365	Piney Point-Nanjemoy	120	11-18-61	100	65	1.5	4	Owner's well Esperanza #5.	SM Df 50
335-350	Piney Point-Nanjemoy	114	05-18-59	75	41	1.8	6	Owner's well Greenview Knolls #1.	SM Df 53
336-358	Piney Point-Nanjemoy	120	07-15-67	44	25	1.8	10	Owner's well Greenview Knolls #2.	SM Df 60
580-600	Aquia	157	03-03-64	200	87	2.3	24	Owner's well #2A(R). Replacement for original well #2A (SM Df 2). Building #524.	SM Df 61
549-630	Aquia	165	02-07-74	328 to 614	131	-	48	Lexington Park. Pegg Rd. well. Gravel pack 487-630 ft.	SM Df 62
266-274	Piney Point-Nanjemoy	50	12-08-52	55	86	0.6	12	Esperanza Owner's well #1.	SM Df 67
308-321	Piney Point-Nanjemoy	97	04-03-56	40 110	55 113	0.7 1.0	8	Town Creek Owner's well #3.	SM Df 69
600-620	Aquia	140	04-10-74	100	95	1.1	6	Tubman Douglass Estates.	SM Df 73

Appendix A. Selected well records (updated from Achmad and Hansen, 1997, app. A)—Continued

Well number	State permit number	Owner	Driller	Approx-imate altitude of land surface surface (ft)	Date well reported completed	Depth Hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM Df 76	SM-05-7673	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	100	07-02-64	602	602	6.5
SM Df 78	SM-01-4838	St. Mary's County Metropolitan Commission	Washington Pump & Well Co.	100	10-08-54	600	600	6
SM Df 80	SM-73-0140	St. Mary's County Metropolitan Commission	Shannahan Artesian Well Co.	41.9	10-10-72	586	565	2
SM Df 86	SM-68-0185	St. Mary's County Metropolitan Commission	Shannahan Artesian Well Co.	112.1	04-30-68	611	609	6
SM Df 89	SM-88-1226	St. Mary's County Metropolitan Commission	Delmarva Drilling	124	07-18-91	700	621	6
SM Df 90	SM-81-2571	St. Mary's County Metropolitan Commission	Calvert Well Drilling Co.	95	08-07-94	620	600	4
SM Df 91	SM-81-3132	St. Mary's County Metropolitan Commission	Calvert Well Drilling Co.	100	02-23-88	630	610	4
SM Df 92	SM-81-1475	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	116	07-20-86	585	585	4
SM Df 93	SM-92-0358	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	42	04-07-94	632	565	6
SM Df 94	SM-92-0357	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	100	04-12-94	625	610	6
SM Df 95	SM-92-0369	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	80	04-24-94	600	580	6
SM Df 96	SM-93-0036	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	9	11-10-94	584	539	6
SM Df 97	SM-94-0925	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	48	1997	-	568	8,6
SM Df 98	SM-94-0410	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	75	1996	-	575	8.6
SM Df 99	SM-92-0642	St. Mary's County Metropolitan Commission	-	-	-	-	-	-
SM Df 101	SM-81-0050	St. Mary's County Metropolitan Commission	J. J. Payne & Sons, Inc.	115	10-12-82	310	310	2
SM Df 103	-	U.S. Navy: Patuxent Naval Air Test Center	-	-	-	-	-	-
SM Dg 2	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	11.3	1943	486	486	7.5
SM Dg 3	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	12	1943	489	489	-

Appendix A.—Continued

Screen settings (ft)	Aquifer	Pumping test data: Depth to static water level (ft)	Date reported	Yield (gpm)	Draw down (ft)	Specific capacity (gpm/ft)	Duration of test (hour)	Remarks	Well number
574-602	Aquia	155	07-02-64	200	47	4.3	8	Lexington Park. Essex Drive well.	SM Df 76
570-600	Aquia	155	10-08-54	300	153	2.0	24	Lexington Park. Willows Rd. well.	SM Df 78
545-565	Aquia	87	10-10-72	25	23	1.1	6	Test well. Cedar Cove Owner's well #2.	SM Df 80
568-609	Aquia	165	04-30-68	83	29	2.9	26	Lexington Park. Bank Square well.	SM Df 86
579-621	Aquia	232	07-18-91	215	85	2.5	24	Town Creek. Owner's well #6B. Gravel pack 480-621 ft.	SM Df 89
540-600	Aquia	165	08-07-94	150	50	3.0	4	Greenview Knolls. Owner's well #3. Gravel pack 480-600 ft.	SM Df 90
530-610	Aquia	175	02-23-88	175	140	1.2	24	Esperanza Farms. Gravel pack; exact location unknown; 101 ft. Formerly owned by Robert G. Dean.	SM Df 91
545-585	Aquia	130	07-20-86	235	30	7.8	16	Sans Souci Estates. Formerly owned by Larry Millison.	SM Df 92
515-565	Aquia	138	04-07-94	314	110	2.8	8	Owner's well 1B(R). Replaced original well 1B (SM Df 7). Building #529.	SM Df 93
560-610	Aquia	210	04-12-94	294	50	5.9	24	Owner's well 3A(R). Replacement for original well #3A (SM Df 3). Gravel pack 480-612 ft.. Building #574.	SM Df 94
530-580	Aquia	198	04-24-94	400	62	6.4	24	Owner's well 4A(R). Replacement for original well #4A (SM Df 4). Gravel pack 470-582 ft.. Building #584.	SM Df 95
489-539	Aquia	109	11-10-94	300	54	5.6	8	Owner's well 5B(R). Replacement for original well #5B (SM Df 12). Gravel pack 400-584 ft.. Building #590.	SM Df 96
515-565	Aquia	-	-	-	-	-	-	Owner's well #2B. Building #530. Replacement for SM Df 9.	SM Df 97
525-575	Aquia	-	-	-	-	-	-	Owner's well #5A. Building #587. Replacement for SM Df 5.	SM Df 98
-	Aquia	-	-	-	-	-	-	Owner's well #4B. Building #2276.	SM Df 99
290-310	Piney Point-Nanjemoy	30	12-12-82	30	33	0.91	3	Hickory Hills Subdivision.	SM Df 101
-	Aquia	-	-	-	-	-	-	Owner's well #6B. Building #671. Well not inventoried.	SM Df 103
466-486	Aquia	17	01-28-44	-	-	-	-	Replaced by SM Dg 18.	SM Dg 2
469-489	Aquia	37	10-23-43	-	-	-	-	Replaced by SM Dg 16.	SM Dg 3

Appendix A. Selected well records (updated from Achmad and Hansen, 1997, app. A)—Continued

Well number	State permit number	Owner	Driller	Approx-imate altitude of land surface surface (ft)	Date well reported completed	Depth Hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM Dg 5	None	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	21.4	1950	494	494	-
SM Dg 8	SM-01-3246	U.S. Navy: Patuxent Naval Air Test Center	Washington Pump & Well Co.	20	1953	-	276	-
SM Dg 13	SM-88-0800	St. Mary's County Metropolitan Commission	Delmarva Drilling	34	11-13-90	610	581	4
SM Dg 14	SM-92-0370	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	12	04-22-94	542	540	6
SM Dg 15	SM-92-0245	U.S. Navy: Patuxent Naval Air Test Center	Patuxent Pump & Well, Inc.	21	12-17-93	500	500	5
SM Dg 16	SM-94-0411	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	11	11-19-96	540	520	8
SM Dg 18	SM-94-0926	U.S. Navy: Patuxent Naval Air Test Center	A.C. Schultes of Maryland, Inc.	17	1997	-	553	8,6
SM Dg 19	SM-81-3345	U.S. Navy: Patuxent Naval Air Test Center	Watson and Johnson Well Drilling, Inc.	9	-	-	532	8
SM Dg 20	SM-88-0946	U.S. Navy: Patuxent Naval Air Test Center	-	-	-	-	-	-
SM Dg 21	SM-94-0074	U.S. Navy: Patuxent Naval Air Test Center	Southern Well and Recovery Corp.	9	1996	-	315	4
SM Dg 22	-	U.S. Navy: Patuxent Naval Air Test Center	-	11	1990	-	-	2
SM Dg 23	SM-73-0095	U.S. Navy: Patuxent Naval Air Test Center	-	-	-	-	555	-
SM Ed 17	SM-81-2634	St. Mary's County Metropolitan Commission	Calvert Well Drilling Co.	85	07-02-87	580	570	4
SM Ed 18	SM-94-2514	St. Mary's County Metropolitan Commission	Patuxent Pump & Well, Inc.	75	10-09-00	560	560	4
SM Ee 49	SM-81-1664	Watson, Alva & Thomas	Watson & Johnson Well Drilling, Inc.	85	09-24-87	595	595	4
SM Ee 50	SM-88-1439	Watson, Alva & Thomas	Watson & Johnson Well Drilling, Inc.	85	03-01-91	575	575	4
SM Ef 66	SM-03-4212	Hills Mobile Home Park	Patuxent Pump & Well, Inc.	90	04-23-59	335	335	5
SM Ef 69	SM-69-0027	St. Mary's College of Maryland	Shannahan Artesian Well Co.	44	08-27-68	740	558	4
SM Ef 81	SM-81-3371	St. Mary's College of Maryland	Sydnor Hydrodynamics, Inc.	44	08-30-88	740	590	10

Appendix A.—Continued

Screen settings (ft)	Aquifer	Pumping test data: Depth to static water level (ft)	Date reported	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)	Duration of test (hour)	Remarks	Well number
474-494?	Aquia	38	08- -50	210	162	1.3	-	Owner's well #2Q. Building #651.	SM Dg 5
-	Piney Point-Nanjemoy	-	-	-	-	-	-	Owner's well W. Replaced by SM Dg 22.	SM Dg 8
501-521 531-551 561-581	Aquia	121	11-13-90	402	81	5.0	8	Cedar Cove. Owner's well #2. Gravel pack 480-585 ft.	SM Dg 13
490-540	Aquia	90	04-22-94	400	170	2.4	24	Owner's well 1Q(R). Replacement for original well 1Q (SM Dg 6). Gravel pack 450-542 ft.. Building #617.	SM Dg 14
450-500	Aquia	-	-	150	-	-	8	Owner's well 1C(R). Replacement for original well 1C (SM Dg 1). Driller's tag on well reads SM-92-0570, but 0245 is correct.. Building #523.	SM Dg 15
470-520	Aquia	118	11-19-96	402	82	4.9	8	Owner's well #3C. Building #583. Replacement for SM Dg 3.	SM Dg 16
500-550	Aquia	-	-	-	-	-	-	Owner's well #2C. Building #575. Replacement for SM Dg 2.	SM Dg 18
480-510	Aquia	-	-	-	-	-	-	Owner's well CTR Building #2136.	SM Dg 19
-	Aquia	-	-	-	-	-	-	Building #2100.	SM Dg 20
295-315	Piney Point-Nanjemoy	-	-	-	-	-	-	Owner's well #1H. Building #1633.	SM Dg 21
640-670	Aquia	-	-	-	-	-	-	Owner's well Weapons. Building #253. Replacement for Dg 8.	SM Dg 22
-	Aquia	-	-	-	-	-	-	Owner's well Golf Course Building #1636. Well not inventoried.	SM Dg 23
510-570	Aquia	125	07-02-87	120	15	8.0	5	Wilderness Run. Owner's well #1. Test well converted to production well.	SM Ed 17
525-560	Aquia	170	10-09-00	150	80	1.87	10	Wilderness Run Subdivision Owner's well #2.	SM Ed 18
555-595	Aquia	136	09-24-87	230	40	5.8	17	Hunting Quarter Subdivision. Owner's well Watson #1.	SM Ee 49
525-575	Aquia	120	03-01-91	246	90	2.7	3	Hunting Quarter Subdivision. Owner's well Watson #2.	SM Ee 50
320-335	Piney Point-Nanjemoy	90	04-23-59	45	40	1.1	4	Owner's well #3.	SM Ef 66
532-558	Aquia	63	08-27-68	107	27	4.0	24	Owner's well #1.	SM Ef 69
505-570	Aquia	103	08-30-88	400	104	3.8	12	Owner's well #4. See cross-section B-B'. Gravel pack 400-740 ft.	SM Ef 81

Appendix A. Selected well records (updated from Achmad and Hansen, 1997, app. A)—Continued

Well number	State permit number	Owner	Driller	Approx-imate altitude of land surface surface (ft)	Date well reported completed	Depth Hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM Ef 82	SM-88-1091	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	112	05-17-91	655	655	4
SM Ef 83	SM-81-0645	St. Mary's College of Maryland	Branham Contractors, Inc.	42	04-13-84	580	572	8
SM Ef 84	SM-81-3288	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	85	07-12-89	395	395	4
SM Ef 86	SM-88-0280	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	85	10-27-89	375	375	4
SM Ef 87	SM-88-0410	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	115	03-30-90	1100	914	6
SM Ef 89	SM-81-2350	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	45	04-06-87	348	348	6
SM Ef 90	SM-93-0782	St. Mary's County Metropolitan Commission	Watson & Johnson Well Drilling, Inc.	115	08-27-97	695	695	4
SM Eg 29	SM-70-0140	Friendly Mobile Manor, Inc.	William F. Freeman	110	1969	335	335	-

Appendix A.—Continued

Screen settings (ft)	Aquifer	Pumping test data						Remarks	Well number
		Depth to static water level (ft)	Date reported	Yield (gpm)	Draw down (ft)	Specific capacity (gpm/ft)	Duration of test (hour)		
605-615 615-635 635-655	Aquia	185	05-17-91	168	55	3.1	24	Southgate Center Townhouses Subdivision.	SM Ef 82
535-572	Aquia	91	04-13-84	150	119	1.3	10	Owner's well #2.	SM Ef 83
375-395	Piney Point-Nanjemoy	140	07-12-89	109	20	5.4	4	Fox Meadow. Owner's well #2. Gravel pack 365-395 ft.	SM Ef 84
355-375	Piney Point-Nanjemoy	140	10-27-89	50	20	2.5	4	Fox Meadow. Owner's well #1. Replacement for well SM Ef 35 (SM-81-3289). Gravel pack 345-375 ft.	SM Ef 86
-	Upper Patapsco	139	03-30-90	306	191	1.6	24	Greenbriar, Whaler's Run Subdivision. Owner's well #1.	SM Ef 87
298-348	Piney Point-Nanjemoy	50	04-06-87	455	20	22.75	12	Great Mills Center.	SM Ef 89
595-695	Aquia	232	08-27-97	258	37	6.9	48	Greenbriar, Whaler's Run Subdivision. Owner's well #2.	SM Ef 90
325-335	Piney Point-Nanjemoy	180	1969	25	35	0.7	10	Owner's well #1.	SM Eg 29

Appendix B. Withdrawal rates from the Piney Point-Nanjemoy aquifer based on annual average ground-water appropriation permits apportioned to individual production wells in St. Mary's County for year 2000

[MGS, Maryland Geological Survey; USGS, U.S. Geological Survey]

Ground-water appropriation permit (GAP)	Appropriated annual average GAP, in gallons per day	Owner/location	Owner's well designation	MGS/USGS well number	Pumpage in model cell, in gallons per day
SM52GAP002	150,000	St. Mary's County Metropolitan Commission, Hills Mobile Home Park	#3	SM Ef 66	150,000
SM52GAP004	200,000	St. Mary's County Metropolitan Commission,			
		Town Creek	#3	SM Df 69	17,623
		Town Creek	#6A	SM Df 49	182,377
SM67GAP001	20,000	St. Mary's County Metropolitan Commission,			
		Greenview Knolls #1,	#1	SM Df 53	3,000
		Greenview Knolls #2	#2	SM Df 60	17,000
SM74GAP118	140,000	U. S. Navy: Patuxent Naval Air Test Center,			
		Building #532	#1P	SM Df 14	127,684
		Building #1633	#1H	SM Dg 21	2,070
		Building #2100		SM Dg 20	802
		Building #596	#1S	SM Df 39	7,929
		Building #536	#1R	SM Df 6	1,514
SM82GAP008[1]	-	St. Mary's County Metropolitan Commission, Hickory Hills		SM Df 101	10,521[1]
SM85GAP03[1]	-	St. Mary's County Metropolitan Commission, Great Mills Center		SM Ef 89	150,810[1]

[1] Reported as part of Lexington Park system (Appendix C, SM46GAP001)

Appendix B. Withdrawal rates from the Piney Point-Nanjemoy aquifer based on annual average ground-water appropriation permits apportioned to individual production wells in St. Mary's County for year 2000—Continued

Ground-water appropriation permit (GAP)	Appropriated annual average GAP, in gallons per day	Owner/location	Owner's well designation	MGS/USGS well number	Pumpage in model cell, in gallons per day
SM87GAP001	7,100	St. Mary's County Metropolitan Commission,			
		Fox Meadow,	#1	SM Ef 86	3,550
		Fox Meadow	#2	SM Ef 84	3,550

Appendix C. Withdrawal rates from the Aquia aquifer based on annual average ground-water appropriation permits apportioned to individual production wells in St. Mary's County for year 2000

[MGS, Maryland Geological Survey; USGS, U.S. Geological Survey]

Ground-water appropriation permit (GAP)	Appropriated annual average GAP, in gallons per day	Owner/location	Owner's well designation	MGS/USGS well number	Pumpage in model cell, in gallons per day (gpd)
SM46GAP001	1,450,000[1)]	St. Mary's County Metropolitan Commission, Lexington Park	Colony Square	SM Df 42	114,768
			Pegg Road	SM Df 62	450,675
			Essex Drive	SM Df 76	132,343
			Willows Road	SM Df 78	96,239
			Bank Square	SM Df 86	225,065
			Town Creek #6B	SM Df 89	60,047
			Esperanza Farms	SM Df 91	138,400
			Sans Souci	SM Df 92	71,133
SM55GAP002	7,500	Tekstar Industries, Leonardtown		SM Dd 64	7,500
SM65GAP002	55,000	St. Mary's County Metropolitan Commission, St. Clements Shores		SM Dc 58	55,000
SM67GAP003	525,000	Leonardtown, Commissioners of	#2	SM Dd 39	137,103
			#3	SM Dd 65	125,903
			#1,#4	SM Dd 30,66	261,994
SM67GAP009	30,000	St. Mary's County Public Schools, Vocational Technical Center	#2	SM Dd 41	15,000
			#1	SM Dd 45	15,000
SM67GAP101	80,000	St. Mary's County Metropolitan Commission, Greenview Knolls Subdivision #3	#3	SM Df 90	80,000

[1)] Included allocated pumpage from Piney Point-Nanjemoy aquifer at Hickory Hills Df 101 of 10,521 gpd (SM82GAP008) and Great Mills Ef 89 of 150,810 gpd (SM85GAP039)

Appendix C. Withdrawal rates from the Aquia aquifer based on annual average ground-water appropriation permits apportioned to individual production wells in St. Mary's County for year 2000—Continued

Ground-water appropriation permit (GAP)	Appropriated annual average GAP, in gallons per day	Owner/location	Owner's well designation	MGS/USGS well number	Pumpage in model cell, in gallons per day (gpd)
SM69GAP017	85,000	St. Mary's County Metropolitan Commission, Breton Bay Estates, Meadow Drive	#1R,#2	SM Dc 62, Dd 44	85,000
SM71GAP004	31,000	St. Mary's County Metropolitan Commission,	#1	SM Cc 19	5,862
		Loveville Acres, King-Kennedy Estates	#2R	SM Cc 27	25,138
SM72GAP004	13,000	Mt. Pleasant Water Company	#1,#2	SM Dc 59,60	13,000
SM73GAP003	160,000	St. Mary's County Metropolitan Commission,	#1	SM Df 80	73,262
		Cedar Cove, Shannon Farm	#2	SM Dg 13	86,738
SM74GAP002	50,000	St. Mary's County Metropolitan Commission, Tubman Douglas Estates		SM Df 73	50,000
SM74GAP018	830,000	U.S. Navy: Patuxent Naval Air Test Center,			
		Building #253	Weapons	SM Dg 22	691
		Building #2136	CTR	SM Dg 19	3,804
		Building #575	#2C	SM Dg 18	33,248
		Building #583	#3C	SM Dg 16	94,505
		Building #587	#5A	SM Df 98	68,643
		Building #530	#2B	SM Df 97	36,068
		Building #590	#5BR	SM Df 96	102,619
		Building #584	#4AR	SM Df 95	66,485
		Building #574	#3AR	SM Df 94	19,960
		Building #529	#1BR	SM Df 93	148,356
		Building #531	#3B	SM Df 10	18,010
		Building #617	#1QR	SM Dg 14	6,507
		Building #2276	#4B	SM Df 99	60,095
		Building #523	#1CR	SM Dg 15	29,693

Appendix C. Withdrawal rates from the Aquia aquifer based on annual average ground-water appropriation permits apportioned to individual production wells in St. Mary's County for year 2000—Continued

Ground-water appropriation permit (GAP)	Appropriated annual average GAP, in gallons per day	Owner/location	Owner's well designation	MGS/USGS well number	Pumpage in model cell, in gallons per day (gpd)
		Building #524	#2AR	SM Df 61	29,639
		Building #651	#2Q	SM Dg 5	6,880
		Building #671	#6B	SM Df 103	24,836
		Building #1636	Golf Course	SM Dg 23	65,287
		Building #522	#1A	SM Df 1	14,674
		Building #1677	Goose Creek	SM Dg[2)]	0
SM74GAP025	59,200	St. Mary's County Metropolitan Commission, Rolling Acres, Indian River, and Summit	#1,#2R	SM Bc 30,35	59,200
SM74GAP035	30,000	St. Mary's County Metropolitan Commission,	#1	SM Cc 15	15,000
		Birch Manor Subdivision	#2	SM Cc 16	15,000
SM74GAP043	25,000	St. Mary's County Metropolitan Commission,	#1	SM Ce 34	11,297
		Fenwick Manor Subdivision	#2R	SM Ce 45	13,703
SM76GAP003	240,000	St. Mary's County Metropolitan Commission,	#1B	SM Cb 18	48,000
		Country Lakes and Beverly Estates	#3	SM Cb 29	147,000
		Subdivisions	#2 (Tower)	SM Cb 30	45,000
SM76GAP004	34,000	St. Mary's County Metropolitan Commission, St. Mary's Industrial Park	#1R	SM De 53	34,000
SM76GAP014	350,000	St. Mary's County Metropolitan Commission,	#1	SM De 36	96,599
		Wildewood Subdivision and Technology Park	#2	SM De 50	25,118
			#3R	SM De 56	228,283
SM76GAP024	40,000	Maryland Rock Industries, Breton Bay Plant		SM Dd 47	40,000

Appendix C. Withdrawal rates from the Aquia aquifer based on annual average ground-water appropriation permits apportioned to individual production wells in St. Mary's County for year 2000—Continued

Ground-water appropriation permit (GAP)	Appropriated annual average GAP, in gallons per day	Owner/location	Owner's well designation	MGS/USGS well number	Pumpage in model cell, in gallons per day (gpd)
SM76GAP025	15,200	International Association of Machinists, Placid Harbor Education Center		SM Ce 38	15,200
SM81GAP018	70,000	Maryland Environmental Service,	#1	SM Bb 26	35,000
		Charlotte Hall Veterans Home	#2	SM Bb 28	35,000
SM83GAP016	40,800	St. Mary's County Metropolitan Commission, Hunting Quarter Subdivision	#1,#2	SM Ee 49,50	40,800
SM83GAP022	15,000	Wentworth Nursery, Inc.		SM Ab 6	7,500
				SM Ab 7	7,500
SM84GAP033[3)]	5,700	St. Mary's County Metropolitan Commission, Mulberry South	#1,#2	SM Dd 73,74	5,700
SM85GAP051	5,300	St. Mary's County Metropolitan Commission, Hearts Desire Subdivision		SM Bc 36	5,300
SM86GAP016	61,300	St. Mary's County Metropolitan Commission, Laurel Ridge Subdivision	#2,#1	SM Bc 33,34	61,300
SM86GAP060	25,000	St. Mary's County Metropolitan Commission, Wilderness Run Subdivision	#1,#2	SM Ed 17,18	25,000
SM89GAP008	10,000	Patty Dean-Kelly, Bushwood Bottling Plant		SM Db [4)]	10,000
SM89GAP010	39,700	St. Mary's County Metropolitan Commission, Persimmon Hills Subdivision		SM Bc 32	39,700

3) GAP was for Piney Point-Nanjemoy aquifer, but well depth indicated wells were screened in Aquia aquifer
4) Well not inventoried, well number unknown.

Appendix C. Withdrawal rates from the Aquia aquifer based on annual average ground-water appropriation permits apportioned to individual production wells in St. Mary's County for year 2000—Continued

Ground-water appropriation permit (GAP)	Appropriated annual average GAP, in gallons per day	Owner/location	Owner's well designation	MGS/USGS well number	Pumpage in model cell, in gallons per day (gpd)
SM89GAP074	53,000	St. Mary's County Metropolitan Commission,	#1	SM Ef 87[5]	--
		Greenbriar, Whaler's Run Subdivision	#2	SM Ef 90	26,500
SM66GAP006	57,200	St. Mary's County Metropolitan Commission,			
		McKays Plaza,		SM Ab 9	14,500
		Charlotte Hall 1,	#1R	SM Bb 29	23,600
		Charlotte Hall 2	#1	SM Bb 30	19,100
SM90GAP065	7,100	St. Mary's County Metropolitan Commission, Holland Forest	#2,#1	SM Dd 69,70	
SM91GAP021	13,600	St. Mary's County Metropolitan Commission, Southgate Center Townhouse Subdivision		SM Ef 82	13,600
SM92GAP010	60,300	St. Mary's County Recreation and Parks Department, Wicomico Shores Golf Course	#1	SM Ca 9	60,300
SM92GAP031	7,500	St. Mary's County Metropolitan Commission, Hollywood	#2	SM Ce 43	7,500
SM94GAP004	55,300	St. Mary's County Metropolitan Commission, Laurel Glen Subdivision		SM De 55	55,300
SM95GAP042	119,000	South Star Limited Partnership, sand and gravel mine		SM Dc [6]	119,000
SM97GAP002	20,300	St. Mary's County Board of Education, Chopticon High School		SM Cc 30	20,300

[5] Well screened in Upper Patapsco aquifer
[6] Well not inventoried, well number unassigned