SIMULATED EFFECTS OF PROJECTED WITHDRAWALS FROM THE WENONAH-MOUNT LAUREL AQUIFER ON GROUND-WATER LEVELS IN THE CAMDEN, NEW JERSEY, AREA AND VICINITY

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	0.00405	square kilometer
	Flow	
million gallons per day (Mgal/d)	0.04381	cubic meters per second
million gallons per year (Mgal/yr)	15.99065	cubic meters per second

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

The Wenonah-Mount Laurel aquifer is being considered as a potential source of future water supply for the Camden, New Jersey, area. The deeper Potomac-Raritan-Magothy aquifer system is currently the major source of water supply for the area, but its use may be curtailed or reduced by 35 percent of 1983 withdrawals through its designation by the New Jersey Department of Environmental Protection and Energy as "Water Supply Critical Area #2." Withdrawals from the Wenonah-Mount Laurel aquifer currently (1989) total about 7 million gallons per day. The anticipated use of this aquifer by communities with access to it, as an alternative supply, could increase to more than 14 million gallons per day by 2020. If the communities of Clayton and Glassboro decrease their withdrawals from the Potomac-Raritan-Magothy aquifer system by 50 percent or cease them entirely because of their proximity to saline water, the use of the Wenonah-Mount Laurel aquifer could increase to greater than 15 million gallons per day by 2020.

Simulation of the ground-water system indicates that the projected increase in withdrawals will cause cones of depression in the potentiometric surface of the Wenonah-Mount Laurel aquifer in the Camden metropolitan area by 2020, that extend to depths ranging from 10 feet above sea level to 60 feet below sea level. This represents a decline of about 40 to 100 feet from 1990 conditions. Withdrawals in northeastern Burlington County will cause a large cone of depression that, by 2020, will extend to depths of about 220 feet below sea level, representing a decline of about 140 feet from 1990 conditions. Simulation results indicate that water levels in the Wenonah-Mount Laurel aquifer near the Salem Nuclear Power Plant are somewhat insensitive to withdrawals elsewhere in the aquifer. In some areas, especially in Burlington County, the cones of depression have developed near the aquifer-outcrop area and could induce infiltration from streams crossing the outcrop. Because of the hydraulic connection to adjacent aquifers, future management plans need to be developed in a comprehensive manner with regard to all aquifers. Further study of the aquifer in Salem County could provide additional information on the hydraulic connection to Delaware Bay and the potential for saltwater intrusion.

INTRODUCTION

The Wenonah-Mount Laurel aquifer is anticipated to be the focus of significant future water-supply withdrawals (pumpage) in the Camden, New Jersey, area. Currently, the major source of water supply in this area is the deeper Potomac-Raritan-Magothy aquifer system. The New Jersey Department of Environmental Protection and Energy (NJDEPE) determined that the magnitude and rate of water-level decline in the Potomac-Raritan-Magothy aquifer system was indicative of overpumping and declared it a "Water-Supply Critical Area" (New Jersey Department of Environmental Protection, 1986). The NJDEPE and others (Camp Dresser and McKee Inc. and Speitel Associates, 1987) suggested several strategies to ameliorate the critical conditions, all of which would involve either a freeze or cutback in withdrawals from the Potomac-Raritan-Magothy aquifer system and use of alternative sources to maintain sufficient water supply for present and future needs. The Wenonah-Mount Laurel aquifer is a potential alternative source; however, its viability must first be evaluated to ensure that its use can be sustained without deleterious consequences.

Therefore, the U.S. Geological Survey, in cooperation with the NJDEPE, conducted a study to (1) estimate the potential future withdrawals from the Wenonah-Mount Laurel aquifer in Camden area of Burlington, Camden, and Gloucester Counties, New Jersey, that compensates for the proposed decrease in withdrawals from the Potomac-Raritan-Magothy aquifer system; and (2) evaluate the potential hydrogeologic effects of these withdrawals on the Wenonah-Mount Laurel aquifer. This report presents an estimate of future withdrawals and describes the use of a ground-water-flow model to simulate the effects of these withdrawals on the potentiometric surface in the aquifer.

Location

The study focuses on the Camden area, which consists of the western part of Burlington County and nearly all of Camden and Gloucester Counties, all in the New Jersey Coastal Plain. This study area, however, is not an isolated hydrologic entity. Therefore, consideration of the hydrologic system and associated stresses of the Coastal Plain beyond the study area is necessary. The calibrated ground-water flow model used in this investigation represents the entire New Jersey Coastal Plain. The location of the study area and the model boundaries are shown in figure 1.

Hydrogeologic Setting

The New Jersey Coastal Plain is a seaward-dipping wedge of unconsolidated sediments that range in age from Cretaceous to Holocene (table 1). These sediments consist mainly of clay, silt, sand, and gravel. Units that are mostly sand and gravel are permeable and are considered aquifers, and those that are mostly silt or clay are relatively impermeable and are considered confining units. The relative positions of units that make up the Coastal Plain are indicated in table 1, along with their hydrogeologic-unit and geologic-unit names, and corresponding model layers (discussed further on).

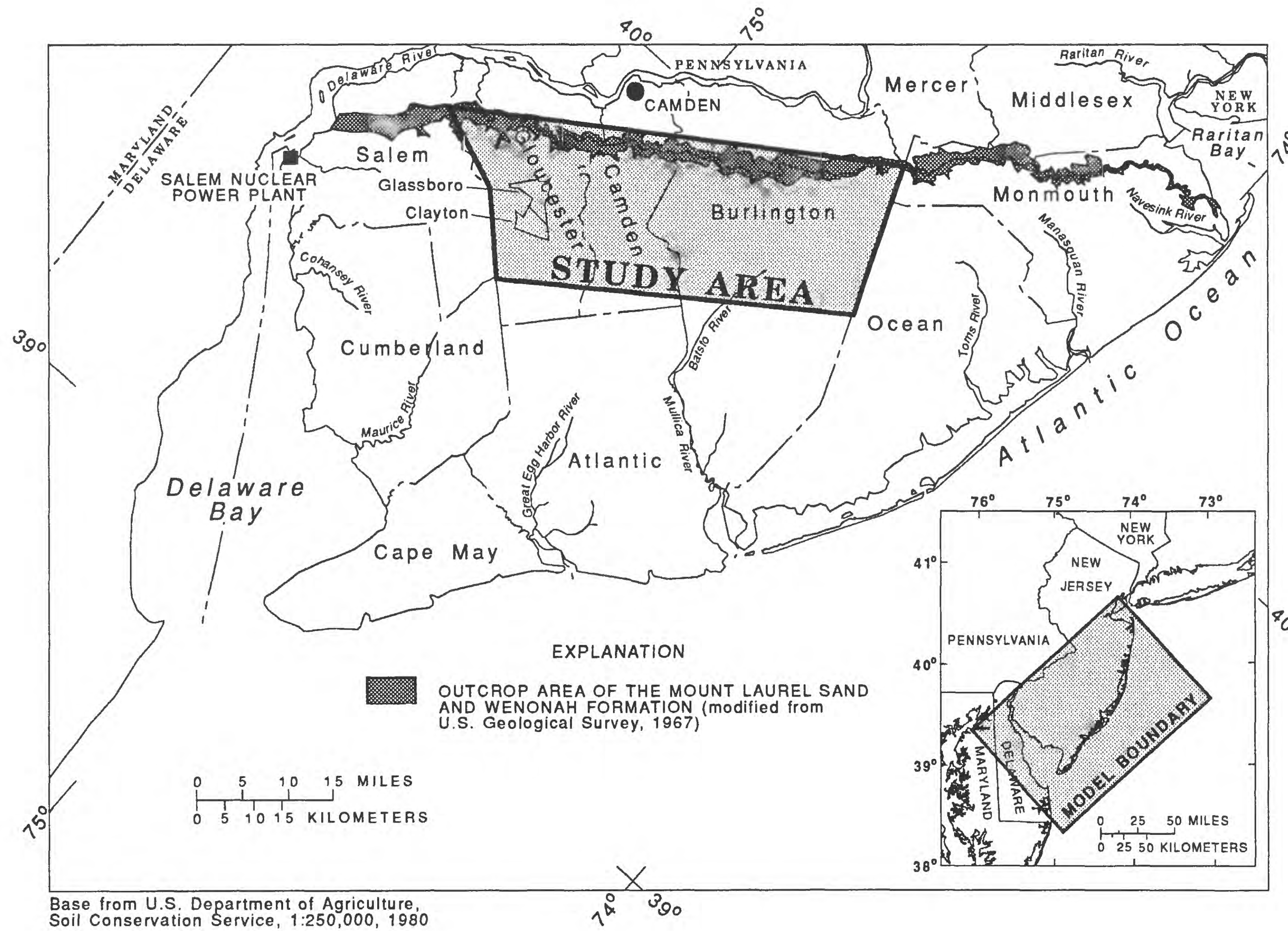


Figure 1.--Location of the study area and ground-water-flow model boundary.

Table 1.--Geologic and hydrogeologic units of the New Jersey Coastal Plain and model units used in this study

[Modified from Zapecza, 1984, table 1]

SYSTEM	SERIES	GEOLOGIC UNIT	LITHOLOGY	HYDROGEOLOGIC UNIT	MODEL UNIT[1] UPDIP	MODEL UNIT[1] DOWNDIP
Quaternary	Holocene	Alluvial deposits	Sand, silt, and black mud.	Undifferentiated	[Units not present]	[Units not present]
		Beach sand and gravel	Sand, quartz, light-colored, medium-to coarse-grained, pebbly.		[Units not present]	A10
	Pleistocene	Cape May Formation	Sand, quartz, light-colored, heterogeneous clayey, pebbly.		[Units not present]	C9
					[Units not present]	A9
Tertiary	Miocene	Pensauken Formation			[Units not present]	[Units not present]
		Bridgeton Formation		Kirkwood-Cohansey aquifer system		
		Beacon Hill Gravel	Gravel, quartz, light colored, sandy.			
		Cohansey Sand	Sand, quartz, light-colored, medium to coarse-grained, pebbly; local clay beds.		A9	A9
		Kirkwood Formation	Sand, quartz, gray and tan, very fine-to, medium-grained, micaceous, and dark-colored diatomaceous clay.	Confining unit		C8
				Rio Grande water bearing zone	A8	A8
				Confining unit		
				Atlantic City 800-foot sand		
				Composite confining unit	C7	C7
	Oligocene / Eocene	Piney Point Formation / Shark River Formation	Sand, quartz and glauconite, fine-to coarse-grained.	Piney Point aquifer	A7	A7
	Eocene	Manasquan Formation	Clay, silty and sandy, glauconitic, green, gray and brown, fine-grained quartz sand.	Composite confining unit	C6	C6
	Paleocene	Vincentown Formation	Sand, quartz, gray and green, fine-to coarse-grained, glauconitic, and brown clayey, very fossiliferous, glauconite and quartz calcarenite.	Vincentown aquifer	A6	A6
		Hornerstown Sand	Sand, clayey, glauconitic, dark green, fine to coarse-grained.	Composite confining unit	C5	C5
Cretaceous	Upper Cretaceous	Tinton Sand	Sand, quartz, and glauconite, brown and gray, fine-to coarse-grained, clayey, micaceous.			
		Red Bank Sand		Red Bank sand		
		Navesink Formation	Sand, clayey, silty, glauconitic, green and black, medium-to coarse-grained.			
		Mount Laurel Sand	Sand, quartz, brown and gray, fine-to coarse-grained, slightly glauconitic.	Wenonah-Mount Laurel aquifer	A5	A5
		Wenonah Formation	Sand, very fine-to fine-grained, gray and brown, silty, slightly glauconitic.	Marshalltown-Wenonah confining unit	C4	C4
		Marshalltown Formation	Clay, silty, dark greenish gray, glauconitic quartz sand.			
		Englishtown Formation	Sand, quartz, tan and gray, fine-to medium-grained; local clay beds.	Englishtown aquifer system	A4	A4
		Woodbury Clay	Clay, gray and black, micaceous silt.	Merchantville-Woodbury confining unit	C3	C3
		Merchantville Formation	Clay, glauconitic, micaceous, gray and black; locally very fine-grained quartz and glauconitic sand.			
		Magothy Formation	Sand, quartz, light-gray, fine-to coarse-grained. Local beds of dark-gray lignitic clay.	Potomac-Raritan-Magothy aquifer system: Upper aquifer	A3	A3
		Raritan Formation	Sand, quartz, light-gray, fine-to coarse-grained, pebbly, arkosic, red, white, and variegated clay.	Confining unit	C2	C2
				Middle aquifer	A2	A2
	Lower Cretaceous	Potomac Group	Alternating clay, silt, sand, and gravel.	Confining unit	C1	C1
				Lower aquifer	A1	A1
Pre-Cretaceous		Bedrock	Precambrian and lower Paleozic crystalline rocks, metamorphic schist and gneiss; locally Triassic sandstone, shale and Jurassic basalt.	Bedrock confining unit		

[Hatched box] Units not present

[1] 'A' refers to modeled aquifer, 'C' refers to modeled confining unit, number refers to model layer

The Wenonah-Mount Laurel aquifer consists of the coarse-grained part of the Wenonah Formation and the Mount Laurel Sand, both of Late Cretaceous age (table 1 and Zapecza, 1989). The Wenonah-Mount Laurel aquifer extends beneath much of the Coastal Plain of New Jersey in the subsurface and crops out in a narrow band 1 to 3 mi wide that trends from Monmouth County southwest into Salem County (fig. 2). The aquifer reaches thicknesses of 100 to 120 ft near its outcrop area in Burlington, Camden, Gloucester, and Salem Counties. Elsewhere, thicknesses of 60 to 80 feet are common.

The Wenonah-Mount Laurel aquifer is overlain by a complex series of sands and clays that, as a group, are considered a "composite" confining unit (Zapecza, 1989, p. B14). This overlying confining unit separates the Wenonah-Mount Laurel aquifer from the younger Kirkwood-Cohansey aquifer system and can be considered leaky.

The Wenonah-Mount Laurel aquifer is underlain by the Marshalltown confining unit, which is considered leaky. The Marshalltown confining unit is, in turn, underlain by the Englishtown aquifer system, which is present in parts of Camden County and Burlington County, and extends northeastward into Monmouth and Ocean Counties. Southwestward into Gloucester and Salem Counties, it undergoes a transition from sands to mostly silts and clays. The Englishtown aquifer system and the equivalent silt and clay are underlain by the Woodbury-Merchantville confining unit, which is fairly impermeable. Underlying this confining unit is the Potomac-Raritan-Magothy aquifer system. Further discussion of the hydrogeology of the New Jersey Coastal Plain, including these units, can be found in Zapecza (1989).

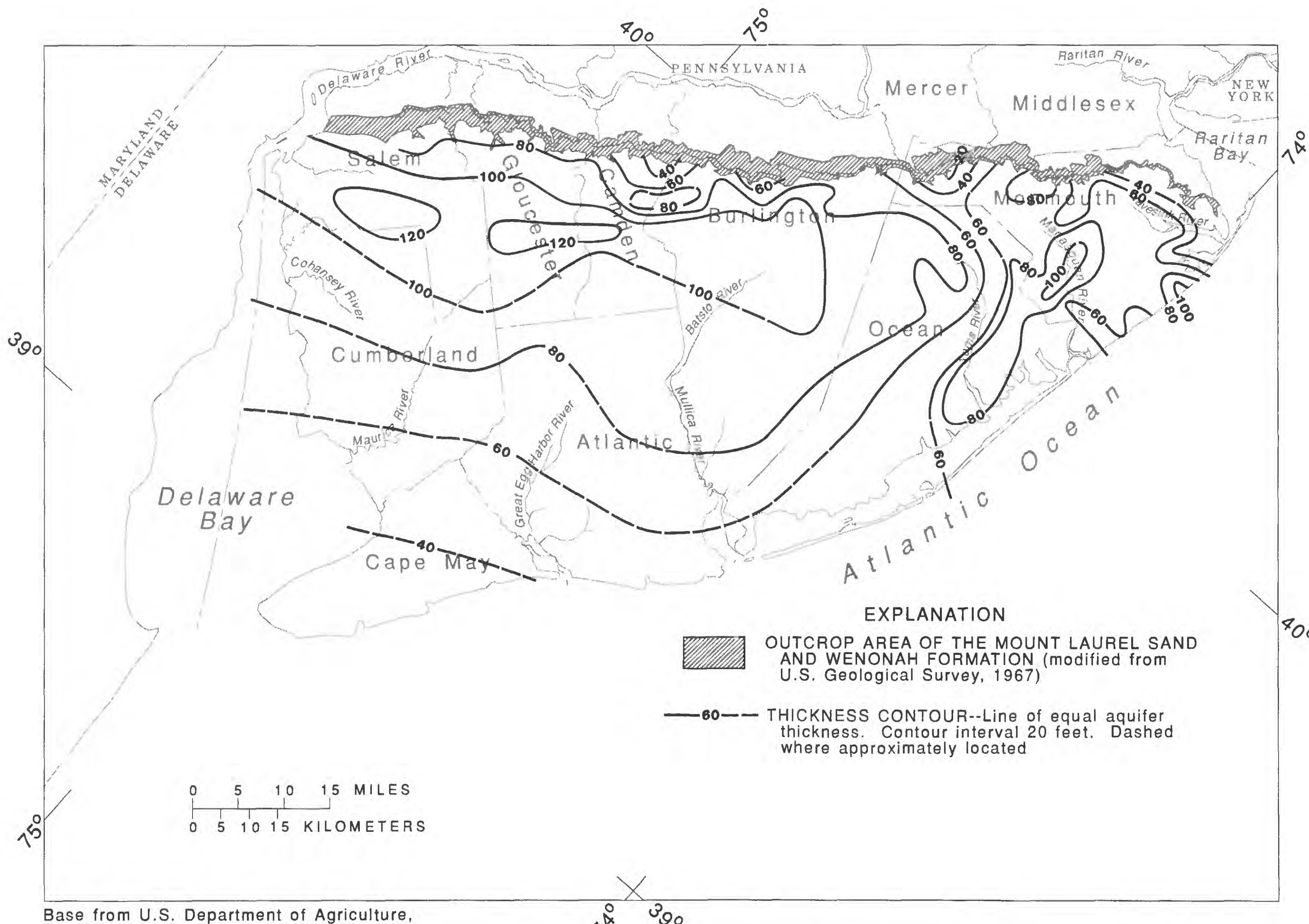
The potentiometric surface of the Wenonah-Mount Laurel aquifer within the study area (fig. 3) ranges in altitude from below sea level to more than 100 feet above sea level. Recharge to the aquifer generally occurs along those parts of the outcrop area at relatively high elevations. Discharge from the aquifer generally occurs as leakage to underlying aquifers and along the outcrop area located in low-lying areas, such as to Delaware Bay. Withdrawals and changes in withdrawals can have a significant effect on the ground-water flow regime.

Methods and Approach

The evaluation of the effects of future withdrawals on the Wenonah-Mount Laurel aquifer required several steps. First, future demands on the aquifer were assessed. Next, withdrawal scenarios were developed. The scenarios were evaluated with a ground-water-flow model that calculates water levels resulting from the simulation of the withdrawal scenarios. Finally, the water levels for each scenario were evaluated with respect to magnitude of decline.

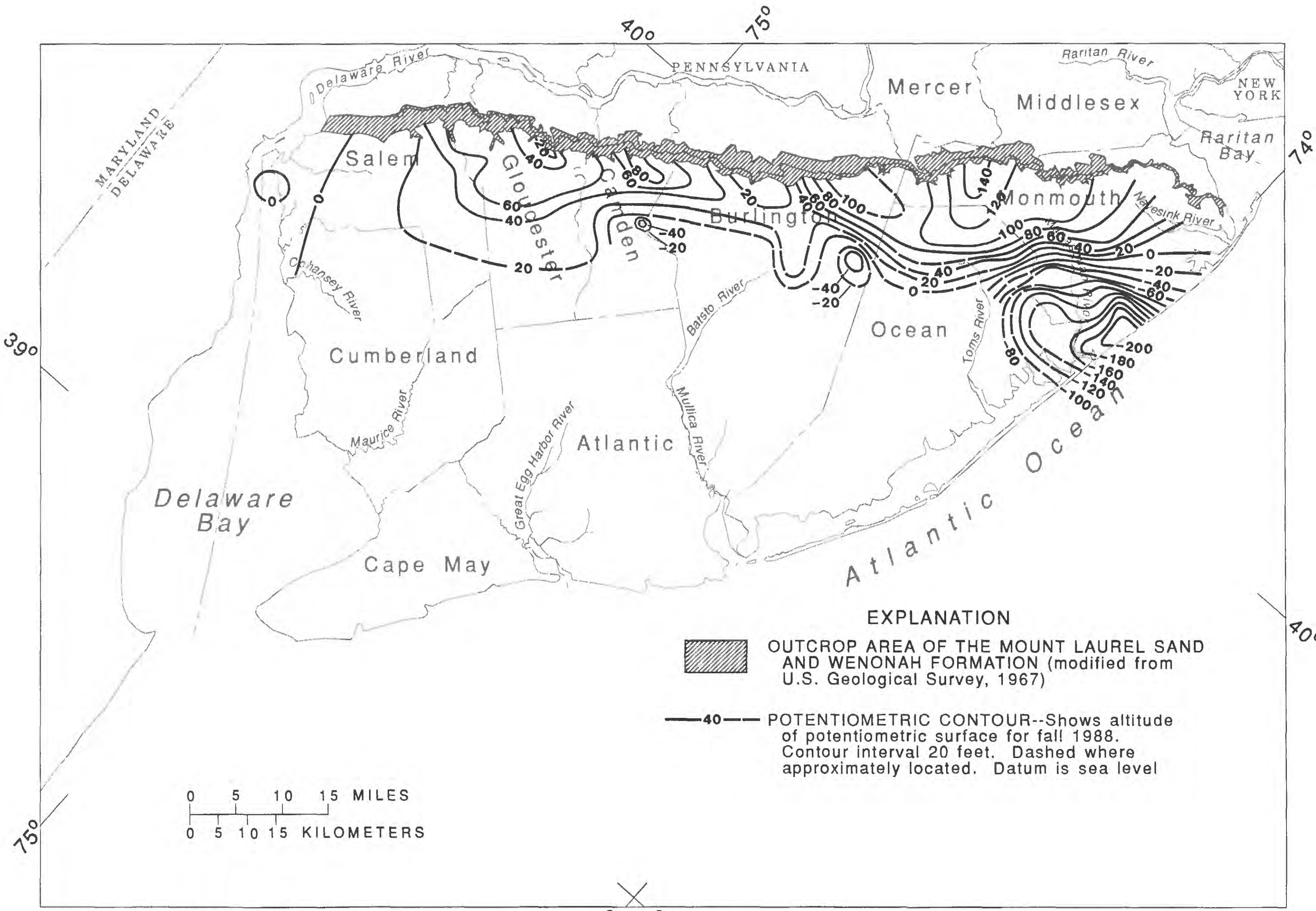
PROJECTED WITHDRAWALS FROM THE WENONAH-MOUNT LAUREL AQUIFER

Currently, the primary source of water supply in Burlington, Camden, and Gloucester Counties is the Potomac-Raritan-Magothy aquifer system. Large cones of depression in the Potomac-Raritan-Magothy aquifer system's potentiometric surface have developed as a result of heavy withdrawals (Eckel and Walker, 1986). In 1986, NJDEPE determined that the magnitude and rate of water-level decline in the Potomac-Raritan-Magothy aquifer system



Base from U.S. Department of Agriculture, Soil Conservation Service, 1:250,000, 1980

Figure 2.--Outcrop area and thickness of the Wenonah-Mount Laurel aquifer.



Base from U.S. Department of Agriculture, Soil Conservation Service, 1:250,000, 1980

Figure 3.--Potentiometric surface of the Wenonah-Mount Laurel aquifer in fall 1988.

were indicative of overpumping and declared a "Water-Supply Critical Area" (New Jersey Department of Environmental Protection, 1986) for parts of Burlington, Camden, and Gloucester Counties. This area (fig. 1) encompasses the City of Camden and its suburbs. This declaration may result in a freeze or cutback in the amount of water pumped from the Potomac-Raritan-Magothy aquifer system. The anticipated cutback is 35 percent of 1983 withdrawals within the area designated as "Water Supply Critical Area #2." Consequently, an alternative water supply is needed to provide for the present and future water demands of the area.

The Wenonah-Mount Laurel aquifer is a possible water-supply alternative to the Potomac-Raritan-Magothy aquifer system in Camden, Burlington, and Gloucester Counties. Current (1989) withdrawals from the Wenonah-Mount Laurel aquifer average 4.46 and 3.06 Mgal/d for purveyors in Burlington and Camden Counties, respectively. Withdrawals from the Wenonah-Mount Laurel aquifer in Gloucester County currently are not significant (U.S. Geological Survey State Water-Use Data System--computerized data on file at the U.S. Geological Survey office, West Trenton, N.J.). The 30-year planning period from 1990 to 2020 was chosen to determine water-supply needs and to evaluate the effects of withdrawals.

Future withdrawals by specific water purveyors within the study area were estimated in conjunction with the NJDEPE and are given in table 2 as three scenarios. The purveyors listed have potential access to the aquifer that will not require lengthy pipelines or other long-distance transmission facilities and have communicated their interest in the Wenonah-Mount Laurel aquifer to NJDEPE. Each purveyor's current demand, cutback of withdrawals from the Potomac-Raritan-Magothy aquifer system, and anticipated growth in demand through the year 2020 was determined. The withdrawal scenarios listed in table 2 are based on estimates of future demand provided by each purveyor to NJDEPE and from requests for water-allocation permits.

The situation in which the purveyors use the Wenonah-Mount Laurel aquifer as a supply to supplement their cutback to 65 percent of 1983 withdrawals from the Potomac-Raritan-Magothy aquifer system and to provide for future demand is considered in scenario 1. This will result in withdrawals of greater than 14 Mgal/d in 2020. Because the confining unit between the Wenonah-Mount Laurel aquifer and the Englishtown aquifer system is leaky, withdrawals from the Englishtown aquifer system within and near the study area need to be accurately respresented. These withdrawal estimates are also indicated in table 2. The withdrawals from the Kirkwood-Cohansey aquifer system within the study area are generally from privately owned domestic wells and thus are not significant in this analysis.

The communities of Clayton and Glassboro, both located in central Gloucester County, currently rely on the Potomac-Raritan-Magothy aquifer system for their water supply. Water in the Potomac-Raritan-Magothy aquifer system undergoes a transition from fresh to saline in that area (Gill and Farlekas, 1976); however, that could force Clayton and Glassboro to reduce their Potomac-Raritan-Magothy aquifer system withdrawals further than required to avoid impending saline-water intrusion. The situation in which Clayton and Glassboro will reduce their Potomac-Raritan-Magothy aquifer system withdrawals to 50 percent of their 1983 levels, withdrawing additional water from the Wenonah-Mount Laurel aquifer, is considered in

Table 2.--Withdrawal scenarios

[AFB, Air Force Base; Ctr., Center; Co., Company; Dept., Department; G.C., Golf Club; H.S., High School; Inc., Incorporated; MUA, Municipal Utilities Authority; Twp., Township; PRM, Potomac-Raritan-Magothy aquifer system; withdrawals are in million gallons per year; negative values indicate injection; --, indicates no withdrawal

Water purveyor	Model location: Layer	Row	Column	Simulation period: 1983 to 1985	1985 to 1990	1990 to 1995	1995 to 2000	2000 to 2005	2005 to 2010	2010 to 2015	2015 to 2020
SCENARIO 1											
Englishtown aquifer system withdrawals											
Clementon Borough	4	8	22	--	--	208	208	208	208	208	208
Freehold Twp. and Borough	4	8	41	--	--	539	539	539	539	539	539
Mt. Holly Water Co.	4	6	28	--	--	451	451	564	564	704	845
New Jersey Water Co.	4	7	22	--	--	393	393	470	470	565	680
Pemberton Twp. (1)	4	9	30	-15	-19	-24	-29	-34	-39	-44	-49
Total withdrawal				-15	-19	1,567	1,562	1,747	1,742	1,972	2,223
Wenonah-Mount Laurel aquifer withdrawals											
Berlin Borough	5	9	22	--	--	243	243	382	382	419	455
Clayton Borough	5	9	17	--	--	89	89	114	114	151	187
Deborah Heart and Lung Ctr.	5	10	31	--	--	--	20	26	28	28	28
Evesham Twp.	5	7	25	--	--	387	387	582	582	708	834
Garden State Water Co.	5	9	21	--	--	401	401	541	541	720	899
Glassboro	5	8	17	--	--	227	227	254	254	284	313
Mantua Twp. MUA	5	7	17	--	--	151	151	290	290	325	360
McGuire AFB	5	9	32	--	--	278	278	278	278	278	278
Estaugh T/A Medford Leasing	5	8	26	--	--	30	30	40	40	50	60
Medford Twp. MUA	5	8	26	--	--	425	425	510	510	610	730
New Jersey Water Co.	5	7	22	--	--	--	3	4	4	4	4
New Jersey Water Co.	5	8	22	--	--	285	285	350	350	420	505
New Jersey Water Co. (1)	5	8	23	--	--	--	--	-2	-5	-8	-11
Overbrook Regional Senior H.S.	5	9	21	--	--	--	6	13	19	26	32
Pine Hill MUA & Pine Valley G.C.	5	8	21	16	16	195	195	277	277	277	277
Pitman Boro	5	7	18	--	--	243	243	294	294	353	411
Salem Nuclear Plant (1)	5	7	7	--	--	-44	-118	-193	-269	-342	-417
Salem Water Dept.	5	6	10	--	--	300	300	300	300	300	300
South Jersey Water Co.	5	6	17	--	--	91	91	113	113	202	292
Sybron Chemicals, Inc.	5	8	29	--	--	300	300	350	350	400	450
Vorhees Golf Farm (1)	5	7	23	--	--	--	-29	-57	-86	-115	-143
Winslow Twp. Ivy Stone Farm	5	10	22	--	--	--	1	2	3	4	5
Total withdrawal				16	16	3,601	3,530	4,469	4,371	5,095	5,850
SCENARIO 2											
(Clayton and Glassboro reduce PRM withdrawals by 50 percent) same as scenario #1, except: Wenonah-Mount Laurel aquifer withdrawals											
Clayton Borough	5	9	17	--	--	152	152	178	178	214	251
Glassboro	5	8	17	--	--	399	399	426	426	456	485
Total withdrawal				16	16	3,836	3,765	4,705	4,607	5,330	6,086
SCENARIO 3											
(Clayton and Glassboro cease PRM withdrawals) same as scenario #1, except: Wenonah-Mount Laurel aquifer withdrawals											
Clayton Borough	5	9	17	--	--	215	215	241	241	277	314
Glassboro	5	8	17	--	--	571	571	599	599	628	657
Total withdrawal				16	16	4,071	4,000	4,941	4,843	5,565	6,321

(1) Adjustment to offset excessive withdrawal estimates used in Battaglin and Hill (1989), Scenario F.

scenario 2. The situation in which Clayton and Glassboro will cease withdrawing from the Potomac-Raritan-Magothy aquifer system and will use the Wenonah-Mount Laurel aquifer exclusively is considered in scenario 3. In scenarios 2 and 3, the Wenonah-Mount Laurel aquifer withdrawals for supplementary purposes exceed 15 Mgal/d in 2020. All other withdrawals in the Coastal Plain remain the same as in scenario 1.

The ground-water-flow model used to evaluate the withdrawal scenarios simulates the entire Coastal Plain of New Jersey (Martin, 1990). The evaluation of the scenarios in the study area required that withdrawals from the entire Coastal Plain be specified. Battaglin and Hill (1989) developed a series of withdrawal scenarios to evaluate proposed ground-water management schemes in the northeastern part of the New Jersey Coastal Plain. Although their scenarios do not address the objectives of this investigation, one, scenario F (Battaglin and Hill, 1989, table 2, p. 14), incorporates a 30-percent reduction in Potomac-Raritan-Magothy aquifer system withdrawals in the Camden area to approximate Critical Area #2 cutbacks and accounts for increases in withdrawals elsewhere in the Coastal Plain through the year 2020. The scenarios shown in table 2, used in conjunction with Battaglin and Hill's scenario F, provide a comprehensive treatment of withdrawals that accounts for all effects on ground water in the Coastal Plain. Although Battaglin and Hill did not foresee the projected interest in the Wenonah-Mount Laurel aquifer, they applied a growth factor to existing withdrawals to project the demand to the year 2020. For some withdrawals, the estimated growth is unrealistically high, resulting in too much use by 2020; therefore, several entries in table 2 have been adjusted through a hypothetical injection or recharge well to correct for the excessive withdrawals. The combination of the scenarios in table 2 with Battaglin and Hill's scenario F forms the basis for the evaluation of withdrawals.

SIMULATED EFFECTS OF PROJECTED WITHDRAWALS

The evaluation of the effects of projected withdrawals on the Wenonah-Mount Laurel aquifer used a ground-water flow model of the New Jersey Coastal Plain with Battaglin and Hill's (1989) scenario F in conjunction with three scenarios developed for this study. The model generates a simulated potentiometric surface as a principal output. The important factors for evaluation of the effects of the scenarios are (1) depth of cone of depression, (2) lateral extent of cones of depression, (3) proximity of drawdown to aquifer outcrop area, (4) proximity of drawdown below sea level near the aquifer outcrop area at Delaware Bay in Salem County.

Model Design

The ground-water flow model of the New Jersey Coastal Plain aquifers used to evaluate the effects of withdrawals on the Wenonah-Mount Laurel aquifer in Burlington, Camden, and Gloucester Counties was developed and calibrated by Martin (1990), as part of the U.S. Geological Survey's New Jersey Coastal Plain Regional Aquifer-System Analysis (RASA) project. The model computer code is a modified version (Leahy, 1982) of the computer program developed by Trescott (1975) that is based on finite-difference methods. The model was developed to simulate water levels in 10 New Jersey Coastal Plain aquifers and consists of a grid with 29 rows and 51 columns.

Model nodes are located at the center of each grid cell and are designated by layer, row, and column number. The 10 model layers representing Coastal Plain aquifers and their relation to geologic and hydrogeologic units are summarized in table 1. Model layer 5 represents the Wenonah-Mount Laurel aquifer. The model grid and locations of withdrawals used in the scenarios developed for this report are shown in figure 4.

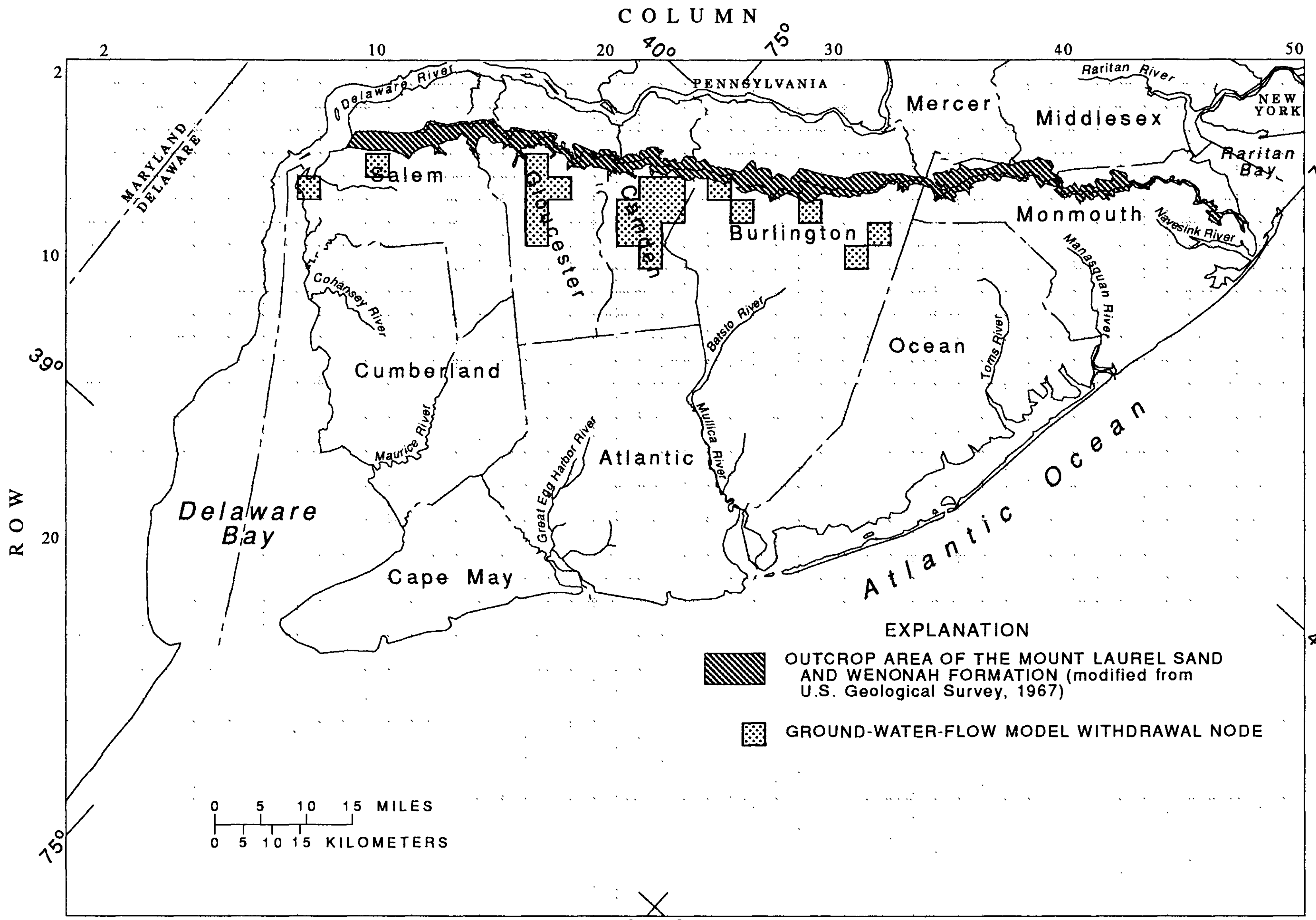
The major lateral boundaries that constrain the RASA model (Martin, 1990, fig. 25) are the Fall Line, the updip contact of Coastal Plain deposits with low-permeability crystalline rocks to the northwest, modeled as a no-flow boundary; the 10,000-milligrams-per-liter chloride-concentration line, located offshore to the southeast, modeled as a no-flow boundary; a flow line in a ground-water discharge area in Raritan Bay, to the northeast, modeled as a no-flow boundary; and a flow line along the ground-water divide between Delaware Bay and Chesapeake Bay, modeled as a no-flow boundary. The vertical boundaries are the crystalline rocks underlying the Coastal Plain deposits, modeled as a no-flow boundary; and an overlying constant-head boundary representing the altitude of the water table in the unconfined parts of the aquifers. Further information pertaining to the model's design and calibration is available in Martin (1990).

The hydrologic boundaries that are of interest to an investigation of the Wenonah-Mount-Laurel aquifer within the study area are the aquifer's outcrop (fig. 4), with associated recharge; the part of the outcrop area that is in contact with sea water in Delaware Bay; and leakage with underlying aquifers.

Simulation Results

The results of simulation of the three withdrawal scenarios are summarized in table 3, which includes the drawdown of the potentiometric surface of the Wenonah-Mount Laurel aquifer from initial conditions at nodes that represent withdrawals of interest. The drawdowns listed are attributable only to withdrawals defined in this report, not those arising from Battaglin and Hill's (1989) scenario F. Therefore, the values in table 3 can be added to any defined potentiometric surface. The range of values is from drawdowns in excess of 90 ft to rises (buildup) of as much as 30 ft. The water-level rises (indicated in tables 2 and 3) are the result of adjustments to Battaglin and Hill's (1989) scenario F. These adjustments represent the injection of water to counteract excessive estimates of future withdrawals, such as those at the Salem Nuclear Plant (fig. 1). All other adjustments are of smaller magnitude and become overshadowed by other withdrawals. Consequently, a reduction in the rate of water-level decline is seen rather than a rise.

The simulated potentiometric surface of the Wenonah-Mount Laurel aquifer in 1990, before the projected increase in withdrawals, is shown in figure 5. The effects of existing withdrawals that are not directly related to the supplemental use in the Camden area are evident at the Salem Nuclear Power Plant, where a cone of depression extends 20 feet below sea level in



Base from U.S. Department of Agriculture, Soil Conservation Service, 1:250,000, 1980

Figure 4.--Ground-water-flow model grid and withdrawal locations.

Table 3.--Simulated drawdown from withdrawal scenarios at selected model nodes

[AFB, Air Force Base; Ctr., Center; Co., Company; Dept., Department; G.C., Golf Club; H.S., High School; Inc., Incorporated; MUA, Municipal Utilities Authority; Twp., Township; T/A, traded as]

Water purveyor	Model node: Layer	Model node: Row	Model node: Column	Drawdown, in feet below 1990 conditions: Scenario 1	Scenario 2	Scenario 3
Berlin Borough	5	9	22	77	92	93
Clayton Borough	5	9	17	39	60	71
Deborah Heart and Lung Ctr.	5	10	31	12	17	18
Evesham Twp.	5	7	25	5	5	5
Garden State Water Co.	5	9	21	45	78	79
Glassboro	5	8	17	39	58	71
Mantua Twp. MUA	5	7	17	31	36	40
McGuire AFB	5	9	32	17	18	18
Estaugh T/A Medford Leasing	5	8	26	73	75	75
Medford Twp. MUA	5	8	26	(same as Estaugh T/A Medford Leasing)		
New Jersey Water Co.	5	7	22	19	21	21
New Jersey Water Co.	5	8	22	48	55	55
New Jersey Water Co.[1]	5	8	23	18	22	23
Overbrook Regional Senior H.S.	5	9	21	(same as Garden State Water Co.)		
Pine Hill MUA & Pine Valley G.C.	5	8	21	42	59	59
Pitman Boro	5	7	18	30	37	39
Salem Nuclear Plant[1]	5	7	7	-33	-32	-32
Salem Water Dept.	5	6	10	7	8	8
South Jersey Water Co.	5	6	17	7	7	8
Sybron Chemicals, Inc.	5	8	29	31	36	36
Vorhees Golf Farm[1]	5	7	23	1	4	4
Winslow Twp. Ivy Stone Farm	5	10	22	40	56	57

[1] Adjustment to offset excessive withdrawal estimates used in Battaglin and Hill (1989), Scenario F. Negative (-) sign indicates water-level rise.

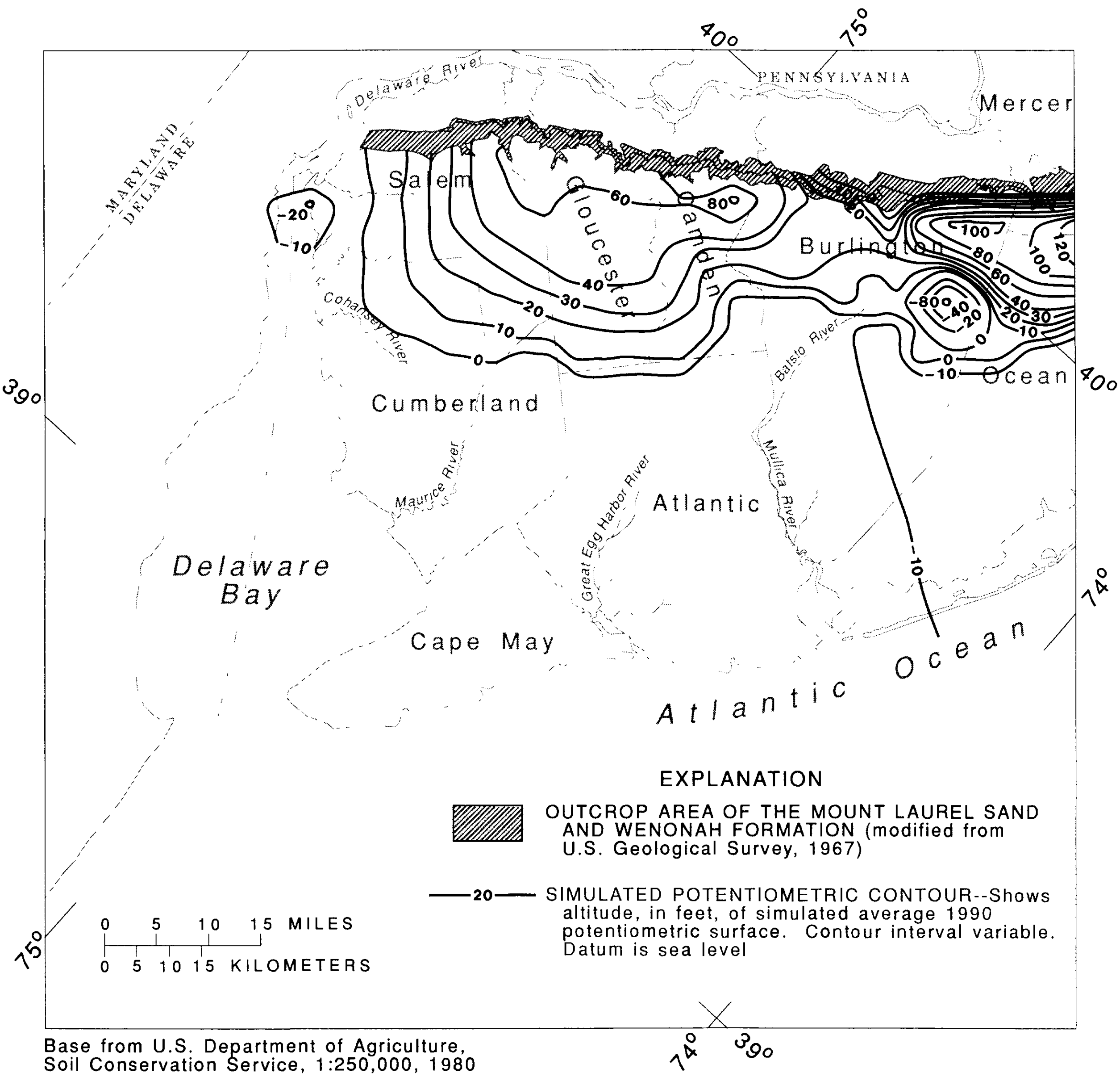


Figure 5.--Simulated potentiometric surface of the Wenonah-Mount Laurel aquifer prior to withdrawals for supplemental purposes, 1990.

southwestern Salem County, and especially in northeastern Burlington County, where a cone of depression extends to about 80 feet below sea level. Camden and Gloucester Counties, however, do not show significant cones of depression; in fact, heads in much of the area are greater than 40 ft above sea level.

The simulated potentiometric surface of the Wenonah-Mount Laurel aquifer for scenario 1 in 2020 is shown in figure 6. The need for supplemental supply has caused some cones of depression to form and has deepened others. Their depths range from 10 ft above to 60 ft below sea level, a decline of about 40 to 90 ft from 1990 conditions. The sizable cone of depression in northeastern Burlington County has widened and extends to 160 ft below sea level, a decline of about 80 ft from 1990. The cone of depression near the Salem Nuclear Power Plant also has widened, but still extends to a depth of about 20 ft below sea level. New cones of depression have developed in proximity to the outcrop area in Burlington County. In the case of wells sited near the aquifer's outcrop area, the increased withdrawals and resultant cones of depression would likely increase infiltration from streams crossing the outcrop area. In the case of wells sited downdip from the outcrop, vertical flow could cause secondary drawdown in an adjacent aquifer, such as the Englishtown aquifer system.

The simulated potentiometric surface of the Wenonah-Mount Laurel aquifer in 2020 for withdrawal scenario 2 is shown in figure 7. In this scenario, it is assumed that Clayton Borough and Glassboro will reduce their withdrawals from the Potomac-Raritan-Magothy aquifer system by 50 percent and will use the Wenonah-Mount Laurel aquifer as the alternative supply. The additional withdrawals have widened and increased the depth of all cones of depression in the Camden area. The range in depth is from about 10 to 60 ft below sea level, representing a decline of 60 to 100 ft from 1990 conditions. The cone of depression in the Clayton and Glassboro area extends to 10 ft below sea level. The large cone of depression in northeastern Burlington County extends to about 220 ft below sea level, a decline of about 140 ft from 1990. The cone of depression in the vicinity of the Salem Nuclear Power Plant extends to about 20 ft below sea level, similar to that in scenario 1 (fig. 6). The cones of depression in Burlington County have developed steeper gradients near the outcrop area than in scenario 1.

The simulated potentiometric surface of the Wenonah-Mount Laurel aquifer in 2020 for withdrawal scenario 3 is shown in figure 8. This scenario has the largest withdrawals and assumes that Clayton Borough and Glassboro will cease all withdrawals from the Potomac-Raritan-Magothy aquifer system and will use the Wenonah-Mount Laurel aquifer for their entire supply. By the year 2020, the cone of depression in the Clayton and Glassboro area extends to 20 ft below sea level, an increase of about 10 ft because of the additional withdrawals. Elsewhere, the potentiometric surface does not change significantly from its position in scenario 2 (fig. 7). The insensitivity of water levels in the vicinity of the Salem Nuclear Power Plant to the change in withdrawals in the Camden area indicates a degree of isolation that may stem from local recharge. If the recharge originates in Delaware Bay, the potential for saltwater intrusion would exist. Otherwise, the recharge could originate from the southernmost part of the aquifer's recharge area or vertical flow from overlying aquifers.

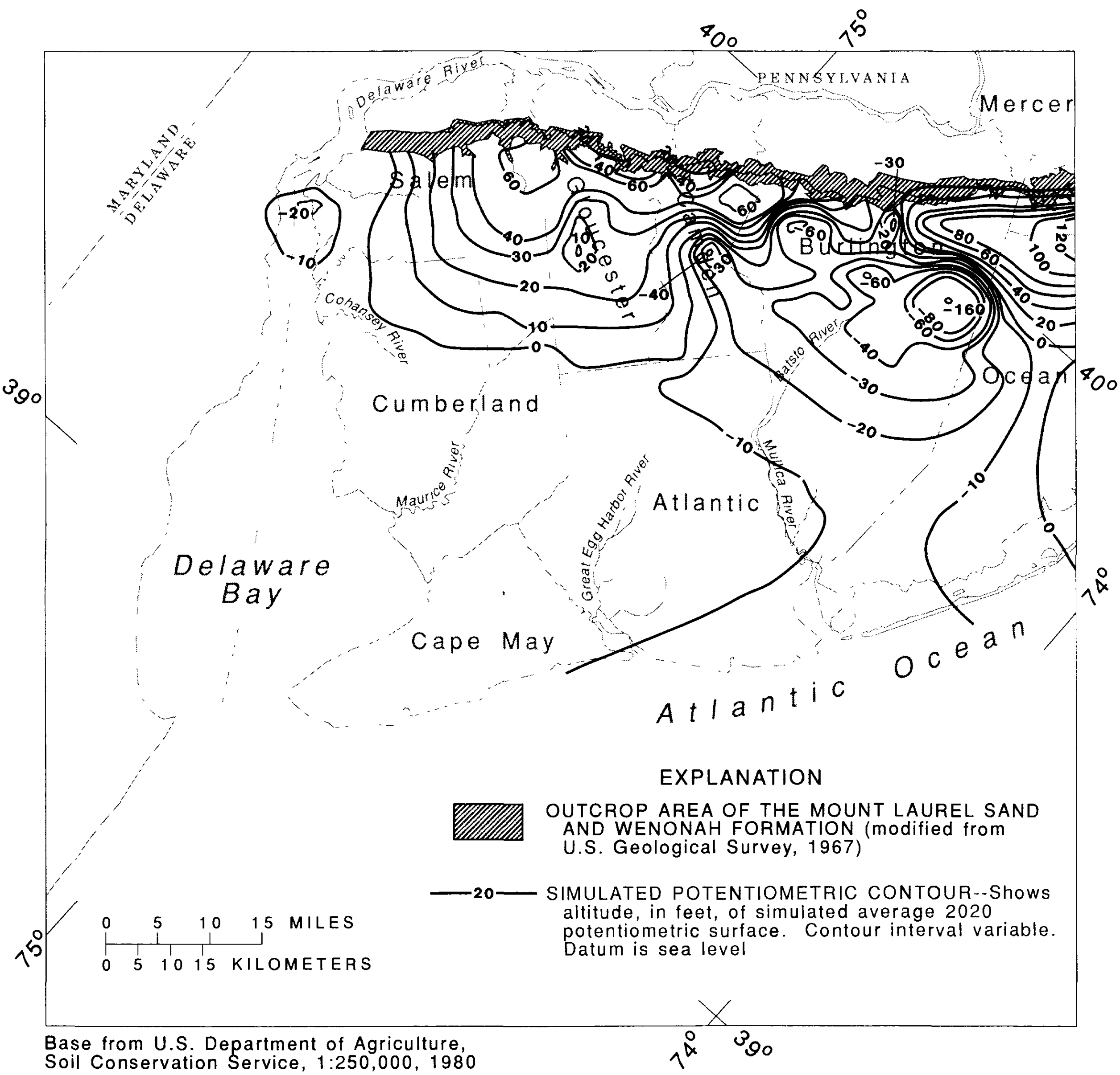


Figure 6.--Simulated potentiometric surface of the Wenonah-Mount Laurel aquifer scenario 1 (withrawals to supplement 35 percent Potomac-Raritan-Magothy aqufier system reductions), 2020.

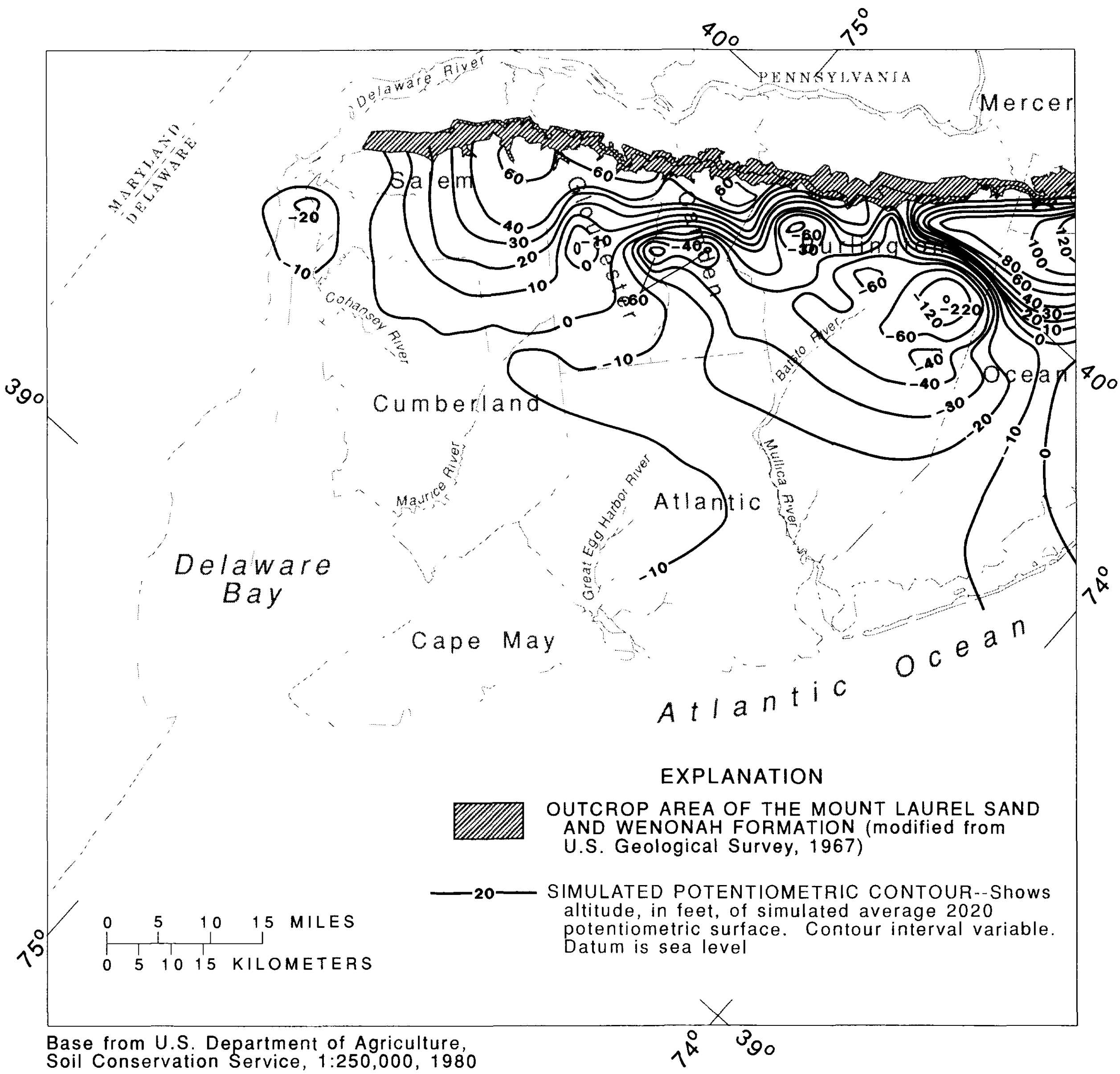


Figure 7.--Simulated potentiometric surface of the Wenonah-Mount Laurel aquifer scenario 2 (withrawals to supplement 35 percent Potomac-Raritan-Magothy aqufier system reduction; Clayton and Glassboro reduce Potomac-Raritan-Magothy aquifer system withdrawals by 50 percent), 2020.

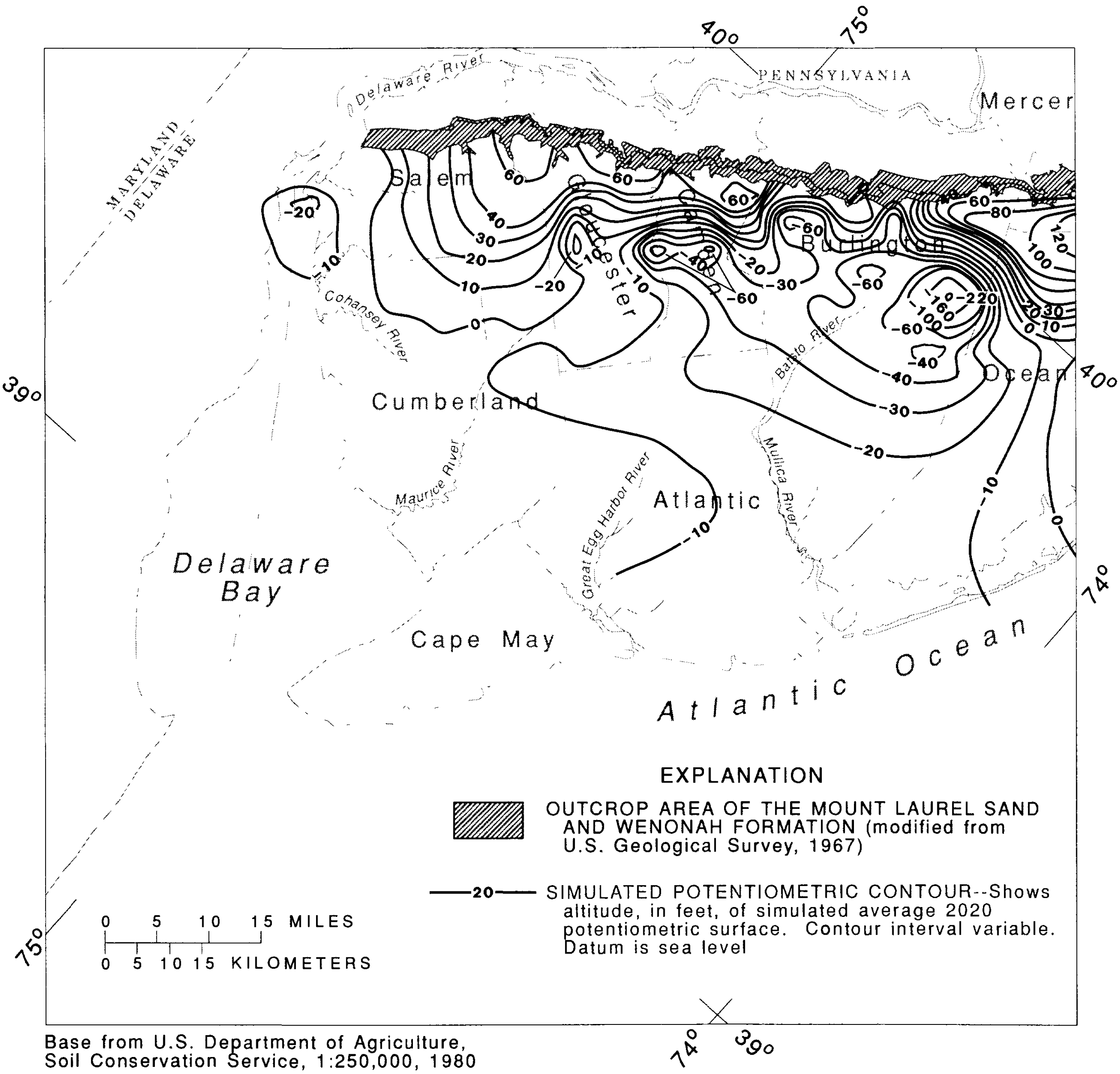


Figure 8.--Simulated potentiometric surface of the Wenonah-Mount Laurel aquifer scenario 3 (withrawals to supplement 35 percent Potomac-Raritan-Magothy aqufier system reduction; Clayton and Glassboro cease Potomac-Raritan-Magothy aquifer system withdrawals), 2020.

Limitations of Model

The extent to which model-generated potentiometric surfaces and related data can be used to evaluate withdrawal scenarios is subject to certain limitations. These limitations are related to the fundamental assumptions of the numerical simulation procedure, the spatial discretization of the model grid, the discretization through time, and the reliability of the model's calibration. The RASA model grid has a minimum spacing of 2.5 mi by 2.5 mi, but in places, especially in the southeastern part, the grid spacing increases (coarsens). The simulated water level represents average conditions within each model cell, which in areas where the potentiometric gradient is steep might not accurately indicate the water level at a particular point. Similarly, the numerical procedure used in the modeling process assigns various hydrologic stresses, such as withdrawals, or the sense of whether the node represents an outcrop or confined conditions, to the center of the grid block and thereby can result in a locational inaccuracy. The model was calibrated using average annual recharge and withdrawal data and thus does not account for any seasonality in these factors. Therefore, the model is realistically applied only to assess scenarios on a multi-year basis rather than for individual years or less. Because water levels can fluctuate as much as 6 ft seasonally and elevations of observation wells used for calibration of water levels could be as much as 10 ft in error, the absolute accuracy is probably in the range of +/- 8 to 10 ft.

SUMMARY AND CONCLUSIONS

The potential reduction in Potomac-Raritan-Magothy aquifer system (Potomac-Raritan-Magothy aquifer system) withdrawals for potable water supply in the Camden area, in response to restrictions associated with NJDEPE's declaration of "Water Supply Critical Area #2" (New Jersey Department of Environmental Protection, 1986), has created interest in using the Wenonah-Mount Laurel aquifer as an alternative supply. Three withdrawal scenarios were developed to evaluate the resulting drawdowns for the year 2020. These three scenarios consider (1) the use of the Wenonah-Mount Laurel aquifer to supplement for a 35-percent reduction in withdrawals from the Potomac-Raritan-Magothy aquifer system; (2) the same withdrawals as in scenario 1, except that Clayton Borough and Glassboro reduce their withdrawals from the Potomac-Raritan-Magothy aquifer system by 50 percent; and (3) the same withdrawals as in scenario 1, except that Clayton Borough and Glassboro cease their withdrawals from the Potomac-Raritan-Magothy aquifer system and rely entirely on the Wenonah-Mount Laurel aquifer.

Simulation results indicate that the additional withdrawals from the Wenonah-Mount Laurel aquifer will result in the development of large cones of depression in the Camden area by the year 2020. The cones of depression resulting from scenario 1 range in depth from 10 ft above sea level in the Clayton and Glassboro area to 60 ft below sea level in parts of Burlington County. This represents a decline from 1990 conditions of 40 to 90 ft. Outside of the immediate Camden area, the present cones of depression in northeastern Burlington County would extend to 160 ft below sea level, a decline of about 80 ft from 1990 conditions. The cone in the vicinity of the Salem Nuclear Power Plant would extend to a depth of 20 ft below sea level, representing no change from 1990.

Scenarios 2 and 3 specify increased withdrawals from the Wenonah-Mount Laurel aquifer in the Clayton and Glassboro vicinity. This would increase the depth of the cone of depression in the Clayton and Glassboro area to 10 ft below sea level for scenario 2 and to 20 ft below sea level for scenario 3; this represents a decline of about 60 to 100 ft from 1990 conditions. Although withdrawals elsewhere would remain at the scenario 1 levels, the cones of depression in Camden and Burlington Counties would deepen. The base of the large cone in northeastern Burlington County would deepen from 160 to 220 ft below sea level; this represents a decline of about 140 ft from 1990 conditions. The extent and depth of the cone of depression in the Salem Nuclear Power Plant vicinity would remain essentially the same as in scenario 1.

The evaluation of simulation results leads to several observations and conclusions pertaining to the effects of the projected withdrawals on the Wenonah-Mount Laurel aquifer:

(1) The projected withdrawals would cause significant drawdown in the Camden area, and also would enlarge present cones of depression outside that area. Those in Burlington County would be affected most severely because they are wider and deeper than those elsewhere. Cones of depression in themselves, however, are not necessarily deleterious. They are the necessary response of the natural system to provide the gradient to move water.

(2) The simulations of scenarios 2 and 3 do not result in potentiometric surfaces that are significantly different from each other.

(3) The probable effects of the projected withdrawals, other than creating cones of depression, will include an increase in infiltration from streams crossing the aquifer's outcrop and an increase in recharge rates. Because these effects will be spread across the outcrop area, they probably will not be readily measurable.

(4) The Wenonah-Mount Laurel aquifer is hydraulically connected to adjacent aquifers. Any cone of depression in the Wenonah-Mount Laurel aquifer could cause a secondary cone of depression in an adjacent aquifer, or the reverse; thus resource-management planning should consider all interconnected aquifers in a comprehensive manner. For instance, the Englishtown aquifer system, which underlies the Wenonah-Mount Laurel aquifer, is used in Burlington County and northeastward. Because the simulations indicate large cones of depression in the Wenonah-Mount Laurel aquifer in Burlington County, the effects on the Englishtown aquifer system warrant consideration in future water-use planning.

(5) The cone of depression near the Salem Nuclear Power Plant did not change significantly in any of the scenarios. This apparent insensitivity to the additional withdrawals in the Camden area could indicate isolation caused by the proximity of recharge from Delaware Bay (possibly indicating potential for saltwater intrusion) or recharge from the southernmost part of the aquifer's recharge area.

(6) The model representation of the outcrop area and boundary with Delaware Bay is relatively coarse. Thus, model analyses of withdrawal scenarios in parts of Salem County and near the outcrop area will be constrained and possibly compromised by the lack of spatial resolution. Further study of the aquifer, its outcrop area, and connection to the bay is warranted to provide adequate definition for detailed modeling.

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