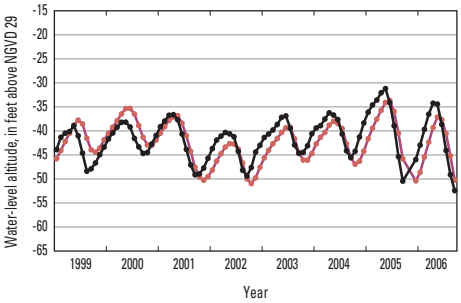
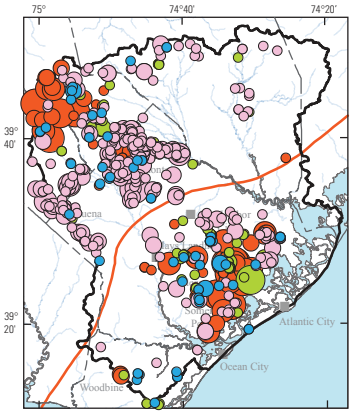
Prepared in Cooperation with the
New Jersey Department of Environmental Protection

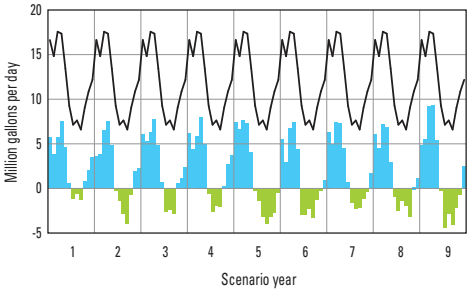
Simulated Effects of Alternative Withdrawal Strategies on Groundwater Flow in the Unconfined Kirkwood-Cohansey Aquifer System, the Rio Grande Water-Bearing Zone, and the Atlantic City 800-Foot Sand in the Great Egg Harbor and Mullica River Basins, New Jersey

Well at Mullica River campsite





Annual 2005



Wading River

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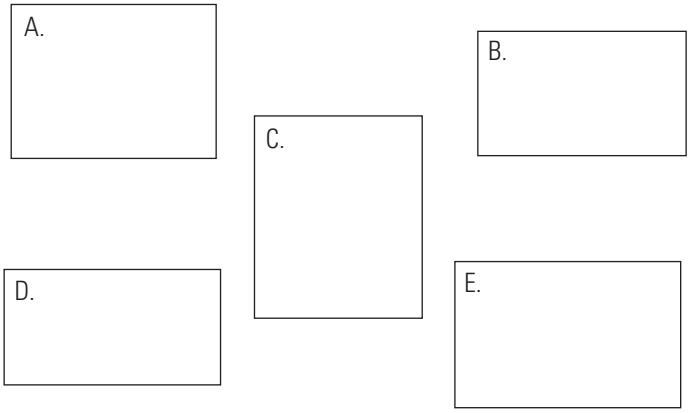

Cover:

A. Hand pump well at Mullica River Campsite. (Photograph by W. Jones, U.S. Geological Survey)

B. Hydrograph of simulated and observed water levels at well 010180 (Oceanville) in the Atlantic City 800-foot sand, southeastern New Jersey, 1999–2006.

C. Map showing annual groundwater withdrawals from the Atlantic City 800-foot sand, southeastern New Jersey, 2005.

D. Final available water, simulated base-flow depletion, monthly remaining available water, and base-flow deficit under the Full Allocation scenario for Hydrologic Unit Code 02040301160, southeastern New Jersey.

E. Wading River, New Jersey (Photograph by W. Jones, U.S. Geological Survey)

Simulated Effects of Alternative Withdrawal Strategies on Groundwater Flow in the Unconfined Kirkwood-Cohansey Aquifer System, the Rio Grande Water-Bearing Zone, and the Atlantic City 800-Foot Sand in the Great Egg Harbor and Mullica River Basins, New Jersey

By Daryll A. Pope, Glen B. Carleton, Debra E. Buxton, Richard L. Walker, Jennifer L. Shourds, and Pamela A. Reilly

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U.S. Geological Survey, Reston, Virginia: 2012

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft3/d)/ft2]ft. In this report, the mathematically reduced form, foot squared per day (ft2/d), is used for convenience.

Simulated Effects of Alternative Withdrawal Strategies on Groundwater Flow in the Unconfined Kirkwood-Cohansey Aquifer System, the Rio Grande Water-Bearing Zone, and the Atlantic City 800-Foot Sand in the Great Egg Harbor and Mullica River Basins, New Jersey

By Daryll A. Pope, Glen B. Carleton, Debra E. Buxton, Richard L. Walker, Jennifer L. Shourds, and Pamela A. Reilly

Abstract

Groundwater is essential for water supply and plays a critical role in maintaining the environmental health of freshwater and estuarine ecosystems in the Atlantic Coastal basins of New Jersey. The unconfined Kirkwood-Cohansey aquifer system and the confined Atlantic City 800-foot sand are major sources of groundwater in the area, and each faces different water-supply concerns. The U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection (NJDEP), conducted a study to simulate the effects of withdrawals in the Kirkwood-Cohansey aquifer system, the Atlantic City 800-foot sand, and the Rio Grande water-bearing zone and to evaluate potential scenarios. The study area encompasses Atlantic County and parts of Burlington, Camden, Gloucester, Ocean, Cape May, and Cumberland Counties. The major hydrogeologic units affecting water supply in the study area are the surficial Kirkwood-Cohansey aquifer system, a thick diatomaceous clay confining unit in the upper part of Kirkwood Formation; the Rio Grande water-bearing zone; and the Atlantic City 800-foot sand of the Kirkwood Formation.

Hydrogeologic data from 18 aquifer tests and specific capacity data from 230 wells were analyzed to provide horizontal hydraulic conductivity of the aquifers. Groundwater withdrawals are greatest from the Kirkwood-Cohansey aquifer system, and 65 percent of the water is used for public supply. Groundwater withdrawals from the Atlantic City 800-foot sand are about half those from the Kirkwood-Cohansey aquifer system. Ninety-five percent of the withdrawals from the Atlantic City 800-foot sand is used for public supply. Data from six streamgaging stations and 51 low-flow partial record sites were used to estimate base flow in the area. Base flow ranges from 60 to 92 percent of streamflow.

A groundwater flow model of the Kirkwood-Cohansey aquifer system, the Rio Grande water-bearing zone, and the Atlantic City 800-foot sand was developed and calibrated using water-level data from 148 wells and base-flow data from 22 gaging or low-flow partial record stations. The Kirkwood-Cohansey aquifer system within the Great Egg Harbor River and the Mullica River Basins was simulated on a monthly basis from 1998 through 2006. An existing regional model of the New Jersey Coastal Plain was revised to provide boundary conditions for the Great Egg Harbor and Mullica River Basin model (referred to as the Great Egg-Mullica model). In the Great Egg-Mullica model, monthly groundwater recharge rates used in the model ranged from 10–15 inches per year in 2001 to 20–25 inches per year in 2005. The mean-absolute error for 10 of the 14 long-term hydrographs used in model calibration was less than 5 ft. Groundwater flow budgets for the Great Egg-Mullica model calibration periods, May 2005 and September 2006, and for the entire model calibration period 1998 to 2006, showed that nearly 70 percent of the water entering the Atlantic City 800-foot sand came from the horizontal connection with the Kirkwood-Cohansey aquifer system in updip areas.

The groundwater flow model was used to simulate scenarios under three possible conditions: average 1998 to 2006 withdrawals (Average scenario), full-allocation withdrawals (Full Allocation scenario), and projected 2050-demand withdrawals (2050 Demand scenario). Withdrawals in the Full Allocation scenario are nearly twice the withdrawals from the Average scenario, primarily because of the potential for large agricultural withdrawals if all allocations are used. Withdrawals for the 2050 Demand scenario are about 50 percent greater than those for the Average scenario, primarily due to expected increases in withdrawals for public supply. Monthly base-flow depletion criteria were determined using the Low-Flow Margin method, currently under consideration by NJDEP, to estimate available water on an annual basis at the Hydrologic Unit Code 11 (HUC11) level and to determine whether a water-supply deficit exists. Simulations of various

groundwater-withdrawal scenarios were made using the calibrated model, and results were compared with baseline conditions (no withdrawals) to determine where and when base-flow deficits may be occurring and may be expected to occur in the future. Scenarios were simulated to assess base-flow depletion that could occur from different groundwater-withdrawal situations. In the Average scenario, deficits occurred in 7 of the 14 subbasins. In the Full Allocation scenario, deficits occurred in 11 of the subbasins. In the 2050 Demand scenario, deficits occurred in 9 of the 14 subbasins. The largest deficits occurred in the Absecon Creek subbasin because the base-flow depletion criteria for this subbasin is small due to the surface-water diversions that are already occurring there and because existing groundwater withdrawals in the subbasin have resulted in base-flow depletion under current (1998–2006) conditions. Three adjusted scenarios, variations of the Average, Full Allocation, and 2050 Demand scenarios, were simulated; for the adjusted scenarios, the withdrawals were modified in stages with the intent to successively eliminate or minimize the base-flow deficits. Modifications included shifting withdrawals to a deeper part of the Kirkwood-Cohansey aquifer system, implementing seasonal conjunctive use of shallow and deep aquifers, and specifying reductions in withdrawals within a HUC11 subbasin in deficit. The adjusted scenarios are intended to show the relative effectiveness of each of the three approaches in reducing the deficits. Most of the deficits under the Average, Full Allocation, and 2050 Demand scenarios were eliminated by reductions in withdrawals or allocations. Shifting withdrawals to a deeper part of the Kirkwood-Cohansey aquifer system or seasonal conjunctive use did not eliminate deficits for any subbasin. Reductions in withdrawals accounted for more than 95 percent of the total reduction of deficits in all but one subbasin.

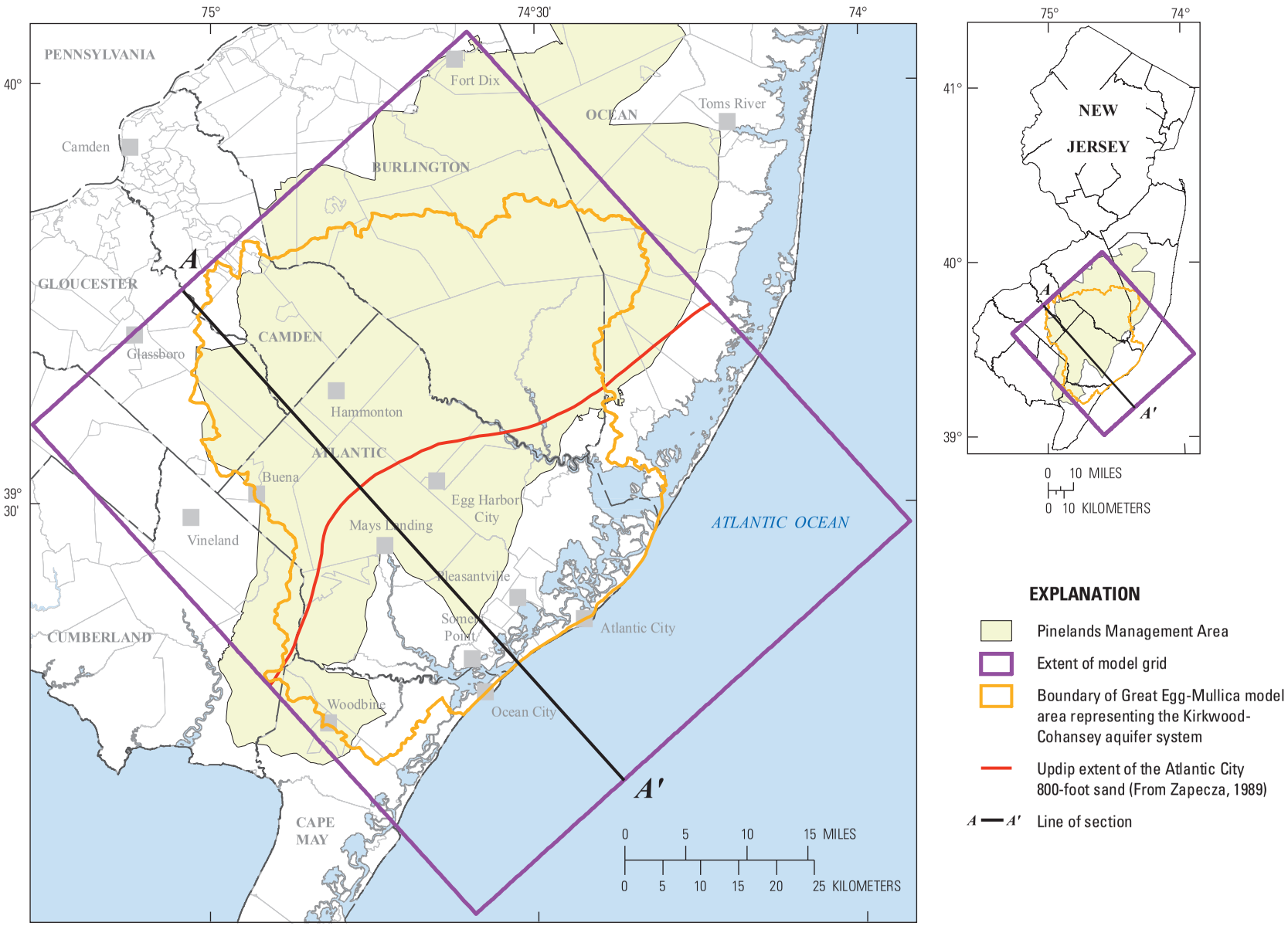
Introduction

Groundwater is an essential water supply and plays a critical role in maintaining the environmental health of freshwater and estuarine ecosystems in the Atlantic Coastal Basins of New Jersey (fig. 1). The unconfined Kirkwood-Cohansey aquifer system and the confined Atlantic City 800-foot sand are major sources of groundwater in the area. The unconfined and confined aquifer systems face different water-supply concerns in an area where water demand is on the rise. Increasing groundwater withdrawals from the unconfined Kirkwood-Cohansey aquifer system is a major concern because of the potential for streamflow depletion and the resulting ecological effects on aquatic habitats, wetlands, and vernal ponds. The Pinelands ecosystem, which includes the Pinelands area, is intensely dependent on the Kirkwood-Cohansey aquifer system to maintain streamflow during dry periods, as the groundwater system generally supplies 60 to 80 percent of annual streamflow as base flow. Groundwater withdrawals can reduce groundwater inflow to wetlands and vernal ponds and can decrease base flow to streams. In the confined Atlantic City 800-foot sand aquifer a major concern is that water levels have been steadily declining for many years and were more than 80 feet (ft) below National Geodetic Vertical Datum of 1929 (NGVD 29) during all of 2003. Most of the groundwater withdrawn from the Atlantic City 800-foot sand ultimately comes from the Kirkwood-Cohansey aquifer system. In updip areas where the confining unit overlying the Atlantic City 800-foot sand is not present there is a lateral connection between the two aquifers (fig. 2). Water flows from the overlying unconfined aquifer through the confining unit to the Atlantic City 800-foot sand. Although the effects of withdrawals from the Atlantic City 800-foot sand on streamflow and water levels in the Kirkwood-Cohansey aquifer system are much less than the effects of withdrawals directly from the unconfined aquifer, there is still the potential for severe effects on the unconfined aquifer system, especially near the updip limit of the Atlantic City 800-foot sand. A groundwater flow model of the Great Egg Harbor and Mullica River Basins was developed to simulate the effects of withdrawals from the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand on the unconfined aquifer and on streamflow in the subbasins.

Additional concerns associated with declining water levels in the Atlantic City 800-foot sand are saltwater movement in the aquifer and land subsidence in Atlantic County. South of the study area in Cape May County, saltwater intrusion in the Atlantic City 800-foot sand is an issue where the 250-milligram per liter (mg/L) isochlor is located onshore. In the Atlantic City area, water with a chloride concentration of 250 mg/L is located more than 5 miles offshore (dePaul and others, 2009), but a cone of depression in the Atlantic City 800-foot sand is causing landward movement of the saltwater. Declining water levels in the Atlantic City 800-foot sand have also contributed to land subsidence of nearly 1 inch from 1980 through 2007, as measured at a site in Atlantic County (unpublished data on file at the U.S. Geological Survey, New Jersey Water Science Center in West Trenton, N.J.). If water levels in the Atlantic City 800-foot sand continue to decline, the rate of saltwater movement and land subsidence may continue to increase. The groundwater model developed in this study will provide estimates of the decline in water levels in the Atlantic City 800-foot sand resulting from various scenarios, which resource managers can then use to evaluate future saltwater intrusion or subsidence that may result from the declines.

When adopted, the Pinelands Comprehensive Management Plan established nine land-use management areas, one being Regional Growth Areas (RGAs) where most future residential growth would occur (Pinelands Comprehensive Management Plan, N.J.A.C.7:50-5.28). Eleven RGAs were established in the Mullica and Great Egg Harbor Basins that allow for housing densities of 2.0 to 3.5 houses per acre. Any future growth in these RGAs will increase water use, and the demand for water ideally will be satisfied in ways that do not severely affect the unconfined and confined aquifers.

The U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection



Base from U.S.Geological Survey digital line graph files, 1:24,000

Figure 1. Location of model grid and active model area of the Great Egg-Mullica model, southeastern New Jersey. (Section is shown in figure 2)

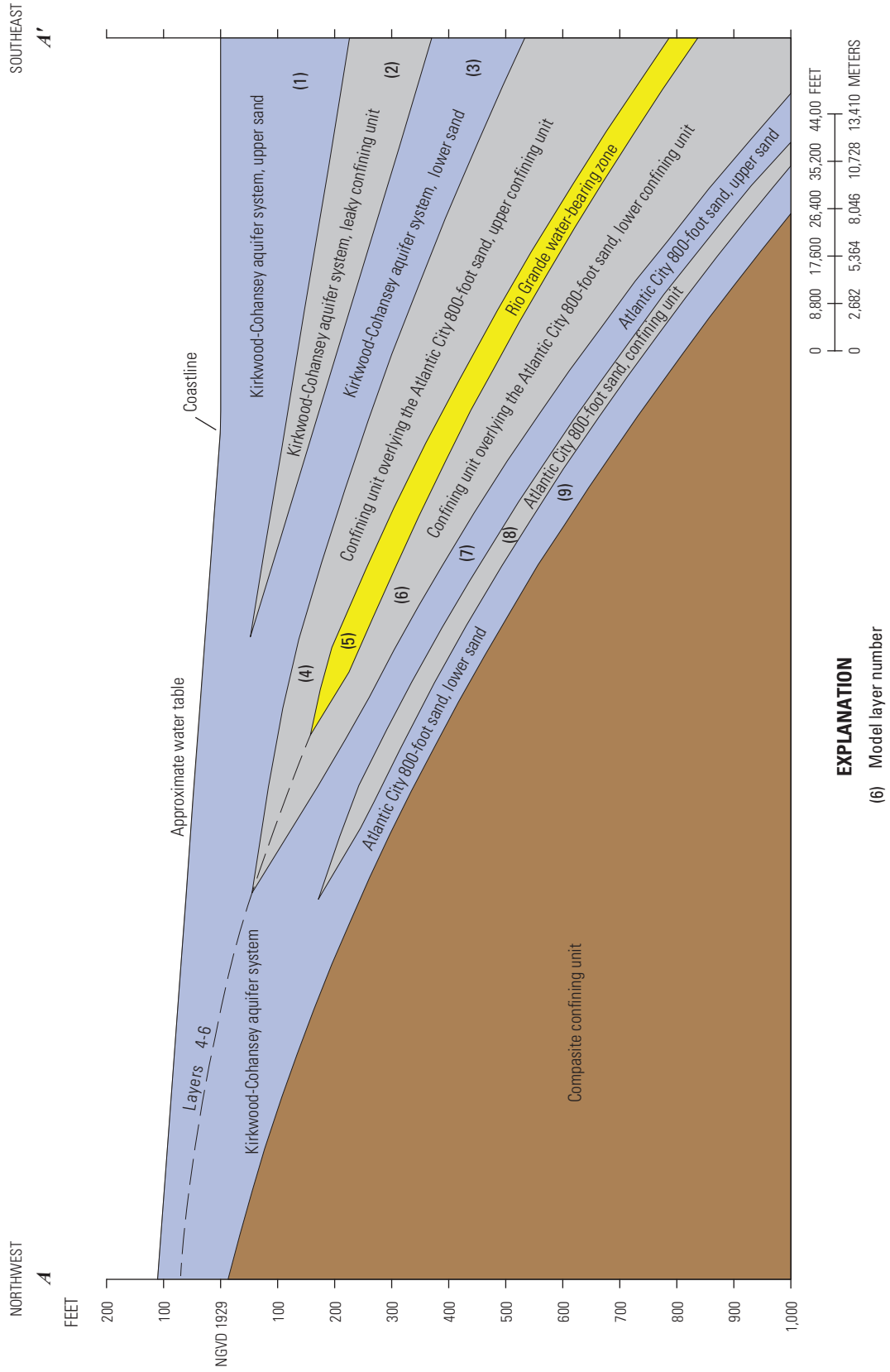


Figure 2. Generalized hydrogeologic section, southeastern New Jersey. (Line of section shown in figure 1)

(NJDEP), conducted a study to examine the likely effects of withdrawals from the Kirkwood-Cohansey aquifer system, the Rio Grande water-bearing zone, and the Atlantic City 800-foot sand on streamflow and groundwater supply. The study area covers the drainage areas of the Mullica and Great Egg Harbor Rivers in the Coastal Plain of New Jersey (fig. 3) and includes Atlantic County and parts of Burlington, Camden, Gloucester, Ocean, Cape May, and Cumberland Counties.

Purpose and Scope

This report documents the development and application of a groundwater flow model for the Great Egg Harbor and Mullica River Basins in the Atlantic Coastal Plain of New Jersey. The aquifers in the study area are the unconfined Kirkwood-Cohansey aquifer system, the confined Rio Grande water-bearing zone, and the confined Atlantic City 800-foot sand. Groundwater withdrawal data and estimated recharge for the period 1998 to 2006 were used to calibrate the flow model. Recharge for the period from 1998 to 2006 was used to simulate future water-use scenarios. A regional model of the confined Coastal Plain aquifers in New Jersey was updated to provide boundary conditions for the Great Egg Harbor and Mullica River model (hereafter referred to as the Great Egg-Mullica model).

Results of the Great Egg-Mullica model were used to evaluate the effects of current groundwater withdrawals on the system. The effects of potential future groundwater withdrawals were assessed by simulating Full Allocation (maximum permitted withdrawals) and projected 2050 Demand scenarios. The effects on aquifer water levels and on base-flow depletion of streams also were evaluated.

Base-flow depletion criteria were determined for 14 Hydrologic Unit Code 11 (HUC11) subbasins within the study area. Scenarios were simulated in which current and future withdrawals were modified in stages in order to meet the base-flow depletion criteria without creating substantial declines in the potentiometric surface of the confined Atlantic City 800-foot sand. Results of the modified scenarios are discussed.

Previous Investigations

Numerous reports describe the hydrogeologic framework and the freshwater flow system in the New Jersey Coastal Plain. Zapecza (1989) defines 15 regional hydrologic units of the Coastal Plain, describing the subsurface occurrence and configuration of the aquifers and confining units. Martin (1998) compiled an extensive list of previous investigations and simulated the freshwater flow system using a numerical groundwater flow model for the USGS Regional Aquifer-System Analysis (RASA). Mullikin (Lloyd Mullikin, New Jersey Departement of Environmental Protection, written commun., 1989) used lithologic logs, cores, and drill cuttings from boreholes and geophysical data to examine the hydrostratigraphy of the Kirkwood Formation and its relation to adjoining units.

Work by Sugarman (2001) describes the hydrostratigraphy of the Kirkwood Formation and Cohansey Formation, principally using geophysical logs compiled by Mullikin. Pope and Gordon (1999) simulated the New Jersey Coastal Plain groundwater flow system using a quasi-three-dimensional finite-difference computer model that showed the location and movement of the freshwater-saltwater interface in nine aquifers and eight confining units. The Coastal Plain RASA model was updated by Voronin (2004) using a rediscretization of model parameters to a finer cell size, a spatially variable recharge rate, and updated groundwater withdrawal data.

A groundwater model and the hydrogeology of the Atlantic City 800-foot sand are described in McCauley and others (2001). Pope (2006) used RASA model simulations to assess the effects of increased groundwater withdrawals from the Atlantic City 800-foot sand and the unconfined Kirkwood-Cohansey aquifer system on water levels in the Atlantic City 800-foot sand in the New Jersey Coastal Plain. This study highlighted the need for a model of both the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand to address water-supply issues in the area. Studies of the surficial aquifer systems in the Great Egg Harbor and Mullica River Basins (Johnson and Watt, 1996; Watt and Johnson, 1992) provide information on the hydrogeology, water levels, water quality, surface water, and a water budget of the Kirkwood-Cohansey aquifer system.

Lacombe and Carlton (2002) discuss the hydrogeologic framework, availability of freshwater supplies, and saltwater intrusion in Cape May County, N.J. Lacombe and others (2009) describe the simulation of water-supply scenarios for Cape May County. Walker and others (2008) prepared a detailed hydrogeologic framework for each of three small (less than 85 square miles (mi^2)) study areas in the New Jersey Pinelands to be used for the groundwater flow models developed for the Kirkwood-Cohansey aquifer system in those areas. Hydrologic conditions in these study areas during 2004–06 were also assessed (Walker and others, 2011)

Well-Numbering System

The well-numbering system used in this report has been used by the USGS in New Jersey since 1978. The well number consists of a county code number and a sequence number assigned to the well in the county. County code numbers used in this report are 01, Atlantic; 05, Burlington; 07, Camden; 09, Cape May; and 15, Gloucester. For example, well 01-578 is the 578th well inventoried in Atlantic County.

Hydrogeology

The hydrogeology of the Kirkwood-Cohansey aquifer system, the Rio Grande water-bearing zone, and the Atlantic City 800-foot sand was assembled from published reports, existing data, and data collected as part of this study. The

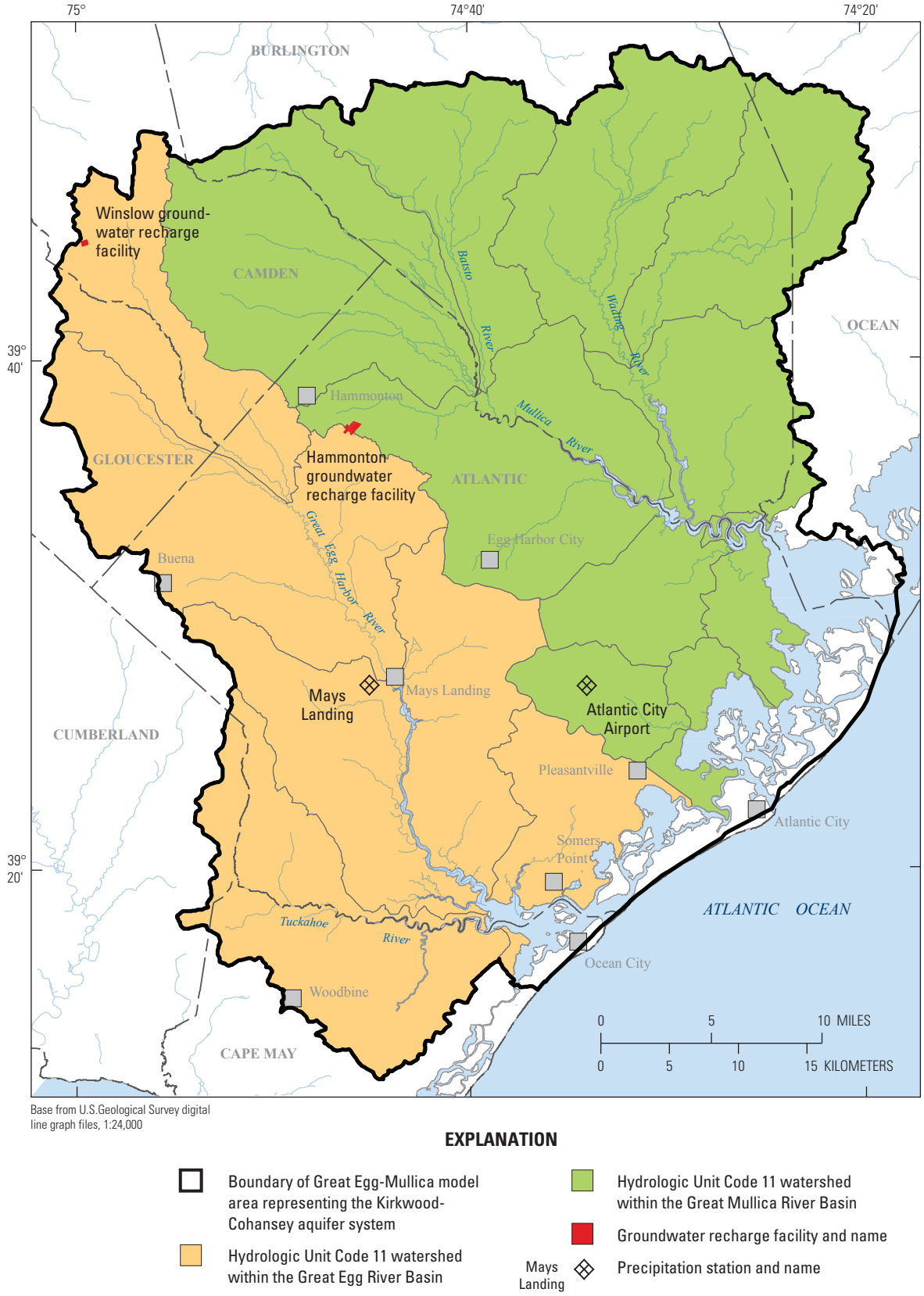


Figure 3. Location of precipitation stations and watersheds, southeastern New Jersey.

following sections discuss the study area hydrogeologic framework, aquifer properties, water-use data, stream base flow, and groundwater recharge used in the groundwater flow model of the study area.

Hydrogeologic Framework

The hydrogeologic framework of the entire Coastal Plain is described by Zapecza (1989). The New Jersey Coastal Plain is composed of a series of seaward dipping wedges of sediment of alternating sand or gravel and clay units. Generally, units composed predominantly of sand and gravel compose the aquifers of the Coastal Plain, whereas those composed predominantly of silt and clay compose the confining units.

Figure 2 is a generalized hydrogeologic section that runs from Camden County, through Atlantic City, N.J., and shows the vertical extent of the Coastal Plain aquifers and confining units that are addressed in this report. These primary hydrogeologic units of the Great Egg Harbor and Mullica River Basins are listed in table 1 in relation to time stratigraphic geologic units.

The major hydrogeologic units affecting water supply in the study area are described below from shallow to deep. The surficial Kirkwood-Cohansey aquifer system is underlain by a thick diatomaceous clay confining unit in the upper part of Kirkwood Formation. Within this clay lies the Rio Grande water-bearing zone. The Atlantic City 800-foot sand is composed of upper and lower sand units. A leaky confining bed separates the sand layers. A composite confining unit (Zapecza, 1989) forms the basal clay beneath the Atlantic City 800-foot sand and the semi-confined or unconfined Kirkwood-Cohansey aquifer system. The Piney Point aquifer lies directly below this clay, but in the Atlantic County area the aquifer is not used for water supply because of its depth and the presence of saltwater in some areas. Because the composite confining unit is relatively impermeable in the study area, it is represented as a lower boundary in the model.

The hydrogeologic framework was revised for this study from a regional representation of the New Jersey Coastal Plain aquifer system described by Martin (1998). The purpose of the revisions was to improve the conceptual model of the flow system using additional work that has been done. A clay layer within the Kirkwood-Cohansey aquifer system may function locally as a confining unit in eastern Atlantic County. The Rio Grande water-bearing zone is modeled explicitly in the RASA model. The updip limit of the confining unit overlying the Atlantic City 800-foot sand was extended farther updip to investigate the connection between the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand in updip areas during model calibration. A thin confining unit within the Atlantic City 800-foot sand separates the Atlantic City 800-foot sand into upper and lower sand units.

Kirkwood-Cohansey Aquifer System

The Kirkwood-Cohansey aquifer system is present throughout the entire study area. The aquifer system consists primarily of gravel, sand, silt, and clay sediments of the Cohansey and Kirkwood Formations, both of Miocene age. In some areas, younger sediments of Holocene, Pleistocene, or Miocene age may overlie the Cohansey Formation. In these areas, the younger sediments although shown as undifferentiated in table 1 are considered to be part of the aquifer system. The Kirkwood-Cohansey aquifer system thickens toward the coast to a depth of about 300 ft at the top of the confining unit overlying the Atlantic City 800-foot sand (fig.2)

The Kirkwood-Cohansey aquifer system is generally considered to be unconfined; however, discontinuous clays are common, especially in sediments of the Cohansey Formation (Walker and others, 2008). Data from boreholes that penetrate the aquifer system in the eastern part of the study area indicate that sediments trend toward finer textures with depth. In the western part of the study area, the Kirkwood-Cohansey aquifer system includes the lower sand of the Kirkwood Formation, the lateral updip equivalent of the Atlantic City 800-foot sand. The deeper sediments also tend to be finer with depth, forming a gradational contact with the basal composite confining unit. Results of a study to investigate hydrologic and ecological conditions in the Pinelands, known as the Kirkwood-Cohansey Project, include detailed hydrogeologic framework models of the Kirkwood-Cohansey aquifer system in three small subbasins in the New Jersey Pinelands (Walker and others, 2008). Data and interpretations from that investigation were used in the development of the hydrogeologic framework for this study. The study included collection of borehole and geophysical data in three subbasins.

Clay layers within the Kirkwood-Cohansey aquifer system are commonly of variable extent, and few can be traced over distances of miles using geophysical logs and borehole data. Walker and others (2008) identified an extensive but leaky confining layer in the deeper part of the Kirkwood-Cohansey aquifer system that lies above the principal water-bearing sands in the lower part of this aquifer system in the vicinity of Pomona, New Jersey.

The current study used the data accumulated during the Kirkwood-Cohansey Project, combined with data from additional geophysical logs and boring logs collected as part of this study, to address data gaps in the hydrogeologic framework. Additional interpretative work in the study area defined the position of an extensive leaky confining unit within the Kirkwood-Cohansey aquifer system that could have regional importance. This leaky confining unit divides the Kirkwood-Cohansey aquifer system in the downdip areas into upper and lower sands. The structure contours of the top and bottom of this clay, referred to herein as the “Kirkwood-Cohansey leaky confining unit,” are shown in figures 4 and 5, respectively.

The lower sand of the Kirkwood-Cohansey aquifer lies immediately beneath the leaky confining unit described above. The bottom of this sand lies directly on the top of the

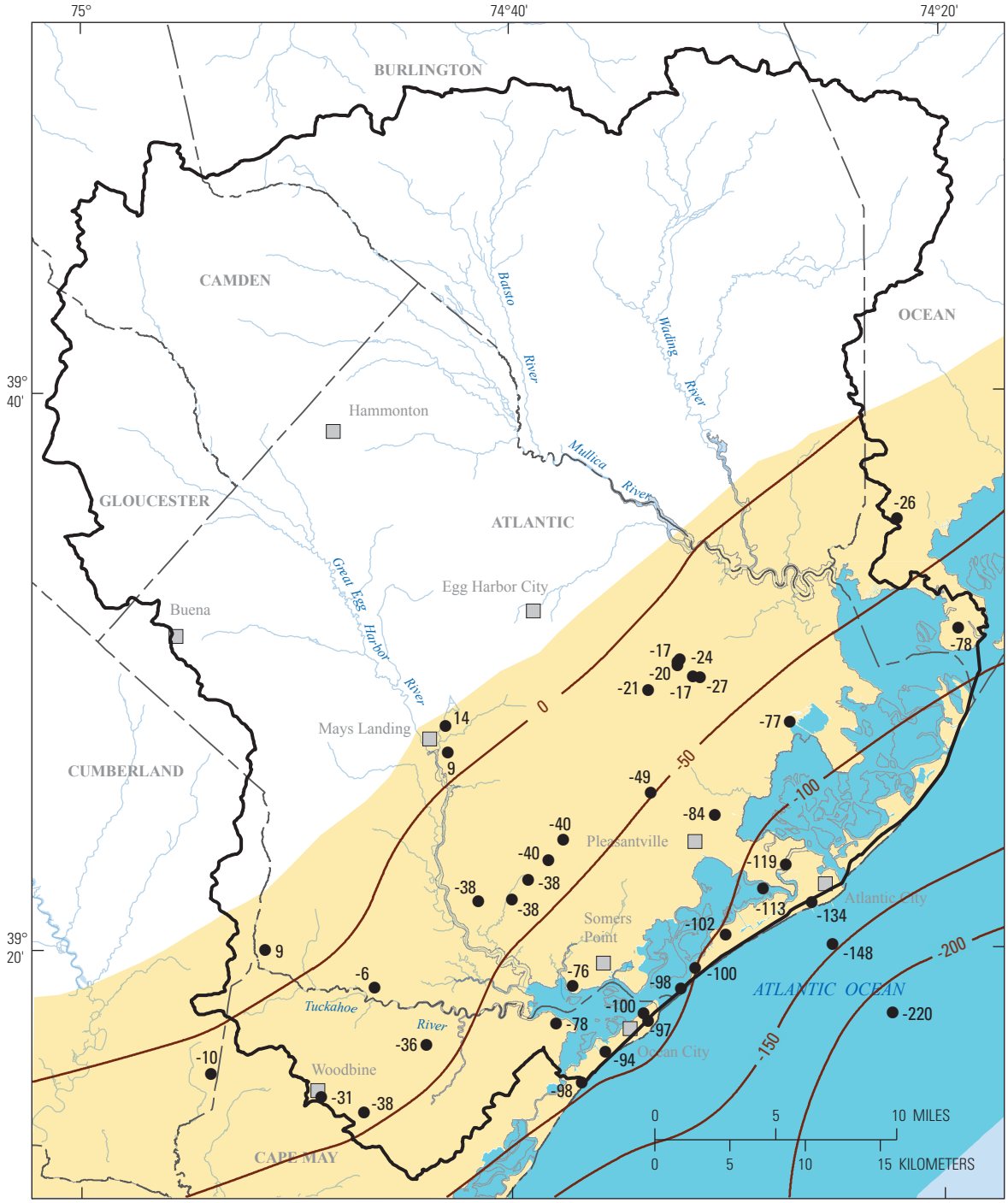
Table 1. Geologic and hydrogeologic units, southeastern New Jersey.

ERA	System	Series	Geologic unit[1]	Hydrogeologic unit[2]	
Cenozoic	Quaternary	Holocene	Swamp, salt marsh and beach deposits, dune fields	Undifferentiated	
		Pleistocene	Colluvium-alluvium		
			Cape May Formation		
	Tertiary	Miocene	Bridgeton Formation	Kirkwood-Cohansey aquifer system, upper sand	
			Cohansey Formation	Kirkwood-Cohansey leaky confining unit	
				Kirkwood-Cohansey aquifer system, lower sand	
			Kirkwood Formation	Confining unit overlying the Atlantic City 800-foot sand	Upper confining unit
					Rio Grande water-bearing zone
					Lower confining unit
				Atlantic City 800-foot sand	Upper sand
					Confining unit
					Lower sand
		Oligocene	Piney Formation	Composite confining unit[3]	Piney Point aquifer
		Eocene	Shark River Formation		
			Manasquan Formation		

[1] Nomenclature from Owens and others, 1998; Newell and others, 2000.

[2] Nomenclature from Zapecza, 1989; and Lloyd Mullikin (New Jersey Geological Survey, written commun., 2001).

[3] Includes older geologic units not shown in the table.



Base from U.S.Geological Survey digital line graph files, 1:24,000

EXPLANATION

Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

EXTENT OF KIRKWOOD-COHANSEY LEAKY CONFINING UNIT

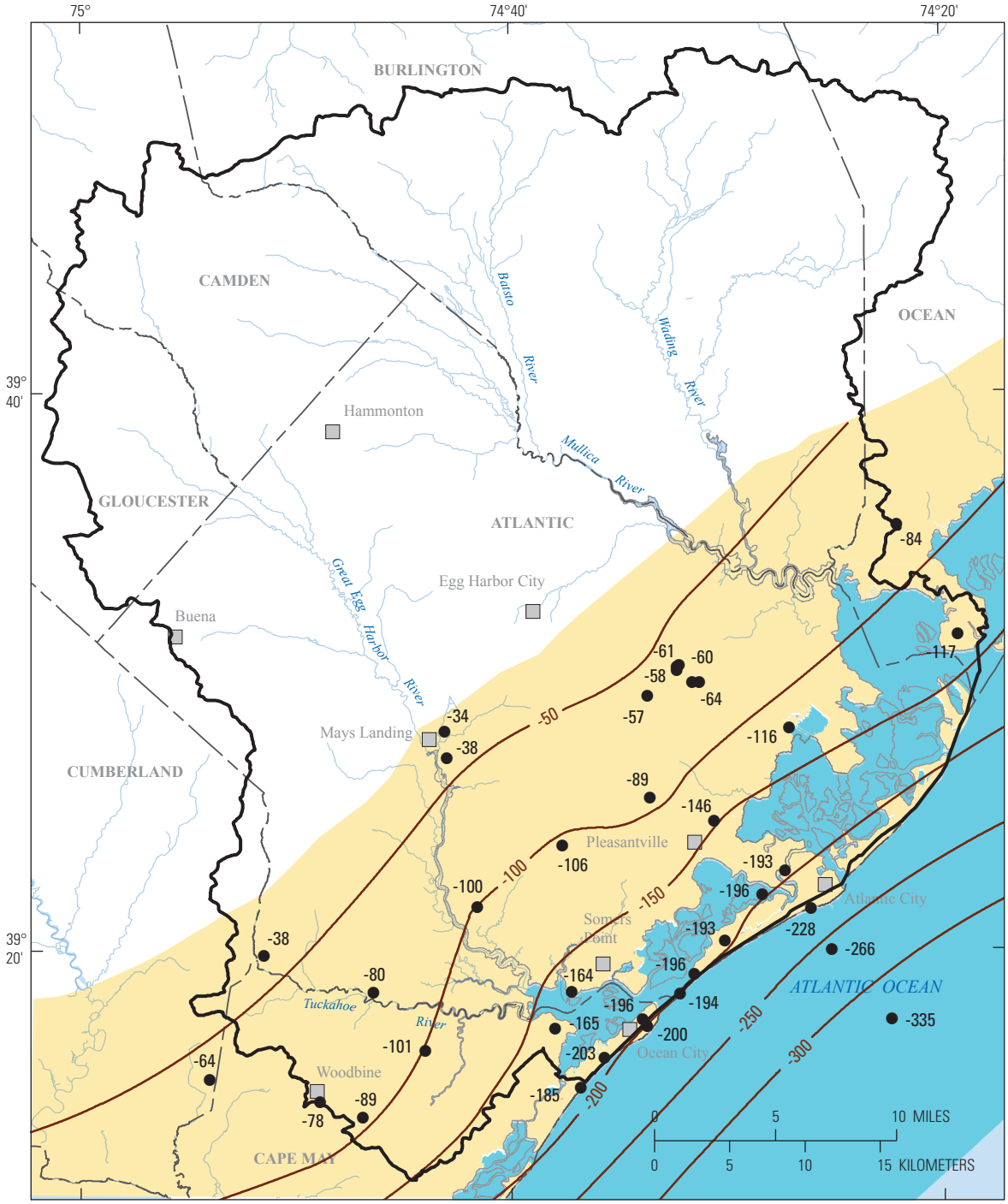
Beneath the ocean

Beneath land

—0— **STRUCTURE CONTOUR**—Shows altitude of top of the Kirkwood-Cohansey leaky confining unit, in feet. Datum is National Geodetic Vertical Datum of 1929. Interval is 50 feet

● 14 **WELL USED TO INTERPRET HYDROGEOLOGIC FRAMEWORK**—Number is altitude of top of the Kirkwood-Cohansey leaky confining unit, in feet. Datum is National Geodetic Vertical Datum of 1929

Figure 4. Structure contours of the top of the Kirkwood-Cohansey leaky confining unit, southeastern New Jersey.



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EXPLANATION

Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

EXTENT OF KIRKWOOD-COHANSEY LEAKY CONFINING UNIT

Beneath the ocean

Beneath land

–0– **STRUCTURE CONTOUR**—Shows altitude of bottom of the Kirkwood-Cohansey leaky confining unit, in feet. Datum is National Geodetic Vertical Datum of 1929. Interval is 50 feet

-34 **WELL USED TO INTERPRET HYDROGEOLOGIC FRAMEWORK**—Number is altitude of bottom of the Kirkwood-Cohansey leaky confining unit, in feet. Datum is National Geodetic Vertical Datum of 1929

Figure 5. Structure contours of the bottom of the Kirkwood-Cohansey leaky confining unit, southeastern New Jersey.

diatomaceous clay, the basal confining unit of the Kirkwood-Cohansey aquifer in the eastern part of the study area. A structure contour map of the bottom of the lower sand aquifer is shown in figure 6.

Confining Unit Overlying the Atlantic City 800-Foot Sand

The basal confining unit of the Kirkwood-Cohansey aquifer system over much of the southeastern part of the study area is the thick diatomaceous clay (fig. 2) that forms an extensive confining unit in the upper part of the Kirkwood Formation (Zapecza, 1989). The approximate updip extent of this confining unit (fig. 7) is present only in subcrop, and available data indicate either an abrupt change from sand to clay or a truncation of the clay (Zapecza, 1989). From the approximate updip edge, the diatomaceous clay thickens to as much as 350 ft in the vicinity of Atlantic City (Zapecza, 1989, pl. 22), confining the lower sands of the Kirkwood Formation beneath it; the lower sands comprise the Rio Grande water-bearing zone and the Atlantic City 800-foot sand.

There is uncertainty about the updip extent and character of the confining unit overlying the Atlantic City 800-foot sand. This uncertainty has limited the understanding of the extent to which the Atlantic City 800-foot sand is connected vertically to the generally unconfined Kirkwood-Cohansey aquifer system, which appears to transition into a single Kirkwood-Cohansey aquifer beyond the updip limit of the clay. Although the diatomaceous clay thins toward the west, there is apparently little evidence indicating a gradual pinching out of the clay west of the updip extent approximated by Zapecza (1989, pl. 22). Reasonable assumptions by previous investigators indicate that the absence of this clay to the west may be a result of an abrupt erosional truncation or simply a lateral change in lithology. Mullikin (Lloyd Mullikin, New Jersey Department of Environmental Protection, written commun., 1989) interpreted electrical resistivity soundings in an effort to determine the depth of the confining unit overlying the Atlantic City 800-foot sand and concluded that the clay may extend farther updip than that approximated by Zapecza (1989). Sugarman (2001) also makes a similar assertion using the data compiled by Mullikin (Lloyd Mullikin, New Jersey Department of Environmental Protection, written commun., 1989). For the groundwater flow model, the framework was used as described by Mullikin, including a zone of vertical hydraulic conductivity in this area so that the confinement of the Kirkwood Formation sediments could be tested during model calibration. In the calibrated model, the Kirkwood Formation sediments are simulated as unconfined.

Rio Grande Water-Bearing Zone

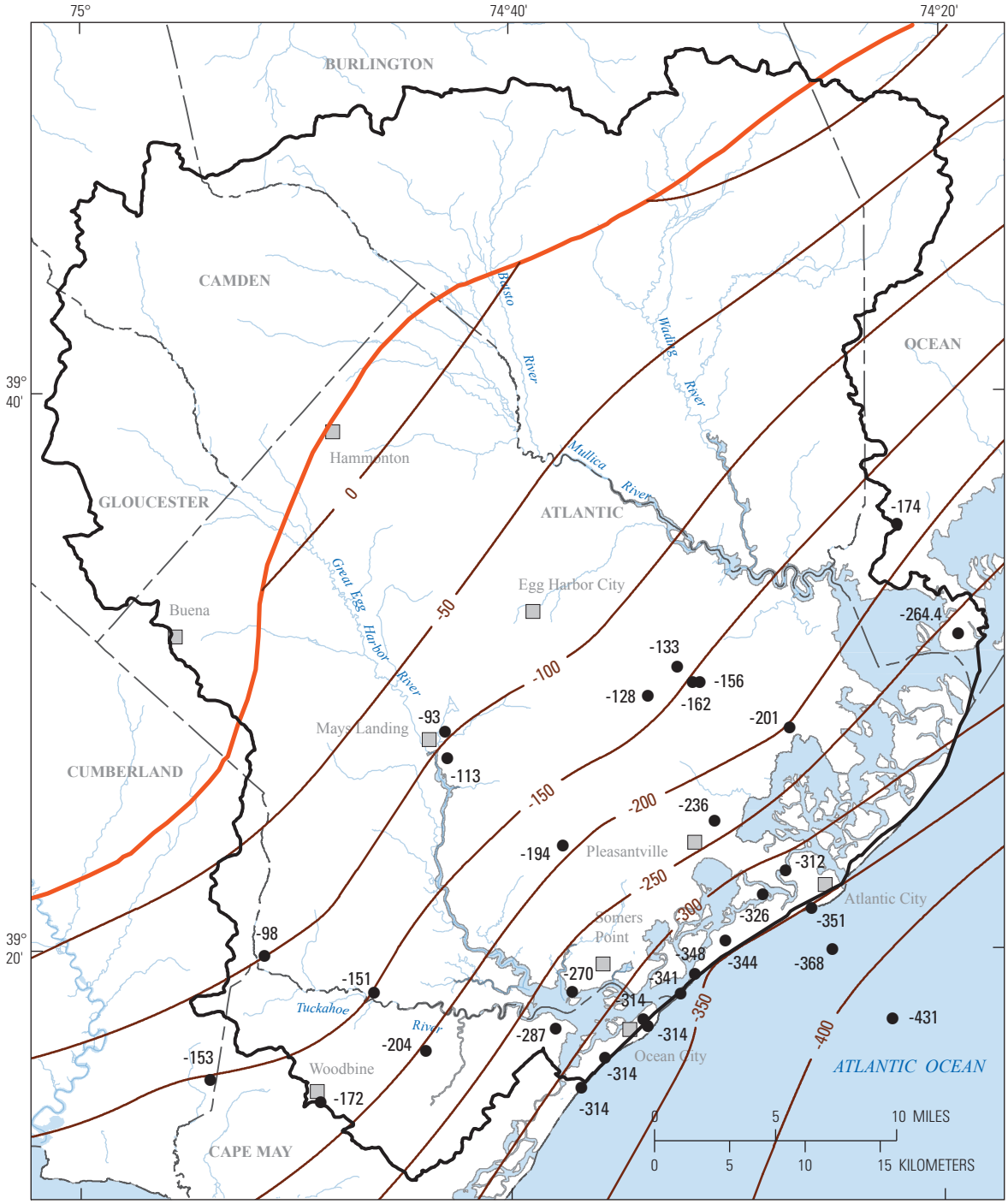
The Rio Grande water-bearing zone is a thin aquifer located within the confining unit that overlies the Atlantic City 800-foot sand (Zapecza, 1989, pl. 5). Zapecza (1989) describes the Rio Grande water-bearing zone but does not define its geometry. The Rio Grande water-bearing zone extends throughout the southeastern half of the study area. In general, the thickness increases in the downdip direction from northwest to southeast. The thickness ranges from 0 to almost 140 ft with most areas being less than 50 ft thick. The updip extent of the aquifer pinches out into the surrounding diatomaceous clay unit.

The framework of the Rio Grande water-bearing zone was developed using information from approximately 150 geologic and geophysical well logs. Many of the logs had been used in previous work conducted by Lacombe and Carlton (2002), Sugarman (2001), Mullikin (Lloyd Mullikin, New Jersey Department of Environmental Protection, written commun., 2006), and Zapecza (O.S. Zapecza, U.S. Geological Survey, written commun., 2006). For the purpose of this study, the log information was analyzed to differentiate where the Rio Grande water-bearing zone is present. The structure contours of the top and bottom of the Rio Grande water-bearing zone are shown in figures 7 and 8, respectively.

Atlantic City 800-Foot Sand

The Atlantic City 800-foot sand is the principal water-supply aquifer in coastal Atlantic and Cape May Counties. In the study area, the aquifer has been subdivided into upper and lower sands separated by a thin confining unit. The basal clay is the thick composite confining unit, the top of which is the basal clay layer of the Kirkwood Formation. The aquifer is well defined in coastal areas because of the many water-supply and test wells drilled there. Maps showing the structure contours of the top and bottom of the Atlantic City 800-foot sand as described by Mullikin (Lloyd Mullikin, New Jersey Department of Environmental Protection, written commun., 2006) are shown in figures 9 and 10, respectively.

The updip extent of the Atlantic City 800-foot sand is not well defined with regard to its hydraulic connection to the generally semi-confined or unconfined Kirkwood-Cohansey aquifer system. Sugarman (2001) indicates that sediments of the Atlantic City 800-foot sand and the Kirkwood-Cohansey aquifer system are difficult to differentiate where the diatomaceous clay confining unit is absent to the west. Zapecza (1989), however, describes the lithologic differences between sediments of the Atlantic City 800-foot sand beneath the clay (medium- to coarse-grained sand containing considerable shell material) and sediments of the generally unconfined parts of Kirkwood Formation (fine to medium sand) where it is unconfined, indicating a distinct sediment character in each area. Zapecza (1989) approximates the updip extent of the diatomaceous clay subcrop and the Atlantic City 800-foot sand based on lithology and confirms the approximate extent using water levels in the lower part of the Kirkwood Formation west of the limit of the confining bed where it is part of the largely unconfined Kirkwood-Cohansey aquifer system. Martin (1998) represents the lower sands of the Kirkwood Formation as laterally continuous with the lower sands of the Kirkwood-Cohansey



Base from U.S.Geological Survey digital line graph files, 1:24,000

EXPLANATION

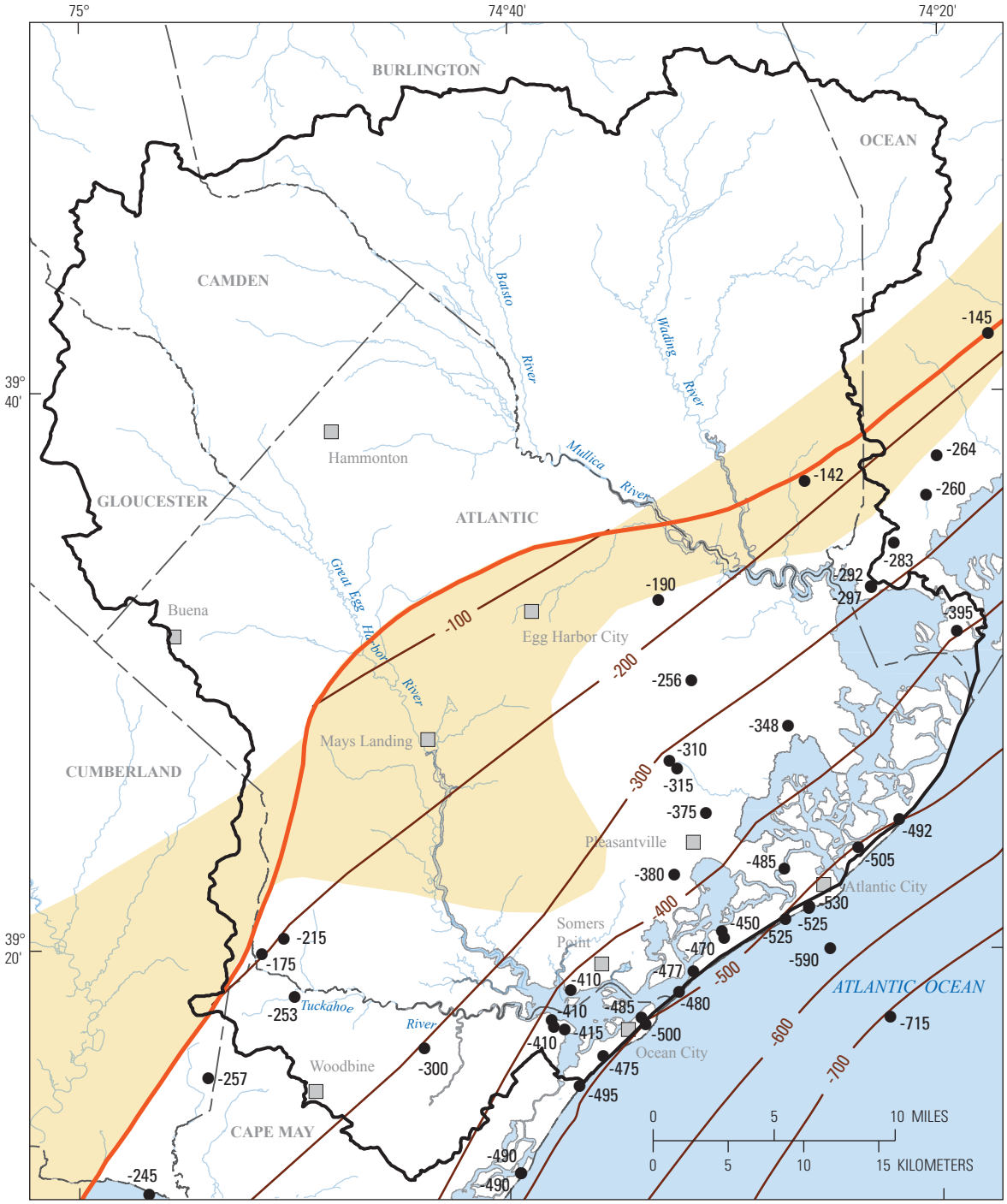
Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

Updip extent of the lower sand, Kirkwood-Cohansey aquifer system

–0– **STRUCTURE CONTOUR**—Shows altitude of bottom of the lower sand, Kirkwood-Cohansey aquifer, in feet. Datum is National Geodetic Vertical Datum of 1929. Interval is 50 feet

●-93 **WELL USED TO INTERPRET HYDROGEOLOGIC FRAMEWORK**—Number is altitude of bottom of the lower sand, Kirkwood-Cohansey aquifer, in feet. Datum is National Geodetic Vertical Datum of 1929

Figure 6. Structure contours of the bottom of the lower sand, Kirkwood-Cohansey aquifer system, southeastern New Jersey.



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EXPLANATION

Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

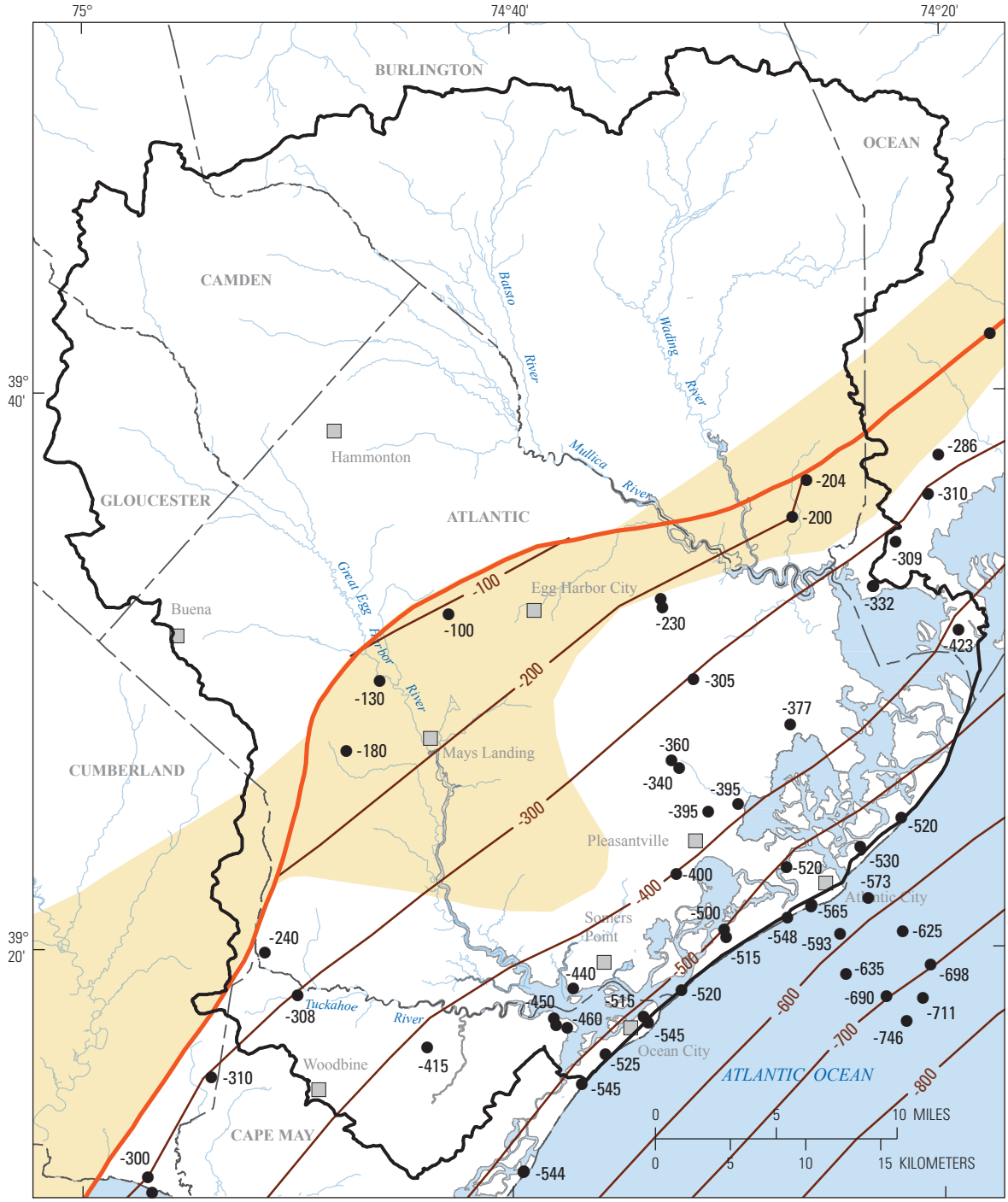
Area of transition between the Rio Grande water-bearing zone and the confining unit overlying the Atlantic City 800-foot sand

Updip extent of the Atlantic City 800-foot sand (From Zapecza, 1989)

-100 **STRUCTURE CONTOUR**—Shows altitude of top of the Rio Grande water-bearing zone, in feet. Datum is National Geodetic Vertical Datum of 1929. Interval is 100 feet

-215 **WELL USED TO INTERPRET HYDROGEOLOGIC FRAMEWORK**—Number is altitude of top of the Rio Grande water-bearing zone, in feet. Datum is National Geodetic Vertical Datum of 1929.

Figure 7. Structure contours of the top of the Rio Grande water-bearing zone, southeastern New Jersey.



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EXPLANATION

Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

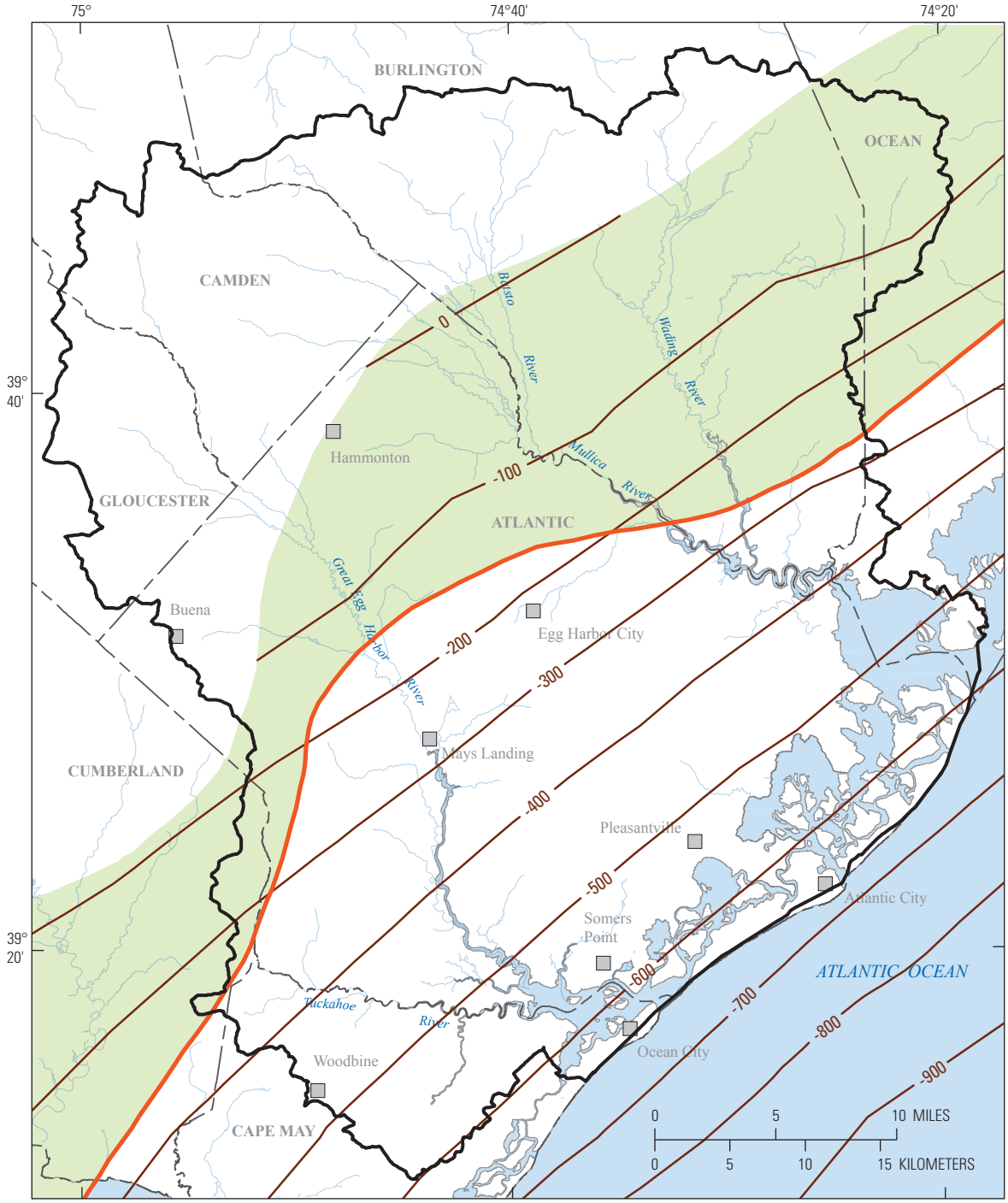
Area of transition between the Rio Grande water-bearing zone and the confining unit overlying the Atlantic City 800-foot sand

Updip extent of the Atlantic City 800-foot sand (From Zapecza, 1989)

-100 **STRUCTURE CONTOUR**—Shows altitude of bottom of the Rio Grande water-bearing zone, in feet. Datum is National Geodetic Vertical Datum of 1929. Interval is 100 feet

-286 **WELL USED TO INTERPRET HYDROGEOLOGIC FRAMEWORK**—Number is altitude of bottom of the Rio Grande water-bearing zone, in feet. Datum is National Geodetic Vertical Datum of 1929.

Figure 8. Structure contours of the bottom of the Rio Grande water-bearing zone, southeastern New Jersey.



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EXPLANATION

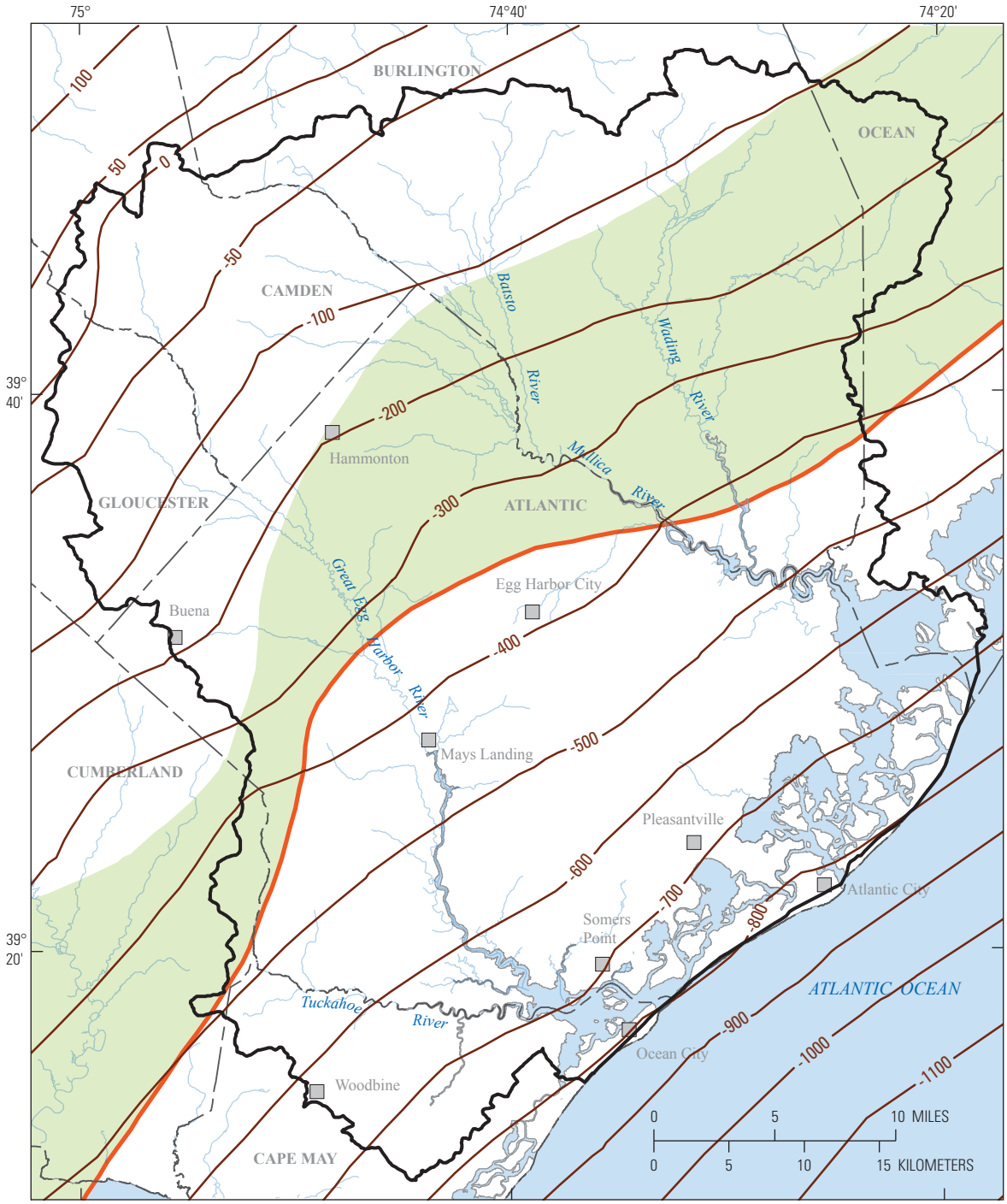
Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

Area of semi-confining zone for the confining unit overlying the Kirkwood Formation

Updip extent of the Atlantic City 800-foot sand (From Zapecza, 1989)

-100 **STRUCTURE CONTOUR**—Shows altitude of top of the Atlantic City 800-foot sand, in feet. Datum is National Geodetic Vertical Datum of 1929. Interval is 100 feet

Figure 9. Structure contours of the top of the Atlantic City 800-foot sand, southeastern New Jersey. (model layer 7)



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EXPLANATION

Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

Area of semi-confining zone for the confining unit overlying the Kirkwood Formation

Updip extent of the Atlantic City 800-foot sand (From Zapecza, 1989)

-100 **STRUCTURE CONTOUR**—Shows altitude of bottom of the Atlantic City 800-foot sand, in feet. Datum is National Geodetic Vertical Datum of 1929. Interval is 100 feet

Figure 10. Structure contours of the bottom of the Atlantic City 800-foot sand, southeastern New Jersey. (model layer 9)

aquifer system updip from the diatomaceous clay. It is reasonable to conclude that the sediment textures of the Atlantic City 800-foot sand may grade to permeable sediments west of the approximate extent of the diatomaceous clay subcrop (Zapecza, 1989), where the aquifer has been referred to as part of the unconfined Kirkwood-Cohansey aquifer. Because of the limited data in the transition area, the effectiveness of the lateral hydraulic connection between the Atlantic City 800-foot sand and the Kirkwood-Cohansey aquifer system near the approximate updip limit of the confining unit remains unknown.

For this study, the model framework includes a transition zone that effectively extends the confining unit overlying the Atlantic City 800-foot sand updip from the position approximated by Zapecza (1989), which bridges the gap of hydrogeologic uncertainty about the extent and character of this clay posed by the various investigators cited above. This transition zone is an area of lateral change in the lithology and vertical hydraulic conductivity, and it represents a transition from confining bed to aquifer. The lateral connection between the Atlantic City 800-foot sand and the Kirkwood-Cohansey aquifer system is represented as a zone of transition based on an assumed lateral hydraulic connection as represented by Martin (1998).

Hydrogeologic Properties

Data to characterize the hydraulic properties were obtained from the NJDEP hydroparameters database (New Jersey Department of Environmental Protection, 2002a) and from specific capacity data from public supply wells. Horizontal hydraulic conductivity data from 18 aquifer tests conducted in the area were used. Fourteen of these tests were conducted in the Kirkwood-Cohansey aquifer system, and four were conducted in the Atlantic City 800-foot sand. Hydraulic conductivity data for wells associated with these tests are shown in table 2.

Because aquifer test data for the study are sparse, the hydraulic conductivity dataset was augmented with specific capacity data from well-acceptance tests conducted on large-capacity wells. Specific capacity is a measure of the productivity of a well and is calculated as the pumping rate divided by the resulting drawdown after the well is pumped at the same rate for some period of time (Freeze and Cherry, 1979). Reported specific-capacity data and ancillary information (well diameter, pumping rate and duration, drawdown, and screen length) for wells in the study area were retrieved from the USGS National Water Information System (NWIS) database to estimate hydraulic conductivity. The transmissivity was estimated using the Theis equation, as described in Heath (1983). An estimate of storage coefficient is needed to apply the Theis equation. For the unconfined Kirkwood-Cohansey aquifer system, the storage coefficient is approximately equal to specific yield and a value of 0.15 was assumed. This value is consistent with the range of specific yield values for unconfined aquifers presented by Freeze and Cherry (1979) and with that for the Kirkwood-Cohansey aquifer system presented by Rhodehamel (1973). Heath (1983) indicates that the transmissivity estimated from specific capacity be applied to the screened interval of the aquifer. Horizontal hydraulic conductivity is calculated for the screened interval of the wells by dividing the calculated transmissivity by the length of the screened interval. In order to obtain estimates that are most representative of the aquifer near the well screen (and less influenced by well construction), estimates were made for about 250 wells that were pumped at a rate of at least 200 gallons per minute (gal/min) for at least 4 hours. Horizontal hydraulic conductivities estimated using specific-capacity data are listed in table 3 (at end of report).

The distribution of horizontal hydraulic conductivity values in the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand are shown in figure 11. For sites in close proximity, estimates of hydraulic conductivity determined using well-acceptance specific-capacity data and estimates derived from aquifer test results are generally comparable for the Kirkwood-Cohansey aquifer system. Therefore, it is reasonable to use the well-acceptance test estimates where aquifer test data are not available, thus allowing for a much larger set of wells and a better spatial distribution of horizontal hydraulic conductivity.

Water-Use Data

Water use varies from year to year because of population changes, the resulting increased demand, and variable climatic conditions. Water use also varies seasonally because public supply withdrawals and especially irrigation withdrawals are greater during the summer months. The population growth in the study area, especially just outside the Pinelands Management Area has put increased demand on the aquifers supplying the withdrawals.

Groundwater withdrawals reported by permitted users to the NJDEP provide information that allows the NJDEP to manage the State's water resources effectively. Withdrawals are reported quarterly by permitted high-volume public supply and industrial water users. Withdrawals are reported annually by agricultural and low-volume users. The USGS verifies the data following routine quality-assurance checks, including comparison of reported annual and monthly withdrawals with the withdrawals permitted by the NJDEP for each permit and comparison of annual withdrawals with yearly average withdrawals for each well. Additional quality-assurance procedures for the agricultural withdrawal data were used for this study because of the large volumes of agricultural withdrawals within the study area. Paper copies of the agricultural data were collected from NJDEP and checked against the electronic data for the period 1998 to 2005. Withdrawal data that were missing, and for which copies of original paper submissions were unavailable, were estimated. The estimated value was the withdrawal value reported for the most recent preceding year.

Table 2. Horizontal hydraulic conductivity from aquifer tests in the New Jersey Department of Environmental Protection Hydroparameters database for southeastern New Jersey.

[Aquifer: 121CKKD, Kirkwood-Cohansey aquifer system; 122KRKDL, Atlantic City 800-foot sand; ft/d, feet per day; gal/min, gallons per minute; NJDEP, New Jersey Department of Environmental Protection; --, no data]

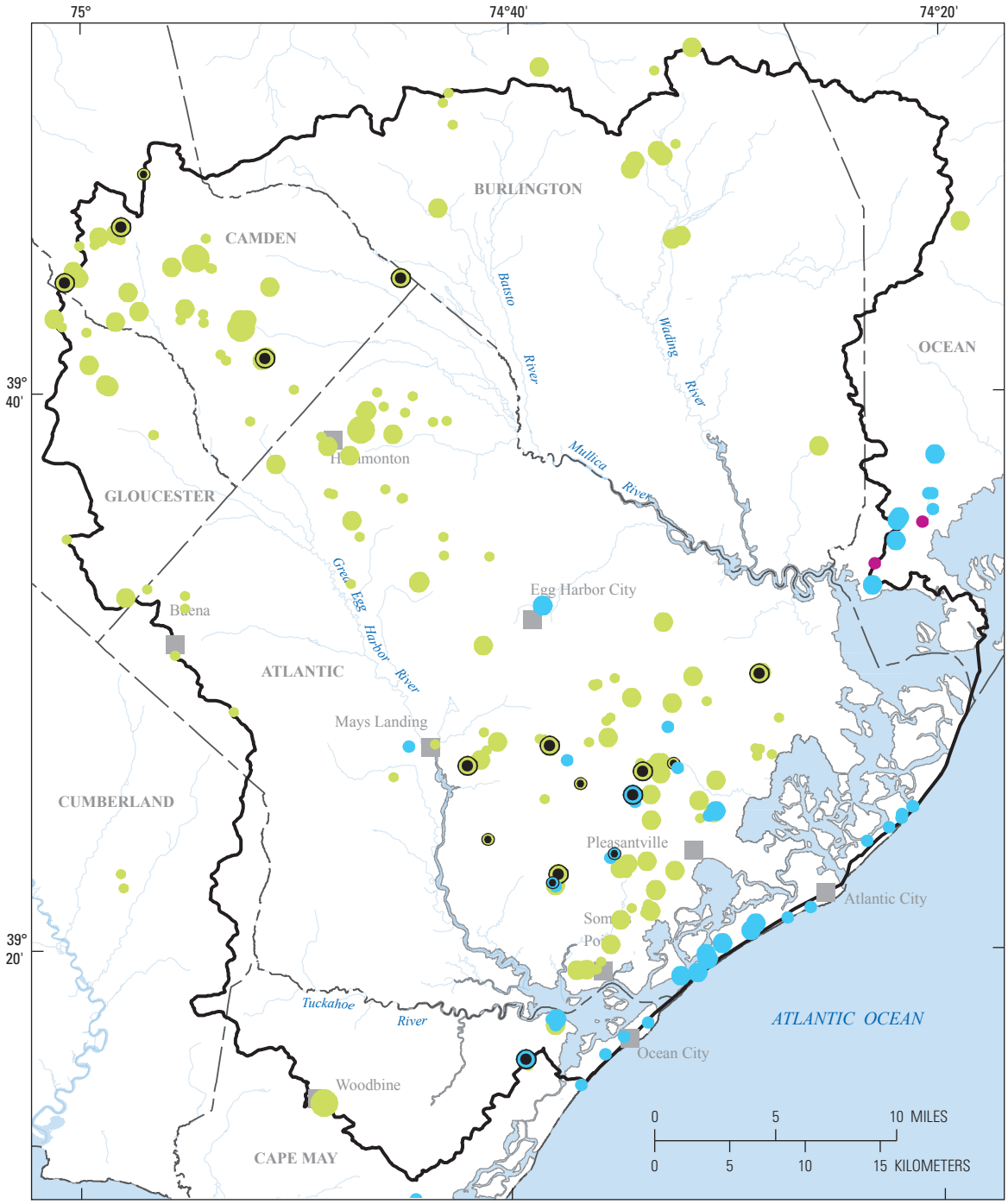
U.S. Geological Survey well number	NJDEP well permit number	Aquifer	Well depth (feet below land surface)	Test date	Pumping rate (gal/min)	Test length, hours	Hydraulic conductivity (ft/d)
010156	--	121CKKD	56	01/16/1990	400	73	52
010220	--	121CKKD	169	10/18/1993	1,024	76	110
010689	3600013216	121CKKD	180	05/04/1990	680	119	191
010696	--	121CKKD	180	02/21/1984	0	72	50
010958	--	121CKKD	180	05/21/1990	1,808	72	190
011301	3600015053	121CKKD	102	01/20/1992	135	72	216
011448	3600022614	121CKKD	144	03/24/1999	307	72	196
011519	3600024082	121CKKD	170	07/26/2000	412	73	38
070671	--	121CKKD	144	07/02/1974	503	8	107
070829	3100037164	121CKKD	72	09/27/1991	324	72	118
070901	3100043595	121CKKD	150	07/24/1994	1,120	72	160
070905	3100032361	121CKKD	100	01/29/1990	925	26	198
070936	--	121CKKD	85	06/20/1994	425	72	75
090381	3600012777	121CKKD	98	--	170	72	160
010990	3600016110	122KRKDL	657	10/27/1992	1,150	70	64
010991	3600016201	122KRKDL	647	11/17/1992	1,295	72	122
011974	3600024432	122KRKDL	665	01/26/2001	1,400	72	57
090481	--	122KRKDL	743	10/05/1993	1,400	72	107

Withdrawal data for the Kirkwood-Cohansey aquifer system, the Atlantic City 800-foot sand, and the Rio Grande water-bearing zone in the study area are used as input for simulating pumping stress in the groundwater flow model. The average withdrawals by aquifer for 1998 to 2005 and total withdrawals by aquifer for 2005 are shown in table 4. Withdrawals from the Kirkwood-Cohansey aquifer system are about twice those from the deeper Atlantic City 800-foot sand. Withdrawals from the Rio Grande water-bearing zone are relatively minor. Groundwater withdrawals from each aquifer for 1998 to 2005 are shown in figure 12. The withdrawals from the Atlantic City 800-foot sand were fairly constant over the study period. Withdrawals from the Kirkwood Cohansey aquifer system were more variable. The greatest withdrawals were made in 2001; most of the withdrawals came from the Kirkwood-Cohansey aquifer system. The least withdrawals were made in 2000, when withdrawals from the Kirkwood-Cohansey aquifer system were the lowest of the 8-year period.

The distribution of withdrawals, by use category, is shown in figure 13. Withdrawals, by aquifer, water-use category, and percentage, for 2005 only are listed in table 5. Groundwater withdrawals reported for the study area are primarily used for public supply and irrigation. Domestic use is not reported to the NJDEP, and domestic withdrawals in the study area tend to be from the shallow aquifers. Domestic use is primarily non-consumptive, so that most of the water is returned to the shallow aquifer. Withdrawals from the Kirkwood-Cohansey aquifer system in 2005 were used primarily for public supply with about 29 percent used for irrigation (table 5). In contrast, about 95 percent of the withdrawals from the Atlantic City 800-foot sand were used for public supply. Withdrawals from the Rio Grande water-bearing zone were

Table 4. Groundwater withdrawals from major aquifers in southeastern New Jersey, 2005 and 1998–2005.

Aquifer	Time period	
	Withdrawals (millions of gallons per year)	
	2005	Average (1998–2005)
Kirkwood-Cohansey aquifer system	15,767	14,742
Rio Grande water-bearing zone	65	71
Atlantic City 800-foot sand	7,597	7,200
Total	23,429	



Base from U.S.Geological Survey digital line graph files, 1:24,000

EXPLANATION

Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

AQUIFER TEST

- Kirkwood-Cohansey aquifer system
- Atlantic City 800-foot sand

HORIZONTAL HYDRAULIC CONDUCTIVITY, IN FEET PER DAY

- Less than 100
- 100 - 300

WELL-ACCEPTANCE TEST

- Kirkwood-Cohansey aquifer system
- Rio Grande water-bearing zone
- Atlantic City 800-foot sand

HORIZONTAL HYDRAULIC CONDUCTIVITY, IN FEET PER DAY

- Less than 100
- 100 - 299.99
- 300 - 999.99
- Greater than 1,000

Figure 11. Horizontal hydraulic conductivities at sites of aquifer-test wells and well-acceptance test wells in the area of the active model grid, Great Egg-Mullica model, southeastern New Jersey.

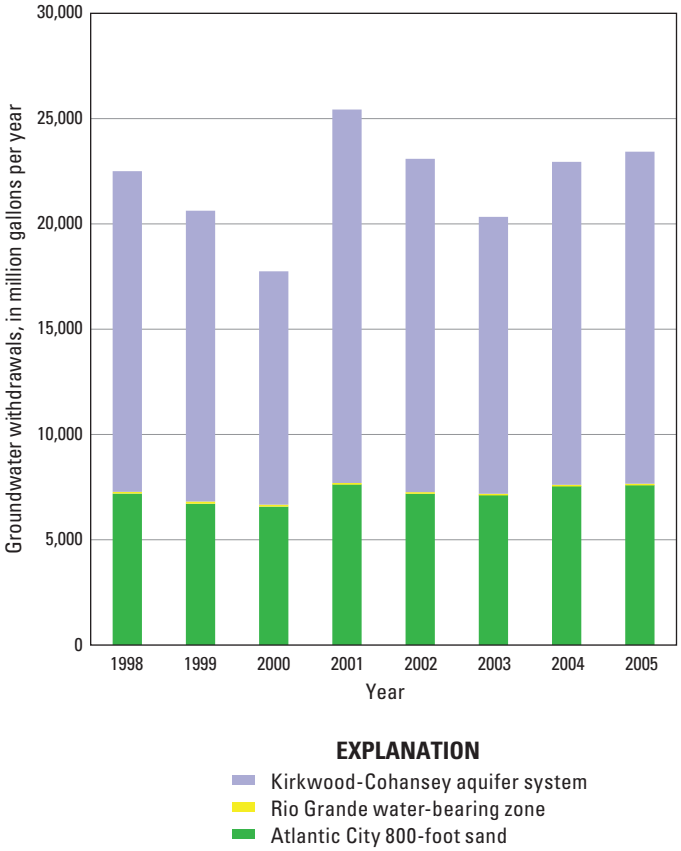


Figure 12. Groundwater withdrawals, by aquifer, in the Great Egg Harbor and Mullica River Basins, southeastern New Jersey, 1998–2005.

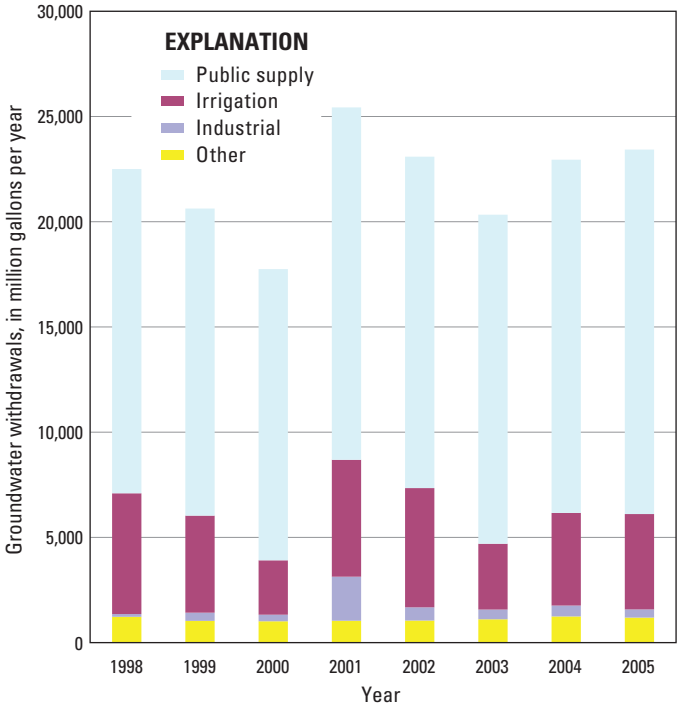


Figure 13. Groundwater withdrawals, by use category, in the Great Egg Harbor and Mullica River Basins, southeastern New Jersey, 1998–2005.

used exclusively for public supply. For the most part, the distribution of withdrawals by water-use category remained relatively stable from 1998 to 2005 (fig. 13). Withdrawals for public supply and other uses remained fairly constant.

The monthly average withdrawals for 1998 to 2005, as well as the monthly minimum and monthly maximum, are shown in figure 14. Seasonal variations in withdrawals in the study area are apparent. Withdrawals in the summer months (June through August) can be more than twice the withdrawals in the winter months (December through February). Also, the variability in withdrawals (difference between maximum and minimum withdrawals) is greater in the summer. The average monthly withdrawals for 1998 to 2005, by water-use category, are shown in figure 15. In the summer months, when usage is higher, more water is required for irrigation and for public supply.

Withdrawals from the Kirkwood-Cohansey aquifer system, by use category, for all of 2005, February 2005, and July 2005 are shown in figure 16. For the entire year, most public-supply withdrawals occurred near Pleasantville and along the Camden-Gloucester County border in the northwestern part of the study area. Most of the irrigation withdrawals occurred in the northern half of the study area near Hammonton. Withdrawals for industrial and other uses occurred primarily in central Atlantic, and southeastern Camden, and Gloucester Counties. In February 2005, most of the large withdrawals were for public supply. The distribution of withdrawals for industrial and other uses in February 2005 is similar to that of annual 2005 withdrawals. Fewer wells were used for irrigation in February 2005 than annually in 2005. The usage pattern in July 2005 is similar to the pattern for the 2005 annual withdrawals.

Withdrawals from the Atlantic City 800-foot sand, by use category, for all of 2005, February 2005, and July 2005 are shown in figure 17. Withdrawals from the Atlantic City 800-foot sand, by season, did not vary as much as those

Table 5. Percentage of groundwater withdrawals from major aquifers, by use, in southeastern New Jersey, 2005.

[All values are in percent]

	Kirkwood-Cohansey aquifer system	Rio Grande water-bearing zone	Atlantic City 800-foot sand
Public Supply	64	100	95
Irrigation	29	0	0
Industrial	2	0	0
Other	5	0	5

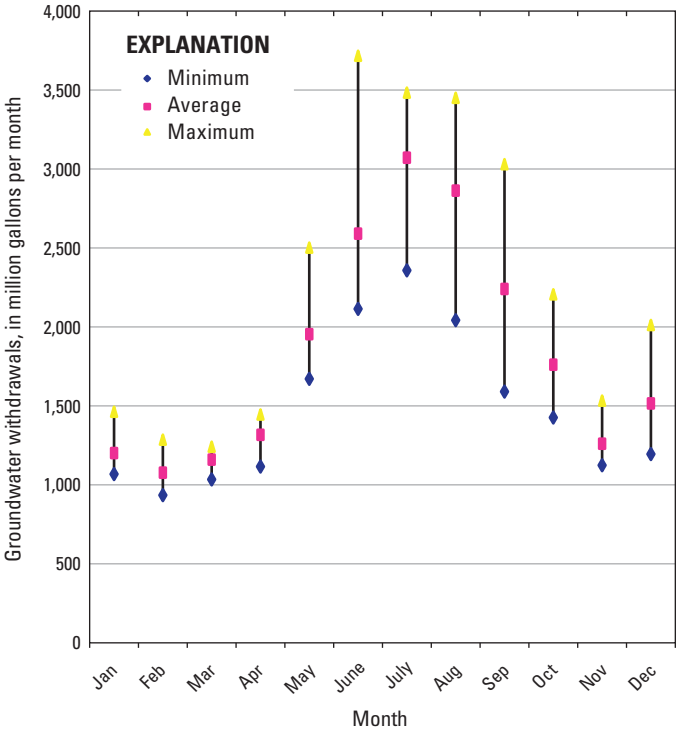


Figure 14. Average, minimum, and maximum monthly ground water withdrawals in the Great Egg Harbor and Mullica River Basins, southeastern New Jersey, 1998–2005.

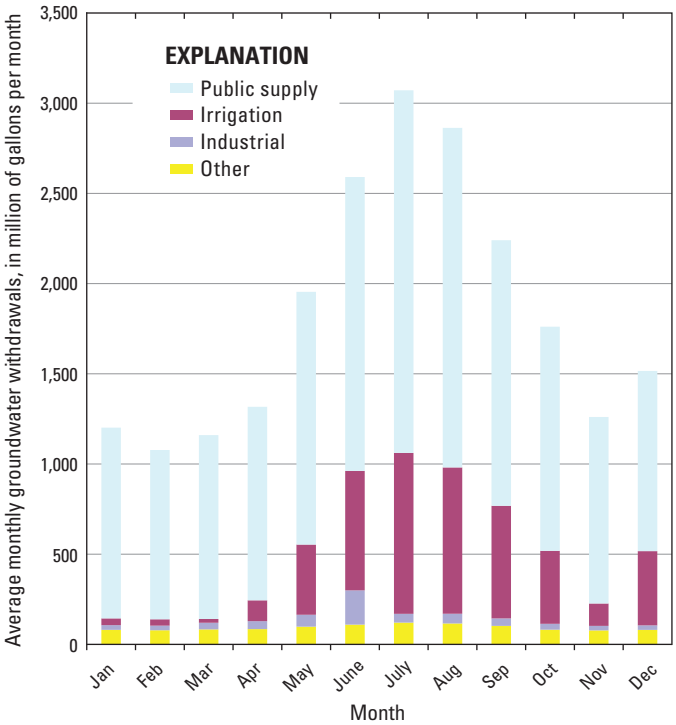


Figure 15. Average monthly groundwater withdrawals, by use category, in the Great Egg Harbor and Mullica River Basins, southeastern New Jersey, 1998–2005.

withdrawals from the Kirkwood-Cohansey aquifer system. Overall, withdrawal rates were lower during February than during the entire year, and some wells near Pleasantville, N.J., were not used during February.

Base Flow

Base flow is the groundwater contribution to the total flow of a stream. Monthly base-flow data are needed to calibrate the groundwater flow model. This is important because one of the main uses of the flow model will be to predict changes in base flow resulting from changes in groundwater withdrawals. Where possible, base-flow data from the six streamgaging stations within the study area were used for model calibration. However, to get a more complete distribution of base flow for calibration purposes (especially in downdip areas), base flow was estimated for 51 low-flow partial-record sites within the study area. Locations of the streamgaging stations and low-flow partial-record basins are shown in figure 18. These are sites where discrete measurements were made during low-flow conditions over a period of several years. These discrete data can then be used with data from nearby long-term streamgaging stations to estimate statistics for the low-flow stations. Monthly base flows for January 1992 to September 2006 were estimated for 12 streamgaging stations (6 within the study area and 6 nearby stations) with continuous records using the streamflow partioning program PART (Rutledge, 1998). Base-flow estimates for the streamgaging stations with continuous records of instantaneous streamflow were used to estimate low-flow statistics for 51 low-flow partial-record stations. The Maintenance of Variance Extension Type 1 (MOVE1) program was used to estimate the low-flow statistics at partial-record stations (Hirsch, 1982). Three or more streamgaging stations with similar hydrologic characteristics were used as index stations for each partial-record station. Watson and others (2005) describe how the low-flow partial-record correlations were done for a statewide analysis of common streamflow statistics. The index stations used in that analysis were those used for this study. The same analyses were used in this study as were used by Watson and others (2005) to estimate base flow at the partial-record stations. Daily mean flows at the index stations were correlated with instantaneous base-flow measurements at the partial-record stations to produce monthly estimated base flows at the partial-record stations. The correlations between flows at the index stations and the low-flow partial-record stations were used to estimate monthly base flows and direct runoff at the 51 low-flow sites. The correlation statistics used to estimate base flow are listed in table 6 (at end of report).

The base-flow values were used as model calibration targets for each subbasin. Average direct runoff for the study area was used to estimate recharge. Summary statistics for the streamgaging and low-flow partial-record stations are shown in table 7. The values for the streamgaging stations were determined from the long-term data and from the hydrograph

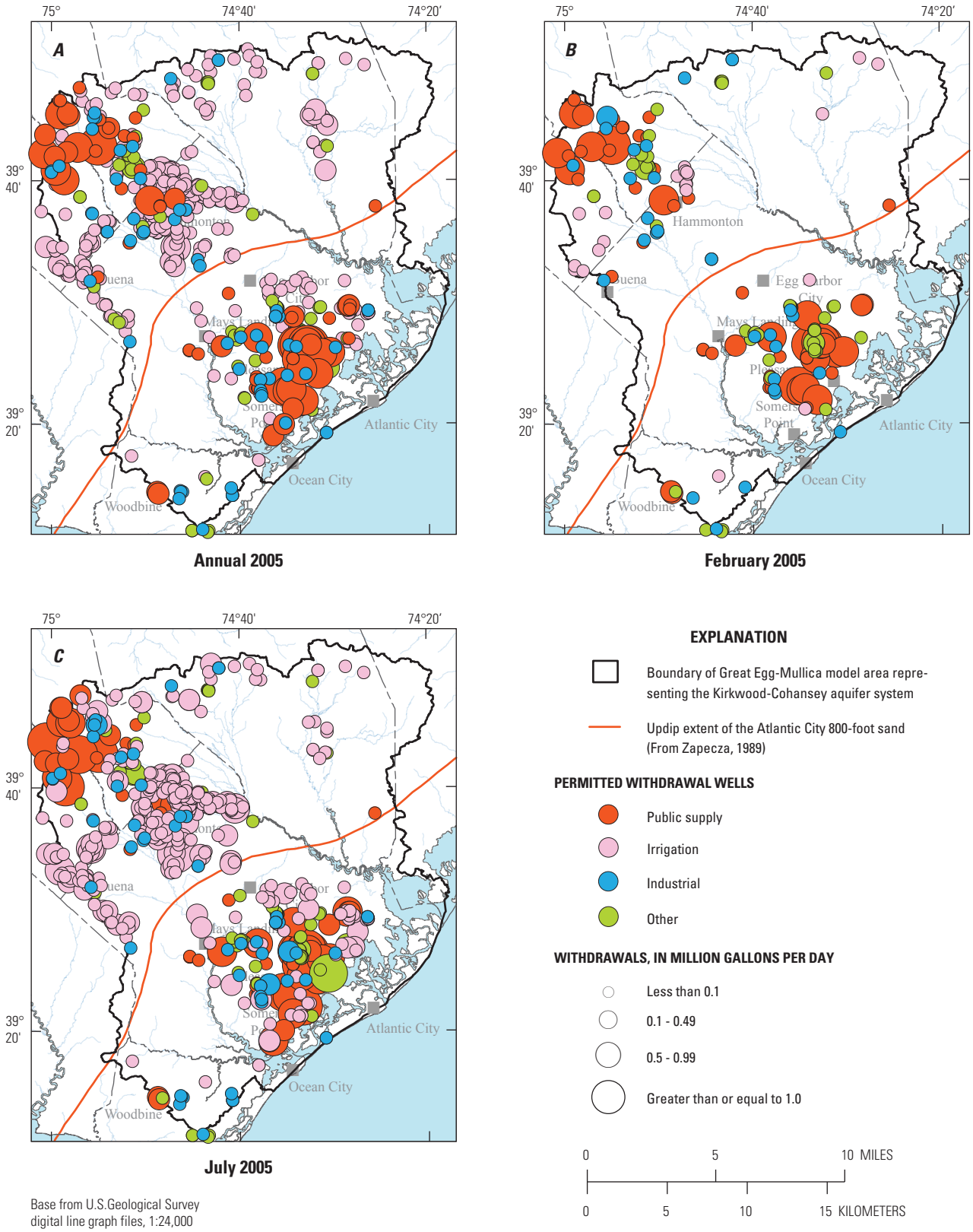


Figure 16. Groundwater withdrawals from the Kirkwood-Cohansey aquifer system, southeastern New Jersey: A, annual 2005, B, February 2005, and C, July 2005.

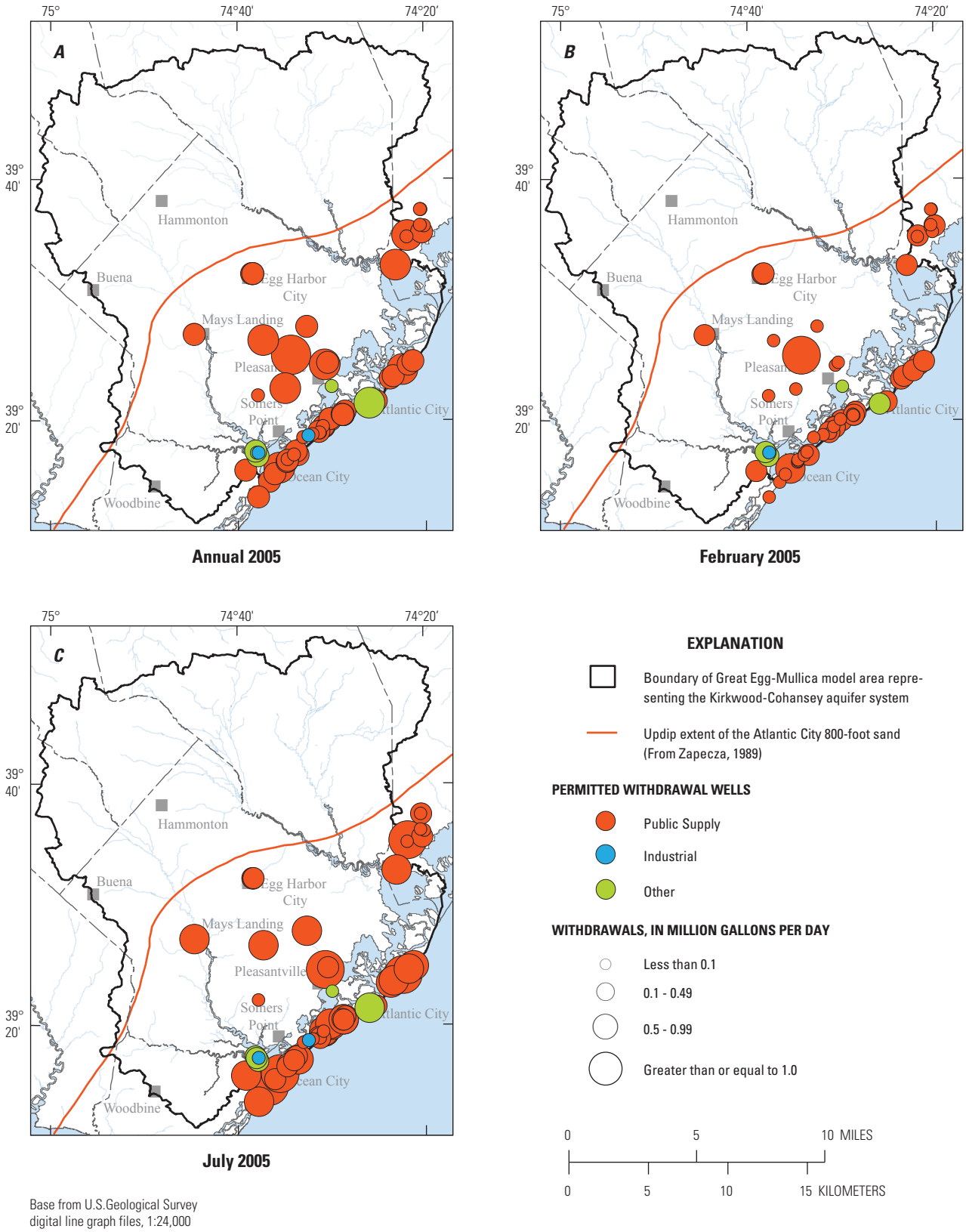


Figure 17. Groundwater withdrawals from the Atlantic City 800-foot sand, southeastern New Jersey: A, annual 2005, B, February 2005, and C, July 2005.

Base from U.S.Geological Survey digital line graph files, 1:24,000

EXPLANATION

- Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system
- Wetlands
- 01411000 — Streamgaging station used in model calibration. Number is station number of the surface-water site at the downstream end of the basin
- 01411170 — Low-flow partial-record station used in model calibration. Number is station number
- Updip extent of the Atlantic City 800-foot sand (From Zapecza, 1989)

Figure 18. Subbasins of streamgaging and low-flow partial-record stations used in model calibration, southeastern New Jersey.

Table 7. Statistics for streamgaging and low-flow partial-record stations, southeastern New Jersey.

[Type: G, gaging station; LF, low-flow partial-record station, percentage of base flow is caluclated using 1998–2006 mean annual streamflow (not shown) and 1998–2006 base flow; 7Q10, 7-day-10 year flow; ft^3/s, cubic feet per second]

Station number	Station name	Drainage area, square miles	Type	Mean annual stream-flow (ft^3/s)	7Q10 stream-flow (ft^3/s)	1998–2006 base flow (ft^3/s)	Base flow, percent of stream-flow	Mean annual streamflow per square mile (ft^3/s)
01408500	Toms River near Toms River	123	G	216	66	174	84	1.8
01409400	Mullica River near Batsto	46.7	G	105	15	88	87	2.2
01409500	Batsto River at Batsto	67.8	G	122	40	96	90	1.8
01409810	West Branch Wading River near Jenkins	84.1	G	140	26	113	79	1.7
01410000	Oswego River at Harrisville	72.5	G	86	21	65	84	1.2
01410150	East Branch Bass River near New Gretna	8.11	G	17	6.4	15	88	2.1
01411000	Great Egg Harbor River at Folsom	57.1	G	85	22	72	89	1.5
01411300	Tuckahoe River at Head of River	30.8	G	43	7.2	32	84	1.4
01411500	Maurice River at Norma	112	G	163	38	142	92	1.5
01409375	Mullica River near Atco	3.22	LF	3.7	0.1	2.2	73	1.1
01409387	Mullica River at outlet of Atsion Lk at Atsion	26.7	LF	45	7	33	82	1.7
01409390	Mullica R at Atsion	33.1	LF	55	8.2	43	86	1.7
01409395	Mullica R tr near Atsion	4.1	LF	18	1	13	81	4.4
01409401	Hays Mill Creek at Atco	3.8	LF	3.1	0.8	2.6	90	0.8
01409403	Wildcat Branch at Chesilhurst	1.03	LF	26	6.8	21	88	25.2
01409404	Sleeper Branch at US Route 206 near Atsion	18.2	LF	7.8	0.3	3.4	62	0.4
01409405	Clark B at US Rt 206 near Atsion	7.12	LF	25	5.7	20	87	3.5
01409406	Sleeper Branch at Batsto	36.2	LF	9	0.8	6.5	82	0.2
01409407	Pump B near Blue Anchor	6.2	LF	2.1	0.3	1.6	84	0.3
01409408	Pump Branch near Waterford Works	9.78	LF	12	4.1	10	91	1.2
01409409	Blue Anchor Brook near Blue Anchor	3.01	LF	23	7.3	20	91	7.6
01409410	Albertson Brook near Hammonton	19.3	LF	23	7.2	19	90	1.2
01409411	Nescochague Creek at Pleasant Mills	43.7	LF	68	15	55	87	1.6
01409416	Hammonton Creek at Wescoatville	9.57	LF	16	3.1	13	87	1.7
01409450	Springers Brook near Indian Mills	12.6	LF	15	1.5	8.9	81	1.2
01409460	Springers Brook near Atsion	21.2	LF	27	1	17	77	1.3
01409500	Batsto River at Batsto	67.8	LF	117	36	101	90	1.7
01409575	Landing C at Phila Ave at Egg Harbor City	4.86	LF	6.9	1.5	5.4	86	1.4
01409730	West Branch Wading River near Chatsworth	44.8	LF	49	7.5	35	83	1.1
01409780	Tulpehocken Creek near Jenkins	21.8	LF	25	3.9	19	83	1.1
01409800	West Branch Wading River near Harrisville	83.9	LF	182	28	126	82	2.2
01409815	West Branch Wading River at Maxwell	85.9	LF	130	30	103	88	1.5
01409970	Oswego River at Oswego Lake	61.4	LF	54	13	42	86	0.9
01410200	West Branch Bass River near New Gretna	6.54	LF	14	3.8	11	92	2.1
01410215	Clarks Mill Stream at Port Republic	8.61	LF	12	3	9.9	90	1.4
01410225	Morses Mill Stream at Port Republic	8.25	LF	9.3	1.6	6.7	86	1.1
01410775	Great Egg Harbor River at Berlin	1.88	LF	0.8	0.1	0.7	87	0.4
01410784	Great Egg Harbor R near Sicklerville	15.1	LF	11	1.5	8.2	85	0.7
01410787	Great Egg Harbor R tr at Sicklerville	1.64	LF	0.2	0	0.1	50	0.1

Table 7. Statistics for streamgaging and low-flow partial-record stations, southeastern New Jersey.—Continued

[Type: G, gaging station; LF, low-flow partial-record station, percentage of base flow is caluclated using 1998–2006 mean annual streamflow (not shown) and 1998–2006 base flow; 7Q10, 7-day-10 year flow; ft³/s, cubic feet per second]

Station number	Station name	Drainage area, square miles	Type	Mean annual stream-flow (ft³/s)	7Q10 stream-flow (ft³/s)	1998–2006 base flow (ft³/s)	Base flow, percent of stream-flow	Mean annual streamflow per square mile (ft³/s)
01410800	Fourmile Branch near Williamstown	5.34	LF	3.2	0.6	2.7	90	0.6
01410803	Fourmile Branch at Winslow Crossing	6.22	LF	5.8	1.5	4.7	89	0.9
01410810	Fourmile Branch at New Brooklyn	7.74	LF	10	2.4	8.6	91	1.3
01410820	Great Egg Harbor River near Blue Anchor	37.3	LF	52	13	44	90	1.4
01410855	Squankum B ab Sewage Plant at Williamstown	1.5	LF	0.7	0.1	0.5	83	0.5
01410865	Squankum B at Malaga Rd near Williamstown	3.02	LF	1.9	0	1.3	76	0.6
01411020	Penny Pot Stream near Folsom	5.35	LF	5.4	0.4	3.2	78	1
01411035	Hospitality Branch at Blue Bell Road near Cecil	4.51	LF	4.2	0.4	3.2	86	0.9
01411040	Hospitality Branch near Cecil	8.3	LF	12	2.4	9.7	88	1.4
01411042	Whitehall Branch near Cecil	2.21	LF	2.8	0.2	2	83	1.3
01411047	Whitehall Branch below Victory Lakes near Cecil	4.6	LF	6	0.4	4.3	83	1.3
01411053	Hospitality Branch at Berryland	20	LF	33	5.3	27	87	1.6
01411110	Great Egg Harbor River at Weymouth	154	LF	225	56	191	90	1.5
01411140	Deep Run at Weymouth	20	LF	33	6.1	26	87	1.6
01411170	Great Egg Harbor R at Mays Landing	205	LF	419	48	305	84	2
01411196	Babcock Creek near Mays Landing	16.3	LF	15	3.1	12	86	0.9
01411200	Babcock Creek at Mays Landing	20	LF	23	2.5	17	81	1.2
01411220	South River near Belcoville	20.4	LF	32	6.1	25	86	1.6
01411250	English Creek near Scullville	3.8	LF	5.1	1.6	4.3	90	1.3
01411299	Tarkiln Brook near Head of River	7.4	LF	6.8	0.4	4.5	78	0.9
01411302	Mill Creek near Steelmantown	3.82	LF	4	0.1	2	67	1
01411305	Mill Branch near Northfield	7.47	LF	8.5	2.6	7.3	91	1.1

separation program. The values for the partial-record stations were estimated using low-flow correlation.

Recharge

Natural recharge consists of rainfall and snow melt that infiltrates the ground and replenishes water in the aquifer. The rate of recharge can fluctuate on a daily basis. Recharge was estimated on a monthly basis using the water-budget approach used for the Toms River Basin, located in the Coastal Plain north of the study area (Nicholson and Watt, 1997). This indirect approach for estimating recharge is a common method used to account for all water that reaches the land surface as precipitation. The following equation, adapted from Nicholson and Watt (1997), was used for this study:

$$R = P - Q_{dr} - ET - \Delta SM \quad , \qquad (1)$$

where

R is recharge, in inches;
P is precipitation, in inches;
Q_{dr} is direct runoff (determined through hydrograph-separation techniques), in inches;
ET is evapotranspiration (determined by the Thornthwaite method), in inches; and
ΔSM is change in soil-moisture storage, in inches.

When soil moisture is less than the maximum soil-moisture capacity, then a soil-moisture deficit occurs. Recharge will take place only when the deficit is alleviated. In the calculation of monthly recharge, the recharge rate could be underestimated when the sum of total monthly evapotranspiration and

the soil-moisture deficit exceeds total monthly precipitation, especially during summer months. To compensate for this situation, recharge must be estimated on a daily basis to account for separate storm events that could produce high rates of infiltration that exceed the sum of evapotranspiration and the soil-moisture deficit for that same period. For the transient simulations, daily recharge was calculated and totaled for each month from January 1998 through December 2006. An initial soil-moisture deficit of zero was assumed for January 1998, and an initial maximum daily soil-moisture deficit of 1.5 inches was assumed. However, during model calibration this value was reduced to 0.75 inch to produce a better match to base-flow estimates. Daily precipitation data from the Mays Landing, N.J., weather station were used with supplemental data from the Atlantic City Airport weather station when data from Mays Landing were not available. Daily evapotranspiration was interpolated from monthly estimated potential evapotranspiration determined by Watt and Johnson (1992) at Hammonton, N.J. The soil-moisture deficit for the entire study area was calculated using the daily potential evapotranspiration from Hammonton and the precipitation from Mays Landing with supplemental data from the Atlantic City Airport. The water-budget equation was modified to include the soil-moisture deficit as shown in the following equation:

$$R_m = [[\sum_{n=1}^{d(m)} P_{(m,n)} - ET_{(m,n)} - SMD_{(m,n-1)}] - Q_{dr(m)}] \quad , \qquad (2)$$

where

R_m is recharge for month m, in inches;
$d_{(m)}$ is number of days in month m;
$P_{(m,n)}$ is precipitation on day n in month m, in inches;
$ET_{(m,n)}$ is evapotranspiration on day n in month m, in inches;
$SMD_{(m,n-1)}$ is soil-moisture deficit from the day preceding day n in month m, in inches; and
$Q_{dr(m)}$ is direct runoff for month m, in inches.

The combined Great Egg Harbor and Mullica River Basins were divided into four areas to estimate direct runoff. The areas were determined by major stream drainage area, surface-water discharge station locations, and distribution of average annual direct runoff at streamgaging and low-flow partial-record sites. An average value of direct runoff was calculated for each area. For each area, monthly recharge was calculated from the monthly soil-moisture deficit and the average direct runoff. To determine a monthly recharge factor, the monthly recharge rates for the four areas were averaged. From this, an average recharge rate for 1998 to 2006 was calculated. This process allowed calculation of a monthly recharge factor (monthly rate/average monthly rate) that was used in the groundwater flow model to adjust recharge over time.

Groundwater Flow Model

The objective for the groundwater flow model was to represent the water levels and flow in the Kirkwood-Cohansey aquifer system, the Rio Grande water-bearing zone, and the Atlantic City 800-foot sand with sufficient accuracy and resolution to facilitate an analysis of the regional flow system. The model is calibrated to water-level and base-flow data for the period from 1998 to 2006. The model was used to predict probable hydrologic changes that result from changes in groundwater withdrawals under various conditions. Model results will be used to identify subbasins where base-flow depletion exceeds criteria that were defined during the study. Several approaches were used in a defined order to attempt to eliminate deficits in the subbasins. The model code used was the USGS modular model (MODFLOW-2000) by Harbaugh and others (2000).

The boundary of the model is shown in figures 1 and 19. The Kirkwood-Cohansey aquifer system was simulated within the drainage basins of the Great Egg Harbor River and the Mullica River so that base-flow and recharge data for the large basins could be used in model calibration. Also, because the Kirkwood-Cohansey aquifer system is connected to the Atlantic City 800-foot sand in updip parts of the basins, this area needed to be simulated to represent the flow between the Atlantic City 800-foot sand and the unconfined Kirkwood-Cohansey aquifer system updip. The confined aquifers were simulated over a larger area so that the boundary conditions were distant from the main area of interest. Boundary flows for the confined aquifers were obtained from a modified version of the New Jersey RASA model (Voronin, 2004).

Spatial Discretization and Layering

The finite-difference model grid limits and grid spacing are shown in figure 19. The areas with different grid spacing are shown in different colors. The model consists of 276 rows, 288 columns, and 9 layers. Grid-cell dimensions in the onshore part of the model are 880 x 880 or 880 x 1,100 ft. This discretization was used to adequately represent surface-water features in the model. Grid-cell dimensions are larger in offshore areas. Grid alignment and spacing were selected so that the model grid fits within the RASA model (Voronin, 2004) such that boundary conditions for the confined Atlantic City 800-foot sand could easily be imported. The specified-flux boundaries from the RASA model for the confined aquifers are also shown in figure 19. In addition, the map shows the model cells where streams, freshwater wetlands, and saltwater wetlands are represented as boundaries.

The model vertical discretization uses nine layers. The model layers are shown in the generalized section in figure 2. In the updip part of the model, all nine layers are used to represent the Kirkwood-Cohansey aquifer system. Layer 1 was assigned a thickness of 50 ft. The estimated top of the Kirkwood-Cohansey aquifer system was used to represent

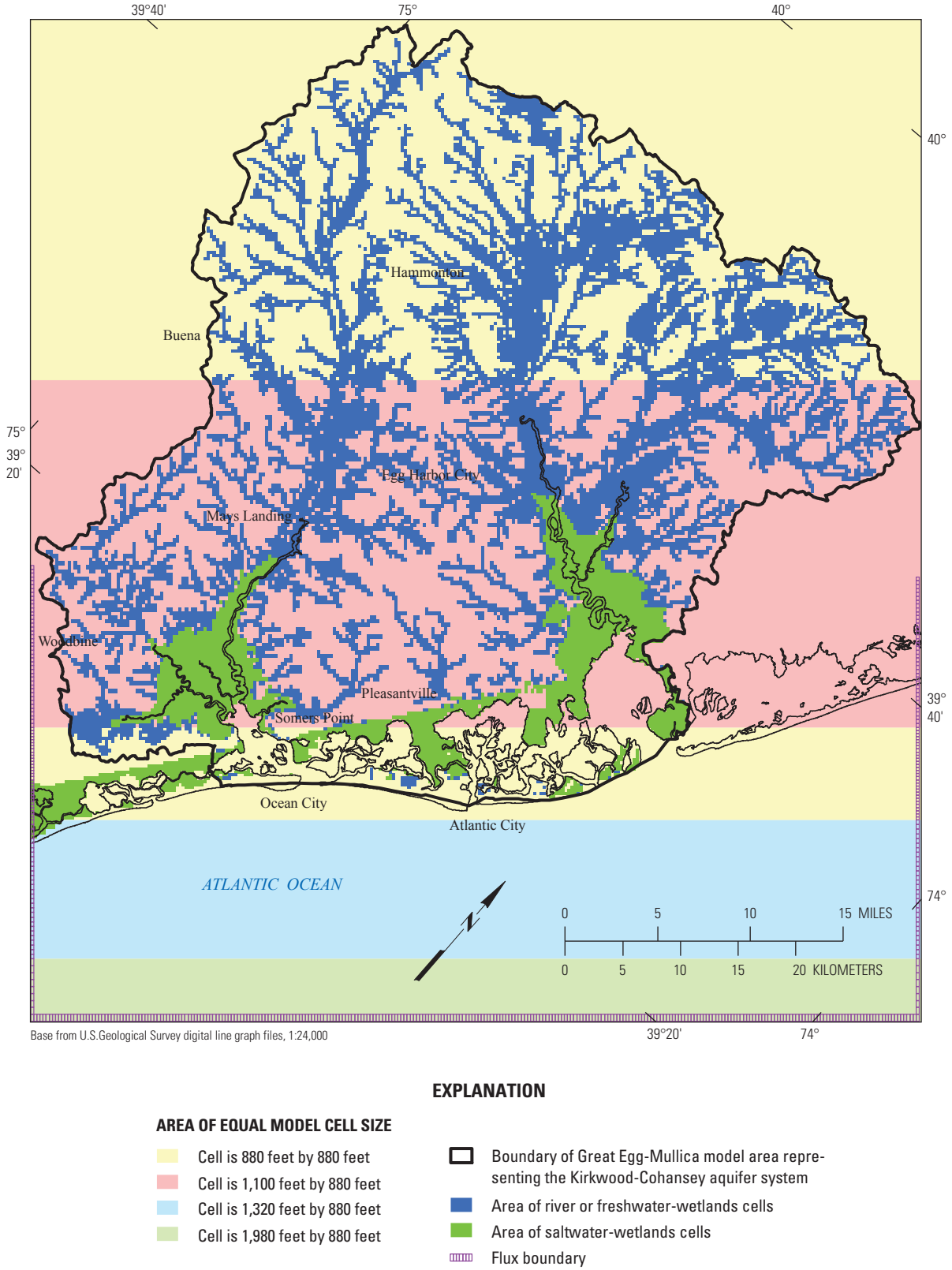


Figure 19. Areas of equal cell size in the model grid, specified-flux lateral model-boundary cells, and river and wetlands cells of the Great Egg-Mullica model, southeastern New Jersey.

the top of layer 7. In this updip area, layers 4 to 6 and layer 8 were arbitrarily assigned 1-foot thicknesses in the model. Layers 2 to 3, 7, and 9 were subdivided to create equal layer thicknesses for the model. Vertical hydraulic conductivities in this area are high; vertical flow in the area is not impeded, so the aquifer functions as a single unit. For the flow model, the altitudes of the top and bottom of layer 1 and the altitudes of the bottom of layers 2 through 9 were used as model input. MODFLOW-2000 calculates the thickness used in the flow model from these altitudes.

In downdip parts, the Kirkwood-Cohansey aquifer system, including the leaky confining unit within the system, was modeled using layers 1 to 3. In offshore areas and saltwater wetland areas, layer 1 is a constant-head boundary representing the Atlantic Ocean at sea level. The confining unit overlying the Atlantic City 800-foot sand, where present, is represented by layers 4 to 6. Where the Rio Grande water-bearing zone is present, it is represented by a variable thickness in model layer 5, based on the structural contours of the top and bottom of the layer, previously described. Finally, the Atlantic City 800-foot sand is represented by the downdip parts of layers 7 to 9. The confining unit within the Atlantic City 800-foot sand is represented by layer 8.

Temporal Discretization

The simulation period for model calibration was January 1998 through September 2006. A total of 130 monthly stress periods was used. The calibration period was represented in stress periods 26 through 130. Stress period 1 was simulated as steady state to represent average annual 1998 conditions as initial conditions for the model. Stress periods 2 to 25 were transient stress periods that repeated the 1998 cycle of monthly withdrawals two times. This process allows a transition period from the steady-state 1998 period (stress period 1) to the transient period used for model calibration in January 1998 (stress period 26). This strategy ensures that the conditions simulated at the beginning of the calibration period are realistic.

Hydrologic Boundaries

Hydrologic boundaries were used to represent the locations and quantity of flow into and out of the model. For the unconfined aquifer, these boundaries represent lateral and vertical flow, recharge, surface-water features, and groundwater withdrawals. For the confined aquifers, the boundaries represent lateral and vertical flow and groundwater withdrawals.

Recharge

The recharge boundary represented in the model varies spatially and temporally. The formulation of this variability is described below. The spatial distribution of average annual recharge was obtained from the New Jersey Geological Survey recharge map. The methodology used to estimate recharge for this map is documented in Charles and others (1993) and was later made available in a geographic information system dataset (New Jersey Department of Environmental Protection, 2002b). A map of the average-annual recharge distribution for the study area is shown in figure 20. Average-annual recharge was 10 to 15 inches per year over much of the study area. Less recharge (0–10 inches per year) occurred near streams or wetlands. The greatest average-annual recharge rates (15–20 inches per year) occurred in upland areas in the northeastern part of the study area. The recharge in the model was assigned to variable-head cells in the top layer of the model, which represents the shallowest part of the Kirkwood Cohansey aquifer system.

Monthly recharge was estimated using a soil-water balance, as described in an earlier section of this report. An average monthly recharge rate for the study area was calculated from the monthly recharge for the period 1998 to 2006. A monthly recharge factor was calculated using the monthly recharge rate for each month during this period divided by the average monthly recharge rate for the simulation period. The factor was applied to each model stress period using time-varying parameters (instances) in the recharge package. Changes to the overall recharge rate were handled by creating the four areal zones shown in figure 20 and three zones (not shown), representing stream features or wetland areas.

The resultant total recharge distribution for the years 2001 and 2005 is shown in figure 21. Recharge distribution was calculated by summing the monthly recharge rates for each of the 2 years. Dry conditions in 2001 resulted in recharge of about 10 to 15 inches per year throughout much of the study area. Wetter conditions in 2005 resulted in large areas with recharge rates ranging from 20 to 25 inches per year. Recharge was specified in the model using the Recharge package (RCH) of MODFLOW-2000.

Artificial recharge to the Kirkwood-Cohansey aquifer system from land-application recharge basins of wastewater-treatment plants was also simulated. Two wastewater-treatment plants within the study area apply wastewater to the land surface. One wastewater-treatment plant is in Hammonton, and the other is in Winslow Township. Data on monthly discharges from the treatment plants into the recharge basins were used. The discharges were simulated in the model using the Well package (WEL), and the recharge from the basins was applied to model layer 1. All of the recharge water was assumed to enter the groundwater system; evapotranspiration from the recharge basins was assumed to be negligible.

Surface-Water Features

Surface-water features simulated in the model are freshwater wetlands, rivers, streams, lakes, ponds, saltwater wetlands, the ocean, and bays. These features are represented as boundaries using either the River package (RIV) or the Drain package (DRN), or as Constant Head cells (for saltwater wetlands or ocean cells). The USGS National Hydrography

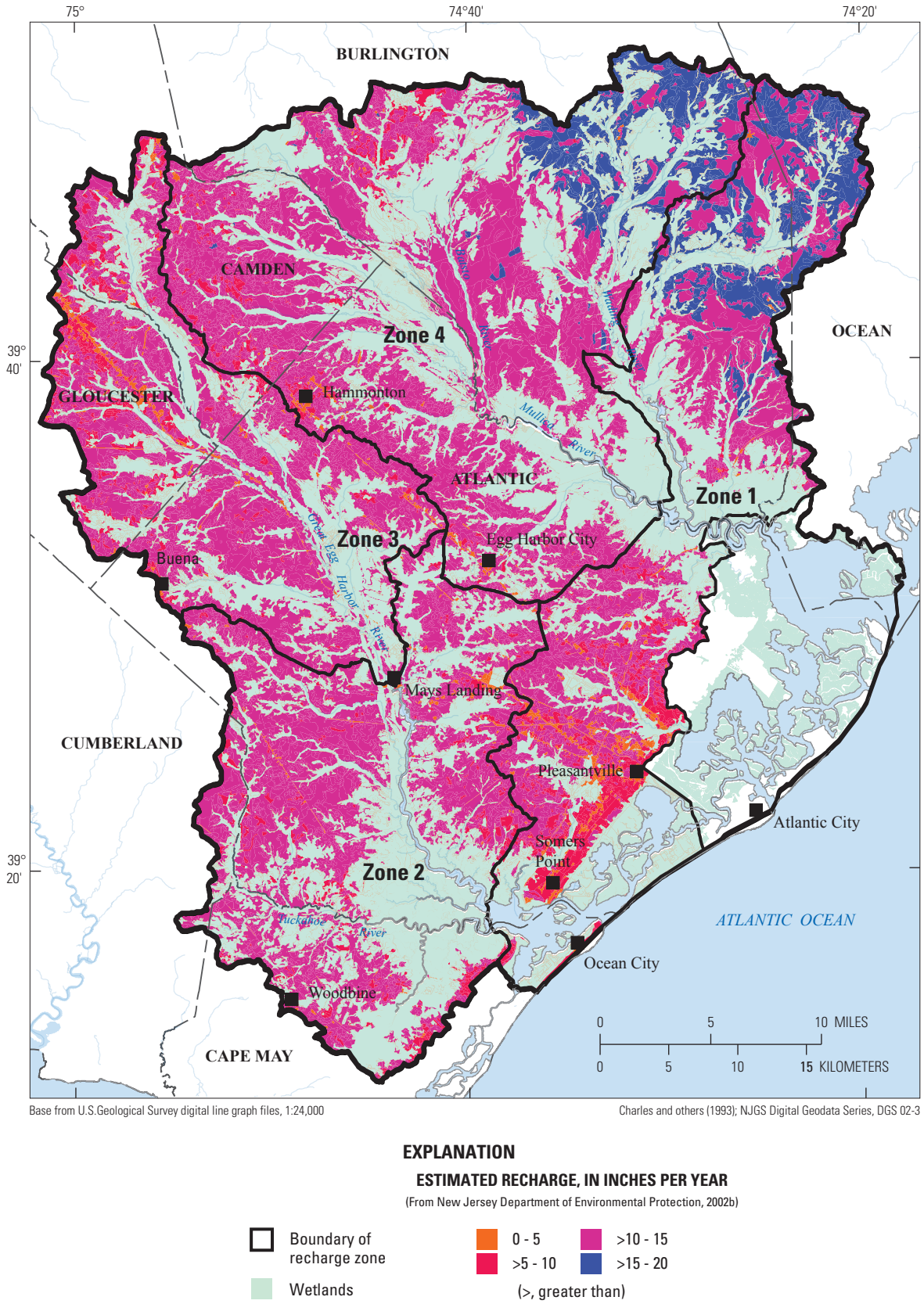
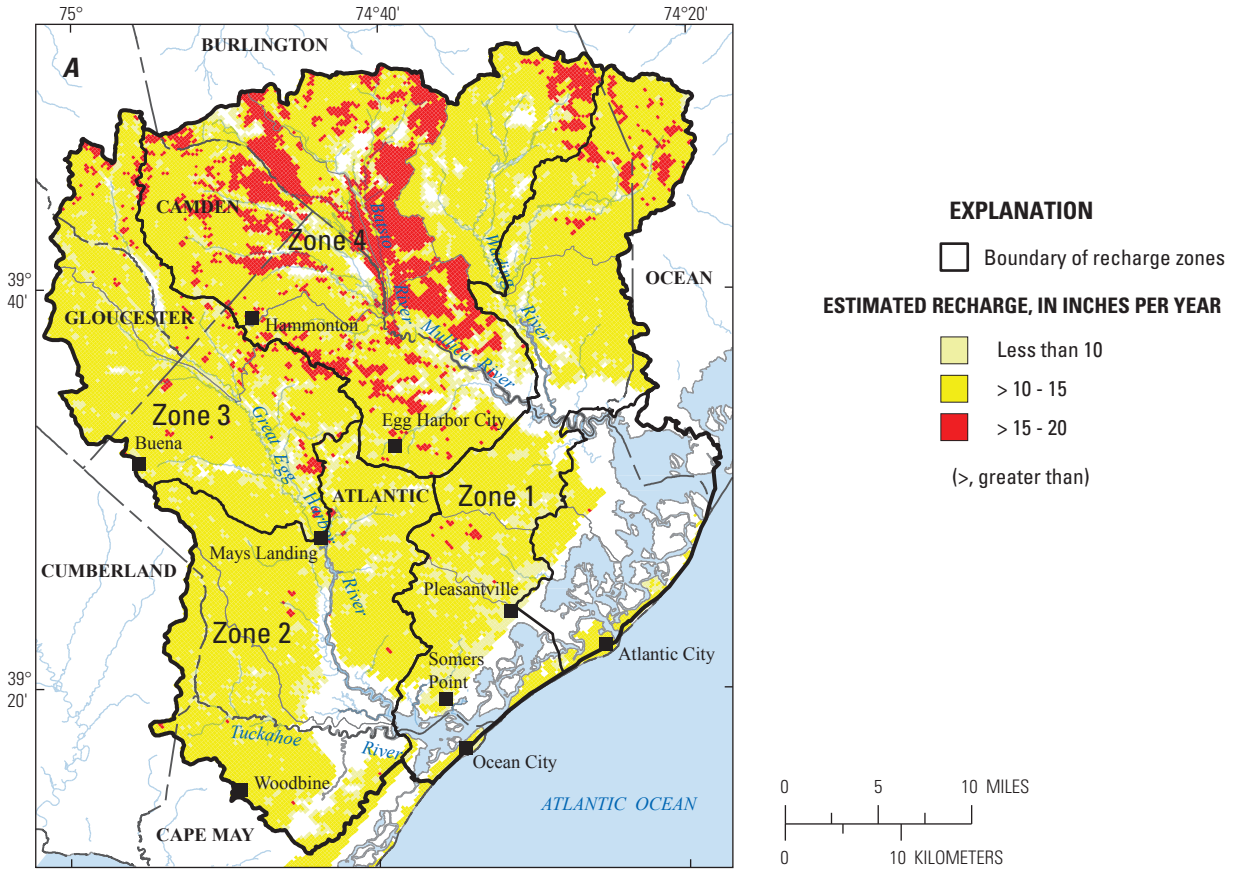
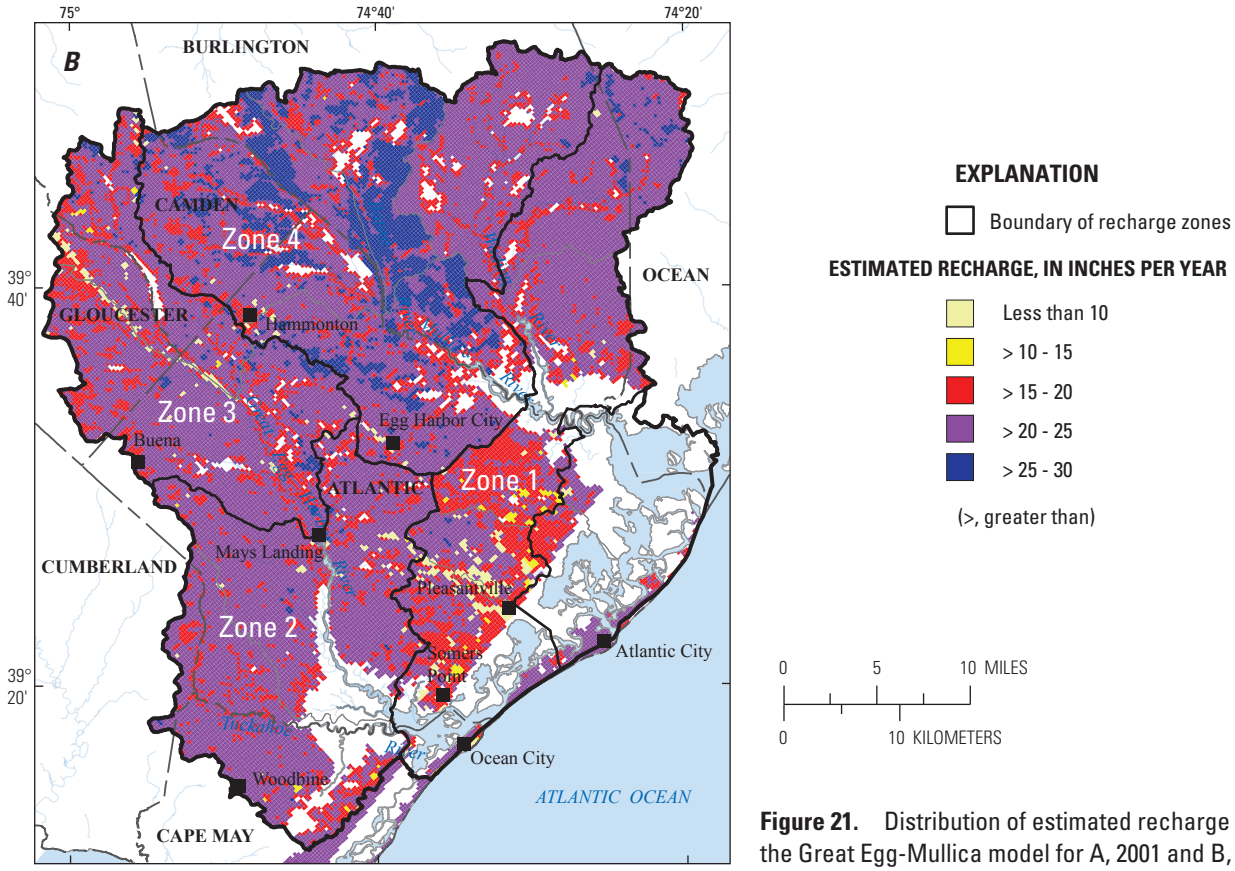


Figure 20. Distribution of estimated recharge and location of recharge zones, southeastern New Jersey.





Base from U.S.Geological Survey digital line graph files, 1:24,000

Figure 21. Distribution of estimated recharge used in the Great Egg-Mullica model for A, 2001 and B, 2005, southeastern New Jersey.

Dataset (NHD) and the location of saltwater wetlands, as delineated on 1:24,000 contour maps, were used to assign the type of features simulated. Digital Elevation Model (DEM) data were used as a starting point to assign an altitude to these features.

Saltwater wetlands along the coast were simulated as constant head cells in layer 1 because these are tidal wetlands and the stage of the wetlands changes on a time scale much shorter than the 1-month stress periods used in the model. A stage of 0.0 ft was used for these constant head cells. The limit of these wetlands areas was delineated using the contact between the land (green areas) and the wetlands (white areas) along the coast or bay areas as shown on coastal topographic maps. Wetlands or river features above this limit line were represented using either the River or Drain package. The Atlantic Ocean and bays were also represented as constant heads cells in layer 1 with a constant head value of 0.0 to represent sea level.

Freshwater surface-water features were derived from the NHD. Data were extracted from the NHD and processed to assemble the model input for the freshwater features. Areal rivers were extracted from the NHD and used to assign some of the River package cells in the model. The area of the river feature in each model cell was used as input to the River package. Lakes or pond features were extracted from the NHD and were used to create input to the DRN package to model the lakes. Cranberry bogs are included in this dataset and were modeled using the DRN package. Ponds or lakes, which were disconnected from other surface-water features, were removed from the model. Canals and ditches in coastal areas where saltwater wetlands were to be modeled were removed from the model. The area of lake, pond, or wetland in each model cell was used to prepare input to the DRN package. Linear stream features were modeled as either rivers or drains, depending on the position within the watershed. Streamflows from first-order streams were simulated using the DRN package to avoid unrealistic boundary flows into the model from losing sections in the upstream areas because of the steep gradients in these areas and because it is reasonable to assume that these upstream reaches will be gaining reaches. The remaining linear stream features were modeled using the RIV package. In either case, the area for the feature was determined by using the length of the stream within each model cell and a stream width of 5 ft, which is a reasonable estimate for the study area.

Altitudes of the stage of the river, stream, pond or wetland were initially assigned using the best available DEM data, which were obtained from the National Elevation Dataset. For the study area, 30-meter DEMs were the best available for all areas, except in Burlington County where more detailed Light Detecting and Ranging (LiDAR) data were available. Linear features were converted to points spaced 10 meters (3.281 ft) apart, and altitudes were obtained for these points. The minimum altitude of points within a model cell for each feature was used as the initial stage value for that cell. For areal features, zonal statistics were used to obtain the lowest altitude within the polygon area of the feature. During model calibration, the model flow budget showed areas with unreasonable flow from losing stream segments. To correct this problem, stages were revised to ensure that stream stage always decreased downstream. Estimated stages for the River and Drain packages were held constant throughout the model simulation period. The river bottom was assumed to be 3 ft below the stage in all rivers and drains. Cells assigned to freshwater rivers, lakes/ponds, and wetlands used in the model are shown in figure 22.

Groundwater Withdrawals

Groundwater withdrawals for the model were obtained from the water-use data described earlier in the report. The Well package (WEL) was used to represent withdrawals in the model. Each withdrawal was associated with a particular model layer (or layers) by using the location of the well screen of each well. In cases where a well screen crossed model layers, the withdrawals were distributed based on the percentage of the well screen located within each model layer. This strategy implicitly assumes that the hydraulic conductivity does not vary vertically within the aquifer, which was the case in the calibrated model. The month with the largest number of wells in the model was August 2005. There are 807 wells in the model for this stress period with 728 wells are in the Kirkwood-Cohansey aquifer, 2 are in the Rio Grande water-bearing zone, and 77 in the Atlantic City 800-foot sand.

Lateral and Vertical Flow Boundaries

The Great Egg Harbor and Mullica River Basins overlie the Kirkwood-Cohansey aquifer system in southern New Jersey. For the unconfined part of the model, lateral no-flow boundaries were used because the main area of interest is downdip in Atlantic County and near the updip limit of the Atlantic City 800-foot sand, which are both distant from the basin boundaries. The Atlantic City 800-foot sand, however, is definitely part of a regional confined aquifer. The regional RASA model was used to provide lateral boundary flows to the confined Atlantic City 800-foot sand. In this section, revisions to the RASA model (Voronin, 2004) to incorporate the Rio Grande water-bearing zone and to update water-use data are described, followed by the boundary specifications for the Great Egg–Mullica model.

Revisions to RASA Model

As part of this study, the finite-difference numerical flow model developed for the USGS RASA program to simulate groundwater flow in the New Jersey Coastal Plain was revised by adding the Rio Grande water-bearing zone and recalibrating the model. The model results from this revision serve as initial boundary conditions for the sub-regional Great Egg–Mullica model which nests within the RASA model. The model was recalibrated by matching simulated heads to 2003 observed heads. This process included studying the

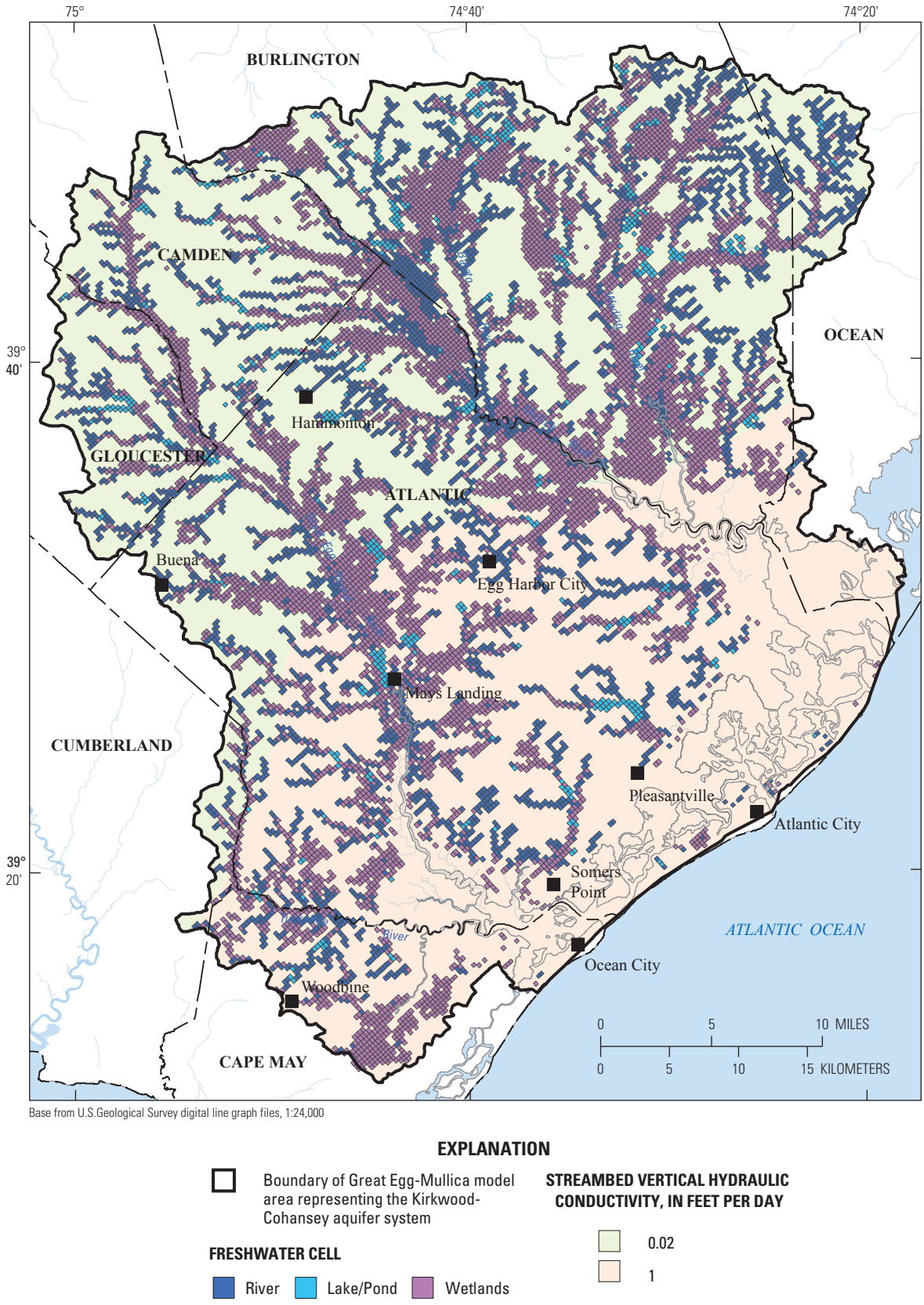


Figure 22. Model cells assigned to freshwater rivers, lakes, ponds, and wetlands in the Great Egg-Mullica model, southeastern New Jersey.

distribution of the residuals and interpreted potentiometric contours in the Kirkwood-Cohansey aquifer system, Rio Grande water-bearing zone, Atlantic City 800-foot sand, and the Piney Point aquifer.

Previous RASA models (Martin, 1998; Voronin, 2004) incorporated the Rio Grande water-bearing zone into the Atlantic City 800-foot sand. Collectively, the combined unit was referred to as the confined Kirkwood aquifer. The goal of adding the Rio Grande water-bearing zone to the RASA model was to separate, and better define, the Kirkwood-Cohansey aquifer system, Rio Grande water-bearing zone, and the Atlantic City 800-foot sand. The Rio Grande water-bearing zone was added to the model as layer 3, which increased the number of model layers from 10 to 11. The previously described Rio Grande water-bearing zone framework was used to define the layer with its overlying and underlying clays.

This RASA model assumes that flow is completely horizontal within the aquifers and vertical through the confining units (Voronin, 2004). For steady-state calibration, a range of horizontal hydraulic conductivities from 25 ft per day (ft/d) to 75 ft/d was tested to calculate the transmissivity of the Rio Grande water-bearing zone. In the final model, a horizontal hydraulic conductivity of 50 ft/d was used in calculating transmissivity. During recalibration, it became evident that heads needed to be higher in the updip area of the Rio Grande water-bearing zone where the thickness of the layer decreases and the layer transitions from confined to semi-confined. Therefore, two zones were created. The vertical hydraulic conductivity could be adjusted separately in each zone, and a range of vertical hydraulic conductivities from 0.4 ft/d to 10 ft/d were tested. The final model used a vertical hydraulic conductivity of 5 ft/d in zone 1 and 1 ft/d to define the clay above the Rio Grande water-bearing zone. This same two-zone concept was applied to define the clay below the Rio Grande water-bearing zone. The final model used a vertical hydraulic conductivity of 1 ft/d in zone 1 and 0.5 ft/d in zone 2 for this confining unit.

The transient run of the revised RASA model simulated conditions from January 1968 to September 2006 with 29 stress periods and 10 time steps within each stress period. The last 8 stress periods cover the simulation period for the Great Egg-Mullica flow model. Stress periods 1 through 21 are the same as those used in the original RASA model, which covered the period from January 2, 1968, to December 31, 1998 (Voronin, 2004). Stress periods 22 through 26 cover the period from January 1, 1999, to December 31, 2003 (M.K. Watt, U.S. Geological Survey, written commun., 2007). Stress periods 27, 28, and 29 were added to bring the model up to 2006 with each stress period representing a calendar year. Withdrawal data from 2003 were used for stress periods 27 to 29 to simulate conditions in 2004 through 2006. The simulated heads from stress period 26, time step 10, representing 2003, were compared to 2003 observed heads in the Kirkwood-Cohansey aquifer system, Rio Grande water-bearing zone, Atlantic City 800-foot sand, and Piney Point aquifer.

Boundary Specification

For the Great Egg–Mullica model, the lateral flow boundary for the Kirkwood-Cohansey aquifer system is a no-flow boundary at the physical boundaries of the Great Egg Harbor and Mullica River Basins. Because the main area of focus for the study is the Atlantic County area, this is an appropriate boundary. For the confined Atlantic City 800-foot sand, the lateral boundaries to the north and south, and offshore to the east, are specified flows that were imported from the revised RASA model. The locations of these boundary flow cells are shown in figure 19. The boundary flow cells are present only where the Atlantic City 800-foot sand is modeled as confined. The lower boundary for the model is a specified-flow boundary, incorporating vertical flows from the New Jersey RASA model into the confined and unconfined parts of the model. Boundary flows were simulated using the Flow and Head Dependent Boundary package (FHB) of MODFLOW.

Model Calibration

Simulated water levels and base flows were compared to observed values to calibrate the Great Egg-Mullica model. A total of 32 parameters was used in the model, and values of these parameters were adjusted to obtain a fit to hydrologic observations. Model calibration was accomplished by initially using UCODE-2005 (Poeter and others, 2005) to calculate parameter sensitivities using initial estimates of parameters. Final calibration was accomplished using the UCODE-2005 parameter sensitivities and manual adjustment of parameters. During calibration, parameters representing horizontal hydraulic conductivity, vertical hydraulic conductivity of confining units, recharge, riverbed hydraulic conductivity and storage were adjusted to fit observed heads and base flows. Synoptic measurements of groundwater levels in fall 1998, fall 2003, spring 2005, and fall 2006 were used to increase spatial coverage of observations for water-level calibration targets for the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand. In addition, water-level hydrographs for 14 wells and base-flow hydrographs for 22 streamgages were used as calibration targets throughout the entire model calibration period. The calibration period for the model was 1998 to 2006. However, because base flow was still responding to initial conditions during 1998, hydrographs of base flow and water levels are shown only for 1999 to 2006. Data from the 1998 synoptic survey were used to calibrate the Atlantic City 800-foot sand because otherwise the model calibration period coincided with only one (2003) of the confined aquifer synoptic surveys of the Coastal Plain aquifer in New Jersey. The goal of model calibration was to match the simulated and observed water levels to within plus or minus 5 ft and to match simulated and observed base flow as much as possible during the summer months.

Model Parameters

The parameters and values used in the model for the Layer Property Flow package (LPF), RIV package, DRN package, and RCH package are shown in table 8. Seven parameter sub-groups were used to represent horizontal hydraulic conductivity, eight for vertical hydraulic conductivity, eight for riverbed hydraulic conductivities in the RIV and DRN packages, seven for recharge, and two for storage. Uniform values for a parameter type were used whenever possible to get a good model fit. In many cases, several zones were created for a single parameter type to allow for spatial variability of various model parameters should they be needed during calibration; however, a single value was often used for adjacent zones.

Hydraulic Properties

Figure 23 shows a conceptual diagram of the model layers that coincide with the section shown in figure 2 along line A-A' (fig.1). The diagram shows the zones within each layer that were used to delineate the parameters for the LPF in MODFLOW. The number of the zone is shown in bold, followed by the names of the parameters for horizontal and vertical hydraulic conductivity in the zone. In the following discussion, different parts of the flow system and the main model parameter controlling flow for the area are described using these zones. For units that are primarily aquifers, the parameter is the horizontal hydraulic conductivity. For units that are primarily confining units, the parameter is the vertical hydraulic conductivity.

The Kirkwood-Cohansey aquifer system was represented in parts of all model layers and is shown in shades of yellow in figure 23. The vertical red line in layers 4 to 9 corresponds to the updip limit of the Atlantic City 800-foot sand that is shown in figure 1 and many subsequent figures. In all areas to the left of this line (fig. 23) and in zones 24, 25, and 34, the Kirkwood-Cohansey aquifer system is modeled as a uniform aquifer system using the parameters *cnsy-k1* and *KW-k* for horizontal hydraulic conductivity. Different zones were established to allow representation of the horizontal hydraulic conductivity of the Kirkwood portion of the aquifer in the updip parts of layers 7 to 9 (*KW-k*). In the eastern part of the modeled area, the leaky-confining unit in the Kirkwood-Cohansey aquifer system is represented in zones 20 and 22 using the parameter *kvcnsyclay* for vertical hydraulic conductivity. Constant head cells representing the Atlantic Ocean and bays are in zone 12. Zones 10, 12, 30, and 32 represent the Kirkwood-Cohansey aquifer system in this area. Different zones were created to allow for different horizontal hydraulic conductivity values for the Kirkwood-Cohansey aquifer system in these downdip areas (*cnsy-k2* and *cnsy-k3*). In the updip part of the model, layers that represent confining units or the Rio Grande water-bearing zone in downdip parts of the model are simulated as 1 foot thick (layers 2, 4, 5, 6, and 8), and the vertical hydraulic conductivity value used (*kv-vertcon*) is large enough that vertical flow between the model layers is not substantially limited.

The horizontal hydraulic conductivity of the Kirkwood-Cohansey aquifer system (*cnsy-k1*, *cnsy-k2*, and *cnsy-k3*) was simulated with a uniform value of 60 ft/d. During calibration, different values for zones in the updip and downdip areas, and for shallow and deep parts of the aquifer system, were tested, but these different values were not needed. The hydraulic conductivity values were generally lower than those estimated from well acceptance tests, but using a higher hydraulic conductivity value did not produce a good match to observed heads and base flows. This same value of horizontal hydraulic conductivity was also used for the Kirkwood Formation part of the Kirkwood-Cohansey aquifer system in layers 4 to 9 where the aquifer is unconfined (*KW-k*). Where the Kirkwood-Cohansey aquifer system is unconfined (zones 21, 31, 41, 51, 61, 71, and 81), the vertical hydraulic conductivity of the aquifer (*kv-vertcon*) is 0.5 ft/d. This parameter value allows vertical connection between all model units in this area. The vertical hydraulic conductivity of the leaky confining unit in the Kirkwood-Cohansey aquifer system (*kvcnsyclay*) is 0.05 ft/d.

The confining unit overlying the Atlantic City 800-foot sand is represented in layers 4 to 6 by zones 43, 53, 63, 40, and 60. The area of the confining unit that is updip from the extent of the Rio Grande water-bearing zone is represented in zones 43, 53, and 63 (this area is shown in figure 7 as the area of transition). The vertical hydraulic conductivity of this zone is controlled by a single parameter (*kv-riosemi*) that effectively separates the overlying Kirkwood-Cohansey aquifer system from the Atlantic City 800-foot sand. The Rio Grande water-bearing zone is represented by zone 50 using the parameter *rio-k* for horizontal hydraulic conductivity with a value of 50 ft/d. The confining unit above and below the Rio Grande water-bearing zone is controlled by two parameters (*kvdclay-u* and *kvdclay-l*) for vertical hydraulic conductivity. The vertical hydraulic conductivity of the confining unit overlying the Atlantic City 800-foot sand (*kvdclay-u* and *kvdclay-l*) was 1×10^{-5} ft/d. Zones 46, 56, and 66 represent the area designated as the semi-confining zone for the confining unit overlying the Kirkwood Formation and are represented by the vertical hydraulic conductivity parameter *kv800semi*. The area in which these zones occur is just updip from the limit of the Atlantic City 800-foot sand, as designated by Zapecza (1989), and is shown in figures 9 and 10 as shaded in light green. These zones were included to test the model sensitivity to the vertical hydraulic conductivity of the confining unit in this area. An initially low value of vertical hydraulic conductivity was used to test the confinement of the deeper aquifer units in this area. However, in the final model calibration, the vertical hydraulic conductivity (*kv800semi*) used in this zone to best match observed heads in the Atlantic City 800-foot sand was the same as that used throughout the Kirkwood-Cohansey aquifer system, which was 0.5 ft/d. This relatively high value of vertical hydraulic conductivity results in the representation of the updip limit of the Atlantic City 800-foot sand as being

Table 8. Final parameters for the calibrated Great Egg-Mullica model.

[NJGS, New Jersey Department of Environmental Protection, Geological Survey; NHD, U.S. Geological Survey National Hydrography Dataset; n/a, not applicable]

Parameter type	Parameter description	Parameter name	Value	Unit	Figure reference for parameter location	Model layer	Composite scaled sensitivity
Horizontal hydraulic conductivity	Cohansey sand, updip	cnsy-k1	60	feet/day	Fig. 23, zones 15, 21, 25, 24, 31, 34, 41, 51, and 61	1-6	92.5
	Cohansey sand, downdip	cnsy-k2	60	feet/day	Fig. 23, zones 10 and 12	1	32.9
	Cohansey sand in semi-confined zone, downdip	cnsy-k3	60	feet/day	Fig. 23, zones 30 and 32	3	35.8
	Confining units	cu-k	1	feet/day	Fig. 23, zones 20, 22, 40, 43, 53, 60, 63, and 80	2, 4-6, 8	33.4
	Rio Grande water-bearing zone	rio-k	50	feet/day	Fig. 23, zone 50	5	24.6
	Unconfined Kirkwood Formation	KW-k	60	feet/day	Fig. 23, zones 46, 56, 66, 71, 75, 76, 81, 86, 95, 94 and 96. Fig 24 green zone.	4-9	229
	Atlantic City 800-foot sand	ac800k	50	feet/day	Fig. 23, zones 70 and 90. Fig 24 gold zone.	7, 9	1,161
Vertical hydraulic conductivity	Kirkwood-Cohansey leaky confining unit	kvcnsclay	0.05	feet/day	Fig. 23, zones 20 and 22. Fig.4	2	18.8
	Semi-confining zone for the confining unit overlying Atlantic City 800-foot sand	kv800semi	0.5	feet/day	Fig. 23, zones 46, 56, and 66. Fig. 9 green shaded area	4-6	15.4
	Vertical connection between aquifers	kv-vertcon	0.5	feet/day		2-8	2.6
	Area of transition between the Rio Grande water-bearing zone and the confining unit overlying the Atlantic City 800-foot sand	kv-riosemi	1.00E-5	feet/day	Fig. 23 zones 43,53, and 63. Fig. 7, gold zone	4-6	11.2
	Upper part of the confining unit overlying Atlantic City 800-foot sand	kvdclay-u	1.00E-5	feet/day	Fig. 23, zone 40	4	15.9
	Lower part of the confining unit overlying Atlantic City 800-foot sand	kvdclay-l	1.00E-5	feet/day	Fig. 23, zone 60	6	21.8
	Semi-confining unit within the Atlantic City 800-foot sand	kv800clay	9.8	feet/day	Fig. 23, zone 80, 86	8	0.75
	Vertical hydraulic conductivity of aquifer material	aquifer	1.00E+1	feet/day	All aquifer units	1-3, 5, 7-9	39.5
River-bed hydraulic conductivity	Drains in the Oswego River Basin, updip	drnk1	0.02	feet/day	Fig. 22, green zone	1	26.3
	Drains, downdip	drnk2	1	feet/day	Fig. 22, pink zone	1	15.3
	Drains in the Great Egg Harbor River Basin, updip	drnk3	0.02	feet/day	Fig. 22, green zone	1	12.4
	Drains in the Mullica River Basin, updip	drnk4	0.02	feet/day	Fig. 22, green zone	1	55.6
	Rivers in the Oswego River Basin, updip	rivk1	0.02	feet/day	Fig. 22, green zone	1	0.99
	Rivers, downdip	rivk2	1	feet/day	Fig. 22, pink zone	1	10.2
	Drains in the Great Egg Harbor River Basin, updip	rivk3	0.02	feet/day	Fig. 22, green zone	1	0.48
	Drains in the Mullica River Basin, updip	rivk4	0.02	feet/day	Fig. 22, green zone	1	17.2

Table 8. Final parameters for the calibrated Great Egg-Mullica model.

[NJGS, New Jersey Department of Environmental Protection, Geological Survey; NHD, U.S. Geological Survey National Hydrography Dataset; n/a, not applicable]

Parameter type	Parameter description	Parameter name	Value	Unit	Figure reference for parameter location	Model layer	Composite scaled sensitivity
Recharge factor	Recharge in zone 1	rechz1	1.25	dimensionless	Fig. 20, zone 1	1	71.6
	Recharge in zone 2	rechz2	1.5	dimensionless	Fig. 20, zone 2	1	24.5
	Recharge in zone 3	rechz3	1.5	dimensionless	Fig. 20, zone 3	1	95.4
	Recharge in zone 6	rechz4	1.5	dimensionless	Fig. 20, zone 4	1	136
	Recharge in area delineated as wetlands in NJGS recharge dataset but not in the NHD	rechz5	1.5	dimensionless	Wetlands in NHD	1	44.8
	Recharge in areas delineated as wetlands in the National Hydrologic Dataset (NHD)	rechz6	1	dimensionless	Welands in NJGS recharge dataset but not in NHD	1	10.9
	Recharge in river or drain cells	rechz7	0	dimensionless	River or drain cells	1	n/a
Storage	Specific Yield	SY	0.15	dimensionless	All active cells	1	33.4
	Specific Storage	SS	4.00E-6	1/foot	All active cells	1-9	69.8

the same as that identified by Zapecza (1989) and used in the RASA model. The final vertical hydraulic conductivity of the units overlying the Kirkwood Formation in layers 4 to 6 is shown in figure 24.

The Atlantic City 800-foot sand is modeled in layers 7 to 9 and is represented using zones 70, 80, and 90. Layer 7 represents the upper part of the aquifer (zone 70); layer 8, the thin confining unit (zone 80); and layer 9, the lower part of the aquifer (zone 90). The horizontal hydraulic conductivity of the Atlantic City 800-foot sand in layers 7 and 9 (*ac800k*) was 50 ft/d. During calibration, a larger value of horizontal hydraulic conductivity was tested for the Atlantic City 800-foot sand, but the lower value was needed to match the observed cones of depression. The horizontal hydraulic conductivity of the Kirkwood Formation part of the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand in layers 7 to 9 is shown in figure 25. The vertical hydraulic conductivity of the confining unit separating the two aquifer units (*kv800clay*) was 9.8 ft/d.

Some uniform parameters were used to represent vertical hydraulic conductivity of the aquifers and the storage terms. The vertical hydraulic conductivity value for most aquifer units (*aquifer*) was 10 ft/d. The specific storage of the confined aquifers and confining units (*SS*) was 4 $x10^{-6}$ ft^{-1} as determined during model calibration. Several models of the Coastal Plain aquifers in New Jersey have used similar low specific storage values (Voronin, 2004). The specific yield used for the unconfined Kirkwood-Cohansey aquifer system in layer 1 (*SY*) was 0.15. Model layer 1 was simulated as a convertible unit in MODFLOW. Layers 2 to 9 were simulated as confined units; the transmissivity was calculated as the hydraulic conductivity times the thickness of the layer.

Recharge

Recharge was simulated using the Recharge package (RCH) in MODFLOW-2000. A recharge multiplier was used to adjust the New Jersey Geological Survey GSR32 recharge number and the monthly recharge factor for each of seven model parameters (fig. 20). Parameters *rechz1* through *rechz4* were used for the main recharge rate in the four areal zones. A recharge factor of 1.5 was used for zones 2 to 4 (parameters *rechz2*, *rechz3*, and *rechz4*). A factor of 1.25 was used in zone 1 (parameter *rechz1*). In addition to the four areal zones, three zones near stream features or wetlands were assigned different recharge factors. All cells representing rivers or drains were assigned a recharge value of zero (parameter *rechz7*). Areas that were delineated as wetlands in the NHD were assigned recharge (parameter *rechz6*) but with a recharge factor of 1.0. Areas that were wetlands in the New Jersey Geological Survey recharge dataset but were not wetlands in the NHD (parameter *rechz5*) were assigned a recharge factor of 1.5.

Layer					
1	**15** cnsy-k1, aquifer			**10** cnsy-k2, aquifer	**12** cnsy-k2, aquifer
2	**21** cnsy-k1, kv-vertcon	**25** cnsy-k1, aquifer	**24** cnsy-k1, aquifer	**20** cu-k, kvcnsyclay	**22** cu-k, kvcnsyclay
3	**31** cnsy-k1, kv-vertcon	**34** cnsy-k1, aquifer		**30** cnsy-k3, aquifer	**32** cnsy-k3, aquifer
4	**41** cnsy-k1, kv-vertcon	**46** KW-k, kv800semi	**43** cu-k, kv-riosemi	**40** cu-k, kvdclay-u	
5	**51** cnsy-k1, kv-vertcon	**56** KW-k, kv800semi	**53** cu-k, kv-riosemi	**50** rio-k, aquifer	
6	**61** cnsy-k1, kv-vertcon	**66** KW-k, kv800semi	**63** cu-k, kv-riosemi	**60** cu-k, kvdclay-l	
7	**71** KW-k, kv-vertcon **75** KW-k, aquifer	**76** KW-k, aquifer	**70** ac800-k, aquifer		
8	**81** KW-k, kv-vertcon	**86** KW-k, kv-800clay	**80** cu-k, kv-800clay		
9	**95** KW-k, aquifer **94** KW-k, aquifer	**96** KW-k, aquifer	**90** ac800-k, aquifer		

Figure 23. Conceptual diagram of the Kirkwood-Cohansey aquifer system, southeastern New Jersey, showing model layers, zone numbers, and hydraulic conductivity parameter names. (Names are defined in table 8)

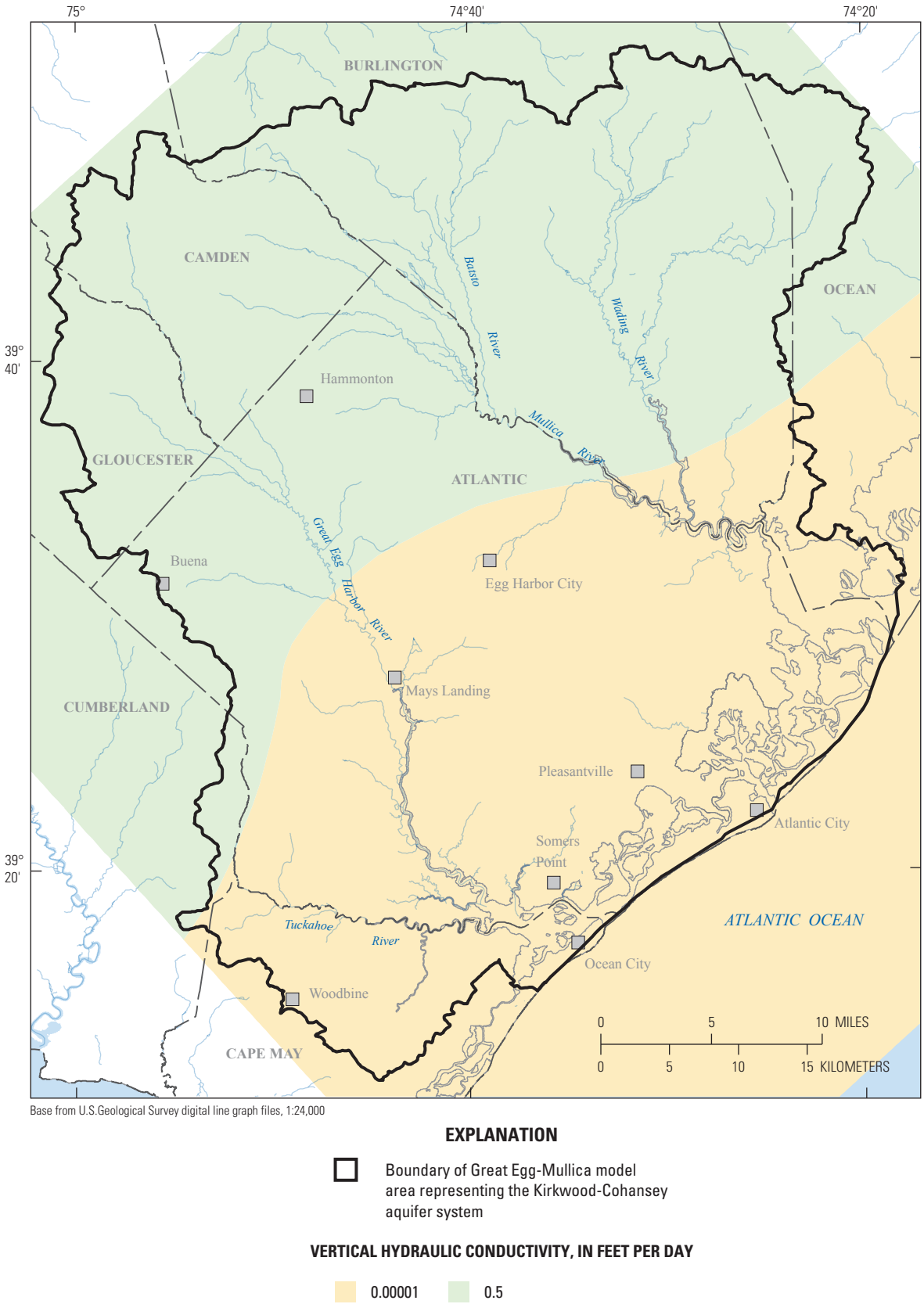


Figure 24. Vertical hydraulic conductivity for the confining unit overlying the Kirkwood Formation, southeastern New Jersey.

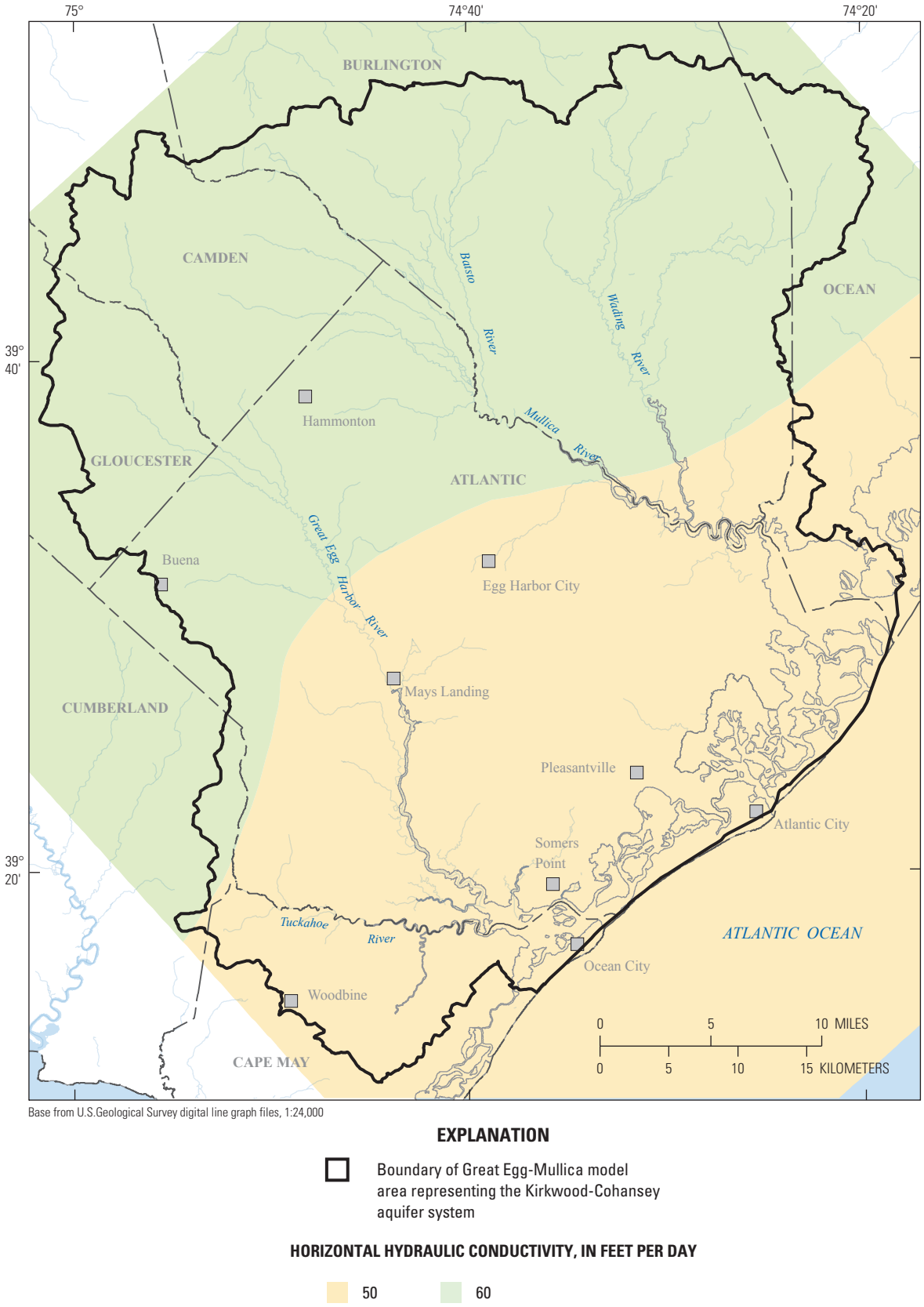


Figure 25. Horizontal hydraulic conductivity zones for the Atlantic City 800-foot sand, southeastern New Jersey.

Surface-Water Features

Eight zoned parameters were used in the model for riverbed vertical hydraulic conductivity for the RIV and DRN packages. One set of four zones was used to simulate hydraulic conductivity for the DRN package, and four zones were used for the RIV package. Three zones (1, 3 ,4) were created for the three major river basins (Oswego, Great Egg Harbor, and Mullica Rivers Basins, respectively) in updip areas (parameters *drnk1*, *drnk3*, *drnk4*, *rivk1*, *rivk3*, and *rivk4*). A fourth zone (2) was created to include all areas downdip from the limit of the confining unit overlying the Atlantic City 800-foot sand (parameters *drnk2* and *rivk2*). This fourth zone was created during calibration to aid in matching heads and base flow in downdip areas.

Initial values of 0.2 ft/d for riverbed vertical hydraulic conductivity were obtained from a previous model of the Mullica River (Harbaugh and Tilly, 1984). The final calibrated values for the updip zones were all 0.02 ft/d. During calibration, this value did not produce a good fit with heads and base flow in downgradient areas. A zone was created for surface-water features in this downdip area that coincides with the updip limit of the Atlantic City 800-foot sand because this area contains subbasins characterized by high base flow (zone 4). A riverbed vertical hydraulic conductivity value of 1 ft/d was used in this zone. The calibrated values of streambed hydraulic conductivity are shown in figure 22. The values of streambed conductance within each zone were the same for both the RIV and DRN packages in the final calibration.

Model Calibration Data

A variety of data was collected or assembled in order to calibrate the groundwater flow model. Data used to calibrate the model include synoptic water levels, long-term water levels, and monthly estimates of base flow.

Synoptic water levels used to calibrate the groundwater flow model were collected for the study during 2005 and 2006. Data were collected in May 2005 to represent high water-level and streamflow conditions that occur in the spring. Data collected in September 2006 are representative of late summer conditions when water levels and streamflows are typically at the lowest levels of the year. Water levels were measured in 113 wells in the Kirkwood-Cohansey aquifer system, 2 wells in the Rio Grande water-bearing zone, and 33 wells in the Atlantic City 800-foot sand. The locations of these wells and identifiers are shown in figure 26. Water-level data are shown in table 9 (at end of report). These data provided two areally extensive datasets for use in model calibration. Low-flow measurements were made at 48 sites in May 2005 and September 2006.

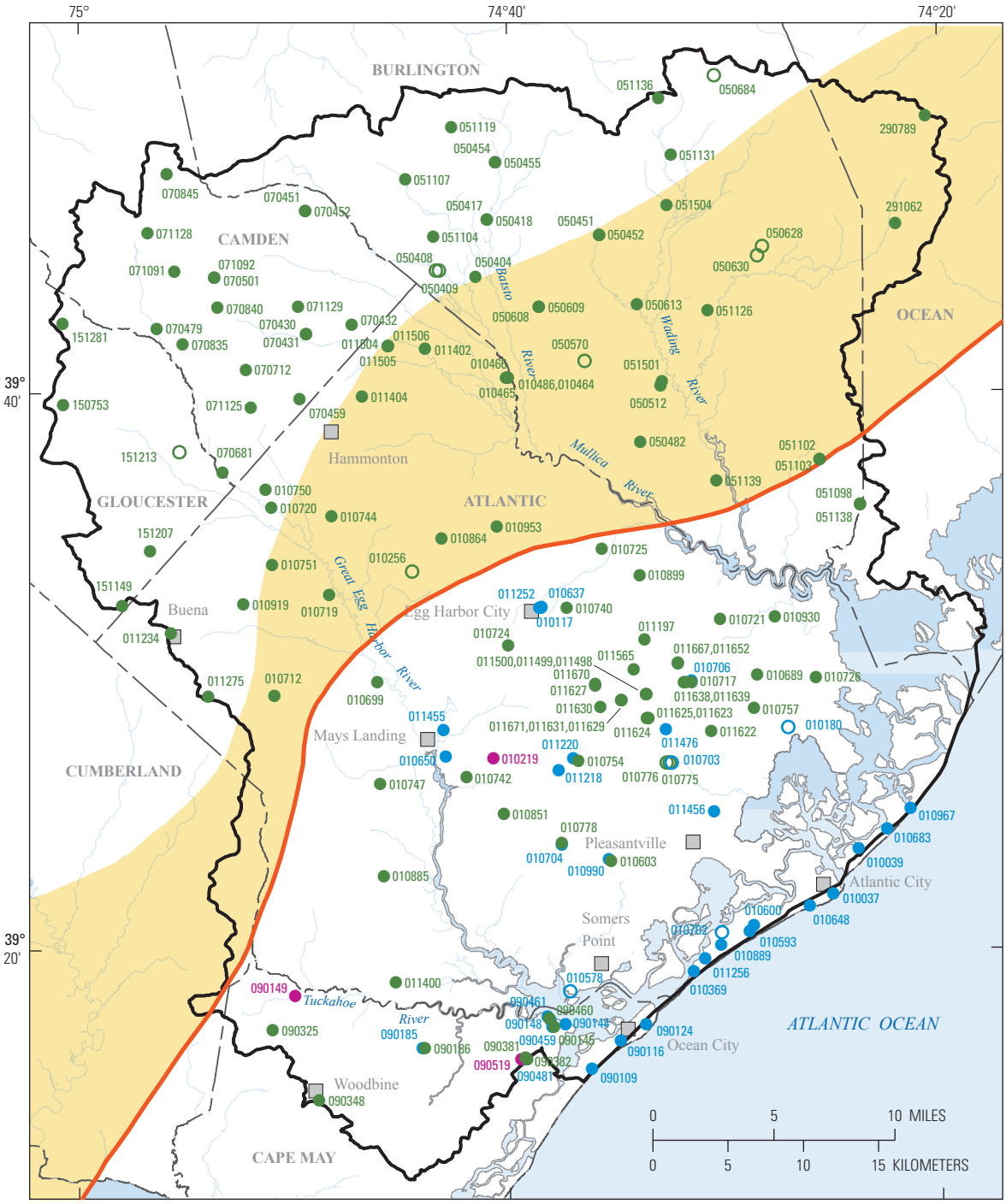
Hydraulic Head Observations

In addition to the water levels measured in 2005 and 2006 as part of this study, other water-level data from the USGS NWIS database were used to calibrate the groundwater flow model. These data include water levels measured in 1998 and 2003 (Lacombe and Rosman, 2001; dePaul and others, 2009) in wells in the USGS New Jersey Coastal Plain Synoptic Water-Level Network that are completed in the Atlantic City 800-foot sand and long-term water levels measured in wells in the New Jersey Water-Level Monitoring Network. All water levels were assigned weights based on the accuracy of the land-surface altitude at the site. Some wells have relatively accurate land-surface altitudes determined by leveling, whereas others have less accurate values interpreted from digital elevation maps or from topographic maps. Using the altitude accuracy is appropriate to determine the weights because the measurement error at all the wells is relatively consistent and small compared to the measurement uncertainty in the land-surface altitude. The error statistic for heads used in UCODE-2005 is a standard deviation calculated using a 90-percent confidence interval. The weighted water levels were used to calculate the composite scaled sensitivity of the model-simulated heads to changes in each of the model parameters.

Daily water levels in 14 wells in the USGS New Jersey Water-Level Monitoring Network were used to create monthly hydrographs for use in model calibration. The monthly hydrographs were made by using the water level on the 15th day of each month during the model calibration period. The locations of these wells are shown in figure 26. Contours of water levels from previous studies were used to evaluate the general direction and slope of the simulated water levels. Contours of measured water levels in the Atlantic City 800-foot sand from the New Jersey Coastal Plain Synoptic Water-Level Network in 1998 and 2003 were used to visually compare the simulated and observed potentiometric surfaces. For the water-table aquifer, contours from surficial aquifer studies done by the USGS in the Mullica and Great Egg Harbor River Basins were used to show the general flow direction in the aquifer. The water-level contour map for the Mullica River Basin (Johnson and Watt, 1996) is based on water-level data collected during 1991. The contour map of the Great Egg Harbor River Basin (Watt and Johnson, 1992) is based on water-level data collected in 1989. In general, these contour maps agree well at the shared boundary between the subbasins; there are some small differences that are not relevant at the scale of this study, however.

Base-Flow Observations

Base-flow data from 22 sites in the area (fig. 18) were used to create the base-flow hydrographs used to calibrate the model. Base-flow separation, described earlier, was used to directly estimate base flow at the six streamgaging stations. For the remaining 16 low-flow partial-record stations, base flow at nearby index sites and the MOVE.1 correlations established for these sites were used to estimate base flow. The observed base flow is for the total subbasin and includes flow in streams simulated by model cells that represent both rivers



Base from U.S.Geological Survey digital line graph files, 1:24,000

EXPLANATION

- Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system
- Area of semi-confining zone for the confining unit overlying the Kirkwood Formation
- Updip extent of the Atlantic City 800-foot sand (From Zapecza, 1989)

NETWORK WELL WITH WATER-LEVEL DATA FOR 1998 TO 2006. NUMBER IS U.S. GEOLOGICAL SURVEY WELL IDENTIFIER

- Kirkwood-Cohansey aquifer system
- Atlantic City 800-foot sand

NON-NETWORK WELL WITH MAY 2005 OR SEPTEMBER 2006 WATER LEVEL. NUMBER IS U.S. GEOLOGICAL SURVEY WELL IDENTIFIER

- Kirkwood-Cohansey aquifer system
- Rio Grande water-bearing zone
- Atlantic City 800-foot sand

Figure 26. Locations of wells with measured water levels, southeastern New Jersey, May 2005 and September 2006.

and drains. A good match between simulated and observed base flows during the summer months was achieved for most basins.

Calibration to Water-Level Observations

Maps and hydrographs of water levels were used to calibrate the groundwater model. Maps show the simulated potentiometric surface and residuals at observed wells. The residuals are the simulated head minus the observed head at the well. Most of the simulated water levels in all aquifers are within 5 ft of the observed water level. In the Kirkwood-Cohansey aquifer system, 69 percent are within 5 ft, and 89 percent are within 10 ft. In the Atlantic City 800-foot sand, 53 percent are within 5 ft, and 79 percent are within 10 ft.

Kirkwood-Cohansey Aquifer System

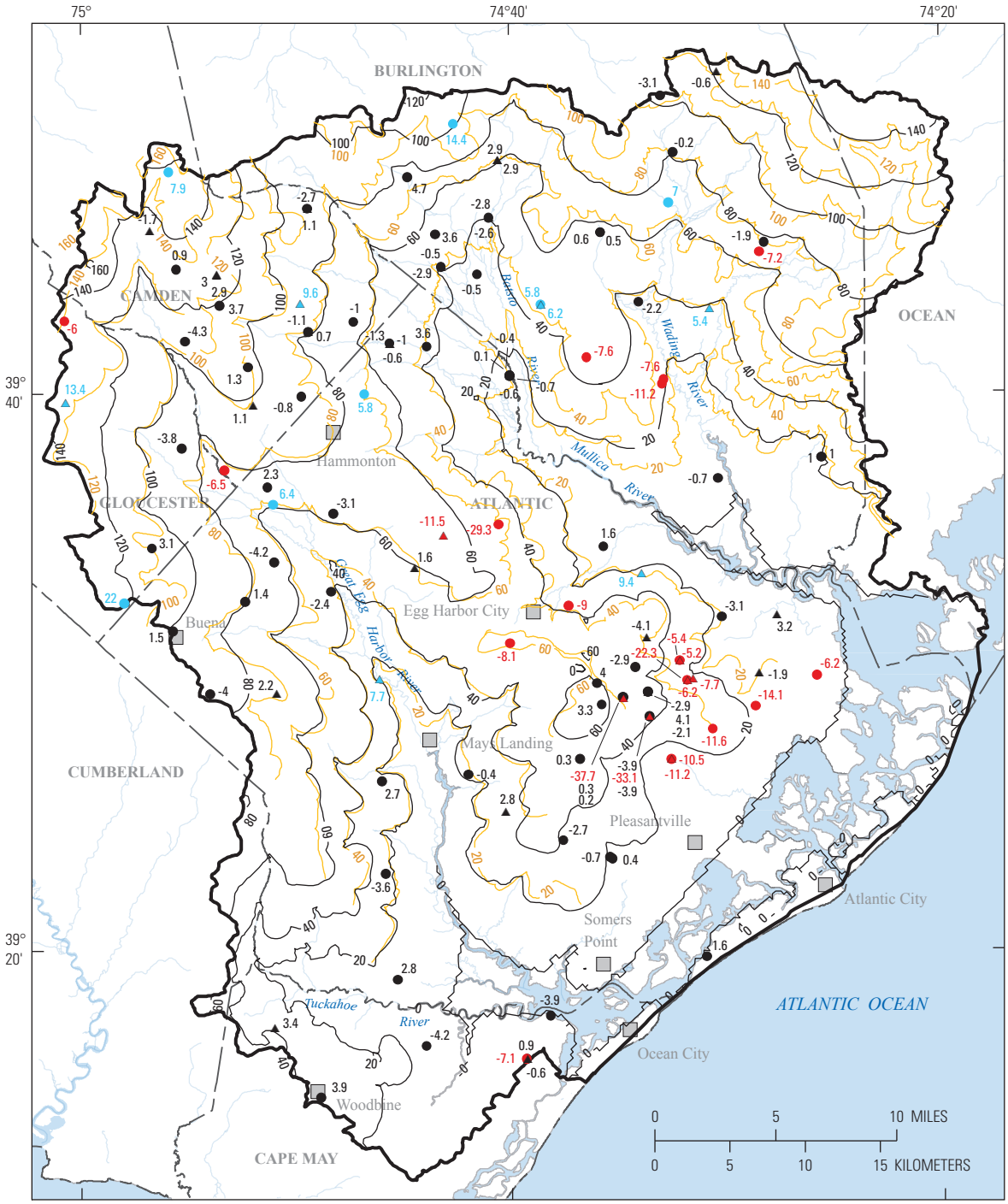
The model of the Kirkwood-Cohansey aquifer system was calibrated by comparing water-level data collected during spring 2005 and fall 2006 with simulated water levels. The model also was evaluated by qualitatively comparing simulated water-level contours for the Mullica and Great Egg Harbor River Basins calculated for the spring 2005 and the fall 2006 with previously mapped water-table contours for the same time period. The simulated water-table contours and residuals (simulated minus observed heads) for the Kirkwood-Cohansey aquifer system in spring 2005 are shown in figure 27. The simulated contours and residuals for the Kirkwood-Cohansey aquifer system in fall 2006 are shown in figure 28. The shapes of the simulated contours for spring 2005 and fall 2006 closely follow the water-table maps created for the Mullica and Great Egg Harbor River Basins surficial aquifer studies (Watt and Johnson, 1992; Johnson and Watt, 1996). The simulated and observed groundwater levels and the residuals for spring 2005 and fall 2006 are listed in table 9. The locations of these wells, labeled with USGS well numbers, are shown in figure 26. Throughout most of the study area, the simulated water levels are within +/- 5 ft of the observed water levels. The largest and most frequent occurrence of residuals of more than +/- 5 ft is in the area northwest of Pleasantville along the divide between the Mullica and Great Egg Harbor River Basins. Residuals of up to 38 ft occurred in this area. For most of these large residuals, the simulated head is much lower than the observed head. However, at other nearby wells, the simulated heads are either greater than the measured heads or within +/- 5 ft. The water-use maps in figure 16 show large withdrawals occurring in this area, especially in the summer. In this area, the regional representation does not match local conditions exactly.

Graphs of the simulated and observed heads in both the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand in spring 2005 and fall 2006 are shown in figure 29A. The heads in the Kirkwood-Cohansey aquifer system (shown in blue) generally plotted along the 1:1 line in figure 29A. The heads above the line are those in the area northwest of Pleasantville (discussed above). The distribution of the residuals for the Kirkwood-Cohansey aquifer system in spring 2005 and fall 2006 is shown in figure 30A. The distribution of residuals does not indicate any spatial bias in the simulated heads.

Hydrographs for wells in the Kirkwood-Cohansey aquifer system are shown in figures 31 and 32. Figure 31 shows hydrographs for wells in the updip areas of the Kirkwood-Cohansey aquifer system. Figure 32 shows hydrographs for wells in the downdip areas. Wells in the Kirkwood-Cohansey aquifer system are labeled CKKD, and wells in the Atlantic City 800-foot sand are labeled AC800. The simulated heads match the observed seasonal water levels fairly well. One goal of calibration was to match both the magnitude and seasonal variation of the observed heads. Most of the simulated heads are within 5 ft of the observed heads. Simulated water levels at the Mount Obs well (050570) are low and do not match the observed levels or seasonal variations as well as simulated water levels match observed water levels for most other wells. Three sets of these hydrographs are for well nests in different model layers at or near the same locations. At the Atsion well nest (050409 and 050408), simulated water levels are close to the observed water levels, especially at the shallow well. At the Penn SF nest (050628 and 050630; fig. 31), simulated water levels for the shallow well are up to 10 ft higher than observed water levels, whereas simulated water levels for the deep well are much closer to observed levels. At the Pomona nest (010776 and 010775; fig. 32), simulated water levels at the shallow well are as much as 15 ft lower than the observed water levels, whereas simulated water levels for the intermediate well match the observed water levels fairly well. Well 010775 (intermediate) is in the area where the leaky confining unit in the Kirkwood-Cohansey aquifer system is present, but both of the wells at the Pomona nest are screened above the leaky confining unit. Statistics for the residuals for these wells are listed in table 10. The absolute value of the mean error at six of the nine long-term wells in the Kirkwood-Cohansey aquifer system is less than 5 ft. The Mount Obs well (050570), the Penn SF shallow well (050628), and the Pomona shallow well (010776) have mean errors with absolute values greater than 5 ft, but the seasonal trends match fairly well. This is considered acceptable because other wells in the area matched magnitude and trends quite well and this area was not the focus of the scenarios.

Atlantic City 800-Foot Sand

Maps of potentiometric surface and residuals for the Atlantic City 800-foot sand in spring 2005 and fall 2006 are shown in figures 33 and 34, respectively. Graphs of simulated and observed heads are shown in figure 29B. Simulated and observed water levels in spring 2005 match well, and the heads plot along 1:1 line in figure 29B. Some observed heads in fall 2006 generally plot high along the 1:1 line in figure 29B. These wells are shown in figure 34 in areas along the coast near and north of Ocean City where simulated water



Base from U.S.Geological Survey digital line graph files, 1:24,000

EXPLANATION

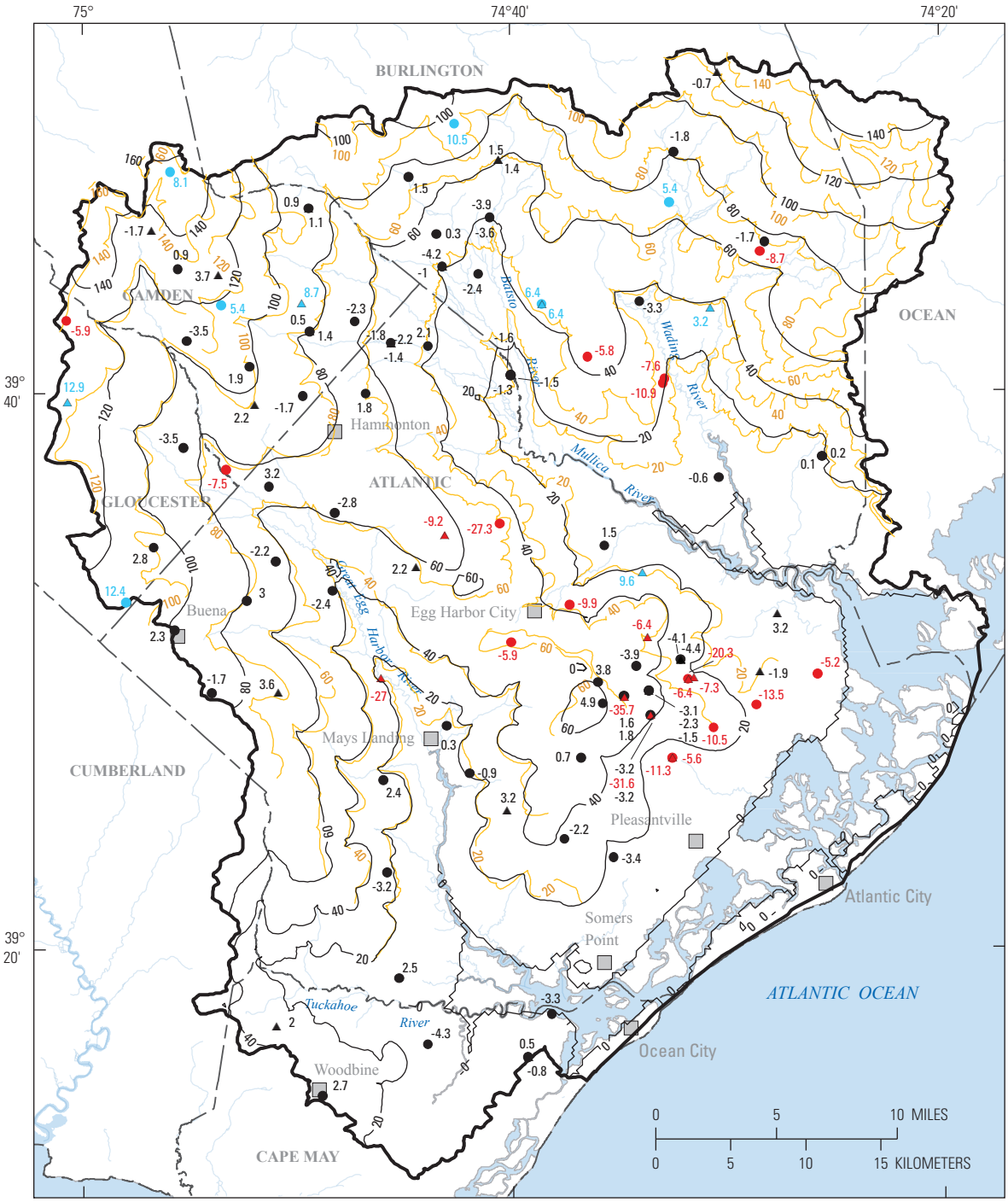
Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

—60— **SIMULATED WATER-TABLE CONTOUR**—Shows altitude of simulated water level. Interval is 20 feet. Datum is National Geodetic Vertical Datum of 1929

—40— **MEASURED WATER-TABLE CONTOUR**—Shows altitude of measured water level. Interval is 20 feet. Datum is National Geodetic Vertical Datum of 1929

RESIDUAL IN LAYER 1	RESIDUAL IN LAYER 3
Less than -5	Less than -5
-5 – 5	-5 – 5
Greater than 5	Greater than 5

Figure 27. Simulated and measured water-level contours and residuals in the Kirkwood-Cohansey aquifer system, southeastern New Jersey, spring 2005.



Base from U.S.Geological Survey digital line graph files, 1:24,000

EXPLANATION

Boundary of Great Egg-Mullica model area representing the Kirkwood-Cohansey aquifer system

–60– **SIMULATED WATER-TABLE CONTOUR**—Shows altitude of simulated water level. Interval is 20 feet. Datum is National Geodetic Vertical Datum of 1929

–40– **MEASURED WATER-TABLE CONTOUR**—Shows altitude of measured water level. Interval is 20 feet. Datum is National Geodetic Vertical Datum of 1929

RESIDUAL IN LAYER 1	RESIDUAL IN LAYER 3
Less than -5	Less than -5
-5 – 5	-5 – 5
Greater than 5	Greater than 5

Figure 28. Simulated and measured water-level contours and residuals in the Kirkwood-Cohansey aquifer system, southeastern New Jersey, fall 2006.

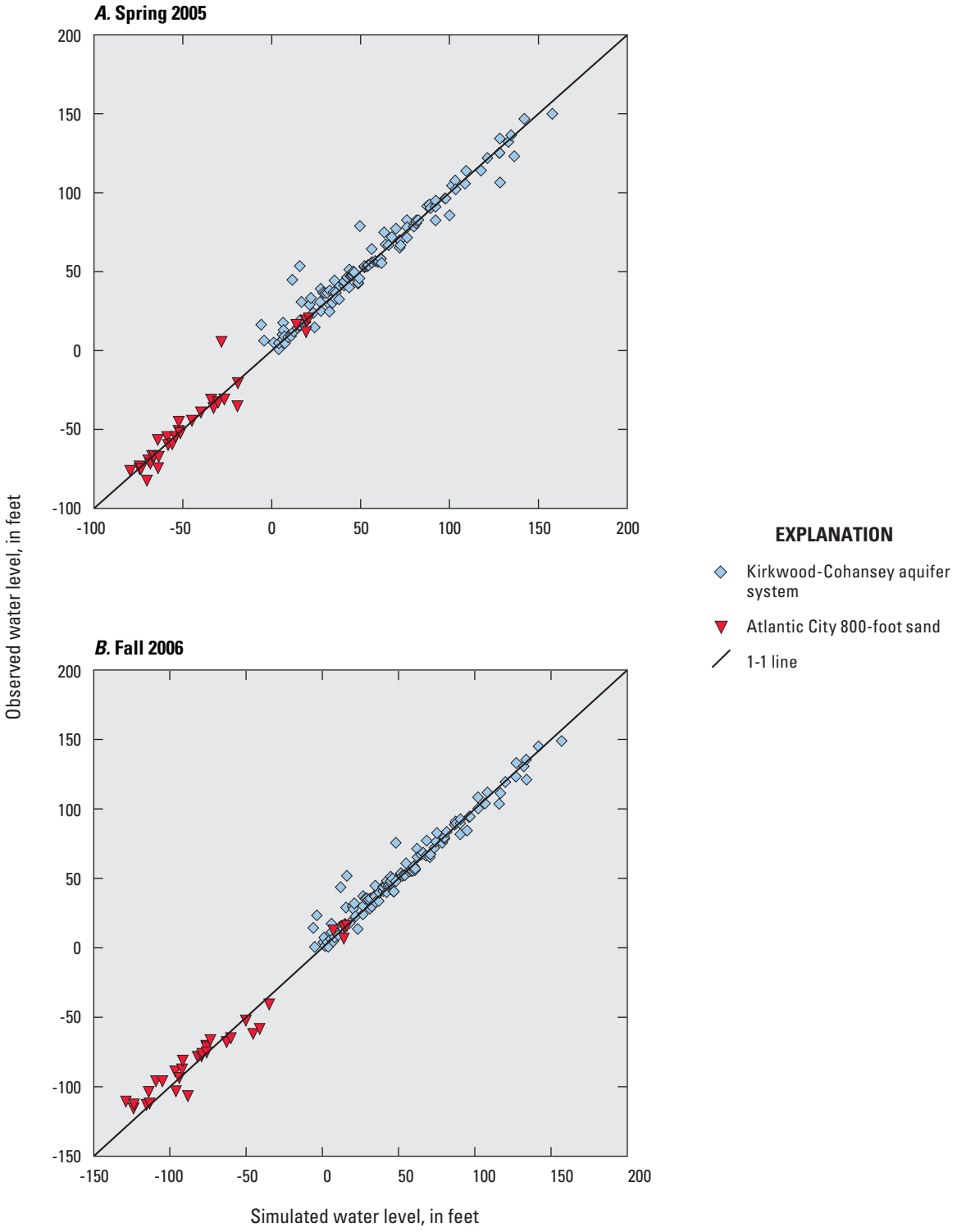


Figure 29. Simulated and observed water levels for the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand, southeastern New Jersey in A, spring 2005 and B, fall 2006.

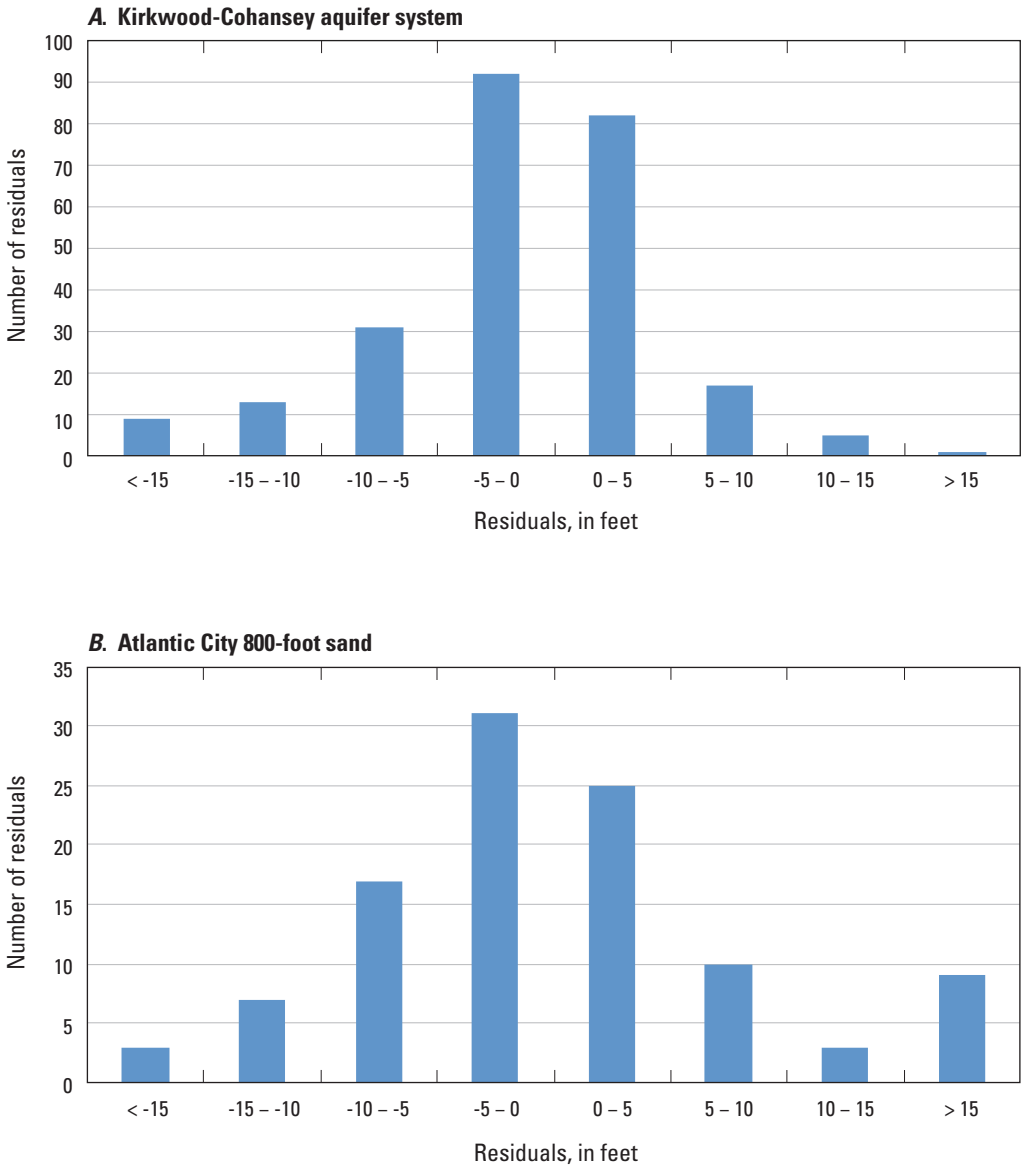


Figure 30. Residuals of water levels for A, Kirkwood-Cohansey aquifer system and B, Atlantic City 800-foot sand, southeastern New Jersey, 2005 and 2006. (<, less than; >, greater than)

levels are as much as 10 ft lower than observed heads. For spring 2005, these water levels match fairly well. A close match between simulated and observed water levels in this area is one of the main reasons that the calibrated vertical hydraulic conductivity of the Atlantic City 800-foot sand is low. Hydrographs of wells in the Atlantic City 800-foot sand are shown in figure 32. The largest residuals are for the Burke Ave Obs well (010702), which is located near the area of simulated low heads in fall 2006. In well 010702, simulated heads are higher than observed heads, but simulated water levels at many wells located south of this location are lower than observed water levels. Well 010703 is located near wells 010775 and 010776 in the Kirkwood-Cohansey aquifer system. Mean errors for residuals for the wells with long-term hydrographs and completed in the Atlantic City 800-foot sand are shown in table 10. The mean errors are reasonable especially given the seasonal water-level fluctuations at these wells. The histogram of residuals in the Atlantic City 800-foot sand in spring 2005 and fall 2006 is shown in figure 30B. Most of the residuals fall within the +/- 5-foot range, and the distribution of residuals does not indicate any systematic bias in simulated heads.

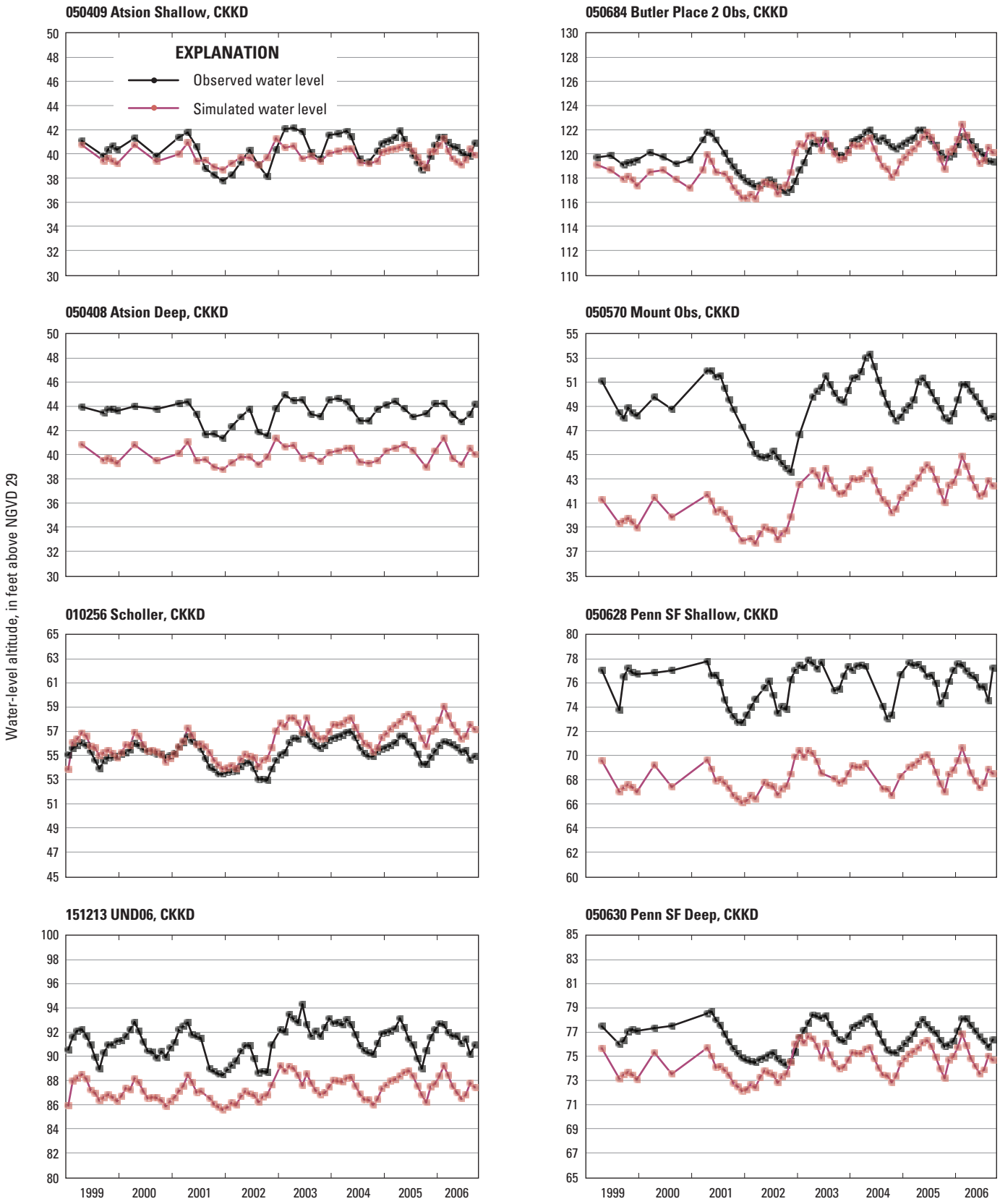


Figure 31. Hydrographs of simulated and observed water levels in selected wells updip in the Kirkwood-Cohansey aquifer system, southeastern New Jersey, 1999–2006.

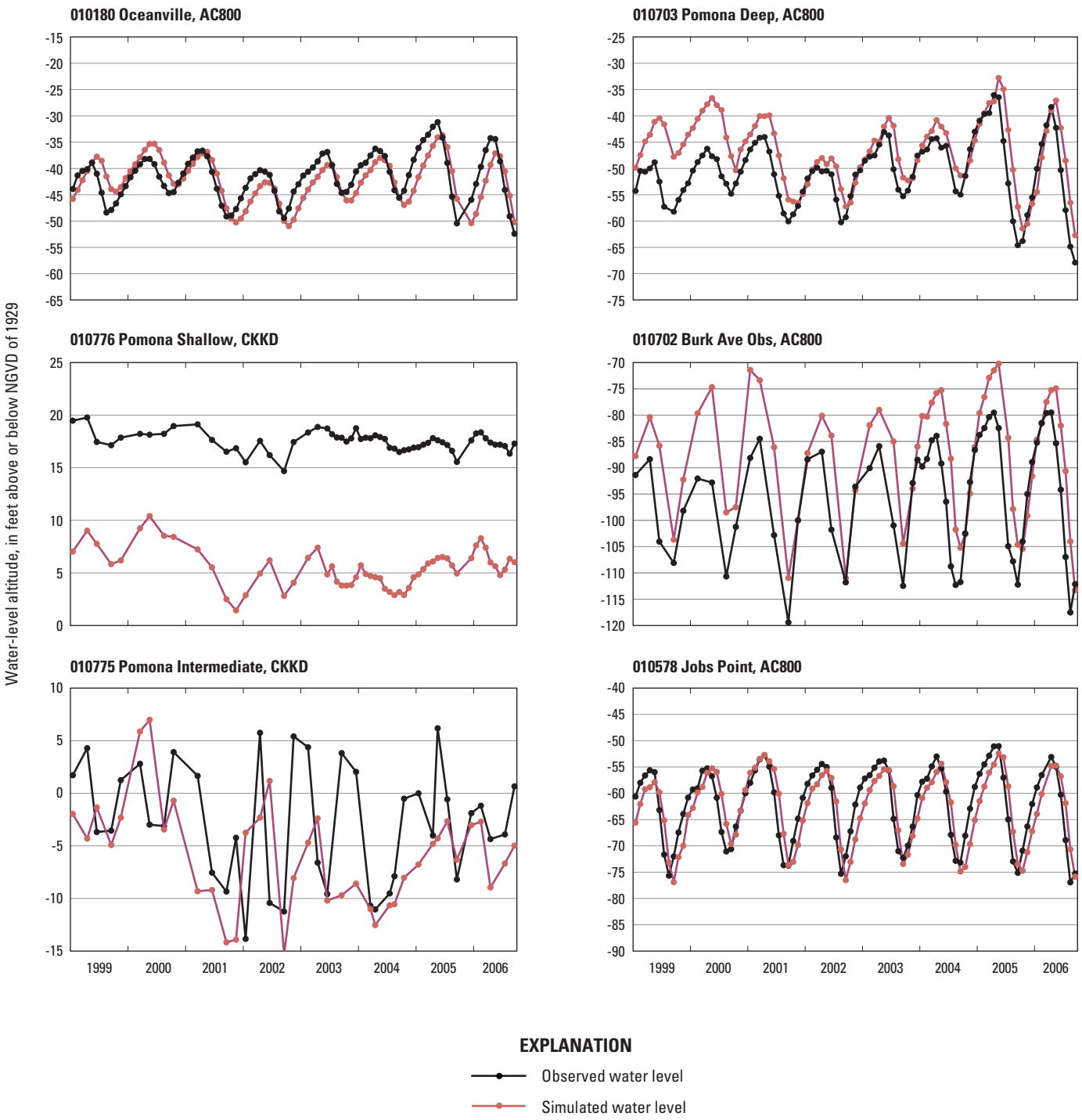


Figure 32. Hydrographs of simulated and observed water levels in selected wells downdip in the Kirkwood-Cohansey aquifer system and Atlantic City 800-foot sand, southeastern New Jersey, 1999–2006.

Table 10. Statistics for residuals at wells with long-term hydrographs, southeastern New Jersey.

[USGS, US Geological Survey, Aquifer: 122KRKDL, Atlantic City 800-foot sand; 121CKKD, Kirkwood-Cohansey aquifer system; RMS, Root mean square error]

USGS well number	Aquifer	Number of observations	Mean error	Mean absolute error	RMS
010180	122KRKDL	102	-0.7	2.7	3.2
010578	122KRKDL	104	-0.9	3.5	4.1
010702	122KRKDL	62	7.8	8.3	10.3
010703	122KRKDL	100	4.2	4.7	5.9
Average			2.6	4.8	5.9
010256	121CKKD	105	0.7	1	1.2
010775	121CKKD	43	-2.8	5.3	6.6
010776	121CKKD	63	-12	12	12.1
050408	121CKKD	45	-3.5	3.5	3.6
050409	121CKKD	56	-0.5	0.8	0.9
050570	121CKKD	71	-7.9	7.9	8.1
050628	121CKKD	68	-7.7	7.7	7.8
050630	121CKKD	76	-2.2	2.2	2.4
050684	121CKKD	81	-0.8	1.2	1.5
151213	121CKKD	103	-4	4	4.1
Average			-4.1	4.6	4.8

Calibration to Base-Flow Values

Hydrographs of simulated base flows were compared to hydrographs of observed base flows at streamgaging stations and at low-flow partial-record stations. Simulated base-flow values were calculated for each stress period from 1998 to 2006 by adding the simulated values from the RIV and DRN packages model output. Hydrographs of simulated and observed base flows are shown in figures 35 to 37. The subbasins in which the streamgaging stations are located are shown in figure 18. Statistics for the monthly residuals for the subbasins with base-flow hydrographs shown in figures 35 to 37 are listed in table 11. The mean error and mean absolute error give an indication of the mean differences between the simulated and observed base flows. The root mean square (RMS) error is the square root of the average of the squared differences. The largest RMS errors are associated with the large streamflows that occur in the large subbasins. A 10-percent difference in a large subbasin will result in a larger RMS error than a 10-percent difference in a small subbasin. For subbasins where winter base flow is high, the matching of simulated and observed base-flow hydrographs was focused on the lower base-flow part of the hydrograph so that the model was best calibrated to low-flow conditions in the summer. Base-flow hydrographs for the six streamgaging stations within the study area are shown in figure 35. Streamgaging stations used for calibrating simulated base flows are located in the updip part of the study area because the large streams in the downdip part are tidal. Observed base flows in the updip part of the modeled area are considered to be the best data for use in calibration. Note that the hydrograph at the Batsto at Batsto streamgage (01409500) extends only through 2004 because the streamgage was discontinued. Base-flow hydrographs for the updip subbasins are shown in figure 36. Most of the simulated and observed hydrographs match fairly well and have moderate to small RMS errors. The hydrograph for station 01411170 (fig. 36; table 11) has the highest RMS error of all stations. This high RMS error is primarily due to high observed base flow during the winters of 2003 to 2006 that occurred in several subbasins in the study area, but the RMS stands out in this subbasin because of the larger flows and residuals. Base-flow hydrographs for the downdip subbasins are shown in figure 37. Because, in general, these are small subbasins with small flows, the RMS values are also small.

In general, the simulated base flows match the observed base flows in all 22 hydrographs fairly well. Complicated surface-water drainage systems result in some observed base-flow values that are anomalous and were not simulated in the model. The observed base flows in Sleeper Branch at Batsto (01409406) are lower than would be expected on the basis of the size of the subbasin, whereas observed base flows at the Mullica near Batsto station (01409400) are slightly higher than would be expected. This difference is due to diversion ditches that contribute substantial flow from the Sleeper Branch into the Mullica River Basin (U.S. Geological Survey, 2007). The hydrographs for the Batsto at Batsto station (01409500) match well, whereas the simulated hydrograph for Mullica near Batsto 01409400 is low, and the simulated hydrograph for Sleeper Branch (01409406) is high. Instead of attempting to match simulated and observed base flows at each subbasin, which would require more zones for parameters in the model, relatively uniform values for parameters were used throughout the model. Hydrographs at adjacent subbasins were calibrated to obtain the best overall fit for the area. During calibration, matching the fit at the six streamgaging stations was given priority over matching the fit at the low-flow partial-record stations. The model calibration using the base-flow hydrographs was most influenced by the streambed vertical hydraulic conductivities and recharge.

Sensitivity Analysis

A sensitivity analysis was conducted on the calibrated model to evaluate the relative effects of the various parameters. The sensitivity of hydraulic heads and streamflow to the model parameters was calculated using the parameter-estimation software UCODE-2005 (Poeter and others, 2005). Composite scaled sensitivities (CSS) were calculated for all 31 parameters using observed heads from 1998, 2003, 2005, and 2006; the observed heads from the monthly hydrographs for the New Jersey Water-level Monitoring Network sites;

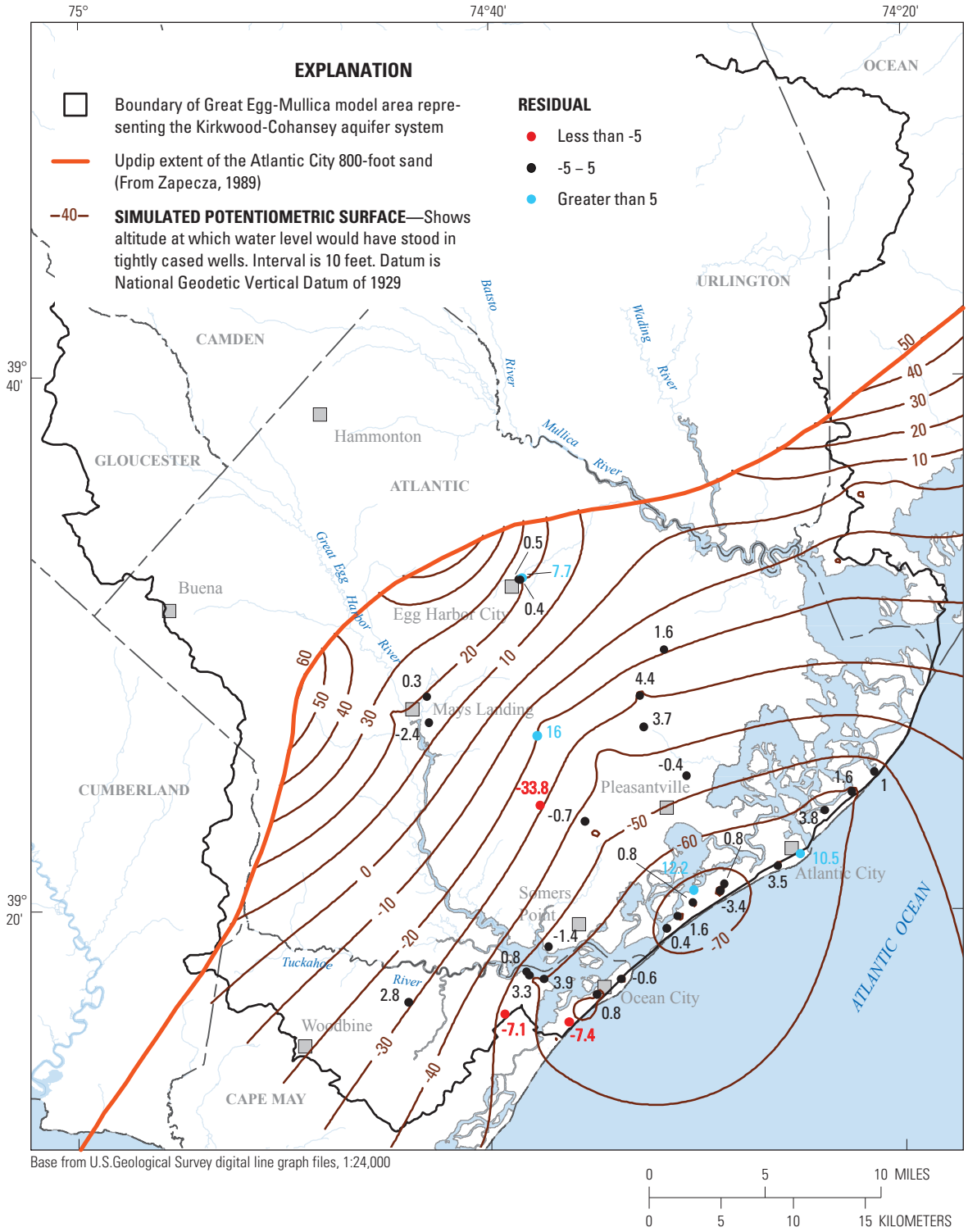


Figure 33. Simulated potentiometric surface of the Atlantic City 800-foot sand and water-level residuals, southeastern New Jersey, spring 2005.

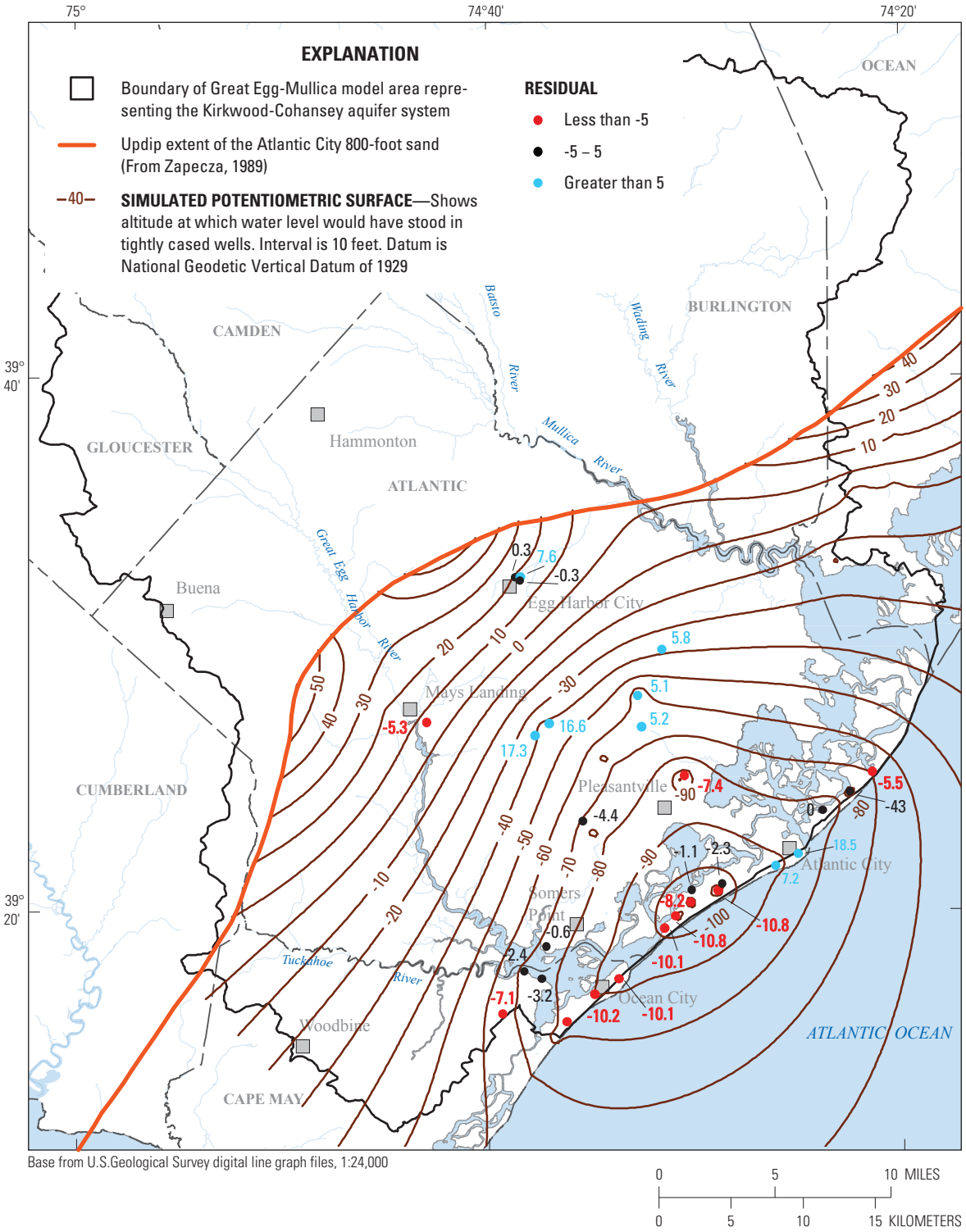


Figure 34. Simulated potentiometric surface of the Atlantic City 800-foot sand and water-level residuals, southeastern New Jersey, fall 2006.

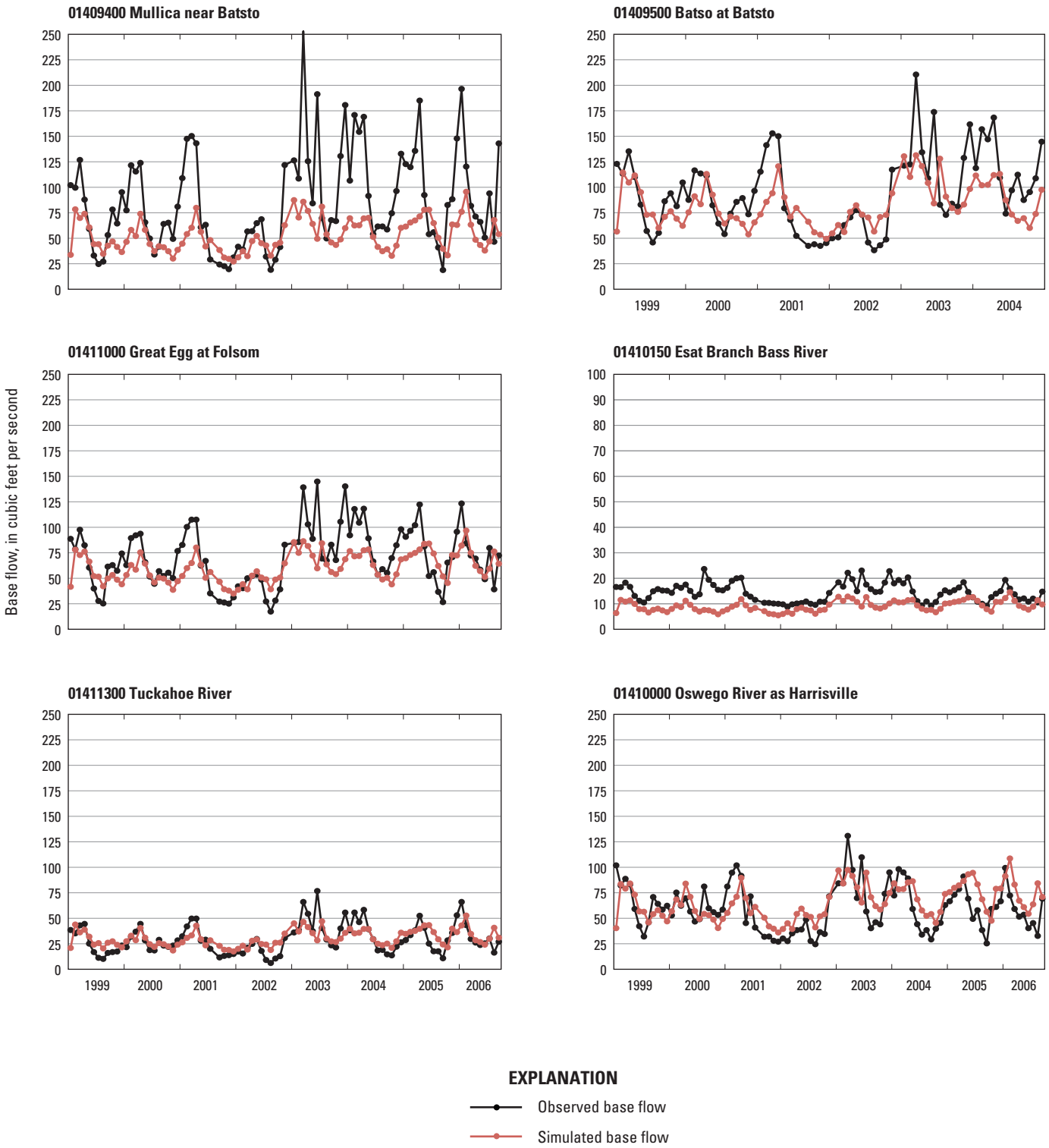


Figure 35. Hydrographs of simulated and observed base flows at selected streamgaging stations, southeastern New Jersey, 1999–2006.

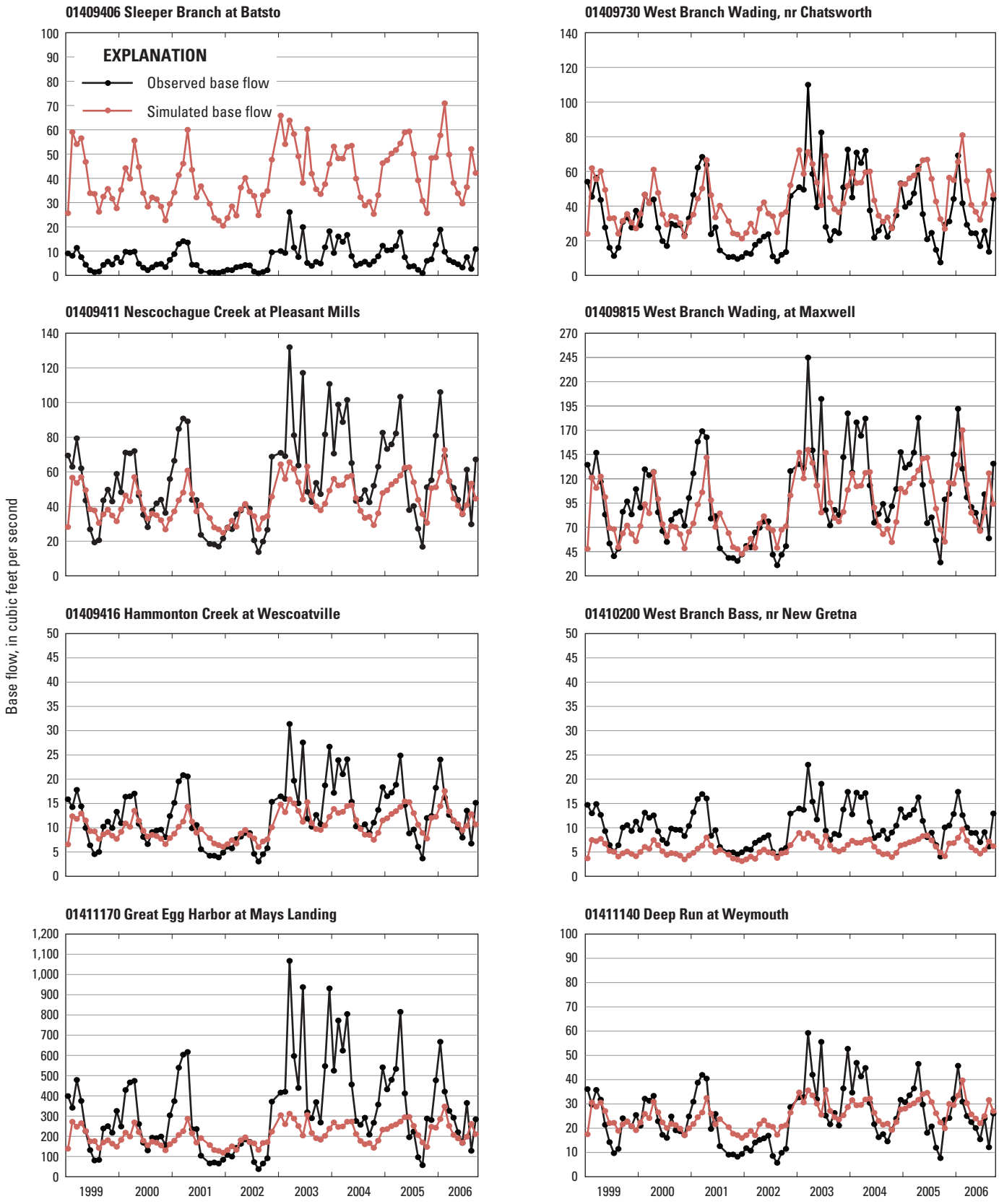


Figure 36. Hydrographs of simulated and observed base flows at selected updip low-flow partial-record stations, southeastern New Jersey, 1999–2006.

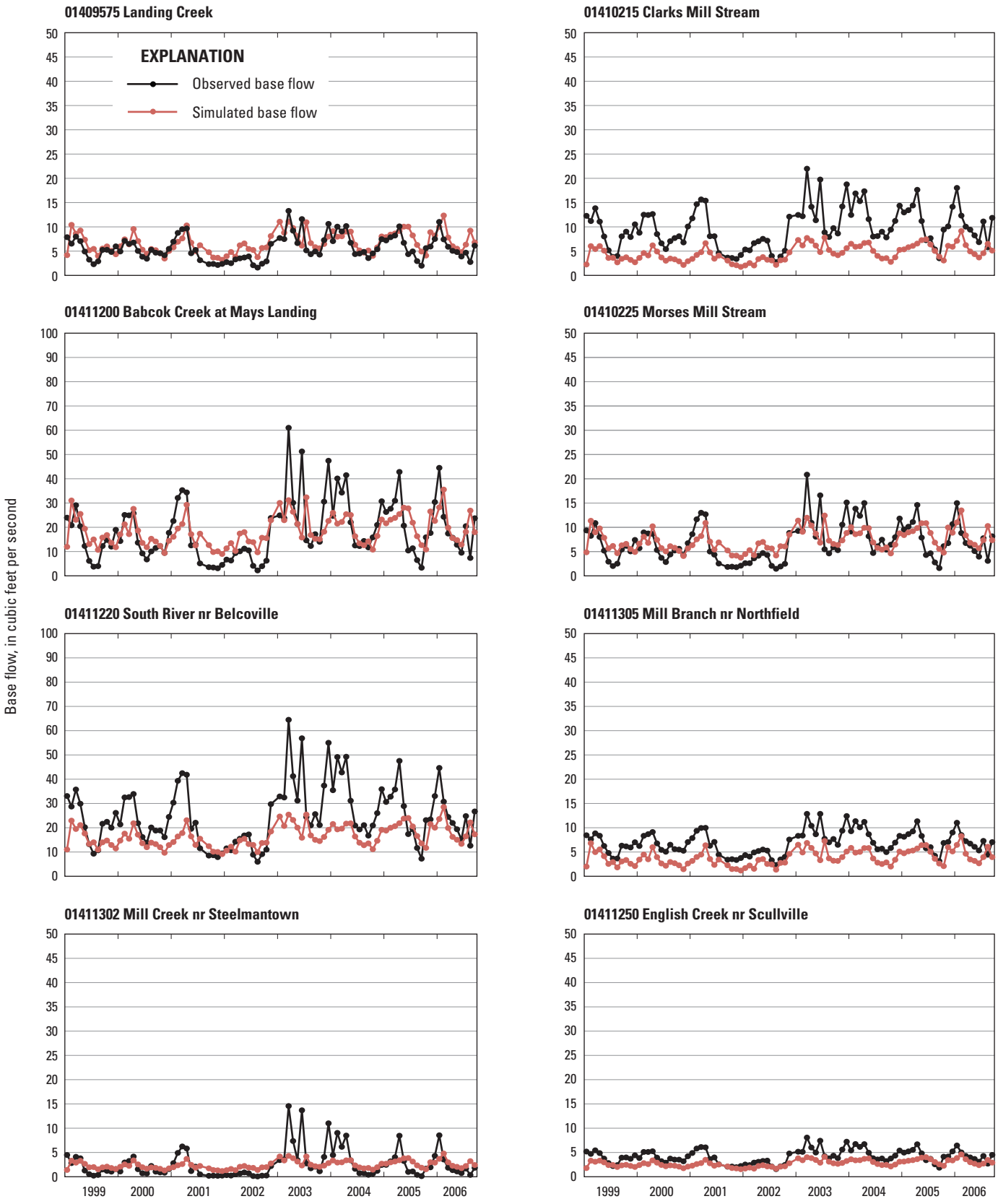


Figure 37. Hydrographs of simulated and observed base flows at selected downdip low-flow partial-record stations, southeastern New Jersey, 1999–2006.

Table 11. Statistics for base-flow residuals at surface-water stations, southeastern New Jersey.

[ft^3/s, cubic foot per second; Type: GS, gaging station; LF, low-flow partial-record station; RMS, Root mean square error]

Station number	Station name	Type	Drainage area, in square miles	Mean error (ft^3/s)	Mean absolute error (ft^3/s)	RMS (ft^3/s)
01409400	Mullica River near Batsto NJ	GS	46.7	-51.3	52.2	69.7
01409406	Sleeper Branch at Batsto NJ	LF	36.2	17.3	17.3	18.2
01409411	Nescochague Creek at Pleasant Mills NJ	LF	43.7	-24.1	25.6	33.7
01409416	Hammonton Creek at Wescoatville NJ	LF	9.57	-7.2	7.3	8.9
01409500	Batsto River at Batsto NJ	GS	67.8	-32.5	35.0	47.1
01409575	Landing C at Phila Ave at Egg Harbor City NJ	LF	4.86	-5.2	5.2	5.8
01409730	West Branch Wading River near Chatsworth NJ	LF	44.8	4.9	15.3	19.5
01409815	West Branch Wading River at Maxwell NJ	LF	85.9	-24.7	34.0	46.4
01410000	Oswego River at Harrisville NJ	GS	72.5	-2.4	16.2	22.5
01410150	East Branch Bass River near New Gretna NJ	GS	8.11	-0.8	3.2	4.6
01410200	West Branch Bass River near New Gretna NJ	LF	6.54	-5.2	5.3	6.3
01410215	Clarks Mill Stream at Port Republic NJ	LF	8.61	-8.1	8.2	9.3
01410225	Morses Mill Stream at Port Republic NJ	LF	8.25	-1.7	3.9	5.1
01411000	Great Egg Harbor River at Folsom NJ	GS	57.1	-28.4	30.9	38.4
01411140	Deep Run at Weymouth NJ	LF	20	-8.2	10.0	13.9
01411170	Great Egg Harbor R at Mays Landing NJ	LF	205	-185.6	206.3	290.3
01411200	Babcock Creek at Mays Landing NJ	LF	20	-9.8	11.3	15.6
01411220	South River near Belcoville NJ	LF	20.4	-13.8	13.9	18.1
01411250	English Creek near Scullville NJ	LF	3.8	-2.1	2.3	2.6
01411300	Tuckahoe River at Head of River NJ	GS	30.8	-13.2	14.3	21.4
01411302	Mill Creek near Steelmantown NJ	LF	3.82	-3.6	3.6	6.7
01411305	Mill Branch near Northfield NJ	LF	7.47	-3.8	4.5	5.2
Average				-18.0	23.4	31.5

and the observed base flows from the monthly hydrographs. The composite scaled sensitivities are shown in figure 38A. These CSS values show, overall, how sensitive all the observations in the model are to changes in each of the parameters. The parameters with the largest CSS values are the horizontal hydraulic conductivities for the Atlantic City 800-foot sand (*ac800k*) and the deep part of the unconfined Kirkwood-Cohansey aquifer system (*KW-k*). The next four most sensitive parameters are a mixture of vertical/horizontal hydraulic conductivities for the Kirkwood-Cohansey aquifer system (*cnsy-k1*) and recharge in three of the four areal recharge zones (*rechz4*, *rechz3*, and *rechz1*). The hydraulic conductivity of the Kirkwood-Cohansey aquifer system downdip (*cnsy-k2* and *cnsy-k3*) and the recharge in the southern part of the study area (*rechz2*) are less sensitive than the other parameters of the same type. Normalized group composite scaled sensitivities for observation groups show the relative sensitivities of each parameter to the different types of observation data (Kirkwood-Cohansey water levels, Atlantic City 800-foot sand water levels, or base-flow observations) (fig. 38B). Figure 38B shows normalized group composite scaled sensitivities. The normalized CSS for each group of observations is the CSS for the group squared, times the number of observations for the group, divided by the total number of observations. When the group CSS values are normalized in this way, the total of the CSS values for the three groups (Kirkwood-Cohansey water levels, Atlantic City 800-foot sand water levels, and base-flow observations) equals the CSS values for the entire

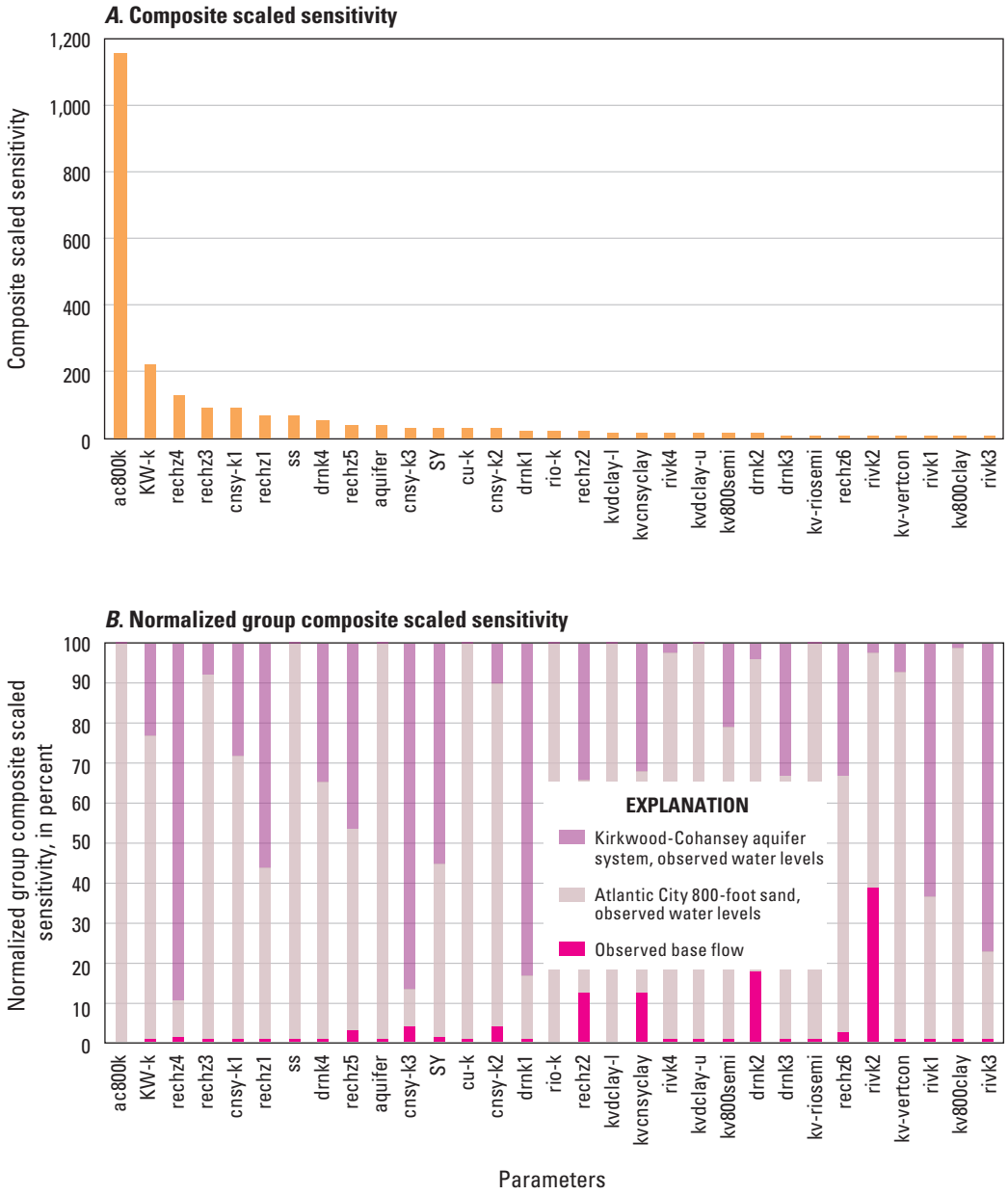


Figure 38. A, composite scaled sensitivities of model parameters and B, normalized group composite scaled sensitivities for the Great Egg–Mullica model. (Parameters are defined in table 8)

set of observations. The parameters *ac800k, SS, kv-riosemi, rio-k*, *cu-k*, *kvdclay-l*, *kvdclay-u*, and *kv800clay* are almost completely controlled by observed heads in the Atlantic City 800-foot sand. Parameters that are at least 50 percent influenced by the observed heads in the unconfined aquifer are *rechz4*, *drnk1*, *SY*, *cnsy-k3*, *rivk1*, *rivk3*, and *rechz1*. Twenty-four of the 31 parameters are affected more by observed heads in the confined aquifers than by observed heads in the unconfined system. This is probably due to the updip connection between the two major aquifers and the fact that the source of most of the water to the Atlantic City 800-foot sand is the updip part of the Kirkwood-Cohansey aquifer system.

Flow Budgets

Groundwater flow budgets were created for spring 2005 and fall 2006 and for the entire model calibration period 1998 to 2006. Budgets are shown for the confined Atlantic City 800-foot sand and for the entire Kirkwood-Cohansey aquifer system. The flow budgets for spring 2005 and fall 2006 used for model calibration are shown in figure 39. These graphs are used for comparison of the contributions from different parts of the groundwater flow system during the spring and fall. Note that scales for the budgets for the unconfined and confined aquifer system are different. Much more water

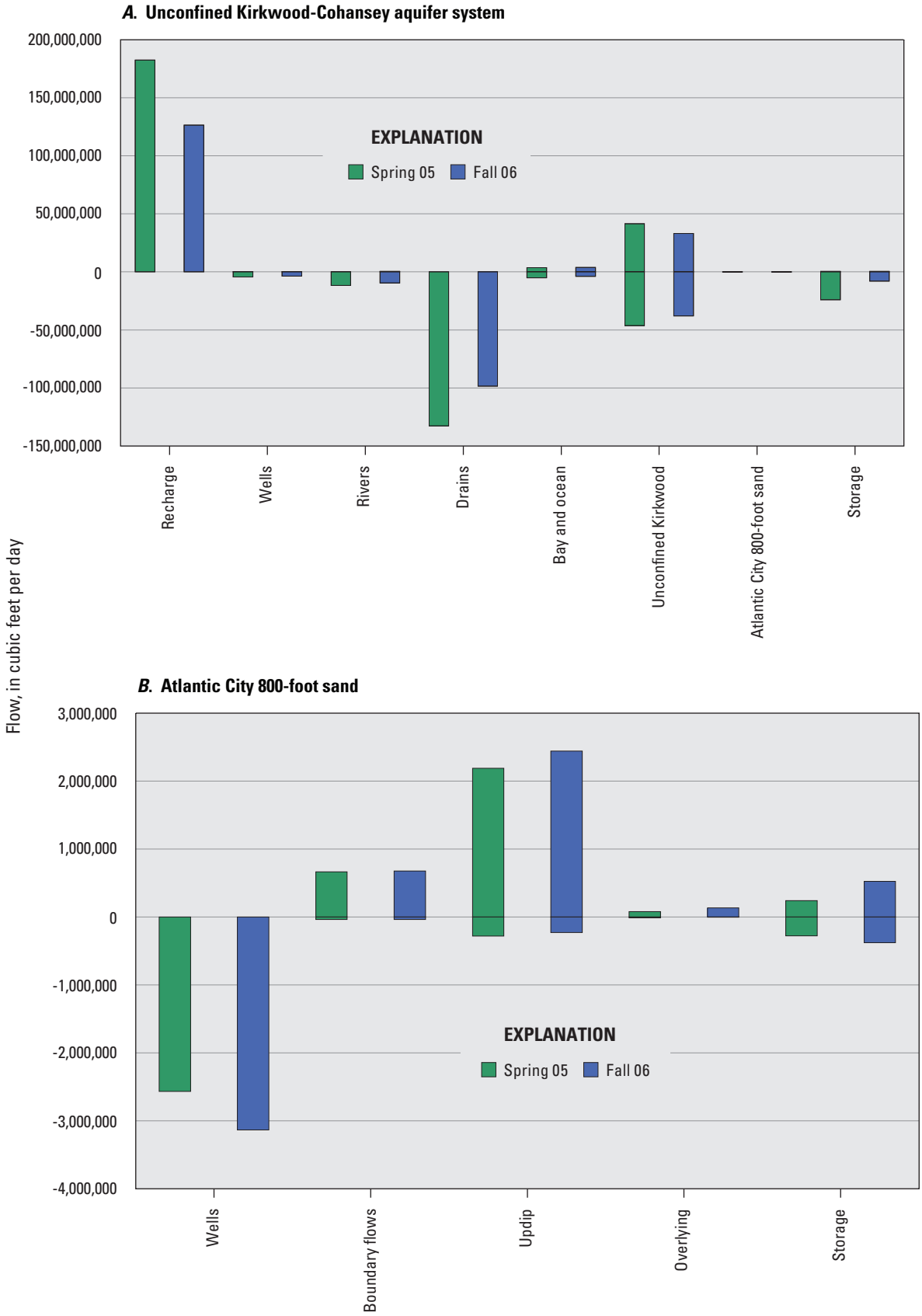


Figure 39. Simulated flow budgets for the A, unconfined Kirkwood-Cohansey aquifer system and B, Atlantic City 800-foot sand, southeastern New Jersey, spring 2005 and fall 2006.

moves through the unconfined aquifer system than through the Atlantic City 800-foot sand. The flow component Atlantic City 800-foot sand in the Kirkwood-Cohansey aquifer system budget is equivalent to the sum of the flow components Updip and Overlying in the Atlantic City 800-foot sand budget. The Atlantic City 800-foot sand component represents flow from the unconfined Kirkwood-Cohansey aquifer to the confined Atlantic City 800-foot sand and is a minor part of the flow budget for the unconfined aquifer. However, the components Updip and Overlying in the Atlantic City 800-foot sand budget represent most of the flow into the confined aquifer. The major input to the flow budget for the Kirkwood-Cohansey aquifer system is the Recharge component. Most of the recharge received is discharged to Drains or Rivers components. The net discharge to the Wells component is relatively small. The flows into and out of constant heads represent flow to or from constant head cells representing the Bay and (or) Ocean components in the model. The Unconfined Kirkwood component represents flow from the shallow Kirkwood-Cohansey aquifer system into the deep layers 7 to 9 that represent the Kirkwood Formation. Most of the water that moves into the Kirkwood Formation then flows back to the upper model layers. A small portion of the water that flows into the Kirkwood Formation goes to the confined Atlantic City 800-foot sand. Recharge is greater in May 2005 than in September 2006, and the flow to the sink components (flow less than zero) is also reduced in the fall. The major input into the Atlantic City 800-foot sand is flow from the unconfined Kirkwood-Cohansey aquifer system updip (Updip component). The Boundary Flows component represents boundary flows into the confined aquifer from both lateral and vertical flow boundaries. This is a substantial source of water to the aquifer in the study area. The major outflow from the confined aquifer is discharge to pumped wells. Withdrawals from the aquifer are greater in the fall than in the spring to meet higher water demands. The flow from the updip unconfined aquifer is also greater in the fall.

The simulated-transient flow budgets for 1999 to 2006 are shown in figure 40. These graphs show the transient effects of the major components of the flow system, including changes in storage during the calibration period. In the Kirkwood-Cohansey aquifer system, recharge varied monthly and was greatest in the winter to early spring. Flow out to drains also was highest at these times (fig. 40A). Water is released into the aquifer from storage in the summer when recharge is low, and water goes into storage from the aquifer in the summer. In the Atlantic City 800-foot sand, withdrawals (Wells) are seasonal and are greatest in the summer and fall (fig. 40B). Flow released from storage also was greatest in the summer. Flow into storage occurred in the winter. Flow into the aquifer from updip and overlying parts of the Kirkwood-Cohansey aquifer system varied slightly throughout the year but did not change as quickly as the storage.

Limitations of the Model

Before the results of the groundwater flow model can be used effectively, it is important to understand the model limitations. The accuracy of the model is limited because of the simplification of components of the aquifer system, spatial and temporal discretization, and assumptions inherent in the governing equations used in the model. Model accuracy is also limited by the number of model layers, accuracy of boundary conditions, accuracy of model input data, distribution of zoned parameters, and parameter sensitivity. Although a model may be calibrated to the available data, the particular values for the simulated parameters may not form a unique representation of the system.

The purpose of the Great Egg-Mullica model is to represent the groundwater flow system in the Great Egg Harbor and Mullica River Basins in the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand and to represent the interaction between the two flow systems. Therefore, a regional scale was used for the model. The size of the model grid cells is adequate for a regional representation of streams, but the model is not intended to simulate detailed groundwater/surface-water interactions. Additionally, a generalized hydrogeologic framework was used to represent the system. Some clay units that may be local confining units and may locally affect the groundwater flow system were not included.

The boundaries of the model were selected to be distant from the main area of interest in Atlantic County and from the area where the confined Atlantic City 800-foot sand connects with the unconfined Kirkwood-Cohansey aquifer system. The assumption that the groundwater flow boundaries coincide with the surface-water boundaries of the Great Egg Harbor and Mullica River Basins is appropriate given the main area of interest. However, care is needed when using the model results for areas near the updip boundaries of the subbasins, even though the heads were simulated reasonably well in these areas. The boundaries for the confined Atlantic City 800-foot sand were taken from the New Jersey RASA model, so some limitations of that model affect the simulation of the boundaries of this model. Because the RASA model was temporally discretized at an annual scale, the boundary flows into the Great Egg-Mullica model may not be representative of actual seasonal changes in these flows. Boundary flows into the model may be smaller than actual flows during the summer months because the RASA model uses annual withdrawals that are smaller than the heavy summer withdrawals in the area. This may be the reason simulation of the cone of depression south of Atlantic City in the Atlantic City 800-foot sand was difficult. Because the RASA model does not include saltwater intrusion and the saltwater was not simulated in the Great Egg-Mullica model, the downdip boundary of the Atlantic City 800-foot sand offshore is uncertain. For the simulation of future scenarios, it was assumed that land use and climatic conditions remain the same as those during the model calibration period.

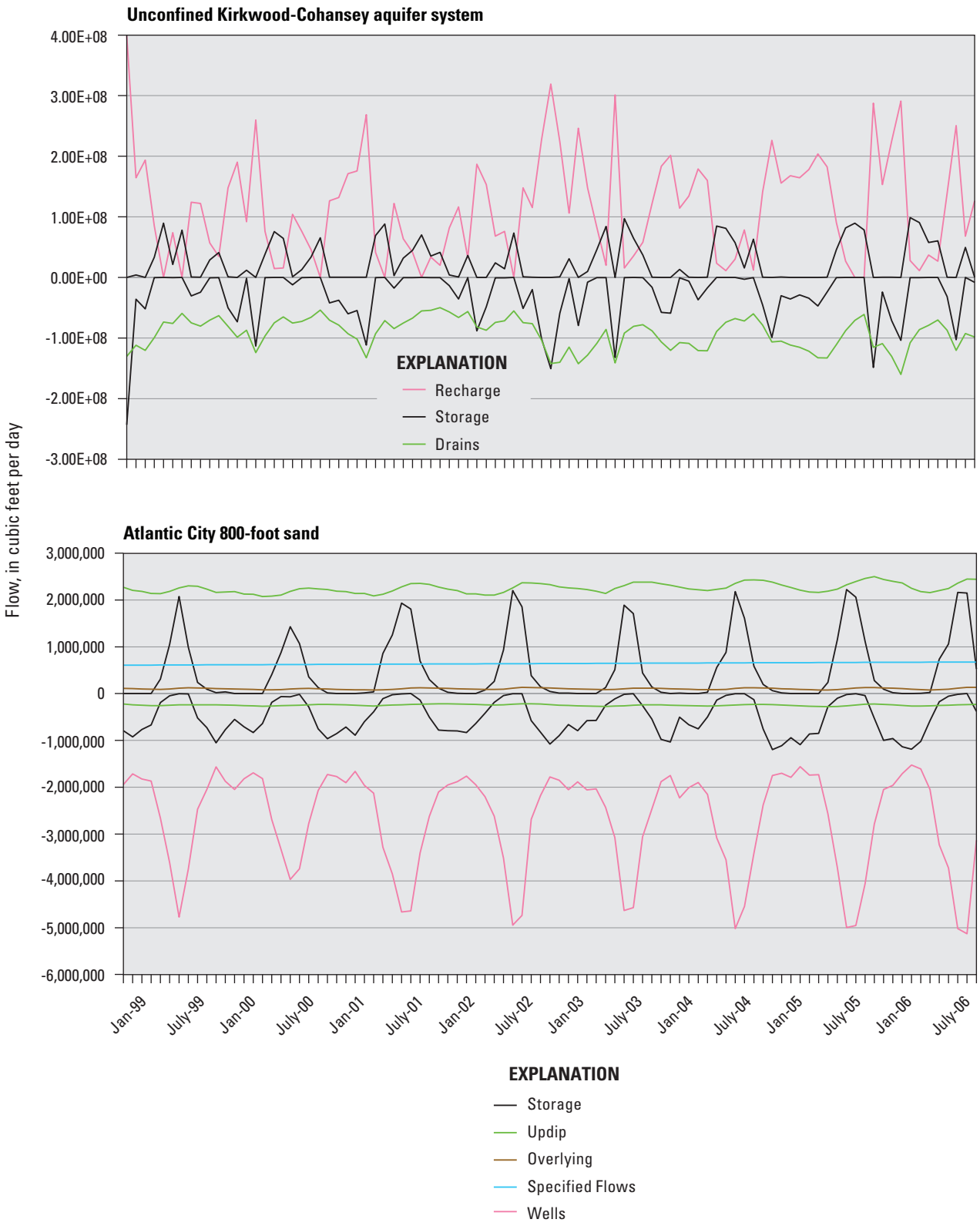


Figure 40. Simulated transient flow budgets for the A, unconfined Kirkwood-Cohansey aquifer system and B, Atlantic City 800-foot sand, southeastern New Jersey, 1999–2006.

Simulation and Results of Withdrawal Scenarios

Simulations of base-flow depletion were conducted for several scenarios and results were compared with base-flow depletion criteria characterized as part of this study to determine where and when base-flow deficits may be occurring or may be expected to occur in the future. Results of the simulations were evaluated using Hydrologic Unit Code 11 (HUC11) subbasins delineated within the study area.

The locations of the HUC11 subbasins are shown in figure 41. The first 6-digits of the HUC designate the region, major river, and accounting unit, and are the same (020403) for all HUCs in the study area. The next two digits represent a subdivision of the accounting unit; 01 represents the Mullica River Basin, and 02 represents the Great Egg Harbor River Basin. The last three digits represent the watershed. The interaction between HUC11 subbasins and the underlying Atlantic City-800-foot sand is shown in figure 41 as updip, mixed, and downdip. The red line on the map in figure 41 shows the extent of the confining unit overlying the Atlantic City 800-foot sand. Subbasins through which this red line passes are designated "mixed." The unconfined Kirkwood-Cohansey aquifer system underlies parts of some subbasins, and where the Atlantic City 800-foot sand is present, parts of subbasins are underlain by confined and unconfined aquifers. The subbasins in the northern part of the study area are designated "updip," and they are entirely underlain by the unconfined Kirkwood-Cohansey aquifer system. In the eastern part of the study area subbasins are designated "downdip." These subbasins are underlain by the shallow flow system within the Kirkwood-Cohansey aquifer system. These designations were made based on the results of the scenario simulations and represent where the model behaved in a similar manner. The interaction between the Kirkwood-Cohansey aquifer system and the confined Atlantic City 800-foot sand beneath the mixed subbasins is an important finding of these simulations. The terms "updip," "downdip," and "mixed" are used throughout this section to discuss the simulation results.

Approach

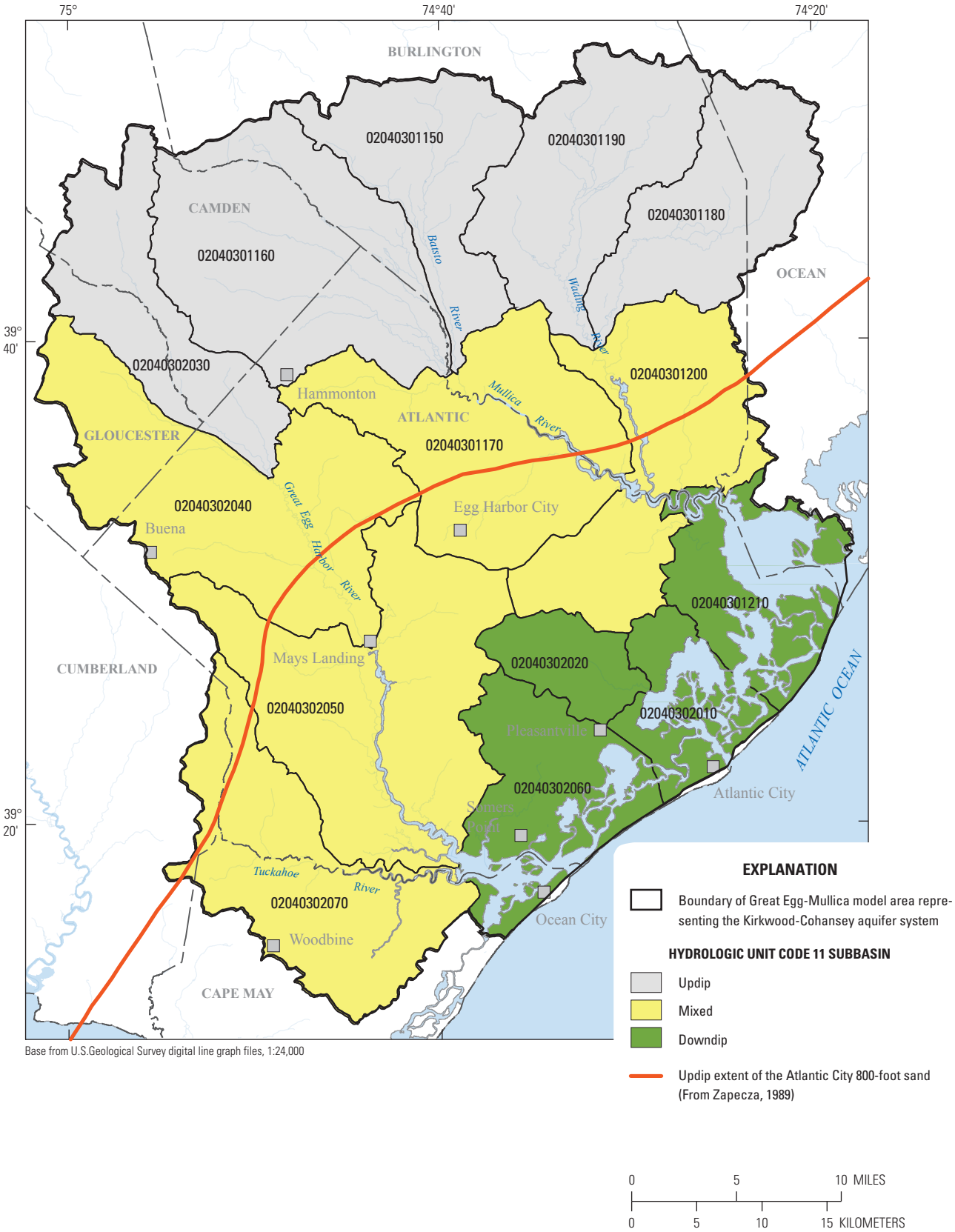
Seven scenarios were simulated to assess base-flow depletion that could occur from different groundwater withdrawal situations (table 12). Scenario 1 represents conditions from 1998 to 2006 if there were no groundwater withdrawals. Scenarios 2 to 4 represent average 1998–2006 withdrawals, full-allocation withdrawals, and withdrawals projected for 2050 demand. These scenarios are intended to identify subbasins where deficits may already be occurring or where deficits may occur under future conditions; these scenarios are referred to as the basic scenarios. The final three scenarios (5–7) are variations of the Average, Full Allocation, and 2050 Demand scenarios for which the withdrawals were modified sequentially to represent management strategies that attempt to eliminate the base-flow deficits. For scenarios 2 to 7, the base-flow depletion was compared with monthly criteria determined by NJDEP. Base-flow depletion was calculated for each scenario by subtracting the base flow for each HUC11 subbasin from the base flow that would have occurred during the simulation period had there been no groundwater withdrawals. HUC11 subbasins and time periods when the base-flow depletion is greater than the monthly available water are considered to be in deficit.

Table 12. Scenarios simulated using the Great Egg-Mullica model.

Scenario	
1	No withdrawals
	Basic—current and future conditions
2	Average
3	Full Allocation
4	2050 Demand
	Adjusted—withdrawals adjusted to eliminate deficits
5	Adjusted Average
6	Adjusted Full Allocation
7	Adjusted 2050 Demand

Simulation of the final three scenarios (5–7) is an attempt to resolve deficits by sequentially simulating three alternative management approaches; these scenarios are referred to as the adjusted scenarios. The three approaches are designated as: Tier 1, moving withdrawals to the deeper part of the Kirkwood-Cohansey aquifer; Tier 2, all changes from Tier 1 and shifting demand seasonally between shallow and deep aquifers for any subbasins still in deficit (seasonal-conjunctive use); and Tier 3, all changes from Tier 1 and Tier 2 plus reduction of withdrawals for any subbasins still in deficit. Simulations of these approaches provide a conceptual understanding of the management benefits these approaches could achieve.

Monthly simulations from 1998 to 2006 were used for the scenarios. This time span includes a generally dry period from 1999 to 2002 and a wetter period from 2003 to 2006. The dry period from 1999 to 2002 produced streamflows comparable to those that occurred during the 1960s drought, which generally is considered to be the drought of record for New Jersey, even though the precipitation was less during the 1960s drought. Monthly mean streamflows at streamgaging stations Mullica River near Batsto (01409400) and Great Egg Harbor River at Folsom (01408000), and total monthly precipitation at the Atlantic City Airport, for the 4-year periods 1963 to 1966 and 1999 to 2002 are shown in figure 42. The total precipitation at Atlantic City Airport during the two 4-year periods 1963 to 1966 and 1999 to 2002 were 148.5 inches and 157 inches, respectively. However, the monthly mean streamflows



Base from U.S.Geological Survey digital line graph files, 1:24,000

Figure 41. Location of Hydrologic Unit Code 11 (HUC11) subbasins, southeastern New Jersey.

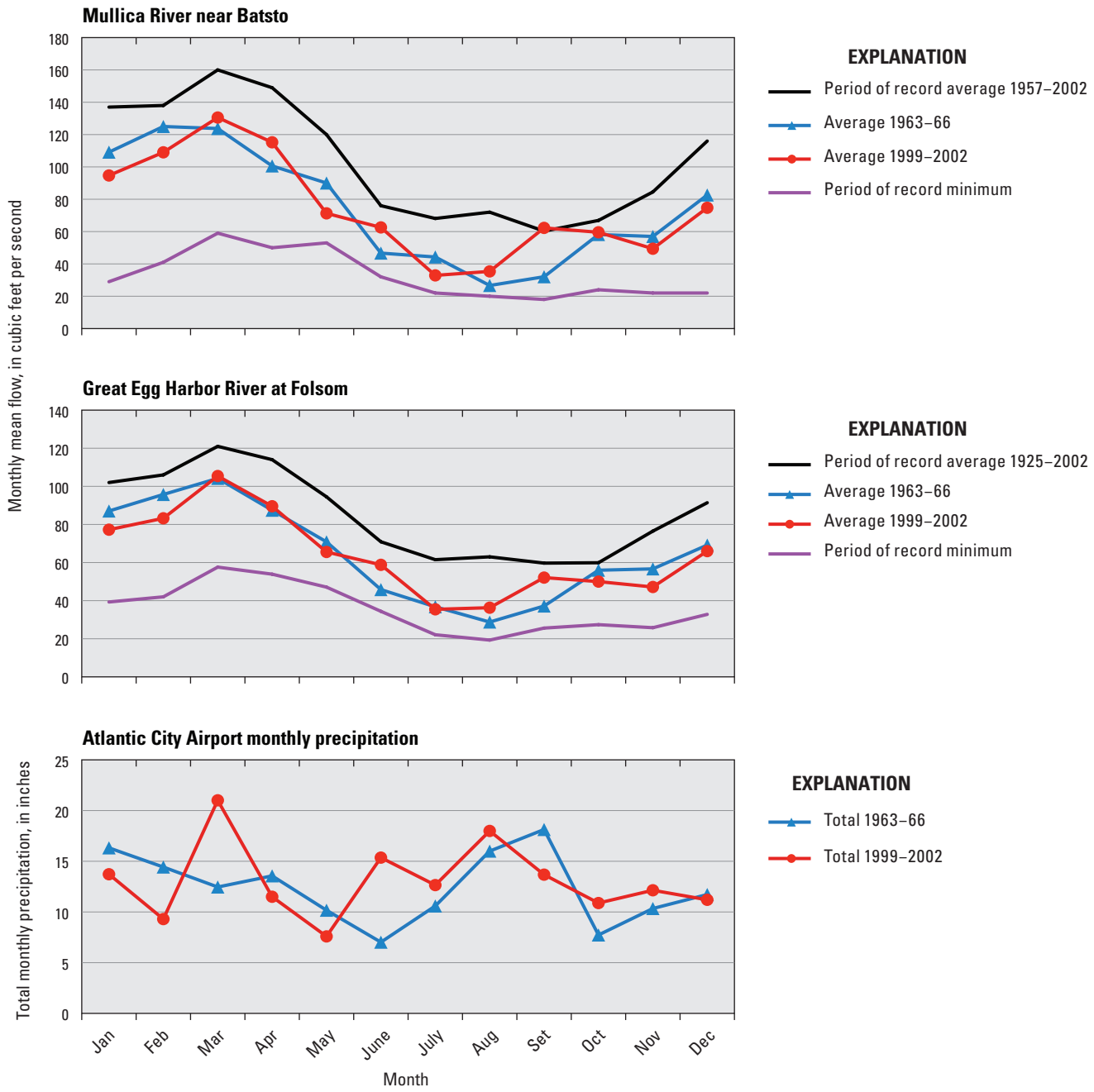


Figure 42. Monthly mean streamflow and total monthly precipitation at selected sites, southeastern New Jersey, for selected periods from 1957 to 2002.

at the two streamgaging stations for the two drought periods are similar. Late summer and fall streamflows during 2001–02 were lower than those during any year in the 1960s drought. The period from 1998 to 2006 represented a strong drought period for the simulation scenarios, which also used groundwater-recharge and water-use datasets that were created for model calibration. For discussion of the scenarios, the years 1998 to 2006 will be referred to as scenarios years 1 to 9. The scenario year and the year of recharge are shown in table 13. Recharge for each year and the ratio of the recharge per year to the largest recharge (2006) are also shown.

Because groundwater withdrawals from the Atlantic-City 800-foot sand differ for each scenario, flows across the model boundaries change, so the RASA model was used to provide boundary conditions for the Great Egg-Mullica model. The RASA model was run using no withdrawal conditions, average 1998–2006 conditions, full-allocation conditions, and 2050 demand conditions for the wells within this study area

Table 13. Scenario years and recharge per year used for simulations with the Great Egg-Mullica model.

[Mgal/d, million gallons per day]

Scenario year	Recharge year	Recharge (Mgal/d)	Recharge ratio
1	1998	7,914	0.65
2	1999	10,204	0.83
3	2000	8,248	0.67
4	2001	7,425	0.61
5	2002	12,135	0.99
6	2003	11,076	0.91
7	2004	9,218	0.75
8	2005	12,233	1
9	2006	10,750	0.88

to match the conditions used in the Great Egg-Mullica model simulations. The RASA model provided fluxes in the Atlantic City 800-foot sand to the Great Egg-Mullica model. The simulations representing Tier 2 (seasonal-conjunctive use) used the same boundary conditions as the respective basic scenarios. The total annual withdrawals used for the RASA model did not change even though the timing of the withdrawals from the Atlantic City 800-foot sand changed because the RASA model is represented using annual stress periods.

Water Use for Scenarios

The calibrated Great Egg Harbor-Mullica model was used to evaluate possible future conditions under several different withdrawal scenarios and groundwater-management approaches. The effects of recent groundwater withdrawals on groundwater flow were simulated using the average annual 1998 to 2006 withdrawals. The long-term effects of groundwater withdrawals on water supply under full-allocation conditions were simulated to evaluate recent groundwater-management policies. Groundwater withdrawals under projected 2050 demand withdrawals were simulated to evaluate possible future groundwater conditions. In order to perform these simulations, estimates of groundwater withdrawals at existing sources were needed. A simplifying assumption was made that future withdrawals would occur at the same locations as existing withdrawals.

The NJDEP Bureau of Water Allocation manages water-allocation permits for users in New Jersey. Public supply and commercial/industrial permits (5,000 and 2,000 series permits) allow the withdrawal of more than 100,000 gallons per day. Diversion limits of 3.1 million gallons per month (Mgal/mo) (up to 37.2 million gallons per year (Mgal/yr)) are assigned for users who have the capacity to divert in excess of 100,000 gallons per day (gal/d) but divert less than that quantity, which is based on monthly average use, under the 10000W series water-use registrations. Permits and registrations also are designated for agricultural users (Ag permits). Limits are specified for all water-allocation permits, which may include more than one source (wells or surface-water intakes). In some cases, allocation limits are assigned for a group of sources within a permit. In order to simulate the Full Allocation scenario, estimates of full-allocation withdrawal rates at individual sources were needed.

Water-allocation data, including withdrawal limits and usage, were supplied by NJDEP. Annual limits were used where they were available. If only monthly limits were available, annual limits were estimated from the monthly limits. For most permits this was done by multiplying the monthly limit times 12. However, for agricultural permits this was not appropriate because withdrawals are made seasonally. Annual limits for simulation of full-allocation conditions for agricultural permits were estimated using the monthly limit times a representative growing season of 3.5 months, based on discussions with NJDEP.

Water demand for the year 2050 for each allocation permit was estimated using several different methods depending on the series of the water-allocation permit. Projected withdrawals for 2050 for each public supply permit (5,000 series) were estimated by the NJDEP using population data from the New Jersey Metropolitan Planning Organization (MPO) municipal population projection data for the drinking-water service areas of the purveyors (Richard Grabowski, New Jersey Department of Environmental Protection, written commun., 2007). Water-demand projections are based on the population growth and withdrawals during 2001–02. Projected 2050 demands for 2,000 and 10,000 series permits were estimated using annual increases in withdrawals of 1.4 and 1.8 percent of 1998–2006 average withdrawal rates, respectively. The NJDEP estimated the 2050 demand for agricultural permits to hold constant at the 1998–2006 average level. This estimate was based on two trends that are expected to continue and create opposite effects on agricultural irrigation, resulting in little net change in irrigation withdrawals. First, the amount of agricultural land is expected to decrease as development continues. Second, however, the percentage of agricultural land that is irrigated is expected to increase and produce more high value crops.

Withdrawals for each well or diversion within the permits were estimated in order to simulate the Full Allocation and 2050 Demand scenarios. The distribution of withdrawals for each scenario was estimated using the distribution of withdrawals for each permit and using recent (2003–05) data. Withdrawals for the year 2005 were used, if available. If data for 2005 were not available, data from 2003 or 2004 were used. These withdrawal data were used to calculate the percentage of withdrawals at each individual well or diversion listed within the permit. This percentage was multiplied by the full-allocation or 2050-demand withdrawal rate for each permit to estimate future withdrawals.

Because the data for the Average 1998–2006, Full Allocation, and 2050 Demand scenarios were provided as

annual totals, the monthly distribution of withdrawals also was estimated using recent withdrawal patterns. NJDEP provided monthly withdrawal percentages for each well or diversion calculated from withdrawal data for 1990 to 1999 from the New Jersey Water-Transfer Data System (NJWaTr) database (New Jersey Department of Environmental Protection, 2010). More recent withdrawal data were used to estimate the monthly withdrawal percentages for sources that were not in use in the 1990s. These monthly percentages were then used with the annual data to estimate the monthly withdrawals for each scenario.

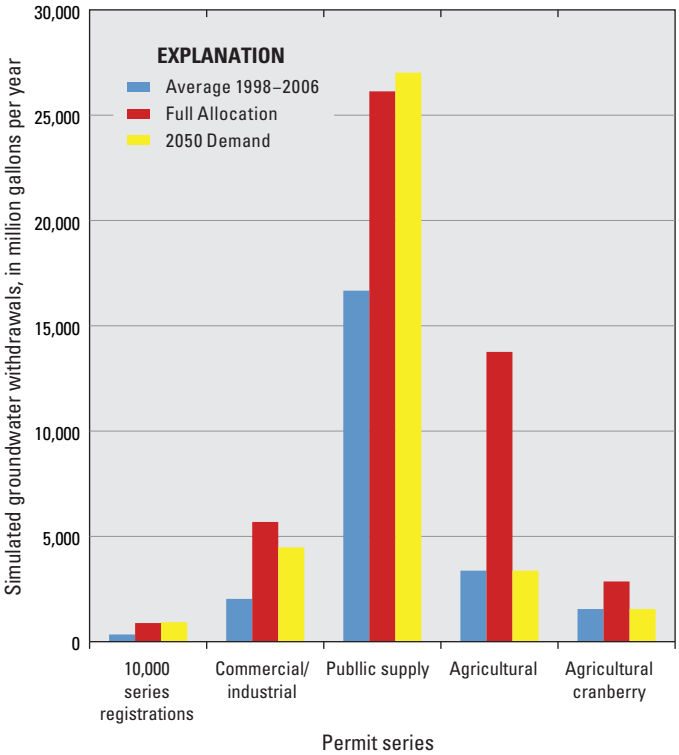


Figure 43. Simulated groundwater withdrawals in the Great Egg and Mullica River Basins, southeastern New Jersey, by permit series, for the Average 1998–2008, Full Allocation, and 2050 Demand scenarios.

Groundwater-withdrawal totals for the three scenarios, by permit series, are shown in figure 43. Commercial/industrial uses and public supply uses have much higher withdrawals under the Full Allocation and 2050 Demand scenarios than under the Average scenario (1998–2006). Public supply use is the only category for which the 2050 demand is greater than the full-allocation demand. Agricultural withdrawals under full-allocation conditions are several times larger than withdrawals under average conditions.

Groundwater withdrawals from the unconfined aquifer in Average, Full Allocation, and 2050 Demand scenarios are listed, by use category, in table 14. Bold values indicate that the withdrawals are more than 50 percent of the total for all permit types for the subbasin and highlights the predominant use by permit type. Several downdip or mixed subbasins are dominated by public supply withdrawals (02040301200, 02040302020, 02040302050, 02040302060, and 02040302070). Several updip subbasins or mixed subbasins are dominated by non-cranberry agricultural withdrawals (02040301150, 02040301160, 02040301170, and 02040302040). Withdrawals from updip subbasins 02040301180 and 02040301190 are completely or almost completely for cranberry use.

Base-Flow Depletion Criteria

In order to evaluate scenario results, monthly base-flow depletion criteria were needed for each of the 14 HUC11 subbasins in the study area. Simulated base-flow depletion for each scenario was compared to criteria to determine subbasins and time periods where deficits occurred. The approach used to determine the monthly base-flow depletion criteria was based on the Low-Flow Margin (LFM) method developed by NJDEP to estimate available water on an annual basis at the HUC11 level for the New Jersey Water Supply Plan. The NJDEP developed the LFM method to estimate the volume of water available in a water-table aquifer for use within a subbasin during ecologically critical flow periods. This method is being used as part of the NJDEP draft of the most recent version of the New Jersey Water Supply Plan (SWSP) (Jeffrey Hoffman, New Jersey Department of Environmental Protection, written commun., 2012). For the method, it was assumed that some percentage of streamflow can be removed without affecting stream ecology. The method defines the available water as a percentage of the difference between normal dry season streamflow and drought streamflow.

The September median flow represents flows typical for September, which are frequently the lowest flows of the year in New Jersey. The 7-day, 10-year (7Q10) flow represents drought flows. In this report, the low-flow margin is defined as the difference between the September median flow and the 7Q10 flow. The NJDEP defines available water as some percentage of this margin. If the entire margin were used for depletive and consumptive purposes, typical flows during summer months would decline to flows observed during droughts. However, according to the rationale of the LFM method, removing only a percentage of this margin would provide streamflows that could still support aquatic ecosystem health.

The NJDEP used the results of detailed studies and a comparison to subbasins with known water-availability issues to determine the percentage of the low-flow margin that can be lost to depletive/consumptive use without creating adverse effects. The Hydroecological Integrity Assessment Process (also known as eco-flow goals) (Kennen and others, 2007; Hoffman and Rancan, 2009) was used to estimate the volume of water available for use in 10 subbasins throughout New

Table 14. Projected withdrawals, by permit type, for selected Hydrologic Unit Code 11 subbasins, southeastern New Jersey.

[HUC11, Hydrologic Unit Code 11; all withdrawals in millions of gallons per year; values in **bold** are more than 50 percent of total withdrawals]

HUC11 number	Scenario	Public supply	Commercial/ industrial	Agricultural non-cranberry	Agricultural cranberry	10,000 series	Total
02040301150	Average	0	61	**110**	57	0	227
02040301150	Full Allocation	0	129	**519**	151	0	798
02040301150	2050 Demand	0	113	110	57	0	280
02040301160	Average	478	144	659	70	65	1,417
02040301160	Full Allocation	725	1,585	**3,963**	151	260	6,684
02040301160	2050 Demand	719	270	659	70	146	1,864
02040301170	Average	159	0	**602**	18	21	800
02040301170	Full Allocation	217	0	**2,541**	185	86	3,029
02040301170	2050 Demand	253	0	**602**	18	48	921
02040301180	Average	0	0	0	**72**	0	72
02040301180	Full Allocation	0	0	0	**330**	0	330
02040301180	2050 Demand	0	0	0	**72**	0	72
02040301190	Average	0	0	4	**1,027**	6	1,036
02040301190	Full Allocation	0	0	15	**1,786**	25	1,826
02040301190	2050 Demand	0	0	4	**1,027**	12	1,043
02040301200	Average	**534**	254	12	0	15	816
02040301200	Full Allocation	866	753	326	0	62	2,007
02040301200	2050 Demand	**953**	475	12	0	34	1,475
02040301210	Average	0	**22**	0	0	0	22
02040301210	Full Allocation	0	**31**	0	0	0	31
02040301210	2050 Demand	0	**42**	0	0	0	42
02040302010	Average	0	**94**	0	0	0	94
02040302010	Full Allocation	0	**97**	0	0	0	97
02040302010	2050 Demand	0	**175**	0	0	0	175
02040302020	Average	**4,017**	142	0	0	17	4,176
02040302020	Full Allocation	**6,395**	582	0	0	53	7,030
02040302020	2050 Demand	**4,567**	265	0	0	37	4,869
02040302030	Average	**1,533**	0	388	0	18	1,938
02040302030	Full Allocation	**2,243**	0	1,697	0	97	4,036
02040302030	2050 Demand	**2,620**	0	388	0	41	3,048
02040302040	Average	188	41	**1,257**	0	47	1,533
02040302040	Full Allocation	324	158	**4,557**	0	152	5,191
02040302040	2050 Demand	370	77	**1,257**	0	105	1,809
02040302050	Average	**297**	94	84	0	51	526
02040302050	Full Allocation	587	269	316	0	123	1,295
02040302050	2050 Demand	**920**	190	84	0	113	1,307
02040302060	Average	**1,667**	92	5	0	50	1,815
02040302060	Full Allocation	**2,594**	148	77	0	133	2,952
02040302060	2050 Demand	**2,910**	172	5	0	112	3,200
02040302070	Average	**105**	15	9	0	3	133
02040302070	Full Allocation	250	326	29	0	5	609
02040302070	2050 Demand	**180**	29	9	0	7	225

Jersey. The percentages of the low-flow margin available ranged from 10 to 34 with an average of 24. For the purposes of this analysis, the water available for depletive/consumptive use is defined as 25 percent of the low-flow margin.

The LFM method was modified for this study to determine monthly base-flow depletion limits that would be allowable under an application of the LFM method. This modification was necessary to guide simulation of a seasonal-conjunctive approach for the use of the shallow unconfined aquifer, along with a deeper confined aquifer, as an alternative. Seasonal-conjunctive use would take advantage of the higher streamflows during winter months and allow withdrawal of additional groundwater from the unconfined aquifer, thus requiring lower rates of withdrawals from the confined aquifer during this time. Withdrawals from the confined aquifer could then be increased by the same amount during the summer months, along with a decrease in withdrawals from the unconfined aquifer. This results in no net annual change in withdrawals from either aquifer. This approach requires that monthly water-availability limits be established so that more water can be withdrawn in the winter months when the difference between the median flow and the low flow is greater, and therefore, more water is available.

To determine monthly water-availability limits, the LFM method was applied on a monthly basis to the 14 HUC11 subbasins in the Great Egg Harbor and Mullica River Basins study area. Streamflow data from streamgaging stations or low-flow partial-record stations in or near the HUC11 subbasins were used to estimate the statistics for the HUC11 subbasins. Monthly medians and monthly 7Q10 statistics were calculated for continuous-streamgaging stations with 20 years of record and low-flow partial-record stations with five or more measurements. These statistics were calculated for the period of record through water year 2009[1]. Monthly statistics at stations were transferred to the HUC11 subbasins using the same techniques used in the Water Capacity Analysis prepared by the USGS for the New Jersey Water Supply Plan. If the drainage area for a streamgaging station corresponded closely to a HUC11 subbasin, the statistics were transferred by adjusting the values by the ratio of drainage area to the HUC11 area. If multiple stations were located within a HUC11 subbasin, the statistics for the stations were summed, and the drainage areas were summed. The values were adjusted by the ratio of the summed drainage area to the HUC11 area. In one subbasin, 02040302040, the flows from the upstream HUC11 (02040302030) were subtracted from the streamflows calculated from index stations in order to get an estimate for the downstream HUC11. The HUC11 subbasins and the index stations that were used to transfer the flows are shown in table 15. In all but one subbasin, HUC 02040302040, the same index stations that were used in the SWSP for each of the HUC11 subbasins were used here. For HUC 02040302040, the average of streamflows at index stations 01411110 and 01411140 was used instead of streamflow at index station 01411170, which was used in the Water Capacity Analysis, because the values estimated using station 01411170 were low compared to those of other HUC11 subbasins when adjusted by drainage area.

Once the monthly statistics were calculated for the HUC11 subbasins, the LFM method was applied. The monthly low-flow margin is the difference between the monthly median flow and the monthly 7Q10 flow. For this analysis, the low-flow margin available water was calculated as 25 percent of the LFM method, unless this value exceeded 50 percent of the monthly 7Q10, in which case it was set to 50 percent of the monthly 7Q10. In the implementation of the LFM method for the New Jersey Water Supply Plan, the low-flow margin available water was reduced in each HUC11 by existing consumptive uses of groundwater and surface water within the subbasin to determine the base-flow criteria. Because the groundwater withdrawals are being directly included in the groundwater flow model, they are not removed from the available water calculation. However, surface-water consumptive use within the subbasins needs to be accounted for. Average surface-water diversions for 1998 to 2006 were calculated and subtracted from the LFM available water to determine the monthly base-flow depletion criteria for each HUC11 subbasin. The HUC11 monthly streamflow statistics, the calculations of LFM, and the monthly base-flow depletion criteria are listed in table 16. Surface-water diversions during June to November in subbasin 02040302020 were larger than the low-flow margin available water for the subbasin.

No-Withdrawal Scenario

The no-withdrawal scenario represents conditions that would have occurred during 1998–2006 if there had been no groundwater withdrawals. This scenario is used as the baseline for comparison with the other scenarios. Base-flow depletion for each of the remaining scenarios is calculated as the base flow simulated for the no-withdrawal scenario minus the base flow simulated for a particular scenario.

Basic Scenarios

The basic scenarios simulate a 9-year hypothetical period during which recharge is equivalent to that estimated for 1998 to 2006 and the withdrawals for each year represent average, full-allocation, and 2050 demand conditions. The withdrawals used represent hypothetical conditions instead of the actual withdrawals. In each of these scenarios, the same cycle of withdrawals is applied during each year of the simulation period. The withdrawals vary by month, using the percentage distribution of average withdrawals by month from the NJDEP. These scenarios represent conditions that would have occurred if the withdrawals for the scenario had occurred during the 1998–2006 period.

[1] A water year is the 12-month period from October 1 to September 30; it is designated by the year in which it ends.

Table 15. Hydrologic Unit Code 11 subbasins and index stations used to transfer monthly flow statistics, southeastern New Jersey.

[HUC11, Hydrologic Unit Code 11; GSP, Garden State Parkway; --, no data]

HUC11 number	Basin name	Basin	Drainage area (square miles)	Station 1	Station 2	Station 3	Station 4	Drainage area ratio
02040301150	Batsto River	Mullica	67.85	01409500	--	--	--	0.995
02040301160	Mullica River (above Batsto River)	Mullica	127.25	01409400	01409406	01409411	--	1.009
02040301170	Mullica River (Turtle Ck to Basto River)	Mullica	109.93	01409416	01409575	--	--	7.663
02040301180	Oswego River	Mullica	72.51	01410000	--	--	--	1.001
02040301190	West Branch Wading River	Mullica	87.03	01409810	--	--	--	1.037
02040301200	Mullica River (GSP bridge to Turtle Ck)	Mullica	95.65	01410150	01410200	01410215	01410225	3.062
02040301210	Great Bay / Mullica R (below GSP bridge)	Mullica	21.72	01409300	01410225	01410500	--	0.703
02040302010	Reeds Bay / Absecon Bay & tribs	Great Egg Harbor	14.81	01410225	01410500	01411305	--	0.442
02040302020	Absecon Creek	Great Egg Harbor	26.42	01410215	01411305	--	--	1.641
02040302030	Great Egg Harbor R (above HospitalityBr)	Great Egg Harbor	71.01	01411000	--	--	--	1.247
02040302040a	Great Egg Harbor R (Lk Lenape to HospBr)	Great Egg Harbor	133.40	01411140	--	--	--	10.2
02040302040b	Great Egg Harbor R (Lk Lenape to HospBr)	Great Egg Harbor	133.40	01411110	--	--	--	1.32
02040302040c	Great Egg Harbor R (Lk Lenape to HospBr)	Great Egg Harbor	133.40	01411170	--	--	--	0.100
02040302050	Great Egg Harbor R (below Lake Lenape)	Great Egg Harbor	142.08	01411200	01411220	01411250	--	3.221
02040302060	Patcong Creek/Great Egg Harbor Bay	Great Egg Harbor	42.68	01411305	--	--	--	5.689
02040302070	Tuckahoe River	Great Egg Harbor	102.14	01411300	--	--	--	3.320

Table 16. Monthly base-flow depletion criteria and associated data for Hydrologic Unit Code 11 subbasins, southeastern New Jersey.

[HUC11, Hydrologic Unit Code 11; SW, surface water]

HUC11 number	Statistic	Monthly base-flow, in million gallons per day											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
		Mullica River Basin											
02040301150	Median[1]	78.82	83.71	93.81	84.36	76.52	57.48	47.45	46.81	44.04	47.26	60.31	68.22
	7Q10[2]	43.98	48.79	53.93	49.29	42.63	34.5	29.81	26.41	26.67	29.55	35.49	38.32
	LFM[3]	34.84	34.92	39.88	35.07	33.89	22.98	17.64	20.4	17.37	17.71	24.82	29.9
	LFM available water[4]	8.71	8.73	9.97	8.77	8.47	5.74	4.41	5.1	4.34	4.43	6.2	7.48
	Average SW diversions[5]	0	0	*0.01*	*0.03*	*1.16*	*2.14*	*1.62*	*1.98*	*1.52*	*0.05*	0	0
	Base-flow criteria[6]	8.71	8.73	9.96	8.74	7.31	3.6	2.79	3.12	2.82	4.38	6.2	7.48
02040301160	Median	129.96	134.34	150.96	137.73	106.69	72.67	56.84	51.66	47.94	58.75	82.05	108.07
	7Q10	57.38	64.83	67.78	62.97	53.25	35.12	27.39	21.76	19.95	25.37	34.07	44.75
	LFM	72.58	69.51	83.18	74.76	53.44	37.55	29.45	29.9	27.99	33.38	47.98	63.32
	LFM available water	18.14	17.38	20.8	18.69	13.36	9.39	7.36	7.48	7	8.34	12	15.83
	Average SW diversions	0	0	*0.01*	*0.1*	*0.29*	*0.35*	*0.5*	*0.34*	*0.16*	*0.07*	*0.03*	0
	Base-flow criteria	18.14	17.38	20.79	18.59	13.07	9.04	6.86	7.14	6.84	8.27	11.97	15.83
02040301170	Median	113.39	118.97	135.77	125.73	102.66	71.6	56.91	54.1	49.95	57.8	78.44	94.99
	7Q10	53.45	60	65.55	61.05	49.57	35.56	28.28	23.75	23.17	28.01	37.47	44.17
	LFM	59.94	58.97	70.22	64.68	53.09	36.04	28.63	30.35	26.78	29.79	40.97	50.82
	LFM available water	14.98	14.74	17.56	16.17	13.27	9.01	7.16	7.59	6.7	7.45	10.24	12.7
	Average SW diversions	0	0	0	*0.03*	*0.24*	*0.52*	*0.81*	*0.58*	*0.32*	*0.02*	*0.01*	0
	Base-flow criteria	14.98	14.74	17.56	16.14	13.03	8.49	6.35	7.01	6.38	7.43	10.23	12.7
02040301180	Median	56.62	58.56	65.68	62.12	51.57	38.12	33	32.87	30.22	34.16	43.93	46.33
	7Q10	28.7	32.35	32.98	30.73	25.85	20.49	17.64	16.12	15.45	17.81	23.03	23.74
	LFM	27.92	26.21	32.7	31.39	25.72	17.63	15.36	16.75	14.77	16.35	20.9	22.59
	LFM available water	6.98	6.55	8.18	7.85	6.43	4.41	3.84	4.19	3.69	4.09	5.22	5.65
	Average SW diversions	0	0	*0.02*	*0.02*	*0.04*	*0.11*	*0.1*	*0.11*	*0.01*	*0.01*	*0.01*	*0.01*
	Base-flow criteria	6.98	6.55	8.16	7.83	6.39	4.3	3.74	4.08	3.68	4.08	5.21	5.64
02040301190	Median	98.3	101.65	104.73	113.04	85.24	54.34	42.08	43.75	38.47	53.87	60.71	62.85
	7Q10	48.31	56.28	54.51	50.15	38.02	26.57	22.17	19.04	19.41	27.31	32.89	32.2
	LFM	49.99	45.37	50.22	62.89	47.22	27.77	19.91	24.71	19.06	26.56	27.82	30.65
	LFM available water	12.5	11.34	12.56	15.72	11.8	6.94	4.98	6.18	4.76	6.64	6.96	7.66
	Average SW diversions	0	0	0	*0.01*	*1.55*	*0.75*	*0.82*	*0.71*	*0.03*	*0.02*	*0.01*	0
	Base-flow criteria	12.5	11.34	12.56	15.71	10.25	6.19	4.16	5.47	4.73	6.62	6.95	7.66

Table 16. Monthly base-flow depletion criteria and associated data for Hydrologic Unit Code 11 subbasins, southeastern New Jersey.—Continued

[HUC11, Hydrologic Unit Code 11; SW, surface water]

HUC11 number	Statistic	Monthly base-flow, in million gallons per day											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
02040301200	Median	132.35	133.14	144.45	139.44	116.16	85.11	70.76	65.1	59.81	73.49	91.91	111.38
	7Q10	65.77	73.86	74.18	70.03	61.9	47.9	42.1	34.59	33.41	37.28	48.43	62.64
	LFM	66.58	59.28	70.27	69.41	54.26	37.21	28.66	30.51	26.4	36.21	43.48	48.74
	LFM available water	16.64	14.82	17.57	17.35	13.56	9.3	7.16	7.63	6.6	9.05	10.87	12.18
	Average SW diversions	0	0	0	0	*0.12*	*0.03*	*0.02*	*0.01*	0	0	0	0
	Base-flow criteria	16.64	14.82	17.57	17.35	13.44	9.27	7.14	7.62	6.6	9.05	10.87	12.18
02040301210	Median	20.43	20.51	23.33	22.57	18.36	12.45	8.75	7.87	7.06	10.44	13.42	17.29
	7Q10	7.74	8.23	9.58	7.84	5.49	3.69	3.15	2.3	2.17	2.42	3.84	6.26
	LFM	12.69	12.28	13.75	14.73	12.87	8.76	5.6	5.57	4.89	8.02	9.58	11.03
	LFM available water	3.17	3.07	3.44	3.68	2.74	1.84	1.4	1.15	1.08	1.21	1.92	2.76
	Average SW diversions	0	0	0	0	0	0	0	0	0	0	0	0
	Base-flow criteria	3.17	3.07	3.44	3.68	2.74	1.84	1.4	1.15	1.08	1.21	1.92	2.76
		Great Egg Harbor River Basin											
02040302010	Median	14.14	14.23	16.12	15.71	12.9	8.96	6.47	5.86	5.31	7.48	9.49	12.06
	7Q10	5.76	6.12	7.11	5.99	4.34	3.05	2.6	1.99	1.92	2.15	3.19	4.8
	LFM	8.38	8.11	9.01	9.72	8.56	5.91	3.87	3.87	3.39	5.33	6.3	7.26
	LFM available water	2.1	2.03	2.25	2.43	2.14	1.48	0.97	0.97	0.85	1.08	1.58	1.82
	Average SW diversions	0	0	0.02	0.05	0.06	0.06	0.04	0.04	0.13	0.02	0.01	0
	Base-flow criteria	2.1	2.03	2.23	2.38	2.08	1.42	0.93	0.93	0.72	1.06	1.57	1.82
02040302020	Median	23.77	24.78	27.66	26.06	22.05	16.33	13.46	12.76	12.01	13.54	17.49	20.67
	7Q10	12.94	14.16	15.45	14.61	12.24	9.26	7.53	6.45	6.38	7.52	9.68	11.21
	LFM	10.83	10.62	12.21	11.45	9.81	7.07	5.93	6.31	5.63	6.02	7.81	9.46
	LFM available water	2.71	2.66	3.05	2.86	2.45	1.77	1.48	1.58	1.41	1.5	1.95	2.36
	Average SW diversions	1.41	1.14	1.2	1.02	1.49	2.57	3.38	3.2	2.37	2.23	2.03	1.8
	Base-flow criteria	1.3	1.52	1.85	1.84	0.96	**0**	**0**	**0**	**0**	**0**	**0**	0.56
02040302030	Median	73.43	76.65	86.89	79.88	67.22	48.2	40.06	37.56	35.78	40.71	54.72	65.04
	7Q10	39.73	43	48.7	45.61	36.83	27.02	21.08	17.7	18.46	21.87	29.73	34.88
	LFM	33.7	33.65	38.19	34.27	30.39	21.18	18.98	19.86	17.32	18.84	24.99	30.16
	LFM available water	8.42	8.41	9.55	8.57	7.6	5.3	4.74	4.96	4.33	4.71	6.25	7.54
	Average SW diversions	0	0	0	0.01	0.14	0.26	0.18	0.27	0.17	0.04	0	0
	Base-flow criteria	8.42	8.41	9.55	8.56	7.46	5.04	4.56	4.69	4.16	4.67	6.25	7.54

Table 16. Monthly base-flow depletion criteria and associated data for Hydrologic Unit Code 11 subbasins, southeastern New Jersey.—Continued

[HUC11, Hydrologic Unit Code 11; SW, surface water]

HUC11 number	Statistic	Monthly base-flow, in million gallons per day											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
02040302040	Median	173.975	182.21	207.975	195.97	159.615	112.52	89.935	85.315	78.63	90.125	121.155	145.735
	7Q10	82.94	92.89	102.055	96.045	76.82	55.855	44.08	37.105	36.155	43.765	58.485	69.22
determined using average of data from 01411110 and 01411140	LFM	91.04	89.32	105.92	99.93	82.8	56.67	45.86	48.21	42.47	46.36	62.67	76.51
	LFM available water	22.76	22.33	26.48	24.98	20.7	14.17	11.46	12.05	10.62	11.59	15.67	19.13
	Average SW diversions	0	0.01	0.06	0.36	0.4	0.59	0.79	0.72	0.58	0.34	0.27	0.29
	Base-flow criteria	22.76	22.32	26.42	24.62	20.3	13.58	10.67	11.33	10.04	11.25	15.4	18.84
02040302050	Median	119.76	126.67	147.61	134.11	106.78	71	55.1	51.72	47.57	55.63	78.51	98.45
	7Q10	51.75	58.7	65.38	60.3	47.77	33.22	25.82	21.35	20.81	25.45	34.75	42.11
	LFM	68.01	67.97	82.23	73.81	59.01	37.78	29.28	30.37	26.76	30.18	43.76	56.34
	LFM available water	17	16.99	20.56	18.45	14.75	9.44	7.32	7.59	6.69	7.54	10.94	14.08
	Average SW diversions	0.05	0.05	0.28	0.58	0.64	0.76	0.9	1	0.76	0.34	0.64	0.07
	Base-flow criteria	16.95	16.94	20.28	17.87	14.11	8.68	6.42	6.59	5.93	7.2	10.3	14.01
02040302060	Median	35.4	36.79	40.58	39.85	34.03	26.15	21.82	20.83	19.58	21.68	26.93	30.95
	7Q10	20.48	22.26	24.17	23.31	19.57	15.38	12.65	11.08	10.96	12.81	16.2	18.25
	LFM	14.92	14.53	16.41	16.54	14.46	10.77	9.17	9.75	8.62	8.87	10.73	12.7
	LFM available water	3.73	3.63	4.1	4.14	3.62	2.69	2.29	2.44	2.16	2.22	2.68	3.18
	Average SW diversions	0	0	0	0.13	0.19	0.22	0.32	0.34	0.23	0.06	0	0
	Base-flow criteria	3.73	3.63	4.1	4.01	3.43	2.47	1.97	2.1	1.93	2.16	2.68	3.18
02040302070	Median	91.84	97.65	107.94	119.1	90.77	62.45	44.86	39.91	36.06	44.42	58.8	71.45
	7Q10	42.23	48.51	51.4	50.63	43.66	29.62	21.95	17.66	15.74	22.11	32.41	37.05
	LFM	49.61	49.14	56.54	68.47	47.11	32.83	22.91	22.25	20.32	22.31	26.39	34.4
	LFM available water	12.4	12.28	14.14	17.12	11.78	8.21	5.73	5.56	5.08	5.58	6.6	8.6
	Average SW diversions	0.48	0.61	0.71	0.8	1.11	1.26	1.18	1.14	1.11	1.02	0.83	0.74
	Base-flow criteria	11.92	11.67	13.43	16.32	10.67	6.95	4.55	4.42	3.97	4.56	5.77	7.86

[1]Median — Monthly median streamflow.

[2]7Q10 — 7-Day, 10-Year streamflow.

[3]LFM — Monthly low-flow margin (LFM) is the monthly median minus the monthly 7Q10.

[4]LFM available water — The LFM available water is 25 percent of the monthly LFM, unless this value exceeds 50 percent of the monthly 7Q10. If so, the LFM available water is set to 50 percent of the monthly 7Q10.

[5]Average SW diversion — Average monthly surface-water diversions for the basin for 2003–06. Values in Italics have been corrected using cranberry withdrawal consumptive use estimates for the growing and nongrowing seasons. These only occur in the Mullica River Basin.

[6]Base-flow criteria — Base-flow depletion criteria that will be used to evaluate groundwater flow model scenario results, calculated as the LFM available water minus the average surface-water diversions. Values in bold indicate the average monthly surface-water diversions are greater than the LFM available water.

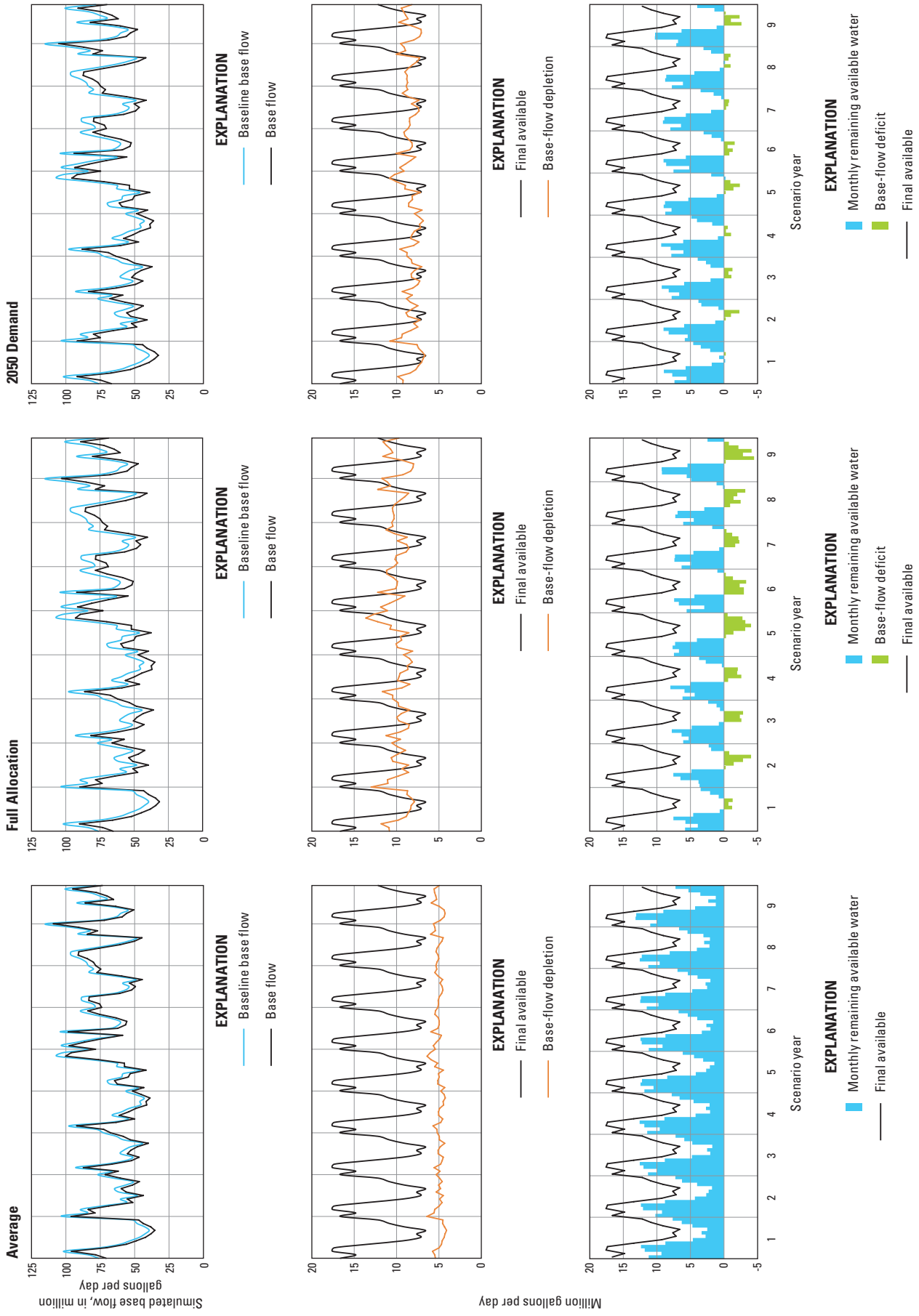


Figure 44. Simulated base flow, base-flow depletion, available water, and base-flow deficits under Average, Full Allocation, and 2050 Demand scenarios for an example Hydrologic Unit Code 11 subbasin, southeastern New Jersey.

An example graph of base flow, base-flow depletion, monthly available water and base-flow deficits for the Average, Full Allocation, and 2050 Demand scenarios is shown in figure 44 for the HUC11 subbasin representing the lower part of the Mullica River (02040301200) (Graphs for all 14 of the HUC11 subbasins are included in Appendix 1.) For each scenario, the top graph shows the base flow under no withdrawal conditions and the base flow for the scenario conditions. The middle graph shows the monthly base-flow depletion and the available water for the subbasin. In the Full allocation and 2050 Demand scenarios, the base-flow depletion during the summer months is often larger than the low-flow margin available water. This results in a base-flow deficit condition. The base-flow deficits, remaining available water, and the monthly base-flow criteria are shown in the bottom graph. Deficits are show in the green bars and are negative values. The remaining available water is shown in the blue bars. The data used to create these graphs are shown in tabular form in Appendix 2.

The monthly base-flow deficits for each subbasin, by scenario, for each scenario year are listed in table 17 (at end of report). If no deficits occurred for a scenario for a subbasin in a given year, that year is not listed. Months shaded in gray in the table are those designated as summer months (June through November) for the seasonal-conjunctive use scenario. The monthly base-flow deficits for the Average scenario are shown first for all subbasins, followed by the Full Allocation and 2050 Demand scenarios. The annual deficit and the total deficit for each subbasin are listed in table 18. The maximum annual base-flow deficit for each subbasin and the scenario year in which it occurred are shown in table 19. The maximum annual deficits for the Average, Full Allocation, and 2050 Demand scenarios are shown in maps in figure 45. The maximum annual base-flow deficits in many of the subbasins occur in either scenario years 5 or 6. In general, scenario years 4 and 5 were dry years in the study area. The budget for the Kirkwood-Cohansey aquifer system from the calibrated model shows that the recharge applied for 2001 to 2002 (scenario years 4 to 5) was low (fig. 40). Therefore, base flow in the subbasins was lower during this time period so more base-flow depletion was simulated.

The deficits are larger under the Full Allocation scenario because the full-allocation limits for agricultural wells (which are all completed within the Kirkwood-Cohansey aquifer system) are much larger than the limits under average annual conditions. Any increases in deficits from average annual to 2050 demand conditions are due to withdrawals from non-agricultural wells because the agricultural 2050 demand numbers were held constant at the average annual withdrawal amount.

The simulated water levels under the Average scenario and water-level decreases under the Full Allocation and 2050 Demand scenarios in the Atlantic City 800-foot sand are shown in figure 46. The maps show water levels and water-level decreases in April and September of scenario year 9 for all three scenarios.

Average

Average conditions were simulated using average annual water-use data for the period 1998 to 2006. This simulation represents current conditions in the study area. Maximum annual base-flow deficits resulting from the Average scenario are shown in figure 45. Small deficits (less than 1.5 Mgal/yr) were simulated for subbasins 02040301190, 02040301180, 02040301170, and 02040302040. These deficits occur in scenario years 5, 6 or 7 (tables 17 and 18). Except for monthly deficits that occur in December in subbasin 02040301190, the deficits all occurred during the period defined as summer (June-November) for the simulations. Deficits for subbasin 02040302030 are somewhat larger than for other subbasins but also occur during the summer months. Withdrawals from subbasin 02040302030 under average conditions are much greater than in the rest of the updip subbasins; most of these withdrawals are for public supply (table 12). Deficits from the two downdip subbasins (02040302020 and 02040302060) are also larger and occur throughout the year (although the winter deficits from subbasin 02040302060 are smaller than the summer deficits). Subbasin 02040302020 (Absecon Creek) shows deficits because the LFM available water for the subbasin is relatively low (table 16; after the surface-water diversions are subtracted from the LFM available water, the base flow is even lower, and during some months base flow is 0 (no depletion allowed). The base-flow depletion simulated in this subbasin is about 10 million gallons per day (Mgal/d), which is the largest volume simulated for any of the subbasins. Withdrawals from the unconfined aquifer in this subbasin are more than double the withdrawals for any other subbasin.

Simulated heads in the Atlantic City 800-foot sand under average conditions are shown in figure 46. Heads at the center of the cone of depression are more than 80 ft below NGVD 29 in April of scenario year 9 (when withdrawals are low) and are more than 100 ft below land surface in September in scenario year 9 (at the end of the summer withdrawal period). The simulated heads from the Average scenario were used to estimate the effects of increased withdrawals on heads in the Full Allocation and 2050 Demand scenarios (fig. 46).

Full Allocation

Simulation of the Full Allocation scenario was made using the projected full-allocation withdrawals discussed previously. This simulation represents conditions that would occur if all wells were pumping at their full-allocation rate. The distribution of these withdrawal increases for agricultural and public supply use has a large effect on the increases in deficits in this scenario. As shown in figure 43, the agricultural withdrawals (which are exclusively from the unconfined Kirkwood-Cohansey aquifer system) in this scenario are much larger than in the Average scenario. The large agricultural withdrawals caused increased deficits in the subbasins. The increases in public supply withdrawals (fig. 43) occur in the Atlantic City 800-foot sand, as well as the

Table 18. Simulated annual and total base-flow deficits from basic scenarios using the Great Egg-Mullica model for Hydrologic Unit Code 11 subbasins, southeastern New Jersey.

[HUC11, Hydrologic Unit Code 11; Deficits are in millions of gallons per year; --, no data]

HUC11 number	Scenario year									Total
	1	2	3	4	5	6	7	8	9	
					Average					
02040301170	--	0.12	--	--	0.75	--	--	--	1.34	2.21
02040301180	--	0.64	0.51	0.43	1.12	0.64	0.45	0.71	1.12	5.62
02040301190	--	--	--	--	0.25	--	--	--	--	0.25
02040302020	110.31	117.67	112.84	111.02	118.86	121.43	113.61	119.01	116.3	1,041.05
02040302030	1.76	5.96	4.49	4.56	6.39	7.3	5.17	6.36	7.46	49.45
02040302040	--	--	--	--	0.12	--	--	--	0.05	0.17
02040302060	12.38	14.82	13.44	12.93	15.36	17.04	13.76	15.51	15.36	130.6
					Full Allocation					
02040301150	--	0.76	0.49	0.25	0.73	1.72	0.04	0.32	1.8	6.11
02040301160	35.53	52.29	45.17	42.7	64.91	60.39	49.13	57.66	60.57	468.35
02040301170	33.13	50.45	41.22	38.21	59.1	55.44	42.04	47.39	51.31	418.29
02040301180	12.19	15.76	14.02	13.25	18.13	15.55	14.57	14.98	15.7	134.15
02040301190	--	2.12	0.93	0.47	7.76	2.62	1.77	3.59	4.24	23.5
02040301200	3.16	9.2	7.79	7.21	15.36	13.15	7.69	9.96	14.45	87.97
02040302020	163.31	179.05	171.13	168.05	180.06	198.61	181.01	192.66	186.42	1,620.3
02040302030	79.65	97.58	86.8	83.86	97.52	109.58	88.49	99.69	94.49	837.66
02040302040	14.04	42.66	29.78	27.37	70.97	71.1	38.27	55.22	67.95	417.36
02040302050	--	2.61	2.16	1.56	4.47	5.8	0.84	2.46	5.53	25.43
02040302060	43.15	47.54	45.2	44.08	48.94	50.95	45.74	48.61	46.62	420.83
					2050 Demand					
02040301170	2.08	7.17	5.58	4.87	10.76	8.19	5.24	6.33	10.08	60.3
02040301180	5.11	8.09	7.35	7.07	10.95	9.5	8.23	8.89	9.56	74.75
02040301190	--	--	--	--	0.45	--	--	--	--	0.45
02040301200	0.05	3.42	3.02	1.9	4.78	4.21	1.69	2.62	6.07	27.76
02040302020	131.39	141.31	135.5	133.26	142.22	149.05	137.76	144.55	140.92	1,255.96
02040302030	21.57	31.4	26.05	23.95	32.12	33.22	28.42	30.87	31.74	259.34
02040302040	--	1.92	0.24	--	7.06	2.27	--	2.73	6.3	20.52
02040302050	--	2.76	2.49	1.64	3.44	5.82	1.05	2.82	5.64	25.66
02040302060	43.6	48.16	45.45	44.13	48.93	50.7	45.9	48.85	47.23	422.95

Kirkwood-Cohansey aquifer system. The increases in public supply withdrawals from the unconfined Kirkwood-Cohansey aquifer system occur mainly in the downdip subbasins. In the Atlantic City 800-foot sand, public supply withdrawals are about 3,300 Mgal/d greater than in the Average scenario.

Maximum annual base-flow deficits for the Full Allocation scenario are shown in figure 45. The only subbasins that are not in deficit are 02040301210, 02040302010, and 02040302070, located downdip near the coast. These subbasins are not in deficit because there are small or no agricultural withdrawals and public supply withdrawals are small. Deficits in the mixed subbasins, and in many of the updip subbasins, are much larger than those for the Average scenario (tables 18 and 19) because of the large unused agricultural allocations. Deficits for three updip undeveloped subbasins in the northern part of the study area (02040301150, 02040301180, and 02040301190) increased from average conditions but not as much as for downdip and mixed subbasins because unused agricultural allocations from the subbasins are relatively small. Deficits in subbasins 02040302020 and 02040302060 increased because of the unused allocations for public supply. Most maximum annual deficits occur in

Table 19. Simulated maximum annual base-flow deficit and scenario year in which the deficit occurred using the Great Egg-Mullica model, by Hydrologic Unit Code 11, in southeastern New Jersey.

[HUC11, Hydrologic Unit Code 11; Mgal/yr, millions of gallons per year; Max, maximum; --, no data]

HUC11 number	Basin subbasin	Average		Full Allocation		2050 Demand	
		Max annual deficit, Mgal/yr	Scenario year	Max annual deficit, Mgal/yr	Scenario year	Max annual deficit, Mgal/yr	Scenario year
02040301150	Batsto River	--	--	1.8	9	--	--
02040301160	Mullica River (1)	--	--	64.9	5	--	--
02040301170	Mullica River (2)	1.3	9	59.1	5	10.8	5
02040301180	Oswego River	1.1	5	18.1	5	11.0	5
02040301190	West Branch Wading River	0.3	5	7.8	5	0.5	5
02040301200	Mullica River (3)	--	--	15.4	5	6.1	9
02040301210	Great Bay/Mullica River	--	--	--	--	--	--
02040302010	Reeds Bay/Absecon Bay	--	--	--	--	--	--
02040302020	Absecon Creek	121.4	6	198.6	6	149.1	6
02040302030	Great Egg Harbor River (1)	7.5	9	109.6	6	33.2	6
02040302040	Great Egg Harbor River (2)	0.1	5	71.1	6	7.1	5
02040302050	Great Egg Harbor River (3)	--	--	5.8	6	5.8	6
02040302060	Patcong Creek	17.0	6	51.0	6	50.7	6
02040302070	Tuckahoe River	--	--	--	--	--	--

scenario years 5 or 6 (all subbasins except 02040301150). Deficits occur throughout the year in subbasins 02040302020, 02040302030, and 02040302060. Deficits in subbasin 02040302030 occur only in summer months under the Average scenario.

Simulated heads in the Atlantic City 800-foot sand under the Full Allocation scenario are shown in figure 46. Simulated heads at the center of the cone of depression were more than 120 ft below NGVD 29 in April of scenario year 9 (when withdrawals are less) and are more than 150 ft below NGVD 29 in September of scenario year 9 (at the end of the summer withdrawal period). An increase in withdrawals to full-allocation levels would cause the heads in the Atlantic City 800-foot sand to drop from levels during average conditions by as much as 60 ft in April of scenario year 9 and by as much as 70 ft in September of scenario year 9. The potential declines in the potentiometric surface of the Atlantic City 800-foot sand may increase the possibility of saltwater intrusion in the aquifer. The water levels are much lower in the Full Allocation scenario than in the Average scenario, and the gradients from the center of the cone of depression towards the east (where the saltwater is) are steeper.

The increased base-flow deficits and declining water levels in the Atlantic City 800-foot sand in the Full Allocation scenario could potentially result from existing water-management policies. However, for this simulation, it was assumed that the increased withdrawals for full allocation would occur at existing well locations. Although this is a reasonable assumption, some increases are likely to occur at new wells. In that case, the declines in water levels would not be as large as simulated in this scenario.

2050 Demand

The 2050 demand conditions were simulated using the projected 2050 demand water-use data discussed previously. The biggest change in this scenario from the Full Allocation scenario is in the projected withdrawals for public supply and agricultural use. As discussed in the section on water-use data for scenarios, the 2050 demand for agricultural use is held constant at the average 1998 to 2006 levels (fig. 43). This is a substantial reduction in withdrawals from the Kirkwood-Cohansey aquifer system compared to withdrawals in the Full Allocation scenario. Because of this difference, deficits in subbasins with large agricultural withdrawals are much smaller than deficits in the Full Allocation scenario because of this difference. Public supply demand in 2050 is about 700 Mgal/d lower for the Kirkwood-Cohansey aquifer system than in the Full Allocation scenario. Public supply withdrawals decreased from Full Allocation levels by about 1,800 Mgal/d in subbasin 02040302020. This decrease is partially offset by increases of about 300 Mgal/d each from subbasins 02040302030 (updip), 02040302050 (mixed), and 02040302060 (downdip). In the Atlantic City 800-foot sand, public supply withdrawals are about 600 Mgal/d greater than in the Full Allocation scenario and about 4,000 Mgal/d greater than in the Average scenario.

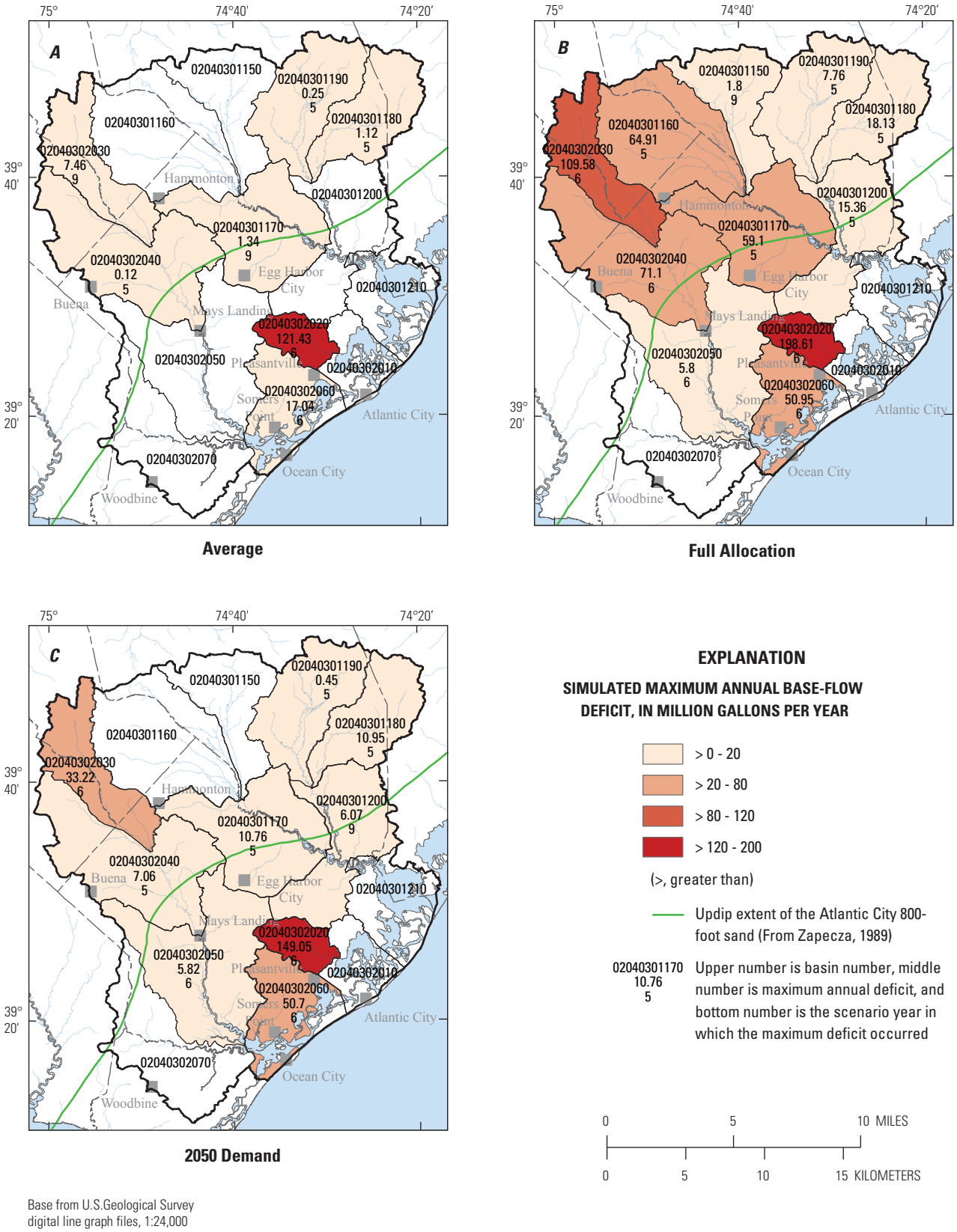
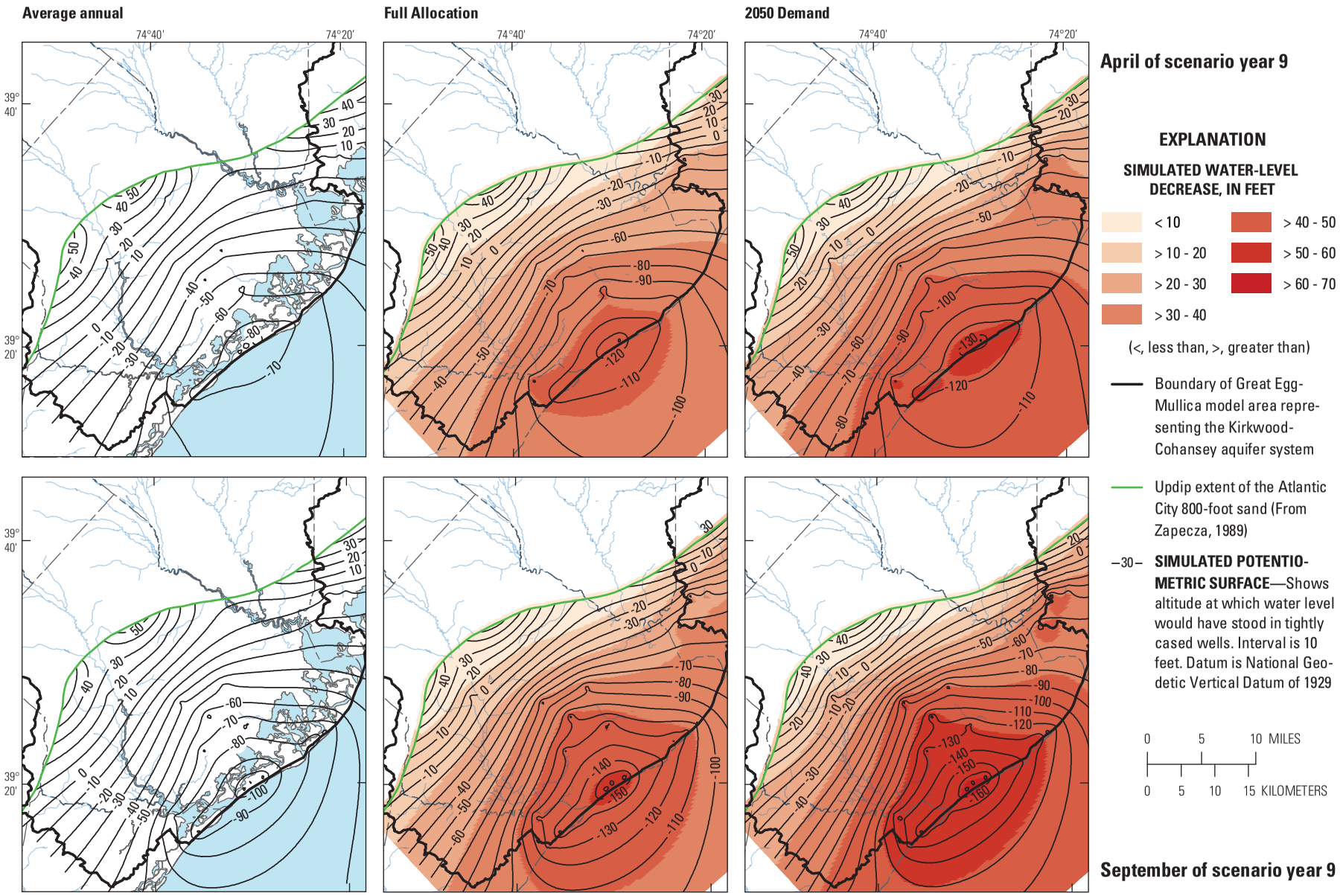


Figure 45. Simulated maximum annual base-flow deficits for Hydrologic Unit Code 11 subbasins in southeastern New Jersey under A, Average, B, Full Allocation, and C, 2050 Demand scenarios, under basic conditions.



Base from U.S.Geological Survey digital line graph files, 1:24,000

Figure 46. Simulated potentiometric surfaces and simulated water-level decreases for the Atlantic City 800-foot sand, southeastern New Jersey, under Average, Full Allocation, and 2050 Demand scenarios, under basic conditions, in April and September of scenario year 9.

Base-flow deficits resulting from the 2050 Demand scenario are shown in figure 45. In addition to the three subbasins that were not in deficit during the Full Allocation scenario (02040301210, 02040302010, and 02040302070), subbasins 02040301150 and 02040301160 located updip in the Mullica River Basin are no longer in deficit. Deficits in many of the updip and mixed subbasins are much lower because, in the 2050 Demand scenario, agricultural withdrawals are decreased compared to those in the Full Allocation scenario. Deficits are also lower in subbasin 02040302020 because public supply withdrawals are decreased compared to those in the Full Allocation scenario. Deficits in the mixed or some updip subbasins (02040301180 and 02040301190) under the 2050 Demand scenario are larger than those under the Average scenario because of the effects of increased public supply withdrawals from the confined Atlantic City 800-foot sand on the unconfined part of the aquifer. Deficits occur throughout the year in subbasins 02040302020 and 02040302060. In subbasin 02040302030, deficits occur through most of the winter months. The deficits in the remaining subbasins that have deficits occur in the summer (with the exception of December deficits in subbasin 02040301180) (table 17).

Simulated heads in the Atlantic City 800-foot sand under 2050 demand conditions are shown in figure 46. Heads at the center of the cone are more than 140 ft below NGVD 29 in April of scenario year 9 (when withdrawals are lower) and are more than 160 ft below NGVD 29 in September of scenario year 9 (at the end of the summer withdrawal period). These heads are about 10 to 20 ft lower than simulated in the Full Allocation scenario in both April and September. The shaded areas showing water-level change from the Average scenario are larger at the center of the cones in the 2050 Demand scenario than in the Full Allocation scenario, and the areas where declines are more than 40 ft in the spring and 50 ft in the fall are much larger.

In the Atlantic City 800-foot sand, the simulated heads are lowest for the 2050 Demand scenario because withdrawals for public supply use are larger than for other use types (fig. 16), and public supply withdrawals for the 2050 Demand scenario are slightly larger than for the Full Allocation scenario. Water-level declines from average conditions to future demand conditions are as much as 60 ft at the center of the cone of depression. The declines are greatest near the center of the cone and towards the ocean. The declines become smaller upgradient in the system towards the area where the Atlantic City 800-foot sand and the Kirkwood-Cohansey aquifer system are hydraulically connected because (1) those areas are farther away from the largest withdrawals and (2) the Kirkwood-Cohansey aquifer system provides additional water to the Atlantic City 800-foot sand near the updip limit of the Atlantic City 800-foot sand.

The increased base-flow deficits and declining water levels in the Atlantic City 800-foot sand in this scenario are those that would result from the expected 2050 demand. However, for this simulation, it was assumed that the increased withdrawals to satisfy the 2050 demand conditions would occur at existing well locations. Although this is a reasonable assumption, some of the increases are likely to occur at new wells. Increased withdrawals from new wells would result in somewhat less decline in heads at the center of the cones of depression and a more dispersed decline in heads throughout the Atlantic City 800-foot sand.

Adjusted Scenarios

Once the basic scenarios (Average, Full Allocation, and 2050 Demand scenarios) were simulated and subbasins with months having base-flow deficits were identified, simulated withdrawals were modified in stages with the intent to progressively eliminate the deficits. Simulated withdrawals were altered under each of the three demand conditions of average, full allocation, and 2050 demand only in those subbasins that experienced deficits under a particular withdrawal condition. Of the 14 subbasins, 7 had deficits in the Average scenario, 11 had deficits in the Full Allocation scenario, and 9 had deficits in the 2050 Demand scenario.

A series of simulations was formulated to test a hypothetical approach for eliminating the deficits. This strategy was developed as part of this study to show several potential ways the base-flow deficits could be reduced and to allow comparison of the effectiveness of various parts of the strategy. There may be other strategies that could be used to eliminate the base-flow deficits. These simulations were done to help the New Jersey Departmental Projection evaluate potential strategies. No plan is currently in place to implement these strategies.

The strategy was implemented using a three-tier approach. Tier 1 represents changes to the depths of the withdrawal wells in the Kirkwood-Cohansey aquifer system downdip. Tier 2 starts with the Tier 1 changes, and then shifts the withdrawals between the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand seasonally for any subbasins still in deficit after Tier 1. Lastly, Tier 3 starts with changes made in Tier 1 and Tier 2 and then reduces the magnitude of withdrawals for any subbasins still in deficit after Tier 2.

In the southeastern part of the study area, the unconfined Kirkwood-Cohansey aquifer system (overlying the Rio Grande water-bearing zone and the Atlantic City 800-foot sand) contains a shallow clay that creates an upper and lower unit within the aquifer. For subbasins with deficits within the area where this clay exists, simulated withdrawals from existing wells open to the shallowest, unconfined part of the Kirkwood-Cohansey aquifer system would be moved to the deeper, semi-confined part of the Kirkwood-Cohansey aquifer system. These changes are referred to as Tier 1 adjustments. For any subbasins that still have deficits and that are at least partly underlain by the Atlantic City 800-foot sand, seasonal-conjunctive use of the Kirkwood-Cohansey aquifer system (winter use) and the confined Atlantic City 800-foot sand (summer use) was implemented. These changes are referred to as Tier 2 adjustments. Third, for any subbasins that have deficits that

were not resolved by the first two adjustments, withdrawals or allocation limits from the Kirkwood-Cohansey aquifer system would be incrementally reduced basin-wide until there was no deficit. These changes are referred to as Tier 3 adjustments.

Tier 1 Adjustments

In order to reduce the stress from withdrawals on the water-table aquifer, which results in a reduction of base flow, simulated withdrawals were first shifted from the unconfined to the semi-confined Kirkwood-Cohansey aquifer system (model layer 1 to model layer 3)— the Tier 1 adjustments. The use of this approach was possible only in the downdip subbasins where the Kirkwood-Cohansey leaky confining unit is present (see fig. 4). The subbasins with at least one well for which withdrawals could be shifted to the deeper part of the aquifer and for which deficits were simulated under any conditions are 02040301170, 02040302020, 02040302050, and 02040302060.

The changes in base flow resulting from Tier 1 adjustments were small. The percentages of the deficit resolved by this approach and the other two approaches are shown in table 20. No base-flow deficits were resolved using this change alone, and improvements were observed in only a few subbasins. The biggest change was for subbasin 02040302060 located downdip, in which the Tier 1 adjustments ultimately accounted for 6 and 3 percent of the deficit reduction in the Average and 2050 Demand scenarios, respectively. The deficits in the Full Allocation scenario actually increased in this subbasin (and in several other subbasins) using this approach. This increase may be due to water moving to the deeper part of the aquifer in adjacent subbasins, which caused head declines in the subbasin with increased withdrawals. The effects of Tier 1 adjustments in other subbasins can be seen in subbasins 02040301150 and 02040301190, which are located updip; only slight reductions in deficits occurred in these subbasins when this change was implemented in downdip subbasins.

Although the concept of using the deeper part of the Kirkwood-Cohansey aquifer system where the clay layer is present has merit on a local scale, the approach did not result in elimination of base-flow deficits. The semi-confining unit within the Kirkwood-Cohansey aquifer system may limit the effects on wetland water levels locally, but at the HUC11 subbasin scale, the withdrawals from the deeper part of the aquifer still affect streamflow and contribute to base-flow depletion. The base flow, base-flow depletion, remaining available water in aquifer, and deficits for the adjusted scenarios are described in tabular form in Appendix 3.

Tier 2 Adjustments

For subbasins overlying both the unconfined Kirkwood-Cohansey aquifer system and the confined Atlantic City 800-foot sand, seasonal-conjunctive use of the unconfined and confined aquifers was implemented as Tier 2 adjustments to eliminate deficits. Tier 2 adjustments incorporate Tier 1 adjustments. Shifting withdrawals from the unconfined aquifer to the confined aquifer during periods of deficit (during the summer) would reduce the strain on the water-table aquifer. To balance the effects on the confined Atlantic City 800-foot sand, the same volume of withdrawals was shifted from the confined aquifer to the unconfined aquifer during times of high flows (winter/spring). The monthly deficits that occurred in downdip subbasins were examined, and it was determined that the summer period for shifting withdrawals would be June through November, and the winter period would be December through May.

Wells that withdraw water from the unconfined Kirkwood-Cohansey aquifer system (model layers 1 or 3) were identified; these wells are in areas underlain by the Atlantic City 800-foot sand. For each of these wells, a hypothetical well at the same location and open to the Atlantic City 800-foot sand was used to simulate the summer withdrawals shifted to the confined aquifer. For each well with withdrawals from the Atlantic City 800-foot sand, a hypothetical well at the same location and open to the Kirkwood-Cohansey aquifer system was used to simulate the winter withdrawals, which were shifted to the shallow aquifer. There are six HUC11 subbasins in the study area with wells that could be used for seasonal-conjunctive use and that have simulated deficits under at least one withdrawal condition—02040301170, 02040301200, 02040302020, 02040302040, 02040302050, and 02040302060.

The concept of seasonal-conjunctive use in this study refers to shifting withdrawals seasonally but maintaining the same net withdrawals from each aquifer so that the scenario does not result in increased water-level declines in the Atlantic City 800-foot sand or increased base-flow deficits. In each subbasin for which seasonal-conjunctive use was an option, the withdrawals from the Kirkwood-Cohansey aquifer system do not match exactly the withdrawals from the Atlantic City 800-foot sand. If unconfined aquifer withdrawals were greater than Atlantic City 800-foot sand withdrawals and all unconfined summer withdrawals for the six subbasins were shifted to the confined aquifer, there would not be the same amount of water available when winter withdrawals were shifted back to the unconfined aquifer, and a net annual increase in withdrawals from the Atlantic City 800-foot sand would result. Similarly, if withdrawals from the Atlantic City 800-foot sand exceed those from the unconfined Kirkwood Cohansey aquifer system, shifting all withdrawals from the confined aquifer to the unconfined aquifer in the winter would increase the stress on the unconfined aquifer.

The maximum annual deficits simulated for each condition using Tier 1 and 2 adjustments (wherever possible, withdrawals shifted from model layer 1 to model layer 3, followed by seasonal-conjunctive use) is shown in figure 47. The percentage of the deficit that was resolved with seasonal-conjunctive use (Tier 2) for each subbasin is shown in table 20. In addition to the potential reduction or elimination of base-flow deficits, the effect of this approach on water levels in the

Table 20. Simulated deficits from basic scenarios and three-tier adjustment approaches for the Great Egg-Mullica model and percentage of total deficit reduction in Hydrologic Unit Code 11 subbasins, southeastern New Jersey.

[HUC11, Hydrologic Unit Code 11; Deficits are in millions of gallons;*, deficits were increased; **, deficits were improved but were made worse by seasonal-conjunctive use]

HUC11 number	Basic scenarios deficit	Deficit			Total deficit reduction, percent		
		Tier 1	Tier 2	Tier 3	Tier 1	Tier 2	Tier 3
Average							
	Average basic						
02040301150	0	0	0	0			
02040301160	0	0	0	0			
02040301170	2.21	2.67	5.76	0	*	*	100
02040301180	5.62	6.18	28.61	18.94	*	*	100
02040301190	0.25	0.25	0.26	0	0	*	100
02040301200	0	0	0	0			
02040301210	0	0	0	0			
02040302010	0	0	0	0			
02040302020	1,041.05	1,040.49	1,017.16	63.34	0	2	98
02040302030	49.45	49.52	49.07	0	*	1	99
02040302040	0.17	0.19	2.26	0	*	*	100
02040302050	0	0	0	0			
02040302060	130.6	123.09	18.35	0	6	80	14
02040302070	0	0	0	0			
Full Allocation							
	Full Allocation basic						
02040301150	6.11	6.07	6.16	0	**	*	100
02040301160	468.35	467.87	456.88	0	0	2	98
02040301170	418.29	419.24	499.32	34.79	*	*	100
02040301180	134.15	134.26	263.23	162.75	*	*	100
02040301190	23.5	23.36	24.54	0	**	*	100
02040301200	87.97	98.65	136.93	0.27	*	*	100
02040301210	0	0	0	0			
02040302010	0	0	0	0			
02040302020	1,620.3	1,698.63	1,620.32	84.55	*	5	95
02040302030	837.66	837.39	835.06	0	0	0	100
02040302040	417.36	417.62	590.05	0	*	*	100
02040302050	25.43	29.66	36.07	0	*	*	100
02040302060	420.83	428.41	256.52	0	*	40	60
02040302070	0	0	0	0			
2050 Demand							
	2050 Demand basic						
02040301150	0	0	0	0			
02040301160	0	0	0	0			
02040301170	60.3	61.52	94.87	14.24	*	*	100
02040301180	74.75	74.97	157.01	141.06	*	*	100
02040301190	0.45	0.45	0.49	0	0	*	100
02040301200	27.76	28.17	58.59	0.31	*	*	100
02040301210	0	0	0	0			
02040302010	0	0	0	0			
02040302020	1,255.96	1,255.57	1,245.09	85.86	0	1	99
02040302030	259.34	259.4	259.43	0	*	*	100
02040302040	20.52	20.69	54.92	0	*	*	100
02040302050	25.66	27.05	25.36	0	*	6	94
02040302060	422.95	409.37	259.78	0	3	35	61
02040302070	0	0	0	0			

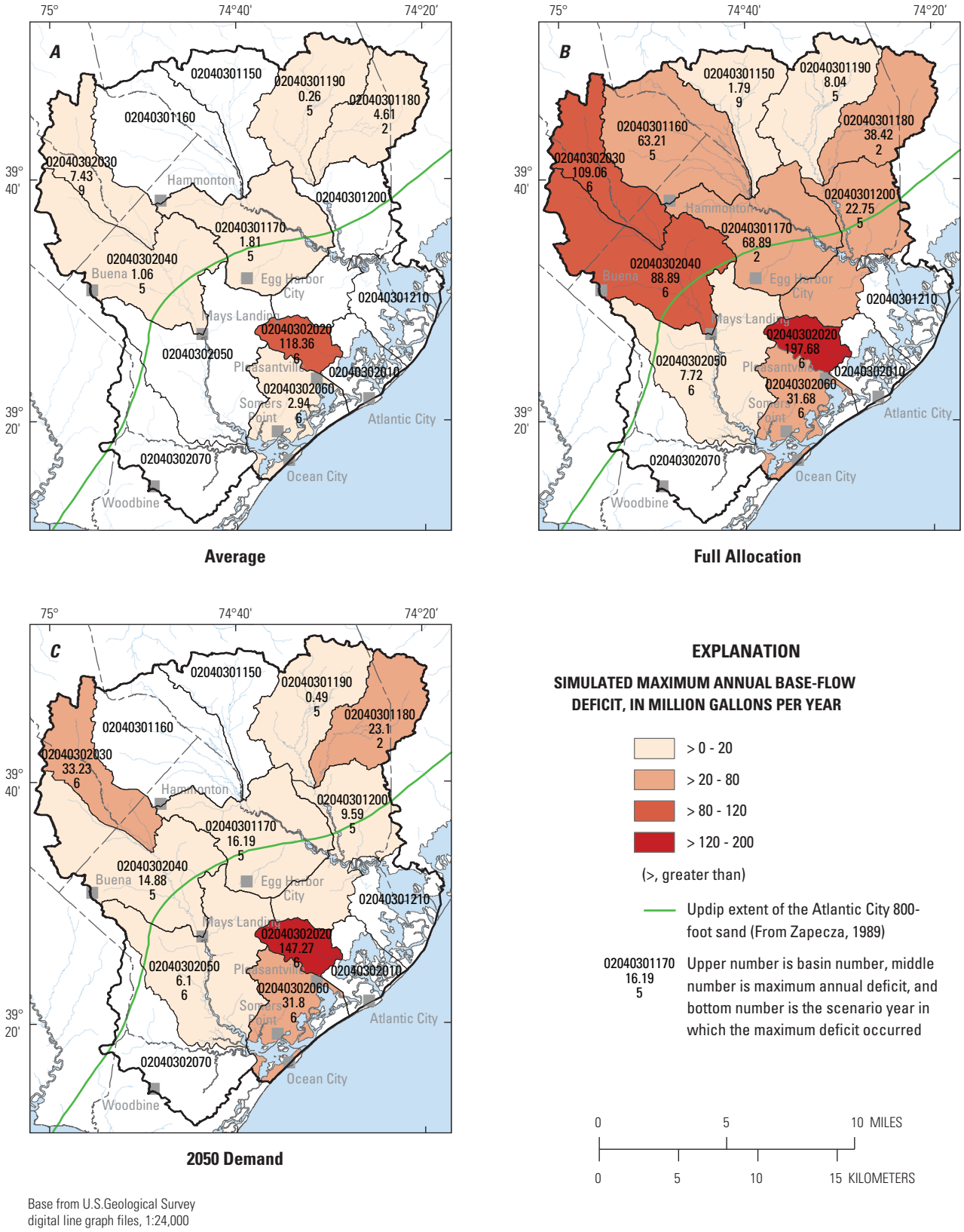


Figure 47. Simulated maximum annual base-flow deficits for Hydrologic Unit Code 11 subbasins in southeastern New Jersey under A, Average, B, Full Allocation, and C, 2050 Demand scenarios with Tier 2 adjustments.

Atlantic City 800-foot sand is important. Figure 48 shows the simulated heads and water-level changes from the basic conditions for each of the three basic scenarios in April of scenario year 9 and September of scenario year 9; the seasonal effects of seasonal-conjunctive use withdrawals from the Atlantic City 800-foot sand can be seen. The top three maps show the simulated heads in April of scenario year 9 with up to 20 ft of recovery from the basic scenarios near the center of the cone of depression in the Atlantic City 800-foot sand. The recovery is greatest near the center of the cone because that is where most withdrawals were made and, under Tier 2 adjustments, were moved to the shallow aquifer during the winter months. In areas away from the cone, a decline of as much as 20 ft from the basic scenario levels still occurred. The bottom three maps show the simulated heads and water-level changes from basic conditions in the Atlantic City 800-foot sand in September of scenario year 9 and the effects of increased summer withdrawals. Simulated heads declined as much as 70 ft from the basic scenarios during September because of the increased summer withdrawals.

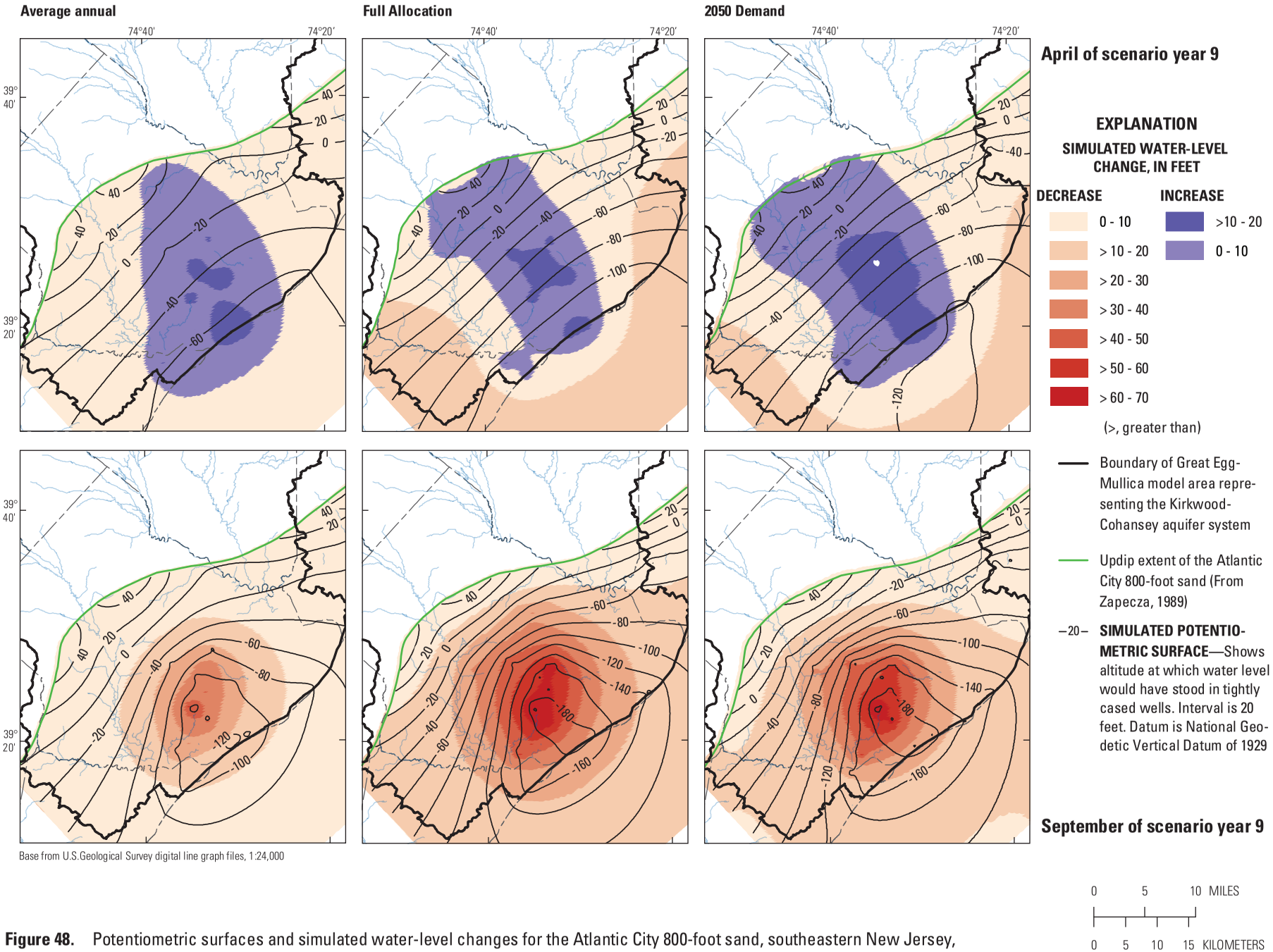
Seasonal-conjunctive use (Tier 2) reduced base-flow deficits in only one downdip subbasin (02040302060) where it accounted for 35 percent to 80 percent of the total deficit reduction in that subbasin (table 20). Minor improvements were also seen in subbasin 02040302020 (1 to 5 percent of total deficit reduction), but the adjustment was not nearly as successful as in subbasin 02040302060. As discussed previously, deficits could not be eliminated in subbasin 02040302020 in the summer months through adjustment of groundwater withdrawals because the base-flow depletion limit for this subbasin of zero is due to the Average scenario surface-water withdrawals. In mixed subbasins where deficits were present (02040302040, 02040302050, 02040301170, and 02040301200), seasonal-conjunctive use actually increased the deficits under at least one scenario. Increased deficits are the result of the declining heads during summer in the Kirkwood-Cohansey aquifer system and base-flow depletion caused by increased summer withdrawals from the Atlantic City 800-foot sand within the mixed subbasins or downdip subbasins. This result is important because it shows that withdrawals from the confined aquifer have an effect on base flow in the subbasins updip from the limit of the confining unit overlying the Atlantic City 800-foot sand. The deficits in subbasin 02040301200 increased substantially under the Full Allocation and 2050 Demand scenarios. In updip subbasins the results were mixed. In general, deficits increased or decreased slightly as a result of seasonal-conjunctive use in the these subbasins. However, deficits in subbasin 02040301180 increased greatly as a result of seasonal-conjunctive use. The deficits nearly doubled in the Full Allocation and 2050 Demand scenarios. This deficit increase is again due to the increased withdrawals from the Atlantic City 800-foot sand in other subbasins during the summer months. The increased deficits occurred in two ways. First, deficits that occurred from June through December under basic conditions increased. Second, deficits occurred during all 12 months of the year in this subbasin.

Under average conditions, seasonal-conjunctive use reduced the deficits in several downdip subbasins but increased deficits in mixed subbasins and some updip subbasins (including large effects on subbasin 02040301180). Simulated groundwater levels in the Atlantic City 800-foot sand recovered in the spring of scenario year 9 by 10 to 20 ft in most areas of the cone of depression and recovered up to 20 ft in some areas near the center of the cone (fig. 48). Water levels decreased slightly in areas away from the center of the cone of depression. Heads near the center of the cone of depression in the late summer for the conjunctive-use simulation were more than 40 ft lower than the heads from the Average scenario basic simulation, as illustrated in the September of scenario year 9 map in figure 48.

Seasonal-conjunctive use (Tier 2) under the Full Allocation scenario improved base-flow deficits in subbasin 02040302060 and to a lesser degree in subbasin 02040302020. Base-flow deficits in mixed or updip subbasins increased, particularly in subbasins 02040301170, 02040301180, 02040301200, and 02040302040. Recovery of water levels in the Atlantic City 800-foot sand are seen near the center of the cone of depression, but declines of 10 to 20 ft occurred in areas away from the center of the cone of depression (fig.48). Water levels declined in September of scenario year 9 more than 50 ft from those resulting from the basic Full Allocation scenario, and heads in the Atlantic City 800-foot sand declined to more than 190 ft below NGVD 29 in the center of the cone of depression.

Under the 2050 Demand scenario, seasonal-conjunctive use worked best in subbasin 02040301160. As under the Average and Full Allocation scenarios, deficits increased in mixed and some updip subbasins (particularly in subbasins 02040301170, 02040301180, 02040301200, and 02040302040). The deficits in the mixed subbasins are not as large as those from the Full Allocation scenario (because the agricultural full-allocation limits are not in use) but are substantially larger than the deficits from the Average scenario. This result is due to the effect of withdrawals from the Atlantic City 800-foot sand on these subbasins. Head recovery in the spring and head decline in the summer in the Atlantic City 800-foot sand are both greater under the 2050 Demand scenario than under the Full Allocation scenario because of the greater withdrawals from the Atlantic City 800-foot sand by public supply wells. Heads in September of scenario year 9 declined as much as 70 ft from basic 2050 demand conditions to more than 190 ft below NGVD 29 because of seasonal-conjunctive use.

Seasonal-conjunctive use worked well in one downdip subbasin, but it caused substantial increases in the deficits in mixed and some updip subbasins because of the decreased heads in the Atlantic City 800-foot sand in the summer. Heads in the Atlantic City 800-foot sand recovered up to 20 ft during the spring but declined as much as 70 ft by the end of the summer, and heads reached levels of more than 190 ft below NGVD 29. Given the increased deficits in the mixed subbasins and the head declines in the Atlantic City 800-foot



Base from U.S.Geological Survey digital line graph files, 1:24,000

Figure 48. Potentiometric surfaces and simulated water-level changes for the Atlantic City 800-foot sand, southeastern New Jersey, under Average, Full Allocation, and 2050 Demand scenarios, with Tier 2 adjustments in April and September of scenario year 9.

sand, seasonal-conjunctive use would not solve the base-flow deficits if applied throughout the study area. However, results for subbasin 02040302060 are promising, and seasonal-conjunctive use may prove an effective tool to manage deficits in this subbasin. The effectiveness of the approach in reducing deficits may be even greater and could result in smaller head declines in the confined aquifer if seasonal-conjunctive use was not occurring concurrently in the adjacent subbasin 02040302020, for which substantial withdrawals were shifted to the Atlantic City 800-foot sand in the summer. A limited application of seasonal-conjunctive use in subbasin 02040302060 could produce better results.

Tier 3 Adjustments

Base-flow deficits simulated using existing wells and average (1998–2006), full-allocation, or 2050 demand withdrawal rates were not eliminated by shifting withdrawals from the shallow to the semi-confined Kirkwood-Cohansey aquifer system (Tier 1) or through seasonal-conjunctive use of the Atlantic City 800-foot sand (Tier 2) in any HUC11 subbasin. Therefore, a third alternative was simulated in which Kirkwood-Cohansey aquifer system withdrawals were reduced on a subbasin-by-subbasin basis until all deficits were eliminated or minimized. The reduction in withdrawals could represent shifting the water supply to a different source or reducing water use. Simulation of this alternative does not imply that the NJDEP will be implementing these reductions in withdrawals but was used to understand the magnitude in changes in withdrawals that would be needed to eliminate the deficits. These adjustments are referred to as Tier 3 adjustments. These adjustments are in addition to those made for Tier 1 and Tier 2.

Withdrawals were reduced in all wells in the Kirkwood-Cohansey aquifer system within each subbasin that had a deficit after implementation of Tier 1 and Tier 2 adjustments. Preliminary simulations in which withdrawals were reduced in increments of 10 percent in all subbasins in deficit were used to determine the approximate percentage of reduction necessary to eliminate deficits. Because of interactions between subbasins, reductions were adjusted (in 10-percent increments) for each subbasin until deficits were eliminated or withdrawals were reduced to zero. In some cases, deficits could not be eliminated even when withdrawals from the shallow Kirkwood-Cohansey aquifer system within the subbasin were eliminated. This is due to the effects of withdrawals from the shallow aquifer in other HUC11 subbasins or the effects of withdrawals from the Atlantic City 800-foot sand withdrawals in other subbasins. No attempt was made to eliminate deficits in one subbasin by reducing withdrawals in adjacent subbasins or by reducing withdrawals from the Atlantic City 800-foot sand downdip from the subbasins.

The reductions in groundwater withdrawals necessary to eliminate base-flow deficits for streams in the Average, Full Allocation, and 2050 Demand scenarios are shown in figure 49. Elimination of withdrawals from the unconfined aquifer (100-percent reduction) did not eliminate the deficit in subbasin 02040302020 because the base-flow depletion limit for this subbasin in summer is zero as a result of the surface-water withdrawals and diversions in that subbasin. All but one of the other subbasins where reductions did not eliminate the deficits are mixed subbasins located along the updip limit of the confined Atlantic City 800-foot sand. Basin 02040301180 was the only updip subbasin where 100-percent reductions did not eliminate the base-flow deficit. This subbasin is affected by withdrawals from the Atlantic City 800-foot sand.

For most subbasins, the deficits were eliminated by reducing withdrawals from the unconfined aquifer until the annual deficit total was zero (no deficit occurred in any month of any simulated year). In most cases, the decrease in deficit was essentially proportional to increases in the percentage of groundwater-withdrawal reduction. That is, reductions in withdrawals were increased in increments of 10 percent until the deficit was eliminated, and the reduction of deficits followed in equal increments until the deficit was eliminated. In a few cases, however, the reduction of withdrawals only partially eliminated the deficit. For subbasin 02040302020, a base-flow deficit remained because of surface-water withdrawals in this subbasin. For other subbasins, including 02040301170 and 02040301180, the deficit was caused primarily by withdrawals from the confined Atlantic City 800-foot sand in downdip subbasins and not by withdrawals within the subbasins. Therefore, even with a 100-percent reduction of unconfined aquifer withdrawals (all of the withdrawals in 02040301180), these two subbasins remained in deficit under the Full Allocation scenario.

In several subbasins, including 02040301200 and 02040302050, reductions in deficits were asymptotic to zero with a linear reduction in withdrawals. That is, initial 10-percent reductions in withdrawals substantially reduced the base-flow deficit, but further 10-percent reductions had less and less effect on deficits. For subbasin 02040301200, the deficit in the Full Allocation scenario was reduced substantially from 137 Mgal/d after an 80-percent reduction in withdrawals, but the deficit was only reduced to 0.8 Mgal/d and 0.2 Mgal/d after a 90- or 100-percent reduction of withdrawals, respectively. Similarly, in subbasin 02040302050, a deficit of 36 Mgal/d was reduced to 2.2 Mgal/d with a 30-percent reduction, but deficits were reduced to 0.7 Mgal/d and 0.3 Mgal/d with 40- and 60-percent reductions in withdrawals, respectively. The deficit was eliminated completely in this case but only with an 80-percent reduction in withdrawals. This behavior may result from withdrawals from the Atlantic City 800-foot sand in downdip parts of the subbasin or in adjacent subbasins.

Under average conditions, reductions in groundwater withdrawals were needed to eliminate deficits in three updip subbasins, two mixed subbasins, and two downdip subbasins. Complete reductions in withdrawals were necessary in subbasins 02040301180 (updip) and 02040302020 (downdip). Reductions of 40 percent from current withdrawals were required in subbasin 02040302030 (updip) because of existing withdrawals for public supply and agriculture. Reductions

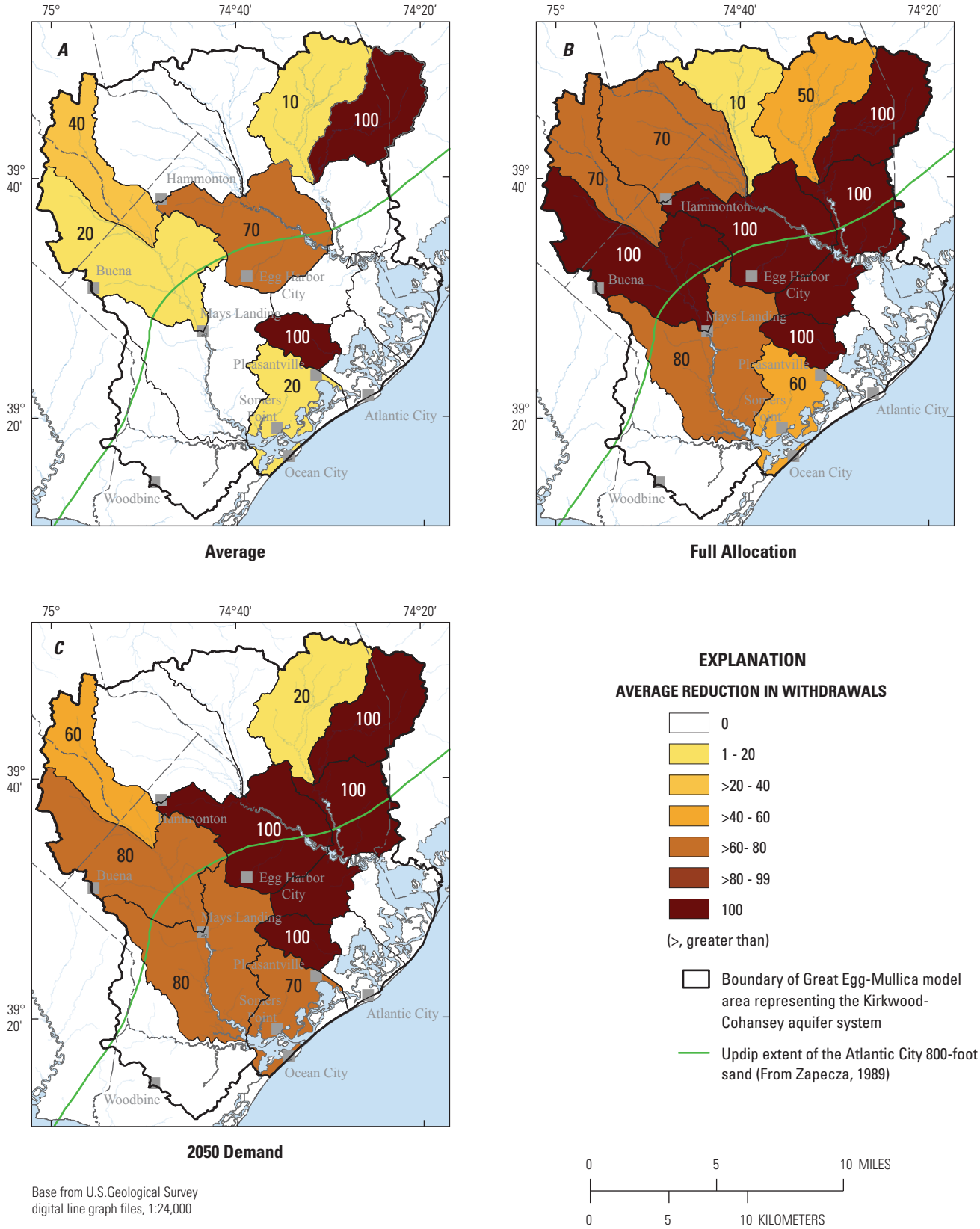


Figure 49. Average reductions in groundwater withdrawals required to eliminate or minimize deficits in Hydrologic Unit Code 11 subbasins, southeastern New Jersey, under A, Average, B, Full Allocation, and C, 2050 Demand scenarios with Tier 3 adjustments.

in withdrawals from mixed subbasins 02040301170 and 02040302040 (70 and 20 percent, respectively) were needed because of the withdrawals already occurring in the subbasins and because of withdrawals for seasonal-conjunctive use from the Atlantic City 800-foot sand downdip. Subbasin 02040302060 located downdip required 20-percent reductions in withdrawals to eliminate base-flow deficits.

In the Full Allocation scenario, reductions in withdrawals were needed in five updip subbasins, four mixed subbasins, and two downdip subbasins. The large base-flow deficit in subbasin 02040301160 in the Full Allocation scenario was caused by the substantial withdrawals for agricultural use. Basin-wide reductions in withdrawals of 70 percent were necessary to eliminate the base-flow deficits. Allocated withdrawals for agricultural use caused a similar (but less severe) increase in deficits; a basin-wide 10-percent reduction in withdrawals was required to eliminate the deficit. In updip subbasins 02040301190 and 02040302030, the deficits increased in the Full Allocation scenario, and additional reductions in withdrawals were needed to eliminate the deficits. Deficits in mixed subbasins 02040301200 and 02040302040 increased in the Full Allocation scenario, and reductions in withdrawals greater than 10 percent (from average conditions) were required to eliminate the deficits. In the mixed subbasins, the increased deficits were due to a combination of increased withdrawals within the subbasin and seasonal-conjunctive use withdrawals from the Atlantic City 800-foot sand. Increased public supply withdrawals caused increased deficits (from average conditions) in downdip subbasin 02040302060; additional reductions in withdrawals were needed to eliminate the deficit.

Under the 2050 Demand scenario, reductions in withdrawals were needed in three updip subbasins, four mixed subbasins, and two downdip subbasins. Withdrawals from the unconfined aquifer in this scenario were generally less than those under the Full Allocation scenario because the agricultural withdrawals remained at average 1998–2006 levels. In some subbasins, public supply withdrawals under the 2050 Demand scenario were substantially increased, such that the total withdrawals within the subbasin were greater than those in the Full Allocation scenario. The same four mixed subbasins that were in deficit under the Full Allocation scenario required substantial reductions (even though the agricultural withdrawals remained at 1998–2006 rates) because of increased public supply withdrawals from the Atlantic City 800-foot sand downdip.

Summary of Base-Flow Deficit Reduction and Elimination with Scenario Adjustments

In general, most of the deficits under the Average, Full Allocation, and 2050 Demand scenarios were eliminated by reductions in withdrawals. The percentage of deficit reduction accomplished using Average, Full Allocation, and 2050 Demand scenarios in each subbasin is shown in table 20. Reductions in withdrawals accounted for more than 95 percent of the total reduction of deficits in all subbasins, except for subbasin 02040302060. Moving withdrawals from the shallow to the deep Kirkwood-Cohansey aquifer system was most successful in this subbasin, but it still accounted for a maximum of only 6 percent of the reduction in the deficit (under average conditions). Seasonal-conjunctive use was successful in this subbasin; 35 to 80 percent of the base-flow deficit reduction for the three scenarios was achieved by seasonal-conjunctive use. Because seasonal-conjunctive use resulted in 80 percent of the deficit reduction, reduction in withdrawals would only need to provide 14 percent of the deficit reduction.

The effects of the three adjustment approaches on eliminating deficits depended on whether the subbasin was updip, mixed, or downdip. The sums of the deficits, grouped by subbasin type, for the average conditions, and adjusted Tier 1, Tier 2, and Tier 3 conditions are shown in figure 50. Under average conditions, most of the deficits occurred in downdip areas and were reduced somewhat by moving withdrawals from the shallow to the deep Kirkwood-Cohansey aquifer system (layer 1 to 3; Tier 1) or by seasonal-conjunctive use (Tier 2), but deficits were eliminated or minimized only by reductions to withdrawals (Tier 3). In the Full Allocation scenario, deficits increased in updip and mixed subbasins with implementation of seasonal-conjunctive use because of increased withdrawals from the Atlantic City 800-foot sand. In downdip subbasins, Tier 1 adjustments increased the deficits slightly, but Tier 2 adjustments ultimately reduced the deficits to less than the initial deficits. Deficits in the Full Allocation scenario were reduced primarily by reductions in withdrawals (Tier 3). In the 2050 Demand scenario, seasonal-conjunctive use (Tier 2) increased deficits in updip and mixed subbasins and reduced deficits in the downdip subbasins. For all of the subbasins combined, the deficits remained similar and were ultimately reduced or minimized through reductions in withdrawals (Tier 3).

Seasonal-conjunctive use (Tier 2) did not eliminate deficits for any subbasin (elimination of deficits was expected) and made deficits worse in the mixed subbasins; however, the manner in which the adjustments were simulated affected these results. With an attempt to eliminate deficits in all subbasins at the same time, there were substantial effects on other downdip subbasins and on the mixed subbasins because of the increased withdrawals from the Atlantic City 800-foot sand during the summer months in the seasonal-conjunctive use approach. The biggest effect was that in attempting to reduce deficits in subbasin 02040302020, increased deficits occurred in adjacent subbasins. The large volume of withdrawals moved from the Kirkwood-Cohansey aquifer system to the Atlantic City 800-foot sand in this subbasin had a great effect on neighboring downdip subbasins, as well as on mixed and updip subbasins. Effects on mixed and updip subbasins would be less severe, and water-level decline in the Atlantic City 800-foot sand would be less, if withdrawals from subbasin 02040302020 were not moved from the Kirkwood-Cohansey aquifer system to the Atlantic City 800-foot sand in the summer.

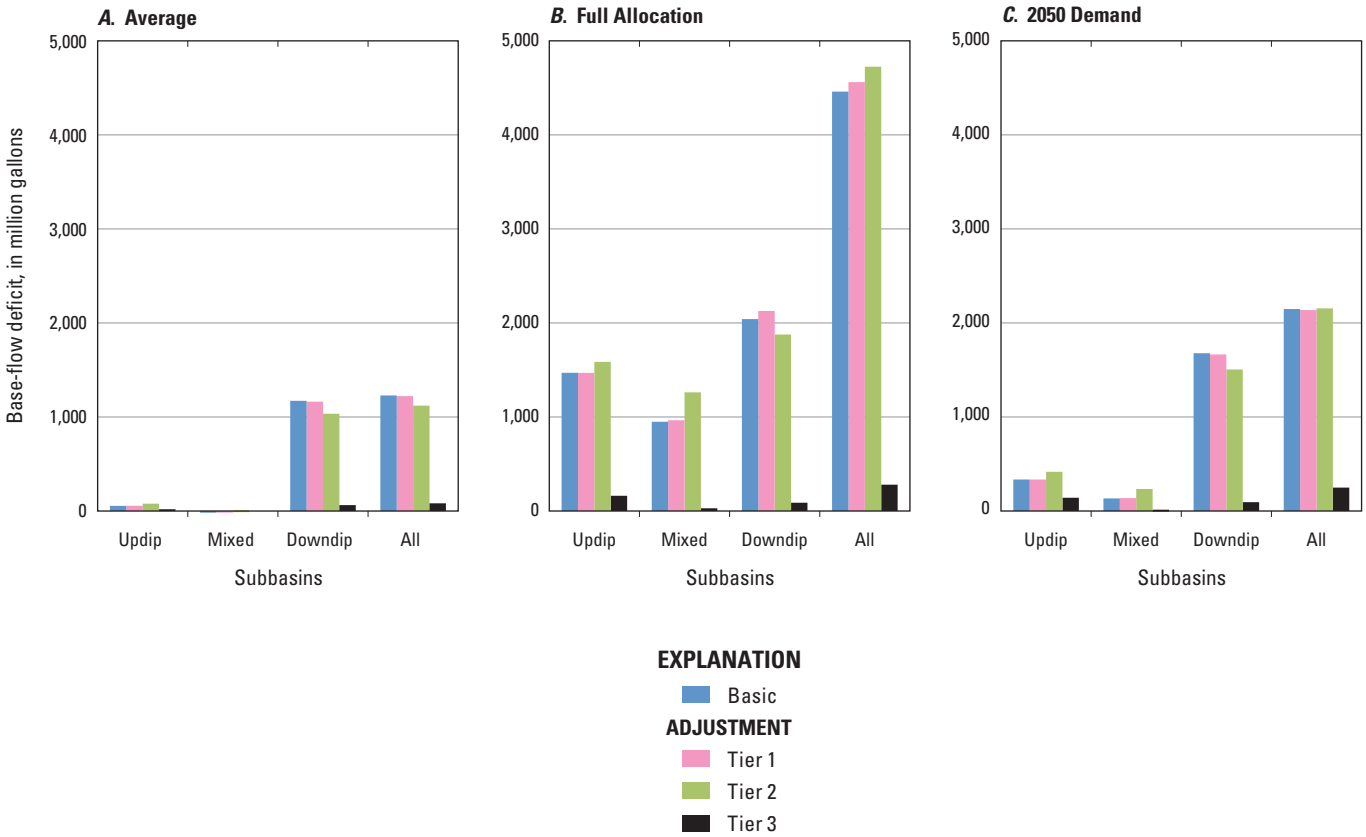


Figure 50. Simulated base-flow deficits under A, Average, B, Full Allocation, and C, 2050 Demand scenarios with basic, Tier 1, Tier 2, and Tier 3 adjustments for the entire study area and updip, mixed, and downdip subbasins, southeastern New Jersey.

Reductions in withdrawals needed to eliminate deficits (Tier 3) were large. In some cases, however, reductions may have been larger than necessary because of the way the simulations were developed and adjusted. Because the seasonal-conjunctive-use adjustment (Tier 2) was applied first, increased deficits in mixed and updip subbasins resulted, which were then decreased by subsequent reductions in withdrawals (Tier 3). Similarly, an attempt to reduce deficits in subbasin 02040302020 caused a larger effect on base-flow deficits in mixed and updip subbasins and on water-level declines in the Atlantic City 800-foot sand than would have occurred if there had been no attempt to reduce deficits in this subbasin. (Deficits could not be eliminated in this subbasin.)

The purpose of the adjustments to scenarios was to illustrate several approaches that could be used to reduce base-flow deficits in the study area. These adjustments, however, are not the only means by which deficits could be reduced or eliminated. Also, these adjustments are not intended to represent any current management plan but are simply intended to illustrate the effects of the different approaches. Simulating reductions of withdrawals is not intended to imply that this approach is part of any plan for the Kirkwood-Cohansey aquifer system. The results of these simulations are presented merely to show the magnitudes of withdrawal reductions that would be needed to reduce or eliminate base-flow deficits. The results of these adjustments could be used in formulating water-management plans by showing a range of possible strategies and relative effectiveness.

Summary of Final Deficits

The final adjusted conditions are the results of the Tier 3 simulations. The maximum annual deficit and the simulation year in which it occurred for each HUC11 subbasin are shown in figure 51. For all basic scenarios, subbasin 02040302020 was in deficit under adjusted conditions because of the zero base-flow depletion criterion for that subbasin in some summer months. The remaining subbasins in deficit are those mixed or updip subbasins discussed previously that were affected by declining heads in the summer in the Atlantic City 800-foot sand that resulted from seasonal-conjunctive use. As discussed previously, some of these deficits might be eliminated if seasonal-conjunctive use was simulated differently or

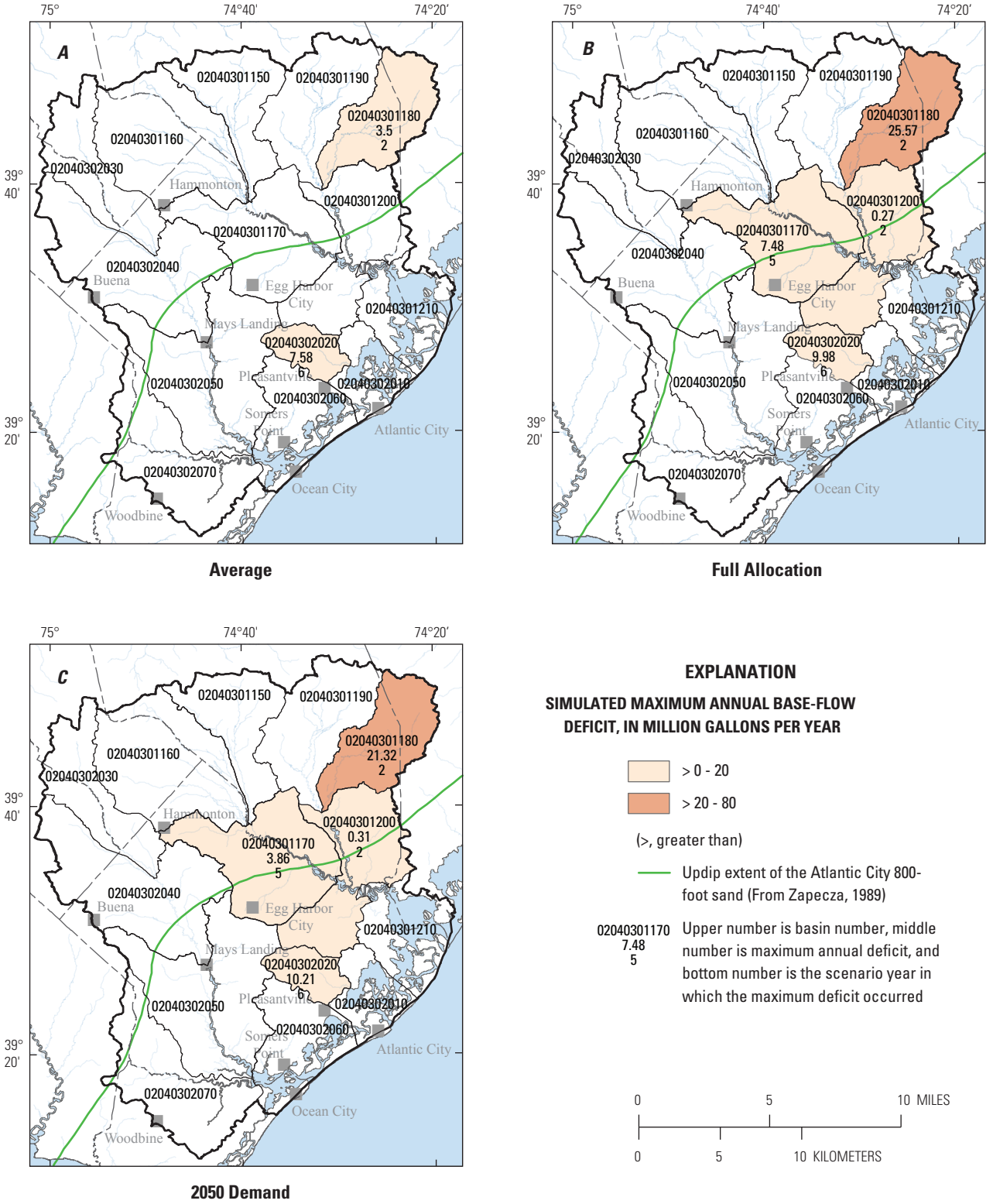


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Figure 51. Simulated maximum annual base-flow deficits for Hydrologic Unit Code 11 subbasins in southeastern New Jersey, under A, Average, B, Full Allocation, and C, 2050 Demand scenarios with Tier 3 adjustments.

was not used as an alternative. Adjusting the base-flow depletion criteria by changing the percentage of the low-flow margin available for use would also result in different deficits for the scenarios. Analysis of basins where deficits are simulated as occurring under Average conditions could be investigated to see if signs of impact of base-flow depletion are visible.

Summary and Conclusions

Groundwater is an essential component of the water supply and plays a critical role in maintaining the environmental health of freshwater and estuarine ecosystems in the Atlantic Coastal basins of New Jersey. The unconfined Kirkwood-Cohansey aquifer system and the confined Atlantic City 800-foot sand are major sources of groundwater in the area, and each is subject to different water-supply concerns in an area where future water demand is on the rise. The U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection (NJDEP), conducted a study to simulate the effects of withdrawals in both aquifers, as well as the Rio Grande water-bearing zone. The study area encompasses Atlantic County and parts of Burlington, Camden, Gloucester, Ocean, Cape May, and Cumberland Counties. Recent groundwater withdrawals have created cones of depression in the Atlantic City 800-foot sand and caused base-flow depletion in streams in some subbasins.

The major hydrogeologic units affecting water supply in the study area are the surficial Kirkwood-Cohansey aquifer system, a thick diatomaceous clay confining unit in the upper part of Kirkwood Formation; the Rio Grande water-bearing-zone; and the Atlantic City 800-foot sand of the Kirkwood Formation. The hydrogeology of the three aquifers was assembled from published reports, available data, and data collected as part of this study. The hydrogeologic framework was revised from a more regional representation of the New Jersey Coastal Plain aquifer system to include a clay-rich zone identified in the southeastern part of the study area within the Kirkwood-Cohansey aquifer system in the model. The Rio Grande water-bearing zone was also included as a separate layer in the model.

The Kirkwood-Cohansey aquifer system is present throughout the entire study area. The aquifer system consists primarily of gravel, sand, silt, and clay sediments of the Cohansey and Kirkwood Formations. The Kirkwood-Cohansey aquifer system is generally considered to be unconfined; however, discontinuous clays are common, especially in sediments of the Cohansey Formation. Many of the clay units within the generally unconfined Kirkwood-Cohansey aquifer system are of variable extent. The Kirkwood-Cohansey aquifer system is underlain by a confining unit in the downdip areas. There has been uncertainty about the updip extent and character of the confining unit. This uncertainty has limited the understanding of how effectively the Atlantic City 800-foot sand is connected vertically to the generally unconfined Kirkwood-Cohansey aquifer system, which appears to transition into a single aquifer beyond the updip edge of the clay. The Rio Grande water-bearing zone is a thin aquifer in the southeastern half of the study area and is present within the major confining unit overlying the Atlantic City 800-foot sand.

Hydrogeologic data needed to prepare the groundwater flow model were collected or assembled during the study. Horizontal hydraulic-conductivity data from 18 aquifer tests conducted in the area were used. Estimates of specific capacity at public supply wells were used to supplement these data. Withdrawal data for the Kirkwood-Cohansey aquifer system, the Atlantic City 800-foot sand, and the Rio Grande water-bearing zone in the study area were used as input to the groundwater flow model. Withdrawals from the Kirkwood-Cohansey aquifer system were about twice those from the deeper Atlantic City 800-foot sand aquifer. Withdrawals from the Rio Grande water-bearing zone were relatively minor. Groundwater withdrawals were primarily used for public supply and irrigation. Seasonal variations in withdrawals in the summer months (June through August) were sometimes more than twice the withdrawals in the winter months (December through February). Also, the variability in withdrawals was greater in the summer. Base flow is the groundwater contribution to the total flow of a stream. Monthly base flow was estimated for 12 streamgaging stations with continuous records. Low-flow statistics at partial-record stations were estimated using data from the 12 streamgaging stations. The correlation of streamflows between the index stations and the low-flow partial-record stations was used to estimate monthly base flow and direct runoff at 51 low-flow partial-record stations. The base-flow values were used as model calibration targets for each subbasin. The direct runoff estimated using base-flow separation was in turn used to estimate average direct runoff for the study area for use in estimation of recharge. Recharge was estimated on a monthly basis using a water-budget approach.

The groundwater flow model is a representation of the heads and groundwater flow in the Kirkwood-Cohansey aquifer system, the Rio Grande water-bearing zone, and the Atlantic City 800-foot sand with sufficient accuracy and resolution to facilitate an analysis of the regional flow system. The Kirkwood-Cohansey aquifer system within the drainage areas of the Great Egg Harbor River and the Mullica River was modeled. The confined aquifers were modeled over a larger area so that the boundary conditions were distant from the main area of interest. Boundary flows for the confined aquifer were obtained by modifying the New Jersey Regional Aquifer-System Analysis (RASA) model and simulating the same conditions over a larger area. Grid spacing in the onshore part of the model is 880 x 880 or 880 x 1,100 ft on a side to adequately represent surface-water features in the model. Grid spacing is larger in offshore areas. Grid alignment and spacing were selected so that the model grid fits within the RASA model and boundary conditions for the confined Atlantic City 800-foot sand could be attained easily. The simulation period

for model calibration is January 1999 through September 2006.

Hydrologic boundaries were used to represent the locations and quantity of flow into and out of the model. Recharge used in the model is based on three factors—spatial variation based on a New Jersey Geological Survey recharge map, temporal variation based on monthly recharge estimated from base-flow data, and model calibration zones. Recharge was simulated using the Recharge package of MODFLOW. Artificial recharge to the Kirkwood-Cohansey aquifer system from land-application recharge basins of two wastewater-treatment plants in the study area was also simulated. Surface-water features represented in the model are freshwater wetlands, rivers, streams, lakes or ponds, saltwater wetlands, the ocean, and bays. These features are simulated using either the River or Drain package or as constant head cells (for saltwater wetlands or ocean cells). Freshwater surface-water features were derived from the National Hydrography Dataset. Altitudes of the stages of the river, stream, pond, or wetland were initially assigned using the best available Digital Elevation Model data, which were obtained from the National Elevation Dataset. Subsequently, stream stages were revised to ensure that downstream stages were lower than upstream stages to correct problems with simulated heads near surface-water features. Groundwater withdrawals were simulated using the Well package in MODFLOW. The lateral flow boundary for the surficial aquifer is a no-flow boundary at the basin boundaries of the Great Egg Harbor and Mullica River Basins. For the confined Atlantic City 800-foot sand, the lateral boundaries to the north and south, and offshore, are flows from the revised New Jersey RASA model. The lower boundary for the model is a flow boundary incorporating vertical flows from the revised New Jersey RASA model into the unconfined and confined parts of the Great Egg Harbor and Mullica River model.

Simulated water levels, base flow, and hydraulic gradients were compared to observed values to calibrate the groundwater flow model. A total of 32 parameters was used to adjust model values to obtain a fit to the observed values. During calibration, parameters representing horizontal hydraulic conductivity, vertical hydraulic conductivity of confining units, recharge, streambed conductance, and storage were adjusted to fit head and base-flow observations. Seven parameters were used to represent horizontal hydraulic conductivity, eight to represent vertical hydraulic conductivity, and eight to represent the streambed hydraulic conductivities for modeled rivers and drains. Seven parameters were used for recharge, and two were used for storage.

A variety of data were collected or assembled in order to calibrate the groundwater flow model—synoptic water levels, long-term water levels, monthly estimates of base flow, and vertical head gradients. Synoptic data used to calibrate the groundwater flow model were collected during 2005 and 2006. Data collected in May 2005 represent high water-level and streamflow conditions during spring. Data collected in September 2006 represent late summer conditions when water levels and streamflow typically are at the lowest levels of the year. In addition to the water levels measured in 2005 and 2006 as part of this study, other water-level data from wells completed in the Atlantic City 800-foot sand and included in the New Jersey Coastal Plain Synoptic Water-Level Network in 1998 and 2003 were used in this study. Daily water-level data from 14 wells in the U.S. Geological Survey New Jersey Water-Level Monitoring Network were used to create monthly hydrographs for use in model calibration. Base-flow data from 22 sites in the area were used to create base-flow hydrographs. Simulated base flows in the River and Drain packages of the model were calibrated to the base-flow hydrographs generated for the study area.

The shapes of the simulated contours for spring 2005 and fall 2006 in the Kirkwood-Cohansey aquifer system closely follow those of the water-table maps created for previous studies of the surficial aquifer in the Mullica and Great Egg Harbor River Basins. Throughout most of the study area, the simulated water levels were within +/- 5 ft of the observed water levels. The largest and most frequent occurrence of residuals (simulated minus observed values) of more than 5 ft was for the area northwest of Pleasantville, N.J., along the divide between the Mullica and Great Egg Harbor River Basins. Most of these large residuals occurred when the simulated head was much lower than the observed head. Hydrographs of wells in the Kirkwood-Cohansey aquifer system show that simulated heads match the observed seasonal changes fairly well. Most of the simulated heads are within 5 ft of the observed heads. In the Atlantic City 800-foot sand, simulated water levels match observed water levels well, except for an area along the coast near and north of Ocean City, N.J., where simulated water levels were as much as 10 ft lower than observed water levels. Most of the residuals fall within +/- 5 ft. Calibration of simulated base-flow values to observed values was accomplished by using visual comparison of hydrographs. Base-flow hydrographs for the six streamgaging stations are considered the best observed base-flow data for use in calibration. Most of the simulated and observed hydrographs match fairly well and have moderate to small root mean square errors. Parameter values that most affected the calibration of the base-flow hydrographs are the streambed conductance values for the River and Drain packages and the multiplier for recharge.

The sensitivity of simulated hydraulic heads to the model parameters was calculated using UCODE-2005. Composite scaled sensitivities (CSS) were calculated for 31 parameters using the observed heads from 1998, 2003, 2005, and 2006 and the data from the monthly hydrographs for the water-level network sites. The parameters with the largest CSS values are the horizontal hydraulic conductivities for the Atlantic City 800-foot sand and the deep part of the unconfined Kirkwood-Cohansey aquifer system.

Groundwater flow budgets were created for the Great Egg Harbor and Mullica River model calibration periods—May 2005, September 2006, and 1998 to 2006, the entire 9-year model calibration period. Flow budgets for the model calibration periods 2005 and 2006 allow comparison of the

contributions from different parts of the flow system during the spring and fall.

Much more water moves through the unconfined Kirkwood-Cohansey aquifer system than through the Atlantic City 800-foot sand. The major input to the flow budget for the Kirkwood-Cohansey aquifer system is recharge. Most of the recharge received is then discharged to drains or rivers. The term representing flow from the unconfined Kirkwood-Cohansey aquifer system to the confined Atlantic City 800-foot sand is a minor part of the flow budget for the unconfined aquifer, but it is the major source of water for the Atlantic City 800-foot sand. Flows into the confined aquifer from lateral and vertical flow boundaries were a substantial source of water to the aquifer. The major outflow from the confined aquifer was discharge to pumped wells. The flow budget for 1999 to 2006 shows the transient effects of the major components of the flow system during the calibration period. In the Kirkwood-Cohansey aquifer system, recharge varies monthly and was greatest in winter to early spring. Flow out to drains was also greatest at these times. In the Atlantic City 800-foot sand, withdrawals were seasonal and greatest in the summer and fall. Flow into this aquifer from storage also was greatest in the summer. Flow from the Atlantic City 800-foot sand into storage occurred in winter.

Simulations of various scenarios were run using the calibrated model to compare simulated base-flow depletion with base-flow depletion criteria to determine, as part of this study, where and when base-flow deficits could occur or be expected to occur in the future. Results of the simulations were analyzed using Hydrologic Unit Code 11 (HUC11) subbasins delineated within the study area. The 14 HUC11 subbasins were categorized as updip, mixed, or downdip for analysis. Subbasins that span the updip limit line for the confining unit overlying the Atlantic City 800-foot sand were designated "mixed." Parts of these subbasins overlie the unconfined aquifer, and parts overlie both confined and unconfined aquifers. The interaction of the Kirkwood-Cohansey aquifer system and the confined Atlantic City 800-foot sand in the mixed subbasins is an important finding from these simulations.

Six scenarios—three basic and three adjusted—were simulated to assess base-flow depletion that could occur in different groundwater-withdrawal situations. Simulated base-flow depletion was compared to monthly criteria determined by NJDEP. Base-flow depletion was calculated for each scenario by subtracting the base flow for each HUC11 subbasin from the base flow that would have occurred during the simulation period had there been no groundwater withdrawals. The basic scenarios represent average 1998–2006 withdrawals, full-allocation withdrawals, and projected 2050 demand withdrawals. These basic scenarios were intended to identify subbasins where deficits may be occurring currently (2012) or where they may occur under future conditions. The adjusted scenarios simulate variations of the Average, Full Allocation, and 2050 Demand scenarios in which the withdrawals were modified in an attempt to eliminate or reduce base-flow deficits. This adjustment was done by moving withdrawals to a deeper aquifer, by seasonal-conjunctive use of shallow and deep aquifers, or by reductions in withdrawals from a HUC11 subbasin in deficit. The results of the simulations are considered to be conceptual evaluations, showing only what the adjustments might achieve.

In order to evaluate simulation results, monthly base-flow depletion criteria were needed for each of the 14 HUC11 subbasins in the study area. The approach used to determine the monthly base-flow-depletion criteria was based on the Low-Flow Margin method used by NJDEP to estimate available water on an annual basis at the HUC11 level. The method assumes that some percentage of streamflow can be removed without affecting stream ecology. For the method, available water is defined as a percentage of the difference between normal dry-season streamflow and drought streamflow. The September median flow represents typical flows for September, which are generally the lowest flows of the year in New Jersey. The 7-day, 10 year (7Q10) flow represents drought flows. The low-flow margin is the difference between the September median flow and the 7Q10 flow. The NJDEP defines available water as a percentage of this margin. The water available for depletive and consumptive use is defined as 25 percent of the Low-Flow Margin. The NJDEP Low-Flow Margin method was modified for this study to determine monthly base-flow depletion limits for the Great Egg Harbor and Mullica River Basins. The modification was necessary in order to consider seasonal-conjunctive use of shallow unconfined and deeper confined sources as an alternative within the study area.

The simulation of the Average scenario was run using average annual water-use data for 1998 to 2006. In this simulation, base-flow deficits occurred during June to November. Simulated heads in the Atlantic City 800-foot sand under average conditions were more than 80 feet below National Geodetic Vertical Datum of 1929 in the spring and more than 100 feet below land surface in September of scenario year 9.

The simulation of the Full Allocation scenario represents conditions that would occur if all wells were pumped at their full-allocation rate. In the Full Allocation scenario, all but three downdip subbasins with few agricultural withdrawals were in deficit. Deficits in the mixed subbasins and in many of the updip subbasins in the Full Allocation scenario were much larger than in the Average scenario because of the increased agricultural withdrawals. Simulated heads in the Atlantic City 800-foot sand near the center of the cone were more than 120 feet below land surface in April of scenario year 9 and more than 150 feet below land surface in September of scenario year 9.

The simulation of the 2050 Demand scenario was run with an agricultural-use constant at the average 1998 to 2006 levels and using estimated 2050 demand for wells with public supply and other permit types. In this scenario, some updip subbasins in the Mullica River Basin were no longer in deficit. However, base-flow deficits in the mixed and updip subbasins were larger under the 2050 Demand scenario than under the Average scenario because of the effects of increased public

supply withdrawals from the confined Atlantic City 800-foot sand in the unconfined part of the aquifer. Simulated heads in the Atlantic City 800-foot sand at the center of the cone of depression were more than 120 feet below NGVD 29 in April of scenario year 9 and were more than 160 feet below NGVD 29 in September of scenario year 9.

Simulation of the basic scenarios identified subbasins that would be in deficit under average, full-allocation, and 2050 demand conditions. These base-flow deficits were addressed by using three tiers of hypothetical adjustments. These hypothetical adjustments are not intended to reflect any management policy in place or under consideration but simply to illustrate the relative effects of the methods. In Tier 1, the depths of the withdrawal wells in the Kirkwood-Cohansey aquifer system in downdip subbasins was changed. Tier 2, seasonal-conjunctive use, incorporated the results of Tier 1, then implemented a shift of withdrawals between the Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand, seasonally. Finally, Tier 3 incorporated the results of Tier 2, then reduced the magnitude of withdrawals. Tier 1 adjustment had little effect and did not eliminate deficits in any subbasin. Tier 2 adjustments (seasonal-conjunctive use) improved base-flow deficits in only one downdip subbasin, reducing the deficit by 40 to 80 percent of the total base-flow deficit in that subbasin for the 2050 Demand, Full Allocation, and 1998 to 2006 Average scenarios. In mixed subbasins, where base-flow deficits were present, seasonal-conjunctive use increased the deficits. This is because of the declining summer heads caused by increased summer withdrawals from the Atlantic City 800-foot sand within the mixed subbasins or downdip subbasins. This finding is important because it shows that withdrawals from the confined aquifer have an effect on base flows in the subbasins located updip from the limit of the confining unit overlying the Atlantic City 800-foot sand. Heads in the Atlantic City 800-foot sand recovered by as much as 20 feet during the spring but declined by as much as 70 feet by the end of the summer, and heads in the aquifer reached levels of more than 190 feet below NGVD 29 in the seasonal-conjuctive use approach. Given the increased deficits in the mixed subbasins and the head declines in the Atlantic City 800-foot sand, seasonal-conjunctive use would not solve the base-flow deficits if applied throughout the study area. Finally, Tier 3 was simulated; withdrawals were reduced on a subbasin-by-subbasin basis until all deficits were eliminated or minimized. The reduction of withdrawals could represent shifting the water supply to a different source or reducing water use. The base-flow deficits for most subbasins were eliminated by reducing withdrawals from unconfined aquifers.

Using the three-tier approach to reduce or eliminate base-flow deficits showed that all three adjustments were necessary to eliminate deficits in most subbasins. The Tier 1 approach of moving withdrawals from the unconfined part of the Kirkwood-Cohansey aquifer system to the semi-confined part of the Kirkwood-Cohansey aquifer system did not substantially reduce deficits. The Tier 2 approach of seasonal-conjunctive use worked well for only one downdip subbasin. Also, the shifting of some withdrawals to the confined Atlantic City 800-foot sand in the summer caused increased deficits in several subbasins near the limit of the confining unit overlying the aquifer. Most of the reductions in deficits were accomplished by reductions in withdrawals. After simulation of the three adjustment tiers, deficits remained in several subbasins. This situation occurred in subbasin 02040302020 because no base-flow depletion was allowed in that subbasin. Deficits remained in subbasins near the updip limit of the Atlantic City 800-foot sand. These subbasins were affected by the increased withdrawals from the Atlantic City 800-foot sand during the summer in the Tier 2 approach. A change in the base-flow depletion criteria would also change the ratio of success in eliminating deficits.

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Table 3. Horizontal hydraulic conductivity estimated from specific-capacity data, Kirkwood-Cohansey aquifer system, Atlantic City 800-foot sand, and Rio Grande water-bearing zone, southeastern New Jersey.

[Aquifer: 121CKKD, Kirkwood-Cohansey aquifer system; 122KRKDL, Atlantic City 800-foot sand; 122KRKDU, Rio Grande water-bearing zone; ft/d, feet per day; gal/min, gallons per minute; NJDEP, New Jersey Department of Environmental Protection; --, no data]

U.S. Geological Survey well number	NJDEP well permit number	Aquifer	Well depth (feet below land surface)	Discharge (gal/min)	Duration (hours)	Drawdown	Hydraulic conductivity (ft/d)
010013	3600000299	121CKKD	205	710	8	27	152
010015	--	122KRKDL	831	554	4	52	62
010040	3600000057	122KRKDL	769	706	8	60	52
010041	5600000009	122KRKDL	829	700	8	93	40
010042	5600000010	122KRKDL	788	700	8	60	73
010114	3100005832	121CKKD	179	351	8	20	52
010116	--	122KRKDL	401	750	6	52	156
010117	3200000477	122KRKDL	432	768	12	82	86
010118	3200000175	122KRKDL	406	415	8	40	48
010121	3600000271	122KRKDL	783	300	8	40	105
010135	3600000429	121CKKD	127	1,016	24	35	297
010138	3600000404	121CKKD	133	1,223	24	23	175
010150	3600000431	121CKKD	222	1,016	22	36	113
010151	3600000428	121CKKD	208	1,016	24	36	201
010154	3600000401	121CKKD	160	503	6	30	66
010160	3600000367	121CKKD	165	670	16	37	214
010172	3600000426	121CKKD	204	1,000	4	40	25
010175	3600000408	121CKKD	250	610	8	52	58
010183	3600000443	121CKKD	192	415	8	20	28
010185	3600000392	121CKKD	173	307	8	33	44
010189	3600000420	121CKKD	159	495	8	41	24
010190	3600000421	121CKKD	167	402	24	31	57
010191	3600000422	121CKKD	159	403	24	26	49
010193	3600000425	121CKKD	150	325	4	20	103
010194	3600000424	121CKKD	145	300	4	20	94
010218	3600000439	121CKKD	118	450	4	20	154
010220	2800008310	121CKKD	169	524	8	30	71
010222	3600000396	121CKKD	87	305	8	20	154
010225	3600000260	121CKKD	160	210	8	20	91
010227	3600000391	122KRKDL	347	754	8	31	73
010229	5600000023	121CKKD	243	427	24	30	52
010231	3600000290	121CKKD	151	300	8	20	115
010232	3600000399	121CKKD	151	800	8	22	82
010250	3200000474	121CKKD	157	210	12	15	202
010251	3200000473	121CKKD	142	201	12	15	144
010264	--	121CKKD	107	200	16	10	76
010276	3100004684	121CKKD	77	480	8	15	208
010279	5100000039	121CKKD	328	675	8	52	231
010281	5100000037	121CKKD	315	700	4	60	68
010284	3100004266	121CKKD	171	600	10	30	88

Table 3. Horizontal hydraulic conductivity estimated from specific-capacity data, Kirkwood-Cohansey aquifer system, Atlantic City 800-foot sand, and Rio Grande water-bearing zone, southeastern New Jersey.—Continued

[Aquifer: 121CKKD, Kirkwood-Cohansey aquifer system; 122KRKDL, Atlantic City 800-foot sand; 122KRKDU, Rio Grande water-bearing zone; ft/d, feet per day; gal/min, gallons per minute; NJDEP, New Jersey Department of Environmental Protection; --, no data]

U.S. Geological Survey well number	NJDEP well permit number	Aquifer	Well depth (feet below land surface)	Discharge (gal/min)	Duration (hours)	Drawdown	Hydraulic conductivity (ft/d)
010292	3100005022	121CKKD	241	1,000	8	40	494
010293	3100004872	121CKKD	252	396	8	50	45
010353	3600000315	121CKKD	71	525	8	15	120
010355	3600000286	121CKKD	252	904	8	106	17
010356	3600000284	121CKKD	262	904	8	20	125
010360	3600000041	121CKKD	165	300	24	20	71
010361	3600000042	121CKKD	165	300	24	20	71
010362	3600000368	121CKKD	146	1,000	8	50	75
010367	5600000038	122KRKDL	800	725	8	50	164
010368	5600000037	122KRKDL	805	517	8	67	78
010369	3600000402	122KRKDL	811	1,007	8	50	79
010370	3600000318	122KRKDL	801	1,000	8	50	136
010372	3600000326	122KRKDL	803	800	8	40	94
010374	--	122KRKDL	810	770	8	50	101
010375	3600000197	122KRKDL	797	700	8	50	112
010376	3600000278	122KRKDL	791	700	8	50	89
010378	3200000529	121CKKD	176	868	5	140	40
010382	3200000623	121CKKD	154	503	7	20	57
010388	--	121CKKD	108	200	16	11	69
010549	3600000008	121CKKD	152	620	8	30	156
010549	3600000008	121CKKD	152	620	8	30	180
010554	3600000383	121CKKD	141	302	8	25	208
010563	--	121CKKD	109	1,100	24	61	88
010565	3600000014	122KRKDL	668	1,056	8	50	71
010568	3600000013	122KRKDL	636	1,050	8	50	125
010572	3600000405	121CKKD	105	1,012	8	30	106
010582	3600000021	121CKKD	99	1,000	8	20	133
010583	--	121CKKD	123	450	8	40	23
010589	3600000388	121CKKD	159	1,000	8	30	74
010593	3600000372	122KRKDL	793	1,022	8	50	103
010596	5600000013	122KRKDL	810	500	8	50	54
010598	3600000371	122KRKDL	803	818	8	60	56
010600	5600000016	122KRKDL	810	750	8	60	178
010636	--	121CKKD	53	402	72	10	259
010637	3200005113	122KRKDL	428	602	8	90	11
010657	3100005464	121CKKD	124	500	5	54	88
010660	3600001866	121CKKD	157	360	8	20	275
010680	--	122KRKDL	835	400	8	62	40
010683	3600002091	122KRKDL	780	1,060	8	50	63

Table 3. Horizontal hydraulic conductivity estimated from specific-capacity data, Kirkwood-Cohansey aquifer system, Atlantic City 800-foot sand, and Rio Grande water-bearing zone, southeastern New Jersey.—Continued

[Aquifer: 121CKKD, Kirkwood-Cohansey aquifer system; 122KRKDL, Atlantic City 800-foot sand; 122KRKDU, Rio Grande water-bearing zone; ft/d, feet per day; gal/min, gallons per minute; NJDEP, New Jersey Department of Environmental Protection; --, no data]

U.S. Geological Survey well number	NJDEP well permit number	Aquifer	Well depth (feet below land surface)	Discharge (gal/min)	Duration (hours)	Drawdown	Hydraulic conductivity (ft/d)
010686	3600003110	121CKKD	172	305	8	20	154
010689	3600002433	121CKKD	180	904	8	50	125
010696	3600003934	121CKKD	180	1,205	72	50	82
010697	3600003935	121CKKD	175	1,205	72	50	66
010698	3600003936	121CKKD	179	1,205	72	50	81
010708	3600000468	121CKKD	168	411	8	40	95
010781	3600005292	121CKKD	182	1,507	8	51	71
010782	3600005296	121CKKD	180	1,705	8	50	104
010783	3600005295	121CKKD	183	1,507	8	51	76
010785	3600005293	121CKKD	184	1,507	8	51	99
010786	3600005297	121CKKD	176	1,507	8	51	79
010789	3600006288	121CKKD	242	473	24	43	95
010864	3200013099	121CKKD	160	400	4	100	17
010866	3600005809	121CKKD	151	340	8	20	259
010874	3600004463	121CKKD	135	212	24	20	54
010889	3600011871	122KRKDL	795	1,216	4	60	100
010918	3600014427	121CKKD	153	802	8	40	205
010933	3200015836	121CKKD	135	300	4	60	47
010958	3600012463	121CKKD	180	1,808	72	60	141
010967	3600013010	122KRKDL	776	1,205	48	74	74
010970	3600002070	121CKKD	200	578	72	30	59
010972	3600008845	121CKKD	156	850	72	32	189
010973	3600014415	121CKKD	185	907	5	51	109
010974	3600006629	121CKKD	150	350	4	50	127
010975	3600011999	121CKKD	150	350	4	60	41
010985	3600015426	122KRKDL	790	1,231	72	51	155
010990	3600016110	122KRKDL	657	1,150	72	156	31
010991	3600016204	122KRKDL	647	1,295	72	150	49
010993	3600007215	121CKKD	150	350	4	50	122
010995	3100007656	121CKKD	120	240	4	80	49
010996	3600013489	121CKKD	160	500	4	70	129
010997	3600009890	121CKKD	160	450	4	80	30
011005	3100029188	121CKKD	140	250	4	70	66
011007	3100029626	121CKKD	153	600	4	100	106
011010	3200000229	121CKKD	117	350	8	26	96
011024	3100028718	121CKKD	135	410	4	80	47
011247	3100020122	121CKKD	170	356	4	60	79
011252	3200020165	122KRKDL	446	730	24	104	114
011253	3600016750	122KRKDL	603	1,275	72	254	24

Table 3. Horizontal hydraulic conductivity estimated from specific-capacity data, Kirkwood-Cohansey aquifer system, Atlantic City 800-foot sand, and Rio Grande water-bearing zone, southeastern New Jersey.—Continued

[Aquifer: 121CKKD, Kirkwood-Cohansey aquifer system; 122KRKDL, Atlantic City 800-foot sand; 122KRKDU, Rio Grande water-bearing zone; ft/d, feet per day; gal/min, gallons per minute; NJDEP, New Jersey Department of Environmental Protection; --, no data]

U.S. Geological Survey well number	NJDEP well permit number	Aquifer	Well depth (feet below land surface)	Discharge (gal/min)	Duration (hours)	Drawdown	Hydraulic conductivity (ft/d)
011255	3600019350	122KRKDL	647	1,295	72	150	49
011256	3600017667	122KRKDL	801	1,200	72	147	71
011257	3600018120	122KRKDL	619	1,800	72	90	93
011294	3600004033	121CKKD	150	350	4	40	75
011295	3100011806	121CKKD	104	210	4	74	15
011297	3600015811	121CKKD	150	250	4	90	19
011299	3500006780	121CKKD	135	500	4	100	94
011310	3500001164	121CKKD	107	268	8	26	37
011315	3100019150	121CKKD	90	300	4	20	284
011319	3500001163	121CKKD	108	200	4	26	36
011323	3600000452	121CKKD	70	500	4	30	90
011325	3600015681	121CKKD	190	500	12	50	36
011328	3200004267	121CKKD	138	280	4	90	24
011341	3200004268	121CKKD	139	310	4	90	24
011346	3600017074	121CKKD	212	1,150	72	40	80
011364	3600015680	121CKKD	190	500	12	50	36
011381	3200021134	121CKKD	120	500	4	80	113
011438	3600000303	121CKKD	182	200	8	20	235
011456	3600021156	122KRKDL	652	916	24	50	55
011460	3600020165	122KRKDL	798	938	72	118	81
011507	3600024428	122KRKDL	665	1,328	72	118	31
011508	3600024429	121CKKD	127	1,200	72	46	147
011576	3600025639	121CKKD	215	752	4	40	69
011614	3200014198	121CKKD	135	500	4	80	43
011616	3200012931	121CKKD	140	500	4	70	27
011649	3600000454	122KRKDL	621	465	8	55	98
011674	3600010221	121CKKD	225	280	6	30	53
011675	3100011576	121CKKD	97	525	4	25	85
011677	3100005469	121CKKD	124	500	5	54	88
011679	3100033895	121CKKD	155	450	4	80	86
011696	3100046647	121CKKD	130	201	4	60	124
050674	3200000688	121CKKD	179	4,447	8	70	112
050708	3200000727	121CKKD	92	200	8	15	221
050710	3200000725	121CKKD	121	315	8	15	131
050727	3200000811	121CKKD	76	850	6	24	127
051119	3200015738	121CKKD	100	450	4	80	22
051132	3200008781	121CKKD	182	4,560	8	72	205
051133	3200013974	121CKKD	161	1,016	6	31	91
051442	3200009228	121CKKD	90	520	4	20	243

Table 3. Horizontal hydraulic conductivity estimated from specific-capacity data, Kirkwood-Cohansey aquifer system, Atlantic City 800-foot sand, and Rio Grande water-bearing zone, southeastern New Jersey.—Continued

[Aquifer: 121CKKD, Kirkwood-Cohansey aquifer system; 122KRKDL, Atlantic City 800-foot sand; 122KRKDU, Rio Grande water-bearing zone; ft/d, feet per day; gal/min, gallons per minute; NJDEP, New Jersey Department of Environmental Protection; --, no data]

U.S. Geological Survey well number	NJDEP well permit number	Aquifer	Well depth (feet below land surface)	Discharge (gal/min)	Duration (hours)	Drawdown	Hydraulic conductivity (ft/d)
051453	3200000508	121CKKD	180	1,350	4	90	161
051463	3200009979	121CKKD	65	300	4	31	45
051469	3200003227	121CKKD	206	600	6	100	105
051470	3200003228	121CKKD	202	1,100	6	90	185
051473	3200008959	121CKKD	182	4,560	8	72	205
051474	3200019150	121CKKD	182	500	4	110	61
051641	3200024086	121CKKD	67	317	4	30	56
070226	3100001449	121CKKD	102	240	24	20	45
070456	3100005389	121CKKD	140	310	8	10	99
070468	3100005716	121CKKD	165	715	8	20	106
070470	3100000995	121CKKD	167	708	8	26	60
070471	3100000996	121CKKD	138	502	5	21	64
070481	3100006874	121CKKD	111	1,012	8	33	162
070483	--	121CKKD	139	225	8	21	224
070490	3100005542	121CKKD	113	1,000	48	31	231
070497	3100005543	121CKKD	101	1,000	48	26	192
070499	3100004678	121CKKD	101	596	8	19	123
070501	3100005295	121CKKD	141	510	8	25	144
070505	3100003277	121CKKD	110	240	8	8	484
070603	3100016697	121CKKD	120	503	8	20	65
070686	3100003194	121CKKD	50	250	10	10	373
070691	3100024727	121CKKD	80	305	24	15	105
070694	3100026187	121CKKD	64	218	8	20	60
070698	3100026123	121CKKD	167	525	72	30	221
070708	3100022373	121CKKD	120	201	72	30	63
070736	3100005578	121CKKD	97	200	4	15	79
070809	3100038740	121CKKD	130	250	4	90	52
070814	3100021345	121CKKD	135	475	4	100	42
070831	3100037167	121CKKD	89	324	72	36	49
070899	3100047169	121CKKD	80	500	4	22	166
070900	3100047168	121CKKD	90	240	8	20	48
070901	3100051329	121CKKD	150	1,146	72	42	253
070982	3100005229	121CKKD	139	225	8	20	209
070983	3100029724	121CKKD	136	300	8	20	80
070995	3100051944	121CKKD	72	352	24	20	67
071002	3100034400	121CKKD	140	425	4	80	67
071003	3100030945	121CKKD	140	500	4	70	39
071084	3100024130	121CKKD	93	200	8	10	137
071093	3100059328	121CKKD	155	805	72	40	88

Table 3. Horizontal hydraulic conductivity estimated from specific-capacity data, Kirkwood-Cohansey aquifer system, Atlantic City 800-foot sand, and Rio Grande water-bearing zone, southeastern New Jersey.—Continued

[Aquifer: 121CKKD, Kirkwood-Cohansey aquifer system; 122KRKDL, Atlantic City 800-foot sand; 122KRKDU, Rio Grande water-bearing zone; ft/d, feet per day; gal/min, gallons per minute; NJDEP, New Jersey Department of Environmental Protection; --, no data]

U.S. Geological Survey well number	NJDEP well permit number	Aquifer	Well depth (feet below land surface)	Discharge (gal/min)	Duration (hours)	Drawdown	Hydraulic conductivity (ft/d)
071095	3100064904	121CKKD	153	850	24	40	78
071139	3100037014	121CKKD	107	400	4	30	57
071144	3100068206	121CKKD	115	720	72	30	125
090108	3600000412	122KRKDL	843	768	24	66	70
090110	3600000373	122KRKDL	814	831	8	55	99
090117	3600000017	122KRKDL	798	700	8	52	82
090124	3600000413	122KRKDL	843	768	24	66	68
090128	5700000010	122KRKDL	870	875	10	70	158
090144	3600000451	122KRKDL	691	457	8	40	94
090145	3600000312	121CKKD	150	300	8	20	128
090146	3600000313	121CKKD	120	300	8	20	105
090147	3600000319	121CKKD	145	300	8	20	161
090148	3600000364	122KRKDL	678	300	8	30	14
090317	3500002729	121CKKD	161	805	24	23	742
090422	3600012682	121CKKD	205	540	8	60	57
090481	3600017001	122KRKDL	743	1,413	72	135	81
090482	3600020238	122KRKDL	889	800	4	160	117
090514	3600017504	122KRKDL	710	700	4	50	201
090527	3600023696	122KRKDL	795	1,001	72	130	16
110279	3500002258	121CKKD	168	750	10	60	83
111226	3500009327	121CKKD	168	205	4	30	27
150200	3100000361	121CKKD	106	805	24	37	218
150365	3100005375	121CKKD	144	412	8	34	54
150375	3100014080	121CKKD	147	805	24	29	186
151018	--	121CKKD	140	340	72	20	204
151048	3100027529	121CKKD	144	492	24	41	51
151068	3100018471	121CKKD	135	300	8	20	235
151336	3100006606	121CKKD	144	355	4	30	121
151624	3100028145	121CKKD	118	300	4	60	90
151628	3100005732	121CKKD	167	200	6	20	51
151629	3100005733	121CKKD	167	200	6	20	51
290455	3300001051	122KRKDU	458	700	8	25	115
290462	3200000609	122KRKDL	564	752	8	44	164
290464	3200000447	122KRKDL	542	508	8	57	173
290465	3200000224	122KRKDU	329	300	8	21	84
290565	3200000479	122KRKDL	497	726	8	35	60
290597	3200005858	122KRKDL	500	1,000	24	100	44
290775	3200008715	122KRKDU	323	366	24	25	58
290927	3300017494	121CKKD	244	340	12	30	254

Table 3. Horizontal hydraulic conductivity estimated from specific-capacity data, Kirkwood-Cohansey aquifer system, Atlantic City 800-foot sand, and Rio Grande water-bearing zone, southeastern New Jersey.—Continued

[Aquifer: 121CKKD, Kirkwood-Cohansey aquifer system; 122KRKDL, Atlantic City 800-foot sand; 122KRKDU, Rio Grande water-bearing zone; ft/d, feet per day; gal/min, gallons per minute; NJDEP, New Jersey Department of Environmental Protection; --, no data]

U.S. Geological Survey well number	NJDEP well permit number	Aquifer	Well depth (feet below land surface)	Discharge (gal/min)	Duration (hours)	Drawdown	Hydraulic conductivity (ft/d)
291063	3200015207	122KRKDL	526	1,245	24	46	169
291421	3200022507	122KRKDL	516	600	72	106	72
291621	3300040378	122KRKDU	461	885	72	39	66
291730	3200025614	122KRKDL	527	1,476	24	61	156
291731	3200023935	122KRKDL	519	1,266	72	98	105

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01409375	Mullica River near Atco, NJ	3.22	114	01409500	0.000	2.947	0.754	114.640	0.39
01409375				01411500	1.0E-5	2.544	0.741	146.620	0.24
01409375				01411000	2.0E-5	2.700	0.780	117.910	0.37
01409387	Mullica River at outlet of Atsion Lake, at Atsion, NJ	26.7	53	01411000	0.106	1.353	0.895	42.690	0.22
01409387				01409400	0.436	0.994	0.925	37.380	0.28
01409387				01410000	0.070	1.505	0.845	54.320	0.13
01409387				01466500	12.012	1.883	0.735	74.840	0.07
01409387				01409500	0.036	1.507	0.903	36.690	0.29
01409390	Mullica River at Atsion, NJ	33.1	25	01411000	0.094	1.419	0.968	23.286	0.29
01409390				01409500	0.020	1.680	0.963	23.854	0.28
01409390				01409400	0.528	0.988	0.988	19.064	0.43
01409395	Mullica River tributary near Atsion, NJ	4.1	**11**	01466500	3.697	2.082	0.696	145.235	0.22
01409395				01411000	0.003	2.012	0.770	137.579	0.24
01409395				01409400	0.016	1.548	0.879	93.076	0.54
01409401	Hays Mill Creek at Atco, NJ	3.8	87	01409500	9.94E-3	1.249	0.739	38.867	0.22
01409401				01477120	0.132	0.980	0.754	42.069	0.19
01409401				01411500	0.033	0.919	0.782	37.173	0.24
01409401				01409400	0.087	0.806	0.754	47.126	0.15
01409401				01411000	0.041	1.025	0.750	39.221	0.21
0140940200	Hays Mill Creek near Chesilhurst, NJ	7.13	98	01409400	0.574	0.638	0.788	33.524	0.27
0140940200				01411000	0.285	0.832	0.827	26.188	0.44
0140940200				01409500	0.119	0.952	0.753	31.742	0.30
0140940250	Cooper Branch near Chesilhurst, NJ	1.93	67	01411000	5.60E-6	2.859	0.653	254.870	0.36
0140940250				01410000	2.35E-6	3.060	0.595	403.700	0.14
0140940250				01409400	6.0E-5	2.148	0.581	539.540	0.08
0140940250				01409500	1.07E-7	3.477	0.657	234.540	0.42
01409403	Wildcat Branch at Chesilhurst, NJ	1.03	19	01411000	1.71E-8	3.928	0.889	139.260	0.35

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.—Continued

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01409403				01409400	1.36E-6	2.823	0.788	370.230	0.05
01409403				01466500	0.011	4.607	0.911	107.300	0.60
0140940310	Wildcat Branch near Chesilhurst, NJ	2.27	86	01411000	0.006	1.418	0.772	54.588	0.28
0140940310				01409400	0.024	1.039	0.776	60.518	0.23
0140940310				01409500	0.001	1.656	0.754	55.546	0.27
0140940310				01410000	0.005	1.479	0.752	60.587	0.23
0140940360	Sleeper Branch above diversion, near Atsion, NJ	16.1	77	01411000	0.355	0.966	0.949	15.696	0.50
0140940360				01409400	0.788	0.743	0.926	21.955	0.25
0140940360				01409500	0.115	1.127	0.899	22.245	0.25
0140940370	Sleeper Branch near Atsion, NJ	16.1	**89**	01409500	0.163	1.029	0.876	22.410	0.17
0140940370				01411500	0.313	0.835	0.927	17.531	0.27
0140940370				01411000	0.439	0.891	0.946	14.754	0.39
0140940370				01409400	0.988	0.667	0.907	21.948	0.17
01409404	Sleeper Branch at Us Rt 206 near Atsion, NJ	18.2	11	01410000	7.8E-4	1.959	0.835	117.690	0.10
01409404				01409400	7.4E-3	1.371	0.970	43.930	0.72
01409404				01411000	8.7E-4	1.953	0.879	89.670	0.17
0140940480	Clark Branch near Atsion, NJ	6.42	87	01409500	7.32E-12	5.775	0.851	214.975	0.23
0140940480				01477120	5.82E-7	4.783	0.696	1,135.492	0.01
0140940480				01411500	4.73E-10	4.580	0.825	295.327	0.12
0140940480				01408000	3.51E-8	4.793	0.777	334.469	0.09
0140940480				01411000	2.62E-9	4.925	0.875	184.387	0.31
0140940480				01409400	1.57E-7	3.783	0.879	223.677	0.21
0140940480				01410000	3.73E-9	4.863	0.756	525.509	0.04
01409405	Clark Branch at US Rt 206, near Atsion, NJ	7.12	**11**	01409400	0.430	0.857	0.961	26.747	0.27
01409405				01411000	0.118	1.207	0.963	22.993	0.37
01409405				01409500	0.132	1.100	0.952	23.533	0.35
01409406	**Sleeper Branch at Batsto, NJ**	36.2	**11**	01409400	0.018	1.314	0.993	24.660	0.47
01409406				01411000	2.7E-3	1.840	0.965	38.032	0.20

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.—Continued

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01409406				01409500	0.001	1.887	0.978	29.451	0.33
01409407	Pump Branch near Blue Anchor, NJ	6.2	18	01466500	1.053	1.918	0.896	42.480	0.61
01409407				01409400	0.036	1.079	0.719	94.120	0.12
01409407				01411000	5.7E-3	1.531	0.818	63.540	0.27
01409408	Pump Branch near Waterford Works, NJ	9.78	86	01410000	0.385	0.774	0.635	41.058	0.25
01409408				01411000	0.355	0.792	0.662	38.872	0.28
01409408				01409400	0.685	0.606	0.627	48.087	0.19
01409408				01409500	0.156	0.901	0.625	39.368	0.28
01409409	Blue Anchor Brook near Blue Anchor, NJ	3.01	23	01466500	0.292	2.370	0.973	29.560	0.56
01409409				01411000	4.2E-4	1.950	0.920	52.148	0.18
01409409				01409400	4.9E-3	1.366	0.954	43.866	0.26
0140940950	Blue Anchor Brook at Elm, NJ	4.86	122	01411000	0.007	1.424	0.802	51.879	0.36
0140940950				01409400	0.022	1.109	0.743	71.777	0.19
0140940950				01409500	1.3E-3	1.677	0.738	61.809	0.25
0140940950				01410000	0.011	1.344	0.699	69.723	0.20
0140940970	Albertson Branch near Elm, NJ	17.1	89	01411000	0.531	0.853	0.841	26.262	0.41
0140940970				01409400	1.119	0.646	0.806	32.846	0.26
0140940970				01409500	0.220	0.972	0.796	29.452	0.33
01409410	Albertson Brook near Hammonton, NJ	19.3	44	01409500	0.297	0.971	0.920	21.003	0.29
01409410				01466500	12.015	1.060	0.922	22.112	0.26
01409410				01409400	1.732	0.614	0.963	16.819	0.45
0140941050	Great Swamp Branch at Elm, NJ	2.83	75	01409400	3.0E-4	2.252	0.679	309.154	0.13
0140941050				01410000	3.72E-6	2.883	0.697	214.787	0.28
0140941050				01411000	3.62E-6	2.911	0.702	198.444	0.32
0140941050				01409500	1.32E-7	3.363	0.671	218.045	0.27
01409411	**Nescochague Creek at Pleasant Mills, NJ**	43.7	50	01409400	1.513	0.810	0.960	22.004	0.29
01409411				01411000	0.356	1.180	0.962	18.267	0.42

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.—Continued

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01409411				01409500	0.138	1.304	0.940	22.123	0.29
01409416	**Hammonton Creek at Wescoatville, NJ**	6.57	66	01409400	0.302	0.848	0.892	35.739	0.28
01409416				01409500	0.025	1.358	0.837	40.114	0.22
01409416				01411500	0.023	1.281	0.828	47.570	0.16
01409416				01411000	0.067	1.223	0.848	39.061	0.23
01409416				01410000	0.154	1.033	0.716	55.356	0.12
01409450	Springers Brook near Indian Mills, NJ	12.6	**11**	01410000	1.1E-3	2.206	0.914	56.262	0.11
01409450				01466500	3.431	1.693	0.929	37.813	0.25
01409450				01409500	0.002	1.942	0.974	23.610	0.64
01409460	Springers Brook nr Atsion	21.2	**27**	01409500	4.0E-5	2.832	0.940	57.868	0.36
01409460				01409400	6.4E-3	1.779	0.938	63.145	0.31
01409460				01411000	4.8E-4	2.428	0.933	60.957	0.33
01409500	Batsto River at Batsto, NJ	67.8		01409400	6.581	0.611	0.933	20.000	0.41
01409500				01410000	2.743	0.860	0.801	34.500	0.14
01409500				01411000	2.525	0.863	0.932	18.910	0.46
01409575	**Landing Creek at Philadelphia Avenue at Egg Harbor City, NJ**	4.86	**19**	01408500	0.023	1.084	0.693	46.826	0.22
01409575				01466500	1.948	1.711	0.556	73.784	0.09
01409575				01410000	0.060	1.086	0.819	35.878	0.38
01409575				01409500	0.011	1.382	0.518	75.344	0.09
01409575				01411000	0.018	1.366	0.657	66.266	0.11
01409575				01409400	0.061	1.055	0.462	121.290	0.03
01409575				01411500	0.039	1.006	0.521	75.033	0.09
01409730	West Branch Wading River near Chatsworth, NJ	44.8	**10**	01409500	0.035	1.529	0.942	35.650	0.43
01409730				01410000	0.094	1.387	0.948	37.543	0.39
01409730				01409400	0.167	1.207	0.918	53.825	0.19
01409780	Tulpehocken Creek near Jenkins, NJ	21.8	**31**	01409500	0.013	1.592	0.948	25.084	0.40

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.—Continued

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01409780				01411000	0.050	1.398	0.931	29.962	0.28
01409780				01409400	0.217	1.007	0.957	27.549	0.33
01409800	West Branch Wading River near Harrisville, NJ	83.9	14	01409500	0.065	1.660	0.949	31.052	0.42
01409800				01411000	0.834	1.198	0.857	49.810	0.16
01409800				01410000	0.302	1.434	0.969	31.050	0.42
01409815	**West Branch Wading River at Maxwell, NJ**	85.9	40	01410000	0.833	1.144	0.815	41.884	0.14
01409815				01409400	3.049	0.812	0.910	29.679	0.28
01409815				01409500	0.365	1.225	0.932	24.462	0.42
01409815				01411000	1.293	1.010	0.774	40.346	0.15
01409970	Oswego River at Oswego Lake, NJ	61.4	13	01411000	0.387	1.138	0.964	28.171	0.07
01409970				01410000	0.830	0.958	0.995	10.757	0.48
01409970				01409500	0.114	1.340	0.965	25.763	0.08
01409970				01409400	1.107	0.868	0.978	25.167	0.09
01409970				01408500	0.287	1.010	0.970	24.102	0.10
01409970				01411500	0.134	1.174	0.964	31.301	0.06
01409970				01466500	15.028	1.468	0.980	21.834	0.12
01410200	**West Branch Bass River near New Gretna, NJ**	6.54	**12**	01409400	0.657	0.633	0.927	26.769	0.26
01410200				01410000	0.133	1.049	0.947	22.623	0.36
01410200				01409500	0.100	1.030	0.942	22.128	0.38
01410215	**Clarks Mill Stream at Port Republic, NJ**	8.61	**16**	01409400	0.360	0.740	0.879	26.411	0.27
01410215				01409500	0.029	1.263	0.856	25.678	0.29
01410215				01411000	0.128	1.029	0.904	20.676	0.44
01410225	**Morses Mill Stream at Port Republic, NJ**	8.25	44	01409400	0.074	1.000	0.588	96.879	0.08
01410225				01411000	0.015	1.438	0.717	64.938	0.18
01410225				01409500	0.006	1.534	0.905	32.311	0.74
01410775	Great Egg Harbor River at Berlin, NJ	1.88	26	01409400	8.4E-3	0.992	0.621	108.868	0.29
01410775				01411000	2.3E-3	1.311	0.649	97.156	0.37

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.—Continued

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01410775				01411500	2.4E-3	1.131	0.612	100.284	0.34
01410775				01409500	1.3E-10	4.837	0.408	15,533.890	0.00
01410775				01466500	0.015	4.794	0.634	2,005.458	0.00
01410775				01410000	0.000	4.357	0.395	30,442.024	0.00
01410784	Great Egg Harbor River near Sicklerville, NJ	15.1	**89**	01409500	7.5E-3	1.572	0.853	47.749	0.21
01410784				01411000	0.019	1.469	0.906	38.799	0.32
01410784				01409400	0.093	1.076	0.900	43.872	0.25
01410784				01464500	0.026	1.360	0.790	66.564	0.11
01410784				01477120	5.9E-2	1.615	0.825	63.675	0.12
01410787	Great Egg Harbor River tributary at Sicklerville, NJ	1.64	2	01411500	6.7E-5	1.900	0.796	124.190	0.17
01410787				01464500	2.2E-4	1.810	0.817	126.282	0.16
01410787				01477120	2.4E-3	1.729	0.929	61.449	0.67
01410800	Fourmile Branch near Williamstown, NJ	5.34	11	01475000	0.092	1.674	0.804	57.260	0.31
01410800				01409400	0.085	0.856	0.791	62.330	0.26
01410800				01411000	0.026	1.165	0.842	48.950	0.43
01410803	Fourmile Branch at Winslow Crossing, NJ	6.22	**68**	01411000	0.061	1.043	0.809	35.101	0.49
01410803				01409500	0.019	1.209	0.776	37.283	0.43
01410803				01475000	0.256	1.321	0.528	89.084	0.08
01410810	Fourmile Branch at New Brooklyn, NJ	7.74	**58**	01409400	0.235	0.804	0.848	38.592	0.23
01410810				01411000	0.096	1.051	0.897	28.444	0.41
01410810				01411500	0.074	0.957	0.881	30.531	0.36
01410820	Great Egg Harbor River near Blue Anchor, NJ	37.3	**9**	01411500	0.384	0.964	0.901	30.896	0.14
01410820				01411000	0.601	0.999	0.978	13.995	0.67
01410820				01409400	1.148	0.828	0.945	25.730	0.20
01410855	Squankum Brook above sewage treatment plant, at Williamstown, NJ	1.5	28	01409400	4.5E-3	1.081	0.610	116.962	0.37
01410855				01411000	1.8E-3	1.335	0.603	98.247	0.53

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.—Continued

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01410855				01411500	7.1E-5	1.806	0.093	1,520.249	0.00
01410855				01409500	1.5E-4	1.756	0.320	224.644	0.10
01410865	Squankum Branch at Malaga Road, near Williamstown, NJ	3.02	55	01411000	3.1E-4	2.688	0.732	139.816	0.32
01410865				01409400	0.000	2.027	0.614	290.910	0.07
01410865				01411500	5.09E-6	2.512	0.822	100.771	0.61
01411020	Penny Pot Stream near Folsom, NJ	5.35	**11**	01475000	3.1E-4	4.093	0.354	2,494.959	0.00
01411020				01411500	6.0E-5	2.187	0.511	636.798	0.02
01411020				01409500	1.0E-4	2.280	0.785	99.803	0.84
01411020				01409400	5.8E-4	1.928	0.643	388.118	0.06
01411020				01411000	5.0E-5	2.547	0.635	325.426	0.08
01411035	Hospitality Branch at Blue Bell Road, near Cecil, NJ	4.51	**91**	01409500	4.8E-4	1.893	0.795	66.562	0.17
01411035				01411000	2.9E-3	1.645	0.865	52.351	0.27
01411035				01411500	1.5E-3	1.552	0.932	35.921	0.57
01411040	Hospitality Branch near Cecil, NJ	8.3	25	01411000	0.073	1.161	0.907	23.513	0.44
01411040				01411500	0.038	1.115	0.928	22.747	0.47
01411040				01409500	0.014	1.393	0.718	50.068	0.10
01411042	Whitehall Branch near Cecil, NJ	2.21	25	01409400	1.3E-3	1.674	0.594	195.175	0.07
01411042				01411500	1.0E-4	1.965	0.832	69.965	0.58
01411042				01409500	1.64E-5	2.498	0.601	144.557	0.14
01411042				01411000	2.0E-4	2.237	0.682	116.064	0.21
01411047	Whitehall Branch below Victory Lakes, near Cecil, NJ	4.6	54	01409500	1.7E-4	2.183	0.661	98.423	0.24
01411047				01411500	6.0E-4	1.795	0.750	84.646	0.33
01411047				01409400	5.7E-3	1.483	0.613	151.188	0.10
01411047				01411000	9.3E-4	1.989	0.743	84.459	0.33
01411053	Hospitality Branch at Berryland, NJ	20	**21**	01409400	0.409	0.963	0.769	48.450	0.16

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.—Continued

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01411053				01411000	0.080	1.359	0.913	27.040	0.53
01411053				01411500	0.066	1.195	0.860	35.530	0.31
01411110	**Great Egg Harbor River at Weymouth, NJ**	154	55	01411000	2.577	1.000	0.960	18.060	0.36
01411110				01409400	6.953	0.750	0.948	21.575	0.25
01411110				01409500	0.875	1.168	0.893	29.536	0.13
01411110				01411500	1.342	1.005	0.948	21.110	0.26
01411140	Deep Run at Weymouth, NJ	20	**40**	01410000	0.156	1.236	0.909	28.953	0.38
01411140				01411500	0.106	1.092	0.877	35.515	0.25
01411140				01411000	0.121	1.251	0.917	29.497	0.37
01411170	**Great Egg Harbor River at Mays Landing, NJ**	205	18	01411000	0.233	1.747	0.817	58.122	0.17
01411170				01409500	0.058	1.875	0.895	39.529	0.37
01411170				01411500	0.185	1.470	0.946	35.172	0.46
01411196	Babcock Creek near Mays Landing, NJ	16.3	34	01411000	0.083	1.165	0.943	27.316	0.30
01411196				01409500	0.018	1.416	0.923	30.872	0.23
01411196				01411500	0.052	1.103	0.936	28.941	0.26
01411196				01409400	0.303	0.845	0.912	32.772	0.21
01411200	**Babcock Creek at Mays Landing, NJ**	20	**30**	01409500	1.3E-3	2.048	0.861	54.929	0.22
01411200				01411000	0.021	1.570	0.931	36.676	0.50
01411200				01409400	0.072	1.249	0.906	49.276	0.28
01411220	South River near Belcoville, NJ	20.39	??	01411000	0.070	1.406	0.795	49.796	0.15
01411220				01409500	0.025	1.535	0.789	43.712	0.19
01411220				01411500	0.055	1.262	0.850	41.098	0.21
01411220				01410000	0.185	1.125	0.869	37.249	0.26
01411220				01409400	1.045	0.700	0.720	44.095	0.19
01411250	**English Creek near Scullville, NJ**	3.8	**21**	01409400	0.289	0.609	0.355	66.916	0.11
01411250				01411000	0.106	0.886	0.427	55.039	0.16
01411250				01411500	0.096	0.764	0.630	40.187	0.30

Table 6. MOVE.1 correlation data for low-flow partial-record stations, southeastern New Jersey.—Continued

[Sites with number of measurements in **bold** indicate that additional data were collected for these sites as part of this project in spring 2005 and fall 2006. Sites with station number and station name in **bold** are used as base-flow calibration sites; ft^3/s, cubic feet per second]

Low-flow partial-record station number	Station name	Drainage area (square miles)	Number of measurements	Index station number	Correlation slope	Correlation exponent	Correlation coefficient	Standard error of estimate (ft^3/s)	Weight
01411250				01409500	0.048	0.987	0.466	48.251	0.21
01411250				01410000	0.144	0.808	0.491	45.657	0.23
01411299	Tarkiln Brook near Head of River, NJ	7.4	13	01411500	1.9E-4	2.038	0.934	49.450	0.25
01411299				01410000	5.3E-4	2.157	0.952	39.740	0.38
01411299				01411000	1.7E-3	1.841	0.943	40.660	0.37
01411302	**Mill Creek near Steelmantown, NJ**	3.82	13	01411300	5.0E-4	2.437	0.974	67.550	0.26
01411302				01411500	2.05E-6	2.783	0.950	60.290	0.33
01411302				01410000	8.49E-6	2.946	0.956	53.470	0.41
01411305	**Mill Branch near Northfield, NJ**	7.47	**28**	01411000	0.232	0.810	0.858	27.480	0.30
01411305				01411300	0.532	0.773	0.735	41.162	0.13
01411305				01410000	0.235	0.805	0.784	32.202	0.22
01411305				01411500	0.114	0.837	0.894	25.378	0.35

Table 9. Simulated and observed groundwater levels and residuals, southeastern New Jersey, May 2005 and September 2006.

[NJDEP, New Jersey Department of Environmental Protection; Simulated and observed water levels are in feet above, NGVD29, National Geodetic Vertical Datum of 1929; NAD83, North American Datum of 1983; --, no data; RMS, Root mean square error]

U.S. Geological Survey well number	NJDEP well permit number	Well use	Latitude (NAD83)	Longitude (NAD83)	Altitude of land surface (NGVD29)	Aquifer	Well depth, in feet	Model layer	May 2005			September 2006		
									Observed water-level altitude	Simulated water-level altitude	Residual, in feet	Observed water-level altitude	Simulated water-level altitude	Residual, in feet
010256	3200000173	Observation	393333	744425	93.19	121CKKD	275	7	56.62	58.217	1.6	54.92	57.119	2.2
010464	--	Unused	394027	743957	21	121CKKD	25	1	16.06	15.454	-0.61	16.32	14.839	-1.48
010465	--	Unused	394027	743957	21	121CKKD	50	1	16.11	15.454	-0.66	16.41	14.839	-1.57
010466	--	Unused	394027	743957	21	121CKKD	99	7	16.17	15.753	-0.42	16.47	15.141	-1.33
010486	--	Unused	394028	743957	20	121CKKD	50	1	15.42	15.493	0.07	--	--	--
010603	3600001849	Observation	392304	743514	25	121CKKD	95	1	12.01	12.449	0.44	15.45	12.046	-3.4
010689	3600002433	Withdrawal	392944.7	742824.1	31.17	121CKKD	180	3	8.93	7.073	-1.86	7.47	1.267	-6.2
010699	3500004370	Observation	392933	744603	40	121CKKD	160	5	24.73	32.426	7.7	23.4	-3.632	-27.03
010712	3500004796	Observation	392902	745050	100	121CKKD	387	9	69.65	71.832	2.18	67.21	70.815	3.61
010717	3600065514	Observation	392933	743129	40	121CKKD	335	5	16.36	-5.947	-22.31	14.32	-5.937	-20.26
010719	3100023946	Observation	393241	744817	68	121CKKD	38	1	47.38	44.940	-2.44	44.67	43.411	-1.26
010720	3100023945	Observation	393549	745058	63	121CKKD	22	1	55.44	61.814	6.37	57.1	60.986	3.89
010721	3600006133	Observation	393145	743008	31	121CKKD	26	1	19.14	16.014	-3.13	17.13	14.846	-2.28
010724	3600006132	Observation	393049	743959	67	121CKKD	23	1	64.35	56.242	-8.11	60.82	54.885	-5.94
010725	3200011807	Observation	393418	743536	15	121CKKD	23	1	9.19	10.773	1.58	9.09	10.569	1.48
010726	3600006134	Observation	392939	742543	25	121CKKD	31	1	12.92	6.699	-6.22	11.35	6.149	-5.2
010740	3600003836	Observation	393210	743715	47	121CKKD	25	1	44.32	35.306	-9.01	44.74	34.823	-9.92
010742	3600005648	Observation	392606	744155	60	121CKKD	52	1	23.82	23.403	-0.42	22.7	21.835	-0.86
010744	3100023886	Observation	393530	744810	75.65	121CKKD	20	1	67.15	64.054	-3.1	65.27	62.469	-2.8
010747	5600000048	Observation	392552	744556	52.2	121CKKD	40	1	25.05	27.739	2.69	24.17	26.569	2.4
010750	3100023857	Observation	393627	745113	90	121CKKD	38	1	69.86	72.158	2.3	67.57	70.803	3.23
010751	--	Observation	393346	745055	85	121CKKD	19	1	71.82	67.595	-4.23	68.42	66.170	-2.25
010754	3600005159	Observation	392640	743645	70.9	121CKKD	32	1	53.37	53.687	0.32	51.91	52.577	0.67
010757	3600001216	Observation	392832.5	742835.1	42.2	121CKKD	32	1	30.79	16.669	-14.12	29	15.508	-13.49
010775	--	Observation	392639	743231	38.1	121CKKD	182	3	6.18	-4.295	-10.47	0.66	-4.972	-5.63
010776	--	Observation	392639	743231	38.1	121CKKD	93	1	17.61	6.419	-11.19	17.29	6.012	-11.28
010778	3600005518	Observation	392344	743731	50	121CKKD	71	1	41.05	38.334	-2.72	39.7	37.485	-2.21
010851	3600005058	Withdrawal	392446	744013	35	121CKKD	114	3	29.41	32.213	2.8	28.16	31.315	3.15
010864	3200013099	Withdrawal	393442	744303	95	121CKKD	160	3	74.76	63.266	-11.49	71.35	62.194	-9.16

Table 9. Simulated and observed groundwater levels and residuals, southeastern New Jersey, May 2005 and September 2006.—Continued

[NJDEP, New Jersey Department of Environmental Protection; Simulated and observed water levels are in feet above, NGVD29, National Geodetic Vertical Datum of 1929; NAD83, North American Datum of 1983; --, no data; RMS, Root mean square error]

U.S. Geological Survey well number	NJDEP well permit number	Well use	Latitude (NAD83)	Longitude (NAD83)	Altitude of land surface (NGVD29)	Aquifer	Well depth, in feet	Model layer	May 2005			September 2006		
									Observed water-level altitude	Simulated water-level altitude	Residual, in feet	Observed water-level altitude	Simulated water-level altitude	Residual, in feet
010885	3600000465	Observation	392233	744547	35	121CKKD	30	1	30.81	27.230	-3.58	30.03	26.821	-3.21
010899	3200015393	Withdrawal	393321	743352	52	121CKKD	102	3	14.75	24.145	9.4	13.6	23.214	9.61
010919	--	Withdrawal	393220	745216	85	121CKKD	26	1	78.51	79.952	1.44	75.68	78.707	3.03
010930	3600011742	Withdrawal	393150	742736	10	121CKKD	100	3	0.83	3.975	3.15	0.71	3.875	3.16
010953	3200012016	Observation	393506	744030	98.65	121CKKD	38	1	78.87	49.603	-29.27	75.57	48.223	-27.35
011197	5600000119	Withdrawal	393101.6	743338	49.54	121CKKD	100	3	49.97	45.879	-4.09	51.26	44.887	-6.37
011234	3500012532	Observation	393117	745538	113.09	121CKKD	30	1	96.33	97.850	1.52	94.45	96.785	2.33
011275	3500018902	Observation	392901	745354	101	121CKKD	25	1	91.51	87.497	-4.01	88.59	86.885	-1.7
011400	3600024011	Observation	391844	744514	7	121CKKD	14	1	4.73	7.495	2.76	4.62	7.147	2.53
011402	3200025196	Observation	394130.2	744347.9	41.99	121CKKD	12	1	39.96	43.612	3.65	40.03	42.112	2.08
011404	3100060862	Observation	393948	744642.7	69.55	121CKKD	14	1	66.61	72.456	5.85	66.26	68.008	1.75
011498	3600028385	Observation	392904.3	743333.8	55.84	121CKKD	65	1	47.71	45.592	-2.12	46.49	44.964	-1.53
011499	3600028384	Observation	392904.3	743334.1	55.12	121CKKD	165	3	47.17	44.249	-2.92	45.98	43.676	-2.3
011500	3600028386	Observation	392904.4	743334.1	55.64	121CKKD	22	1	49.75	45.628	-4.12	48.07	45.000	-3.07
011504	3200027988	Observation	394137.7	744531.8	55.66	121CKKD	160	9	53.52	52.231	-1.29	53.75	51.582	-2.17
011505	3200027990	Observation	394137.9	744531.6	55.54	121CKKD	50	1	52.79	52.168	-0.62	52.92	51.516	-1.4
011506	3200027989	Observation	394138.0	744531.4	55.53	121CKKD	92	7	53.14	52.180	-0.96	53.33	51.532	-1.8
011565	3600028859	Observation	392957.6	743408.5	54.79	121CKKD	20	1	49.42	46.540	-2.88	49.8	45.937	-3.86
011622	3600007181	Observation	392743.7	743034.1	59.91	121CKKD	30	1	39.1	27.545	-11.56	37.22	26.702	-10.52
011624	3600010894	Observation	392811.4	743329.6	51.58	121CKKD	87	1	46.37	42.469	-3.9	45.1	41.883	-3.22
011625	3600010893	Observation	392811.5	743329.1	51.9	121CKKD	17	1	46.33	42.410	-3.92	45.07	41.822	-3.25
011627	3600020934	Observation	392836.7	743542.1	68.24	121CKKD	25	1	58.13	61.395	3.27	55.87	60.761	4.89
011630	3600010906	Observation	392852.4	743443.4	69.1	121CKKD	90	1	53.94	54.148	0.21	52.31	53.955	1.65
011631	3600010903	Observation	392852.6	743444.7	68.15	121CKKD	26	1	54.07	54.349	0.28	52.37	54.148	1.78
011638	--	Observation	392929.5	743144.4	49.54	121CKKD	157	3	36.61	28.882	-7.73	35.34	28.063	-7.28
011639	--	Observation	392929.5	743144.4	49.54	121CKKD	68	1	36.25	30.056	-6.19	35.61	29.180	-6.43
011652	3600025387	Observation	393011.1	743206	56.79	121CKKD	121	3	36.52	31.305	-5.22	34.62	30.257	-4.36
011667	--	Observation	393011.2	743206.1	56.68	121CKKD	84	1	38.05	32.600	-5.45	35.44	31.372	-4.07
011671	3600010215	Observation	392923.26	743556.86	60.75	121CKKD	55	1	56.2	60.161	3.96	55.4	59.212	3.81

Table 9. Simulated and observed groundwater levels and residuals, southeastern New Jersey, May 2005 and September 2006.—Continued

[NJDEP, New Jersey Department of Environmental Protection; Simulated and observed water levels are in feet above, NGVD29, National Geodetic Vertical Datum of 1929; NAD83, North American Datum of 1983; --, no data; RMS, Root mean square error]

U.S. Geological Survey well number	NJDEP well permit number	Well use	Latitude (NAD83)	Longitude (NAD83)	Altitude of land surface (NGVD29)	Aquifer	Well depth, in feet	Model layer	May 2005			September 2006		
									Observed water-level altitude	Simulated water-level altitude	Residual, in feet	Observed water-level altitude	Simulated water-level altitude	Residual, in feet
050404	--	Observation	394406	744126	40.88	121CKKD	35	1	36.55	36.025	-0.52	36.95	34.562	-2.39
050408	--	Observation	394422	744308	47.52	121CKKD	65	7	43.79	40.848	-2.94	44.16	40.006	-4.15
050409	--	Observation	394422	744308	47.13	121CKKD	17	1	41.198	40.740	-0.46	40.89	39.902	-0.99
050417	--	Observation	394608	744053	48.49	121CKKD	100	9	43.36	40.743	-2.62	43.72	40.069	-3.65
050418	--	Observation	394608	744053	48.52	121CKKD	46	1	43.44	40.657	-2.78	43.84	39.983	-3.86
050451	--	Observation	394536	743541	64.86	121CKKD	170	1	55.75	56.367	0.62	--	--	--
050452	--	Observation	394536	743541	64.86	121CKKD	21	1	55.81	56.347	0.54	--	--	--
050454	--	Observation	394812	744030	66.62	121CKKD	142	9	58.36	61.230	2.87	58.6	60.047	1.45
050455	--	Observation	394812	744030	66.54	121CKKD	51	7	58.36	61.235	2.88	58.55	60.051	1.5
050512	--	Observation	394009	743251	42.27	121CKKD	50	1	33.2	22.037	-11.16	31.9	20.976	-10.92
050570	--	Observation	394106	743622	63.24	121CKKD	25	1	51.31	43.703	-7.61	48.18	42.380	-5.8
050609	--	Observation	394300	743829	62.9	121CKKD	45	1	42.9	48.671	5.77	40.49	46.932	6.44
050613	--	Observation	394305	743356	41.07	121CKKD	35	1	36.99	34.821	-2.17	37.49	34.151	-3.34
050628	--	Observation	394452	742818	78.78	121CKKD	12	1	77.15	69.896	-7.25	77.21	68.481	-8.73
050630	--	Observation	394513	742805	104.3	121CKKD	41	1	78.04	76.116	-1.92	76.36	74.663	-1.7
050684	--	Observation	395122	743016	140.82	121CKKD	170	7	121.98	121.368	-0.61	119.34	120.077	0.74
051102	--	Observation	393729	742528	23	121CKKD	18	1	17.98	18.980	1	17.98	18.113	0.13
051103	--	Observation	393729	742528	23	121CKKD	60	1	17.98	18.980	1	17.96	18.113	0.15
051104	3200007214	Withdrawal	394532	744324	50	121CKKD	89	1	45.71	49.326	3.62	47.93	48.248	0.32
051107	3200014423	Observation	394736	744441	77	121CKKD	18	1	71.49	76.204	4.71	71.95	73.477	1.53
051119	3200015738	Withdrawal	394930	744233	105	121CKKD	100	1	85.66	100.045	14.38	84.47	94.950	10.48
051126	3200013665	Withdrawal	394251	743039	40	121CKKD	175	7	32.46	37.842	5.38	33.77	36.939	3.17
051131	3200014078	Observation	394828	743219	87.6	121CKKD	22	1	82.65	82.417	-0.23	83.44	81.672	-1.77
051136	3200012712	Withdrawal	395030	743253	120	121CKKD	80	1	104.47	101.364	-3.11	--	--	--
051139	--	Withdrawal	393644	743017	10	121CKKD	41	1	4.74	4.072	-0.67	3.92	3.341	-0.58
051501	3200025195	Observation	394018	743246	35	121CKKD	18	1	28.96	21.359	-7.6	27.94	20.375	-7.57
051504	3200025728	Observation	394640	743231	68	121CKKD	10	1	65.07	72.017	6.95	65.16	70.543	5.38
070430	--	Observation	394203.1	744919.5	92.52	121CKKD	120	7	80.58	81.286	0.71	78.6	80.038	1.44
070431	--	Observation	394203.2	744919.4	93.64	121CKKD	29	1	82.46	81.355	-1.11	79.59	80.095	0.5

Table 9. Simulated and observed groundwater levels and residuals, southeastern New Jersey, May 2005 and September 2006.—Continued

[NJDEP, New Jersey Department of Environmental Protection; Simulated and observed water levels are in feet above, NGVD29, National Geodetic Vertical Datum of 1929; NAD83, North American Datum of 1983; --, no data; RMS, Root mean square error]

U.S. Geological Survey well number	NJDEP well permit number	Well use	Latitude (NAD83)	Longitude (NAD83)	Altitude of land surface (NGVD29)	Aquifer	Well depth, in feet	Model layer	May 2005			September 2006		
									Observed water-level altitude	Simulated water-level altitude	Residual, in feet	Observed water-level altitude	Simulated water-level altitude	Residual, in feet
070432	--	Observation	394224	744712	69.83	121CKKD	25	1	66.71	65.685	-1.03	67.05	64.740	-2.31
070451	--	Observation	394628	744922	122.36	121CKKD	166	9	91.11	92.177	1.07	89.61	90.533	0.92
070452	--	Observation	394628	744922	122.33	121CKKD	41	1	94.97	92.246	-2.72	92.63	90.590	-2.04
070459	3100004937	Withdrawal	393943.2	744937.2	95.8	121CKKD	180	1	90.18	89.345	-0.84	89.65	87.975	-1.67
070501	3100005295	Withdrawal	394418.5	745527.8	166.34	121CKKD	141	1	132.2	133.092	0.89	130.67	132.138	1.47
070681	3100022928	Observation	393704	745314	88	121CKKD	25	1	82.55	76.057	-6.49	82.66	75.188	-7.47
070712	3100019134	Observation	394046.4	745207.9	129.9	121CKKD	50	1	102.16	103.454	1.29	100.38	102.237	1.86
070835	3100049659	Observation	394141.8	745503.7	140	121CKKD	32	1	113.74	109.399	-4.34	111.8	108.257	-3.54
070840	3100049746	Observation	394259.7	745326.1	131	121CKKD	29	1	114.08	117.784	3.7	111.42	116.794	5.37
070845	3100049625	Observation	394747.9	745549.1	155	121CKKD	19	1	149.99	157.852	7.86	148.93	157.022	8.09
071091	3100068275	Observation	394406.6	745336.1	155.29	121CKKD	95	7	125.17	128.137	2.97	123.34	127.027	3.69
071092	3100068274	Observation	394406.8	745336.1	155.23	121CKKD	160	9	125.24	128.137	2.9	123.35	127.025	3.68
071125	3100048501	Withdrawal	393925.5	745154.3	116.14	121CKKD	80	3	96.37	97.480	1.11	94.11	96.273	2.16
071128	3100055453	Withdrawal	394541	745641.9	160.43	121CKKD	100	7	136.4	134.664	-1.74	135.48	133.745	-1.74
071129	3100061981	Withdrawal	394303.9	744941.6	90.88	121CKKD	110	7	82.52	92.146	9.63	81.75	90.461	8.71
090186	3600006189	Observation	391621	744353	14	121CKKD	22	1	10.13	5.972	-4.16	9.91	5.633	-4.28
090325	3500013059	Observation	391701	745056	55	121CKKD	124	3	32.69	36.108	3.42	32.93	34.945	2.02
090348	3500013019	Observation	391430	744847	43	121CKKD	45	1	30.26	34.179	3.92	29.77	32.441	2.67
090381	3600012777	Observation	391553	743914	30	121CKKD	98	1	8.43	9.295	0.87	7.55	8.091	0.54
090382	3600012681	Observation	391553	743914	30	121CKKD	210	3	6.95	6.301	-0.65	6.49	5.706	-0.78
090460	5600000430	Observation	391726	743809	11.18	121CKKD	35	1	4.98	1.061	-3.92	4.03	0.707	-3.32
150753	--	Withdrawal	393931	750038	140	121CKKD	130	9	123.09	136.485	13.39	121.1	134.004	12.9
151149	5100000068	Observation	393217	745753	120	121CKKD	25	1	106.49	128.495	22	103.63	116.008	12.38
151207	3100049626	Observation	393415.4	745635.1	120	121CKKD	24	1	105.72	108.793	3.07	103.94	106.697	2.76
151213	3100049658	Observation	393751.8	745512.6	97	121CKKD	15	1	92.41	88.650	-3.76	90.91	87.439	-3.47
151281	3100052397	Observation	394225.5	750038.8	145	121CKKD	24	1	134.25	128.268	-5.98	133.11	127.192	-5.92
									Mean error		-0.96			-1.47
									Mean absolute error		4.36			4.36
									RMS		41.05			40.13

Table 9. Simulated and observed groundwater levels and residuals, southeastern New Jersey, May 2005 and September 2006.—Continued

[NJDEP, New Jersey Department of Environmental Protection; Simulated and observed water levels are in feet above, NGVD29, National Geodetic Vertical Datum of 1929; NAD83, North American Datum of 1983; --, no data; RMS, Root mean square error]

U.S. Geological Survey well number	NJDEP well permit number	Well use	Latitude (NAD83)	Longitude (NAD83)	Altitude of land surface (NGVD29)	Aquifer	Well depth, in feet	Model layer	May 2005			September 2006		
									Observed water-level altitude	Simulated water-level altitude	Residual, in feet	Observed water-level altitude	Simulated water-level altitude	Residual, in feet
010037	5600000071	Observation	392151	742458	9.54	122KRKDL	842	9	-74.58	-64.043	10.54	-106.69	-88.173	18.52
010039	5600000012	Withdrawal	392329.6	742346	10	122KRKDL	788	9	-67.4	-63.620	3.78	-93.7	-93.752	-0.05
010117	3200000477	Withdrawal	393212.9	743830.5	40	122KRKDL	432	9	20.45	20.934	0.48	15.76	16.021	0.26
010369	3600000402	Withdrawal	391905.4	743125.4	10	122KRKDL	811	9	-69.76	-69.375	0.39	-103.77	-113.898	-10.13
010578	3600000295	Observation	391826	743708	10	122KRKDL	680	9	-51.04	-52.436	-1.39	-75.26	-75.844	-0.58
010593	3600000372	Withdrawal	392030.5	742850.7	9	122KRKDL	793	9	-76.24	-79.624	-3.38	-110.73	-128.812	-18.08
010600	5600000016	Withdrawal	392045.6	742837.8	8	122KRKDL	810	9	-75.14	-74.294	0.85	-113	-115.307	-2.31
010637	3200005113	Withdrawal	393213.9	743823.9	35	122KRKDL	428	9	11.63	19.360	7.73	6.56	14.134	7.57
010648	3600001084	Withdrawal	392125	742603	7	122KRKDL	835	9	-71.74	-68.239	3.5	-103.3	-96.079	7.22
010650	--	Test	392651	744253	21	122KRKDL	380	7	16.25	13.903	-2.35	12.52	7.212	-5.31
010683	3600002091	Withdrawal	392411.2	742226.3	8	122KRKDL	780	9	-59.87	-58.285	1.58	-87.59	-91.923	-4.33
010702	--	Observation	392032	743007	5	122KRKDL	755	9	-82.45	-70.210	12.24	-112.13	-113.263	-1.13
010703	3600005092	Observation	392639	743231	38	122KRKDL	575	9	-36.46	-32.770	3.69	-67.9	-62.728	5.17
010704	--	Observation	392343	743732	51	122KRKDL	611	9	5.46	-28.314	-33.77	--	--	--
010706	3600004982	Observation	392933	743129	40	122KRKDL	535	9	-20.69	-19.119	1.57	-40.7	-34.889	5.81
010889	3600011871	Withdrawal	392003.3	743009.8	8.2	122KRKDL	795	9	-73.48	-74.272	-0.79	-115.65	-123.882	-8.23
010967	3600013010	Withdrawal	392456.1	742120.3	5	122KRKDL	776	9	-52.45	-51.409	1.04	-70.53	-76.053	-5.52
010990	3600016110	Withdrawal	392308.2	743521.0	30	122KRKDL	657	7	-39.22	-39.885	-0.67	-71.6	-75.969	-4.37
011218	3600017655	Test	392620	743739	66	122KRKDL	610	9	-35.31	-19.330	15.98	-58.42	-41.096	17.32
011220	3600017339	Test	392647	743659	65	122KRKDL	602	9	--	--	--	-61.94	-45.384	16.56
011252	3200020165	Withdrawal	393211.9	743826.0	41	122KRKDL	446	9	19.04	19.436	0.4	14.49	14.186	-0.3
011256	3600017667	Withdrawal	391932.6	743054.2	6	122KRKDL	801	7	-75.07	-73.508	1.56	-112.75	-123.501	-10.75
011455	--	Withdrawal	392749	744259	22	122KRKDL	436	7	18.79	19.089	0.3	--	--	--
011456	3600021156	Withdrawal	392450.0	743026.0	5	122KRKDL	652	9	-44.55	-44.931	-0.38	-89.01	-96.429	-7.42
011476	3600016749	Observation	392749	743240	45	122KRKDL	596	9	-31.11	-26.689	4.42	-65	-59.920	5.08
090109	5600000008	Withdrawal	391535.9	743609.4	8	122KRKDL	814	9	-56.63	-64.066	-7.44	-81.28	-91.506	-10.23
090116	5600000007	Withdrawal	391637.7	743449.4	7	122KRKDL	810	9	-66.98	-66.223	0.76	-96.11	-104.887	-8.78
090124	3600000413	Withdrawal	391711.8	743338.3	8	122KRKDL	843	9	-66.73	-67.337	-0.61	-96.05	-109.146	-13.1
090144	3600000451	Unused	391721.3	743805	9	122KRKDL	691	9	-59.3	-55.984	3.32	--	--	--

Table 9. Simulated and observed groundwater levels and residuals, southeastern New Jersey, May 2005 and September 2006.—Continued

[NJDEP, New Jersey Department of Environmental Protection; Simulated and observed water levels are in feet above, NGVD29, National Geodetic Vertical Datum of 1929; NAD83, North American Datum of 1983; --, no data; RMS, Root mean square error]

U.S. Geological Survey well number	NJDEP well permit number	Well use	Latitude (NAD83)	Longitude (NAD83)	Altitude of land surface (NGVD29)	Aquifer	Well depth, in feet	Model layer	May 2005			September 2006		
									Observed water-level altitude	Simulated water-level altitude	Residual, in feet	Observed water-level altitude	Simulated water-level altitude	Residual, in feet
090185	3700001340	Observation	391621.4	744354.5	15	122KRKDL	655	9	-32.92	-30.124	2.8	--	--	--
090459	3600000377	Withdrawal	391712.9	743722.6	7	122KRKDL	620	7	-54.9	-58.794	-3.89	-78.53	-81.681	-3.15
090461	3600015182	Withdrawal	391729	743812.6	8	122KRKDL	710	9	-54.97	-54.175	0.79	-76.32	-78.735	-2.42
090481	3600017001	Withdrawal	391553.5	743915.0	33	122KRKDL	743	7	-45.15	-52.279	-7.13	-66.35	-73.443	-7.09
									Mean error		0.50			-1.37
									Mean absolute error		4.36			7.13
									RMS		60.87			79.44
090149	3700000005	Withdrawal	391815.3	744953	20	122KRKDU	290	5	18.25	-1.667	-19.92	18.13	-0.868	-19
090519	3600022762	Withdrawal	391554.2	743916	31	122KRKDU	498	5	-22.91	-8.382	14.53	-23.75	-7.808	15.94
									Mean error		-2.70			-1.53
									Mean absolute error		17.23			17.47
									RMS		303.96			307.54

Table 17. Simulated monthly base-flow deficits from basic scenarios in the Great Egg-Mullica model for Hydrologic Unit Code 11 subbasins, southeastern N.J.

[HUC11, Hydrologic Unit Code 11; shaded cells are summer months as defined for seasonal-conjunctive use scenario; deficits are in millions of gallons per month; blank cells indicate no deficits]

HUC11 number	Scenario year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
						Average							
02040301170	2									-0.12			
02040301170	5									-0.31	-0.44		
02040301170	9							-1.03		-0.31			
02040301180	2									-0.61	-0.03		
02040301180	3							-0.13		-0.38			
02040301180	4							-0.19		-0.24			
02040301180	5								-0.05	-0.62	-0.45		
02040301180	6							-0.13		-0.44	-0.07		
02040301180	7							-0.03		-0.3	-0.12		
02040301180	8							-0.1		-0.26	-0.35		
02040301180	9							-0.42		-0.54	-0.16		
02040301190	5												-0.25
02040302020	1	-9.6	-9.6	-10.3	-8.66	-8.81	-9.58	-9.35	-9.12	-8.61	-8.97	-9.16	-8.55
02040302020	2	-11.38	-9.65	-9.62	-8.64	-8.54	-10.15	-9.52	-10.97	-10.82	-9.83	-9.11	-9.44
02040302020	3	-9.49	-8.43	-9.75	-8.41	-8.55	-9.41	-10.64	-10.54	-9.82	-8.73	-9.75	-9.32
02040302020	4	-9.25	-9.12	-10.01	-8.21	-8.38	-10.53	-10.48	-10.17	-9.1	-9	-8.47	-8.3
02040302020	5	-8.33	-7.21	-8.51	-8.59	-8.95	-10.16	-9.39	-11.19	-10.77	-11.65	-12.66	-11.45
02040302020	6	-9.67	-10.22	-9.29	-8.55	-8.75	-12.39	-10.66	-10.51	-10.15	-10.22	-10.68	-10.34
02040302020	7	-9.06	-8.72	-8.89	-8.82	-8.62	-9.45	-9.75	-10.28	-9.23	-10.12	-10.84	-9.83
02040302020	8	-9.38	-9	-8.91	-9.21	-10.16	-10.7	-10.34	-9.8	-9.11	-11.54	-10.5	-10.36
02040302020	9	-10.42	-8.12	-7.27	-7.22	-8	-10.19	-12.12	-10.84	-10.78	-10.83	-11.23	-9.28
02040302030	1						-0.27	-0.66	-0.4	-0.43			
02040302030	2						-0.47	-0.85	-1.58	-2.11	-0.95		
02040302030	3						-0.07	-1.3	-1.45	-1.55	-0.12		
02040302030	4						-0.57	-1.4	-1.3	-1.04	-0.25		
02040302030	5						-0.48	-0.56	-1.58	-1.97	-1.8		
02040302030	6						-1.24	-1.6	-1.62	-1.79	-1.05		
02040302030	7						-0.24	-1.14	-1.43	-1.36			
02040302030	8						-0.7	-1.47	-1.3	-1.34	-1.55		
02040302030	9						-0.54	-2.05	-1.79	-2.01	-1.07		

Table 17. Simulated monthly base-flow deficits from basic scenarios in the Great Egg-Mullica model for Hydrologic Unit Code 11 subbasins, southeastern N.J.—Continued

[HUC11, Hydrologic Unit Code 11; shaded cells are summer months as defined for seasonal-conjunctive use scenario; deficits are in millions of gallons per month; blank cells indicate no deficits]

HUC11 number	Scenario year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Average—Continued													
02040302040	5										-0.12		
02040302040	9							-0.05					
02040302060	1	-0.61	-0.6	-0.38	-0.04	-0.51	-1.43	-2.01	-1.8	-1.75	-1.6	-1.08	-0.57
02040302060	2	-1.07	-0.64	-0.18	-0.04	-0.4	-1.71	-2.08	-2.43	-2.46	-1.91	-1.1	-0.8
02040302060	3	-0.59	-0.26	-0.3		-0.41	-1.39	-2.4	-2.26	-2.13	-1.56	-1.37	-0.77
02040302060	4	-0.51	-0.51	-0.34		-0.35	-1.8	-2.35	-2.12	-1.92	-1.66	-0.89	-0.48
02040302060	5	-0.22				-0.54	-1.62	-1.99	-2.54	-2.38	-2.52	-2.1	-1.45
02040302060	6	-0.7	-0.91	-0.32	-0.14	-0.59	-2.42	-2.48	-2.29	-2.28	-2.15	-1.65	-1.11
02040302060	7	-0.46	-0.42	-0.1	-0.16	-0.51	-1.42	-2.09	-2.13	-1.9	-2	-1.65	-0.92
02040302060	8	-0.46	-0.49	-0.04	-0.26	-1.02	-1.92	-2.33	-2.01	-1.87	-2.51	-1.56	-1.04
02040302060	9	-0.75	-0.31			-0.25	-1.69	-2.84	-2.31	-2.44	-2.19	-1.77	-0.81
Full Allocation													
02040301150	2									-0.76			
02040301150	3							-0.09		-0.4			
02040301150	4							-0.14		-0.11			
02040301150	5									-0.56	-0.17		
02040301150	6						-1.16	-0.13		-0.43			
02040301150	7									-0.04			
02040301150	8										-0.32		
02040301150	9							-1.08		-0.72			
02040301160	1					-0.89	-5.21	-7.36	-7.02	-6.69	-5.71	-2.65	
02040301160	2	-2.41				-0.53	-6.03	-7.83	-10.58	-12.11	-9.15	-3.39	-0.26
02040301160	3					-0.28	-4.72	-9.32	-10.19	-9.96	-6.53	-4.01	-0.16
02040301160	4						-6.5	-9.62	-9.64	-8.5	-6.74	-1.7	
02040301160	5					-1.32	-6.28	-7.43	-10.82	-11.67	-13	-10.57	-3.82
02040301160	6					-0.2	-10.33	-10.46	-10.63	-10.89	-9.92	-6.31	-1.65
02040301160	7						-4.68	-8.06	-9.6	-8.96	-9.48	-7.13	-1.22
02040301160	8					-2.36	-7.25	-9.58	-9.22	-8.71	-12.49	-6.28	-1.77
02040301160	9						-5.42	-12.78	-11.68	-12.36	-11.14	-7.19	
02040301170	1	-0.97	-1.62				-3.88	-6.16	-5.66	-5.74	-5.2	-3.15	-0.75

Table 17. Simulated monthly base-flow deficits from basic scenarios in the Great Egg-Mullica model for Hydrologic Unit Code 11 subbasins, southeastern N.J.—Continued

[HUC11, Hydrologic Unit Code 11; shaded cells are summer months as defined for seasonal-conjunctive use scenario; deficits are in millions of gallons per month; blank cells indicate no deficits]

HUC11 number	Scenario year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Full Allocation—Continued													
02040301170	2	-4.89	-1.86				-4.92	-6.55	-8.4	-9.95	-7.74	-3.71	-2.43
02040301170	3	-0.93					-3.64	-7.81	-8.06	-8.22	-5.77	-4.42	-2.37
02040301170	4	-0.62	-0.77				-5.39	-8.07	-7.55	-7.16	-5.98	-2.33	-0.34
02040301170	5					-0.19	-5.14	-6.5	-8.86	-9.91	-11.56	-10.71	-6.23
02040301170	6	-0.99	-1.81				-8.39	-8.64	-8.25	-8.85	-8.39	-6.38	-3.74
02040301170	7						-3.47	-6.45	-7.59	-7.09	-7.75	-6.75	-2.94
02040301170	8					-0.74	-5.44	-7.69	-6.76	-6.81	-10.42	-5.98	-3.55
02040301170	9	-1.41					-4.16	-10.26	-8.56	-9.53	-9.09	-6.89	-1.41
02040301180	1		-.35				-1.28	-1.76	-1.77	-2.53	-2.1	-1.19	-1.21
02040301180	2	-0.62	-0.39				-1.48	-1.83	-2.38	-3.6	-2.78	-1.28	-1.4
02040301180	3						-1.19	-2.07	-2.34	-3.3	-2.33	-1.39	-1.4
02040301180	4		-0.02				-1.56	-2.16	-2.24	-3.02	-2.43	-0.84	-0.98
02040301180	5					-0.03	-1.79	-1.99	-2.6	-3.67	-3.58	-2.47	-2
02040301180	6		-0.02				-1.9	-2.08	-2.21	-3.3	-2.8	-1.69	-1.55
02040301180	7						-1.19	-1.81	-2.15	-3.05	-2.85	-1.93	-1.59
02040301180	8						-1.55	-2.01	-2.02	-2.93	-3.26	-1.65	-1.56
02040301180	9						-1.43	-2.49	-2.4	-3.5	-2.94	-1.73	-1.21
02040301190	2	-0.32							-0.15	-1.47			-0.18
02040301190	3							-0.35		-0.37			-0.21
02040301190	4							-0.47					
02040301190	5								-0.79	-1.57	-0.99	-1.04	-3.37
02040301190	6							-0.27		-0.42			-1.93
02040301190	7											-0.21	-1.56
02040301190	8							-0.17			-0.93		-2.49
02040301190	9							-1.66	-0.47	-1.44			-0.67
02040301200	1							-1.21	-0.66	-1.29			
02040301200	2						-0.11	-1.45	-2.83	-4.03	-0.78		
02040301200	3							-2.59	-2.36	-2.84			
02040301200	4						-0.61	-2.58	-1.96	-2.06			
02040301200	5						-0.29	-1.41	-3.16	-4.03	-3.18	-2.75	-0.54
02040301200	6						-2.96	-2.96	-2.33	-3.3	-1.33	-0.27	

Table 17. Simulated monthly base-flow deficits from basic scenarios in the Great Egg-Mullica model for Hydrologic Unit Code 11 subbasins, southeastern N.J.—Continued

[HUC11, Hydrologic Unit Code 11; shaded cells are summer months as defined for seasonal-conjunctive use scenario; deficits are in millions of gallons per month; blank cells indicate no deficits]

HUC11 number	Scenario year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Full Allocation—Continued													
02040301200	7							-1.67	-2.28	-2.15	-1.22	-0.37	
02040301200	8						-0.91	-2.48	-1.42	-1.98	-3.17		
02040301200	9						-0.16	-4.48	-2.82	-4.11	-2.15	-0.73	
02040302020	1	-15.08	-15.55	-17.4	-14.37	-13.56	-13.77	-12.84	-12.17	-11.41	-11.97	-12.69	-12.5
02040302020	2	-18.6	-15.8	-16.15	-14.34	-13.03	-14.88	-13.15	-15.64	-15.65	-14.21	-13.09	-14.51
02040302020	3	-15.24	-13.62	-16.57	-14.04	-13.21	-13.56	-15.34	-14.98	-13.89	-12.1	-14.34	-14.24
02040302020	4	-14.74	-15.02	-17.19	-13.68	-12.87	-15.82	-15.17	-14.36	-12.62	-12.53	-11.75	-12.3
02040302020	5	-12.7	-10.83	-13.51	-13.82	-13.46	-14.57	-12.64	-15.77	-15.43	-17.91	-20.31	-19.11
02040302020	6	-16.36	-18.2	-16.64	-15.15	-14.24	-20.55	-16.36	-15.71	-15.15	-15.91	-17.03	-17.31
02040302020	7	-15.42	-15.17	-15.7	-15.65	-14.11	-14.33	-14.28	-15.01	-13.24	-15.23	-16.98	-15.89
02040302020	8	-15.71	-15.47	-15.51	-16.24	-17.18	-17.07	-15.69	-14.35	-13.21	-18.35	-16.56	-17.32
02040302020	9	-18.03	-14.08	-12.44	-12.16	-12.54	-15.55	-18.86	-16.25	-16.47	-16.81	-18.1	-15.13
02040302030	1	-6.38	-7.79	-8.53	-6.59	-6.04	-7.64	-7.36	-6.84	-6.71	-6.3	-5.25	-4.22
02040302030	2	-10.27	-8.64	-7.48	-6.48	-5.59	-8.46	-7.83	-9.73	-10.91	-9.27	-6.43	-6.49
02040302030	3	-7.18	-5.86	-7.2	-5.89	-5.49	-7.23	-9.19	-9.46	-9.24	-7.03	-6.83	-6.2
02040302030	4	-6.53	-7.12	-7.89	-5.66	-5.17	-9.04	-9.55	-9.04	-8.06	-7.17	-4.76	-3.87
02040302030	5	-3.8	-2.59	-3.73	-5.39	-5.75	-8.29	-7.46	-9.91	-10.67	-12.96	-14.61	-12.36
02040302030	6	-8.67	-8.92	-5.93	-5.52	-6.13	-12.76	-10.99	-10.39	-10.57	-10.57	-10.03	-9.1
02040302030	7	-6.62	-5.73	-4.24	-4.79	-5.66	-7.68	-8.39	-9.15	-8.47	-9.46	-10.06	-8.24
02040302030	8	-7.08	-6.27	-4.41	-5.31	-7.53	-10.21	-10.06	-9.04	-8.55	-12.44	-9.91	-8.88
02040302030	9	-7.92	-4.65	-2.08	-2.66	-4.09	-8.35	-12.3	-11.01	-11.79	-11.8	-10.87	-6.97
02040302040	1		-0.4	-0.24			-1.5	-3.37	-2.45	-3.21	-2.8	-0.07	
02040302040	2	-6.22	-1.67				-3.13	-4.13	-7.36	-10.22	-7.48	-1.56	-0.89
02040302040	3						-1.26	-6.77	-6.84	-7.43	-3.98	-2.93	-0.57
02040302040	4						-4.54	-7.04	-6	-5.43	-4.36		
02040302040	5						-3.45	-4.01	-8.11	-10.13	-14.72	-18.33	-12.22
02040302040	6	-1.13	-4.77				-14.1	-8.9	-7.68	-9.14	-9.94	-8.6	-6.84
02040302040	7						-1.65	-4.72	-6	-5.62	-8.04	-8.41	-3.83
02040302040	8					-1.71	-6.55	-7.15	-5.08	-5.35	-14.01	-8.09	-7.28
02040302040	9	-5.18					-2.94	-12.97	-8.66	-11.48	-12.58	-12.52	-1.62

Table 17. Simulated monthly base-flow deficits from basic scenarios in the Great Egg-Mullica model for Hydrologic Unit Code 11 subbasins, southeastern N.J.—Continued

[HUC11, Hydrologic Unit Code 11; shaded cells are summer months as defined for seasonal-conjunctive use scenario; deficits are in millions of gallons per month; blank cells indicate no deficits]

HUC11 number	Scenario year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Full Allocation—Continued													
02040302050	2								-0.82	-1.79			
02040302050	3							-0.63	-0.7	-0.83			
02040302050	4							-0.89	-0.41	-0.26			
02040302050	5								-1.07	-1.58	-1.72	-0.1	
02040302050	6						-1.21	-1.46	-1.04	-1.48	-0.61		
02040302050	7							-0.14	-0.47	-0.23			
02040302050	8							-0.88	-0.12	-0.19	-1.27		
02040302050	9							-1.92	-0.98	-1.79	-0.84		
02040302060	1	-3.54	-3.41	-3.29	-2.57	-2.96	-3.9	-4.4	-4.22	-4.15	-4.06	-3.63	-3.02
02040302060	2	-4.44	-3.4	-3.01	-2.59	-2.8	-4.39	-4.52	-5.43	-5.34	-4.6	-3.54	-3.48
02040302060	3	-3.33	-2.77	-3.17	-2.49	-2.84	-3.87	-5.27	-5.13	-4.86	-3.96	-4.09	-3.42
02040302060	4	-3.22	-3.18	-3.26	-2.36	-2.74	-4.64	-5.12	-4.88	-4.43	-4.16	-3.19	-2.9
02040302060	5	-2.79	-2.09	-2.73	-2.67	-3.17	-4.35	-4.42	-5.72	-5.43	-5.68	-5.4	-4.49
02040302060	6	-3.46	-3.85	-3.08	-2.75	-3.13	-5.73	-5.35	-5.11	-5.06	-4.94	-4.53	-3.96
02040302060	7	-3.13	-3.01	-2.75	-2.84	-3.06	-3.89	-4.64	-4.97	-4.45	-4.85	-4.56	-3.59
02040302060	8	-3.19	-3.11	-2.75	-3.05	-3.95	-4.75	-5.09	-4.55	-4.35	-5.61	-4.29	-3.92
02040302060	9	-3.79	-2.7	-1.81	-1.82	-2.53	-4.36	-6.01	-5.2	-5.3	-5.11	-4.7	-3.29
2050 Demand													
02040301170	1							-1	-0.36	-0.69	-0.03		
02040301170	2							-1.18	-1.88	-2.91	-1.2		
02040301170	3							-1.94	-1.64	-1.94	-0.06		
02040301170	4							-2.03	-1.28	-1.28	-0.28		
02040301170	5							-1.22	-2.27	-2.73	-3.35	-1.19	
02040301170	6						-1.2	-2.09	-1.45	-2.05	-1.4		
02040301170	7							-1.11	-1.49	-1.32	-1.32		
02040301170	8							-1.69	-0.78	-1.08	-2.78		
02040301170	9							-3.6	-1.91	-2.71	-1.86		
02040301180	1						-0.89	-1.3	-0.88	-1.14	-0.84	-0.06	
02040301180	2						-1.1	-1.38	-1.49	-2.17	-1.55	-0.23	-0.17
02040301180	3						-0.84	-1.64	-1.45	-1.86	-1.1	-0.31	-0.15
02040301180	4						-1.21	-1.71	-1.35	-1.61	-1.19		

Table 17. Simulated monthly base-flow deficits from basic scenarios in the Great Egg-Mullica model for Hydrologic Unit Code 11 subbasins, southeastern N.J.—Continued

[HUC11, Hydrologic Unit Code 11; shaded cells are summer months as defined for seasonal-conjunctive use scenario; deficits are in millions of gallons per month; blank cells indicate no deficits]

HUC11 number	Scenario year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
						2050 Demand—Continued							
02040301180	5						-1.3	-1.44	-1.62	-2.18	-2.26	-1.36	-0.79
02040301180	6						-1.64	-1.74	-1.42	-1.94	-1.64	-0.71	-0.41
02040301180	7						-0.92	-1.42	-1.31	-1.67	-1.63	-0.88	-0.4
02040301180	8						-1.28	-1.65	-1.21	-1.6	-2.06	-0.67	-0.42
02040301180	9						-1.14	-2.1	-1.56	-2.14	-1.77	-0.76	-0.09
02040301190	5												-0.45
02040301200	1									-0.05			
02040301200	2							-0.09	-1.04	-2.29			
02040301200	3							-1.1	-0.66	-1.26			
02040301200	4							-1.05	-0.29	-0.56			
02040301200	5							-0.06	-1.41	-2.36	-0.95		
02040301200	6						-0.79	-1.3	-0.53	-1.59			
02040301200	7							-0.31	-0.63	-0.75			
02040301200	8							-0.98		-0.67	-0.97		
02040301200	9							-2.6	-1.03	-2.32	-0.12		
02040302020	1	-11.74	-11.88	-12.89	-10.88	-10.64	-11.2	-10.81	-10.42	-9.83	-10.26	-10.6	-10.24
02040302020	2	-14.01	-12.02	-12.03	-10.86	-10.26	-11.96	-11.04	-12.76	-12.68	-11.56	-10.72	-11.41
02040302020	3	-11.67	-10.45	-12.28	-10.59	-10.33	-11.03	-12.43	-12.28	-11.45	-10.17	-11.56	-11.26
02040302020	4	-11.36	-11.38	-12.63	-10.32	-10.09	-12.55	-12.26	-11.82	-10.58	-10.46	-9.84	-9.97
02040302020	5	-9.98	-8.68	-10.47	-10.62	-10.71	-11.89	-10.81	-12.98	-12.47	-13.97	-15.46	-14.18
02040302020	6	-12.14	-12.97	-11.86	-10.94	-10.8	-15.05	-12.72	-12.41	-12.05	-12.38	-12.97	-12.76
02040302020	7	-11.3	-10.96	-11.21	-11.14	-10.62	-11.21	-11.41	-12.01	-10.75	-12.06	-13.08	-12.01
02040302020	8	-11.59	-11.24	-11.19	-11.55	-12.51	-12.92	-12.23	-11.44	-10.63	-13.84	-12.67	-12.74
02040302020	9	-12.86	-10.24	-9.16	-9.05	-9.67	-12.12	-14.37	-12.77	-12.87	-12.93	-13.52	-11.36
02040302030	1	-0.93	-0.96			-1.11	-3.69	-3.89	-3.51	-3.34	-2.69	-1.31	-0.14
02040302030	2	-2.44	-1.04			-0.99	-4.07	-4.15	-5.23	-5.88	-4.51	-2.01	-1.08
02040302030	3	-0.46				-0.83	-3.43	-4.88	-5.02	-4.99	-3.21	-2.22	-1.01
02040302030	4	-0.32	-0.21			-0.73	-4.21	-5	-4.79	-4.25	-3.37	-1.07	
02040302030	5					-1.11	-3.95	-3.76	-5.18	-5.68	-5.87	-4.4	-2.17
02040302030	6	-0.35	-0.44			-1.13	-5.38	-5.52	-5.45	-5.56	-4.86	-3.09	-1.44

Table 17. Simulated monthly base-flow deficits from basic scenarios in the Great Egg-Mullica model for Hydrologic Unit Code 11 subbasins, southeastern N.J.—Continued

[HUC11, Hydrologic Unit Code 11; shaded cells are summer months as defined for seasonal-conjunctive use scenario; deficits are in millions of gallons per month; blank cells indicate no deficits]

HUC11 number	Scenario year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2050 Demand—Continued													
02040302030	7					-0.98	-3.79	-4.64	-5.04	-4.73	-4.61	-3.31	-1.32
02040302030	8	-0.07				-1.56	-4.47	-5.21	-4.93	-4.79	-5.57	-2.9	-1.37
02040302030	9	-0.6				-0.63	-4.16	-6.06	-5.64	-5.89	-4.95	-3.04	-0.77
02040302040	2									-1.92			
02040302040	3									-0.24			
02040302040	5								-0.17	-1.79	-3.39	-1.71	
02040302040	6						-0.69	-0.22		-0.91	-0.45		
02040302040	8										-2.73		
02040302040	9							-2.9	-0.1	-2.1	-1.2		
02040302050	2							-0.01	-0.89	-1.86			
02040302050	3							-0.83	-0.73	-0.93			
02040302050	4							-0.93	-0.44	-0.27			
02040302050	5								-1.19	-0.6	-1.65		
02040302050	6						-1.22	-1.48	-1.05	-1.49	-0.58		
02040302050	7							-0.19	-0.52	-0.34			
02040302050	8							-0.95	-0.2	-0.34	-1.33		
02040302050	9							-2	-0.94	-1.93	-0.77		
02040302060	1	-3.66	-3.54	-3.38	-2.65	-2.98	-3.86	-4.37	-4.2	-4.1	-4.07	-3.68	-3.11
02040302060	2	-4.57	-3.5	-3.1	-2.67	-2.79	-4.35	-4.47	-5.41	-5.47	-4.62	-3.61	-3.6
02040302060	3	-3.45	-2.86	-3.22	-2.53	-2.81	-3.81	-5.22	-5.08	-4.8	-3.95	-4.19	-3.53
02040302060	4	-3.31	-3.27	-3.32	-2.41	-2.69	-4.6	-5.03	-4.8	-4.35	-4.16	-3.26	-2.93
02040302060	5	-2.85	-2.14	-2.85	-2.72	-3.12	-4.27	-4.35	-5.63	-5.43	-5.69	-5.41	-4.47
02040302060	6	-3.48	-3.84	-3.08	-2.74	-3.13	-5.66	-5.26	-5.04	-5.01	-4.97	-4.55	-3.94
02040302060	7	-3.18	-3.05	-2.8	-2.84	-3.05	-3.83	-4.57	-4.92	-4.4	-4.94	-4.63	-3.69
02040302060	8	-3.26	-3.17	-2.81	-3.06	-3.95	-4.7	-5.02	-4.52	-4.31	-5.65	-4.39	-4.01
02040302060	9	-3.85	-2.79	-1.91	-1.91	-2.56	-4.42	-5.99	-5.2	-5.27	-5.13	-4.78	-3.42

Appendix 1

Appendix 1. Simulated base flow, base-flow depletion, available water, and deficits under Average, Full Allocation, and 2050 Demand scenarios by Hydrologic Unit Code 11 subbasins in southeastern New Jersey.

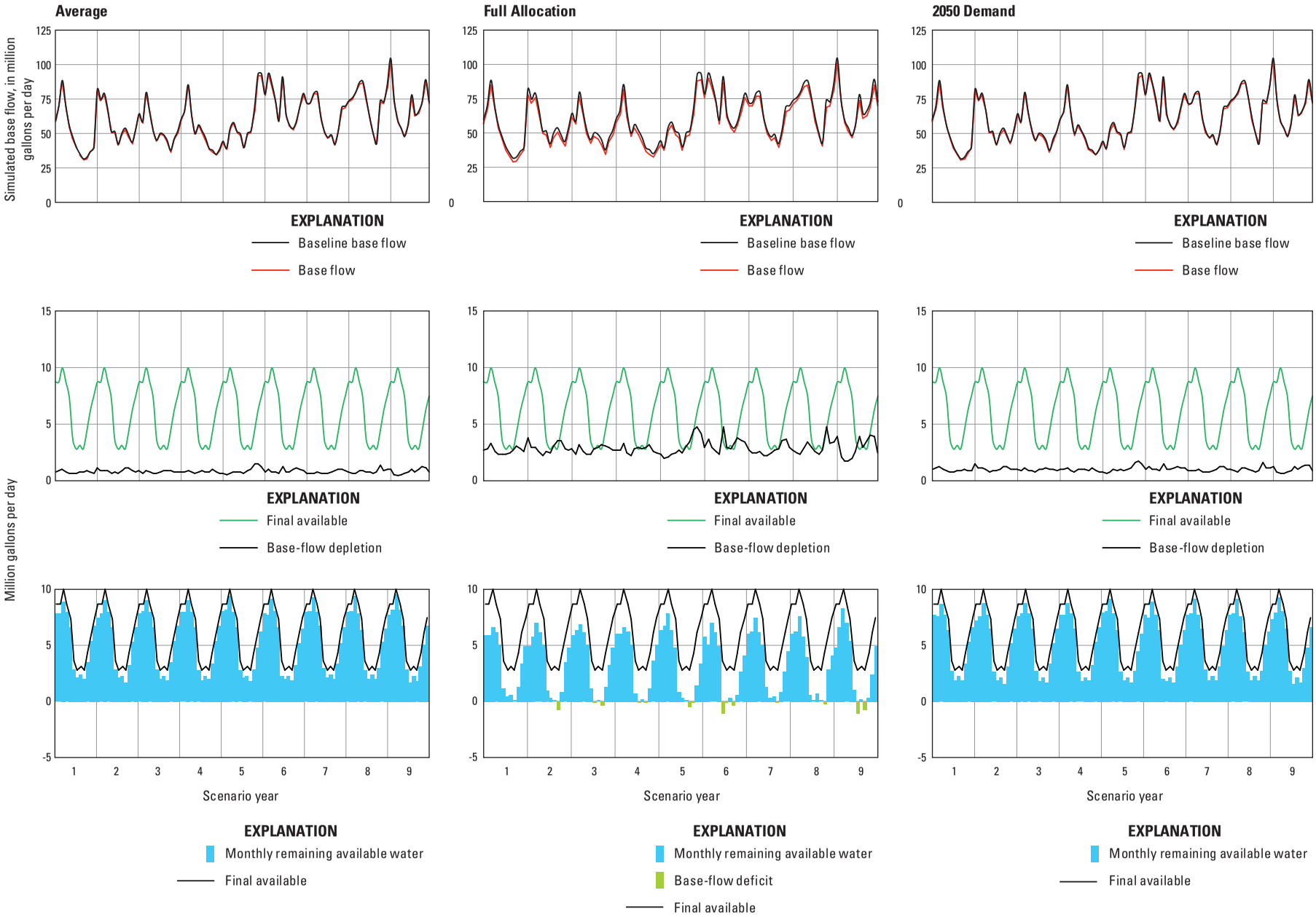

Figure 1-A. Hydrologic Unit Code 11 02040301150, Batsto River.

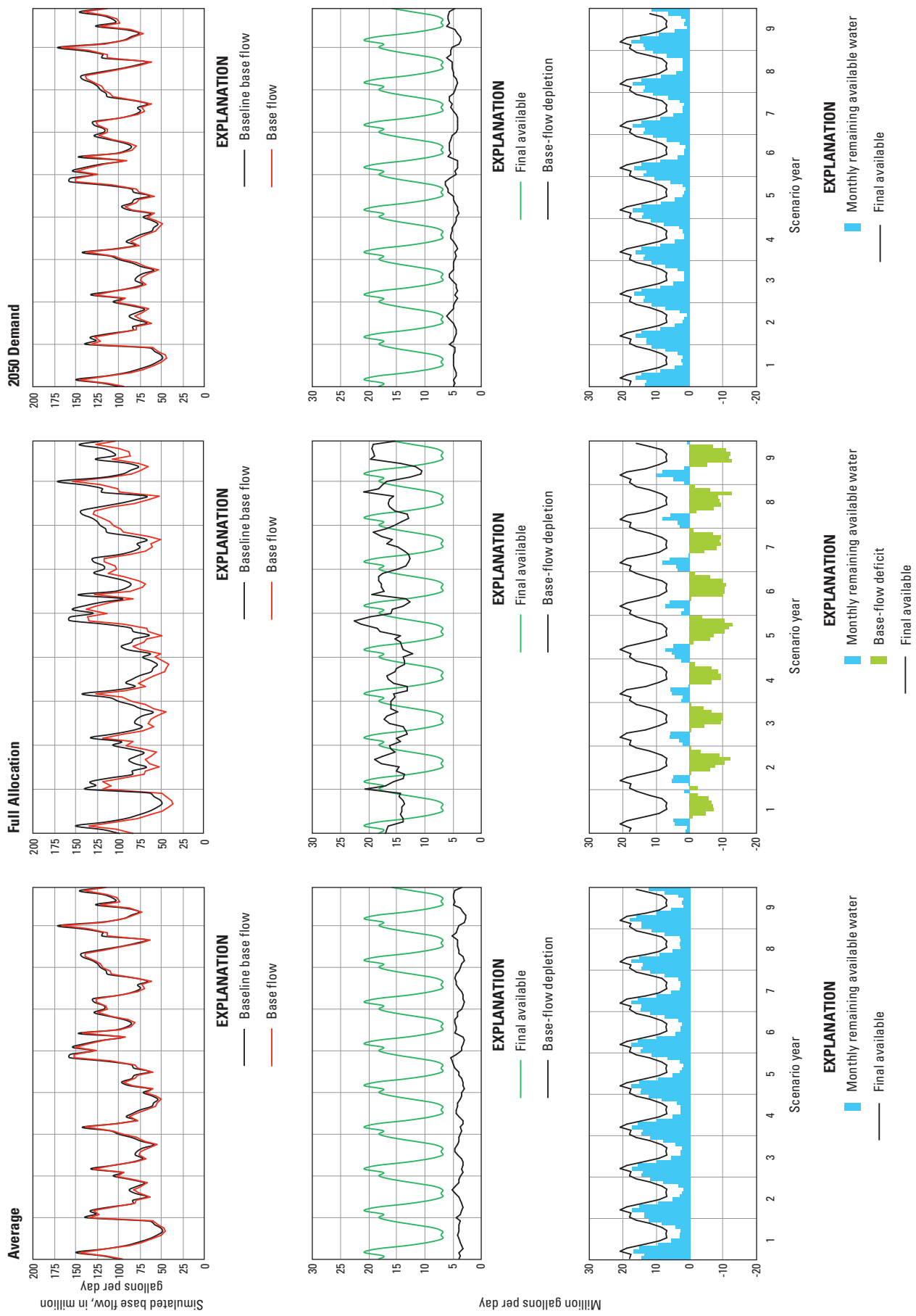

Figure 1-B. Hydrologic Unit Code 11 0204030160, Mullica River. (Above Batsto River)

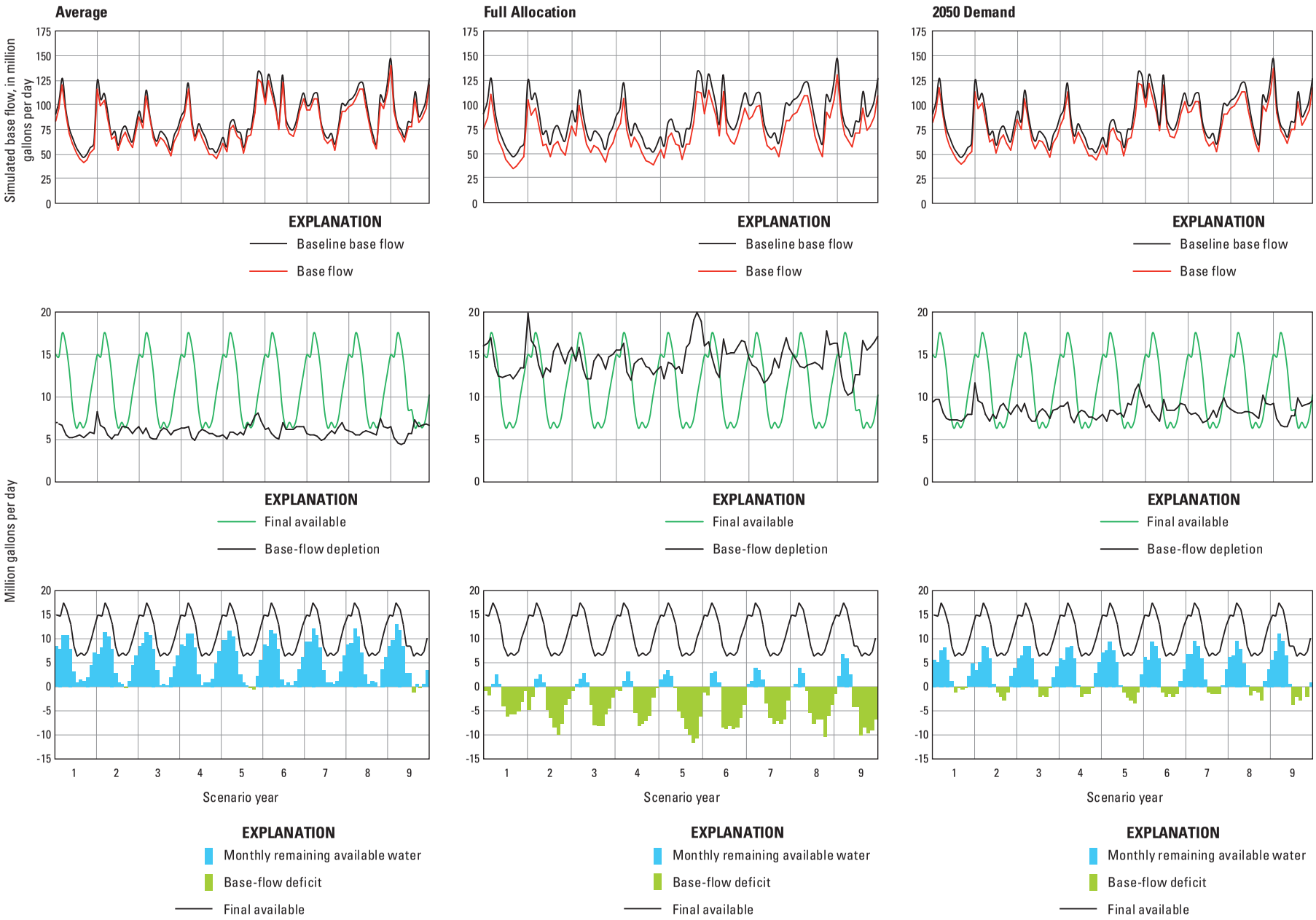

Figure 1-C. Hydrologic Unit Code 11 02040301170, Mullica River. (Turtle Creek Batsto River)

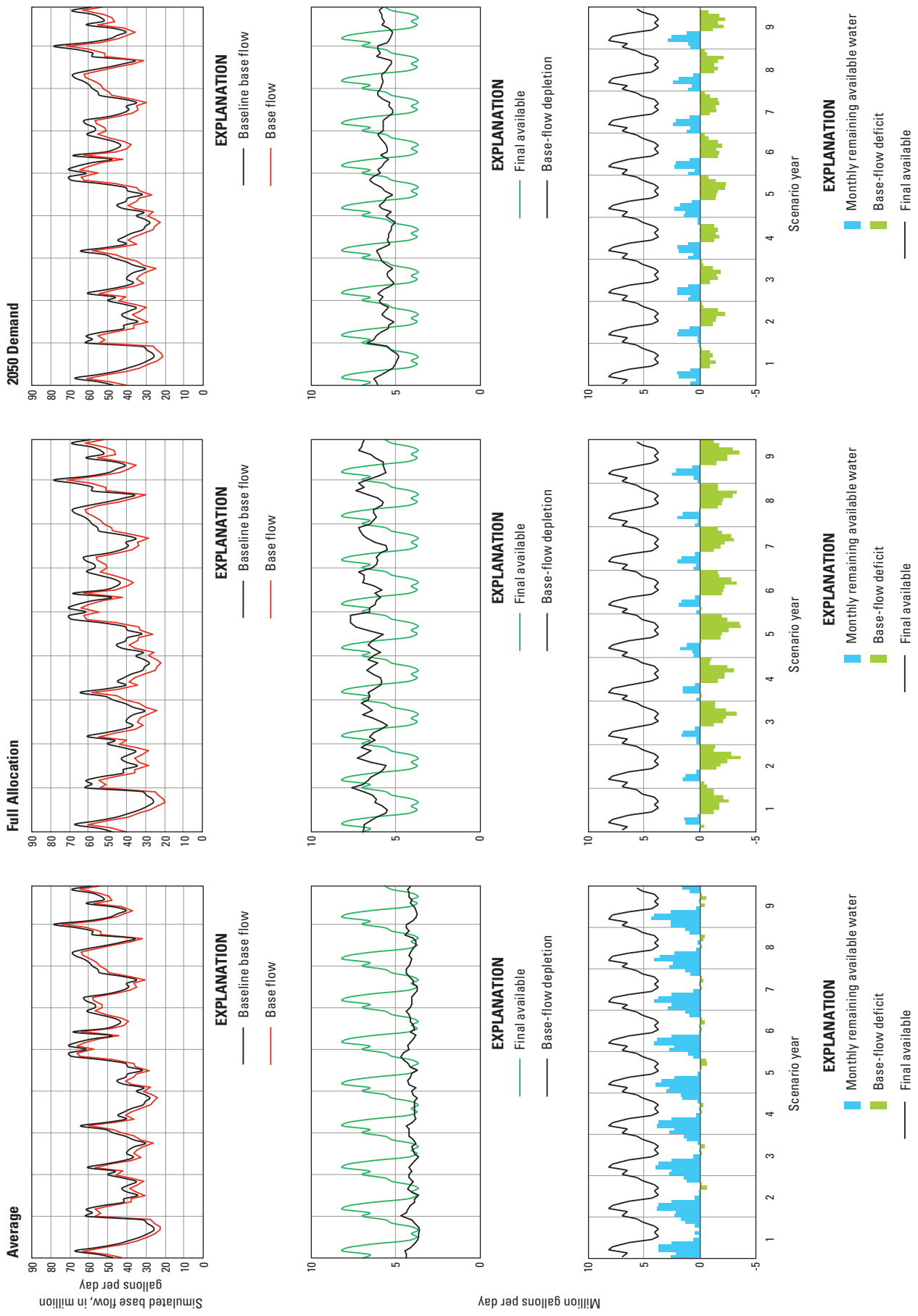

Figure 1-D. Hydrologic Unit Code 11 02040301180, Oswego River.

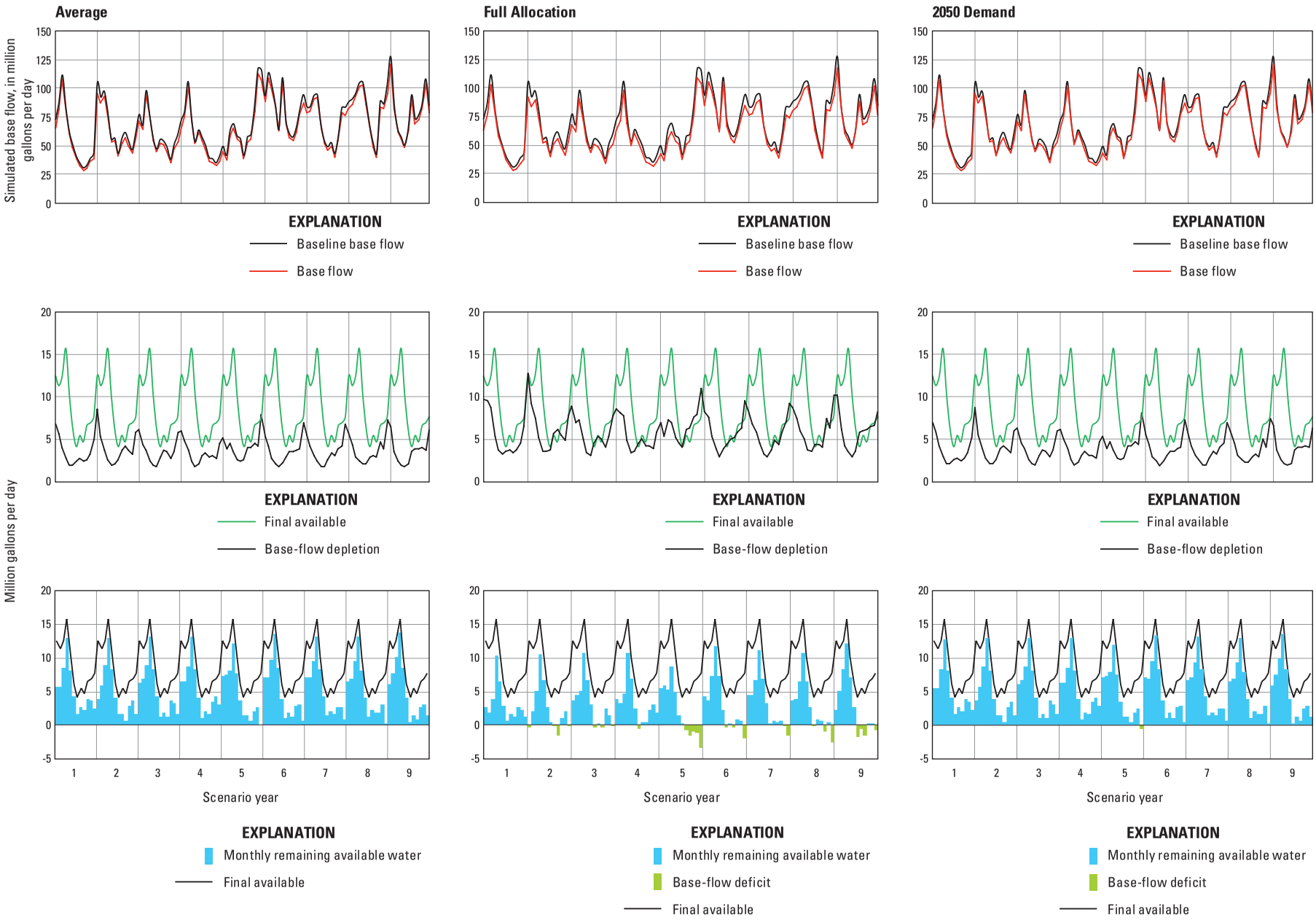

Figure 1-E. Hydrologic Unit Code 11 02040301190, West Branch Wading River.

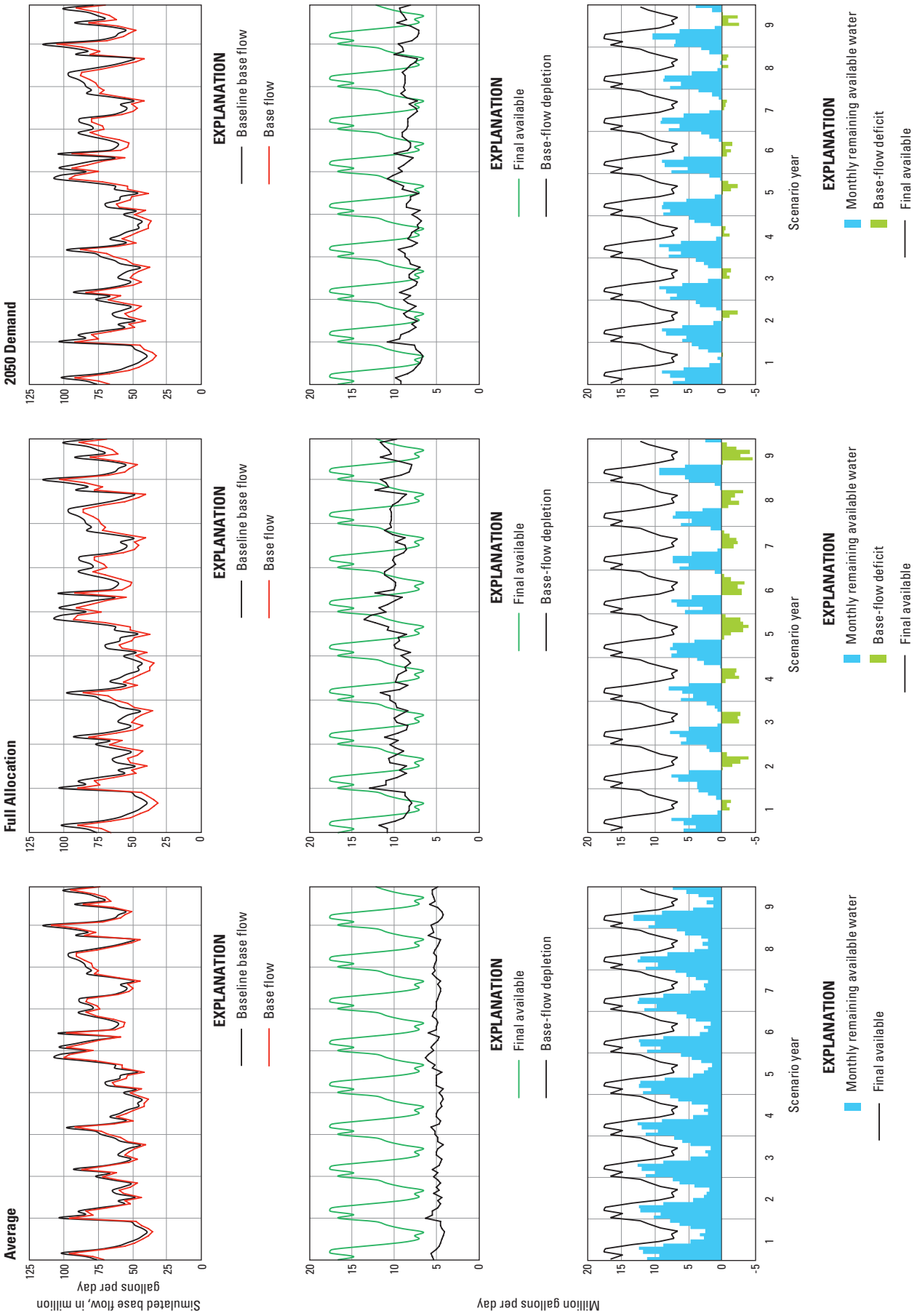

Figure 1-F. Hydrologic Unit Code 11 02040301200, Mullica River. (GSP bridge to Turtle Creek)

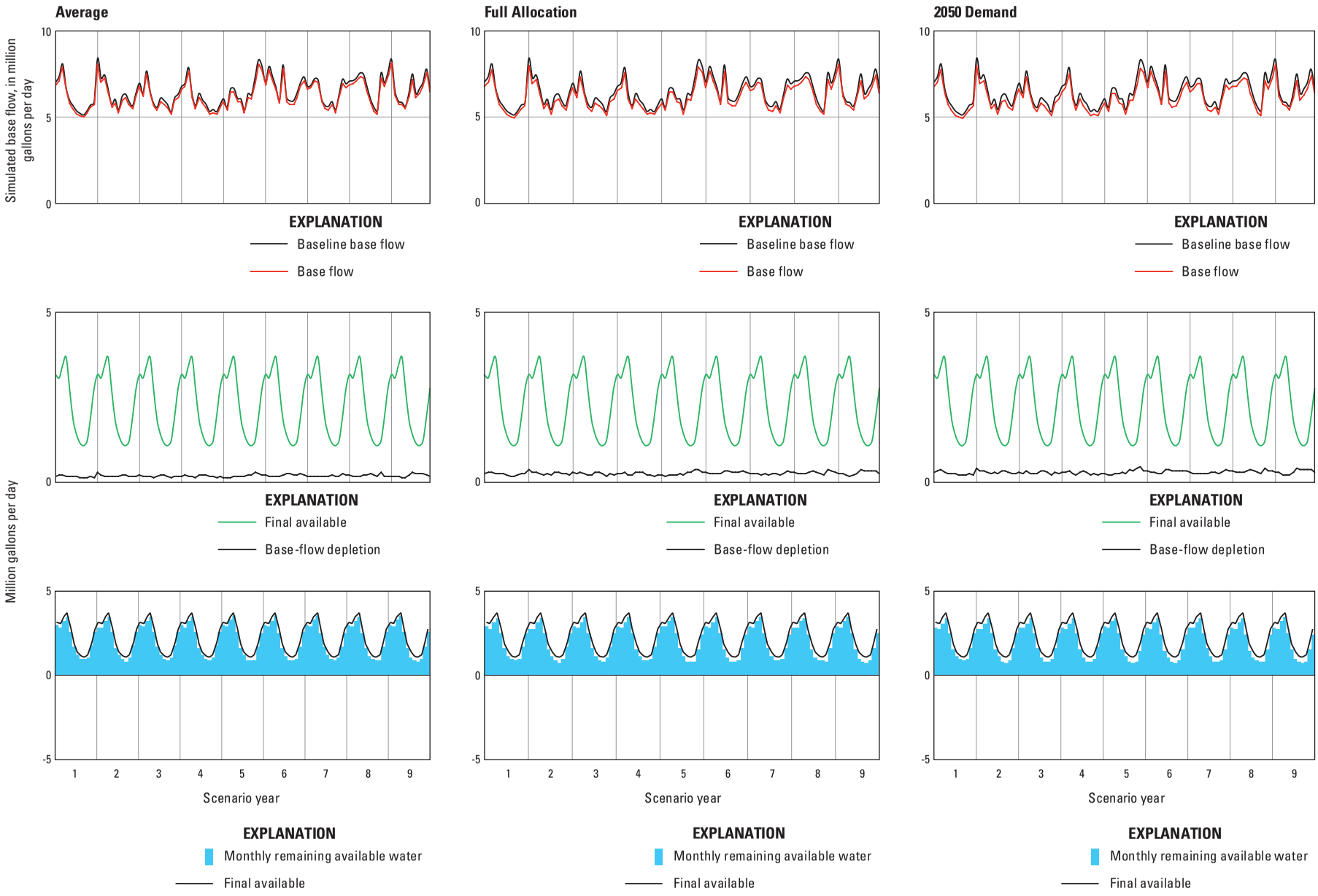

Figure 1-G. Hydrologic Unit Code 11 02040301210, Great Bay / Mullica River. (Below GSP bridge)

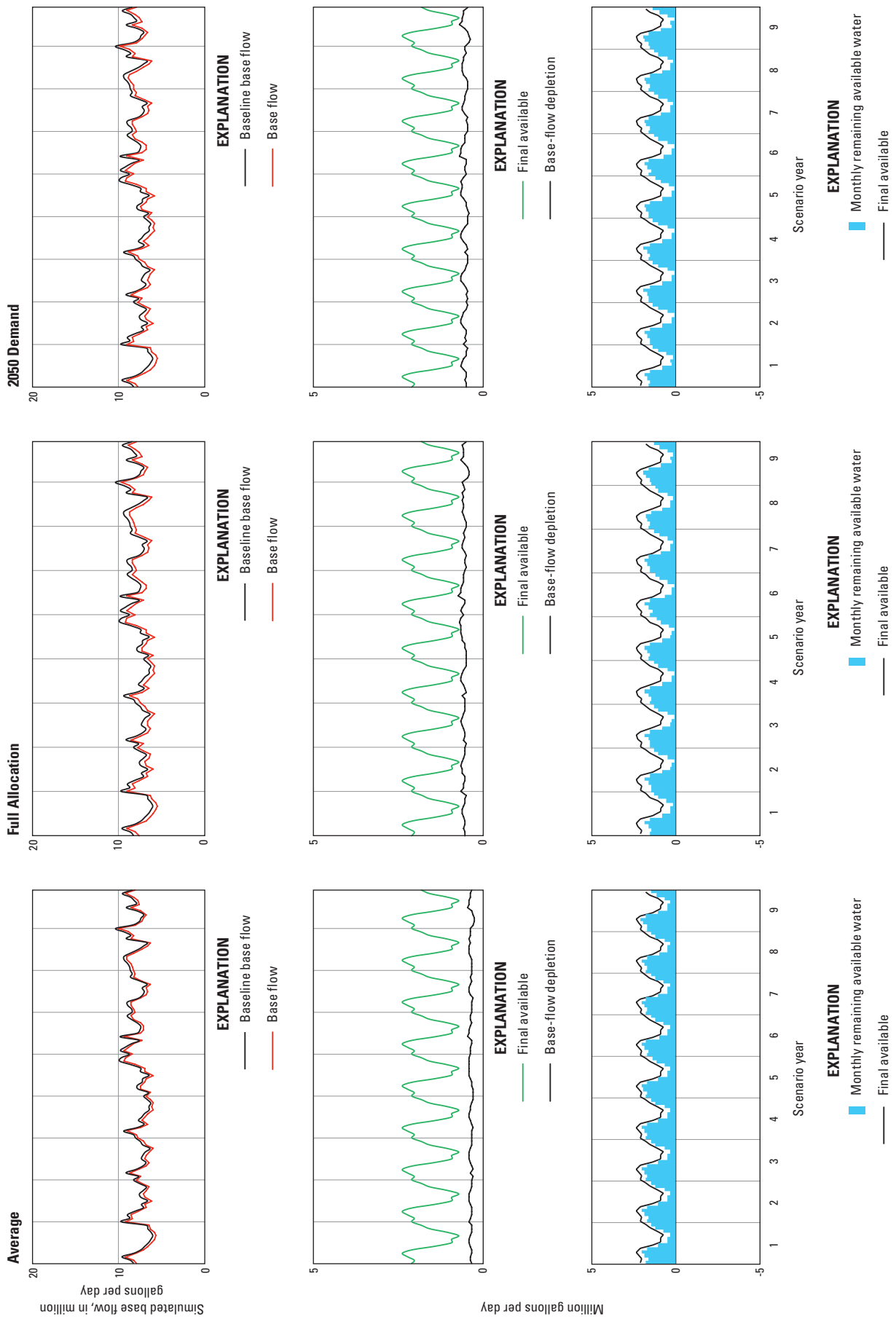

Figure 1-H. Hydrologic Unit Code 11 02040302010, Reeds Bay / Absecon By and tribs.

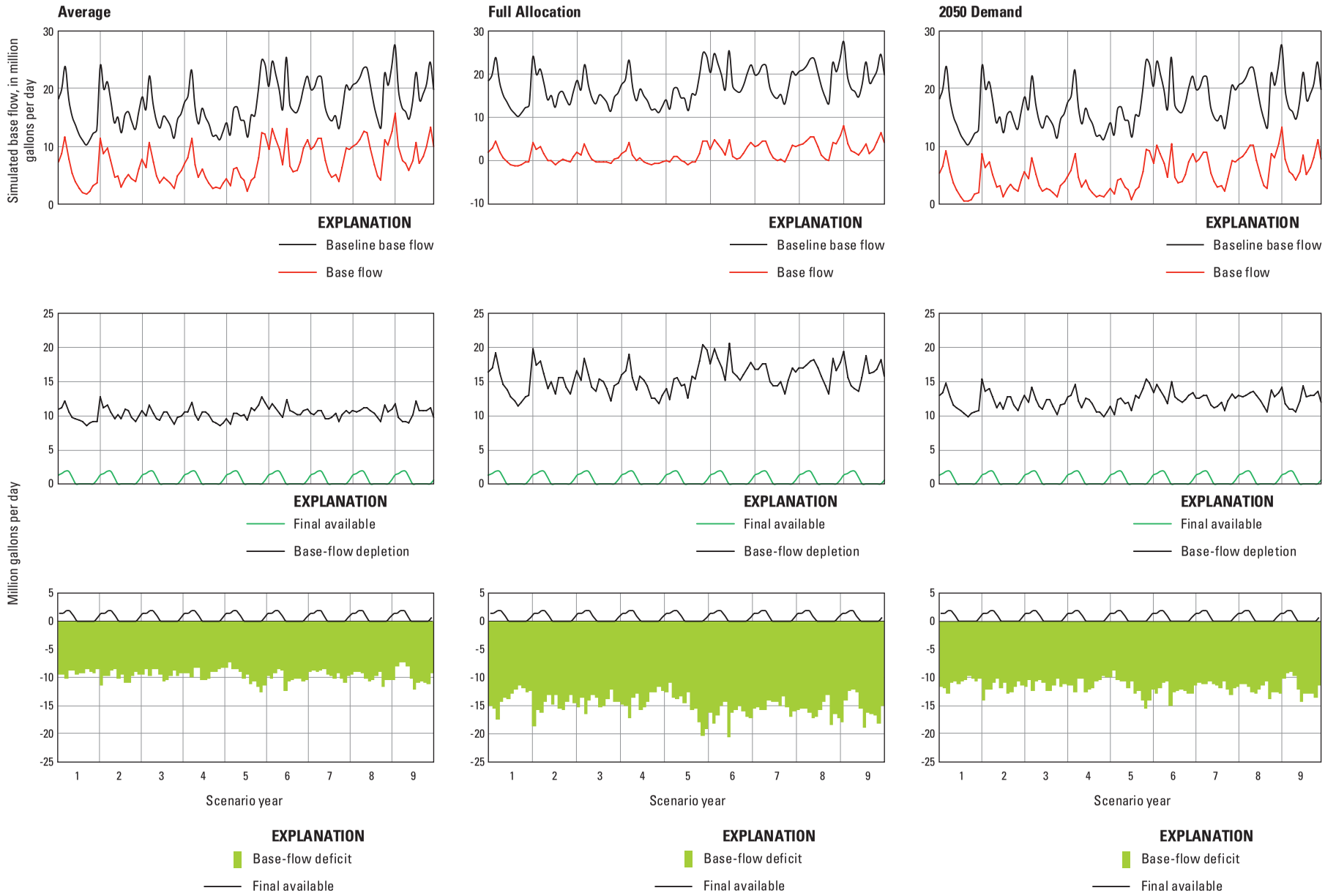

Figure 1-I. Hydrologic Unit Code 11 02040302020, Absecon Creek.

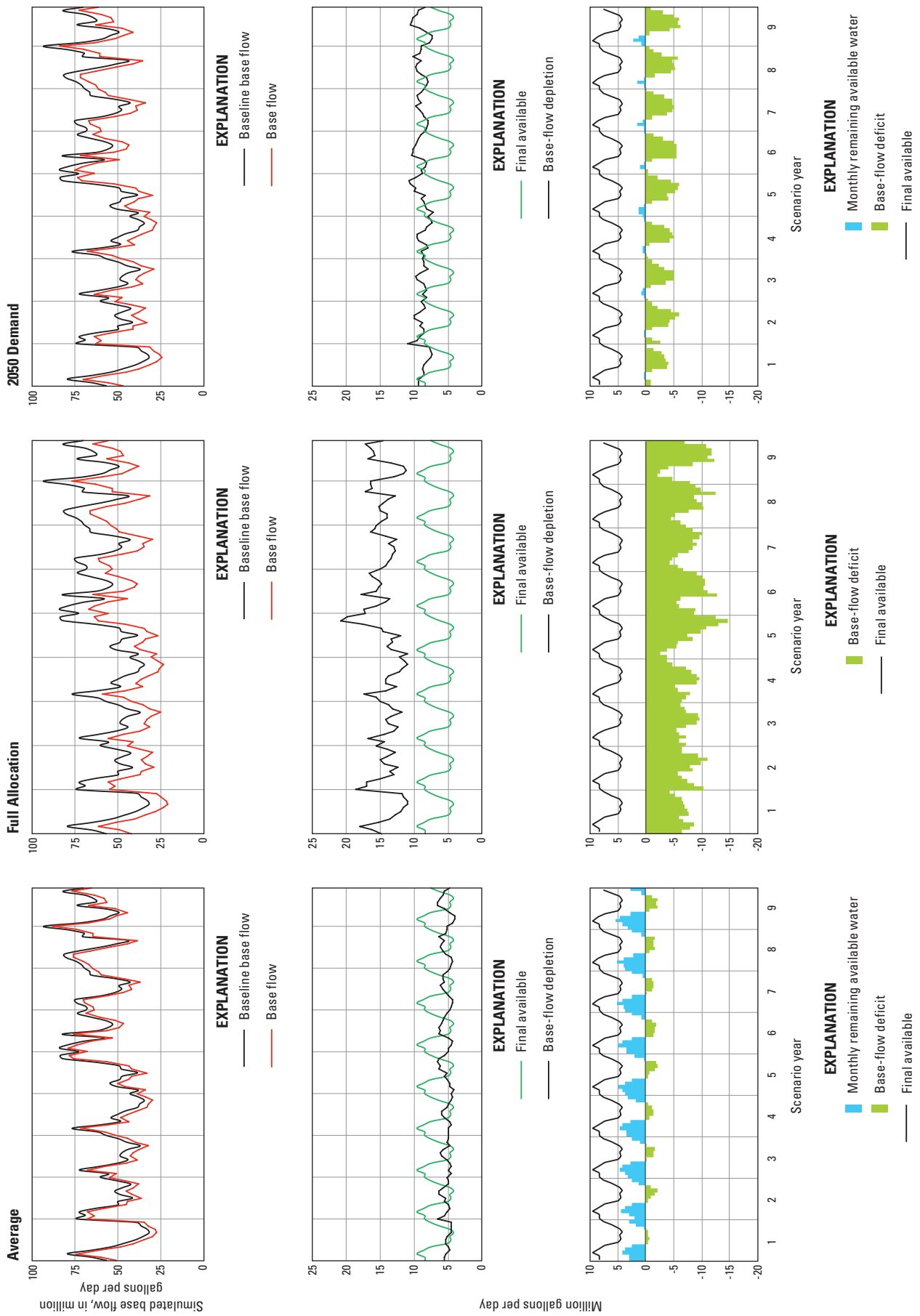

Figure 1-J. Hydrologic Unit Code 11 02040302030, Great Egg Harbor River. (Above Hospitality Branch)

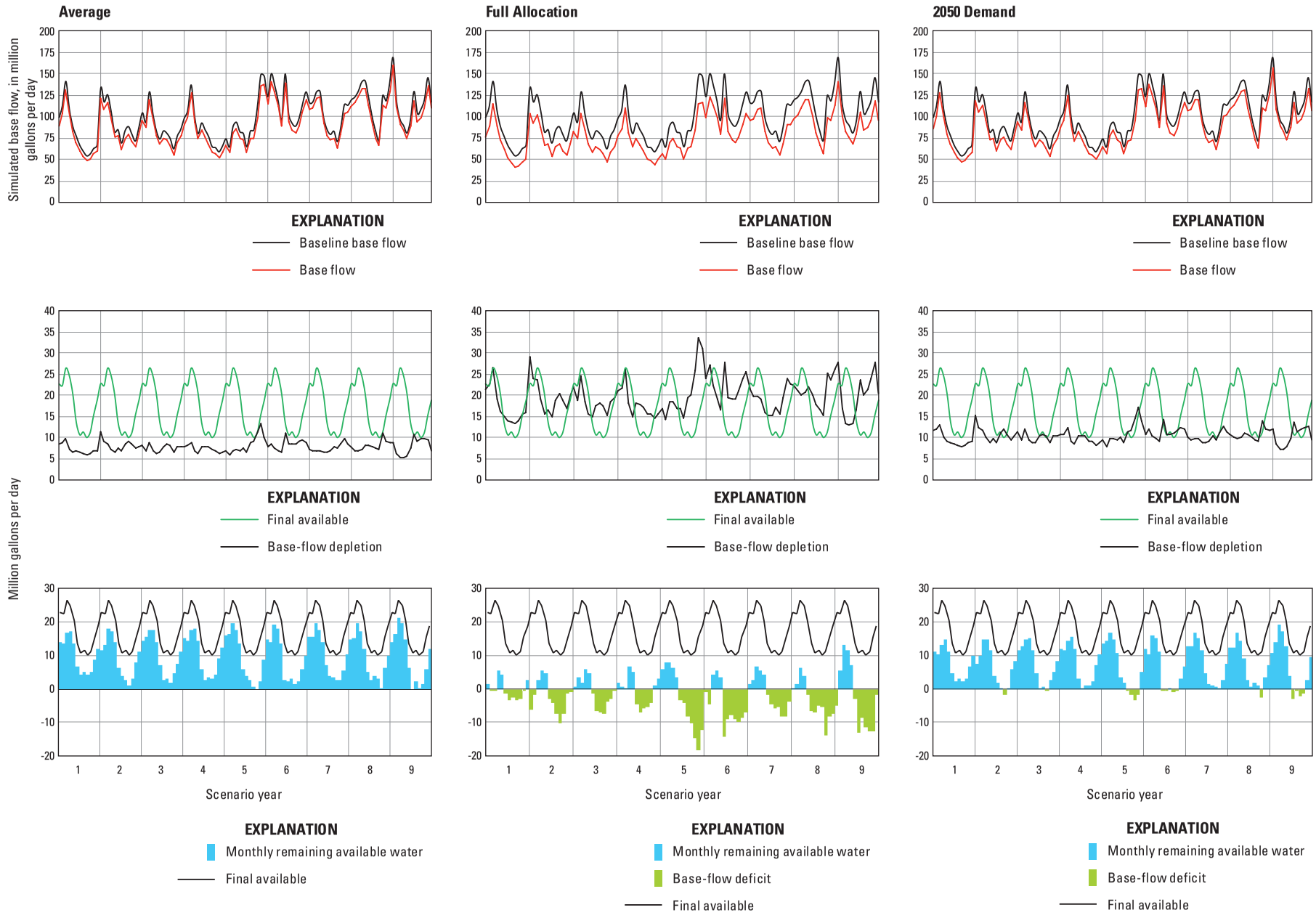

Figure 1-K. Hydrologic Unit Code 11 02040302040, Great Egg Harbor River. (Lake Lenape to Hospitality Branch)

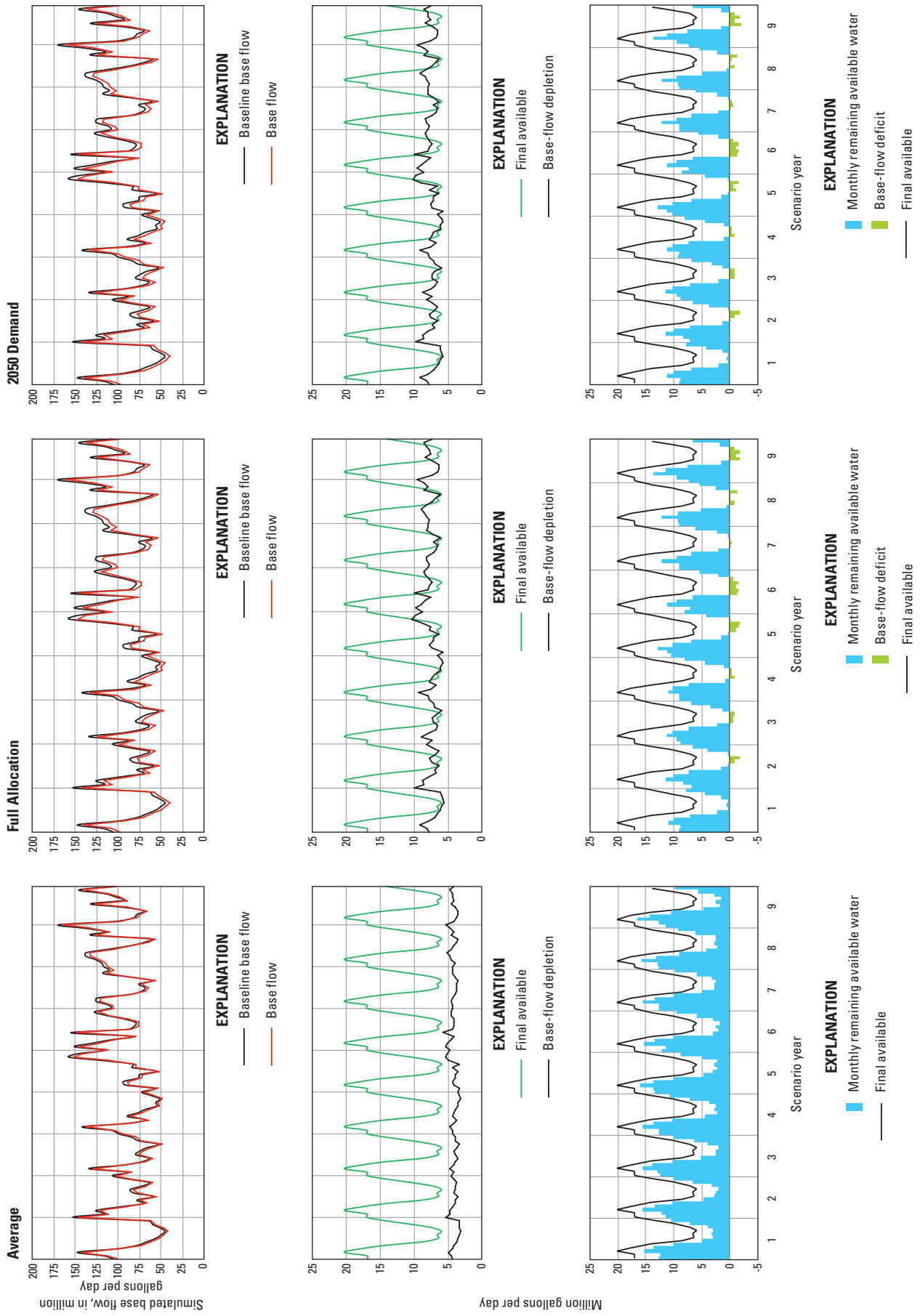

Figure 1-L. Hydrologic Unit Code 11 02040302050, Great Egg Harbor River. (Below Lake Lenape)

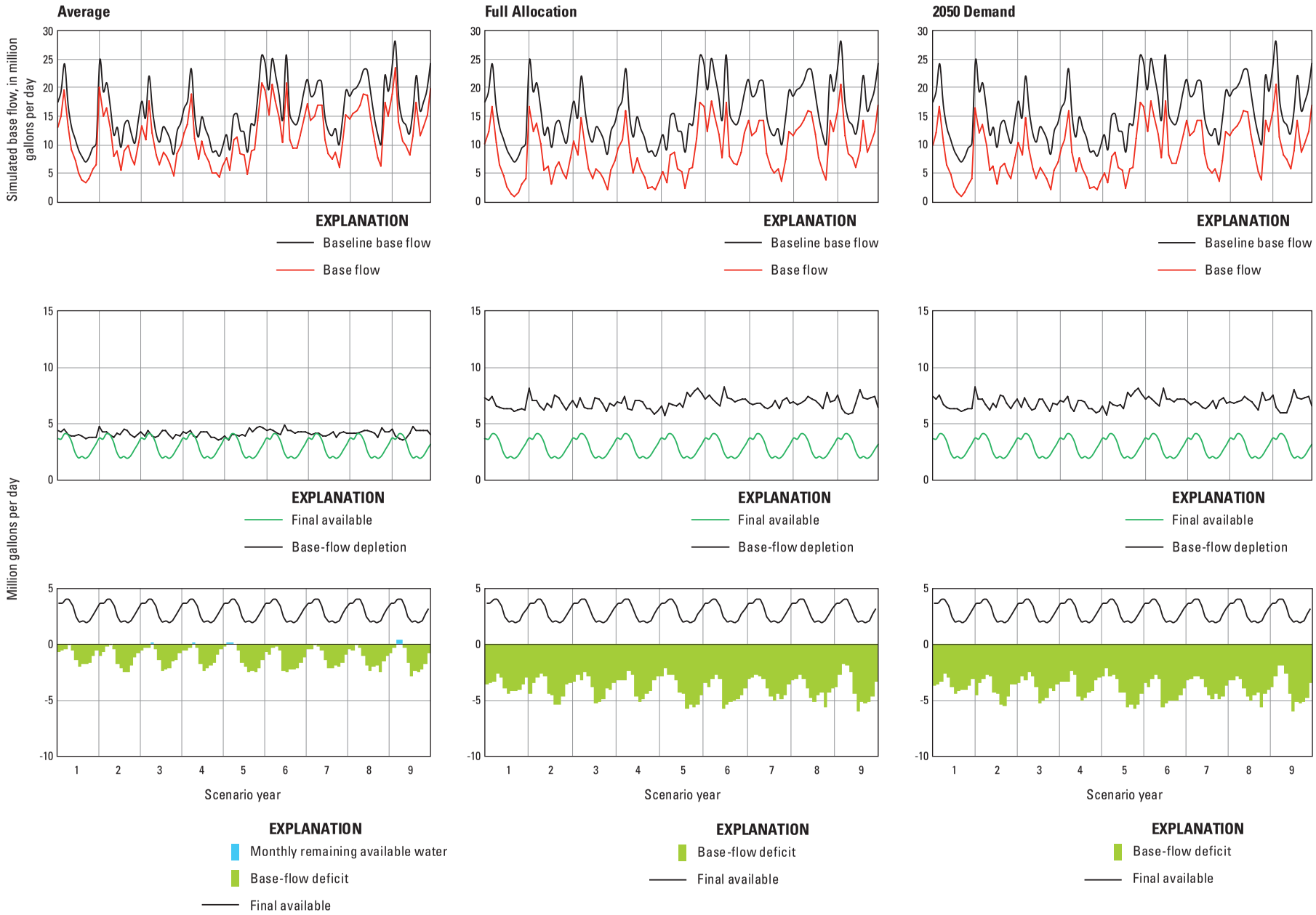

Figure 1-M. Hydrologic Unit Code 11 02040302060, Patcong Creek / Great Egg Harbor Bay.

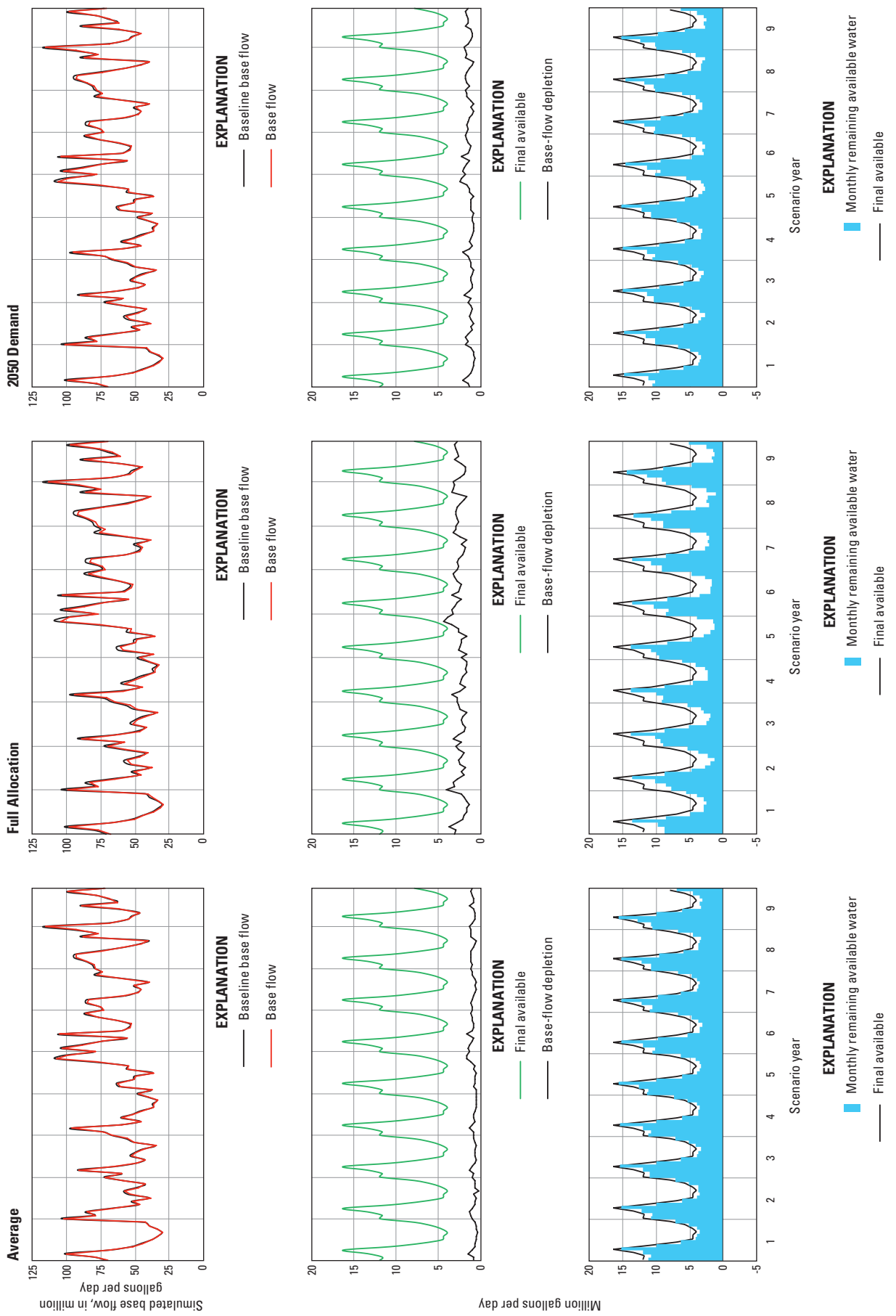

Figure 1-N. Hydrologic Unit Code 11 02040302070, Tuckahoe River.

Appendixes 2 and 3

Appendix 2. Results of simulations of Average, Full Allocation, and 2050 Demand scenarios–basic scenarios–from the Great Egg-Mullica Model. (Excel spreadsheet available online at *http://pubs.usgs.gov/sir/2012/5187/*)

Appendix 3. Results of simulations of Average, Full Allocation, and 2050 Demand scenarios with Tier 1–3 adjustments from the Great Egg-Mullica Model. (Excel spreadsheet available online at *http://pubs.usgs.gov/sir/2012/5187/*)

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