U.S. Department of the Interior
U.S. Geological Survey

SIMULATED EFFECTS OF ALTERNATIVE PUMPING STRATEGIES ON GROUND-WATER-FLOW PATTERNS AND AREAS CONTRIBUTING RECHARGE TO SELECTED WELLS NEAR KENVIL, MORRIS COUNTY, NEW JERSEY

Water-Resources Investigations Report 01-4180

Prepared in cooperation with the

MORRIS COUNTY MUNICIPAL UTILITIES AUTHORITY

USGS
science for a changing world

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West Trenton, New Jersey

2001

science for a changing world

U.S. DEPARTMENT OF THE INTERIOR

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CONTENTS

Page

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Flow	
foot per year (ft/yr)	0.3048	meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallons per minute (gal/min)	0.06308	liters per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
million gallons per year (Mgal/yr)	3,785	cubic meter per year

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 the United States and Canada, formerly called Sea Level Datum of 1929.

SIMULATED EFFECTS OF ALTERNATIVE PUMPING STRATEGIES ON GROUND-WATER-FLOW PATTERNS AND AREAS CONTRIBUTING RECHARGE TO SELECTED WELLS NEAR KENVIL, MORRIS COUNTY, NEW JERSEY

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ABSTRACT

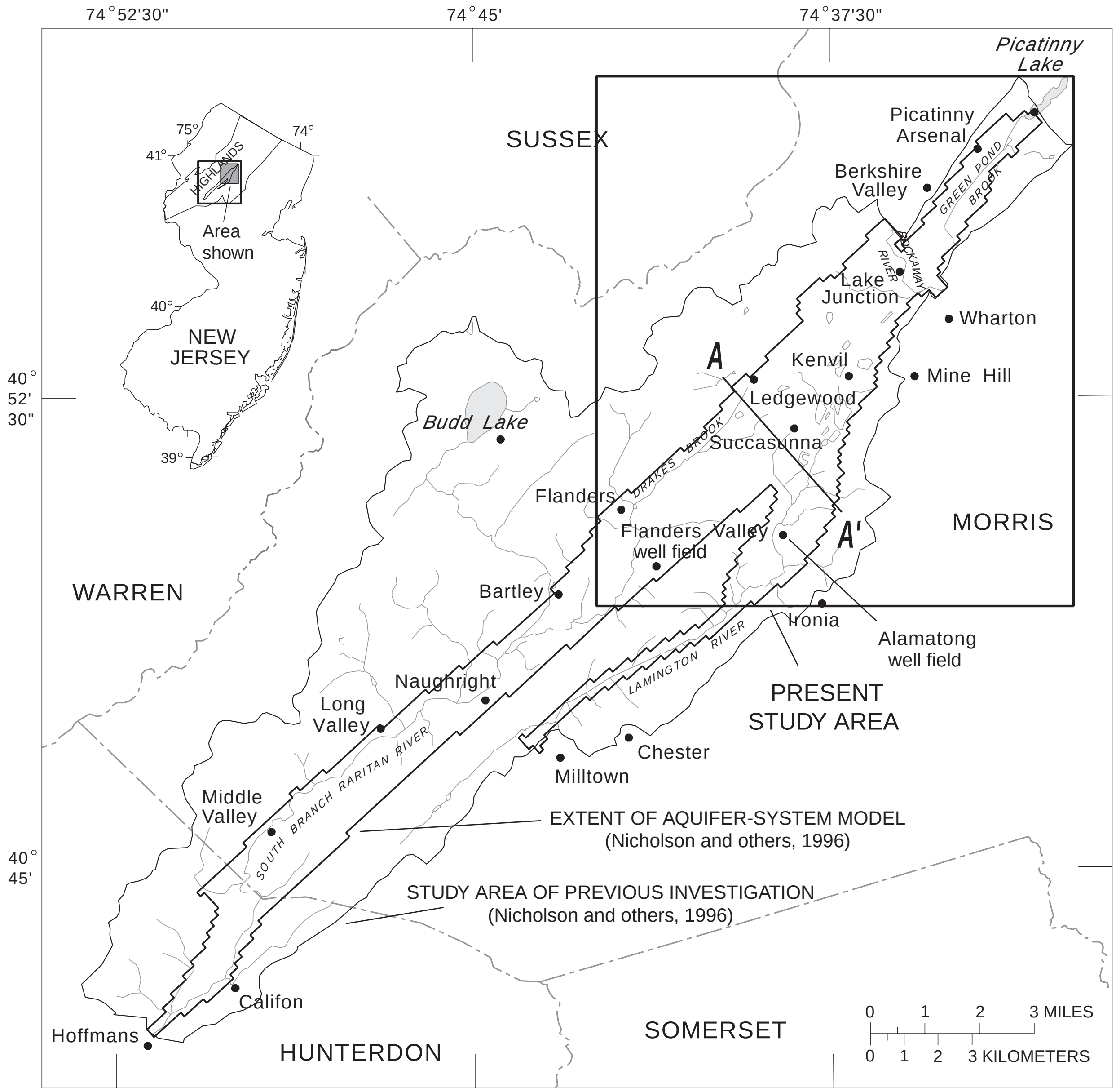
Ground-water-flow patterns and areas contributing recharge to supply wells change in response to new or altered pumping stresses. An understanding of these potential changes is essential for the effective evaluation of possible future water-supply alternatives, especially if the supply wells may be vulnerable to contamination from the land surface. Demand for water from a valley-fill and carbonate-rock aquifer system in the study area near Kenvil in Morris County, New Jersey, is expected to increase as the population of communities grows in and near the area. As withdrawals increase and new supplies are developed over time, ground-water-flow patterns and areas contributing recharge to supply wells in the area are expected to change.

Flow patterns and areas contributing recharge to selected supply wells in the aquifer system in the study area, under a variety of hypothetical withdrawal conditions, were evaluated by use of numerical modeling techniques. Under the four alternative scenarios evaluated, withdrawals from selected wells are increased by a total of 1.3 to 2.4 million gallons per day, or 32 to 56 percent over the recent (1991-95) total withdrawals from the study area. The scenarios were incorporated in simulations of ground-water flow that were conducted by use of a previously developed three-dimensional numerical model.

Flow-path comparisons indicate that ground-water-flow patterns change in response to changes in pumping rates and (or) new pumping stresses. Under the scenarios represented in the simulations, water levels (hydraulic heads) in the study area decline from 0 to as much as 63 ft. Under most of the scenarios evaluated, downward leakage of ground water increases and upward discharge to streams decreases. In some scenarios, supply wells intercept additional local flow, whereas in other scenarios additional regional flow is intercepted. Areas contributing recharge to wells also change or develop. Changes in flow patterns and in the location, size, and shape of areas contributing recharge to supply wells depend on the location and magnitude of the change in withdrawal stress and on other hydrogeologic factors, such as the configuration of aquifer boundaries and differences in aquifer properties.

INTRODUCTION

The valley-fill and carbonate-rock aquifer system near the town of Kenvil, New Jersey, in the New England (Highlands) Physiographic Province has become an increasingly important source of water supply for communities in southwestern and central Morris County. Various water-supply wells tap the aquifer system in the study area, which extends from Flanders in the southwest to Picatinny Lake in the northeast (fig. 1). These wells provide water to communities and industries in and east of the study area. The water supply is threatened by contaminated ground water present in the study area (Nicholson and others, 1996; R.A. Gallagher, N. J. Department of Environmental Protection, written commun., 1989; 1990). As development increases, demand for water from the aquifer system underlying the study area is expected to increase. Ground-water-flow patterns



EXPLANATION

A———A' TRACE OF GENERALIZED HYDROGEOLOGIC SECTION

Figure 1. Location of valley-fill- and carbonate-rock-aquifer study area near Kenvil, Morris County, in the New Jersey Highlands; extent of aquifer-system model; and trace of generalized hydrogeologic section.

and areas contributing recharge to supply wells are expected to change in response to changes in pumping stresses. The area contributing recharge to a well is defined as the area on the land surface through which ground-water recharge passes and eventually flows to the well screen or open interval (Franke and others, 1998). In order to effectively evaluate possible future water-supply alternatives that include new supply wells or long-term changes in pumping rates, water-resource managers need to understand their potential effects. Therefore, in 1997-98, the U.S. Geological Survey (USGS), in cooperation with the Morris County Municipal Utilities Authority, conducted a study of the aquifer system in which a three-dimensional numerical ground-water-flow model of the aquifer system previously developed by the USGS was used to evaluate changes in ground-water-flow patterns and areas contributing recharge to supply wells.

Purpose and Scope

This report describes the ground-water-flow patterns, areas contributing recharge to wells, and changes in water levels and in the ground-water budget that would likely result from each of four alternative pumping scenarios. In these scenarios, six previously installed and proposed wells are pumped at various rates. A numerical ground-water-flow model based on the MODFLOW code (Harbaugh and McDonald, 1996) is used in conjunction with a pathline generator, MODPATH (Pollock, 1994), to determine flow paths (pathlines) and areas contributing recharge to wells. Water budgets and drawdown distributions under each scenario also are examined. Nicholson and others (1996) described the hydrogeology of the valley-fill and carbonate-rock aquifer system, including the hydrogeologic-unit geometry, aquifer characteristics, water levels, geochemistry, and interactions between ground water and surface water. That assessment was achieved through the construction, calibration, and application of a three-dimensional ground-water-flow model of the aquifer system.

Previous Investigations

Nicholson and Watt (1998) evaluated flow patterns and areas contributing recharge to streams and supply wells in the heavily stressed, central part of the aquifer system under two alternative withdrawal scenarios: withdrawals projected for 2005 and withdrawals equal to the full utilization of the permitted allocations in effect in 1996. In both scenarios, withdrawals were assumed to remain in their installed locations. The study area described in this report includes the study area of Nicholson and Watt (1998) but is about three times larger. The authors thank William Ellis for his drafting of the similarly complex figures for this report.

HYDROGEOLOGY OF THE VALLEY-FILL AND CARBONATE-ROCK AQUIFER SYSTEM

The aquifer system extends along the valleys of the South Branch Raritan River and Lamington River Basins in the New Jersey Highlands (fig. 1). The valley fill is a complex assemblage of stratified glacial drift, unstratified glacial sediment (till), sediment deposited by streams (alluvium), and sediment from adjacent slopes deposited by gravity (colluvium). The valley-fill sediments are underlain in most areas by Paleozoic carbonate rock (Leithsville Formation), which commonly is folded, fractured, and highly weathered. In some areas, other Paleozoic rock (primarily conglomerate) underlies the valley fill and overlies the carbonate rock. Paleozoic quartzite and Precambrian gneiss (collectively referred to as crystalline bedrock) underlie and laterally bound the valley-fill and carbonate-rock units (fig. 2).

The aquifer system consists of an upper valley-fill aquifer, a lower valley-fill aquifer, two valley-fill confining units, a Paleozoic-rock confining unit (shale, conglomerate, and sandstone), and a carbonate-rock aquifer (fig. 2). The three aquifers are present in most of the valleys in the study area. The combined thickness of the aquifer system ranges from zero at the valley walls to approximately 1,000 ft along valley axes. The geometries of these aquifers and confining units were defined by L.J. Nicholson and Robert

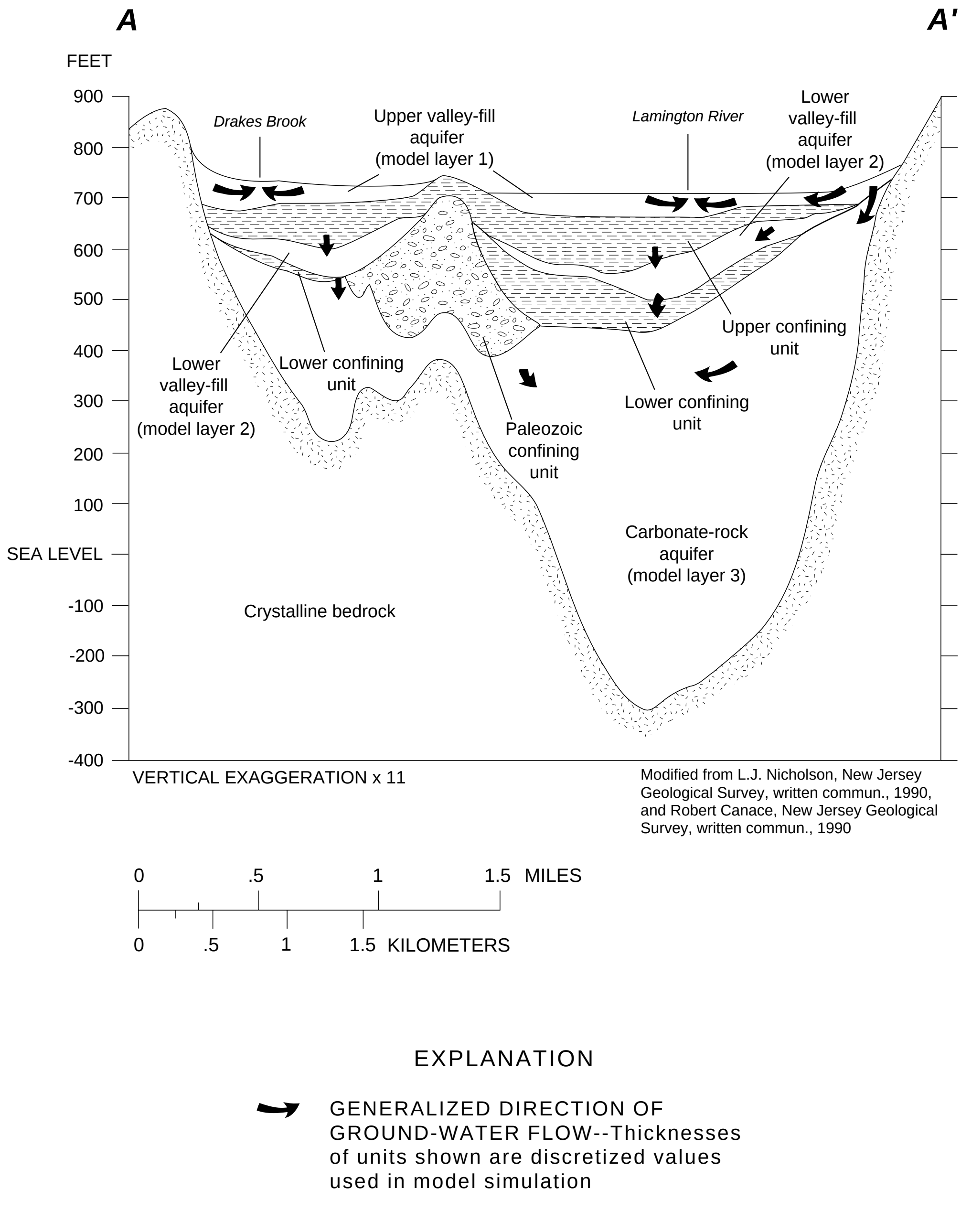


Figure 2. Generalized hydrogeologic section A - A' near Kenvil, Morris County, New Jersey. (Line of section shown in fig. 1; from Nicholson and Watt, 1998)

Canace (N. J. Geological Survey, written commun., 1990) and are documented by Nicholson and others (1996). The valley-fill aquifer materials are relatively permeable and ground water flows through them relatively quickly. In some areas the carbonate-rock aquifer is highly permeable and, as a result of anisotropy, the permeability is higher parallel to the valley than in the cross-valley direction. The permeabilities of the confining-unit materials (silt, clay, and non-carbonate sedimentary rock) and the bounding crystalline rocks are much lower than those of the aquifer materials, and ground water flows through these units relatively slowly.

Recharge to the aquifer system occurs as direct infiltration of precipitation through the valley floor, seepage from streams and lakes, infiltration from adjacent bedrock upland tributary streams, and infiltration of unchanneled runoff from upland areas. The size, shape, and position of the area that contributes recharge to a well is determined by many interrelated hydrogeologic factors that affect flow patterns, including aquifer-system boundaries, aquifer properties, and the characteristics of the pumped well. Furthermore, if surface water infiltrates in an area contributing recharge to the well, then water originating outside the well's contributing area will eventually reach the well.

GROUND-WATER-FLOW MODEL

The numerical model of the aquifer system developed by Nicholson and others (1996) is an application of the MODFLOW computer code (Harbaugh and McDonald, 1996). The model consists of a series of mathematical equations, each representing the flow of ground water within one cell of a discretized (gridded) domain of the aquifer system under average annual conditions. The series of equations is solved simultaneously, resulting in a steady-state simulation (no change in flow conditions through time) of the distribution of hydraulic head and ground-water flow. Each of the three aquifers is represented in the model as a separate layer (fig. 2) with variable thickness, and each layer is discretized by use of a uniform grid spacing of 500 ft with the grid oriented along strike (northeast-southwest, fig. 1). Confining units are represented by leakance terms that control vertical flow between layers representing aquifers. Lateral model boundaries coincide with valley walls, which are the contact between the aquifer system and the low-permeability crystalline bedrock. During model calibration, aquifer-system parameters (for example, hydraulic conductivity, vertical leakance, or recharge rate) were adjusted within a reasonable range until the simulated hydraulic heads and flows were consistent with heads and flows measured in the field.

In this study, flow patterns and areas contributing recharge to wells then were determined by use of MODPATH, a particle-tracking postprocessing package for MODFLOW (Pollock, 1994). Flow patterns were determined by locating hypothetical particles at particular positions within the model domain, and then calculating subsequent particle positions at successive intervals of simulation time. To generate the pathlines displayed in this report, one particle initially was positioned at the center of the top face of each model cell in a layer and then tracked in the forward direction through the simulated flow field. Tracking of a particular particle was complete when the particle either discharged from the aquifer system, passed vertically into an adjacent aquifer, or crossed a model boundary. In the carbonate-rock aquifer (layer 3), many pathlines converged on high-permeability zones and, as a result, the initially selected particle density (one particle per cell) was too high and produced plots of flow patterns that were too crowded with pathlines for effective illustration in this report. In order to improve the clarity of pathline plots for the carbonate-rock aquifer, the procedure was modified for layer 3 so that just one particle was initially positioned at the center of the top of each block of nine adjacent cells. By use of this modified procedure, a lower pathline density was achieved, resulting in a clearer illustration of flow patterns. Pathline coordinates were translated into geographic information system (GIS) line coverages (real-world coordinates) by use of the computer program MODTOOLS (Orzol, 1997).

To determine the areas contributing recharge to the wells of interest in this study, a dense grouping of particles (30 x 30) was positioned on each face of the model cell representing the well screen or open interval and tracked backward through the simulated flow field.

Tracking of a particular particle was complete when the particle discharged from the aquifer system, reached the water table, or crossed a model boundary. The endpoint positions were translated into GIS point coverages. The area enclosing groups of endpoints of particles that originated at a particular well is an estimate of the area contributing recharge to the well.

Limitations of Model Application

The calibrated model is suitable, with some limitations, for use in calculating ground-water-flow paths and for estimating areas contributing recharge to wells. The reliability of these determinations is a function of various factors relating to the conceptual model of the aquifer system, model discretization, and parameter error. The true response of the local aquifer system may be different from the simulated response, potentially in locations where field data were unavailable for use in model calibration.

The level of model discretization in regional-scale simulations commonly is limited to large grid-cell sizes. Accordingly, endpoints of pathlines that enter some of the model cells that contain boundaries representing wells may be indeterminate; that is, it is uncertain in some cases whether an entering particle represents water that discharges to the well or water that bypasses the well and flows downgradient. This limitation was addressed partly by use of a nested rediscretization method (Spitz and Nicholson, 1998) to increase model resolution near the locations of such wells.

Model accuracy also depends on the values selected for input parameters, such as aquifer permeabilities; errors in these estimates contribute to accuracy errors. Results of a sensitivity analysis conducted by Nicholson and Watt (1998) showed that plausible alternative models where different parameter values were used produced estimated boundaries of areas contributing recharge that deviated as much as 300 ft from those determined by use of the calibrated model.

Simulation of Recent (1991-95) Conditions

In the model, water is simulated to be withdrawn from the aquifer system for water supply by two purveyors, the Roxbury Water Company (RWC) and the Morris County Municipal Utilities Authority (MCMUA). The MCMUA wells are clustered in two well fields, known as the Alamatong well field and the Flanders Valley well field (fig. 1). Withdrawals in the study area for industrial use by Hercules Corporation (from wells subsequently used by Alliant Tech Systems) and Westinghouse Elevator (from wells subsequently used by Schindler Elevator) also were included in the simulations. Total ground-water withdrawals in the study area during 1991-95 (table 1) averaged 4.2 Mgal/d. The simulation of recent (1991-95) conditions (also described by Nicholson and Watt, 1998) serves as a baseline for comparison with alternative withdrawal scenarios. Flow patterns in the upper valley-fill aquifer (fig. 3) are affected by the presence of surface-water features and aquifer boundaries. Ground water flows along a pathline in the direction of decreasing hydraulic head. Most pathlines terminate at streams. Some pathlines are very short (250 ft) and appear to terminate a distance from streams, indicating that ground water flows downward to the underlying aquifer.

Flow patterns in the lower valley-fill aquifer (fig. 4) near Flanders, in the southwestern part of the study area, also are dominated by the presence of surface-water features and aquifer boundaries. Where the lower valley-fill aquifer is confined, near the Alamatong well field and the Alliant Tech (formerly Hercules) wells in Kenvil, pathlines converge toward withdrawal wells. The withdrawal of water from a well results in a drawdown of hydraulic head in the aquifer near the well, which causes water to flow downgradient through the aquifer to the well. Near Succasunna, pathlines converge on the area where the aquifer is hydraulically well-connected to the underlying carbonate-rock aquifer, indicating that ground water in this area flows downward.

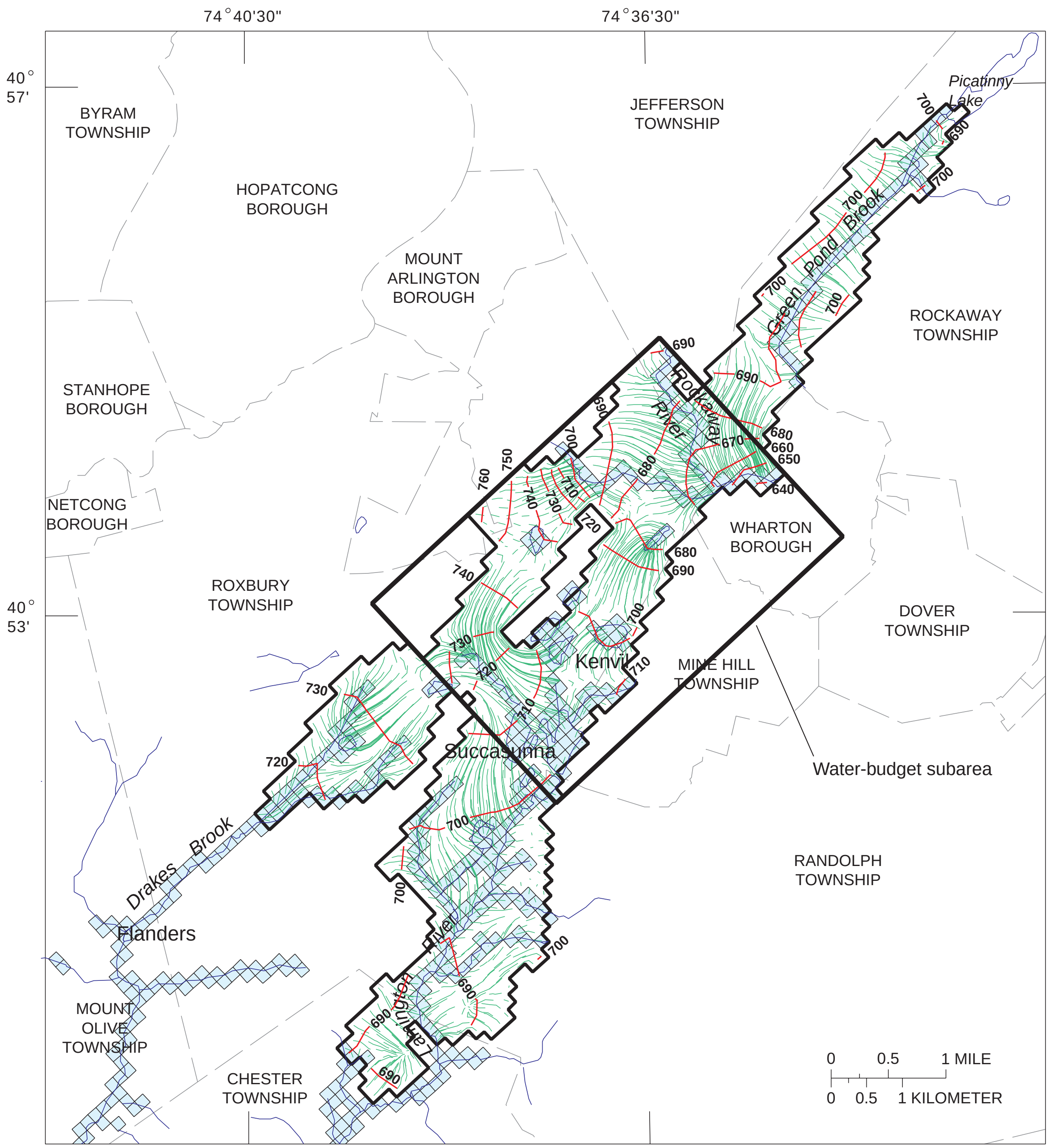
Table 1. Water-supply wells in the study area and pumping rates under recent (1991-95) conditions near Kenvil, Morris County, New Jersey

[USGS, U.S. Geological Survey; NJDEP, New Jersey Department of Environmental Protection; gal/min, gallons per minute; Mgal/d, million gallons per day; MUA, Municipal Utilities Authority; SFDF-U, Stratified drift-upper (upper valley fill); SFDF-L, Stratified drift-lower (lower valley fill); LSVL, Leithsville Formation (carbonate rock)]

USGS well number	NJDEP permit number	Owner	Local well identifier	Aquifer	Average 1991-95 pumping rate	
					Mgal/d	gal/min
27-1314	25-14790	Morris County MUA	Alamatong 1	SFDF-L	0.083	58
27-1315	25-17050	Morris County MUA	Alamatong 2	SFDF-L	.11	76
27-1323	25-17733	Morris County MUA	Alamatong 3	SFDF-L	.091	63
27-1324	25-22600	Morris County MUA	Alamatong 4	SFDF-L	.63	438
27-1090	25-25610	Morris County MUA	Alamatong 5	LSVL	.38	264
27-1707	25-41766	Morris County MUA	Alamatong 6	LSVL	0	0
27-1728	25-41497	Morris County MUA	Flanders 1	LSVL	.52	36
27-1727	25-41592	Morris County MUA	Flanders 2	LSVL	.81	563
27-1733	25-34457	Roxbury Water Company	RWC 1A	LSVL	.15	104
27-1710	25-05279	Roxbury Water Company	RWC 2	LSVL	.16	111
27-1711	45-00314	Roxbury Water Company	RWC 3	SFDF-U	.0005	.3
27-1177	25-25540	Roxbury Water Company	RWC 6	SFDF-U	.084	58
27-1173	25-29720	Roxbury Water Company	RWC 7	LSVL	.20	139
27-1807	25-44470	Roxbury Water Company	RWC 7A	LSVL	.08	56
27-1308	25-29660	Roxbury Water Company	RWC 8	LSVL	.06	42
27-1317	25-05732	Schindler Elevator	Schindler Elevator 1	SFDF-U	.0004	2.8
27-1316	25-26977	Schindler Elevator	Schindler Elevator 2	SFDF-U	.0004	2.8
27-1087	45-00310	Alliant Tech	Alliant Tech 1	SFDF-L	.61	424
27-1713	45-00311	Alliant Tech	Alliant Tech 2	SFDF-L	.21	146
TOTAL					4.18	2909

Ground water in the carbonate-rock aquifer (fig. 5) flows preferentially through fractures and solution openings that trend along strike parallel to the valley axis, and ultimately flows either to major withdrawal wells, upward to the Rockaway River where it exits the study area to the northeast, or out of the study area to the southwest.

Ground-water flow into and out of the aquifer system (or some subarea of the aquifer system) can be summarized by an equation that represents the ground-water budget, in which the sum of average annual inflows equals the sum of average annual outflows. Water budgets were calculated for each aquifer in a subarea of the study area under recent conditions and were compared



EXPLANATION

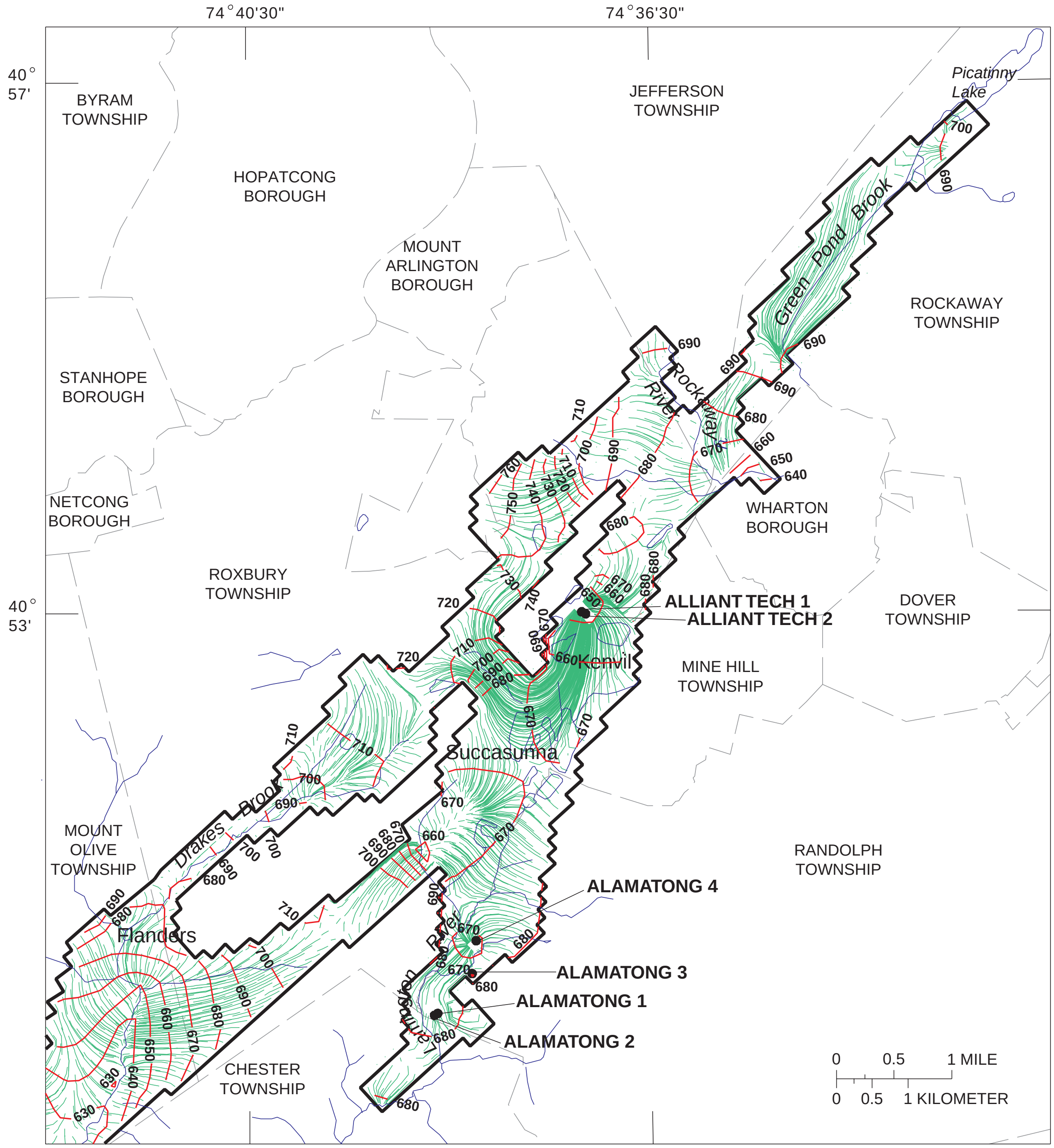
SURFACE-WATER-BOUNDARY CELL

MODEL BOUNDARY--Shows boundary of upper valley-fill aquifer in model

690 WATER TABLE CONTOUR--Shows altitude of water table, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or underlying aquifer

Figure 3. Simulated water levels and flow paths in the upper valley-fill aquifer under recent (1991-95) pumping conditions, and location of the water-budget subarea near Kenvil, Morris County, New Jersey.



EXPLANATION

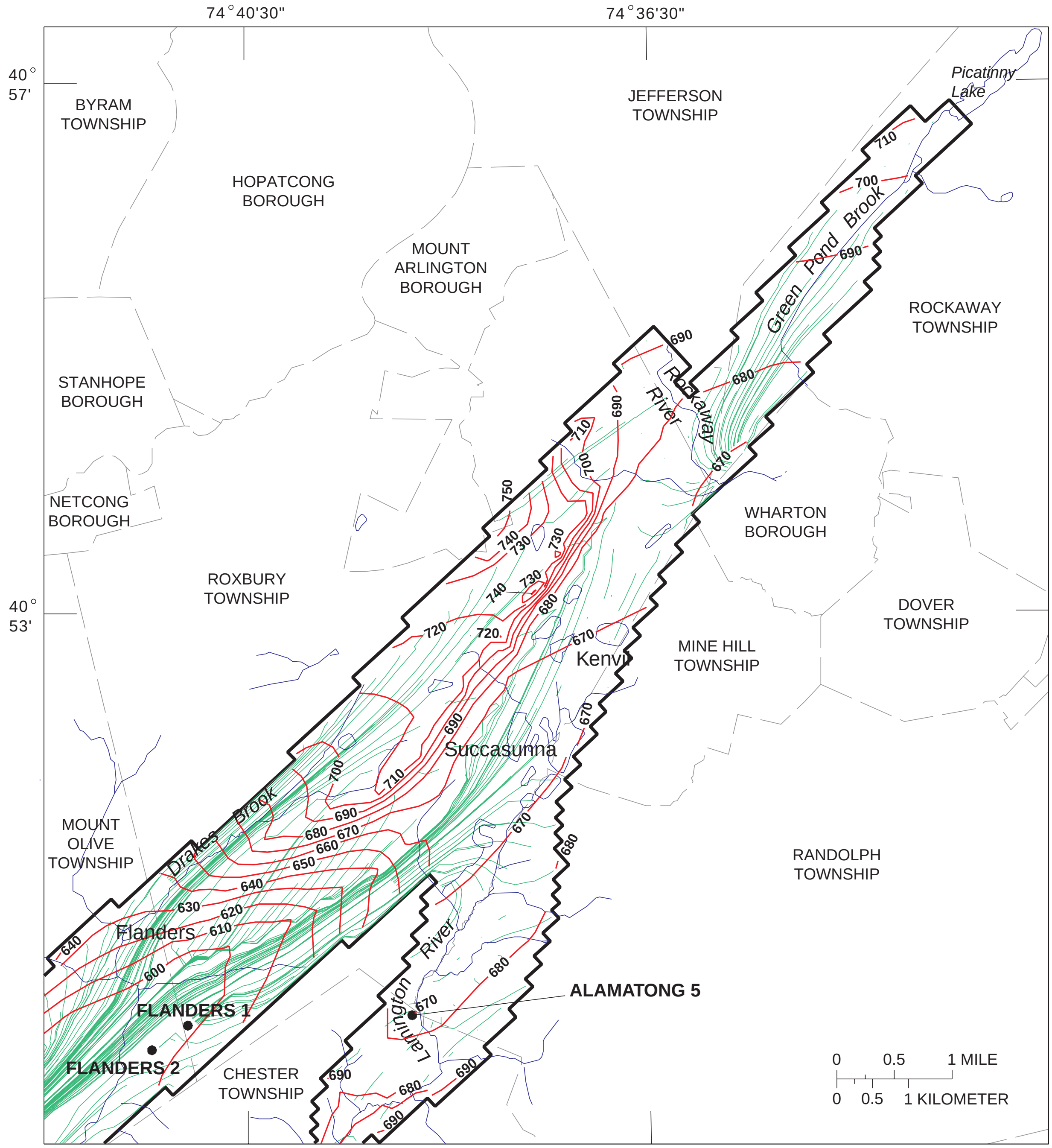
MODEL BOUNDARY--Shows boundary of lower valley-fill aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area, upper valley-fill aquifer or carbonate-rock aquifer

ALAMATONG 3 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 4. Simulated water levels and flow paths in the lower valley-fill aquifer under recent (1991-95) pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

MODEL BOUNDARY--Shows boundary of carbonate-rock aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or overlying valley-fill aquifer

ALAMATONG 5 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 5. Simulated water levels and flow paths in the carbonate-rock aquifer under recent (1991-95) pumping conditions near Kenvil, Morris County, New Jersey.

with corresponding water budgets calculated for each of the four alternative withdrawal scenarios. The water-budget subarea (fig. 3) encompasses the withdrawal wells included in the scenarios, and extends from Kenvil to just north of the Rockaway River. This comparative water-budget analysis provides an indication of potential changes in the amount of leakage between aquifers and in the amount of ground-water discharge to streams.

Simulated areas contributing recharge to selected wells under recent conditions are shown in figure 6. The areas contributing recharge to some wells may be distant (1-5 mi) from the well. Travel times from the recharge area to the well screen or open interval range from several days to centuries, depending on the length of the flow path, the direction of the flow path, and the average velocity along the flow path.

EFFECTS OF ALTERNATIVE PUMPING STRATEGIES ON GROUND-WATER-FLOW PATTERNS AND AREAS CONTRIBUTING RECHARGE TO WELLS

Withdrawals from the aquifer system in the study area are projected to be increased to meet increasing demand. Alternative withdrawal scenarios for individual wells in respective purveyor service areas were provided to the USGS (John Scarmozza, MCMUA, written commun., 1997). These scenarios, described in table 2, represent a range of possible alternatives, although other scenarios are possible. Hypothetical withdrawals are as large as 6.5 Mgal/d (scenario 3), an increase of 56 percent over recent (1991-95) withdrawals. Changes in water levels, water budgets, flow patterns, and areas contributing recharge to wells for each of the four scenarios are described below. Changes in water budgets for each scenario are evaluated for the part of the aquifer system enclosed by the water-budget subarea shown in figure 3.

Scenario 1

Scenario 1 involves a 430-gal/min increase in the combined rates of withdrawal from Alliant Tech wells 1 and 2, screened in the lower valley-fill aquifer (fig. 8), added to an additional 500 gal/min withdrawn from a proposed new well open to the carbonate-rock aquifer at Kenvil (RWC 3A) (fig. 9). Pumping rates and a summary of results for this scenario are listed in table 2. Simulated ground-water-flow patterns in the three aquifers are shown in figures 7 through 9. The water-level decline is greatest (as much as 44 ft) in the lower valley-fill aquifer near the Alliant Tech wells. Water levels decline less than 14 ft in the carbonate-rock aquifer and less than 4 ft in the upper valley-fill aquifer.

The net downward leakage to the lower valley-fill aquifer in the water-budget subarea increased by 1.1 ft^3/s (480 gal/min) compared to leakage under recent conditions. Net downward leakage to the carbonate-rock aquifer increased by 0.5 ft^3/s (220 gal/min). Ground-water discharge to streams decreased by 0.7 ft^3/s (310 gal/min). Lateral flow from the southwest in the carbonate-rock aquifer increased by 0.6 ft^3/s (280 gal/min). Pathlines indicate that the Alliant Tech wells capture mostly local flow, particularly from areas southwest of the wells. The new RWC well 3A captures regional flow from the northeast, including flow originating near the Rockaway River. Areas contributing recharge to wells under projected conditions for scenario 1 are shown in figure 10. Pumping rates for the Alliant Tech wells in scenario 1 are larger than those used in the simulation of recent conditions; therefore, areas contributing recharge to these wells are slightly larger than those shown in figure 6. The areas contributing recharge for the new RWC well 3A are mostly north of the Alliant Tech wells. The areas contributing recharge to the MCMUA Alamatong and Flanders wells changed slightly in size and location in response to the distant change in pumping stress.

Scenario 2

In scenario 2, two proposed new wells are open to the carbonate-rock aquifer: a 700-gal/min MCMUA well (Kenvil A4-B) and the same 500-gal/min well (RWC 3A) simulated in scenario 1. The pumping rates for the two Alliant Tech wells remain the same as under recent conditions. Pumping rates and a summary of results for this scenario are listed in table 2. Simulated ground-water-flow patterns in the three aquifers are shown

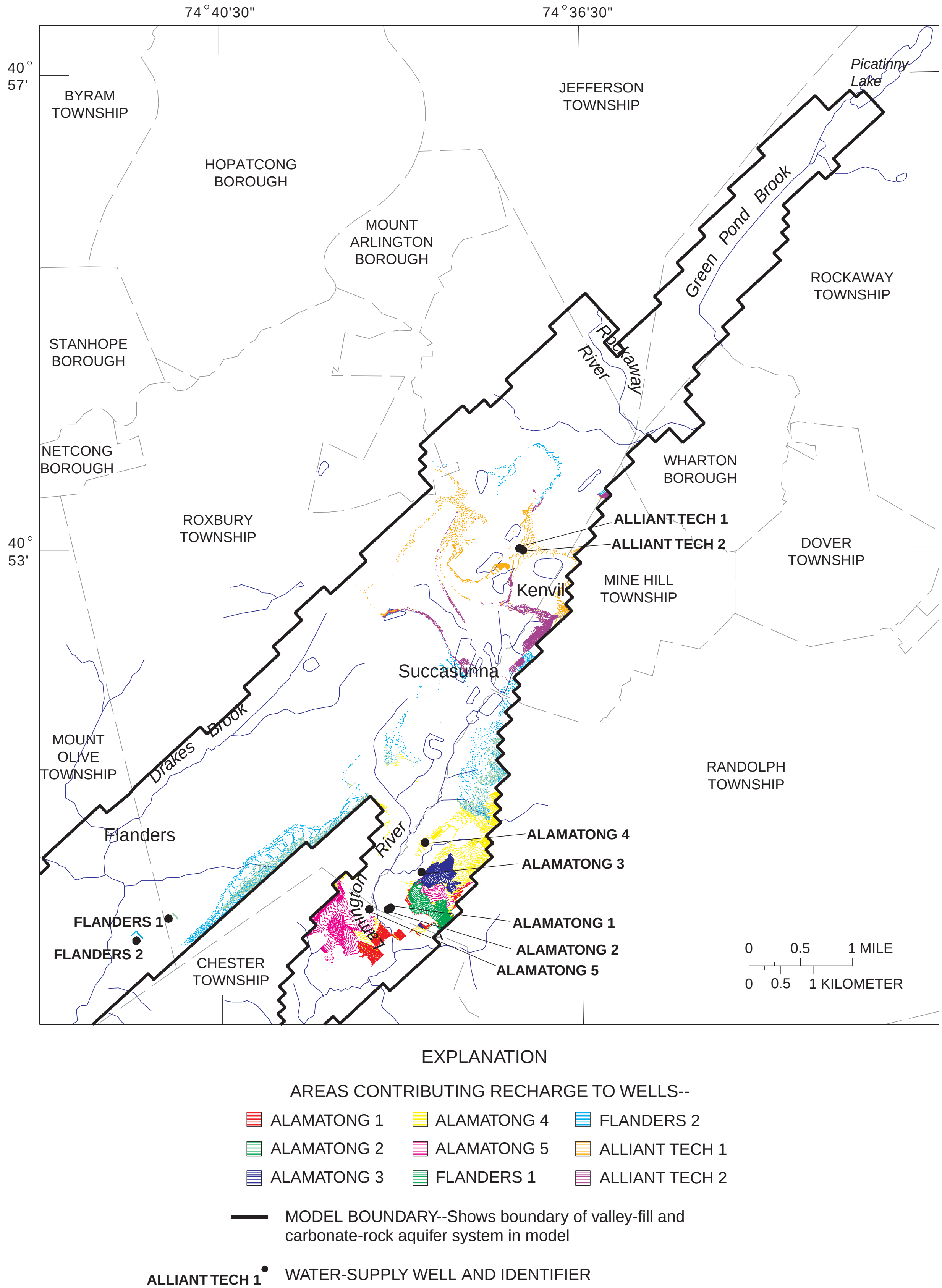


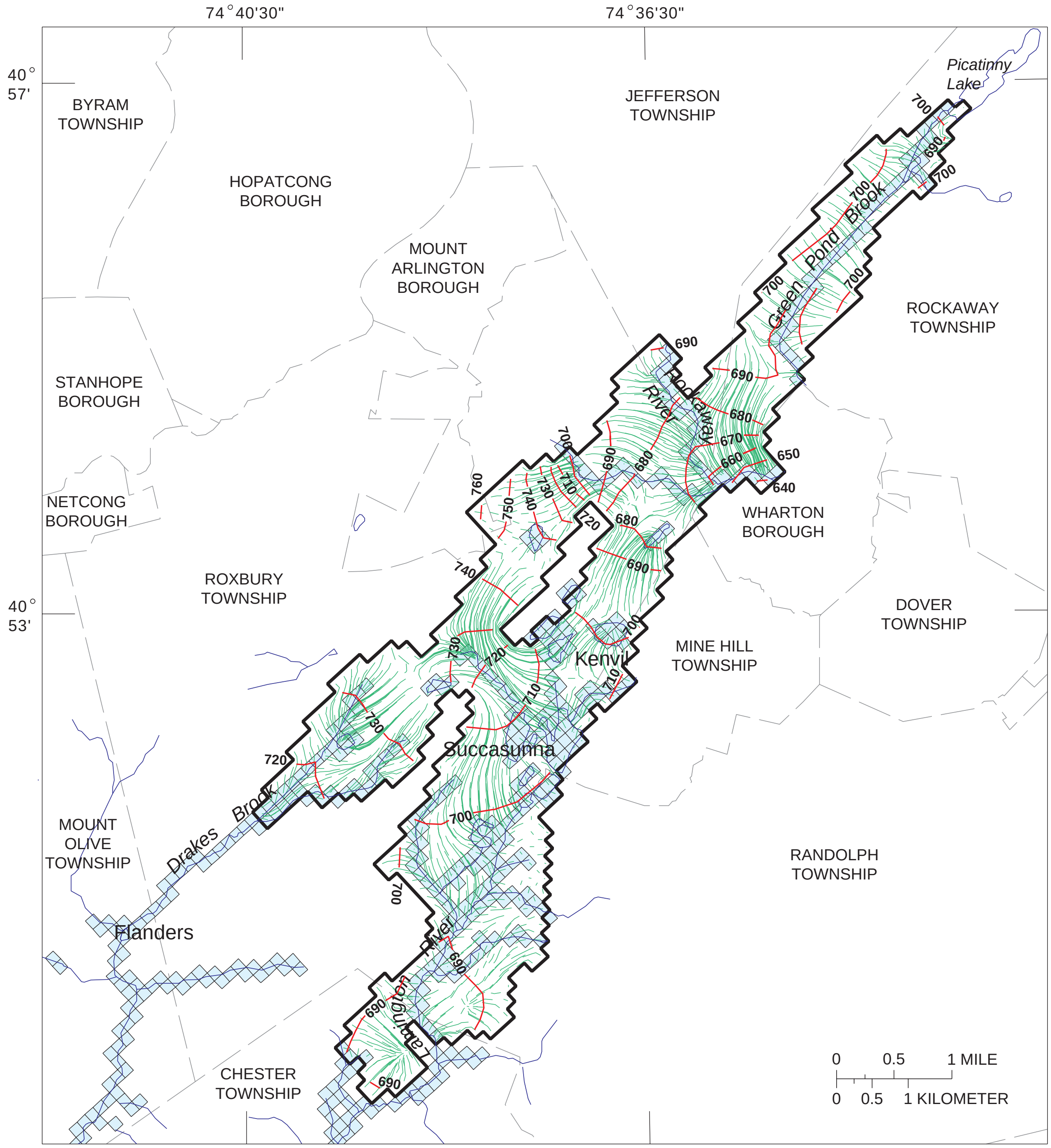
Figure 6. Simulated areas contributing recharge to selected wells under recent (1991-95) pumping conditions near Kenvil, Morris County, New Jersey.

Table 2. Alternative pumping scenarios and summary of simulated results compared to recent (1991-95) pumping conditions near Kenvil, Morris County, New Jersey

[gal/min, gallons per minute; Mgal/d, million gallons per day; ft, feet; ft^3/s, cubic feet per second; ---, not applicable; <, less than; MCMUA, Morris County Municipal Utilities Authority; RWC, Roxbury Water Company; SFDF-U, Stratified drift-upper (upper valley fill); SFDF-L Stratified drift-lower (lower valley fill); LSVL, Leithsville Formation (carbonate rock)]

Scenario	Aquifer	Wells for which assumed pumping rate is different from average rate during 1991-95	Total pumping rate: Gal/min	Total pumping rate: Mgal/d	Maximum drawdown (ft)	Comparison of simulated results to recent conditions: [1]Water-budget change (ft^3/s)		Ground-water pathlines	Areas contributing recharge to wells
1	SFDF-U	---	---	--	4	Decreased discharge to streams	(0.7)	No appreciable change	---
	SFDF-L	Alliant Tech 1 Alliant Tech 2	743 257	1.07 .37	44	Increased leakage from upper valley-fill aquifer[2]	(1.1)	Wells capture local flow, particularly from southwest	Areas increase in size
	LSVL	RWC 3A	500	.72	14	Increased leakage from lower valley-fill aquifer[2]	(0.5)	Well intercepts regional flow from northeast	Area is created north of well
						Increased lateral flow from southwest[3]	(0.6)		
2	SFDF-U	---	---		6	Decreased discharge to streams	(1.2)	No appreciable change	---
	SFDF-L	---	---		16	Increased leakage from upper valley-fill aquifer[2]	(1.4)	No appreciable change	---
	LSVL	RWC 3A MCMUA Kenvil A4-B	500 700	.72 1.01	43	Increased leakage from lower valley-fill aquifer[2]	(1.4)	Wells intercept regional flow from northeast and southwest	Area for MCMUA well is created north and south of the well; area for RWC well shifts south from that for scenario 1
						Increased lateral flow from southwest[3]	(1.2)		
3	SFDF-U	---	---		8	Decreased discharge to streams	(1.5)	No appreciable change	---
	SFDF-L	Alliant Tech 1 Alliant Tech 2	743 257	1.07 .37	63	Increased leakage from upper valley-fill aquifer[2]	(1.9)	Similar to scenario 1	Areas are larger than those under scenario 1
	LSVL	RWC 3A MCMUA Kenvil A4-B	500 700	.72 1.01	48	Increased leakage from lower valley-fill aquifer[2]	(1.3)	Similar to scenario 2	Areas for both wells are larger than those under scenario 2
						Increased lateral flow from southwest[3]	(1.3)		
4	SFDF-U	Wharton Borough	500	.72	4	Decreased discharge to streams	(2.4)	No appreciable change	Area is created northeast and southwest of well
	SFDF-L	---	---		6	Increased leakage from upper valley-fill aquifer[2]	(1.4)	No appreciable change	---
	LSVL	MCMUA Mill Pond	700	1.01	11	Increased leakage from lower valley-fill aquifer[2]	(1.4)	Well captures local flow from the southwest	Area is created northeast and southwest of well

1. Only changes in water-budget components that equalled or exceeded 0.5 ft^3/s are listed.
2. Changes in downward leakage *from* an overlying aquifer are net of changes in upward leakage *to* the overlying aquifer.
3. Changes in lateral flows *from* the southwest are net of changes in lateral flows *to* the southwest.



EXPLANATION

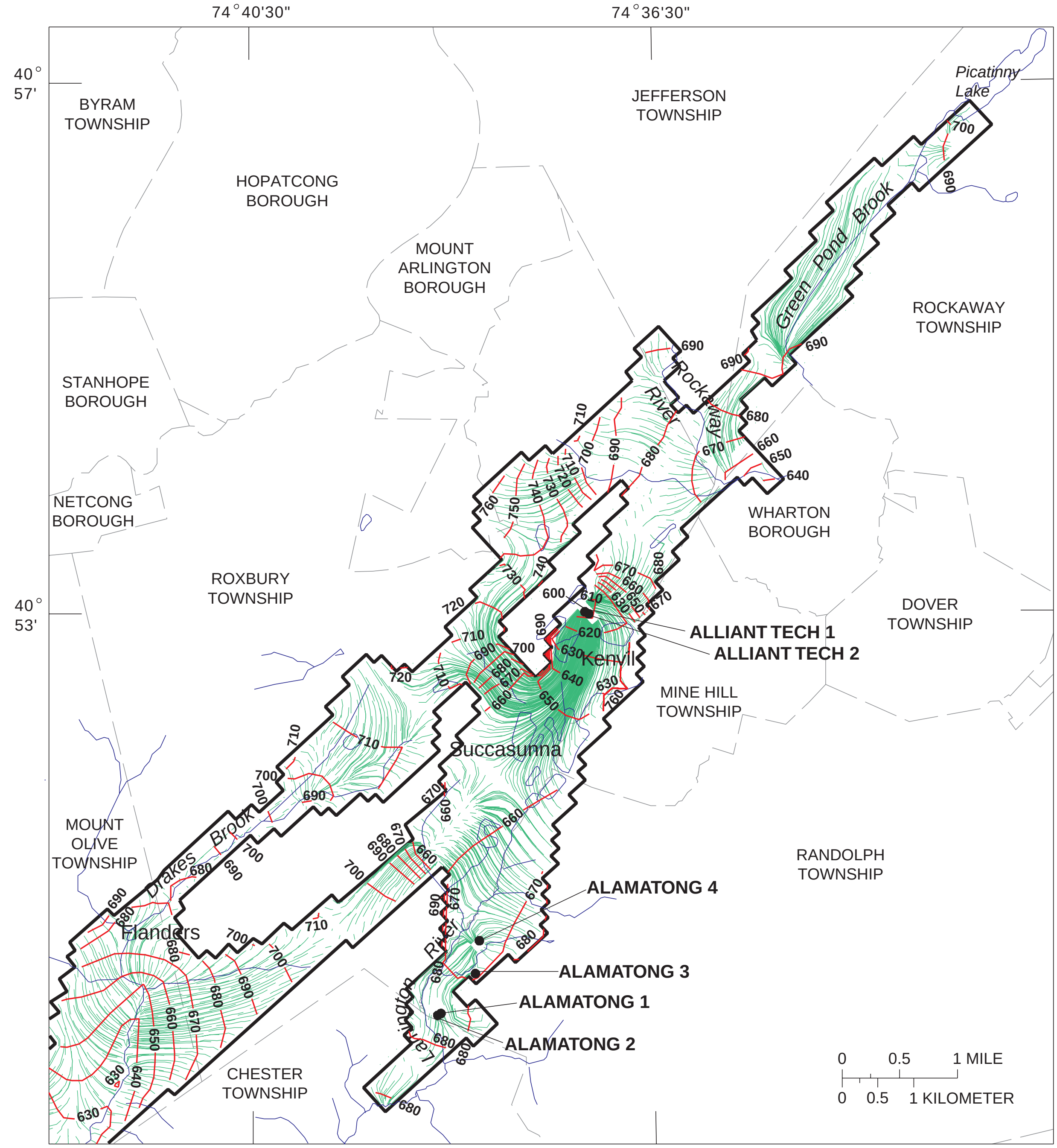
SURFACE-WATER-BOUNDARY CELL

MODEL BOUNDARY--Shows boundary of upper valley-fill aquifer in model

690 WATER-TABLE CONTOUR--Shows altitude of water table, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or underlying aquifer

Figure 7. Simulated water levels and flow paths in the upper valley-fill aquifer under scenario 1 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

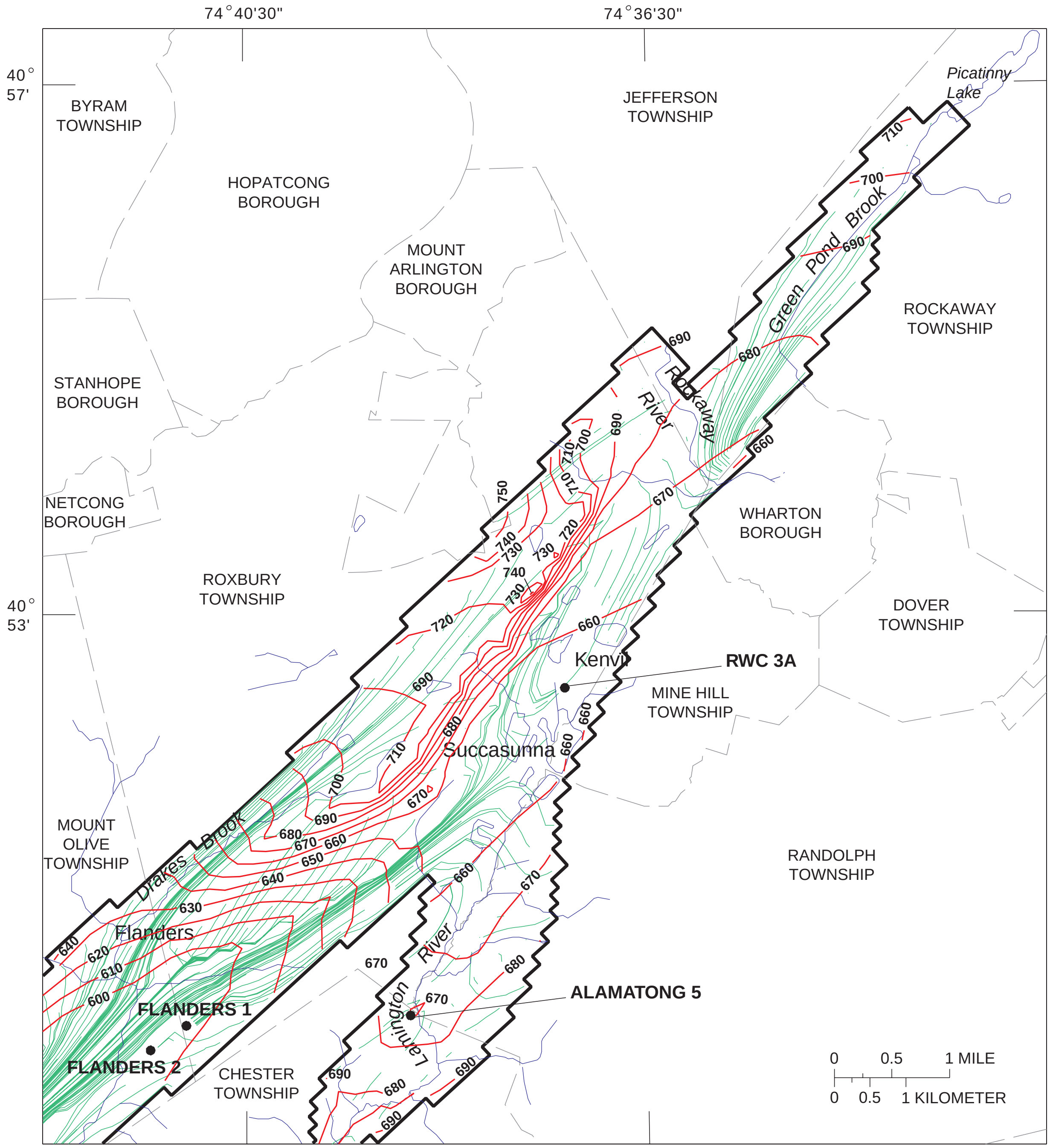
MODEL BOUNDARY--Shows boundary of lower valley-fill aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area, upper valley-fill aquifer, or carbonate-rock aquifer

ALAMATONG 4 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 8. Simulated water levels and flow paths in the lower valley-fill aquifer under scenario 1 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

MODEL BOUNDARY--Shows boundary of carbonate-rock aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or overlying valley-fill aquifer

ALAMATONG 5 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 9. Simulated water levels and flow paths in the carbonate-rock aquifer under scenario 1 pumping conditions near Kenvil, Morris County, New Jersey.

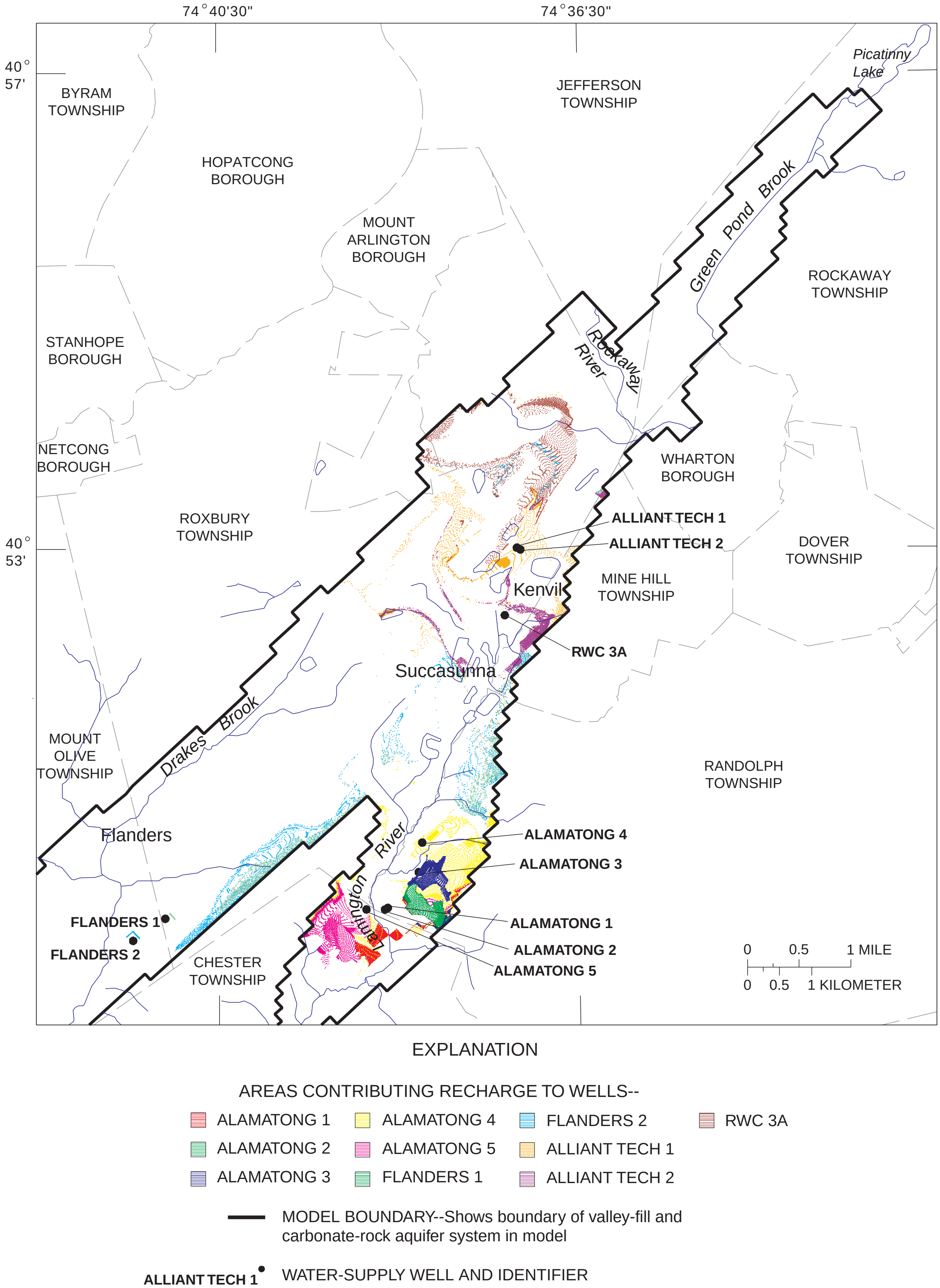
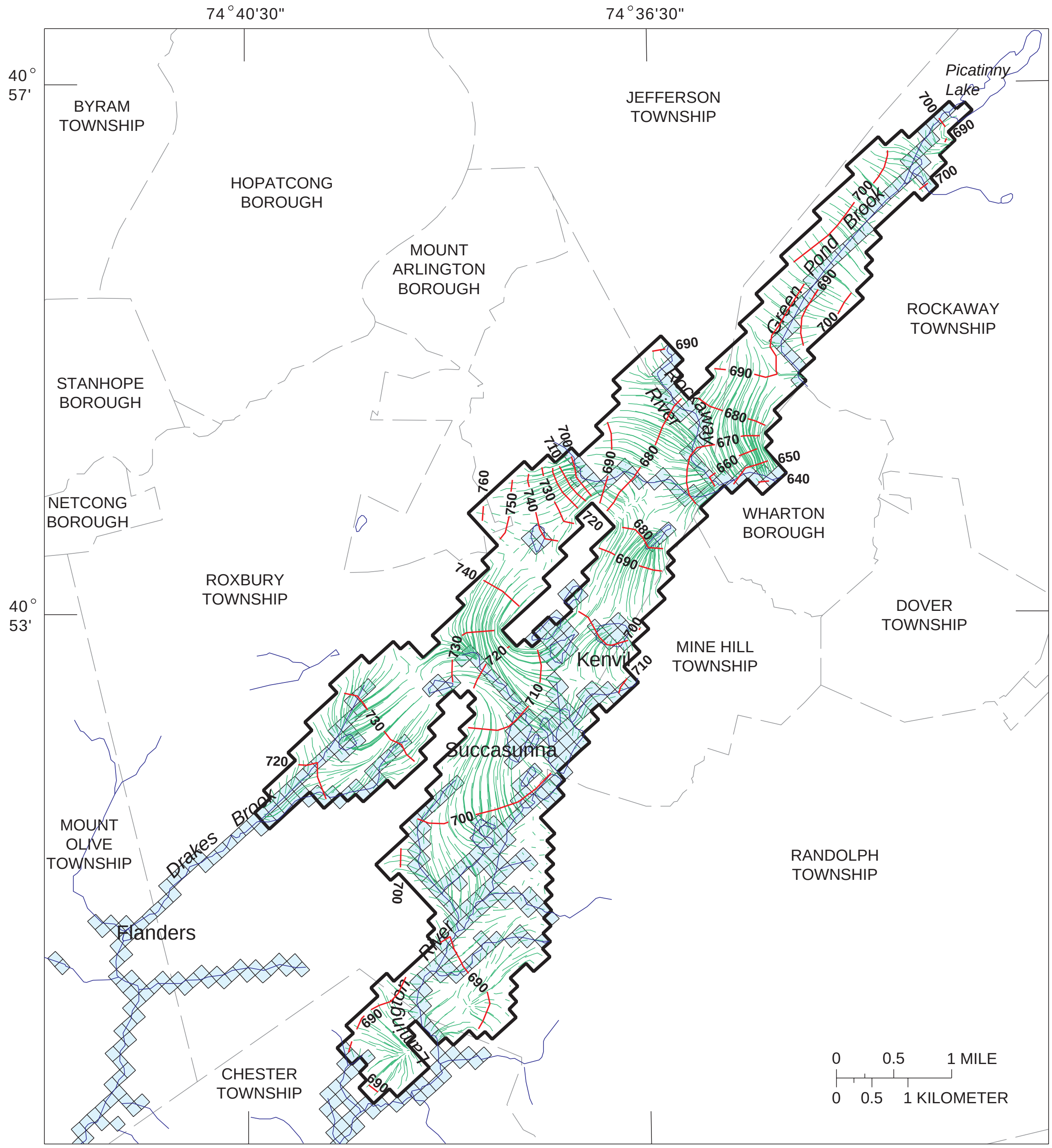


Figure 10. Simulated areas contributing recharge to selected wells under scenario 1 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

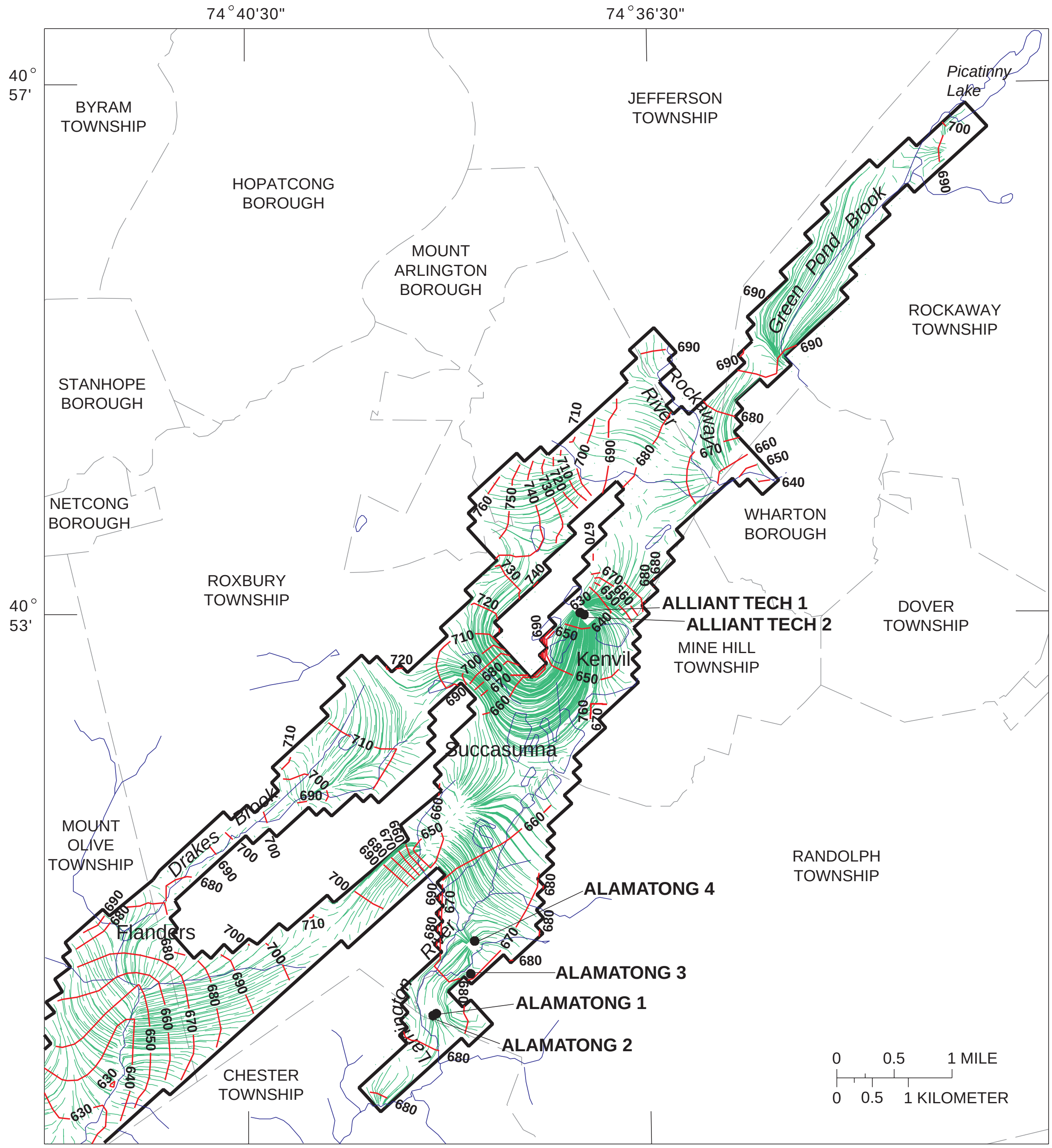
SURFACE-WATER-BOUNDARY CELL

MODEL BOUNDARY--Shows boundary of upper valley-fill aquifer in model

690 WATER-TABLE CONTOUR--Shows altitude of water table, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or underlying aquifer

Figure 11. Simulated water levels and flow paths in the upper valley-fill aquifer under scenario 2 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

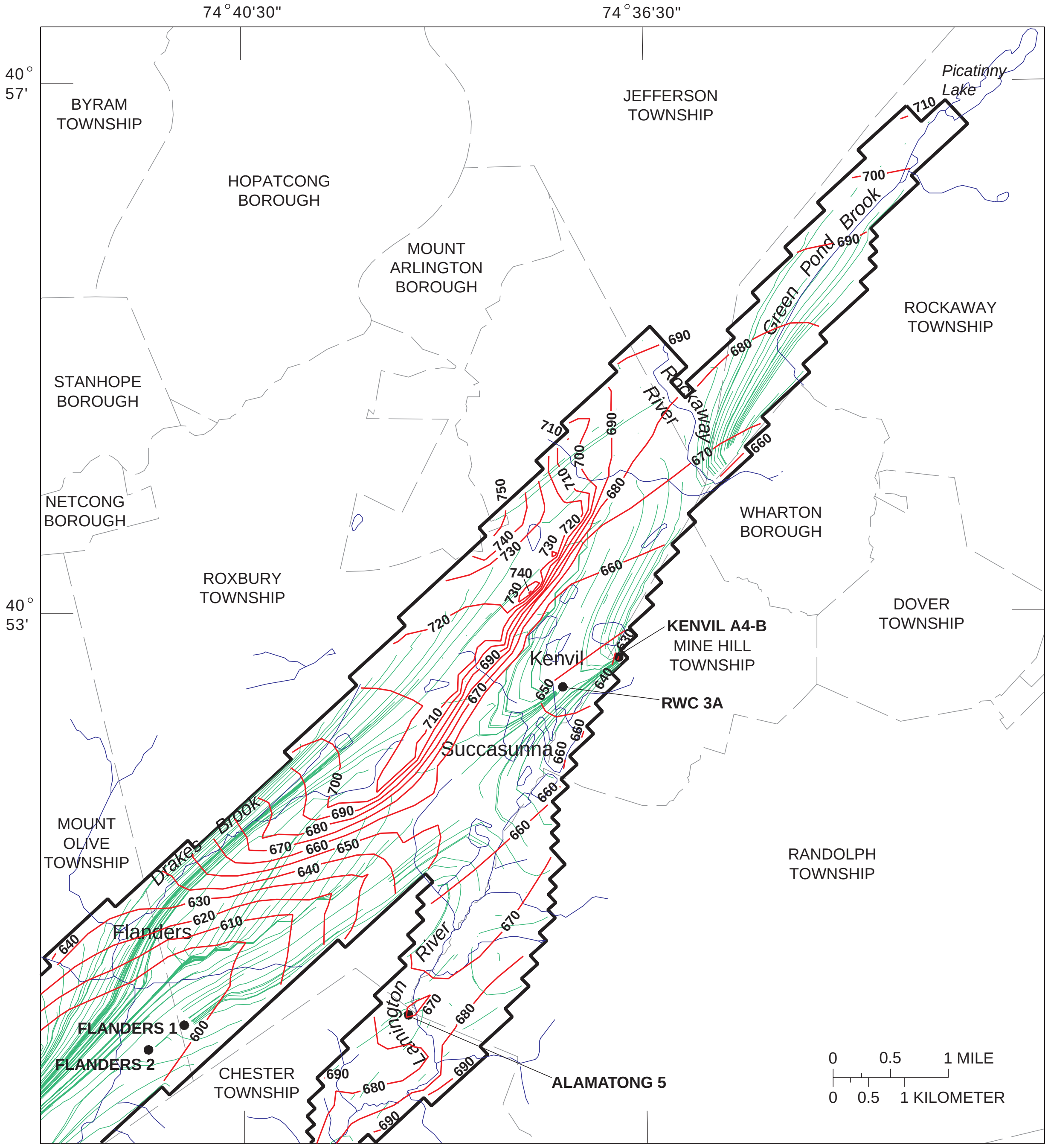
MODEL BOUNDARY--Shows boundary of lower valley-fill aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area, upper valley-fill aquifer, or carbonate-rock aquifer

ALAMATONG 4 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 12. Simulated water levels and flow paths in the lower valley-fill aquifer under scenario 2 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

MODEL BOUNDARY--Shows boundary of carbonate-rock aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or overlying valley-fill aquifer

ALAMATONG 5 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 13. Simulated water levels and flow paths in the carbonate-rock aquifer under scenario 2 pumping conditions near Kenvil, Morris County, New Jersey.

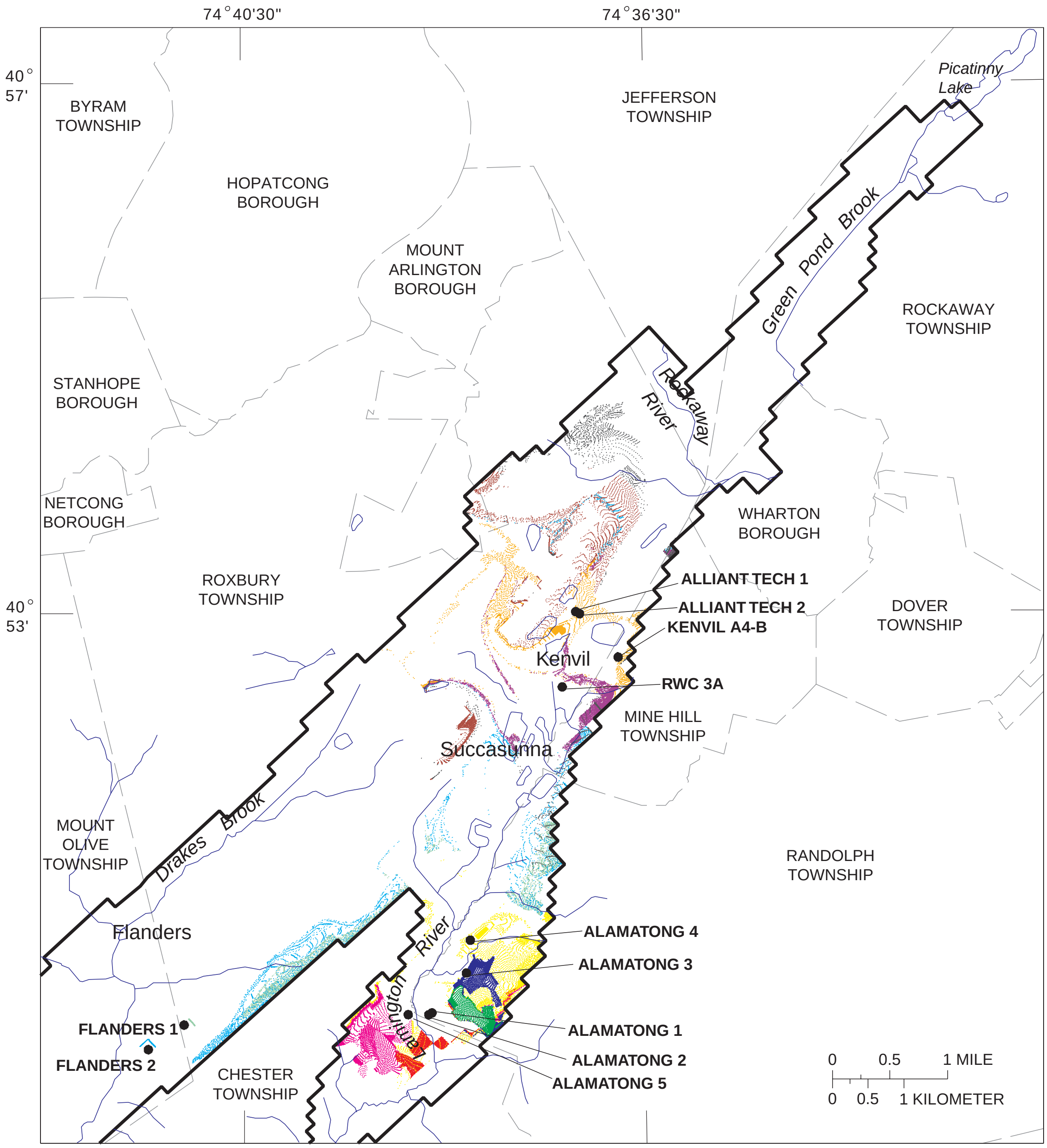
in figures 11 through 13. Water levels decline as much as 43 ft in the carbonate-rock aquifer near the MCMUA well A4-B and as much as 16 ft in the lower valley-fill aquifer. Water levels decline less than 6 ft in the upper valley-fill aquifer. As a result of the decline in water levels, net ground-water discharge to streams decreased by 1.2 ft^3/s (530 gal/min), net downward leakage from the upper valley-fill aquifer to the lower valley-fill aquifer and from the lower valley-fill aquifer to the carbonate-rock aquifer increased by 1.4 ft^3/s (640 gal/min), and net lateral flow from the southwest in the carbonate-rock aquifer increased by 1.2 ft^3/s (540 gal/min) compared to these components of the water budget under recent conditions. Pathlines indicate that the new wells capture regional flow from the surrounding area. Simulated areas contributing recharge to wells under projected conditions for scenario 2 are shown in figure 14. Contributing areas are north and south of the new MCMUA well 4A-B. Parts of the areas contributing recharge to the new RWC well 3A are farther south than in scenario 1 (fig. 10).

Scenario 3

Scenario 3 is similar to scenario 2 except that withdrawals from the two Alliant Tech wells are increased by 430 gal/min for a combined rate of 1,000 gal/min, as in scenario 1. This scenario represents the largest increase in withdrawals from the aquifer system simulated in this study. Pumping rates and a summary of results for this scenario are listed in table 2. Simulated ground-water-flow patterns in the three aquifers are shown in figures 15 through 17. Water levels decline as much as 63 ft in the lower valley-fill aquifer near the Alliant Tech wells and as much as 48 ft in the carbonate-rock aquifer near new Kenvil well A4-B. Water levels decline less than 8 ft in the upper valley-fill aquifer. Changes in the water budget are similar to, but more pronounced than, those in scenario 2. Within the water-budget subarea, net ground-water discharge to streams decreased by 1.5 ft^3/s (650 gal/min), net downward leakage to the lower valley-fill aquifer increased by 1.9 ft^3/s (840 gal/min), and net downward leakage to the carbonate-rock aquifer increased by 1.3 ft^3/s (580 gal/min). Lateral flow from the southwest in the carbonate-rock aquifer increased by 1.3 ft^3/s (590 gal/min). Pathlines in the lower-valley fill aquifer near the Alliant Tech wells and in the carbonate-rock aquifer near the hypothetical new wells are similar to those in scenarios 1 and 2, respectively, except that flow is diverted from a wider area. Simulated areas contributing recharge to wells under projected conditions for scenario 3 are shown in figure 18. The areas contributing recharge to the Alliant Tech wells are larger than those under scenario 1. Parts of the areas contributing recharge for the new wells open to the carbonate-rock aquifer (Kenvil A4-B and RWC 3A) are larger than in scenario 2, whereas parts of the areas contributing recharge to the Flanders wells are shifted southward.

Scenario 4

In scenario 4, a proposed new 500-gal/min well screened in the upper valley-fill aquifer at Wharton Borough and a proposed new 700-gal/min MCMUA well open to the carbonate-rock aquifer at Baker Mill Pond are added. The pumping rates for the two Alliant Tech wells are the same as those under recent conditions. No other hypothetical wells are simulated. Pumping rates and a summary of results for this scenario are listed in table 2. Simulated ground-water-flow patterns in the three aquifers are shown in figures 19 through 21. Water levels declined only 11 ft in the carbonate-rock aquifer and less than 6 ft in the valley-fill aquifers. Within the water-budget subarea, net ground-water discharge to streams decreased by 2.4 ft^3/s (1,080 gal/min) and net downward leakage from the upper valley-fill aquifer to the lower valley-fill aquifer and from the lower valley-fill aquifer to the carbonate-rock aquifer increased by 1.4 ft^3/s (610 gal/min). Pathlines indicate that the MCMUA Mill Pond well captures local flow from the area southwest of the well. Simulated areas contributing recharge to wells under projected conditions for scenario 4 are shown in figure 22. Contributing areas for the new wells are in the northeastern and southwestern parts of the study area.



EXPLANATION

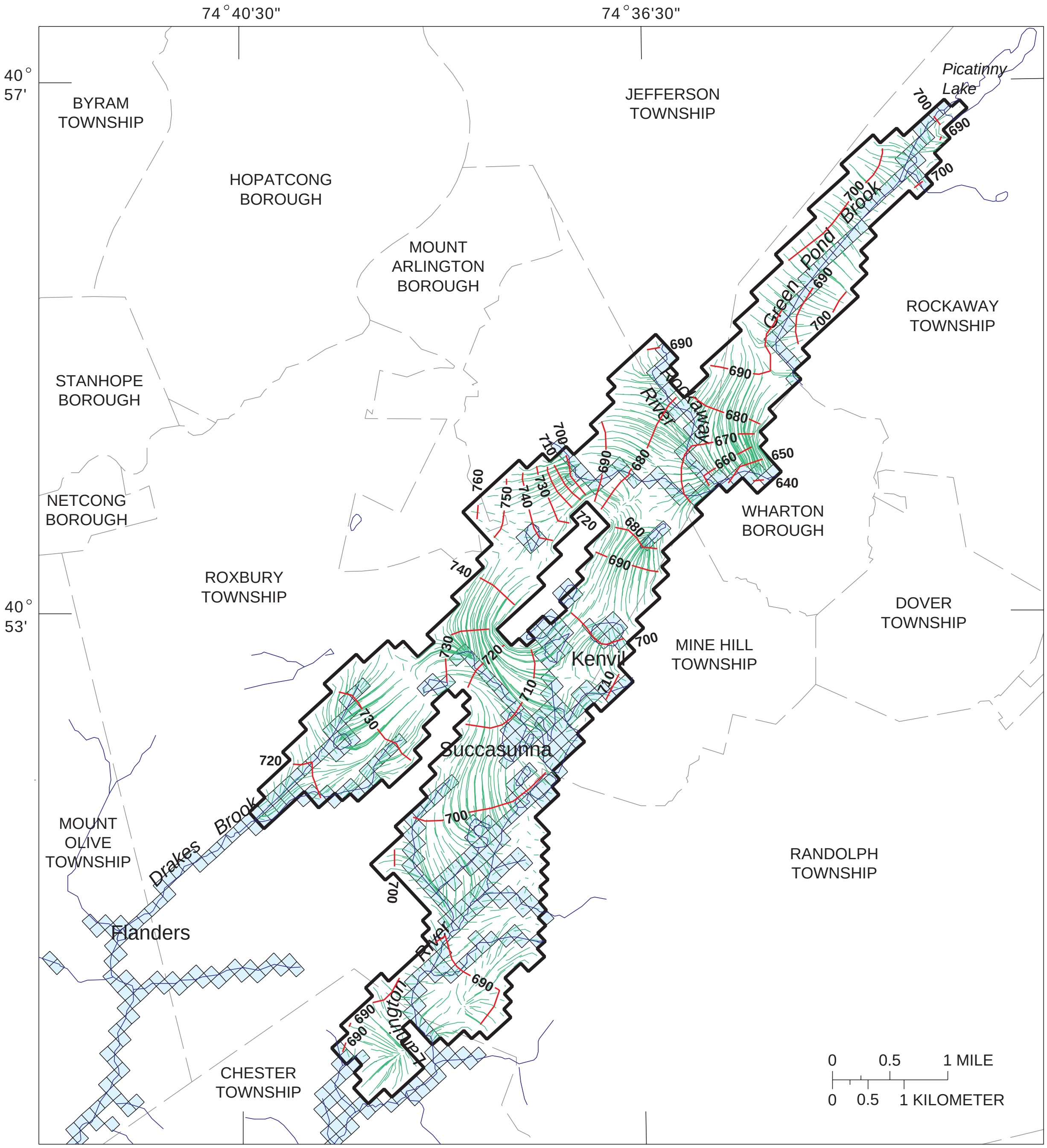
AREAS CONTRIBUTING RECHARGE TO WELLS--

ALAMATONG 1	ALAMATONG 4	FLANDERS 2	RWC 3A
ALAMATONG 2	ALAMATONG 5	ALLIANT TECH 1	KENVIL A4-B
ALAMATONG 3	FLANDERS 1	ALLIANT TECH 2	

MODEL BOUNDARY--Shows boundary of valley-fill and carbonate-rock aquifer system in model

ALLIANT TECH 1 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 14. Simulated areas contributing recharge to selected wells under scenario 2 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

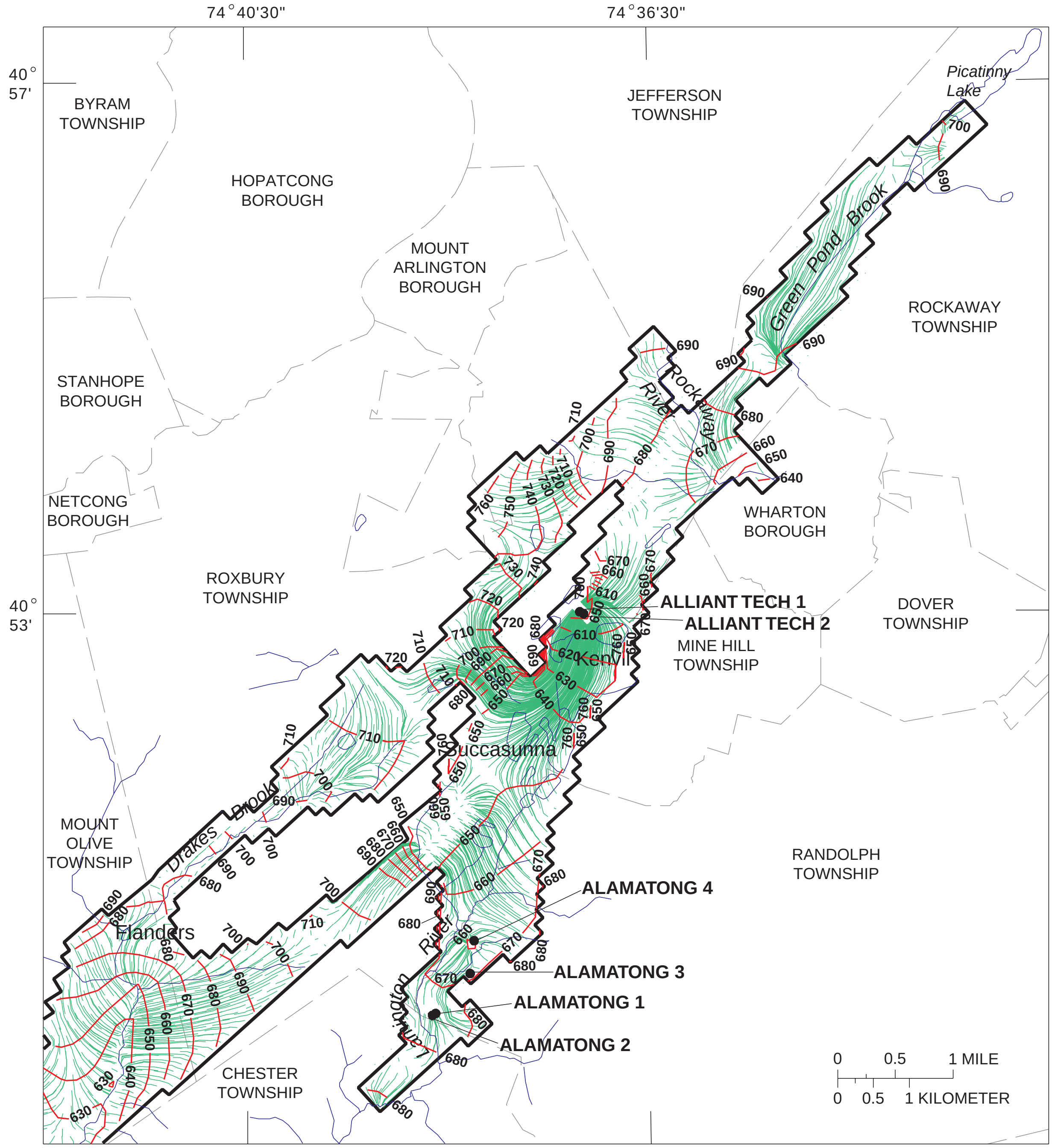
SURFACE-WATER-BOUNDARY CELL

MODEL BOUNDARY--Shows boundary of upper valley-fill aquifer in model

690 WATER-TABLE CONTOUR--Shows altitude of water table, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or underlying aquifer

Figure 15. Simulated water levels and flow paths in the upper valley-fill aquifer under scenario 3 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

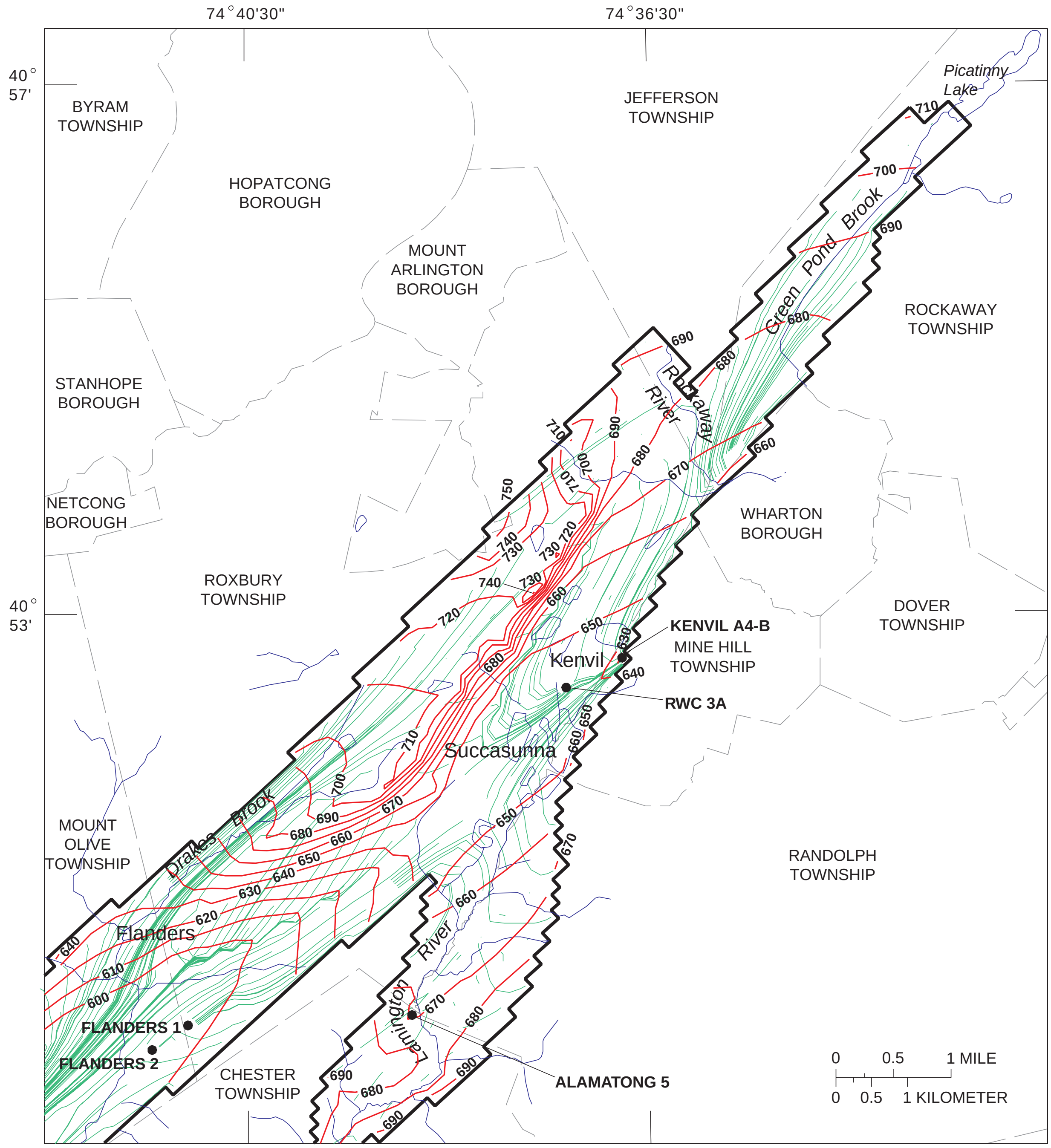
MODEL BOUNDARY--Shows boundary of lower valley-fill aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area, upper valley-fill aquifer, or carbonate-rock aquifer

ALAMATONG 4 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 16. Simulated water levels and flow paths in the lower valley-fill aquifer under scenario 3 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

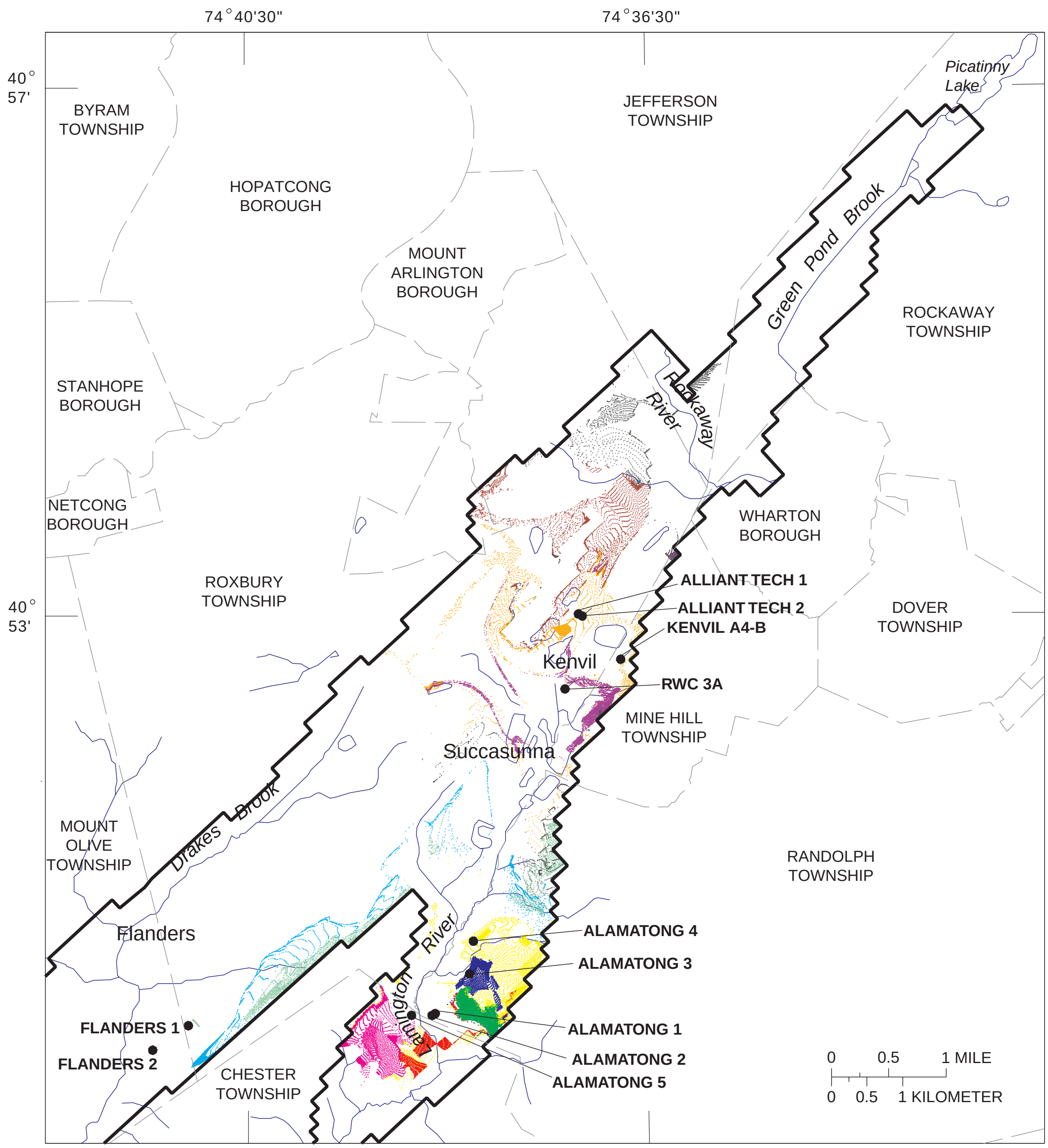
MODEL BOUNDARY--Shows boundary of carbonate-rock aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or overlying valley-fill aquifer

ALAMATONG 5 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 17. Simulated water levels and flow paths in the carbonate-rock aquifer under scenario 3 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

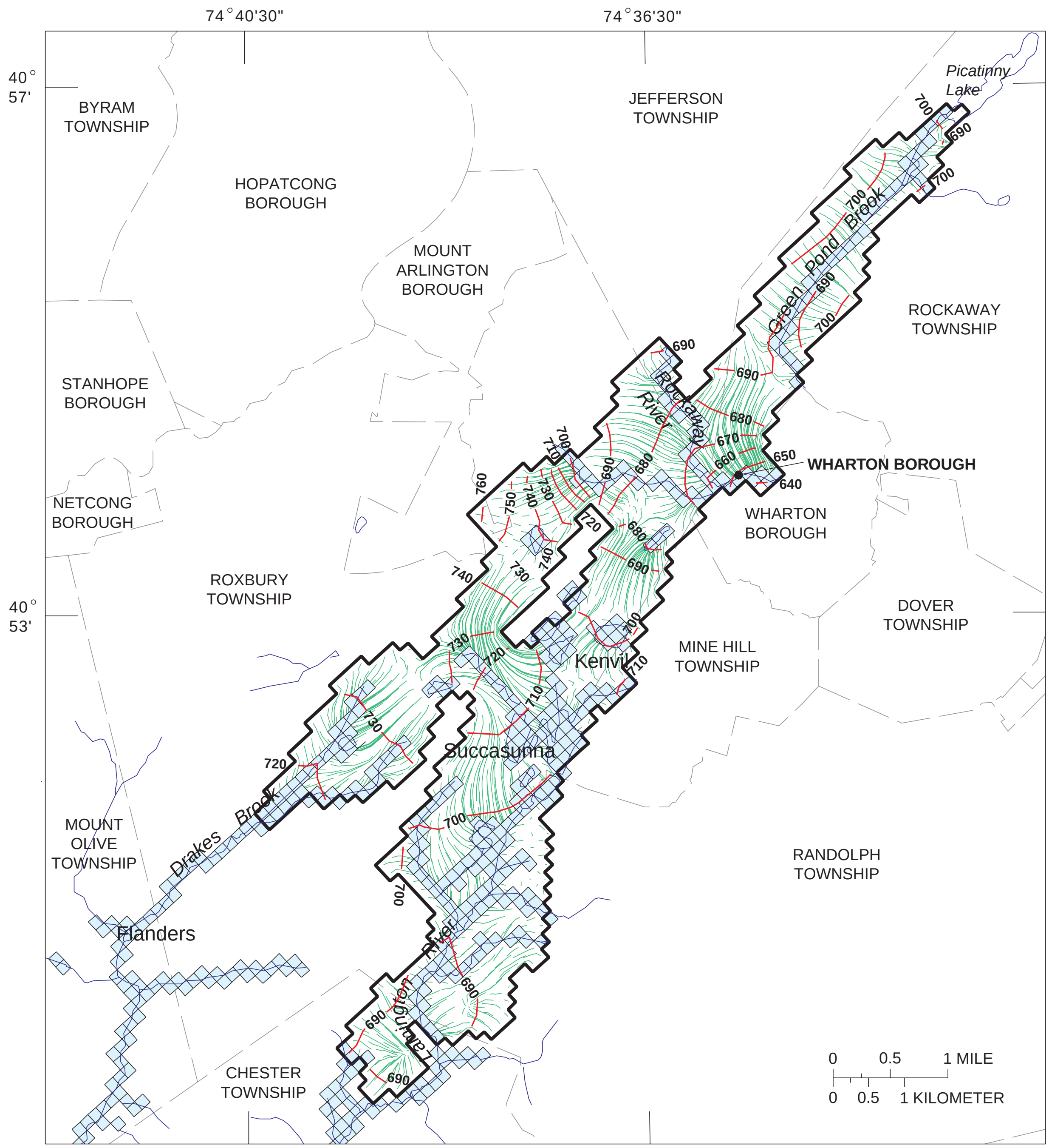
AREAS CONTRIBUTING RECHARGE TO WELLS--

- ALAMATONG 1
- ALAMATONG 2
- ALAMATONG 3
- ALAMATONG 4
- ALAMATONG 5
- FLANDERS 1
- FLANDERS 2
- ALLIANT TECH 1
- ALLIANT TECH 2
- RWC 3A
- KENVIL A4-B

MODEL BOUNDARY--Shows boundary of valley-fill and carbonate-rock aquifer system in model

ALLIANT TECH 1 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 18. Simulated areas contributing recharge to selected wells under scenario 3 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

SURFACE-WATER-BOUNDARY CELL

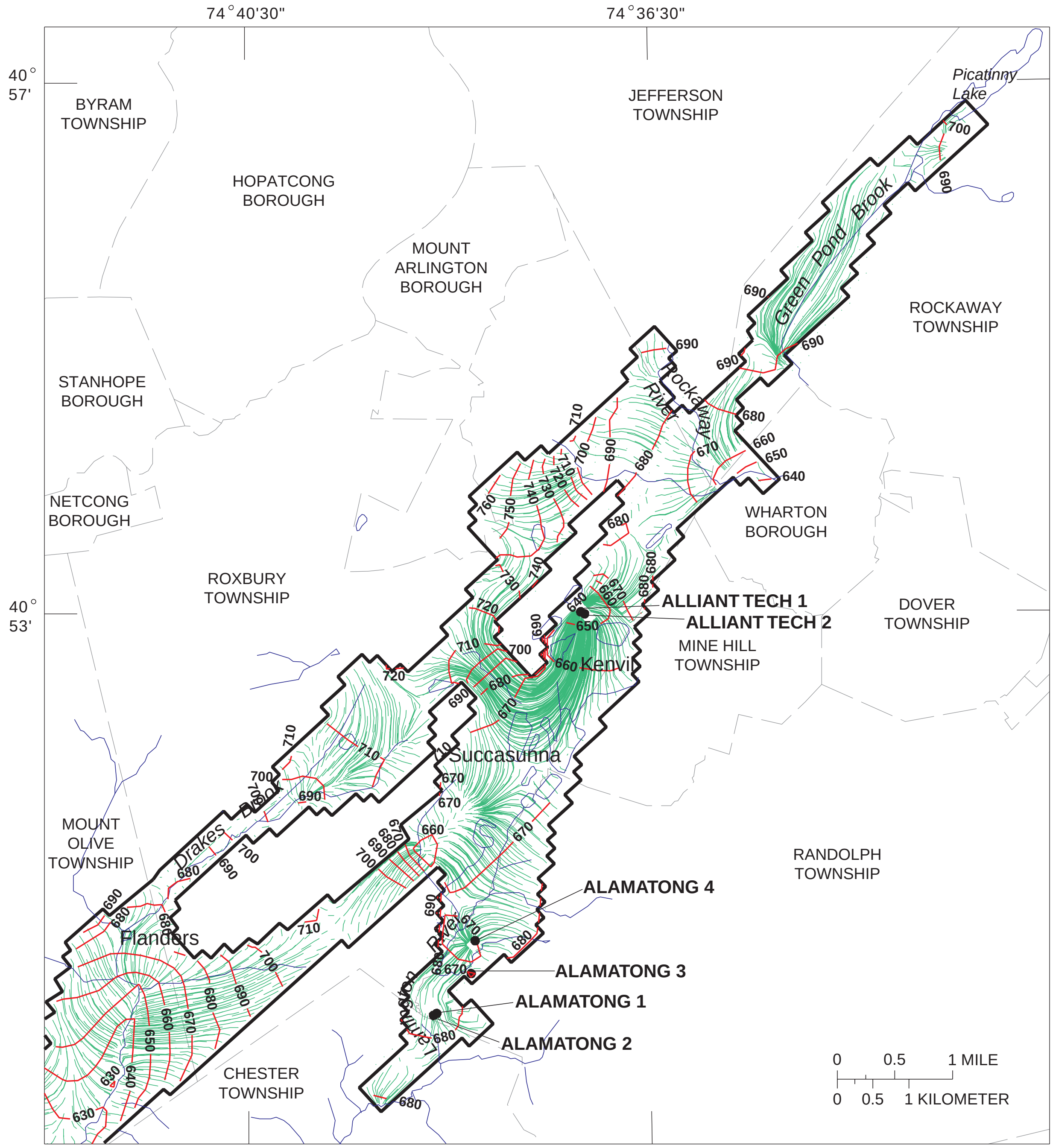
MODEL BOUNDARY--Shows boundary of upper valley-fill aquifer in model

690 WATER-TABLE CONTOUR--Shows altitude of water table, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or underlying aquifer

WHARTON BOROUGH ● WATER-SUPPLY WELL AND IDENTIFIER

Figure 19. Simulated water levels and flow paths in the upper valley-fill aquifer under scenario 4 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

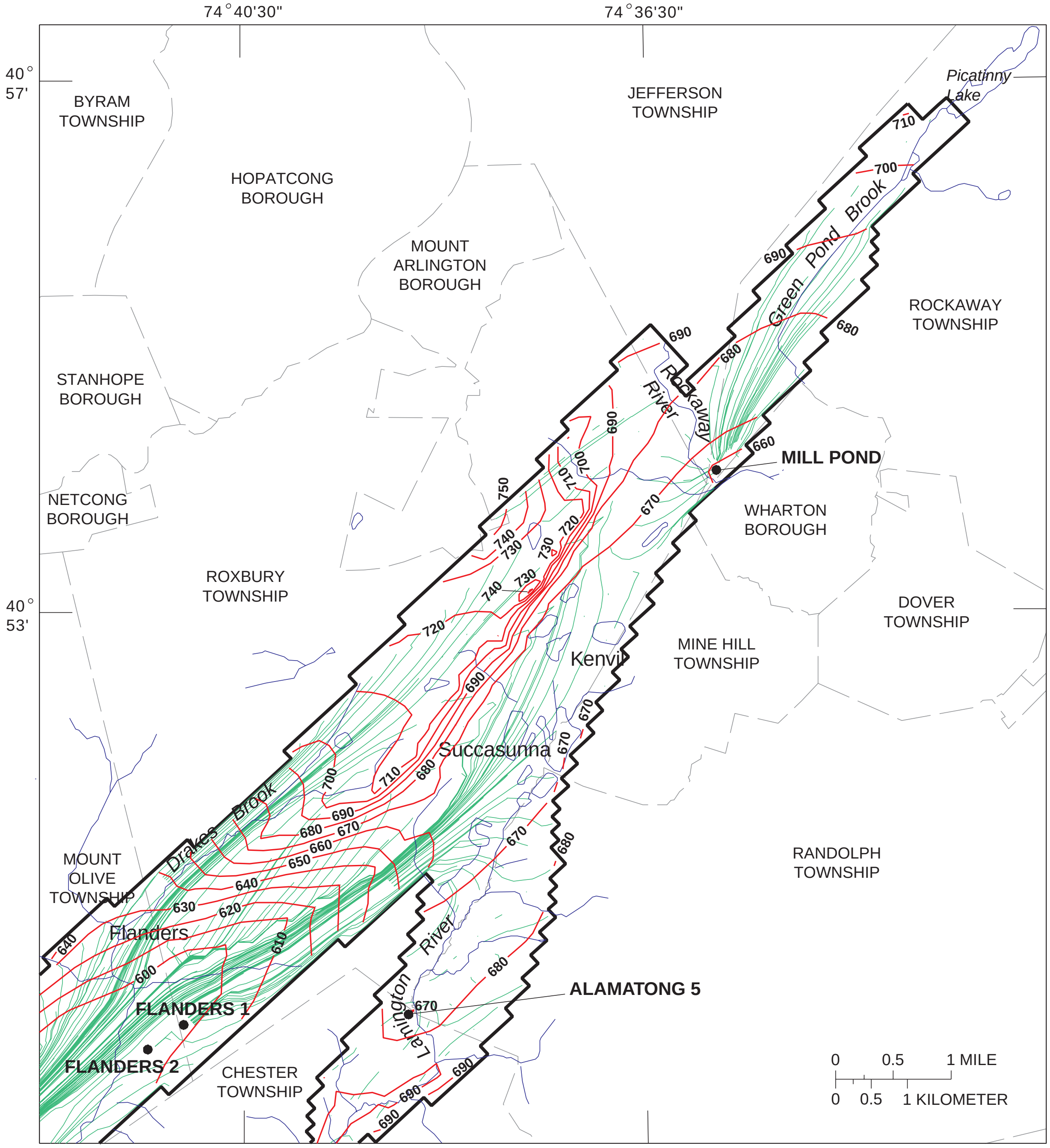
MODEL BOUNDARY--Shows boundary of lower valley-fill aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area, upper valley-fill aquifer, or carbonate-rock aquifer

ALAMATONG 4 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 20. Simulated water levels and flow paths in the lower valley-fill aquifer under scenario 4 pumping conditions near Kenvil, Morris County, New Jersey.



EXPLANATION

MODEL BOUNDARY--Shows boundary of carbonate-rock aquifer in model

690 POTENTIOMETRIC CONTOUR--Shows altitude at which water would stand in tightly cased wells, in feet above sea level. Contour interval 10 feet

PATHLINE--Shows flow path from recharge area to discharge area or overlying aquifer

ALAMATONG 5 • WATER-SUPPLY WELL AND IDENTIFIER

Figure 21. Simulated water levels and flow paths in the carbonate-rock aquifer under scenario 4 pumping conditions near Kenvil, Morris County, New Jersey.

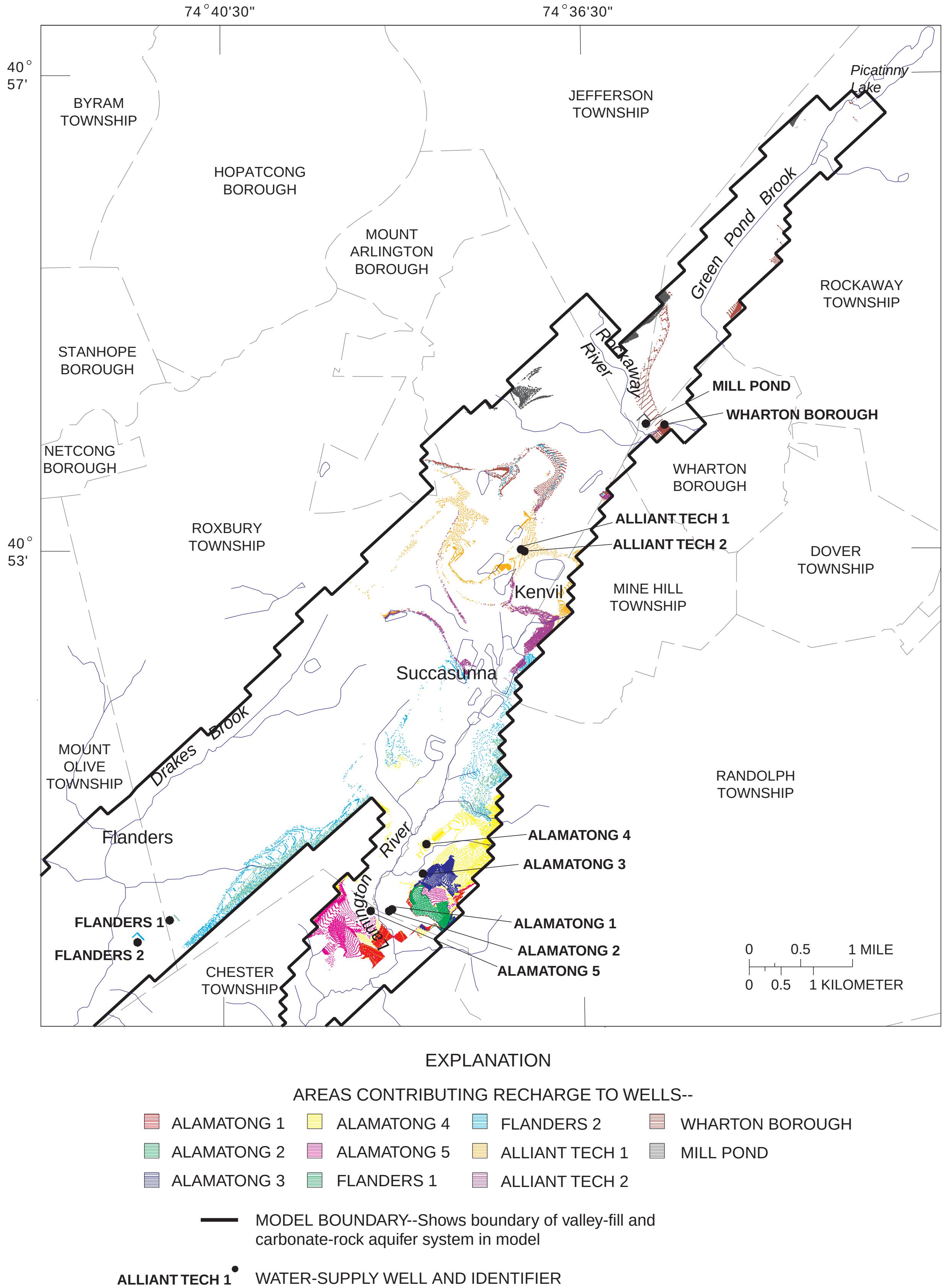


Figure 22. Simulated areas contributing recharge to selected wells under scenario 4 pumping conditions near Kenvil, Morris County, New Jersey.

SUMMARY

The valley-fill and carbonate-rock aquifer system near Kenvil in the New Jersey Highlands is an important source of water supply for many communities in southwestern and central Morris County, New Jersey. The aquifer material is an assemblage of alluvium, colluvium, stratified and unstratified glacial sediments, low-permeability sedimentary rock, and permeable carbonate rock that is underlain and bounded by low-permeability crystalline bedrock. The aquifer system consists of an upper valley-fill aquifer, a lower valley-fill aquifer, two valley-fill confining units, a Paleozoic-rock confining unit (shale, conglomerate, and sandstone), and a carbonate-rock aquifer. Flow patterns in the uppermost valley-fill sediments are affected by the presence of surface-water features and aquifer boundaries, and most of the flow in this aquifer discharges to surface water. Flow patterns in the lower valley-fill and carbonate-rock aquifers are affected by pumping from water-supply wells and the presence of zones characterized by either high aquifer permeability or good vertical hydraulic connection between aquifers.

As the population in the study area increases, demand for water from the aquifer system is expected to increase. In response to new pumping stresses, ground-water-flow patterns and recharge source areas to withdrawal wells can be expected to change. Therefore, the USGS, in cooperation with the Morris County Municipal Utilities Authority, conducted a study of the aquifer system in which a three-dimensional numerical ground-water-flow model of the aquifer system previously developed by the USGS was used to evaluate changes in ground-water-flow patterns and areas contributing recharge to supply wells. Changes resulting from four alternative water-supply scenarios, in which six previously installed and proposed wells are pumped at various rates, were simulated.

Flow patterns and recharge areas simulated under recent average withdrawal conditions (1991-95) were used as a basis for comparison with results obtained for each of the four alternative scenarios. Water levels declined most in scenario 3 (8, 63, and 48 ft in the upper valley-fill, lower valley-fill, and carbonate-rock aquifers, respectively), in which hypothetical withdrawals were increased 56 percent over recent withdrawals. Water levels declined least in scenario 4 (4, 6, and 11 ft, respectively), in which hypothetical withdrawals were increased 41 percent over recent withdrawals. In the water-budget subarea, discharge to streams decreased by as much as 2.4 ft^3/s (1,080 gal/min), downward leakage to the lower valley-fill aquifer increased by as much as 1.9 ft^3/s (840 gal/min), downward leakage to the carbonate-rock aquifer increased by as much as 1.4 ft^3/s (640 gal/min), and lateral flow in the carbonate-rock aquifer from the southwest increased by as much as 1.3 ft^3/s (590 gal/min). Results of pathline analyses indicate that flow patterns in the aquifer system changed in response to changes in pumping rates and (or) the addition of new pumping stresses, and aeas contributing recharge to proposed wells developed. The size, shape, and location of areas contributing recharge to wells also changed in response to changes in withdrawal stresses. Changes were smallest for scenario 1 and greatest for scenario 3. All of these changes depended on the location and magnitude of the change in withdrawal stress and on other hydrogeologic factors, such as the configuration of aquifer boundaries and differences in aquifer properties.

REFERENCES CITED

Franke, O.L., Reilly, T.E., Pollock, D.W., and LaBaugh, J.W., 1998, Estimating areas contributing recharge to wells--Lessons from previous studies: U.S. Geological Survey Circular 1174, 14 p.

Harbaugh, A.W., and McDonald, M.G., 1996, User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96-485, 56 p.

Nicholson, R.S., McAuley, S.D., Barringer, J.L., and Gordon, A.D., 1996, Hydrogeology of, and ground-water flow in, a valley-fill and carbonate-rock aquifer system near Long Valley in the New Jersey Highlands: U.S. Geological Survey Water-Resources Investigations Report 93-4157, 159 p., 3 pls.

Nicholson, R.S., and Watt, M.K., 1998, Simulation of ground-water-flow patterns and areas contributing recharge to streams and water-supply wells in a valley-fill and carbonate-rock aquifer system, southwestern Morris County, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 97-4216, 40 p.

Orzol, L.L., 1997, User's guide for MODTOOLS: Computer programs for translating data of MODFLOW and MODPATH into geographic information system files: U.S. Geological Survey Open-File Report 97-240, 86 p.

Pollock, D.W., 1994, User's guide for MODPATH/MODPATH-PLOT, Version 3.0: A particle-tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water-flow model: U.S. Geological Survey Open-File Report 94-464, 234 p.

Spitz, F.J., and Nicholson, R.S., 1998, Use of a nested rediscretization method to improve pathline resolution by eliminating weak sinks representing wells, *in* Poeter, E.P., Zheng, C., and Hill, M.C., eds., Proceedings of the MODFLOW '98 Conference at the International Groundwater Modeling Center, October 4-8, 1998, v. II: Golden, Colo., Colorado School of Mines, p. 905-914.