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Future Water-Supply Scenarios, Cape May County, New Jersey, 2003-2050

Scientific Investigations Report 2009-5187

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

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Ken Salazar, Secretary

U.S. Geological Survey
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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
square mile (mi^2)	640	acres
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)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot (ft^3)	7.48	gallons
acre foot	325,851.4	gallons
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
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)
gallon per minute (gal/min)	.5256	million gallons per year (Mgal/yr)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
cubic foot per second (ft^3/s)	235.9	million gallons per year (Mgal/yr)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
	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)
	Leakance	
foot per day per foot [(ft/d)/ft]	1	meter per day per meter [(m/d)m]
inch per year per foot [(in/yr)/ft]	83.33	millimeter per year per meter [(mm/yr)/m]

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 North American Vertical Datum of 1988 (NAVD 88).

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 [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

CMCWU	Cape May City Water Utility
LTMUA	Lower Township Municipal Utilities Authority
NJA	New Jersey American Water Company
NJA-CMCH	New Jersey American Water Company for Cape May Court House service area
NJA-U	New Jersey American Water Company for Upper Township service area
NJDEP	New Jersey Department of Environmental Protection
SHWD	Stone Harbor Water Department
SMCL	Secondary Maximum Contaminant Level
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey
WWU	Wildwood Water Utility
WWD	Woodbine Water Department

Future Water-Supply Scenarios, Cape May County, New Jersey, 2003-2050

By Pierre J. Lacombe, Glen B.Carleton, Daryll A. Pope, and Donald E. Rice

Abstract

Stewards of the water supply in New Jersey are interested in developing a plan to supply potable and non-potable water to residents and businesses of Cape May County until at least 2050. The ideal plan would meet projected demands and minimize adverse effects on currently used sources of potable, non-potable, and ecological water supplies.

This report documents past and projected potable, non-potable, and ecological water-supply demands. Past and ongoing adverse effects to production and domestic wells caused by withdrawals include saltwater intrusion and water-level declines in the freshwater aquifers. Adverse effects on the ecological water supplies caused by groundwater withdrawals include premature drying of seasonal wetlands, delayed recovery of water levels in the water-table aquifer, and reduced streamflow. To predict the effects of future actions on the water supplies, three baseline and six future scenarios were created and simulated.

Baseline Scenarios 1, 2, and 3 represent withdrawals using existing wells projected until 2050. Baseline Scenario 1 represents average 1998-2003 withdrawals, and Scenario 2 represents New Jersey Department of Environmental Protection (NJDEP) full allocation withdrawals. These withdrawals do not meet projected future water demands. Baseline Scenario 3 represents the estimated full build-out water demands. Results of simulations of the three baseline scenarios indicate that saltwater would intrude into the Cohansey aquifer as much as 7,100 feet (ft) to adversely affect production wells used by Lower Township and the Wildwoods, as well as some other near-shore domestic wells; water-level altitudes in the Atlantic City 800-foot sand would decline to -156 ft; base flow in streams would be depleted by 0 to 26 percent; and water levels in the water-table aquifer would decline as much as 0.7 ft. [Specific water-level altitudes, land-surface altitudes, and present sea level when used in this report are referenced to the North American Vertical Datum of 1988 (NAVD 88).]

Future scenarios 4 to 9 represent withdrawals and the effects on the water supply while using estimated full build-out water demands. In most townships, existing wells would be used for withdrawals in the simulation. However, in Lower and Middle Townships, the Wildwoods, and the Cape Mays, withdrawals from some wells would be terminated, reduced, or increased. Depending on the scenario, proposed production wells would be installed in locations far from the saltwater fronts, in deep freshwater aquifers, in deeper saltwater aquifers, or proposed injection wells would be installed to inject reused water to create a freshwater barrier to saltwater intrusion. Simulations indicate that future Scenarios 4 to 9 would reduce many of the adverse effects of Scenarios 1, 2, and 3. No future scenario will minimize all adverse impacts.

In Scenario 4, Lower Township would drill two production wells in the Cohansey aquifer farther from the Delaware shoreline than existing wells and reduce withdrawals from wells near the shoreline. Wildwood Water Utility (WWU) would reduce withdrawals from existing wells in the Cohansey aquifer and increase withdrawals from wells in the Rio Grande water-bearing zone. Results of the simulation indicate that saltwater intrusion and ecological-water supply problems would be reduced but not as much as in Scenarios 5, 7, 8, and 9.

In Scenario 5, the Wildwoods and Lower Township each would install a desalination plant and drill two wells to withdraw saltwater from the Atlantic City 800-foot sand. Saltwater intrusion problems would be reduced to the greatest extent with this scenario. Ecological water supplies remain constant or decline from 2003 baseline values. Water-level altitudes would decline to -193 ft in the Atlantic City 800-foot sand, the deepest potentiometric level for all scenarios.

In Scenario 6, Lower Township would build a tertiary treatment system and drill three wells open to the Cohansey aquifer, west of their existing production wells. Lower Township would inject reclaimed water into the Cohansey aquifer to create a freshwater barrier to prevent saltwater intrusion. Results of the simulation indicate that the barrier would work as designed near the injection wells, but elsewhere in the county, the adverse effects of withdrawals would be similar to those of the baseline scenarios.

In Scenario 7, Lower Township, the Wildwoods, and Middle Township would drill two wells into the Cohansey aquifer and four wells into the Atlantic City 800-foot sand along the spine of the peninsula. Results of the simulation indicate that this scenario reduces saltwater intrusion in the shallow aquifers and reduces the depletion of ecological water

supplies. Water-level altitudes would decline to -177 ft within the Atlantic City 800-foot sand.

In Scenario 8, Lower Township and the Wildwoods would build a desalination plant at the airport and install four wells to withdraw salty water from Atlantic City 800-foot sand. Results of the simulation indicate that this scenario reduces saltwater intrusion and reduces depletion of the ecological-water supplies. Water-level altitudes would decline to -192 ft the Atlantic City 800-foot sand.

In Scenario 9, Lower Township, Cape May City, and Wildwood would expand the existing Cape May City desalination plant by increasing the number of reverse osmosis units and drilling four additional wells into the salty part of the Atlantic City 800-foot sand. Results indicate that this scenario would reduce saltwater intrusion in the Cohansey aquifer, cause the saltwater front in the Atlantic City 800-foot sand to move southward away from more northerly freshwater production wells, and reduce the effects on the ecological-water supply. In Scenario 9, the water-level altitude would decline to -156 ft within the Atlantic City 800-foot sand near Cape May City, the greatest decline in water levels in the Cape May City area.

Introduction

The New Jersey Legislature passed bill A658 in July 2001 (P.L. 2001 chapter 165) pertaining to the water supplies in the Pinelands and Cape May County, New Jersey. Statements within the legislation mandate that the New Jersey Department of Environmental Protection (NJDEP) assess and prepare a report on sustainable potable water-supply alternatives within Cape May County, but outside the Pinelands area, necessary to meet the current and future water-supply needs of the county while avoiding any adverse groundwater or ecological effects on the county.

Cape May County (fig. 1), which occupies a peninsula in southernmost New Jersey, is flanked by Delaware Bay and the Atlantic Ocean. The county is experiencing one of the greatest problems in the State with respect to saltwater intrusion. The intrusion, like in other parts of the State, is caused by excessive withdrawals from the confined aquifers. In addition, the county is internationally recognized for its strategic ecological location because it is a critical stopover location within the Atlantic Migratory Bird Flyway (U.S. Fish and Wildlife Service). Water managers are concerned that continued excessive groundwater withdrawals could affect potable water supplies by causing further water-level declines in the confined aquifers thus exacerbating saltwater intrusion and impacting supply well intakes. Water managers also are concerned that excessive groundwater withdrawals could lower water levels within the water-table aquifer and decrease streamflow, thus adversely affecting the two sources of ecological-water supply to the flora and migratory and native fauna of Cape May County.

Saltwater with chloride concentrations greater than 250 milligrams per liter (mg/L) and sodium concentrations greater than 50 mg/L [New Jersey Department of Environmental Protection (NJDEP) Secondary Maximum Contaminate Level (SMCL)] historically existed near the shoreline in the three shallow aquifers (Holly Beach water-bearing zone, estuarine sand aquifer, Cohansey aquifer). This pre-existing saltwater has rendered the three shallow aquifers non-potable in Stone Harbor, Avalon, Sea Isle City, and Ocean City. The high-chloride, high-sodium water has intruded into wells in the estuarine sand aquifer and Cohansey aquifers in the five Wildwood island townships (North Wildwood, West Wildwood, Wildwood, Wildwood Crest, and part of Lower Township), the three Cape May townships (Cape May Point, West Cape May, and Cape May City), and in Lower, Middle, and Upper Townships (fig. 1).

Saltwater with sodium concentrations greater than 50-mg/L exists naturally in the Atlantic City 800-foot sand for most of the peninsula and in the Rio Grande water-bearing zone for most of the southern part of the peninsula. In spite of exceeding NJDEP SMCL by 1 to 8 mg/L, the slightly salty water from these aquifers is still used by four townships.

The U.S. Geological Survey (USGS), NJDEP, Cape May County, and local water purveyors are acutely aware of the problems of potable water supply in Cape May County. To address the problems, Wildwood Water Utility (WWU), Cape May City Water Utility (CMCWU), and Lower Township Municipal Utilities Authority (LTMUA) have, over the decades, drilled new production wells close to the center of the peninsula to avoid saltwater intrusion. WWU developed an aquifer storage and recovery (ASR) system to deal with high water demand during the summer. CMCWU built a desalination plant to eliminate the long-term problem of saltwater intrusion and increased the price of water to about $7.50 per 1,000 gallons, nearly double the amount that users in other county townships pay. WWU, N.J. American Water Company (NJAWC) in Avalon and Cape May Court House, and Stone Harbor Water Department (SHWD) have blended water from multiple wells to keep the sodium concentration below 50 mg/L or have informed customers about the slightly elevated sodium concentration. Cape May County government mandated that all tourist accommodations install low-flow toilets and shower heads. Tourist accommodations have made operational changes to reduce water consumption. Farms, golf courses, and landscaping practices have changed and are monitored to reduce irrigation water demands or use native vegetation that has a low water demand. Federal, State, county, local, and private agencies have purchased land and created or encouraged legislation to preserve and protect the ecological and potable water supplies. Ecological water supplies are the water used by the flora and fauna, and the water used to maintain the climatic conditions needed to sustain such biota. NJDEP placed a moratorium on an increase in existing water allocations and reevaluated all water allocation permits to limit groundwater withdrawals per legislation passed in 2001 (New Jersey Legislature bill A658). Each action has been

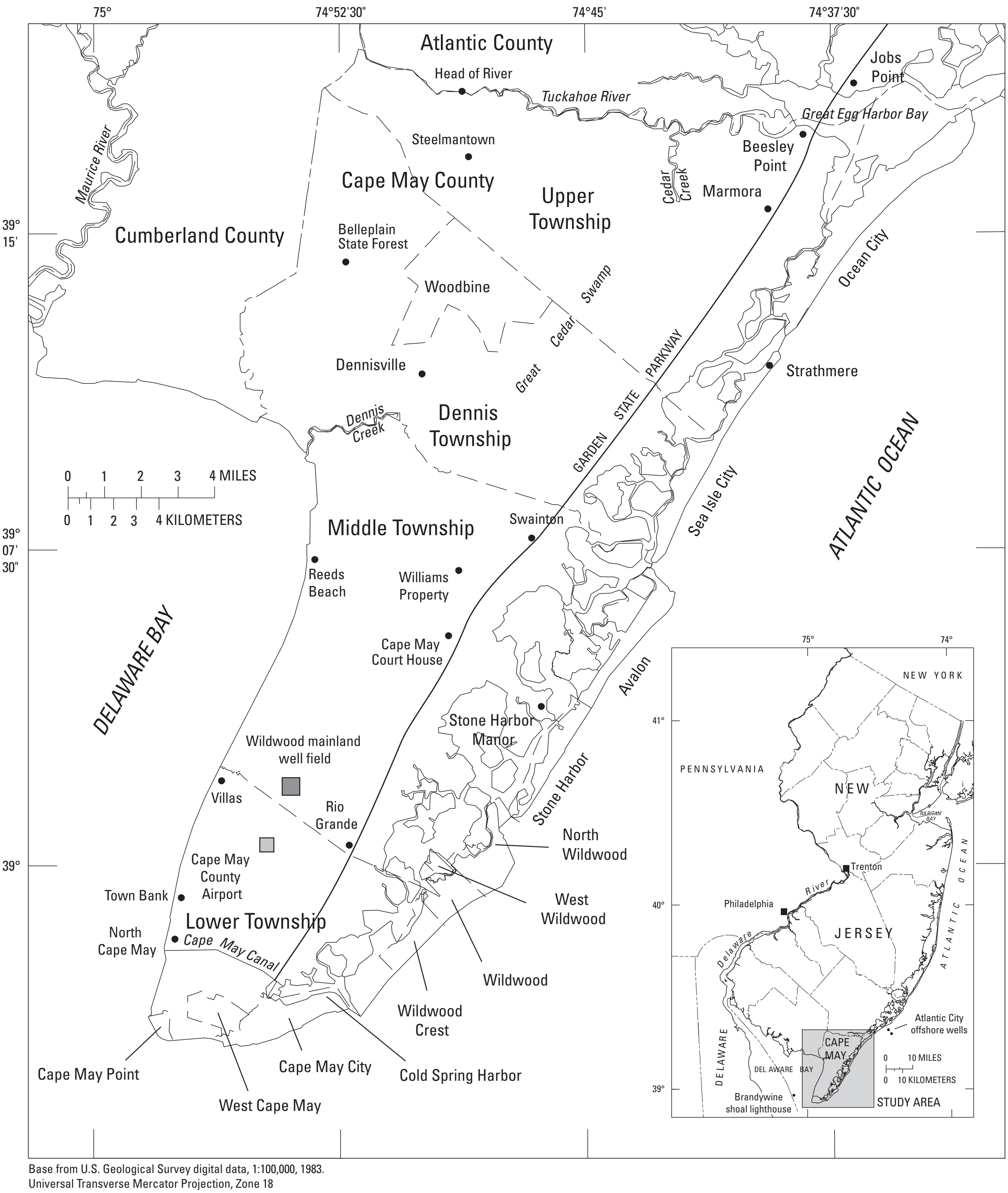


Figure1. Location of the study area, Cape May County, New Jersey.

conducted to protect the ecological and potable water supplies of the county.

The problems associated with saltwater intrusion and balancing potable and non-potable water demands with ecological water demands are becoming more common in coastal areas of the United States. The techniques described in this report can be used for other coastal communities experiencing similar problems.

To develop long-term plans for viable water supplies, the USGS, in cooperation with the NJDEP and the Cape May County Board of Chosen Freeholders investigated past and present (2005) potable, non-potable, and ecological water demands and estimated the water demands of each category until 2050. The USGS, NJDEP, Cape May County, and major water purveyors developed three baseline and six future scenarios to assess the effects of withdrawals. In the baseline scenarios, each township continues to withdraw water using the present withdrawal system and scheme. In Scenario 1 groundwater withdrawals are simulated at the average 1998-2003 rates until 2050. In Scenario 2 withdrawals are simulated at NJDEP full allocation rates until 2050. In Scenario 3 withdrawals are simulated at the estimated full build-out rates until 2050. Estimated "full build out" water demand for 2050 is the water demand that the NJDEP calculated will be needed to meet projected population increases and projected commercial, industrial, and agricultural needs for 2050 (Grabrowski, 2005). The three baseline scenarios were used to compare and contrast the effects of alternative future withdrawal schemes.

The six future scenarios are designed so that each township increases withdrawals to meet 2050 full build-out water demands as simulated in Scenario 3. As in Scenario 3, northern Cape May County water users will continue to use the existing withdrawal wells. However, major purveyors in southern Cape May County make changes in their system and scheme by withdrawing greater quantities of water from deep aquifers and lesser quantities from shallow aquifers, increasing withdrawals from wells in the center of the peninsula and decreasing withdrawals from the shoreline wells, desalinating salty groundwater and reducing use of fresh groundwater, or injecting reused water to create a freshwater barrier thus preventing the intrusion of saltwater.

Water withdrawal rates and locations for new wells for each future scenario were input into two calibrated groundwater-flow models. The shallow flow model simulated flow in the Holly Beach water-bearing zone, estuarine sand aquifer, and Cohansey aquifer. The computer models MODFLOW (Harbaugh and others, 2000) and SEAWAT (Langevin and others, 2003) are used to determine the effects of withdrawals on the location and movement rate of the chloride saltwater front, on the changes in water levels of the unconfined and confined aquifers, and on the changes in streamflow. The model of the deep confined aquifers simulated flow in the Rio Grande water-bearing zone and Atlantic City 800-foot sand. The model uses MODFLOW-2000 (Langevin and others, 2003) with particle tracking to determine the effects of withdrawal on the location and movement of the chloride front and on water levels in the deep confined aquifers.

Purpose and Scope

The purpose of this report is to describe the three baseline and six future scenarios designed to predict the availability of potable water in Cape May County until 2050. The outcome of the simulations of baseline and future scenarios are evaluated to determine the ability of the withdrawal schemes to meet future water needs without adversely affecting the ecological-water supply, increasing saltwater intrusion, or causing large declines in water levels in the confined aquifers.

This report documents historical potable and non-potable water withdrawals; presents estimates of full build-out potable water demands, as well as non-potable demands; and presents estimates of historical and future ecological freshwater demands. Effects on the ecological-water supply are documented by presenting historical and present (2005) water levels for the water-table aquifer, surface-water bodies, and streamflows. The 250-mg/L chloride and 50-mg/L sodium isopleths in the five freshwater aquifers are presented to assess movement of the saltwater fronts. The computer simulation of the three baseline and six future water-supply scenarios are described along with the change in the location of the saltwater front in each aquifer as well as changes in water levels and stream discharge.

Location and Extent of Study Area

Cape May County is the southernmost county in New Jersey (fig. 1). The Atlantic Ocean lies to the east of this peninsular county, and Delaware Bay lies to the west and south. Cape May County is south of, and separated from Atlantic County by, the Tuckahoe River and Great Egg Harbor Bay. Cumberland County borders Cape May County on the northwest.

Cape May County encompasses 263 square miles (mi^2) and can be divided into three geographic areas: mainland, barrier islands, and tidal saltwater wetlands. The mainland covers about 163 mi^2 of which 108 mi^2 is uplands, and 55 mi^2 is freshwater wetlands. Land use on the upland part of the mainland is categorized as forested, agricultural, residential, and commercial. Freshwater wetlands, for the most part, are preserved for ecological habitats.

Five barrier islands cover about 25 mi^2 along the Atlantic shoreline. The barrier islands are mostly urban/suburban environments with densely packed residences and commercial and tourist accommodations.

Tidal saltwater wetlands cover about 75 mi^2. The largest contiguous saltwater wetlands are in the back-bay region between the barrier islands and the mainland. Additional saltwater wetlands include the lower reaches of Dennis Creek, Cedar Creek, Tuckahoe River, and numerous other small creeks on the Delaware Bay side of the County (fig. 1).

Climate, Precipitation, and Evapotranspiration

The climate of Cape May County is characterized by a moderate range of temperatures and mild winters. Warming during the past 10,000 years caused sea level to rise hundreds of feet. The saltwater front has moved landward, and the ecosystem changed from tundra to mid-latitude coastal forests. During the past 100 years, the warming trend caused the average annual temperature to increase less than 1°C (degrees Celsius) and sea level to rise about 10 inches (in.) (30 centimeters) (Titus, 1990)

Annual precipitation in the county ranged from 28.6 to 59.1 in., and the mean precipitation was about 41.9 in. during 1958-87 (Lacombe and Carleton, 2002). Mean monthly precipitation in the county was about 3.5 in. during the same period. The minimum and maximum monthly precipitation values were 0.17 and 16.64 in. Droughts during the past 50 years that lasted 5 months or more occurred in 1965 and 1992.

Precipitation that falls on the upland part of the mainland generally is available for potable and ecological freshwater supply. In an average year, precipitation adds about 78,700 million gallons (Mgal) to land surface. Precipitation that falls on freshwater and saltwater wetland is used for ecological supply and some non-potable supply but is generally unavailable for potable supply. Precipitation that falls on the urbanized land of the barrier islands irrigates lawns but most water quickly flows to culverts and is transmitted to the ocean or back bay.

Evapotranspiration (ET) generally exceeds precipitation during the growing season. As a result, nearly all the growing season precipitation is used for ecological-water supply, and little is available for potable supply. Additional water needed for ET during the growing season comes from water that is stored in wetlands, vernal ponds, and the water-table aquifer. The use of this stored water causes seasonal declines in groundwater levels, decreases in streamflows, and late summer drying of vernal ponds and forested wetlands. During the non-growing season, precipitation generally exceeds ET. Much of the non-growing season precipitation is stored for the growing season ecological supply by raising water levels in the water-table aquifer, and by filling vernal ponds and other intermittent wetlands. Some non-growing season precipitation is used to increase stream discharge to sustain the aquatic habitats.

Prior to 1900, less than 0.2 inch per year (in/yr) of precipitation infiltrated the confined aquifers because groundwater withdrawals were trivial. However, by the 1990s about 0.4 to 1.2 in. of precipitation infiltrated the confined aquifers each year because of groundwater withdrawals (Spitz, 1998).

Well-Numbering System

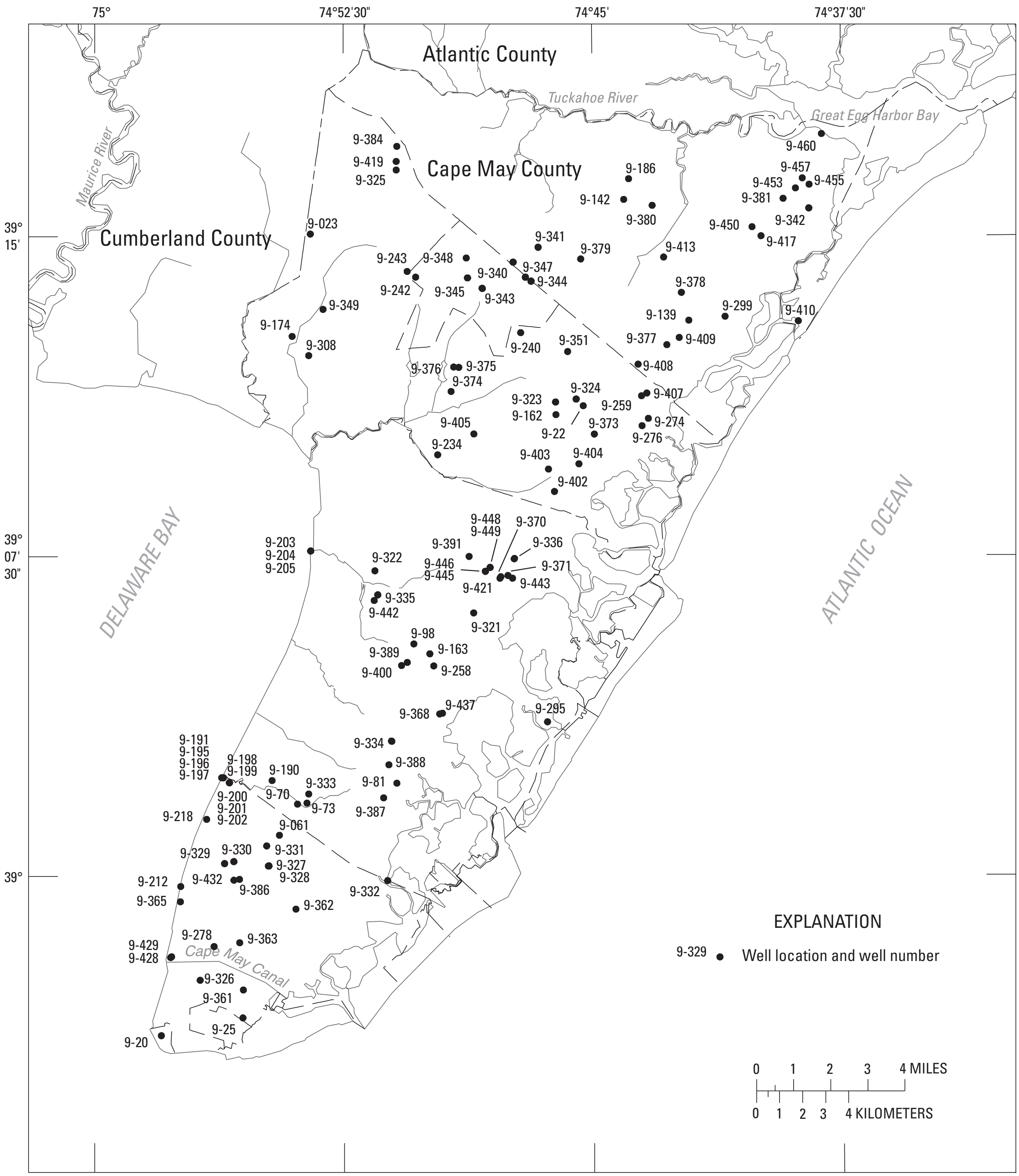
The well-numbering system used in this report is based on the number system used by the U.S. Geological Survey in New Jersey since 1978. The well number consists of a county code number and a sequence number assigned to a well within the county. County code numbers for the study area are 1, Atlantic County; 9, Cape May County; and 11, Cumberland County. A representative well number 9-181 (or 090181) designates the 181st well inventoried by the USGS in Cape May County. The USGS used other numbering systems in reports prior to 1978. Figures 2 to 5 are the index maps for each aquifer showing the location of wells and a well number for each well. Well-construction and other well information are contained in Appendix A at the end of the report.

Hydrogeology

The aquifers and confining units in Cape May County lie within the Atlantic Coastal Plain Physiographic Province. The Coastal Plain sediments consist of layers of gravel, sand, silt, and clay that gently dip to the southeast. Generally, the deposits thicken to the southeast. The shallow freshwater aquifers of Cape May County are the Holly Beach water-bearing zone, estuarine sand aquifer, and Cohansey aquifer. The deep freshwater aquifers are the Rio Grande water-bearing zone, and Atlantic City 800-foot sand (fig. 6). These aquifers are separated by confining units that are well defined in southern Cape May County. In northern Cape May County, the confining units above the Rio Grande water-bearing zone and Atlantic City 800-foot sand are well defined. However, the confining unit above the Cohansey aquifer is less well defined, and the confining unit above the estuarine sand is discontinuous. The aquifers and confining units are briefly described below; a more detailed description can be found in Lacombe and Carleton (2002).

The Holly Beach water-bearing zone is an unconfined aquifer and consists of gravel, sand, silt, and clays (Lacombe and Carleton, 2002). In the southern part of the county the thickness of the Holly Beach water-bearing zone ranges from 10 to 80 ft. In the northern part of the county, the underlying estuarine sand confining unit is laterally discontinuous, and the Holly Beach water-bearing zone and the estuarine sand aquifer behave as one aquifer with a thickness of 10 to 200 ft (Lacombe and Carleton, 2002).

The estuarine clay is the confining unit that separates the Holly Beach water-bearing zone from the estuarine sand aquifer in southern Cape May County (Lacombe and Carleton, 2002). The thickest, most continuous part of the confining unit underlies parts of Lower and Wildwood. The confining unit is marine clay that was deposited in an ancestral channel of the Delaware River during an interglacial Pleistocene transgression of the Atlantic Ocean (Gill, 1962). The clay probably crops out in Delaware Bay within a few miles of the western shore of the county (Lacombe and Carleton, 2002). In northern Cape May County, the clay is discontinuous. Lacombe and Carleton (2002) mapped the estuarine clay as a distinct unit south of the northern part of Middle Township and described it as a discontinuous clay that is present in Dennis and more northerly townships.



Base from U.S. Geological Survey digital data, 1:100,000, 1983.
Universal Transverse Mercator Projection, Zone 18

Figure 2. Locations of selected wells open to the Holly Beach water-bearing zone, Cape May County, New Jersey.

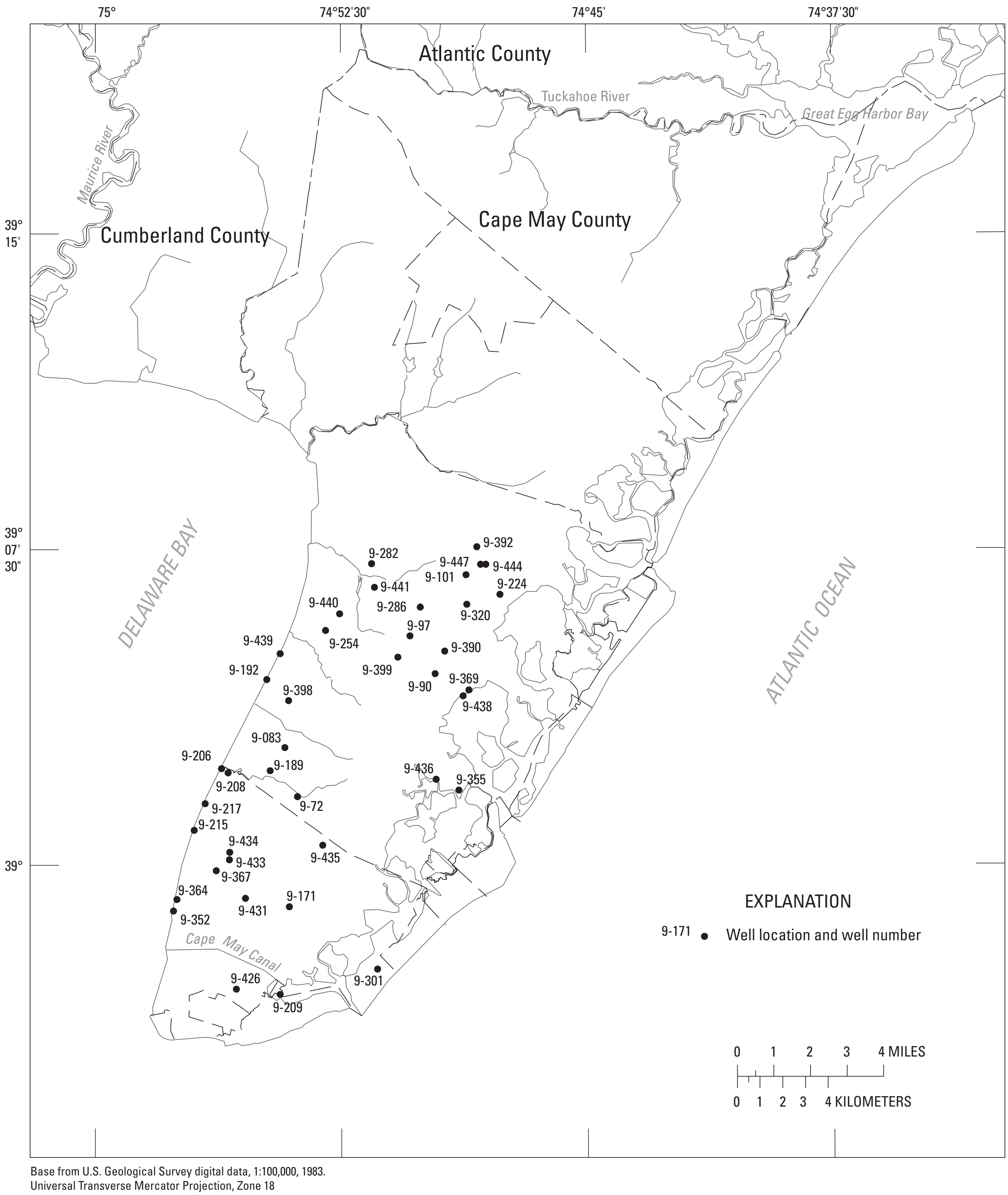
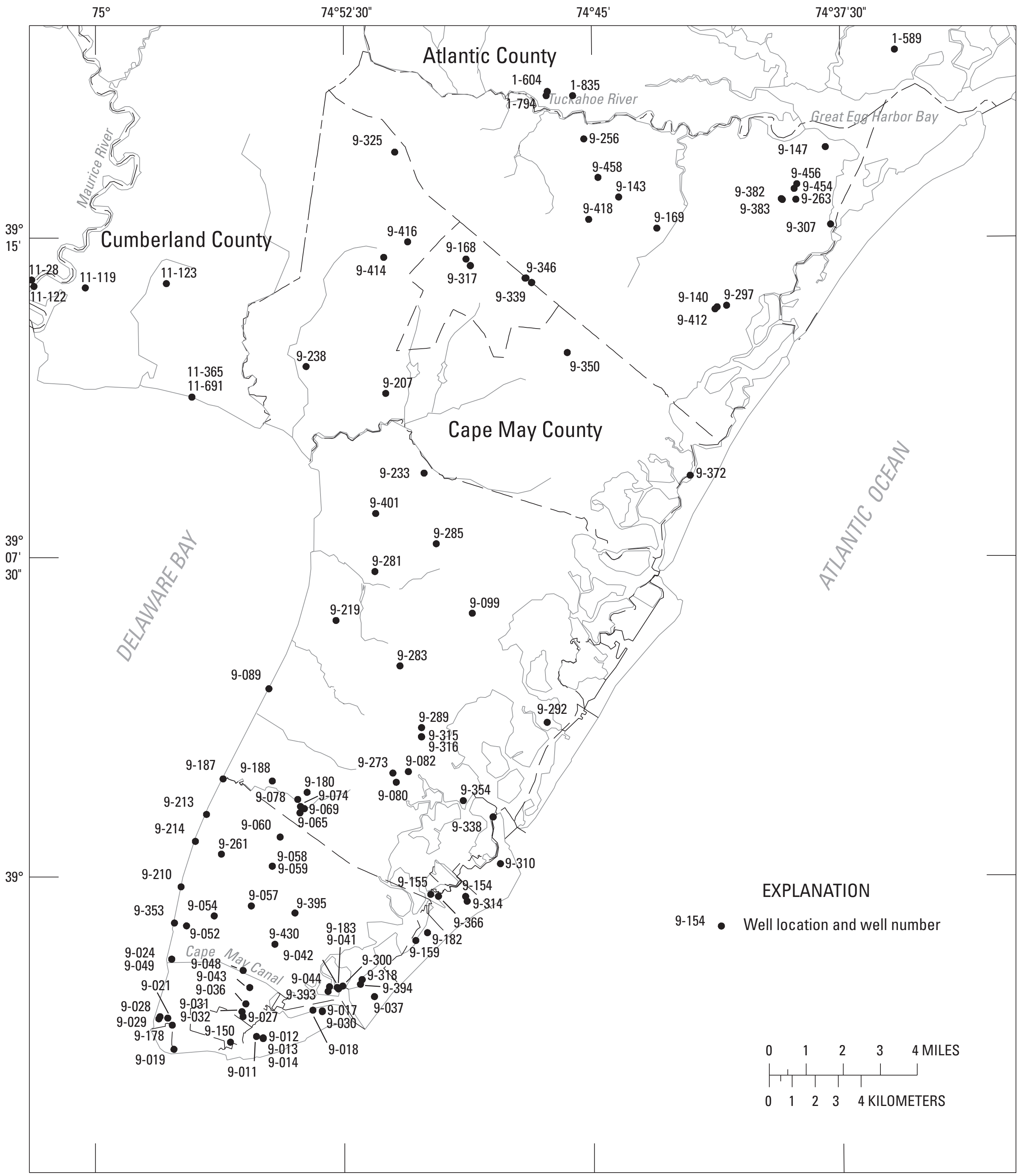


Figure 3. Locations of selected wells open to the estuarine sand aquifer, Cape May County, New Jersey.



Base from U.S. Geological Survey digital data, 1:100,000, 1983.
Universal Transverse Mercator Projection, Zone 18

Figure 4. Locations of selected wells open to the Cohansey aquifer, Cape May, Atlantic, and Cumberland Counties, New Jersey.

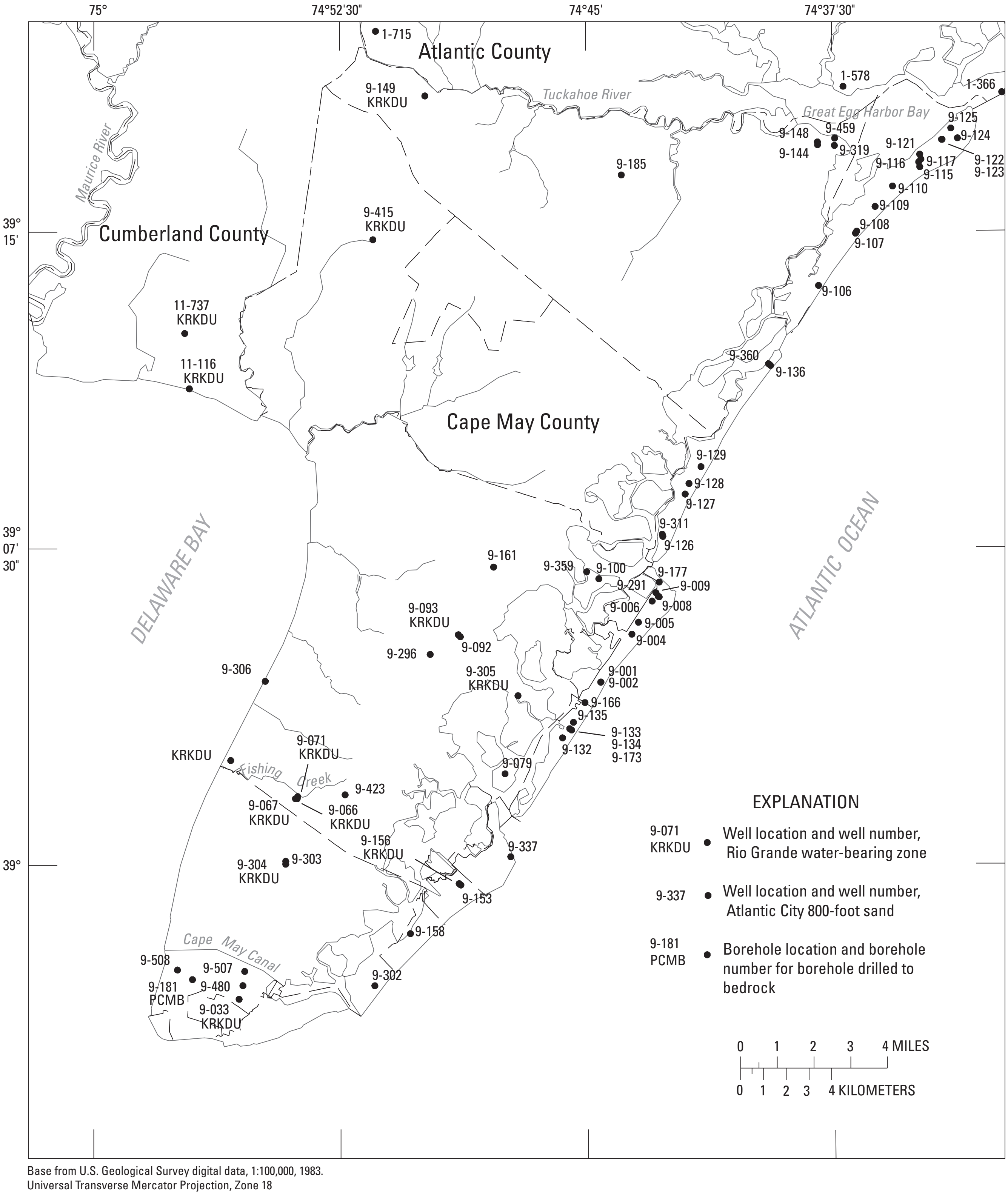


Figure 5. Locations of selected wells open to the Rio Grande water-bearing zone and Atlantic City 800-foot sand, Cape May, Atlantic, and Cumberland Counties, New Jersey.

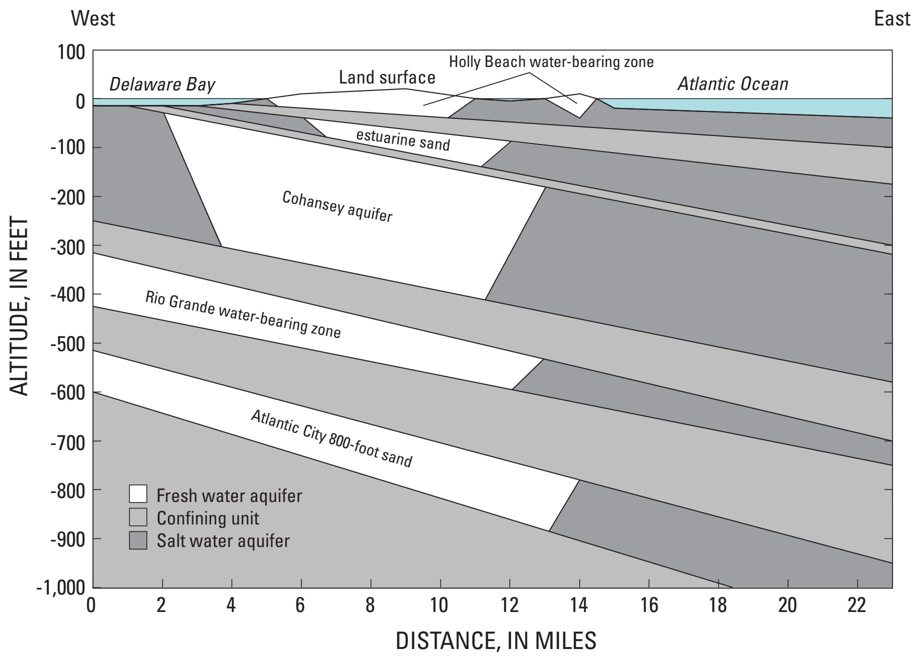


Figure 6. Generic section showing aquifers and confining units as well as freshwater and saltwater aquifers of southern Cape May County, New Jersey. (Additional maps and sections are in Lacombe and Carleton, 2002)

The estuarine sand aquifer is mapped as a distinct aquifer only where it is overlain by the estuarine clay (Lacombe and Carleton, 2002). The aquifer primarily consists of quartz-rich estuarine and fluvial deposits of early Sangamonian age (Zapecza, 1989; Gill, 1962). Its thickness ranges from 25 to 160 ft (Lacombe and Carleton, 2002).

The confining unit overlying the Cohansey aquifer is part of an unnamed geologic unit consisting of ascending fluvial, estuarine, and marine upper Pliocene? deposits (Newell and others, 2000; Zapecza, 1989). The clay is discontinuous with a thickness that ranges from 10 to 75 ft. Lacombe and Carleton (2002) map the confining unit as extending north and west of Cape May County, but the discontinuous depositional environment and paucity of data on subsurface features make it difficult to determine the extent and thickness of the confining unit in the northwest. The confining unit probably crops out in Delaware Bay about 4 to 5 mi west of Cape May peninsula (Lacombe and Carleton, 2002).

The Cohansey aquifer in southern Cape May County is the Cohansey Sand described by Gill (1962), but more recently investigations show it is in the lower part of an unnamed geologic unit identified by Newell and others (2000). In northern Cape May, the Cohansey aquifer is made up of the Cohansey Formation and sandy strata of the upper part of the Kirkwood Formation. The aquifer is about 60 ft thick in the northern part of the county and more than 180 ft thick in the southern part.

The confining unit separating the Cohansey aquifer and the Rio Grande water-bearing zone is composed of a massive clay layer within the Kirkwood Formation (Zapecza, 1996). The thickness of the unit ranges from 50 to 225 ft.

The Rio Grande water-bearing zone and the Atlantic City 800-foot sand are in the Kirkwood Formation of middle Miocene age. These aquifers are extensive and cover all of Cape May, much of Atlantic, and parts of Cumberland, Burlington, and Ocean Counties (fig. 1). The Rio Grande water-bearing zone is composed of coarse to fine-grained sand. The aquifer ranges from 30 to 170 ft thick and is thickest in eastern Middle Township (Lacombe and Carleton, 2002).

The confining unit overlying the Atlantic City 800-foot sand is composed of massive clay and silt layers. The unit is from 40 to 190 ft thick in Cape May County (Lacombe and Carleton, 2002; Zapecza, 1989). The confining unit is thickest in eastern Middle Township. The western limit of the confining unit terminates below Delaware Bay, eastern Cumberland County, and western Atlantic County.

The Atlantic City 800-foot sand is composed of coarse to fine-grained sand. The aquifer ranges from 125 to 150 ft thick in the county (Lacombe and Carleton, 2002) and is locally divided into upper and lower units by a semi-confining layer that is 10 to 30 ft thick.

The Piney Point aquifer, Wenonah-Mount Laurel aquifer, and Potomac-Raritan-Magothy aquifer system and their associated confining units underlie the Atlantic City 800-foot sand. These aquifers do not provide potable water in Cape May County.

Chloride, Sodium, and Saltwater Intrusion

Lacombe and Carleton (2002) describe, in detail, chloride and sodium concentrations, the locations of the 250 mg/L isochlor and 50 mg/L sodium isopleth (which represent the NJDEP SMCLs), and areas and rates of saltwater intrusion in the five freshwater aquifers of Cape May County.

Saltwater intrusion is defined as increasing concentrations of chloride and (or) sodium. Saltwater intrusion in Cape May County forced the abandonment of more than 20 public- and industrial-supply wells and hundreds of domestic wells (Lacombe and Carleton, 1992). Most of the abandoned wells are completed in confined aquifers in the Wildwoods, Cape Mays, Lower, Middle, and Upper Townships.

Lacombe and Carleton (2002) show the location of the chloride and sodium fronts in the Holly Beach water-bearing zone (fig. 7). For most locations, the line separating high chloride (>250-mg/L) and high sodium (>50-mg/L) water from freshwater in the water-table aquifer is defined as the line that separates saltwater tolerant from freshwater tolerant flora. The contact between the saltwater tolerant and non-tolerant flora is the tip or top of the saltwater front. The front forms a dipping surface that plunges under the freshwater so that the toe or bottom of the saltwater front is as much as 600 ft inland of the tip of the saltwater front in the Holly Beach water-bearing zone. Historical saltwater intrusion in the Holly Beach water-bearing zone is limited to a few shoreline wells in northwest Lower Township (Lacombe and Carleton, 2002)

The estuarine sand aquifer contains freshwater in most areas of the mainland peninsula and a short distance offshore under Delaware Bay and the back bay (Lacombe and Carleton, 2002) (fig. 8). Since 2000, water with high chloride concentrations has intruded into observation wells 9-192, 9-206, and 9-217 on the west side of the peninsula as a result of ground-water withdrawals (fig. 9). The chloride concentration of water from well 9-192 increased from less than 200 mg/L prior to 2000 to about 300 mg/L after 2000. The chloride concentration of water from well 9-206 ranged from 250 to 500 mg/L prior to 2000 (with four anomalously high values) and steadily increased to 922 mg/L during 2000-05. Chloride concentrations in water from well 9-217 were about 50-mg/L prior to 1980 but increased to more than 325 mg/L during 1990-2005. Water samples from other wells in the estuarine sand aquifer that are near the shoreline (9-189, 9-352) have remained at less than 25 mg/L of chloride since 2000. The Cape May County Health Department analyzed water samples from many domestic wells across the county and determined that, in the Villas area, many of the domestic wells have high chloride concentrations (Lacombe and Carleton, 1992). In addition, local well drillers typically do not install wells into the estuarine sand aquifer in the Villas area because they cannot guarantee freshwater in the area (Roger Smith of R.W. Smith Well Drilling and Del Clark of Del Clark Well Drilling oral commun., 2000).

The Cohansey aquifer contains freshwater with chloride and sodium concentrations that are less than the NJDEP SMCL in most areas of the mainland and a short, but unknown, distance offshore (fig. 10). The aquifer produced freshwater during the first half of the 1900s in the Wildwood and the Cape May townships but by the latter half of the 1900s, saltwater had intruded production, military-, and industrial-supply wells in Cape May Point, Cape May City, Lower Township, the Wildwoods and Upper Township (Lacombe and Carleton, 1992, 2002). The aquifer has always produced salty water for each barrier island township north of the Wildwoods, and though it was used for cooling water in many theaters during the past, the water was never used for potable supply in these townships.

Chloride concentrations in excess of 250 mg/L intruded into two CMCWU wells completed in the Cohansey aquifer about 1947 and 1961 (fig. 11A) forcing the abandonment of production wells (9-12, 9-14) within 5 years of drilling the wells. The remaining three production wells (9-27, 9-36, and 9-43) were judiciously pumped to keep chloride concentrations below 250 mg/L. By the mid 1990s the chloride concentrations in water from wells 9-27 and 9-36 were slightly less than 250-mg/L; therefore, well 9-43 was heavily relied upon for water supply. The increasing chloride concentrations in well 9-43 prompted the CMCWU to build a desalination facility and drill supply wells into the Atlantic City 800-foot sand to obtain salty water for desalination. CMCWU preferred to use water from the Atlantic City 800-foot sand because the chloride and sodium concentrations from such water would remain high but stable for a longer time than water from the Cohansey aquifer.

Water with high chloride concentrations intruded into public- and industrial-supply wells in and near Cape May Point (wells 9-19, 9-21, 9-28, and 9-29) (fig. 4) during 1972-83 (Lacombe and Carleton, 2002). The chloride concentrations ranged from 200 to 248 mg/L; well 9-19 had a maximum concentration of 570 mg/L. However, well 9-19 is open to both the Cohansey aquifer and Rio Grande water-bearing zone, so it is unclear whether the water with high chloride concentration was from the Cohansey aquifer, Rio Grande water-bearing zone, or both. Chloride concentrations in samples collected from USGS observation well 9-150 in West Cape May increased from less than 20 mg/L in 1955 to nearly 500 mg/L in 2005.

Chloride concentrations in water from near-shore wells 9-52, 9-54, 9-353, and 9-213 (fig. 11b) in western Lower Township north of the Cape May Canal were less than 25 mg/L during 1965-2005. However, chloride concentrations in water from nearby well 9-206 increased from 325 to 900 mg/L during 1985-2005 (fig. 9b). Chloride concentrations that were in excess of 250 mg/L in northwestern and southwestern Lower Township indicate that the 250-mg/L isochlor is not far offshore, but its precise location is unknown.

Chloride concentrations in water from well 9-89 (fig. 11D) were about 10 mg/L during 1957 to 2001, and increased to 27 mg/L in 2005, indicating the onset of saltwater intrusion. Chloride concentrations in water from well 9-188, (fig. 11D) were about 20 mg/L during 1970-2005.

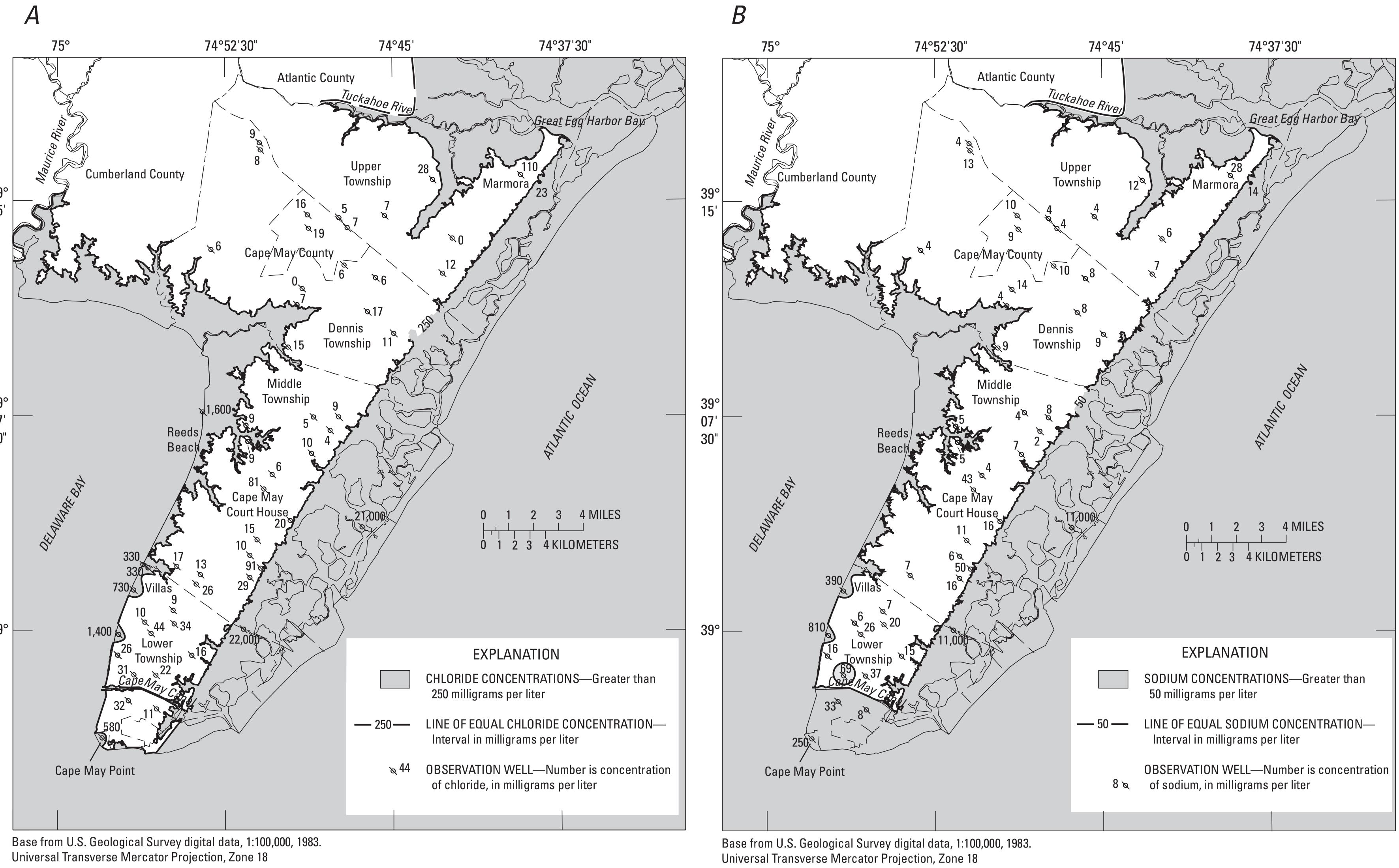


Figure 7. *(A)* Chloride and *(B)* sodium concentrations measured in water from wells open to the Holly Beach water-bearing zone, Cape May County, New Jersey. (Modified from Lacombe and Carleton, 2002)

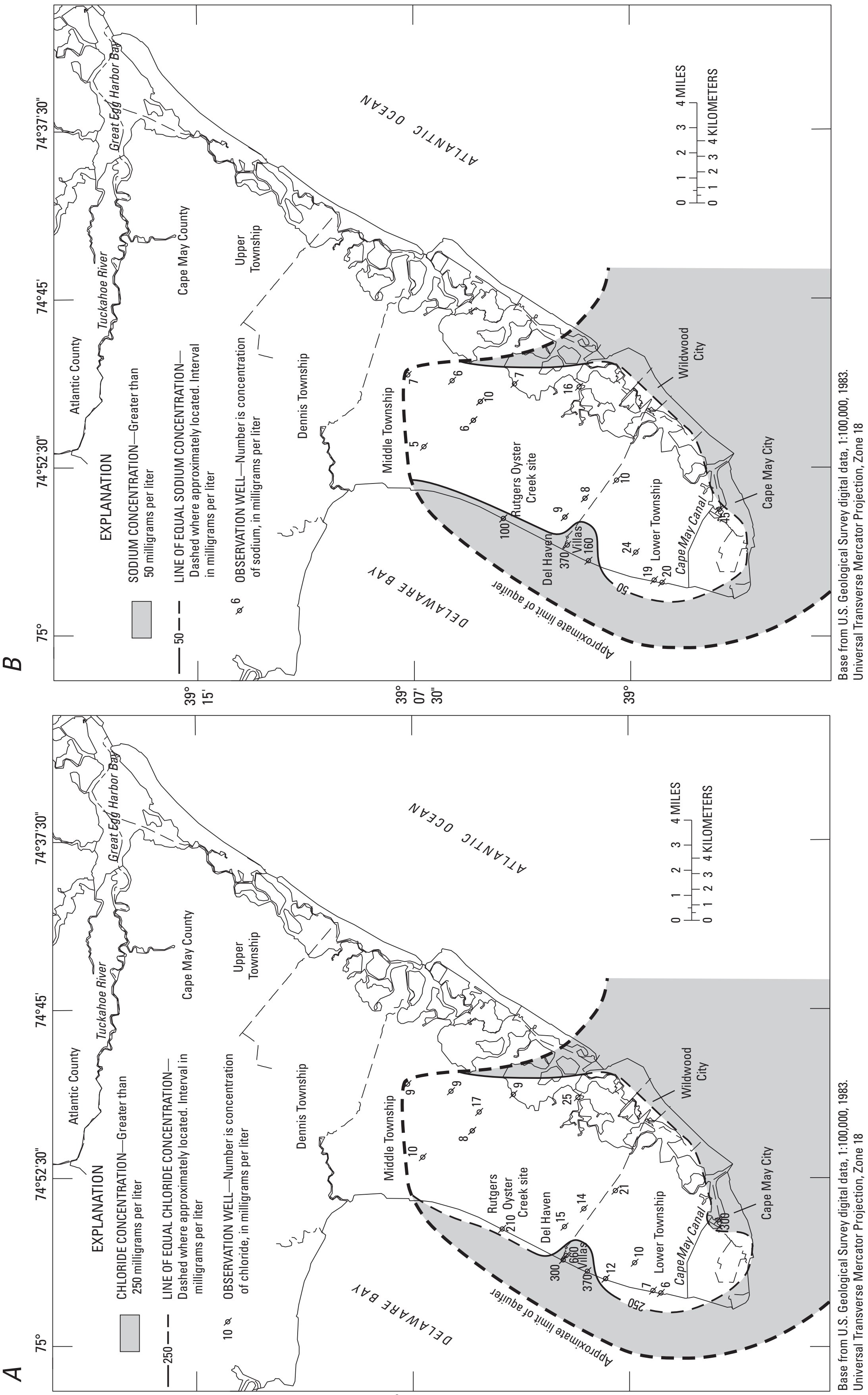


Figure 8. *(A)* Chloride and *(B)* sodium concentrations measured in water from wells open to the estuarine sand aquifer, Cape May County, New Jersey. (Modified from Lacombe and Carleton, 2002)

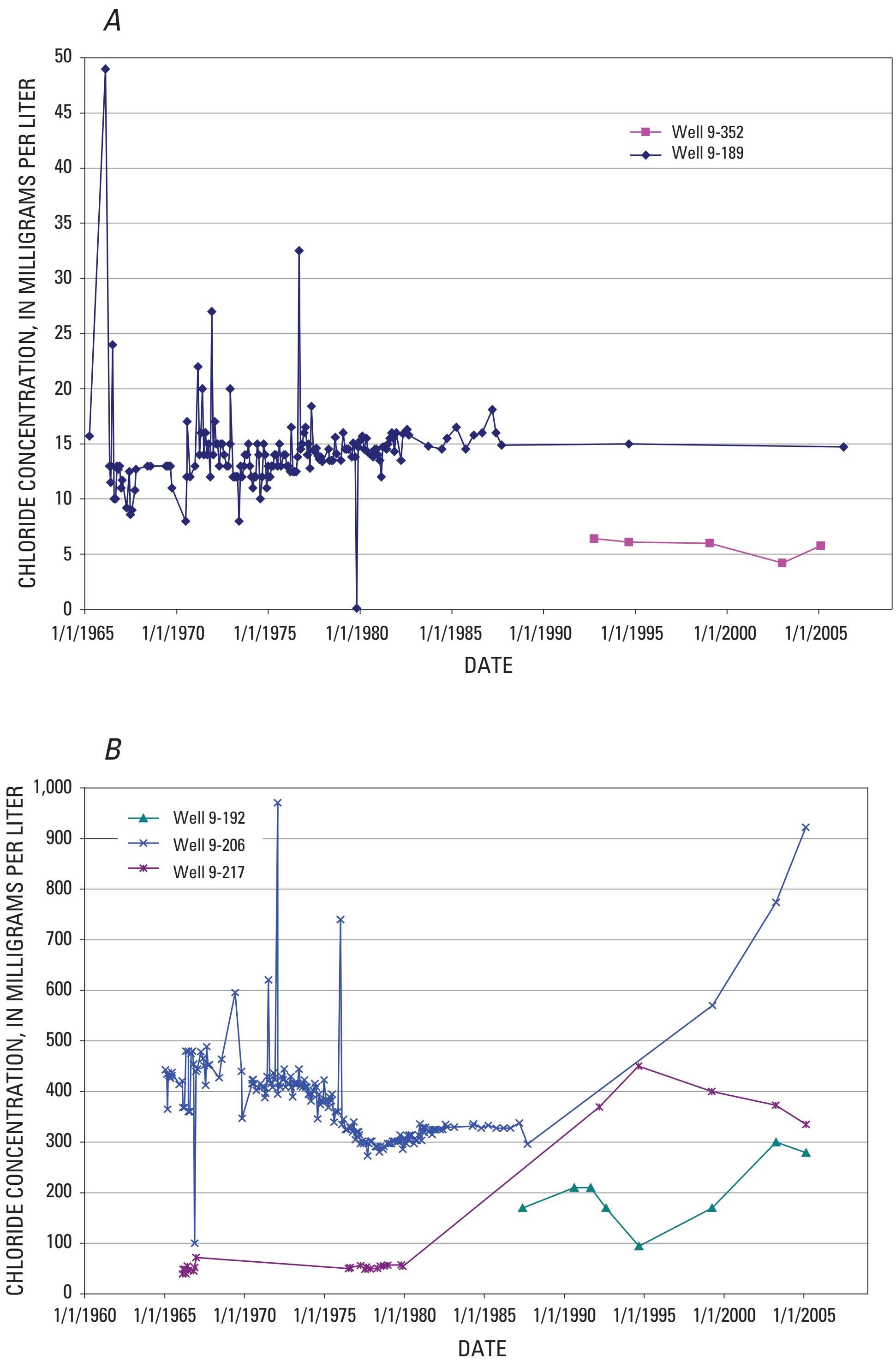


Figure 9. Chloride concentrations in groundwater samples from *(A)* wells 9-352 and 9-189 and *(B)* wells 9-192, 9-206, and 9-217 open to the estuarine sand aquifer, Cape May County, New Jersey, 1965-2005.

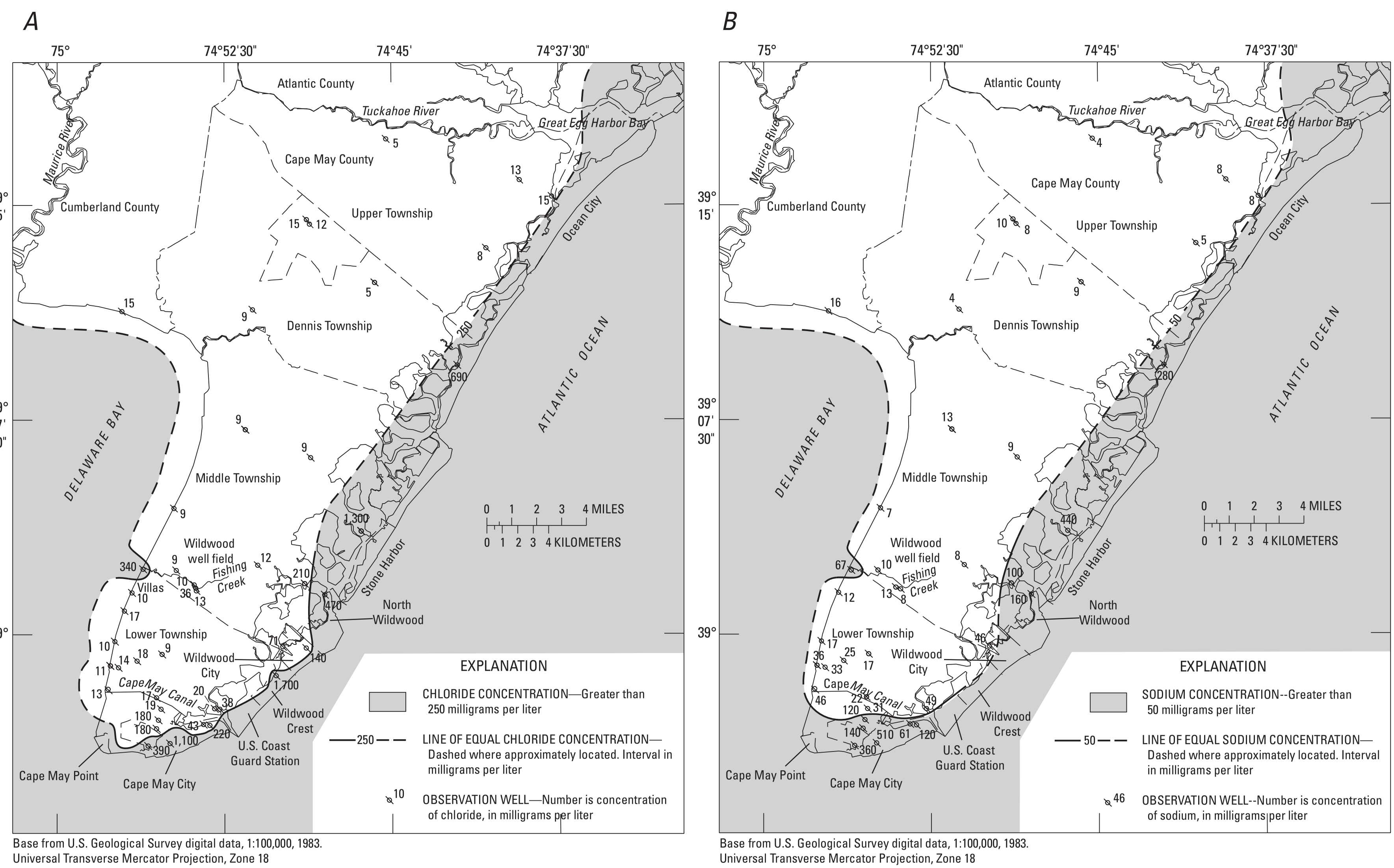


Figure 10. *(A)* Chloride and *(B)* sodium concentrations measured in water from wells open to the Cohansey aquifer, Cape May County, New Jersey. (Modified from Lacombe and Carleton, 2002)

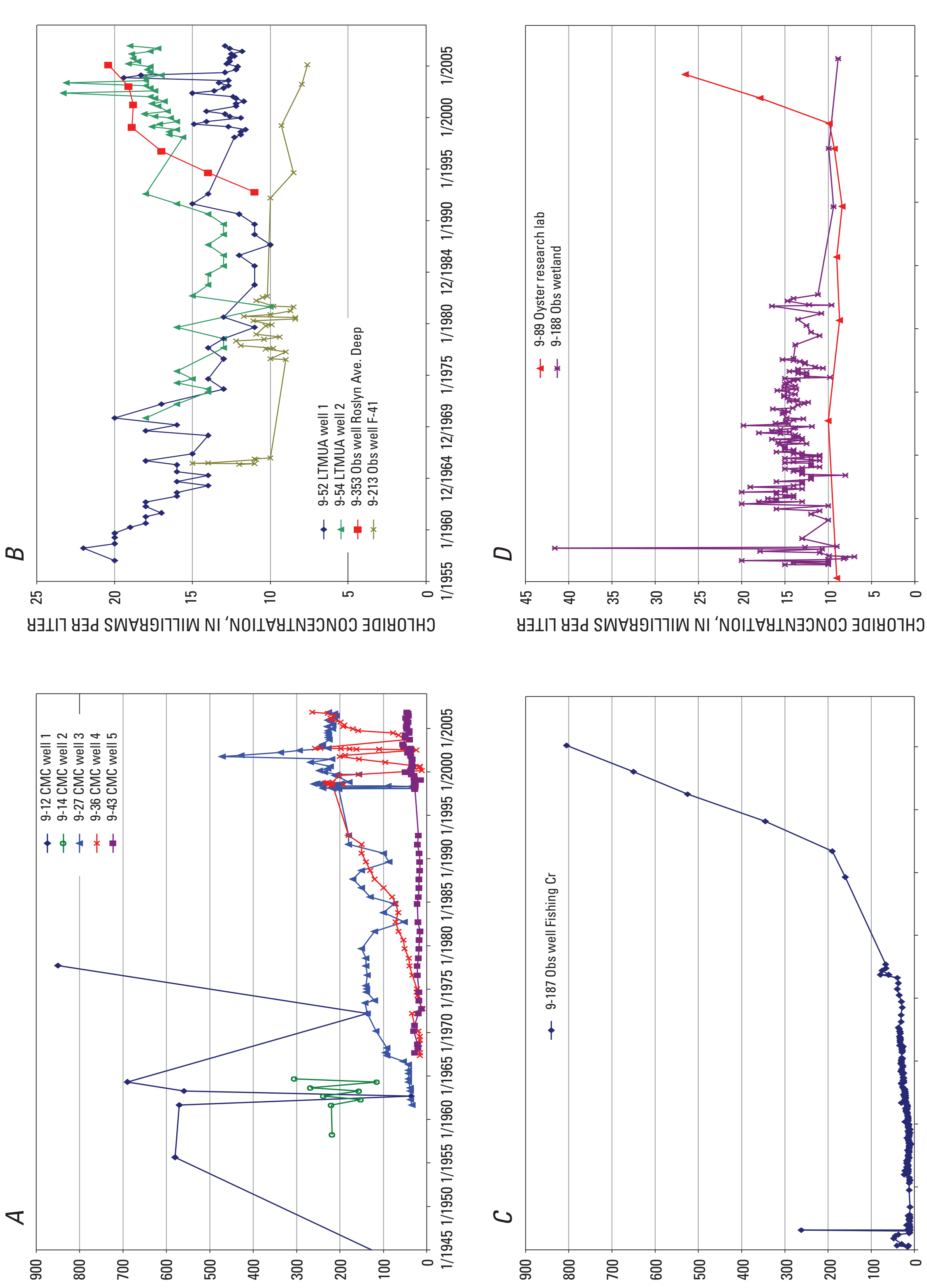


Figure 11. Chloride concentrations in groundwater samples from selected wells open to the Cohansey aquifer, Cape May County, New Jersey.

Sodium concentrations exceeded the NJDEP drinking-water standard in or near all areas where water with high chloride concentrations intruded into the Cohansey aquifer. The chloride to sodium ratio for this aquifer ranges from about 1:1 to 3:1; however, the ratio of water from well 9-187 is about 4:1, indicating a much higher sodium concentration than a simple mix of seawater and freshwater. One possible source of the excess sodium is water from the confining units where cation exchange increases the sodium concentration.

Chloride concentrations in well 9-187 (fig. 11c) have increased more than in other wells during 2000-05 with an increase of about 400 mg/L. The intrusion is likely caused by withdrawals from the WWU supply wells that are less than 2 mi east of the observation well.

The Rio Grande water-bearing zone contains water with low chloride concentrations in most mainland areas north of the Cape May County Airport (fig. 12) (Lacombe and Carlton, 2002). The aquifer also has low chloride water in off-shore areas north of Town Bank and north of Avalon. Gill (1962) noted two wells south of the Cape May Canal that produced water with chloride concentrations in excess of 250 mg/L; however, those wells are now sealed.

The 50-mg/L sodium isopleth (fig. 12b) is about 5 mi north of the 250-mg/L isochlor near the spine of the mainland. As a result, less of the mainland is underlain by freshwater as defined by sodium concentrations than as defined by the chloride concentrations. WWU is currently the only user of water from the Rio Grande water-bearing zone. Chloride concentrations in water from the aquifer at WWU wells have decreased from 92 mg/L to about 72 mg/L during 1926-2004 (fig. 13). Sodium concentrations ranged from 70 to 85 mg/L during 1956-2004.

The Atlantic City 800-foot sand contains water with chloride concentrations less than 250-mg/L in most mainland areas north of the airport (fig. 14) (Lacombe and Carlton, 2002). The aquifer also contains water with low chloride concentrations in off-shore areas north of Villas and north of North Wildwood. The 50-mg/L sodium isopleth is about 9 mi north of the 250-mg/L chloride isopleth near the spine of the mainland. As a result, less of the mainland is underlain by water with a low sodium concentration (<50-mg/L) than with a low chloride concentration (250-mg/L). The isopleth for sodium and chloride are not collocated; therefore, the water supply for Stone Harbor, Avalon, and Cape May Court House meets the NJDEP drinking-water standard for chloride but exceeds the SMCL for sodium.

Previous Investigations

Thompson (1928) evaluated water withdrawals during 1917-28 in the greater Atlantic City area, which included Ocean City, to estimate water demand in 1938, 1948, and 1958. His estimates of future water demand were high because they were made prior to the Great Depression and World War II. He had anticipated increases in population and economic growth that did not occur. Thomson also discussed the advantages and disadvantages of using the Great Egg Harbor River, shallow aquifers, and deep aquifers. He described water quality, seasonal water availability, taste, expense, and human prejudices. He concluded that the easiest, most economical and most socially acceptable method to obtain potable water was to install new wells into the Atlantic City 800-foot sand.

Barksdale and others (1936) reported water withdrawals during 1924-33 in the greater Atlantic City area, which included Ocean City, to estimate future water demand. Like Thompson, their estimates of future water demand were high because they were made before the onset of World War II.

Gill (1962) described the hydrogeologic framework, water levels, water quality, and water use of Cape May County in detail. Though he did not project water demand, he discussed problems and proposed possible ways to meet future water demand.

Gill (1962) indicated that the Holly Beach water-bearing zone had the highest potential to meet future water demand. He suggested locating wells adjacent to streams and lakes where there is a known hydraulic connection and thereby induce infiltration of surface water. The major drawbacks according to Gill were saltwater intrusion and high iron concentrations. He did not discuss streamflow depletions or the effects on the ecological-water supply.

Gill (1962) noted little potential for increased withdrawals from the estuarine sand aquifer because the aquifer has a small recharge area, and it relies on vertical movement of water through the overlying confining unit. He stated that Middle Township is the most favorable area for water-supply development but that water from the estuarine sand aquifer was generally high in iron.

Gill (1962) highlighted that water withdrawal from the Cohansey aquifer in North Wildwood and in Cape May City had already exceeded the sustainability limit because of the saltwater intrusion to wells in these townships. He proposed that because withdrawals in Upper Township, Woodbine, and Dennis Township were distant from the saltwater fronts, future water supplies could be developed in this area. Gill recommended that new production wells that use the Cohansey aquifer south of the Cape May Canal should be located in uplands areas near the canal, and existing production wells should be abandoned. Gill stated that saltwater intrusion in the Wildwood and Cape May City areas dictates caution in future withdrawals from the aquifer. He advised that, if economic conditions require additional water withdrawals, then the wells should be located on the mainland in northern Cape May County or in Atlantic County because withdrawals there would not increase the hydraulic gradient or movement rate of the saltwater front. His suggestions were made prior to the establishment of the Pinelands Commission, which issues regulations to limit shallow withdrawals and the export of water from the Pinelands region.

Gill (1962) noted the clay that overlies the Atlantic City 800-foot sand has a low hydraulic conductivity that limits

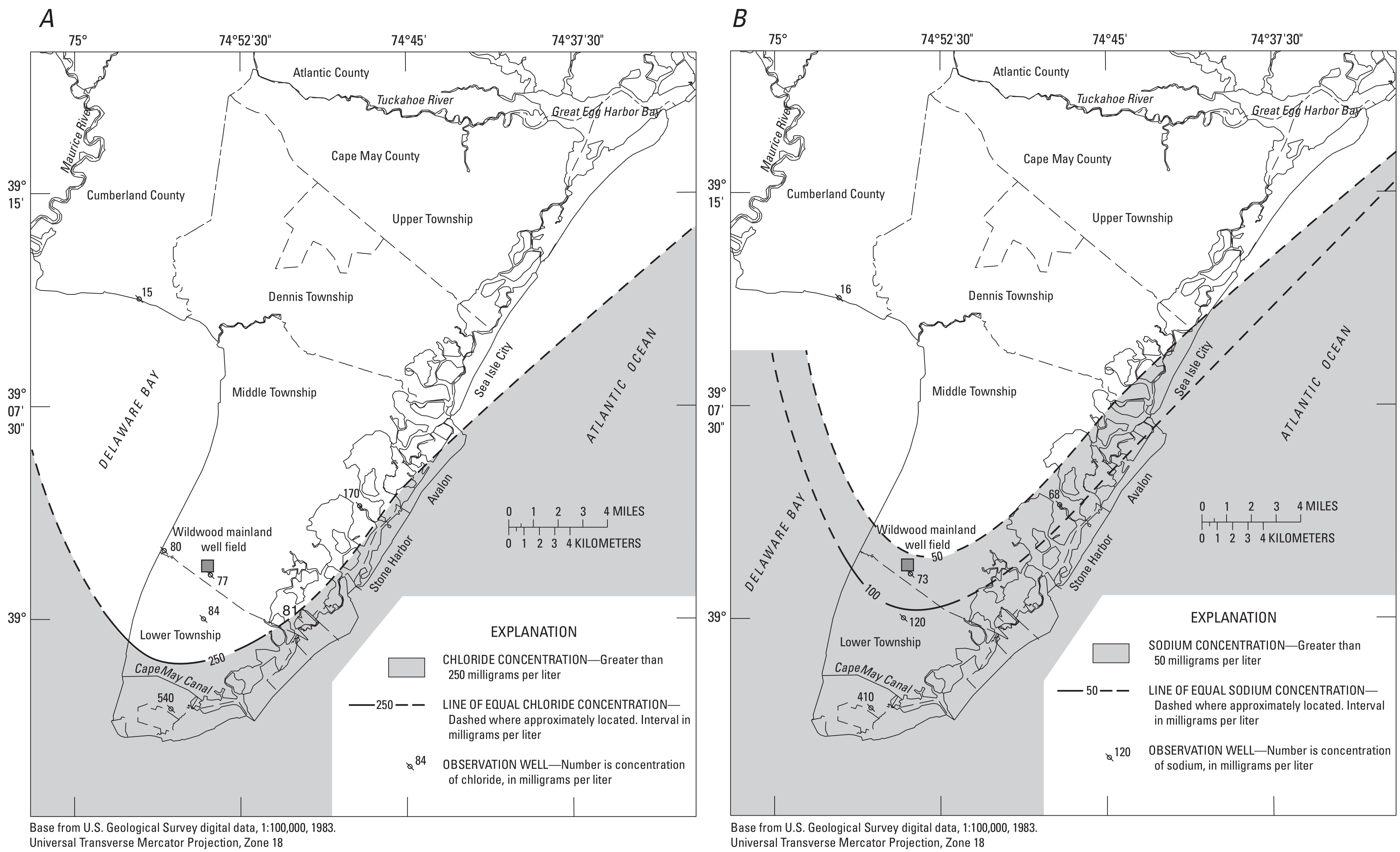


Figure 12. *(A)* Chloride and *(B)* sodium concentrations measured in water from wells open to the Rio Grande water-bearing zone, Cape May County, New Jersey. (Modified from Lacombe and Carleton, 2002)

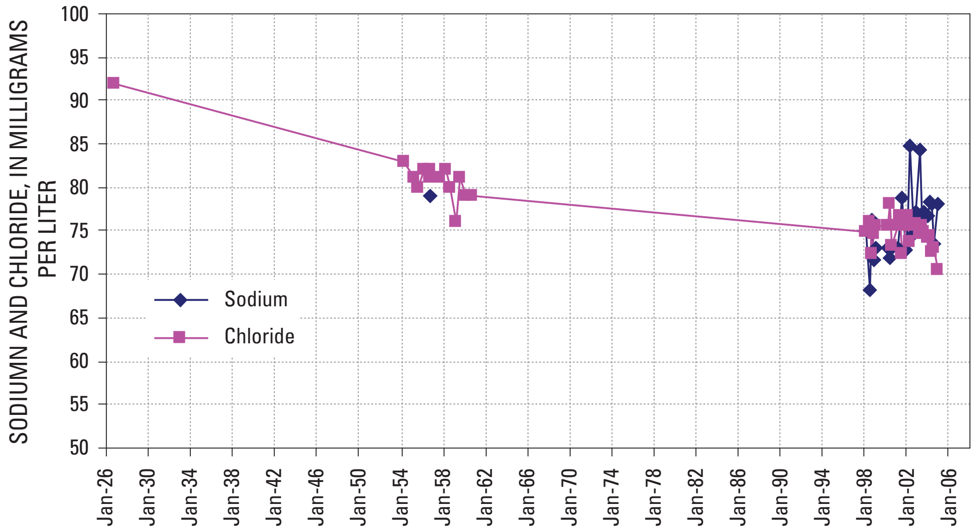


Figure 13. Chloride concentrations in groundwater samples from the Rio Grande water-bearing zone, at the Wildwood Water Utility well field, Cape May County, New Jersey.

vertical recharge to the aquifer. Total withdrawals remained constant during 1932-62, and the cone of depression remained relatively stable. The cone of depression, however, had reversed the direction of groundwater flow west of the barrier islands.

Gill (1962) recommended maintenance of tidal dams to prevent saltwater from reaching the headwaters of streams. He noted that prevention or abatement of saltwater encroachment can be accomplished by artificial recharge using properly spaced and located wells. He defined a scheme to pump shoreline wells to waste and wells along the center of the peninsula for supply, but ultimately he speculated that the county's future source of water might be from dependable large supplies located in the Belleplain area (fig. 1).

Zapecza and others (1987) tabulated the annual withdrawals by aquifer and County during 1919-1955 and by individual well for the major water purveyors during 1956-80. Lacombe and Carleton (2002) described in detail the hydrogeologic framework, availability of water supplies and the saltwater intrusion. They highlighted preferred locations for production wells in all five freshwater aquifers, specifically along the centerline of the mainland part of the peninsula. Spitz (1998) developed a groundwater-flow model for the Cohansey aquifer and estuarine sand aquifer. He simulated two groundwater-withdrawal scenarios; the first scenario decreases water demand, and the second scenario increases demand from the Cohansey aquifer. Spitz showed that the rate of movement of the 250-mg/L chloride line during 1995-2025 towards supply wells of the WWU, LTMUA, and CMCWU ranged from 1,140 to 1,280 ft for his first scenario and from 1,390 and 1,950 ft for his second scenario.

Voronin and others (1996) developed a groundwater-flow model for the Atlantic City 800-foot sand to simulate present and future groundwater-withdrawal scenarios. Voronin showed that with continued withdrawals from existing wells, the 250-mg/L chloride front would not reach any of the existing production wells for many hundreds of years.

The NJDEP (1996) estimated the availability of water in Cape May County to be 32 million gallons per day (Mgal/d) which is based on 19 in/yr of recharge over the extent of the county. The NJDEP further estimated that water demand in 2040 would be 39 Mgal/d, (14,235 million gallons per year (Mgal/yr)) with a deficit of about 7 Mgal/d (2,555 Mgal/yr) for the whole county. The NJDEP plan defines possible methods to address the deficit through water conservation, wastewater reuse, aquifer recharge, recharge protection and alternative supply development such as interconnects, desalination, and well relocation.

Historical Events Affecting Recharge and Withdrawals

Prior to the 1700s, the upland, barrier islands, and freshwater wetlands of Cape May County were covered with primal forests (Dorwart, 1992). There likely were no open fields and few if any permanent freshwater ponds. The saltwater wetlands of the county were covered with saltwater-tolerant flora. Sea level continued to rise about 1 ft per century, causing saltwater wetlands and the shoreline to migrate landward. The freshwater ecosystem encompassed the headwater regions of streams, upland areas between streams, and the barrier islands. Headwaters consisted of multiple, small, interwoven stream channels draining discontinuous seasonally wet forests. Large, single-channel, freshwater streams rarely formed on the flat sandy soil. Vernal ponds likely were the only ponds, but they were seasonal. All surface water and shallow groundwater were available for, or used for, ecological supply and all deep

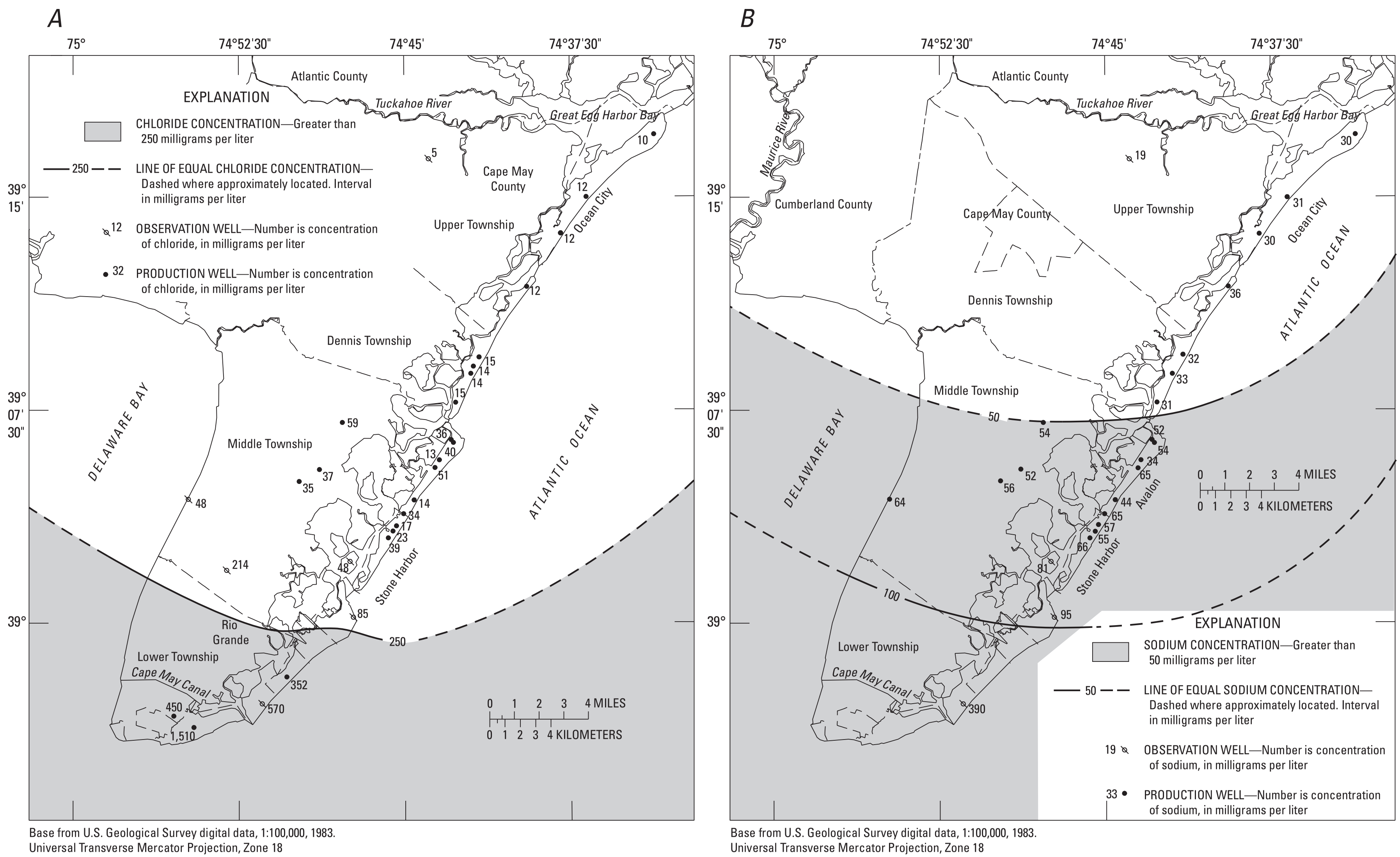


Figure 14. *(A)* Chloride and *(B)* sodium concentrations measured in water from wells open to the Atlantic City 800-foot sand, Cape May County, New Jersey. (Modified from Lacombe and Carleton, 2002)

groundwater was essentially unused by the ecosystem. Human water demand was virtually nonexistent.

During 1700-1900, the population increased from 350 to 13,200 in Cape May County (New Jersey Department of Labor and Industry, 1978). Some primal forests were logged, and some freshwater and saltwater wetlands were diked, drained, ditched, or dammed to create farmland, cranberry bogs, ponds, power supply, or prevent seawater flooding. Selected upland and shore areas such as Cape May Court House, Cape May City, Anglesea, and Ocean City were converted to commercial and residential land use. However, the inaccessible and harsh conditions on the barrier islands left most of them unused until the late 1800s. As such, much of the county remained in its primal forest ecological state.

Demand for potable water generally was met by use of shallow domestic wells that tapped the water-table aquifer, whereas demand for non-potable water was limited to mills and was met by damming the streams. The limited groundwater withdrawals likely had no effect on water demand of nearby ecologically intact land; however, the dams likely caused adverse effects by impeding fish migration.

In the early 1890s, large drilling rigs transported by rail cars were first used to tap the Atlantic City 800-foot sand for steam engine and public-water supply (Dorwart, 1992). The new potable supply radically impacted the county by delivering, for the first time, a constant source of bacteria-free water to the densely settled areas of Ocean City, Wildwood, Cape May City, and Stone Harbor.

During 1900-2000, the permanent population increased to about 100,000 and the budding summer tourist population increased to more than 600,000. In the mid-1920s truck-mounted well drilling rigs enabled the drilling of many production wells into the Cohansey aquifer, which also produce bacteria-free freshwater but at a greatly reduced cost compared to the cost of drilling into the Atlantic City 800-foot sand. Most townships developed either a large public-water supply system while trailer parks and camping grounds developed a small community based water-supply system. Unfortunately, large water withdrawals in the Wildwoods, the Cape Mays, and in Lower, Middle, and Upper Townships lowered groundwater levels and caused saltwater intrusion.

Since the 1960s, ecological water demand on the barrier islands has decreased to nearly zero as a result of the construction of residences, tourist accommodations and roadways. Ecological water demand on farmland, golf courses, residential and commercial tracts and gravel mines also has decreased but the range of ecological water demand is from very little to a great deal depending on how the land was converted from the original forest land to the present land use. Ecological water demand in the remaining forests is likely the same as it was 500 years ago.

Land use in Cape May County changed dramatically during the 1900s. Sea level rose about 1 ft. Low shoreline areas were slowly flooded and shoreline erosion moved the beach line as much as 1,000 ft inland. Construction of the Cape May Canal lowered groundwater levels adjacent to the canal and filled former wetland areas with dredge material. Residential, commercial, and other construction created extensive impermeable surfaces that reduced recharge. Installation of culverts diverted precipitation and shallow groundwater to the ocean and bay, causing higher stormwater discharge and lower base-flow discharge than is typical of local intermittent stream channels. Sand and gravel excavations created many water-filled pits that increased evaporation and large deforested mines that decreased transpiration. Land deforested for residential, commercial, and agricultural uses decreased evapotranspiration and increased recharge and run off. Dike and tide-gate removal returned wetlands to their natural salty conditions. Substantial tracts of uplands and wetlands were purchased by the government and by private agencies to create state parks, forest preserves, and wildlife refuges, thus maintaining much of the original ecological system. Legislation was created to protect the ecological integrity of all wetlands and many upland areas.

Methods

This section contains descriptions of the techniques used to determine future potable, non-potable, and ecological water-supply demands; the effects that past withdrawals had on potable and ecological water supplies; and the three baseline and six future scenarios to meet full build-out water demand until 2050 to limit adverse affects to potable or ecological water supplies.

Methods Used to Determine Potable Demand

Potable water demands for each township were estimated for 2000-50 by the NJDEP (Grabrowski, 2005) by conducting a build-out analysis based on projected population and generalized composite zoning for 2005, which was developed by the New Jersey Department of Community Affairs. The full build-out demand for each township was estimated for the regional service area, which consists of the existing production wells, and for local service areas, which consist of domestic, industrial, and commercial self supply wells. The NJDEP build-out demand for 2000 was compared with reported and estimated withdrawals for quality control. The full build-out demand for 2050 was compared with two linearly extrapolated demand estimates based on low, middle, and high water-withdrawal extrapolation and based on a per acre of developable land water-withdrawal extrapolation to ensure a reasonable 2050 demand estimate.

For most townships, the estimated build-out demand and reported water withdrawals in 2005 are similar. However, discrepancies exist for some townships between the estimated and reported withdrawals for a number of reasons. The discrepancies by township include withdrawals made by major water utilities that serve large areas outside the township boundary, or are served by a water utility that is not within their township. Examples of such townships are the Wildwoods, Lower, and Middle Townships. Other withdrawal discrepancies are for purveyors that atypically use water. Examples include withdrawals by the WWU, which operates an aquifer storage and recovery (ASR) system, and CMCWU which operates a desalination system. Finally, major withdrawal discrepancies occur for Lower Township with LTMUA actively connecting residents to the water supply system but have not completed all connections.

The barrier island townships are projected to reach their estimated full build-out demand prior to 2010. Water demands in these townships are expected to increase as a result of the razing of existing structures and construction of larger buildings to accommodate a larger population. The mainland townships will reach full-build out after 2050 and as late as 2159. To simulate a worst-case scenario for water demand in 2050, the estimated full build-out water demand for each township was assumed to occur in 2050, even if full build-out was projected to occur decades later. The term “model simulation build-out for 2050” refers to the maximum demand for each township.

Estimated full build-out water demand in 2050 for each township was compared with linear extrapolations of historical and estimated withdrawals during 1920-2006 to show low, medium, and high water demand in 2050. The low, medium, and high demand estimates were rounded to the nearest 50 Mgal/yr in 2050. Values for historical demand are available in Zapecza (1989), Lacombe and Carleton (2002), and from NJDEP and USGS records [on file at the NJDEP offices in Trenton and the USGS New Jersey Water Science Center, West Trenton, New Jersey].

The estimated full build-out water demands for the barrier island townships are compared with a linear extrapolation of historical water withdrawals normalized with respect to available buildable acreage within the township. For example, Avalon’s withdrawal increased from less than 10 to 450 Mgal/yr during 1920-2006; however, the land available for construction remained constant at about 1,082 acres. The township water demand increased from 0 to 1.2 acre foot per year during the period of record (1920-2006).

Future per-acre water demand was extrapolated for the barrier island townships at the same rate; then the per-acre water demand was converted to million gallons per year. An acre foot of water is the amount of water that will cover one acre of land to a depth of one foot or 328,000 gallons of water. This is a commonly used method for measuring water use for irrigation and other agricultural water use. Land available on the barrier islands for commerce, residents, and public purposes is generally constant. The per-acre method normalized historical water withdrawal data to highlight townships that are more densely settled because they have smaller lots and taller buildings and townships that may have greater water-service line leakage. Future water demands to the nearest 0.25 acre foot were estimated on the basis of straight line extrapolation from past withdrawals.

Methods Used to Determine Non-Potable Demand

Non-potable water is predominantly used for mining, agricultural irrigation, and golf-course irrigation. Non-potable water demand during 2003-50 was assumed to be equivalent to average demand during 1998-2003.

The four active sand and gravel mines report withdrawals in billions of gallons per year. However, nearly all water used for mining is recycled many times by high capacity pumps. The only water that leaves each mine is moisture within each load of sand and gravel. As a result, water consumption at the mines is small. All water was assumed to be withdrawn from the water-table aquifer.

Water withdrawals for agricultural irrigation and golf-course irrigation generally are limited to the growing season. As a result, these irrigators generally have monthly NJDEP allocations, registrations, or certifications which in this report will collectively be referred to as an allocation. These irrigators do not have an NJDEP annual allocation, but the general rule of thumb is that they may withdraw up to six times the monthly allocation. NJDEP allocations for irrigation are based on drought years, not normal precipitation years, so six times the monthly allocation is generally much greater than the annual withdrawals.

Farm irrigation withdrawal data reported to the NJDEP varied widely during 1998-2003. Farmers may choose to plant a non-irrigated crop one year and an irrigated crop the next year and, therefore, may not have withdrawal data to report every year. Some farms are idle for years and then are reopened as the market changes. Most farms have a few ponds and a few wells and do not always differentiate between surface-water and groundwater sources when reporting withdrawals.

Seven of the 13 golf courses report irrigation withdrawals to the NJDEP each year. As a result, golf course irrigation water demand is quite predictable and is not expected to increase in the future.

Methods Used to Determine Ecological Demand

The source of freshwater for ecological use in Cape May County is precipitation. Precipitation is used for transpiration to support the flora, evaporation to moderate the climate, and recharge to maintain soil moisture. Precipitation is stored for the growing season in vernal ponds, freshwater wetlands, and the water-table aquifer. Precipitation maintains streamflow used by aquatic flora and fauna for habitat and reproduction. Streamflow that discharges to a saltwater wetland is reused to maintain the brackish ecosystem.

Precipitation data were obtained from weather stations at Belleplain State Forest and Cape May County Airport (fig. 1). Stream discharge values were obtained from a permanent gaging station on the Tuckahoe River at Head of River and from 13 partial-record stream-gaging stations. Water-level data for vernal ponds were collected specifically for this study. Groundwater-level data were obtained from observation wells across the county.

Changes in land use and groundwater withdrawals have affected the ecological-water supply. Because the focus of this investigation was on developing a future potable-water supply, the effects of groundwater withdrawals on the ecological-water supply were evaluated but not the effects of land use on the ecological-water supply.

Methods Used to Develop and Evaluate Future Withdrawal Scenarios

USGS, in cooperation with the NJDEP, and with input from Cape May County officials and local water purveyors, developed three baseline scenarios and six future alternative scenarios. Each scenario incorporated the use of local fresh groundwater, local salty groundwater, or local wastewater treated to potable standards. The NJDEP pre-determined that for a scenario to be viable it must supply enough potable and non-potable water to meet the estimated full build-out demand. In addition, each viable scenario would minimize movement of the chloride and sodium fronts, minimize saltwater intrusion into existing supply wells, minimize drawdown in the aquifers, and minimize depletion of water in streams and wetlands.

The three baseline scenarios were designed to use all existing supply wells, but groundwater withdrawals would be considered at three different rates. The least volume of withdrawal was the mean 1998-2003 withdrawal rate. The moderate volume of withdrawal was the NJDEP full allocation withdrawal rate. The maximum withdrawal volume was the estimated 2050 full build-out withdrawal rate.

All six future withdrawal scenarios use the estimated full build-out withdrawal rate as if it occurred in 2050. Each scenario includes proposed changes in withdrawals for existing wells and proposed strategically located wells to optimize withdrawals of the freshwater, saltwater, or injection of reusable-water supply. Three of the scenarios are township-based and designed, in part, with information from local water purveyors. Locations of proposed wells and aquifers to be used were determined by the purveyor in each township. The results of the township-based options are that these allow each township water-supply purveyor to be independent of neighboring township water purveyors. Three cooperative- based scenarios use regional options designed by the NJDEP and USGS. Proposed wells were strategically placed, and alternative aquifers were tapped. The purpose of these scenarios is to treat the water supply as a regional resource with all major purveyors working in unison to meet the estimated full build-out water demand.

The six future scenarios include reducing the amount of water withdrawals from existing production wells and (1) drilling new freshwater production wells closer to the spine of the county, (2) drilling new saltwater production wells into deeper salty aquifers and building a plant to desalinate the water, and (3) drilling saltwater barrier wells between the saltwater front and the existing production wells and building a tertiary wastewater-treatment plant that purifies water to be injected to form the saltwater barrier.

To evaluate each baseline and future scenario two calibrated groundwater-flow models were built. The Shallow Model was used to simulate surface-water and groundwater flow, saltwater-front movement, and water levels in the three shallow aquifers. The Deep Model was used to simulate groundwater flow, saltwater movement, and water levels in the two deep aquifers.

Potable Water Demand

This section describes the past potable water demand and projected water demand by township or group of townships. In Cape May County, potable water is provided to the barrier island townships and large mainland population centers by large water purveyors using major production wells. Historical withdrawals exist for each major water purveyor from 1918 to present (Zapecza and others, 1987; USGS water-use database). Potable water demand for most trailer parks, campgrounds, and other such isolated population centers is provided by small purveyors using public non-community-water supply wells. Historical withdrawals by the small purveyors are generally reported to the NJDEP if they possess a registration or allocation permit. Homeowners and small business owners in the rest of the county use privately owned domestic and commercial wells. Historical water withdrawals from commercial and domestic supply wells has been estimated by Lacombe and Carleton, (2002).

Cape May County's annual mean potable water withdrawal during 1998-2003 for public supply was 4,820 Mgal/yr and for self supply was 1,740 Mgal/yr for a total of potable water withdrawal of 6,560 Mgal/yr. Full allocation potable water withdrawal for the same time for public supply was 6,473 Mgal/yr. If combined with the non-allocated self-supply withdrawal for 1998-2003, the total maximum withdrawals for 1998-2003 would be 8,213 Mgal/yr. The sum of the 2050 build out potable water demand for all townships in the county is 7,054 Mgal/yr. However, all barrier island townships are considered to be fully built out prior to 2050, and all mainland townships are considered to be built out well after 2050. As a result, the maximum potable water demand for the county, based on the maximum demand for production and maximum demand for self supply for all the townships, is 11,725 Mgal/yr.

Northern Barrier Island Municipalities: Avalon, Stone Harbor, Sea Isle City, and Ocean City

Avalon, Stone Harbor, Sea Isle City, and Ocean City obtain their potable-water supply from wells tapping the

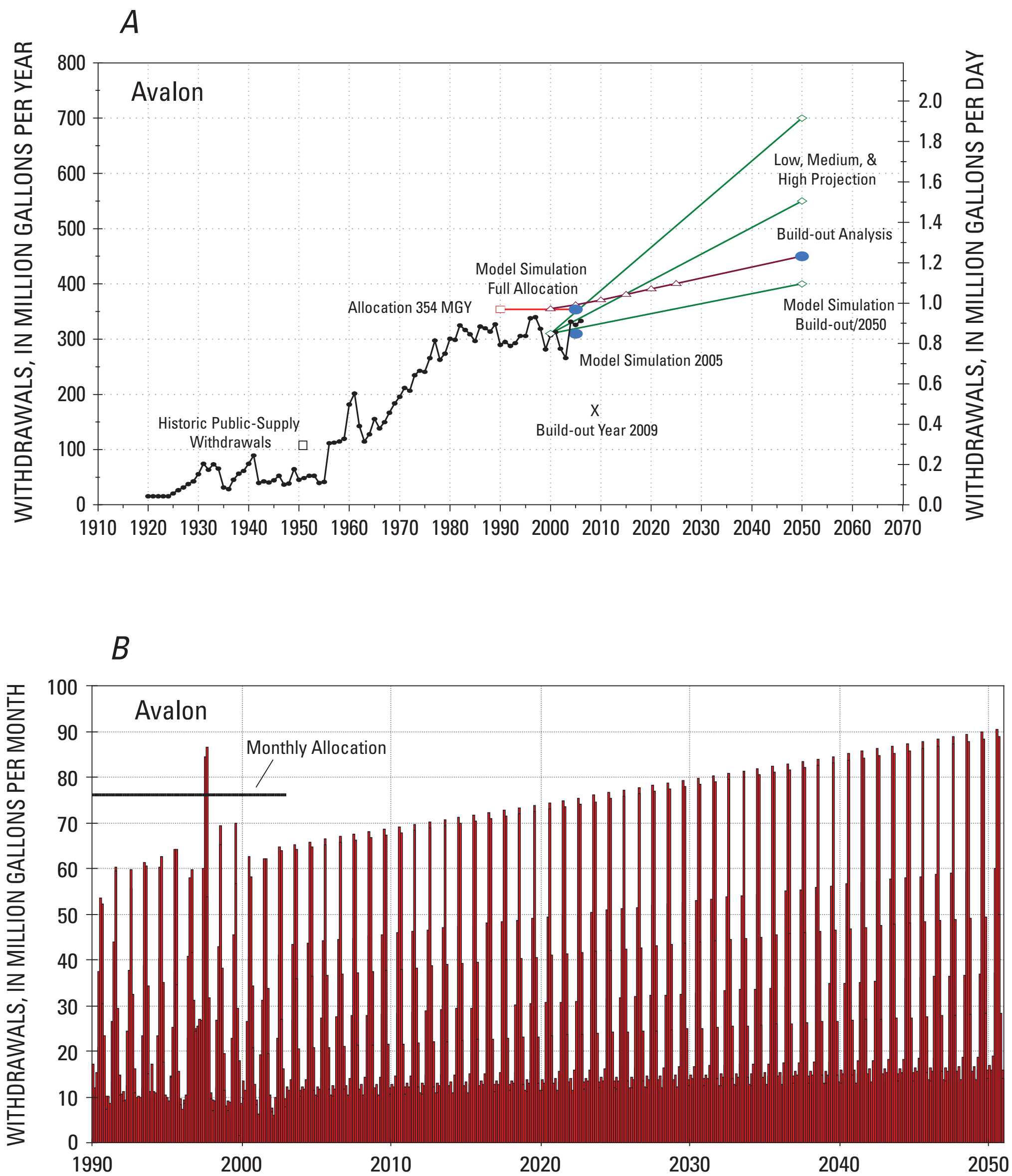


Figure 15. Water demands for Avalon, N.J., *(A)* annual withdrawals 1920-2002; estimated low, medium, and high projected water demands, and estimated full build-out water demands, 2000-50, and *(B)* monthly withdrawals, 1990-2002, and estimated monthly demands prorated to 450 million gallons per year withdrawals in 2050.

Atlantic City 800-foot sand, their only freshwater source. There are few, if any, domestic and non-community wells in these townships. During the early 1920s to 2005, each township increased the number of supply wells so that by 2005 Avalon had 5 wells, Stone Harbor had 5 wells, Sea Isle City had 5 wells, and Ocean City had 10 wells with one additional well in Upper Township.

Water withdrawals during 1920-2005 within the four townships increased in the same general pattern (figs. 15-18), with increasing and decreasing withdrawals impacted by the Roaring 1920s, the Great Depression, World War II, and post war growth. By 1980, most non-tidal lands in these townships were built up with residences, tourist accommodations, and businesses. During 1980-2005 water withdrawals leveled out or may have decreased. This leveling of withdrawals was a result of conservation efforts, population stabilization, and lack of land available for expansion. New construction required razing old structures and building new ones.

During 1998-2003, each barrier island township withdrew the following approximate amount of water: Avalon, 310 Mgal/yr; Stone Harbor, 200 Mgal/yr; Sea Isle City, 350 Mgal/yr; and Ocean City, 1,250 Mgal/yr. (figs. 15-18, table 1).

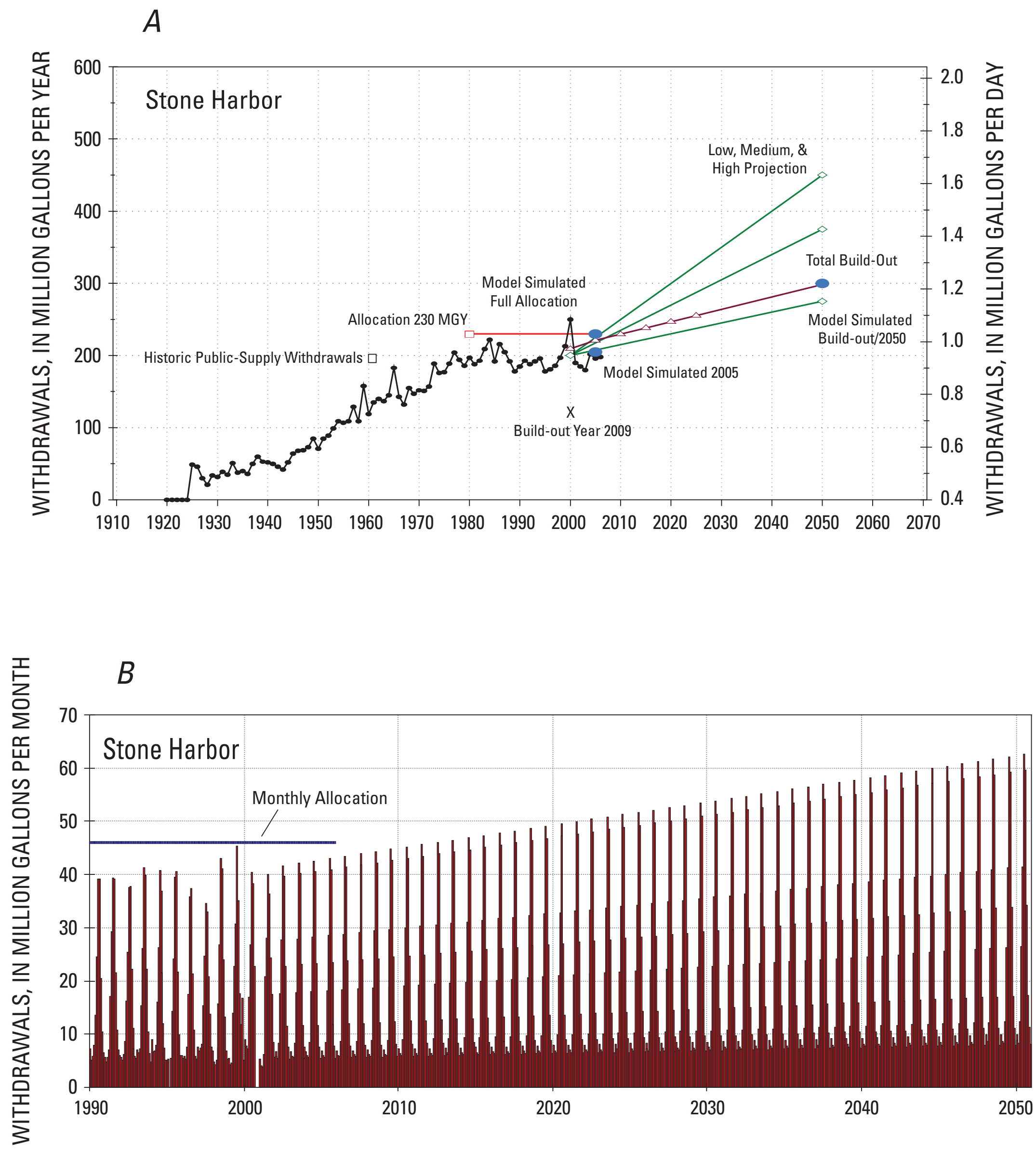
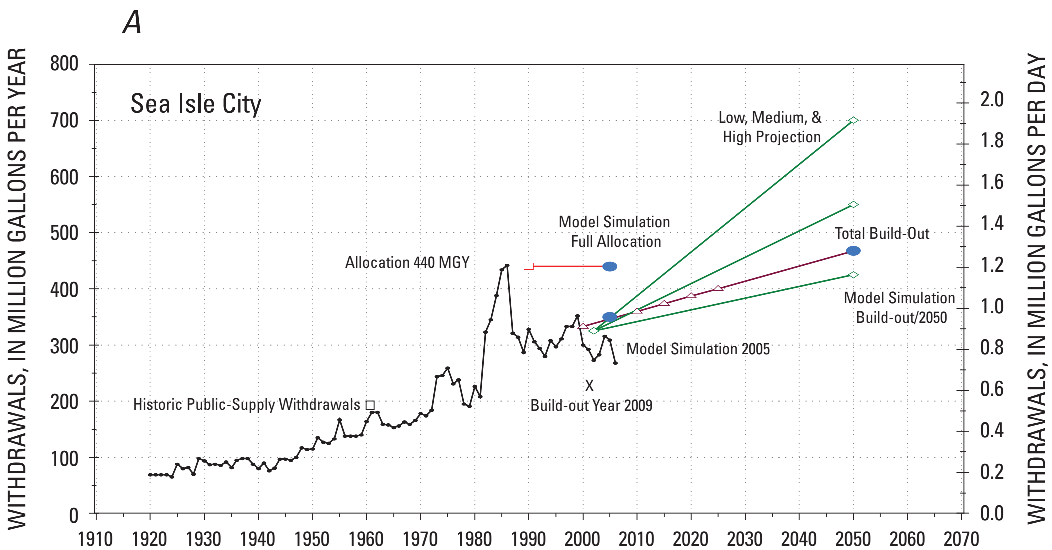


Figure 16. Water demands for Stone Harbor, N.J., *(A)* annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and estimated full build-out water demands, 2000-50, and *(B)* monthly withdrawals, 1990-2002, and estimated monthly demands prorated to 298 million gallons per year withdrawals in 2050.

Ocean City transmitted about an additional 50 Mgal/yr from a production well in Upper Township. Potable-water withdrawals from industrial, commercial, or domestic supply wells in these townships were trivial, if there were any.

The NJDEP build-out analysis projects each township will be fully built-out by 2010: Avalon by 2009, Stone Harbor by 2000, Sea Isle City by 2001, and Ocean City by 2001 (table 1). Water demand is projected to increase until 2050 as smaller, single-family structures are replaced by larger, multi-family structures. NJDEP water-demand estimates for 2000 are within the range of reported withdrawals for 1998-2003 for each township. Water demand in 2050 is projected to be as follows: Avalon, 450 Mgal/yr; Stone Harbor, 298 Mgal/yr; Sea Isle City, 468 Mgal/yr; and Ocean City, 1,558 Mgal/yr (table 1).

Extrapolation of historical withdrawal data to 2050 for each township of low, medium, and high estimates (figs. 15-18) gives a wide range of future water demands. The estimated full build-out water demand for each township is 10 to 20 percent greater than the estimate generated by the low extrapolation of the historical water demand.



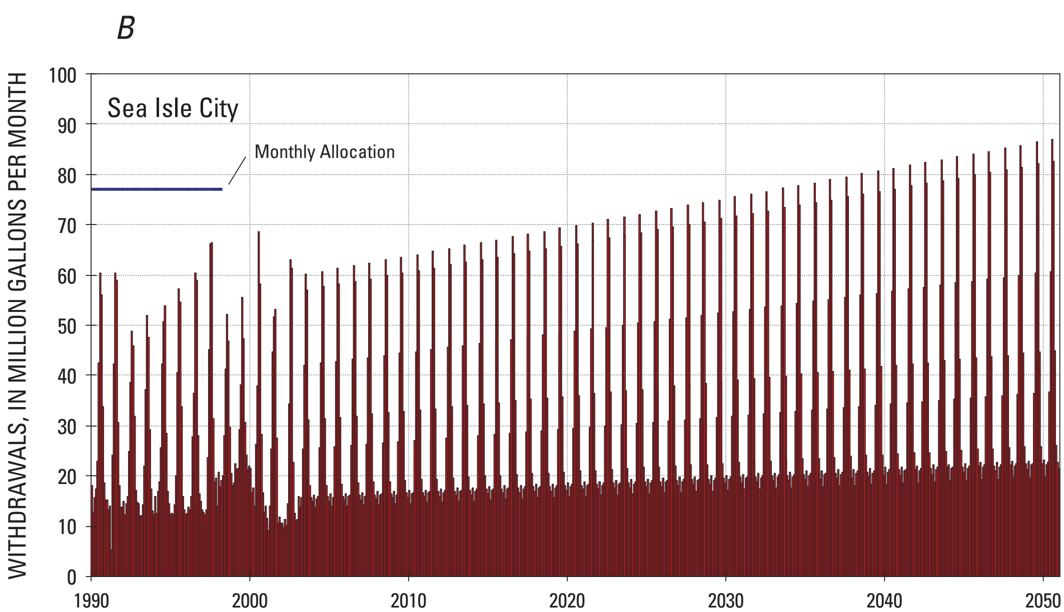


Figure 17. Water demands for Sea Isle City, N.J., *(A)* annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and estimated full build-out water demands, 2000-50, and *(B)* monthly withdrawals, 1990-2002, and estimated monthly demands prorated to 468 million gallons per year withdrawals in 2050.

Extrapolation of historical per-acre water demand to 2050 (fig. 19) is based on the non-tidal acreage available for construction of commercial, residential, and public facilities. The non-tidal land in each township is as follows: Avalon, 1,082 acres; Stone Harbor, 568 acres; Sea Isle City, 740 acres; and Ocean City, 2,225 acres. The approximate 1998-2003 per-acre water demand for each township is Avalon 0.9 acre-ft; Stone Harbor, 1.1 acre-ft; Sea Isle City, 1.3 acre-ft; and Ocean City, 1.7 acre-ft. These data show that Ocean City uses nearly twice as much water per acre of developable land as Avalon uses. A simple linear extrapolation to 2050 of the per-acre water demand and the equivalent demand in million gallons per year shows that each township will use the following amount of potable water: Avalon 1.2 acre-ft or 425 Mgal/yr; Stone Harbor 1.4 acre-ft or 260 Mgal/yr; Sea Isle City 1.65 acre-ft or 400 Mgal/yr; and Ocean City or 2.0 acre-ft or 1,460 Mgal/

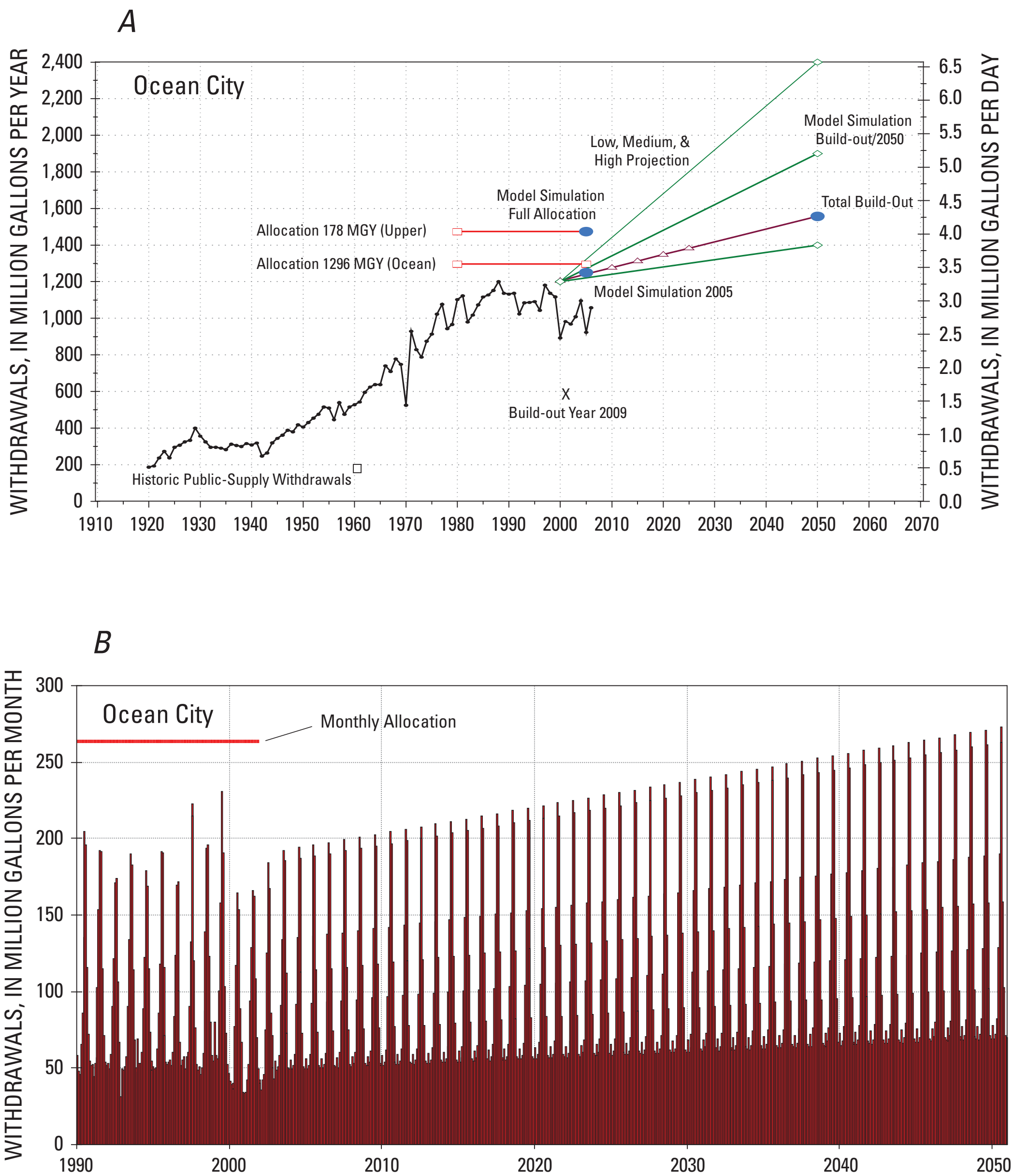


Figure 18. Water demands for Ocean City, N.J., *(A)* annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and estimated full build-out water demands, 2000-50, and *(B)* monthly withdrawals, 1990-2002, and estimated monthly demands prorated to 1,365 million gallons per year withdrawals in 2050.

yr. The per-acre water demand is 7 to 15 percent less than the estimated full build-out water demand for 2050.

The above three methods of projecting water demand to 2050 give similar results. The future demand values developed by the NJDEP are used for further analysis and simulation.

NJDEP annual water allocations for each northern barrier island township are Avalon, 354 Mgal/yr; Stone Harbor, 230 Mgal/yr; Sea Isle City, 440 Mgal/yr; and Ocean City, 1,296 Mgal/yr plus as much as 178 Mgal/yr available from Upper Township. Future annual water demand likely will exceed the NJDEP annual allocation during 2010 and 2040 for each township and the annual allocation will need to be increased (figs. 15-18).

NJDEP monthly allocations for each township are Avalon 76.8 Mgal/mo; Stone Harbor, 46 Mgal/mo; Sea Isle City, 77.1 Mgal/mo; and Ocean City, 263.5 Mgal/mo. The projected monthly water demand for 2003 to 2050, using 1990-2002 monthly withdrawal ratios and the projected annual water demand for 2050, indicates that summer demand will likely continue to be 3 to 4 times the winter demand. Monthly water demand during the summer is predicted to exceed NJDEP monthly allocations before 2050, but the existing allocations likely will be sufficient for the non-summer months.

Southern Barrier Island Municipalities: Cape Mays and Wildwoods

The Cape Mays, which consists of the townships of Cape May City, Cape May Point, West Cape May, and small parts of Lower Township south of the Cape May Canal, are serviced by CMCWU and obtain their public-water supply from wells that are on the mainland in Lower Township. The Wildwoods, which consist of the townships of North Wildwood, West Wildwood, Wildwood City, Wildwood Crest and parts of Lower and Middle Townships are serviced by WWU and obtain their public-water supply from wells that are on the mainland in Middle Township. Major aquifers beneath the Cape Mays and the Wildwoods are salty or contain water that is very close to the SMCL for chloride and sodium. For this reason, CMCWU and WWU do not have production wells within their respective townships.

During 1999 to present (2005), the CMCWU almost exclusively used brackish water obtained from two wells that tap the Atlantic City 800-foot sand. The water was desalinated to potable standards. During 1998-2003, WWU withdrew water from wells open to the estuarine sand aquifer (1 well), Cohansey aquifer (7 wells), and Rio Grande water-bearing zone (1 well). WWU had drilled two new wells open to the Rio Grande water-bearing zone in 2005, but they would not be put into service for a while. A few residents in these townships still rely on domestic wells, but the amount withdrawn is minor.

Cape Mays

CMCWU has serviced Cape May City since at least 1910. The U.S. Coast Guard base became part of the service area sometime during 1940-50 when the government ceased using the base supply wells. CMCWU began to serve Cape May Point in 1972 when their supply well was abandoned because of saltwater intrusion. CMCWU also began to serve West Cape May about 1972. CMCWU provides water to the parts of Lower Township near Cold Spring Harbor and south of the Cape May Canal.

Prior to 1930, CMCWU obtained most of its water from the Holly Beach water-bearing zone and the estuarine sand aquifer. During 1930-98, most water was pumped from the Cohansey aquifer, but the wells experienced saltwater intrusion and the two near-shore wells were abandoned (Lacombe and Carleton, 2002). Since 1998, CMCWU has obtained nearly all of its water supply from two wells tapping the Atlantic City 800-foot sand. The raw water has a chloride concentration of about 700 mg/L and is desalinated in a 2-Mgal/d desalination plant. On rare occasions, the CMCWU supply is supplemented by slightly salty water from two slightly saltwater wells and one freshwater well screened in the Cohansey aquifer. Cohansey aquifer water is blended with the desalinated water to meet potable standards.

Water withdrawals in the Cape Mays varied during 1920-2000 from about 350 to 425 Mgal/yr (fig. 20). Withdrawals increased dramatically to about 600 Mgal/yr during 1956-64 as a result of the heavy pumping of supply wells that tapped the Cohansey aquifer in the attempt to pump saltwater out of the Cohansey aquifer. It was hoped that the well water would eventually become fresh (David Carrick, Cape May City Water Utility, oral commun., 1998). CMCWU installed the desalination system in 1998. The desalination process converts 72 percent of the withdrawn saltwater to potable water. During 1998-2003, CMCWU average annual withdrawals were about 520 Mgal/yr thus only about 375 Mgal/yr of potable water was delivered after desalination.

NJDEP build-out analysis projects that each Cape May township will reach the build-out year as follows: Cape May City, 2006; Cape May Point, 2008; and West Cape May, 2040. The NJDEP build-out water-demand estimate for 2000 is 425 Mgal/yr which is about equal to the reported withdrawal. Build-out analysis shows that water demand in 2050 will be 605 Mgal/yr. CMCWU will need to withdraw 840 Mgal/yr of salty water for desalination to meet projected demand.

Extrapolation of historical withdrawal data to 2050, shown as low, medium, and high estimates (fig. 20), gives a wide range of future water demand. The NJDEP full build-out projection for each township is nearly equal to the medium linear extrapolation of the historical water demand.

A commercial, residential, and other buildable land in the Cape Mays served by CMCWU covers about 2.2 mi^2 (1,405 acres). Ecologically preserved land in the Cape Mays, such as saltwater wetlands, open saltwater, dunes, and beaches, cover more than 6.5 mi^2 (4,185 acres). Cape May City and Cape May Point have many Victorian and gingerbread style homes. Unlike the other barrier island townships such ornate homes typically are not razed to make room for 2- and 3-story multi-family vacation residences. Therefore, there appears to be less potential redevelopment in the Cape Mays than in other barrier island townships. The U.S. Coast Guard base will likely remain property of the U.S. Government and will not be as heavily developed as other buildable land.

Extrapolation of historical per-acre water demand to 2050 (fig. 19) is based on the acreage available for construction of commercial, residential, and public facilities. The 2000-05 per-acre water demand in the CMCWU service area is 0.9 acre-ft (fig. 19). A linear extrapolation to 2050 of the per-acre water demand indicates that CMCWU townships will demand 1.25 acre-ft (576 Mgal/yr) or about 5 percent of the full build-out estimate. The three methods of projecting the water demand of the Cape Mays during 2003-2050 show a reasonable estimate is 605 Mgal/yr in 2050.

Table 1. Historical, allocated, and future potable water demand by township, Cape May County, New Jersey.

[Mgal/yr, million gallons per year; Mgal/mo, million gallons per month; **Bold**, maximum withdrawal values used in computer simulation; na-- no allocated value; NJDEP, New Jersey Department of Environmental Protection]

Township(s)			NJDEP water allocation for production		1998-2003 Average potable water withdrawals		2050 or Full build-out withdrawals					
	NJDEP permit number	Aquifer	Monthly allocation (Mgal/mo)	Annual allocation (Mgal/yr)	Public supply (Mgal/yr)	Domestic and other supply (Mgal/yr)	2050 Public supply	Full build-out public supply	Year of full build-out	2050 Domestic non-community and commercial supply	Full build-out domestic, non-community & commercial supply	2050 – Full build-out maximum for simulation
Avalon	5104	[1]AC-800	[5]76.8	[5]354	[5]310	0	**450**	368	2009	0	0	450
Stone Habor	5182	AC-800	[5]46.0	[5]230	[5]200	0	**298**	211	2000	0	0	298
Sea Isle City	5133	AC-800	[5]77.1	[5]440	[5]350	0	**468**	335	2001	0	0	468
Ocean City	5324	AC-800	263.5	1296	1250	0	**1,558**	1,212	2001	0	0	1,558
Ocean City Upper	5324x 5360	Cohansey AC-800 Total	[3]na [5]na [9]na	[3]na [5]na [9]178	[3]0 [5]150 [9]150	0	525	**623**	2079	687	**971**	1,594
Cape May City Cape May Point West Cape May	5210	Cohansey AC-800 Total	na[3] na[5] na[9]	[3]160 [5]678 [9]838	[3]0 [5]450 [9]450	0	**605**	473	[6]2008	0	0	605
Wildwoods Active Alloc.[10]	5057	Holly B. E-sand Cohansey Rio G Total	18.6 31.0 217.0 46.5 313.1	na na na na 1,880	0 56 1,068 207 1,331	0	**1,885**	1,355	2002	0	0	1,912
Wildwoods Proposed Alloc.[11]	5057	Holly B. E-sand Cohansey Rio G Total	[1]18.6 [2]31.0 [3]132.4 [4]131.5 [9]313.1	[1]na [2]na [5]na [5]na [9]1,880	--	--	--	--	--	--	--	--
Lower Self Alloc.	5240	Shallow Aquifers	[3]58.6	[3]514	[3]400	[1,2,3]500	773	**889**	2100	384	**646**	1,535
Lower other Alloc[7]	5240	Shallow Aquifers	[3,7]35.6	[3,7]354	--	--	--	--	--	--	--	--
Lower Total Alloc.	5240	Shallow Aquifers	[3]93.0	[3,7]868	--	--	--	--	--	--	--	--
Middle	5054	Cohansey AC-800 Total	[3]10 [5]29 [8]33	[3]36.5 [5]235 [9]271.5	[3]30 [5]230 [9]260	[1,2,3]550	813	**1,139**	2140	600	**1,081**	2,220
Dennis	--	Shallow Aquifers	0	0	0	[1,3]240	185	**224**	2068	445	**534**	758
Upper	-- -- -- --	Holly B. Cohansey Rio G AC-800 Total	-- -- -- -- --	--	--	[1,3]450	**522**	623	2079	687	**971**	1,594

Table 1. Historical, allocated, and future potable water demand by township, Cape May County, New Jersey.—Continued

[Mgal/yr, million gallons per year; Mgal/mo, million gallons per month; **Bold**, maximum withdrawal values used in computer simulation; na-- no allocated value; NJDEP, New Jersey Department of Environmental Protection]

Township(s)			NJDEP water allocation for production		1998-2003 Average potable water withdrawals		2050 or Full build-out withdrawals					
	NJDEP permit number	Aquifer	Monthly allocation (Mgal/mo)	Annual allocation (Mgal/yr)	Public supply (Mgal/yr)	Domestic and other supply (Mgal/yr)	2050 Public supply	Full build-out public supply	Year of full build-out	2050 Domestic non-community and commercial supply	Full build-out domestic, non-community & commercial supply	2050 – Full build-out maximum for simulation
Woodbine	5124	Shallow Aquifers	[3]25.0	[3]250	[3]100	0	150	**225**	2159	91	**208**	433
Total				6,473	4,820	1,740	7,710	7,054		2,207	3,361	11,725

[1] Holly Beach water-bearing zone = Holly B.

[2] Estuarine sand aquifer = E-sand.

[3] Cohansey aquifer = Cohansey.

[4] Rio Grande water-bearing zone = Rio G.

[5] Atlantic City 800-foot sand = AC-800.

[6] Mean full build-out year for three townships.

[7] Lower available diversion if it sells to other entities.

[8] NJDEP total monthly allocation is less than sum of aquifer monthly allocation.

[9] NJDEP Total Allocation.

[10] Wildwood initial permit phase with existing well system.

[11] Wildwood final permit phase, if the Rio Grande water-bearing zone wells are put on line.

[12] Water from Marmora supply.

The NJDEP maximum annual allocation for CMCWU is 838 Mgal/yr, and that likely will meet build-out demand until after 2050. CMCWU monthly water demand during 2003-50 was developed by using 1990-2002 monthly withdrawal ratios and the projected annual water demand of 605 Mgal/yr in 2050 indicates that monthly withdrawals will range from 30 to 84 Mgal/mo in 2050 (fig. 20b). The NJDEP monthly water allocation of 95 Mgal/mo for the Atlantic City 800-foot sand likely will be sufficient until after 2050.

Wildwoods

WWU has serviced the four Wildwood townships and nearby areas of Lower and Middle Townships since prior to 1910. In 1910, WWU drilled about 15 wells into the wetlands near the headwaters of Fishing Creek in Middle Township for supply and constructed a pipeline to transmit the water to the barrier island. Residential and commercial water construction along the service line in Middle, Lower Townships, and on the island tapped into the water main. As a result, WWU expanded its service area. By 1926 WWU began to drill wells into the estuarine sand aquifer, Cohansey aquifer, and Rio Grande water-bearing zone for a better quality of water. In 1959, WWU experimented with Aquifer Storage and Recovery (ASR) to augment the summer demand. In 1964, at the height of a severe drought in New Jersey, WWU began the first water supply ASR system via groundwater injection in the Nation and continues using ASR as an important component of its supply system. By 2005, WWU had nine production wells in Middle Township with one well in the estuarine sand aquifer, seven wells in the Cohansey aquifer, and one well and Rio Grande water-bearing zone. They also have four ASR wells on the barrier island. WWU drilled two production wells into the Rio Grande water-bearing zone in 2005 and plan to use them within the next year or two. Though the Rio Grande water-bearing zone can be a productive aquifer on the peninsula, WWU is the sole user of this aquifer in the county.

Water withdrawals increased from about 100 Mgal/yr in 1920 to about 1,300 Mgal/yr in 2000 (fig. 21). Like the other barrier island townships, withdrawals increased during

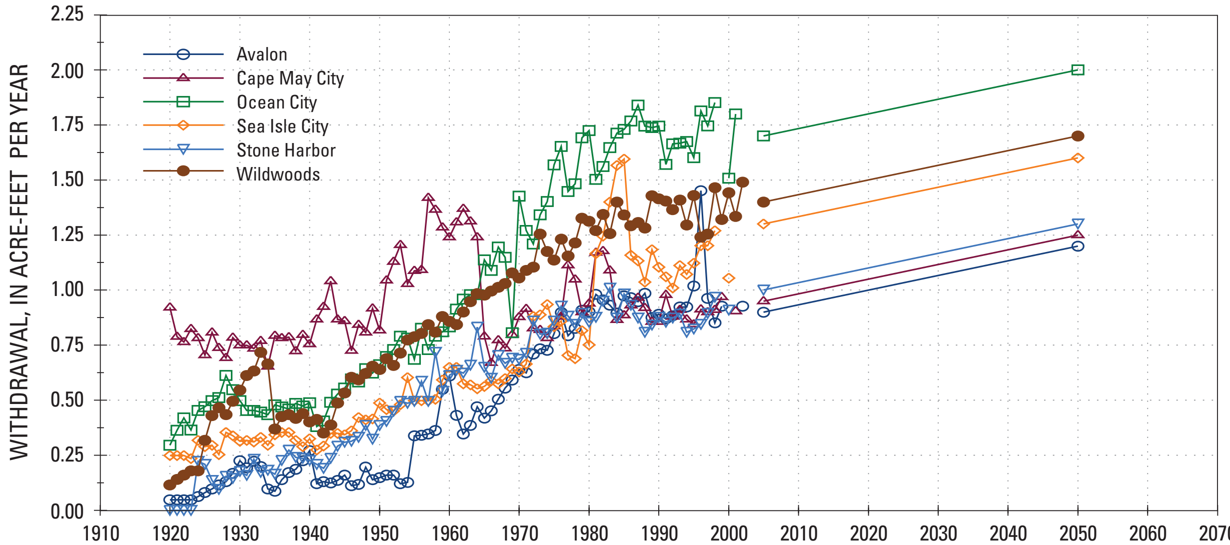


Figure 19. Annual withdrawals in acre-feet during 1920-2002 and projected acre-feet water demand during 2000-50 for barrier island townships/multiple townships, Cape May County, New Jersey.

the Roaring 20s, decreased during the Great Depression and World War II (WWII), and then increased steadily after the war to the early 1970s. During 1970-2005, withdrawals remained relatively constant at about 1,300 Mgal/yr.

The NJDEP build-out analysis projects that the four Wildwood townships were built-out during 2002-03. The parts of Lower and Middle Townships that are served by WWU were not included as part of the NJDEP build-out analysis for the Wildwoods but they are included in the full build-out estimate in their respective townships. In this report, it is assumed that the areas served by WWU in Lower Township are built-out and that the Rio Grande village will continue to grow by expanding into forested and agricultural land near the community.

The NJDEP estimated build-out water demand for 2000 is 1,200 Mgal/yr. The build-out estimate is about 131 Mgal/yr less than the average reported withdrawals during 1998-2003. Increases were made to the 2000 build-out demand estimate to include water pumped and delivered to Middle and Lower Townships, about 100 Mgal/yr and water needed to operate the ASR system about (20 Mgal/yr).

By combining water delivered to Lower and Middle Townships, and ASR system demands, and NJDEP build-out demand for 2000, total water demand for WWU is 1,320 Mgal/yr which is within 1 percent of the reported withdrawals. NJDEP estimated build-out demand for 2050 is 1,625 Mgal/yr. By increasing projected demand by 120 Mgal/yr, the same amount as in 2000, the total water demand for WWU is estimated to be 1,745 Mgal/yr in 2050.

Extrapolation of historical withdrawal data to 2050 is shown as low, medium, and high estimates with a range of 1,500 to 2,500 Mgal/yr in 2050 (fig. 21). The build-out demand for 2050 is about 15 percent more than the low linear extrapolation of historic withdrawals. Extrapolation of historical per-acre water demand to 2050 (fig. 19) is based on the acreage available for construction of commercial, residential, and public facilities. The Wildwood island townships range in size from 0.3 to 1.71 mi^2 (table 2). Commercial, residential, and buildable land served by the WWU covers 2,856 acres.

The approximate 2000-05 per-acre water demand in the area serviced by WWU service area is 1.5 acre-ft, similar to the per-acre withdrawals for Ocean City and Cape May City. The linear extrapolation of the per-acre water demand to 2050 indicates that the area serviced by WWU will use 1.7 acre-ft (1,620 Mgal/yr) of water which is about 93 percent of the projected build-out estimate.

The three methods of projecting water demand for the Wildwoods during 2003-2050, indicate a reasonable estimate is 1,745 Mgal/yr in 2050. NJDEP maximum annual allocation for the WWU is 1,880 Mgal/yr. This allocation will meet demand until after 2050. Monthly water demand during 2003-50 was estimated using 1990-2002 monthly withdrawal ratios and the projected annual water demand of 1,745 Mgal/yr in 2050. Monthly withdrawals will range from 100 to 275 Mgal/mo in 2050. The monthly water allocation of 313 Mgal for WWU likely will be enough to meet demand until after 2050.

Peninsular Mainland Townships: Lower and Middle

Lower and Middle Townships obtain their potable water supplies from production, non-community, and

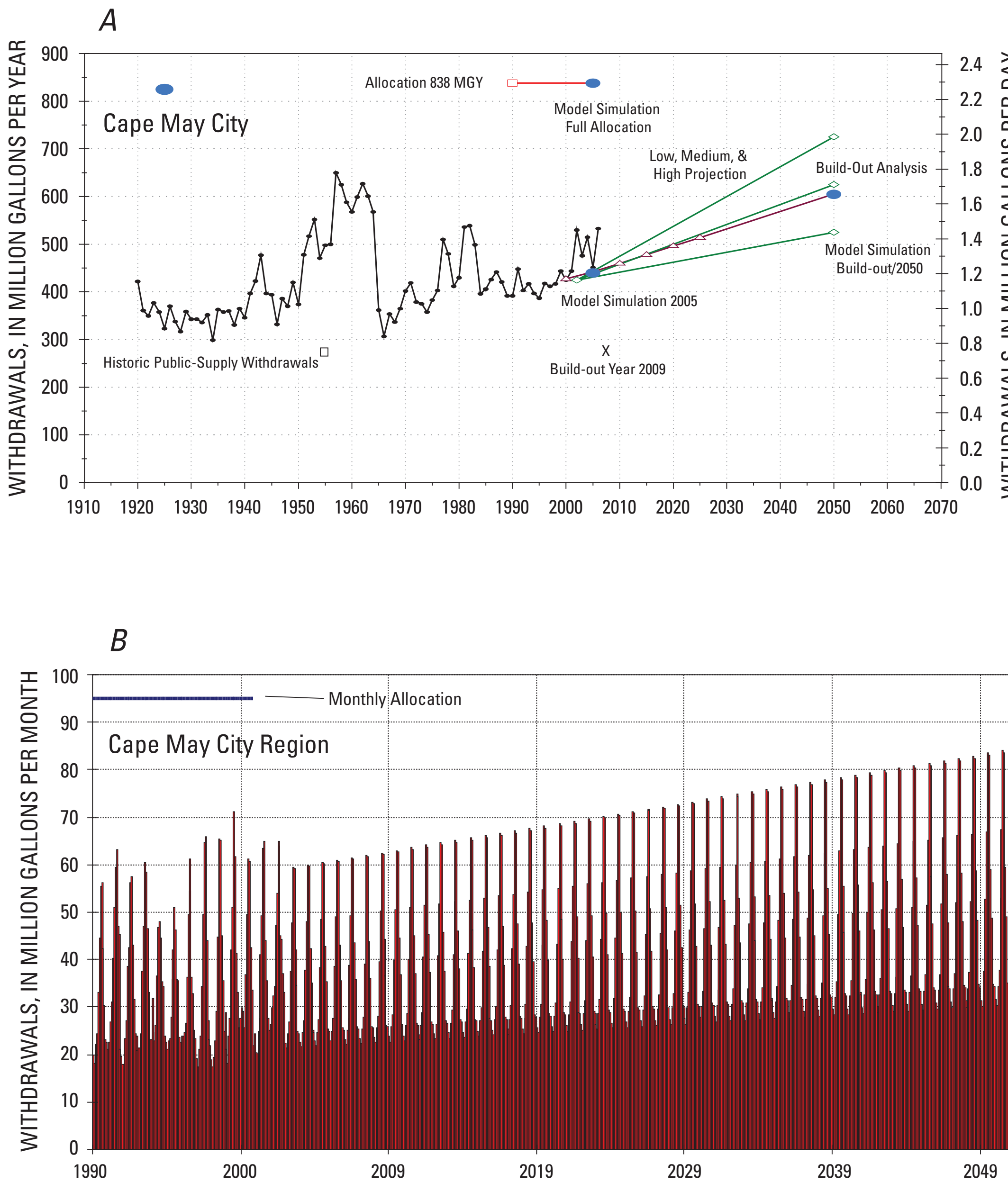


Figure 20. Water demands for Cape May City, N.J., and nearby townships, *(A)* annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and estimated full build-out water demands, 2000-50, and *(B)* monthly withdrawals, 1990-2002, and estimated monthly demands prorated to 605 million gallons per year withdrawals in 2050.

Table 2. Land area of the Wildwood Townships, and nearby areas served by Wildwood Water Utility, Cape May County, New Jersey.

[mi², square miles; --, data not applicable]

	Area of township, in		Water service area, in acres
	mi²	acres	
Wildwood	1.30	832	746
Wildwood Crest	1.10	704	657
North Wildwood	1.71	1,094	832
West Wildwood	0.30	192	121
Total Wildwoods	4.41	2,822	2,356
Middle: Rio Grande area on Rt. 47	72.40	--	340
Lower: on island & for Trailer park & Rt. 47 area	27.80	--	160
Total	--	--	2,856

domestic-supply wells within their townships. LTMUA provides water to many homes and businesses along Delaware Bay and has plans to supply all homes and businesses in its Delaware Bay communities, as well as much of the central part of the township (Clifford Gall, Lower Township Municipal Utilities Authority, written commun., 2002,). In addition WWU supplies water to residents in a small part of Lower Township west of Wildwood City and south of Wildwood Crest and CMCWU provides water to Lower Township residents south of the canal and near Cold Spring Harbor. Seven well owners with NJDEP registration numbers (table 3) provide potable domestic, industrial, and institutional supply to campgrounds, schools, and the fishing industry. Hundreds of domestic and commercial self-supply wells serve the rest of Lower Township.

New Jersey American-Cape May Court House division (NJA-CMCH) provides water to homes in the greater Cape May Court House area in Middle Township. WWU supplies water to homes in the greater Rio Grande area. Eight well owners with NJDEP registration numbers (table 3) provide potable, domestic, industrial, and institutional supply, and hundreds of domestic and commercial self-supply wells serve the rest of Middle Township. Water supplied by CMCWU and WWU was discussed in the previous section.

Potable water for domestic supply in Lower Township is obtained from the Holly Beach water-bearing zone, estuarine sand aquifer, and Cohansey aquifer. Middle Township also obtains water from these aquifers and from the Atlantic City 800-foot sand.

LTMUA began withdrawals in 1958, and demand increased to 400 Mgal/yr by 2000 (fig. 22). Estimated withdrawals for domestic and other potable water demands increased from 199 to 409 Mgal/yr during 1970-90 (Lacombe and Carleton, 2002). The estimated withdrawals increased to about 500 Mgal/yr in 2000 using the methods that Lacombe and Carleton (2002) developed. Total potable water withdrawals for Lower Township were about 900 Mgal/yr in 2000.

Total potable water demand in 2000, based on the NJDEP build-out analysis for Lower Township, is 780 Mgal/yr. Build-out demand is 16 percent less than reported and estimated potable withdrawals. NJDEP build-out analysis assumed that the LTMUAs plan to connect to its water distribution system more than 1,000 homes from Villas to North Cape May had already occurred. For that reason, the NJDEP build-out production demand calculated for 2000 is high, and the domestic self-supply demand is low when compared to reported and estimated withdrawals. The total build-out demand is considered to be a reasonable estimate.

NJDEP build-out analysis projects that Lower Township will be built-out in 2100. Potable water demand is calculated to be 1,150 Mgal/yr in 2050 and 1,535 Mgal/yr in 2100 (fig. 22).

On the basis of extrapolation of reported and estimated withdrawals, it is estimated that low, medium, and high demands in 2050 will range from 1,100 to 1,800 Mgal/yr (fig. 22). The total build-out demand for 2050 is similar to the low extrapolation, and the full build-out demand for 2100 is similar to the medium extrapolation.

Water for public supply in the greater Cape May Court House area, Middle Township, is provided by the NJA-CMCH system, which uses two wells that tap the Atlantic City 800-foot sand and one well that taps the Cohansey aquifer. NJA-CMCH purchased 35 to 75 Mgal/yr from WWU starting about 2004 to meet peak summer demand. NJA-CMCH withdrawals during 1930-2005 increased from 17 to 250 Mgal/yr. Estimates of domestic and other potable self-supply withdrawals for Middle Township increased from 285 to 458 Mgal/yr during 1970-90 (Lacombe and Carleton, 2002). By using the same methods as Lacombe and Carleton (2002), the 2000 domestic and non-community self-supply water demand estimate is 500 Mgal/yr. Reported and estimated potable water withdrawals for Middle Township totaled 750 Mgal/yr in 2000.

The estimate for NJDEP full build-out demand for Middle Township in 2000 is 850 Mgal/yr. This calculated demand is 13 percent more than the public-supply and self-supply withdrawals but is considered to be reasonable because WWU provided public-supply water to Rio Grande village. NJDEP build-out analysis projects that Middle Township's potable water demand in 2050 will be 1,325 Mgal/yr and 2,125 Mgal/yr in 2140 at the time of full build-out (fig. 23).

Based on low, medium, and high extrapolations of reported and estimated potable withdrawals, it is estimated that in 2050 demand will range from 1,100 to 1,700 Mgal/yr (fig. 23). The total build-out demand for 2050 is similar to the medium extrapolation, and the total build-out demand

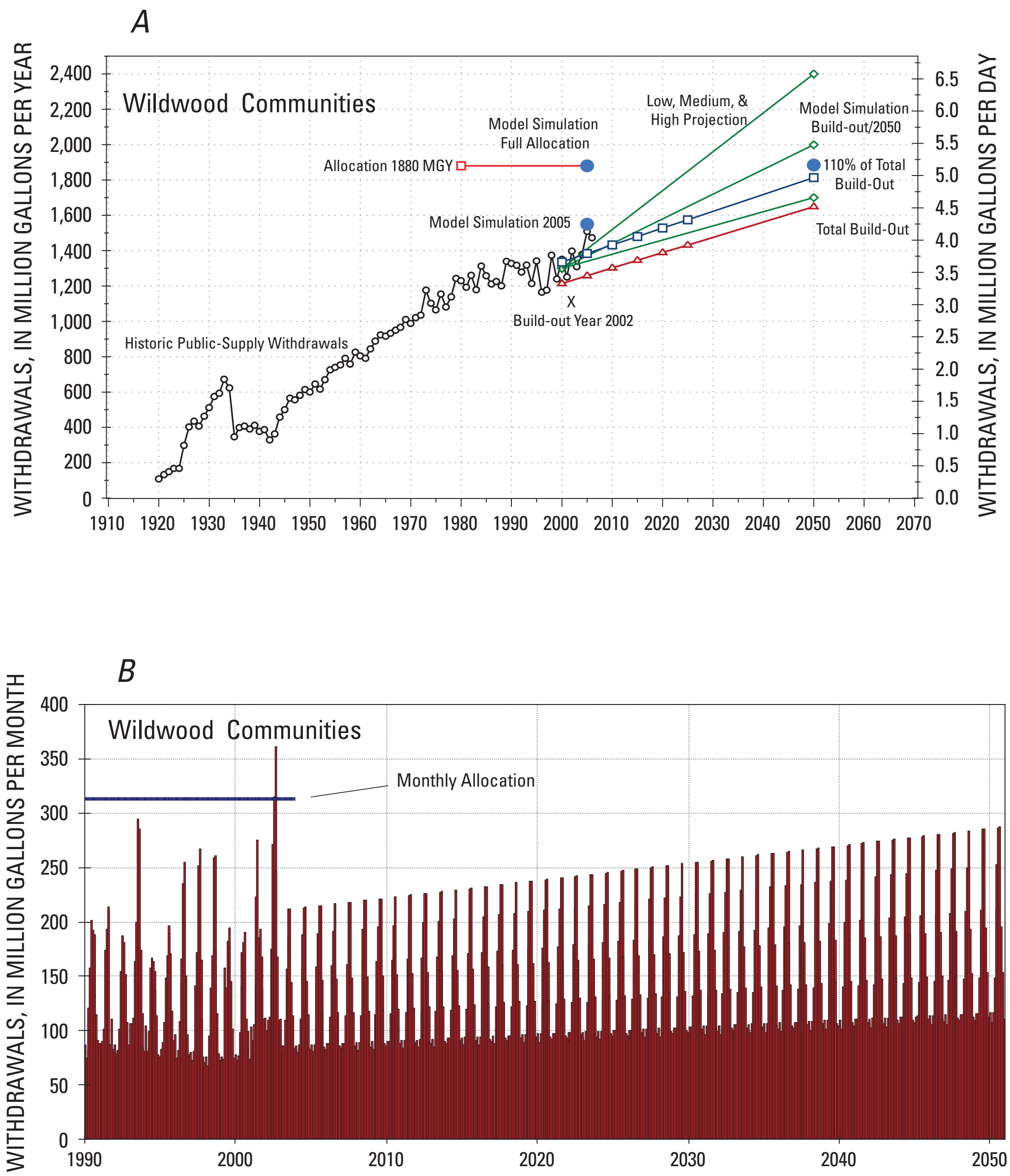


Figure 21. Water demands for Wildwood, N.J., and nearby townships, *(A)* annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and augmented full build-out water demands, 2000-50, and *(B)* monthly withdrawals, 1990-2002, and estimated monthly demands prorated to 2,100 million gallons per year withdrawals in 2050.

for 2140 is 2,220 Mgal/yr greater than the high extrapolation because it will occur decades after 2050.

NJDEP maximum annual allocation for the public supply is 514 Mgal/yr for LTMUA, and that amount is projected to be sufficient until 2020. Annual allocation for NJA-CMCH is 271.5 Mgal/yr, but the purveyor may not meet the mid-2000s demand with that allocation.

The NJDEP maximum monthly allocation for LTMUA is 94 Mgal/mo and for NJA-CMCH is 29 Mgal/mo. The monthly allocation for LTMUA probably is sufficient until 2020, but the allocation for NJA-CMCH was exceeded during summer months for 5 of the past 10 years. To alleviate the supply/demand problem during the summer, NJA-CMCH contracted with WWU to purchase from 35 to 75 Mgal/yr of bulk water.

One major caveat of the NJDEP water allocation permit (on file at the NJDEP Trenton, N.J.) for LTMUA is that it allows LTMUA to withdraw up to 868 Mgal/yr only if any amount over 514 Mgal/yr is transmitted to another township or purveyor. The permit mandates that the extra 354 Mgal/yr

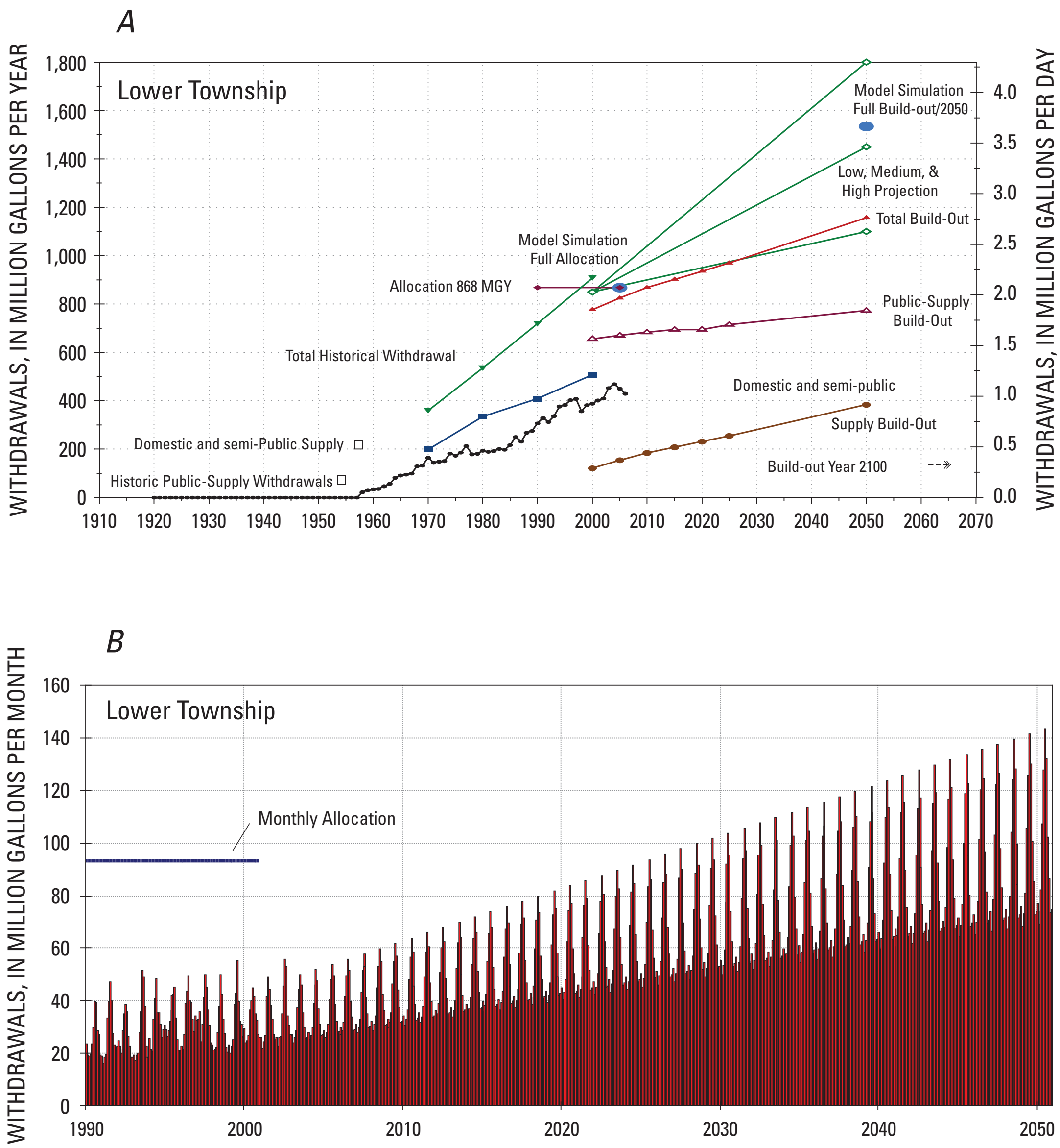


Figure 22. Water demands for Lower Township, N.J., *(A)* annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and full build-out water demands, 2000-50, and *(B)* monthly production withdrawals, 1990-2002, and estimated monthly demands prorated to 450 million gallons per year withdrawals in 2050.

cannot be used for potable supply within the LTMUA service area.

Northern Mainland Municipalities: Dennis, Upper, and Woodbine

Dennis and Upper Townships, and Woodbine obtain their potable-water supply from production wells within their respective townships. Woodbine Public Works (WPW) operates a production system for Woodbine. NJ American Water-Upper (NJA-U) manages the production system for Upper Township with one well in Marmora area. Much of the water from that well is transmitted to Ocean City. Nine small public- and institutional-supply systems (table 3) and thousands of domestic and commercial self-supply wells provide potable water to other parts of each township. Potable water is withdrawn from the Holly Beach water-bearing zone, Cohansey aquifer, and Atlantic City 800-foot sand.

Table 3. NJDEP water supply registration numbers, township, water use, and withdrawals in Cape May County, New Jersey.

[Mgal/yr, million gallons per year; Holly B, Holly Beach water-bearing zone; E-sand, estuarine sand aquifer; AC-800, Atlantic City 800-foot sand; NJDEP New Jersey Department of Environmental Protection; <, less than]

NJDEP registration number	Well owner	Water use	Township	Maximum permitted withdrawal (Mgal/yr)	Reported withdrawal 1999-2005 (Mgal/yr)	Number of wells and aquifer
			Potable supply systems			
10354W	Lutheran Home At Oceanview	Institutional	Dennis	37.2	4 to 10	3 Cohansey
10703W	Holly Lake Campground	Domestic	Dennis	37.2	4 to 6	3 Cohansey
10990W	Lake & Shore Entertainment Cent	Domestic	Dennis	37.2	18 to 29	4 Holly B
10998W	Dennisville Lake Campground	Domestic	Dennis	37.2	<2	2 Holly B
10422W	Lund's Fisheries	Industrial	Lower	37.2	<2	2 Cohansey
10453W	Cold Spring Packing Co	Industrial	Lower	37.2	8 to 9	1 E-sand
2133P	Borden Co (Snow)	Industrial	Lower	65.0	42 to 68	3 Cohansey
10115W	Lower Cape May Board of Ed	Institutional	Lower	37.2	0 to 10	2 Cohansey
10547W	Cape Island Campground	Domestic	Lower	37.2	3 to 4	2 Cohansey
10837W	Delcamino Mobile Home Park	Domestic	Lower	37.2	0 to 10	2 Cohansey
10910W	Beachcomber Campgrounds	Domestic	Lower	37.2	3 to 5	8 Holly B
10165W	Cape May Canner	Industrial	Middle	37.2	2 to 34	2 Cohansey
11092W	Cape May County-Park Zoo	Institutional, irrigation	Middle	37.2	<2	7 Holly B, 4 E-sand
10309W	Middle Twp Water District	Domestic	Middle	37.2	5 to 15	2 AC-800
10320W	Garden Lake Mobile Homes	Domestic	Middle	37.2	14 to 19	2 Cohansey
10675W	Grande Woods Mobile Home	Domestic	Middle	37.2	5 to 7	2 Cohansey
10751W	Delsea Woods	Domestic	Middle	37.2	3 to 8	3 E-sand
10892W	Sea Pines Camp Ground	Domestic	Middle	37.2	2 to 5	2 E-sand
11121W	Hideaway Beach Campground	Domestic	Middle	37.2	<2	3 Cohansey
10217W	Cape May Co Freeholders	Institutional	Upper	37.2	<2	1 Holly B
10236W	Garden State Parkway	Institutional	Upper	37.2	2 to 6	2 Holly B
10526W	NJ Marine Science Consortium	Institutional	Upper	37.2	0 to 5	1 Cohansey
10132W	Shore Acres	Domestic	Upper	37.2	5 to 12	2 Cohansey
10303W	NJ/American WC-Strathmere	Domestic	Upper	37.2	14 to 16	2 AC-800
2375P	Stokes Laundry	Industrial (inactive)	Wildwood	37.2	0	2 Cohansey
			Total	957.8	144 to 278	
			Non-potable supply systems			
10863W	Dennis Twp Municipal Park	Irrigation	Dennis	18.6	3 to 5	2 Cohansey
10217W	Cape May Co Freeholders	Irrigation	Middle	18.6	0 to 4	1 E-sand
10233W	Upper Twp Board of Ed	Irrigation	Upper	18.6	<2	1 Holly B, 2 Cohansey
2103P	Atlantic City Electric Co	Power generation	Upper	360	210 to 220	2 Cohansey, 4 AC-800
2434E	State of NJ-DEP-Williams Property	Remediation	Middle	58.8	0 to 5	2 Holly B
			Total	474.6	215 to 230	

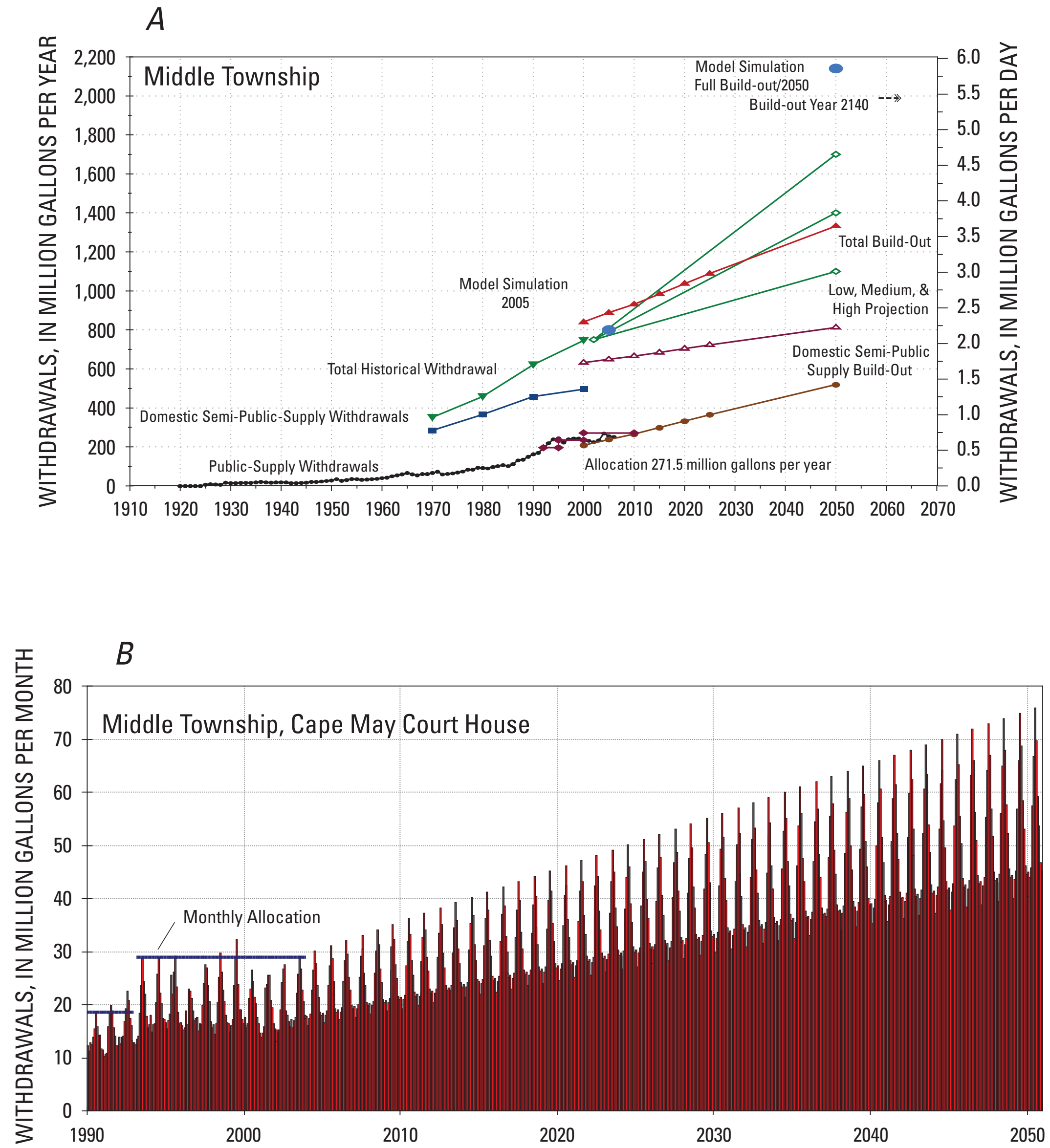


Figure 23. Water demands for Middle Township, N.J., *(A)* annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and full build-out water demands, 2000-50, and *(B)* monthly production withdrawals, 1990-2002, and estimated monthly demands prorated to 1,150 million gallons per year withdrawals in 2050.

Public-supply withdrawals totaled about 100 Mgal/yr in Woodbine during 1998-2003 (fig. 24). Dennis Township has had no withdrawals for public supply, and Upper Township has used production wells for less than 10 years with an average withdrawal that was about 100 Mgal/yr. (figs. 25 and 26). Withdrawal data for small public supply systems and institutional supply (table 3) are reported to the NJDEP. Domestic and other potable self-supply withdrawals were estimated for each township for 1970, 1980, and 1990 by Lacombe and Carleton (2002). Estimates for domestic and other self-supply withdrawals for 2000 using the methods of Lacombe and Carleton (2002) for Dennis Township were 240 Mgal/yr and for Upper Township were 380 Mgal/yr. Self-supply withdrawal for domestic use in Woodbine is trivial. The estimated NJDEP build-out total demand in 2000 for Dennis Township was 275 Mgal/yr, for Upper Township was 550 Mgal/yr, and for Woodbine was 150 Mgal/yr. The estimated withdrawals and build-out withdrawals for 2000 are similar.

NJDEP build-out analysis projects that each township will reach full build-out after 2050: Dennis Township in

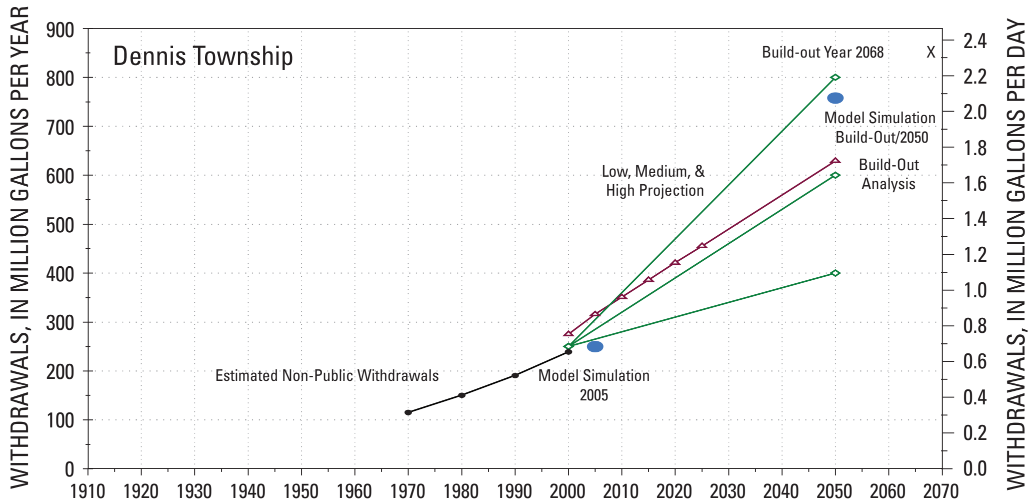


Figure 24. Water demands for Dennis Township, N.J., annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and full build-out water demands, 2000-50.

2068, Upper Township in 2079, and Woodbine in 2159. Water demand at full build-out was estimated as follows: Dennis Township, 750 Mgal/yr; Upper Township, 1,200 Mgal/yr; and Woodbine, 450 Mgal/yr.

Low, medium, and high demand estimates were extrapolated from historical withdrawal data. However, because full build-out will not occur until well past 2050, the build-out estimate exceeds the high extrapolation for 2050 in each township. Though the full build-out withdrawals exceed the projected demand for 2050, the full build-out demand will be used in the simulations to represent the worse-case scenario.

NJDEP maximum annual allocation for the public supply for WPW is 250 Mgal/yr and for NJA-U is 200 Mgal/yr. The WPW system is not likely to exceed allocation until after 2050. The NJA-U production system has been operating for less than 10 years; therefore, it is premature to assess the long-term viability of the allocation. NJDEP monthly allocation for WPW is 25 Mgal/yr. The allocation value will not be exceeded

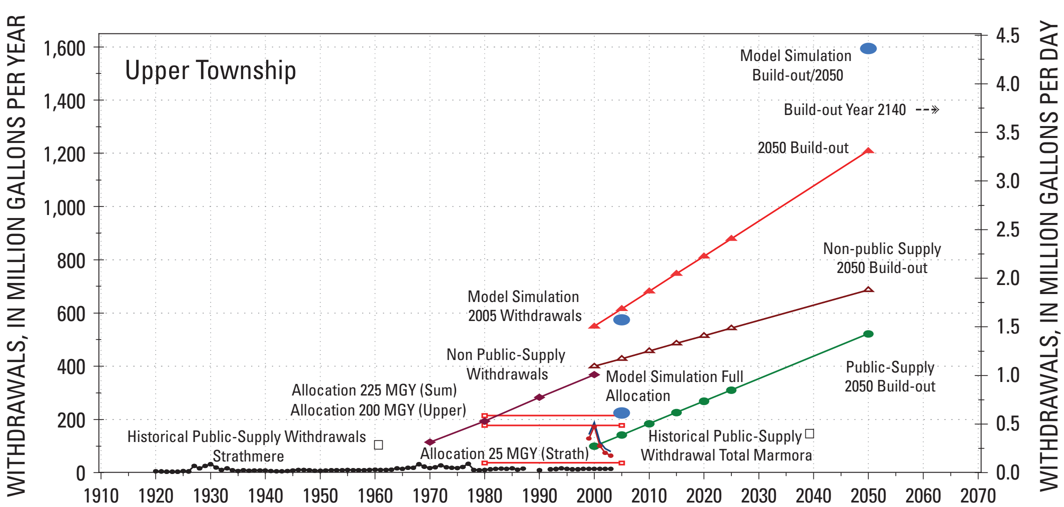


Figure 25. Water demands for Upper Township, N.J., annual withdrawals, 1920-2002; build-out analysis water demands, 2000-50. (MGY, million per year)

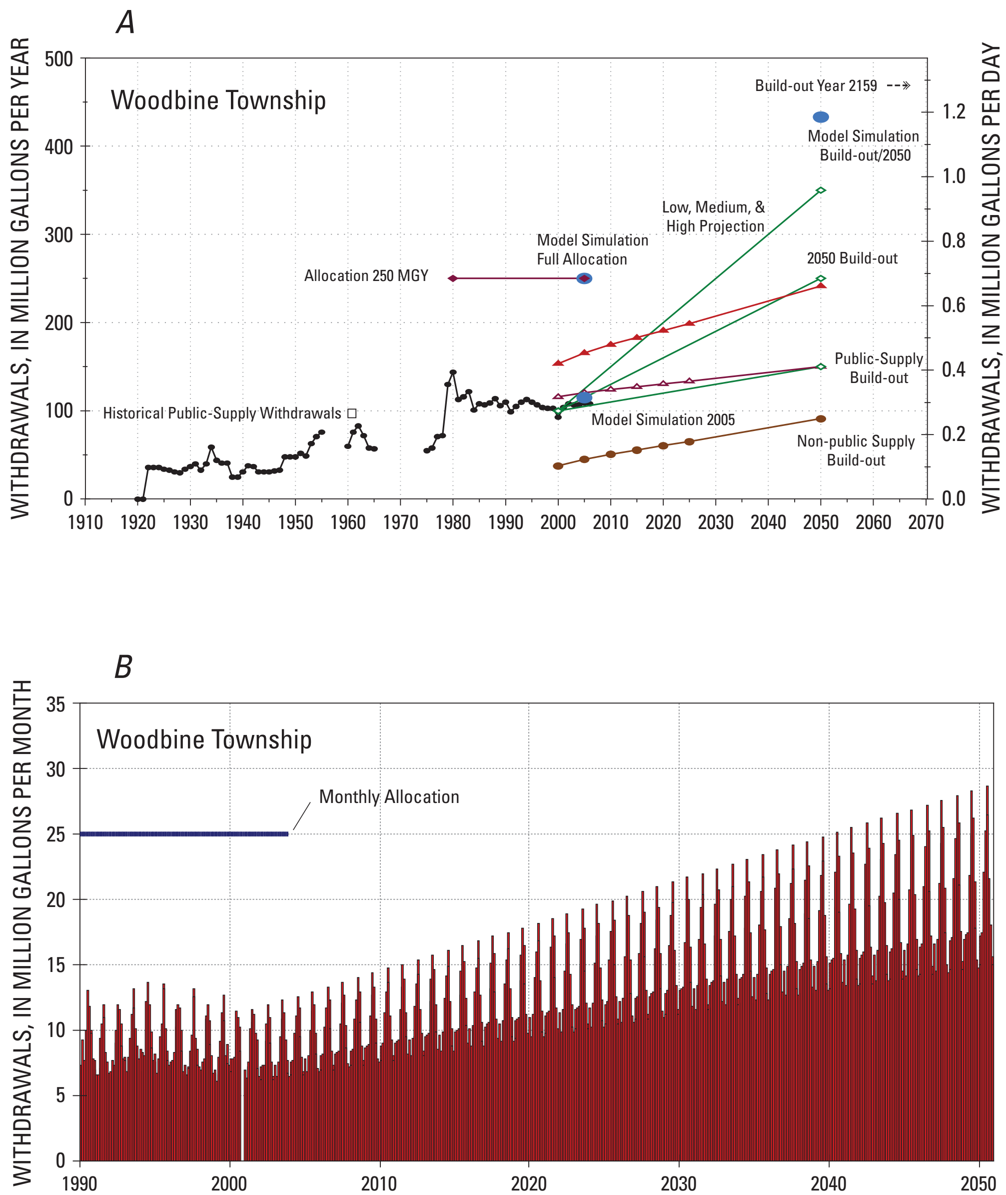


Figure 26. Water demands for Woodbine, N.J., *(A)* annual withdrawals, 1920-2002; estimated low, medium, and high projected water demands, and full build-out water demands, 2000-50, and *(B)* monthly withdrawals, 1990-2002, and estimated monthly demands prorated to 630 million gallons per year withdrawals in 2050.

by build-out demand in 2050, but it will be exceeded by full build-out demand in 2159.

Non-Potable Water Demand

Non-potable water is used mainly for sand and gravel mining, farm irrigation, golf course irrigation and power generation. Small amounts of water also are used for park irrigation and groundwater remediation. The NJDEP regulates the amount of water used for these activities.

Mining Demand

Sand and gravel mined in Cape May County is used for clean fill, building foundation material, cement aggregate, road base, landscaping gravel, golf course material, and septic-tank fill. The four largest mines use dredges that pump sand and water from the bottom and sides of a pond (fig. 27A). Dredge

Photograph by Pierre Lacombe

Figure 27. Photographs showing *(A)* dredge barge used to pump sand and water from bottom and sides of pond, and *(B)* sand washing machinery used to pump water to sieve sand into various grain sizes. Each pump is capable of moving 2,000 to 4,000 gallons per minute.

mines receive water allocations permits from the NJDEP. A few small mines use cranes with a drag line that digs into the bottom and side of a pond. The smallest mines use front end loaders that dig into a bank of sand. Such small operations do not use water for excavation; therefore, they do not need a NJDEP water permit.

Dredge pumps are able to move 2,000 to 5,000 gallons per minute (gal/min) from the mine ponds. The slurry of water and sand is pumped to a staging area where the sand and gravel settle out, and the water is returned to the pond through short canals or pipes. The NJDEP permits withdrawal of 4.7 to 214.3 Mgal/mo for each of the four mines listed in table 4.

Sand and gravel are sold washed or unwashed. Production of washed sand and gravel uses large volumes of water to move the sand and gravel through a series of sieves that separate the mined material into two to six piles each with a specific range of grain sizes (fig. 27B). Water used to wash and sieve the sand comes from the mine pond and is returned to pond.

Though the dredge mines pump some of the largest volumes of water in the county, very little of the water leaves the mine. Consumptive use is considered to occur for water that leaves the mine with each outgoing load of sand and gravel. Paul Castellini (Tuckahoe Sand and Gravel Co., oral commun., 2005) stated that, for each ton of sand and gravel

Table 4. Active large sand and gravel mines in Cape May County that have NJDEP water allocation permits, active during 2003-2005.

[Mgal/mo, million gallons per month; Mgal/yr, million gallons per year; NJDEP, New Jersey Department of Environmental Protection]

Mine owner	NJDEP permit number	Township	Monthly permit, in Mgal/mo	Open water, in acres	Deforested land, in acres	Additional evaporation from pond (Mgal/yr)	Water demand for each scenario (Mgal/yr)
Action Supply	2285P	Upper	28.8	20	9	2.8	2
Better Materials Inc	2269P	Upper	214.3	76	230	-48.1	2
Earthwork Assoc	2388P	Dennis	4.7	30	85	-17.3	1
Tuckahoe Sand and Gravel	2314P	Upper	174.0	170	400	-73.3	2
Total			421.8	296	724		7

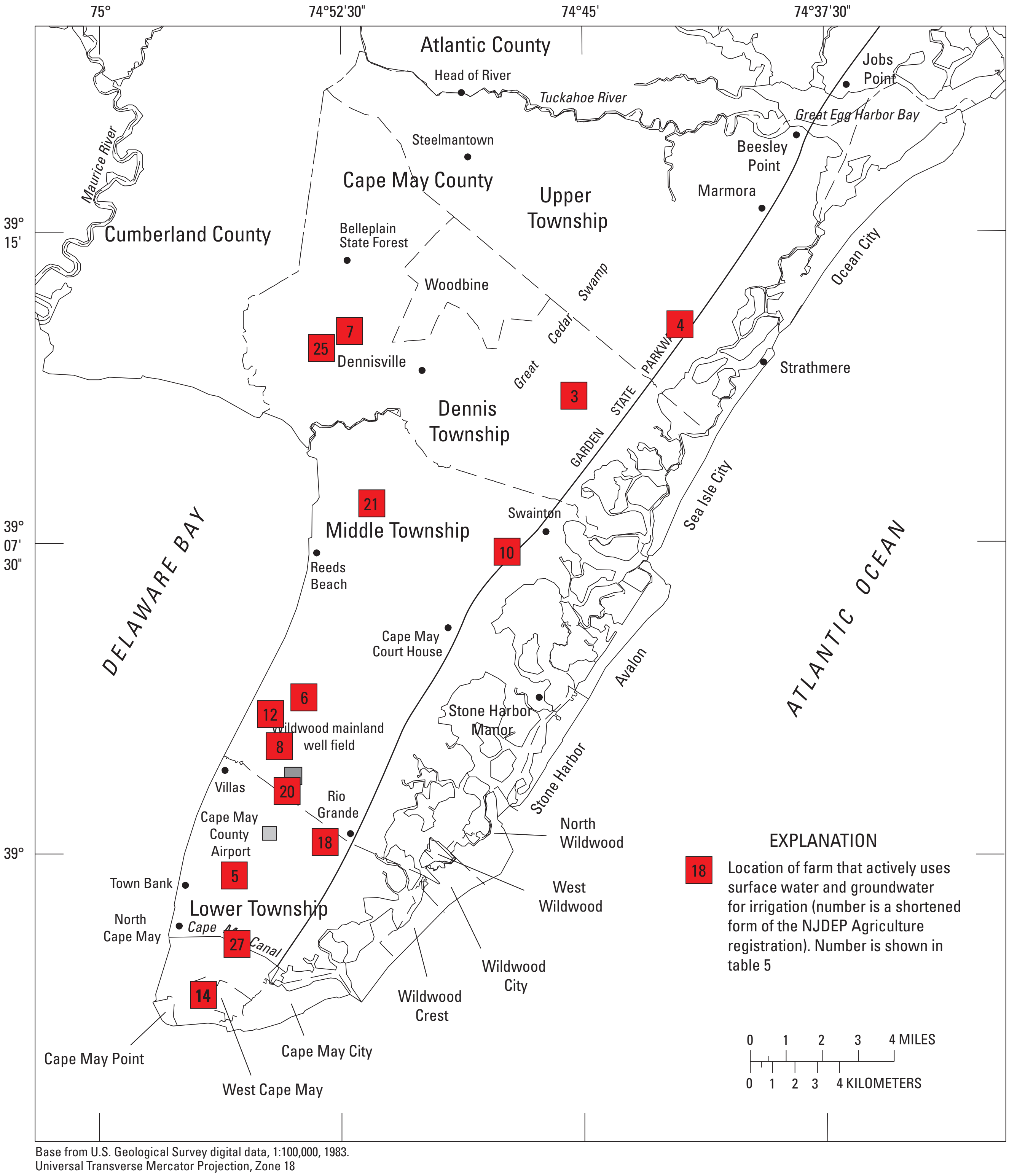


Figure 28. Location of active farms that reported groundwater or surface-water withdrawals during 2000-2005. (See table 5 for the name of each active farm)

Table 5 Agriculture water permitted diversions and withdrawals, 2000-05 for active and 1990-2005 for inactive farms, Cape May County, New Jersey.

[*, inactive farms that reported < 0.1 Mgal/yr during 1990-2005; #, active farms that reported higher usage during 1990-2000; R, Registration number; no letter suffix, Certification number; Mgal/mo, million gallons per month; Mgal/yr, million gallons per year; italics (*red*), estimate based on monthly permitted diversion times 6; <, less than; Holly B, Holly Beach water-bearing zone; E-sand, estuarine sand aquifer; Cohansey, Cohansey aquifer; --, no data.]

Farm	NJDEP Certification and registration number	Township	Water source	Diversion (Mgal/mo)	Diversion (Mgal/yr)	Status 2000-05 withdrawal (Mgal/yr)
Sod farms						
Novasack Sod Farm	CM0003	Dennis	Pond 1 Cohansey Well1 (120 ft) Cohansey Well 2 (112 ft)	71.8	431.0	Active 10-70
Bohm's Sod Farm	CM0025	Dennis	Holly B Well 1 (26 ft) Cohansey Well 2 (100 ft) Cohansey Well 3 (160 ft) Cohansey Well 4 (98 ft) Cohansey Well 5 (100 ft)	78.1	468.7	Active 70-210
Total Sod farms				149.9	899.7	80-280
Active fruit and vegetable farms						
Nagasaki Farm	CM0004R	Dennis	Holly B Well 1 (46 ft)	3.1	15.5	Active <5
Buganski Farm	CM0007	Dennis	Cohansey Well 1 (87 ft)	8.9	57.6	Active 5-10
LeGates Farm	CM0005	Lower	Pond 1, Pond 2, Stream 1 E-sand Well 1 (60 ft)	8.9	31.2	Active 1-10
Wuerker Farm	CM0008	Lower	Pond 1, Pond 2 E-sand Well 1 (50 ft)	19.53	68.4	Active 5-10
Taylor Sheppard (No Frills Farm)	CM0027	Lower	Pond 1 Well 1 (30 ft)	7.6	26.6	Active <1
Fulling Mills Enterprises (Hoff Farm)	CM0020	Lower/ Middle	Pond 1 Holly B Well1, 2, 3, 4 (each 35 ft)	11.5	40.3	Active 1-2 1-5#
Conover Farm	CM0006	Middle	Pond1, Pond 2, Pond 3	18.0	62.9	Active 3-10
US Department of Agriculture	CM0010	Middle	Pond 1	4.34	15.2	Active 1-5
Shivers Farm	CM0012	Middle	Pond 1, Pond 2 E-sand Well 1 (110 ft)	8.5	29.9	Active 1-10
Matteria Farm	CM0018	Middle	Pond 1, Pond 2 E-sand Well 1 (65 ft) E-sand Well 2 (65 ft)	3.47	12.2	Active 1-3
Wheeler Farm	CM0021	Middle	Pond 1 Pond 2 Well 1, 2, 3	20.6	72.2	Active 1-2 10-50#
Leslie Rea Farms	CM0014	West Cape May	Pond 1, Pond 2 E-sand, Well 1	3.1	18.6	Active <1
Total active fruit and vegetable farms				117.5	450.6	20-70

Table 5 Agriculture water permitted diversions and withdrawals, 2000-05 for active and 1990-2005 for inactive farms, Cape May County, New Jersey.—Continued

[*, inactive farms that reported < 0.1 Mgal/yr during 1990-2005; #, active farms that reported higher usage during 1990-2000; R, Registration number; no letter suffix, Certification number; Mgal/mo, million gallons per month; Mgal/yr, million gallons per year; italics (*red*), estimate based on monthly permitted diversion times 6; <, less than; Holly B, Holly Beach water-bearing zone; E-sand, estuarine sand aquifer; Cohansey, Cohansey aquifer; --, no data.]

Sod farms						
Farm	**NJDEP Certification and registration number**	**Township**	**Water source**	**Diversion (Mgal/mo)**	**Diversion (Mgal/yr)**	**Status 2000-05 withdrawal (Mgal/yr)**
Inactive fruit and vegetable farms						
Walter Rice Farm	CM0009R	Middle	Well 1 (55 ft) Well 2 (55 ft)	3.1	8.05	Inactive*
Clarkson Farm	CM0030R	Dennis	--	*3.1*	*18.6*	Inactive
Cordes Farm	CM0031R	Lower	Well 1 (150 ft) Well 2 (146 ft) Well 3 (62 ft)	3.1	*18.6*	Inactive
Myers	CM0034R	Middle	--	*3.1*	*18.6*	Inactive
Selover, Richard Farm	CM0033	Dennis	Well 1 (160 ft)	9.3	55.9	Inactive
Grier, David (formely Russel Taylor Farm)	CM0002	Lower	Pond 1	3.25	11.4	Inactive*
Leslie Rea Farms (McPherson Farm)	CM0015	Lower	Pond 1 Pond 2	13.3	79.5	Inactive*
Leslie Rea Farms (Schellinger Farm)	CM0016	Lower	Well 1 (30 ft) Well 2 (30 ft) Well 3 (30 ft) Well 4 (30 ft)	15.6	54.7	Inactive
Leslie Rea Farms (Bennet Farm)	CM0017	Lower	Pond 1 Well 1	10.6	37.2	Inactive*
Conover, Arthur (McPherson Farm)	CM0026	Lower	Pond 1, Pond 2, Pond 3 E-sand Well1 (70 ft)	21.9	76.6	Inactive*
Phillips Ronald	CM0023	Lower	Pond 1 Well 1	*3.1*	*18.6*	Inactive
Hoff, Ed	CM0024	Lower	Well 1	*3.1*	*18.6*	Inactive*
Ewing George	CM0028	Lower	Pond 1	10.6	37.1	Inactive
Atlantic Gardens Vineyard Inc	CM0035	Lower	Pond 1 Well 1 (145 ft)	11	*39.1*	Inactive
McLaine Allen	CM0019	Middle	Pond 1, 2, 3, 4, & 5	*3.1*	*18.6*	Inactive
Cushman Robert (Hand)	CM0022	Middle	Pond 1 Well 1	*3.1*	*18.6*	Inactive
Futrell Farms	CM0038R	Middle	Well 1 (65 ft)	*3.1*	*18.6*	Inactive
Howells Farms	CM0039R	Middle	Well 1 (100 ft)	*3.1*	*18.6*	Inactive

Table 5 Agriculture water permitted diversions and withdrawals, 2000-05 for active and 1990-2005 for inactive farms, Cape May County, New Jersey.—Continued

[*, inactive farms that reported < 0.1 Mgal/yr during 1990-2005; #, active farms that reported higher usage during 1990-2000; R, Registration number; no letter suffix, Certification number; Mgal/mo, million gallons per month; Mgal/yr, million gallons per year; italics (*red*), estimate based on monthly permitted diversion times 6; <, less than; Holly B, Holly Beach water-bearing zone; E-sand, estuarine sand aquifer; Cohansey, Cohansey aquifer; --, no data.]

Sod farms						
Farm	**NJDEP Certification and registration number**	**Township**	**Water source**	**Diversion (Mgal/mo)**	**Diversion (Mgal/yr)**	**Status 2000-05 withdrawal (Mgal/yr)**
Giberson, Fred	CM0001	Upper	Well1 (150 ft) Well 2 (50 ft)	*3.1*	*18.6*	Inactive*
DiLuzio Farm	CM0011	Upper	--	*3.1*	*18.6*	Inactive
Tuckahoe Turf Farm	CM0013	Upper	Well 1	*3.1*	*18.6*	Inactive*
Eatmor Cranberries Inc (Former April Farm)	CM0029	Upper	Pond 1 Well 1 Well 2	6.5	22.0	Inactive
Rivers Edge Nursery	CM0032	Upper	Pond 1	*5.4*	*19*	Inactive
Total Inactive Farms				147.8	663.8	0
Total Farms				415.2	2,015.1	180-350

that is sold, about 3 percent of the load is water. If the four dredge mines collectively sell 1 million tons of sand, they will consume about 7 Mgal/yr of water.

Future mining demand likely will increase as pump size increases so that the mine owners will be capable of pumping larger volumes of water. However, consumptive water demand will likely remain at less than 10 Mgal/yr and will be simulated as such. This is because most of the water used in dredge mining is recycled, and very little is consumed.

Agricultural Demand

Thirty-seven farms in Cape May County received NJDEP agricultural water-withdrawal registration or certification numbers (table 5, fig. 28). As of 2005, only 25 registrations are still actively approved by the NJDEP. Agricultural withdrawal registration is required for farms that have pumps in ponds or wells that are able to withdraw more than 70 gal/min. Fourteen active farms reported water withdrawals during 2000-05, and eight additional farms reported water withdrawals during 1990-99. Fifteen farms have not reported withdrawals for irrigation since 1990. The non-reporting farms either no longer exist as farms or they no longer irrigate crops.

All farms are on the mainland. Most fruit and vegetable farms that irrigate are in Middle and Lower Townships, and the two sod farms are in Dennis Township. Reported withdrawals for the 13 active fruit and vegetable farms range from less than 1 to 10 Mgal/yr each. Their combined withdrawals ranged from 20 to 70 Mgal/yr during 2000-05. Most fruit and vegetable farms withdraw from streams, excavated ponds, or wells that tap the water-table aquifer and are less than 50 ft deep because the cost of withdrawal is lower than for deep wells. A few farms withdraw from wells that are 50 to 150 ft deep, thereby, possibly tapping the confined aquifers.

Bohm's Sod Farm and Novasack's Sod Farm began operations in 1973 and 1972, respectively. Reported withdrawals for Bohm's Farm are from 70 to 210 Mgal/yr and for Novasack's Farm, from 10 to 70 Mgal/yr during 2000-05 (table 5). Most withdrawals are from wells that are deeper than 100 ft because they provide a reliable source. Because of the high cost of pumping water, the sod farms apply various management schemes to reduce costs. The sod farms use soil moisture meters to aid the farmer in determining the appropriate time and amount of water to be applied to the sod. The sod farms are irrigated in cycles to prevent ponding, and most use automatic shut-off valves to stop irrigation if precipitation should occur. (Russell Blair, Rutgers Cooperative Extension, oral commun., 2003)

Total reported withdrawals for agriculture ranged from 100 to 350 Mgal/yr during 2000-05. NJDEP permitted withdrawals ranged from 3.1 to 78.1 Mgal/mo and from 12.2 to 468.7 Mgal/yr. Total NJDEP registration/certification/allocation for agricultural irrigation within the county is 2,015.1 Mgal/yr and 415.2 Mgal/mo.

Agricultural water withdrawals in 2050 likely will remain constant or decrease. During the past 30 years, much of the active farmland has been converted to residential or commercial land, and very little of the forested land has been cleared for farming. If this trend continues, then less land will be available for farming in the future. Water demand for farming will be simulated for 2050 at present withdrawal rates. This is thought to be the greatest future demand. The allocation likely will have to remain high for drought years, but normal withdrawals will rarely, if ever, meet drought year demand.

Golf Course Irrigation Demand

Cape May County has 13 golf courses (table 6, fig. 29). Twelve courses have NJDEP registration numbers, and one course receives irrigation supply from a nearby public-water supply system.

Allocation for each course ranges from 3.1 to 80 Mgal/mo and from about 6.9 to 100.9 Mgal/yr. Total water allocation for golf courses in the county is 417.3 Mgal/yr. Reported irrigation withdrawals are available for seven courses, and the authors estimate total withdrawals for the remaining six courses at less than 10 Mgal/yr. Annual reported plus estimated irrigation for the all the golf courses ranges from less than 193 to less than 298 Mgal/yr during 2000-05.

Some courses have only one source of water, but many have multiple sources for irrigation (table 6). Six golf courses use ponds created by damming streams or by digging into the Holly Beach water-bearing zone. Two courses have wells tapping the Holly Beach water-bearing zone. Three courses have wells tapping the estuarine sand aquifer. Eight courses have wells tapping the Cohansey aquifer, and one course obtains some water from the Atlantic City 800-foot sand. The small golf course in Ocean City receives its irrigation water from the public-water supply. Many golf courses pump water from wells into ponds and then irrigate from the ponds.

Water conservation is strongly encouraged by the NJDEP; as a result, most golf courses apply various management schemes to reduce water demand. The major golf courses have soil moisture meters to aid the grounds keeper in determining the appropriate time and amount of water to be applied to the fairways and putting surfaces. Most golf courses are irrigated in cycles to prevent ponding on the course surface, and most use automatic shut-off valves to stop irrigation if precipitation should occur. Some of the courses add wetting agents to increase adsorption and decrease ponding. (Russell Blair, Rutgers Cooperative Extension, oral commun., 2003).

Golf course irrigation withdrawals in 2050 likely will remain constant or decrease. During 1980-2000, about seven new golf courses were installed in the county. Most course operators think that the market has been saturated (David Carrick, Cape May City Water Utility, oral commun., 2005). This may or may not be the case, but no new courses have been built since 2000. None are being planned, and one course has closed and the land purchased by the Green Acres program. If the trend in present use continues, then the existing withdrawals likely will meet present and future recreational demand. Water demand for golf course irrigation will be simulated for 2050 at present irrigation rates. Present demands are thought to be the greatest future demand. The allocation likely will remain high for drought years, but withdrawals in years of normal precipitation will rarely, if ever, meet drought year water demand. Water from some golf course wells also is used for the restaurant or clubhouse. This potable water use is small and generally incorporated with the irrigation water use.

Other Non-Potable Demand

A fossil-fuel electric-generation plant is present in Upper Township that withdraws as much as 220 Mgal/yr for steam generation and cooling (table 3). The plant is permitted to withdraw 360 Mgal/yr. The water supply is withdrawn from the Atlantic City 800-foot sand.

Three parks and recreation sites have NJDEP registration permits that allow each permitee to withdraw up to 18.6 Mgal/yr for irrigation (table 3). Maximum reported irrigation is about 5 Mgal/yr. The water is withdrawn from the three shallow aquifers.

The U.S. Environmental Protection agency (USEPA) oversees the remediation of the William Property contamination site in Middle Township (fig. 1) (NJDEP, 1994). Groundwater remediation of the site consists of a pump-and-treat system. The NJDEP permit allows the USEPA to withdraw 58.8 Mgal/yr. During 2000-05 the USEPA withdrew 0 to 5 Mgal/yr and then injected the treated water back into the water-table aquifer.

Ecological Water Demand

Ecological freshwater supplies in Cape May County are provided by precipitation that replenishes perennial and seasonal surface-water bodies and the water-table aquifer. The ecosystem has evolved so that the uplands, freshwater wetlands, barrier islands, and saltwater wetland niches use nearly 100 percent of precipitation. In this section, present (2000-05) ecological water demands for uplands and freshwater wetlands are evaluated, and ecological water demands for the urbanized barrier islands and saltwater wetlands are discussed briefly.

The focus of this section is on evaluation of precipitation, and major facets of ecological water demands including evapotranspiration, streamflow, and seasonal storage and recovery. Special attention is given to water levels in the water-table aquifer, vernal ponds, and streamflow near and

Table 6. Description of Golf Courses in Cape May County, New Jersey.

[Mgal/mo, million gallons per month; Mgal/yr, million gallons per year, Holly-B, Holly Beach water-bearing zone, E-sand, estuarine sand aquifer; Cohansey, Cohansey aquifer; AC-800, Atlantic City 800-foot sand; NJDEP New Jersey Department of Environmental Protection; DR, driving range; <, less than; numbers in red are estimated; --, no number.]

	Golf Course	NJDEP Registration number	Township	Holes	Total acres Acres irrigated	Irrigation-water source	NJDEP Permit, in Mgal/mo	NJDEP Permit, in Mgal/yr	Reported estimated mean annual irrigation 1995-2003, in Mgal/yr
1	Ponder Lodge Golf Course (Beer World)	11227W	Lower	18	75 75	1 pond 5 wells (Cohansey)	3.1	10.8	<10
2	Cape May National Golf Club	2414P	Lower	18	125 65	2 ponds 4 wells (Holly-B) 1 well (E-sand) 4 wells (Cohansey)	7.5	44	20-40
3	Cape May Par 3	11162W	Lower	18	25 25	1 well (E-sand)	3.1	18.6	<10
4	Wildwood Golf and County Club	2090P	Middle	18	120 60	2 wells (Cohansey)	15.0	39	20-25
5	Stone Harbor Golf Club	2384P	Middle	18	180 132	2 ponds 1 well (E-sand)	24 3	100.9	30-70
6	Avalon Development & Golf Inc	4062PS	Middle	18	175 39	1 pond	5.6	33	12-25
7	Sand Barrens Golf Course (ERM Golf Co)	2484P	Dennis	27	-- 135	1 pond 1 well (Cohansey)	19.0	80	32-46
8	Pines at Clermont Golf Course	11037W	Dennis	9	-- --	3 wells (Cohansey)	1.55	6.984	7-12
9	Somerset Spring Golf Course Clermont Billy Bob Entertainment	10905W	Dennis	DR	-- --	1 well (Cohansey)	3.1	18.6	<10
10	Shore Gate Golf Club	2538P	Dennis	18	95 --	7 ponds 1 well (AC-800)	12	36	<10
11	Heritage Links Golf Course	11095W	Dennis	9	-- --	1 well (Holly-B) 3 wells (Cohansey)	3.1	18.6	12-20
12	BL England Golf Course	11183W	Upper	9	32 --	3 wells (Cohansey)	3.1	10.8	<10
13	Ocean City Golf Course	--	Ocean City	12	23 --	From Ocean City production	0	0	<10
	Total						103.5	417.3	193-298

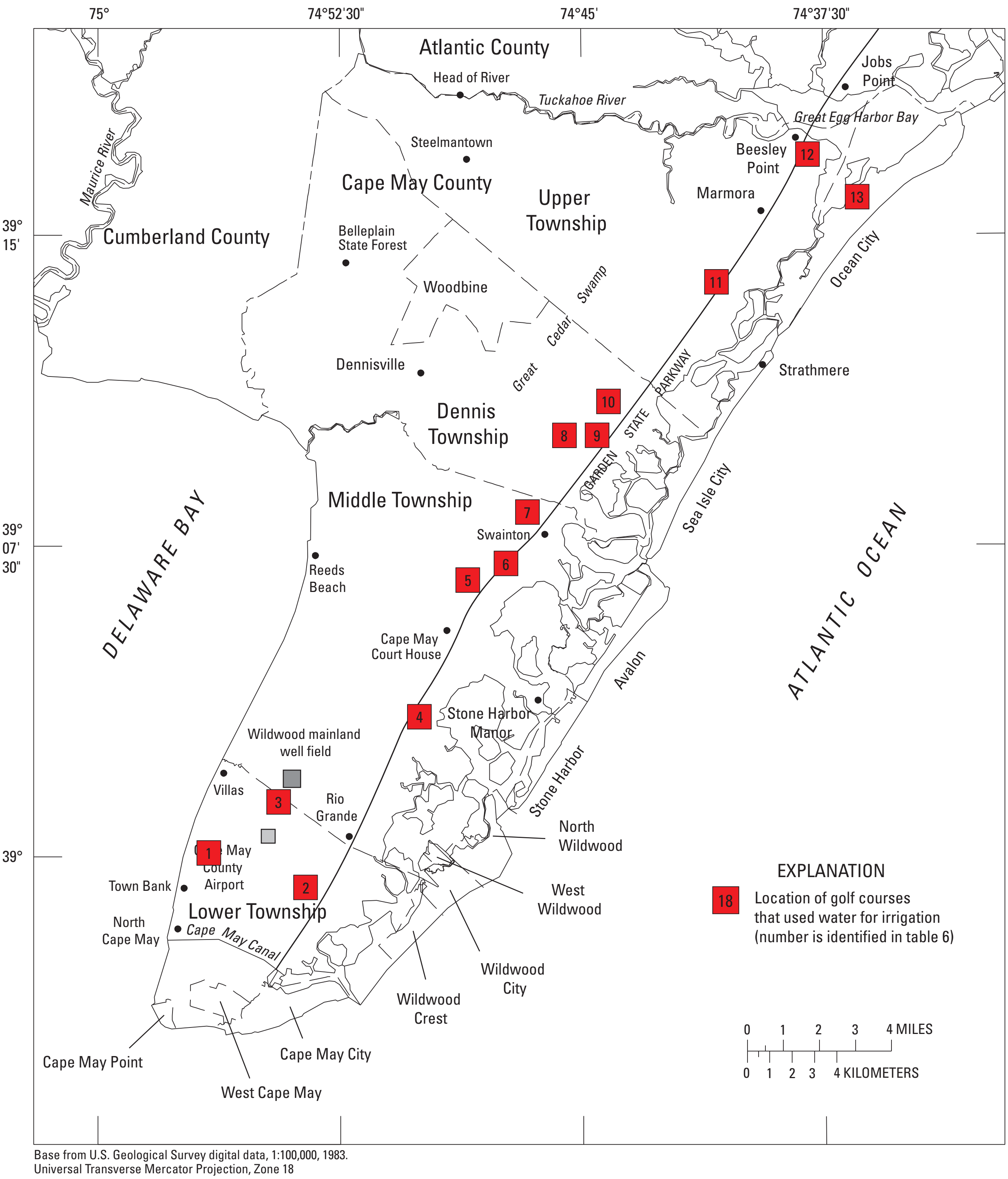


Figure 29. Location of golf courses during 2005, Cape May County, New Jersey. (See table 6 for the name of each golf course.)

distant from major shallow production wells. Ecological water demand for the various land-use types are qualitatively evaluated by assessing six sets of air photographs from the 1930s and 2002.

Precipitation

Mean annual precipitation during 1894-1987 in Cape May County was about 41.9 in. or 733 million gallons per year per square mile ($Mgal/yr/mi^2$) (Gill, 1962; Lacombe and Carleton, 2002). Annual precipitation ranged from 28.6 to 59.1 in. or 500 to 1,035 $Mgal/yr/mi^2$ (Gill, 1962; Lacombe and Carleton, 2002). During drought years, the ecosystems survive on about 70 percent of mean precipitation, and during wet years, the ecosystem accepts as much as 140 percent of mean precipitation.

Mean monthly precipitation in Cape May County is about 3.5 in. or 61 million gallons per month per square mile ($Mgal/mo/mi^2$), whereas the minimum and maximum monthly precipitation are 0.17 and 16.64 in. or 3 to 291 $Mgal/mo/mi^2$, respectively. Ecological niches must tolerate drought months with less than 5 percent or wet months with more than 460 percent of the mean monthly precipitation. Cape May County ecosystems are quite resilient and tolerate broad fluctuations in precipitation for a few months to as long as a few years. However, indefinite increases or decreases likely will cause the flora and fauna of the ecosystem to change to varieties that are more tolerant of the new conditions.

Historical Demand for Ecological Supply

During the 1600s and early 1700s, uplands and freshwater wetlands of the mainland, as well as the barrier islands above high tide, were mostly forested. The saltwater wetlands were covered with saltwater tolerant grasses or open water. The four major land areas, the amount of land they encompassed, and the amount of precipitation that fell on them were upland, 108 mi^2, 78,700 Mgal/yr; freshwater wetland, 55 mi^2, 40,000 Mgal/yr; barrier islands, 25 mi^2, 18,200 Mgal/yr; and saltwater wetlands, 100 mi^2, 72,800 Mgal/yr (Lacombe and Carleton, 2002). Each land type received the same precipitation, about 733 $Mgal/yr/mi^2$. Precipitation that fell on the saltwater wetlands was used for flora and fauna of brackish ecosystems and will not be considered further in this report.

Ecological water demand is greatest during the growing season when flora transpire large volumes of water and when high rates of evaporation from open water, soil, and the surface of trees keep the atmosphere appropriately moist and cooled for the temperate climate demanded by the ecosystem of the region. Evaporation and transpiration (commonly referred to as evapotranspiration, ET) water demands for the ecosystem are approximately 22.4 in/yr or 392 $Mgal/yr/mi^2$.

Ecological water supplies also are used for reproduction, habitat, and other functions. Massive amounts of ecological water supplies are used each spring to convert winter buds to full leaves. Amphibians, diadromous fish, and insects use streams, wetlands, and vernal ponds for reproduction. Fish, water fowl, freshwater mammals, and aquatic plants use the surface water as their habitat. Ecological-water supply is used by micro and macro organisms to decompose dead flora and fauna, release chemicals from soils, and stimulate a multitude of physical, chemical, and biological activities within the ecosystem. Freshwater that flows into the saltwater ecosystem blends with it to create brackish water and maintain the habitat used by all brackish-water flora and fauna. Annual flow from the streams to the saltwater wetlands was approximately 13 in/yr or 228 $Mgal/yr/mi^2$, and discharge to the saltwater wetlands from the water-table aquifer was approximately 7 in/yr or 123 $Mgal/yr/mi^2$.

During the growing season, ecological water demands exceeded precipitation. To compensate for the deficit during the fall and winter, water is stored by filling vernal ponds and freshwater wetlands, and by raising water levels in the water-table aquifer. The stored water is recovered and used during the next growing season.

Present Demand for Ecological Supply

During 2000-05 the water demand and use of the ecological-water supply for most uplands, freshwater wetlands, barrier islands, and saltwater wetlands was related to the amount of change that land had undergone in the past 300 years. Much of the uplands areas remain forested, much as they were more than 300 years ago. However, extensive areas have been converted to residential land, farmland, golf courses, and mines. Most freshwater wetlands are legislatively protected; therefore, the ecological water demand has not changed in the past few centuries. The barrier islands above the high-tide level are almost completely urbanized; therefore, they have little native ecological water demand. The saltwater wetlands in most areas remain in near primal condition with the exception of the ditching system that was installed in the 1930s for mosquito control (Peter Bozak, Cape May County Mosquito Commission, oral commun., 2002). For the saltwater wetlands, the current demand is the same as the historical demand.

Uplands that remain as forests retain annual ecological water demands identical to historical demands. Uplands that have been partially cleared of forests and used for small farms, golf courses, or residences have ecological water demands that are markedly to subtly decreased from historical demands. Such partially or totally deforested land has less biomass, and therefore, needs less water for transpiration. The limited biomass intercepts less precipitation, so there is less evaporation for climate control. It is arbitrarily estimated that about 75 percent of the ET value for forested lands or about 16.5 in/yr of precipitation evapotranspires from farmland, golf courses, and residential areas. The balance of the precipitation may recharge the water-table aquifer or may be diverted to a culvert and transmitted to a nearby saltwater wetland.

Deforested uplands, such as urban areas, large commercial tracts, sand and gravel mines, and irrigation and mining ponds have a greatly diminished ecological water demand. Such areas have virtually no transpiration. Evaporation from impermeable surfaces and run off to culverts is rapid in urban and commercial areas, and thus the climate control ecological water demand is limited. It is arbitrarily estimated that about 25 percent or about 5.9 in/yr of average annual ET is used for evapotranspiration in the deforested lands. The balance of the precipitation does not remain long enough to recharge the water table or be stored as surface water. Generally, most of the precipitation is diverted to culverts and transmitted to nearby saltwater wetlands. Completely denuded land surfaces, such as sand and gravel mines, do not transpire water, and there is little evaporation. Most precipitation in deforested areas immediately recharges the water-table aquifer. However, the water-table aquifer soon reaches capacity, and the water discharges to nearby streams and then saltwater wetlands. Farm and golf course irrigation ponds, as well as mining ponds, have no transpiration, but evaporation increases to 36 in/yr. The balance of the precipitation may be stored for ecological use in the water-table aquifer or may flood nearby freshwater wetlands.

Surface-Water Demand for Ecological Supply

Surface water in Cape May is heavily used to meet ecological water demand and rarely used for human demands. It is assumed by the authors that the ecological demand requires 100 percent of the water supply that flows in the small creeks. Historically, surface water was used in-stream for power generation and cranberry production. Dams were constructed on the following creeks to form the associated ponds and bogs (fig. 30):

- West Creek to form Pickle Factory Pond,
- East Creek to form East Creek Pond and Nummy Lake,
- Tributaries to Dennis Creek to form Ludlams Pond and Station Pond,
- Mill Creek near Ocean View to form Magnolia Lake,
- Mill Creek near Steelmantown to form cranberry bogs and unnamed ponds,
- Tarkiln Brook to form cranberry bogs, and
- Tuckahoe River to form cranberry bogs.

Additional small dams have been built on golf courses for water hazards and in parks for aesthetic purposes. Today nearly all dammed ponds are used only for aesthetics and recreation. Their original industrial or agricultural purpose generally no longer exists.

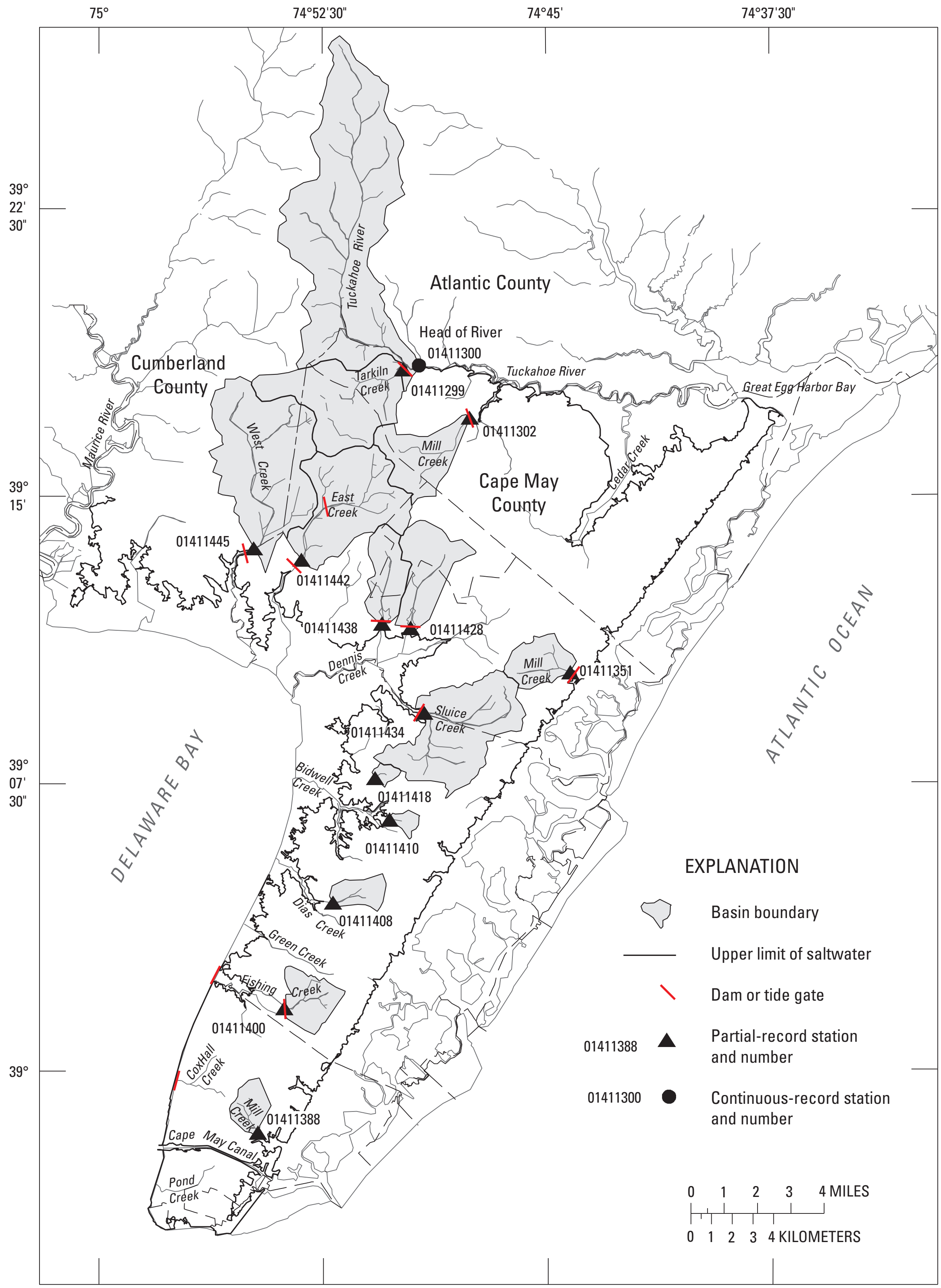
The ecological-water supply in streams is used by local flora and by local and migratory fauna. Diadromous fish migrate between the freshwater of Cape May streams and salty or brackish water of the bay and ocean. Annual migration of fish has been impeded by dams and tide gates. The fish ladder on the Tuckahoe River at Head of River removes one impediment on that stream. Numerous other dams have been removed by floods. Federal, State, and local organizations have removed tide gates from Green Creek and Pond Creek. However, most other streams still haves dams or tide gates that prevent migration of fish for spawning.

Continuous flow measurements for the Tuckahoe River at Head of River are available for 1969 to 2006. Periodic flow measurements are available for 13 small creeks in the county. Flow in each creek has been measured about 10 to 20 times since 1970. Lacombe and Carleton (2002) present drainage areas and estimated flow in cubic feet per second for the 1-day 10-year and 7-day 10-year flows, mean base flow, mean annual flow, and base flow per square mile, as well as the correlation equation to determine discharge and create discharge graphs for the 14 partial-record stations using discharge of the Tuckahoe River at Head of River.

Lacombe and Carleton (2002) tried to determine whether groundwater withdrawals during the mid-1990s caused a decrease in surface-water flow in relation to flow during the 1950s and 60s. The small amount of flow in the streams, changes in land use from forests and farms to residential and commercial land, and construction of storm sewers that divert water across topographic divides and by-pass the streams with direct flow to saltwater bays make interpretation of streamflow data tenuous at best.

Streamflow for the Tuckahoe River at Head of River ranges from about 200 to 8 cubic feet per second (ft^3/s) (fig. 31A). The streamflow correlation equations (Lacombe and Carleton, 2002) were used to create hydrographs showing maximum, mean, and minimum monthly flow for 11 of the partial record stations (fig. 31). Data collected for Sluice Creek at the outlet of Clint Mill Pond is classified as “fair,” and the low-flow correlation gives ambiguous results so the interpretation is not included. West Creek at Pickle Factory Pond is partly outside of the county, so the interpretation is not included.

Peak monthly flows generally occur during a storm, and they have a short duration. Peak flows during the spring can be as much as 25 ft^3/s or about 16.2 Mgal/d for the larger creeks such as Tarkiln Brook near Head of River (fig. 31B), Mill Creek at Steelmantown (fig. 31C), Dias Creek near Cape May Court House (fig. 31G), Dennis Creek at Dennisville (fig. 31J), Dennis Creek near North Dennis Township (fig. 31K), East Creek at East Creek Pond (fig. 31L), and the tributaries to Dennis Creek. Peak flows during the spring do not exceed 25 ft^3/s or about 16.2 Mgal/d for smaller streams such as Mill Creek at Magnolia Lake (fig. 31D), Mill Creek at Cold Springs (fig. 31E), Fishing Creek at Rio Grande (fig. 31F), and Bidwell Creek near Cape May Court House (fig. 31H). During the summer, the minimum, and sometimes the mean, streamflows



Base from U.S. Geological Survey digital data, 1:100,000, 1983.
Universal Transverse Mercator Projection, Zone 18

Figure 30. Location of major streams, partial-record station, contribution areas based on topographic divides, and dams, Cape May County, New Jersey.

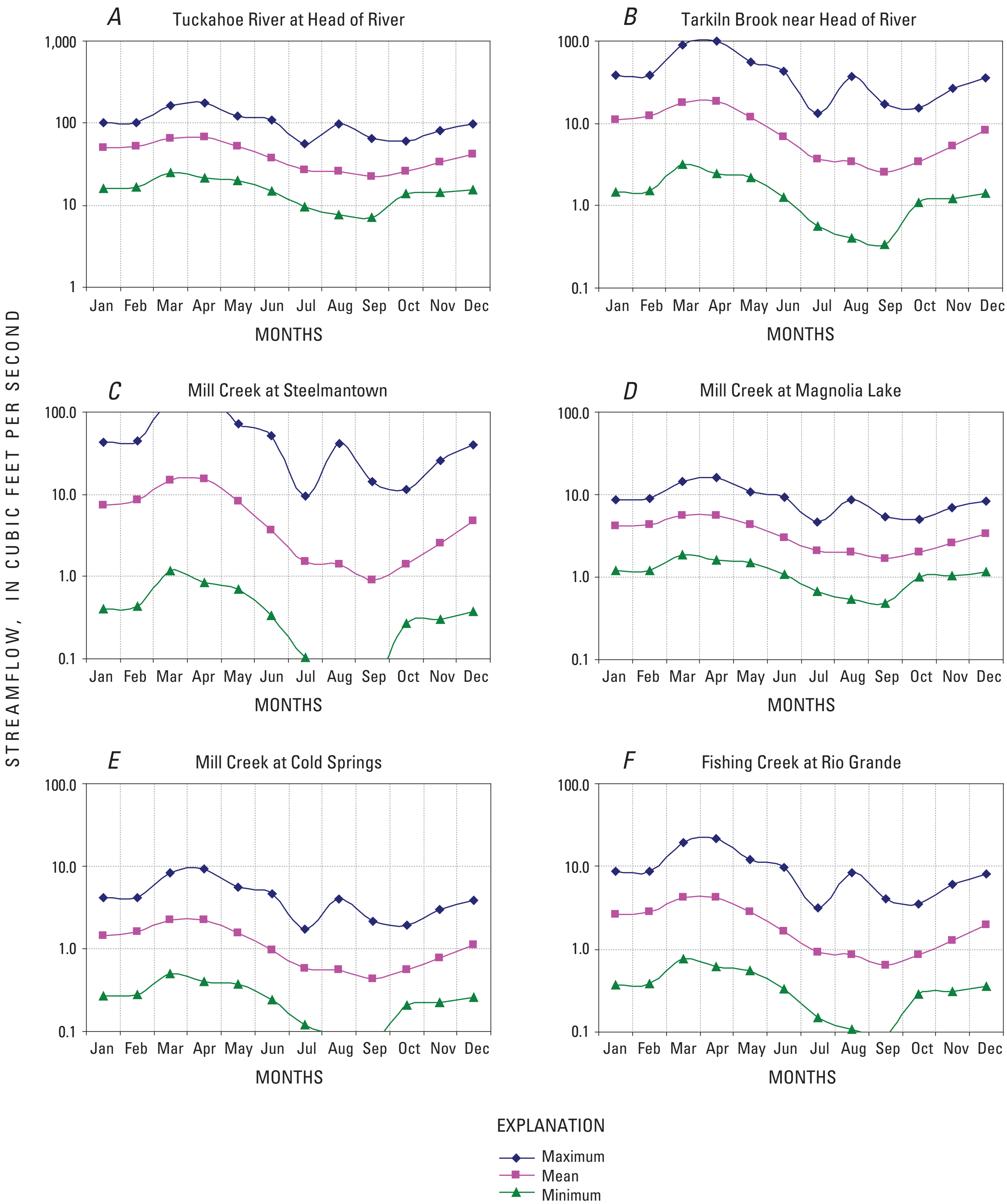


Figure 31. Hydrographs showing calculated maximum, mean, and minimum monthly streamflow at 11 partial record stations calculated using correlation equations based on streamflow of the Tuckahoe River at Head of River, Cape May County, New Jersey.

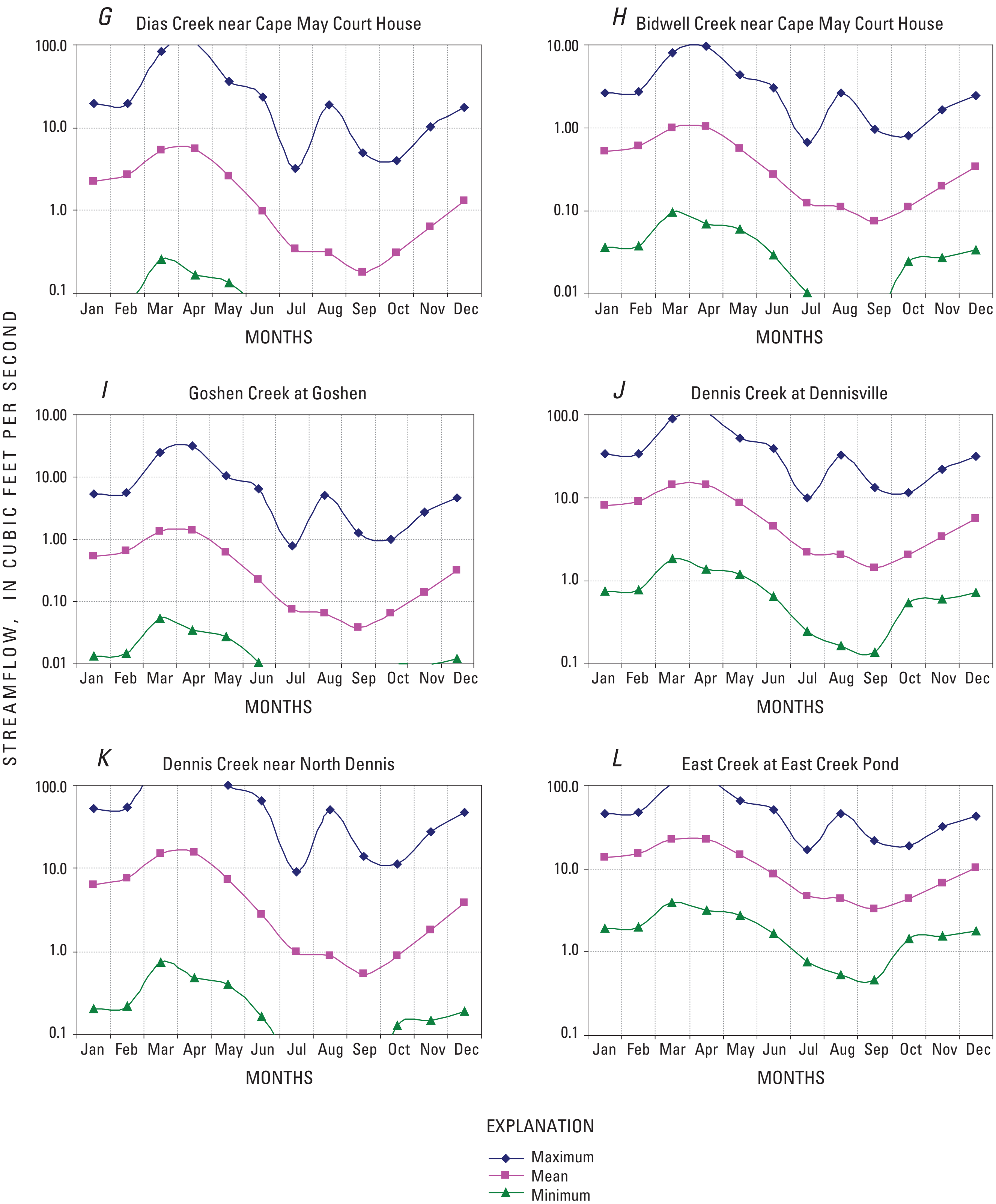


Figure 31. Hydrographs showing calculated maximum, mean, and minimum monthly streamflow at 11 partial record stations calculated using correlation equations based on streamflow of the Tuckahoe River at Head of River, Cape May County, New Jersey.—Continued

Table 7. Conversion of streamflow from cubic feet per second (ft^3/s) to million gallons per day (Mgal/d), million gallons per month (Mgal/mo), and million gallons per year (Mgal/yr).

ft^3/s	Mgal/d	Mgal/mo	Mgal/yr
0.1	0.1	2	24
0.5	0.3	10	118
1	0.6	20	236
5	3.2	98	1,180
10	6.5	197	2,359
15	9.7	295	3,539
20	12.9	393	4,718
25	16.2	491	5,898

have decreased to less than 1 ft^3/s (0.6 Mgal/d) in all streams except the Tuckahoe River. Conversions of streamflow from cubic feet to million gallons are shown in table 7.

Groundwater Levels and Ecological Demand

Groundwater levels in the Holly Beach water-bearing zone are affected by precipitation, seasonal fluctuations in evapotranspiration, and proximity to nearby surface water. Water levels in the water-table aquifer also can be affected locally by withdrawals from the shallow aquifers. The USGS monitors water levels in the Holly Beach water-bearing zone and the Cohansey aquifer at nine observation wells in Cape May County (table 8).

In this section, the relation between major withdrawals and long-term water levels in the water-table aquifer, shallow confined aquifers, and surface waters are described. In areas where withdrawals from confined aquifers causes declines in streamflow, seasonal wetlands, and the water-table aquifer, then the withdrawals have the potential to negatively impact the ecological-water supply.

The USGS maintains water-level recorders at five water-table observation wells and four wells completed in the Cohansey aquifer in upland ecologic niches of Cape May County (figs. 32 to 35). Each water-table well is within 1,000 ft of a surface-water body, and four of those wells are within 0.5 mi of an observation well completed in the Cohansey aquifer. Water levels in each well open to the water table are 5 to 10 ft below land surface, about 2 to 4 ft above the nearest surface-water level, and fluctuate seasonally.

Water levels in the Holly Beach water-bearing zone fluctuate seasonally in response to ecological water demands but have changed only slightly over the period of record (figs. 32 to 35). Water levels in the Cohansey aquifer fluctuate seasonally and in response to increased summer withdrawals for potable-water supply. Typical pre-development seasonal fluctuations would not cause water levels to drop below sea level; however, summer withdrawals to meet potable demand will cause water levels to drop below sea level.

Observation Wells near Cape May City Production Wells

The USGS has monitored water levels in well 9-20 open to the Holly Beach water-bearing zone at Cape May Point and in well 9-150 open to the Cohansey aquifer in West Cape May since 1963 and 1958, respectively. Well 9-20 is about 200 ft from Lake Lily, and well 9-150 is about 1,000 ft from tidal creeks and the ocean (fig. 32). Cape May Point Water Department (CMPWD) pumped its production wells during 1916-72. Those wells were within 2,000 ft of observation well 9-20. CMCWU pumped its wells open to the Cohansey aquifer during 1926-98. These wells are about 5,000 ft northeast of observation well 9-150.

In the late 1950s, water-level altitudes in the Holly Beach water-bearing zone were +3 to +5 ft while water-level altitudes in the Cohansey aquifer were -10 to -30 ft. Water-level altitudes in the Holly Beach water-bearing zone fluctuated seasonally from +3.02 to +6.42 ft during the period of record. However, during summer 1988, when Lily Lake was drained for maintenance purposes, the water-level altitude in well 9-20 dropped to +1.32 ft.

In contrast, water levels in the Cohansey aquifer in well 9-150 responded repeatedly to increases and decreases in withdrawals by CMPWC and CMCWU. During the drought of the mid-1960s, CMCWU increased withdrawals to meet demand and, as stated earlier, to freshen the salty well water. The increased withdrawals caused the winter water-level altitudes in the Cohansey aquifer to decline from -15 to -18 ft. In 1972, CMPWD abandoned its production well (9-178) because of saltwater intrusion. As a result, water levels increased during 1972-75 in the Cohansey aquifer. In the early 1980s, CMCWU halted withdrawals from its then southernmost production well because of saltwater intrusion. As a result, water levels in the Cohansey aquifer at well 9-150 rose more than 5 ft during 1980-87. In 1998, CMCWU halted nearly all withdrawals from the Cohansey aquifer, and water levels rose an additional 5 ft during 1998-2000.

During 1957-2006, water-level altitudes in the Cohansey aquifer rose from -15 to -5 ft, yet water-level altitudes in the Holly Beach water-bearing zone remained constant at about +3 to +6 ft. As a result, it is thought that the ecological-water supply south of the Cape May Canal was not affected by major withdrawals from the Cohansey aquifer.

Observation Wells near Wildwood Water Utility Production Wells

Observation wells 9-61 and 9-333 open to the Holly Beach water-bearing zone are within 3,000 ft of the Wildwood Water Utility (WWU) production wells and within 1,000 ft of a nearby stream (fig. 33A). Water-level altitudes in well 9-333

Table 8. Observation wells used to compare measured water levels in the Holly Beach water-bearing zone and Cohansey aquifer, Cape May County, New Jersey.

USGS well number	Local identifier	Township	Aquifer	Open interval below land surface, in feet
9-20	Traffic Circle Obs	Cape May Point	Holly Beach	15-20
9-150	West Cape May Obs	West Cape May	Cohansey	283-293
9-60	Cape May Airport	Lower	Cohansey	242-257
9-61	Cape May Airport	Lower	Holly Beach	24-27
9-333	Pump Pond North Obs	Middle	Holly Beach	28-38
9-80	Cape May 42 Obs	Middle	Cohansey	242-252
9-81	Cape May 23 Obs	Middle	Holly Beach	23-26
9-510	Belleplain MW44	Dennis	Holly Beach	6-11
9-23	Fire tower	Dennis	Cohansey	15-18

fluctuated seasonally over the period of record from +5.84 to +11.31 ft, and water-level altitudes in well 9-61 fluctuated seasonally from +6.35 to +8.95 ft. The water-level altitude of the nearest surface waters, Pumping Station Pond and the perennial part of Fulling Mill Stream, were about +5 ft. Water levels in observation wells 9-61 and 9-333, open to the water table did not drop below the level of the nearby surface water or below sea level but always stayed more than 5.5 ft above sea level.

Observation well 9-60 is open to the Cohansey aquifer and adjacent to well 9-61. Water-level altitudes ranged from -29.29 to -2.89 ft during 1960-2005. Seasonal fluctuations in water levels were predominately the result of seasonal withdrawals from the WWU well field and to a lesser extent were the result of withdrawals from the LTMUA wells. Seasonal high water levels decreased about 5 ft during 1970-75 (fig. 33B). Withdrawals from the WWU wells increased more than those from other wells, from about 1,000 to 1,500 Mgal/yr during 1970-75 (fig. 21A).

Water levels in wells 9-61 and 9-333 do not appear to have been affected by the withdrawals from the nearby production wells tapping the Cohansey aquifer. However, closer evaluation of water levels in well 9-333 and three nearby vernal ponds show that the WWU groundwater withdrawals had seasonal effects on the water table and wetlands. Such effects are below the resolution shown in the water-level hydrograph in figure 33B.

Observation Wells near Production Wells in Middle Township

Observation well 9-81 open to the Holly Beach water-bearing zone and well 9-80 open to the Cohansey aquifer are within 200 ft of Creese Creek (fig. 34). The creek is tidal near the wells and has an average water-level altitude of 0 ft. Land-surface altitude at the wells is about +14 ft. Water levels were measured in these observation wells during 1958-2005. Water-level altitudes in well 9-81 fluctuated seasonally over the period of record from +4.1 to +9.3 ft, and water-level altitudes in well 9-80 fluctuated from -10.33 to +3.97 ft. Water levels in well 9-81 never declined to below the level of the nearby surface water or below sea level.

Seasonal fluctuations in water levels of well 9-80 are about 8 ft. The fluctuations are likely the result of withdrawals from the trailer park well located about 1,000 ft west of the observation wells and withdrawals from the WWU wells located about 3 mi southwest of the observation wells. The decline in water levels in well 9-80 from seasonally above sea level prior to 1973 to nearly always below sea level after 1974 is the result of the increased withdrawals from the WWU wells during 1970-75 (fig. 12A). The greatest increase in withdrawals from WWU wells from about 1,000 to 1,500 Mgal/yr occurred during 1970-75 (fig. 21A). The increase in withdrawals during 1970-75 does not appear to have caused a decrease in water levels in well 9-81.

Water levels in well 9-81 do not appear to have been affected by withdrawals from the nearby production wells tapping the Cohansey aquifer. Water levels in the water-table aquifer remained constant at about 4 to 9 ft above sea level. As a result, it is thought that the ecological-water supply in the

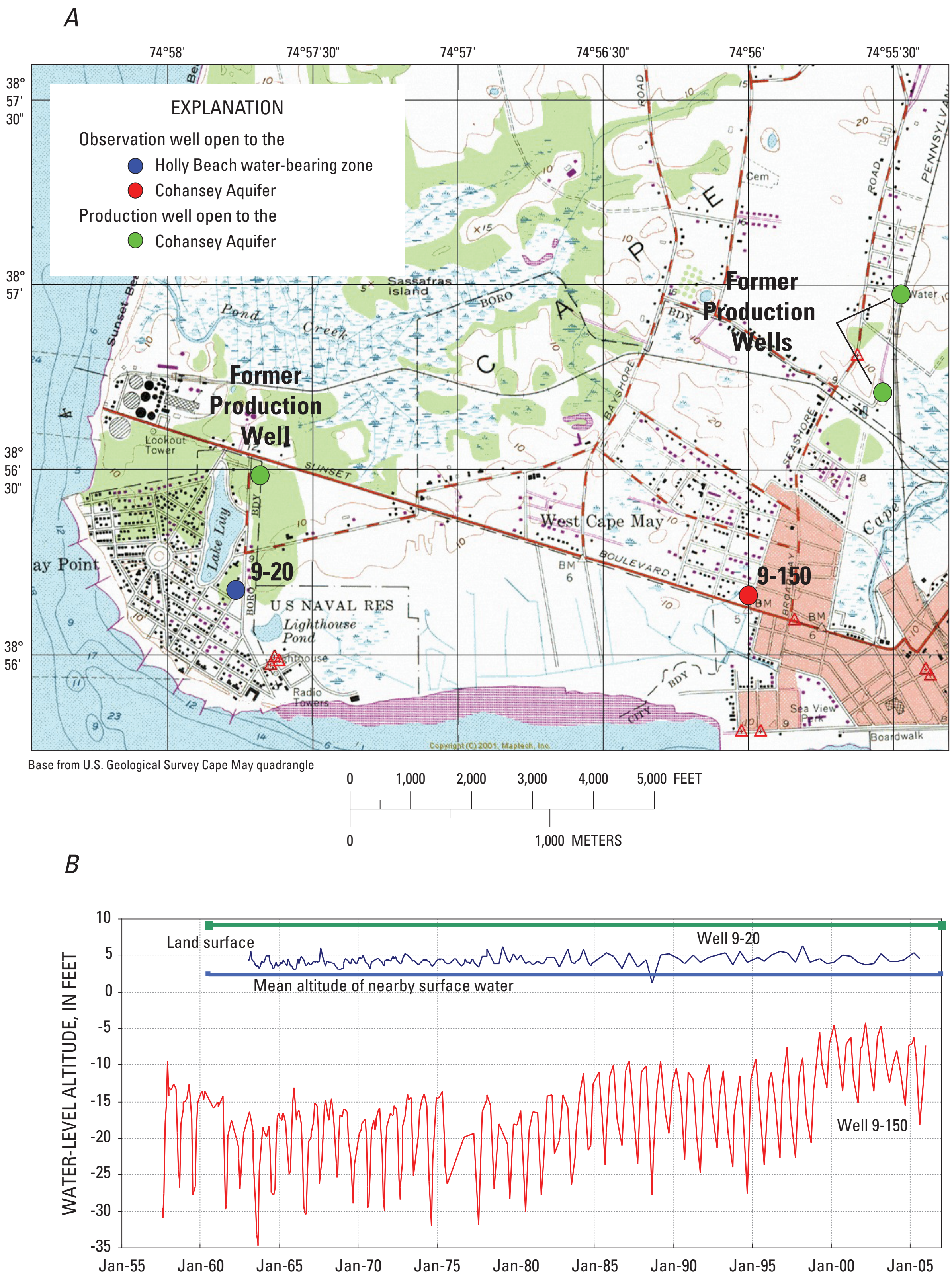


Figure 32. *(A)* map showing the location of water-level observation wells 9-20 and 9-150, nearby surface water, and former production wells, Cape May County, New Jersey, and *(B)* water-level hydrographs for well 9-20 and 9-150, Cape May County, New Jersey, 1956-2005.

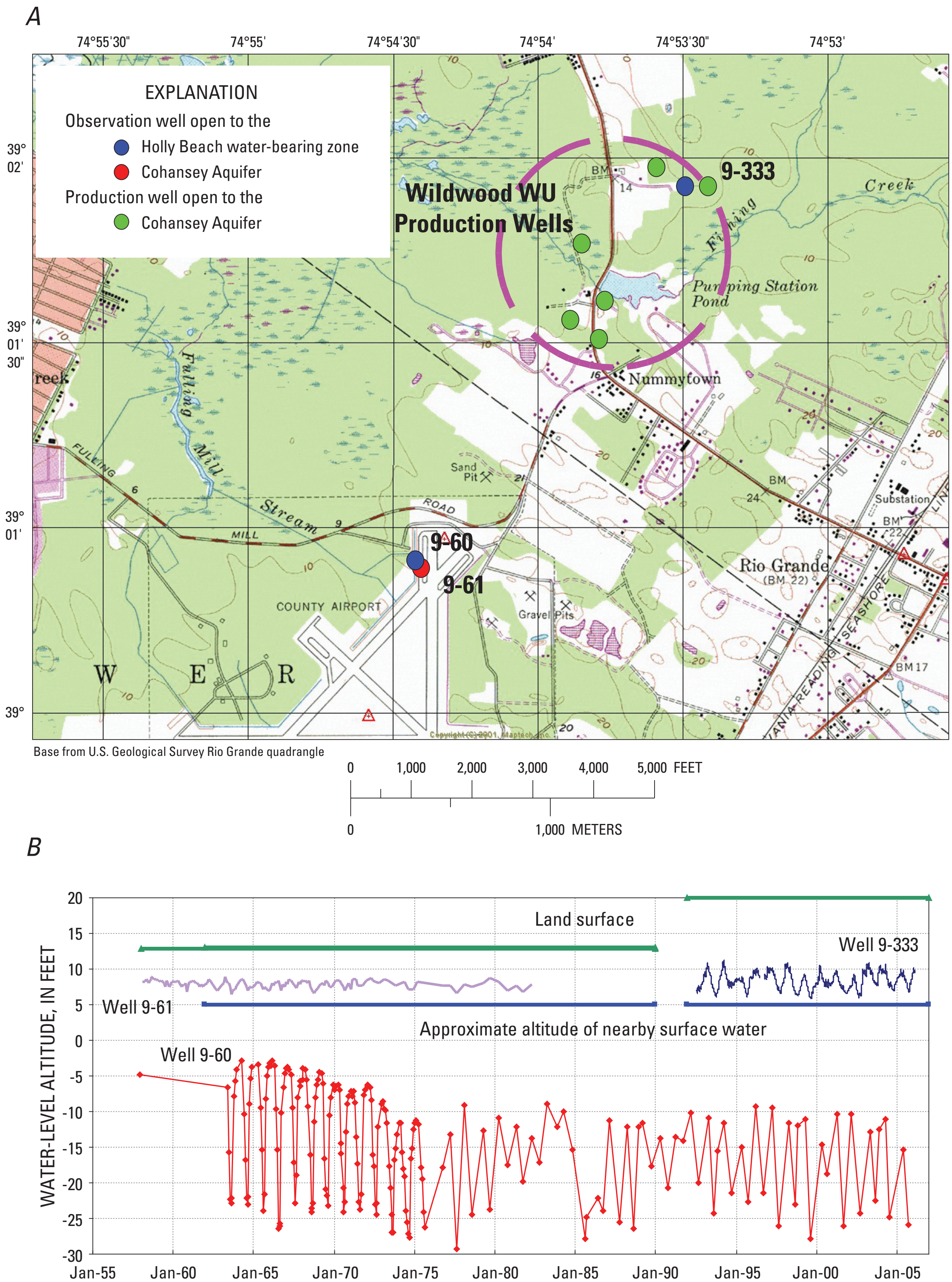


Figure 33. *(A)* Map showing the location of water-level observation wells 9-333, 9-60, and 9-61, and Wildwood Water Utility (WU) well field, surface water, Lower and Middle Townships, Cape May County, New Jersey, and *(B)* water-level hydrographs for observation wells near the Wildwood Water Utility well field 1958-2005. Wells 9-61 and 9-333 are in the Holly Beach water-bearing zone, and well 9-60 is in the Cohansey aquifer,

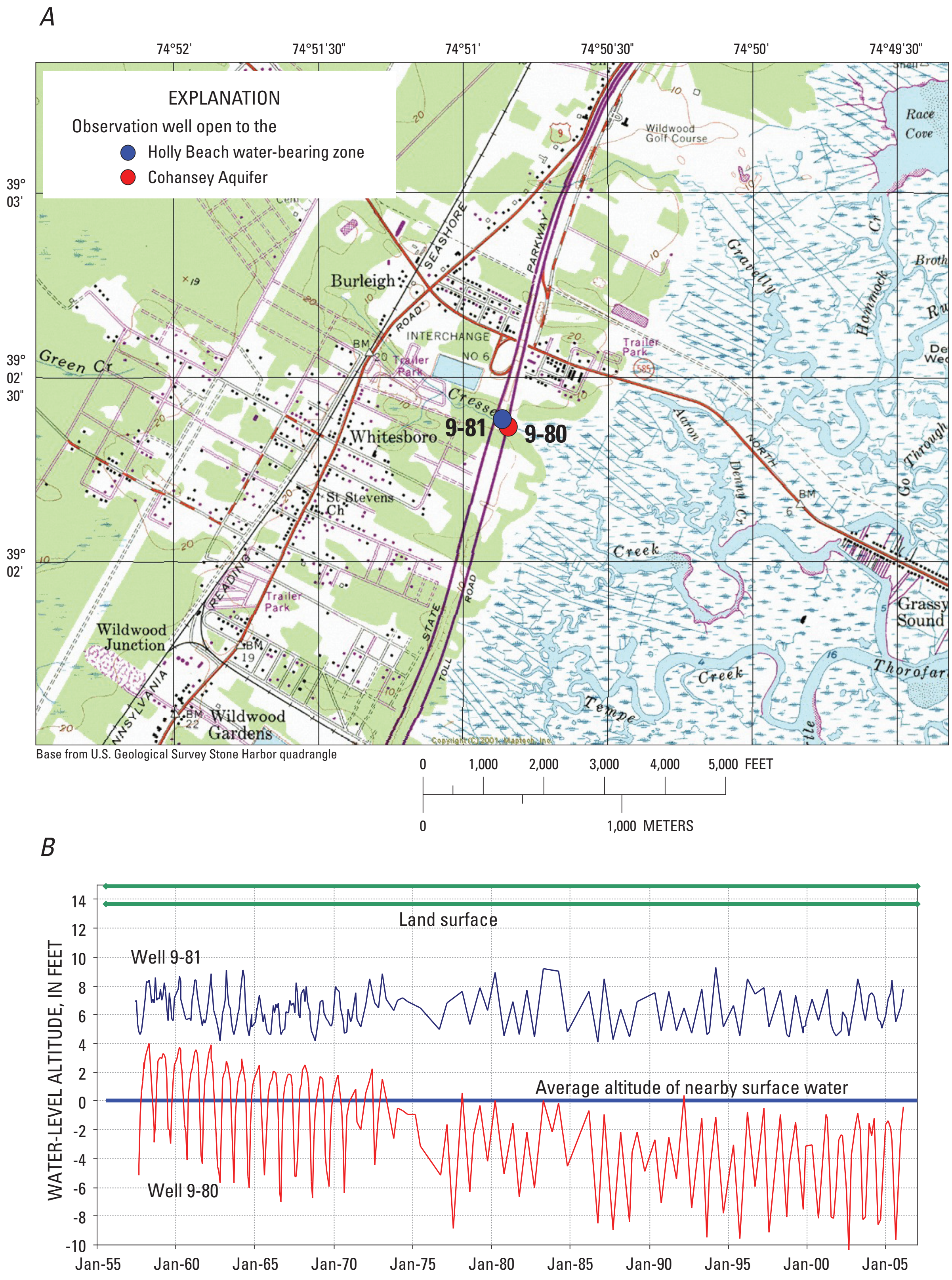


Figure 34. *(A)* Map showing the location of water-level observation wells 9-80 and 9-81, and surface water, Middle Township, Cape May County, New Jersey, and *(B)* water-level hydrographs for observation wells near Whitesboro, New Jersey, 1957-2005. Well 9-80 is in the Holly Beach water-bearing zone and well 9-81 is in the Cohansey aquifer.

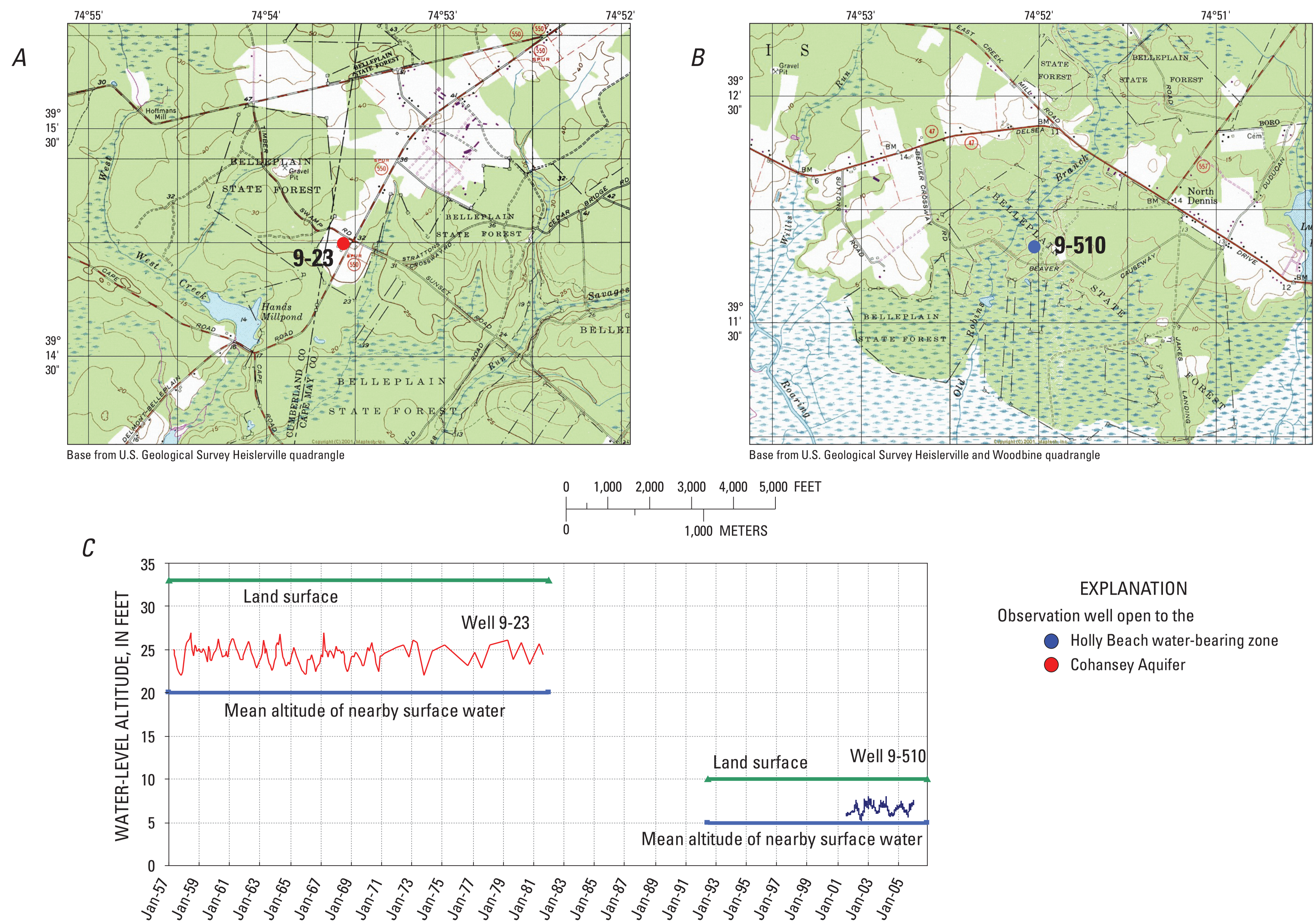


Figure 35. Location of water-level observation wells *(A)* 9-23 and *(B)* 9-510 and *(C)* water-level hydrographs for the observation wells, Dennis Township, Cape May County, New Jersey, 1957-2005.

vicinity of this observation well is not affected by groundwater withdrawals from the Cohansey aquifer.

Observation Wells near Forest Preserve in Dennis Township

Observation wells 9-23 and 9-510 are open to the Holly Beach water-bearing zone near Belleplain State Forest in western Dennis Township (fig. 35). Well 9-23 is about 3,000 ft from Hands Millpond, which has a surface altitude of +14 ft and about 1,000 ft from an unnamed swamp/wetland, which has a surface altitude of +20 to +25 ft (fig. 35). Well 9-510 is about 1,000 ft from Old Robins Branch, which has a surface altitude of about +5 ft. The land-surface altitude at well 9-23 is +33 ft and at well 9-510 is +10 ft. Water levels were monitored in well 9-23 during 1957-81 and in well 9-510 during 2001-05. Water-level altitudes in well 9-23 fluctuated seasonally over the period of record from +22 to +27 ft and water-level altitudes in well 9-510 fluctuated from +5 to +7.5 ft. Water levels in the observation well did not drop below the water level of the nearby surface water.

No large production wells or long-term observation wells are present near well 9-23 so little can be deduced about water levels. Bohm's Sod Farm operates a few large-capacity irrigation wells open to the Cohansey aquifer in fields that are west of well 9-510. Irrigation withdrawals do not appear to lower water levels at well 9-510.

Seasonal Changes in Water Levels

The ecological water demand is based on seasonal changes and available water. Monthly precipitation is constant. However, the amount of sunlight and warm temperatures are seasonally variable. As a result the demand for water is greater in the growing season which causes fluctuations in groundwater levels and surface-water levels.

Groundwater Levels

Water-level hydrographs for well 9-333 near the WWU production wells and well 9-510 in Belleplain State Forest show water-level fluctuations in the Holly Beach water-bearing zone (fig. 36). Vertical grid lines were added to the graph in figure 36 to indicate March 21 and September 21, the approximate respective dates of the vernal and autumnal equinox each year. Water levels at each well were high every winter and low every summer. Water levels at each well begin to decline about 1 week to 1 month after the vernal equinox. Water-level declines are caused by increased sunlight and warming temperatures that induce sap flow to make buds bloom into leaves, initiate transpiration, and increase evaporation. The three processes use large volumes of water. Water levels remained low in both wells in response to high evapotranspiration in summer and early fall. Water levels in well 9-510 generally began to rise a few weeks earlier than in well 9-333. Water levels in both wells were nearly identical by the winter solstice.

Water levels in observations well 9-333 are 9 to 14 ft below land surface, whereas water levels in well 9-510 are 10 to 13 ft below land surface. The dates when water levels began to decline during mid-spring are remarkably similar. The dates and rates of water-level rise during the fall differ between the two wells, which may be due to the aquifer thickness or transmissivity. However, the difference could be due to withdrawals of 1,100 Mgal/yr by WWU from the shallow aquifers, which could have caused water levels in the Holly Beach water-bearing zone to decline a bit more and recover a bit more slowly than water levels in the same aquifer but in a

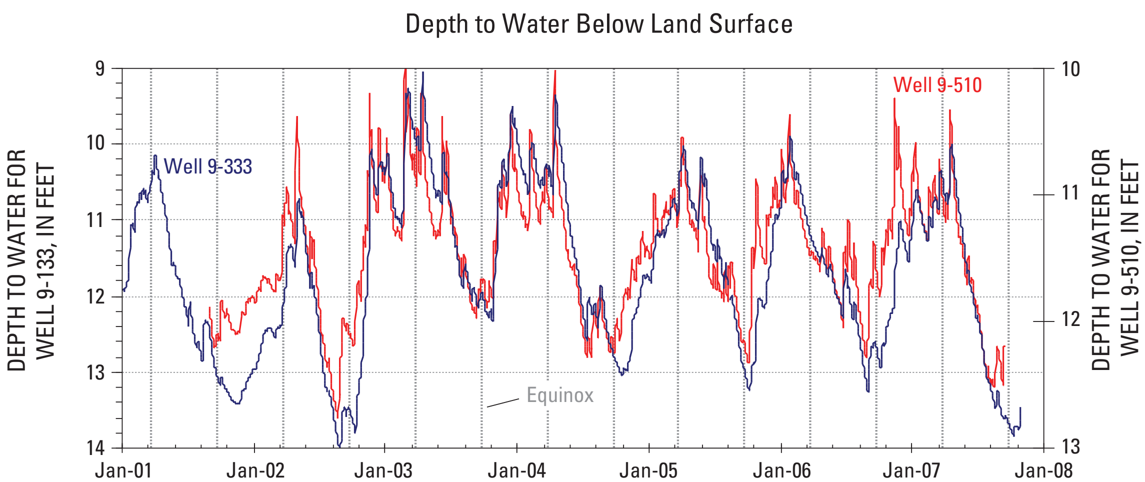


Figure 36. Water-level hydrographs for wells 9-333 and 9-510, Cape May County, New Jersey.

remote part of Belleplain State Forest. This change in water levels may indicate that large withdrawals from the Cohansey aquifer cause lower water levels for a longer time in the Holly Beach water-bearing zone near the pumped wells.

Vernal Ponds

Vernal ponds are confined depressions, either natural or man-made, that hold water for part of the year and are devoid of breeding predatory fish populations. Vernal ponds and seasonal forested wetlands provide habitats for many species of amphibians, several of which breed exclusively in vernal ponds. Vernal ponds and forested wetlands provide the specific habitat for a multitude of flora and fauna.

The New Jersey Freshwater Wetlands Program developed by the NJDEP Division of Land Use Regulations has been in place since 1989 to protect wetlands that are greater than 1 acre, with some exceptions. Most vernal ponds in New Jersey are less than 0.25 acre, and therefore, most are exempt from the regulatory protection. Vernal ponds could be filled, drained, or modified with a general permit. The loss of this critical habitat puts the species that depend on vernal ponds for breeding habitat at risk. The NJDEP Division of Fish and Wildlife, Endangered and Nongame Species Program, identified 626 vernal ponds in Cape May County (fig. 37): 1 pond in Cape May City, 176 ponds in Dennis Township, 75 ponds in Lower Township, 231 ponds in Middle Township, 121 ponds in Upper Township, and 22 ponds in Woodbine.

One species of salamander deposits eggs under the ice in late January or early February; therefore, a vernal pond that provides a viable habitat for this salamander should have water in it by January. As winter ends and spring progresses, various species of frogs and salamanders use the vernal ponds for egg deposition in a sequential pattern. For the animals to survive, each species of amphibian must reach air-breathing maturity before the vernal pond dries up.

The USGS selected 10 vernal ponds in Lower, Middle, and Dennis Townships to be monitored for groundwater and surface-water levels over a 3-year period. The purpose was to determine whether vernal ponds that are near sites of large groundwater withdrawals dried up earlier each summer than vernal ponds that were not near sites of large withdrawals. The 10 vernal ponds are shown in figure 37, and identifying data are in table 9. Vernal ponds 14 and 16 are within 0.5 mi of the WWU production wells. Vernal ponds 12 and 15 are within 1 mi of WWU wells. Vernal ponds 3, 5, 8b, 19, 30, and 31 are more than 2 mi from the WWU wells.

The vernal ponds were first visited during late winter 2001 and early spring 2002 when surface-water levels were highest. The ponds were waded in the effort to find the deepest part. Generally, the deepest part could not be determined accurately because of subtle changes in the bottom topography. A 6-ft long, 0.75-in-diameter steel piezometer was installed in the deepest part of the pond. The top of the piezometer was about 1 ft above the water surface, and the well screen was about 3 to 4 ft below land surface. Each piezometer was developed by pumping and surging until it freely accepted water poured into the top. The top of the piezometer was used as the reference datum. Depth to the groundwater was measured inside the piezometer from the reference datum. Depth to surface water and distance to land surface were measured outside the piezometer.

Eight of the vernal ponds were visited monthly for three wet cycles; three of the ponds were visited for two wet cycles; and one pond was visited for one wet cycle. Surface-water levels, groundwater levels, and distance to land surface were measured during each visit (fig. 38). Water levels declined each summer, and all ponds were dry by late summer. After the tree leaves dropped each autumn, the ponds began to refill, and by January 1 all ponds were nearly full.

For amphibians to use the ponds for egg deposition, the ponds would have to be full by January 1. Starting with January 1 and depending on the year and pond, each pond contained water for as little as 51 days or as long as 242 days, with a mean of 168 days (table 9).

Vernal ponds VP-14 and VP-16, which are closest to the WWU production wells, have the shortest mean period (138 days and 128 days, respectively) for being wet during the 3 years of the investigation. Pond VP-12 was the third closest pond to the WWU production wells, and its mean wet period was 158 days.

Early drying of vernal ponds may be a result of groundwater withdrawals by the WWU or it may be the result of a suite of factors including pond size, underlying sediment type, and well placement and construction.

Vernal ponds VP-3, VP-8b, VP-15, and VP-19 had a mean wet period of 172 to 208 days. There are no large withdrawal wells near these vernal ponds.

Counting the number of days a vernal pond is wet provided a sensitive method to determine the adverse effects of groundwater withdrawals on the ecological water supply. Vernal ponds near the WWU production wells dried up a mean of 10 to 40 days earlier than the mean wet period of the 10 vernal ponds. Vernal ponds that were far from the WWU wells had a mean wet period that was 2 to 40 days longer than the general mean wet period. These results indicate that large withdrawals from the shallow aquifers likely will impact the ecological water supplies. Because there are vernal ponds near the production wells of the WWU, this may indicate that the affect is minor. Alternatively, this could indicate that the ponds that were most sensitive to withdrawals have disappeared, and only the least sensitive vernal ponds remain. A similar survey of all vernal ponds near the WWU wells could be used to evaluate the extent of the effects.

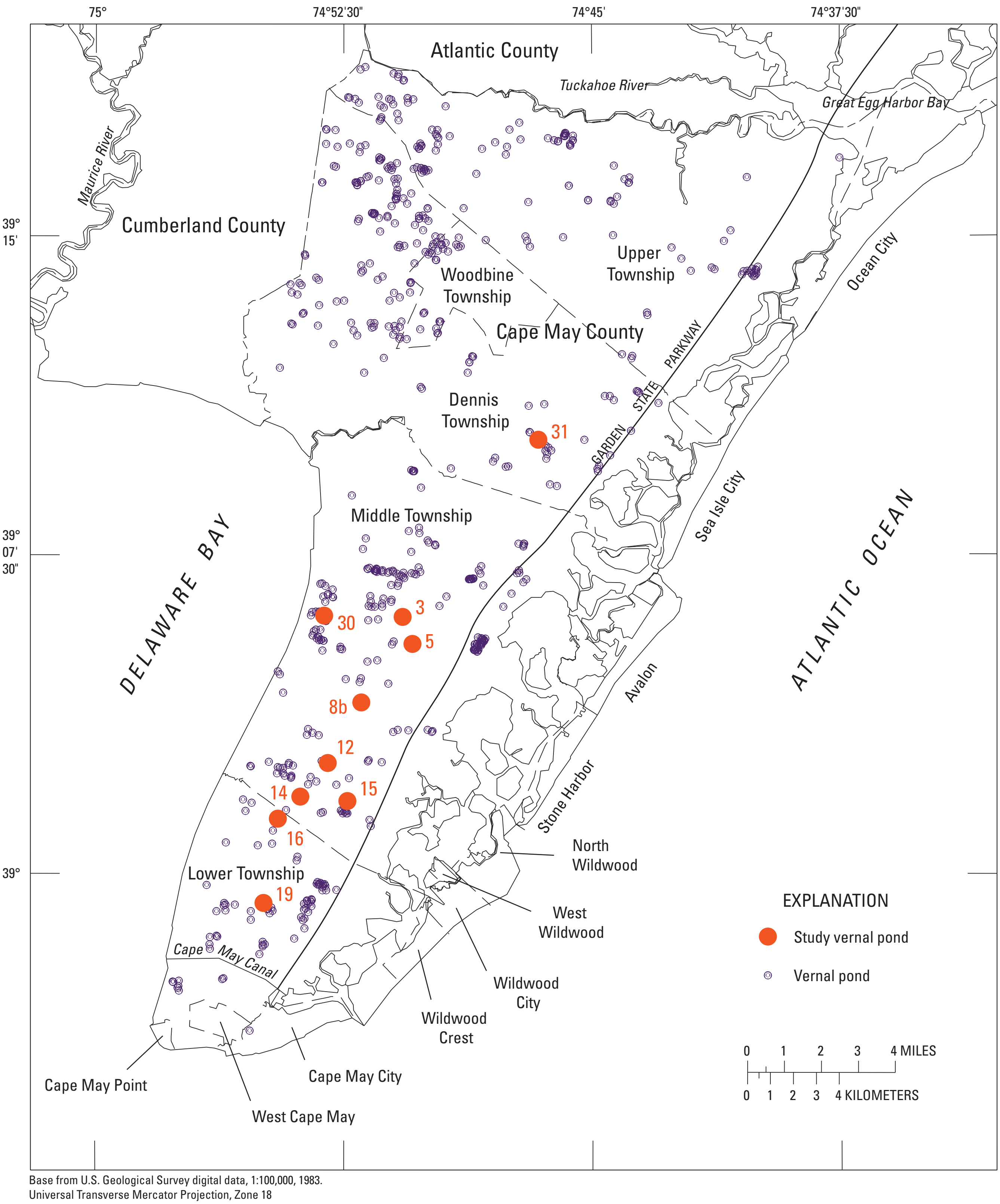


Figure 37. Vernal ponds in Cape May County, New Jersey. (From New Jersey Department of Environmental Protection, Division of Fish and Wildlife, 2002).

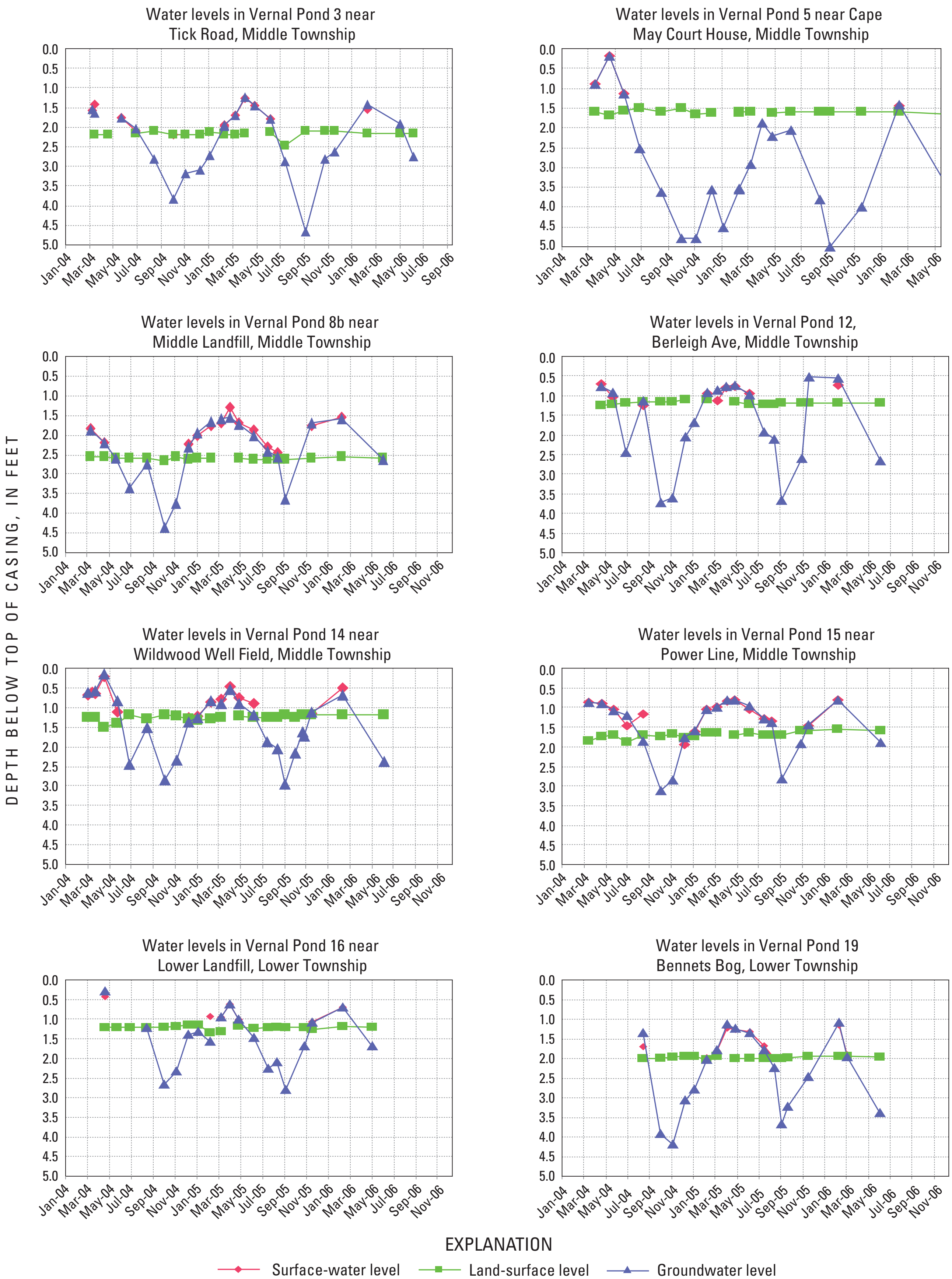


Figure 38. Water-level hydrographs for 10 vernal ponds, Cape May County, New Jersey, 2004-06.

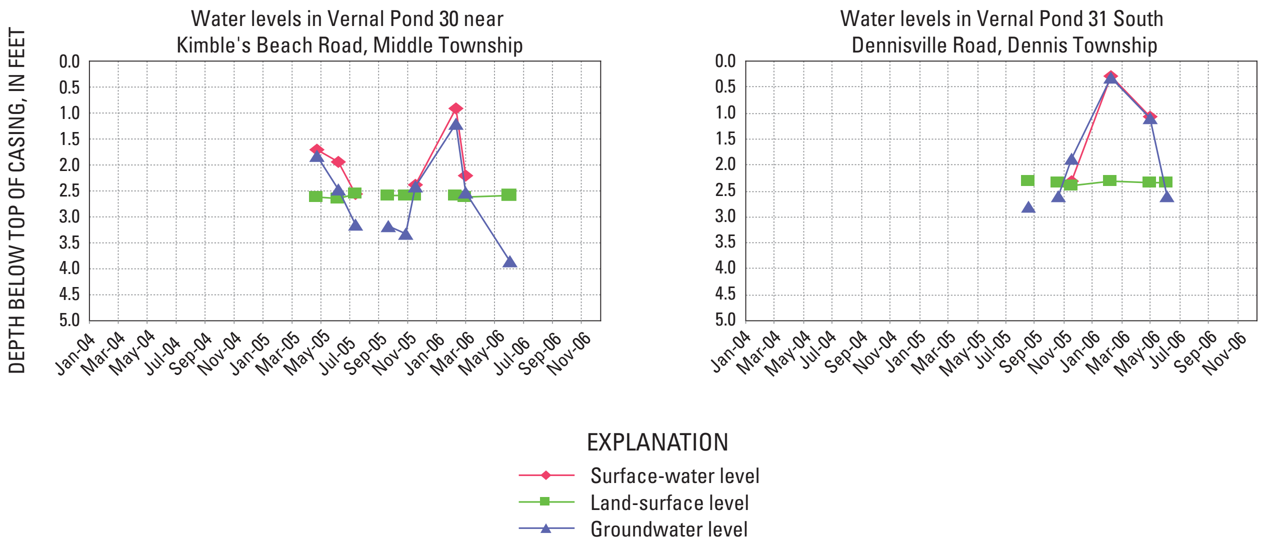


Figure 38. Water-level hydrographs for 10 vernal ponds, Cape May County, New Jersey, 2004-06.—Continued

Ecological Water Demand Based on Air Photographs, 1930s and 2002

Six sets of air photographs of mainland Cape May County (fig. 39) taken in the 1930s and in 2002 (N.J. Department of Environmental Protection, 2004, i-MapNJ DEP Map, accessed April 25, 2005, http://njgin.state.nj.us/dep/DEP_iMapNJDEP/viewer.htm) were compared to assess changes in land use and to qualitatively determine whether changes in areas near major groundwater-withdrawal centers have adversely affected the ecological water supply when compared to more remote areas. Three sets of air photographs show the well fields of CMCWU, LTMUA, and WWU and surrounding land respectively (figs. 40, 41, and 42). Each well field withdrew more than 400 Mgal/yr from the Cohansey aquifer in 2002. Another set of air photographs shows the ecologically preserved lands in the Dias Creek drainage basin, Timber and Beaver Swamp, and the Great Cedar Swamp, respectively (fig. 43, 44, and 45). Withdrawals of groundwater from the shallow aquifers are limited in these predominately forested areas.

Major land-use types that are underlain by freshwater are forests, farm fields, and residential-commercial lands. Forests support the native and migratory fauna and native flora of Cape May County. Farm fields and residential-commercial land, in part, support some native and migratory fauna and some native flora. Major fresh surface-water features include streams, permanent and seasonal ponds, and wetlands. The perennial streams support native and most migratory aquatic fauna, except migratory fish above the first dam. The ponds and wetlands support the indigenous and migratory fauna, as well as the native flora.

Each set of photographs shows land-use changes that decreased, increased, changed, or eliminated ecological freshwater demand. Land-use changes that decreased ecological freshwater demand from 1930 to 2002 are primarily forest lands that were converted to farm fields, golf courses, residential/commercial land, and quarries. The photographs of Cox Hall Creek (fig. 41), the area around Rio Grande, Cape May County Airport, (fig. 42), west of Cape May Court House (fig. 43), the golf courses near Swainton (fig. 44); and the sand and gravel quarries near the Great Cedar Swamp (fig. 45) show the greatest changes.

Land-use changes that increased ecological water demand are farm fields or industrial sites of the 1930s that reverted to forested land by 2002. Such areas are generally small but are ecologically important. Larger areas with increased ecological demand are near Cape May Point, at the shoreline from Cape May City to Cape May Point and at farm fields. The magnesite processing plant north of Cape May Point (fig. 40) was constructed in the 1940s, abandoned in the 1970s, razed during the 1990s by the NJDEP, and replanted with native vegetation. The shoreline between Cape May City and Cape May Point (fig. 40) was eroded almost 1,000 ft during 1930-2002. In 2004, the NJDEP rebuilt the shoreline and replanted it with native vegetation. This is not shown in the 2002 air photograph but is shown in more recent pair photographs. A few farm fields south of the WWU wells and west of the village of Green Creek (fig. 42) and around Timber and Beaver Swamp State Forest (fig. 44) reverted to forested land. There are many other examples of small farm fields reverting to forests in each set of photographs.

Land-use changes that eliminated native ecological freshwater demand include the excavation of the Cape May Canal and Cold Spring Harbor that converted freshwater wetlands to saltwater wetlands and the urbanization of the barrier islands where forests were removed and most vestiges of the ecological habitat were removed.

Table 9. Days per year that selected vernal ponds in Cape May County, New Jersey, are water filled after January 1, 2004-06, and available for ecological water demands of amphibians.

[Locations of ponds are shown on figure 38; --, no data.]

NJDEP vernal pond identifier	Local pond number	Local vernal pond name	Days vernal pond is water filled after January 1			
			2004	2005	2006	Mean for 3 years
12841ocp	VP-3	Tick Road	186	178	153	172
12095ocp	VP-5	Maintenance Yard	Piezometer not in deepest part of pond			
707ocp	VP-8b	Middle Township Landfill	154	239	231	208
726ocp	VP-12	Burleigh Ave	150	237	87	158
3673ocp	VP-14	Wildwood Water Utility	156	172	87	138
3669ocp	VP-15	Electric Powerline	219	232	134	195
3682ocp	VP-16	Lower Township Landfill	145	143	97	128
3712ocp	VP-19	Bennett's Bog	242	221	76	180
37620ocp	VP-30	Kimble's Beach Road	--	--	51	51
12769ocp	VP-31	South Dennisville Road	--	--	170	170
		Mean days pond has water	179	203	121	168

Cape May City Water Utility Well Field

Air photographs of the southern tip of the cape show the area between Delaware Bay and Cape Island Creek, including the CMCWU well field (fig. 40). Groundwater withdrawals from the CMCWU well field have increased from about 350 Mgal/yr in 1930 to 400 Mgal/yr in 1998. During 1910-98 all production water was withdrawn from the Cohansey and shallower aquifers. After 1998, the CMCWU withdrew water from the Atlantic City 800-foot sand for desalination.

The 1930s and 2002 air photographs of the area surrounding the well field show many land-use changes including the canal with deposition of the dredge spoils in the upper reaches of New England Creek and Cape Island Creek wetlands and expansion of residential land use into many areas. Most wetlands appear intact; however, a few wetlands have been excavated to form farm ponds.

The 1930s air photograph shows many farm fields west of the CMCWU well field that encompass small circular forested areas. These small plots were not used for farming because they contained vernal ponds. When many of these circular forested areas were visited in spring 2003 the vernal ponds were still there. Since these ponds still exist, it is believed that local groundwater withdrawals did not greatly affect them. However, like the vernal ponds near the WWU wells, massive groundwater withdrawals may have prematurely dried the wetlands each summer. Since 1998, CMCWU has substantially reduced withdrawals from the Cohansey aquifer. The ponds may have dried up prematurely during the 1970s to 1990s, but that effect likely lessened after CMCWU began desalination of deep aquifer water.

Lower Township Municipal Utilities Authority Well Field

Air photographs of Lower Township near the LTMUA production wells show that most farmland that has been converted to densely populated communities (fig. 41). LTMUA drilled its first production well in 1956 and expanded to five production wells by 2002. Annual withdrawals by LTMUA totaled about 400 Mgal during 2000-05, and all water came from the Cohansey aquifer. Domestic and agricultural supply prior to 1955 predominantly came from the estuarine sand aquifer and Holly Beach water-bearing zone. The 1930s air photograph of the area shows about half of the land is active farm fields located in uplands terrain, and about half of the land is forests and wetlands in lower terrain. The 2002 air photograph shows much of the farm land and some of the forests were converted to residential and commercial land use. Tidal, non-tidal, and riparian land in the Cox Hall Creek area likely retain their historical ecological water demand.

Ecological water demand decreased from 1930s to 2002 along the Cape May Canal corridor and in areas where farms and forested lands were converted to residential/commercial lands. This decrease in ecological water demand is especially

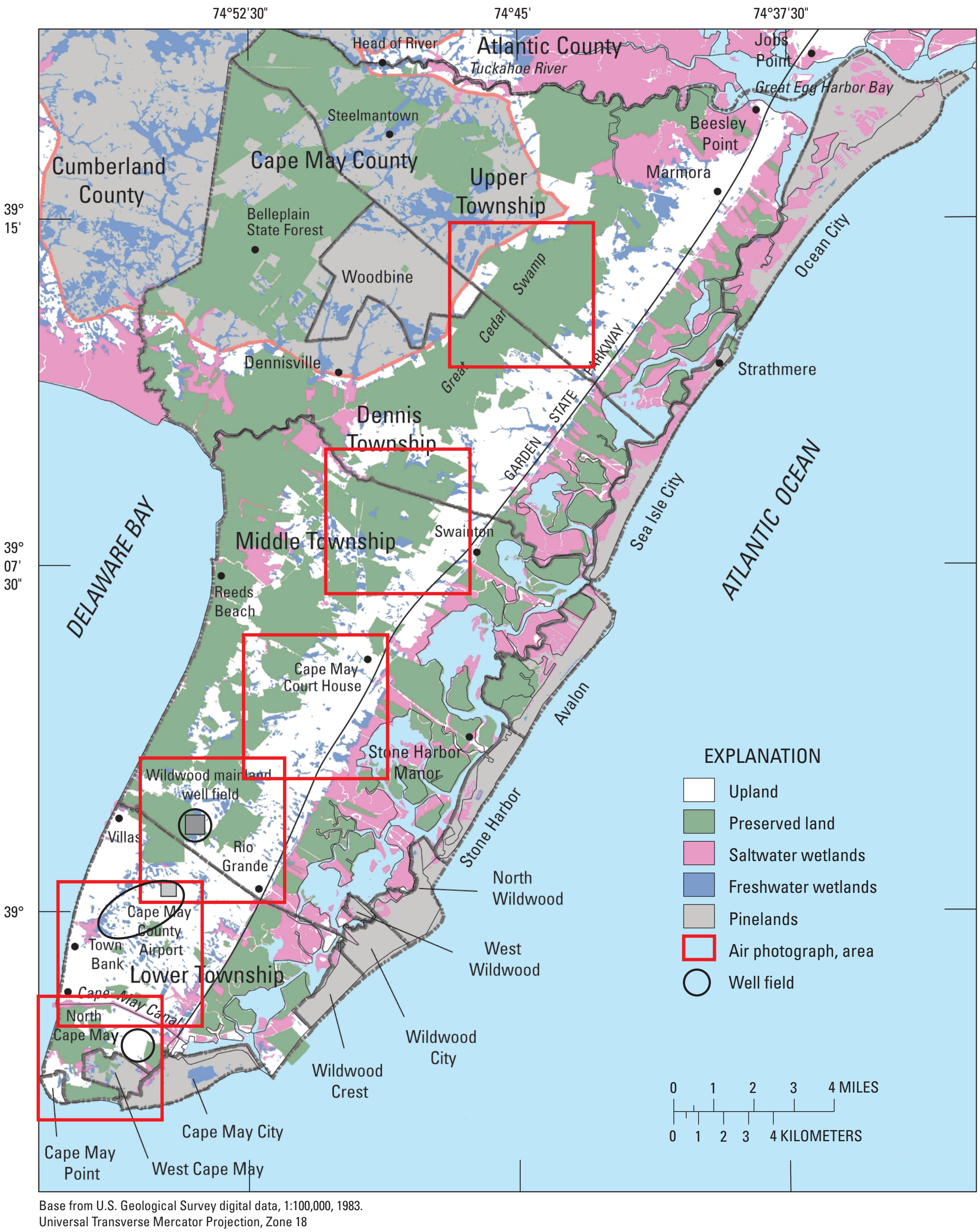


Figure 39. Ecologically preserved land, and location of air photographs for 1930 and 2002, Cape May County, New Jersey.

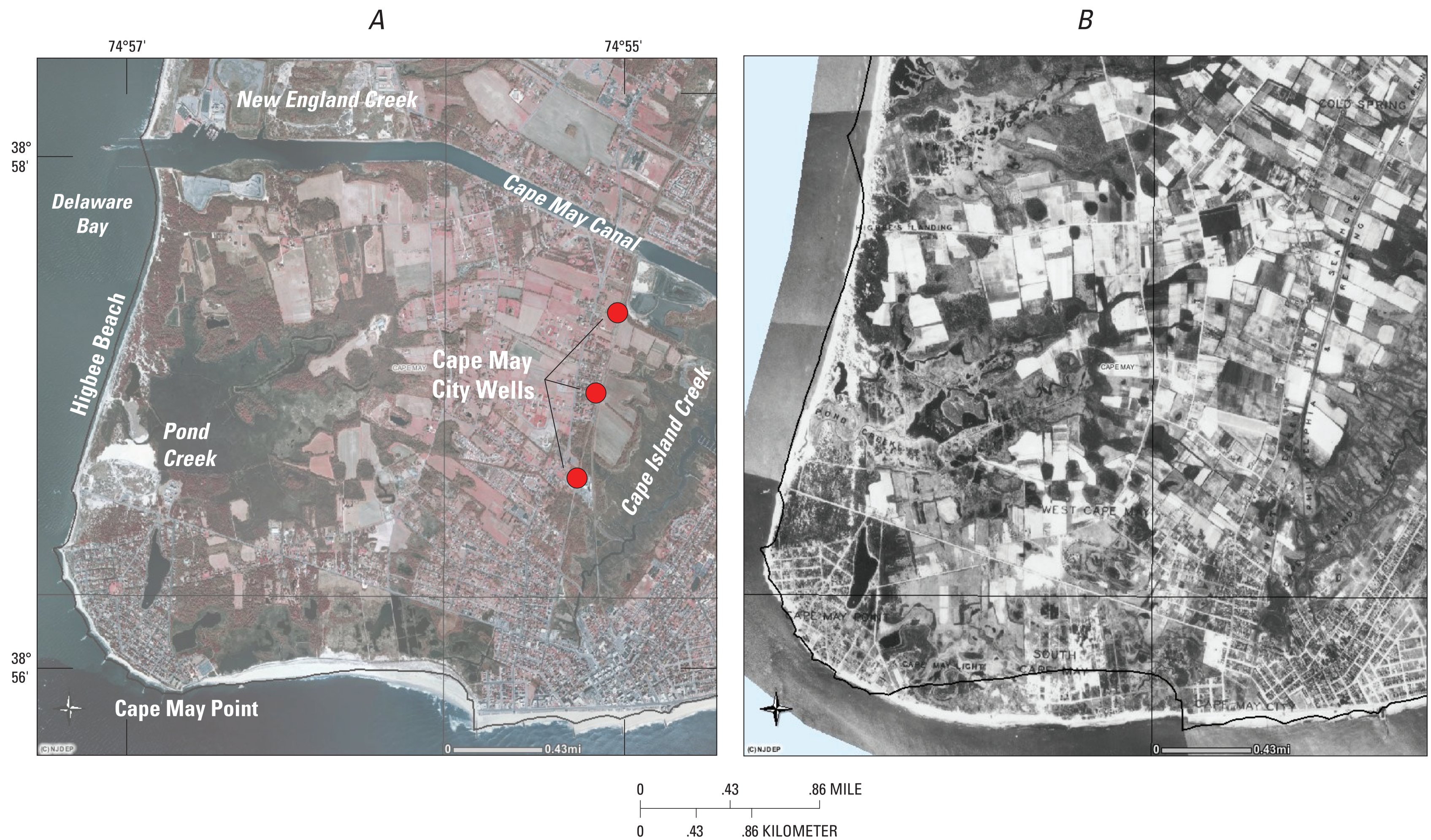


Figure 40. Air photographs from *(A)* 2002 and *(B)* 1930 of the Cape May City Water Utility well field, and villages of Cape May Point, West Cape May, and Cape May City, New Jersey. (Air photographs taken in the 1930s and in 2002 available on the World Wide Web at N.J. Department of Environmental Protection, 2004, i-MapNJ DEP Map, accessed April 25, 2005.)

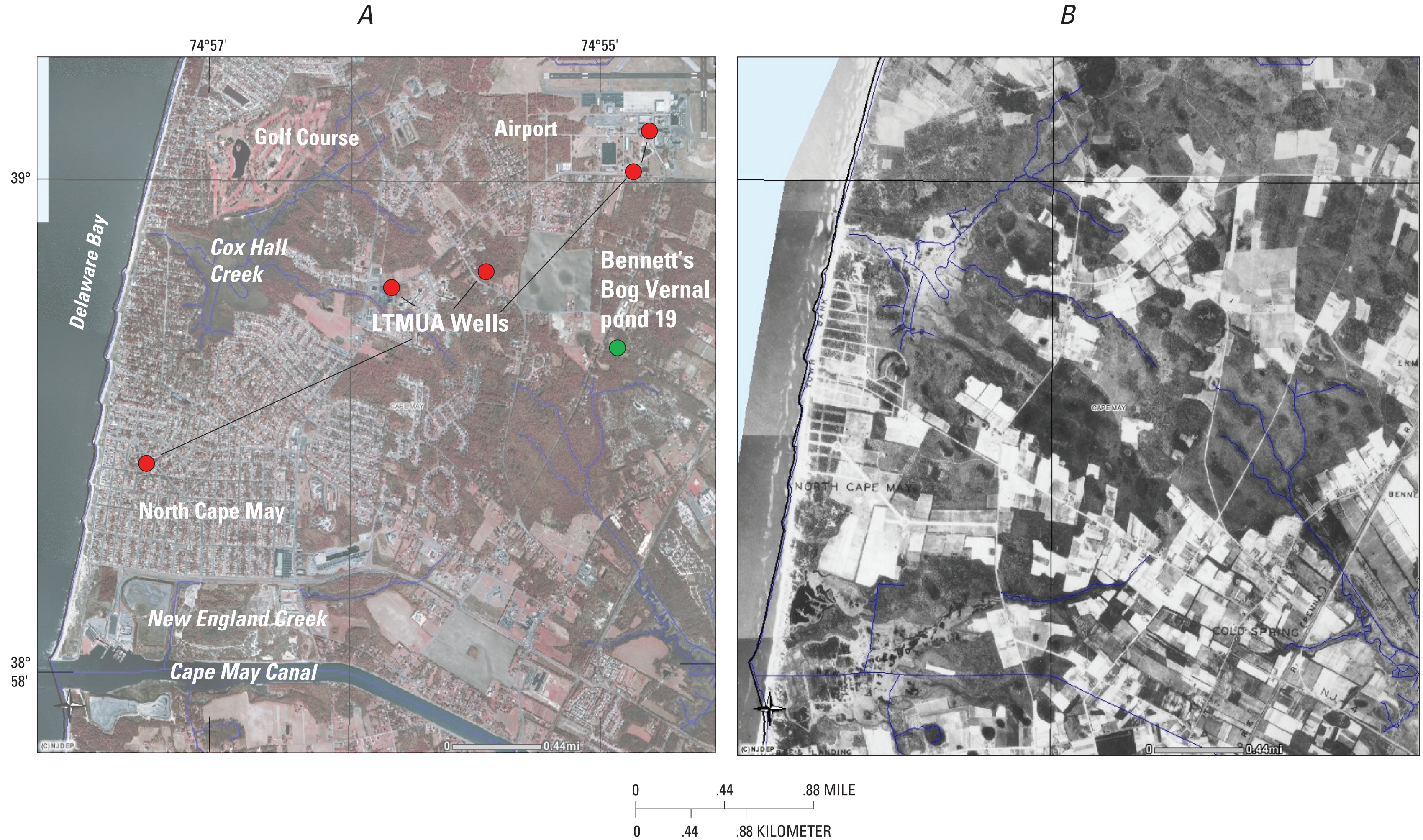


Figure 41. Air photographs from *(A)* 2002 and *(B)* 1930 showing Lower Township Municipal Utilities Authority (LTMUA) wells; village of North Cape May; Cape May Canal; headwaters of Cox Hall Creek, Cold Springs Creek, and the former New England Creek; and vernal ponds (VP), Cape May County, New Jersey. (Air photographs taken in the 1930s and in 2002 available on the World Wide Web at N.J. Department of Environmental Protection, 2004, i-MapNJ DEP Map, accessed April 25, 2005.)

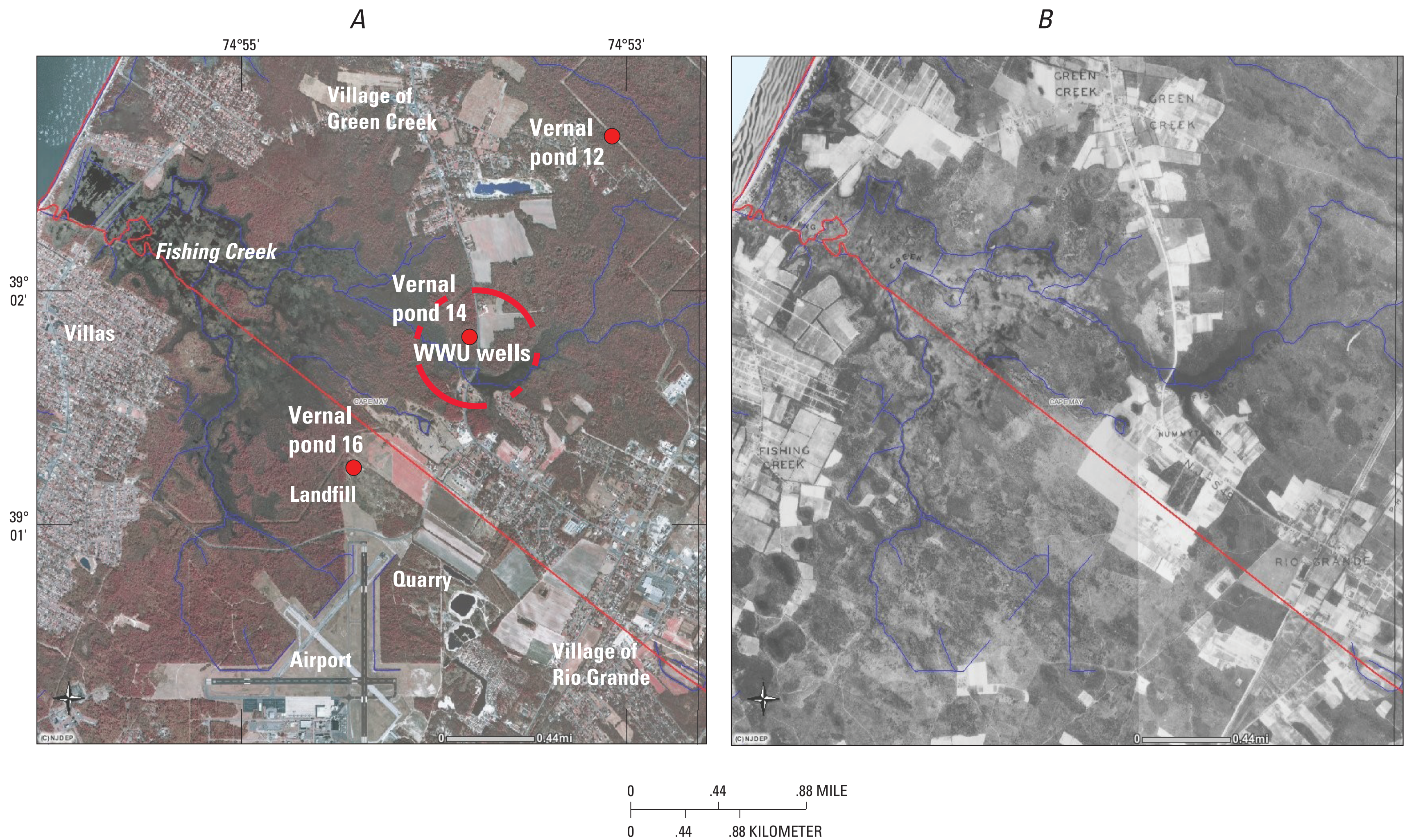


Figure 42. Air photographs from *(A)* 2002 and *(B)* 1930 showing Wildwood Water Utility (WWU) well field, villages of Rio Grande Villas and Green Creek, and headwater of Fishing Creek, a former quarry, Cape May County Airport, and vernal ponds (VP), Cape May County, New Jersey. (Air photographs taken in the 1930s and in 2002 available on the World Wide Web at N.J. Department of Environmental Protection, 2004, i-MapNJ DEP Map, accessed April 25, 2005.)

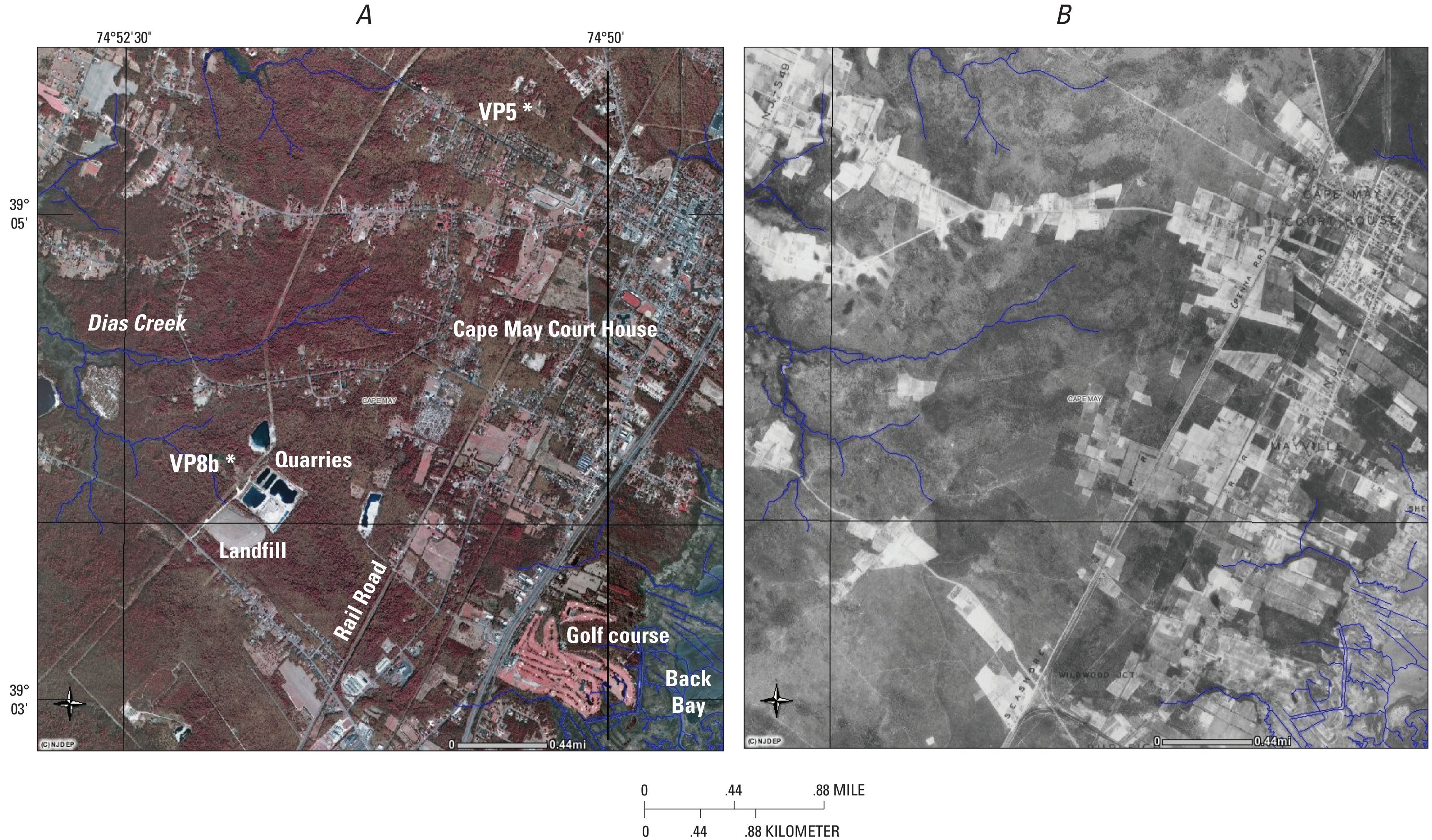


Figure 43. Air photographs from *(A)* 2002 and *(B)* 1930 showing Cape May National Wildlife Refuge, Dias Creek, village of Cape May Court House, sand gravel mines, and vernal ponds, Cape May County, New Jersey. (Air photographs taken in the 1930s and in 2002 available on the World Wide Web at N.J. Department of Environmental Protection, 2004, i-MapNJ DEP Map, accessed April 25, 2005.)

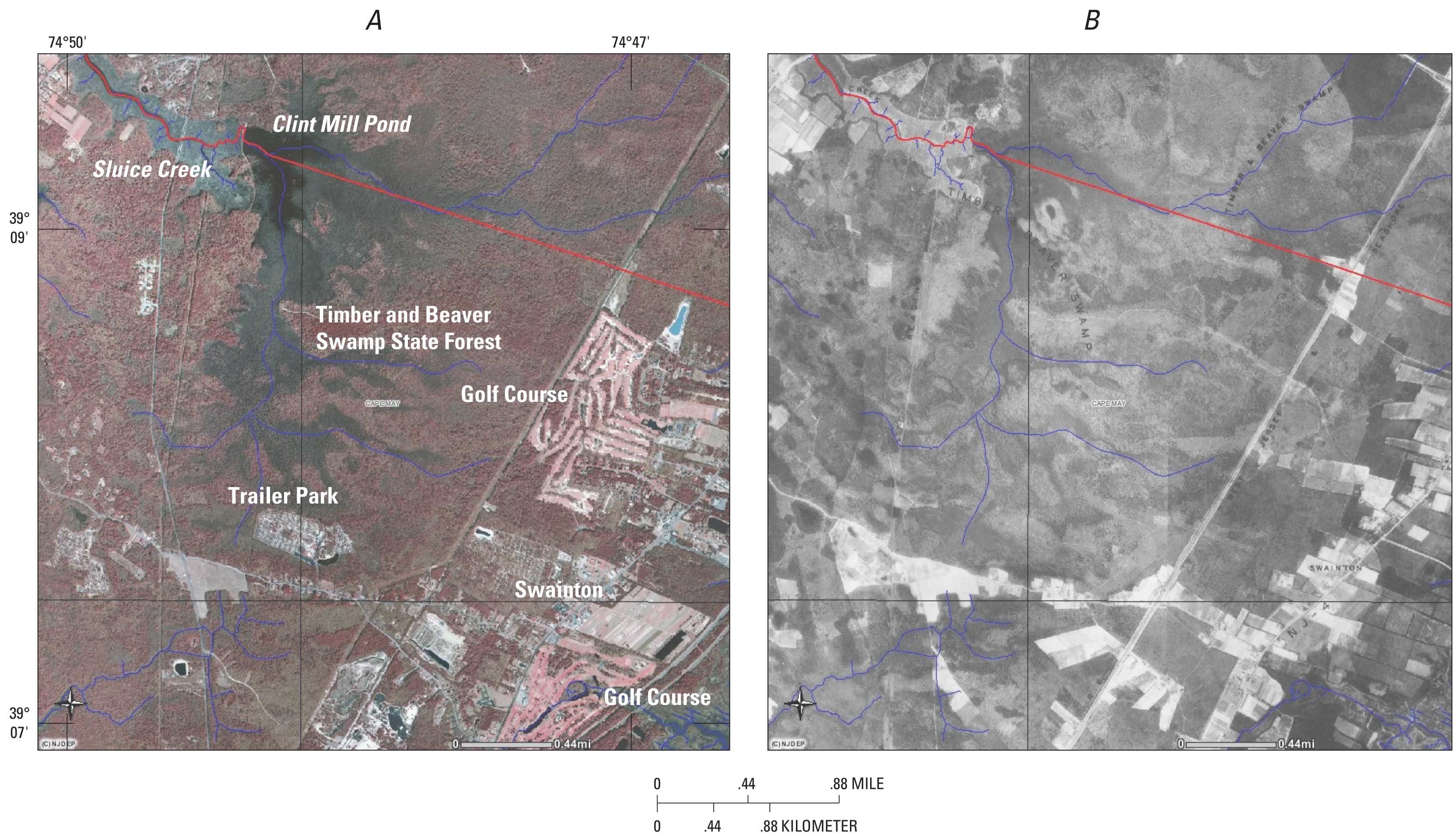


Figure 44. Air photographs from *(A)* 2002 and *(B)* 1930 showing Timber and Beaver Swamp State Forest Preserve, golf courses, headwaters area of Sluice Creek and Clint Mill Pond, and vernal ponds, Cape May County, New Jersey. (Air photographs taken in the 1930s and in 2002 available on the World Wide Web at N.J. Department of Environmental Protection, 2004, i-MapNJ DEP Map, accessed April 25, 2005.)

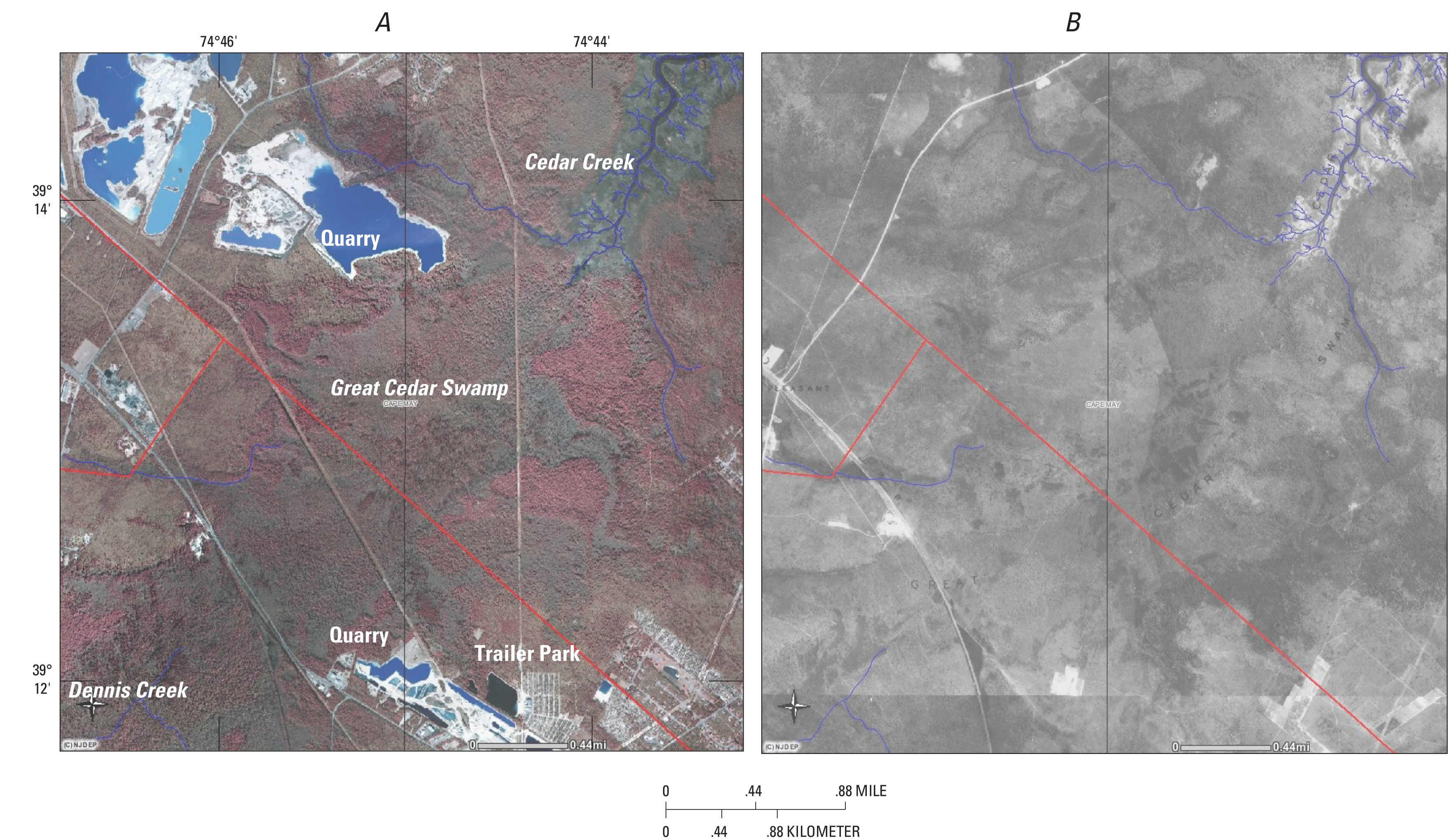


Figure 45. Air photographs from *(A)* 2002 and *(B)* 1930 showing Great Cedar Swamp, sand and gravel mines, headwaters area of the Cedar and Dennis Creeks, Cape May County, New Jersey. (Air photographs taken in the 1930s and in 2002 available on the World Wide Web at N.J. Department of Environmental Protection, 2004, i-MapNJ DEP Map, accessed April 25, 2005.)

extensive along the Delaware Bay shoreline and at the Cape May County Airport. The airport was constructed during WWII in formerly forested areas, and many housing tracts were constructed after WWII. During 1960-2000, farm and forest lands in many interior parts of Lower Township were converted to housing tracts. Preserved forest land such as Bennett's Bog, a former clay mine, still contains vernal ponds. Vernal ponds that were smaller than 0.25 acre likely have been filled in most residential areas.

Vernal ponds in some areas have been excavated and converted to recreation ponds for summer vacationers. Sand and gravel were excavated for road material during construction of the Garden State Parkway and other roads. The former quarries became ponds or are used as water hazards in newly constructed golf courses.

Less forested area exist, and there appear to be fewer vernal ponds in the 2002 photograph than in 1930s photograph. The decline in wetland, forest, and vernal ponds is a result of construction and land-use changes. The vernal ponds that remain near the LTMUA wells may dry up prematurely each summer as a result of groundwater withdrawals. In the future, ecological water demands in Lower Township will decrease as forests and farm lands are converted to residential and commercial lands.

Wildwood Water Utility Mainland Well Field

Air photographs of the Fishing Creek basin (fig. 42) show the WWU well field and the villages of Rio Grande, Green Creek, and Villas. Groundwater withdrawals by WWU began in 1910, and by 1930, withdrawals totaled 500 Mgal/yr. Withdrawals increased to 1,300 Mgal/yr in 2005. More than 80 percent of the withdrawals came from the Cohansey aquifer and the estuarine sand aquifer. Total ecological water demands for the forested areas shown in figure 42 decreased over the years because the extent of the forests has decreased.

The 1930s air photograph shows the bulk of the land was primal forested wetlands and uplands. Farm fields made up the balance of the land. The fields generally flank the major roadways. In the 1930s, the only pond was Pumping Station Pond created (fig. 33) when Fishing Creek was dammed. More than 20 circular or oval dark gray areas are visible in the forests (fig. 42B). Many are forested wetlands with vernal ponds.

The 2002 air photograph shows more than 75 percent of the farm fields were converted to residential and commercial land. In addition, many acres of forested land were converted to residential and commercial land. Hundreds of acres of forests were cleared during WWII to build the airport. Some vernal ponds and freshwater wetlands were excavated to create farm ponds and recreation ponds. Ponds also were created as a result of sand mining.

Ecologically preserved lands include much of the remaining forested area and tidal wetlands of Fishing Creek. Much of the land shown in these photographs is part of the recharge area for WWU well field.

The USGS measured water levels in four vernal ponds (VP12, VP14, VP15, and VP16, figs. 37 and 42) and the water-table aquifer within 1 mi of the WWU well field during 2002-05 to determine whether withdrawals affected ecological water supplies. Water-level measurements made for the vernal ponds showed that the ponds dry sooner and that the water level in the water-table aquifer recovers later compared with ponds and the aquifer in more forested areas with fewer withdrawals.

The ecological water demand of the forests and wetlands remained constant, but the extent of the forest and wetlands decreased, so the total ecological water demand for this area has decreased. The ecological water demand of the streams remained constant, regardless of the surrounding land use.

Cape May National Wildlife Refuge in Dias Creek Basin

Air photographs (fig. 43) of central Middle Township show the community of Cape May Court House and the parts of the Cape May National Refuge in the Dias Creek basin. The 1930s photograph shows most of the land is forested west of the rail line with a few farms along roadways. Most land between the rail line and the back bay is farmed, little of the land remains forested. The village of Cape May Court House is densely inhabited but limited to about a 10-block area. There were no production wells in this area in the 1930s. Potable water was obtained from shallow domestic wells, and disposal was by various domestic systems.

In the 1930s photograph, the darkest, rounded areas in the forests are wetlands and vernal ponds. There are few if any man-made ponds in the 1930s photograph.

The 2002 photograph shows that some of the land west of the rail line has remained forested, though there are many new roads and residential neighborhoods among them. Most farm fields have been converted to residential and commercial land, especially east of the rail line. Hundreds of acres of forest around Cape May Court House have been converted to residential/commercial land. As a result, Cape May Court House in 2002 covers five to six times more land than in the 1930s. Alternatively, many farm fields southwest of the landfill have revegetated with the native trees. Sand and gravel operations have created open ponds.

Ecological water demand within the forested area did not change during the 1930s to 2002. However, it is likely that total ecological water demand has decreased in urban and suburban areas and increased in areas where farmland has returned to forests.

Potable water in much of the area is provided by hundreds of domestic wells that tap the Holly Beach water-bearing zone and estuarine sand aquifer. The water from these wells is disposed of to domestic septic systems. Three production wells in Cape May Court House and along Route 9 withdraw water from the Cohansey aquifer and Atlantic City 800-foot sand. Thus, the net withdrawals in the area are much less than in areas to the south.

The USGS measured water levels in two vernal ponds shown in figure 43A. The ponds remained wet into mid-summer, about the average for ponds in Cape May County (fig. 38). Natural wetlands in both photographs appear to be viable. Groundwater withdrawals may not have had measureable effects on the ecological-water supply in most of this area.

Timber and Beaver Swamp in Sluice Creek Basin

Air photographs (fig. 44) of the Timber and Beaver Swamp region include the hamlet of Swainton and the headwaters of Sluice Creek. The 1930s air photograph shows that almost all of the land was forested with small farm fields along some major roadways. Farm fields were sparse along interconnecting roads. There appears to be a pond in the southwest part of the 1930s air photograph. The Timber and Beaver Swamp area was a primal forest with expansive wetlands. Numerous forested wetlands contain vernal ponds.

The 2002 air photograph shows much of the forest and wetlands in Timber and Beaver Swamp have remained in a primitive state, though all old-growth trees were removed and forest succession is progressing. The construction of Clint Mill Pond dam sometime after 1930 created a large freshwater pond on Sluice Creek. Housing tracts and golf courses have replaced most of the farm fields and some forested land outside of the State Forest. Ponds have been excavated for sand and gravel, golf course irrigation, and summer recreation. Vernal ponds and intermittent wetland forests continue to exist in many parts of the Timber and Beaver Swamp area. A vernal pond (VP-31) was sampled only during the 2006 wet season. It had the second longest wet season for 2006. No groundwater withdrawals were made within the forested swamp land. Sites of minor groundwater withdrawals are the golf courses, camp grounds, and trailer parks, but withdrawals at these sites are seasonal.

Great Cedar Swamp State Forest in Dennis and Cedar Creek Basins

Air photographs of the Great Cedar Swamp show the largest sand and gravel quarries in Cape May County (fig. 45). The Great Cedar Swamp straddles the headwaters of Dennis Creek and Cedar Creek.

In the 1930s the land was virtually all uplands and wetland forests with only a few acres of farmland and possibly a few small sand and gravel quarries. The area had little residential land and no commercial land or man-made ponds. Much of the swamp land was selectively logged for cedar during the 1800s (Kitchell, 1857; Dowart, 1992), but there is little evidence of logging in the 1930s photograph.

The 2002 air photograph shows that uplands and wetland forests are extensive. Large sand and gravel quarries have replaced upland forests in large areas north and south of the Great Cedar Swamp. The quarries consist of expansive dredge ponds and deforested land. Vacation trailer parks now occupy an area south of the Great Cedar Swamp.

Ecological water demand in the forested land likely has changed little over the decades. The affects of land use changes and groundwater withdrawal on the ecological water supply are likely small. Evaporation from the quarry ponds is about 36 in/yr, and the deforested lands around the ponds have little evaporation and no transpiration. It is estimated that the quarry, as a whole, has about the same ET as the forested land. The vacation trailer parks withdraw little water, but they dispose of it in on-site wastewater disposal systems so the lowering of the water level in the shallow aquifers by these withdrawals is minimal.

Most forested wetlands are intact. The sand and gravel pits may affect the ecological water supply outside the boundary of the quarry, but that was not investigated as part of this study.

Simulation of Groundwater Flow and Saltwater Movement

Three-dimensional, aerially extensive groundwater-flow models are the best tool available to quantitatively predict future saltwater intrusion rates, water-level changes, and changes in discharge to surface-water bodies from a number of possible future withdrawal scenarios. Groundwater withdrawals from the shallow aquifer system potentially cause movement of the saltwater front in the Holly Beach water-bearing zone, estuarine sand aquifer, and the Cohansey aquifer and depletion of ecological water supplies from the Holly Beach water–bearing zone and surface waters. Withdrawals from the deep aquifers cause different movement of the saltwater front because the front is more diffuse and farther from production wells in the Rio Grande water-bearing zone and Atlantic City 800-foot sand. There is less concern about the effects of withdrawals from deep aquifers on the ecological water supplies because the effects are so diffuse. However, water levels in the Atlantic City 800-foot sand are already (2008) as much as 75 ft below sea level and will be further lowered by increased withdrawals.

The lateral hydrologic boundaries of the shallow aquifer system generally coincide with the political boundary of Cape May County, whereas the boundaries for the deep aquifer system extend well beyond the county boundaries. Therefore, the USGS simulated groundwater flow in the shallow and deep aquifer systems of Cape May County separately. Flow in the shallow aquifers was simulated with a small-cell-size numerical model extending to the hydrologic boundaries. Flow in the deep aquifers was simulated with a medium-cell-size numerical model encompassing Cape May County and having boundaries that coincide with internal cells of a coarse-cell-size Coastal Plain-wide model from which boundary flows from outside Cape May County were obtained.

Conceptual Model of Groundwater Flow

The groundwater-flow system of Cape May County is conceptualized as having two scales: (1) a local scale, shallow system in which groundwater recharge from precipitation enters the shallow aquifers at or near the area where the precipitation falls and discharges to streams and coastal wetlands within a few miles, and (2) a regional scale, deep system in which recharge and discharge are spatially diffuse and enter and leave the deep aquifers through overlying confining units and aquifers. The Holly Beach water-bearing zone is strictly local scale. The estuarine sand and Cohansey aquifers (shallow system) are local scale in the northern part of the county and transition to an intermediate to regional scale in the southern part of the county. The Rio Grande water-bearing zone and the Atlantic City 800-foot sand (deep system) are regional scale, with recharge and discharge areas extending beyond the county boundary. The hydrologic boundaries of the shallow system are small streams, the Tuckahoe and Maurice Rivers, and overlying saltwater (saltwater wetlands, bays, and open water of the Delaware Bay and Atlantic Ocean), except in the downdip (southeast) direction where relatively stagnant, salty water in the Cohansey aquifer is assumed to extend for miles and acts as a no-flow boundary. The two deep-system aquifers subcrop north and west of Cape May County. Groundwater flow in the part of the deep-system aquifers underlying Cape May County has regional characteristics that include the effects from withdrawals made in Atlantic County.

Description of the Shallow Aquifer System Groundwater-Flow Model

The saltwater transport modeling code, SEAWAT (Langevin and others, 2003; Guo and Langevin, 2002), was used to model the shallow system because of the accurate treatment of variable-density groundwater (saltwater front) and surface-water boundary (ecological water supply) conditions. SEAWAT uses MODFLOW (Harbaugh and others, 2000) to solve the variable-density groundwater-flow equation and MT3D (Zheng and Wang, 1998) to solve the saltwater transport equation. The SEAWAT code uses a one-step lag between solutions of flow and transport (Langevin, 2001). This means that MT3D runs for a time step, and then MODFLOW runs for the same time step using the last concentration values from MT3D to calculate the density terms in the flow equation. In the next time step, velocities from the current MODFLOW solution are used by MT3D to solve the transport equation. Surface-water boundary conditions were simulated using the General Head Boundary, River, or Drain Packages of MODFLOW.

The model area is the same as that in Spitz (1998), extending from near the northern and western borders of Cape May County to the southern end of the county and out into Delaware Bay and the Atlantic Ocean (fig. 46).

Grid, Boundary Conditions, and Time Discretization

The finite-difference model grid has 204 rows and 135 columns that are variably spaced. The smallest grid cells, centered over the mainland part of the peninsula, are 1,000 ft (305 m) on a side, and the largest grid cells are 1,500 ft (460 m) on a side (fig. 47).

The model has 13 layers. Layer 1 represents the Holly Beach water-bearing zone. The estuarine sand aquifer, the Cohansey aquifer, and the two confining units separating the three aquifers are represented by three layers each (fig. 48). The altitudes of the tops and bottoms of the aquifers and confining units are modified from Lacombe and Carleton (2002) so that when represented as layers they extend across the model. As a result, the layers representing the estuarine clay confining unit and estuarine sand aquifer continue past the limits shown by Lacombe and Carleton (2002). The layer properties are such that they reflect and represent the hydrogeologic system similar to that of Lacombe and Carleton (2002). Within each hydrogeologic unit (below the Holly Beach water-bearing zone), the three model layers representing each aquifer and confining unit are of equal thickness.

The top boundary of the model includes recharge (a specified-flow boundary) from precipitation added to the top model layer in non-tidal areas at an estimated mean annual rate (fig. 49). Aquifer recharge typically is estimated by measuring stream base flow, but in Cape May County some recharge to the groundwater system bypasses the stream system and discharges directly to tidal wetlands. Therefore, aquifer recharge in Cape May County was assumed to be greater than estimated base flow. The estimated mean annual base flow of 13 small streams in the county is 12 in/yr (Lacombe and Carleton, 2002). The mean annual base flow of the Tuckahoe River at Head of River (a larger basin than those of the 13 small streams measured for this study with a small percentage of the basin adjacent to tidal wetlands) is 16.2 in/yr. Spitz (1998) used recharge of 16.6 in/yr, which is based on a water budget for the unsaturated zone developed by Lacombe and Carleton (2002) used to estimate recharge by subtracting estimated evapotranspiration and direct runoff from average precipitation.

Estimation of recharge is further complicated by the presence of freshwater wetlands that receive less net groundwater recharge than uplands because precipitation falling on saturated wetlands may runoff more readily than in upland areas (rejected recharge), and because the evapotranspiration rate is greater from saturated wetlands than from upland areas. In Ocean County, New Jersey, Nicholson and Watt (1997) estimated groundwater recharge in wetlands to be 6.5 to 10.0 in. less than in upland areas.

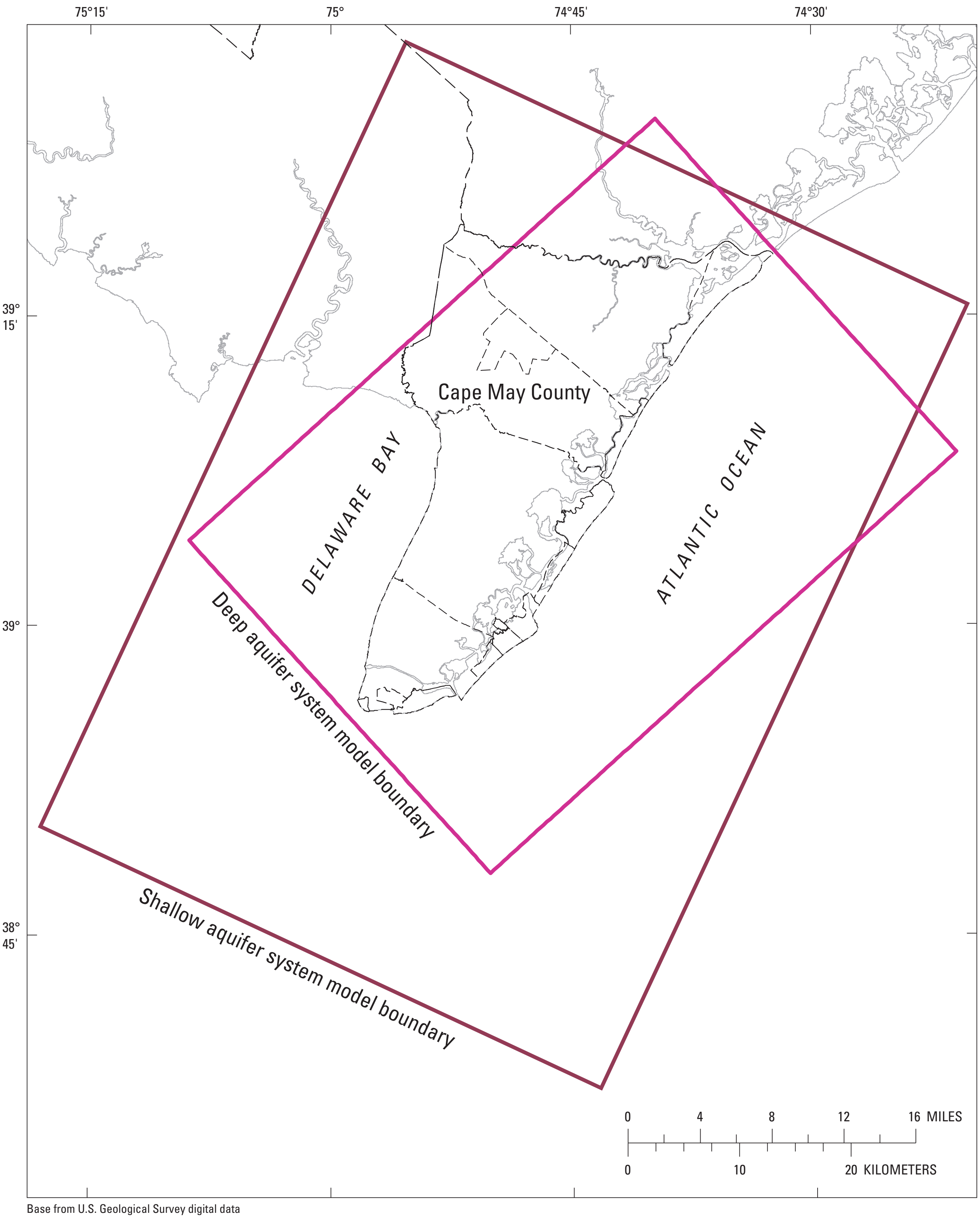


Figure 46. Location of study area and model boundaries, Cape May County, New Jersey.

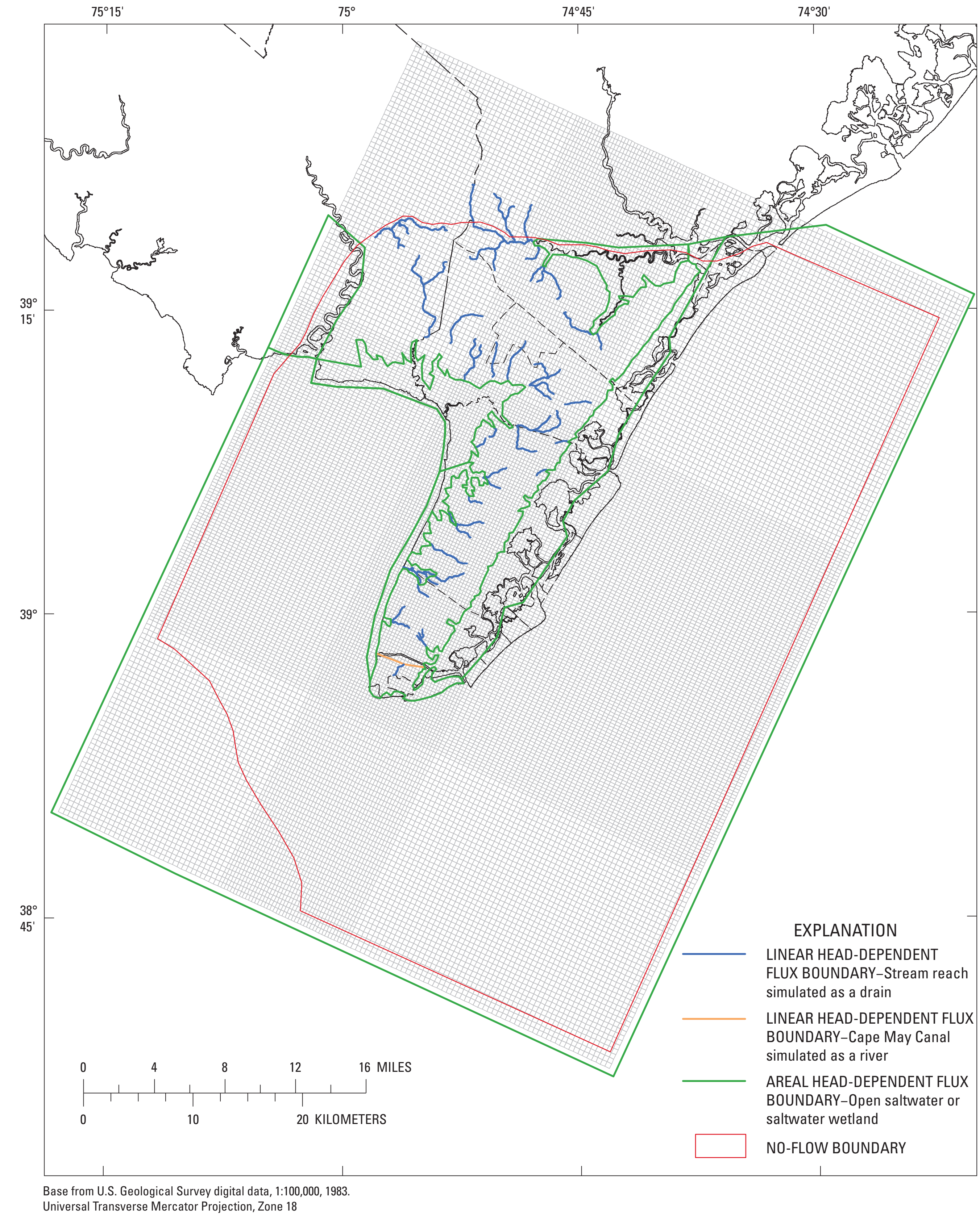


Figure 47. Shallow aquifer system numerical model grid and boundaries, Cape May County, New Jersey.

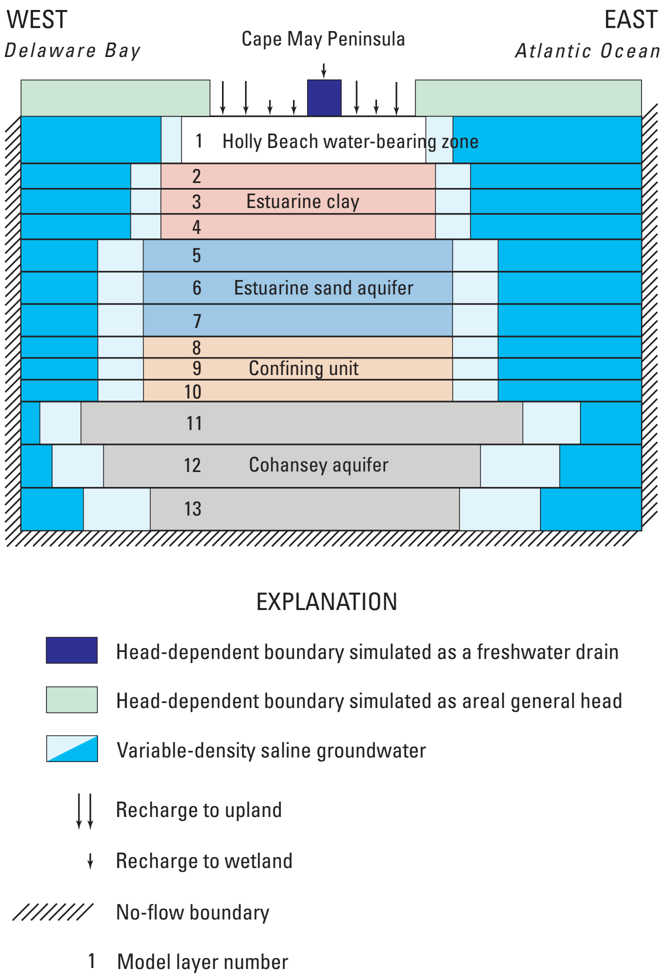


Figure 48. Schematic section showing aquifers, confining units, and the corresponding model layers and boundary conditions in the shallow aquifer system numerical flow model, Cape May County, New Jersey.

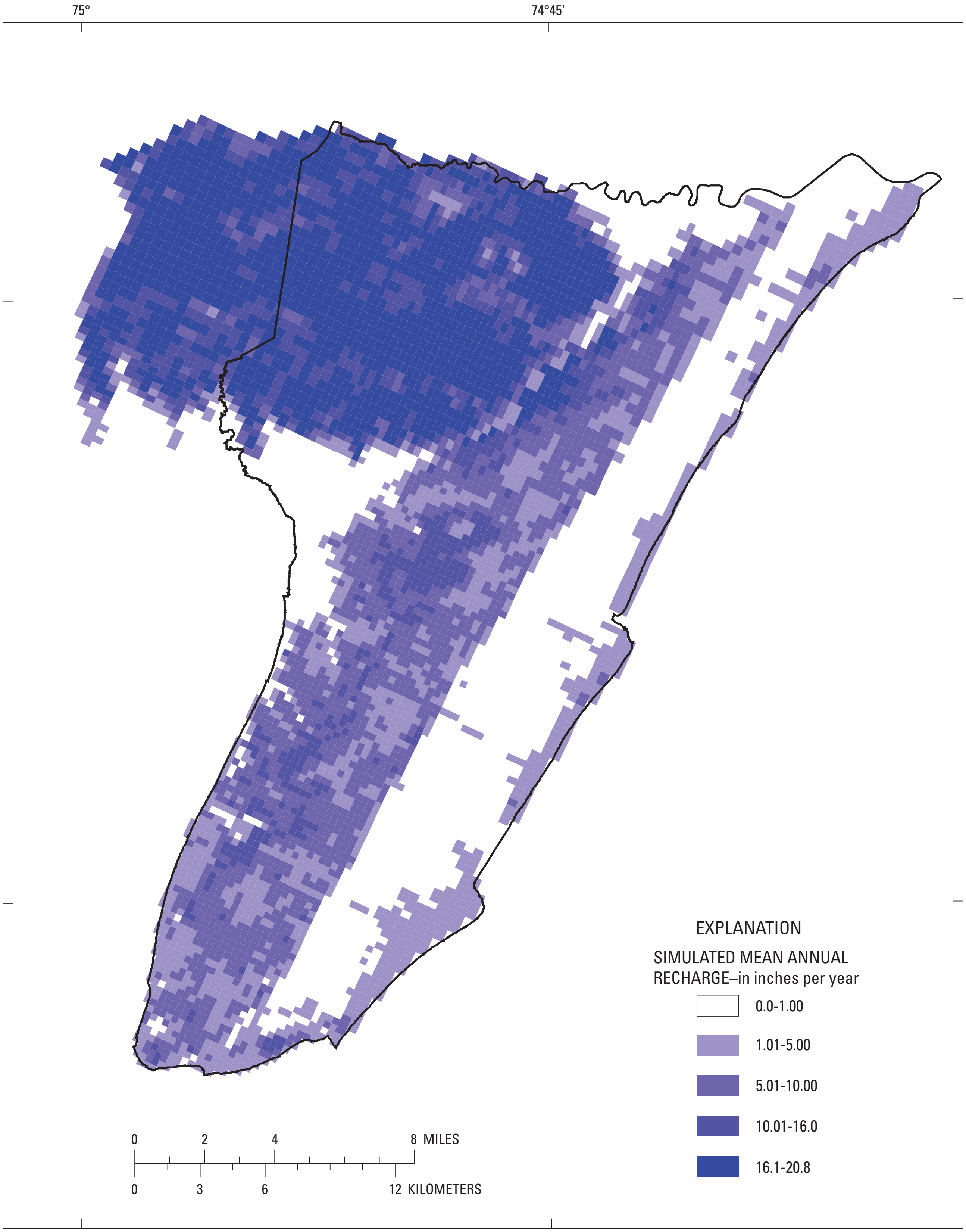
The groundwater recharge rates used in the shallow system model were 0 in/yr in saltwater tidal areas, 1 in/yr in freshwater wetlands, 18.0 in/yr in uplands south of Great Cedar Swamp, and 23.4 in/yr in uplands north of Great Cedar Swamp. The net recharge rate for each model cell was calculated by multiplying the percentage of upland, freshwater wetland, and tidal areas within the cell by the estimated recharge rate for the respective land type. During model calibration, base flows and water levels north and west of Great Cedar Swamp were found to be too low when a recharge rate of 18 in/yr was used, so recharge in uplands was increased to 23.4 in/yr in this area (fig. 49). This was considered reasonable because precipitation measured at Belleplain State Forest in the northern part of the county was 2.5 in/yr greater than precipitation measured at Cape May Airport near the southern tip of the county.

The top boundary, which contains surface-water bodies such as streams, was simulated as head-dependent flux boundaries using the General Head Boundary, River, or Drain Packages of MODFLOW. For each of these boundaries, water flows into or out of the model according to a fixed head in the boundary, a varying head in the aquifer, and a fixed bed-sediment conductance between the boundary and the aquifer. The bed-sediment conductance was calculated as the product of the hydraulic conductivity of the bed sediments and the area of the boundary, divided by the thickness of the bed sediments. For the linear features of streams and the Cape May Canal, the area used is the estimated width of the water body times the length within each model cell. The hydraulic conductivity of bed sediments, sediment thickness, and in some cases, stream widths were not well known, so bed-sediment conductance was treated as a lumped parameter and varied during calibration.

The Atlantic Ocean, Delaware Bay, and tidal wetlands were all represented in the model as aerial head-dependent flow boundaries using the General Head Boundary Package of MODFLOW (fig. 47). The bed-sediment conductance used for the general head boundaries affected the base flow of streams, so the general head boundaries were divided into four separate areas—tidal wetlands along the Atlantic Ocean side of the county, tidal wetlands along the Delaware Bay side of the peninsula, tidal wetlands north and west of Dennis Creek, and the remaining open-water areas of the Atlantic Ocean and Delaware Bay.

The elevation assigned to the general head boundaries for each stress period was adjusted according to estimated sea level during 1896-1910 and measured sea level during 1911-99 at Atlantic City, New Jersey (National Oceanic and Atmospheric Administration, 2007). Sea level rose 1.31 ft per century during that period (3.99 mm/yr). Estimates of future sea-level rise are uncertain. The Intergovernmental Panel on Climate Change (IPCC) estimates that sea level will likely rise 7.2 to 23.6 in. (0.18 to 0.60 m) by 2100, with the rate of rise increasing with time (U.S. Environmental Protection Agency, 2007). For this model, it was assumed that sea level will rise by 10 in. during 1999-2050, with the rate of rise being constant at 0.20 in/yr (5.1 mm/yr). This is a conservative estimate because it is near the high end of the estimated range and increases faster during the early part of the century. Sea level is referenced to a datum and was 0.00 ft in 1929 using NGVD29 (National Geodetic Vertical Datum 1929). NAVD88 (North American Vertical Datum 1988) is 1.33 ft higher than NGVD29, so sea level in 1929 was -1.33 ft referenced to NAVD88. Estimated sea levels for 1896–2050 (model stress periods 1–17) are shown in table 10. In simulations, sea level was set at -1.86 ft (NAVD88) in 1896, -1.33 ft in 1929, -0.32 ft during 1999-2003, and 0.47 ft during 2042-2050.

The small streams of Cape May and Cumberland Counties and the Tuckahoe River were modeled as linear head-dependent flux boundaries using the Drain Package of MODFLOW (fig. 47). The Drain Package only allows groundwater to leave the model; if simulated heads in the aquifer are lower than the specified head in the drain, no flow to or from the boundary occurs. The General Head Boundary and River



Base from U.S. Geological Survey digital data, 1:100,000, 1983.
Universal Transverse Mercator Projection, Zone 18

Figure 49. Mean annual recharge rates applied to the shallow aquifer system numerical model, Cape May County, New Jersey.

Packages allow water to flow into or out of the model, depending on whether the head in the aquifer is lower or higher, respectively, than the boundary head, potentially supplying an unrealistic source of recharge to the aquifer. The small streams of Cape May County typically do not have sufficient flow to recharge the aquifer when heads are below the stream stage. Furthermore, the streams in Cape May County are believed to be generally gaining streams, and any local-scale flow into the model from a stream (using the River Package) would be unrealistic. Therefore, the Drain Package better represents the streams.

Cape May Canal was modeled as a linear head-dependent flux boundary using the River Package of MODFLOW (fig. 47). The general head boundary could have been used, but for ease of model construction and water-budget accounting reasons, the River Package was chosen. Unlike the small streams elsewhere in the County that would not be a source of groundwater recharge, allowing flow into the model from the canal is realistic, so the River Package is more appropriate than the Drain Package.

The lateral boundaries of the model are no-flow boundaries that either correspond with natural hydrologic boundaries or are distant from the area of interest, such that the boundary does not affect model performance. The northern lateral boundary (from east to west) represents Great Egg Harbor, the Tuckahoe River, an unnamed tributary to the Tuckahoe River, a short section that does not correspond with a surface-water body, an unnamed tributary of the Maurice River, and the Maurice River. Except for the short section between the headwaters of the two small tributaries, these lateral boundaries are believed to be no-flow boundaries because groundwater discharges to the surface-water bodies and does not flow under the surface-water body into the model domain from the north. The west, south, and east lateral boundaries of the model all underlie Delaware Bay or the Atlantic Ocean and are designed to be far enough from areas of recharge and discharge that no significant head changes reach the boundary.

The time periods simulated for model calibration (1896-2003) and for prediction of future conditions (2004-2050) were discretized into intervals ranging from 4 to 10 years (table 10). An initial period of 100 days, representing predevelopment conditions, was included solely to establish a numerically stable initial condition for the saltwater transport.

Groundwater Withdrawals

The shallow model was run as a transient model; therefore, withdrawal data were entered for the simulation period of 1896 to 2050. Well-by-well withdrawal data for 1896 to 1979 were taken from Spitz (1998). Withdrawal data for 1980 to 2005 were obtained from the USGS Site-Specific Water Use Data System (SWUDS) into which water-use data reported to the NJDEP by purveyors are entered and checked for accuracy. Estimates of future demands used in the model were developed by the NJDEP and are described in the "Methods to Determine Potable Water Demand" section of this report. Magnitudes of total reported withdrawals are shown in figure 50, and locations of production wells with withdrawals input to the shallow model are shown in figures 51 and 52. Model input data are presented in table 11 (at end of report). Adjustments to the values reported to the NJDEP were made for the Rio Grande well field during 1989-1995 and a sand/gravel mine in 1992. The mine reported 1,300 Mgal/yr withdrawals for 1992 but for no other years. As discussed in the "Mining Demand" section of this report, groundwater or surface-water withdrawals for mining are essentially not consumptive. Furthermore, the inclusion of withdrawals for only 1 year when other years probably had similar usage is potentially misleading, especially when the use reported by the one facility represented about one-half of the total reported groundwater withdrawals from the shallow aquifer system for the entire county. Reported withdrawals for the Rio Grande well field during 1989-92 were about twice those for previous years and zero during 1993-94. Therefore, the withdrawals for 1989-94 were estimated to be similar to the preceding and following years.

Locations and depths of most of the thousands of domestic wells in Cape May County are not known. Therefore, locations and depths of wells listed in the NJDEP database were used as a starting point. Next the total of estimated domestic withdrawals, by town, was divided by the number of known wells. Known wells were sorted by aquifer; withdrawals representing total estimated domestic withdrawals were distributed evenly to all known wells. Wells believed to be open to the water-table aquifer in sewered areas were assumed to have 100 percent consumptive use. Domestic withdrawals were assumed to increase in even increments (9 percent) from one model stress period to the next (table 10) because the effects of domestic withdrawals are relatively small, and estimates of domestic withdrawals prior to the 1990s were not readily available.

WWU uses four wells on the barrier island for aquifer storage and recovery (ASR). During the non-summer months, water is withdrawn from wells in the WWU Rio Grande well field and reinjected into the Cohansey aquifer wells on the island. During the summer, the four ASR wells are used for withdrawals until the chloride concentrations approach 250 mg/L (Gary Ziegler, Wildwood Water Utility, oral commun., 2006). The net annual amount of water injected into or withdrawn from the four ASR wells was input to the model. CMCWU and B.L. England Electrical Generating Station in Upper Township have operated ASR systems intermittently at low injection rates. ASR systems at these two sites were not represented in the model.

Hydraulic Characteristics of Aquifer and Confining Unit Layers

Hydraulic conductivities used in the shallow groundwater-flow model were based largely on model calibration results. Spitz (1998) summarized available aquifer and

Table 10. Discretized time period simulated with the shallow aquifer system model, Cape May County, New Jersey.

[NAVD88, North American Vertical Datum of 1988]

Model stress period		Time period	Duration (in days)	Estimated 2003 domestic withdrawals for stress period (percent)	Estimated sea level altitude for stress period (in feet, NAVD88)
1	Calibration (past)	Predevelopment	100	0	-1.86
2		1896-1921	8,766	9	-1.48
3		1922-50	10,592	18	-1.15
4		1951-58	2,922	27	-0.91
5		1959-65	2,557	36	-0.82
6		1966-69	1,461	45	-0.74
7		1970-79	3,653	55	-0.65
8		1980-83	1,461	64	-0.56
9		1984-88	1,826	73	-0.51
10		1989-93	1,826	82	-0.45
11		1994-98	1,826	91	-0.39
12		1999-2003	1,826	100	-0.32
13	Scenario (future)	2004-10	2,557	100	-0.18
14		2011-20	3,653	100	-0.04
15		2021-30	3,653	100	0.13
16		2031-40	3,653	100	0.30
17		2041-50	3,653	100	0.47

confining-unit transmissivity and hydraulic-conductivity data. The values used in the model were initially guided by these available aquifer-test data but were adjusted during calibration. The model is a comparatively homogeneous representation of a heterogeneous system; therefore, the values of hydraulic conductivity used in the simulations represent an approximation of the areal average of the actual aquifer properties. For all model layers and hydrogeologic units, the vertical hydraulic conductivity was assumed to be one-tenth of the horizontal hydraulic conductivity. All values given in this section and on the accompanying figures are for horizontal hydraulic conductivity.

The hydraulic conductivity for the Holly Beach water-bearing zone (model layer 1) is 300 feet per day (ft/d) (fig. 53). This is slightly higher than the 152 to 286 ft/d range of values used by Spitz (1998) but is a reasonable value for the homogeneous representation of a regional system.

The simulated hydraulic conductivities for model layers 2-4 (representing the estuarine clay which is a confining unit overlying the estuarine sand aquifer in the southern part of the county, and undifferentiated sediments of the Holly Beach water-bearing zone in the northern part of the county) ranged from 0.0013 ft/d to 0.15 ft/d (fig. 54). The value for conductivity for these layers is higher in the northern part of the county than in the southern part of the county but is lower than that for the northern part of the county for the overlying and underlying model layers representing the Holly Beach water-bearing zone and estuarine sand aquifer, respectively. This is a result of attempts to improve the matches between simulated and measured water levels and base flows in the northern part of the county. There are few geophysical or high-quality driller's logs characterizing the hydrogeologic framework in the northern part of the county, and the environment of deposition probably consisted of relatively heterogeneous barrier-island sand/back-bay clay sequences. Therefore, although the locations of intermittent low-permeability zones are not well known, their presence is assumed and represented by the lower permeability model layers 2-4 between the higher permeability model layers 1 and 5-7. The lowest hydraulic conductivity (in the area considered to be the estuarine clay by Gill, 1962 and Lacombe and Carleton, 2002) is 0.0013 ft/d, similar to the value of 0.004 ft/d used by Spitz (1998).

The simulated hydraulic conductivities for model layers 5-7 (representing the estuarine sand aquifer in the southern part of the county and undifferentiated sediments of the Holly Beach water-bearing zone in the northern part of the county) range from 90 ft/d in the southern part of the county to 200 ft/d in the northern part (fig. 55). The hydraulic conductivities are similar to, although slightly higher than, the 55 to 126 ft/d used by Spitz (1998).

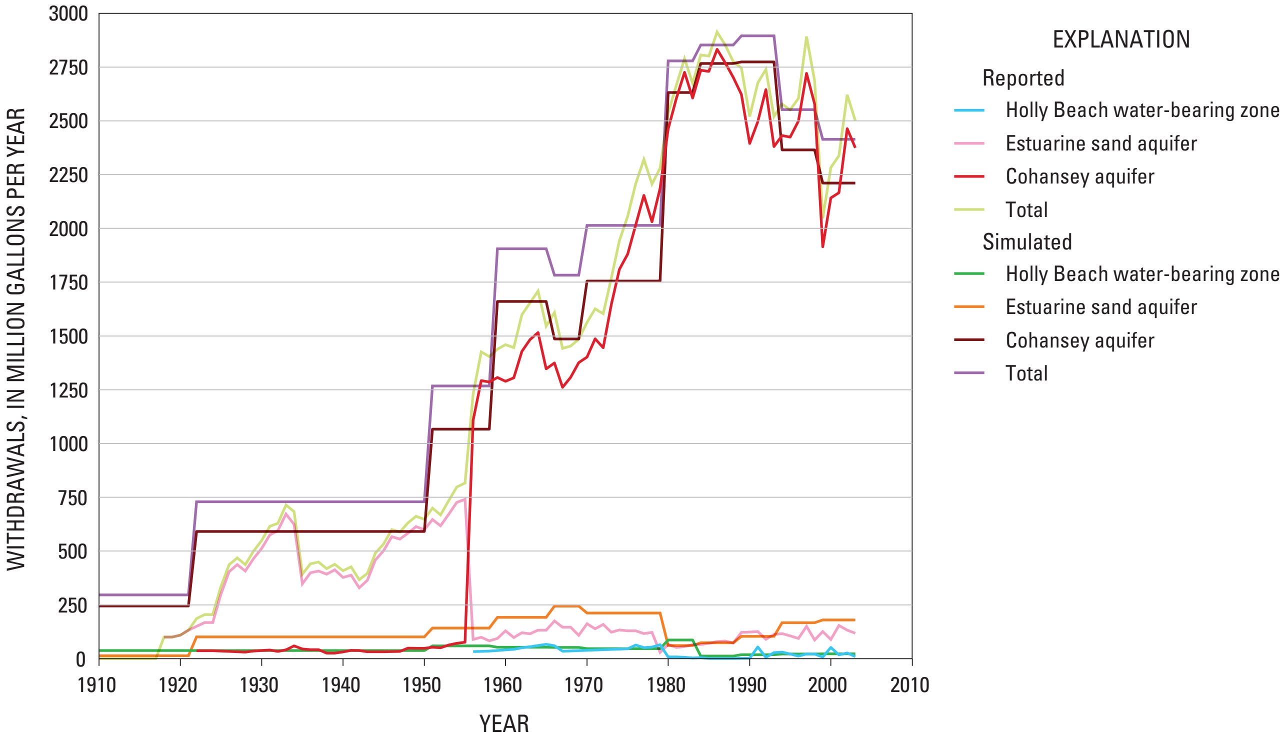


Figure 50. Reported and simulated withdrawals from the shallow aquifer system, Cape May County, New Jersey, 1896 to 2003. (Reported values for 1989-95 include estimates to correct double-reported or non-reported withdrawals from two users.)

The simulated hydraulic conductivities for the confining unit overlying the Cohansey aquifer (model layers 8-10) range from 0.000066 ft/d in the southernmost part of the county to 3.7 ft/d in the northern part of the county (fig. 56). The simulated hydraulic conductivity in the northern part of the county is lower than that of the overlying and underlying aquifers but higher than that in the southern part of the county because of the assumed presence of discontinuous low permeability zones. These zones may have individual permeabilities that are lower than the simulated values, but the average permeability is greater than the permeability of the more continuous clay that is present farther south. The hydraulic conductivity in the southernmost part of the model is about 30 times lower than the 0.002 ft/d value used by Spitz (1998), but the county-wide average is similar. The use of very low permeability values in the southernmost part of the county was indicated during calibration by water levels in wells in Cape May City and southern Lower Township open to the Cohansey aquifer. Spitz (1998) was unable to closely match water levels in the vicinity of the Cape May City and WWU Rio Grande well fields. Decreasing the permeability values in the south improved the model fit at both locations, allowing a better match to measured water levels. The low value (0.000066 ft/d) of hydraulic conductivity may be unrealistically low, but it is believed to represent a possible decrease in the leakance (hydraulic conductivity divided by thickness) of the confining unit to the south and east that is represented in this model by low hydraulic conductivities instead of by increased thickness in the hydrogeologic framework.

The simulated hydraulic conductivities for the Cohansey aquifer (model layers 11-13) range from 5 ft/d southeastern corner of the model (underlying the Atlantic Ocean) to 200 ft/d in the northern part of the county (fig. 57). The hydraulic conductivities are similar to, although slightly higher than the 18 to 90 ft/d used by Spitz (1998). The decrease in hydraulic conductivity to the south and east was indicated during calibration and is believed to represent a gradual decrease in the grain size of aquifer sediments with depth representing deposition in a more distal environment and greater compaction in the deep environment.

The value of porosity used in the model does not affect simulated water levels or discharge to streams but greatly affects the rate of saltwater intrusion, especially where withdrawals have lowered water levels to below sea level. The porosities of the aquifers and confining units were assumed to be 30 percent and 40 percent, respectively. No measurements of the porosity of confined aquifers in Cape May County were available. Masterson and others (1997, p. 20) summarize investigations on Cape Cod, Massachusetts, and Long Island, New York, that yielded porosity estimates of sand aquifers of 35 to 42 percent and 34 to 38 percent, respectively. For this study it was assumed that the Cohansey aquifer was deeper and, therefore, more compressed than the shallower, younger aquifer in Cape Cod. Because a lower value of porosity leads

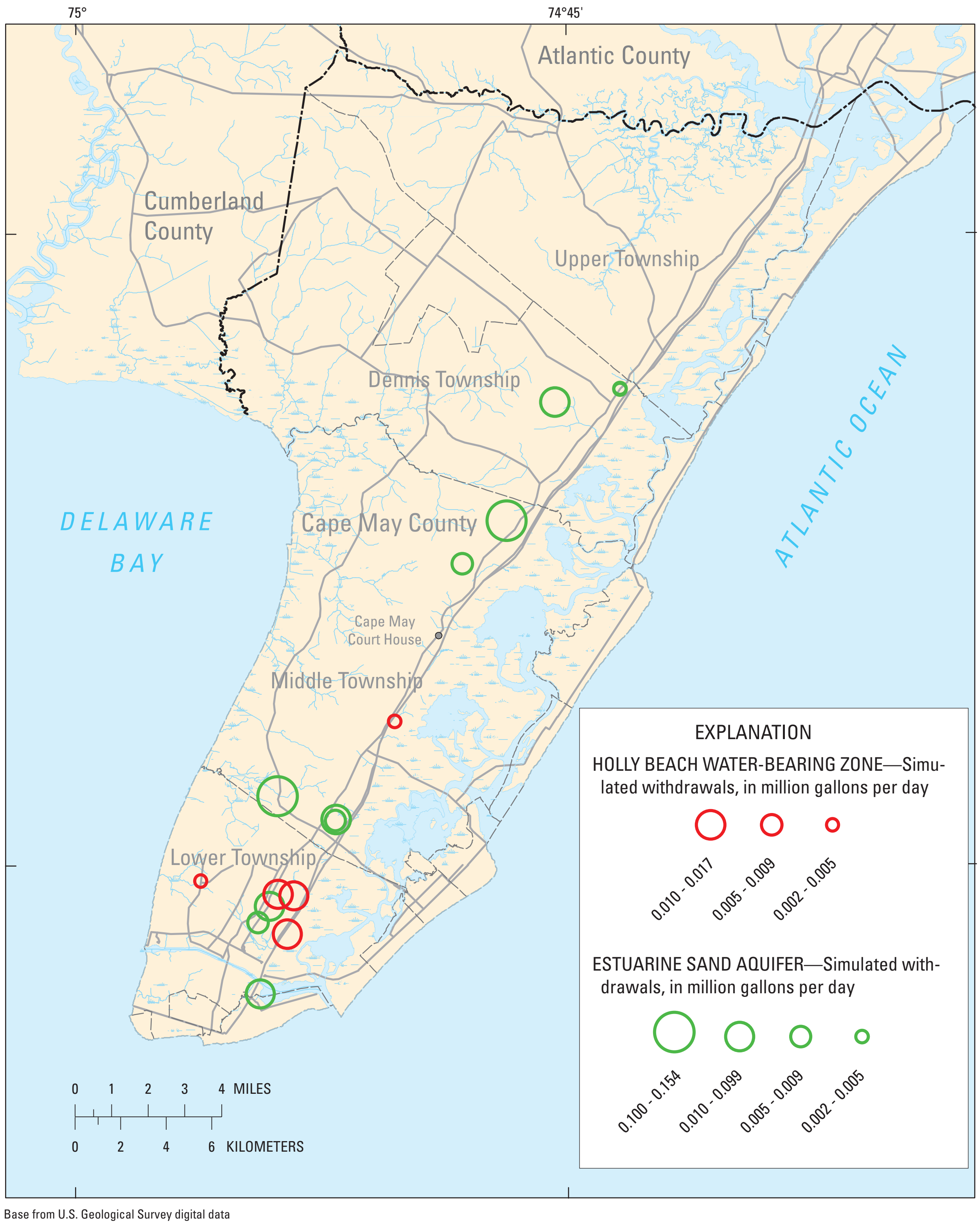


Figure 51. Locations of wells and magnitude of reported average Holly Beach water-bearing zone and estuarine sand aquifer withdrawals input to the shallow aquifer system model, Cape May County, New Jersey, 1999-2003.

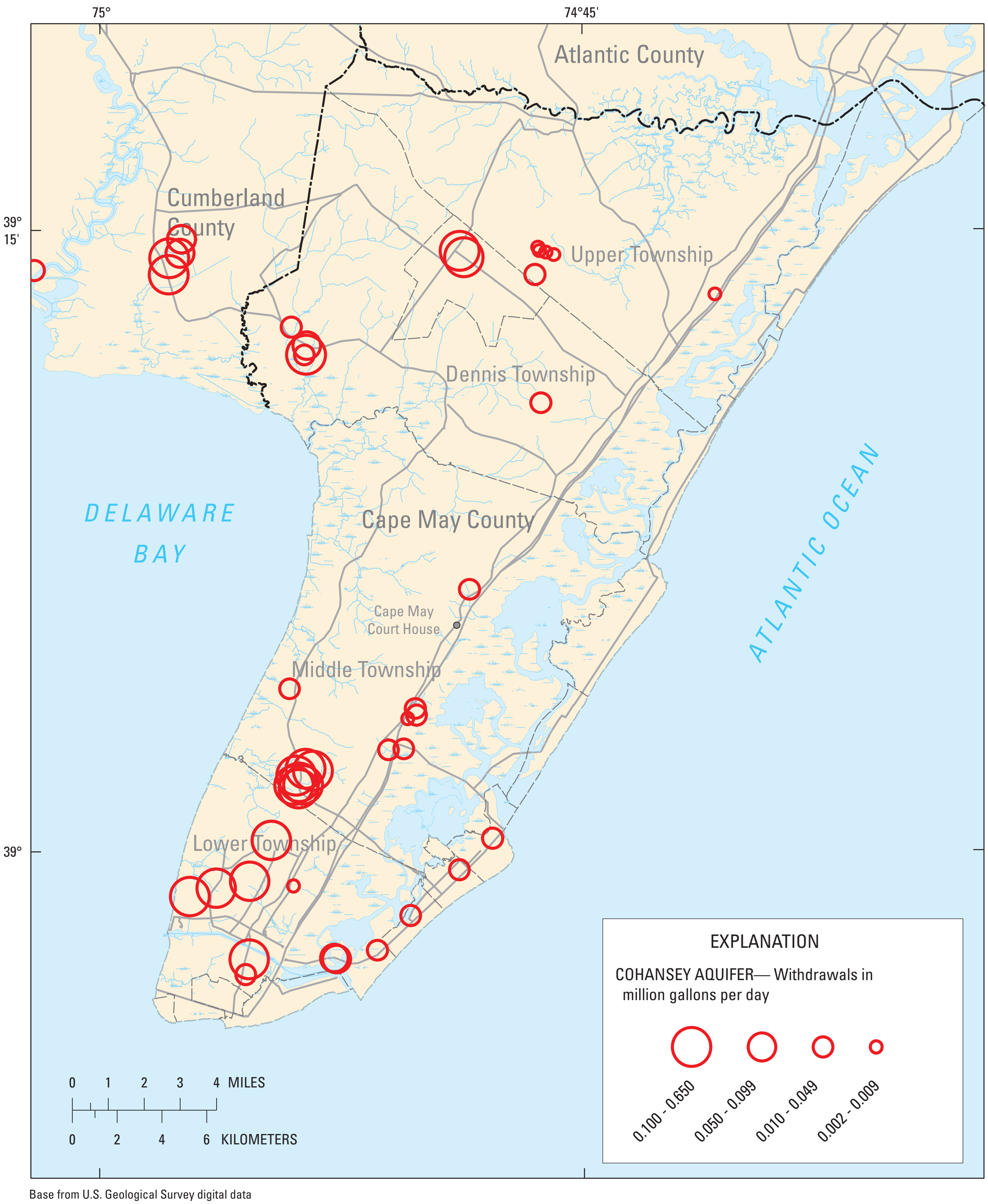


Figure 52. Locations of wells and magnitude of reported average Cohansey aquifer withdrawals input to the shallow aquifer system model, Cape May County, New Jersey, 1999-2003.

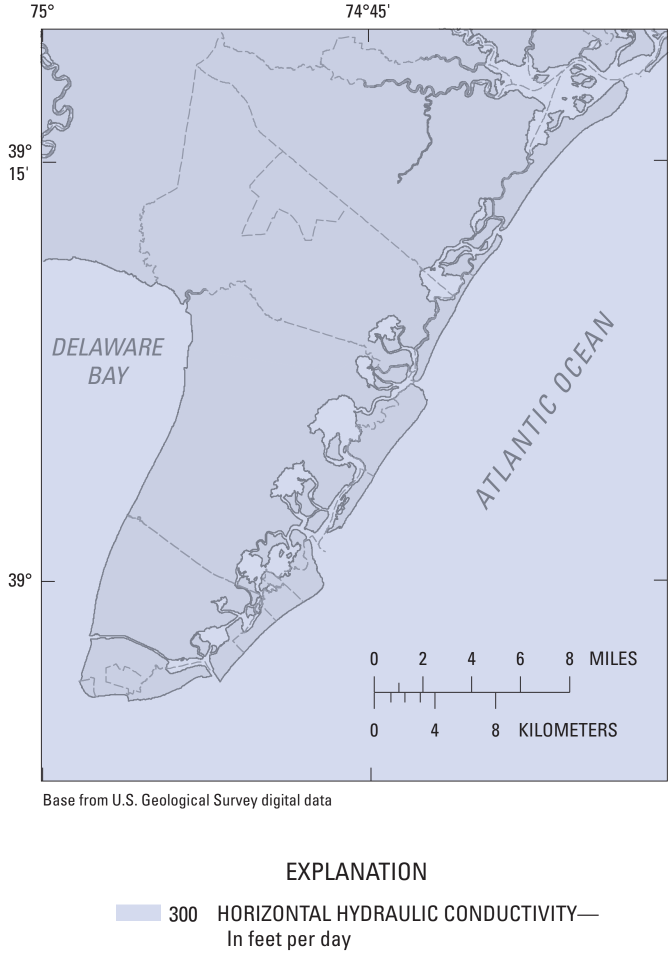


Figure 53. Hydraulic conductivity in the Holly Beach water-bearing zone (model layer 1) used in the shallow system numerical model, Cape May County, New Jersey.

to more rapid saltwater intrusion, use of 30 percent, instead of the higher values found in the above referenced studies, is a conservative choice. For simplicity, the same value of porosity was used for all three aquifers.

Location of Saltwater/Freshwater Interface

The location of the saltwater/freshwater interface (defined in this report as the location of the 250-mg/L isochlor, unless otherwise stated) in the shallow confined aquifers prior to 1900 is not known and cannot be readily estimated with long-term simulations because of other uncertainties (for example, varying post-ice age sea levels, long-term recharge, and initial location of the interface). Multi-century simulations under non-stressed (predevelopment) conditions for this study show movement of the saltwater/freshwater interface in the Cohansey aquifer towards locations inland from the current location, indicating that conditions in 1900 were not in equilibrium with modern sea level. Pope and Gordon (1999) concluded that sea levels were approximately stable during the period 110,000 to 84,000 years ago, then simulated the movement of a sharp saltwater/freshwater interface with changing sea levels from 84,000 years ago to 100 years ago for the major aquifers of the New Jersey Coastal Plain. They concluded that the simulated sharp interface in the Atlantic City 800-foot sand was moving inland as groundwater conditions adapt to sea levels rising from 18,000 years ago to 100 years ago and had not yet reached equilibrium. The shallow groundwater system in Cape May County responds more rapidly to sea-level change than the deep aquifer system, and the smaller scale of this model made simulations over tens of thousands of years difficult to calibrate. Therefore, the initial location of the saltwater/freshwater interface was estimated by comparing movement and simulated location in the past 100 years to measured and estimated results, then adjusting the initial conditions such that known and presumed locations of the interface from 1896 to 2003 were well reproduced. This approach does not guarantee

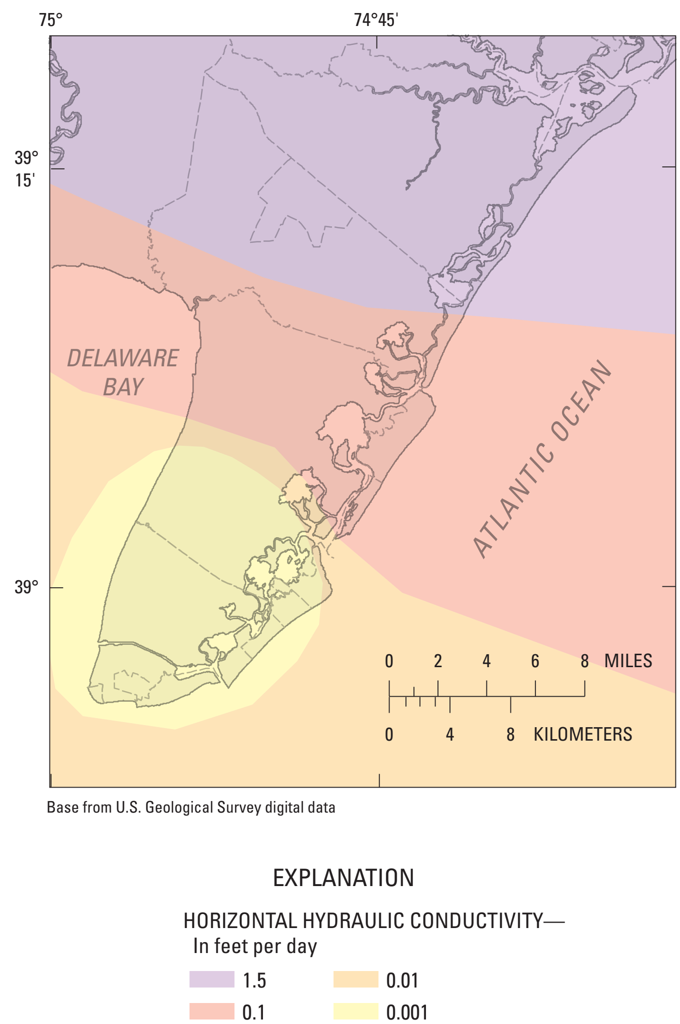


Figure 54. Zones of hydraulic conductivity in the estuarine clay (model layers 2-4) used in the shallow system numerical model, Cape May County, New Jersey.

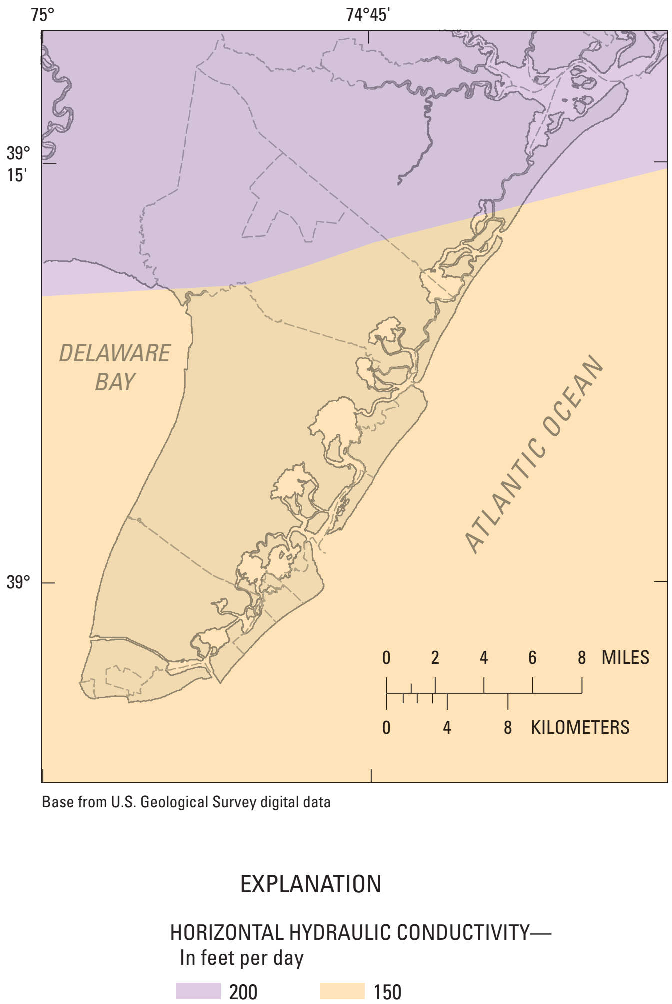


Figure 55. Zones of hydraulic conductivity in the estuarine sand aquifer (model layers 5-7) used in the shallow system numerical model, Cape May County, New Jersey.

a unique solution because of dependencies between initial location and other model parameters (such as porosity and hydraulic conductivity), but yielded acceptable results.

Model Calibration

The goals for the calibration of the shallow aquifer system groundwater-flow model were to produce 80 percent of simulated water levels within 5 ft of measured levels and 90 percent within 10 ft of measured levels, simulated base flows within 50 percent of estimated base flow, and simulated chloride concentrations within a factor of 10 of measured concentrations. Water-level measurements made in 2003 that were used to calibrate the model had error margins of as much as 5 ft or greater. The water-level error margins were caused by the estimation of land-surface altitude based on the 10-ft contour interval of the 7.5-minute topographic quadrangle maps; measurements made in or near stressed wells; and measurements made in December, closer to winter/spring high water levels than summer/fall low water levels. Although average annual water levels for most locations are not known, continuous water-level data for four wells open to the Cohansey aquifer (measurements in three wells were made only in the 2006 and part of the 2005 water years) and periodic water-level data for three wells open to the Cohansey aquifer (approximately four measurements per year) indicate that synoptic measurements in December 2003 were 1 to 5 ft higher than approximate average annual water levels. The greatest difference, about 5 ft, was observed at the airport, between the two pumping centers of Lower Township and the WWU Rio Grande well field. Water-level data for two wells open to the Holly Beach water-bearing zone, one with continuous measurements and one with about four measurements per

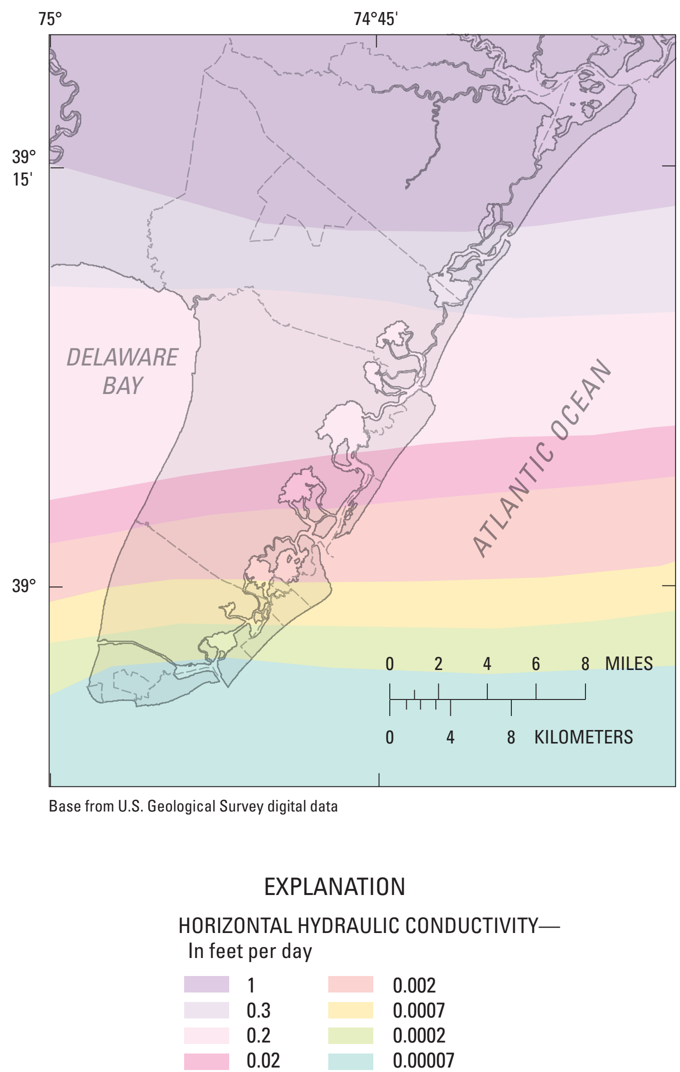


Figure 56. Zones of hydraulic conductivity in the confining unit overlying the Cohansey aquifer (model 8-10) used in the shallow system numerical model, Cape May County, New Jersey.

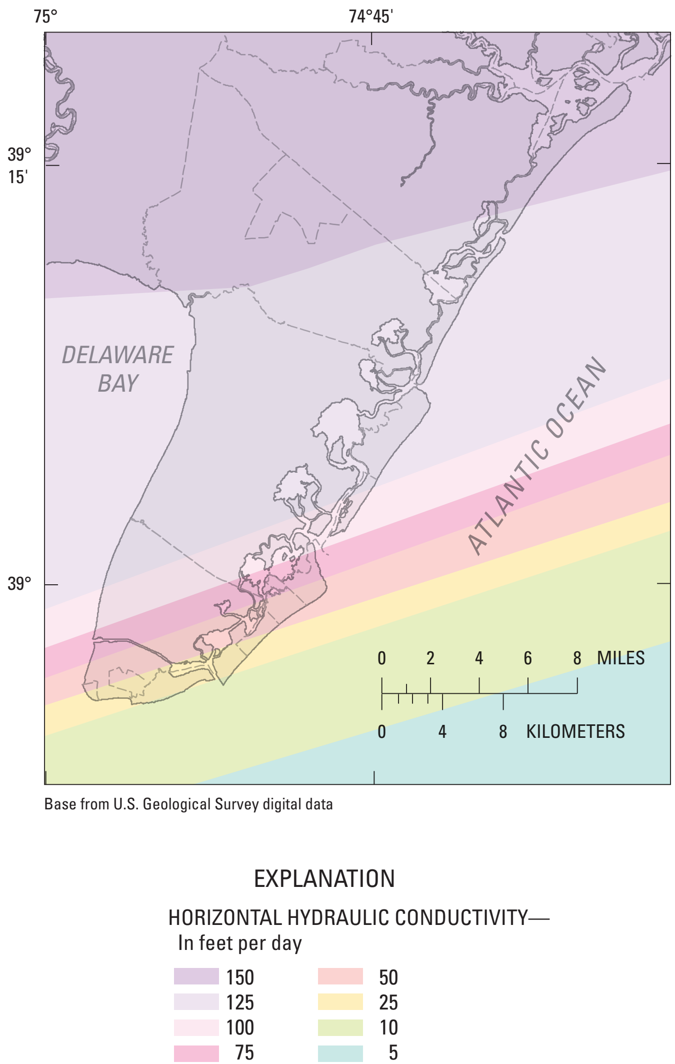


Figure 57. Zones of hydraulic conductivity in the Cohansey aquifer (model layers 11-13) used in the shallow system numerical model, Cape May County, New Jersey.

year, indicate that December 2003 water levels were about 1 ft higher than average annual water levels.

Estimates of base flow in the 13 small stream basins included in the model are considered accurate to within about 30 percent. Additional model error of as much as 50 percent was considered acceptable because of the uncertainty of small-scale aquifer heterogeneity and recharge variation due to the presence of wetlands.

Simulated chloride concentrations were considered acceptable if they were within an order of magnitude of measured values. Measured chloride concentrations in samples from wells with relatively low concentrations fluctuated over time by as much as an order of magnitude (for example, from 7 to 20 mg/L in well 9-188 and 8 to 83 mg/L in well 9-189, figs. 7, 8, and 10). Groundwater samples were rarely collected and analyzed prior to the 1950s, and changes in chloride concentrations over time are not well known for most locations. Furthermore, the simulation of transport in this model was affected by simplifying assumptions. For example, only three layers were modeled per aquifer, whereas more layers would have improved the resolution.

Simulated and Measured Water Levels

Simulated and measured water levels were compared to quantify the calibration, or fit, of the model to the measured data (table 12). Water levels measured in 2003 were compared to simulated water levels at the end of stress period 12 (1999-2003), and residuals (measured minus simulated) were calculated. A positive residual indicates the simulated water level was lower than the measured water level. Residual statistics were used to summarize the quality of the calibration. Minimum and maximum residuals identify outliers. The mean of all residuals, if non-zero, indicates whether most simulated water levels are higher or lower than measured water levels, thus indicating model bias. The sum of the residuals indicates the magnitude of error bias, and the standard deviation indicates how far above and below the mean the errors are distributed.

Water levels output from SEAWAT are the level to which water would rise in a tightly cased well, accounting for the density of the water in the well (which is a function of the salt content). For example, if two hypothetical wells were open to the same depth, but one well contained saltwater (more dense) in the casing and the other contained freshwater (less dense), the water level in the well containing saltwater would be lower, although the equivalent freshwater heads in the two wells would be identical. Therefore, some maps of simulated water levels include water levels that are below sea level in saltwater off-shore areas.

Water-level residuals for the Holly Beach water-bearing zone (model layer 1) were less than 5 ft for 9 of 11 wells (fig. 58), ranging from -3.7 to 6.3 ft, with a mean error of 1.8 ft, sum of 20 ft, and standard deviation of 3.1 ft. The residuals appear to be random, with four less than zero, seven greater than zero, and no obvious areal bias. (For example, some of the negative residuals occur at inland wells, and others occur at wells located close to the coastline).

Water-level residuals in the estuarine sand aquifer (model layers 5-7) were less than 5 ft for the 13 wells (fig. 59), ranging from –1.6 to 3.9 ft, with a mean of 0.92 ft, sum of 12 ft, and standard deviation of 1.5 ft. A slight bias becomes evident from inspection of figure 59: all residuals in the vicinity of Cape May Court House are greater than zero, indicating simulated water levels are too low in that area. The reason for this may be heterogeneities in the aquifer or encompassing confining units.

Water-level residuals for 50 wells in the Cohansey aquifer range from -7.5 to 11.5 ft, with a mean error of 0.39, sum of 19, and standard deviation of 3.8 (fig. 60). Simulated water levels in 9 of 50 wells (18 percent) were more than 5 ft higher or lower than observed, and 1 was more than 10 ft lower than observed. Although residuals for the Cohansey aquifer have a

Table 12. Water levels measured in, and water-level residuals for, the shallow aquifer system, Cape May County, New Jersey, 2003.

[UID, Unique identification number; NJDEP, New Jersey Department of Environmental Protection; --, none]

UID	NJDEP well permit number	Owner	Local identifier	Measured water level, in feet	Residual (measured less simulated), in feet
			Holly Beach water-bearing zone		
090020	--	US GEOLOGICAL SURVEY	TRAFFIC CIRCLE OBS	4.00	3.9
090081	--	US GEOLOGICAL SURVEY	CAPE MAY 23 OBS	6.07	6.2
090098	--	US GEOLOGICAL SURVEY	BDWLL DCH 31HB	15.75	6.6
090190	--	WILDWOOD CITY	CAPE MAY F-40	2.10	2.0
090191	37-02472.1	US GEOLOGICAL SURVEY	FC HB-1 DRIVEPOINT	3.42	3.3
090212	--	CAPE MAY COUNTY	CAPE MAY C-3	-1.04	-3.9
090218	--	CAPE MAY COUNTY	CAPE MAY F-43	2.70	-1.3
090295	37-03038	US GEOLOGICAL SURVEY	WETLANDS 4 OBS	0.00	-0.7
090321	--	US GEOLOGICAL SURVEY	BD-24HB COUNTY PARK	8.44	-.3
090322	--	US GEOLOGICAL SURVEY	BD-21HB	6.15	3.0
090333	37-04769	US GEOLOGICAL SURVEY	PUMP POND N OBS	8.22	1.3
			Estuarine sand aquifer		
090022	37-00229	NOVASACK BROTHERS	NOVASACK IRR	10.49	.3
090097	--	US GEOLOGICAL SURVEY	BDWLL DCH 31ES	8.58	3.9
090162	38-00238	NOVASACK BROTHERS	NOVASACK BROS IRR-2	8.70	-1.0
090189	--	CAPE MAY COUNTY	CAPE MAY F-37	-3.80	.7
090206	--	CAPE MAY COUNTY	CAPE MAY F-7	-3.10	1.0
090208	37-02602-0	US GEOLOGICAL SURVEY	BSR-6	-4.37	-.3
090217	--	CAPE MAY COUNTY	CAPE MAY F-42	-3.45	.3
090282	37-00250	SOIL CONSERVATION SERVICE	BD-21ES	5.31	2.0
090286	37-00253	SOIL CONSERVATION SERVICE	BD-23ES	7.24	2.0
090320	--	US GEOLOGICAL SURVEY	BD-24ES COUNTY PARK	6.46	.7
090352	37-04872	US GEOLOGICAL SURVEY	ROSLYN AVE SHALLOW OBS	0.98	2.0
090355	37-04874	US GEOLOGICAL SURVEY	GRASSY SOUND 1-S OBS	2.81	2.0
090407	36-04715	LUTHERAN HOME AT OCEAN CITY	LUTHERAN HOME PW 3	6.84	-1.6
			Cohansey aquifer		
090011	57-04898	CAPE MAY CITY WATER DEPT	CMCWD 1 OBS	-11.37	-2.3
090018	--	US COAST GUARD	USCG 2	-14.40	-4.3
090027	37-00013	CAPE MAY CITY WATER DEPT	CMCWD 3	-11.47	-1.6
090030	--	US GEOLOGICAL SURVEY	USGS TEST 6	-12.59	-2.6
090036	--	CAPE MAY CITY WATER DEPT	CMCWD 2/CMCWD 4 (NEW)	-14.58	-3.6
090042	37-00268	BORDON CO(SNOW)	SNOW 3	-18.50	-6.9
090043	57-00011	CAPE MAY CITY WATER DEPT	CMCWD 5	-8.19	4.3
090048	37-00159	US GEOLOGICAL SURVEY	CANAL 5 OBS	-11.59	-.7
090049	--	US GEOLOGICAL SURVEY	HIGBEE BEACH 3 OBS	-10.63	-3.3
090052	37-00113	LOWER TWP MUA	LOWER TWP MUA 1	-14.01	-4.3
090054	37-00223	LOWER TWP MUA	LOWER TWP MUA 2	-16.77	-5.6
090057	37-00293	LOWER TWP MUA	LOWER TWP MUA 3	-12.77	-0.7

Table 12. Water levels measured in, and water-level residuals for, the shallow aquifer system, Cape May County, New Jersey, 2003.—Continued

[UID, Unique identification number; NJDEP, New Jersey Department of Environmental Protection; --, none]

UID	NJDEP well permit number	Owner	Local identifier	Measured water level, in feet	Residual (measured less simulated), in feet
Cohansey aquifer—Continued					
090060	--	US GEOLOGICAL SURVEY	AIRPORT 7 OBS	-12.51	1.0
090080	--	US GEOLOGICAL SURVEY	CAPE MAY 42 OBS	-1.58	3.6
090089	37-00158	US GEOLOGICAL SURVEY	OYSTER LAB 4 OBS	-2.27	.0
090099	35-00680	US GEOLOGICAL SURVEY	CAPE MAY COUNTY PK 8 OBS	5.26	.3
090150	37-00155	US GEOLOGICAL SURVEY	WEST CAPE MAY 1 OBS	-9.71	-1.3
090159	37-00241	WILDWOOD CITY WATER DEPT	WWD 35	-6.48	.3
090187	--	CAPE MAY COUNTY	CAPE MAY F-35	-4.05	3.0
090188	--	CAPE MAY COUNTY	CAPE MAY F-36	-7.25	3.3
090207	35-06772-1	US GEOLOGICAL SURVEY	JAKES LANDING-1	5.07	-.7
090210	--	CAPE MAY COUNTY	CAPE MAY C-1	-9.92	-2.0
090213	--	CAPE MAY COUNTY	CAPE MAY F-41	-5.38	2.3
090219	35-03380	BAYSHORE ASSOCIATES	1982-200 HAND & RT 47	4.80	3.3
090233	35-04815	HAZLET, JAMES	HAZLET IRR	5.77	1.0
090256	36-01106	TUCKAHOE FIRE CO	TUCKAHOE FIRE CO	14.55	2.0
090281	37-00254	SOIL CONSERVATION SERVICE	BD-21CH	6.27	3.0
090292	37-03035	US GEOLOGICAL SURVEY	WETLANDS 1 OBS	.37	-1.6
090297	36-06829	SHORE ACRES	SHORE ACRES A	7.62	.7
090301	37-00831	WILDWOOD CITY WATER DEPT	WILDWOOD 44-RECHARGE 4	-10.15	-1.6
090308	35-06359	BOHM, DAVID	BOHM SOD FARM 1987	6.67	-2.0
090310	37-01781	WILDWOOD CITY WATER DEPT	RIO GRANDE 39NEW-RECHRG4	2.90	4.9
090314	37-00640	WILDWOOD CITY WATER DEPT	RECHARGE 3	.65	4.6
090315	35-01373	WILDWOOD GOLF	GOLF CLUB 2-1975-OW 3	7.29	9.2
090317	35-02729	WOODBINE MUA	WOODBINE MUA 7	27.22	1.0
090325	35-13059	US GEOLOGICAL SURVEY	MW-1 FIRETOWER OBS	34.08	5.9
090350	36-16171	US GEOLOGICAL SURVEY	GRT CEDAR SWAMP 1-D OBS	14.57	2.3
090353	37-04871	US GEOLOGICAL SURVEY	ROSLYN AVE DEEP OBS	-8.28	.0
090354	37-04873	US GEOLOGICAL SURVEY	GRASSY SOUND 1-D OBS	3.69	5.9
090358	37-02274	NJ/AMERICAN WATER CO – SOUTH	SHELL BAY MHP	2.34	2.3
090366	37-01039	POST CREEK SEAFOOD	1984 788 W MONTGOMERY	-1.92	3.3
090372	--	LARSEN’S BOAT RENTAL	1956 BROGDEN WELL	4.52	3.6
090385	37-00861	WILDWOOD CITY WATER DEPT	RIO GRANDE 43	-10.12	4.9
090394	37-00327	OTTEN’S HARBOR CLAM	2 MILE BOAT DOCK	-10.76	-1.3
090395	37-04368	CRAIG, TOBY	CMNGC CART BLDG 1991	-15.45	-4.3
090402	36-07750	DRIFTWOOD CAMPGRND	1987 CLERMONT NR SHOWERS	13.75	7.2
090412	36-07565	NJ MARINE SCIENCE CO	NJMSC 2 REDRILLED	6.90	-1.0
090492	35-16575	ERM PARTNERSHIP	ERM TW-1	6.96	1.0
090518	36-24677	UPPER TWP BOARD OF ED	MIDDLE SCH WELL	9.00	-5.9
090520	35-17699	D’ABUNDO & MCCREESH	RIVERVIEW CAMPGROUND	15.00	11.5

Figure 58. Simulated water table, water-level residuals, stream base flow residuals, and estimated and simulated 250-milligram per liter (mg/L) isochlor in the Holly Beach water-bearing zone, Cape May County, New Jersey, 2003.

mean close to zero, an aerial bias is apparent near Cape May City (fig. 60) where residuals are all less than zero, indicating simulated water levels are too high in this area. The reasons for this may be heterogeneities in the aquifer or overlying confining unit, fluxes from the Cohansey aquifer to the underlying Rio Grande water-bearing zone greater than indicated by the regional model, or substantial unreported withdrawals. During calibration, simulated water levels could be lowered near Cape May City (for example, by decreasing the hydraulic conductivity of the Cohansey aquifer) to produce low, randomly distributed residuals in that area but only at the expense of high positive residuals near the Lower Township MUA and WWU Rio Grande production wells.

Simulated and Estimated Stream Base Flow

The range of estimated mean annual base flows of the small streams spans nearly two orders of magnitude (0.20 to 13.5 ft^3/s); therefore, the calibration criterion was set at 50 percent of estimated base flow at each station. Expressed as a percentage of estimated base flow, residuals range from -117 percent to 42 percent (fig. 58, table 13). The mean, sum, and standard deviation of the base flow residual percentages were -5, -62, and 0.4; respectively. The residuals are relatively randomly distributed. For example, the streams in the mainland part of the county (northwest of Great Cedar Swamp) have both positive and negative residuals. On the peninsular part of the county, the simulated base flow is less than the estimated base flow for three streams and greater than the estimated base flow for three streams. The largest residual measured in units of discharge is 4.56 ft^3/s at station 01411434, Sluice Creek at Clint Mill Pond. This station has the lowest correlation coefficient of the 13 partial-record stations for which correlations to index stations were made, which was attributed to the large percentage of the basin that is wetlands (Lacombe and Carleton, 2002). This basin had unusually low discharges per unit area in the summer (months with high ET) and unusually high discharges per unit area in the winter (months with low ET and a high water table). Therefore, given the high uncertainty of the estimated base flow and the difficulty of simulating mean annual flows where the summer and winter conditions are very different from the mean, this error was considered acceptable.

Bidwell Creek tributary has the highest residual, -117 percent. Although this exceeds the goal of 50 percent, the residual of -0.35 ft^3/s is small and was considered acceptable given that nearby, similar streams had better matches.

Simulated and Observed Saltwater Interface

For the southern third of Cape May County, saltwater intrusion in the Cohansey aquifer is of greater concern than is intrusion in the shallower aquifers in the same area or in any of the aquifers in the northern two thirds of the county. As a result, calibration of the location of the saltwater front was primarily focused on representing the location and movement of the 250-mg/L isochlor in the Cohansey aquifer in southern Cape May rather than in other areas or in other aquifers.

The 2003 location of the simulated 250-mg/L isochlor in the Holly Beach water-bearing zone (model layer 1) in the northern half of the county is close to the estimated location at the boundary between saltwater wetlands and uplands (fig. 58). In the southern half of the county, the layer 1 simulated 250-mg/L isochlor is offshore of the saltwater wetland/uplands boundary (used by Lacombe and Carleton (2002) to estimate the location of the 250-mg/L isochlor). The simulated offshore location of the isochlor is a consequence of simulated fresh groundwater discharge from layer 1 to the overlying saltwater boundaries over a relatively broad area rather than the sharp interface assumed by Lacombe and Carleton (2002). How far from shore the actual 250-mg/L isochlor occurs and the width of the transition area from freshwater to saltwater is not known, and the simulated location has little effect on the location of the saltwater interface in the deeper aquifers, so the location was not considered crucial to the accuracy of the model predictions. Furthermore, a sea-level rise of about 1.5 ft over the past century (National Oceanic and Atmospheric Administration, 2007) has had a greater effect on saltwater intrusion into the Holly Beach water-bearing zone than the limited groundwater withdrawals.

The 2003 locations of the simulated 250-mg/L isochlor in the estuarine sand aquifer (model layers 5-7) in the southern half of the county are close to the Delaware Bay shoreline, Cape May Point, and Cape May City, and are inland of the Wildwood Townships (fig. 59). The simulated isochlor moved as much as 1,400 ft during 1896-2003, in the area of high withdrawals near Villas and the WWU Rio Grande well field. Saltwater intrusion in the estuarine sand aquifer has been well documented in the Villas area (Lacombe and Carleton, 2002). In the northern half of the county (where layers 5-7 represent the deeper part of the Holly Beach water-bearing zone), the simulated 250-mg/L isochlor locations are similar to the locations for model layer 1.

The 2003 locations of the simulated 250-mg/L isochlor in the Cohansey aquifer in the southern half of the county are similar to the estimated locations (fig. 60). The simulated isochlor moved inland during 1896-2003 around the southern third of the peninsula, with the most rapid movement occurring near the Cape May City and Rio Grande well fields. Simulated chloride concentrations in Cape May City wells 3 (9-27) and 4 (9-36) match measured data closely (figs. 10 and 60), and simulated concentrations increased because of horizontal saltwater intrusion within the bottom third of the Cohansey aquifer (model layer 13) and subsequent upconing of water with higher chloride concentrations to the top third of the aquifer (model layer 11, which wells 3 and 4 are open to). This simulated vertical movement, upward during periods of high withdrawal rates and downward during periods of low withdrawal rates, provides an explanation for the varying chloride concentrations, which are not well explained by the solely horizontal intrusion concept of previous investigations. The rate of intrusion and location of the simulated 250-mg/L

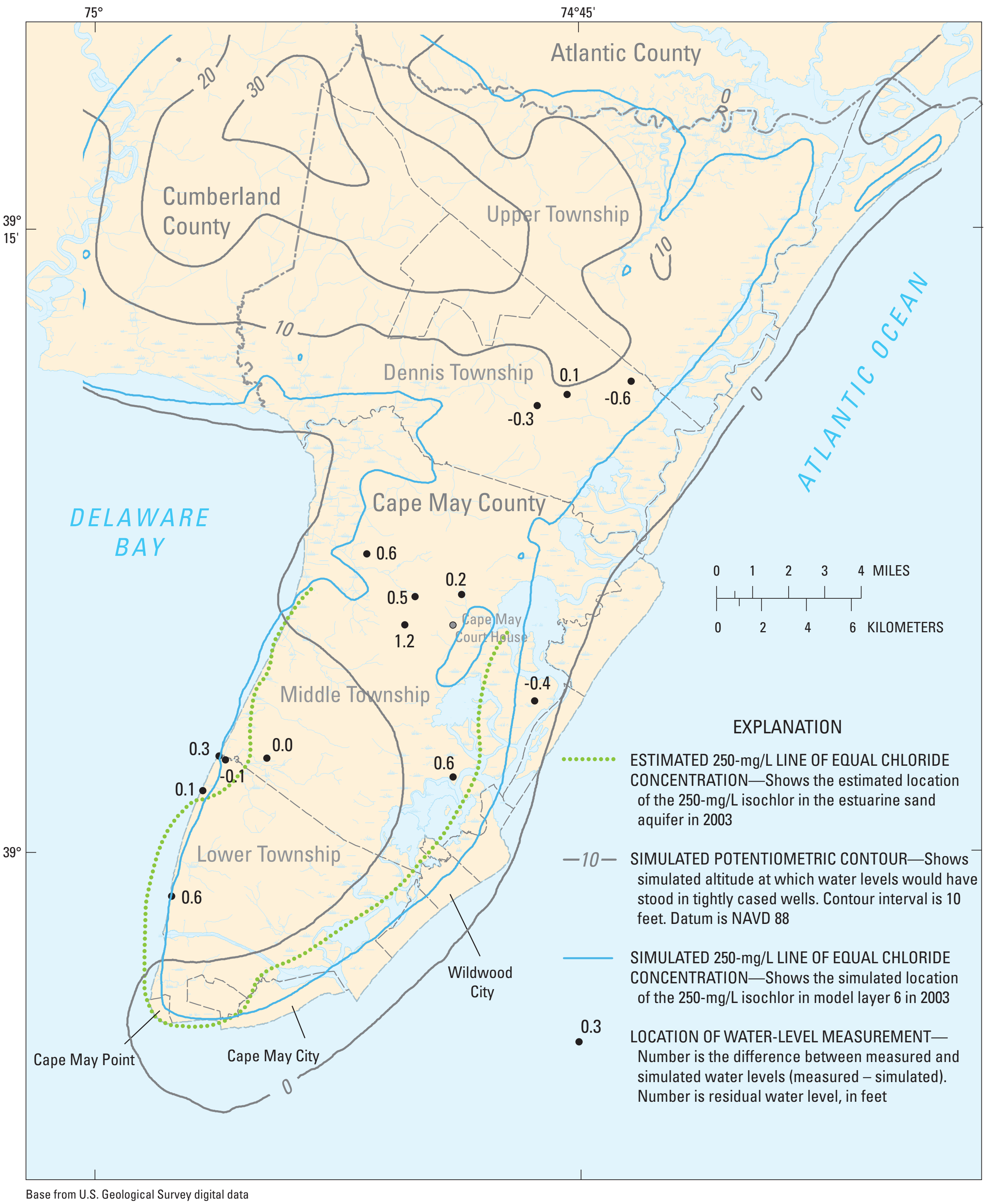


Figure 59. Simulated potentiometric surface, residuals, and estimated and simulated 250-milligram per liter (mg/L) isochlor in the estuarine sand aquifer, Cape May County, New Jersey, 2003.

Base from U.S. Geological Survey digital data

Figure 60. Simulated potentiometric surface, residuals, and estimated and simulated 250-milligram per liter (mg/L) isochlor in the Cohansey aquifer, Cape May County, New Jersey, 2003.

Table 13. Estimated and simulated base flow for 13 small streams, Cape May County, New Jersey.

[ft^3/s, cubic feet per second]

Low-flow station number	Stream	Estimated base flow (ft^3/s)	Simulated base flow (ft^3/s)	Residual (estimated - simulated) (ft^3/s)	Residual (percent of estimated)
01411299	Tarkiln Brook, near Head of River	6.50	6.08	0.42	6
01411302	Mill Creek, near Steelmantown	3.39	3.47	-0.08	-2
01411351	Mill Creek at outlet Magnolia Lake, at Ocean View	2.90	3.13	-0.23	-8
01411388	Mill Creek, at Cold Spring	0.90	0.52	0.38	42
01411400	Fishing Creek at Rio Grande	1.59	2.21	-0.62	-39
01411408	Dias Creek, near Cape May Court House	0.90	1.15	-0.26	-28
01411410	Bidwell Creek tributary, near Cape May Court House	0.30	0.65	-0.35	-117
01411418	Goshen Creek, at Goshen	0.20	0.20	0.00	-2
01411428	Dennis Creek tributary, at Dennisville	4.29	2.79	1.50	35
01411434	Sluice Creek at outlet Clint Mill Pond at South Dennis	11.0	6.43	4.56	41
01411438	Dennis Creek tributary at North Dennis	2.62	2.47	0.15	6
01411442	East Creek at East Creek Pond, near Eldora	8.09	7.86	0.23	3
01411445	West Creek at Pickle Factory pond, near Eldora	13.5	13.3	0.15	1

isochlor west of the Rio Grande well field are similar to those measured in observation wells located at the mouth of Fishing Creek and inland. In the northern half of the county (where layers 11-13 are less confined), the simulated 250-mg/L isochlor locations are similar to the locations in model layer 1.

Sensitivity Analysis

During model calibration, hydrogeologic parameters were adjusted within a reasonable range to achieve the best possible fit to groundwater levels, stream base flow, and location of the saltwater interface (table 14, fig. 61). The model is considered insensitive to parameters that can be varied by a large change in values with minimal or no effect on model results. For example, simulated water levels and stream base flows exhibit large percentage changes with small adjustments to recharge rates (not shown in fig. 61), but little change with large changes in the storage coefficients of the aquifers (fig. 61). Simulated water levels are most sensitive to changes in the hydraulic conductivity of model layers 11-13 (Cohansey aquifer) and layers 8-10 (confining unit overlying the Cohansey aquifer). Simulated water levels also are sensitive to recharge rates, hydraulic conductivities of shallower aquifers and confining units, and bed conductance of surface-water bodies, especially drains (representing small streams) and the general head boundaries close to the coastline.

Stream base flows are most sensitive to adjustments to recharge rates, bed conductance of drains and general head boundaries, and hydraulic conductivity of the aquifers. Stream base flows are least sensitive to adjustments to hydraulic conductivity of confining units.

Saltwater interface movement in the confined aquifers is most sensitive to changes in aquifer porosity and hydraulic conductivity. In areas with little or no confinement, the location of the saltwater interface is stationary and is dependent on

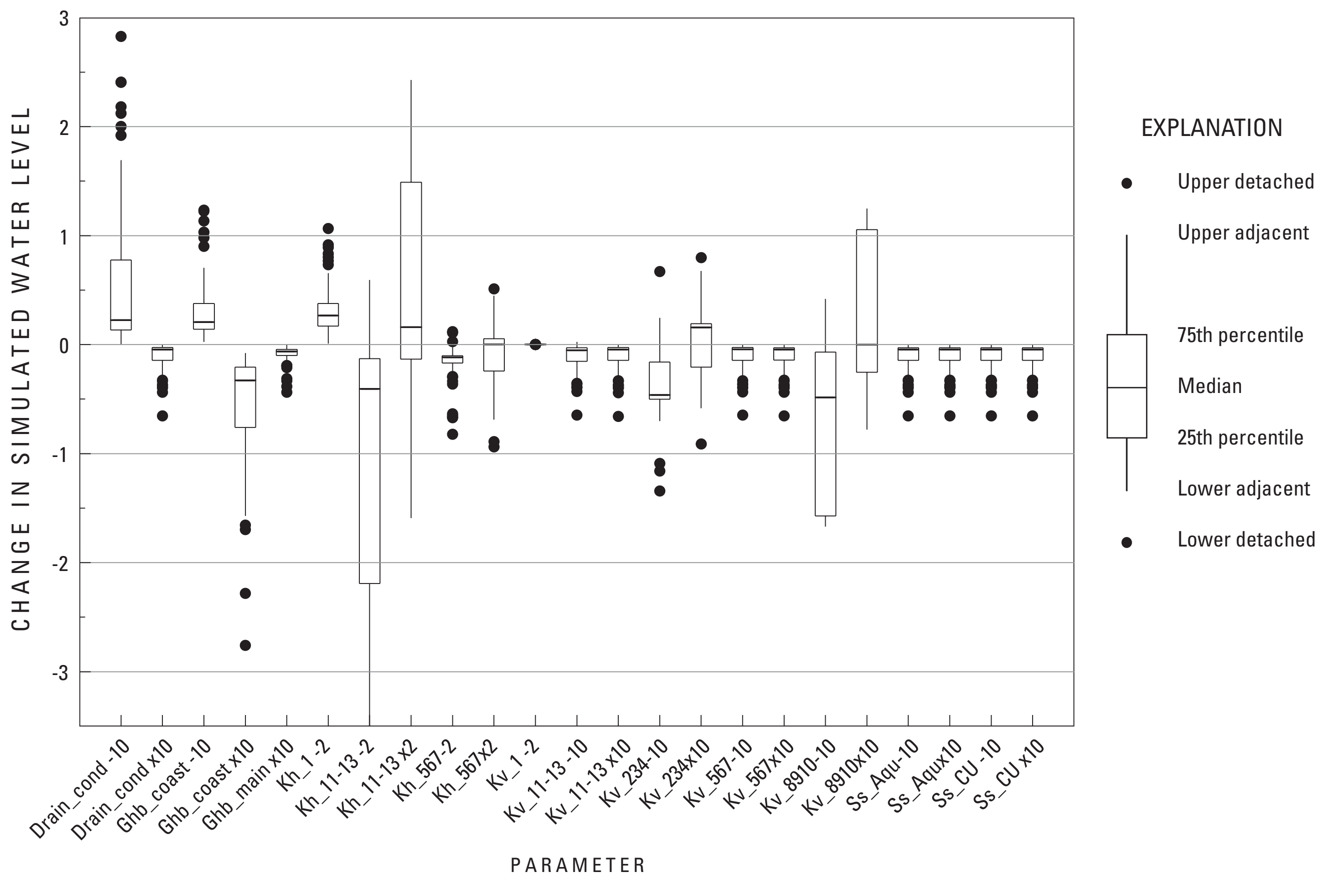


Figure 61. Box plot showing change in head resulting from changes in individual model parameters, shallow aquifer system model, Cape May County, New Jersey. (See table 14 for model parameters names.)

the location of the general head boundary representing tidal areas.

Limitations of the Shallow Aquifer System Model

Based on the calibration statistics of simulated water-level changes and simulated movement of the saltwater interface, the numerical model of the shallow aquifer system, with fully three-dimensional simulation of the aquifers and confining units and variable-density groundwater and surface water, is an improvement over previous models of groundwater flow in Cape May County. Nonetheless, as with all models, many simplifying assumptions were made, and predicted flow will differ from actual flow in ways that may or may not be important. The version of the model chosen as the best calibration is not unique; other representations of the aquifer system could be simulated with similar levels of differences from measured data but different predicted results. The model has a finer grid spacing and more thorough treatment of boundary conditions and variable density groundwater than previous models, but variabilities of inputs and outputs (for example, hydraulic conductivity and water levels, respectively) at a spacing of less than 1,000 ft are not reproduced. Different recharge rates were used for freshwater wetlands and upland areas; however, detailed spatial and temporal variations of recharge rate are not accurate for the small basins within the model. The simulated interrelation between wetlands and surface-water bodies (represented with variable recharge and the River, Drain, and General Head Boundary Packages of MODFLOW) is not very sensitive to the hydraulic parameters that represent the connection between the water-table aquifer and surface-water bodies. Therefore, the accuracy of those estimated parameters cannot be determined with this model.

The shallow aquifer system model is a transient model, incorporating changes of groundwater withdrawals over time. However, the duration of stress periods ranges from 4 to 26 years and the model is only calibrated to estimated average annual water levels and streamflow. Because of the coincidence of low recharge and substantial increase in groundwater withdrawals during the summer tourist season, average annual conditions may differ substantially from seasonal highs and lows. Time discretization of the model to bi-annual stress periods could reveal important predictions about summertime water levels, streamflow declines, and variable-rate saltwater intrusion.

Table 14. Description of parameters used for sensitivity analysis of the shallow aquifer system model, Cape May County, New Jersey.

[Effects of parameters are shown in figure 61.]

Parameter	Description
Drain_cond-10	Bed conductance of drains divided by 10
Drain_condx10	Bed conductance of drains multiplied by 10
GHB_coast-10	Bed conductance of general head boundaries close to coast divided by 10
GHB_coastx10	Bed conductance of general head boundaries (close to coast) multiplied by 10
GHB_mainx10	Bed conductance of general head boundaries (ocean areas) multiplied by 10
Kh_1-2	Horizontal hydraulic conductivity of layer 1 divided by 2
Kh_11-13-2	Horizontal hydraulic conductivity of layers 11, 12, and 13 divided by 2
Kh_11-13x2	Horizontal hydraulic conductivity of layers 11, 12, and 13 multiplied by 2
Kh_567-2	Horizontal hydraulic conductivity of layers 5, 6, and 7 divided by 2
Kh_567x2	Horizontal hydraulic conductivity of layers 5, 6, and 7 multiplied by 2
Kv_1-2	Vertical hydraulic conductivity of layer 1 divided by 2
Kv_11-13-10	Vertical hydraulic conductivity of layers 11, 12, and 13 divided by 10
Kv_11-13x10	Vertical hydraulic conductivity of layers 11, 12, and 13 multiplied by 10
Kv_234-10	Vertical hydraulic conductivity of layers 2, 3, and 4 divided by 10
Kv_234x10	Vertical hydraulic conductivity of layers 2, 3, and 4 multiplied by 10
Kv_567-10	Vertical hydraulic conductivity of layers 5, 6, and 7 divided by 10
Kv_567x10	Vertical hydraulic conductivity of layers 5, 6, and 7 multiplied by 10
Kv_8910-10	Vertical hydraulic conductivity of layers 8, 9, and 10 divided by 10
Kv_8910x10	Vertical hydraulic conductivity of layers 8, 9, and 10 multiplied by 10
Ss_Aqu-10	Specific storage of all aquifer layers (1, 5, 6, 7, 11, 12, and 13) divided by 10
Ss_Aqux10	Specific storage of all aquifer layers (1, 5, 6, 7, 11, 12, and 13) multiplied by 10
Ss_CU-10	Specific storage of all confining unit layers (2, 3, 4, 8, 9, and 10) divided by 10
Ss_CUx10	Specific storage of all confining unit layers (2, 3, 4, 8, 9, and 10) multiplied by 10

Movement of groundwater with varying concentrations of sodium and chloride required representing each hydrogeologic unit (below the Holly Beach water-bearing zone) with three layers. Numerical dispersion would be reduced and better resolution could be obtained with more model layers and finer grid spacing.

Description of the Deep Aquifer System Groundwater-Flow Model

Groundwater flow in the Rio Grande water-bearing zone and Atlantic City 800-foot sand were simulated using a coupled-model approach. The boundary of the current study area does not extend to the natural hydrologic boundaries of the deep aquifer system. Therefore, a Cape May County sub-regional model was used to simulate aquifer response to future withdrawal scenarios within the study area. Fluxes across arbitrary Cape May County sub-regional model boundaries were obtained from a New Jersey Coastal Plain regional model (Pope and Gordon, 1999). The sub-regional groundwater-flow model was originally developed by Voronin (1996) to simulate advective flow in the Atlantic City 800-foot sand from the estimated 250-mg/L isochlor toward Stone Harbor. Voronin's sub-regional model was revised to include the Rio Grande water-bearing zone and recalibrated with recent (2003) withdrawal data and water-level measurements. The New Jersey Coastal Plain regional model simulates saltwater movement by treating the transition from freshwater to saltwater as a sharp interface, and therefore, only predicts large-scale movements of the 10,000-mg/L isochlor. The Cape May County sub-regional model does not simulate saltwater movement or changes in density, but because the location of the sharp interface is not close to the area of interest in southern Cape May County, the density changes during the time period of this study are considered trivial. Therefore, predicting movement of the 250-mg/L isochlor by simulation of advective movement using particle tracking was considered to be an acceptable technique for predicting future conditions.

The New Jersey Coastal Plain regional model extends to the natural boundaries consisting of the feather edge outcrop toward the northwest and the subcrop toward the southeast, at the continental shelf. The northeast and southwest boundaries of the regional model are artificial boundaries in offshore areas where flows were calculated using a multi-region model of the Northern Atlantic Coastal Plain (Leahy and Martin, 1993). The New Jersey Coastal Plain regional model is coarsely discretized, with a grid-cell size of 13,200 ft on each side in Cape May County. Groundwater flow in the regional model area was simulated with SHARP (Essaid, 1990), a quasi-three-dimensional finite-difference computer model of freshwater and saltwater flow separated by a sharp interface in a layered coastal aquifer system. The New Jersey Coastal Plain regional model simulates groundwater flow and movement of the saltwater/freshwater interface (defined for this model as the 10,000-mg/L isochlor), including the quantity and distribution of flow across the interface and accounts for density differences between freshwater and saltwater.

An existing sub-regional model of the Atlantic City 800-foot sand (Voronin, 1996) was augmented to include the overlying Rio Grande water-bearing zone in order to assess the effects of proposed alternatives for water supply in Cape May County on the Rio Grande water-bearing zone and Atlantic City 800-foot sand. In this study, the Cape May County sub-regional model was recalibrated to 2003 water levels using 2003 groundwater withdrawal data. Groundwater flow in the Rio Grande water-bearing zone and the Atlantic City 800-foot sand in the sub-regional model area (fig. 62) was simulated using MODFLOW-2000 (Harbaugh and others, 2000). The sub-regional model is more finely discretized than the New Jersey Coastal Plain regional model (Pope and Gordon, 1999). The cell size in the sub-regional Cape May County model grid, 1,320 ft on each side, allows for a sufficiently detailed representation of local variations in thickness, water levels, and distribution of groundwater withdrawals to estimate travel time of saltwater moving toward production wells.

Particle-tracking was used to estimate groundwater-flow paths and travel time from the location of the 250-mg/L isochlor as mapped by Lacombe and Carleton (2002) to the production wells at Stone Harbor or, for future scenarios, to other actual or hypothetical production wells. This is the same general approach that was used in Voronin (1996) to estimate the movement of the saltwater interface in the Atlantic City 800-foot sand. The mathematical derivation of, and analytical expressions for, the particle-tracking algorithm are given in Pollock (1989).

Flow paths calculated by the particle-tracking method are based on average linear velocities computed by the finite-difference model. Hydrodynamic dispersion (mixing or spreading) of a chemical species as a result of small-scale velocity variations was not considered. Although flow paths calculated with this method are accurate for the model representation of the groundwater-flow system, any numerical model is a simplification of the actual groundwater-flow system and can produce inaccurate results (Pollock, 1989).

Grid and Boundary Conditions

The sub-regional model consists of a finite-difference grid with 100 rows and 140 columns (fig. 62). Each cell is 1,320 ft on a side. This model is a quasi-three dimensional groundwater-flow model with the Rio Grande water-bearing zone and the upper and lower sand units of the Atlantic City 800-foot sand each represented by three model layers. The confining units overlying and within the Atlantic City 800-foot sand are not explicitly represented as model layers but are implicitly represented by adjusting the vertical hydraulic conductivity between model layers (quasi-three-dimensional confining units). The groundwater-flow system was simulated using MODFLOW-2000 (Harbaugh and others, 2000). The Flow and Head Boundary (FHB) Package (Leake and Lilly,

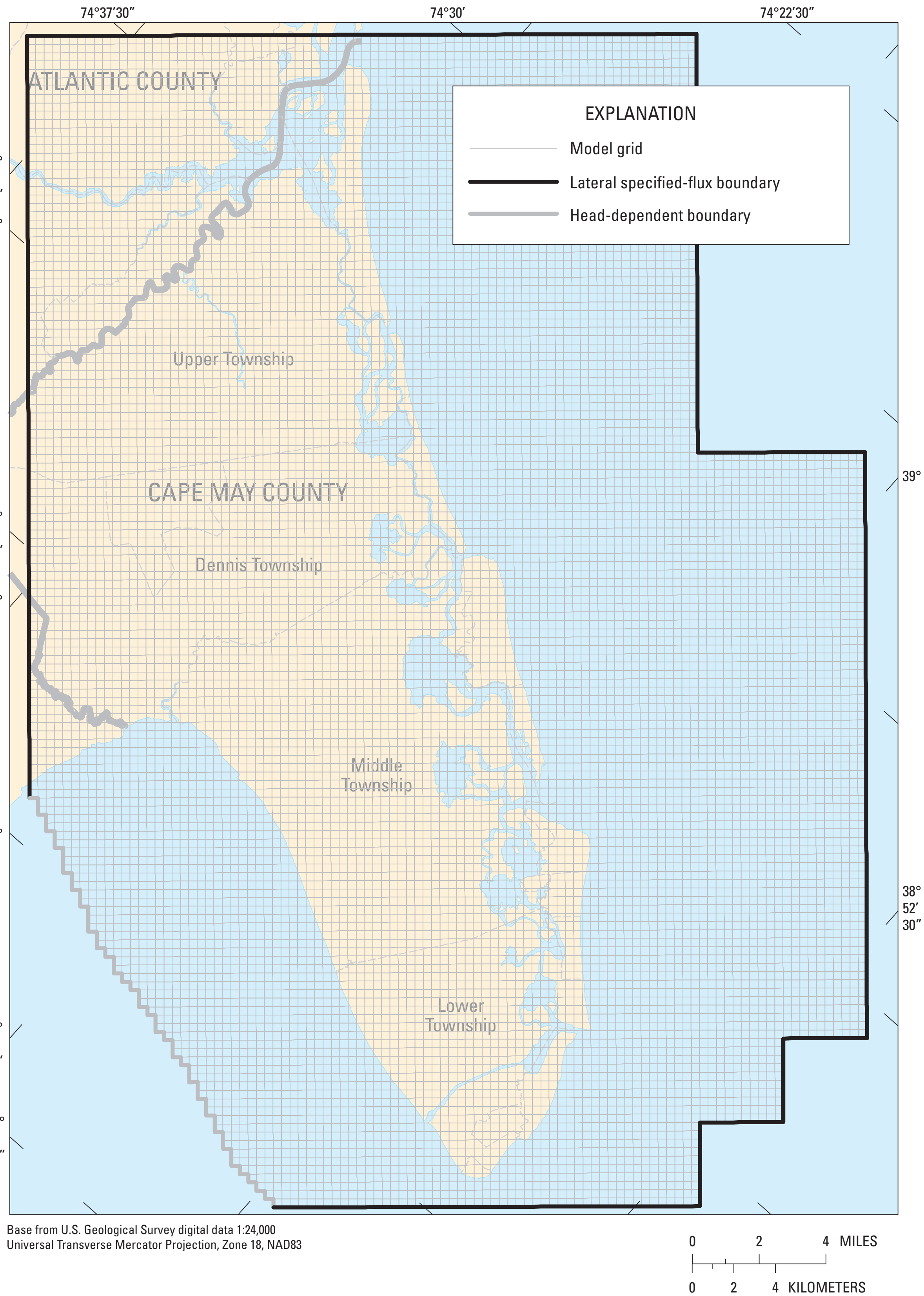


Figure 62. Sub-regional deep aquifer system model grid and location of model boundaries, Cape May County, New Jersey.

1997) was used to input boundary flows from the New Jersey Coastal Plain regional model (Pope and Gordon, 1999).

The boundaries of the sub-regional model are shown in figures 62 and 63. The top and bottom boundaries were represented as specified fluxes across confining units. The lateral boundaries were assigned specified groundwater fluxes derived from the regional model, except at the limit of the confining unit overlying the Atlantic City 800-foot sand under the Delaware Bay, where the sediments are unconfined (fig. 63). At this location, a head-dependent boundary was used (figs. 62 and 63). Specified fluxes into or out of the Cape May County sub-regional model area were obtained from the regional model. At the lateral boundaries, the specified flows from the regional model were apportioned according to the transmissivity of the three aquifer layers in the sub-regional model. This approach is reasonable because, although the regional model did not simulate the Rio Grande water-bearing zone as a separate layer, the Rio Grande was considered to be part of the confined Kirkwood aquifer (Martin, 1998). The Rio Grande water-bearing zone is a minor aquifer compared to the Atlantic City 800-foot sand and, in the areas within the model boundaries, is generally much thinner and less conductive than the Atlantic City 800-foot sand. Weighting of flows from the regional model, on the basis of transmissivity, reasonably allocates the boundary flows from the regional model.

For the head-dependent boundary under the Delaware Bay, the water level and vertical conductance were specified. A water level of zero, which represents the water level in the Delaware Bay, and a vertical conductance of 0.0012 ft/d, which represents the product of the hydraulic conductivity of the sediments and the area of the model cell divided by the thickness of the sediments, were assigned to model nodes.

Groundwater Withdrawals

The sub-regional model was run as a steady-state model; therefore, only reported withdrawal data for 2003 or estimated withdrawals in 2050 were required; no estimation of increases during 2003-50 was required. Withdrawal data for 2003 were obtained from the USGS New Jersey Water Science Center (NJWSC) water-use database. Estimates of future demands developed by the NJDEP are described in the "Potable Water Demand" section of this report. Locations of withdrawal wells open to the deep aquifer system are shown in figure 12, and magnitudes of 2003 withdrawals are listed in table 15.

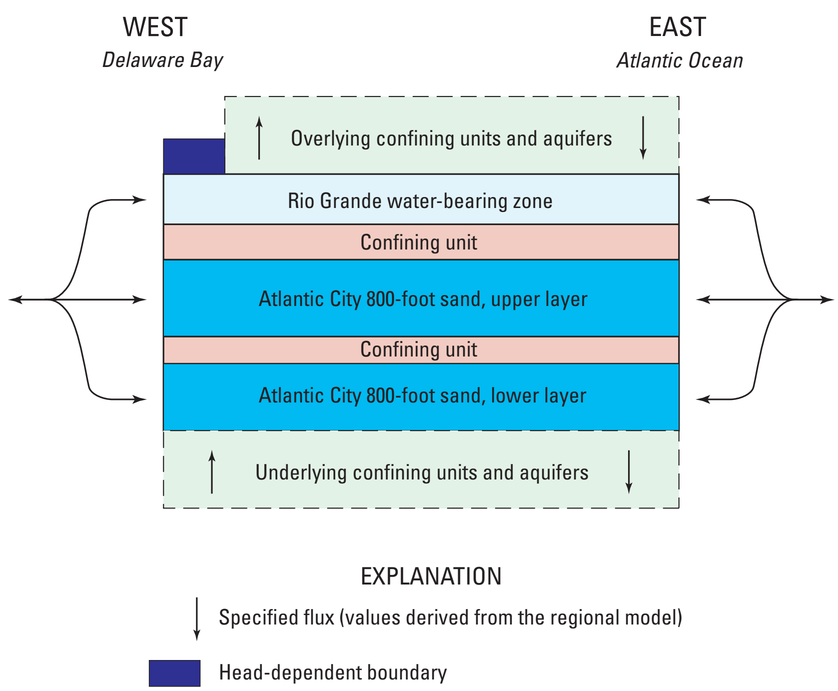


Figure 63. Schematic section showing aquifers, confining units, and the corresponding model layers and boundary conditions in the deep aquifer, system numerical flow model, Cape Cape May County, New Jersey.

Hydraulic Characteristics of Aquifer and Confining Unit Layers

Hydraulic conductivity estimates (from a number of sources) for the Rio Grande water-bearing zone and the Atlantic City 800-foot sand in Cape May County are reported by Lacombe and Carleton (2002). For the Rio Grande water-bearing zone, one aquifer test is reported with a horizontal hydraulic conductivity value of about 30 ft/d. For the Atlantic City 800-foot sand, 10 aquifer tests are reported with hydraulic conductivities ranging from 4 to 89 ft/d and an average of 35 ft/d.

Horizontal hydraulic conductivities used in the subregional model were 35 ft/d for the onshore part of the Rio Grande water-bearing zone where the aquifer is thickest and 10 ft/day in the rest of the modeled area (fig. 64). The horizontal hydraulic conductivities of the upper and lower layers of the Atlantic City 800-foot sand were 40 ft/day.

The vertical hydraulic conductivities of the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand are shown in figure 65. The conductivities used in the model increase gradually from the south to the north. A vertical hydraulic conductivity of 0.08 ft/d was assigned to the confining unit between the two layers in the Atlantic City 800-foot sand.

In order to simulate the advective movement of saltwater using the flow model, an estimate of aquifer and confining-unit porosity was required. The porosity used in the particle tracking methodology is 15 percent for the deep aquifers and 35 percent for the deep confining units. A lower porosity was assumed for the deep aquifers than for the shallow aquifers (30 percent) because greater compaction and cementation were assumed.

Model Calibration

The goals for the calibration of the deep aquifer system groundwater-flow model were to produce simulated water levels within 5 ft of measured 2003 levels. The water-level error margin of 5 ft was chosen because the altitude of land-surface at some wells was based on interpolation from USGS 7.5-minute topographic quadrangle maps with a 10-ft contour interval. Other sources of error include, water-level measurements made in or near stressed wells and measurements made in December, closer to winter/spring high water levels than summer/fall low water levels.

Although average annual water levels for most locations are not known, continuous water-level data for two wells open to the Rio Grande water-bearing zone indicate that synoptic measurements in December 2003 were 5 to 20 ft higher than approximate average annual water levels (DePaul and others, 2009). The greatest difference was observed near the WWU Rio Grande well field.

Continuous water-level data for four wells open to Atlantic City 800-foot sand within the subregional model indicate that December 2003 water levels were about 1 ft lower than the average annual water levels in southern Cape May County and about the annual average in northern Cape May County (DePaul and others, 2009).

Simulated and Measured Water Levels

The deep model was calibrated to reported 2003 groundwater withdrawals and water levels measured in fall 2003 at six wells open to the Rio Grande water-bearing zone. The simulated potentiometric surface, water levels measured in 2003, and residuals for the Rio Grande water-bearing zone are shown in figure 66. The simulated water levels are within 5 ft of the measured water levels for all wells except well 9-71 (-8.6 ft). Simulated water levels at a nearby well (9-67) were close to the measured water levels.

The model was calibrated to reported 2003 groundwater withdrawals and water levels measured in fall 2003 at 33 wells open to the Atlantic City 800-foot sand. The simulated potentiometric surface, water levels measured in 2003, and residuals in 2003 in the two layers of the Atlantic City 800-foot sand are shown in figures 67 and 68. Simulated water levels are within 10 ft of measured water levels in 11 of 15 wells in the upper layer of the Atlantic City 800-foot sand. Simulated water levels are within 5 ft of measured water levels in 9 of 18 wells in the lower layer of the Atlantic City 800-foot sand and are within 10 ft of measured water levels at 7 of the remaining 9 wells. Simulated water levels in all three aquifers are low towards the southern part of Cape May County.

Simulated Vertical Hydraulic Conductivity

To calibrate the vertical hydraulic conductivity of the confining units, simulated and measured water levels from six sets of wells screened in different aquifers but located close together were used to calculate simulated and measured vertical water-level differences. Simulated and measured water-level differences are shown in table 16. Vertical hydraulic conductivity values of the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand were zoned and adjusted to match the water-level differences and were used to simulate the heads in the aquifers above and below the confining unit.

Sensitivity Analysis

The predictive ability of the flow model (including path line predictions discussed below) is dependent on the model sensitivity to parameters. Model sensitivity was evaluated by increasing and decreasing each model parameter by 25 percent (table 17) and assessing the water-level change in each observation well used in the model that resulted from these changes. Box plots showing the water-level changes resulting from 25 percent increases and decreases in the model parameter are shown in figure 69. Of the parameters tested, the model is most sensitive to changes in the horizontal hydraulic conductivity of the Atlantic City 800-foot sand. The 25-percent

Table 15. Well construction, water-level and groundwater withdrawal data for selected wells in Cape May, Atlantic, and Cumberland Counties, New Jersey.–

[Withdrawals in million gallons per year; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; --, not applicable; *, multiple open intervals; **, open interval not available, well depth shown instead]

USGS well Number	NJDEP permit number	Model layer	Screen interval (in feet below land surface)	2003 Measured altitude of water level, (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)	Annual groundwater withdrawals (2003)	Percent of well screen in the upper layer of the Atlantic City 800-foot sand	Percent of well screen in the lower layer of the Atlantic City 800-foot sand
Rio Grande water-bearing zone									
9-67	37-00271	1	461 - 590	-33	-32.17	0.8	188.37	--	--
9-71	--	1	473 - 523	-23.96	-32.59	-8.6	--	--	--
9-304	37-03763	1	495 - 505	-19.44	-23.19	-3.8	--	--	--
9-305	37-00214	1	590**	-20.71	-19.49	1.2	--	--	--
9-415	35-01233	1	306**	6.52	4.05	-2.5	--	--	--
9-519	36-22762	1	478 - 498	-25	-23.23	1.8	--	--	--
9-526	37-05559	1	578 - 598	--	--	--	--	--	--
11-737	35-03449	1	307 - 317	1	1.25	0.3	--	--	--
Upper layer of the Atlantic City 800-foot sand									
9-2	37-00280	2	821 - 861	-49.65	-47.72	1.9	90.423	100	0
9-5	37-00313	2	784 - 839	--	--	--	77.747	100	0
9-92	37-00240	2	681 - 791	-41.97	-41.86	0.1	211.986	100	0
9-100	37-00224	2	763 - 815	--	--	--	5.8	100	0
9-126	37-00162	2	736 - 802*	--	--	--	69.837	100	0
9-127	37-00064	2	742 - 830*	-48.18	-48.22	0	40.876	100	0
9-135	37-00009	2	838 - 878	-40.4	-47.26	-6.9	--	100	0
9-148	36-00364	2	645 - 675	--	--	--	133.496	100	0
9-161	--	2	639 - 654	-37.33	-37.71	-0.4	--	100	0
9-166	37-00312	2	820 - 860	--	--	--	31.647	100	0
9-173	37-00579	2	810 - 860	--	--	--	54.476	100	0
9-291	36-09846	2	764 - 941*	-48.54	-48.2	0.3	16.714	47	53
9-306	35-09239	2	656 - 666	-22.49	-26.64	-4.1	--	100	0
9-359	36-07286	2	708 - 773*	-49.98	-43.4	6.6	4.014	100	0
9-459	36-00377	2	620**	-65.78	-63.64	2.1	--	100	0
9-479	37-06313	2	655 - 825	-36.71	-38.92	-2.2	--	83	17
9-481	36-17001	2	603 - 738*	-54.95	-52.56	2.4	64.215	63	37
9-482	36-20238	2	724 - 884*	-48.61	-47.21	1.4	59.756	53	47

Table 15. Well construction, water-level and groundwater withdrawal data for selected wells in Cape May, Atlantic, and Cumberland Counties, New Jersey.—Continued

[Withdrawals in million gallons per year; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; --, not applicable; *, multiple open intervals; **, open interval not available, well depth shown instead]

USGS well Number	NJDEP permit number	Model layer	Screen interval (in feet below land surface)	2003 Measured altitude of water level, (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)	Annual groundwater withdrawals (2003)	Percent of well screen in the upper layer of the Atlantic City 800-foot sand	Percent of well screen in the lower layer of the Atlantic City 800-foot sand
9-506	37-05659	2	795 - 880*	--	--	--	52.322	100	0
9-507	37-06563	2	615 - 810*	-33.31	-38.6	-5.3	152.599	78	22
9-508	37-06564	2	585 - 765	-22.6	-30.54	-7.9	--	100	0
9-521	37-07541	2	830 - 953*	-40.14	-45.14	-5	45.644	100	0
Lower layer of the Atlantic City 800-foot sand									
1-578	36-00295	3	670 - 680	-64.36	-57.36	7	--	0	100
9-4	37-00265	3	880 - 920	-47.86	-48.28	-0.4	81.277	0	100
9-79	--	3	833 - 876	-40.63	-39.46	1.2	--	0	100
9-106	56-00006	3	760 - 810	-60.64	-63.47	-2.8	158.143	0	100
9-108	36-00412	3	774 - 840	-66.73	-71.13	-4.4	153.598	0	100
9-109	56-00008	3	749 - 809	-65.46	-68.87	-3.4	46.069	0	100
9-116	56-00007	3	760 - 810	-73.79	-82.53	-8.7	99.039	0	100
9-117	36-00017	3	746 - 798	--	--	--	79.161	0	100
9-121	56-00004	3	825**	--	--	--	29.098	0	100
9-122	56-00005	3	825**	--	--	--	50.44	0	100
9-124	36-00413	3	774 - 840	--	--	--	268.305	0	100
9-125	36-00314	3	800**	-73.08	-89.13	-16.1	63.846	0	100
9-136	56-00147	3	802 - 834	-53.88	-48.68	5.2	8.924	0	100
9-144	36-00451	3	650 - 690	-66.43	-62.21	4.2	12.709	0	100
9-185	37-013408	3	640 - 650	-40.94	-22.66	18.3	--	0	100
9-296	35-06073	3	682 - 812*	-36.24	-38.64	-2.4	14.305	67	33
9-302	37-036289	3	883 - 893*	-26.99	-34.03	-7	--	0	100
9-311	36-10378	3	732 - 896*	-47.9	-52.04	-4.1	112.206	54	46
9-337	37-04660	3	910 - 960	-28.28	-37.18	-8.9	--	0	100
9-360	36-13154	3	636 - 836*	--	--	--	5.617	68	32
9-423	37-05244	3	825 - 875	-22.92	-32.51	-9.6	--	0	100
9-461	36-15182	3	639 - 710	-65.48	-60.1	5.4	48.43	0	100
9-480	37-06314	3	621 - 820*	-48.99	-51.79	-2.8	243.356	89	11
9-514	36-17504	3	660 - 710	--	--	--	16.372	0	100

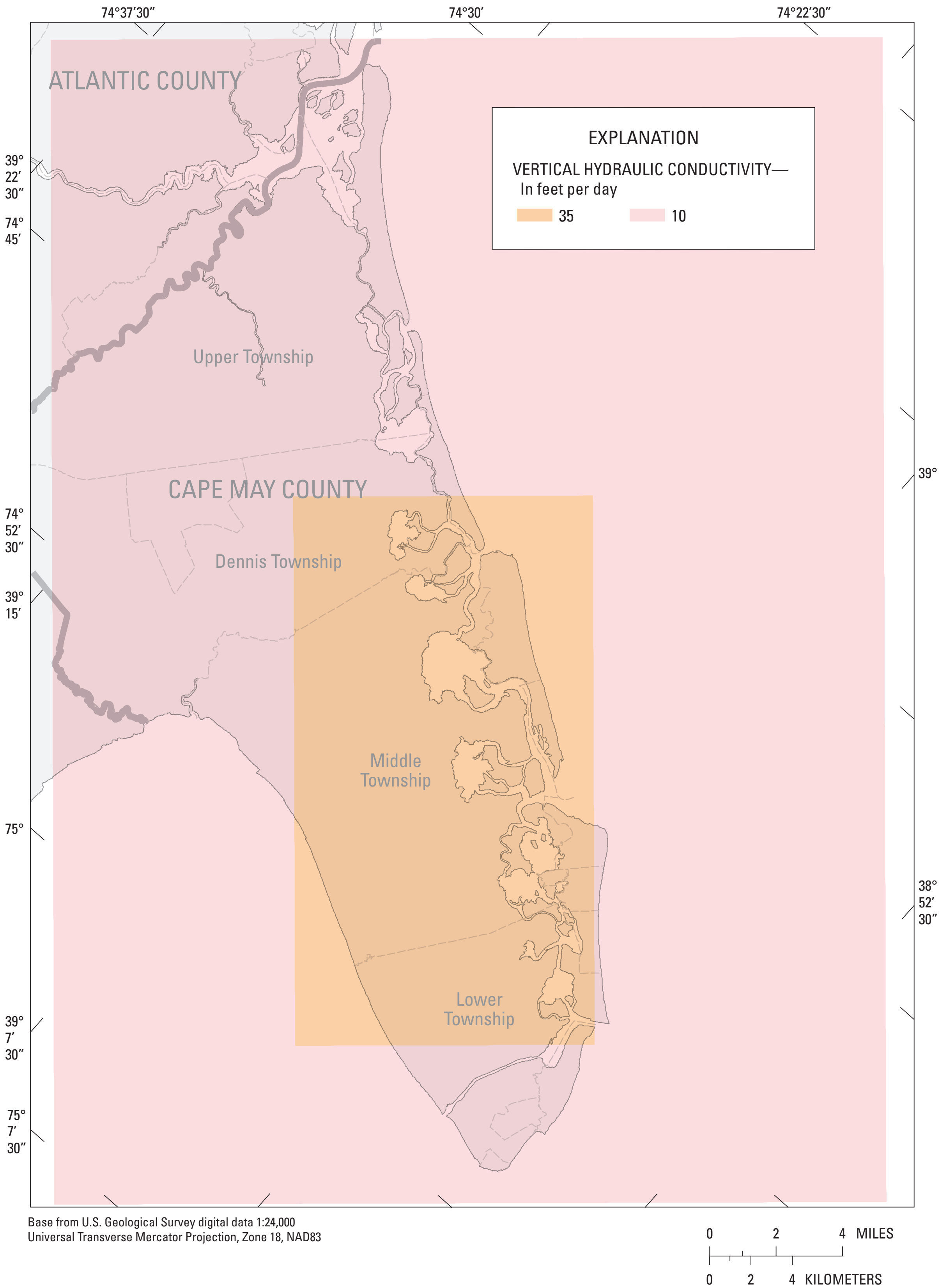


Figure 64. Zones of horizontal hydraulic conductivities in the Rio Grande water-bearing zone used in the sub-regional deep aquifer system model, Cape May County, New Jersey.

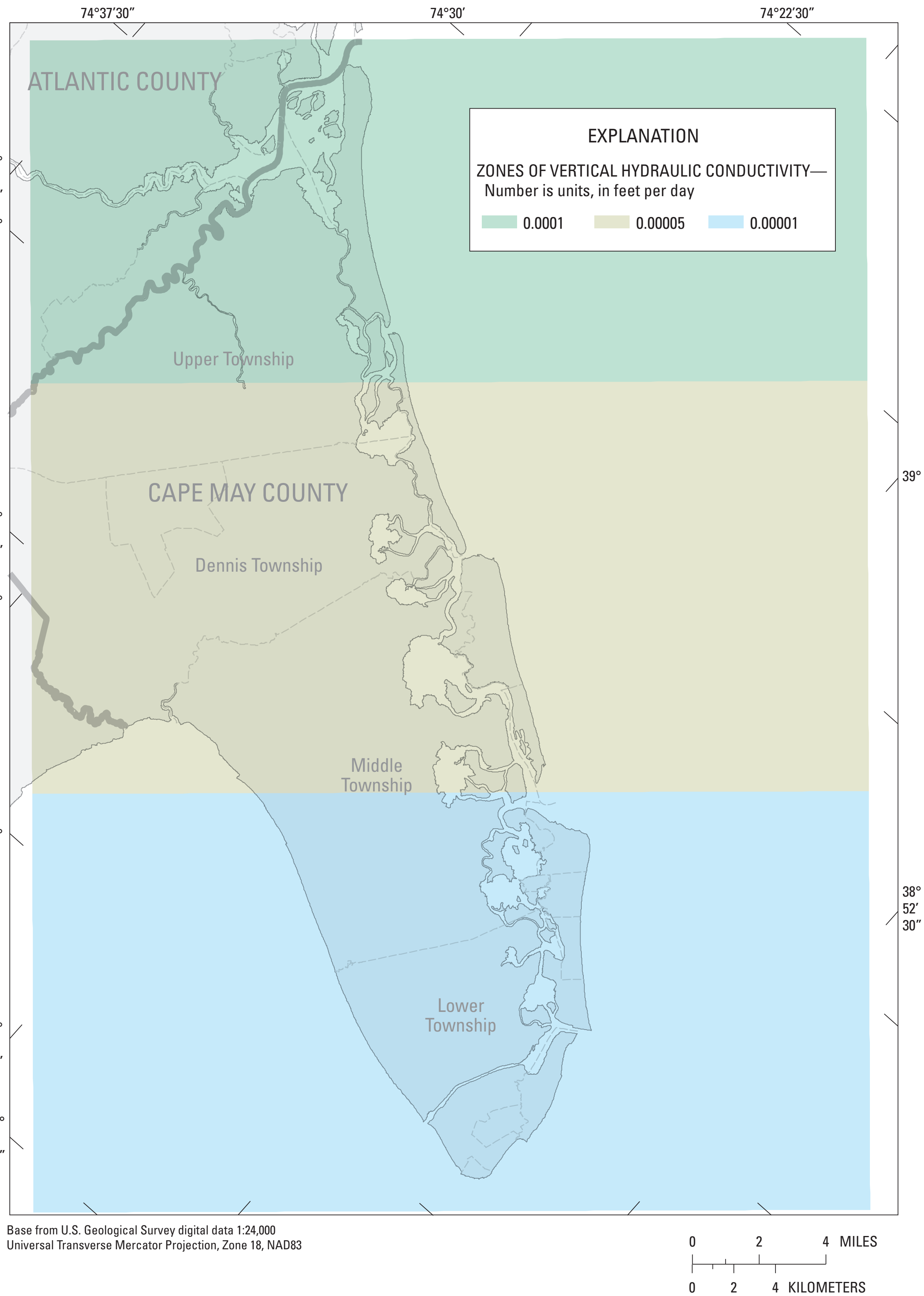


Figure 65. Zones of vertical hydraulic conductivity in the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand used in the sub-regional deep aquifer system model, Cape May County, New Jersey.

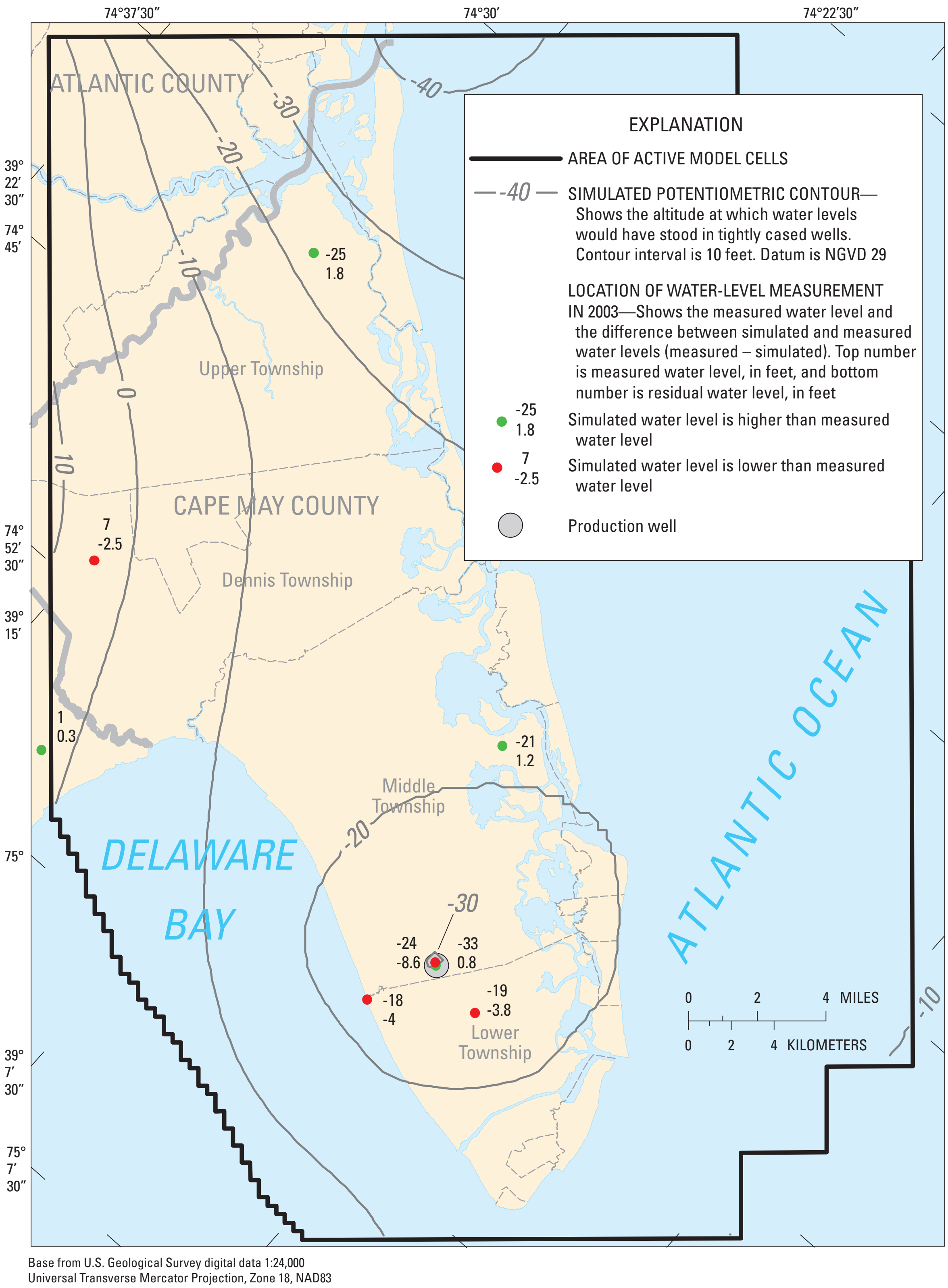


Figure 66. Simulated potentiometric surface, measured water levels, and residuals in the Rio Grande water-bearing zone, Cape May County, New Jersey, 2003.

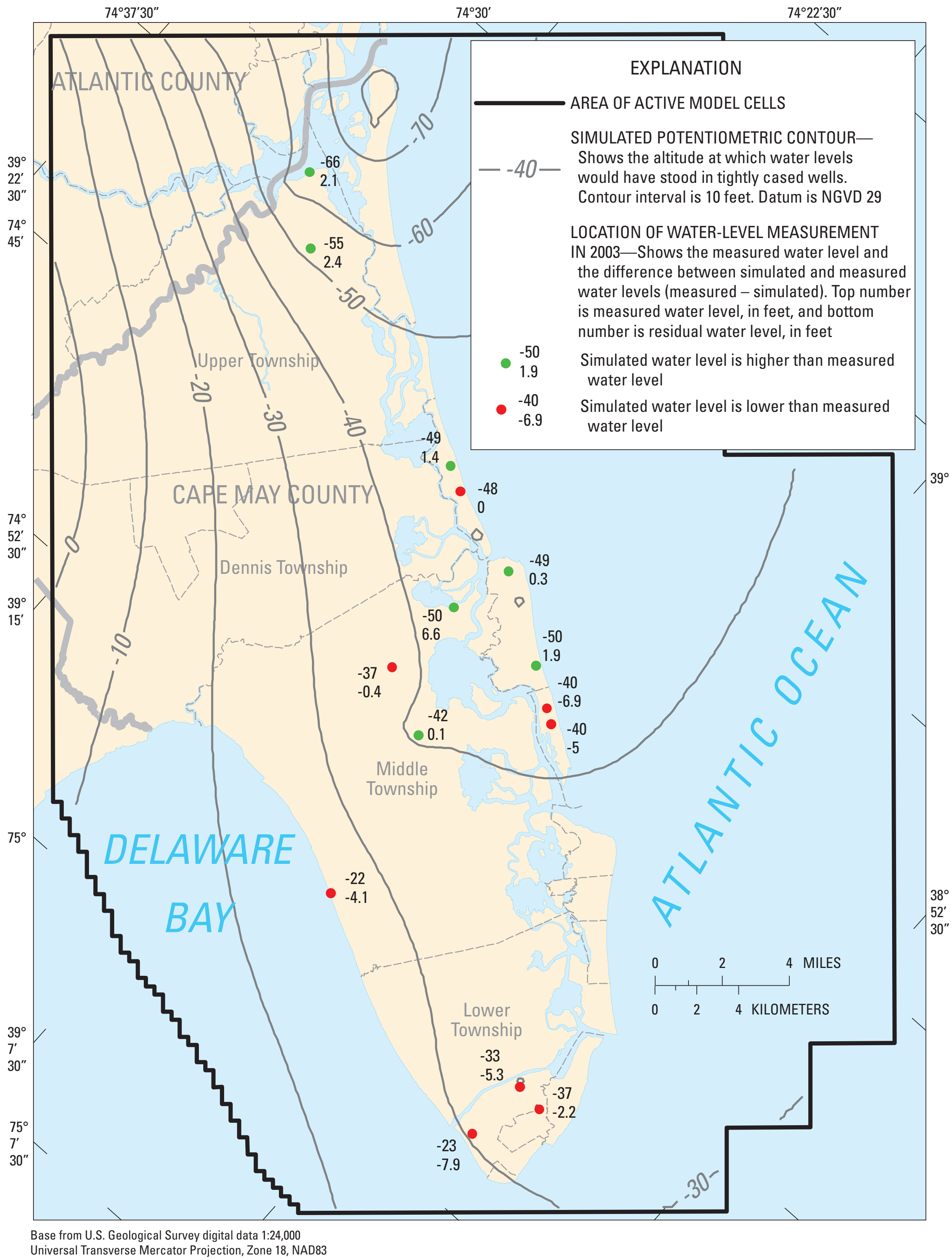


Figure 67. Simulated potentiometric surface, measured water levels, and residuals in the upper layer of the Atlantic City 800-foot sand, Cape May County, New Jersey, 2003.

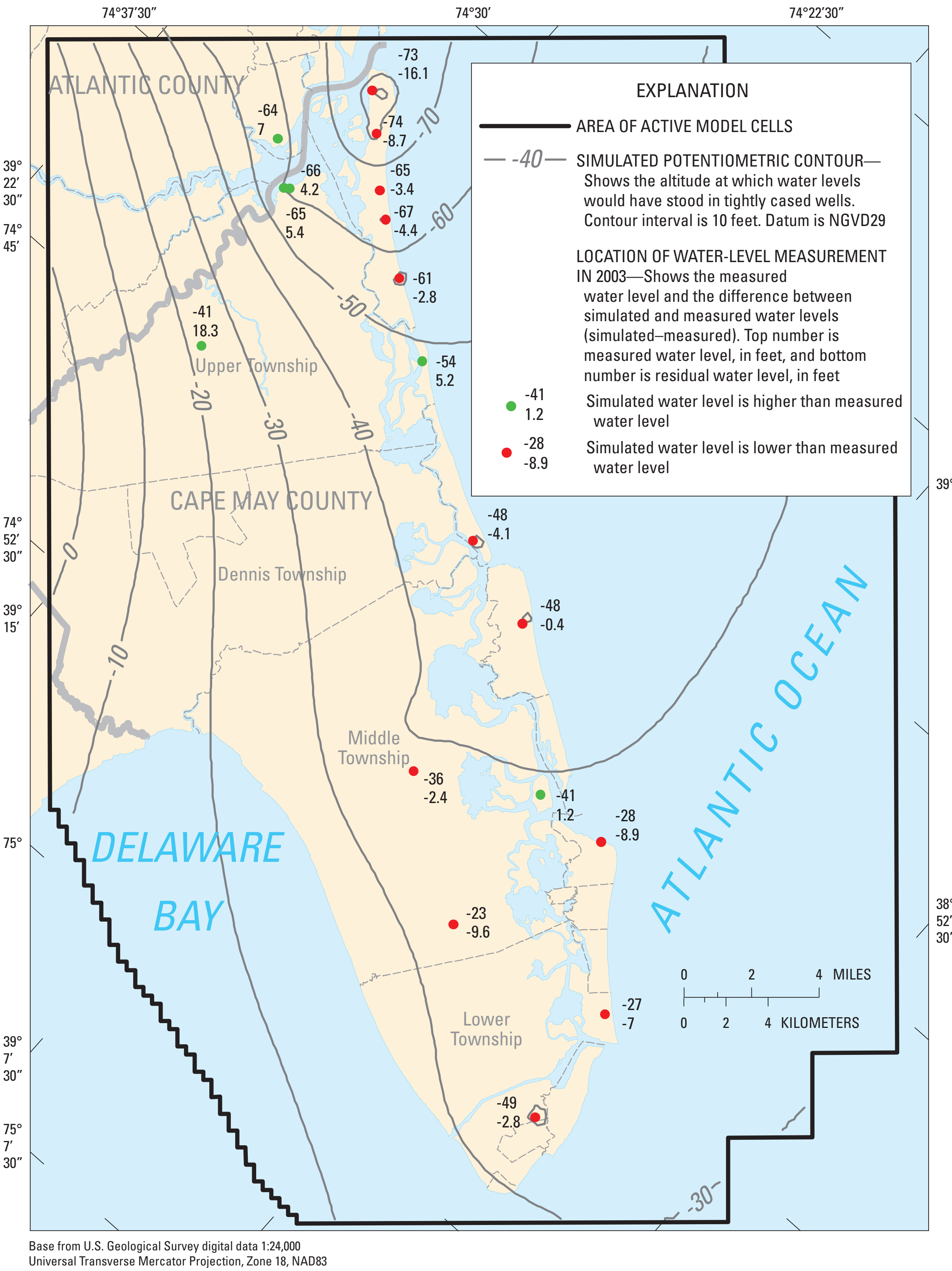


Figure 68. Simulated potentiometric surface, measured water levels, and residuals in the lower layer of the Atlantic City 800-foot sand, Cape May County, New Jersey, 2003.

Table 16. Simulated and measured water-level differences and residuals, deep aquifer system model, Cape May County, New Jersey.

[Well locations are shown in figure 4; UID, unique identifer.]

Rio Grande water-bearing zone UID	Atlantic City 800-foot sand UID	Confining unit[1]	Measured water-level difference[2] (feet)	Simulated water-level difference (feet)	Residual[3] (feet)
9-479	9-480	C2	-12.28	-12.87	-.59
9-92	9-296	C2	5.73	3.22	-2.51
9-127	9-311	C2	.28	-3.82	-4.1
9-459	9-144	C2	-.65	1.43	2.08
9-71	9-423	C	1.04	.08	-.96
9-519	9-481	C1	-29.95	-29.33	.6

[1] C1, confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand; C2, confining unit separating the upper and lower units of the Atlantic City 800-foot sand; C, includes the effects of both confining units C1 and C2.

[2] The measured water-level difference is the water level in the well below the confining unit minus the water level above the confining unit. Negative differences indicate a downward gradient.

[3] The residual is the simulated difference minus the measured difference.

change in the value of this parameter caused water levels in 50 percent of the observation wells to change by 1.5 to 4 ft. Most of the other parameters tested showed little sensitivity to 25 percent changes in simulated water levels. Although the sensitivity of the model to changes in boundary fluxes was not tested explicitly, simulation of future Scenario 4 (described further on in this report) with two hypothetical withdrawal wells open to the Rio Grande water-bearing zone yielded simulated water levels that were 10 to 20 ft different when fluxes were generated by the Coastal Plain-wide model including or not including the two hypothetical wells.

Simulated Saltwater Intrusion and Travel Time

The inferred location of the 250-mg/L isochlor in the Rio Grande water-bearing zone (fig. 14) is within 5 mi of the WWU supply wells open to the aquifer. The location is based on chloride values from less than six wells and the configuration of the 250-mg/L chloride line in the Atlantic City 800-foot sand. The inferred location of the 250-mg/L isochlor in the Atlantic City 800-foot sand in 1992 (Lacombe and Carleton, 2002) is shown in figure 70. The estimated orientation of the line is nearly east-west as it crosses the peninsula, bending to the northeast under the Atlantic Ocean to approximately parallel to the mainland coast and the continental shelf. The inferred location of the 250-mg/L line of equal chloride concentration in the offshore area is based on data from four wells (not shown)—two offshore near Atlantic City, one at North Wildwood, and one at the U.S. Coast Guard base electronic station. Under the Delaware Bay, the line is estimated to curve slightly towards the northwest-southeast to be approximately parallel to the termination of the overlying confining unit. It is likely that saltwater flows from the Delaware Bay into the confined aquifer under the Delaware Bay as a result of groundwater withdrawals in Cape May and Atlantic Counties.

A particle-tracking post-processor was used to compute three-dimensional flow paths from the 250-mg/L chloride line to production wells for the Rio Grande water-bearing zone and the Atlantic City 800-foot sand. The tracks of eight flow paths in the Atlantic City 800-foot sand, based on 2003 groundwater withdrawals, are shown in figure 70. The red part of the travel path is the distance the particle will move in 100 years. The green part of the travel path is the balance of the travel time. All travel times shown below are for lateral flow. The fastest particle to reach the Stone Harbor wells is particle number 8 which reaches the wells in about 800 years. A similar analysis was conducted on travel paths for particles in the Rio Grande water-bearing zone. Actual travel times may differ from predicted travel times as a result of the uncertainty in estimating the location of the 250-mg/L line of equal chloride concentration (isochlor).

Predicted travel times	
Particle number	**Travel time, in years**
1	2,050
2	2,525
3	3,400
4	2,250
5	1,400
6	1,075
7	900
8	800

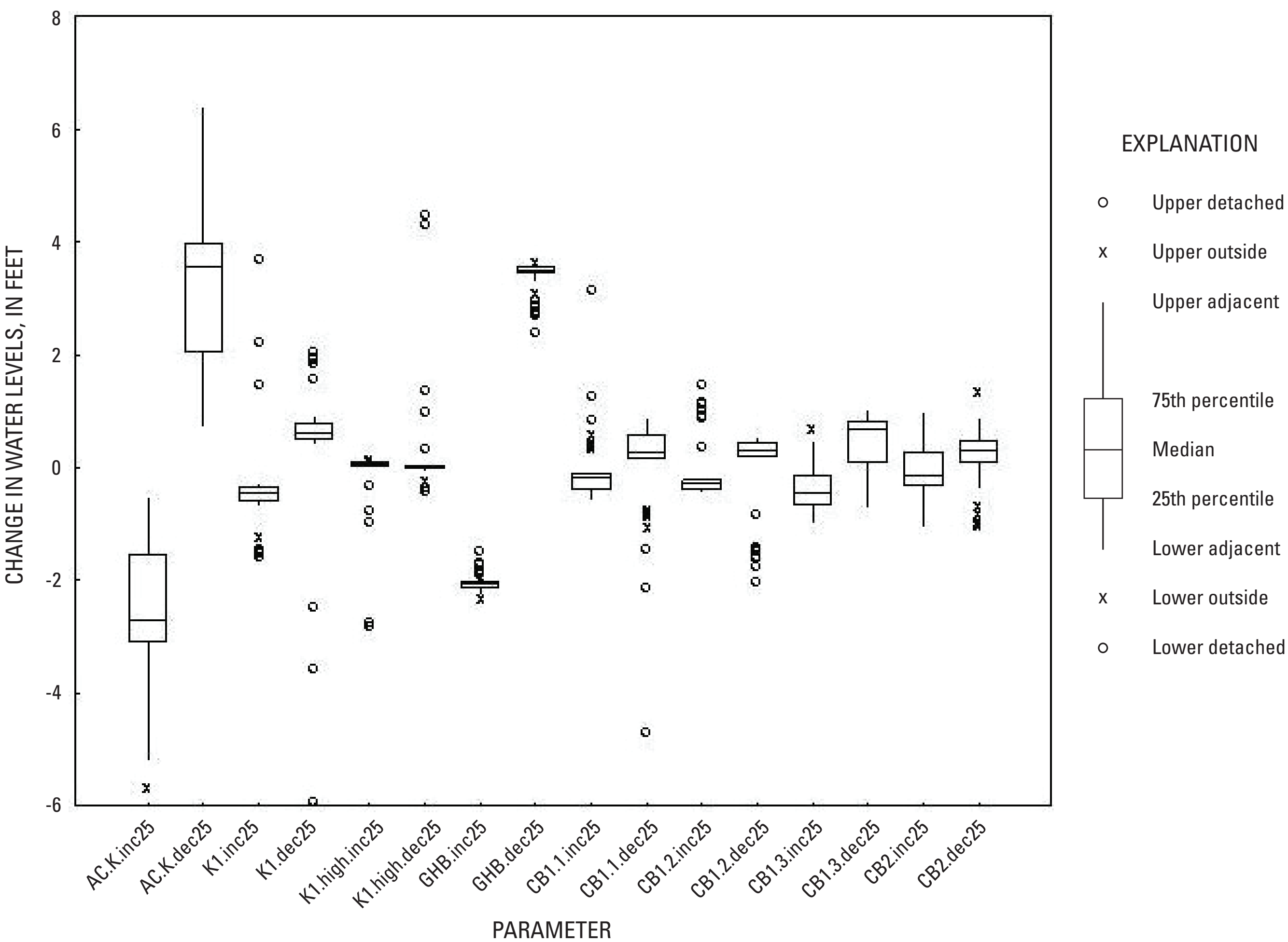


Figure 69. Changes in simulated water levels as a result of 25 percent changes in individual model parameter values, deep aquifer system model, Cape May County, New Jersey, 2003. (See table 17 for model parameters names.)

Table 17. Description of parameters used for sensitivity analysis of the deep aquifer system model, Cape May County, New Jersey.

[Effects of parameters are shown in figure 69.]

Parameter	Description
AC.K.inc25	Atlantic City 800-foot sand aquifer horizontal hydraulic conductivity increased 25 percent
AC.K.dec25	Atlantic City 800-foot sand aquifer horizontal hydraulic conductivity decreased 25 percent
K1.inc25	Rio Grande water-bearing zone horizontal hydraulic conductivity low conductance zone increased 25 percent
K1.dec25	Rio Grande water-bearing zone horizontal hydraulic conductivity low conductance zone decreased 25 percent
K1.high.inc25	Rio Grande water-bearing zone horizontal hydraulic conductivity high conductance zone increased 25 percent
K1.high.dec25	Rio Grande water-bearing zone horizontal hydraulic conductivity high conductance zone decreased 25 percent
GHB.inc25	Bed conductance of general head boundary increased by 25 percent
GHB.dec25	Bed conductance of general head boundary decreased by 25 percent
CB1.1.inc25	Vertical hydraulic conductivity zone 1 of the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand increased 25 percent
CB1.1.dec25	Vertical hydraulic conductivity zone 1 of the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand decreased 25 percent
CB1.2.inc25	Vertical hydraulic conductivity zone 2 of the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand increased 25 percent
CB1.2.dec25	Vertical hydraulic conductivity zone 2 of the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand decreased 25 percent
CB1.3.inc25	Vertical hydraulic conductivity zone 3 of the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand increased 25 percent
CB1.3.dec25	Vertical hydraulic conductivity zone 3 of the confining unit between the Rio Grande water-bearing zone and the Atlantic City 800-foot sand decreased 25 percent
CB2.inc25	Vertical hydraulic conductivity of the confining unit separating the lower and upper units of the Atlantic City 800-foot sand increased 25 percent
CB2.dec25	Vertical hydraulic conductivity of the confining unit separating the lower and upper units of the Atlantic City 800-foot sand decreased 25 percent

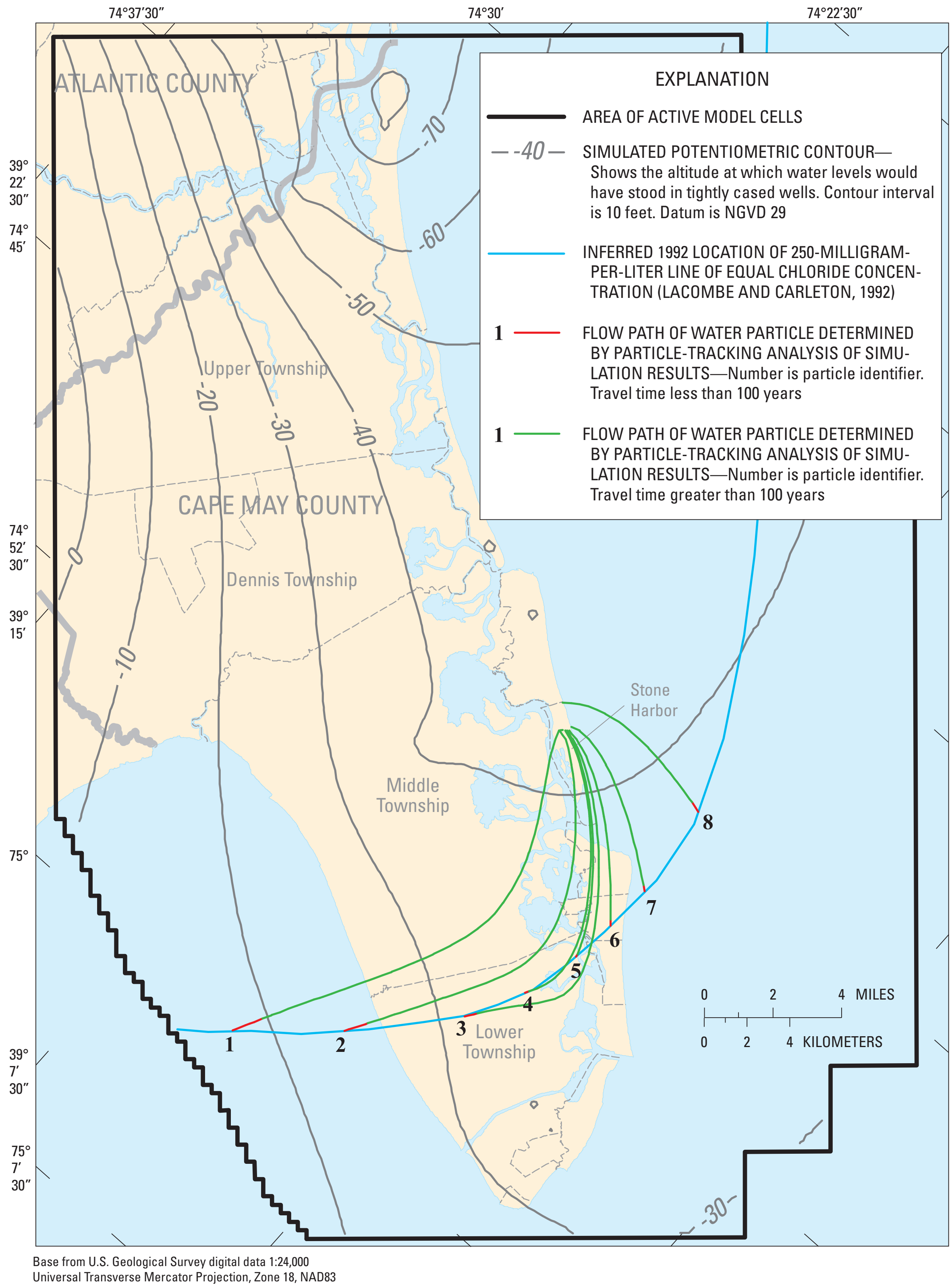


Figure 70. Simulated potentiometric surface in the Atlantic City 800-foot sand and simulated travel times of particles near the inferred 250-milligram-per-liter isochlor, Cape May County, New Jersey, 2003.

Results of particle-tracking analysis indicate that the time required for saltwater to reach the production wells for each aquifer if groundwater withdrawals are maintained at 2003 rates is on the order of hundreds of years. However, these results are based on the assumptions that the aquifers are homogeneous and the porosities are 15 percent. The presence of local zones of high permeability in the aquifer could reduce the predicted travel time of the saltwater from its present location to high volume production wells. In addition, the accuracy of predicted travel times is limited by the uncertainties inherent in the representation of the natural hydrologic conditions and the possibility that the rate of groundwater withdrawals will increase. Therefore, travel times could be shorter or longer than those predicted.

Limitations of the Deep Aquifer System Model

The deep aquifer system model is a steady-state model and, therefore, does not include the release of water from storage and the subsequent delay of the decline in water levels associated with increases in withdrawals. These limitations result in conservative estimates of future declines in water levels because actual declines will occur more slowly. The model does not include direct simulation of solute transport, and estimates of travel times from the estimated location of the 250-mg/L isochlor are based on advective transport only, disregarding dispersion and diffusion. The limited data available to estimate the location of the 250-mg/L isochlor and the travel times of hundreds of years to existing (2008) withdrawal wells indicate any errors related to the difference between explicit simulation of solute transport and the simpler assumption of advective transport are not important and are likely less than errors introduced through other uncertainties, such as porosity. The sub-regional model used to simulate flow within Cape May County includes an explicit representation of the Rio Grande water-bearing zone but receives boundary flows from the regional Coastal Plain model that does not have an explicit representation of it. Therefore, in the Coastal Plain model withdrawals from the Rio Grande water-bearing zone are simulated to be from the Atlantic City 800-foot sand, and the simulated effects of those withdrawals on the deeper aquifer are greater than would actually be the case.

Scenarios and Results of Simulations

The USGS, NJDEP, Cape May County Planning Board, and local community water purveyors cooperatively developed three baseline and six alternative future water-withdrawal scenarios to be simulated. The simulations were used to predict three major adverse effects, (1) saltwater intrusion—meaning movement of the 250-mg/L isochlor, (2) depletion of ecological water supplies—meaning decreases in base flow of streams and declines of water levels in the water-table aquifer, and (3) declines in water levels in the confined aquifers during 2003-2050. The simulations used reported withdrawals, NJDEP full allocation withdrawals, or estimated full build-out water withdrawals for potable and non-potable water supplies. The goal of simulating the three baseline scenarios was to determine the extent of adverse effects if each community were to continue using existing wells with current (1999-2003) or greater withdrawal rates. The goal of simulating the six alternative future withdrawal scenarios was to identify one or more scenarios that would provide enough potable and non-potable water to meet projected demand and cause the least adverse effects on the county's water supplies. The scenarios are described below.

For baseline Scenarios 1, 2, and 3, changes in saltwater-front locations, streamflows, and groundwater levels in each aquifer were simulated. Groundwater withdrawals from existing (2003) wells were simulated in baseline Scenarios 1, 2, and 3 to be at the average 1999-2003 rate, at NJDEP full allocation rates, and at estimated full build-out demand rates, respectively.

For future Scenarios 4 through 9, changes in the salt-water-front location, streamflow, and groundwater levels were simulated. Future scenarios only used estimated full build-out water demands. The results of the simulations are used to quantitatively assess the effects of the three major changes on 2050 water supplies. Future Scenarios 4 through 9 were designed to selectively increase, decrease, or cease withdrawals from existing production wells. For these future scenarios, proposed new wells were added to the simulation in the Cohansey aquifer in areas that are far from the saltwater fronts to cause less saltwater intrusion and (or) were added to the model in the Rio Grande water-bearing zone and Atlantic City 800-foot sand. Water withdrawn from some proposed wells open to the deeper aquifers would require desalination but would cause less depletion of the ecological water supply. One future scenario includes injecting reclaimed water into the Cohansey aquifer to create a barrier to additional saltwater intrusion.

Future Scenarios 4, 5, and 6 were structured to allow local communities to develop their full build-out water demand within their own community or their own supply system. Future Scenarios 7, 8, and 9 were structured to allow the communities of southern Cape May County to work cooperatively with neighboring communities supply systems to collectively meet their full build-out water demand.

The locations of wells in each of the nine scenarios are not changed for Ocean City, Sea Isle City, Avalon, and Stone Harbor. These four northern barrier island communities obtain nearly all water from production wells (fig. 71) within their own community and all the wells tap the Atlantic City 800-foot sand. Each scenario is designed so that all future water supplies come from the existing wells. The initial withdrawal rate for each scenario is the average 1999-2003 withdrawal rate. Withdrawals for each community and type of supply, by scenario, are given in table 18. Future withdrawals in each community are assumed to be equally divided among the existing production wells. The water purveyor for Ocean City and Upper Township has one production well in the village of Marmora in Upper Township, and part of the withdrawals from that well is used to meet demand in Ocean City. For simplicity, it was assumed that all future increases in withdrawals will come from wells in Ocean City.

The locations of wells in each of the nine scenarios are not changed for Dennis Township, Upper Township, and Woodbine. These three northern mainland communities predominantly use domestic-supply wells. Woodbine and Upper Township use production wells for potable-water supply; they also have major water withdrawals for golf and farm irrigation, industrial supply, small production, and mining supply. Most water is withdrawn from the Holly Beach water-bearing zone and the Cohansey aquifer; only five wells tap the Atlantic City 800-foot sand. All future withdrawals are assumed to come from the existing production wells (fig. 71, table 18).

The locations of wells in each of the nine scenarios in the Cape May communities and Middle Township are identical in most aspects. The CMCWU desalinates water from the salty part of the Atlantic City 800-foot sand to meet production demands, but a few domestic, industrial, and farm-irrigation wells tap shallow freshwater aquifers to meet local needs. Middle Township (NJA-CMCH) has two production wells that tap the Atlantic City 800-foot sand, and one well that taps the Cohansey aquifer. Many small production, farm, and golf irrigation wells, and thousands of domestic-supply wells tap the Cohansey and shallower aquifers. Important changes introduced in Scenario 9 for the Cape May communities and introduced in Scenario 7 for Middle Township are discussed below.

The six future scenarios for Lower Township and the Wildwood communities differ substantially from the baseline scenarios. The baseline withdrawal scenarios for Lower Township include five production wells that tap the Cohansey aquifer, thousands of domestic wells, and a few small production, industrial, farm, and golf-irrigation wells. Baseline withdrawal scenarios for the Wildwood communities include nine production wells. One well taps the estuarine sand aquifer, seven tap the Cohansey aquifer, and one taps the Rio Grande water-bearing zone. Future scenarios for Lower Township and the Wildwood communities include substantial changes, and each scenario is discussed individually in the following sections.

The 2050 water levels, saltwater intrusion, and base flow in streams were predicted using the shallow and deep groundwater-flow models with the nine withdrawal scenarios as input. The withdrawal rates used in the model are the greater of those projected for the year 2050 or for full build-out. The shallow system model is transient, meaning the water levels and location of the saltwater front can change with time. Therefore, the withdrawal rates for individual production wells were increased linearly over five stress periods (tables 18, 19, and 20) from the average 1999-2003 rates to the predicted 2050 rates. The deep system model is steady state, meaning that simulated conditions do not change with time, and the simulated water levels represent conditions that would occur after water is released from storage and water levels stabilize. Drawdowns in the model represent those that would occur after release from storage had ended and withdrawals from the aquifer are balanced by recharge and inflow through overlying and underlying confining units. Therefore, the drawdowns and estimated times of travel from the deep model are conservative, yielding slightly greater drawdowns and slightly faster travel times in 2050 than would be the case if contributions from aquifer storage were included.

The results described below and in following sections include estimated water-level changes (drawdowns), streamflow depletion, and estimated travel times from the saltwater front to production wells or estimated distance of saltwater front intrusion. The results of the baseline and future scenarios include the estimated water-level changes (drawdowns), estimated depletion of base flow in the streams, estimated distance that the sodium/chloride saltwater front moves in the shallow aquifer, and the travel times of the 250-mg/L isochlor in the deep aquifer to the nearest production well. All of the estimated values given should be assumed to be approximate because the models from which they are derived include many assumptions about the model parameters. As shown in the previous section of this report, changing any parameter could yield different results. However, comparisons between simulations that indicate relative differences between possible future scenarios are very useful for estimating possible relative positive and negative consequences of different actions. The relative changes between scenarios are less sensitive to different assumptions about the physical system because such changes affect the future scenarios similarly if not identically. Therefore, a predicted doubling of saltwater front intrusion rate or water-level drawdown from one scenario to another is likely accurate even if the magnitude of the estimated rate or drawdown differs from the actual.

Scenario 1, 2, and 3: Baseline

Scenarios 1, 2, and 3 are baseline options that were designed to use annual water withdrawals during 2005-2050 that are as follows: Scenario 1, annual mean withdrawals during 1999-2003 (7,711 Mgal/yr); Scenario 2, NJDEP full allocation rates (11,730 Mgal/yr); and Scenario 3, full build-out demand rates (12,864 Mgal/yr). Baseline scenarios assume that withdrawals are from existing production wells (fig. 72). Baseline Scenarios 1 and 2 are not expected to meet future demand. Baseline Scenario 3 is expected to meet predicted future full build-out demand. Scenarios 1, 2, and 3 provide a quantitative baseline to which the movement and future location of the saltwater front, depletion of the ecological water supplies, and declines in water levels of the confined aquifers in other future alternatives (Scenarios 4-9) can be compared.

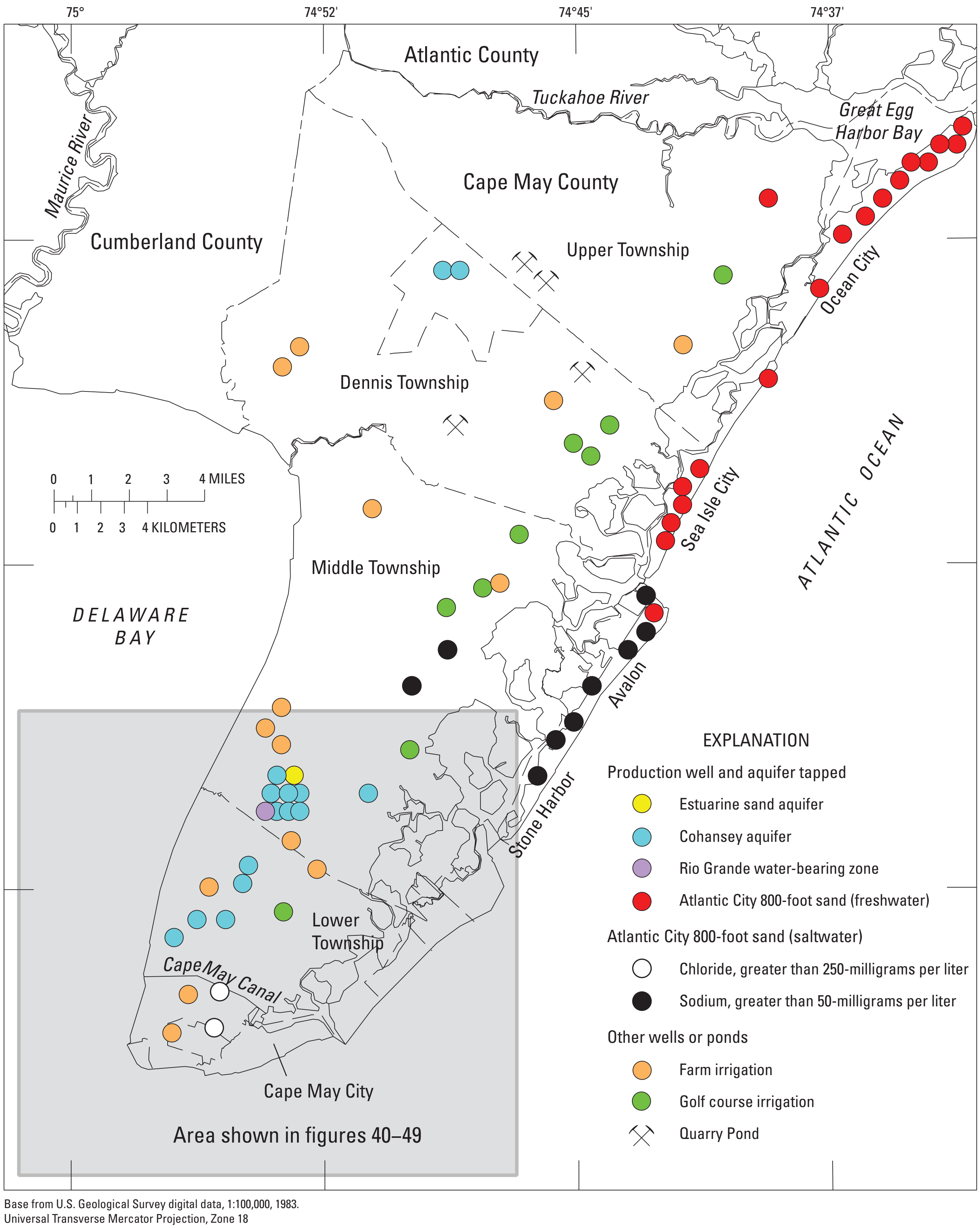


Figure 71. Location of existing production wells, active farm and golf course irrigation sites, and quarry wells/ponds with withdrawal permits, Cape May County, New Jersey.

Table 18. Water demand for 1999-2003, full allocation, and full build-out by community.

[Values are in million gallons per year. Color is for ease of determining source aquifer; grey numbers. Withdrawals are divided by well in Scenarios 4 to 9 and shown in tables 19 and 20. *Desalination: 72 percent of withdrawn saltwater is desalinated to potable water. Holly-B, Holly Beach water-bearing zone; Esand, estuarine sand aquifer; Cohansey, Cohansey aquifer; Rio G, Rio Grande water-bearing zone; AC800, Atlantic City 800-foot sand; -, no withdrawals.]

		Initial water demand for Scenarios 1 to 9 and mean 1999-2003 in 2050 for Scenario 1						Full allocation (2005) demand in 2050 for Scenario 2						Full build-out demand in 2050 for Scenario 3 to 9					
Township/ Purveyors	Aquifer	Production	Domestic supply	Small-public, commercial	Farm irrigation	Golf irrigation	Mining supply	Production	Domestic supply	Small-public, commercial	Farm irrigation	Golf irrigation	Mining supply	Production	Domestic supply	Small-public, commercial	Farm irrigation	Golf Irrigation	Mining Supply
Avalon	AC-800	310	-	-	-	-	-	354	-	-	-	-	-	450	-	-	-	-	-
Ocean City	AC-800	1,250	-	-	-	-	-	1,296	-	-	-	-	-	1,558	-	-	-	-	-
Sea Isle City	AC-800	350	-	-	-	-	-	440	-	-	-	-	-	468	-	-	-	-	-
Stone Harbor	AC-800	200	-	-	-	-	-	230	-	-	-	-	-	298	-	-	-	-	-
Cape Mays	Holly-B	-	-	-	1	-	-	-	-	-	5	-	-	-	-	-	1	-	-
	E-sand	-	-	-	-	-	-	-	-	-	14	-	-	-	-	-	-	-	-
	Cohansey	-	-	-	-	-	-	160	-	-	-	-	-	-	-	-	-	-	-
	AC-800	324*	-	-	-	-	-	488*	-	-	-	-	-	605*	-	-	-	-	-
Desalination	AC-800	450	-	-	-	-	-	678	-	-	-	-	-	840	-	-	-	-	-
Wildwoods	E-sand	120	-	-	-	-	-	186	-	-	-	-	-	224	-	-	-	-	-
	Cohansey	1,220	-	-	-	-	-	1,303	-	-	-	-	-	1,344	-	-	-	-	-
	Rio G	210	-	-	-	-	-	450	-	-	-	-	-	317	-	-	-	-	-
Lower Twp	Holly-B	-	-	-	14	30	-	-	-	-	231	27	-	-	-	-	14	30	-
	E-sand	-	500	84	14	10	-	-	480	325	231	27	-	-	606	40	14	10	-
	Cohansey	400	-	-	-	20	-	868	-	-	-	27	-	889	-	-	-	10	-
Middle Twp	Holly-B	-	-	-	25	60	-	-	-	-	165	33	-	-	-	-	25	45	-
	E-sand	-	550	10	5	10	-	-	530	20	120	-	-	-	981	100	5	-	-
	Cohansey	30	-	42	-	25	-	37	-	-	-	140	-	200	-	-	-	75	-
	AC-800	230	-	10	-	-	-	235	-	-	-	-	-	939	-	10	-	-	-
Dennis Twp	Holly-B	-	240	30	133	44	2	-	230	93	47	55	2	-	500	30	133	44	2
	Cohansey	-	-	20	160	44	-	-	-	93	957	55	-	-	200	28	160	44	-
	AC-800	-	-	-	-	10	-	-	-	-	-	11	-	-	-	-	-	10	-
Upper Twp	Holly-B	-	400	8	-	5	6	-	500	80	95	11	6	-	250	100	-	5	6
	Cohansey	-	50	18	-	-	-	-	-	95	-	-	-	-	500	121	-	-	-
	AC-800	150	-	236	-	-	-	178	-	397	-	-	-	623	-	236	-	-	-
Woodbine	Cohansey	100	-	-	-	-	-	250	-	-	-	-	-	225	200	8	-	-	-
Subtotal A	Holly-B	-	640	38	173	139	8	-	730	173	543	126	8	-	750	130	173	80	8
	E-sand	120	1,050	94	19	20	-	186	1,010	345	365	27	-	224	1,587	140	19	10	-
	Cohansey	1,650	50	80	160	89	-	2,581	-	188	957	222	-	2,658	900	157	160	129	-
Subtotal B	Shallow	1,770	1,740	212	352	248	8	2,767	1,740	706	1,865	375	8	2,882	3,237	427	352	219	8
Total	Shallow	4,305						7,461						7,125					

Table 18. Water demand for 1999-2003, full allocation, and full build-out by community.—Continued

[Values are in million gallons per year. Color is for ease of determining source aquifer; grey numbers. Withdrawals are divided by well in Scenarios 4 to 9 and shown in tables 19 and 20. *Desalination: 72 percent of withdrawn saltwater is desalinated to potable water. Holly-B, Holly Beach water-bearing zone; Esand, estuarine sand aquifer; Cohansey, Cohansey aquifer; Rio G, Rio Grande water-bearing zone; AC800, Atlantic City 800-foot sand; -, no withdrawals.]

		Initial water demand for Scenarios 1 to 9 and mean 1999-2003 in 2050 for Scenario 1						Full allocation (2005) demand in 2050 for Scenario 2						Full build-out demand in 2050 for Scenario 3 to 9					
Township/ Purveyors	**Aquifer**	**Production**	**Domestic supply**	**Small-public, commercial**	**Farm irrigation**	**Golf irrigation**	**Mining supply**	**Production**	**Domestic supply**	**Small-public, commercial**	**Farm irrigation**	**Golf irrigation**	**Mining supply**	**Production**	**Domestic supply**	**Small-public, commercial**	**Farm irrigation**	**Golf Irrigation**	**Mining Supply**
Subtotal C	Rio G	210	-	-	-	-	-	450	-	-	-	-	-	317	-	-	-	-	-
	AC-800	2,940	-	246	-	10	-	3,411	-	397	-	11	-	5,176	-	236	-	10	-
Subtotal D	Deep	3,406						4,269						5,739					
Grand Total		7,711						11,730						12,864					

Description of Scenarios 1, 2, and 3

Scenario 1 was designed to assess the effects of continued withdrawals by all users at the same rate as the average withdrawal during 1999-2003. This scenario will have the least withdrawals of all scenarios (tables 18-20) at 7,711 Mgal/yr.

Scenario 2 was designed to assess the effects of withdrawing groundwater at the maximum rate permitted by NJDEP Bureau of Water Allocation in 2005 for regulated users (full allocation). Regulated users are owners of wells who can withdraw more than 70 gallons per minute and include production, small production, farm irrigation, golf course irrigation, industrial, commercial, and mining wells. NJDEP allocations exist for production, farm irrigation, and golf course irrigation withdrawals from the shallow aquifers, and the allocated amounts exceed the withdrawals that are projected for the full build-out demand. Scenario 2 withdrawals are 11,730 Mgal/yr, about 1.5 times the withdrawals of Scenario 1. Withdrawals for domestic supply and mining supply are kept at the same rate of withdrawal as in Scenario 1 because domestic supply has no allocation and mining supply uses recirculated water (table 18).

Scenario 3 was designed to assess the effects of withdrawing full build-out water demand. Baseline Scenario 3 has the greatest total withdrawals for the aquifers, with 12,864 Mgal/yr or about 1.7 times the withdrawal of Scenario 1 and nearly 1.1 times the withdrawal of Scenario 2. Withdrawals for public, small public, domestic, and industrial supply were developed from the NJDEP build-out analysis. Withdrawals for irrigation and mining supply are the same as in Scenario 1 because such withdrawals will likely remain constant over time.

Results of Simulations of Scenarios 1, 2, and 3

A major result of the simulation of Scenarios 1, 2, and 3 is that saltwater will intrude into LTMUA production well 1 (9-52) by 2050 and, in Scenarios 2 and 3, will reach (or very nearly reach) LTMUA well 2 (9-54) and the WWU well field (figs. 73A, 73B, 73C, 74, table 21). The simulated saltwater front (defined for the shallow-system aquifers as the 250-mg/L isochlor, which is in nearly the same location as the 50-mg/L sodium isopleth) in the upper third of the Cohansey aquifer west of the WWU wells intrudes 6,000 to 7,000 ft by 2050. The sodium/chloride saltwater front in the bottom third of the aquifer intrudes 7,100 to 9,500 ft by 2050 toward the WWU production wells (table 21). Once the sodium/chloride saltwater front intrudes as far as the WWU well field, chloride concentrations in some wells may increase about 50 mg/L/yr, similar to the intrusion rate observed in former production wells that tapped the Cohansey aquifer in other parts of Cape May County. Model results indicate that without careful management, saltwater intrusion will render the water from all WWU production wells open to the Cohansey aquifer unfit for potable supply (unless desalinated) within a few years of the intrusion into the first well.

Under Scenarios 1, 2, and 3, the simulated sodium/chloride saltwater front west of LTMUA production well 2 (9-54) intrudes 3,400 to 5,300 ft in the upper third of the aquifer, and 3,700 to 5,400 ft in the bottom third of the aquifer (figs. 73A, 73B, 73C, table 21). Intrusion into LTMUA production well 1 (9-52) will render the water unfit for potable supply (unless desalinated). The simulated sodium/chloride saltwater front moves inland as much as 1,600 ft under Wildwood, Cape May City, and Cape May Point (figs. 73A, 73B, 73C,

Table 19. Water demand for Lower Township Municipal Utilities Authority for Scenarios 1 to 9 and estimated withdrawal per well for each scenario.

[Values are in million gallons per year; AC-800, Atlantic City 800-foot sand; --, not applicable.]

Lower Township Municipal Utilities Authority wells	Aquifer	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
Production well 1 (9-52)	Cohansey	112	243	249	0	0	0	0	0	0
Production well 2 (9-54)	Cohansey	86	182	185	87	87	87	87	87	87
Production well 3/7 (9-57)	Cohansey	87	182	185	87	87	87	87	87	87
Production well 4/6 (9-58)	Cohansey	63	130	135	177	76	177	76	76	76
Production well 5 (9-59)	Cohansey	59	131	135	177	77	177	77	77	77
Hypothetical wells										
Production well 8	Cohansey	--	--	--	180	--	180	--	--	--
Production well 9	Cohansey	--	--	--	181	--	181	--	--	--
Local Desalination well 11	AC-800	--	--	--	--	[1]390	--	--	--	--
Local Desalination well 10	AC-800	--	--	--	--	[1]390	--	--	--	--
Injection well 1	Cohansey	--	--	--	--	--	[2]-80	--	--	--
Injection well 2	Cohansey	--	--	--	--	--	[2]-80	--	--	--
Injection well 3	Cohansey	--	--	--	--	--	[2]-80	--	--	--
Spine AC-800-1	AC-800	--	--	--	--	--	--	236	--	--
Spine AC-800-2	AC-800	--	--	--	--	--	--	236	--	--
Spine Cohansey 1	Cohansey	--	--	--	--	--	--	90	--	--
Airport Desalination 1	AC-800	--	--	--	--	--	--	--	[1]390	--
Airport Desalination 2	AC-800	--	--	--	--	--	--	--	[1]390	--
Cape Desalination 1	AC-800	--	--	--	--	--	--	--	--	[1]390
Cape Desalination 2	AC-800	--	--	--	--	--	--	--	--	[1]390
Withdrawal subtotal	Cohansey	407	868	889	889	327	889	417	327	327
Injection subtotal	Cohansey	--	--	--	--	--	-240	--	--	--
Withdrawal subtotal	AC-800	--	--	--	--	780	--	472	780	780
[3]Desalination subtotal	AC-800	0	0	0	0	562	--	340	562	562
Total potable		407	868	889	889	889	889	889	889	889

[1]Saltwater withdrawal.

[2]Injected water.

[3]Withdrawal from saltwater wells must be desalinated before use. About 72 percent of the water that is withdrawn from the salty aquifer is used to meet demand and 28 percent of the water is disposed of.

table 21). This movement may intrude into a few domestic or commercial wells, and the well owners will probably have to connect to a production system. The intrusion rate in Scenario 2 is slightly higher in Scenario 3 because NJDEP full allocation for the LTMUA, CMCWU, and some other registered well users exceeds full build-out water demand (fig. 74).

The simulated location of the sodium/chloride saltwater front in the Holly Beach water-bearing zone does not change for any scenario. Sea level is projected to rise 4 to 9 in. during 2000-50 (US Environmental Protection Agency, 2008). Nearly all increases in the salinity of the water-table aquifer are the result of sea-level rise, and minimal intrusion is the result of groundwater withdrawals. Some local intrusion may occur in domestic wells along the Delaware Bay shoreline.

Simulated movement of the sodium/chloride saltwater front in the estuarine sand aquifer, south of Cape May Court House, during 2003-50, in Scenarios 1, 2, and 3, ranges from near zero to 2,100 ft. The greatest rate of intrusion occurs in the Wildwood communities and along the Delaware Bay shoreline northwest of WWU wells. WWU has the only major production well open to the estuarine sand aquifer. Domestic wells withdraw the most water from the estuarine sand aquifer (table 18). Results from simulations of Scenarios 1, 2, and 3 indicate saltwater intrusion in the estuarine sand aquifer in

Table 20. Water demand for (A) Wildwood Water Utility and (B) New Jersey American-Cape May Court House for Scenario 1 to 9 and estimated withdrawal per well for each scenario.

[Withdrawals are in million gallons per year; --, not applicable; E-sand, estuarine sand aquifer; AC-800, Atlantic City 800-foot sand; Holly Beach, Holly Beach water-bearing zone; Rio Grande, Rio Grande water-bearing zone.]

Table 20A Wildwood Water Utility Wells	Aquifer	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
Holly Beach	Holly Beach	--	--	--	--	--	--	--	--	--
Rio 31 (9-72)	E-sand	56	186	80	42	42	42	42	42	42
Rio 30 (9-78)	Cohansey	156	191	221	97	97	97	97	97	97
Rio 33 (9-69)	Cohansey	215	262	304	97	97	97	97	97	97
Rio 34 (9-65)	Cohansey	237	289	336	97	97	97	97	97	97
Rio 42 (9-375)	Cohansey	132	162	188	97	97	97	97	97	97
Rio 43 (9-385)	Cohansey	100	122	141	97	97	97	97	97	97
Rio 28 (9-68)	Cohansey	124	151	175	97	97	97	97	97	97
Rio 29 (9-74)	Cohansey	103	126	146	97	97	97	97	97	97
Rio 38 (9-71)	Rio Grande	207	279	294	388	226	388	224	226	226
Rio-G 2002 well A	Rio Grande	--	--	--	388	226	388	224	226	226
Rio-G 2002 well B	Rio Grande	--	--	--	388	226	388	224	226	226
Hypothetical Wells										
Local Desalination A	AC-800	--	--	--	--	[1]340	--	--	--	--
Local Desalination B	AC-800	--	--	--	--	[1]335	--	--	--	--
Spine AC-800 3	AC-800	--	--	--	--	--	--	211	--	--
Spine AC-800 4	AC-800	--	--	--	--	--	--	211	--	--
Spine Cohansey 2	Cohansey	--	--	--	--	--	--	70	--	--
Airport Desalination 3	AC-800	--	--	--	--	--	--	--	[1]350	--
Airport Desalination 4	AC-800	--	--	--	--	--	--	--	[1]350	--
Cape Desalination 3	AC-800	--	--	--	--	--	--	--	--	[1]350
Cape Desalination 4	AC-800	--	--	--	--	--	--	--	--	[1]350
Withdrawal subtotal	Holly Beach	--	--	--	--	--	--	--	--	--
Withdrawal subtotal	E-sand	56	186	147	42	42	42	42	42	42
Withdrawal subtotal	Cohansey	1,068	1,303	1,495	679	682	679	749	682	682
Withdrawal subtotal	Rio Grande	207	279	243	1,164	675	1,164	672	675	675
Withdrawal subtotal	AC-800	--	--	--	--	675	--	422	700	700
Desalinated subtotal	AC-800	--	--	--	--	486	--	--	486	486
Total Potable		1,331	1,768	1,885	1,885	1,885	1,885	1,885	1,885	1,885
Table 20B										
Production well 1 (9-296)	AC-800	115	120	500	500	500	500	115	500	500
Production well 2 (9-92)	AC-800	115	115	500	500	500	500	115	500	500
Production well 3/7 (9-273)	Cohansey	30	36.5	140	140	140	140	30	140	140
Hypothetical Wells										
Spine AC-800 1	AC-800	--	--	--	--	--	--	195	--	--
Spine AC-800 2	AC-800	--	--	--	--	--	--	195	--	--
Spine Cohansey 1	Cohansey	--	--	--	--	--	--	50	--	--
Spine AC-800 3	AC-800	--	--	--	--	--	--	195	--	--
Spine AC-800 4	AC-800	--	--	--	--	--	--	195	--	--
Spine Coh 2	Cohansey	--	--	--	--	--	--	50	--	--
Total potable		260	272	1,140	1,140	1,140	1,140	1,140	1,140	1,140

[1]Saltwater withdrawal.

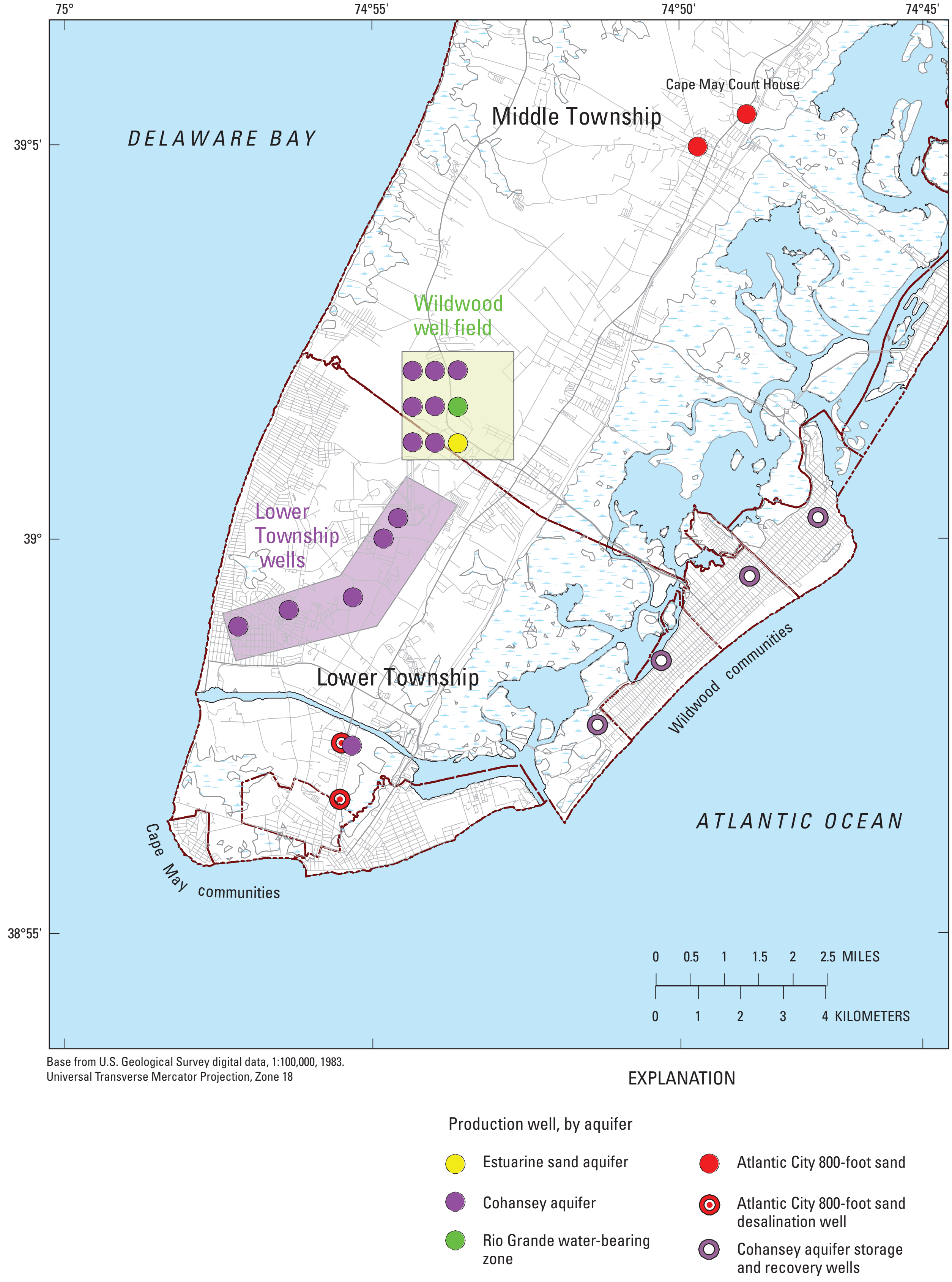
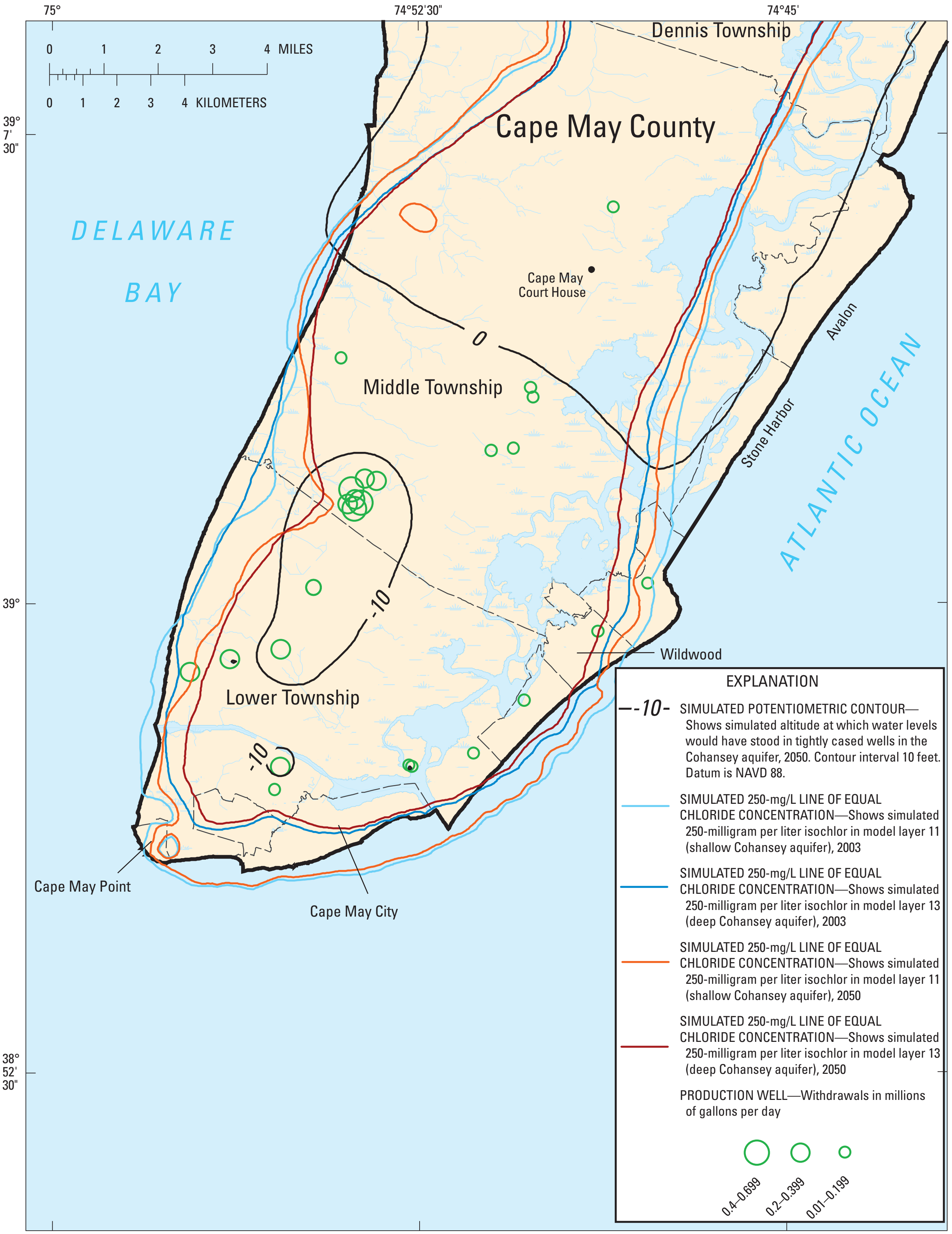


Figure 72. Location of production wells used in Scenarios 1, 2, and 3, by aquifer, supplying Lower Township, the Wildwood communities, the Cape May communities, and Cape May Court House, Cape May County, New Jersey.



Base from U.S. Geological Survey digital data

Figure 73A. Scenario 1 simulated potentiometric surface and location of the 250-milligram per liter isochlor in the Cohansey aquifer in 2050, assuming no change in withdrawals from wells in use during 2003, Cape May County, New Jersey.

Figure 73B. Scenario 2 simulated potentiometric surface and location of the 250-milligram per liter isochlor in the Cohansey aquifer in 2050, assuming fully allocated withdrawals from wells in use during 2003, Cape May County, New Jersey.

Base from U.S. Geological Survey digital data

Figure 73C. Scenario 3 simulated potentiometric surface and location of the 250-milligram per liter isochlor in the Cohansey aquifer in 2050, assuming full build-out withdrawals from wells in use during 2003, Cape May County, New Jersey.

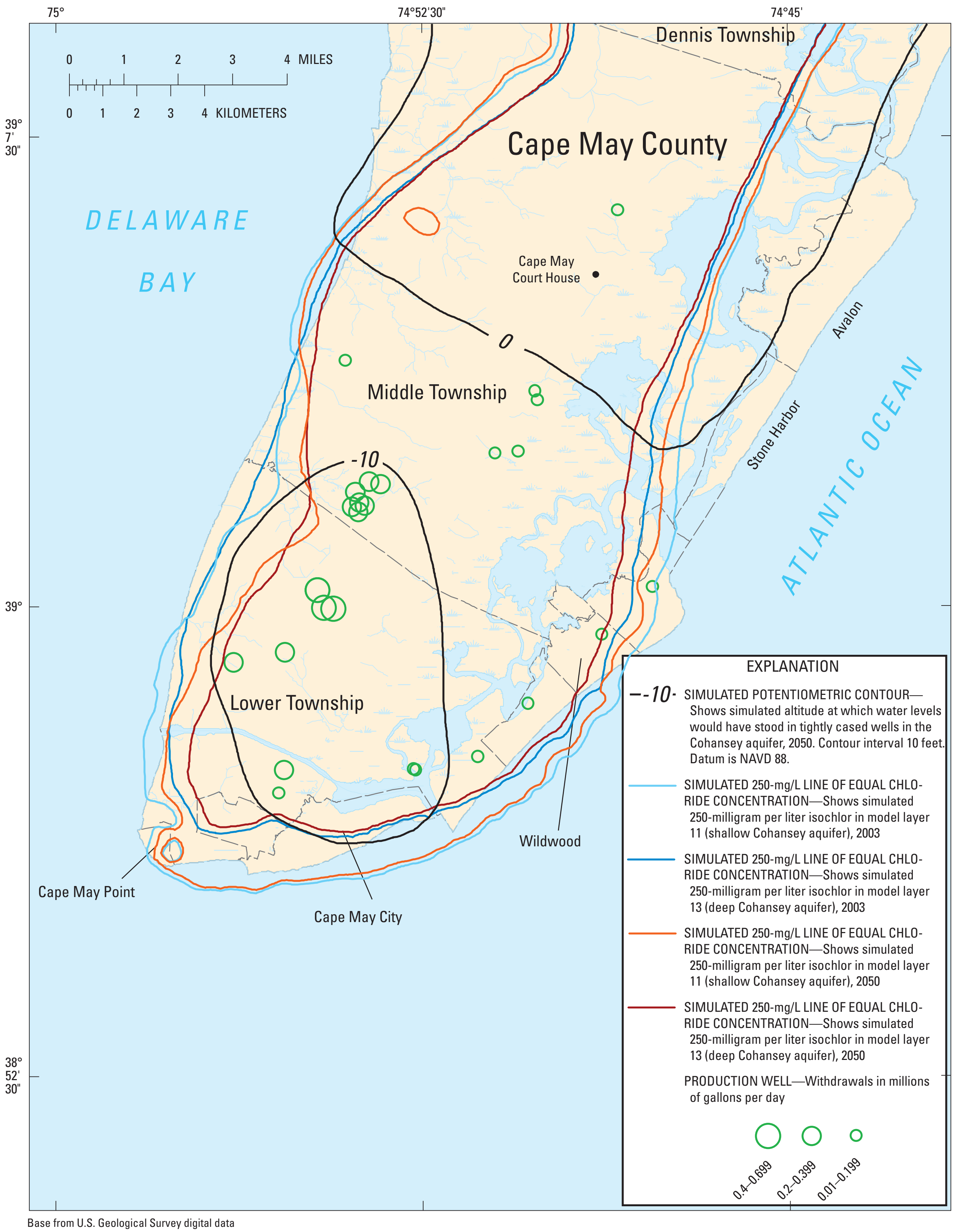


Figure 73D. Scenario 4 simulated potentiometric surface and location of the 250-milligram per liter isochlor in the Cohansey aquifer in 2050, assuming full build-out withdrawals and hypothetical Lower Township Municipal Utilities Authority and Wildwood Water Utility wells producing potable water from the Cohansey aquifer and Rio Grande water-bearing zone, Cape May County, New Jersey.

Figure 73E. Scenarios 5, 8, and 9 simulated potentiometric surface and location of the 250-milligram per liter isochlor in the Cohansey aquifer in 2050, assuming full build-out withdrawals and hypothetical Lower Township Municipal Utilities Authority and Wildwood Water Utility wells producing brackish water from the Atlantic City 800-foot sand, Cape May County, New Jersey.

Base from U.S. Geological Survey digital data

Figure 73F. Scenario 6 simulated potentiometric surface and location of the 250-milligram per liter isochlor in the Cohansey aquifer in 2050, assuming full build-out withdrawals, hypothetical Lower Township Municipal Utilities Authority and Wildwood Water Utility wells producing potable water from the Cohansey aquifer and Rio Grande water-bearing zone, and hypothetical injection of reclaimed water into the Cohansey aquifer to create a barrier to future saltwater intrusion, Cape May County, New Jersey.

Figure 73G. Scenario 7 simulated potentiometric surface and location of the 250-milligram per liter isochlor in the Cohansey aquifer in 2050, assuming full build-out withdrawals and new Lower Township Municipal Utilities Authority and Wildwood Water Utility wells in Middle Township producing potable water from the Cohansey aquifer and Atlantic City 800-foot sand, Cape May County, New Jersey.

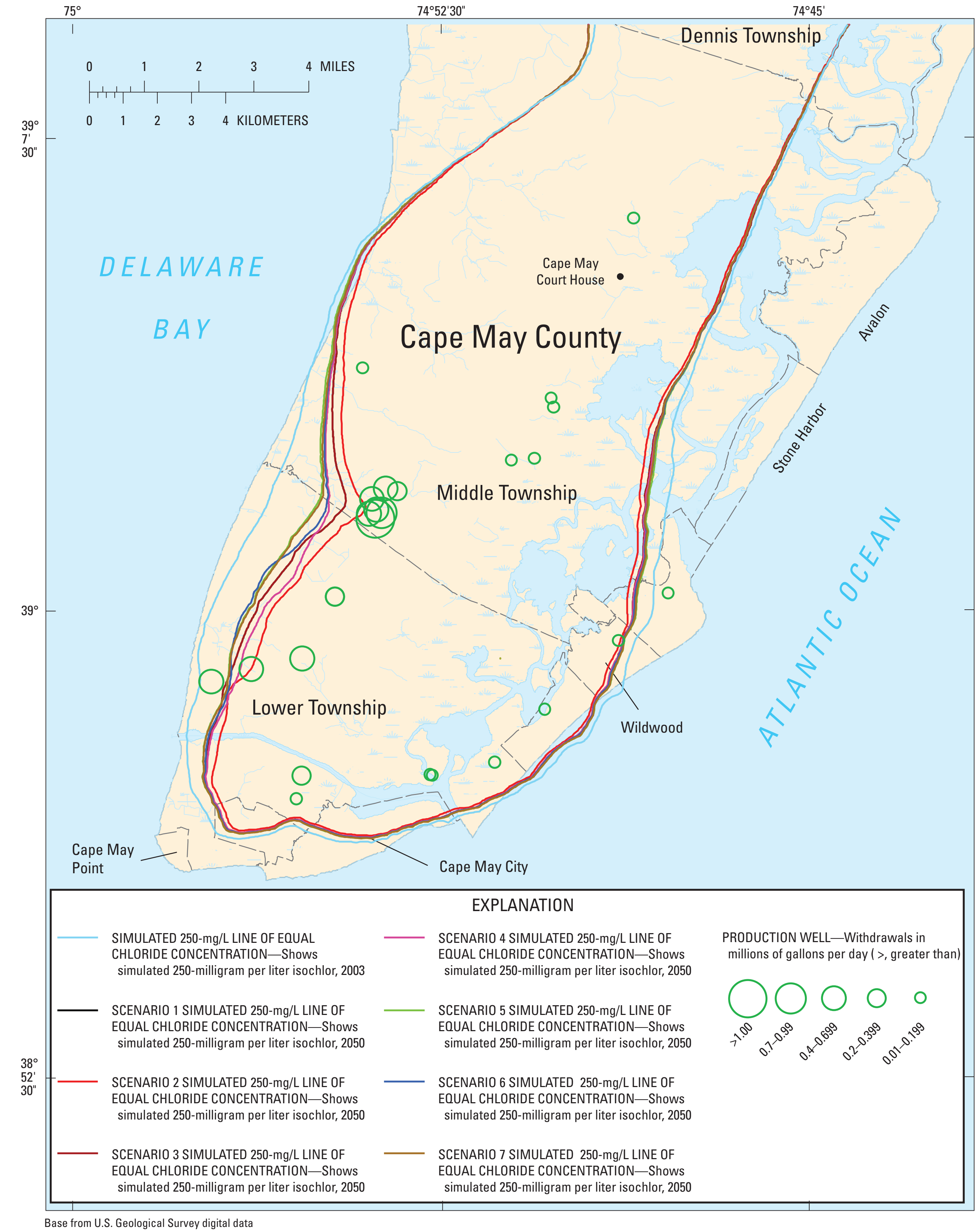


Figure 74. Simulated location of the 250-milligram per liter isochlor in the lower one-third of the Cohansey aquifer in 2050 for each of the nine scenarios, Cape May County, New Jersey.

Table 21. Simulated intrusion of the sodium/chloride saltwater front in the shallow aquifers for each scenario during 2003-50, Cape May County, New Jersey.

[WWU, Wildwood Water Utility; LTMUA, Lower Township Municipal Utilities Authority; CMCWU, Cape May City Water Utility; mg/L, milligrams per liter; red number, maximum intrusion; green number, minimum intrusion]

Simulated intrusion of sodium/chloride saltwater front (feet)														
	Estuarine sand aquifer			Cohansey aquifer								Simulated distance from 250-mg/L isochlor to production well in 2050		
													Lower third of aquifer	
Scenario	West of WWU production wells	Wildwood island	East and west coasts of county north of Cape May Court House	Part of aquifer	West of WWU production wells	West of airport	West of LTMUA production well 2 (9-54)	At Cape May Point	South of CMCWU production wells	Wildwood island	East and west coasts of county north of Cape May Court House	West of WWU production wells, upper third of aquifer	West of LTMU production well 1 (9-52)	West of LTMUA production well 2 (9-54)
1	500	1,400	0 to 100	Top third Bottom third	6,000 7,100	3,800 4,600	3,400 3,700	700 1,100	300 600	700 900	0 to 100	1,100	0	1,700
2	1,700	2,100	0 to 100	Top third Bottom third	6,900 9,000	5,400 6,300	5,300 5,400	1,300 1,600	400 800	1,000 1,100	0 to 100	200	0	0
3	1,000	1,800	0 to 100	Top third Bottom third	7,000 9,500	5,400 6,300	5,100 5,200	1,100 1,400	300 700	900 1,100	0 to 100	100	0	200
4	900	1,400	0 to 100	Top third Bottom third	4,100 5,500	4,600 5,700	3,300 4,300	700 1,200	300 600	700 900	0 to 100	3,000	0	1,100
5	1,000	1,300	0 to 100	Top third Bottom third	4,400 5,200	3,000 3,800	2,700 3,300	600 1,000	200 500	600 700	0 to 100	2,700	0	2,100
6	1,000	1,300	0 to 100	Top third Bottom third	4,500 5,300	2,900 3,400	2,700 3,300	700 1,100	200 500	700 800	0 to 100	2,600	0	2,100
7	1,100	1,300	0 to 100	Top third Bottom third	4,200 4,800	2,800 3,600	2,600 3,200	600 1,000	200 500	600 800	0 to 100	2,700	0	2,200
8	1,000	1,300	0 to 100	Top third Bottom third	4,400 5,200	3,000 3,800	2,700 3,300	600 1,000	200 500	600 700	0 to 100	2,700	0	2,100
9	1,000	1,300	0 to 100	Top third Bottom third	4,400 5,200	3,000 3,800	2,700 3,300	600 1,000	200 500	600 700	0 to 100	2,700	0	2,100
Range for 4-9	900 1,100	1,300 1,400	0 to 100	Top third Bottom third	4,100 4,500 4,800 5,500	2,800 4,600 3,400 5,700	2,600 3,300 3,300 4,300	600 700 1,000 1,200	200 300 500 600	600 700 700 900	0 to 100	2,600 3,000	0	1,100 2,100

the Villas area will continue. Past intrusion was likely caused by withdrawals from domestic wells in Villas and production wells of WWU that tap the estuarine sand and Cohansey aquifer (Gill, 1962; Lacombe and Carleton, 2002). However, the rate of saltwater intrusion may decrease because LTMUA connected many homes in Villas to the production system, thereby taking the homes off domestic self-supply. Data on which domestic wells have been replaced by production were not available and were not included in the simulations.

The time of travel from the 250-mg/L chloride front in the Rio Grande water-bearing zone to the WWU production wells is greater than 200 years for Scenarios 1, 2, and 3 (table 22). No other production wells in the county tap the aquifer. The WWU production wells are south of the Rio Grande water-bearing zone 50-mg/L sodium front and the concentration of sodium in water from these wells already exceeds the Secondary Maximum Contaminant Limit (SMCL). The high concentrations of sodium relative to chloride is the result of dissolution of sodium from encompassing clay confining units and not lateral movement of a sodium/chloride saltwater front (Szabo and others, 2006).

The 250-mg/L chloride front in the Atlantic City 800-foot sand will intrude into freshwater production wells in Stone Harbor in 400 or more years (fig. 75, table 22). Intrusion to other existing freshwater wells in the Atlantic City 800-foot sand will take much longer. The rate of increase of chloride concentrations in Stone Harbor's southernmost production well 9-132 was less than 1 mg/L per year (Lacombe and Carleton, 2002). In 2002, a chloride concentration was 85.8 mg/L in the southernmost production well. Since then, withdrawals have been discontinued from this well.

Sodium concentrations in water from most production wells open to the Atlantic City 800-foot sand in Stone Harbor, Avalon, and Cape May Court House already (2005) exceed the SMCL. As explained earlier, the elevated sodium concentration is attributed to vertical flow from overlying and underlying clay confining units in which cation exchange increases the sodium concentration. Sodium concentration in water supplies from Sea Isle City also may exceed standards in the future as a result of continued withdrawals.

The two major adverse effects on the ecological water supplies, based on results of simulations of Scenarios 1, 2 and 3, are that water levels in the water-table aquifer will decline as much as 0.7 ft (table 23), and base flow in streams will decrease as much as 26 percent (table 24). Water levels in the water-table aquifer and base flows in streams remain virtually constant north of Middle Township for each baseline simulation. Maximum simulated declines in ecological-water supply occur near Cape May Court House where reduced confinement and withdrawals from the shallow aquifers create adverse effects on the ecological supply.

The third major result of the simulations of baseline Scenarios 1, 2, and 3 involves water-level changes in the confined aquifers. Pre-development water levels were above sea level in all aquifers in all areas of the county (tables 23 and 25). By 2003, water levels in the estuarine sand and Cohansey aquifers were 4 to 20 ft below sea level south of Cape May Court House, above sea level in central Cape May County, and near predevelopment water levels in northern Cape May County. Scenario 1 simulated 2050 water levels in the estuarine sand and Cohansey aquifers are relatively unchanged from 2003 levels. Water levels for Scenarios 2 and 3 decline about 1 to 9 ft in southern Cape May County but are unchanged in northern Cape May County. The greatest simulated water-level declines are near the WWU wells, with the simulated 2050 water-level altitude of about -21 ft, which is about 9 ft lower than in 2003.

Predevelopment average water levels in the Rio Grande water-bearing zone are estimated to have ranged from about +20 ft in Woodbine to about +6 ft in southern Cape May County (table 25). By 2003, water levels declined 10 to 53 ft and their altitude ranged from about +5 ft in Woodbine to -25 ft at the airport near the WWU production well. The declines in northern Cape May County are the result of withdrawals from the Atlantic City 800-foot sand (Lacombe and Rosman, 2001). The declines in southern Cape May County are a result of withdrawals from both the Rio Grande water-bearing zone aquifer and the Atlantic City 800-foot sand (Lacombe and Rosman, 2001).

Predevelopment water-level altitudes in the Atlantic City 800-foot sand are estimated to have ranged from about +29 ft near Woodbine to about +4 ft in Cape May City (table 25) (from Zapecza and others, 1987). By 2003, measured water-level altitudes had declined to 0 ft in Woodbine, -74 ft in Ocean City, -41 ft in Stone Harbor, -37 ft in Cape May Court House, -24 ft near the airport, and -38 ft at the Cape May City Water Utility (CMCWU) well field (dePaul and others, 2009). Simulated 2003 water levels (Scenario 1) are similar to measured water levels but range from about 1 ft higher in Sea Isle City to about 12 ft lower in Ocean City. Simulated 2050 water levels for future scenarios are compared to simulated 2003 water levels (not to measured water levels). Simulated water levels in 2050 are at 2003 levels for Scenario 1 because withdrawals are unchanged, and the steady-state model does not include storage and, therefore, has no lag effect that would lower water levels.

Simulated Scenario 2 water levels decline from 2 to 15 ft (table 25) by 2050, except for the northwestern part of the county, resulting in a minimum water level of -98 ft in Ocean City. Simulated Scenario 3 water levels decline 39 to 70 ft from simulated 2003 levels, with the lowest water level of -156 ft occurring in Ocean City (table 25).

Scenario 4, 5, and 6: Community Based, Full Build-Out

For Scenarios 4, 5, and 6, the withdrawal rates and withdrawal wells for 2003-50 are identical to those for Scenario 3 for all users except WWU and LTMUA. In these scenarios, WWU and LTMUA alter their 2003 withdrawal schemes by locating hypothetical wells closer to the center of the

Table 22. Simulated travel times in the deep aquifers in years needed for a particle to move from the estimated 250-milligram per liter isochlor in 2003 to a production well, Cape May County, New Jersey.

[--, not applicable; >, greater than; WWU, Wildwood Water Utility; RGWBZ, Rio Grande water-bearing zone; CMCWD, Cape May City Water Department; LTMUA, Lower Township Municipal Utilities Authority]

	Rio Grande water-bearing zone		Atlantic City 800-foot sand							
Scenario	Particle path lines end at Wildwood Water Utility production well	Particle path lines end at Atlantic City 800-foot sand freshwater production well	Particle 1 from Delaware Bay	Particle 2 from near Villas	Particle 3 from near Airport	Particle 4 from Erma area	Particle 5 from back bay	Particle 6 from Wildwood	Particle 7 from 1 mile offshore Wildwood	Particle 8 from 5 miles offshore North Wildwood
			Travel time, in years[1]							
1	>200	--	>1,000	>1,000	>1,000	>1,000	>1,000	>1,000	900	800
2	--	>1,000	>1,000	700	400	600	>1,000	>1,000	1,000	800
3	--	>1,000	700	>1,000	>1,000	1,000	700	600	500	450
4	100	--	600	1,000	900	800	600	500	450	400
5	--	>1,000	250	50	250	50	<50	50	200	800
6	100	--	600	1,000	900	800	600	500	450	400
7	100	--	350	200	150	250	600	700	600	400
8	--	>1,000	150	50	<50	<50	200	600	1,000	450
9	>100	--	350	200	100	200	500	>1,000	1,000	500

[1] Particle travels to existing freshwater production wells in Stone Harbor.
Particle travels to existing freshwater production wells Cape May Court House.
Particle travels to hypothetical freshwater production wells along the spine of Cape May County.
Particle travels to existing Cape May City Water Department saltwater production wells or hypothetical LTMUA or WWU saltwater production wells.

Red number shortest travel time to a freshwater production well for each scenario.

peninsula and, in deeper aquifers, by changing the volume of withdrawals from the existing wells. Scenarios 4, 5, and 6 allow each community to remain autonomous with respect to developing their future water supplies.

Description of Scenario 4

Scenario 4 is designed to allow WWU and LTMUA to continue withdrawing freshwater within the existing well fields. In Scenario 4, it is assumed WWU withdraws water from three production wells (fig. 76) completed in the Rio Grande water-bearing zone including two wells that were installed in 2002 and brought into production about 2006. WWU would increase withdrawals from the Rio Grande water-bearing zone from 207 to 1,164 Mgal/yr (table 20) and decrease withdrawals from the estuarine sand aquifer from 56 to 42 Mgal/yr. More importantly, WWU would reduce withdrawals from the Cohansey aquifer from 1,068 to 679 Mgal/yr.

Scenario 4 assumes LTMUA would install two hypothetical wells (8 and 9) completed in the Cohansey aquifer, south of the Cape May County Airport (fig. 76). After completion of the proposed wells, LTMUA would cease withdrawals from production well 1 (9-52), continue withdrawals from production wells 2 (9-54) and 3/7 (9-57) at 1999-2003 rates, and increase withdrawals from production wells 4/6 (9-58), 5 (9-59), 8, and 9 (table 19).

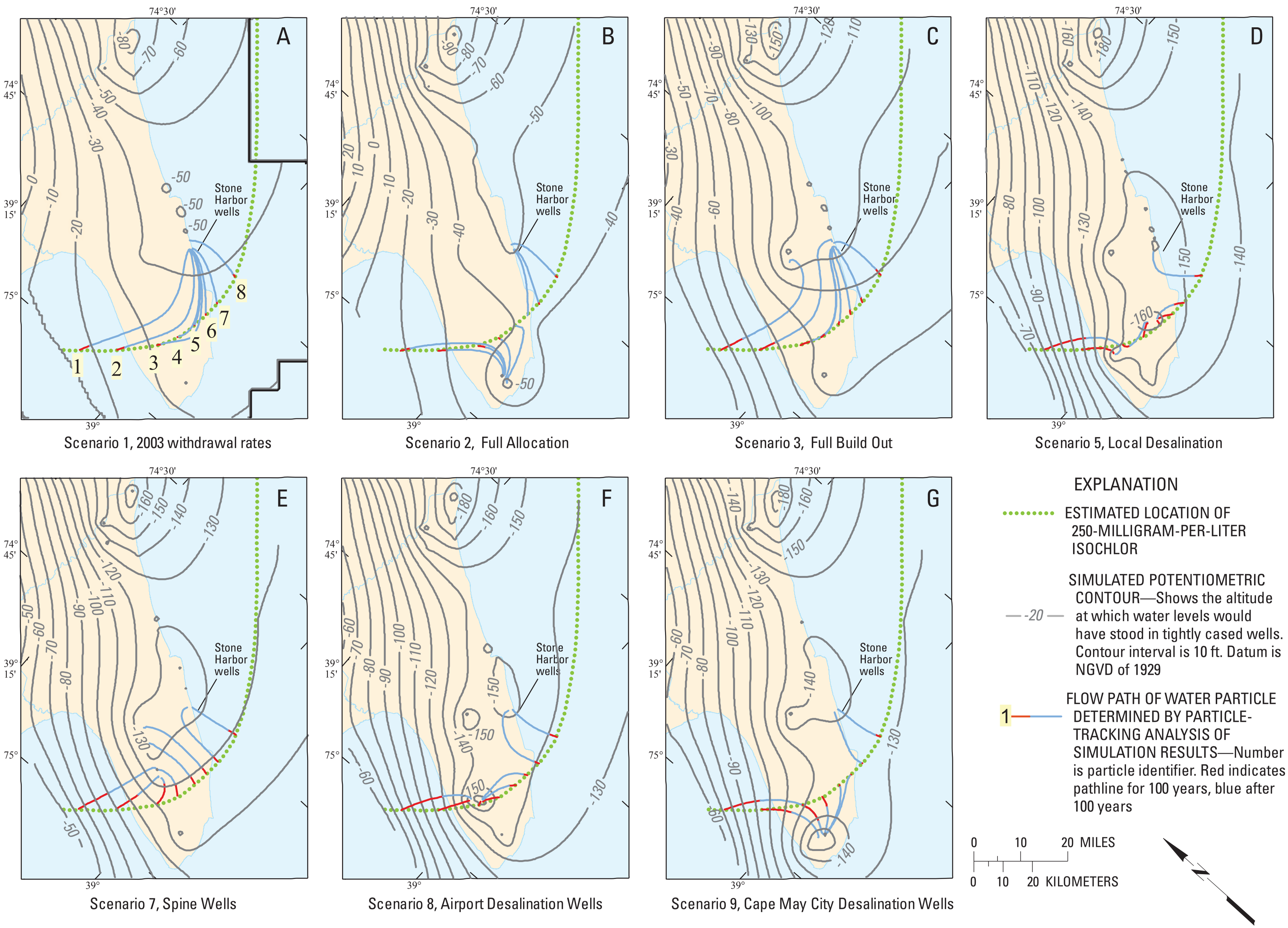


Figure 75. Simulated potentiometric surfaces and path lines from the estimated 250 milligram-per-liter isochlor in the Atlantic City 800-foot sand in 2050 for Scenarios 1, 2, 3, 5, 7, 8, and 9, Cape May County, New Jersey.

Table 23. Simulated water levels and water-level changes in 2050 in the shallow aquifers as a result of groundwater withdrawals for each scenario, Cape May County, New Jersey

[~, approximate water level; **bold number**, water level below sea level; black number, no change or water-level rise; red number, water-level decline; WWU, Wildwood Water Utility; CMCH, Cape May Court House; LTMUA, Lower Township Municipal Utilities Authority; Twp, Township.]

	Holly Beach water-bearing zone				Estuarine sand aquifer					Cohansey aquifer					
Location	**South of Canal**	**Bay shoreline**	**WWU wells**	**Near CMCH**	**Near LTMUA wells**	**Bay shoreline**	**Near WWU wells**	**Near CMCH**	**Northern Middle Twp**	**South of Canal**	**Bay shoreline**	**WWU wells**	**Near CMCH**	**Near Seaville**	**Belleplain Forest**
Well Number	9-20	9-218	9-333	9-98	9-352	9-206	9-189	9-97	9-282	9-150	9-353	9-60	9-99	9-412	9-325
Scenarios	Approximate predevelopment water-level altitude in feet, NAVD 88[1]														
	~4	~3	~8	~16	~0	~1	~1	~9	~6	~1	~1	~1	~5	~8	~34
	Approximate 2003 water-level altitude in feet, NAVD 88														
	4.0	2.7	8.2	15.7	1.0	**-3.1**	**-3.8**	8.6	5.3	**-9.7**	**-8.3**	**-12.5**	5.3	6.9	34.1
	Simulated water-level change 2003 to 2050 in feet														
1	0	0	0	0	0	**0**	**.2**	0	0	**.5**	**.2**	**.3**	0	0	0
2	0	-.1	-.1	-.5	-2.0	**-3.8**	**-4.7**	-1.2	-.4	**-8.2**	**-8.7**	**-8.7**	-1.9	-.8	-.1
3	0	-.1	0	-.7	-1.1	**-2.7**	**-2.9**	-1.0	-.3	**-6.0**	**-7.6**	**-8.6**	-.6	-.5	-.1
4	0	0	0	-.5	-.3	**-.6**	**-.4**	-.4	-.1	**-1.0**	**-.4**	**-2.0**	-.2	-.5	-.1
5	0	0	0	-.3	**.2**	**.5**	**.7**	-.1	-.1	**2.7**	**3.2**	**3.4**	0	-.5	-.1
6	0	0	0	-.4	0	**0**	**.1**	-.2	-.1	**0.8**	**1.9**	**0**	-.2	-.5	-.1
7	0	0	0	-.4	**.2**	**.5**	**.6**	-.2	-.1	**2.8**	**3.3**	**3.8**	-.1	-.5	-.1
8	0	0	0	-.3	**.2**	**.5**	**.7**	-.1	-.1	**2.7**	**3.2**	**3.4**	0	-.5	-.1
9	0	0	0	-.3	**.2**	**.5**	**.7**	-.1	-.1	**2.7**	**3.2**	**3.4**	0	-.5	-.1

[1]Predevelopment water-level altitude estimated by simulating groundwater flow with shallow system flow model with no withdrawals.

Table 24. Estimated base flow of 13 streams during 1959-1998 and decrease of simulated stream base flow in percent in 2050 as a result of groundwater withdrawals for Scenario 1 to 9, Cape May County, New Jersey.

[Red number, decrease in base flow greater than or equal to 5 percent; Trib, Tributary.]

Scenario	Mill Creek at Cold Spring	Fishing Creek	Dias Creek	Bidwell Creek	Goshen Creek	Sluice creek	Mill Creek at Magnolia Lake	Dennis Creek Trib. at Dennisville	Dennis Creek Trib. near North Dennis	East Creek	Mill Creek near Steelmantown	Tarkiln Creek	West Creek
	Estimated mean base flow, in cubic feet per second												
	0.9	1.6	0.9	0.3	0.2	11	2.9	4.3	2.6	8.1	3.4	6.5	13.5
	Percent change in simulated 2050 base-flow discharge from simulated 2003 base flow												
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	-6	-6	-8	-23	-26	-10	-24	-4	-5	-3	-1	-1	-1
3	-3	-4	-15	-18	-14	-7	-6	-2	-1	-1	-1	-1	0
4	-3	-3	-11	-10	-9	-6	-6	-2	-1	-1	-1	-1	0
5	-3	-3	-10	-7	-6	-5	-6	-2	-1	-1	-1	-1	0
6	-3	-3	-11	-9	-8	-5	-6	-2	-1	-1	-1	-1	0
7	-3	-3	-11	-9	-7	-5	-6	-2	-1	-1	-1	-1	0
8	-3	-3	-10	-7	-6	-5	-6	-2	-1	-1	-1	-1	0
9	-3	-3	-10	-7	-6	-5	-6	-2	-1	-1	-1	-1	0

Results of Simulation of Scenario 4

The results of simulation of Scenario 4 is that the sodium/chloride saltwater front in the Cohansey aquifer would intrude closer to the LTMUA production wells than in Scenarios 5-9 (table 21, figs. 73D and 74). West of LTMUA well 2 (9-54), the sodium/chloride saltwater front in the upper third of the Cohansey aquifer would intrude 3,300 ft, and the saltwater front in the bottom third of the aquifer would intrude 4,300 ft. West of the WWU Rio Grande well field, the saltwater front would intrude 4,100 ft and 5,500 ft in the upper and bottom thirds of the Cohansey aquifer, respectively (table 21). The sodium/chloride saltwater front under the Cape Mays and Wildwoods would intrude the same distance as in Scenario 1 and 100 to 200 ft more than in Scenarios 5-9. In the southern end (the Cape Mays) and the northern part of the county (north of Cape May Court House), the simulated saltwater front location is essentially the same as in baseline scenarios.

The Scenario 4 location of the simulated sodium/chloride saltwater front in the Holly Beach water-bearing zone is the same as the location in the baseline scenarios, and most of its movement is the result of sea-level rise. Simulated movement of the saltwater front in the estuarine sand aquifer is less than movements simulated in baseline Scenarios 2 and 3 because of a reduction in withdrawals from the estuarine sand aquifer by the WWU to 42 Mgal/yr. The intrusion in the estuarine sand aquifer west of the WWU well field in Scenario 4 is greater than in Scenario 1 (despite a modest reduction in withdrawals from the estuarine sand aquifer by the WWU) because of increased simulated withdrawals by domestic wells in Lower and Middle Townships.

Sodium concentrations in the WWU wells that tap the Rio Grande water-bearing zone have exceeded the SMCL of 50 mg/L since the wells were first drilled. The travel time of the 250-mg/L chloride front in the Rio Grande water-bearing zone to the WWU wells under Scenario 4 is simulated to be about 100 years. Chloride intrusion within the Atlantic City 800-foot sand is simulated to reach a Stone Harbor production well in about 400 years.

The ecological-water supply in Scenario 4, as estimated from base flow in the streams (table 24), is essentially unchanged north of Great Cedar Swamp but is simulated to decrease from simulated 2003 flows from 3 to 11 percent on the peninsula, about half the decrease simulated in Scenario 2 and less than the decreased flows simulated in Scenario 3. The water table is simulated to be unchanged in Lower Township but declines as much as 0.5 ft in central Middle Township compared to simulated 2003 levels, similar to the predicted decline in Scenarios 2 and 3. Simulated water levels in the estuarine sand aquifer in 2050 are as much as 0.6 ft lower than simulated water levels in 2003. However, the water levels

Table 25. Simulated water-level altitudes and changes in 2050 in the deep aquifers as a result of groundwater withdrawals, by scenario, Cape May County, New Jersey.

[~, approximately; Red, minimum water-level altitude or decline greater than 90 feet; WWU, Wildwood Water Utility; CMCWU, Cape May City Water Utility]

	Rio Grande water-bearing zone		Atlantic City 800-foot sand						
	Wildwood Water Utility wells	Ocean City	Woodbine	Ocean City	Sea Isle City	Stone Harbor	Cape May Court House	Cape May County Airport	CMCWU
	Estimated predevelopment water-level altitude, in feet NAVD 88								
	~+6	~+20	~+29	~+23	~+24	~+21	~+9	~+8	~+4
	Measured 2003 water-level altitude, in feet NAVD 88								
	-25	~-30	~0	-74	-49	-41	-37	~-24	-38
Scenario	Simulated 2050 water-level altitude, in feet NAVD 88								
1	-27	-37	-11	-86	-48	-47	-47	-31	-41
2	-26	-31	-2	-98	-52	-51	-49	-37	-55
3	-54	-84	-49	-156	-105	-105	-117	-76	-89
4	-180	-102	-62	-170	-119	-119	-131	-87	-99
5	-128	-119	-86	-193	-150	-159	-168	-151	-152
6	-180	-102	-62	-170	-119	-119	-131	-87	-99
7	-103	-104	-71	-177	-130	-136	-140	-109	-118
8	-128	-119	-85	-192	-146	-153	-163	-151	-144
9	-123	-113	-79	-186	-139	-145	-154	-130	-156
Scenario	Simulated change in water level from 2003 (Scenario 1) levels, in feet								
2	+1	+6	+9	-12	-3	-4	-2	-6	-15
3	-27	-47	-39	-70	-57	-58	-70	-45	-48
4	-153	-65	-52	-84	-71	-72	-84	-56	-58
5	-101	-82	-76	-107	-101	-112	-121	-120	-112
6	-153	-65	-52	-84	-71	-72	-84	-56	-58
7	-76	-67	-60	-91	-82	-89	-93	-78	-77
8	-101	-82	-74	-106	-98	-106	-116	-120	-103
9	-96	-76	-68	-100	-91	-98	-107	-99	-115

in 2050 are higher than water levels for Scenarios 2 and 3 (table 23).

The extent of the simulated water-level altitudes below -10 ft in southern Cape May County is smaller in Scenario 4 (table 23, fig. 73D) than in Scenarios 2 and 3 but is much larger than in Scenarios 5-9 (figs. 73E-G). Water levels in wells in the southern part of the peninsula are from 0.2 to 2.0 ft lower than simulated 2003 water levels (table 23). Simulated water levels in the Cohansey aquifer in northern Cape May County are essentially the same in Scenarios 3-9. However, the increased domestic-well withdrawals for Scenario 4 cause water levels to decline from 0.1 to 0.5 ft in Dennis and Upper Townships from Scenario 1 water levels.

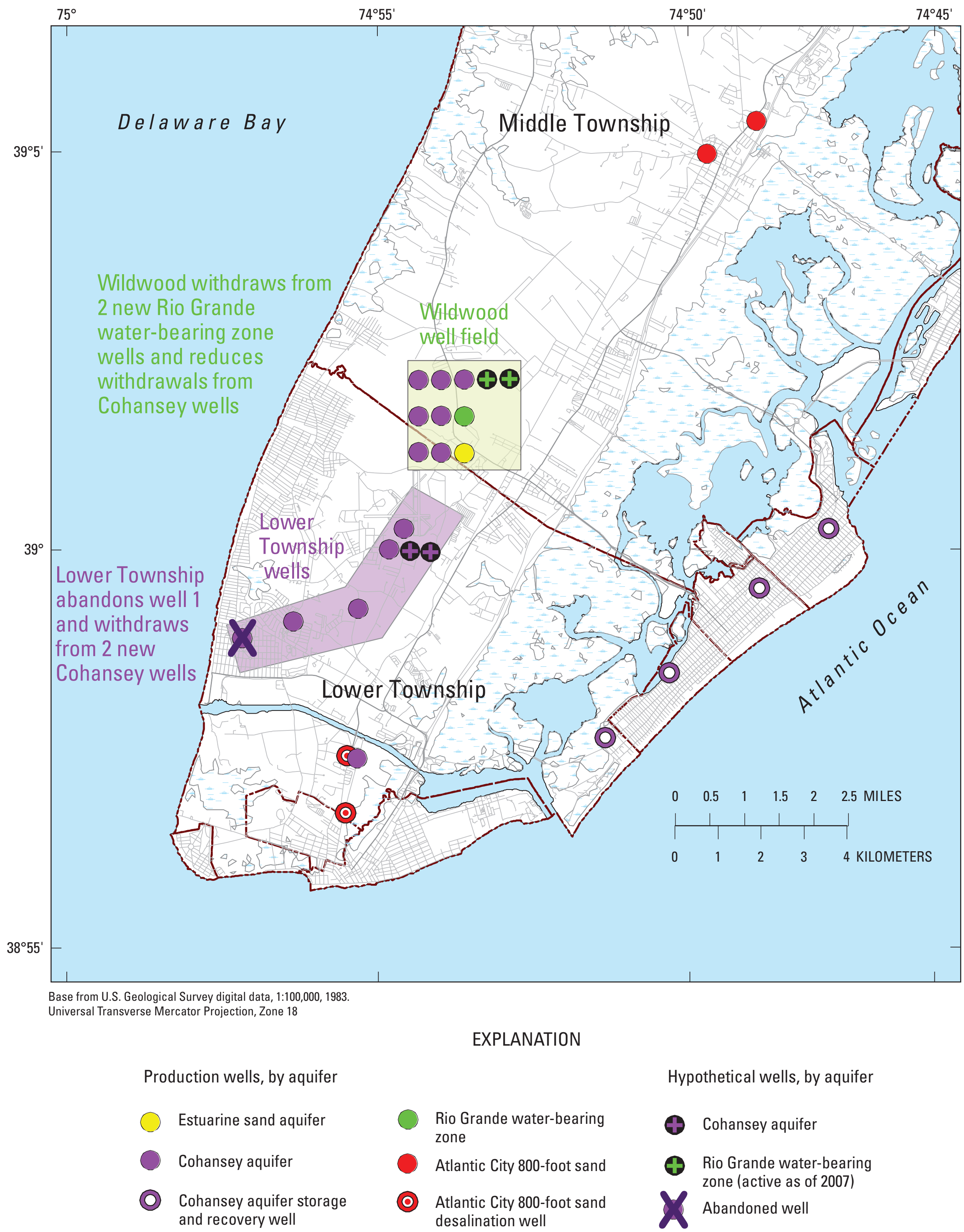


Figure 76. Location of existing and hypothetical wells for Scenario 4, by aquifer, supplying Lower Township, the Wildwood communities, the Cape May communities, and Cape May Court House, Cape May County, New Jersey.

Scenario 4 water levels in the Rio Grande water-bearing zone are much lower than levels for 2003 and are the lowest of all future scenarios except Scenario 6, which is identical to Scenario 4 in the deep system. The low water levels are because WWU future increases for the scenario are concentrated in the Rio Grande water-bearing zone. The simulated water levels in the vicinity of the WWU wells are 153 ft lower than the 2003 simulated levels. In Ocean City, simulated Scenario 4 water levels are 84 ft lower than in 2003 and 8 ft lower than in Scenario 3. Scenarios 5, 7, 8, and 9 water levels in the Rio Grande water-bearing zone are lower in the vicinity of Ocean City in 2050 than in 2005, but this is primarily caused by downward flow attributed to substantially lower water levels in the Atlantic City 800-foot sand, rather than WWU withdrawals.

Scenario 4 water levels in the Atlantic City 800-foot sand are much lower than water levels in Scenarios 1 and 2 and are 10 to 14 ft lower than Scenario 3 (table 24). The difference between Scenario 3 and Scenario 4 simulated Atlantic City 800-foot sand water levels is largely an artifact of the modeling approach: the Coastal Plain-wide regional flow model does not have a layer explicitly representing the Rio Grande water-bearing zone, so withdrawals from that aquifer are included in the simulated withdrawals from the underlying Atlantic City 800-foot sand. Therefore, the horizontal fluxes into and out of the Atlantic City 800-foot sand in the sub-regional model are affected more by the increase in simulated WWU withdrawals than would realistically be the case, and the Scenario 4 water levels in the Atlantic City 800-foot sand should be close to, although slightly lower than, Scenario 3 water levels.

Description of Scenario 5

Scenario 5 is designed to allow LTMUA and WWU to meet future demands by each installing two new wells open to the Atlantic City 800-foot sand in their current well fields and each building a desalination plant to desalinate the brackish water (fig. 77). The aquifer in this area is slightly salty with chloride concentrations of 250 to 300 mg/L and sodium concentrations of 75 to 100 mg/L. Upon completion of the wells and desalination plants, WWU and LTMUA would withdraw 675 and 780 Mgal/yr, respectively, of salty groundwater and desalinate the water to yield 486 and 562 Mgal/yr, respectively, of potable water (tables 19 and 20). Desalination of brackish water is about 72 percent efficient so for every 100 gallons of saltwater that is withdrawn 72, gallons of potable water are created and 28 gallons of higher salt-content water are discharged to a nearby saltwater body.

With the desalination system in operation, WWU and LTMUA then would decrease withdrawals from existing wells open to the estuarine sand and Cohansey aquifers in the same fashion as described in Scenario 4. WWU would reduce withdrawals in the estuarine sand aquifer from 56 to 42 Mgal/yr and in the Cohansey aquifer from 1,068 to 682 Mgal/yr, and would increase withdrawals in the Rio Grande water-bearing zone from 207 to 675 Mgal/yr (table 20). LTMUA would reduce withdrawals in the Cohansey aquifer from 407 to 327 Mgal/yr (table 19).

Results of Simulation of Scenario 5

The major advantage of Scenario 5, as in Scenarios 8 and 9 described below, is that it would cause the least saltwater intrusion in the Cohansey aquifer of all baseline and future scenarios, except west of LTMUA wells in Scenario 6 where water is injected to create a saltwater barrier (figs. 73E and 74; table 21). West of the WWU wells, the sodium/chloride saltwater front in the upper third of the Cohansey aquifer would intrude 4,400 ft and in the lower third would intrude 5,200 ft, whereas west of the LTMUA production wells, the front would intrude 2,700 ft and 3,300 ft in the upper and lower thirds of the aquifer, respectively (table 21). From Cape May Point to Stone Harbor, intrusion would be less than or equal to that in the other future scenarios. North of Cape May Courthouse, no difference in simulated saltwater front location resulted between Scenario 5 and the other scenarios.

The location of the sodium/chloride front in the Holly Beach water-bearing zone is the same as in other scenarios. The location of the simulated sodium/chloride front in the estuarine sand aquifer is about the same as in other “full build-out” scenarios (table 21).

The sodium front in the Rio Grande water-bearing zone is already located to the north of the WWU well field, and sodium concentrations in WWU wells that tap the Rio Grande water-bearing zone have exceeded the SMCL of 50 mg/L since before 1950. Simulated travel time from the 250-mg/L chloride front in the Rio Grande water-bearing zone aquifer to the WWU wells is more than 1,000 years, in part, because there is greater vertical flow to the underlying Atlantic City 800-foot sand that is attributed to lowered water levels in that aquifer rather than horizontal flow to the production wells (table 22).

Withdrawal of brackish water from the Atlantic City 800-foot sand for Scenario 5 diverts movement of the 250-mg/L chloride front away from Stone Harbor wells and increases the simulated time of travel to those wells from about 450 years for Scenario 3 to about 800 years for Scenario 5. The locations of the Scenario 5 hypothetical WWU desalination wells are about 1.5 mi north of the 250-mg/L chloride line and simulated travel times are 50 years or less (table 22). The hypothetical LTMUA desalination wells are about 1.5 mi south of the 250-mg/L chloride line. Simulations indicate that chloride concentrations could decrease as less salty water is drawn from the north. The small and relatively slow changes in chloride concentrations over the next 50 years are considered to be a minor problem for a typical desalination facility.

North of Great Cedar Swamp the ecological-water supply in Scenario 5, as estimated from base flow in the streams (table 24), is nearly unchanged from simulated 2003 conditions and is the same as other full build-out scenarios. On the peninsula, simulated base flows decrease from simulated 2003 base flows from 3 to 10 percent which is the smallest decrease of simulated flow for Scenarios 3 to 7. Simulated base flows

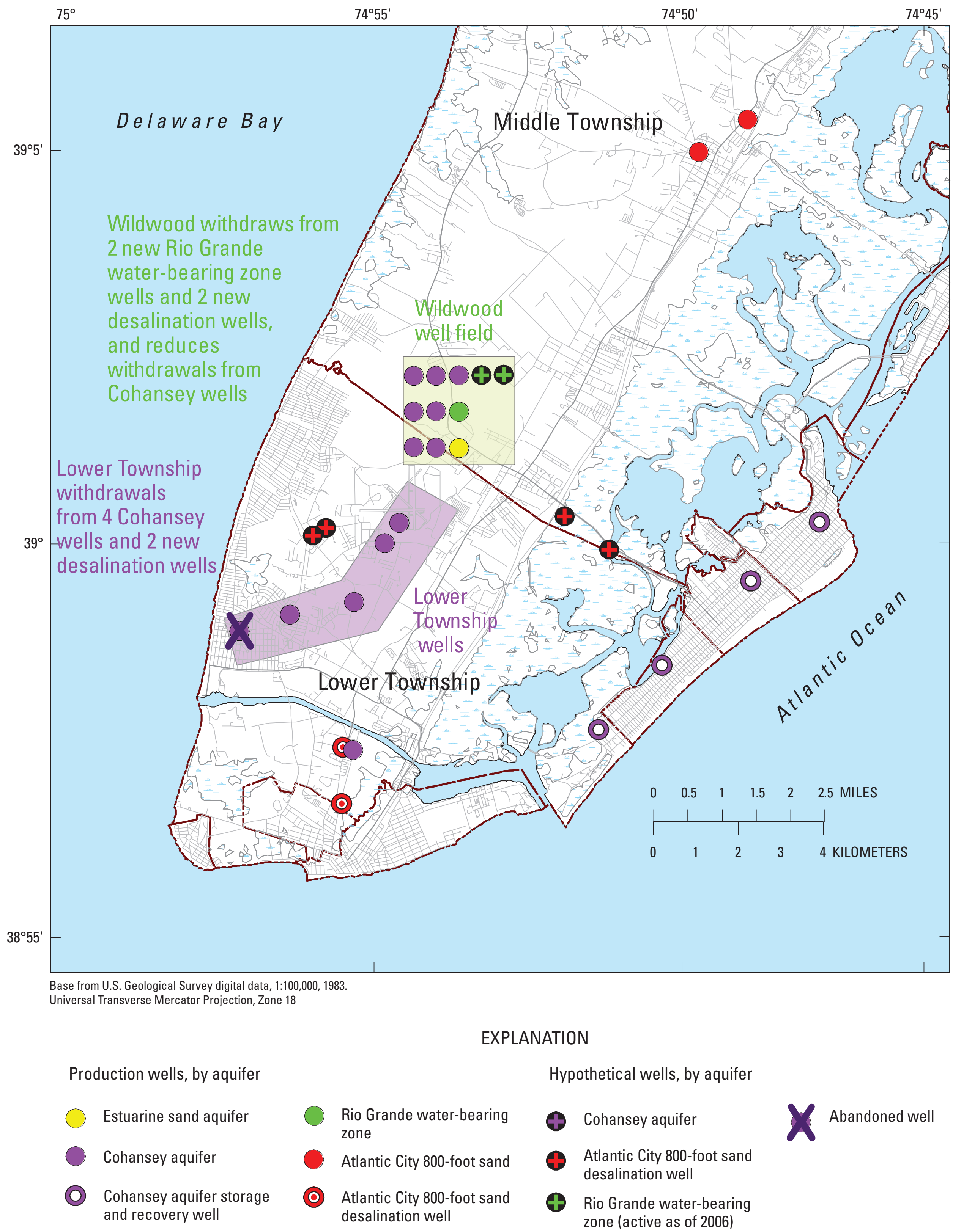


Figure 77. Location of existing and hypothetical wells for Scenario 5, by aquifer, supplying Lower Township, the Wildwood communities, the Cape May communities, and Cape May Court House, Cape May County, New Jersey.

for Scenarios 8 and 9 are identical to Scenario 5 in the shallow system. The water-table altitude is simulated to be unchanged in Lower Township but declined as much as 0.3 ft in central Middle Township compared to simulated 2003 levels, the smallest decline of the full build-out scenarios. Simulated water levels in the estuarine sand aquifer in 2050 are as much as 0.7 ft higher than simulated 2003 levels, the highest simulated water levels of the full build-out scenarios (table 23).

The Scenario 5 extent of the area of simulated water levels below -10 ft in southern Cape May County is the smallest for all scenarios and is limited to the vicinity of the WWU Rio Grande well field and the LTMUA airport wells (table 23, fig. 73E). Simulated water levels in the southern part of the peninsula are as much as 3.4 ft higher than simulated 2003 water levels (table 23). The simulated water-level rise occurs because withdrawal rates from the Cohansey aquifer are lower than 2003 withdrawal rates, made possible by the hypothetical new withdrawals from the Atlantic City 800-foot sand. However, simulated water levels in the Cohansey aquifer continue to be below sea level south of Cape May Court House, and saltwater intrusion would continue with Scenario 5 withdrawal rates.

Simulated water levels in the Rio Grande water-bearing zone are higher than in Scenarios 4 and 6, but are lower than Scenario 3 and simulated 2003 levels (table 25). The lower water levels, when compared to Scenario 3, are caused by increased downward flow because the simulated withdrawals from the underlying Atlantic City 800-foot sand are greater than those in Scenario 3. The simulated decline of 101 ft near the WWU well field could force WWU to lower the pump intakes. WWU is the only user of the aquifer in Cape May County; therefore, it is the only well owner that would be affected by lower water levels in the Rio Grande water-bearing zone.

Water levels have the greatest decline in the Atlantic City 800-foot sand for Scenario 5 (table 25, fig. 75). Simulated water-level altitudes decline to -193 ft in Ocean City and -150 to about -170 ft in the other barrier islands and the southern peninsula. Such declines could cause many well owners to lower pump intakes or install larger pumps on the wells and thus increase pumping costs for power consumption for all users.

Description of Scenario 6

Scenario 6 is designed to simulate the creation of a saltwater-intrusion barrier west of most LTMUA wells. The barrier is developed by injecting highly treated water into the Cohansey aquifer. For this scenario, LTMUA would hypothetically install a linear array of three injection wells screened in the Cohansey aquifer near the Delaware Bay shoreline to protect the wells near and at the airport (fig. 78). Withdrawals in Scenario 6 are identical to those in Scenario 4.

NJDEP regulations do not allow degradation of aquifer water quality, so injected water would be required to have lower concentrations of dissolved solids and contaminants than drinking-water standards require (Robert Kecskes, N.J. Department of Environmental Protection, oral commun., 2007). To supply the injection wells with water, LTMUA would need to build a tertiary water-treatment and purification plant (such as reverse osmosis) to process reusable water to exceed drinking-water standards and build transmission lines from the treatment plant to the injection wells. The simulated rate of injection for each well is 80 Mgal/yr (table 19). This amount of injected water is about 25 percent of the simulated LTMUA withdrawals and about 15 percent of combined LTMUA and WWU simulated withdrawals from the Cohansey aquifer.

Results of Simulation of Scenario 6

The result of simulating Scenario 6 is that the sodium/chloride saltwater front in the Cohansey aquifer west of the injection wells would have the least movement of all scenarios, thereby protecting the LTMUA wells east of the injection wells (LTMUA well 3 (9-57) and wells at the airport). However, in all other parts of the peninsula, the injection does little to protect the aquifer from intrusion and results are similar to those of Scenario 4 (table 21). The effectiveness of the saltwater barrier would be enhanced by installing more injection wells west of the WWU and LTMUA wells. However, for injection of treated water to be successful over a period of years many components, which are beyond the scope of this report, would need to be considered including chemistry of the injected water, biological and chemical interactions with the native aquifer sediments and water, well-screen clogging, injection rates per well, cost, and other issues.

Simulated Cohansey aquifer water levels in Lower and Middle Townships in 2050 for Scenario 6 are similar to simulated 2003 levels, higher than Scenarios 4 levels, and lower than Scenarios 5, 7, 8, and 9 levels (fig. 73F, table 23). Simulated water levels near the LTMUA well field are up to 1.9 ft higher than simulated 2003 levels, but north of Cape May Court House simulated water levels are the same (or nearly the same) as water levels in all full build-out scenarios.

In Scenario 6, simulated movement of the saltwater fronts and water-level changes in the Holly Beach water-bearing zone, estuarine sand aquifer, Rio Grande water-bearing zone, and Atlantic City 800-foot sand is the same or nearly the same as that for Scenario 4 because simulated withdrawals are the same in those aquifers (tables 21, 23, and 25). Simulated base flows in the streams are the same or slightly greater as a result of water injections (table 24).

Scenario 7, 8, and 9: Cooperative Based, Full Build-Out

Scenarios 7, 8, and 9 are designed to cooperatively withdraw groundwater and expand the WWU, LTMUA, NJA-CMCH, and CMCWU production systems. In the three scenarios, LTMUA would cease withdrawals from production

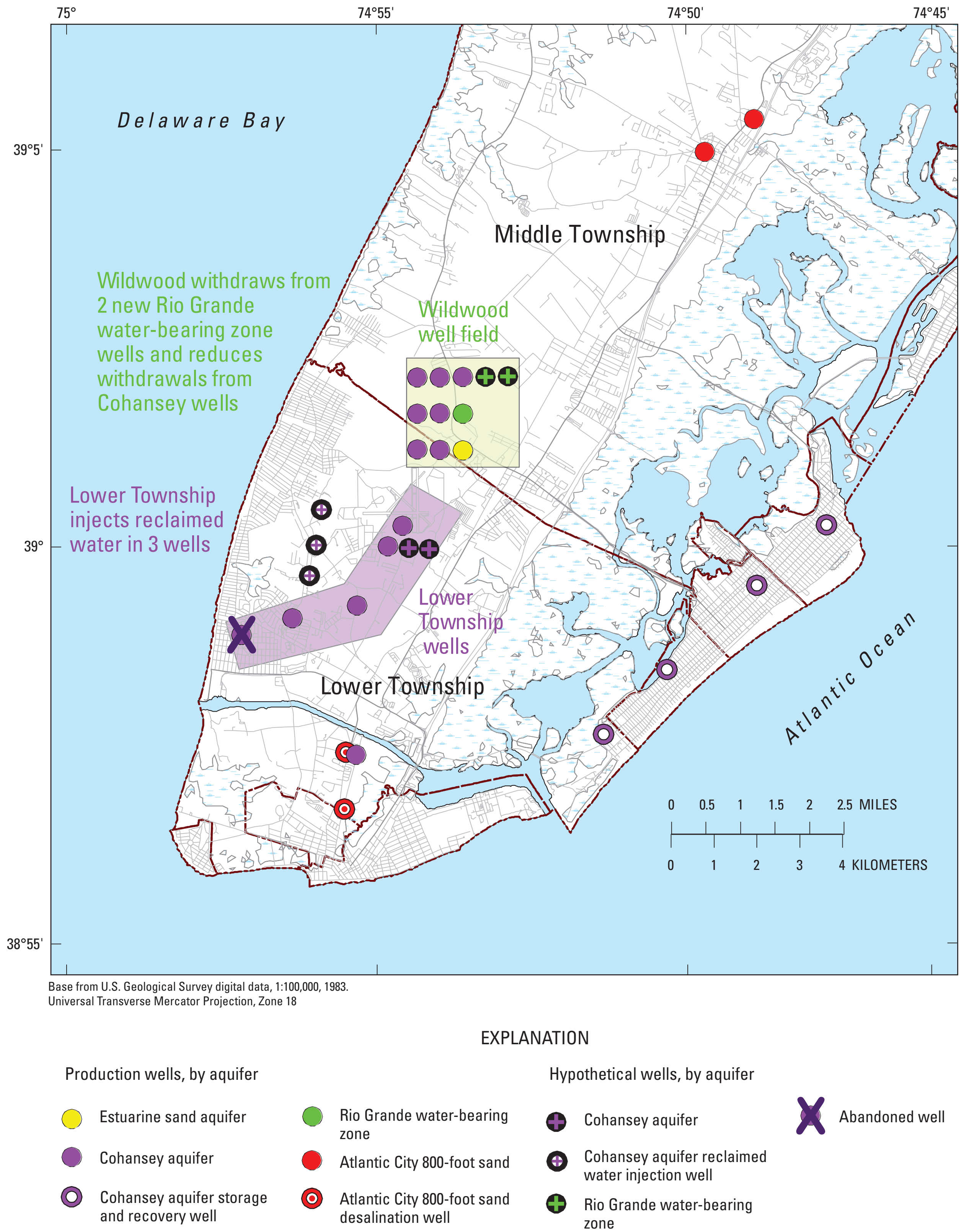


Figure 78. Location of existing and hypothetical wells for Scenario 6, by aquifer, supplying Lower Township, the Wildwood communities, the Cape May communities, and Cape May Court House, Cape May County, New Jersey.

well 1 (9-52), and LTMUA and WWU would reduce withdrawals from existing wells that tap the Cohansey aquifer. The source of water to meet future increases in demand would be from hypothetical strategically located wells installed in the Cohansey aquifer and Atlantic City 800-foot sand. Specific changes in the withdrawal scheme are described for each scenario.

Description of Scenario 7

Scenario 7 is designed so that WWU, LTMUA, and NJA-CMCH would cooperatively install six wells—two production wells screened in the Cohansey aquifer and four production wells screened in the Atlantic City 800-foot sand. The hypothetical wells would be located along the spine of the peninsula north of Rio Grande and south of Cape May Court House (fig. 79). Upon completion of the hypothetical wells and connection to existing water transmission lines, LTMUA and WWU would cease or decrease withdrawals from existing wells and withdraw from the hypothetical wells at the same rates described in Scenario 5 (tables 19 and 20a). In addition, NJA-CMCH would obtain additional water supply from the six hypothetical wells along the spine (table 20b).

Results of Simulation of Scenario 7

The result of simulating Scenario 7 is that water purveyors do not need to build a desalination system. Movement of the simulated sodium/chloride saltwater front in the Cohansey aquifer is essentially the same as that for Scenarios 5, 8, and 9 (table 21; figs. 73G and 74).

Water from the Atlantic City 800-foot sand in the vicinity of the hypothetical spine wells during the past 100 years has exceeded the NJDEP SMCL for sodium (50 mg/L) by 5 to 10 mg/L; however, blending the Atlantic City 800-foot sand water with Cohansey aquifer water could produce finished water with sodium concentrations below the SMCL. Some simulated particles originating on the 250-mg/L isochlor reach a hypothetical spine well in about 150 years or more and others travel to a Stone Harbor well in 400 or more years (table 22; fig. 75E). This is the fastest chloride intrusion into Stone Harbor wells of all scenarios; however, the rates of movement for every scenario are affected by model limitations as discussed earlier. Because the chloride front is diffuse in the Atlantic City 800-foot sand, the intrusion of saltwater would increase chloride concentrations gradually over time.

The effects on the ecological-water supply through movement of the sodium/chloride front and water-level changes in the Holly Beach water-bearing zone as well as changes in stream base flows are essentially the same as those in Scenarios 4 to 6. Simulated base flows in Dias Creek are slightly lower than those in Scenarios 5, 8, and 9 because of the increased hypothetical withdrawals from the Cohansey aquifer in the Dias Creek basin (tables 21, 23, 24).

Simulated water levels in the estuarine sand aquifer are as much as 0.6 ft higher than simulated 2003 water levels and about the same as those for Scenarios 5, 8, and 9 (table 23). The simulated location of the sodium/chloride saltwater front essentially is the same as that for other full build-out scenarios (table 21).

Scenario 7 simulated water levels in the Cohansey aquifer near the WWU well field are 0.4 ft higher than those in Scenarios 5, 8, and 9 but are 12.4 and 5.8 ft higher than those in Scenarios 3 and 4, respectively. North of Middle Township, simulated water levels in the Cohansey aquifer are the same as those in other full build-out scenarios. (fig. 73G; table 23). As in Scenario 5, 8, and 9, water levels south of Cape May Court House are higher than simulated 2003 water levels but remain below sea level, indicating that saltwater intrusion would continue in that area (table 21).

Simulated water levels in the Rio Grande water-bearing zone decline more than 60 ft county wide with a maximum of 76 ft at the WWU well field. The simulated water levels are higher than those in Scenarios 4, 5, 6, 8, and 9. (table 25). Simulated water-level altitudes in the Atlantic City 800-foot sand range from -71 to -177 ft, or 60 to 93 ft lower than simulated 2003 levels (table 25). Simulated water-level altitudes in the Atlantic City 800-foot are about 10 to 20 ft lower than those in Scenario 4 and 10 to 40 ft higher than those in Scenarios 5, 8, and 9.

Description of Scenario 8 and 9

Scenario 8 is designed so that WWU and LTMUA would cooperatively drill four new wells into the brackish Atlantic City 800-foot sand and build a desalination plant at the Cape May County Airport (fig. 80). Scenario 9 is designed so that WWU, LTMUA, and CMCWU would cooperatively expand the CMCWU desalination plant by increasing the number of reverse osmosis units and drill four new wells into the Atlantic City 800-foot sand aquifer to meet full build-out demand (fig. 81).

Withdrawals from the shallow aquifers and from the Rio Grande water-bearing zone for the Scenarios 8 and 9 are the same as for Scenario 5 (tables 20, 21, and 23). Withdrawals from the Atlantic City 800-foot sand are the same as in Scenario 3 for most purveyors.

Results of Simulation of Scenarios 8 and 9

Water levels, base flows, and the location of the saltwater front in 2050 in the shallow aquifer system are the same for Scenarios 5, 8, and 9 because the distribution of withdrawals from the shallow aquifer system is the same (tables 18, 19, and 20; figs. 73E and 74). Movement of the 250-mg/L chloride front in the Atlantic City 800-foot sand to the hypothetical desalination wells would occur in about 50 years for Scenario 8 (table 22; fig. 75F) and about 100 years for Scenario 9 (table 22; fig. 75F). This movement would cause water from

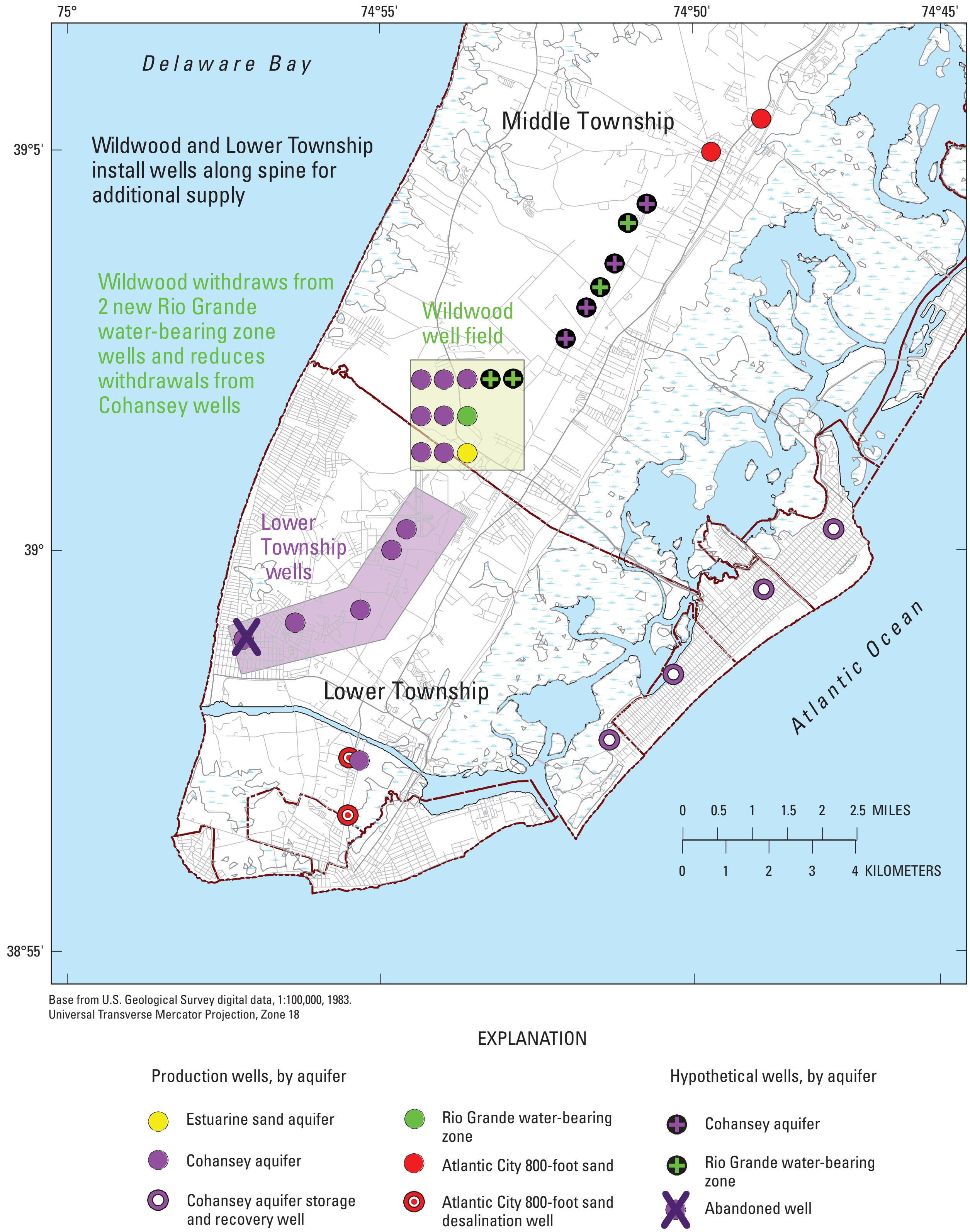


Figure 79. Location of existing and hypothetical wells for Scenario 7, by aquifer, supplying Lower Township, the Wildwood communities, the Cape May communities, and Cape May Court House, Cape May County, New Jersey.

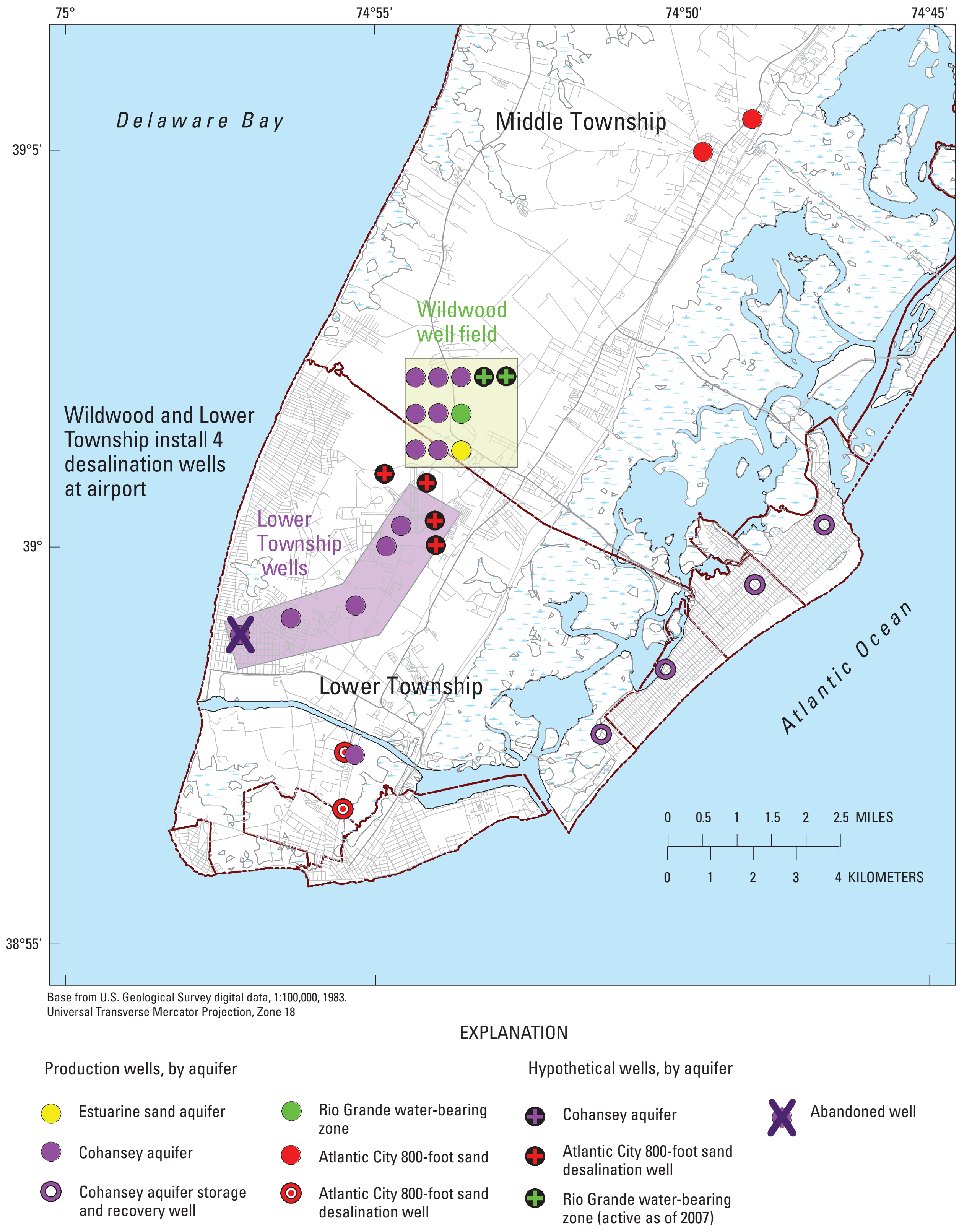


Figure 80. Location of existing and hypothetical wells for Scenario 8, by aquifer, supplying Lower Township, the Wildwood communities, the Cape May communities, and Cape May Court House, Cape May County, New Jersey.

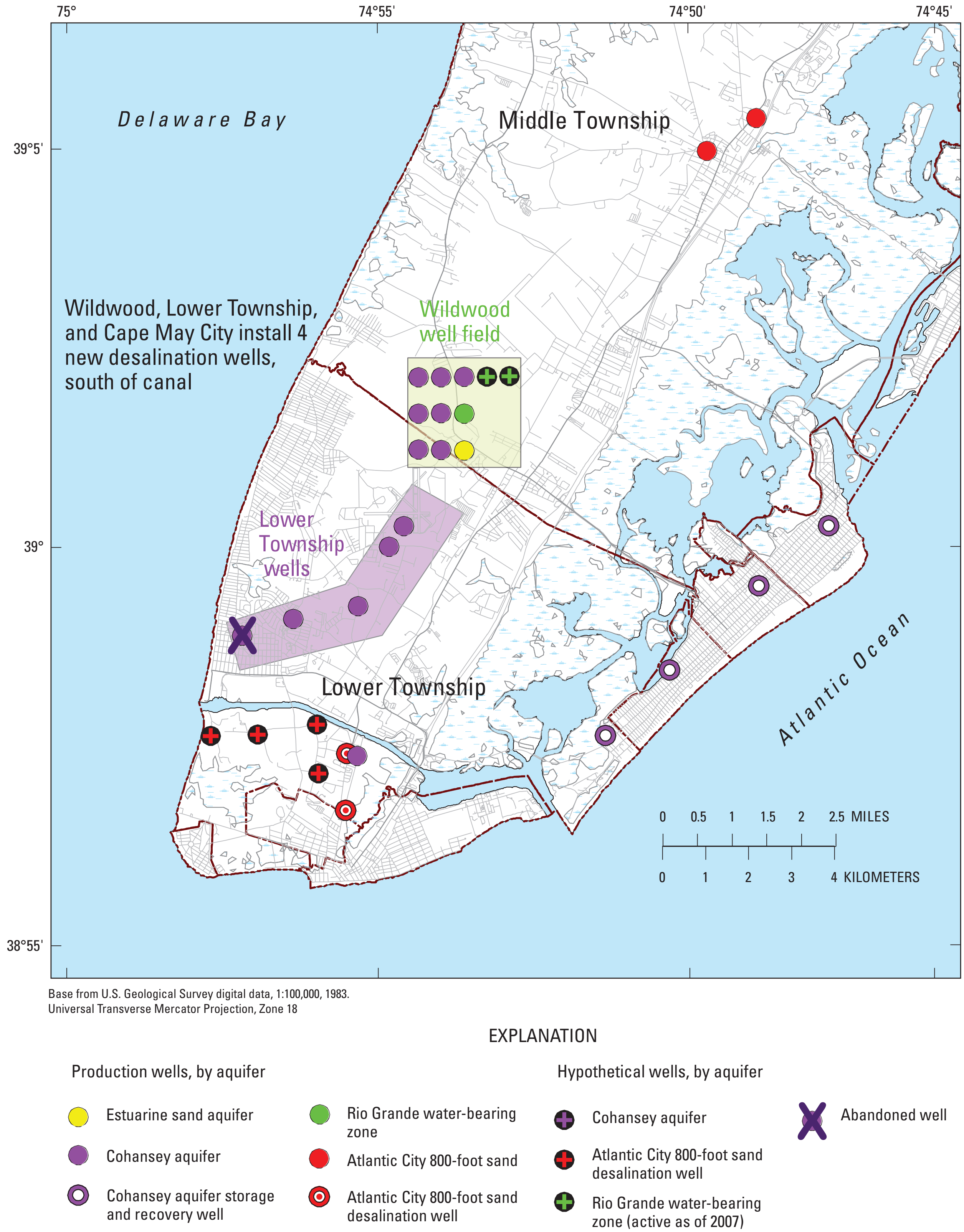


Figure 81. Location of existing and hypothetical wells for Scenario 9, by aquifer, supplying Lower Township, the Wildwood communities, the Cape May communities, and Cape May Court House, Cape May County, New Jersey.

the Scenario 8 hypothetical wells at the airport to become slightly more salty and would freshen water that is withdrawn by hypothetical wells of Scenario 9 and existing wells of CMCWU. In all likelihood, the chloride concentration in the new desalination wells would remain constant or increase slowly, as has occurred in the existing desalination wells of CMCWU because of the diffuse nature of the chloride front. Simulated path lines from the estimated location of the 250-mg/L isochlor mostly end at the hypothetical wells of Scenario 8 or 9, but some path lines end at Stone Harbor wells, with travel times of 450 years or more (table 22).

The Scenario 8 simulated path lines from the estimated 250-mg/L isochlor in the Rio Grande water-bearing zone end at the underlying hypothetical wells with travel times greater than 1,000 years. Scenario 9 simulated path lines from the estimated 250-mg/L isochlor in the Rio Grande water-bearing zone end at the WWU wells with a simulated travel time between 100 and 200 years. The simulated Scenario 9 travel time to the WWU wells is greater than the Scenarios 4, 6, and 7 travel times, less than the Scenario 1 travel time, and less than Scenarios 2, 3, and 5 in which path lines end in the underlying Atlantic City 800-foot sand (table 22). Simulated water levels in the Rio Grande water-bearing zone in Scenarios 8 and 9 are higher than in Scenarios 5 and 7 and lower than in Scenarios 4 and 6 (table 25).

Simulated water-levels in the Atlantic City 800-foot sand on the barrier islands and peninsula are -144 to -192 ft for Scenario 8 and -130 to -186 for Scenario 9 (table 25). The greatest decline from 2003 water levels ranges from 115 to 120 ft and would occur near the hypothetical desalination wells. The water-level declines would be about 60 ft or more in western Upper and Dennis Townships and about 90 to 115 ft along the barrier islands and in Middle and Lower Townships.

Summary and Conclusions

The water supply of Cape May County is shared by humans and the ecosystem. Humans use water for domestic, industrial, commercial, and agricultural supplies. The ecosystem uses water for evaporation/climate control, transpiration, reproduction, and habitat. Humans obtain most of their potable-water supply from the four confined aquifers. Humans obtain most of their non-potable-water supply and the ecosystem obtains all of its ecological water supplies from precipitation, the water-table aquifer, and surface water. Historically, the ecosystem used all precipitation, all surface water, and all water from the shallow water-table aquifer.

Mean annual precipitation is 41.9 in., which results in about 78,700 Mgal/yr of water that falls onto the upland part of the county, which is also the major recharge area of the potable-water supply. Precipitation that falls onto saltwater wetlands is immediately rendered non-potable for humans but all of this precipitation can be used by the saltwater ecosystem. Most precipitation that historically fell onto the barrier island was used for ecosystem water demands, but now it generally flows into storm sewers. Aquifers and confining units store more than trillion gallons of freshwater that fell as precipitation during the past. Groundwater withdrawals for human use have increased annually since the mid-1800s and during 1998-2003 average annual withdrawals were about 7,700 Mgal/yr or nearly 10 percent of the precipitation that fell on upland areas. Estimated full build-out water demand is 12,860 Mgal/yr or about 16 percent of average annual precipitation. Future annual potable and non-potable demands are about 0.2 percent per year of the water stored in the aquifers.

The major potable water-supply problem over the past century has been saltwater intrusion. Intrusion forced well owners to abandon hundreds of wells as chloride concentrations increased to exceed the NJDEP SMCL of 250 mg/L. Prior to 1960, intrusion into production and industrial-supply wells adversely impacted WWU, CMCWU, CMPWD, Northwest Magnesite, U.S. Coast Guard, B.L. England Electrical Generation Plant, and three small industries in the Wildwoods (Lacombe and Carleton, 1992). During 1990-2003, saltwater intrusion forced CMCWU to install New Jersey's first desalination plant, and forced LTMUA to install water mains in Villas and other shoreline communities to replace scores of saltwater-intruded domestic-supply wells.

The NJDEP and Cape May County are concerned that saltwater will intrude some LTMUA supply wells, most WWU supply wells, and some shallow, near-shore, private withdrawal wells within the next 50 years.

Other potable water-supply problems associated with groundwater withdrawals are elevated sodium concentrations and declining water levels in the deep confined aquifers. Ambient sodium concentrations range from 51 to 60 mg/L in the Atlantic City 800-foot sand and Rio Grande water-bearing zone aquifers in the southern half of the county, and exceed the NJDEP SMCL of 50 mg/L. WWU, NJA-CMCH, Stone Harbor, and Avalon production wells withdraw water with elevated sodium concentration. These utilities are forced to blend their water with low sodium water from the Cohansey aquifer or to notify their customers of slightly elevated sodium concentrations in their water supply.

By 2003, water levels had declined in the Atlantic City 800-foot sand and Rio Grande water-bearing zone aquifers as much as 110 ft below pre-pumping levels and as much as 90 ft below sea level. Regional cones of depression developed and caused the NJDEP to create Critical Areas 1 and 2 in other parts of the New Jersey Coastal Plain. Water-level declines of this magnitude increase the rate of saltwater intrusion and cause well interference problems, which has forced many well owners to lower pump intakes and install bigger pumps to lift the water.

Ecological water-supply problems associated with high volume shallow groundwater withdrawals include the premature drying of freshwater wetlands such as vernal ponds; lowered water levels in the water-table aquifer; and decreased streamflow. Water levels cycle annually in streams, wetlands, vernal ponds and the water-table aquifer. Water levels rise during the non-growing season and are highest in the spring. Water levels decline during the growing season and are lowest in mid- to late summer. Near the WWU supply wells, vernal ponds tend to dry up sooner each summer, and the water-table aquifer tends to recover later at the end of each summer, when compared to similar ecological water sources in more rural parts of the county. Depletion of ecological water supplies caused the NJDEP to closely evaluate high capacity shallow production wells in other areas of the New Jersey Coastal Plain.

The USGS compiled historical withdrawal records and assessed ecological water demands. Human water demands in Cape May County have increased during the last century with greater demands during periods of economic growth, such as the 1920s and the post-WWII era, and decreased demand during the Great Depression of the 1930s and WWII. Human demands also have changed after water conservation laws have been enacted and as the price of water has increased. Human water demand is seasonally cyclic with six times greater demand during the summer tourist season than during the non-summer months (Lacombe and Carleton, 2002).

Ecological water demands within the forested lands have remained constant while ecological water demands for the former forested areas of the county have changed as land use has changed. The ecological water system uses more water during the summer than is provided by precipitation. As a result, the ecosystem has evolved to use water that has been stored in wetlands and the water-table aquifer. During the non-growing season precipitation is stored in wetlands by flooding and in the water-table aquifer by increasing water levels as much as 6 ft. Water in wetlands is used by the ecosystem during the non-growing season for reproduction, hibernation, and other habitat needs.

The NJDEP and County are concerned that groundwater withdrawals will continue the suite of ongoing problems and may even exacerbate some problems. The USGS, in cooperation with the NJDEP, assessed these problems by designing and then evaluating simulated baseline and future county-wide water-supply withdrawal scenarios. Baseline withdrawal Scenarios 1, 2, and 3 were designed to use existing wells and the following withdrawal rates: average annual withdrawal rates during 1999-2003 of 7,711 Mgal/yr; NJDEP full allocation withdrawal rates of 11,730 Mgal/yr; and estimated full build-out withdrawal rates of 12,864 Mgal/yr, respectively (table 26).

Six future withdrawal scenarios were designed to use the estimated full build-out water demands as in Scenario 3, but the amount of withdrawal from each well, the source aquifers, and the well locations were changed for many production wells of the WWU, LTMUA, CMCWU, and NJA-CMCH supply systems. Scenarios 4, 5, and 6 were designed so that each community would manage its own water supply and Scenarios 7, 8, and 9 were designed to have the communities work cooperatively (table 26).

The major adverse impact of the three simulated baseline scenarios is that the sodium/chloride front (defined for this report as 50 mg/L sodium and 250 mg/L chloride) will move inland from Delaware Bay and intrude LTMUA production well 1 (well 9-52). In addition, the front in the Cohansey aquifer will move to within 200 ft of WWU production wells and LTMUA production well 2. Saltwater intrusion will occur in the Cohansey aquifer in other parts of the peninsula especially on the Bay side and southern end of the Cape.

Intrusion of the sodium/chloride front in the Holly Beach water-bearing zone will be caused predominately by sea-level rise and not by groundwater withdrawal. Simulated saltwater intrusion in the estuarine sand aquifer is minimal and will not impact most existing domestic-supply wells or the ecological-water supply during the planning period of 2006-2050. Simulated saltwater intrusion in the Cohansey in scenarios 1-3 is the greatest of all scenarios simulated. The chloride and sodium fronts in the Rio Grande water-bearing zone and the Atlantic City 800-foot sand aquifers are not collocated. Sodium concentrations already exceed the NJDEP SMCL (50 mg/L) that is permitted for water supply in wells open to the Rio Grande water-bearing zone for WWU and in the Atlantic City 800-foot sand in many production wells in Stone Harbor, Avalon, and Cape May Court House.

The ecological water supplies when simulated with Scenarios 1, 2, and 3 show maximum water-level declines in the water-table aquifer of 0.1 ft in Lower Township and 0.7 ft in Middle Township. Base flow in streams decreases on the peninsula by 3 to 26 percent but decreases by less than 5 percent in northern Cape May County.

Water-level altitudes in the Rio Grande water-bearing zone and Atlantic City 800-foot sand aquifer were -30 and -74 ft in Ocean City in 2003. Simulations of scenarios 1-3 show that wate levels in these two respective aquifers will decline to -84 and -156 ft by 2050. Minimum water-level altitudes in the estuarine sand and Cohansey aquifers on the peninsula were about -3.8 ft and -12.5 ft, respectively, in 2003. Simulations show that on the peninsula, water levels in these two respective aquifers will decline an additional 4.7 and 8.7 ft by 2050.

Local Scenarios 4, 5, and 6 are identical in design to baseline Scenario 3 for most communities. However, to stem the adverse impacts caused by the baseline scenarios and to allow each community to maintain control of its existing public-water supply, the following changes were made. For Scenario 4, WWU would withdraw more water from the Rio Grande water-bearing zone and reduce withdrawals from the estuarine sand and Cohansey aquifers. LTMUA would install hypothetical new wells in the Cohansey aquifer south of the Cape May County Airport and transfer withdrawals from shoreline wells to the new wells.

Adverse impacts for Scenario 4 would be less for most parameters than for Scenarios 2 and 3. Simulations indicate that saltwater intrusion in the confined aquifer for Scenario 4 is less than for Scenarios 1 and 2. Impacts to the ecological water supplies also are less with Scenario 4 and water-level declines will be less. Adverse impacts for Scenario 4 are mixed when compared to the effects of the other future

Table 26. Description of nine water-use scenarios, with major infrastructure needs and simulated major effects on potable and ecological water supplies, Cape May County, New Jersey, 2003-2050.

[WWU, Wildwood Water Utility; LTMUA, Lower Township Municipal Utilities Authority; CMCWD, Cape May City Water Department; NJA-CMCH, New Jersey American Water Company-Cape May Court House; WBZ, water-bearing zone; AC800, Atlantic City 800-foot sand; CNSY, Cohansey aquifer; max, maximum; desal, desalination; 250 mg/L Cl, 250 milligram per liter isochlor; w.l., water level; Mgal/yr, million gallons per year.]

Scenario		Description of scenario	Infrastructure needs	Simulated effects on potable supply			Simulated change in ecological supply		Comments
				Advance of 250 mg/L Cl near LTMUA wells, 2003 to 2050 (feet)	Advance of 250 mg/L Cl west of WWU wells, 2003 to 2050 (feet)	Max decline of AC800 water level (feet)	Max decrease in stream-flow on peninsula (percent)	Max decrease in water-table aquifer water levels (feet)	
1	Baseline scenarios—All withdrawals from existing wells	Withdrawals equal to average annual withdrawals during 1999-2003 (7,711 Mgal/yr)	None	3,700	7,100	None	None	None	Saltwater front ~1,200 ft from WWU well field, reaches LTMUA Well 1 (9-52), ~1,700 ft from LTMUA Well 2 (9-54). Water levels in AC 800 unchanged (assuming no effects from changes outside Cape May County)
2		Withdrawals equal to NJDEP full allocation (11,730 Mgal/yr)	Minor	5,400	9,000	15	26	0.5	Saltwater front approaches WWU well field, reaches LTMUA Wells 1 and 2 (9-52, 9-54). Water levels in AC800 up to 15 ft lower than Scenario 1
3		Withdrawals equal to estimated full build-out demand (12,864 Mgal/yr)	Minor	5,200	9,500	70	18	0.7	Saltwater front approaches WWU well field, LTMUA Well 2 (9-54), reaches LTMUA Well 1 (9-52). Water levels in AC800 up to 70 ft lower than in Scenario 1

Table 26. Description of nine water-use scenarios, with major infrastructure needs and simulated major effects on potable and ecological water supplies, Cape May County, New Jersey, 2003-2050.—Continued

[WWU, Wildwood Water Utility; LTMUA, Lower Township Municipal Utilities Authority; CMCWD, Cape May City Water Department; NJA-CMCH, New Jersey American Water Company-Cape May Court House; WBZ, water-bearing zone; AC800, Atlantic City 800-foot sand; CNSY, Cohansey aquifer; max, maximum; desal, desalination; 250 mg/L Cl, 250 milligram per liter isochlor; w.l., water level; Mgal/yr, million gallons per year.]

Scenario		Description of scenario	Infrastructure needs	Simulated effects on potable supply			Simulated change in ecological supply		Comments
				Advance of 250 mg/L Cl near LTMUA wells, 2003 to 2050 (feet)	Advance of 250 mg/L Cl west of WWU wells, 2003 to 2050 (feet)	Max decline of AC800 water level (feet)	Max decrease in stream-flow on peninsula (percent)	Max decrease in water-table aquifer water levels (feet)	
4	Community based scenarios—most withdrawals from existing wells, withdrawals equal to Scenario 3	WWU transfers ~800 Mgal/yr in shallow with-drawals to the Rio Grande WBZ; LTMUA drills new wells near airport and tranfers ~450 Mgal/yr to four airport wells	WWU: 2 new wells in Rio Grande WBZ LTMUA: 2 new wells in Cohan-sey aquifer near airport	4,300	5,500	84	11	0.5	Saltwater front 2,900 ft from WWU well field, 1,100 ft from LTMUA Well 2 (9-54), reaches LTMUA Well 1 (9-52), is about 600 to 800 ft farther from LTMUA airport wells than in Scenario 3. Water levels in AC800 as much as 84 ft lower than in Scenario 1
5		WWU and LTMUA each build a desalination plant and drill 2 wells into the brackish AC800. Then transfer 800 and 450 Mgal/yr, respectively, from shallow to desalination wells	WWU and LMUA each build desal plant and install two new wells in AC800	3,300	5,200	120	10	0.3	Saltwater front 2,900 ft from WWU well field, 2,300 ft from LTMUA Well 2 (9-54), reaches LTMUA Well 1 (9-52), is about 2,100 to 2,500 ft farther from LTMUA airport wells than in Scenario 3. Water levels in AC800 as much as 121 ft lower than in Scenario 1, 37 to 75 ft lower than in Scenario 3
6	Community base scenarios—most withdrawals from existing wells, withdrawals equal to Scenario 3	Same as Scenario 4 except LTMUA builds a tertiary water-treatment plant and drills 3 wells into the Cohansey aquifer. Then injects treated water to create a freshwater barrier	Scenario 4 plus LTMUA builds tertiary water treatment plant, installs 3 injection wells in Cohansey aquifer, constructs water line	3,300	5,300	84	11	0.4	Similar to Scenario 4 except has the least intrusion towards LTMUA airport wells (up to 3,200 ft less) of all scenarios, slightly less intrusion (200 feet less) towards WWU well field. Water levels in AC800 are the same as in Scenario 4, as much as 84 ft lower than Scenario 1

Table 26. Description of nine water-use scenarios, with major infrastructure needs and simulated major effects on potable and ecological water supplies, Cape May County, New Jersey, 2003-2050.—Continued

[WWU, Wildwood Water Utility; LTMUA, Lower Township Municipal Utilities Authority; CMCWD, Cape May City Water Department; NJA-CMCH, New Jersey American Water Company-Cape May Court House; WBZ, water-bearing zone; AC800, Atlantic City 800-foot sand; CNSY, Cohansey aquifer; max, maximum; desal, desalination; 250 mg/L Cl, 250 milligram per liter isochlor; w.l., water level; Mgal/yr, million gallons per year.]

Scenario		Description of scenario	Infrastructure needs	Simulated effects on potable supply			Simulated change in ecological supply		Comments
				Advance of 250 mg/L Cl near LTMUA wells, 2003 to 2050 (feet)	Advance of 250 mg/L Cl west of WWU wells, 2003 to 2050 (feet)	Max decline of AC800 water level (feet)	Max decrease in stream-flow on peninsula (percent)	Max decrease in water-table aquifer water levels (feet)	
7	Cooperatively based scenarios—most withdrawals from existing wells, withdrawals equal to Scenario 3	WWU and LTMUA cooperatively build a desalination plant and install 4 wells in the brackish AC800, transfer ~800 and ~450 Mgal/yr, respectively, from Cohasey aquifer to desalination wells	WWU+LTMUA build desal plant, install 4 wells in AC800	3,200	4,800	93	11	0.4	Saltwater front 2,800 ft from WWU well field, 2,200 ft from LTMUA Well 2 (9-54), reaches LTMUA Well 1 (9-52), is about 2,600 ft farther from LTMUA airport wells than in Scenario 3. Water levels in AC800 as much as 93 ft lower than in Scenario 1, 21 to 33 ft lower than in Scenario 3
8		Same as Scenario 4 except WWU, LTMUA, and NJA-CMCH cooperatively install wells along spine, transfer 800, 450, and 880 Mgal/yr, respectively, from existing to spine wells	WWU+LTMUA + NJA CMCH install 2 new wells in CNSY and 4 new wells in AC800, costruct water transmission line	3,300	5,200	120	9	0.3	Saltwater front movement towards WWU and LTMUA well fields same as Scenario 5. Water levels in AC800 as much as 120 ft lower than in Scenario 1, 35 to 75 ft lower than in Scenario 3
9	Cooperatively based scenarios—most withdrawals from existing wells, withdrawals equal to Scenario 3	Same as Scenario 8 except WWU and LTMUA cooperatively expand CMCWU desalination system, transfer ~800 and 450 Mgal/yr, respectively, from CMCWU system	WWU, LTMUA, + CMCWU Expand desal plant install 4 new wells in AC800	3,300	5,200	115	9	0.3	Saltwater front movement toward WWU and LTMUA well fields same as Scenario 5. Water levels in AC800 as much as 115 ft lower than in Scenario 1, 29 to 67 ft lower than in Scenario 3

scenarios. Simulated saltwater intrusion generally is greater in the shallow aquifers and less in the deeper aquifers. Water-level declines are greater in the shallow aquifers and less in the deeper aquifers. Stream discharge is equal for most streams when compared to the other future scenarios.

Scenario 5 is designed so WWU and LTMU would each build a desalination plant and install two wells into a brackish part of the Atlantic City 800-foot sand. Upon completion of the desalination system, each community would reduce withdrawals from the shallow aquifers. Simulation of Scenario 5 shows that the sodium/chloride front in the shallow aquifers at the southern tip of the county intrudes the least for all of the scenarios. The chloride front in the Atlantic City 800-foot sand reverses its present slow northward movement, which would tend to make the water withdrawn by the desalination wells to become less salty in the future. The ecological-water supply is less impacted in Scenario 5 than in the baseline scenarios, and along with Scenarios 8 and 9, Scenario 5 has the least impact of the future scenarios. Water levels in the shallow aquifers are 0 to 3.4 ft higher than the baseline scenarios. Simulations of Scenario 5 along with Scenarios 8 and 9 show the greatest decline in water levels in the deep confined aquifers.

Scenario 6 was designed to replicate Scenario 4 except that LTMUA also would drill and install a linear array of three injection wells into the Cohansey aquifer and build a tertiary water-treatment plant. Upon completion, LTMUA would inject 240 Mgal/yr of reclaimed water into the Cohansey aquifer to create a barrier of freshwater to protect production wells near the airport from saltwater intrusion. The results of the simulation indicate that Scenario 6 would work as designed. The LTMUA wells are protected; however, saltwater intrusion in the other parts of the aquifer was nearly identical to the other future scenarios. Intrusion, ecological water-supply depletion, and water-level declines in the other confined aquifers are identical to Scenario 4.

It is possible to expand the linear array of injection wells and create a larger freshwater barrier along both sides of the southern part of the Cape. However, this freshwater barrier system would need to be evaluated with respect to chemical, biological, and physical interactions between the tertiary treated water and the well screen, the aquifer material, and the aquifer water.

Scenarios 7, 8, and 9 are identical to baseline Scenario 3 for most communities; however for WWU, LTMUA, NJA-CMCH, and CMCWU, the scenarios were designed to withdraw water in a cooperative fashion to meet estimated full build-out water demands. Scenario 7 is designed so that a linear array of two Cohansey wells and four Atlantic City 800-foot sand wells would be installed along the spine of the peninsula between Rio Grande and Cape May Court House. Withdrawals would be reduced in WWD and LTMUA supply wells identical to Scenario 4 and new withdrawal demands for NJA-CMCH would be obtained from the spine wells.

The adverse impacts to the shallow aquifer system and the ecological water supplies, generally are the least in Scenario 7 when compared to all future scenarios. Simulated saltwater intrusion in the Cohansey aquifer is generally the same as in scenarios 5, 8, and 9 and less than in the other scenarios. The impact to the deep system is that water levels in the Atlantic City 800-foot sand will decline to -140 ft on the peninsula (table 26).

Scenarios 8 and 9 are designed to use the salty part of the Atlantic City 800-foot sand for future potable-water supply. Scenario 8 is designed to locate four new desalination wells at the airport and then construct a desalination plant. Scenario 9 is designed to locate four new desalination wells near CMCWU and then expand the existing CMCWU desalination plant to accommodate increased withdrawal. Upon completion of either system, LTMUA and WWU would alter withdrawals in their existing supply wells identical to Scenario 4.

Scenarios 7, 8, and 9 are designed to meet full build-out water demand. Potable and ecological water-supply impacts within the shallow aquifers in scenarios 8 and 9 are the same as in scenario 5 and generally the same as in scenario 7. The major adverse impact is on water-level altitudes in the Atlantic City 800-foot sand. Simulations indicate that water-level altitudes will decline to as low as -192 ft and induce the inflow of sodium-rich water from nearby clay strata. Other impacts will be that the saltwater front in the Atlantic City 800-foot sand will intrude the aquifer but will only move a few thousand feet. The advantages of these scenarios is that the saltwater fronts in the shallow aquifers will intrude less than the average for the future scenarios; however, as in the other scenarios the saltwater front in the shallow aquifers may impact some potable water-supply wells on the Bay and southern shore of the Cape.

Stewardship of the potable, non-potable, and ecological water supplies of Cape May County will likely modify and incorporate many of the concepts developed and simulated in Scenarios 4 to 9. Past and ongoing practices to use and improve the potable-water supply include relocating wells in the interior of the county to lessen the impact of saltwater intrusion; using multiple aquifers to disperse the stresses of groundwater withdrawal; locating wells farther apart to reduce drawdown; drilling deeper to maintain water quality; using legislation to increase water conservation; employing conservation practices at tourist accommodations and government and educational facilities; closely monitoring irrigation at golf courses, farms, public parks, and residences; using native vegetation for landscaping; adjusting price structure for water; improving solid waste and wastewater management facilities; employing desalination; and using aquifer storage and recovery techniques.

It is possible that in the future, additional techniques will be implemented such as construction practices that incorporate the reuse of water for irrigation, sanitary waste, and power generation. Changes may occur in the construction of storm-sewer lines and where water is diverted. Drilling in the future may tap deep saltwater aquifers as a source water for desalination.

Ecological water demands have been preserved in many locations as a result of implementing many of the above-mentioned activities and including the purchase of land for ecological preservation, dam removal to improve access to ecological water supplies by migrating fish, and legislation that preserves saltwater and freshwater wetland and streams. Land purchases for ecological preservation and legislation written with a sense of ecological stewardship is becoming more common in practice. Sea-level rise accompanied by shoreline erosion has impacted Cape May County for more than 200 years and will continue to impact the future of Cape May County and its water supply.

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Glossary

A

Active and passive ecologically preserved land (Active) land owned by governmental or environmental organizations with the purpose of preserving or restoring the natural ecological niche of the land, for example wildlife refuges, state forests, green acres, farm preservation, (Passive) land legislatively protected to preserve the natural ecological niche. for exammple wetland protection, shoreline protection, stream corridor protection, legislation.

aquifer A thick strata of sand that contains sufficient saturated permeable material to yield significant quantities of water to wells.

B

base flow Sustained flow of a stream in the absence of direct runoff. Natural base flow is sustained largely by groundwater discharges.

biomass The total amount of living material in a given habitat, population, or sample. Specific measures of biomass are generally expressed in dry weight (after removal of all water from the sample) per unit area of land or unit volume of water.

C

collocated saltwater front Saltwater front in which both the sodium and chloride front occur at the same location.

consumptive use Water that is withdrawn and removed from the immediate water environment, for example water removed from an aquifer, used, transported to a wastewater-treatment plant, and released to the ocean. Also, water consumed by humans or livestock, evaporated, transpired by plants, incorporated into products or crops.

coupled model In circumstances where natural hydrologic boundaries are distant from an area of study, it can be appropriate to have a large-scale model that extends to all relevant boundaries and a small, study-area-scale model that receives boundary flows from the large-scale model. For the deep aquifer system of Cape May County, hydrologic boundaries of the aquifer extend well beyond the county borders, so boundary flows of a county-wide (small-scale) model are derived from a Coastal Plain-wide (large-scale) model.

D

desalination The removal of salts from saline water to provide freshwater. Reverse osmosis is used by Cape May City Water Utility to remove salt from salty groundwater.

discontinuous seasonally wet forests Forested lands that are filled with unconnected wetlands and vernal ponds that are water filled only part of the year.

E

ecological water demand Water demand used to maintain a region's ecology. Includes precipitation, evaporation for climate control, transpiration, water in storage in wetlands and the water-table aquifer for spring bud out, reproduction, habitat, hibernation, etc.

ecologically preserved land Land purchased by government or private foundations or promulgated by legislation to ensure that the landform maintains its native flora and fauna or be permitted to return back to its native flora and fauna.

evapotranspiration The combination of evaporation and transpiration.

F

fecundate Fruitful with vegetation.

fluvial Of or pertaining to a river.

freshwater Water that contains less than 250 mg/L of dissolved chloride and less than 50 mg/L of dissolved sodium. Generally, more than 500 mg/L of dissolved solids is undesirable for drinking and many industrial uses.

G

groundwater (1) Water that flows underground and supplies springs and wells. (2) Water stored underground in soils and sediments.

groundwater, confined Groundwater under pressure significantly greater than atmospheric, with its upper limit the bottom of a bed with hydraulic conductivity distinctly lower than that of the material in which the confined water occurs.

groundwater recharge Inflow of water to a groundwater reservoir from the surface. Infiltration of precipitation and its movement to the water table is one form of natural recharge. Also, the volume of water added by this process.

groundwater, unconfined Water in an aquifer that has a water table that is exposed to the atmosphere.

H

hydraulic conductivity Generally, a constant value for a sand aquifer that relates the amount of water which will flow through a cross-sectional area of the sand under a specific gradient of water levels. Specifically, the proportionality constant in Darcy's Law, which relates the amount of water which will flow through a unit cross-sectional area of aquifer under a unit gradient of hydraulic head.

I

irrigation water use Water application on lands to assist in the growing of crops and pastures or to maintain vegetative growth in recreational lands, such as parks and golf courses.

isochlor A line on a map or section connecting points at which chloride has a specific constant value. In this report isochlor is used to describe the line of points with chloride concentrations that are 250 mg/L.

isopleth A line on a map or section connecting points at which a given variable has a specific constant value. In this report isopleths is used to describe the line of points with sodium concentrations that are 50 mg/L.

M

mining water use Water use during mining sand and gravel from quarries.

model flux The amount that flows through a unit area per unit time. The rate of flow of water, as the tide or current, through a defined area.

N

NAD 27 The North American Datum of 1927 is the horizontal control datum for the United States that (was) defined by (a) location and azimuth on the Clarke spheroid of 1866, with origin at the survey station Meades Ranch, Kansas. The geoidal height at Meades Ranch (was) assumed to be zero. Geodetic positions on the North American Datum of 1927 were derived from the (coordinates of and an azimuth at Meades Ranch).

NAD 83 The North American Datum of 1983 is the horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the *Geodetic Reference System 1980.* This datum, is the newest geodetic reference system and is based on the adjustment of 250,000 points including 600 satellite Doppler stations which constrain the system to a geocentric origin. It is used exclusively in this report.

NAVD 88 The North American Vertical Datum of 1988 is the vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations. It held fixed the height of the primary tidal bench mark, referenced to the new International Great Lakes Datum of 1985 local mean sea-level height value at Father Point/Rimouski, Quebec, Canada. It is used exclusively in this report.

NGVD 29 The National Geodetic Vertical Datum of 1929 the vertical control datum is a geodetic datum derived from a general adjustment of the first order level nets of the United States and Canada. It was formerly called "Sea-level Datum of 1929" or "mean sea-level" in the older USGS series of reports. Although the datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts, it does not necessarily represent local mean sea level at any particular place.

NJDEP allocation numbering system 5000 series: production that can withdraw more than 100,000 gal/d. 2000 P series: private supply that can withdraw more than 100,000 gal/d. 10000 series: supply that can withdraw less than 100,000 gal/d. CM series:agricultural supply that can withdraw up to 100,000 gal/d.

P

particle tracking Computer simulation method to follow a specific particle of water from a predetermined point for a defined period or until the particle reaches a discharge boundary (for example, a pumping well or stream). Often used to predict the movement of a salty parcel of water from the saltwater front to a pumping well.

per capita use The average amount of water used per person during a standard time period, generally per day.

piezometer A device used to measure groundwater pressure head at a point in the subsurface.

porosity A measure of the water-bearing capacity of sediments. With respect to water movement, it is not just the total magnitude of porosity that is important, but the size of the voids and the extent to which they are interconnected, as the pores in a formation may be open, or interconnected, or closed and isolated. For example, clay may have a very high porosity with respect to potential water content, but it constitutes a poor medium as an aquifer because the pores are usually so small.

potable water Water of a quality suitable for drinking.

precipitation Rain, snow, hail, sleet, dew, and frost.

primeval forest Relating to the earliest ages, native to a region.

public-water supply Water withdrawn by public and private companies that is then delivered to users. Public suppliers provide potable water for domestic, commercial, industrial, and public water users.

R

recharge Water added to an aquifer. For instance, rainfall that seeps into the ground.

reclaimed wastewater Treated wastewater that can be used for beneficial purposes, such as irrigating certain plants, building saltwater barriers.

recycled water Water that is used more than one time before it passes back into the natural hydrologic system.

S

saltwater Water that contains significant amounts of chloride and sodium.

Freshwater—water with less than 250-mg/L of chloride and 50-mg/L of sodium.
Saltwater—water with 250-mg/L or more of chloride and 50-mg/L or more of sodium.
Brackish water—more than 250-mg/L of chloride but less than chloride concentration of sea water.
Half seawater—about 10,000 mg/L chloride.
Sea water—about 19,200 mg/L chloride and 10,700 mg/L sodium.
Brine—chloride and sodium concentrations greater than sea water.

self-supplied water Water withdrawn from a surface- or groundwater source by a user rather than being obtained from a production. Examples, domestic self supply: homeowners getting their water from their own well; commercial self supply and industrial self supply: small business or industries that obtain their water supply from their own well.

small public-water supply Water withdrawn by a trailer park, marina, campground, or similar small self-contained communities and then delivered to users.

stress period Period of time (generally 5 to 10 years in this report) developed for the computer simulation program MODFLOW during which a specific groundwater withdrawal rates occur. Multiple stress periods occur in a typical transient simulation.

sustainable A method of using a resource so that the resource is replenished at about the same rate that it is withdrawn.

T

tertiary wastewater treatment Selected biological, physical, and chemical separation processes to remove organic and inorganic substances that resist conventional treatment practices; the additional treatment of effluent beyond that of primary and secondary treatment methods to obtain a very high quality of effluent.

transmissivity A measure of how much water can be transmitted horizontally through a unit width of an aquifer under a unit gradient. Transmissivity is equal to the aquifer thickness times the hydraulic conductivity.

U

upconing Process by which saline water underlying freshwater in an aquifer rises upward into the freshwater zone as a result of pumping water from the freshwater zone.

V

vernal pond Pond that exist in the spring, and dries in late summer. Supports amphibian reproduction populations without a predatory permanent fish population.

W

wastewater Water that has been used in homes, industries, and businesses that is not for reuse unless it is treated.

water-bearing zone Aquifer

water table The top of the water surface in the saturated part of an aquifer.

water-level altitude Altitude of water level in a well. Static water-level altitude is when the well is not being pumped. Stressed or pumping water level is when the well is actively being pumped.

Table 11. Well construction and groundwater-withdrawal data for production wells included in the shallow aquifer system model, Cape May, New Jersey.-

[USGS, U.S. Geological Survey; NJDEP, New Jersey Department of Environmental Protection; CPMY, Cape May Formation; HLBC, Holly Beach water-bearing zone; CKKD, undifferentiated Kirkwood-Cohansey aquifer; ESRNS, estuarine sand aquifer; CNSY, Cohansey aquifer]

USGS well number	NJDEP well permit number	Well owner	Well name	Model layer number	Aquifer code	Altitude of land surface (feet above NAVD 88)	Depth of well (feet below land surface)	Stress period 2 1896–1921	Stress period 3 1922–1950	Stress period 4 1951–1958	Stress period 5, 1959–1965	Stress period 6, 1966-1969	Stress period 7, 1970–1979	Stress period 8, 1980–1983	Stress period 9, 1984–1988	Stress period 10, 1989–1993	Stress period 11, 1994–1998	Stress period 12, 1999–2003
090062		Cordes, William	Irr	1	112CPMY	9	50	0.00	0.00	0.91	3.96	3.92	2.43	0.00	0.00	0.00	0.00	0.00
090063		Hand, Holmes N	2 1958	1	112CPMY	19	50	0.00	0.00	0.00	2.71	0.84	0.00	0.00	0.00	0.00	0.00	0.00
090070	3700242	Wildwood City WD	Rio Grande 36	1	112HLBC	9	63	37.76	37.76	50.03	0.00	0.00	23.20	71.07	10.36	0.00	0.00	0.00
090075	3700243	Wildwood City WD	Rio Grande 37	1	112HLBC	9	60	0.00	0.00	0.00	0.00	0.00	13.05	8.86	0.00	0.00	0.00	0.00
090084		Howell, Howard N	Irr 2	1	112CPMY	4	28	0.00	0.00	0.00	0.00	0.11	0.10	0.00	0.00	0.00	0.00	0.00
090085		Howell, Howard N	Irr 3	1	112CPMY	4	28	0.00	0.00	0.00	0.00	2.38	1.03	0.00	0.00	0.00	0.00	0.00
090137		Nagatsuka, John K	Irr 3	1	112CPMY	19	84	0.00	0.00	0.00	0.00	1.37	0.34	0.00	0.00	0.00	0.00	0.00
090138		Nagatsuka, John K	Irr 1	1	112CPMY	19	67	0.00	0.00	0.00	0.00	2.88	1.29	0.00	0.00	0.00	0.00	0.00
090139		Nagatsuka, John K	Irr 2	1	112CPMY	19	79	0.00	0.00	0.00	0.00	0.51	0.33	0.00	0.00	0.00	0.00	0.00
090142	3700287	Gieberson, Fred	2-Irr	1	112CPMY	29	45	0.00	0.00	0.00	0.00	0.00	4.51	0.00	0.00	0.00	0.00	0.00
090463	5700058	Taylor, Sheppard	Irr 1	1	121CKKD	7	30	0.00	0.00	8.33	46.25	40.12	0.00	0.00	0.59	0.74	0.04	0.02
090471	5700022	Hoff, Edward III & Frank	Irr 1	1	121CKKD	21	35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	5.86	0.61	0.00
090484	3704447	Cape May National Golf Club	I-2	1	112HLBC	9	32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04	5.56	6.06
090485	3704422	Cape May National Golf Club	I-1	1	112HLBC	9	32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88	7.73	6.28
090486	3704771	Cape May National Golf Club	I-3	1	112HLBC	9	32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	5.27	4.45
090489	3703350	Wildwood Golf & Country Club	Irr 4	1	112HLBC	11	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.63
090502	5700052	Wuerkers New Acres Farm	Irr 1	1	112HLBC	7	50	0.00	0.00	0.00	0.00	0.00	0.00	6.40	0.24	5.54	0.00	0.59
090515	5705082	Cape May National Golf Club	I-4	1	112HLBC	14	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.12	0.04
090528	3701398	Legates, Bolton	Irr1	1	112HLBC	11	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	1.63	0.74
090556	3704444	Beachcomber Campgrounds	Dom 8	1	112HLBC	9	42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29
090557	3705436	Brodesser, Tom	PW 5	1	112HLBC	9	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
090558	3705437	Brodesser, Tom	PW 6	1	112HLBC	20	45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
090559	3705438	Brodesser, Tom	Dom 7	1	112HLBC	19	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
090560	3705435	Brodesser, Tom	Dom 4	1	112HLBC	19	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
090561	3702389	Beachcomber Campgrounds	Dom 1	1	112HLBC	14	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
090562	3700378	Beachcomber Campgrounds	PW 2	1	112HLBC	19	46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27
090570	3516842	Cape May County Park Commission	PW 11	1	112ESRNS	11	125	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
090572	3512372	Cape May County-Park Zoo	Irr 8	1	112HLBC	14	38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
090573	3506894	Cape May County-Park Zoo	Irr 4	1	112HLBC	19	34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52
090576	3507417	Cape May County-Park Zoo	Irr 1	1	112HLBC	16	34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
090596	3701128	Cape May County-Park Zoo	Well 2	1	112HLBC	21	35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
090597	5700021	McPherson Farm	Well 1	1	112ESRNS	12	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
090600	3701940	Beachcomber Campgrounds	Well 3	1	112ESRNS	20	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
090022	3700229	Novasack Bros	Irr	6	112ESRNS	24	112	0.00	0.00	0.00	5.10	32.33	36.58	58.38	56.42	50.98	50.52	3.84
090072	3700012	Wildwood City WD	Rio Grande 31	6	112ESRNS	9	135	0.00	0.00	18.88	82.35	94.15	79.52	0.00	0.00	0.46	56.33	56.31
090077	5700004	Wildwood City WD	Rio Grande 14	6	112ESRNS	7	108	13.80	100.76	118.93	82.35	94.15	80.23	0.00	0.00	915.02	0.00	0.00
090083		Howell, Howard N	Irr 1	6	112ESRNS	4	110	0.00	0.00	0.00	0.04	0.20	0.17	0.00	0.00	0.00	0.00	0.00

Table 11. Well construction and groundwater-withdrawal data for production wells included in the shallow aquifer system model, Cape May, New Jersey.—Continued

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090090	3700080	Keuffel & Esser Co	Ind	6	112ESRNS	14	120	0.00	0.00	4.22	22.16	23.10	15.74	0.43	0.00	0.00	0.00	0.00
090162	3800238	Novasack Bros	Irr-2	6	112ESRNS	29	138	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	31.16	0.00	0.00
090171	3700289	Lower Twp Bd of Ed	Institutional 1	6	112ESRNS	9	161	0.00	0.00	0.00	0.00	0.00	0.00	1.57	1.28	0.61	4.94	3.75
090209	3701425	Cold Spring Packing Co	Ind 1	6	112ESRNS	4	110	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.21	8.18	5.25
090260	3600579	Lutheran Home At Oceanview	124 Ft	6	121CNSY	24	124	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.99	9.42	3.79	1.38
090299	3600478	State of NJ-Highway Auth GSP	Upper 1-A	6	112HLBC	4	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.46	5.07	2.09	0.00
090356	3702568	Grande Woods Mobile Home Park	PW 3	6	112ESRNS	14	181	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.01	8.04	3.62
090357	3702569	Grande Woods Mobile Home Park	PW 4	6	112ESRNS	14	180	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.48	7.85	4.80
090398	3504740	Delsea Woods	2 1986	6	112ESRNS	9	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
090407	3604715	Lutheran Home At Oceanview	PW 3	6	121CKKD	22	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85
090462	5500069	Wheeler, John H	Irr 2	6	121CKKD	3	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.53	2.01	0.00	0.00
090475	5700053	Shivers, Walter W	Irr 1	6	121CKKD	7	110	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	3.48	1.81	0.55
090476	5500068	Wheeler, John H	Irr 1	6	121CKKD	3	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.47	0.00
090492	3516575	ERM Partnership	Tw-1	6	121CKKD	21	137	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.07	53.95
090500	3702979	Lower Cape May Bd of Ed	Institutional 2	6	121CNSY	8	180	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	2.37
090501	3705519	Delcamino Mobile Home Park	PW 1	6	121CNSY	19	160	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
090503	5500070	Wheeler, John H	Irr 3	6	121CKKD	2	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
090516	3515509	State of NJ-DEP-Williams Property	RWa1-1	6	112ESRNS	20	70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.43	1.93
090517	3515510	State of NJ-DEP-Williams Property	RW93-1R	6	112ESRNS	20	68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
090531	3600496	Lutheran Home At Oceanview	Dom 1	6	121CKKD	14	116	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92
090532	3503314	Cape May Co Freeholders	Irr 2	6	112ESRNS	11	110	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.17	1.02
090550	3700307	Cape Island Campground	Dom 1	6	121CNSY	9	155	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.96
090551	3700308	Cape Island Campground	Dom 2	6	121CNSY	9	155	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79
090563	3702871	Omnivest Consortium Inc	Dom 1	6	112ESRNS	9	105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.13
090564	3702872	Omnivest Consortium Inc	Dom 2	6	112ESRNS	9	105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48
090565	3621119	Lake & Shore Entertainment Ctr	Rec 1S	6	121CKKD	24	70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.51
090566	3621121	Lake & Shore Entertainment Ctr	Rec 3R	6	121CKKD	24	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82
090567	3621120	Lake & Shore Entertainment Ctr	Rec 2S	6	121CKKD	24	70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.06
090571	3513333	Cape May County-Park Zoo	Irr 9	6	112ESRNS	21	116	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
090574	3518396	Cape May County-Park Zoo	PW 5	6	112ESRNS	22	107	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43
090575	3515887	Cape May Co Freeholders	Irr 10	6	112ESRNS	19	120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03
090585	3622199	Pines at Clermont Golf Course	Well 2	6	121CKKD	23	140	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.31
090591	3622193	Pines at Clermont Golf Course	Well 3	6	121CKKD	23	140	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.81
090603	3707280	Cape May Park	Well 1	6	121CKKD	10		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95
090605	3606903	Seaville Rest Area	Well 2R	6	121CKKD	6	84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44
090612	3705520	Delcamino Mobile Home Park	Well 2	6	112ESRNS	19	144	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
090012		Cape May City WD	Columbia 1	11	121CNSY	9	395	0.00	43.42	16.12	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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090014		Cape May City WD	Lafayette 2	11	121CNSY	11	322	0.00	20.03	245.41	169.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
090019	5700036	Cape May Point WD	Lighthouse 1	11	121CNSY	5	592	6.06	19.40	27.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
090021		Cape May Point WD	Discontinued 2	11	121CNSY	12	280	0.00	0.00	0.00	29.26	28.08	10.41	0.00	0.00	0.00	0.00	0.00
090027	3700013	Cape May City WD	PW 3	11	121CNSY	9	306	0.00	0.00	245.41	427.11	175.33	15.41	32.94	14.00	36.02	74.90	0.25
090028	3700038	NW Magnesite Co	Ind 2	11	121CNSY	9	265	0.00	0.00	0.16	97.22	177.69	146.07	0.00	0.00	0.00	0.00	0.00
090029		NW Magnesite Co	Ind 1	11	121CNSY	9	321	0.00	0.00	46.25	124.83	80.23	89.67	0.00	0.00	0.00	0.00	0.00
090031		Cape May City WD	Broadway 3	11	121CNSY	11	300	0.00	113.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
090032		Cape May City WD	Broadway 1	11	121CNSY	11	300	226.53	187.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
090041	3700134	Snow Canning	Discontinued 2	11	121CNSY	9	320	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.42	0.00	0.00
090042	3700268	Borden Co (Snow)	Ind 3	11	121CNSY	4	291	0.00	0.00	0.00	23.41	13.07	30.44	32.04	27.39	28.41	18.41	23.18
090043	5700011	Cape May City WD	PW 5	11	121CNSY	17	276	0.00	0.00	0.00	0.00	58.05	184.06	204.06	225.80	292.41	284.97	96.65
090045	3700231	Cape May City WD	PW 4	11	121CNSY	9	300	0.00	0.00	0.00	0.00	0.00	0.00	263.96	178.68	81.98	34.27	15.37
090052	3700113	Lower Twp MUA	Lower Twp PW 1	11	121CNSY	17	262	0.00	0.00	0.00	31.15	52.39	67.49	175.21	171.05	114.73	161.46	112.29
090054	3700223	Lower Twp MUA	Lower Twp PW 2	11	121CNSY	13	247	0.00	0.00	0.00	13.33	52.39	67.49	38.33	65.30	99.44	103.20	85.59
090057	3700293	Lower Twp MUA	Lower Twp PW 3	11	121CNSY	19	308	0.00	0.00	0.00	0.00	0.00	30.20	76.98	65.69	87.09	98.92	86.74
090058	5700012	Cape May County	Airport 1	11	121CNSY	19	279	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.59	22.30	63.21
090058	5700012	Cape May County	Airport 1	11	121CNSY	19	279	0.00	0.00	2.55	10.19	11.11	19.30	0.00	0.00	0.00	0.00	0.00
090059	5700013	Cape May County	PW 2	11	121CNSY	19	283	0.00	0.00	3.00	12.01	12.01	22.63	0.00	0.00	0.91	0.00	59.43
090064	3700062	Wildwood City WD	Rio Grande 32	11	121CNSY	7	254	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	296.01	0.00	0.00
090065	3700235	Wildwood City WD	Rio Grande 34	11	121CNSY	11	242	0.00	0.00	0.00	0.00	0.00	0.00	937.05	1281.68	938.07	119.87	237.20
090068	5700006	Wildwood City WD	Rio Grande 28	11	121CNSY	7	244	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	111.68	123.71
090069	3700234	Wildwood City WD	Rio Grande 33	11	121CNSY	8	260	0.00	147.25	410.59	658.36	752.75	950.97	316.40	0.00	0.00	137.10	214.60
090074	5700007	Wildwood City WD	Rio Grande 29	11	121CNSY	8	244	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	93.74	102.95
090076	5700005	Wildwood City WD	Rio Grande 15	11	121CNSY	7	235	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.58	0.00
090078	3700002	Wildwood City WD	Rio Grande 30	11	121CNSY	8	251	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	107.71	156.37
090082	3700269	Cape May Canner	1-1969	11	121CKKD	9	260	0.00	0.00	0.00	0.00	0.00	3.33	11.56	15.86	10.82	29.07	7.93
090101	3500982	Bohm, Lawrence H	Irr	11	121CKKD	8	92	0.00	0.00	0.00	0.00	0.00	0.61	0.09	9.21	8.75	57.86	43.03
090142	3700287	Gieberson, Fred	2-Irr	11	112CPMY	29	45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
090143	3700286	Gieberson, Fred	Irr	11	121CNSY	24	140	0.00	0.00	0.00	0.00	0.00	3.16	0.48	0.39	0.27	0.15	0.00
090145	3600312	Atlantic City Electric Co	Acec 1	11	121CKKD	8	150	0.00	0.00	0.00	6.98	3.30	2.08	3.96	3.03	1.52	0.27	0.00
090147	3600319	Atlantic City Electric Co	2R-Layne3	11	121CKKD	8	145	0.00	0.00	0.00	12.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
090154	5700008	Wildwood City WD	PW 2	11	121CNSY	9	354	12.51	25.01	24.31	0.00	0.00	0.00	22.40	21.83	0.00	0.00	0.00
090157	3700232	Stokes Laundry	Discontinued 1	11	121CNSY	6	338	0.00	0.00	0.00	0.00	0.99	19.77	1.31	0.00	0.00	0.00	0.00
090159	3700241	Wildwood City WD	Recharge 35	11	121CNSY	7	360	0.00	0.00	0.00	0.00	-14.35	-0.53	27.17	0.00	0.00	37.03	5.75
090167	3700217	Woodbine WC	Discontinued 2	11	121CNSY	34	159	0.00	35.40	45.31	43.89	76.93	67.72	124.00	107.05	44.29	0.00	0.00
090168	3700239	Woodbine MUA	PW 6	11	121CKKD	44	157	0.00	0.00	0.00	0.00	0.00	0.00	70.60	3.58	51.72	53.59	62.74
090169	3600394	Betts, Walter	36-394	11	121CNSY	9	162	0.00	0.00	0.00	0.00	6.09	24.78	30.99	38.22	4.41	0.00	0.00

Table 11. Well construction and groundwater-withdrawal data for production wells included in the shallow aquifer system model, Cape May, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJDEP, New Jersey Department of Environmental Protection; CPMY, Cape May Formation; HLBC, Holly Beach water-bearing zone; CKKD, undifferentiated Kirkwood-Cohansey aquifer; ESRNS, estuarine sand aquifer; CNSY, Cohansey aquifer]

USGS well number	NJDEP well permit number	Well owner	Well name	Model layer number	Aquifer code	Altitude of land surface (feet above NAVD 88)	Depth of well (feet below land surface)	Stress period 2 1896–1921	Stress period 3 1922–1950	Stress period 4 1951–1958	Stress period 5, 1959–1965	Stress period 6, 1966-1969	Stress period 7, 1970–1979	Stress period 8, 1980–1983	Stress period 9, 1984–1988	Stress period 10, 1989–1993	Stress period 11, 1994–1998	Stress period 12, 1999–2003
090170	3600063	Upper Twp Bd of Ed	Institutional 1	11	112CPMY	29	80	0.00	0.00	0.00	0.00	0.00	0.00	4.80	0.70	0.32	0.00	0.00
090174	3501863	Buganski, Anthy	Irr	11	121CKKD	11	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.83	11.93	7.84	4.79
090176	3700319	Wildwood City WD	35A	11	121CNSY	7	338	0.00	0.00	0.00	0.00	0.00	0.00	53.57	43.96	9.60	13.65	0.00
090180	3700375	Wildwood City WD	Rio Grande 42	11	121CNSY	14	250	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	137.54	132.38
090182	3700484	Stokes Laundry	Ind 2	11	121CNSY	6	350	0.00	0.00	0.00	0.00	0.00	0.00	9.91	33.69	5.50	0.00	0.00
090183	3700403	Borden Co (Snow)	Ind 4	11	121CNSY	4	290	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.81	33.83	16.46	22.30
090184	3604557	Upper Twp Bd of Ed	Irr-2	11	121CKKD	14	140	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.30	0.09	0.11	0.01
090238	3504183	Bohm, David	Sod	11	121CKKD	6	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.43	1.29	19.17	17.92
090273	3701613	Garden Lake Mobile Homes	1985	11	121CNSY	14	260	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.25	5.11	7.80
090289	3700595	Garden Lake Mobile Homes	1981	11	121CNSY	14	257	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.59	1.42	0.00
090297	3606829	Shore Acres	PW A	11	121CNSY	9	180	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.90	1.28	1.99	2.26
090300	3700314	Lunds Fisheries	Ind 2	11	121CNSY	4	286	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.42	0.11	0.06	0.32
090301	3700831	Wildwood City WD	44-Recharge 4	11	121CNSY	1	250	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.48	10.21	28.11	6.80
090308	3506359	Bohm, David	Sod 1987	11	121CKKD	11	98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.29	19.28
090310	3701781	Wildwood City WD	Rio Grande 39New-Rechrg4	11	121CNSY	6	362	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.64	8.66
090314	3700640	Wildwood City WD	Recharge 3	11	121CNSY	6	328	0.00	0.00	0.00	0.00	0.00	0.00	19.16	49.43	9.69	33.92	8.06
090315	3501373	Wildwood Golf & Country Club	2-1975-OW 3	11	121CNSY	9	248	0.00	0.00	0.00	0.00	0.00	0.00	11.80	16.47	0.00	11.29	14.39
090316	3700306	Wildwood Golf & Country Club	1-1975-OW 2	11	121CNSY	9	247	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.28	5.43	0.00
090317	3502729	Woodbine MUA	Woodbine PW 7	11	121CKKD	41	161	0.00	0.00	0.00	0.00	0.00	0.00	61.17	104.19	54.77	54.36	40.44
090385	3700861	Wildwood City WD	Rio Grande 43	11	121CNSY	14	276	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	140.37	99.88
090395	3704368	Cape May National Golf Club	Cart Bldg 1991	11	121CNSY	14	275	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	2.76	2.36
090412	3607565	NJ Marine Science Consortium	2 Redrilled	11	121CKKD	20	165	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01	3.77	0.08	0.00
090464	5700016	Mattera, Frank	Irr 1	11	121CKKD	46	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.00
090465	5700017	Mattera, Frank	Irr 2	11	121CKKD	46	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.07	0.00	0.00	0.00
090466	5700018	Mattera, Frank	Irr 3	11	121CKKD	46	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.00
090477	5600027	Morie Co-Morie, Jesse & Son	Obs 1	11	121CKKD	19	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	260.00	0.00	0.00
090487	3511432	Cape May National Golf Club	S-2	11	121CNSY	9	281	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	1.06	0.23
090488	3700034	Wildwood Golf & Country Club	Irr 1	11	121CNSY	4	268	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	3.28
090490	3704087	Wildwood Golf & Country Club	Irr 5	11	121CNSY	11	230	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.26	10.65
090491	3700277	Stone Harbor Golf Club	Irr 1	11	121CNSY	14	240	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.40	11.02
090493	5620039	Tuckahoe Sand & Gravel Co	Ind 3	11	121CKKD	29	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.35	6.27
090494	3610935	Tuckahoe Sand & Gravel Co	Ind 1B	11	121CKKD	28	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	2.49
090495	5620040	Tuckahoe Sand & Gravel Co	Ind 1A	11	121CKKD	35	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.99
090496	5620041	Tuckahoe Sand & Gravel Co	Ind 2	11	121CKKD	33	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	2.05
090497	5620042	Tuckahoe Sand & Gravel Co	Ind 1	11	121CKKD	32	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	1.33
090498	5515249	Soco Enterprises	PW 1	11	121CKKD	8	185	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.06
090504	3700238	Novasack Bros Turf Farm	Irr-1	11	121CKKD	34	138	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.64	55.09	10.01

Table 11. Well construction and groundwater-withdrawal data for production wells included in the shallow aquifer system model, Cape May, New Jersey.—Continued

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090524	3512485	Purex Industries	RW-1-91	11	121CKKD	34	25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
090533	3600482	Cape May Co Freeholders	Sc 1	11	121CKKD	19	76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.49
090534	3700285	Upper Twp Bd of Ed	Elem 1	11	121CKKD	22	150	0.00	0.00	0.00	0.00	0.00	0.00	2.69	0.70	0.45	0.11	0.25
090535	3520490	Tuckahoe Nurseries Inc	Irr 1	11	121CKKD	29	155	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.01
090536	3505712	Bohm, David	Irr 5	11	121CKKD	11	160	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.30	2.94	5.85
090549	3700777	Lunds Fisheries	Ind 3	11	121CNSY	4	288	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.78	0.00	0.00	0.08
090552	3513009	Holly Lake Campground	PW 2	11	121CKKD	14	136	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93
090553	3701894	Holly Lake Campground	Dom 1	11	121CKKD	9	120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89
090554	3515412	Dennis Twp Municipal Park	Irr 1	11	121CKKD	19	105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28
090555	3513236	Bellplain/Edora Area Recreation	Irr 3	11	121CKKD	47	154	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28
090568	3505411	D'Abundo & Mccreesh	PW 3 Repl	11	121CKKD	14	90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
090569	3505368	D'Abundo & Mccreesh	PW 1 Repl	11	121CKKD	14	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.31
090577	3610618	B L England Recreation Center	Irr 1	11	121CKKD	9	52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
090578	3610616	B L England Recreation Center	Irr 2	11	121CKKD	9	52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26
090581	3624733	Shore Gate Golf Course	Well 4	11	121CKKD	21	180	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
090586	3622263	Pines at Clermont Golf Course	Well 1	11	121CKKD	14	120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.57
090587	3623695	Shore Gate Golf Course	Well 3	11	121CKKD	28	184	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
090588	3624195	Heritage Links Golf Course	Well 1	11	121CKKD	20	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89
090589	3519563	Holly Lake Campground	Well 3	11	112ESRNS	10	130	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46
090590	3624196	Heritage Links Golf Course	Well 3	11	121CKKD	20	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.10
090592	3624732	Shore Gate Golf Course	Well 2	11	121CKKD	28	165	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
090598	3511637	Hideaway Beach Campground	Well 1	11	121CKKD	10	115	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
090602	3506782	Hideaway Beach Campground	Well 2	11	121CKKD	9	115	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
090604	3624197	Heritage Links Golf Course	Well 2	11	121CKKD	20	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.09
110038	3500984	J S Morie Inc	Ind 2	11	121CKKD	9	205	0.00	0.00	0.00	0.00	0.00	0.00	9.78	1.32	0.01	0.00	0.00
110123	3500947	State of NJ-Dept Insts & Agencies	Leesburg 3/Bayside Prison 3	11	121CKKD	12	268	0.00	0.00	0.00	0.00	0.00	0.00	89.38	200.01	133.70	92.59	68.50
110282	3500948	State of NJ-Leesburg Prison	PW 4	11	121CKKD	11	269	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	53.64	76.45	75.56
110715	5500003	State of NJ-Leesburg Prison	Farm 1	11	121CKKD	16	282	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.21	12.12	23.16
110716	5500004	State of NJ-Leesburg Prison	Farm 2	11	121CKKD	16	275	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.28	24.87	34.83
111052	3510522	Surfside Products Inc	Ind 1	11	121CKKD	2	212	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.49	9.25
111225	3520016	State of NJ-Dept of Treasury	Bayside Prison TW5	11	121CKKD	9	275	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	31.65
111320	3516814	Tuckahoe Nurseries Inc	Irr 2	11	121CKKD	39	145	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.58

For additional information, write to:
Director
U.S. Geological Survey
New Jersey Water Science Center
Mountain View Office Park
810 Bear Tavern Rd., Suite 206
West Trenton, NJ 08628

or visit our Web site at:
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