Department of Natural Resources
Resource Assessment Service
MARYLAND GEOLOGICAL SURVEY
Emery T. Cleaves, Director

OPEN-FILE REPORT NO. 2001-02-14

ESTIMATION OF AREAS CONTRIBUTING RECHARGE TO SELECTED PUBLIC-SUPPLY WELLS IN DESIGNATED METRO CORE AREAS OF UPPER WICOMICO RIVER AND ROCKAWALKING CREEK BASINS, MARYLAND

by

David C. Andreasen
and T. Brandon Fewster

Prepared in cooperation with
the City of Salisbury
Department of Public Works
and
the Maryland Department of the Environment
Water Management Administration

2001

Department of Natural Resources
Resource Assessment Service
MARYLAND GEOLOGICAL SURVEY
Emery T. Cleaves, Director

OPEN-FILE REPORT NO. 2001-02-14

ESTIMATION OF AREAS CONTRIBUTING RECHARGE TO SELECTED PUBLIC-SUPPLY WELLS IN DESIGNATED METRO CORE AREAS OF UPPER WICOMICO RIVER AND ROCKAWALKING CREEK BASINS, MARYLAND

by

David C. Andreasen
and T. Brandon Fewster

Prepared in cooperation with
the City of Salisbury
Department of Public Works
and
the Maryland Department of the Environment
Water Management Administration

2001

CONTENTS

ILLUSTRATIONS

TABLES

PLATES

ESTIMATION OF AREAS CONTRIBUTING RECHARGE TO SELECTED PUBLIC-SUPPLY WELLS IN DESIGNATED METRO CORE AREAS OF UPPER WICOMICO RIVER AND ROCKAWALKING CREEK BASINS, MARYLAND

by

David C. Andreasen and T. Brandon Fewster

KEY RESULTS

Contributing areas of existing and hypothetical public-supply wells screened in the unconfined Salisbury aquifer in the Upper Wicomico River Basin and the Metro Core Area west of that basin (Rockawalking Creek study area) were determined using two separate finite-difference, ground-water-flow models (MODFLOW) and a particle-tracking routine (MODPATH). The contributing area of a pumping well is the area supplying recharge to the well from precipitation. The Salisbury aquifer, which is a shallow, water-table aquifer with relatively high transmissivity, is vulnerable to contamination. The mapped contributing areas can be used in the development of a well-head protection plan to protect supply wells from contamination. The wells selected for analysis include City of Salisbury Park wells 17 and 18, other public-supply wells serving 25 people or more such as mobile-home parks and some commercial wells, and hypothetical production wells. Contributing areas of all other public-supply wells operated by the City of Salisbury were determined in an earlier study. The key results of the study include:

UPPER WICOMICO RIVER BASIN

- The 50-year contributing area of City of Salisbury Park wells 17 and 18, pumping at a simulated rate of 0.36 million gallons per day, form an elongated pattern that extends approximately 4 miles from the wells in an east-northeast direction. Minimum travel time was 242 and 425 days for wells 17 and 18, respectively. (p. 8)

- The 50-year contributing area of 14 public-supply wells or well fields range in length from 0.25 to 3.2 miles and width from 0.1 to 0.5 miles and are either contiguous with the wells or occur at distances up to 1.8 miles from the wells. (p. 10)

- The 50-year contributing area of three hypothetical wells pumped simultaneously at 2 million gallons per day and located in the paleochannel range in length from 1.3 to 4 miles and width from 0.3 to 1 miles. The 50-year contributing area of a hypothetical well pumped at 0.36 million gallons per day and located in the Park well field was 3.5 miles long and less than 0.2 miles wide. (p. 11)

- Particles tracked forward from the West Road rubble landfill and an application area of waste-water sludge are intercepted by Paleochannel well 1 after 26 and 7 years, respectively. Particles tracked forward from two hazardous-waste sites are not intercepted by public-water supply wells. (p. 11)

ROCKAWALKING CREEK STUDY AREA

- Currently there are no public-supply wells pumping from the Salisbury aquifer in the Rockawalking Creek study area. The 50-year contributing area of three hypothetical wells pumped independently at 0.25 million gallons per day range in length from 0.7 to 1.6 miles and width from 0.5 to 0.65 miles. Minimum particle travel time ranged from 62 to 95 days. (p. 33) When the pumping rate is increased two-fold (0.5 million gallons per day) the 50-year contributing area expands down-gradient (southward) an additional 0.28 miles. (p. 33)

- Water for potable use in the Salisbury aquifer is currently limited to domestic supply from individual wells. The 20-year contributing area for clustered domestic wells within subdivisions are generally localized, occurring within 500 to 2,500 feet from withdrawal sites determined by particles backtracked from the mid-point of the aquifer. The average particle travel time was 6.8 years. (p. 37)

INTRODUCTION

A study previously conducted by the Maryland Geological Survey and U.S. Geological Survey, with funding support from the City of Salisbury, delineated the contributing areas of well fields supplying water to the city (Andreasen and Smith, 1997). Results of the study could be used as a basis for developing a well-head protection plan. In that study, data from hydrogeologic analyses were applied using the U.S. Geological Survey's three-dimensional, ground-water-flow model (MODFLOW) (McDonald and Harbaugh, 1988) and particle-tracking routine (MODPATH) (Pollock, 1989) to determine contributing areas. The modeled area consisted of the Upper Wicomico River Basin. Contributing areas were delineated for production wells in the city's Paleochannel well field (wells 1 and 2 located in the USGS 1:24,000 quadrangle DELMAR, MD-DEL) and Park well field (wells 2a, 6a, 7b, 8a, 10a, 14a, and 16a located in the USGS 1:24,000 quadrangle SALISBURY, MD) (pl. 1). During the study, wells 17 and 18 were constructed in the Park well field (pl. 1). Limited ground-water-flow simulations were made incorporating these wells. Future municipal and other public-supply wells were excluded from the analysis. This study expands the previous study to include these wells. In this report, public-supply wells other than municipal wells are defined as wells supplying potable water to more than 25 people on a regular basis or more than 15 connections (housing units). This includes commercial, industrial, institutional, and residential use, such as mobile homes. The study area is also expanded to include most of the Metro Core Area west of the Upper Wicomico River Basin and north of the Wicomico River. In this report that area is referred to as the Rockawalking Creek study area.

OBJECTIVES

The objectives of the study are to: (1) estimate contributing areas of: (a) Park wells 17 and 18, other existing public-supply wells, and future public-supply production wells within the Upper Wicomico River Basin using 0 to 1, 1 to 10, 10 to 20, and 20 to 50-year travel times; and, (b) future public-supply production wells within the Rockawalking Creek study area; and, (2) locate potential ground-water contaminant sites in the study area and track particles forward to determine if particle paths intercept municipal- or public-supply wells.

LOCATION OF STUDY AREA AND PHYSICAL SETTING

The study area consists of the Upper Wicomico River Basin and the Rockawalking Creek Basin, which is located within most of the Metro Core Area west of the Upper Wicomico River Basin (fig. 1). The Metro Core Area, extending from the City of Salisbury northward to Delmar and southward to Fruitland, is a designated growth area within Wicomico County. Delmar and Fruitland are excluded from this study. In this report the area that includes the part of the Metro Core Area west of the Upper Wicomico River Basin is referred to as the Rockawalking Creek study area. Most of that area consists of the Rockawalking Creek Basin with the addition of two smaller drainage basins (Bell Creek and Cottonpatch Creek Basins). To adequately simulate ground-water flow, the entire Rockawalking Creek Basin along with the two smaller basins were included in the ground-water-flow model area (fig. 1).

Land use in the Upper Wicomico River Basin is predominantly a mixture of urban, commercial, and light industrial use in and around the City of Salisbury. Farther from the city, land use is predominantly agricultural and rural with scattered housing subdivisions. Land use in the Rockawalking Creek study area is predominantly agricultural with scattered housing subdivisions in the northwestern, central, and southwestern part of the study area.

Construction records for selected wells used in the study are listed in Appendix A. The well locations are shown on Plates 1 and 3.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of the City of Salisbury and, in particular, Newell Messick, Chief, Department of Public Works. The authors also greatly appreciate the efforts of: Anthony Tallman and David Hudson, U.S. Geological Survey, for baseflow measurements; Wayne Witzke, Wicomico County Health Department and Denise Swatzbaugh, Maryland Department of the Environment, for well construction records; Edward Stephens and Paul Hall, Retired and Senior Volunteer Program of the Lower Eastern Shore, and Herman Twining, Maryland Department of the Environment, for surveying altitudes of water-level observation wells; Judith Wheeler, U.S. Geological Survey, for water-use information; Stephen

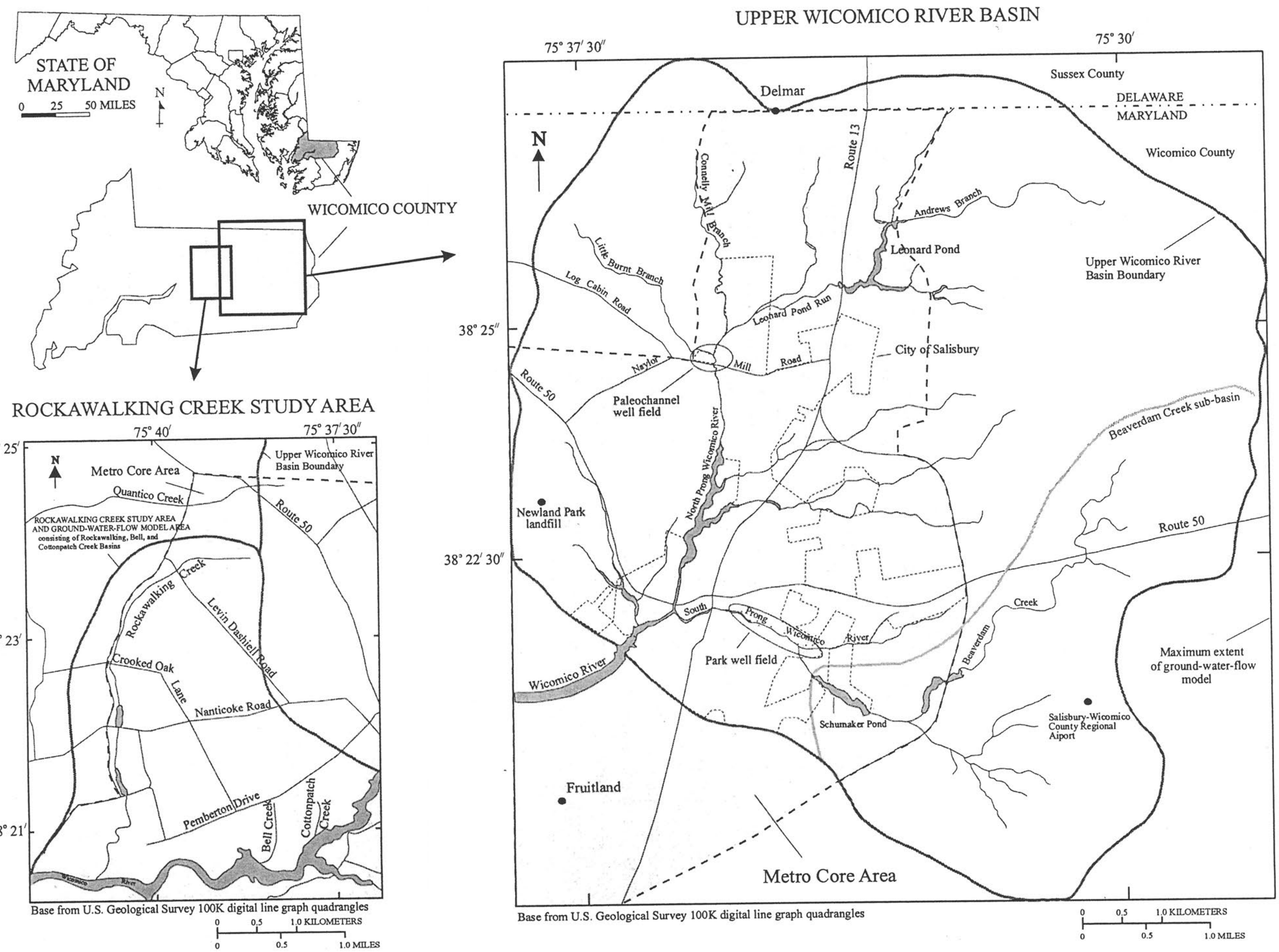


Figure 1. Location of study area.

Curtin, U.S. Geological Survey, for geophysical logging; Harry Hansen, Maryland Geological Survey, William Fleck, U. S. Geological Survey, and John Grace and Norman Lazarus, Maryland Department of the Environment, for technical review of the manuscript; and Donajean Appel, for editorial review and typing of the manuscript. The project was funded partially through a grant from the Maryland Department of the Environment as authorized by the 1992 Amendment of the Safe Water Drinking Act.

SUPPLEMENTAL PARTICLE TRACKING IN THE UPPER WICOMICO RIVER BASIN

BRIEF REVIEW OF PREVIOUS (1997) STUDY

Concern over the vulnerability of the City of Salisbury's well fields to contamination prompted the Maryland Geological Survey and the U.S. Geological Survey, in cooperation with the City of Salisbury Department of Public Works, to delineate areas contributing recharge to well fields. A study, conducted between 1993 and 1996 (Andreasen and Smith, 1997): (1) refined the hydrogeology of the Salisbury and Manokin aquifers within the Upper Wicomico River Basin; (2) simulated ground-water flow using the three-dimensional, ground-water-flow model MODFLOW and, (3) mapped the contributing areas of wells in both the city's Paleochannel and Park well fields using the particle-tracking program MODPATH. Contributing areas delineated for particle travel times of 0 to 1, 1 to 10, 10 to 20, and 20 to 50 years could provide the basis for the development of a well-head protection plan. Forward-particle tracking from potential ground-water contaminant sites such as ground-water discharge sites, CERCLA (Superfund) sites, and the proposed northern Route 50 bypass was also conducted. A complete discussion of the hydrogeology, construction of the ground-water-flow model, and particle-tracking results is presented in Maryland Geological Survey Report of Investigations No. 65. A brief summary is provided in the following two sections.

Hydrogeology

The Salisbury aquifer, comprised of the Pensauken Formation and Beaverdam Sand, is an unconfined aquifer composed of coarse sand and gravel. In the model area, transmissivity ranges from 8,200 to 57,000 feet squared per day (ft^2/d). Values average about 22,000 ft^2/d in the city's Park well field and 53,500 ft^2/d in the city's Paleochannel well field, where an unusually thick (greater than 200 feet [ft]) paleochannel deposit occurs. In the paleochannel, the confining bed at the base of the Salisbury aquifer is eroded, resulting in a hydraulic connection with the underlying Manokin aquifer. Sediment in the paleochannel consists of very coarse sand and gravel. Outside the paleochannel, the Salisbury aquifer is separated from the Manokin aquifer by the lower confining bed which is composed of 25 to 65 ft of low permeability, bluish-gray clay.

The Salisbury aquifer receives recharge from precipitation in topographically high areas in the basin and discharges water to numerous small streams, man-made ponds, the tidal part of the Wicomico River, and wells. The aquifer's flow boundaries coincide with the surface-water drainage divide of the Upper Wicomico River Basin. The water-table altitude ranges from approximately 50 ft above sea level on the east side of the basin to sea level near the tidal part of the Wicomico River south of Route 50. The estimated ground-water-recharge rate ranges from 11.4 to 13.4 inches per year (in/yr).

Ground-Water-Flow Model and Particle Tracking

Ground-water flow in the Upper Wicomico River Basin was simulated using the U.S. Geological Survey's three-dimensional, ground-water-flow model (MODFLOW). The model simulated steady-state conditions using 1993 pumpage data. The model consisted of five layers: (1) layers 1 and 2 outside the paleochannel, and layers 1 through 5 within the paleochannel represented the Salisbury aquifer, (2) layers 4 and 5 outside the paleochannel represented the Manokin aquifer, and; (3) layer 3 outside the paleochannel represented the intervening confining bed. The model grid consisted of 80 columns and 84 rows. The grid spacing was finest in the area of the two city well fields. The lateral boundary of the Salisbury aquifer was simulated as no-flow to represent the ground-water divide. The tidal part of the Wicomico River was represented as a constant-head boundary (sea level). The lateral boundary of the Manokin aquifer

was simulated as a constant-head boundary. The St. Mary's Formation, a low- permeability clay underlying the Manokin aquifer, was treated as a no-flow boundary.

Contributing areas were determined using output from the calibrated, steady-state ground-water-flow model and the U.S. Geological Survey's particle-tracking program MODPATH. Particles placed on the faces of model cells representing pumping wells were back-tracked along ground-water-flow lines until they reached the water-table surface. The surface areas where particles terminated at the water table form the contributing areas. Contributing areas of the city's wells extend upgradient from the wells approximately 1,000 ft for the 1-year time zone; 6,000 ft for the 10-year time zone, and 10,000 ft for the 20-year-time zone. The areal distribution of the contributing areas are irregular and are affected by streams, ponds, and temporal changes in stresses such as recharge and pumping. The contributing areas of the Paleochannel well field are predominantly in agricultural and open areas, whereas the contributing areas of the Park well field are predominantly in commercial and residential areas.

Water particles tracked from two potential contaminant sites, a railroad line and a site with a ground-water discharge permit located at Route 13 and Naylor Mill Road, were captured by Paleochannel well 2 after 2 and 11 years of travel time, respectively. Particles tracked forward from CERCLA sites, the Newland Park landfill, and other sites with discharge permits were not captured by the city's wells.

REVISED GROUND-WATER-FLOW MODEL

A revised version of the ground-water-flow model developed in the previous study (Andreasen and Smith, 1997) was used in this study. The model grid was refined to improve particle-tracking performance in areas where model cell size was relatively large. Model cells were added in areas originally represented with large cells by dividing those cells. The largest model cell dimension in the previous model was 5,770 ft by 3,840 ft compared to 1,150 ft by 960 ft in the revised model. The revised model grid contains 115 columns and 136 rows (fig. 2). Stresses, such as rivers and discharge wells, assigned to model cells that were divided were distributed evenly within the subdivided cell.

The location of the no-flow boundary representing the ground-water divide in the Salisbury aquifer (layers 1 and 2) was refined with the addition of more model cells. While the west side of the basin was expanded slightly to include the area of the West Road rubble landfill, the overall active area of model layers 1 and 2 (Salisbury aquifer) decreased slightly. The area of the landfill was included in the basin as a result of water-level data obtained from observation wells at the landfill that show an eastward head gradient toward discharge areas in the Upper Wicomico River Basin (Rust Environment and Infrastructure, 1997).

Appropriated pumpage from the Salisbury aquifer greater than 10,000 gallons per day (gal/d) represented in the model was updated to 1998. Pumpage from individual users are given in Appendix B and pumping-well locations are shown on Plate 1. An estimated 8.4 million gallons per day (Mgal/d) was pumped in 1998 by users appropriated for more than 10,000 gal/d compared to 8.0 Mgal/d in 1993. These pumping rates represent annual averages. Average appropriated amounts were used when reported pumpage figures were unavailable. Pumpage from the city's Paleochannel and Park well fields for 1998 totaled 3.8 and 1.8 Mgal/d compared to 3.5 and 1.7 Mgal/d in 1993. Pumpage represented in the revised ground-water-flow model in the Park well field was divided evenly between wells 8a, 14a, 16a, 17, and 18, which were wells used most frequently in 1998 (William Dodson, City of Salisbury Water Plant, oral commun., 1999). Each well was pumped at 0.36 Mgal/d. The entire amount pumped in the Paleochannel well field was assigned to Paleochannel well 1. Self-supplied, domestic ground-water use was left at the same rate (0.7 Mgal/d) and areal distribution used in the previous model. Total pumpage from all users of the Salisbury aquifer equaled 9.1 Mgal/d.

Model calibration was checked after the model was re-gridded and the pumpage array was updated. The sum of the absolute differences between simulated water levels and measured water levels decreased from 181 ft in the previous model to 135 ft in the re-gridded model. Measured water levels used in model calibration are the same as those used in calibration of the previous model (Andreasen and Smith, 1997, p. 46). They include median water levels obtained from four wells with long-term water-level records and from 61 wells with either a few measured water levels or with less than 2 years of continuous water-level record. The median water levels are assumed to represent approximate steady-state, hydrologic conditions within the basin. The improvement in the water-level match resulted in part because water levels are averaged over smaller cell areas of the finer grid in the revised model. Baseflow to Beaverdam Creek (sub-basin of Upper Wicomico River Basin) increased from 16 cubic feet

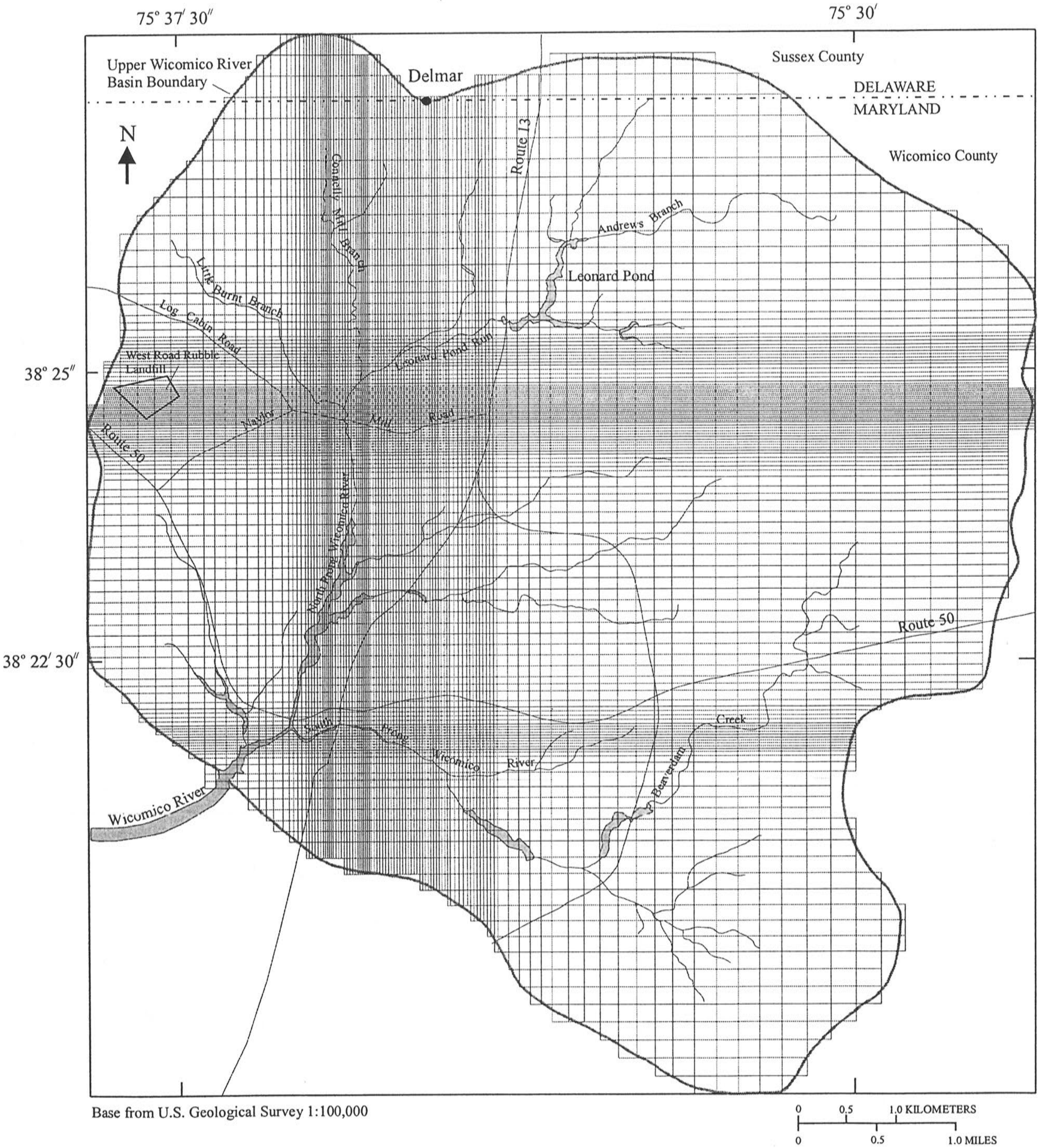


Figure 2. Revised ground-water-flow model grid for the Upper Wicomico River Basin.

per second (cfs) in the previous model to 17.7 cfs in the revised model. This also is an improvement in model performance since the median baseflow calculated from long-term, stream-flow measurements in Beaverdam Creek was 19.3 cfs.

Inflow from river cells increased over the entire model domain by a net amount of 0.43×10^6 cubic feet per day (ft^3/d)(3.2 Mgal/d) from the previous model. This equates to a 12-percent increase from the previous model. The increase in inflow was caused by a change in the vertical-head gradient between the specified river heads and the simulated model-cell heads in cells that were subdivided. In many subdivided model cells representing rivers the increase in inflow to the model was balanced by an increase in outflow to the rivers. Inflow from river cells accounts for 5 percent of the total inflow to the model. The effect of the increased inflow from rivers on head distributions in the Salisbury aquifer is localized and does not significantly alter simulated ground-water flow within the basin. Inflow from constant-head boundaries along the perimeter of the model in layers 4 and 5 (Manokin aquifer) increased from 0.79×10^6 to 0.91×10^6 ft^3/d; however, the increase was offset by a comparable increase (0.16×10^6 ft^3/d) in outflow to those same boundaries. Inflow from recharge decreased from 6.7 to 6.3×10^6 ft^3/d. The decrease was attributed to a smaller active model area in the revised model.

ESTIMATION OF CONTRIBUTING AREAS

Contributing areas for selected public-supply wells and sites for future public-supply wells were determined using the U.S. Geological Survey's particle-tracking program MODPATH and output from the steady-state solution of the revised ground-water-flow model. MODPATH calculates ground-water velocities using inter-cell flow rates and heads obtained from MODFLOW, and user-specified aquifer and confining-bed porosities. The porosity array used in the previous study (Andreasen and Smith, 1997) of 25 to 30 percent for the Salisbury aquifer, 30 percent for the Manokin aquifer, and 55 percent for the lower confining bed were used in this study. Particles placed on the top and sides of model cells representing pumping wells were back-tracked until they reached the water table. The array consisted of 20 x 20 particles placed on the top and side faces of each model cell for a total of 2,000 particles. Where the particles intercept the water table form the contributing area of the well. Particles were stopped after 1, 10, 20, and 50 years. The contributing areas reflect steady-state conditions. Short-term, seasonal changes in stresses, such as pumpage and recharge, could affect both the size and shape of the contributing areas.

MODPATH allows particles to be captured by strong sinks, weak sinks, or by a sink of specified strength. A strong sink is defined as outflow from a model cell that exceeds the flow passing through the cell. In the particle-tracking simulations (forward and backward), particles were captured by strong sinks. Particles passed through weak sinks where outflow from model cells were less than flow passing through the cell. Assigning the particle-capture criteria is subjective and can affect both the size and shape of contributing areas and forward-tracked particle path lines.

City of Salisbury Park Wells 17 and 18

Contributing areas were determined for Park wells 17 and 18 for travel times of 0 to 1, 1 to 10, 10 to 20, and 20 to 50 years. The contributing areas for Park wells 17 and 18 form an elongated pattern extending outward approximately 4 miles (mi). from the wells in an east-northeast direction (pl. 2). These contributing areas develop when Park wells 8a, 14a, 16a, 17, and 18 are pumped at 0.36 Mgal/d each (1.8 Mgal/d total). The minimum travel time from contributing areas to wells 17 and 18 are 242 and 425 days, respectively. Particles entering the water table immediately surrounding the wells travel along shallow ground-water-flow paths and discharge to Beaverdam Creek and Beaglin Branch. Because of the inability of the model to simulate localized flow patterns surrounding the pumping wells and streams precisely, the area between the wells and the contributing areas should be included in the model-calculated contributing areas (Andreasen and Smith, 1997, p. 63).

Public-Supply Wells

Contributing areas were determined for all of the public-supply wells or well fields within the Upper Wicomico River Basin excluding City of Salisbury's Paleochannel and Park wells covered in the earlier investigation (Andreasen and Smith (1997) (tab. 1) (pl. 2). In this report public-supply wells are defined as publicly- or privately-owned wells supplying potable water to more than 25 people on a regular basis or more than 15 connections (housing units). This includes commercial, industrial, institutional, and residential use, such as mobile homes.

Table 1. Public-water supplies used in contributing area analysis in the Upper Wicomico River Basin

Public water supply (Ground-water appropriation permit)	Well number	Estimated pumping rate, thousand gallons per day	Average amount appropriated, thousand gallons per day	Minimum travel time
Beaver Run Elementary School (WI85G006)	WI Cf 225	7.0	6.8	30 years
Bennett Mobile Home Park (WI87G003)	WI Ce 321, 322	4.8	4.5	6.5 years
Eastwood Mobile Home Park (WI74G011)	WI Cf 214, 215	7.6	9.0	22 years
Faith Baptist Church (WI81G032)	WI Bf 88	1.0	1.0	20.5 years
Gateway Village Mobile Home Park (WI80G015)	WI Bf 86	4.8	5.8	23 years
Green Meadows Mobile Home Park (WI70G011)	WI Bf 84	4.7	6.3	30 years
Naylor Mill Mobile Home Park (WI76G017)	WI Ce 253, 254	14.4	9.8	--[1]
Perdue Farms Inc., main office (WI82G016)	WI Cf 221, 222	16.0	16.0	1 day
Perdue Farms Inc., Zion Church Road (WI55G001)	WI Cf 200	320.0	565.0 (WI Cf 200) 1,700.0 (well field)	1 day
Industrial site (formerly Royal Foods, Inc.) (Inactive)	WI Ce 261, 262, 263	500.0	--	206 days
Salisbury School (WI72G016)	WI Cf 223, 224	5.0	5.3	470 days
Salisbury-Wicomico County Regional Airport (Inactive)	WI Cf 220	8.0	--	27 years
Walston Mobile Home Park (WI68G016)	WI Cf 216, 217, 218, 219	13.2[2]	15.2	1 day
Wicomico Mobile Home Park (WI72G011)	WI Bf 87	4.4	3.9	9.3 years

[1] Source of recharge is through the Manokin aquifer west of the Upper Wicomico River Basin
[2] Estimated from population served

Particles were backtracked from a total of 14 public-supply wells or well fields. The contributing areas for these public supplies corresponding to travel times ranging from up to 1, 1 to 10, 10 to 20, and 20 to 50 years are shown on plate 2. In the model simulations, the wells or well fields were pumped at estimated 1998 rates (tab. 1). In some instances, the average amount appropriated was greater than the 1998 amount. With the exception of Perdue Farms, Inc. at Zion Church Road and Eastwood Mobile Home Park, the contributing areas calculated using the 1998 amount and the average appropriated amount differed by less than 5 percent. The average appropriation amount was used for Perdue Farms, Inc. at Zion Church Road and Eastwood Mobile Home Park because the resulting contributing areas were more than 10-percent larger than the contributing areas calculated using estimated 1998 pumpage amounts. The larger contributing area calculated using the average appropriated pumpage is more appropriate for use in a well-head protection plan because it represents the maximum contributing area size for the particular well field.

The larger contributing areas are associated with the higher producing wells—Perdue Farms, Inc. at Zion Church Road (0.56 Mgal/d), an industrial site (formerly Royal Foods, Inc.)(0.5 Mgal/d), Perdue Farms, Inc. main office (0.016 Mgal/d), and Walston Mobile Home Park (0.0132 Mgal/d) (tab. 1). The Royal Foods plant is closed; therefore, to determine the potential contributing area for that well field, the previously permitted pumping amount of 0.5 Mgal/d was used. The contributing areas for these supplies are contiguous with the wells and range in length from 2.0 to 3.2 mi and width from 0.1 to 0.5 mi. Minimum time-of-travel from contributing area to well(s) ranges from 1 to 206 days (tab. 1). Wells with the shortest travel times such as Walston Mobile Home Park are screened, at least in part, in the upper part of the Salisbury aquifer (model layer 1). Minimum travel time to the former Royal Foods well field of 206 days is greater because these wells are screened in the lower part of the Salisbury aquifer (layer 2).

The contributing areas for the lower-yielding wells—less than 0.010 Mgal/d (tab. 1)—form relatively narrow (less than 500 ft) elongated shapes ranging from 0.25 to 2.75 mi in length and occurring at distances up to 1.8 mi from the wells. These wells essentially intercept ambient ground-water flow traveling from recharge areas to discharge areas. Minimum particle travel time ranges from 1.3 to 30 years (tab. 1). The contributing areas for Bennett Mobile Home Park and Faith Baptist Church are located within the contributing areas for two hypothetical production (public-supply) wells discussed in the next section. When the hypothetical wells are pumped the contributing areas for Bennett Mobile Home Park and Faith Baptist Church shift to a position adjacent to and north of the hypothetical well contributing areas.

The Naylor Mill Mobile Home Park pumps from two wells screened in the middle to lower part of the paleochannel (Salisbury aquifer). Particles back-tracked from this site travel along deeper ground-water-flow paths. The source of recharge for these wells is through the Manokin aquifer west of the Upper Wicomico River Basin.

The width of contributing areas are controlled by pumping rate and aquifer transmissivity. A higher pumping rate and lower transmissivity results in a wider contributing area. Model-cell size also has an effect on contributing area width. A larger model-cell size artificially widens the contributing area. The distance between a pumping well and its contributing area is a function of pumping rate, location of the well within the ground-water-flow regime, and well-screen depth. The lower the pumping rate the greater the distance between well and contributing area. Contributing areas contiguous with a pumping well are indicative of higher pumping rates. The distance between well and contributing area is also greater if the well is located lower in the basin (further from recharge areas) and screened at a greater depth. Finally, boundaries such as rivers and other pumping wells can affect the shape of contributing areas.

Hypothetical Public-Supply Production Wells

Growth within the Metro Core Area may require additional water supplied by the city's well fields. Four sites for future public-supply production wells were selected for model analysis: Hypothetical wells 1, 2, and 3 were located in the Paleochannel well field and hypothetical well 19 was located in the Park well field (pl. 2). Hypothetical wells 1, 2, and 3 in the Paleochannel well field were spaced approximately equidistant from one another and from the two existing Paleochannel wells. The hypothetical wells were positioned along Naylor Mill Road between Route 50 and Route 13. The well locations are aligned with the deepest part of the Salisbury Paleochannel and were represented in the model as withdrawals from model layers 3 and 4 (Salisbury aquifer within the paleochannel). Each well was pumped at a rate of 2 Mgal/d. Hypothetical well 19 in the Park well field was

located approximately 400 ft south of existing wells 17 and 18 across Beaglin Branch. This well was pumped at 0.36 Mgal/d from model layer 2 (Salisbury aquifer outside the paleochannel). Pumping from the hypothetical wells in both well fields were in addition to the 1998 pumpage from the existing production wells.

The 50-year contributing areas for hypothetical wells 1, 2, and 3 range from 0.3 to 1 mi wide and 1.3 to 4 mi long (pl. 2). The areas extend westward from hypothetical well 1 and eastward from hypothetical wells 2 and 3. The 50-year contributing area for hypothetical well 19 is relatively narrow (less than 0.2 mi) and approximately 3.5 mi long. The 1- to 10-year contributing area for hypothetical well 1 includes nearly the entire area of the West Road rubble landfill. The contributing areas for hypothetical wells 2, 3, and 19 include a mixture of recreational (park), commercial, residential, and agricultural land use.

FORWARD-PARTICLE TRACKING FROM POTENTIAL SOURCES OF CONTAMINATION

Potential sources of contamination identified within the Upper Wicomico River Basin include: West Road rubble landfill, two hazardous waste sites, and an area of wastewater sludge land application. These sites are in addition to 14 sites with the potential for contaminating ground water addressed in the previous study (Andreasen and Smith, 1997).

Particles were tracked forward from the West Road rubble landfill (fig. 3). Seven particles released from the top face of model cells located within the boundary of the landfill flowed eastward and were captured by Paleochannel well 1 (WI Ce 200). The average travel time of the particles was 26 years. The particles travel along relatively shallow ground-water-flow paths before discharging to the well. Flow velocity increases as particles approach the well. Particles reach the Bennett Mobile Home Park well field after approximately 15 years.

Particles were released from the top face of two model cells containing hazardous waste sites. The sites are located south of Naylor Mill Road and east of the North Prong Wicomico River. Particles travel in a westerly direction before discharging to the river (fig. 4). Particle travel times range from 1.5 to 3.8 years and 1.4 to 2.0 years for sites A and B, respectively. Particles are not captured by public-supply wells.

Particles released from an area of wastewater sludge application discharge to Little Burnt Branch and Paleochannel well 1 (fig. 5). Paleochannel well 1 began capturing particles after approximately 7 years. Most particles captured by Paleochannel well 1 required a travel time of more than 10 years. Little Burnt Branch captured most particles flowing from the east side of the application area. An irrigation well (WI Be 57) located within the area of wastewater sludge application began capturing particles after one day. This well has a relatively high average annual pumping rate (0.65 Mgal/d in 1998) and the top of the well screen is relatively shallow (20 ft below land surface).

HYDROGEOLOGY OF THE SALISBURY AQUIFER IN THE ROCKAWALKING CREEK STUDY AREA

The Salisbury aquifer is the primary source of ground water in the Rockawalking Creek study area. Similar to its occurrence in the Upper Wicomico River Basin, the aquifer is highly productive, unconfined (water-table condition), and recharged rapidly by infiltrating precipitation. These characteristics, while beneficial for producing water from wells, make the aquifer vulnerable to contamination. A relatively small amount of water in the Rockawalking Creek study area is supplied by the deeper, confined (artesian) Manokin and Choptank aquifers. These aquifers, although less productive than the Salisbury aquifer, are not as vulnerable to contamination. This section of the report is focused primarily on the unconfined Salisbury aquifer. Brief descriptions of the Manokin and Choptank aquifers are also included.

HYDROGEOLOGIC FRAMEWORK

The hydrogeologic framework of the Rockawalking Creek study area was developed using published literature (including Andreasen and Smith, 1997; Rasmussen and Slaughter, 1955; and Wiggle, 1972), well-driller's reports, and file geophysical logs. Additional geophysical logs of three test wells and four newly drilled production wells were obtained during the study.

Two sections constructed through the Rockawalking Creek study area illustrate the

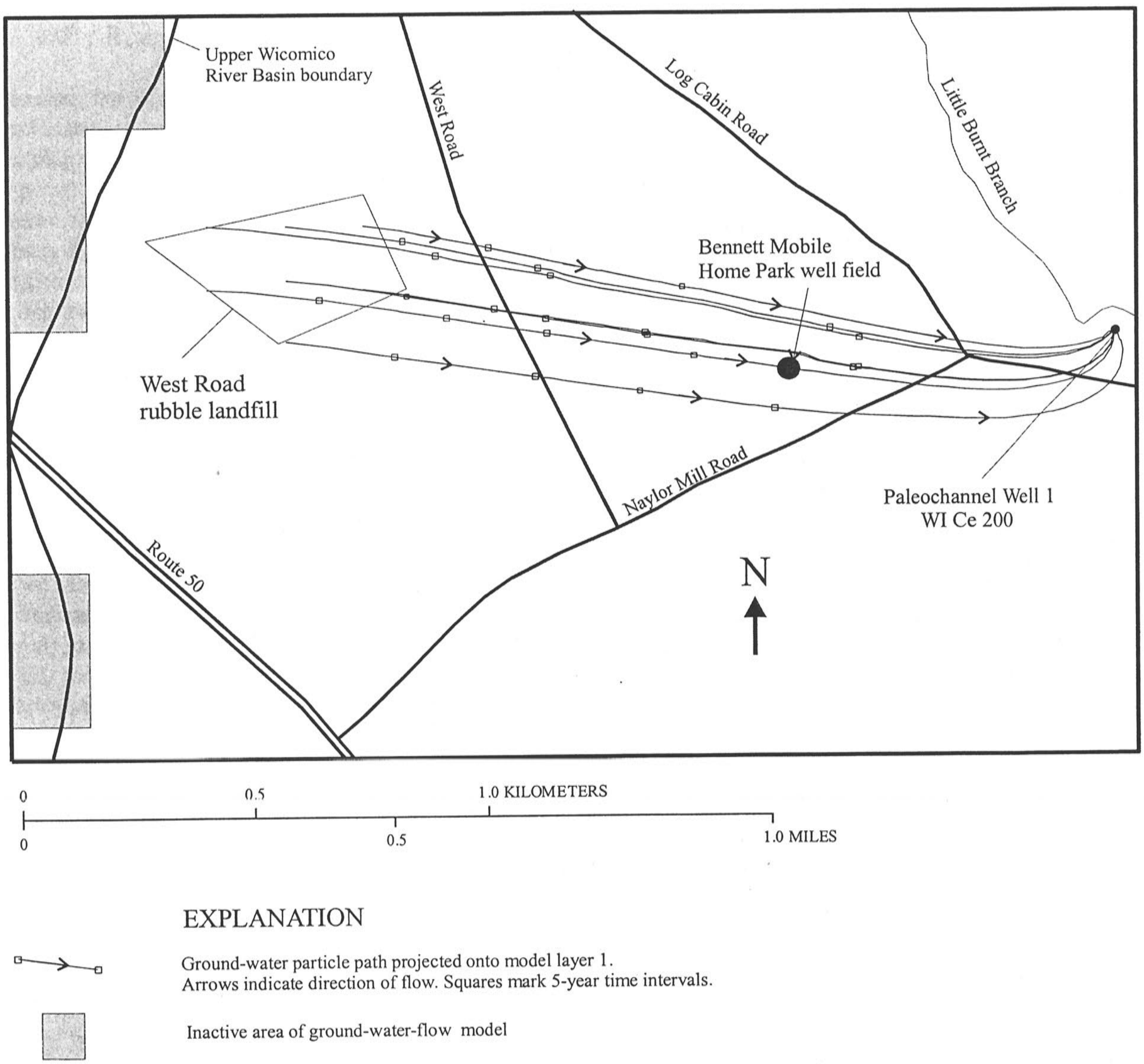
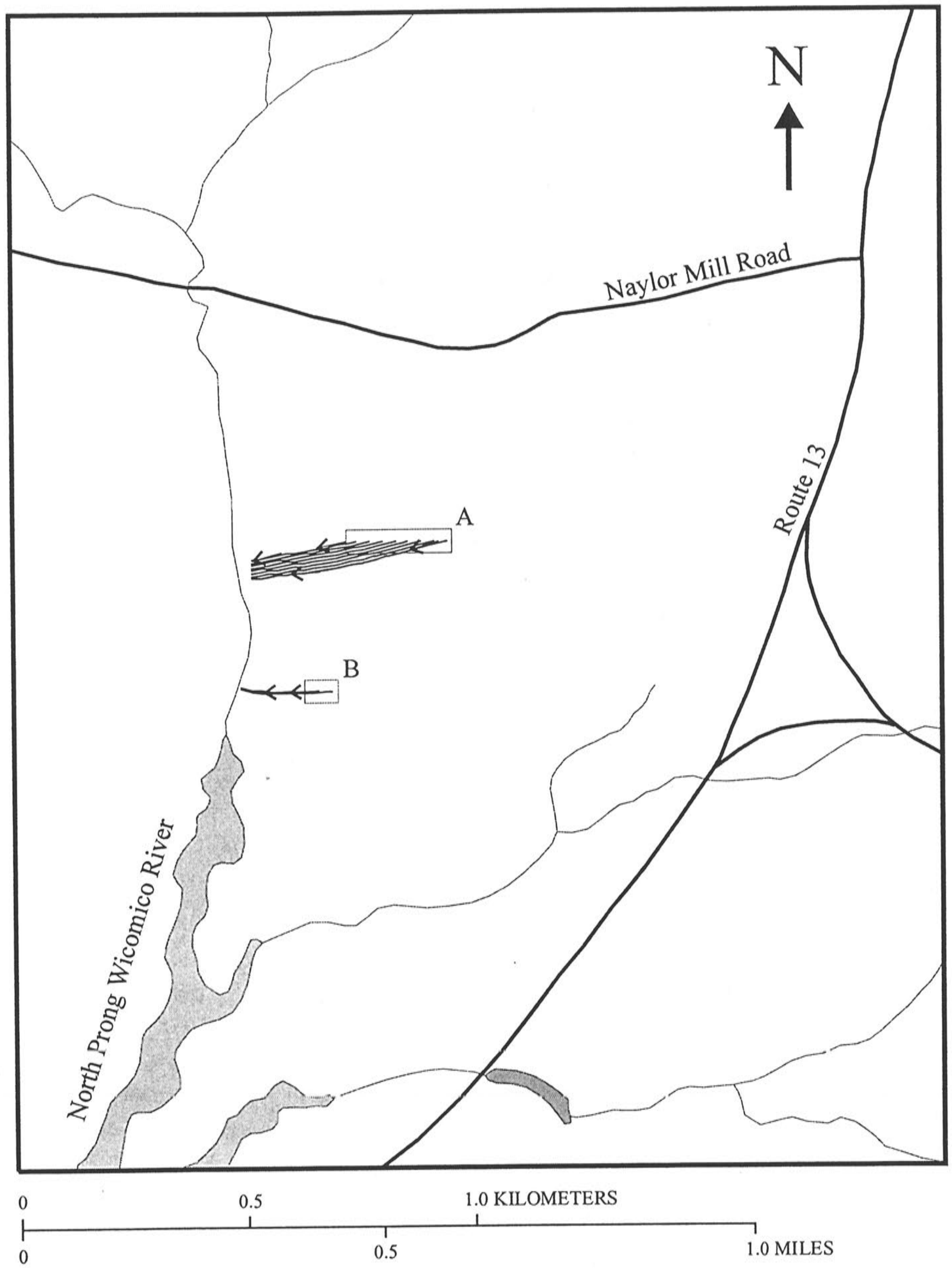


Figure 3. Forward-particle tracking from West Road rubble landfill.



EXPLANATION

Ground-water particle path projected onto model layer 1. Arrows indicate direction of flow.

B — Model cell containing hazardous-waste site.

Figure 4. Forward-particle tracking from hazardous-waste sites.

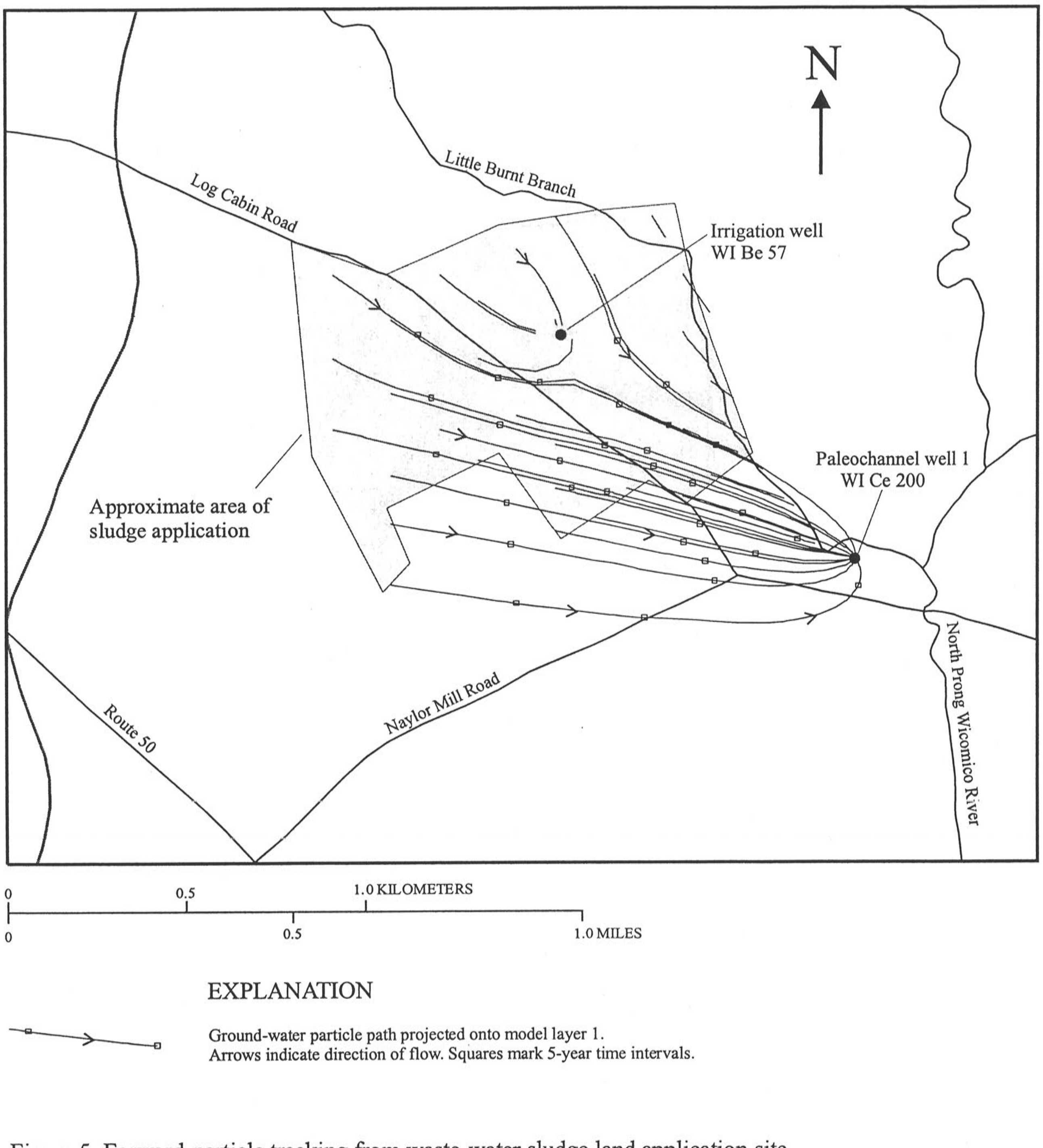


Figure 5. Forward-particle tracking from waste-water sludge land application site.

hydrogeologic framework. Section A-A' (fig. 6) trends west to east from the Quantico Wharf area to the City of Salisbury's Park well field. Section B-B' (fig. 7) trends north to south from the Town of Hebron to the Town of Allen. The hydrogeologic units shown in Section B–B' include, from oldest to youngest, the Choptank aquifer, the St. Mary's Formation (confining bed), the Manokin aquifer, lower confining bed, and the Salisbury aquifer.

The Choptank aquifer is a marginal marine to middle-shelf marine deposit (Owens and Denny, 1979b). The Choptank is predominantly an olive-gray, fine- to coarse-grained sand with shell fragments. It may be interbedded with olive gray, glauconitic, fine- to silty-grained sand and clayey silt (Achmad and Wilson, 1993). The Choptank aquifer dips to the southeast. Depth to the top of the Choptank is approximately 275 ft below sea level at WI Bd 72 and increases to 325 ft below sea level at WI Cd 92 (fig. 7).

The St. Mary's Formation unconformably overlies the Choptank aquifer throughout the Rockawalking Creek study area. The St. Mary's Formation, consisting primarily of olive gray, glauconitic, silty clay, forms a low-permeability confining bed. The top of the St. Mary's Formation dips in a southeasterly direction approximately 140 ft below sea level at WI Bd 72 (fig. 7) to 205 ft below sea level at WI Ce 276 (fig. 6). Thickness of the St. Mary's Formation in well WI Cd 92 is approximately 130 ft.

The Manokin aquifer, overlying the St. Mary's Formation, is a marginal marine to fluvial-deltaic deposit (Owens and Denny, 1979b; Hansen, 1981). The aquifer consists predominantly of gray, fine- to medium-graincd sand with shell fragments. Depth to the top of the Manokin aquifer increases from 37 ft below sea level near the northwestern part of the basin to 90 ft below sea level at Sharps Point south of the Wicomico River (fig. 8). Aquifer thickness is approximately 100 ft throughout the Rockawalking Creek study area.

Overlying the Manokin aquifer is the lower confining bed (Rasmussen and Slaughter, 1955; Andreasen and Smith, 1997). The lower confining bed is a relatively low permeability silty clay layer that separates the Salisbury and Manokin aquifers. Thickness of the bed ranges from 20 ft in the northwestern part of the Rockawalking Creek study area to 50 ft in the southern part of the basin near the Wicomico River. The lower confining bed is missing north of the Rockawalking Creek study area within the westward extension of the Salisbury Paleochannel (fig. 7).

Overlying the lower confining bed is the unconfined Salisbury aquifer (Hansen, 1966). Sands of the Salisbury aquifer are medium- to very coarse-grained and light tan in color. The Salisbury aquifer is composed of the Pensauken Formation and Beaverdam Sand (Andreasen and Smith, 1997). The bottom of the Salisbury aquifer is relatively flat, ranging in depth from 38 ft below sea level in the northern part of the study area to 33 ft below sea level in the southern part of the study area (fig. 9). North of the Rockawalking Creek study area the bottom of the Salisbury aquifer decreases to 58 ft below sea level near the southern limit of the Salisbury Paleochannel. Saturated thickness of the aquifer ranges from approximately 70 ft in the upper part of the study area to 35 ft in the southern part of the study area near the Wicomico River (fig. 10).

The Parsonsburg Formation (omitted from Sections A-A' and B-B') overlies the Salisbury aquifer throughout most of the Rockawalking Creek study area (Owens and Denny, 1979a). The Parsonsburg Formation consists of medium- to coarse-grained sand. Because of its permeable characteristic, the formation functions as part of the Salisbury aquifer in areas where it is saturated.

The Walston Silt (omitted from Sections A-A' and B-B') overlies the Salisbury aquifer in a relatively small area along the eastern part of the Rockawalking Creek study area (Owens and Denny, 1979a). This unit consists of silty-clay interbedded with thin layers of medium-grained sand. Its clayey characteristic may in places impede infiltration of recharge water from precipitation.

WATER LEVELS

A network of observation wells was established in the Rockawalking Creek study area to determine the hydraulic gradient and the direction of ground-water flow in the Salisbury aquifer. The network consisted of 12 domestic wells, three irrigation wells, and three test wells. In addition, six domestic wells screened in the Manokin aquifer were measured. Water levels measured in the wells were used to calibrate a ground-water-flow model. Altitudes of the water-level measuring points for 15 observation wells were surveyed to within 0.1 ft using National Geodetic Survey benchmarks. The accuracy of the altitudes of the water-level measuring points for the remaining wells in the network is within 5 ft. Synoptic water-level measurements were made during the spring (late March through early June) and fall (September and early October) of 1999.

A water-table map of the Salisbury aquifer was

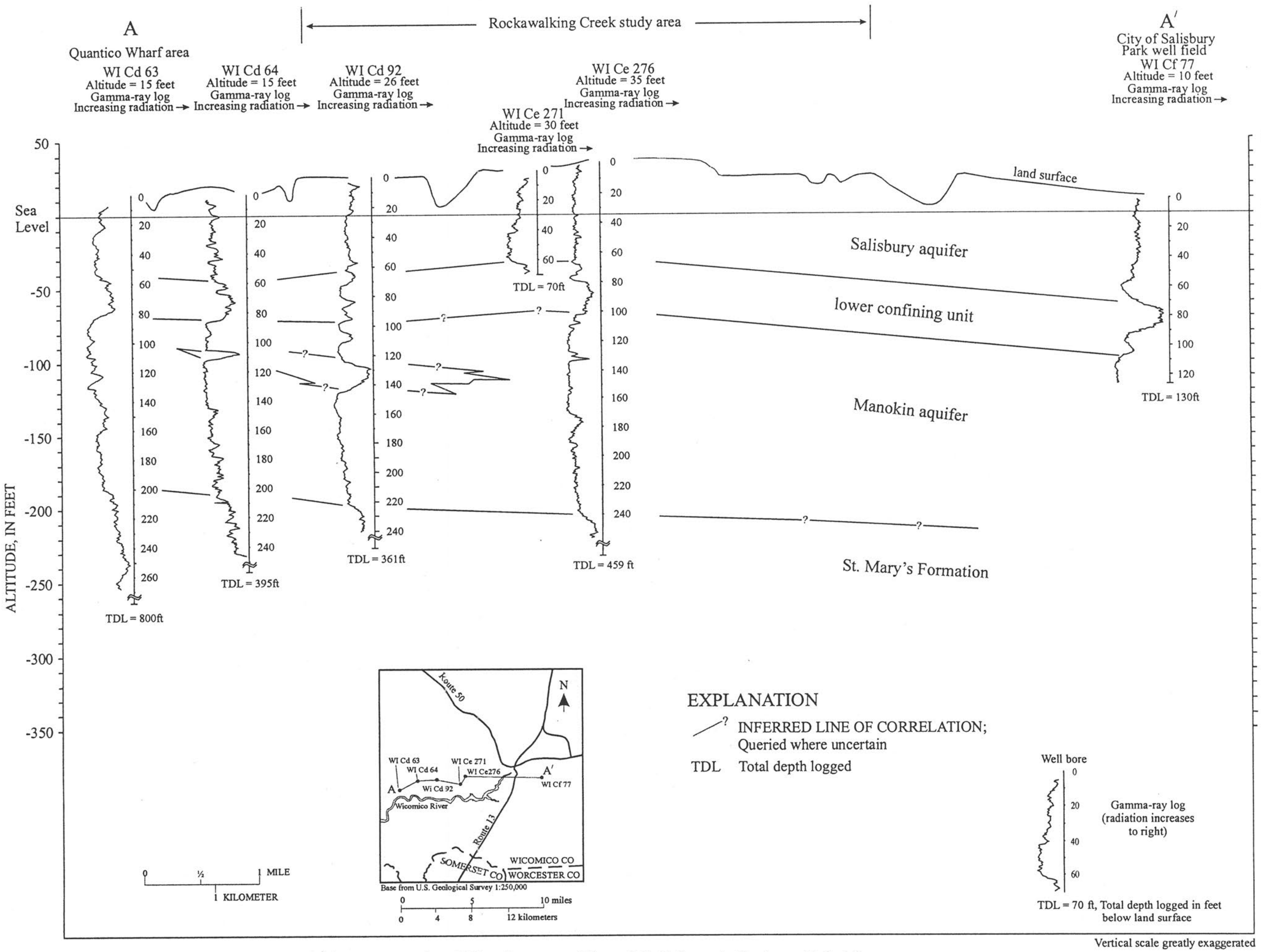


Figure 6. Hydrogeologic section A-A′ from Quantico Wharf area to City of Salisbury's Park well field.

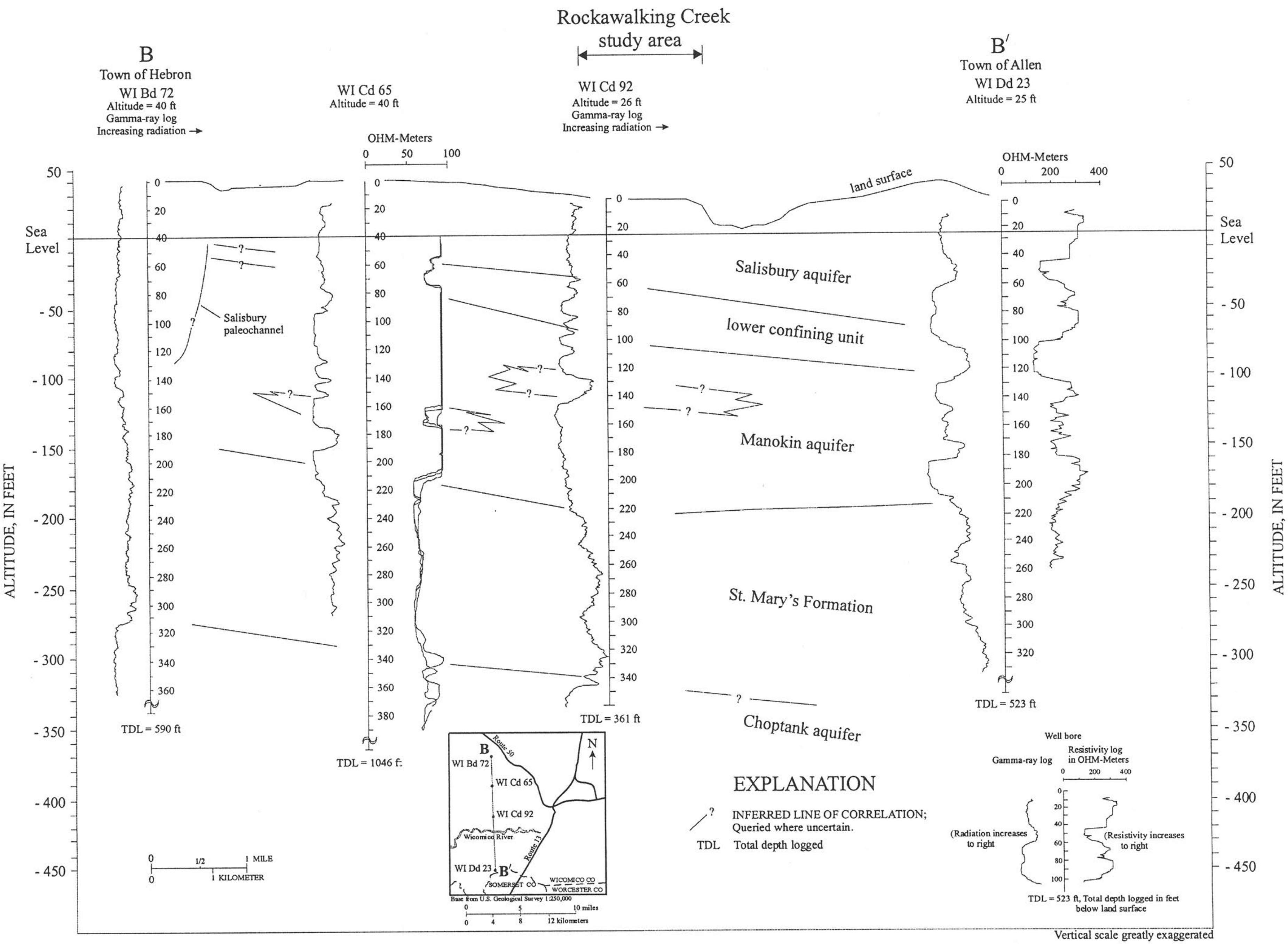
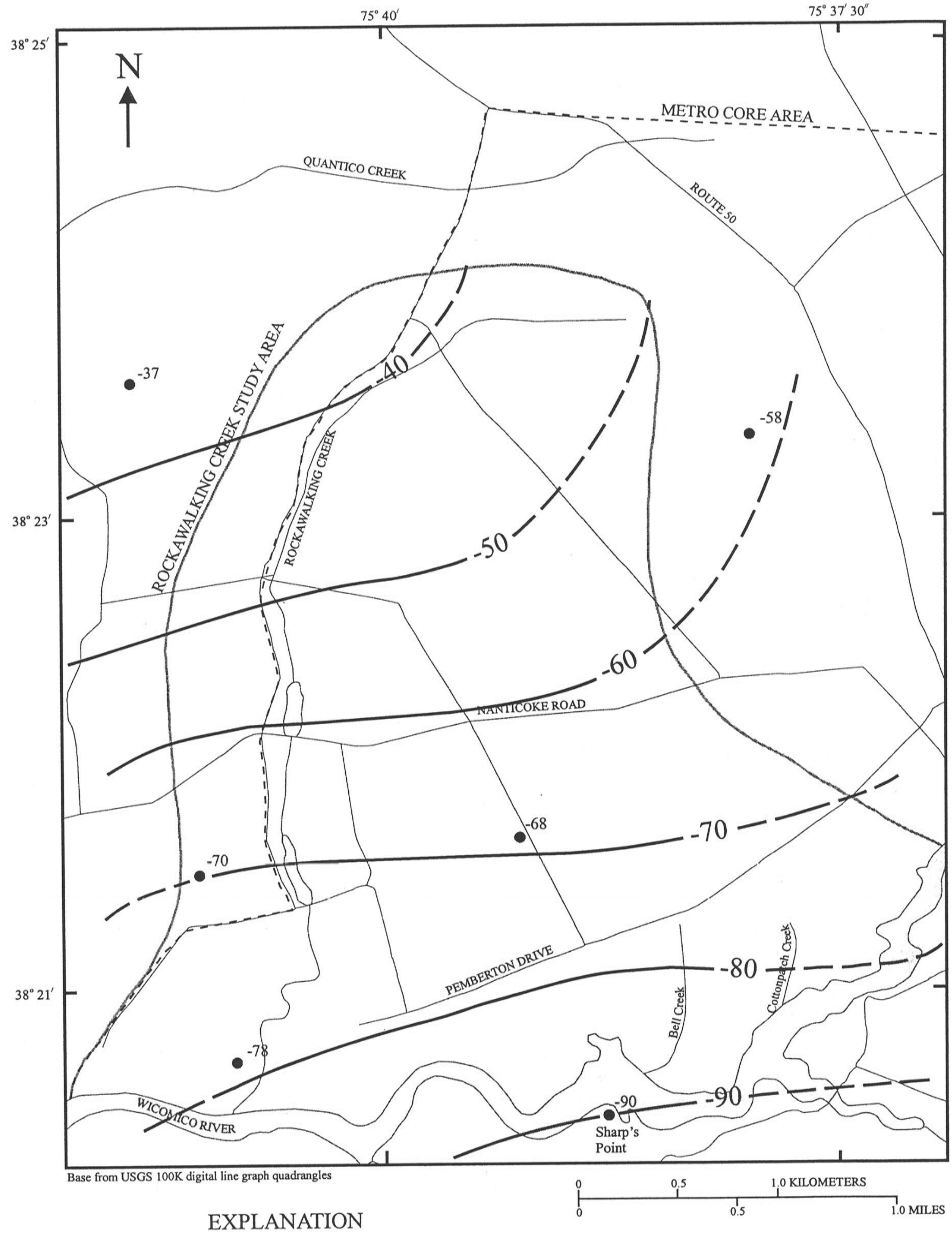


Figure 7. Hydrogeologic section B-B′ from Town of Hebron to Town of Allen.

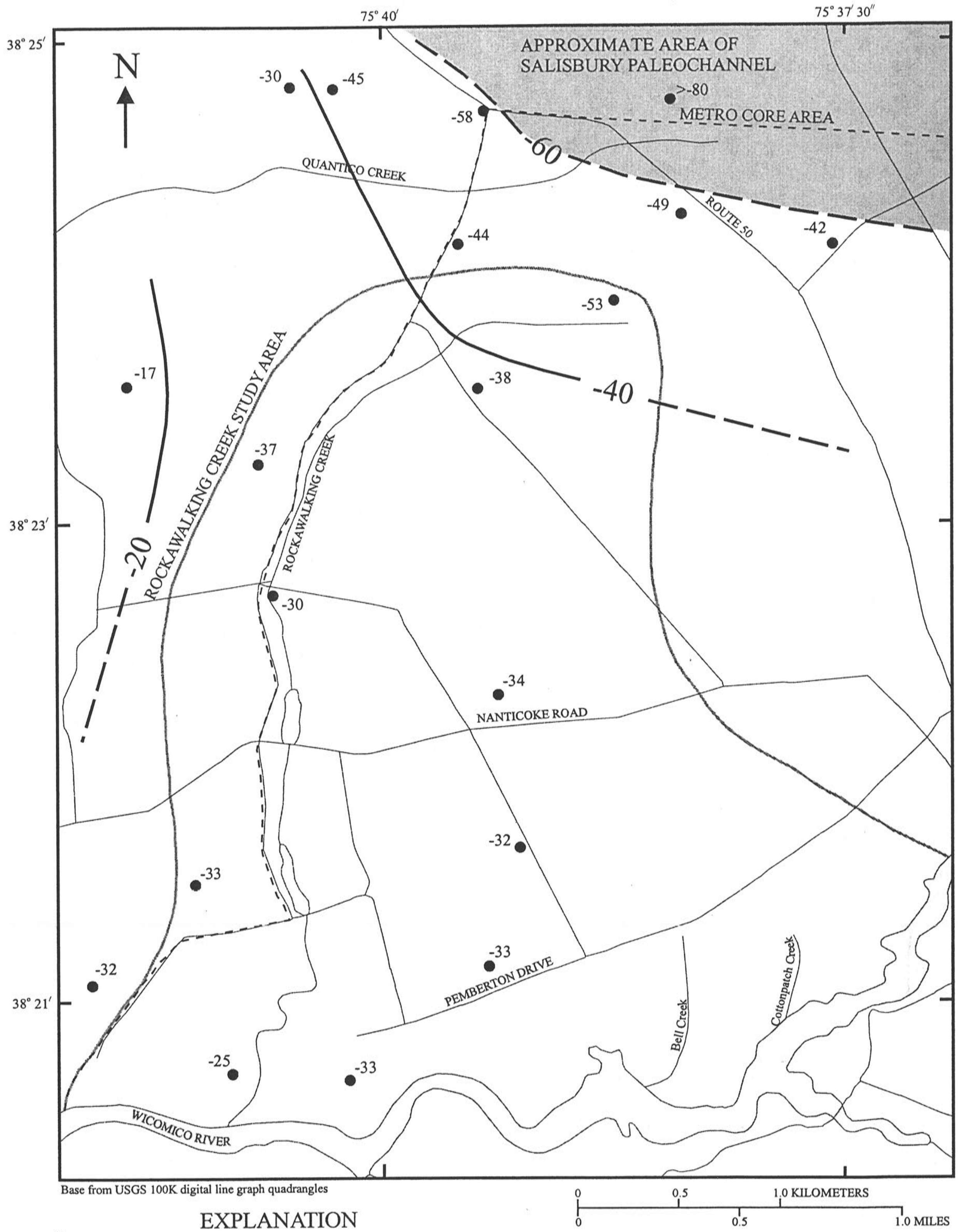


EXPLANATION

-40 LINE OF EQUAL ALTITUDE OF THE TOP OF THE MANOKIN AQUIFER -- Dashed where uncertain. Interval is 10 feet. Datum is sea level.

-78 ● WELL-DATA POINT -- Number is altitude of the top of the Manokin aquifer, in feet. Datum is sea level.

Figure 8. Altitude of the top of the Manokin aquifer.



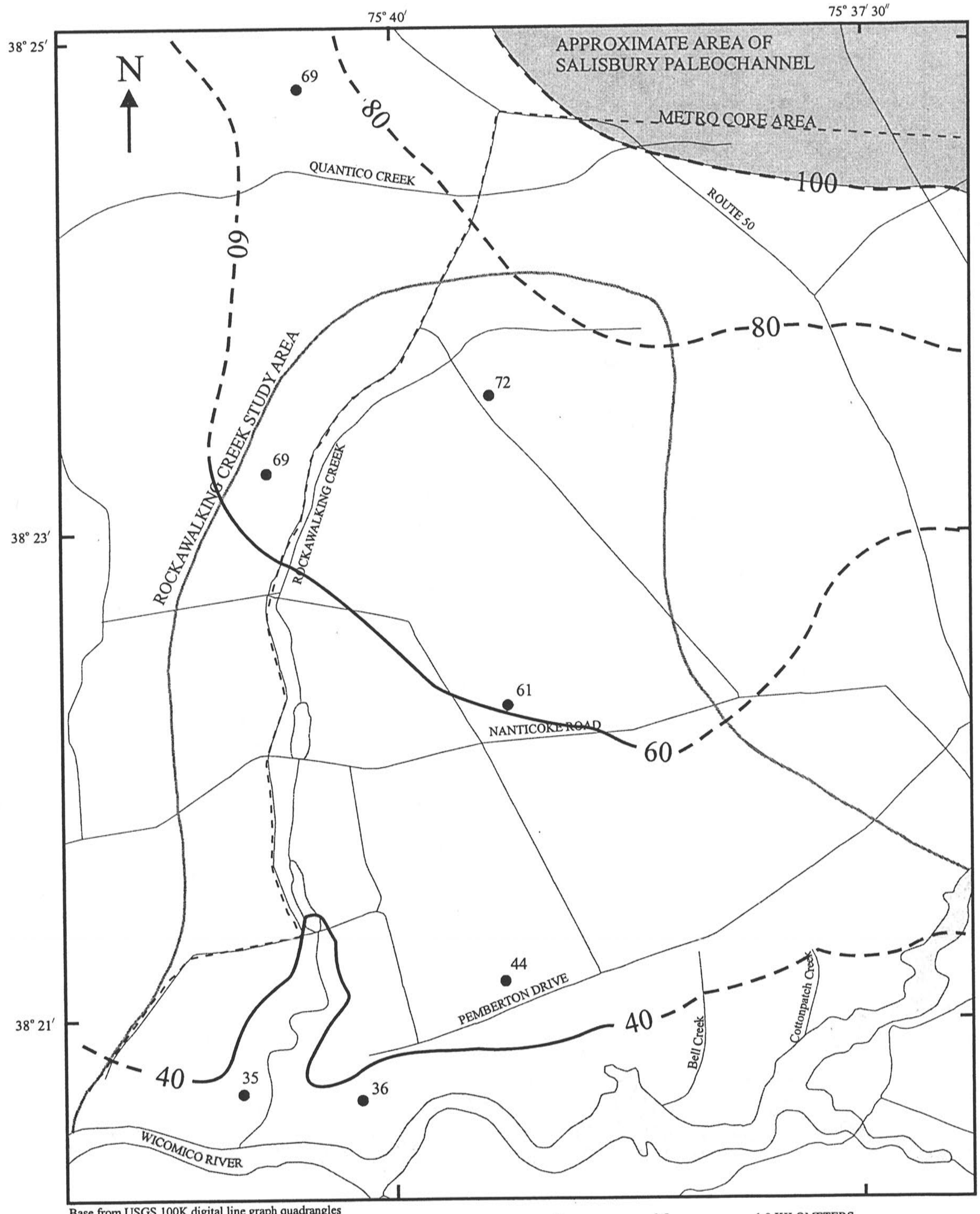
EXPLANATION

-40 LINE OF EQUAL ALTITUDE OF THE BOTTOM OF THE SALISBURY AQUIFER -- Dashed where uncertain. Interval is 20 feet. Datum is sea level.

-25 ● WELL-DATA POINT -- Number is altitude of the bottom of the Salisbury aquifer, in feet. Datum is sea level.

Approximate location of Salisbury paleochannel

Figure 9. Altitude of the bottom of the Salisbury aquifer.



EXPLANATION

40 — LINE OF EQUAL THICKNESS OF THE SALISBURY AQUIFER -- Dashed where uncertain Interval is 20 feet. Datum is sea level.

• 35 WELL-DATA POINT -- Number is thickness of the Salisbury aquifer, in feet. Datum is sea level.

Approximate location of Salisbury paleochannel

Figure 10. Saturated thickness of the Salisbury aquifer.

prepared using an average of the spring and fall measurements and 12 historical water levels (fig. 11). The water table in the northern part of the study area is relatively flat with water levels ranging from 30 to 36 ft above sea level. In the central and southern parts of the study area, the water table slopes toward the Wicomico River and Rockawalking Creek. Water levels in this area range from 3 to 30 ft above sea level. The water-table contours indicate no flow occurs across the boundary of the study area.

A water-level recorder was installed on observation well WI Ce 315, which is located in the central part of the study area at the University of Maryland Experimental Agricultural Station (UMEAS) (pl. 3), and screened in the Salisbury aquifer. Water-level fluctuations in WI Ce 315 respond to precipitation events (fig. 12) and pumpage from the adjacent irrigation well WI Ce 326, which is screened in the Salisbury aquifer. WI Ce 326 is located approximately 20 ft south of the observation well and periodically pumps 300 to 585 gallons per minute (gpm) for a duration of 4 to 8 hours within a 24-hour period (Fred Wells, University of Maryland Experimental Agricultural Station, oral commun., 2000). Daily water levels fluctuated from zero to 0.3 ft between November 1999 and late April 2000 as a result of infiltrating precipitation and barometric pressure changes. During that same period water levels overall fluctuated from approximately 31.5 to 32.5 ft above sea level as a result of seasonal changes in ground-water recharge. Between late April and September 2000 water levels fluctuated by as much as thirteen feet daily caused by pumping from well WI Ce 326. Two additional irrigation wells, WI Ce 123 and WI Ce 295 (pl. 3), at UMEAS may also cause minor water-level fluctuations in WI Ce 315. WI Ce 123 is located approximately 1,700 ft to the south and pumps intermittently at a rate of 300 to 425 gpm. WI Ce 295 is located approximately 900 ft to the west-southwest and is pumped at a similar rate, frequency, and duration as WI Ce 326 (Fred Wells, University of Maryland Experimental Agricultural Station, oral commun., 2000).

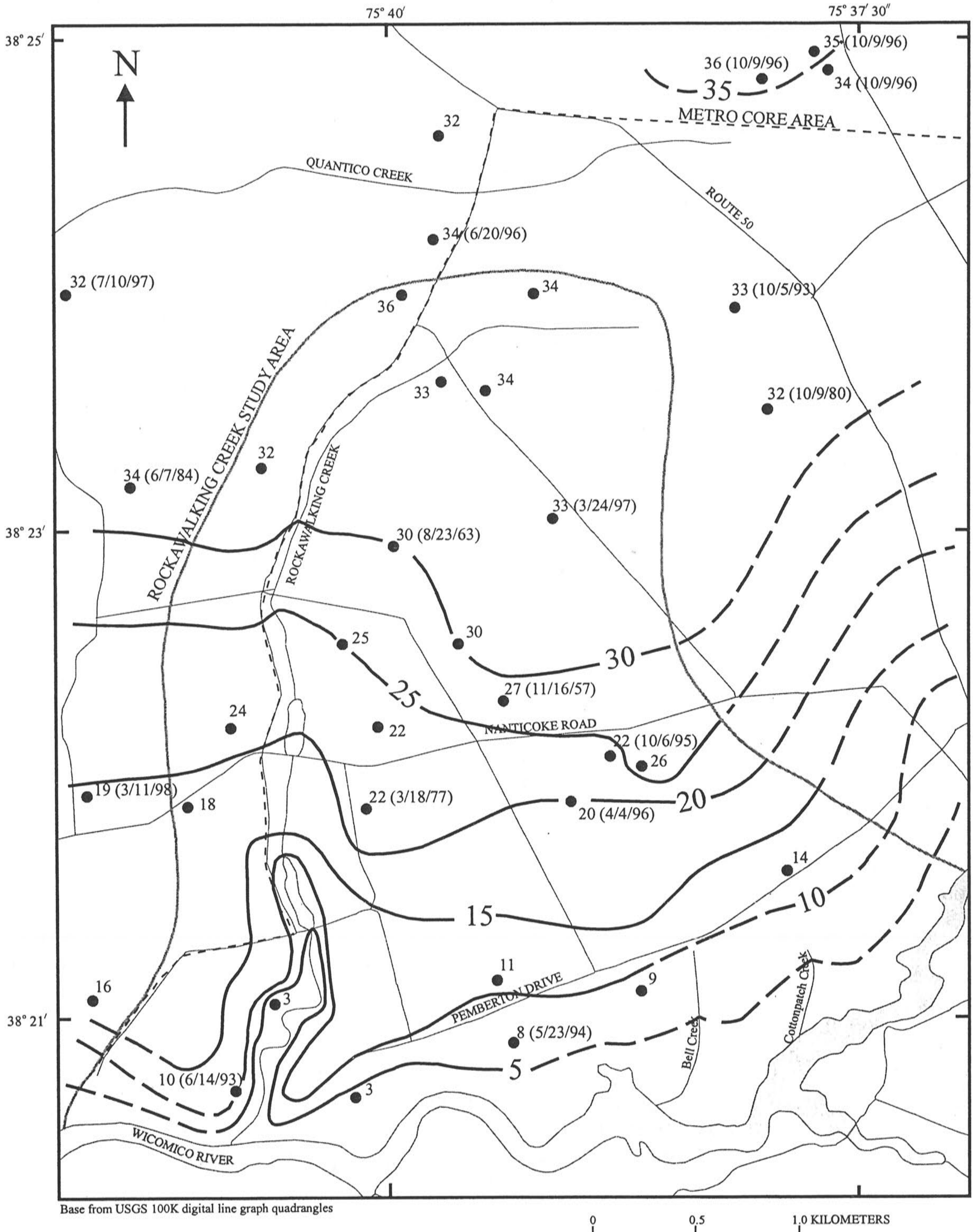
Water levels in the Salisbury aquifer measured in the fall of 1999 were higher than those measured in the spring of 1999. Water levels increased by an average of 1.19 ft. The higher water levels may be in part attributed to several episodic precipitation events that preceded the fall measurements. Water levels in the Salisbury aquifer are also affected locally by pumping wells. At observation well WI Ce 271 (pl. 3), a water-level fluctuation of 22.5 ft was measured over a 24-hour period caused by pumping from the irrigation well WI Ce 287 (pl. 3) which is located at a distance of approximately 15 ft. The discharge rate and duration of pumping of the irrigation well are unknown.

The vertical-head gradient between the Salisbury aquifer and the underlying Manokin aquifer was observed at two locations. In the northern part of the study area the water level in the Salisbury aquifer (measured in well WI Ce 280) was 6 ft higher than the water level in the Manokin aquifer (measured nearby in well WI Ce 279) (pl. 3). In the southern part of the study area the water level in the Salisbury aquifer (measured in well WI Cd 78) was 8 ft lower than that in the Manokin aquifer (measured nearby in well WI Cd 77) (pl. 3).

HYDRAULIC PROPERTIES

Limited data are available regarding the hydraulic properties of the Salisbury aquifer in the Rockawalking Creek study area. Aquifer tests from 4- to 6-hours in duration were conducted by well-drilling contractors at four irrigation wells (WI Cd 73, WI Ce 272, WI Ce 315, and WI Ce 325) located in the central and northern parts of Rockawalking Creek study area (pl. 3). Transmissivity was calculated from the test data using a formula developed by Theis (1935) and Cooper and Jacob (1946). During the tests the wells were pumped at constant rates ranging from 116 to 343 gallons per minute (gpm). The transmissivity values calculated ranged from 2,400 to 14,400 ft^2/d. The horizontal hydraulic conductivity, which is equal to the transmissivity divided by the saturated thickness, of the Salisbury aquifer at the four sites tested ranged from 32 to 221 feet per day (ft/d). No discernible spatial trend is apparent in the transmissivity data. Transmissivity of the Salisbury aquifer in the Rockawalking Creek study area is generally less than that in the nearby City of Salisbury Park well field. In the Park well field, transmissivity averages approximately 13,000 ft^2/d (Andreasen and Smith, 1997; Boggess and Heidel, 1968).

The lower confining bed separating the unconfined Salisbury aquifer from the deeper confined Manokin aquifer has reported vertical hydraulic conductivity values ranging from 2.8×10^{-5} to 1.8×10^{-3} ft/d (Andreasen and Smith, 1997; Wolff, 1970). These values were obtained from field and laboratory analyses of core material from the City of Salisbury's Park well field.



EXPLANATION

—10— WATER-TABLE CONTOUR, IN FEET ABOVE SEA LEVEL -- Dashed where uncertain. Contour interval is 5 feet.

16 ● WELL-DATA POINT -- Average water level between spring and fall 1999, in feet above sea level

● 20 (4/4/96) WELL-DATA POINT -- Historic water level, in feet above sea level, and date measured

Figure 11. Altitude of the water table of the Salisbury aquifer.

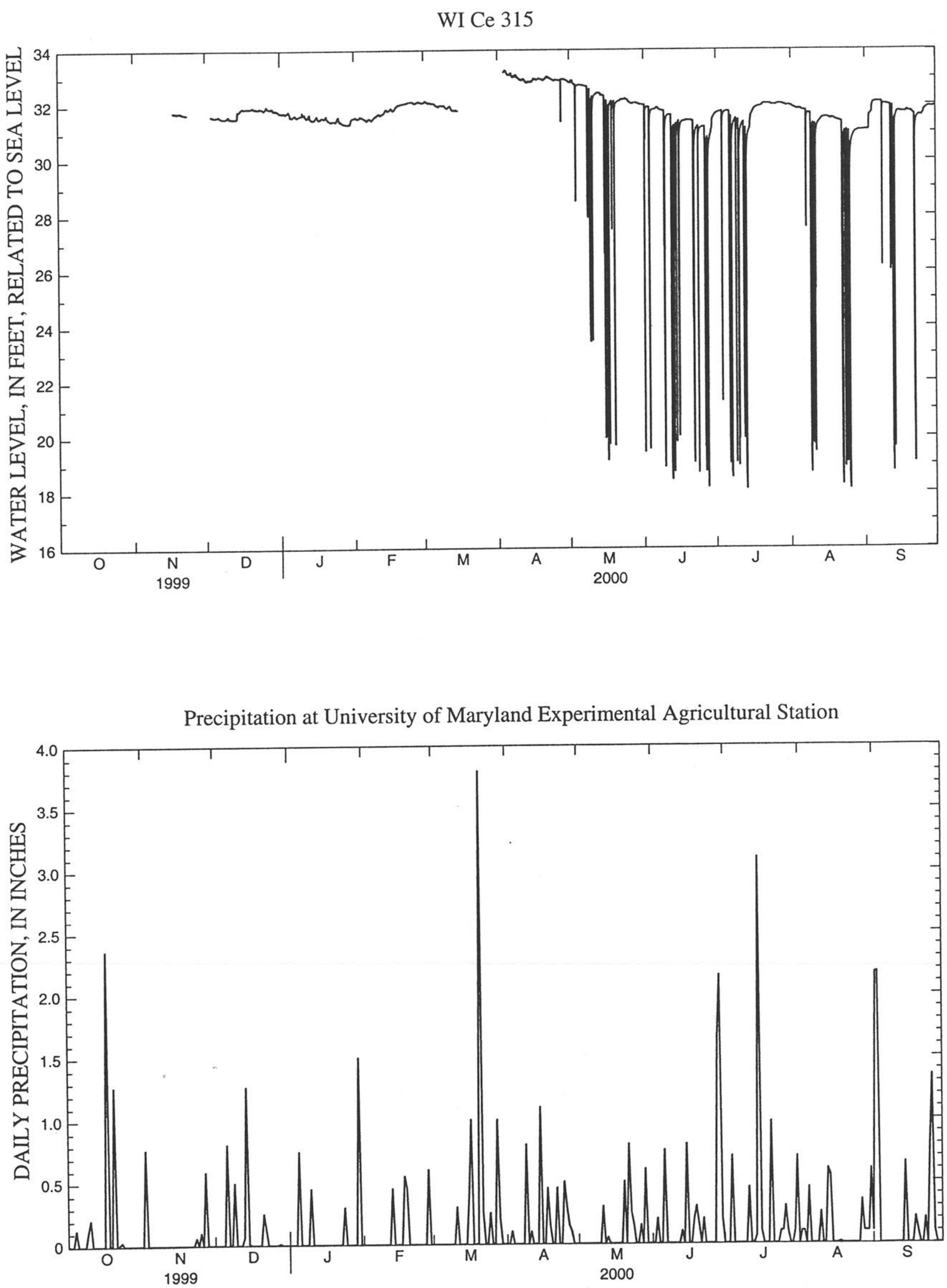


Figure 12. Water-level fluctuations in well WI Ce 315 and precipitation measured at the University of Maryland Experimental Agricultural Station.

BASEFLOW

In this report, the amount of water supplying an unconfined aquifer from precipitation after evapotranspiration is subtracted is referred to as effective recharge. The effective recharge is equal to the amount discharged from the aquifer to surface-water bodies (baseflow) and to wells. This relation assumes no change in aquifer storage, no ground-water flow in or out of the basin, and no exchange of water with deeper aquifers. Provided these assumptions are met, baseflow and pumpage within a ground-water basin can be used as a gross estimate of the effective recharge.

Baseflow measurements were made at four sites during the spring and fall of 1999 (fig. 13). Site 1 was located at the downstream extent of the non-tidal part of Rockawalking Creek at the outlet of Anderson Mill Pond. Site 2 was located on Rockawalking Creek approximately 100 yards downstream of Crooked Oak Lane. Site 3 was located on Bell Creek and Site 4 was located on Cottonpatch Creek. Two sets of synoptic measurements were made during both the spring and fall of 1999. All measurements were made at least 5 days after rainfall with the exception of the first measurements which were made 1 day after rainfall, so that flow in the streams would be close to baseflow conditions. A period of higher than normal rainfall prior to the fall measurements resulted in high water levels, which in turn resulted in high baseflow.

Baseflow for Rockawalking Creek Basin, which is the largest basin in the study area above Site 1 was converted to a linear effective recharge rate by dividing by the approximate basin area of 7 x 10^7 feet squared (ft^2). Baseflow at the site ranged from 3.05 to 7.86 cfs. Pumpage was not added to the baseflow amount in calculating effective recharge because total pumpage in the Rockawalking Creek Basin is relatively low. The resulting effective recharge values ranged from 16.49 to 42.49 in./yr. Calculated effective recharge to the Salisbury aquifer in the Beaverdam Creek Basin (pl. 1) ranged from 11.4 in./yr for the period 1950-52 (Rasmussen and Andreasen, 1959) to 13.4 in./yr for the period 1931-76 (Andreasen and Smith, 1997). Several factors that may have attributed to the high values calculated in the Rockawalking Creek Basin compared to the Upper Wicomico River Basin include: (1) slow drainage from up-gradient ponds and wetlands (Halford and Mayer, 2000); (2) low estimate of basin drainage area; (3) errors associated with baseflow measurements including measurements at Site 1, which were characterized as "poor" during the fall 1999 measurements because of channel constrictions and required use of an undersized-flow meter, and; (4) baseflow measurements were higher than the long-term average baseflow for the creek.

Baseflow in Bell Creek (Site 3) and Cottonpatch Creek (Site 4) ranged from 0.03 to 0.58 cfs. Effective recharge for these relatively small basins were not calculated because of difficulty delineating basin boundaries.

GROUND-WATER USE

All appropriated ground-water use over 10,000 gal/d from the Salisbury aquifer is for irrigation wells (fig. 14; app. C). Annual average pumpage from these well fields totaled approximately 0.74 Mgal/d in 1998. Pumpage from the most recent year reported was used for well fields that did not report in 1998. Most of the irrigation wells are located in the north-central and south-central part of the study area.

Reported withdrawals are estimates of either pump operation time and pumping rate or the amount of water required for a particular crop during a drought year. Reported withdrawals may overestimate actual withdrawals by as much as 25 percent (Patrick Hammond, Maryland Department of Environment, oral communication, 1999). Factors that may contribute to the overestimation of reported withdrawals include: (1) use of estimated pumping rates based on 100-percent pump efficiency; (2) water-use calculations using a drought year for a reporting period without a drought, and; (3) water-use calculations using a crop requiring higher water use than the crop actually planted during the year reported. The only exception to these methods of estimation was the method used by University of Maryland Experimental Agricultural Station (Ground-water Appropriation Permit [GAP] WI97G012). For that site ground-water use was estimated by multiplying the acreage irrigated by the number of inches of water accumulated in a pan located in the irrigated field.

Domestic water use of the Salisbury aquifer from individual wells is approximately 0.37 Mgal/d. This estimate was made by counting lots within housing subdivisions located on county tax maps. The number of developed lots was estimated at 90 percent of the total recorded lots and the associated ground-water withdrawals were estimated to be 90 percent from the Salisbury aquifer. These estimates were derived from field inspection of subdivisions and a review of well depths from well-completion reports. Ground-water use was estimated to be 300 gal/d for each domestic well. Most of the domestic use is from 2- and 4-inch diameter wells located in the western half of the study area.

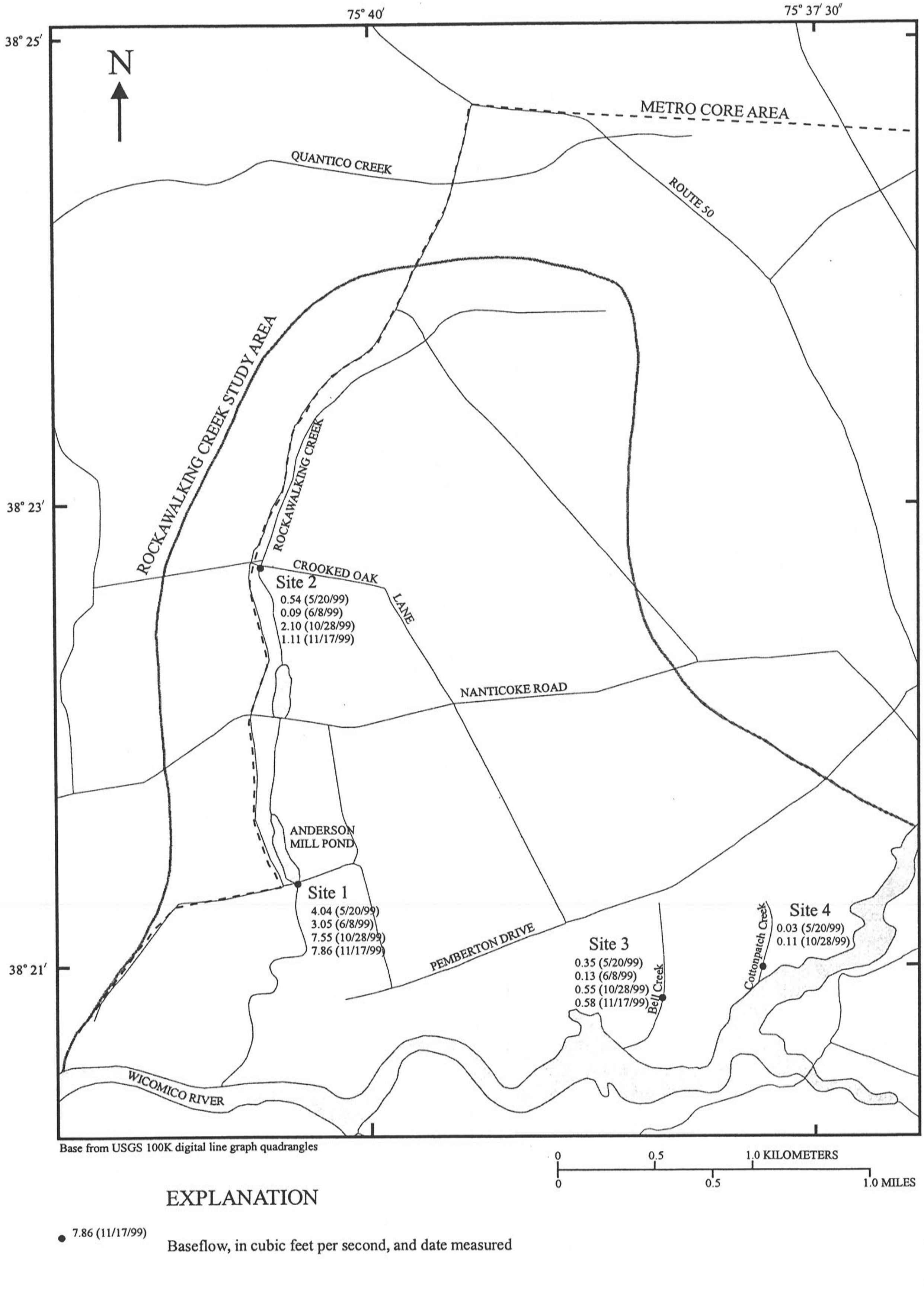


Figure 13. Location of baseflow measurement sites in the Rockawalking Creek study area.

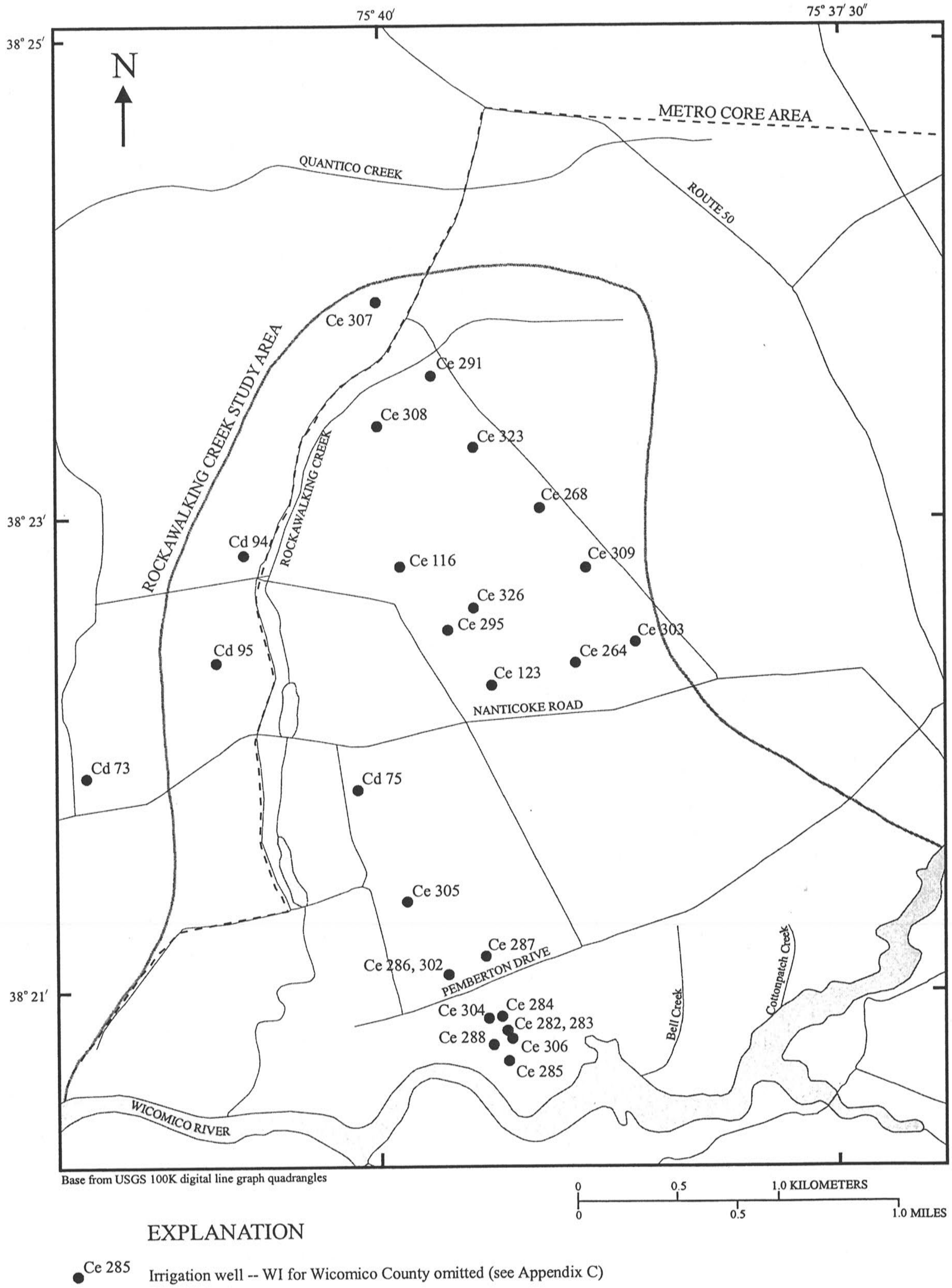


Figure 14. Location of wells screened in the Salisbury aquifer with ground-water appropriation permits over 10,000 gallons per day in the Rockawalking Creek study area.

There is no appropriated ground-water use of the Manokin aquifer within the Rockawalking Creek study area. The Manokin aquifer is primarily used for domestic supply. Ground-water use in the Choptank aquifer within the study area consists of domestic use and one public-water supply (Steeplechase subdivision—GAP WI92G048).

SIMULATION OF GROUND-WATER FLOW IN THE ROCKAWALKING CREEK STUDY AREA

Ground-water flow in the Salisbury aquifer within the Rockawalking Creek study area was simulated using the U.S. Geological Survey's three-dimensional, finite difference model MODFLOW (McDonald and Harbaugh, 1988). The modeled area included the Rockawalking Creek Basin and smaller adjacent basins including Cottonpatch Creek and Bell Creek.

A single-layer model was developed using the hydrogeologic framework discussed previously. The model simulated steady-state, water-table conditions in the Salisbury aquifer using estimated pumpage from the most recent year available as indicated in Appendix C. Starting heads used in the model were averages of synoptic, water-level measurements made mostly during the spring and fall of 1999. Model-input parameters included recharge, horizontal hydraulic conductivity, Salisbury aquifer bottom elevations, river stage, river-bottom elevation, river-bottom conductance, and pumpage. The model was calibrated to average water levels observed in the Salisbury aquifer and estimated recharge from baseflow measurements from Rockawalking Creek by systematically varying recharge, aquifer horizontal hydraulic conductivity, river-bottom conductance, and pumpage.

CONCEPTUAL MODEL

The conceptual model incorporates the hydrogeologic features of the Salisbury aquifer in the Rockawalking Creek study area. The flow system of the Salisbury aquifer within the study area corresponds to the surface-water basins of Rockawalking, Cottonpatch, and Bell Creeks. In general, water enters the aquifer in topographically high areas in the northern part of the study area and discharges to Rockawalking Creek, the Wicomico River, and the smaller streams within the study area. A relatively low-permeability clay layer, which is referred to in this report as the lower confining bed, impedes the amount of vertical flow between the Salisbury aquifer and the underlying artesian Manokin aquifer.

The conceptual model assumes steady-state conditions. The Salisbury aquifer in the study area is assumed to be in a state of dynamic equilibrium with respect to the effect of changing stresses of recharge and pumpage on water levels. Water levels respond to short-term changes in recharge and pumpage, but show no long-term trends; therefore, there is no change in aquifer storage. Long-term, steady-state conditions in the Salisbury aquifer were observed in the adjacent Upper Wicomico River Basin using historical ground-water level and baseflow records (Andreasen and Smith, 1997).

GRID DESIGN AND BOUNDARY CONDITIONS

The model grid consists of 70 columns, 90 rows, and 1 layer (fig. 15). The grid is aligned in a north-south orientation. Model cells measure 170 x 170 ft and are of uniform dimension throughout the model area. The total area covered by the grid is approximately 6.5 square miles (mi^2).

Boundary conditions within the model correspond to natural flow boundaries. The lateral boundary of the Salisbury aquifer along the basin perimeter of Rockawalking, Cottonpatch, and Bell Creeks (topographic highs) was represented by a general-head boundary (fig. 15). This boundary is assumed stationary over the long term. A low horizontal hydraulic conductivity was assigned to the general-head boundary to simulate a no-flow condition. On the eastern side of the basin, however, pumping wells may induce flow from outside the basin. To represent this condition, the horizontal hydraulic conductivity of the general-head boundary was increased in that area to allow flux across the boundary. Hydraulic heads along the general-head boundary were estimated using water-level contours derived from the observation-well network.

The Salisbury aquifer is underlain by the low-permeability clay of the lower confining bed. This contact was modeled as a no-flow boundary because:

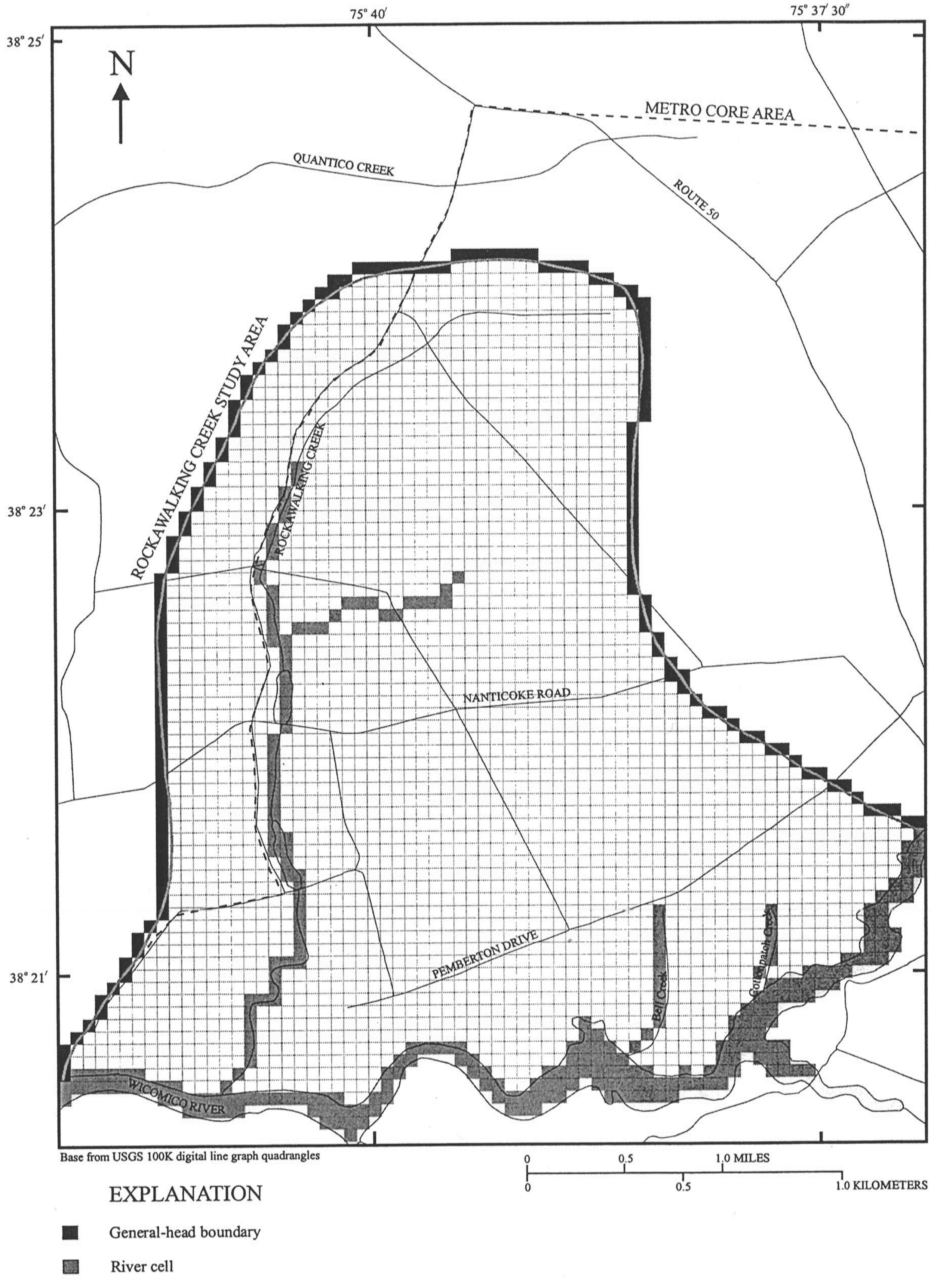


Figure 15. Location of grid and boundary conditions used in the finite-difference, ground-water-flow model of the Rockawalking Creek study area.

(1) laboratory and field tests of the lower confining bed at the nearby City of Salisbury Park well field indicated a relatively low vertical hydraulic conductivity ranging from 2.8 x 10^{-5} to 1.8 x 10^{-3} ft/d (Andreasen and Smith, 1997; Wolff, 1970); and (2) the lower confining bed is approximately 20 to 50 ft thick.

HYDRAULIC PARAMETERS

For unconfined conditions, MODFLOW calculates transmissivity by multiplying horizontal hydraulic conductivity by saturated thickness. Saturated thickness was calculated by the model using model-generated water levels from which the input values of the Salisbury aquifer bottom elevations were subtracted. A uniform horizontal hydraulic conductivity was assigned to the model. The initial value assigned was within the estimated range for the Salisbury aquifer in the Rockawalking study area, but was later adjusted downward during model calibration.

RECHARGE

The recharge term in the model represents the effective recharge (recharge after evapotranspiration has been subtracted). The recharge rate initially applied to the model was 13 in./yr or 3.0 x 10^{-3} ft/d (Andreasen and Smith, 1997). This amount was distributed evenly to the Salisbury aquifer. During calibration, the rate was increased to 20 in./yr or 4.6 x 10^{-3} ft/d.

RIVER SIMULATION

Surface-water bodies, including creeks, ponds, and rivers, were represented in the model. The model simulates rivers as head-dependent flux boundaries. Flux across the river boundaries is calculated using Darcy's Law and assigned values for river stage, river-bottom elevation, and hydraulic conductance of the river-bottom sediment. The hydraulic conductance of the river-bottom sediment is a product of the river length, width, and vertical hydraulic conductivity of the bottom sediment divided by the thickness of river-bottom sediment. Vertical hydraulic conductivity of the river-bottom sediment was estimated based on sediment type (Freeze and Cherry, 1979). The values assigned were 200 ft/d in the non-tidal part of Rockawalking Creek and approximately 0.1 ft/d in the tidal part of the creek south of Anderson Pond. Visual examination of stream-bottom sediment indicated clean, medium to coarse sand in the non-tidal part of the creeks and muddy silt in the tidal part. A horizontal to vertical hydraulic conductivity ratio of 1:1 was assumed. Only perennial stream segments were represented in the model. All river cells were gaining in which water discharged from the aquifer to the river with the exception of a few river cells in the upper reaches of Rockawalking Creek, which were losing reaches with water flowing from the river to the aquifer. This anomaly was an erroneous situation caused by averaging of water levels over model cells.

The Wicomico River and tidal part of Rockawalking Creek were initially represented by constant-head boundaries set to sea level. However, this representation resulted in simulated heads lower than measured heads in the central and northern parts of the basin. To reduce the flux to the Wicomico River and the tidal part of Rockawalking Creek and in turn increase the heads in the Salisbury aquifer the boundary was represented by the river package with a river-bottom vertical hydraulic conductivity of 0.1 ft/d.

PUMPAGE

Pumpage from wells appropriated for more than 10,000 gal/d totaled approximately 0.73 Mgal/d. This amount, initially used in the model, resulted in simulated water levels lower than measured water levels. During model calibration the initial pumpage estimate was reduced by 50 percent - given the possible error in the methods used to report pumpage and model results. Pumpage at the University of Maryland Experimental Agricultural Station (wells WI Ce 123, WI Ce 295, and WI Ce 326) was left at the reported amount of 0.03 Mgal/d because of higher confidence in their reporting methods. Pumpage from individual model cells for wells appropriated for more than 10,000 gal/d ranged from 1.8 x 10^{-3} to 4.8 x 10^{-2} Mgal/d (fig. 16).

Domestic ground-water use from individual wells was input to the model in areas of subdivisions. Pumpage from individual model cells ranged from 370 to 930 gal/d and totaled approximately 0.37 Mgal/d (fig. 16).

STEADY-STATE CALIBRATION

During model calibration recharge, horizontal hydraulic conductivity, river-bottom vertical hydraulic conductivity, and pumpage were systematically varied throughout a range of values that was considered

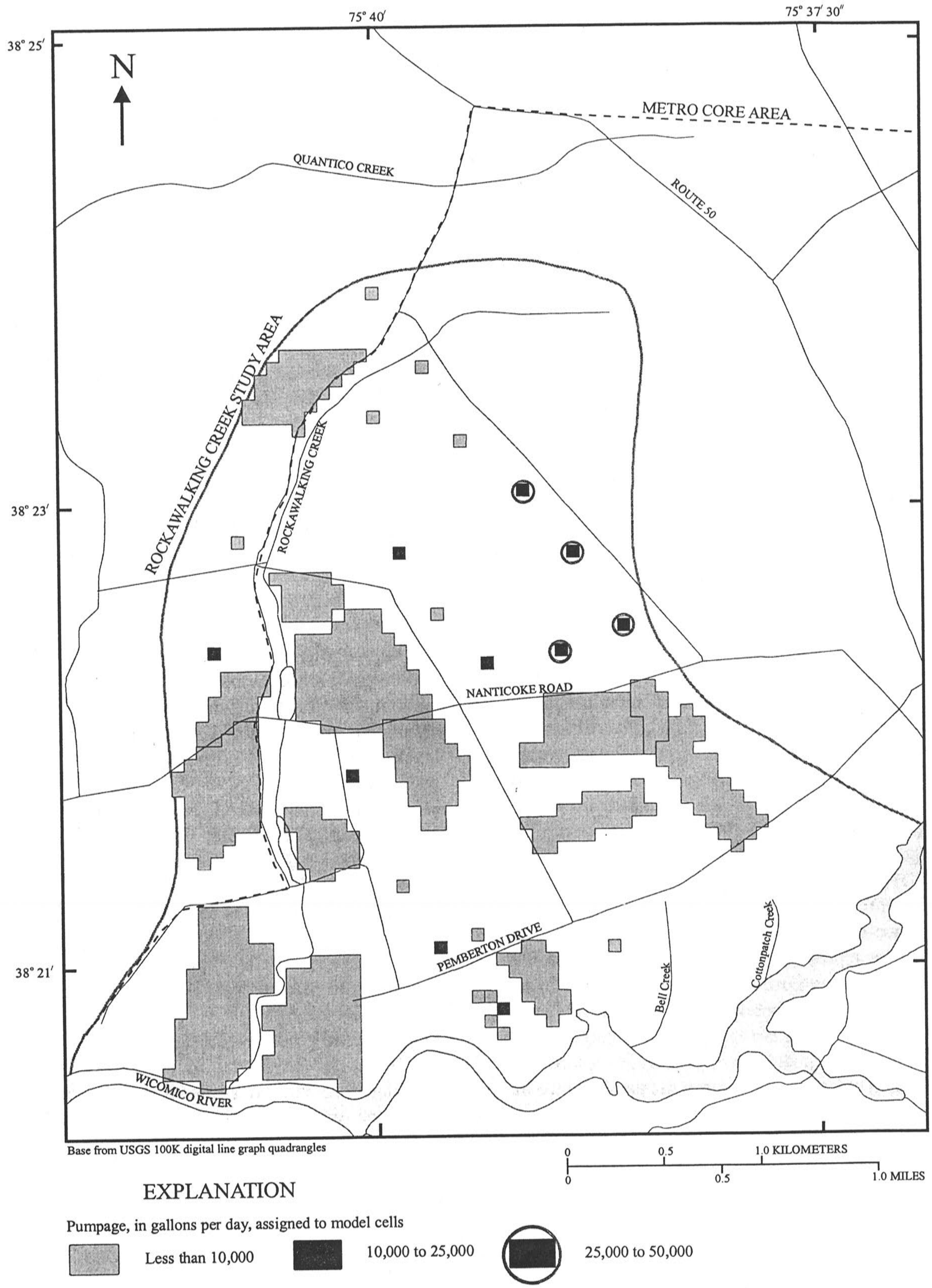


Figure 16. Location of pumpage used in the calibrated, steady-state model of the Rockawalking Creek study area.

representative of the conditions found in the Rockawalking Creek study area. Recharge was varied from 13 to 20 in./yr. The calibrated value was 20 in./yr, which is within the range of the estimated effective recharge determined from baseflow measurements in Rockawalking Creek. Pumpage from wells appropriated for more that 10,000 gal/d was varied from 100 percent to 50 percent of the reported values. The calibrated value of 0.37 Mgal/d was 50 percent of the reported values. Domestic pumpage from individual wells within subdivisions were held constant at the estimated value of 0.37 Mgal/d. Total calibrated pumpage equaled 0.74 Mgal/d. Horizontal hydraulic conductivity of the Salisbury aquifer was varied from 20 to 300 ft/d. Changes to horizontal hydraulic conductivity were initially uniform over the entire model domain. To improve the match between simulated and measured water levels, three zones of horizontal hydraulic conductivity were assigned: (1) a northern zone located north of Nanticoke Road at 100 ft/d; (2) a central zone surrounding and paralleling Nanticoke Road at 20 ft/d, and; (3) a southern zone located south of Nanticoke Road at 50 ft/d. Transmissivity is a product of horizontal hydraulic conductivity and saturated thickness of the aquifer. The assigned horizontal hydraulic conductivity array together with the saturated thickness of the aquifer resulted in modeled transmissivity values ranging from 800 to 7,500 ft^2/d. Transmissivities calculated from four aquifer tests ranged from 2,400 to 14,400 ft^2/d. The highest modeled transmissivities of 6,500 to 7,500 ft^2/d occur in the northern part of the study area where both the horizontal hydraulic conductivity and saturated thickness are greatest. River-bottom vertical hydraulic conductivities were varied during model calibration from 0.07 to 600 ft/d. The final calibrated values were 0.07 ft/d for tidal reaches and 200 ft/d for non-tidal reaches.

The model was considered calibrated when a best match was obtained between simulated and measured water levels (fig. 17) and baseflow in Rockawalking Creek. The sum of the absolute differences between simulated and an average of measured water levels from 14 observation wells ranged from 39 to 93 ft for a number of model simulations. The model was considered calibrated at 39 ft. Simulated outflow (baseflow) to modeled river cells representing Rockawalking Creek, which conceptually represent baseflow to the creek, ranged from 1.39 to 1.75 cubic feet per second (ft^3/s). The calibrated baseflow equaled 1.72 ft^3/s compared to the average baseflow measured in Rockawalking Creek (Site 1) of 5.63 ft^3/s. The difference between simulated and measured baseflow may be caused in large part by Rockawalking Creek not being at baseflow conditions at the time of measurement.

Model calibration was limited for several reasons: (1) water levels used to calibrate the model may be different than the long-term average steady-state water levels; (2) limited knowledge of the hydraulic characteristics of the Salisbury aquifer and river-bottom sediments and, (3) uncertainty of the actual pumpage rates in the study area.

The water budget for the calibrated model consisted of a total inflow of 3.124 Mgal/d. This was balanced by an equal outflow. Inflow consisted of recharge (3.070 Mgal/d) and river leakage (0.055 Mgal/d). Outflow consisted of pumpage from wells (0.740 Mgal/d) and river leakage (2.384 Mgal/d). Flux across the general-head boundary on the east side of the model was insignificant. The difference between total inflow and outflow was less than 0.01 percent.

SENSITIVITY ANALYSIS

Model input parameters derived from the available field data approximate the complex, heterogeneous characteristics of the aquifer and flow system. As such, variations between approximated and actual parameter values are inevitable. To determine the sensitivity of the model to variations in input parameters, measured heads and baseflow were compared to simulated heads and baseflow as model-input parameters were varied over a range considered reasonable. Model parameters varied included recharge, horizontal hydraulic conductivity of the Salisbury aquifer, river-bottom hydraulic conductivity, and pumpage. Simulated heads were most affected by changes in recharge and aquifer horizontal hydraulic conductivity. A 50-percent reduction in the calibrated recharge rate resulted in a 44-percent increase in the sum of the absolute differences between measured and simulated water levels. A 50-percent reduction and two-fold increase in the horizontal hydraulic conductivity resulted in an 88- and 18-percent increase in the sum of the absolute differences between measured and simulated water levels, respectively. Simulated baseflow was primarily affected by changes in the recharge rate. A 25- and 50-percent reduction in the recharge rate lowered simulated baseflow by 41 and 82 percent, respectively. A three-fold increase in the calibrated river-bottom hydraulic conductivity decreased the sum of the absolute differences between measured and simulated water levels by 31 percent. However, the three-fold increase in the river-bottom

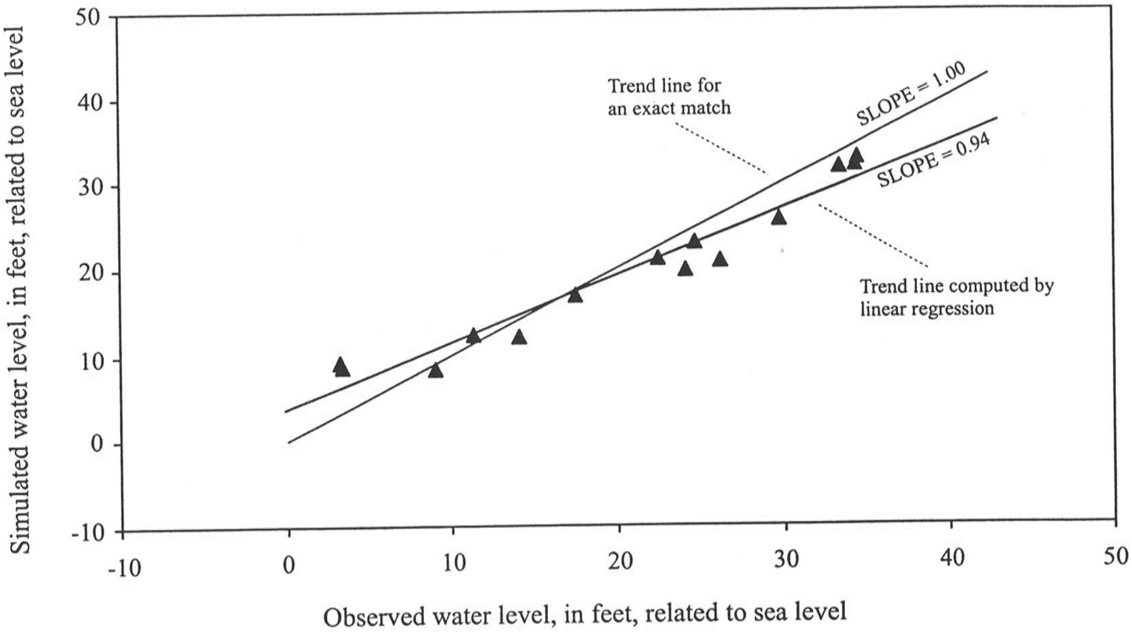


Figure 17. Relation between observed and simulated water levels in the Salisbury aquifer.

hydraulic conductivity resulted in only a 7-percent decrease in simulated baseflow. A three-fold increase in the calibrated pumpage resulted in a 23-percent increase in the sum of the absolute differences between measured and simulated water levels and 55-percent decrease in the simulated baseflow.

PARTICLE TRACKING IN THE ROCKAWALKING CREEK STUDY AREA

The steady-state, ground-water flow model (MODFLOW) developed for the Rockawalking Creek study area was used in conjunction with the U.S. Geological Survey's particle-tracking program MODPATH to estimate contributing areas of four hypothetical public-supply production wells and existing domestic wells within subdivisions. Particles were tracked backwards from model cells that represented the pumping wells. The area where particles terminated at the water table defined the contributing areas of the wells. In addition to the outputs of head and budget terms from the ground-water-flow model, MODPATH requires the input of porosity to calculate particle velocity. A uniform porosity of 0.25 was used for the Salisbury aquifer. This value is typical of medium- to coarse-grained sand (Freeze and Cherry, 1979).

CONTRIBUTING AREAS FOR HYPOTHETICAL PUBLIC-SUPPLY PRODUCTION WELLS

Currently, there are no public-supply wells pumping from the Salisbury aquifer in the Rockawalking Creek study area. Continued growth will require additional ground-water withdrawals which could be obtained from high-capacity public-supply production wells. Five model runs were made to determine the potential contributing areas of hypothetical production wells screened in the Salisbury aquifer. The first four model runs simulated that the pumpage from the hypothetical production wells were in addition to existing irrigation and domestic use. The fifth model run simulated a hypothetical production well that replaced appropriated irrigation use at one site.

Contributing areas for the hypothetical public-supply production wells were determined by placing an array of particles on each side face of the model cells representing the hypothetical production wells. Three hypothetical production wells were located in the northern, central, and southern parts of the study area.

The sites were located along the north-south axis of the study area approximately equidistant from the east-west model boundaries. The sites were situated on undeveloped or agricultural land and, in the case of the southern and central hypothetical wells, located adjacent to existing residential development. The hypothetical wells were pumped independently at 0.25 Mgal/d. Contributing areas representing 0 to 1, 1 to 10, 10 to 20, and 20 to 50-year travel times were determined for each hypothetical production well. The 20-year contributing area was also determined for a scenario where all three hypothetical wells pumped simultaneously at a rate of 0.25 Mgal/d.

The 50-year contributing area for the southern hypothetical well pumping independently at 0.25 Mgal/d is approximately 0.5 mi wide and 1.3 mi long (fig. 18). The contributing area was centered around the hypothetical well. The up-gradient part of the contributing area within the 20- to 50- year range developed two prongs resulting from pumping at nearby irrigation wells. Minimum particle travel time was 62 days and the average time was 9.5 years (tab. 2).

The 50-year contributing area for the central hypothetical well, pumping independently at 0.25 Mgal/d, is approximately 0.65 mi wide and 1.6 mi long (fig. 19). The contributing area expanded concentrically about the hypothetical well. The contributing area becomes elongated within the 10- to 50-year interval resulting from the higher modeled transmissivity assigned to the northern part of the study area. The contributing area also developed two prongs caused by nearby irrigation wells pumping at relatively high rates. Minimum particle travel time was 78 days and the average time was 10.4 years (tab. 2).

The 50-year contributing area for the northern hypothetical well pumping independently at 0.25 Mgal/d is roughly concentric with an approximate diameter of 0.7 mi (fig. 20). The more concentric shape as opposed to the elongated patterns of the southern and central wells was a result of the higher modeled transmissivity in the northern part of the study area and the presence of the ground-water divide, represented by a general-head boundary simulating no flow, located 0.4 mi north of the well. The ground-water divide could shift due to pumpage in close proximity. A shift of the ground-water divide would result in an extension of the contributing area in the direction of the divide. Pumping from nearby irrigation wells and inflow of water from river cells in the upstream reaches of Rockawalking Creek resulted in an irregular shape in the down-gradient extension of the contributing area. Minimum particle travel time was 95 days and the average time was 11.1 years (tab. 2).

The 20-year contributing area of the northern hypothetical production well was also determined using a withdrawal rate of 0.50 Mgal/d (fig. 20). The northern hypothetical well was evaluated at the higher pumping rate because it is located in the area with the greatest supply potential where the highest modeled transmissivities and saturated thicknesses occur. The higher withdrawal rate resulted in a broader (1.1 mi)

Table 2. Contributing area analysis for Rockawalking Creek study area

Simulated pumpage	Estimated pumping rate, thousand gallons per day	Travel time	
		Minimum, days	Average, years
Hypothetical (south)	250	62	9.5
Hypothetical (central)	250	78	10.4
Hypothetical (north)	250	95	11.1
Hypothetical (south, central, and north)	750	62	10.3
Hypothetical (east-central)	250	82	10.7
Domestic (major subdivisions)	370	Not calculated	6.8

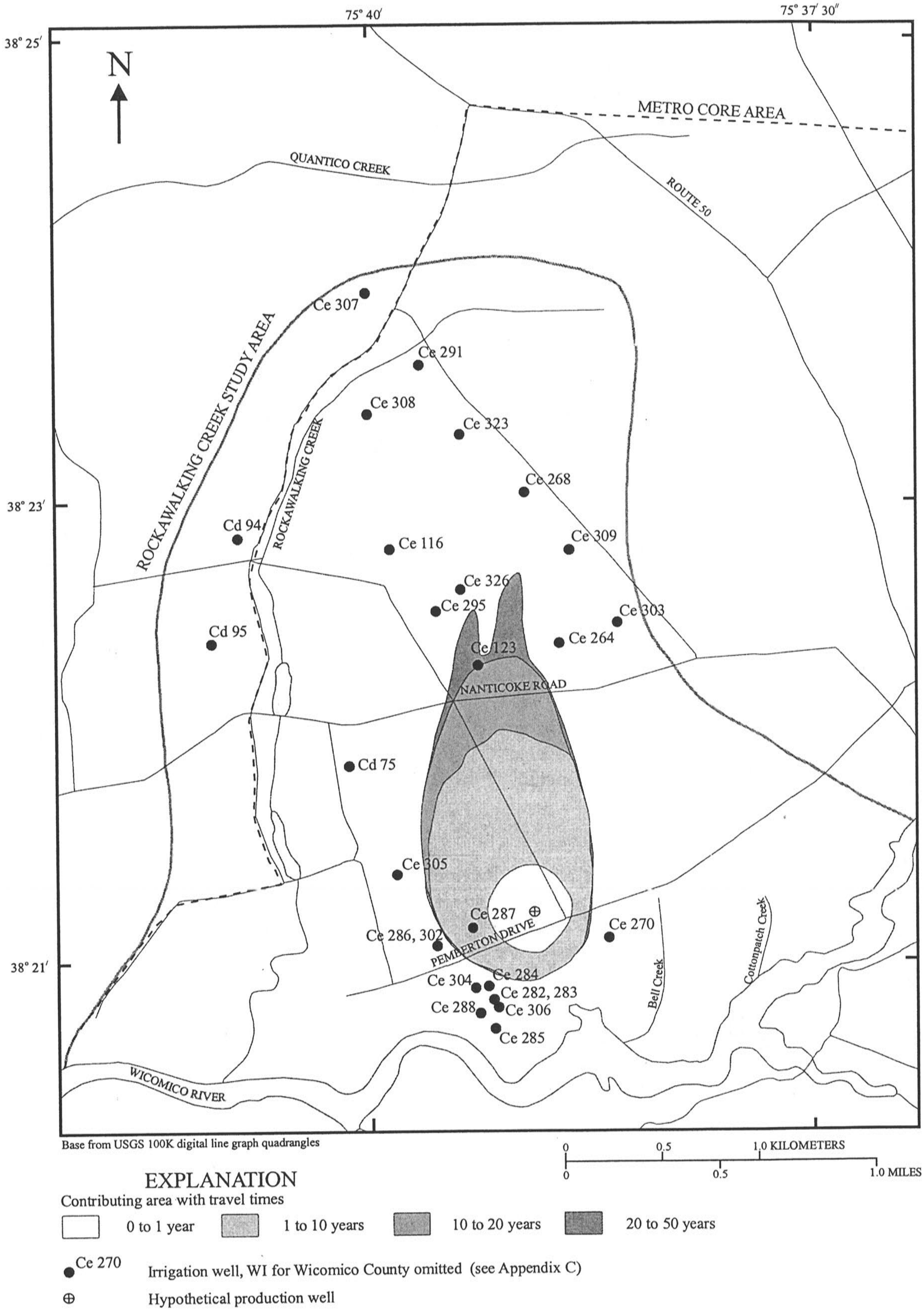


Figure 18. Location of contributing areas for the southern hypothetical production well.

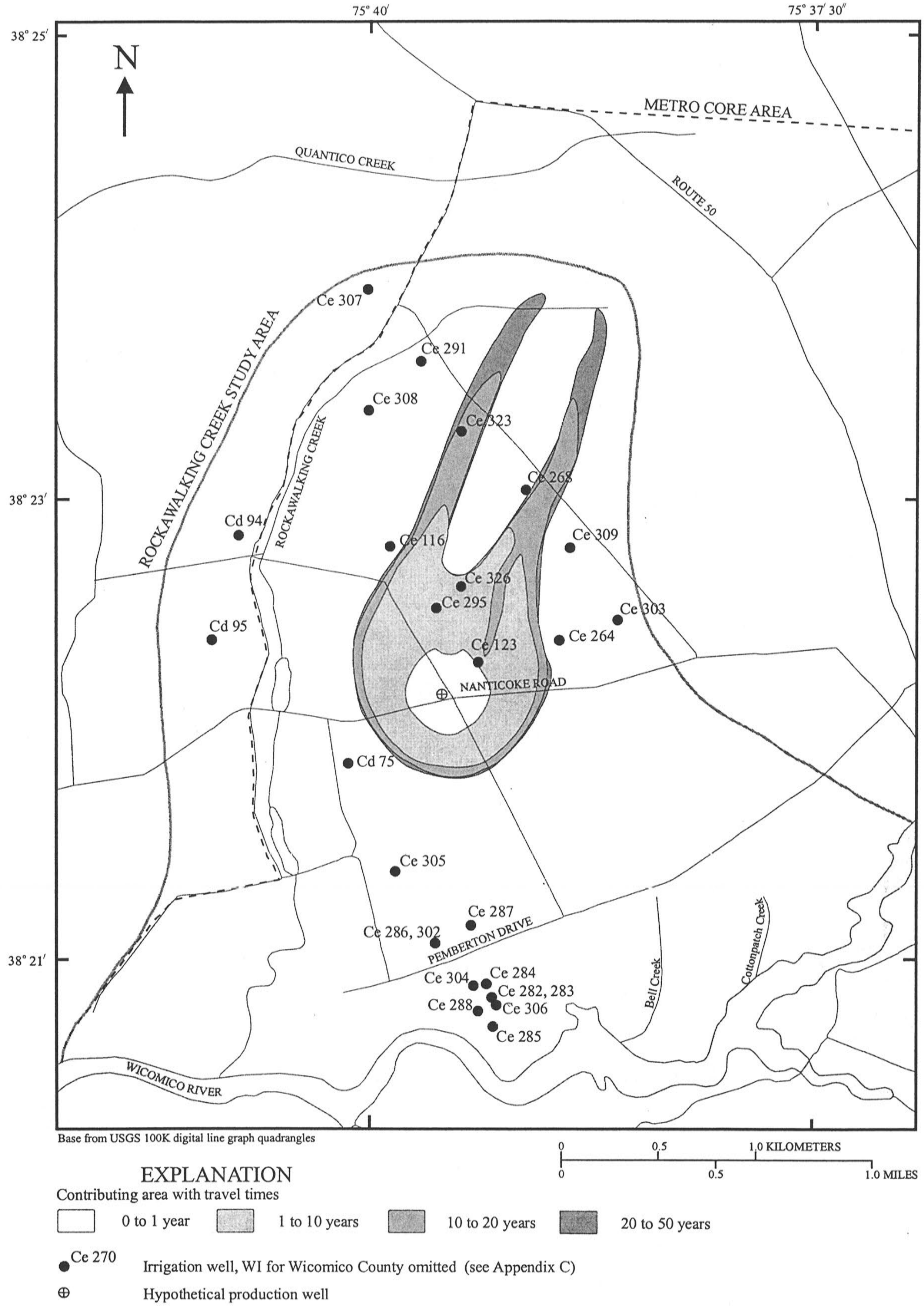
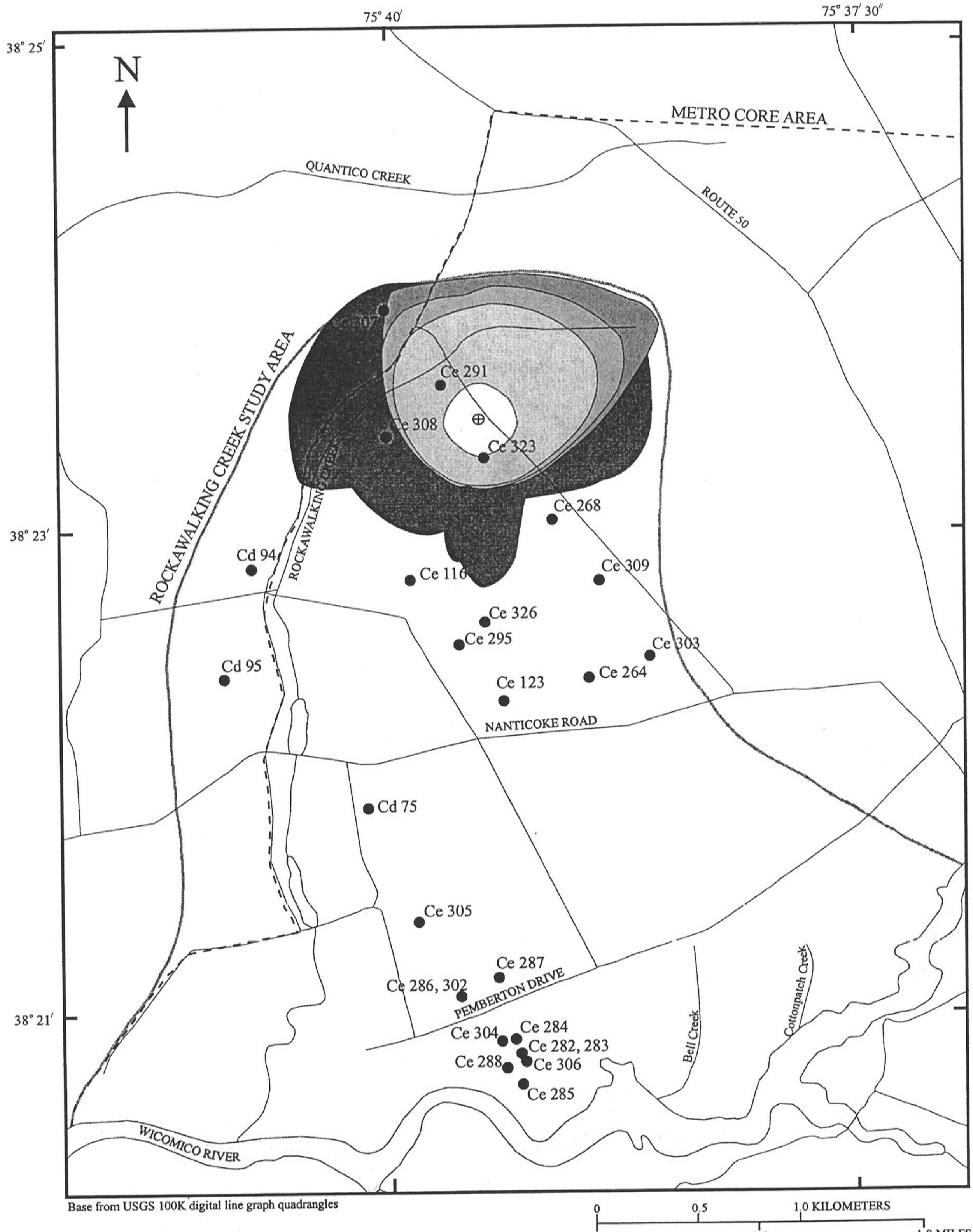


Figure 19. Location of contributing areas for the central hypothetical production well.



EXPLANATION

Contributing area with travel times

0 to 1 year | 1 to 10 years | 10 to 20 years | 20 to 50 years | Up to 20 years at 0.5 Mgal/d

● Ce 270 — Irrigation well, WI for Wicomico County omitted (see Appendix C)

⊕ — Hypothetical production well

Figure 20. Location of contributing areas for the northern hypothetical production well.

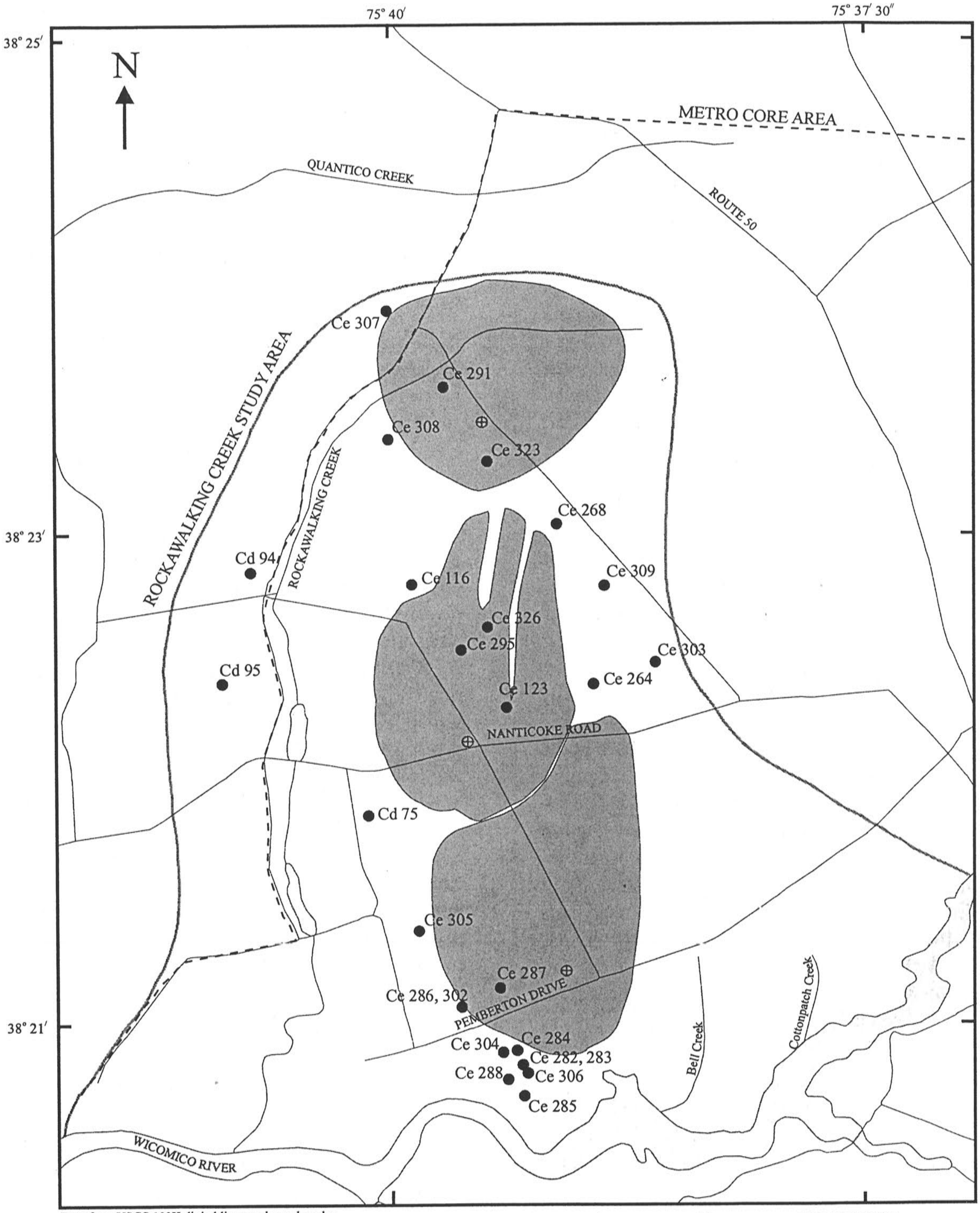
contributing area, which extended southward down-gradient from the well approximately 0.5 mi and approximately 0.28 mi further than when the well was pumped at 0.25 Mgal/d.

In the fourth scenario, each hypothetical well was pumped simultaneously at a rate of 0.25 Mgal/d. The 20-year contributing areas of these wells are shown on figure 21. The contributing area for the northern well was similar to the 20-year contributing area determined when the well was pumped independently at 0.25 Mgal/d (fig. 20). The contributing areas for the southern and central wells, however, are not as wide and do not extend as far north as the 20-year contributing areas determined when the wells are pumped independently (figs. 18 and 19). This is caused by well interference from the northern and central wells, respectively. Minimum particle travel time was 62 days and the average time was 10.3 years (tab. 2).

The final scenario simulated a hypothetical public-supply production well in the east-central part of the Rockawalking Creek study area. The hypothetical well was located in an area of possible residential growth (Wicomico Department of Planning, oral commun., 1999) (fig. 22) and pumped at a rate of 0.25 Mgal/d. Pumpage from the hypothetical well was partially offset by eliminating the irrigation pumpage associated with GAP WI90G012 (app. C) which is located in the same area. The pumpage assigned to the irrigation GAP in the calibrated model was 0.19 Mgal/d. The 50-year contributing area for the hypothetical production well ranged from 0.2 to 0.6 mi wide and 0.2 to 1.4 mi long (fig. 22). The higher modeled transmissivity in the northern part of the Rockawalking Creek study area and the proximity of the ground-water-flow divide contributed to the northward extension of the contributing area. Minimum particle travel time was 82 days and the average time was 10.7 years (tab. 2).

CONTRIBUTING AREAS FOR DOMESTIC WELLS

Currently there are no public-supply production wells screened in the Salisbury aquifer within the Rockawalking Creek study area. Most of the ground-water use consists of domestic supply from individual wells located in subdivisions in the central, southwestern, and northwestern part of the study area. The 20-year contributing areas for clustered domestic wells located within subdivisions were determined by back-tracking an array of particles consisting of one particle placed on the side faces of each model cell representing domestic pumpage. This array is representative of wells screened at the mid-point of the Salisbury aquifer. Pumpage for domestic and irrigation wells was maintained at the calibrated pumping rates. Figure 23 shows the contributing areas for domestic wells within the subdivisions for a 20-year period. The contributing areas occur mostly in the southwestern and central part of the study area. The average particle travel time was 6.8 years (tab. 2). The contributing areas are generally localized, occurring within 500 to 2,500 ft from withdrawal sites. This is a result of the relatively low pumping rates of the domestic wells, which largely capture ambient ground-water flow. The position of the array of particles, which simulates the depth of the well screen in the aquifer, affects the location of the contributing area. An array simulating a well screen at a shallower depth would result in a contributing area closer to the pumping well. Figure 24 illustrates in cross section the gap that forms between low yielding domestic pumpage and its contributing areas. The cross section extends through two subdivisions located in the east-central part of the study area.



EXPLANATION

Contributing area with travel times

0 to 20 years

Ce 270 Irrigation well, WI for Wicomico County omitted (see Appendix C)

⊕ Hypothetical production well

Figure 21. Location of contributing areas for the southern, central, and northern hypothetical production wells.

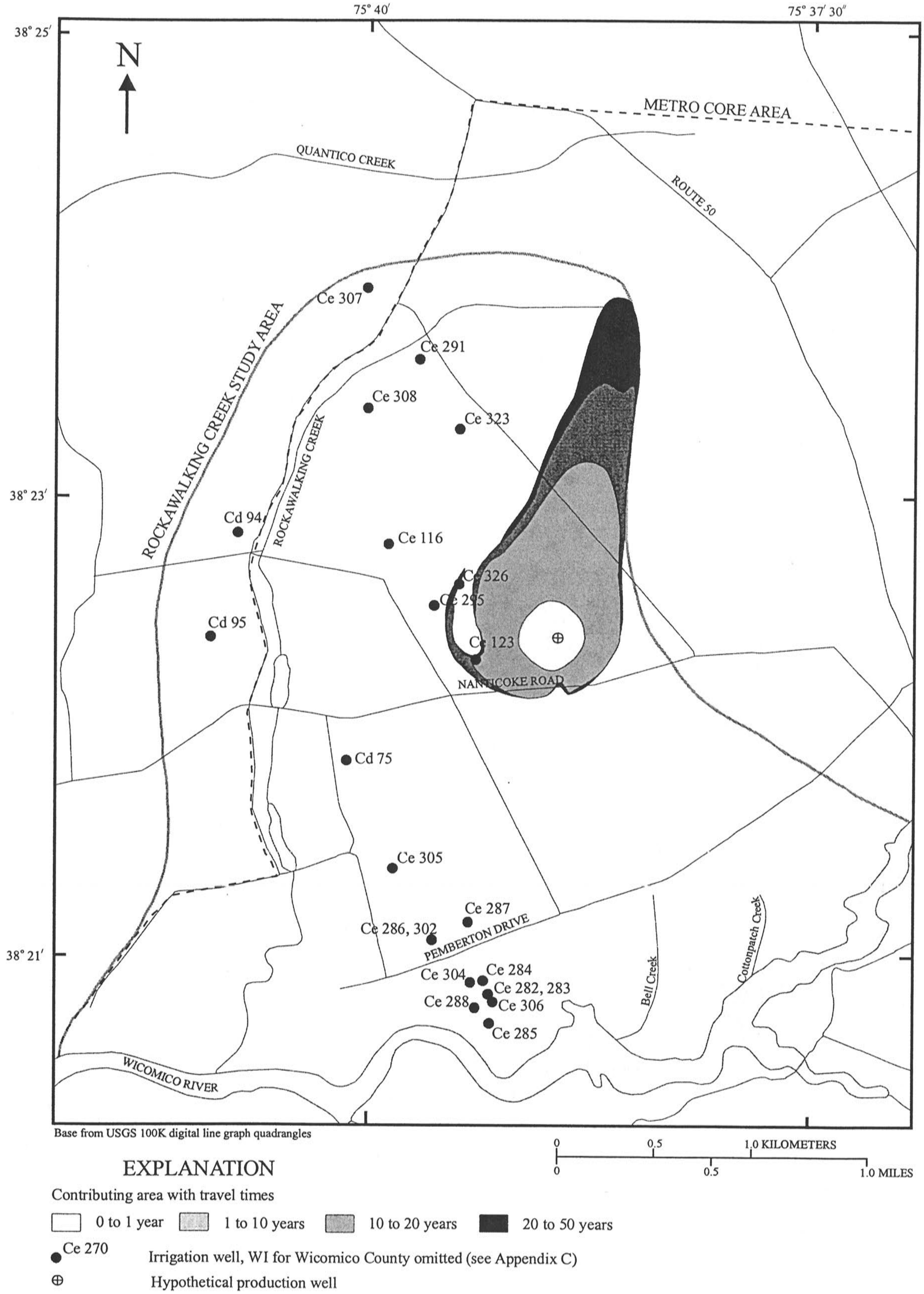


Figure 22. Location of contributing areas for the east-central hypothetical production well.

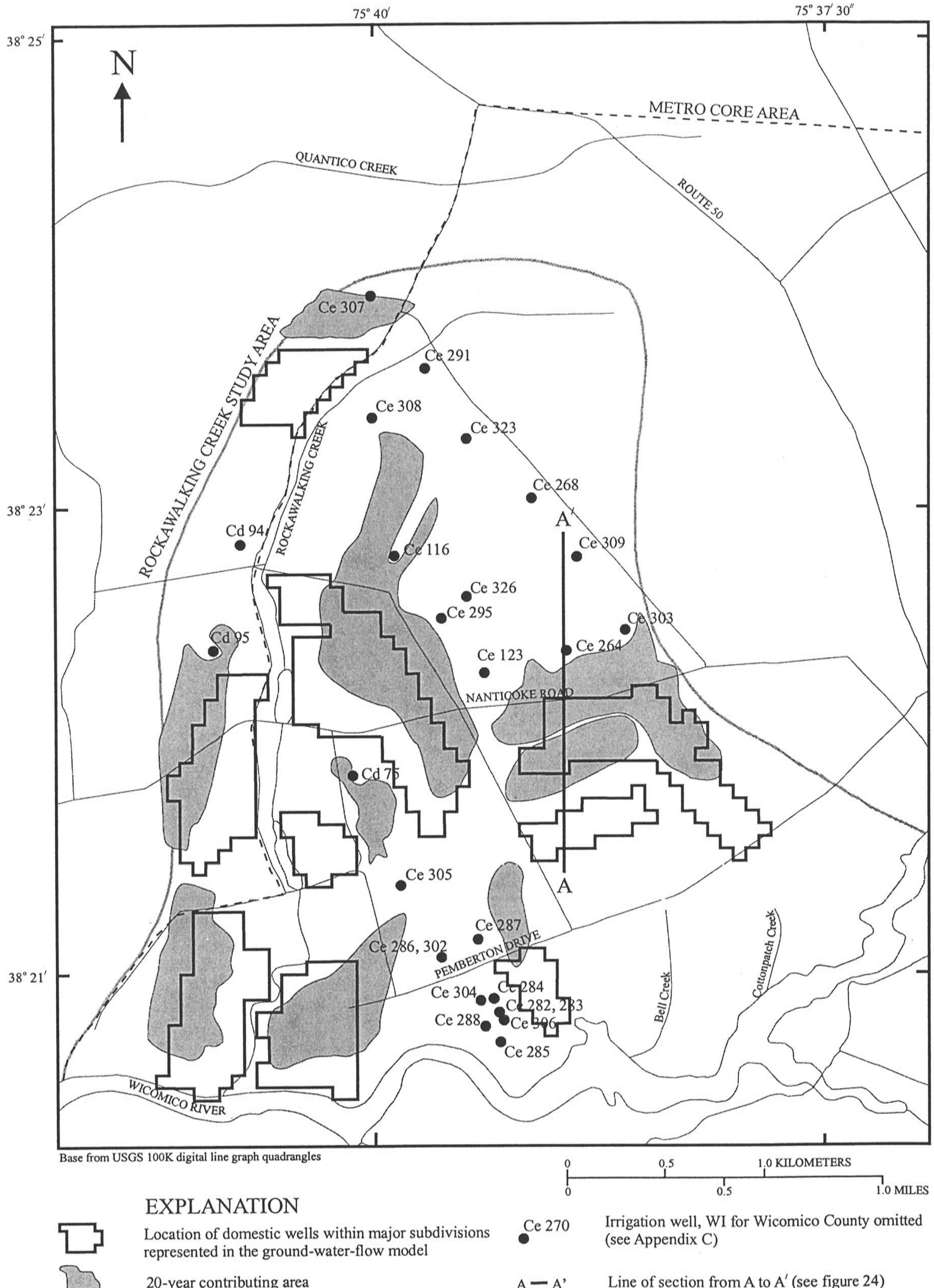


Figure 23. Location of contributing areas for domestic wells.

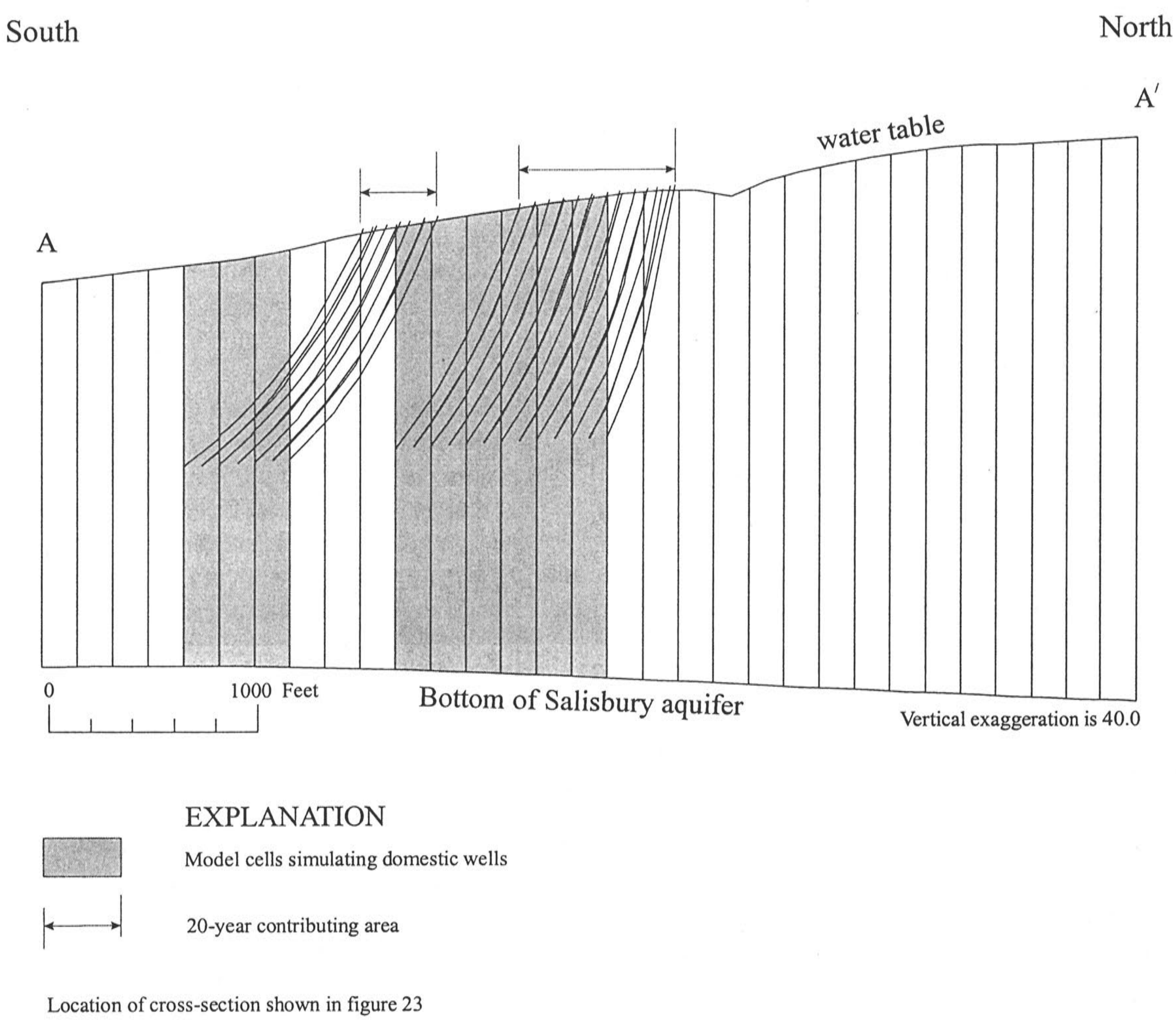


Figure 24. Cross section showing contributing areas for domestic wells.

SUMMARY

The Salisbury aquifer is a shallow, unconfined aquifer with relatively high transmissivity throughout central Wicomico County. The aquifer, recharged rapidly from precipitation, is potentially vulnerable to both point-sources, such as disposal and storage sites and non-point sources of pollution, such as pesticides, fertilizers and road salt. Delineation of contributing areas of recharge to wells serves as a basis for the development of a well-head protection plan. Contributing areas for public-supply wells in the Upper Wicomico River Basin and clustered domestic wells in the Rockawalking Creek study area were determined using two separate finite-difference, ground-water-flow models (MODFLOW) and a particle-tracking routine (MODPATH). The public-supply wells selected for analysis include supply wells for mobile-home parks, commercial wells serving 25 people or more, and City of Salisbury Park wells 17 and 18. Contributing areas for the remainder of the wells within the City of Salisbury's well fields were determined in an earlier study (Andreasen and Smith, 1997). Contributing areas were also determined for several hypothetical public-supply production wells.

The finite-difference ground-water-flow model developed by Andreasen and Smith (1997) was used to determine contributing areas for existing and hypothetical public-supply wells within the Upper Wicomico River Basin. The model grid was refined

from 80 columns and 84 rows to 115 columns and 136 rows. The finer grid size improved the overall accuracy of simulated ground-water flow in the Salisbury aquifer and allowed for a more precise discretization of the lateral no-flow basin-boundary. Pumpage applied to the model was updated using 1998 figures. Total 1998 pumpage from the Salisbury aquifer was about 9.1 Mgal/d.

Contributing areas for City of Salisbury Park wells 17 and 18, pumping at a simulated rate of 0.36 Mgal/d per well, form an elongated pattern that extends approximately 4 mi from the wells in an east-northeast direction. Particles were backtracked 50 years. Minimum travel time was 242 and 425 days for wells 17 and 18, respectively. Particles entering the water table immediately adjacent to the wells bypass the wells and flow to Beaverdam Creek and Beaglin Branch.

Contributing areas for public-supply wells (commercial, industrial, institutional and residential use such as mobile-home parks) were determined for periods ranging from up to 1, 1 to 10, 10 to 20, and 20 to 50 years. Contributing areas for wells pumped at higher rates (13,200 to 500,000 gal/d) are contiguous with the wells and range in length from 2.0 to 3.2 mi and width from 0.1 to 0.5 mi. Contributing areas for the lower yielding wells (1,000 to 8,000 gal/d) form narrow elongated shapes occurring at distances up to 1.8 mi from the wells. These wells essentially capture ambient ground-water flow.

Contributing areas for three hypothetical wells pumping at rates of 2.0 Mgal/d and located in the deepest part of the Salisbury Paleochannel form broad bands extending away from the pumping sites in easterly and westerly directions. The contributing areas range in width from 0.3 to 1 mi wide and 1.3 to 4 mi long.

Particles tracked forward from the West Road rubble landfill and an application area for waste-water sludge were captured by Paleochannel well 1 after 26 and 7 years, respectively. Particles tracked forward from two hazardous-waste sites, located south of Naylor Mill Road and east of the North Prong Wicomico River, were not captured by public-water supply wells.

The Rockawalking Creek study area shares similar hydrogeologic characteristics with the adjacent Upper Wicomico River Basin. The unconfined Salisbury aquifer has a relatively high transmissivity, ranging from 2,400 to 14,400 ft^2/d. The direction of ground-water flow is generally southward toward the tidal Wicomico River. Water use in the Salisbury aquifer consists solely of agricultural (irrigation) and domestic supply from individual wells. A total of approximately 1.1 Mgal/d is withdrawn from the Salisbury aquifer. A finite-difference ground-water flow model (MODFLOW) was developed and calibrated to water levels measured in an observation-well network established during the study and to baseflow measured in Rockawalking Creek. The flow model consisted of one layer with 70 columns and 90 rows. Model cell size was uniform at 170 x 170 ft. Output from the model was used with a particle-tracking routine (MODPATH) to determine contributing areas for wells within the Rockawalking Creek study area.

Currently there are no public-supply wells pumping from the Salisbury aquifer in the Rockawalking Creek study area. Contributing areas were therefore determined for three hypothetical wells located in the south, central, and northern parts of the study area. The 50-year contributing area of the three hypothetical wells - pumped independently at 0.25 Mgal/d - range in length from 0.7 to 1.6 mi and width from 0.5 to 0.65 mi. Minimum particle travel times ranged from 62 to 95 days. When the pumping rate is increased two-fold (0.5 Mgal/d) in the northern well, the 20-year contributing area expands southward downgradient approximately 0.28 mi farther than when the well is pumped at 0.25 Mgal/d.

Contributing areas for clustered domestic wells within subdivisions are generally localized occurring within 500 to 2,500 ft from withdrawal sites determined by particles backtracked from the mid-point of the aquifer. The 20-year contributing areas cover broad areas mostly in the southwestern and central part of the study area. Domestic wells primarily capture ambient ground-water flow. The average particle travel time was 6.8 years.

SELECTED REFERENCES

Achmad, G., and Wilson, J.M., 1993, Hydrogeologic framework and the distribution and movement of brackish water in the Ocean City-Manokin aquifer system at Ocean City, Maryland: Maryland Geological Survey Report of Investigation No. 57, 125 p.

Andreasen, D.C., and Smith, B.S., 1997, Hydrogeology and simulation of ground-water

flow in the Upper Wicomico River Basin and estimation of contributing areas of the City of Salisbury well fields, Wicomico County, Maryland: Maryland Geological Survey Report of Investigation No. 65, 87 p.

Boggess, D.H., and Heidel, S.G., 1968, Water resources of the Salisbury area, Maryland: Maryland Geological Survey Report of Investigations No. 3, 69 p.

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union Transactions, vol. 27, p. 526-534.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, Inc., 604 p.

Halford, K.J., and Mayer, G.C., 2000, Problems associated with estimating ground water discharge and recharge from stream-discharge measurements: Ground Water, vol. 38, no. 3, p. 331-342.

Hansen, H.J., 1966, Pleistocene stratigraphy of the Salisbury area, Maryland and its relationship to the lower Eastern Shore –a subsurface approach: Maryland Geological Survey Report of Investigations No. 2, 56 p.

_____ 1981, Stratigraphic discussion in support of a major unconformity separating the Columbia Group from the underlying Upper Miocene aquifer complex in eastern Maryland: Southeastern Geology, vol. 22, no. 3, p. 123-138.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference flow model: Techniques of Water Resources Investigations of the U.S. Geological Survey, Book 6, Chap. A1, 586 p.

Owens, J.P., and Denny, C.S., 1979a, Geologic map of Wicomico County: Maryland Geological Survey, 1 sheet, scale 1:62,500.

_____ 1979b, Upper Cenozoic deposits of the central Delmarva Penninsula, Maryland and Delaware: U.S. Geological Survey Professional Paper 1067-A, 28 p.

Pollack, D.W., 1989, Documentation of computer programs to compute and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 89-381, 188 p.

Rasmussen, W.C., and Andreasen, G.E., 1959, Hydrologic budget of the Beaverdam Creek Basin, Maryland: U.S. Geological Survey Water-Supply Paper 1472, 106 p.

Rasmussen, W.C., and Slaughter, T.H., 1955, Ground-water resources *in* Water resources of Somerset, Wicomico, and Worcester Counties: Maryland Department of Geology, Mines and Water Resources Bulletin 16, p. 1-469.

Rust Environment and Infrastructure, 1997, West Road Rubble Landfill Expansion Phase II Report: Albany, NY, 26 p.

Theis, C.V., 1935, The relation between the lowering of the potentiometric surface and the rate and duration of discharge of a well using ground-water storage: American Geophysical Union Transactions, pt. 2, p. 519-525.

Weigle, J.M., 1972, Part 2 - Exploration and mapping of Salisbury paleochannel, Wicomico County, Maryland: Maryland Geological Survey Bulletin 31, p. 61-124.

Wolff, R.G., 1970, Field and laboratory determination of the hydraulic diffusivity of a confining bed: Water Resources Research, vol. 6, no. 1, p. 194-203.

APPENDIXES

Appendix A. Selected well records

[ft = feet; in. = inches; m-d-y = month-day-year; gal/min = gallons per minute; (gal/min)/ft - gallons per minute per foot]

Well number	State permit number	Owner or location	Driller	Date of completion	Altitude of land surface (ft)	Depth of well (ft)	Diameter (in.)		Depth to top of screen (ft)	Length of screen (ft)	Aquifer	Water level (ft below land surface)		Date measured (m-d-yr)	Yield (gal/ min)	Hours pumped	Specific capacity ([gal/min] /ft)
							Casing	Screen				Static	Pumping				
WI Bd 72	WI-88-1264	Town of Hebron	Delmarva	5/7/90	40	370	4-2	2	320	50	Choptank	25.3	93	5/7/90	60	24	0.9
WI Be 39	–	Wicomico County	USGS	11/18/68	44	128	4.5	–	–	–	Salisbury	–	–	–	–	–	–
WI Be 42	–	Wicomico County	USGS	5/15/69	48	260	6	–	–	–	Salisbury	–	–	–	–	–	–
WI Be 63	WI-94-2382	Mitchell, Blair	A.C. Schultes	11/25/98	45	100	12	12	20	80	Salisbury	8	11	11/25/98	115	1	38.3
WI Be 64	WI-94-2737	King, Edwin	Somerset	5/7/99	45	120	12	12	40	80	Salisbury	17.6	19.2	5/7/99	100	3	62.5
WI Be 65	WI-94-1676	Adkins, Elizabeth	Lifetime	3/17/98	40	90	12	12	20	70	Salisbury	11	12	3/17/98	–	–	–
WI Be 66	WI-93-0378	Wilber, Gary	Lifetime	3/6/95	50	85	12	12	20	65	Salisbury	12	15(?)	3/6/95	900(?)	3	–
WI Be 67	WI-94-0921	Wilber, Allen	Lifetime	2/6/97	45	85	8	8	20	65	Salisbury	21	22(?)	2/6/97	700(?)	2	–
WI Bf 83	WI-94-1262	Lowe, Herbert	Lifetime	7/17/97	48	90	8	8	20	70	Salisbury	9.5	11(?)	7/17/97	400(?)	2	–
WI Bf 84	WI-94-0613	Green Meadows MHP	Coastal Water	8/14/96	40	97	4	4	87	10	Salisbury	12	20	8/14/96	100	3	12.5
WI Bf 86	WI-73-6523	Gateway Village MHP	Ideal	10/21/80	45	80	4	4	70	10	Salisbury	18	21	10/21/80	80	1	26.7
WI Bf 87	WI-73-6522	Wicomico MHP	Ideal	10/21/80	45	100	4	4	90	10	Salisbury	18	21	10/21/80	80	1	26.7
WI Bf 88	WI-73-7108	Faith Baptist Church	Coastal Drilling	11/25/81	50	105	2	2	100	5	Salisbury	15	20	11/25/81	60	1	12
WI Bf 89	WI-94-3284	Green Meadows MHP	Atlantic	12/20/99	40	398	4-2	2	368	30	Choptank	45	100	12/20/99	15	5	0.3
WI Cd 63	WI-69-0097	Cutchin, J.H.	L. Lien	1969	15	370	–	–	345	25	Choptank	6	–	–	15	–	--
WI Cd 64	WI-72-0186	West Side Mobile Park	E. Kauffman	2/14/72	15	140	4	4	129.8	10.4	Manokin	1	6	2/14/72	60	20	12
WI Cd 65	WI-73-5046	Gruy Federal, Inc.	T.J. Clardy	11/2/78	40	1,034	4.5	–	–	–	–	–	–	–	–	–	–
WI Cd 73	WI-94-1646	Culver, Robert	A.C. Schultes	3/11/98	33	80	12	12	20	60	Salisbury	11	19	3/11/98	343	4	42.9
WI Cd 74	WI-81-1000	Drew, George	Lifetime	6/7/84	40	82	12	12	27	55	Salisbury	5.5	9.5	6/7/84	80	5	20
WI Cd 75	WI-73-2650	Guy, William	W. Wood	3/18/77	30	75	8	8	40	35	Salisbury	8	10	3/18/77	300(?)	10	–
WI Cd 76	WI-88-2623	Rudnick, Mark	Delmarva	5/17/91	15	50	4	4	20	30	Salisbury	10	26	5/17/91	100	1	6.2
WI Cd 77	WI-88-2624	Rudnick, Mark	Delmarva	5/17/91	15	120	4	4	110	10	Manokin	0.5	35	5/17/91	50	1	1.4

Appendix A. Selected well records–Continued

Well number	State permit number	Owner or location	Driller	Date of completion	Altitude of land surface (ft)	Depth of well (ft)	Diameter (in.)		Depth to top of screen (ft)	Length of screen (ft)	Aquifer	Water level (ft below land surface)		Date measured (m-d-yr)	Yield (gal/min)	Hours pumped	Specific capacity ([gal/min]/ft)
							Casing	Screen				Static	Pumping				
WI Cd 78	WI-88-2594	Rudnick, Mark	Delmarva	5/7/91	15	50	4	4	40	10	Salisbury	10	28	5/7/91	60	1	3.3
WI Cd 79	WI-94-1144	Bennett, David	A & E	6/10/97	29	100	4	4	90	10	Manokin	6	16	6/10/97	60	1	6
WI Cd 80	WI-92-0991	Jekada, Inc.	Coastal Water	6/14/93	25	145	4	4	135	10	Manokin	10	25	6/14/93	40	3	2.7
WI Cd 81	WI-94-1245	Fields, Jim	Somerset	7/10/97	35	50	4	4	40	10	Salisbury	10	13	7/10/97	40	2	13.3
WI Cd 82	WI-94-0249	Tuthill, Linda	Somerset	4/3/96	23	150	4	4	140	10	Manokin	10	12	4/3/96	80	3	40
WI Cd 83	WI-92-0895	Waters, David	Coastal Water	11/24/92	35	65	4	4	60	5	Salisbury	10	20	11/24/92	20	2	2
WI Cd 84	WI-93-0241	Vane Construction Co.	Somerset	12/7/94	25	420	4	4	397	23	Choptank	25	110	12/7/94	20	4	0.2
WI Cd 85	WI-94-0162	Wolfe Homes, Inc.	Coastal Water	9/19/96	40	395	4	4	375	20	Choptank	31	100	9/19/96	30	6	0.4
WI Cd 86	WI-94-1070	Adkins, E.S.	Somerset	7/10/97	40	55	4	4	35	20	Salisbury	5	11	7/10/97	100	3	16.7
WI Cd 87	WI-94-1289	Parker, Robert	Coastal Water	8/7/97	36	89	4	4	79	10	Salisbury	15	24	8/7/97	60	4	6.7
WI Cd 88	WI-94-1807	Kutchen, Jack	Somerset	4/24/98	32	50	4	4	40	10	Salisbury	8	10	4/24/98	55	2	27.5
WI Cd 89	WI-92-1406	Tuthill, David	P. Johnson	9/2/93	23	82	2	2	72	10	Salisbury	12	21	9/2/93	32	2	3.5
WI Cd 90	WI-88-0018	Willey, Kenneth	G. Fries	8/15/88	9	70	4	4	65	5	Salisbury	9	14	8/15/88	80	1	16
WI Cd 91	WI-93-0813	Willey, Kenneth	Somerset	9/8/95	9	30	4	4	20	10	Salisbury	7	9	9/8/95	50	2	25
WI Cd 92	WI-94-2725	Snyder, Paul	Somerset	7/14/99	26	370	4	4	350	20	Choptank	26	37	7/14/99	60	4	5.4
WI Cd 93	WI-94-1975	Delmarva Construction	Somerset	7/7/98	30	370	4	4	350	20	Choptank	29	32	7/7/98	50	4	16.7
WI Cd 94	WI-73-2420	Toadvine, William	W. Wood	6/14/76	38	71	8	8	41	30	Salisbury	8	25	6/14/76	200	4	11.8
WI Cd 95	–	Venture Manor Farms	–	–	34	–	–	–	–	–	Salisbury	–	–	–	–	–	--
WI Ce 116	WI-04-1486	Guy, Irvine H.	E. Kauffman	1/12/61	36	85	22	22	4	40[1]	Salisbury	5	28	1/12/61	943	4	41
WI Ce 123	WI-02-8976	University of Maryland Experimental Agricultural Station	S. Shannahan	11/16/57	36	67	10	10	47	20	Salisbury	11	35	11/16/57	400	10	16.7
WI Ce 253	WI-81-0405	Naylor Mill Village Trailer Park	Dashiell	5/24/83	43	150	4	4	140	10	Salisbury	15	21	5/24/83	75	1	12.5

[1] Alternating 4-foot sections of casing and screen.

Appendix A. Selected well records–Continued

Well number	State permit number	Owner or location	Driller	Date of completion	Altitude of land surface (ft)	Depth of well (ft)	Diameter (in.)		Depth to top of screen (ft)	Length of screen (ft)	Aquifer	Water level (ft below land surface)		Date measured (m-d-yr)	Yield (gal/min)	Hours pumped	Specific capacity ([gal/min]/ft)
							Casing	Screen				Static	Pumping				
WI Ce 254	WI-81-0404	Naylor Mill Village Trailer Park	Dashiell	5/18/83	43	150	4	4	140	10	Salisbury	15	21	5/18/83	75	1	12.5
WI Ce 261	WI-66-0016	Royal Quality Foods, Inc.	S. Shannahan	10/23/65	20	68	10-8	8	51	17	Salisbury	18	39	10/23/65	350	10	16.7
WI Ce 262	WI-73-4817	Royal Quality Foods, Inc.	S. Shannahan	10/23/78	20	66	10	10	45	21	Salisbury	16	38	10/23/78	400	6	18.2
WI Ce 263	WI-70-0142	Royal Quality Foods, Inc.	S. Shannahan	5/21/71	20	70	16-12-8	8	46	24	Salisbury	14	38	5/21/71	400	24	16.7
WI Ce 264	WI-94-1670	Adkins, E.S.	Lifetime	5/19/98	37	76	8	8	20	56	Salisbury	5.2	–	5/19/98	400	2	–
WI Ce 265	WI-92-1974	Shockley, James	Lifetime	5/13/94	55	95	6	6	55	40	Salisbury	14	25	5/13/94	150	4	13.6
WI Ce 266	WI-93-0922	Frederick Holly	Johnson	10/6/95	35	87	4	4	77	10	Salisbury	13	20	10/6/95	46	2	6.6
WI Ce 267	WI-94-0102	Ruark, Thomas	Coastal Water	4/4/96	30	82	4	4	72	10	Salisbury	14	19	4/4/96	100	2	20
WI Ce 268	WI-94-0949	Adkins, E.S.	Lifetime	3/24/97	40	70	8	8	20	50	Salisbury	7	10	3/24/97	12	2	4
WI Ce 269	WI-94-0961	Burks, Leon	Coastal Water	3/28/97	30	154	4	4	144	10	Manokin	12	21	3/28/97	75	3	8.3
WI Ce 270	WI-94-0490	Brittingham Plant Farm	Coastal Water	6/19/96	23	78	8	8	35	43	Salisbury	16	26	6/19/96	140	30	14
WI Ce 271	WI-92-2333	Chesapeake Nurseries	Coastal Water	8/25/94	30	78	4	4	48	30	Salisbury	19.2	22.3	8/25/94	80	2	25.8
WI Ce 272	WI-94-2147	Adkins, Frank	A.C. Schultes	11/4/98	50	84	4	–	24	60	Salisbury	22	31	11/4/98	78	4	8.7
WI Ce 273	WI-92-1157	Nichols, Kenneth	Somerset	4/29/93	42	80	4	4	70	10	Salisbury	5	6	4/29/93	75	3	75
WI Ce 274	WI-93-0500	Pemberton Ponds Ltd. Liability Co.	Somerset	4/14/95	30	55	4	4	45	10	Salisbury	9	11	4/14/95	20	3	10
WI Ce 275	WI-92-1127	Steeplechase Waterworks, Inc.	Somerset	10/24/94	35	450	6	6	400	50	Choptank	20	65	10/24/94	150	24	3.3
WI Ce 276	WI-92-1223	Steeplechase Waterworks, Inc.	Somerset	10/24/94	35	450	6	6	400	50	Choptank	20	65	10/24/94	150	24	3.3
WI Ce 277	WI-92-0893	Wolfe Homes, Inc.	Coastal Water	3/15/93	40	420	4-2	2	390	30	Choptank	31	61	3/15/93	30	7	1
WI Ce 278	WI-94-2184	Adkins, Frank	A.C. Schultes	12/3/98	50	90	12	12	30	60	Salisbury	25	35	12/3/98	315	5.5	31.5
WI Ce 279	WI-94-2488	Hales, Brenda	Somerset	1/27/99	40	170	4	4	150	20	Manokin	12	17	1/27/99	70	4	14
WI Ce 280	WI-94-2356	Hales, Brenda	Somerset	12/22/98	40	70	4	4	60	10	Salisbury	12	15	12/22/98	50	3	16.7
WI Ce 281	WI-94-0425	Williams, Doug P.	Lifetime	6/20/96	40	80	8	8	20	60	Salisbury	9	40	6/20/96	600	2	19.3

Appendix A. Selected well records–Continued

Well number	State permit number	Owner or location	Driller	Date of completion	Altitude of land surface (ft)	Depth of well (ft)	Diameter (in.)		Depth to top of screen (ft)	Length of screen (ft)	Aquifer	Water level (ft below land surface)		Date measured (m-d-yr)	Yield (gal/min)	Hours pumped	Specific capacity ([gal/min]/ft)
							Casing	Screen				Static	Pumping				
WI Ce 282	WI-81-4084	Chesapeake Nurseries	G. Fries	6/2/88	20	70	6	6	40	30	Salisbury	20	25	6/2/88	400	1	80
WI Ce 283	WI-92-2043	Chesapeake Nurseries	Coastal Water	5/18/94	20	72	4	4	57	15	Salisbury	22	32	5/18/94	60	2	6
WI Ce 284	WI-92-2008	Chesapeake Nurseries	Coastal Water	5/23/94	20	83	6	6	43	40	Salisbury	17	19	5/23/94	30	6	15
WI Ce 285	WI-92-2009	Chesapeake Nurseries	Coastal Water	5/18/94	20	74	4	4	59	15	Salisbury	24	34	5/18/94	60	2	6
WI Ce 286	WI-93-0096	Chesapeake Nurseries	Coastal Water	4/11/95	25	80	8	8	55	25	Salisbury	20	25	4/11/95	100	4	20
WI Ce 287	WI-93-0097	Chesapeake Nurseries	Coastal Water	10/5/94	30	80	8	8	20	60	Salisbury	16	45	10/5/94	350	20	12.1
WI Ce 288	WI-92-1535	Chesapeake Nurseries	Coastal Water	9/30/93	20	80	6	6	30	50	Salisbury	23	27	9/30/93	120	4	30
WI Ce 289	WI-94-0060	Parsons, Wayne	Coastal Water	12/18/95	40	111	4	4	91	20	Manokin	19	30	12/18/95	15	2	1.4
WI Ce 290	WI-94-0587	Hall, Bob	Johnson	8/22/96	35	80	4	4	70	10	Salisbury	8	16	8/22/96	48	2	6
WI Ce 291	–	Miller, Robert G.	–	–	38	75	8	–	–	–	Salisbury	–	–	–	–	–	–
WI Ce 295	WI-94-1213	University of Maryland-Experimental Agricultural Station	Lifetime	6/25/97	36	80	8	8	20	60	Salisbury	9	10.5 (?)	6/25/97	1,200(?)	2	–
WI Ce 297	WI-88-1713	Elliott-Kinnamon	Larson	10/5/90	44	152	4	4	142	10	Salisbury	12	15	10/5/90	80	5	26.7
WI Ce 298	WI-88-1792	Landry Construction	Coastal Water	7/15/90	47	105	2	2	95	10	Salisbury	15	22	7/15/90	35	2	5
WI Ce 299	WI-81-4154	Hayman, Charles	Lifetime	9/17/87	42	85	4	4	55	30	Salisbury	12	20	9/17/87	80	5	10
WI Ce 302	WI-93-0446	Chesapeake Nurseries	Coastal Water	10/3/95	25	77	8	8	57	20	Salisbury	21	23	10/3/95	75	7	37.5
WI Ce 303	WI-88-1630	Adkins, E.S.	Lifetime	–	40	–	–	–	–	–	Salisbury	–	–	–	–	–	–
WI Ce 304	WI-92-2297	Chesapeake Nurseries	Coastal Water	8/13/94	25	78	6	6	20	58	Salisbury	18	29	8/13/94	75	10	6.8
WI Ce 305	–	Toadvine, William	–	–	30	–	–	–	–	–	Salisbury	–	–	–	–	–	--
WI Ce 306	WI-88-1791	Chesapeake Nurseries	Coastal Water	7/19/90	23	80	6	6	20	60	Salisbury	21	39	7/19/90	250	10	13.9
WI Ce 307	–	Adkins, Kathleen	–	–	42	–	–	–	–	–	Salisbury	–	–	–	–	–	–

Appendix A. Selected well records–Continued

Well number	State permit number	Owner or location	Driller	Date of completion	Altitude of land surface (ft)	Depth of well (ft)	Diameter (in.)		Depth to top of screen (ft)	Length of screen (ft)	Aquifer	Water level (ft below land surface)		Date measured (m-d-yr)	Yield (gal/min)	Hours pumped	Specific capacity ([gal/min]/ft)
							Casing	Screen				Static	Pumping				
WI Ce 308	WI-73-5511	Toadvine, Theodore	W. Wood	6/27/79	40	75	8	8	25	50	Salisbury	3.5	25	6/27/79	508	6	23.6
WI Ce 309	–	Adkins, E.S.	–	–	42	–	–	–	–	–	Salisbury	–	–	–	–	–	--
WI Ce 310	WI-88-0030	Bernstein, Constance	Delmarva	10/27/88	5	172	4	4	152	20	Manokin	3	20	10/27/88	65	1	3.8
WI Ce 311	WI-94-0718	J. Roland Dashiell Landfill	Geomatrix	10/2/96	46.7	34	2	2	24	10	Salisbury	11	–	10/9/96	–	–	–
WI Ce 312	WI-94-0719	J. Roland Dashiell Landfill	Geomatrix	10/2/96	45.0	30	2	2	20	10	Salisbury	9.29	–	10/9/96	–	–	–
WI Ce 313	WI-94-0720	J. Roland Dashiell Landfill	Geomatrix	10/4/96	49.1	30	2	2	20	10	Salisbury	14.55	–	10/9/96	–	–	–
WI Ce 314	WI-94-0731	J. Roland Dashiell Landfill	Geomatrix	10/5/96	47.3	24	2	2	14	10	Salisbury	12.66	–	10/9/96	–	–	–
WI Ce 315	WI-94-3189	University of Maryland - Experimental Agricultural Station	A.C. Schultes	10/12/99	38	80	4	4	20	60	Salisbury	8	15	10/12/99	118	4	16.8
WI Ce 316	WI-94-1075	Harcum, Ralph	Lifetime	5/1/97	45	90	8	8	20	70	Salisbury	13	16(?)	5/1/97	500(?)	2	–
WI Ce 317	WI-88-1093	Dashiell, J. Roland & Sons	Hardin-Huber	10/16/89	53.2	40	4	4	30	10	Salisbury	19.02	–	10/9/96	–	–	–
WI Ce 318	WI-88-1095	Dashiell, J. Roland & Sons	Hardin-Huber	10/14/89	56.3	40	4	4	30	10	Salisbury	22.24	–	10/9/96	–	–	–
WI Ce 319	WI-88-1094	Dashiell, J. Roland & Sons	Hardin-Huber	10/16/89	53.0	30	4	4	20	10	Salisbury	18.46	–	10/9/96	–	–	–
WI Ce 320	WI-88-2309	Dashiell, J. Roland & Sons	Hardin-Huber	1/28/91	46.6	30	4	4	20	10	Salisbury	11.49	–	10/9/96	–	–	–
WI Ce 321	WI-81-3510	Bennett MHP	G. Fries	7/6/87	40	80	4	4	70	10	Salisbury	18	23	7/6/87	80	1	16
WI Ce 322	WI-81-3511	Bennett MHP	G. Fries	7/6/87	40	80	4	4	70	10	Salisbury	18	23	7/6/87	80	1	16
WI Ce 323	–	Guy Farms, Inc.	–	–	40	–	–	–	–	–	Salisbury	–	–	–	–	–	--
WI Ce 324	WI-94-2189	Adkins, Frank	A.C. Schultes	11/23/99	40	80	8	8	20	60	Salisbury	6	10	11/23/99	116	2	29
WI Ce 325	WI-94-3190	Adkins, Frank	A.C. Schultes	11/5/99	40	100	4	4	20	80	Salisbury	6	10	11/5/99	116	4	29
WI Ce 326	WI-94-3473	University of Maryland - Experimental Agricultural Station	Lifetime	3/30/00	38	80	12	12	25	55	Salisbury	7.4	11.4	3/30/00	55	2	13.8

Appendix A. Selected well records–Continued

Well number	State permit number	Owner or location	Driller	Date of completion	Altitude of land surface (ft)	Depth of well (ft)	Diameter (in.)		Depth to top of screen (ft)	Length of screen (ft)	Aquifer	Water level (ft below land surface)		Date measured (m-d-yr)	Yield (gal/min)	Hours pumped	Specific capacity ([gal/min]/ft)
							Casing	Screen				Static	Pumping				
WI Cf 77	WI-04-9744	City of Salisbury	Middletown Well Drilling	1962	10	135	4	2	131	4	Manokin	+12.0	–	11/13/62	40	–	--
WI Cf 200	WI-73-0024	Perdue, Inc. Well No. 4	Shannahan Art.	9/26/72	47	92	16-10	10	67	25	Salisbury	11	17	9/26/72	148	10	24.7
WI Cf 212	WI-94-0424	Guerrieri, Alan	Somerset	5/29/96	48	90	6	6	40	50	Salisbury	8	13	5/29/96	100	8	20
WI Cf 213	WI-92-1324	Wilber, Roy	Lifetime	7/2/93	58	100	8	8	20	80	Salisbury	10	12	7/2/93	200	5	100
WI Cf 214	WI-94-3312	Eastwood MHP	R. Johnson	12/10/99	44	80	4	4	70	10	Salisbury	18	26	12/10/99	48	2	6
WI Cf 215	WI-81-2857	Eastwood HP	Larson	8/8/86	44	96	4	4	91	5	Salisbury	16	19	8/8/86	70	1	23.3
WI Cf 216	WI-81-3459	Walston's MHP	Brittingham	1/21/87	50	90	2	2	80	10	Salisbury	12	26	1/21/87	40	2	2.9
WI Cf 217	WI-81-0308	Walston's MHP	Larson	2/10/83	50	99	2	2	94	5	Salisbury	8	12	2/10/83	65	1	16.2
WI Cf 218	WI-81-0311	Walston's MHP	Larson	1/27/83	50	83	2	2	78	5	Salisbury	10	13	1/27/83	40	1	13.3
WI Cf 219	WI-68-0113	Walston's MHP	C. Daisey	4/2/68	50	90	2	2	84	6	Salisbury	8	16	4/2/68	40	3	5
WI Cf 220	WI-88-1538	Wicomico County Airport	Larson	4/24/90	49	100	6	6	80	20	Salisbury	14	19	4/24/90	80	1	16
WI Cf 221	WI-81-0241	Perdue, Inc., Main Office	Larson	2/21/83	50	65	6	6	60	5	Salisbury	12	25	2/21/83	150	1	11.5
WI Cf 222	WI-92-0489	Perdue, Inc., Main Office	Larson	6/25/92	50	105	6	6	95	10	Salisbury	15	25	6/25/92	200	5	20
WI Cf 223	WI-81-2049	Salisbury School	G. Fries	9/3/85	44	100	4	4	90	10	Salisbury	12	17	9/3/85	80	1	16
WI Cf 224	WI-94-0890	Salisbury School	Somerset	8/20/97	44	110	4	4	95	15	Salisbury	12	15	8/20/97	70	3	23.3
WI Cf 225	WI-81-2863	Beaver Run Elementary School	Larson	8/1/86	50	117	4	4	107	10	Salisbury	12	16	8/1/86	100	4	25

OWNER OR LOCATION

MHP - Mobile Home Park

CONTRACTORS

A & E - A & E Well Drilling
Atlantic - Atlantic Coastal Well Drilling
Brittingham - N.P. Brittingham Well Drilling
Coastal Water - Coastal Water, Inc.
Dashiell - Dashiell Well Drilling
Delmarva - Delmarva Drilling Co.
Geomatrix - Geomatrix, Inc.
Hardin-Huber - Hardin-Huber, Inc.

CONTRACTORS–CONTINUED

Ideal - Ideal Well Drillers
Johnson - Johnson Well Drilling
Larson - Larson Wells, Inc.
Lifetime - Lifetime Well Drilling Co.
Shannahan Art. - Shannhan Artesian Well Co., Inc.
Somerset - Somerset Well Drilling Co., Inc
USGS - U.S. Geological Survey

Appendix B. - Appropriated ground-water use in the Salisbury aquifer over 10,000 gallons per day in the Upper Wicomico River Basin

[-- - pumpage data not available; NRS - no report submitted]

Owner or name	Maryland State ground-water appropriation permit number (GAP)	U.S. Geological Survey well number (see appendix A; Andreasen and Smith, 1997) (Owners well number)	Average amount appropriated (1,000 gallons per day)	Average daily pumpage in 1998 (1,000 gallons per day)	Type of use
Perdue Farms, Inc., at Zion Church Road	WI55G001	WI Cf 154 (well 1) WI Cf 155 (well 2) WI Cf 200 (well 4)	1,700	958	Industrial
Royal Quality Foods, Inc.[1/]	WI66G007	WI Ce 261 (well 1) WI Ce 262 (well 2) -- (well 4) WI Ce 263 (well 5)	500	0	Industrial
Town of Delmar	WI81G008	WI Bf 76	210	0.18 NRS-Jan.	Public supply
Walston Mobile Home Park	WI68G016	--	15	5.0 NRS-July-Dec.	Public supply
City of Salisbury	WI73G001	Paleochannel well field: WI Ce 200 (well 1) WI Ce 241 (well 2) Park well field: WI Ce 244 (well 2a) WI Ce 246 (well 6A) WI Ce 247 (well 7b) WI Ce 248 (well 8a) WI Cf 193 (well 14a) WI Cf 194 (well 10a) WI Cf 195 (well 16a) WI Cf 201 (well 17) WI Cf 202 (well 18)	7,600	5,530	Public supply
Arundel Concrete	WI73G003	WI Ce 259	24	3.5	Industrial
Cedarhurst Trailer Park	WI74G008	WI Ce 255	12	9.6	Public supply
Webcraft Technologies	WI81G016	WI Ce 260	125	123	Industrial
Perdue Farms Inc., main office	WI82G016	WI Cf 221, 222	16	16[2/]	Commercial
Louis E. Brown	WI89G004	WI Cf 207	95	0	Irrigation
Shockley Farm, Inc.	WI90G006	WI Cf 205	212	1.9	Irrigation
Oakwood Sod Farm, Inc. (Brown Road)	WI92G011	WI Cf 206	108	98	Irrigation
Oakwood Sod Farm, Inc. (Hampshire Road)	WI92G013	WI Bf 79	81	268	Irrigation
Randolf Stadler	WI93G014	WI Cf 203	16	--	Irrigation
Lee Townsend (Gunby Road)	WI93G004	WI Cf 199	54	--	Irrigation
Lee Townsend (Mt. Herman Road)	WI93G005	WI Cf 198	20	--	Irrigation

Appendix B. - Appropriated ground-water use in the Salisbury aquifer over 10,000 gallons per day in the Upper Wicomico River Basin - Continued

Owner or name	Maryland State ground-water appropriation permit number (GAP)	U.S. Geological Survey well number (see appendix A; Andreasen and Smith, 1997) (Owners well number)	Average amount appropriated (1,000 gallons per day)	Average daily pumpage in 1998 (1,000 gallons per day)	Type of use
Lee Townsend (Gunby Road)	WI93G006	WI Cf 204	12	--	Irrigation
Lee Townsend	WI93G007	-	16	--	Irrigation
Alan Lankford	WI93G011	WI Be 59	150	--	Irrigation
Thomas Culver	WI93G012	WI Be 57	168	649	Irrigation
Brittingham Plant Farms	WI93G040	WI Cf 197	27	53	Irrigation
Oakwood Sod Farm (Holt Road)	WI94G007	WI Cf 213	41	0	Irrigation
Oakwood Sod Farm (Waller Road)	WI94G030	WI Be 66 WI Be 67	94	173	Irrigation
Michael Guerrier (Jenkins Farm)	WI96G013	WI Cf 212	50	--	Irrigation
Edwin King	WI96G017	[3]	42	0	Irrigation
Elizabeth Adkins	WI96G018	WI Be 65	60	39	Irrigation
Ralph Harcum	WI96G036	WI Ce 316	66	11	Irrigation
Herbert Lowe	WI97G028	WI Bf 83	76	5.7	Irrigation
Blair Mitchell	WI98G017	WI Be 63	120	0	Irrigation
Nelson Larger	WI99G019	WI Be 64	41	[4]	Irrigation

[1] Plant is closed.
[2] Estimated.
[3] Well has not been drilled.
[4] Ground-water appropriation issued 4/23/99.

Appendix C. Appropriated ground-water use in the Salisbury aquifer over 10,000 gallons per day in the Rockawalking Creek study area

[-- - pumpage data not available]

Pumpage owner	Maryland State ground-water appropriation permit (GAP)	U.S. Geological Survey well number (see Appendix A)	Average amount appropriated (1,000 gallons per day)	Average daily pumpage (1,000 gallons per day)		
				1996	1997	1998
William Toadvine	WI89G012	WI Cd 94	46	9.4	10.1	14.2
Venture Manor Farms	WI89G020	WI Cd 73 WI Cd 95	254	40.9	175.8	58.1[1/]
E.S. Adkins & Co.	WI90G012	WI Ce 264 WI Ce 268 WI Ce 303 WI Ce 309	344	380.3	--	--
Guy Farms, Inc.	WI91G031	WI Ce 323	20	1.8	7.4	--
Theodore Toadvine	WI92G001	WI Ce 308	15	0.0	3.5	3.3[2/]
Guy Farms, Inc.	WI92G066	WI Cd 75	79	13.0	37.2	--
Guy Farms, Inc.	WI92G067	WI Ce 116	158	3.7	39.3	--
William Toadvine	WI93G020	WI Ce 305	55	0.0	10.5	12.2
Robert G. Miller	WI93G037	WI Ce 291	29	9.1	12.6	0.0
Chesapeake Nurseries, Inc.	WI93G041	WI Ce 282 WI Ce 283 WI Ce 284 WI Ce 285 WI Ce 286 WI Ce 287 WI Ce 288 WI Ce 302 WI Ce 304 WI Ce 306	288	146.1	153.8	146.6
University of Maryland Agricultural Experiment Station	WI97G012	WI Ce 123 WI Ce 295 WI Ce 326	16	--	--	29.8[3/]
Kathleen Adkins	WI98G036	WI Ce 307	62	--	--	--

[1/] Well WI Cd 73 is located outside the study area.
[2/] Water use in January through June.
[3/] Water use in 1999.

MARYLAND DEPARTMENT OF NATURAL RESOURCES
580 Taylor Avenue
Annapolis, Maryland 21401
General DNR Public Information Number: 1-877-620-8DNR
http://www.dnr.state.md.us

MARYLAND GEOLOGICAL SURVEY
2300 St. Paul Street
Baltimore, Maryland 21218
(410) 554-5500
http://www.mgs.md.gov