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Simulation of Potential Water Allocation Changes, Cape May County, New Jersey

Scientific Investigations Report 2020–5052

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

Cover: Cohansey aquifer simulated 250- (green) and 50-milligrams per liter (red) isochlors and the location and magnitude of groundwater withdrawals in southern Cape May County, New Jersey. Circles, production wells.

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By Glen B. Carleton

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), except for figure 10, which is referenced to the National Geodetic Vertical Datum of 1929 (NGVD29).

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.

Sea level in this report is defined as an altitude of 0.0 NAVD 88.

Supplemental Information

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

Abbreviations

CMAC	Cape May Atlantic County model
CMCWD	Cape May City Water Department
ft	feet
LTMUA	Lower Township Municipal Utilities Authority
Mgal/d	million gallons per day
Mgal/yr	million gallons per year
mg/L	milligrams per liter
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
NJAW	New Jersey American Water Corporation
NJCP	New Jersey Coastal Plain
NJDEP	New Jersey of Department of Environmental Protection
NJUID	New Jersey Unique Identification number
PW	pumping well
USGS	U.S. Geological Survey
WWU	Wildwood Water Utility

Simulation of Potential Water Allocation Changes, Cape May County, New Jersey

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Abstract

Saltwater intrusion and declining water levels have been a water-supply problem in Cape May County, New Jersey, for decades. Cape May County is surrounded by saltwater on three sides. Several communities in the county have only one aquifer from which freshwater withdrawals can be made, and that sole source is threatened by saltwater intrusion and (or) substantial declines in water levels caused by groundwater withdrawals. Growth of the year-round and summer tourism populations have caused water demand for some purveyors to approach the full-allocation withdrawal rates set by the New Jersey Department of Environmental Protection, leading these purveyors to request increases in allocations. Simulated water levels resulting from withdrawals including proposed increases in allocations by four purveyors and a shift of some withdrawals from one aquifer to another by a fifth purveyor were compared to simulated baseline water levels with withdrawals at 2012 full-allocation rates.

The Lower Township Scenario simulates proposed full-allocation withdrawals of 1,079 million gallons per year (Mgal/yr) from the Cohansey aquifer, 211 Mgal/yr (24 percent) higher than the 2012 full allocation withdrawals. Lower Township Scenario simulated water levels are between 2 and 4 feet (ft) lower than those of the shallow-aquifer-system Baseline Scenario simulation in much of Lower Township. The simulated 250-milligrams per liter (mg/L) isochlor is a maximum of 750 ft farther eastward than the simulated position in the shallow-aquifer-system Baseline Scenario, and the isochlor is simulated to be 700 ft from the northwestern-most Lower Township Municipal Utility Authority well at the airport in 2050.

The Wildwood Scenario simulates proposed full-allocation withdrawals of 388 Mgal/yr at the Wildwood Water Utility Rio Grande well field in Middle Township from the Rio Grande water-bearing zone (upper Kirkwood Formation) and 776 Mgal/yr from the Atlantic City 800-foot sand (lower Kirkwood Formation). Simulated water levels in the Atlantic City 800-foot sand near the well field are 30–55 ft lower than in the deep-aquifer-system Baseline Scenario, more than 15 ft lower south and west of Cape May Court House, and 5–10 ft lower between Cape May Court House and Woodbine and Upper Township.

The Avalon Scenario simulates proposed full-allocation withdrawals from the Atlantic City 800-foot sand in Avalon Borough of 495 Mgal/yr, which is 141 Mgal/yr (40 percent) higher than the 2012 full-allocation withdrawals. The Cape May Court House Scenario simulates proposed full-allocation withdrawals near Cape May Court House from the Atlantic City 800-foot sand of 495 Mgal/yr, which is 150 Mgal/yr (64 percent) higher than 2012 full-allocation withdrawals. The Strathmere Scenario simulates proposed full-allocation withdrawals in Strathmere from the Atlantic City 800-foot sand of 30 Mgal/yr, which is 11 Mgal/yr (58 percent) higher than 2012 full-allocation withdrawals. All three of these scenarios generally show simulated water levels to be less than 10 ft lower compared to the deep-aquifer-system Baseline Scenario.

The Combined Scenario simulates proposed full-allocation withdrawals, including increased withdrawals from the Atlantic City 800-foot sand in all four locations—the Rio Grande well field, Avalon, Cape May Court House, and Strathmere. Water levels from the Combined Scenario are 40–65 ft lower than those from the deep-aquifer-system Baseline Scenario near the Wildwood Water Utility Rio Grande well field, 15–40 ft lower south of Dennis Township, and 5–15 ft lower in much of the rest of Cape May County.

Introduction

Providing long-term sustainable water supplies in Cape May County (fig. 1) is challenging because of the limited number of viable water sources, proximity to saltwater, substantial summer demand in resort communities, and a sensitive environmental habitat. Groundwater is the sole source of potable water in Cape May County. Saltwater intrusion has led to the abandonment of tens of public- and industrial-supply wells and hundreds of domestic wells (Lacombe and Carleton, 1992), and threatens some existing production wells. Growing water demand plus conversion of some homes with shallow, private wells (with potentially poor water quality) to public supply have led purveyors to request additional allocation from the New Jersey Department of Environmental Protection (NJDEP). To determine the effects of possible increased withdrawals and a shift of withdrawals between two aquifers in Cape May County, New Jersey (fig. 1 and table 1), the U.S.

Geological Survey (USGS), in cooperation with the NJDEP, conducted a study to compare six possible future groundwater withdrawal scenarios to Baseline Scenarios in an effort to balance the need for additional water with protection of the limited water resources in the county.

Water levels in the Cohansey aquifer are below sea level in the southern part of Cape May County (Lacombe and Carleton, 2002; Lacombe and others, 2009), creating a widespread potential for saltwater intrusion. Threats to a sustainable water supply in the Cohansey aquifer include saltwater intrusion from the Atlantic Ocean side of the peninsula, which has resulted in abandonment of Cohansey aquifer wells in the Wildwoods (North Wildwood, Wildwood, West Wildwood, and Wildwood Crest) and Cape May City (Lacombe and Carleton, 1992), and from the Delaware Bay side of the peninsula (fig. 2). Water levels in the Cohansey aquifer have been below sea level in southern Cape May County since before 1958 because of sustained groundwater withdrawals (Gill, 1962). In 2013, groundwater levels were more than 10 feet (ft) below sea level in wells in the Wildwood Water Utility (WWU) Rio Grande well field and south throughout all of Lower Township (U.S. Geological Survey, 2015). With continued withdrawals, water levels are unlikely to recover to above sea level in those locations for the foreseeable future and saltwater intrusion is expected to continue.

Saltwater intrusion in the Cohansey aquifer has been observed in sentinel observation wells at the Delaware Bay shoreline west of the WWU Rio Grande well field since about 1987, and chloride concentrations in some Cohansey aquifer wells in the WWU Rio Grande well field have been increasing since about 2003. Chloride concentrations in Lower Township Municipal Utility Authorities (LTMUA) wells have been generally stable from the time they were installed in the late 1950s through 2013. However, saltwater intrusion remains a concern for the LTMUA because LTMUA PW 1 (090052) is located relatively close to the Delaware Bay shoreline (about 2,000 ft inland) and wells at the LTMUA airport well field are less than 9,000 ft from increasing chloride concentrations at the WWU Rio Grande well field.

In 2008 water levels in the Atlantic City 800-foot sand were about 50 ft below sea level in Ocean City, Cape May County, and more than 90 ft below sea level in the vicinity of Atlantic City, Atlantic County (about 5 miles northeast of Ocean City) (dePaul and Rosman, 2015). Water levels in the aquifer continue a downward trend in coastal communities in Atlantic and Cape May Counties.

To meet future demand in Cape May County, water purveyors—LTMUA, Wildwood Water Utility, Avalon Borough Water Utilities, New Jersey American Water–Cape May Court House, and New Jersey American Water–Strathmere, have requested an increase in full-allocation rates specified in NJDEP water-allocation permits. To determine the effects of the proposed full-allocation withdrawals on the saltwater intrusion rates in the Cohansey aquifer and water levels in the Cohansey aquifer, Rio Grande water-bearing zone, and Atlantic City 800-foot sand, six groundwater flow model scenarios were simulated. In the LTMUA Scenario, proposed full-allocation withdrawals from the Cohansey aquifer are 213 Mgal/yr higher than 2012 full-allocation withdrawals. In the Wildwood Scenario, 766 Mgal/yr of the 2012 Rio Grande water-bearing zone full-allocation withdrawals are simulated to instead be from the Atlantic City 800-foot sand. In the Avalon, Court House, and Strathmere Scenarios, proposed full-allocation withdrawals from the Atlantic City 800-foot sand are higher than the 2012 full-allocation withdrawals in the respective well fields. The Combined Scenario includes the combined changes in withdrawals of the Wildwood, Avalon, Court House, and Strathmere Scenarios.

Purpose and Scope

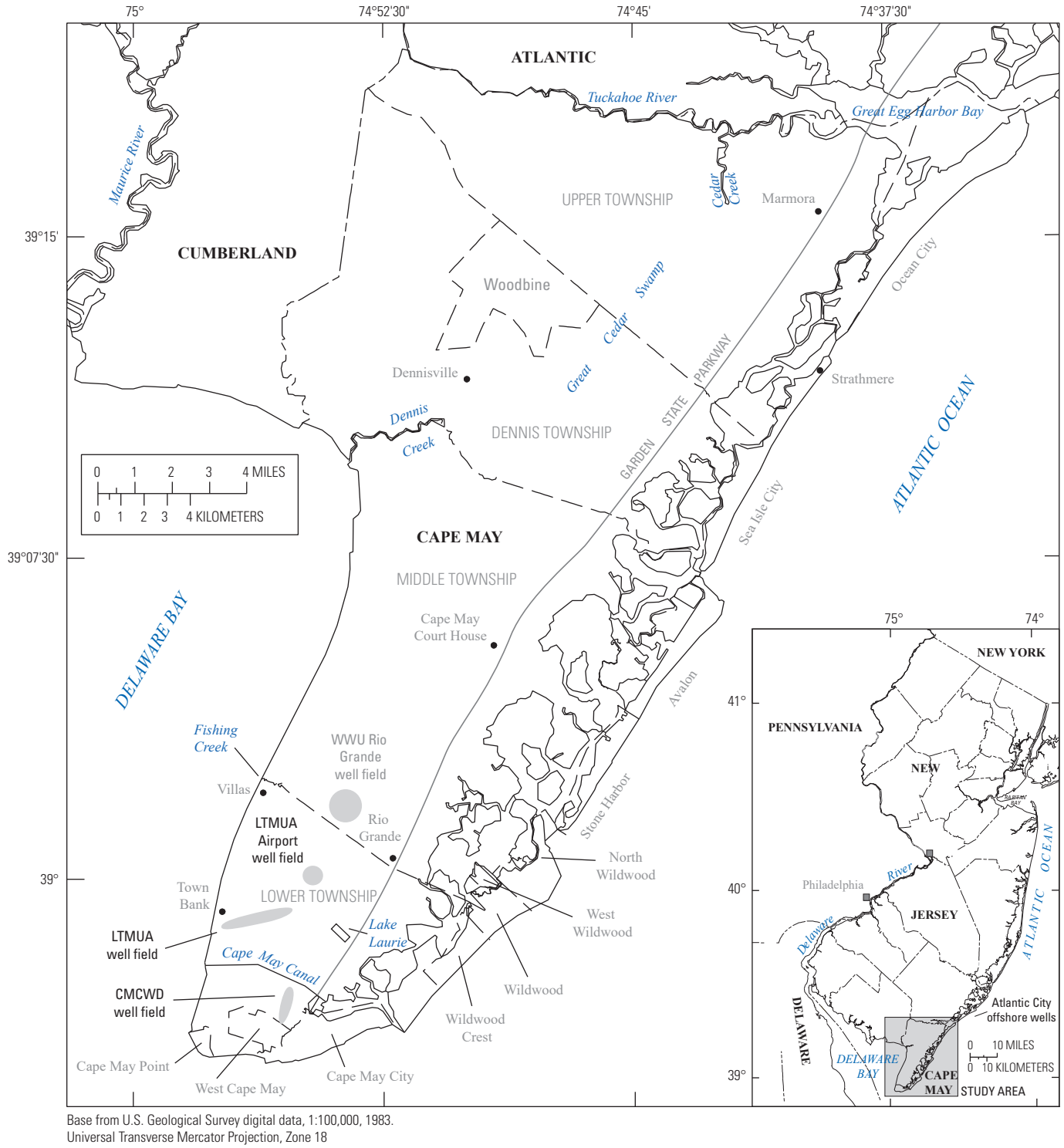
This report discusses the potential effects of withdrawals at proposed full-allocation rates on saltwater intrusion rates in the Cohansey aquifer and water levels in the Cohansey aquifer, Rio Grande water-bearing zone, and Atlantic City 800-foot sand in Cape May County. Simulated water levels, changes in water levels, and saltwater-front location in 2050 resulting from simulated proposed full-allocation withdrawals for LTMUA from the Cohansey aquifer are discussed and are presented in tables and figures. Simulated water levels and differences in water levels compared to the Baseline Scenario for the Atlantic City 800-ft sand for five scenarios are discussed and presented in tables and figures. The groundwater model archive including the input and output data files generated as part of this study are available as a USGS data release in Carleton (2021).

Well-Numbering System

Wells in the report are identified by their New Jersey Unique Identification (NJUID) number. The well number consists of a county code followed by a sequential number assigned to the well, for example 090043. All of the wells identified in this report are in Cape May County with well numbers starting with 09.

Study Area and Hydrogeologic Setting

The study area is Cape May County, with emphasis on the barrier-island communities along the Atlantic coast, the WWU Rio Grande well field in southern Middle Township, and LTMUA wells in Lower Township. All potable water supplied to houses and businesses in Cape May County is groundwater withdrawn from the five aquifers—Holly Beach water-bearing zone, estuarine sand, Cohansey aquifer, Rio Grande water-bearing zone, and Atlantic City 800-foot sand—that underlie the peninsula (fig. 3). The hydrogeology of Cape May County is described in detail in a number of reports, including Gill (1962), Zapecza (1989), and Lacombe and Carleton (2002) and is summarized below.



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

Figure 1. Location of study area, Cape May County, New Jersey.

Table 1. Well construction data for selected production and observation wells in Cape May County, New Jersey.

[USGS, U.S. Geological Survey; Obs, observation well; Twp, Township; ft bls, feet below land surface; --, not available; WD, Water Department; MUA, Municipal Utilities Authority; CNSY, Cohansey aquifer; ESRNS, estuarine sand aquifer; KRKDL, lower Kirkwood Formation; KRKDU, upper Kirkwood Formation]

USGS well number and well name	New Jersey permit number	Well owner	Aquifer code	Screened interval (ft bls)
090027 PW 3	3700000013	Cape May City WD	121CNSY	277–306
090043 PW 5	--	Cape May City WD	121CNSY	246–276
090045 PW 4	3700000231	Cape May City WD	121CNSY	270–300
090048 Canal 5 Obs	3700000159	U.S. Geological Survey	121CNSY	242–252
090052 Lower Twp PW 1	3700000113	Lower Twp MUA	121CNSY	241–262
090054 Lower Twp PW 2	3700000223	Lower Twp MUA	121CNSY	212–247
090064 Rio Grande 32	3700000062	Wildwood City WD	121CNSY	226–250
090065 Rio Grande 34	3700000235	Wildwood City WD	121CNSY	172–242
090068 Rio Grande 28	--	Wildwood City WD	121CNSY	209–244
090069 Rio Grande 33	3700000234	Wildwood City WD	121CNSY	236–260
090074 Rio Grande 29	5700000007	Wildwood City WD	121CNSY	191–231
090076 Rio Grande 15	5700000005	Wildwood City WD	121CNSY	235
090078 Rio Grande 30	3700000002	Wildwood City WD	121CNSY	229–250
090089 Oyster Lab 4 Obs	3700000158	U.S. Geological Survey	121CNSY	195–210
090150 West Cape May 1	3700000155	U.S. Geological Survey	121CNSY	283–293
090180 Rio Grande 42	3700000375	Wildwood City WD	121CNSY	250
090187 F-35	--	Cape May County	121CNSY	186–190
090188 F-36	--	Cape May County	121CNSY	229–233
090213 F-41/Sealed	--	Cape May County	121CNSY	203–208
090302 Coast Guard 800	3700003628	U.S. Geological Survey	122KRKDL	883–893
090304 Airport Rio Grande	3700003763	U.S. Geological Survey	122KRKDU	495–505
090306 Oyster 800 Obs	3500009239	U.S. Geological Survey	122KRKDL	656–666
090310 Rio Grande 39Ne	3700001781	Wildwood City WD	121CNSY	279–357
090314 Recharge 3	3700000640	Wildwood City WD	121CNSY	212–290
090337 N Wildwood 800	3700004660	U.S. Geological Survey	122KRKDL	910–960
090385 Rio Grande 43	3700000861	Wildwood City WD	121CNSY	156–171
090480 6 Desal	3700006314	Cape May City WD	122KRKDL	621–626
090507 7 Desal	3700006563	Cape May City WD	122KRKDL	615–620
090522 PW 47	3700007594	Wildwood City WD	122KRKDL	570–664
090523 PW 46	3700007593	Wildwood City WD	122KRKDL	563–653
090525 PW 6	--	Lower Twp MUA	121CNSY	260
090617 7	3700009043	Lower Twp MUA	121CKKD	--
090630 Recharge 48	3700009436	Wildwood City	121CNSY	148–254
090662 PW 9	3700009403	Lower Twp MUA	121CNSY	245–275
090684 MW 1	E201215464	Lower Twp MUA	121CNSY	250–260
090685 MW 3	E201215463	Lower Twp MUA	121CNSY	220–230
090686 MW 5	E201300367	Lower Twp MUA	121CNSY	243–258
090687 MW 7	E201300369	Lower Twp MUA	121CNSY	230–245
090688 MW 8	E201300370	Lower Twp MUA	112ESRNS	110–125
090689 MW 9	E201301310	Lower Twp MUA	121CNSY	245–260
090690 TW 8	P201100104	Lower Twp MUA	121CNSY	224–264

Table 1. Well construction data for selected production and observation wells in Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; Obs, observation well; Twp, Township; ft bls, feet below land surface; --, not available; WD, Water Department; MUA, Municipal Utilities Authority; CNSY, Cohansey aquifer; ESRNS, estuarine sand aquifer; KRKDL, lower Kirkwood Formation; KRKDU, upper Kirkwood Formation]

USGS well number and well name	New Jersey permit number	Well owner	Aquifer code	Screened interval (ft bls)
090691 MW 4	E201215462	Lower Twp MUA	112ESRNS	130–140
090710 ASR 49	E201113837	Wildwood City	121CKKD	285–345
090711 MW-1	E201317480	Wildwood City	121CNSY	230–250

The Holly Beach water-bearing zone is present only in Cape May County and is the water-table aquifer. The estuarine sand is a minor confined aquifer below the Holly Beach aquifer that is present only in the southern half of Cape May County (south of the Middle Township/Dennis Township boundary), where it is overlain by a confining unit believed to have been deposited in the channel of the ancestral Delaware River estuary during a period of high sea level (Gill, 1962). The Cohansey aquifer is part of the Kirkwood-Cohansey aquifer system that is present throughout much of the southern half of New Jersey and is identified as a distinct confined aquifer only in southern Cape May County. The Cohansey aquifer transitions from fully confined in southern Cape May County (occurring at depths of about 200 to 300 ft below land surface) to semi-confined in northern Middle Township and Dennis Township to unconfined in northwestern Cape May County. The line demarcating where the Holly Beach aquifer no longer is present and the unconfined Cohansey aquifer is the water-table aquifer is not well defined but is sometimes for convenience considered to be coincident with the northeast boundary of Cape May County (Lacombe and Carleton, 2002). The Rio Grande water-bearing zone (also known as the Upper Kirkwood aquifer) is a thin (about 100-ft thick or less), sandy stratum within the Kirkwood-Cohansey aquifer system that is present within the confining unit separating the Cohansey aquifer and the underlying Atlantic City 800-foot sand. The Rio Grande water-bearing zone was first described by Gill (1962) as present in Cape May County only but has since been identified as a narrow band near the Atlantic coast extending from southernmost Cape May County through Atlantic County and into southernmost Ocean County (Zapecza, 1989; Pope and others, 2012). The Atlantic City 800-foot sand (also known as the Lower Kirkwood aquifer) is a major confined aquifer that is the deepest component of the Kirkwood-Cohansey aquifer system and underlies Cape May County and parts of Cumberland, Atlantic, Burlington, and Ocean Counties.

Although parts of Cape May County are underlain by five aquifers containing potable water, for several municipalities only one of the five aquifers contains potable water in sufficient quantities for public supply. The Holly Beach water-bearing zone and the estuarine sand are tapped for water supply primarily by domestic and commercial self-supply wells. The Holly Beach water-bearing zone has high iron concentrations (>0.3 milligram per liter [mg/L]) in some locations (Lacombe and Carleton, 2002) and, because it is the water-table aquifer, is vulnerable to saltwater intrusion from surface water and anthropogenic contamination, such as septic-system discharges or accidental chemical spills. The estuarine sand is affected by saltwater intrusion in western Lower Township in and near Villas (Lacombe and Carleton, 1992) and is limited in its extent and productivity. The Cohansey aquifer is an important water-supply aquifer in Cape May County and is tapped by the LTMUA, WWU, New Jersey American Water–Cape May Court House, Woodbine Water Company, and numerous campground, golf-course, and other commercial and domestic wells. The Cohansey aquifer is the only potable-water aquifer tapped by the LTMUA, in part because in Lower Township the underlying aquifers have sodium concentrations that exceed the secondary drinking water standard (New Jersey Department of Environmental Protection, 2005) of 50 mg/L. The only substantial withdrawals from the Rio Grande water-bearing zone in Cape May County are made at the WWU Rio Grande well field. The Atlantic City 800-foot sand is the primary, if not sole, source of potable water for Cape May City, Cape May Court House, and the barrier island communities of Stone Harbor, Avalon, Sea Isle City, Strathmere, and Ocean City.

WWU is the only purveyor in Cape May County that taps all five aquifers. At the Rio Grande well field, WWU in the first quarter of 2014 withdrew about 3 percent of its supply from the Holly Beach water-bearing zone, 3 percent from the estuarine sand, 54 percent from the Cohansey aquifer, and 40 percent from the Rio Grande water-bearing zone and Atlantic City 800-foot sand (Edward Cerrone, Wildwood Water Utility, oral commun., 2014). WWU has four withdrawal wells open to the Cohansey aquifer on the barrier island, but because of saltwater intrusion concerns, these wells are used for aquifer storage and recovery (ASR), in which water from the Rio Grande well field is injected during the offseason and from which water is withdrawn during the summer tourist season.

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

Figure 2. Location of selected production and observation wells, Cape May County, New Jersey.

Downward vertical flow from the water-table aquifer is the primary source of recharge for the estuarine sand and the confined part of the Cohansey aquifer, and lateral flow from northern Cape May County and inflow from saline parts of the aquifers make up the remainder. The altitude of the water table in the Holly Beach water-bearing zone in Middle and Lower Townships ranges from near sea level to about 15 ft above sea level (Lacombe and Carleton, 2002). The potentiometric surface of the estuarine sand aquifer is similar to, but lower than, that in the overlying Holly Beach water-bearing zone north of the Rio Grande well field, but it is below sea level in the vicinity of the WWU Rio Grande well field. The potentiometric

surface of the Cohansey aquifer is about the same altitude as the water table in northern Cape May County, but it is below sea level from central Middle Township south, a function of both the greater confinement and higher withdrawals in southern Cape May County (Lacombe and Carleton, 2002; dePaul and Rosman, 2015).

Chloride in Groundwater in Cape May County

Saltwater intrusion has been documented in Cape May County since the 1940s (Gill, 1962; Lacombe and Carleton, 1992; Lacombe and Carleton, 2002), and sodium and chloride concentrations elevated above background levels are a concern in all five aquifers used for water supply in the county. Most areas north of Middle Township that are more than 0.5 mile from surficial saltwater are underlain by aquifers containing freshwater to a depth of about 900 ft (Lacombe and Carleton, 2002). However, no reliable source of fresh groundwater underlies the Wildwood communities, Cape May City, and Cape May Point because of elevated sodium and chloride concentrations in all the aquifers. The secondary drinking water standards for sodium and chloride are 50 and 250 mg/L, respectively (New Jersey Department of Environmental Protection, 2005). Chloride concentrations greater than 20 mg/L indicate contamination from anthropogenic sources (for example, road salt or septic systems) or intrusion of saltwater from adjacent, overlying, or underlying sources of groundwater.

Holly Beach Water-Bearing Zone and Estuarine Sand Aquifer

The Holly Beach water-bearing zone is the water-table aquifer in southern Cape May County (south of Dennis Township) and, therefore, directly receives freshwater recharge from precipitation, but is also vulnerable to surficial

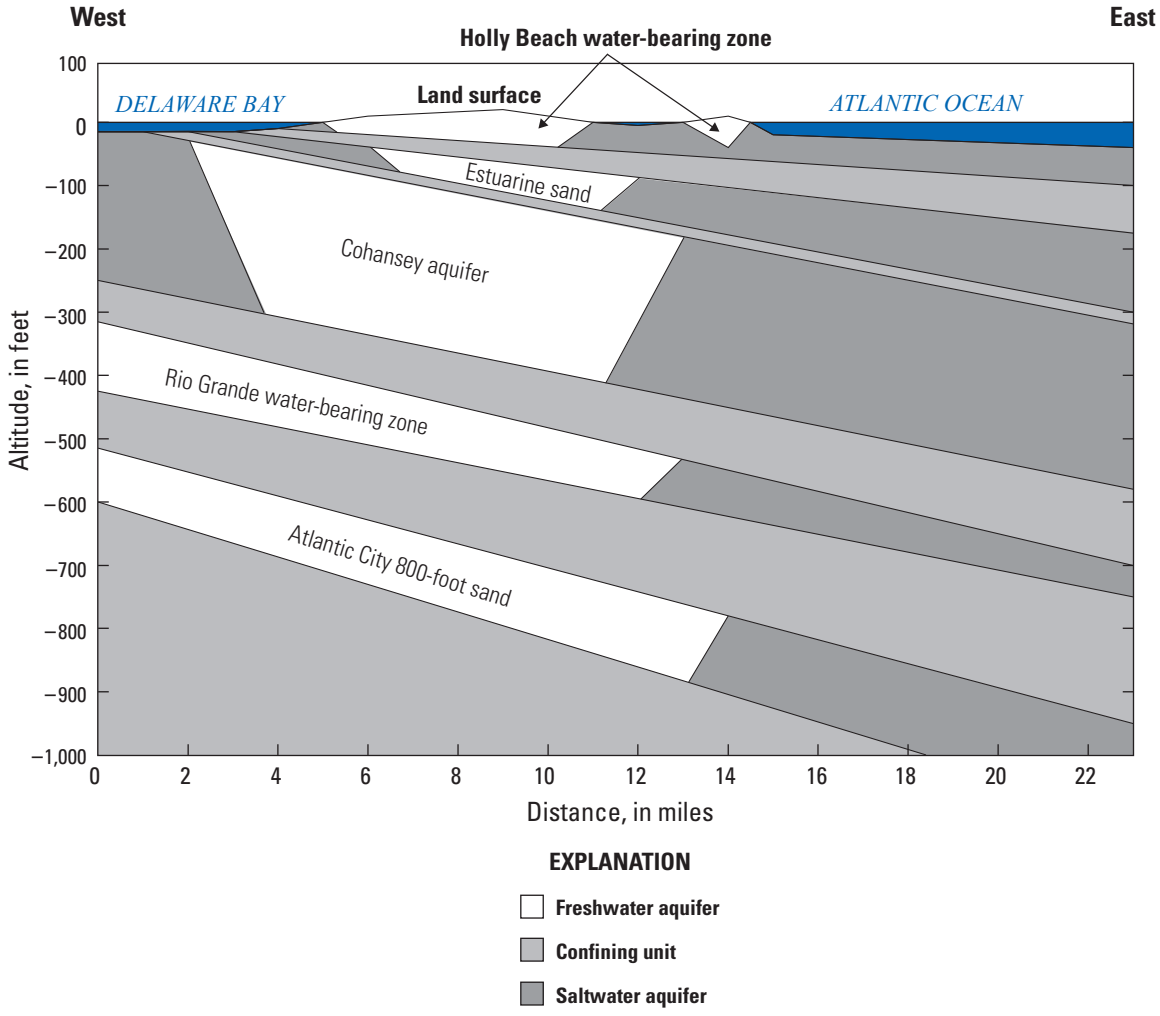


Figure 3. Schematic hydrogeologic section of Cape May County, New Jersey.

saltwater intrusion in areas close to saltwater wetlands, bays, and the ocean. The estuarine sand aquifer is present only in southern Cape May County and the aquifer generally is fresh beneath the mainland areas and salty beneath the Wildwoods and Cape May City. Saltwater intrusion in the estuarine sand has been documented since the 1960s in Villas (Lacombe and Carleton, 1992; Lacombe and Carleton, 2002).

Cohansey Aquifer

Saltwater intrusion in the Cohansey aquifer has been documented in Cape May City since the mid-1940s, in Villas and the Wildwood communities since the mid-1960s, and west of the WWU Rio Grande well field since the mid-1970s (Lacombe and Carleton, 1992; Lacombe and Carleton, 2002; Vincent dePaul, U.S. Geological Survey, written commun., 2014). Chloride concentrations in samples collected from selected wells open to the Cohansey aquifer in Cape May County (fig. 4) show that chloride concentrations greater than 250 mg/L underlie the mouth of Fishing Creek, Cape May Point, West Cape May and Cape May City. Also, the Cohansey aquifer beneath the Wildwood communities and Stone Harbor Manor presumably has concentrations greater than 250 mg/L, but there are no recent data to confirm this assumption.

In some locations in southern Cape May County, saltwater intrusion in the Cohansey aquifer is from lateral flow of saltier, offshore water drawn towards pumped wells. However, in some locations the saltwater intrusion is likely from saltier water entering the aquifer vertically because of induced flow through overlying or underlying confining units. In areas of upward intrusion and vertical flow of denser saline water towards a withdrawal well (upconing), if pumping ceases and recharge of freshwater through overlying confining units occurs, the denser saline water will sink, and chloride concentrations will decline. Aspects of saltwater intrusion near the WWU Rio Grande, LTMUA, and Cape May City Water Department (CMCWD) well fields are discussed below.

Wildwood Water Utility Rio Grande Well Field

Chloride concentrations in water-quality samples collected from WWU Rio Grande well field Rio Grande 28 (well 090068, fig. 2) have increased from about 29 mg/L in 2006 to as much as 310 mg/L in 2017 (Ed Cerrone, Wildwood Water Utility, written commun., 2017) (figs. 4 and 5*A*). Chloride concentrations reached the drinking water standard of 250 mg/L by 2017, about two decades faster than the projections of Lacombe and others (2009). The future rate of increase of chloride concentrations will be governed partly by changes in groundwater withdrawals. Any future increased withdrawal rates from the Cohansey aquifer by LTMUA and others possibly will increase the rate of intrusion, and any future reduced withdrawal rates from the Cohansey aquifer in the WWU Rio Grande well field will possibly reduce the rate of intrusion.

Chloride concentrations in samples from observation well F-35 obs (090187) open to the Cohansey aquifer at the mouth of Fishing Creek, 2.1 miles west-northwest of the WWU well field have been increasing since about 1975, from 16 mg/L in 1975 to 1,154 mg/L in 2010 (figs. 4 and 5*B*). The increasing Cohansey aquifer chloride concentrations at the mouth of Fishing Creek and the WWU Rio Grande well field are consistent with lateral saltwater intrusion. Chloride concentrations in samples from observation well Oyster Lab 4 (090089) near the Delaware Bay shoreline about 3 miles north of the mouth of Fishing Creek began to increase in the early 2000s, indicating possible saltwater intrusion from the northwest towards the WWU Rio Grande well field, but concentrations remained at or below 40 mg/L through 2018 (figs. 4 and 5*C*). The chloride concentrations in samples from observation well F-36 (090188) in a wetland area 1.3 miles east of the mouth of Fishing Creek and 1.0 mile northwest of the WWU well field and observation well F-41 (090213) near the Delaware Bay shoreline 1.1 miles south-southwest of the mouth of Fishing Creek and 2.4 miles west of the WWU well field have not increased through 2010 (figs. 4 and 5*C*), indicating that the lateral saltwater intrusion that has reached the WWU Rio Grande well field is apparently occurring in a tongue that is much longer than it is wide (fig. 4).

Lower Township Municipal Utility Authority Well Fields

The proximity of documented saltwater intrusion in the Cohansey aquifer near the Atlantic Ocean and Delaware Bay shorelines and the lack of offshore chloride data, have caused investigators to assume that the salt front in the Cohansey aquifer is a short distance (thousands of feet) offshore from LTMUA PW 1 (090052) and that the primary threat to LTMUA wells is from the west. Simulations of the predevelopment location of the saltwater front in the Cohansey aquifer (Lacombe and others, 2009) indicate that LTMUA PW 1 (090052) is the closest LTMUA well to the predevelopment saltwater front, but there are not adequate data available to calibrate the model to offshore chloride concentrations and transient aquifer response to the Holocene post-glacial-maximum sea-level rise (Lacombe and others, 2009). The location of the saltwater front near the LTMUA wells is not known and may or may not be an imminent threat. Because saltwater intrusion has begun to reach the Rio Grande well field, LTMUA wells at the airport are at risk for saltwater intrusion from the northwest, and it is not known whether LTMUA wells near the airport will be affected by saltwater intrusion before or after LTMUA PW 1 (090052).

Cape May City Water Department Well Field

Upconing of denser, saltier water during periods of greater withdrawals, and subsequent decline of chloride concentrations during periods of reduced withdrawals, may explain the fluctuating chloride concentration in samples from Cape May City Water Department (CMCWD) wells PW 3 (090027) and PW 4 (090045, figs. 4 and 5*D*). Chloride

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

EXPLANATION

Measured isochlor
250 milligrams per liter, dashed where approximate

Measured isochlor
50 milligrams per liter, dashed where approximate

38 **Well from which most recent chloride sample was collected prior to 1990**
Number is chloride concentration, in milligrams per liter

71 **Well from which most recent chloride sample was collected during 1990–99**
Number is chloride concentration, in milligrams per liter

62 **Well from which most recent chloride sample was collected during 2000–14**
Number is chloride concentration, in milligrams per liter

Figure 4. Chloride concentrations in the Cohansey aquifer, southern Cape May County, New Jersey.

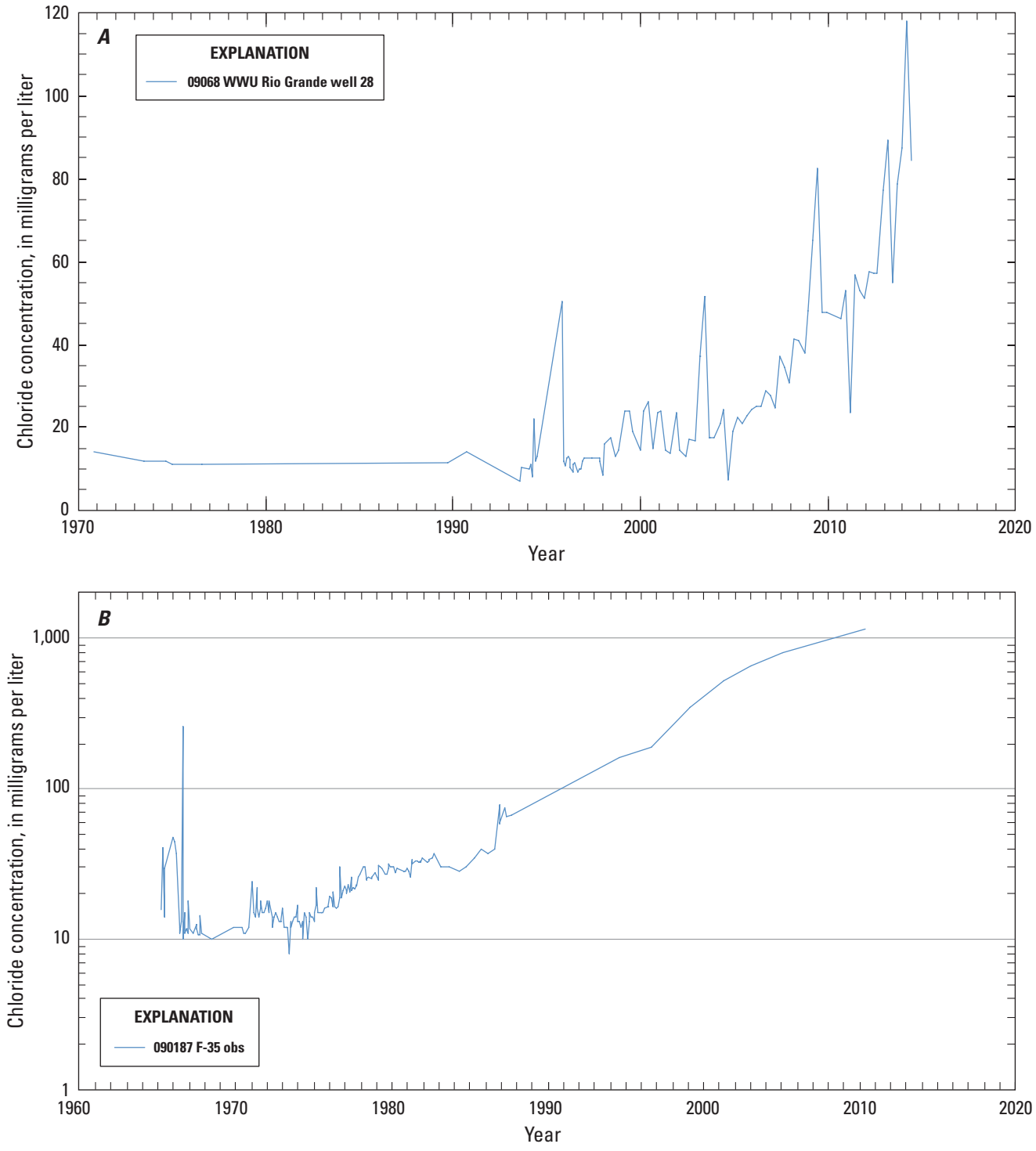
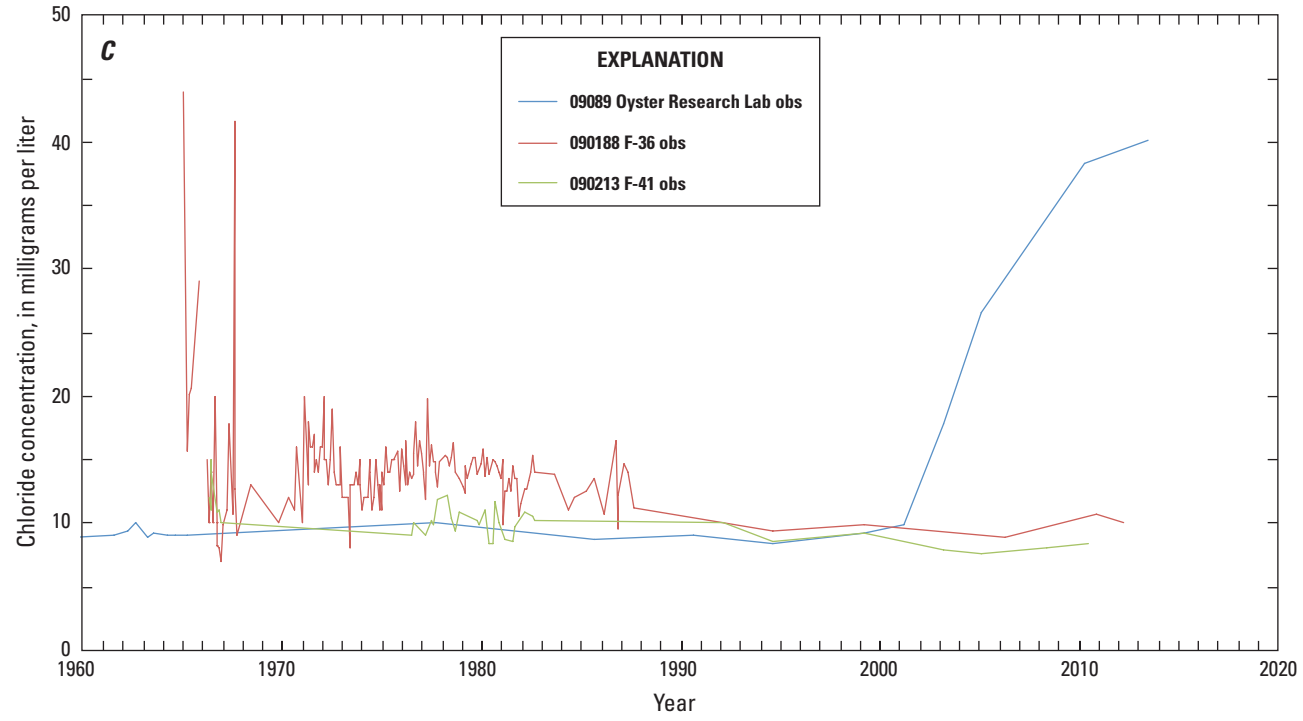


Figure 5. Chloride concentrations in samples collected from selected wells open to the Cohansey aquifer, southern Cape May County, New Jersey 1946–2014.



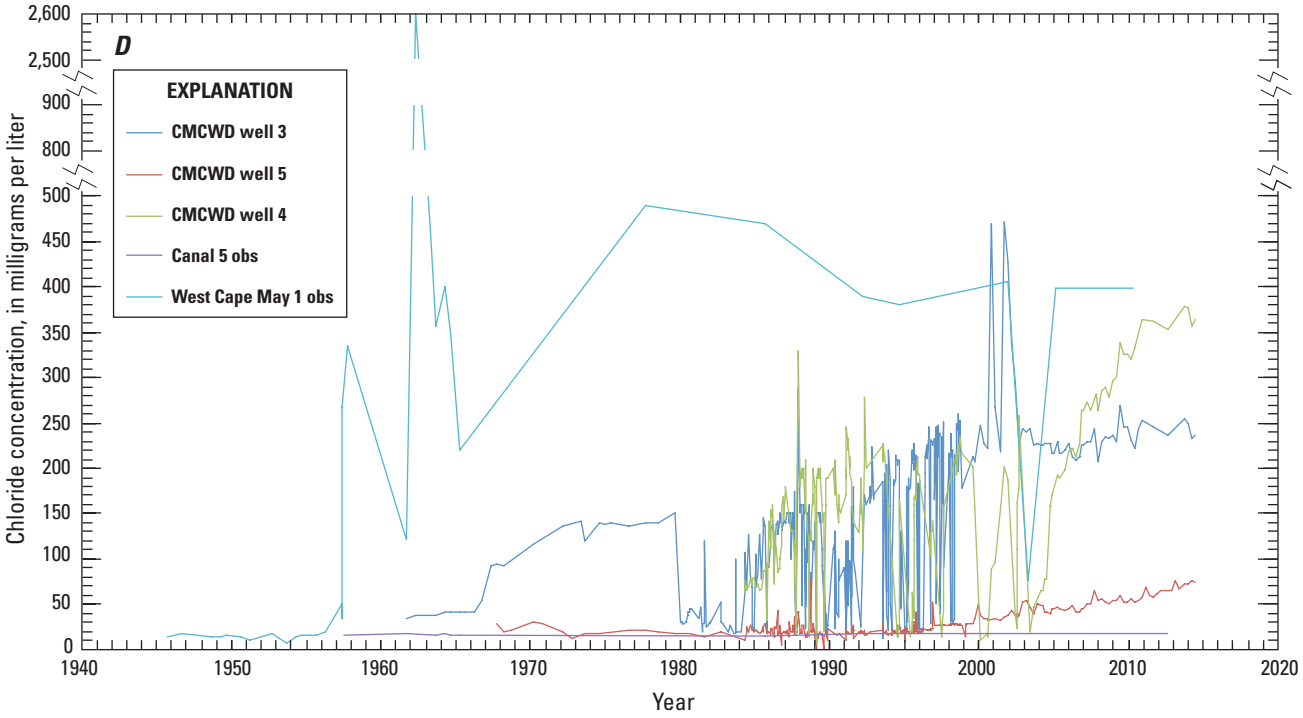


Figure 5.—Continued

concentrations in water from CMCWD PW 3 increased from 34 mg/L to 42 mg/L during 1961-1965 then increased from 54 mg/L to 150 mg/L during 1966-1979 after wells CMCWD PW 4 and PW 5 were installed in 1965. Chloride concentrations in CMCWD PW 3 were generally less than pre-1966 concentrations (less than 50 mg/L) during 1980–83, perhaps because CMCWD PW 1 was pumped to waste for about a year around this time in hopes of drawing freshwater towards CMCWD PW 3 (Pierre Lacombe, U.S. Geological Survey, oral commun., 2012). Seasonal high chloride concentrations in samples from CMCWD PW 3 then increased from about 100 mg/L in 1984 to about 250 mg/L in 1998. Except for a few unexplained high concentrations during 2000–02, chloride concentrations in samples from CMCWD PW 3 remained at about 250 mg/L or less since CMCWD reduced withdrawals from the Cohansey aquifer in 1998.

Chloride concentrations in samples from CMCWD PW 4 (fig. 5*C*) were, in general, like those from CMCWD PW 3, although concentrations in CMCWD PW 4 were lower during 2000–04 when it was used as a recharge well during the winter (Carl Behrens, Cape May City Water Department, oral commun., 2014). Chloride concentrations in CMCWD PW 4 increased during 2005–10 and were between 350 mg/L and 380 mg/L during 2011–14.

The saltwater intrusion affecting CMCWD PW 3 (090027) is likely vertical intrusion from underlying sediments; if lateral intrusion from the south was the dominant source of saline water, chloride concentrations in samples from CMCWD PW 3 (090027) would be consistently higher than those from CMCWD PW 4 (090045). Furthermore, water levels below sea level would have caused continued lateral intrusion and CMCWD PW 3 (090027) chloride concentrations would have increased during 1999–2014.

It is possible that water is also moving vertically downward from the estuarine sand aquifer to the Cohansey aquifer near CMCWD PW 3 (090027) and PW 4 (090045) because a chloride concentration of 300 mg/L was measured in a sample collected from a well completed in the estuarine sand aquifer in 1987, and the confining unit is locally thinner (25 ft thick) near CMCWD PW 3 (090027) than near CMCWD PW 5 (090043, 90 ft thick) (Lacombe and Carleton, 2002). If chloride concentrations in the overlying estuarine sand aquifer have not increased above 400 mg/L, this may explain concentrations in samples from CMCWD PW 3 (090027) and PW 4 (090045) generally remaining below 400 mg/L.

Chloride concentrations in samples from CMCWD PW 5 (090043) rose steadily after the mid-1990s; concentrations were greater than 50 mg/L in 2007 and rose to 99 mg/L in 2018 (fig. 5*C*). The rising chloride concentrations in CMCWD PW 5 clearly indicate saltwater intrusion is affecting the well, but it is not yet clear whether that intrusion is lateral from the south, upward (upconing), downward (downconing), or some combination of the three.

Chloride concentrations in samples from USGS observation well West Cape May 1 obs (090150, figs. 4 and 5*D*), south of the Cape May City well field, began to increase in the late 1950s, spiked in 1962 when the wellhead was flooded by seawater during the March nor'easter, then remained below 500 mg/L from 1977 to 2010, despite water levels remaining below sea level in the area since before 1958 (Gill, 1962, Lacombe and Carleton, 2002, dePaul and Rosman, 2015). Chloride concentrations in samples from USGS observation well Canal 5 obs (090048, figs. 4 and 5*D*), north of CMCWD PW 5 (090043), have remained constant at background concentrations of less than 20 mg/L from 1958 to 2012.

Rio Grande Water-Bearing Zone and Atlantic City 800-Foot Sand

The Rio Grande water-bearing zone contains water with chloride concentrations greater than 250 mg/L and sodium concentrations greater than 50 mg/L beneath all barrier-island communities south of Sea Isle City and south of the Cape May Canal (Lacombe and Carleton, 2002; Vincent dePaul, U.S. Geological Survey, written commun., 2014). The Atlantic City 800-foot sand contains water with chloride concentrations greater than 250 mg/L south of Middle Township and North Wildwood and sodium concentrations greater than 50 mg/L south of Dennis Township and Sea Isle City. Although sodium and chloride concentrations are a substantial concern in the Rio Grande water-bearing zone and Atlantic City 800-foot sand, no pattern of saltwater intrusion has been detected, despite potentiometric surfaces that are below sea level. The lack of observed saltwater intrusion is likely because the transition zone is sufficiently wide that any intrusion that may have occurred is obscured by the natural variability of chloride and sodium concentrations.

Simulation of Groundwater Flow

Scenario simulations for this study were done using three groundwater-flow models developed or revised by Lacombe and others (2009); the models are described in detail in that report. For this study, proposed full-allocation withdrawals from the Cohansey aquifer (Lower Township scenario) were simulated with the shallow-aquifer system, transient, variable-density model developed by Lacombe and others (2009). Proposed full-allocation withdrawals from the Rio Grande water-bearing zone and the Atlantic City 800-foot sand for the Wildwood, Avalon, Court House, Strathmere, and Combined scenarios were simulated with the deep-aquifer system, steady-state model of Cape May County created by Voronin and others (1996) and modified by Pope (2006) and Lacombe and others (2009). Boundary flows for the deep-aquifer system model were simulated with the steady-state model of the Coastal Plain developed by Pope and Gordon (1999) and revised by Lacombe and others (2009).

Approach

The effects of proposed full-allocation groundwater withdrawals are evaluated by comparing baseline scenario results with the results of various full-allocation scenarios. To assess the effects of proposed withdrawals by LTMUA (Lower Township Scenario), water levels and saltwater front location in 2050 are compared to results of a transient baseline simulation that has full-allocation withdrawals beginning at actual 2003 rates and increasing to 2012 full-allocation rates by 2050. Both the baseline and proposed full-allocation scenarios are simulated using the shallow-aquifer-system, variable-density model developed by Lacombe and others (2009). The Baseline Scenario was modified from Scenario 4 of Lacombe and others (2009) and is described in the "Shallow-Aquifer-System Baseline Scenario" Section of this report. The Lower Township Scenario simulates a proposed increase in the full-allocation withdrawal rate by LTMUA by increasing withdrawals from actual 2003 rates to the proposed full-allocation rate in 2050.

The effects of changes to proposed full-allocation withdrawals from the Rio Grande water-bearing zone and Atlantic City 800-foot sand by Wildwood Water Utility, Avalon Borough Water Utilities, New Jersey American Water–Cape May Court House, and New Jersey American Water–Strathmere are simulated in individual scenarios and in the Combined Scenario. The resulting water levels are compared to those from a deep-aquifer-system Baseline Scenario. The baseline and full-allocation scenarios are simulated using a steady-state coupled-model approach. The baseline simulation of 2012 full-allocation withdrawals is a modification of Scenario 2 of Lacombe and others (2009) using the constant-density Cape May Atlantic City 800-foot sand and Rio Grande water-bearing zone (CMAC) model, described in the "Deep-Aquifer-System Baseline Scenario" section of this report. The boundary of the sub-regional CMAC model does not extend to the natural hydrologic boundaries of the deep-aquifer system. Therefore, the New Jersey Coastal Plain regional multi-density model (NJCP Sharp) of Pope and Gordon (1999), as revised by Lacombe and others (2009), was used to supply fluxes across the arbitrary lateral and vertical model boundaries of the CMAC model of Voronin and others (1996), as revised by Pope (2006) and Lacombe and others (2009). Lacombe and others (2009) conclude that the steady-state, constant-density CMAC model (as opposed to a transient and (or) variable density model) provides accurate simulations of future conditions because water levels in the deep aquifers respond relatively quickly to changes in withdrawals, substantial changes in sodium and chloride concentrations in the deep aquifers have not been observed in Cape May County, and the estimated location of the 250-mg/L isochlor is distant from production wells.

Simulated Groundwater Withdrawals

Groundwater withdrawals for the scenarios are summarized in table 2 and detailed in tables 3 and 4. The following discussion emphasizes the differences between the proposed full-allocation scenarios of this study and those of Lacombe and others (2009).

Shallow-Aquifer-System Baseline Scenario

A transient baseline simulation of the shallow-aquifer system for 1896–2050 was developed to compare with the proposed full-allocation withdrawal scenario simulation for LTMUA. The shallow-aquifer-system Baseline Scenario includes minor modifications of the withdrawal rates used in Scenario 4 of Lacombe and others (2009). In Scenario 4,

Table 2. Proposed and 2012 full-allocation withdrawal rates for Lower Township Municipal Utilities Authority, Wildwood Water Utility, Avalon Borough, New Jersey American Water—Cape May Court House, and New Jersey American Water—Strathmere, Cape May County, New Jersey.

[KRKDU, upper Kirkwood Formation; KRKDL, lower Kirkwood Formation; Mgal/yr, million gallons per year]

Purveyor/scenario	Aquifer	2012 allocation (Mgal/yr)	Proposed allocation (Mgal/yr)
Lower Township Municipal Utilities Authority/ Lower Township Scenario	Cohansey	868	1,079
Wildwood Water Utility/Wildwood Scenario	Rio Grande water-bearing zone (KRKDU)	1,164	388
Wildwood Water Utility/Wildwood Scenario	Atlantic City 800-foot sand (KRKDL)	0	776
Avalon Borough Water Utilities/Avalon Scenario	Atlantic City 800-foot sand	354	495
New Jersey American Water, Cape May Court House Division/Court House Scenario	Atlantic City 800-foot sand	235	385
New Jersey American Water, Strathmere Division/ Strathmere Scenario	Atlantic City 800-foot sand	19	30

Table 3. Simulated withdrawals from shallow-aquifer-system production wells, Cape May County, New Jersey.

[USGS, U.S. Geological Survey; NJ, New Jersey; DEP Department of Environmental Protection; ft, foot; Mgal/yr, million gallons per year; WD, Water Department; WC, Water Company; WU, Water Utility; LT, Lower Township; MUA, Municipal Utilities Authority; Twp, Township; Bd of Ed, Board of Education; Inc, Incorporated; Co, Company; Ctr, Center; Insts, Institutions; Dept, Department; Irr, Irrigation; Dom, Domestic; Ind, Industrial; Rec, Recreational; PW, Pumping well; CKDD, undifferentiated Kirkwood-Cohansey aquifer system; CPMY, Cape May formation; HLBC, Holly Beach water-bearing zone; ESRNS, estuarine sand aquifer; CNSY, confined Cohansey aquifer; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Stress period 12, 1999–2003 (Mgal/yr)	Stress period 17, 2041–2050 (Mgal/yr)		
								Lacombe and others, 2009, scenario 4	Shallow-aquifer-system baseline scenario	Scenario A LTMUA increased allocation
Wells simulated as being in the water-table aquifer										
090062 Irr	--	Private owner	112CPMY	--	50	1	0	0	0	0
090063 2 1958	--	Private owner	112CPMY	--	50	1	0	0	0	0
090070 Rio Grande 36	3700000242	Wildwood City WU	112HLBC	48	63	1	0	0	0	0
090075 Rio Grande 37	3700000243	Wildwood City WU	112HLBC	40	60	1	0	0	0	0
090084 Irr 2	--	Private owner	112CPMY	--	28	1	0	0	0	0
090085 Irr 3	--	Private owner	112CPMY	--	28	1	0	0	0	0
090137 Irr 3	--	Private owner	112CPMY	--	84	1	0	0	0	0
090138 Irr 1	--	Private owner	112CPMY	--	67	1	0	0	0	0
090139 Irr 2	--	Private owner	112CPMY	--	79	1	0	0	0	0
090142 2-Irr	3700000287	Private owner	112CPMY	25	45	1	0	0	0	0
090463 Irr 1	5700000058	Private owner	121CKKD	--	30	1	0.02	0.02	0.02	0.02
090471 Irr 1	5700000022	Private owner	121CKKD	--	35	1	0	0	0	0
090484 I-2	3700004447	Cape May National Golf Club	112HLBC	29	32	1	6.06	6.06	6.06	6.06
090485 I-1	3700004422	Cape May National Golf Club	112HLBC	29	32	1	6.28	6.28	6.28	6.28
090486 I-3	3700004771	Cape May National Golf Club	112HLBC	28	32	1	4.45	4.45	4.45	4.45
090489 Irr 4	3700003350	Wildwood Golf & Country Club	112HLBC	40	50	1	1.63	1.63	1.63	1.63
090502 Irr 1	5700000052	Wuerkers New Acres Farm	112HLBC	--	50	1	0.59	0.59	0.59	0.59
090515 I-4	5700005082	Cape May National Golf Club	112HLBC	26	30	1	0.04	0.04	0.04	0.04
090528 Irr1	3700001398	Private owner	112HLBC	45	65	1	0.74	0.74	0.74	0.74
090556 Dom 8	3700004444	Beachcomber Campgrounds	112HLBC	32	42	1	0.29	0.29	0.29	0.29
090557 PW 5	3700005436	Private owner	112HLBC	30	40	1	0.06	0.06	0.06	0.06
090558 PW 6	3700005437	Private owner	112HLBC	35	45	1	0.14	0.14	0.14	0.14
090559 Dom 7	3700005438	Private owner	112HLBC	30	40	1	0.05	0.05	0.05	0.05
090560 Dom 4	3700005435	Private owner	112HLBC	30	40	1	0.25	0.25	0.25	0.25
090561 Dom 1	3700002389	Beachcomber Campgrounds	112HLBC	27	30	1	0.08	0.08	0.08	0.08

Table 3. Simulated withdrawals from shallow-aquifer-system production wells, Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJ, New Jersey; DEP Department of Environmental Protection; ft, foot; Mgal/yr, million gallons per year; WD, Water Department; WC, Water Company; WU, Water Utility; LT, Lower Township; MUA, Municipal Utilities Authority; Twp, Township; Bd of Ed, Board of Education; Inc, Incorporated; Co, Company; Ctr, Center; Insts, Institutions; Dept, Department; Irr, Irrigation; Dom, Domestic; Ind, Industrial; Rec, Recreational; PW, Pumping well; CKDD, undifferentiated Kirkwood-Cohansey aquifer system; CPMY, Cape May formation; HLBC, Holly Beach water-bearing zone; ESRNS, estuarine sand aquifer; CNSY, confined Cohansey aquifer; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Stress period 12, 1999–2003 (Mgal/yr)	Stress period 17, 2041–2050 (Mgal/yr)		
								Lacombe and others, 2009, scenario 4	Shallow-aquifer-system baseline scenario	Scenario A LTMUA increased allocation
Wells simulated as being in the water-table aquifer—Continued										
090562 PW 2	3700000378	Beachcomber Campgrounds	112HLBC	42	46	1	0.27	0.27	0.27	0.27
090570 PW 11	3500016842	Cape May County Park Commission	112ESRNS	110	125	1	0.03	0.03	0.03	0.03
090572 Irr 8	3500012372	Cape May County-Park Zoo	112HLBC	28	38	1	0.34	0.34	0.34	0.34
090573 Irr 4	3500006894	Cape May County-Park Zoo	112HLBC	31	34	1	0.52	0.52	0.52	0.52
090576 Irr 1	3500007417	Cape May County-Park Zoo	112HLBC	31	34	1	0.19	0.19	0.19	0.19
090596 Well 2	3700001128	Cape May County-Park Zoo	112HLBC	--	35	1	0.13	0.13	0.13	0.13
090597 Well 1	5700000021	Private owner	112ESRNS	--	60	1	0.01	0.01	0.01	0.01
090600 Well 3	3700001940	Beachcomber Campgrounds	112ESRNS	27	30	1	0.04	0.04	0.04	0.04
Wells simulated as being in the confined estuarine sand aquifer										
090022 Irr	3700000229	Private owner	112ESRNS	56	112	6	3.84	3.84	3.84	3.84
090072 Rio Grande 31	3700000012	Wildwood City WU	112ESRNS	108	135	6	56.31	56.31	56.31	56.31
090077 Rio Grande 14	5700000004	Wildwood City WU	112ESRNS	82	103	6	0	0	0	0
090083 Irr 1	--	Private owner	112ESRNS	--	110	6	0	0	0	0
090090 Ind	3700000080	Keuffel & Esser Co	112ESRNS	100	120	6	0	0	0	0
090162 Irr-2	3800000238	Private owner	112ESRNS	90	138	6	0	0	0	0
090171 Institutional 1	3700000289	Lower Twp Bd of Ed	112ESRNS	149	161	6	3.75	3.75	3.75	3.75
090209 Ind 1	3700001425	Cold Spring Packing Co	112ESRNS	90	110	6	5.25	5.25	5.25	5.25
090260 124 Ft	3600000579	Lutheran Home At Oceanview	121CNSY	104	124	6	1.38	1.38	1.38	1.38
090299 Upper 1-A	3600000478	State of NJ-Highway Authority, Garden State Parkway	112HLBC	62	65	6	0	0	0	0
090356 PW 3	3700002568	Grande Woods Mobile Home Park	112ESRNS	146	176	6	3.62	3.62	3.62	3.62
090357 PW 4	3700002569	Grande Woods Mobile Home Park	112ESRNS	145	175	6	4.8	4.8	4.8	4.8
090398 2 1986	3500004740	Delsea Woods	112ESRNS	90	100	6	0.38	0.38	0.38	0.38
090407 PW 3	3600004715	Lutheran Home At Oceanview	121CKKD	90	100	6	0.85	0.85	0.85	0.85
090462 Irr 2	5500000069	Private owner	121CKKD	--	40	6	0	0	0	0

Table 3. Simulated withdrawals from shallow-aquifer-system production wells, Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJ, New Jersey; DEP Department of Environmental Protection; ft, foot; Mgal/yr, million gallons per year; WD, Water Department; WC, Water Company; WU, Water Utility; LT, Lower Township; MUA, Municipal Utilities Authority; Twp, Township; Bd of Ed, Board of Education; Inc, Incorporated; Co, Company; Ctr, Center; Insts, Institutions; Dept, Department; Irr, Irrigation; Dom, Domestic; Ind, Industrial; Rec, Recreational; PW, Pumping well; CKDD, undifferentiated Kirkwood-Cohansey aquifer system; CPMY, Cape May formation; HLBC, Holly Beach water-bearing zone; ESRNS, estuarine sand aquifer; CNSY, confined Cohansey aquifer; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Stress period 12, 1999–2003 (Mgal/yr)	Stress period 17, 2041–2050 (Mgal/yr)		
								Lacombe and others, 2009, scenario 4	Shallow-aquifer-system baseline scenario	Scenario A LTMUA increased allocation
Wells simulated as being in the confined estuarine sand aquifer—Continued										
090475 Irr 1	5700000053	Private owner	121CKKD	--	110	6	0.55	0.55	0.55	0.55
090476 Irr 1	5500000068	Private owner	121CKKD	--	40	6	0	0	0	0
090492 Tw-1	3500016575	Sand Barrens Golf Course	121CKKD	105	135	6	53.95	53.95	53.95	53.95
090500 Institutional 2	3700002979	Lower Cape May Bd of Ed	121CNSY	170	180	6	2.37	2.37	2.37	2.37
090501 PW 1	3700005519	Delcamino Mobile Home Park	121CNSY	150	160	6	0.01	0.01	0.01	0.01
090503 Irr 3	5500000070	Private owner	121CKKD	--	40	6	0.13	0.13	0.13	0.13
090516 RWa1-1	3500015509	State of NJ-DEP-Williams Property	112ESRNS	--	70	6	1.93	1.93	1.93	1.93
090517 RW93-1R	3500015510	State of NJ-DEP-Williams Property	112ESRNS	48	68	6	0.2	0.2	0.2	0.2
090531 Dom 1	3600000496	Lutheran Home At Oceanview	121CKKD	106	116	6	0.92	0.92	0.92	0.92
090532 Irr 2	3500003314	Cape May Co Freeholders	112ESRNS	70	110	6	1.02	1.02	1.02	1.02
090550 Dom 1	3700000307	Cape Island Campground	121CNSY	135	155	6	1.96	1.96	1.96	1.96
090551 Dom 2	3700000308	Cape Island Campground	121CNSY	135	155	6	0.79	0.79	0.79	0.79
090563 Dom 1	3700002871	Omnivest Consortium Inc	112ESRNS	95	105	6	2.13	2.13	2.13	2.13
090564 Dom 2	3700002872	Omnivest Consortium Inc	112ESRNS	95	105	6	0.48	0.48	0.48	0.48
090565 Rec 1S	3600021119	Lake & Shore Entertainment Ctr	121CKKD	65	70	6	20.51	20.51	20.51	20.51
090566 Rec 3R	3600021121	Lake & Shore Entertainment Ctr	121CKKD	70	80	6	0.82	0.82	0.82	0.82
090567 Rec 2S	3600021120	Lake & Shore Entertainment Ctr	121CKKD	65	70	6	3.06	3.06	3.06	3.06
090571 Irr 9	3500013333	Cape May County-Park Zoo	112ESRNS	106	116	6	0.06	0.06	0.06	0.06
090574 PW 5	3500018396	Cape May County-Park Zoo	112ESRNS	97	107	6	0.43	0.43	0.43	0.43
090575 Irr 10	3500015887	Cape May Co Freeholders	112ESRNS	100	120	6	1.03	1.03	1.03	1.03
090585 Well 2	3600022199	Pines at Clermont Golf Course	121CKKD	--	120	6	1.31	1.31	1.31	1.31
090591 Well 3	3600022193	Pines at Clermont Golf Course	121CKKD	--	140	6	3.81	3.81	3.81	3.81
090603 Well 1	3700007280	Cape May Park	121CKKD	--	140	6	0.95	0.95	0.95	0.95
090605 Well 2R	3600006903	Seaville Rest Area	121CKKD	64	84	6	1.44	1.44	1.44	1.44
090612 Well 2	3700005520	Delcamino Mobile Home Park	112ESRNS	--	144	6	0.01	0.01	0.01	0.01

Table 3. Simulated withdrawals from shallow-aquifer-system production wells, Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJ, New Jersey; DEP Department of Environmental Protection; ft, foot; Mgal/yr, million gallons per year; WD, Water Department; WC, Water Company; WU, Water Utility; LT, Lower Township; MUA, Municipal Utilities Authority; Twp, Township; Bd of Ed, Board of Education; Inc, Incorporated; Co, Company; Ctr, Center; Insts, Institutions; Dept, Department; Irr, Irrigation; Dom, Domestic; Ind, Industrial; Rec, Recreational; PW, Pumping well; CKDD, undifferentiated Kirkwood-Cohansey aquifer system; CPMY, Cape May formation; HLBC, Holly Beach water-bearing zone; ESRNS, estuarine sand aquifer; CNSY, confined Cohansey aquifer; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Stress period 12, 1999–2003 (Mgal/yr)	Stress period 17, 2041–2050 (Mgal/yr)		
								Lacombe and others, 2009, scenario 4	Shallow-aquifer-system baseline scenario	Scenario A LTMUA increased allocation
Wells simulated as being in the confined Cohansey aquifer										
090012 Columbia 1	--	Cape May City WD	121CNSY	--	395	11	0	0	0	0
090014 Lafayette 2	--	Cape May City WD	121CNSY	282	322	11	0	0	0	0
090019 Lighthouse 1	5700000036	Cape May Point WD	121CNSY	260	592	11	0	0	0	0
090021 Discontinued 2	--	Cape May Point WD	121CNSY	250	280	11	0	0	0	0
090027 PW 3	3700000013	Cape May City WD	121CNSY	277	306	11	0.25	0.25	0.25	0.25
090028 Ind 2	3700000038	NW Magnesite Co	121CNSY	235	265	11	0	0	0	0
090029 Ind 1	--	NW Magnesite Co	121CNSY	296	321	11	0	0	0	0
090031 Broadway 3	--	Cape May City WD	121CNSY	270	300	11	0	0	0	0
090032 Broadway 1	--	Cape May City WD	121CNSY	270	300	11	0	0	0	0
090041 Discontinued 2	3700000134	Snow Canning	121CNSY	--		11	0	0	0	0
090042 Ind 3	3700000268	Borden Co (Snow)	121CNSY	259	289	11	23.18	23.18	23.18	23.18
090043 PW 5	5700000011	Cape May City WD	121CNSY	246	276	11	96.65	96.65	96.65	96.65
090045 PW 4	3700000231	Cape May City WD	121CNSY	270	300	11	15.37	15.37	15.37	15.37
090052 Lower Twp PW 1	3700000113	Lower Twp MUA	121CNSY	241	262	12	117.01	0	0	0
090054 Lower Twp PW 2	3700000223	Lower Twp MUA	121CNSY	212	247	12	86.96	86.96	86.96	86.96
090057 Lower Twp PW 3	3700000293	Lower Twp MUA	121CNSY	262.5	302.5	13	87.03	87.03	87.03	87.03
090058 Airport 1	5700000012	Cape May County	121CNSY	248	275	12	61.16	176.75	173.5[a]	226.25[a]
090059 PW 2	5700000013	Cape May County	121CNSY	252	278	12	61.65	176.75	173.5[a]	226.25[a]
090064 Rio Grande 32	3700000062	Wildwood City WU	121CNSY	226	250	11	0	0	0	0
090065 Rio Grande 34	3700000235	Wildwood City WU	121CNSY	172	242	12	237.2	97.22	97.22	97.22
090068 Rio Grande 28	5700000006	Wildwood City WU	121CNSY	209	244	12	123.71	97.22	97.22	97.22
090069 Rio Grande 33	3700000234	Wildwood City WU	121CNSY	236	260	12	214.6	97.22	97.22	97.22
090074 Rio Grande 29	5700000007	Wildwood City WU	121CNSY	191	231	11	102.95	97.22	97.22	97.22
090076 Rio Grande 15	5700000005	Wildwood City WU	121CNSY	--	235	11	0	0	0	0
090078 Rio Grande 30	3700000002	Wildwood City WU	121CNSY	229	250	12	156.37	97.22	97.22	97.22

Table 3. Simulated withdrawals from shallow-aquifer-system production wells, Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJ, New Jersey; DEP Department of Environmental Protection; ft, foot; Mgal/yr, million gallons per year; WD, Water Department; WC, Water Company; WU, Water Utility; LT, Lower Township; MUA, Municipal Utilities Authority; Twp, Township; Bd of Ed, Board of Education; Inc, Incorporated; Co, Company; Ctr, Center; Insts, Institutions; Dept, Department; Irr, Irrigation; Dom, Domestic; Ind, Industrial; Rec, Recreational; PW, Pumping well; CKDD, undifferentiated Kirkwood-Cohansey aquifer system; CPMY, Cape May formation; HLBC, Holly Beach water-bearing zone; ESRNS, estuarine sand aquifer; CNSY, confined Cohansey aquifer; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Stress period 12, 1999–2003 (Mgal/yr)	Stress period 17, 2041–2050 (Mgal/yr)		
								Lacombe and others, 2009, scenario 4	Shallow-aquifer-system baseline scenario	Scenario A LTMUA increased allocation
Wells simulated as being in the confined Cohansey aquifer—Continued										
090082 1-1969	3700000269	Cape May Canner	121CKKD	229	260	11	7.93	7.93	7.93	7.93
090101 Irr	3500000982	Private owner	121CKKD	40	92	11	43.03	43.03	43.03	43.03
090142 2-Irr	3700000287	Private owner	112CPMY	25	45	11	0	0	0	0
090143 Irr	3700000286	Private owner	121CNSY	110	140	11	0	0	0	0
090145 Acec 1	3600000312	Atlantic City Electric Co	121CKKD	130	150	11	0	0	0	0
090147 2R-Layne3	3600000319	Atlantic City Electric Co	121CKKD	125	145	11	0	0	0	0
090154 PW 2	5700000008	Wildwood City WU	121CNSY	293	354	11	0	0	0	0
090157 Discontinued 1	3700000232	Stokes Laundry	121CNSY	312	338	11	0	0	0	0
090159 Recharge 35	3700000241	Wildwood City WU	121CNSY	249	360	11	5.75	5.75	5.75	5.75
090167 Discontinued 2	3700000217	Woodbine WC	121CNSY	139	159	11	0	0	0	0
090168 PW 6	3700000239	Woodbine WC	121CKKD	134.92	156.75	11	62.74	141.2	141.2	141.2
090169 36-394	3600000394	Private owner	121CNSY	116	160	11	0	0	0	0
090170 Institutional 1	3600000063	Upper Twp Bd of Ed	112CPMY	65	80	11	0	0	0	0
090174 Irr	3500001863	Private owner	121CKKD	45	75	11	4.79	4.79	4.79	4.79
090176 35A	3700000319	Wildwood City WU	121CNSY	251.92	338	11	0	0	0	0
090180 Rio Grande 42	3700000375	Wildwood City WU	121CNSY	--	250	11	132.38	97.22	97.22	97.22
090182 Ind 2	3700000484	Stokes Laundry	121CNSY	320	350	11	0	0	0	0
090183 Ind 4	3700000403	Borden Co (Snow)	121CNSY	260	290	11	22.3	22.3	22.3	22.3
090184 Irr-2	3600004557	Upper Twp Bd of Ed	121CKKD	110	140	11	0.01	0.01	0.01	0.01
090238 Sod	3500004183	Private owner	121CKKD	60	100	11	17.92	17.92	17.92	17.92
090273 1985	3700001613	Garden Lake Mobile Homes	121CNSY	220	260	11	7.8	7.8	7.8	7.8
090289 1981	3700000595	Garden Lake Mobile Homes	121CNSY	237	257	11	0	0	0	0
090297 PW A	3600006829	Shore Acres	121CNSY	145	180	11	2.26	2.26	2.26	2.26
090300 Ind 2	3700000314	Lunds Fisheries	121CNSY	261	286	11	0.32	0.32	0.32	0.32
090301 44-Recharge 4	3700000831	Wildwood City WU	121CNSY	190	245	11	6.8	6.8	6.8	6.8

Table 3. Simulated withdrawals from shallow-aquifer-system production wells, Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJ, New Jersey; DEP Department of Environmental Protection; ft, foot; Mgal/yr, million gallons per year; WD, Water Department; WC, Water Company; WU, Water Utility; LT, Lower Township; MUA, Municipal Utilities Authority; Twp, Township; Bd of Ed, Board of Education; Inc, Incorporated; Co, Company; Ctr, Center; Insts, Institutions; Dept, Department; Irr, Irrigation; Dom, Domestic; Ind, Industrial; Rec, Recreational; PW, Pumping well; CKDD, undifferentiated Kirkwood-Cohansey aquifer system; CPMY, Cape May formation; HLBC, Holly Beach water-bearing zone; ESRNS, estuarine sand aquifer; CNSY, confined Cohansey aquifer; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Stress period 12, 1999–2003 (Mgal/yr)	Stress period 17, 2041–2050 (Mgal/yr)		
								Lacombe and others, 2009, scenario 4	Shallow-aquifer-system baseline scenario	Scenario A LTMUA increased allocation
Wells simulated as being in the confined Cohansey aquifer—Continued										
090308 Sod 1987	3500006359	Private owner	121CKKD	58	98	11	19.28	19.28	19.28	19.28
090310 Rio Grande 39Ne	3700001781	Wildwood City WU	121CNSY	278.67	357	11	8.66	8.66	8.66	8.66
090314 Recharge 3	3700000640	Wildwood City WU	121CNSY	212	325	11	8.06	8.06	8.06	8.06
090315 2-1975-OW 3	3500001373	Wildwood Golf & Country Club	121CNSY	228	248	11	14.39	14.39	14.39	14.39
090316 1-1975-OW 2	3700000306	Wildwood Golf & Country Club	121CNSY	229	247	11	0	0	0	0
090317 Woodbine PW 7	3500002729	Woodbine MUA	121CKKD	135	158	11	40.44	86.96	86.96	86.96
090385 Rio Grande 43	3700000861	Wildwood City WU	121CNSY	156	274	12	99.88	97.22	97.22	97.22
090395 Cart Bldg 1991	3700004368	Cape May National Golf Club	121CNSY	255	275	11	2.36	2.36	2.36	2.36
090412 2 Redrilled	3600007565	NJ Marine Science Consortium	121CKKD	155	165	11	0	0	0	0
090464 Irr 1	5700000016	Private owner	121CKKD	--	65	11	0	0	0	0
090465 Irr 2	5700000017	Private owner	121CKKD	--	65	11	0	0	0	0
090466 Irr 3	5700000018	Private owner	121CKKD	--	65	11	0	0	0	0
090477 Obs 1	5600000027	Morie Co-Morie, Jesse & Son	121CKKD	--	75	11	0	0	0	0
090487 S-2	3500011432	Cape May National Golf Club	121CNSY	275	280	11	0.23	0.23	0.23	0.23
090488 Irr 1	3700000034	Wildwood Golf & Country Club	121CNSY	256	268	11	3.28	3.28	3.28	3.28
090490 Irr 5	3700004087	Wildwood Golf & Country Club	121CNSY	200	230	11	10.65	10.65	10.65	10.65
090491 Irr 1	3700000277	Private owner	121CNSY	210	240	11	11.02	11.02	11.02	11.02
090493 Ind 3	5600020039	Tuckahoe Sand & Gravel Co	121CKKD	--	100	11	6.27	6.27	6.27	6.27
090494 Ind 1B	3600010935	Dial Realty	121CKKD	80	100	11	2.49	2.49	2.49	2.49
090495 Ind 1A	5600020040	Tuckahoe Sand & Gravel Co	121CKKD	--	100	11	0.99	0.99	0.99	0.99
090496 Ind 2	5600020041	Tuckahoe Sand & Gravel Co	121CKKD	--	100	11	2.05	2.05	2.05	2.05
090497 Ind 1	5600020042	Tuckahoe Sand & Gravel Co	121CKKD	--	100	11	1.33	1.33	1.33	1.33
090498 PW 1	5500015249	Soco Enterprises	121CKKD	--	185	11	4.06	4.06	4.06	4.06
090504 Irr-1	3700000238	Novasack Bros Turf Farm	121CKKD	90	138	11	10.01	10.01	10.01	10.01
090524 RW-1-91	3500012485	Cape May County MUA	121CKKD	10	25	11	0.38	0.38	0.38	0.38

Table 3. Simulated withdrawals from shallow-aquifer-system production wells, Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJ, New Jersey; DEP Department of Environmental Protection; ft, foot; Mgal/yr, million gallons per year; WD, Water Department; WC, Water Company; WU, Water Utility; LT, Lower Township; MUA, Municipal Utilities Authority; Twp, Township; Bd of Ed, Board of Education; Inc, Incorporated; Co, Company; Ctr, Center; Insts, Institutions; Dept, Department; Irr, Irrigation; Dom, Domestic; Ind, Industrial; Rec, Recreational; PW, Pumping well; CKDD, undifferentiated Kirkwood-Cohansey aquifer system; CPMY, Cape May formation; HLBC, Holly Beach water-bearing zone; ESRNS, estuarine sand aquifer; CNSY, confined Cohansey aquifer; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Stress period 12, 1999–2003 (Mgal/yr)	Stress period 17, 2041–2050 (Mgal/yr)		
								Lacombe and others, 2009, scenario 4	Shallow-aquifer-system baseline scenario	Scenario A LTMUA increased allocation
Wells simulated as being in the confined Cohansey aquifer—Continued										
090533 Sc 1	3600000482	Cape May Co Freeholders	121CKKD	66	76	11	0.49	0.49	0.49	0.49
090534 Elem 1	3700000285	Upper Twp Bd of Ed	121CKKD	135	150	11	0.25	0.25	0.25	0.25
090535 Irr 1	3500020490	Tuckahoe Nurseries Inc	121CKKD	115	155	11	3.01	3.01	3.01	3.01
090536 Irr 5	3500005712	Private owner	121CKKD	100	160	11	5.85	5.85	5.85	5.85
090549 Ind 3	3700000777	Lunds Fisheries	121CNSY	252	288	11	0.08	0.08	0.08	0.08
090552 PW 2	3500013009	Holly Lake Campground	121CKKD	116	136	11	0.93	0.93	0.93	0.93
090553 Dom 1	3700001894	Holly Lake Campground	121CKKD	100	120	11	0.89	0.89	0.89	0.89
090554 Irr 1	3500015412	Dennis Twp Municipal Park	121CKKD	85	105	11	0.28	0.28	0.28	0.28
090555 Irr 3	3500013236	Bellplain/Edora Area Recreation	121CKKD	124	154	11	0.28	0.28	0.28	0.28
090568 PW 3 Repl	3500005411	Private owner	121CKKD	70	90	11	0.3	0.3	0.3	0.3
090569 PW 1 Repl	3500005368	Private owner	121CKKD	40	60	11	0.31	0.31	0.31	0.31
090577 Irr 1	3600010618	B L England Recreation Center	121CKKD	48	52	11	0.15	0.15	0.15	0.15
090578 Irr 2	3600010616	B L England Recreation Center	121CKKD	48	52	11	0.26	0.26	0.26	0.26
090581 Well 4	3600024733	Shore Gate Golf Course	121CKKD	--	180	11	0.01	0.01	0.01	0.01
090586 Well 1	3600022263	Pines at Clermont Golf Course	121CKKD	--	120	11	6.57	6.57	6.57	6.57
090587 Well 3	3600023695	Shore Gate Golf Course	121CKKD	--	184	11	0.07	0.07	0.07	0.07
090588 Well 1	3600024195	Heritage Links Golf Course	121CKKD	55	75	11	0.89	0.89	0.89	0.89
090589 Well 3	3500019563	Holly Lake Campground	112ESRNS	--	130	11	0.46	0.46	0.46	0.46
090590 Well 3	3600024196	Heritage Links Golf Course	121CKKD	40	80	11	4.1	4.1	4.1	4.1
090592 Well 2	3600024732	Shore Gate Golf Course	121CKKD	--	165	11	0.07	0.07	0.07	0.07
090598 Well 1	3500011637	Hideaway Beach Campground	121CKKD	--	115	11	0.06	0.06	0.06	0.06
090602 Well 2	3500006782	Hideaway Beach Campground	121CKKD	100	115	11	0.13	0.13	0.13	0.13
090604 Well 2	3600024197	Heritage Links Golf Course	121CKKD	70	80	11	2.09	2.09	2.09	2.09
110038 Ind 2	3500000984	J S Morie Inc	121CKKD	175	205	11	0	0	0	0
110123 Leesburg 3/Bays	3500000947	State of NJ-Dept Insts & Agencies	121CKKD	248	268	11	68.5	68.5	68.5	68.5

Table 3. Simulated withdrawals from shallow-aquifer-system production wells, Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJ, New Jersey; DEP Department of Environmental Protection; ft, foot; Mgal/yr, million gallons per year; WD, Water Department; WC, Water Company; WU, Water Utility; LT, Lower Township; MUA, Municipal Utilities Authority; Twp, Township; Bd of Ed, Board of Education; Inc, Incorporated; Co, Company; Ctr, Center; Insts, Institutions; Dept, Department; Irr, Irrigation; Dom, Domestic; Ind, Industrial; Rec, Recreational; PW, Pumping well; CKDD, undifferentiated Kirkwood-Cohansey aquifer system; CPMY, Cape May formation; HLBC, Holly Beach water-bearing zone; ESRNS, estuarine sand aquifer; CNSY, confined Cohansey aquifer; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Stress period 12, 1999–2003 (Mgal/yr)	Stress period 17, 2041–2050 (Mgal/yr)		
								Lacombe and others, 2009, scenario 4	Shallow-aquifer-system baseline scenario	Scenario A LTMUA increased allocation
Wells simulated as being in the confined Cohansey aquifer—Continued										
110282 PW 4	3500000948	State of NJ-Leesburg Prison	121CKKD	249	269	11	75.56	75.56	75.56	75.56
110715 Farm 1	5500000003	State of NJ-Leesburg Prison	121CKKD	--	282	11	23.16	23.16	23.16	23.16
110716 Farm 2	5500000004	State of NJ-Leesburg Prison	121CKKD	--	275	11	34.83	34.83	34.83	34.83
111052 Ind 1	3500010522	Surfside Products Inc	121CKKD	192	212	11	9.25	9.25	9.25	9.25
111225 Bayside Prison	3500020016	State of NJ-Dept of Treasury	121CKKD	230	270	11	31.65	31.65	31.65	31.65
111320 Irr 2	3500016814	Tuckahoe Nurseries Inc	121CKKD	115	145	11	2.58	2.58	2.58	2.58
LTMUA airport hypothetical 1	--	Lower Township MUA	121CNSY	--	--	12	0	176.75	173.5[a]	226.25[a]
LTMUA airport hypothetical 2	--	Lower Township MUA	121CNSY	--	--	12	0	176.75	173.5[a]	226.25[a]

[a]Baseline or LTMUA Scenario withdrawal that is different from Lacombe and others (2009) Scenario 4.

Table 4. Simulated withdrawals from deep-aquifer-system production wells, Cape May County, New Jersey.

[USGS, U.S. Geological Survey; NJDEP, New Jersey Department of Environmental Protection; Mgal/yr, million gallons per year; KRKDU, upper Kirkwood Formation; KRKDL, lower Kirkwood Formation; NJAW, New Jersey American Water Company; Twp, Township; WD, Water Department; Co, Company; PW, Pumping well; Assoc, Association; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Lacombe and others, scenario 2, full allocation	Baseline scenario	Wildwood scenario	Avalon scenario	Court house scenario	Strathmere scenario	Combined scenario
										Mgal/yr			
Wells simulated as being in the Rio Grande water-bearing zone (KRKDU)													
090067 Rio Grande 38	37-271	Wildwood City WD	122KRKDU	461	590	1	248.253	388	388	388	388	388	388
090522 PW 47	37-7594	Wildwood City WD	122KRKDL	570	664	1 or 2[a]	0	388	388[a]	388	388	388	388[a]
090523 PW 46	37-7593	Wildwood City WD	122KRKDL	563	653	1 or 2[a]	0	388	388[a]	388	388	388	388[a]
Wells simulated as being in the upper layer of the Atlantic City 800-foot sand (KRKDL)													
090002 Avalon 2R-71/Ne	37-280	Avalon	122KRKDL	821	861	2	115.255	115.255	115.255	161.16[b]	115.255	115.255	161.16[b]
090005 5-76/New 8	37-313	Avalon	122KRKDL	784	839	2	105.848	105.848	105.848	148.01	105.848	105.848	148.01
090092 NeptunUS 7	37-240	NJAW--Neptune System	122KRKDL	681	791	2	201.148	201.148	201.148	201.148	329.482[b]	201.148	329.482[b]
090100 Avalon M Ww 1	37-224	Middle Twp Water District	122KRKDL	763	815	2	5.800	5.800	5.800	5.800	5.800	5.800	5.800
090126 PW 5	37-162	Sea Isle City WD	122KRKDL	736	768	2	118.627	118.627	118.627	118.627	118.627	118.627	118.627
090127 Sea Isle City P	37-64	Sea Isle City WD	122KRKDL	742	830	2	41.471	41.471	41.471	41.471	41.471	41.471	41.471
090135 Stone Harbor PW	37-9	Stone Harbor WD	122KRKDL	837.5	877.5	2	--	--	--	--	--	--	--
090136 CIWC 1	36-147	NJAW--Strathmere	122KRKDL	802	834	2	--	6.600	6.600	6.600	6.600	18.000[b]	18.000[b]
090148 3-Layne 4	36-364	Atlantic City Electric Co	122KRKDL	645	675	2	230.13	230.13	230.13	230.13	230.13	230.13	230.13
090161 Institutional 1		Eastern Shore Convalescent Center	122KRKDL	639	654	2	10.308	10.308	10.308	10.308	10.308	10.308	10.308
090166 PW 5	37-312	Stone Harbor WD	122KRKDL	820	860	2	39.419	39.419	39.419	39.419	39.419	39.419	39.419
090173 PW 6	37-579	Stone Harbor WD	122KRKDL	810	860	2	66.369	66.369	66.369	66.369	66.369	66.369	66.369
090291 Avalon PW 9	36-9846	Avalon	122KRKDL	764	940.66	2	28.971	28.971	28.971	145.69[b]	28.971	28.971	145.69[b]
090359 Middle Twp PW 2	36-7286	Middle Twp Water District	122KRKDL	708	773	2	4.014	4.014	4.014	4.014	4.014	4.014	4.014
090360 CIWC Vincent Ave Sta 2	36-13154	NJAW--Strathmere	122KRKDL	636	836	2	--	4.400	4.400	4.400	4.400	12.000[b]	12.000[b]
090459 Hria 1966	36-377	Harbor Rd Improvement Assoc	122KRKDL	--	620	2	--	--	--	--	--	--	--
090481 Old Stagecoach	36-17001	NJAW--Cape May Court House	122KRKDL	603	738	2	178.131[b]	178.131[b]	178.131[b]	178.131[b]	178.131[b]	178.131[b]	178.131[b]
090482 Sea Isle City P	36-20238	Sea Isle City WD	122KRKDL	724	884	2	112.483	112.483	112.483	112.483	112.483	112.483	112.483
090506 PW 3	37-5659	Stone Harbor WD	122KRKDL	795	880	2	65.118	65.118	65.118	65.118	65.118	65.118	65.118

Table 4. Simulated withdrawals from deep-aquifer-system production wells, Cape May County, New Jersey.—Continued

[USGS, U.S. Geological Survey; NJDEP, New Jersey Department of Environmental Protection; Mgal/yr, million gallons per year; KRKDU, upper Kirkwood Formation; KRKDL, lower Kirkwood Formation; NJAW, New Jersey American Water Company; Twp, Township; WD, Water Department; Co, Company; PW, Pumping well; Assoc, Association; --, not available or not applicable]

USGS well number and well name	NJDEP well permit number	Well owner	Aquifer code	Depth to top of screen (feet)	Depth to bottom of screen or well depth (feet)	Model layer number	Lacombe and others, scenario 2, full allocation	Baseline scenario	Wildwood scenario	Avalon scenario	Court house scenario	Strathmere scenario	Combined scenario
							Mgal/yr						
Wells simulated as being in the upper layer of the Atlantic City 800-foot sand (KRKDL)—Continued													
090507 7 Desal	37-6563	Cape May City WD	122KRKDL	615	810	2	140.253	140.253	140.253	140.253	140.253	140.253	140.253
090521 7(4R)	37-7541	Stone Harbor WD	122KRKDL	830	953	2	59.264	59.264	59.264	59.264	59.264	59.264	59.264
Wells simulated as being in the lower layer of the Atlantic City 800-foot sand (KRKDL)													
090004 Avalon PW 6	37-265	Avalon	122KRKDL	880	920	3	104.187	104.187	104.187	145.690	104.187	104.187	145.690
090106 Shore div 7	56-6	NJAW--Ocean City	122KRKDL	760	810	3	136.981	136.981	136.981	136.981	136.981	136.981	136.981
090108 Shore div 14-19	36-412	NJAW--Ocean City	122KRKDL	774	840	3	197.135	197.135	197.135	197.135	197.135	197.135	197.135
090109 Shore div 9	56-8	NJAW--Ocean City	122KRKDL	749	809	3	60.735	60.735	60.735	60.735	60.735	60.735	60.735
090110 Shore div 12	36-373	NJAW--Ocean City	122KRKDL	759	814	3							
090116 Shore div 8	56-7	NJAW--Ocean City	122KRKDL	760	810	3	109.291	109.291	109.291	109.291	109.291	109.291	109.291
090117 Shore div 10	36-17	NJAW--Ocean City	122KRKDL	746	798	3	96.641	96.641	96.641	96.641	96.641	96.641	96.641
090121 Shore div 4	56-4	NJAW--Ocean City	122KRKDL	--	825	3	52.769	52.769	52.769	52.769	52.769	52.769	52.769
090122 Shore div 5	56-5	NJAW--Ocean City	122KRKDL	--	825	3	64.80	64.80	64.80	64.80	64.80	64.80	64.80
090124 Shore div 13	36-413	NJAW--Ocean City	122KRKDL	774	840	3	303.624	303.624	303.624	303.624	303.624	303.624	303.624
090125 Shore div 11	36-314	NJAW--Ocean City	122KRKDL	--	800	3	68.270	68.270	68.270	68.270	68.270	68.270	68.270
090136 CIWC 1	56-147	NJAW--Strathmere	122KRKDL	802	834	3	--	--	--	--	--	--	--
090144 BL England 5	36-451	Atlantic City Electric Co	122KRKDL	650	690	3	21.506	21.506	21.506	21.506	21.506	21.506	21.506
090296 Hand Ave 8	35-6073	NJAW--Neptune System	122KRKDL	682	812	3	34.025	34.025	34.025	34.025	55.735[b]	34.025	55.73[b]
090311 Sea Isle City 6	36-10378	Sea Isle City WD	122KRKDL	732	960	3	167.734	167.734	167.734	167.734	167.734	167.734	167.734
090360 Ciwc Vincent Av	36-13154	NJAW--Strathmere	122KRKDL	636	836	3	--	--	--	--	--	--	--
090461 Acec 6 Deep	36-15182	Atlantic City Electric Co	122KRKDL	639	710	3	78.93	78.93	78.93	78.93	78.93	78.93	78.93
090480 6 Desal	37-6314	Cape May City WD	122KRKDL	621	626	3	538.247	538.247	538.247	538.247	538.247	538.247	538.247
090514 Ind 7	36-17504	Atlantic Electric Co	122KRKDL	660	710	3	29.702	29.702	29.702	29.702	29.702	29.702	29.702

[a]Wildwood Water Utility withdrawals simulated as being from layer 2 instead of layer 1 in the Wildwood and Combined Scenarios.

[b]Withdrawal that is different from Lacombe and others (2009) Scenario 2.

withdrawals are set at full build-out rates (the rate of withdrawals required to supply all homes and businesses if all land is developed to the full extent of each municipality's zoning as of 2005), withdrawals from LTMUA PW 1 (090052) ceased in 2010, withdrawals from LTMUA PW 2 (090054) and PW 3 (replaced by PW 7, 090617) are maintained at 2003 rates through 2050, and all increases in withdrawals after 2010 are from two existing and two hypothetical wells near the airport. In Scenario 4, WWU withdrawals are set at full build-out rates, but some withdrawals are shifted from the Cohansey aquifer to the deep-aquifer system after 2010 and proposed full-allocation in WWU withdrawals are from the deep-aquifer system. Withdrawals in the shallow-aquifer-system baseline simulation for this study are the same as Scenario 4 for all purveyors other than LTMUA. Baseline Scenario LTMUA withdrawals were modified as follows: (1) the total LTMUA withdrawal rate is changed from the full build-out rate, 880 million gallons per year (Mgal/yr), to the 2012 full-allocation rate, 868 Mgal/yr; (2) withdrawals from Well 1 (still in service in 2014) continue through 2019; and (3) simulated withdrawals from Well 1 during 2010–19 are offset by reducing to zero simulated withdrawals from one well at the airport during 2010-19. The shallow-aquifer-system Baseline Scenario includes full-allocation, rather than full build-out, withdrawals for LTMUA, therefore, it has characteristics of Lacombe and others (2009) Scenario 2 (full-allocation) and Scenario 4 (full build-out).

The simulated Cohansey aquifer water levels from the shallow-aquifer-system Baseline Scenario (fig. 6) are within 1 ft of those from Scenario 4 in Lacombe and others (2009). The simulated locations of the 250-mg/L isochlor in 2050 for the shallow-aquifer-system Baseline Scenario (fig. 6) are also essentially identical to those for Scenario 4 in Lacombe and others (2009). The similarities of the water levels and isochlor locations between Scenario 4 and the shallow-aquifer-system Baseline Scenario indicate that the minor differences in simulated LTMUA withdrawals between the two scenarios has little effect.

Deep-Aquifer-System Baseline Scenario

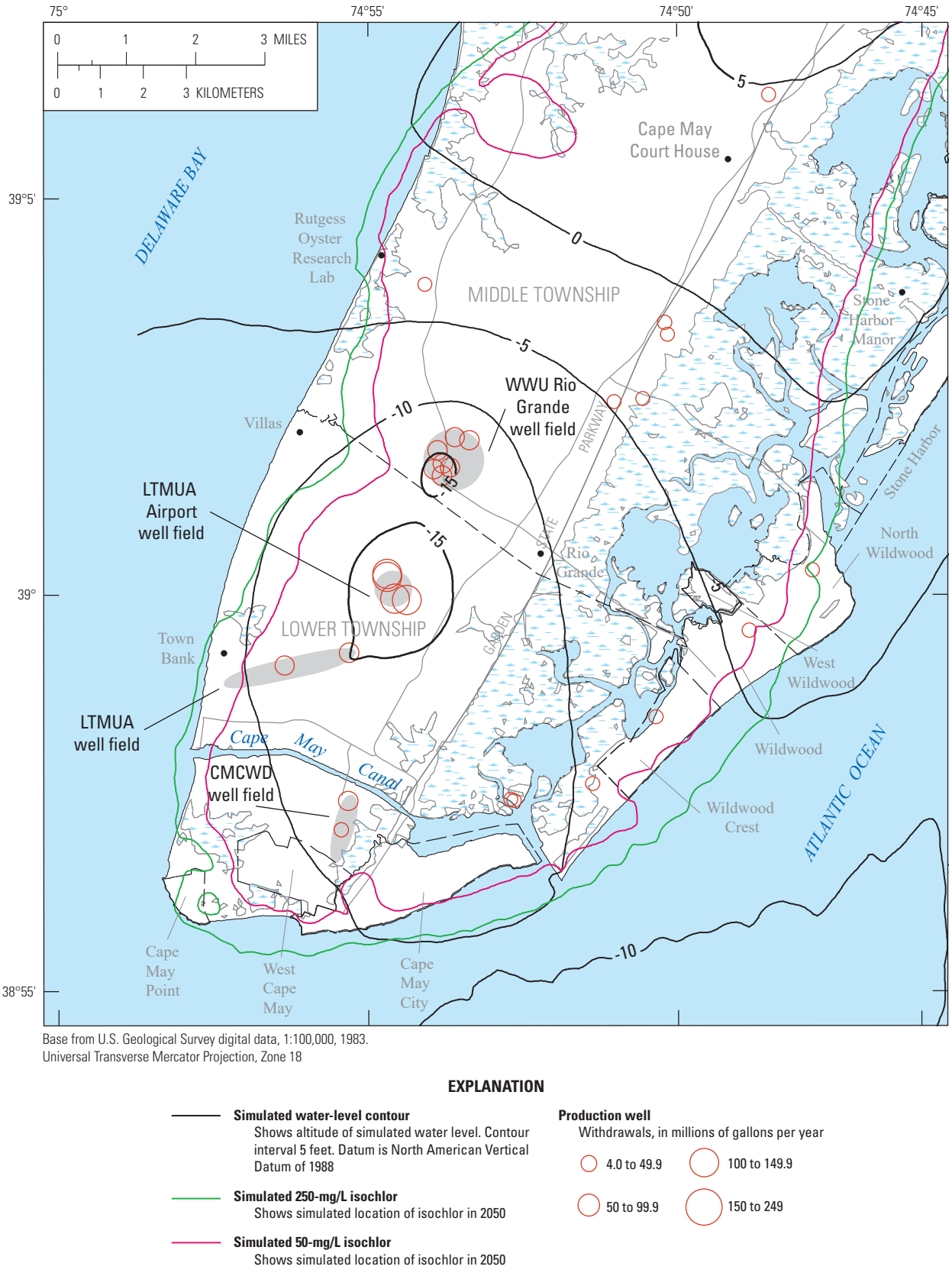
Simulations of the deep-aquifer system for this study used the steady-state, coupled-model approach of Voronin and others (1996), Pope (2006), and Lacombe and others (2009) in which fluxes across lateral boundaries of the CMAC model are derived from the NJCP Sharp model. The deep-aquifer-system Baseline Scenario simulates all withdrawals at 2012 full-allocation rates (table 2), which is the same as the full-allocation Scenario 2 of Lacombe and others (2009), except withdrawals are modified at the WWU Rio Grande well field as follows. The full-allocation Rio Grande well field withdrawals in the deep-aquifer-system Baseline Scenario of this study are 388 Mgal/yr for each well (1,164 Mgal/yr total), the same rate as in Scenario 4 of Lacombe and others (2009). Therefore, the deep-aquifer-system Baseline Scenario for this study has characteristics of Scenarios 2 and 4 from Lacombe and others (2009).

Simulated steady-state water levels in the Atlantic City 800-foot sand for the deep-aquifer-system Baseline Scenario (fig. 7) are similar to, but 10-20 ft lower than, those of Scenario 2 of Lacombe and others (2009). Water levels are lower because of upward vertical flow from the Atlantic City 800-foot sand caused by greater withdrawals from the Rio Grande water-bearing zone. In the Rio Grande water-bearing zone, the effects of larger withdrawals from the aquifer are substantial, with deep-aquifer-system Baseline Scenario water levels near the well field as much as 140 ft lower than those for Scenario 2.

Lower Township Scenario

The Lower Township Scenario uses a transient shallow-aquifer-system simulation to examine the effect of proposed full-allocation withdrawals for LTMUA of 1,079 Mgal/yr. This scenario differs from the shallow-aquifer-system Baseline Scenario with: 1) a 2012 full-allocation withdrawal rate of 868 Mgal/yr (table 2) and 2) domestic wells in Lower Township are removed from service when LTMUA expands its public-supply service area. The simulated LTMUA withdrawal rates are increased in decadal steps, reaching the proposed full-allocation rate of 1,079 Mgal/yr during the 2041–50 stress period. LTMUA PW 1 (090052, table 3) is cut back to zero withdrawals in 2021, and LTMUA PW 2 (090054) and PW 3 (090057, now sealed, replaced by LTMUA PW 7, 090617, at the same location) are held at 2003 withdrawal rates during 2003–50. The remaining withdrawals are made from two existing wells, LTMUA PW 6 (090525) and PW 9 (090662), and two hypothetical wells near the airport. One airport well is assigned zero withdrawals during 2011–19, because simulated withdrawals from LTMUA PW 1 (090052) continue through 2019. Well-by-well simulated shallow-aquifer-system withdrawal rates for users that report withdrawals to the NJDEP are shown in table 3.

Lacombe and others (2009) included withdrawals from domestic wells in the shallow-aquifer-system model throughout Cape May County. The depth and location of domestic wells were determined from NJDEP well-permit applications. Domestic withdrawals from the Holly Beach water-bearing zone are simulated as 100-percent consumptive in sewered areas and 50-percent consumptive in areas with on-site septic systems. Domestic withdrawals from the Cohansey aquifer and estuarine sand are 100-percent consumptive for those aquifers. The simulated rates of withdrawals from domestic wells in each municipality are based on estimates of the total self-supply withdrawal rate for that municipality (calculated by multiplying the self-supplied population for that municipality by estimated per-capita water use) divided by the number of known domestic wells in that municipality (according to available NJDEP well-permit applications). LTMUA expects about 4,500 new connections to the public-supply system



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

EXPLANATION

Simulated water-level contour
Shows altitude of simulated water level. Contour interval 5 feet. Datum is North American Vertical Datum of 1988

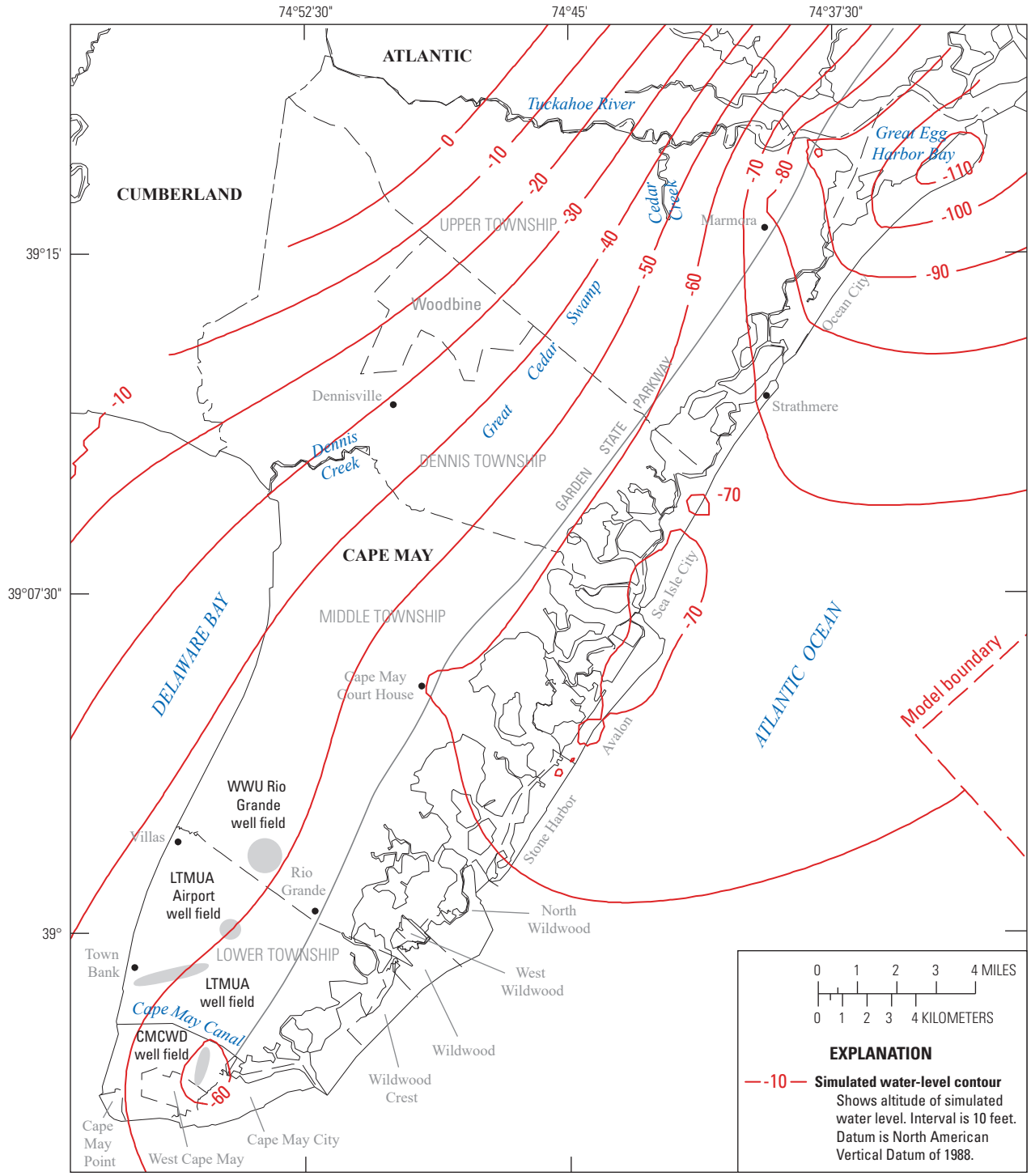
Simulated 250-mg/L isochlor
Shows simulated location of isochlor in 2050

Simulated 50-mg/L isochlor
Shows simulated location of isochlor in 2050

Production well
Withdrawals, in millions of gallons per year

- 4.0 to 49.9
- 50 to 99.9
- 100 to 149.9
- 150 to 249

Figure 6. Simulated water levels, chloride concentrations, and groundwater withdrawals in the Cohansey aquifer in 2050 for the shallow-aquifer-system Baseline Scenario, southern Cape May County, New Jersey.



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

Figure 7. Simulated water levels in the Atlantic City 800-foot sand in 2050 for the deep-aquifer-system Baseline Scenario, Cape May County, New Jersey.

(2,015 in Townbank, 1,770 in Villas, and 750 at the Lake Laurie Campground). Assuming a usage of 270 gallons per day per connection, domestic withdrawals would be reduced by 1.23 Mgal/d. Therefore, the domestic self-supply withdrawal rate in the Lower Township Scenario is 1.23 Mgal/d less than the rate in the shallow aquifer baseline simulation with 50 percent of the reduction occurring during the 2011–20 model stress period and 100 percent thereafter.

Wildwood, Avalon, Cape May Court House, Strathmere, and Combined Scenarios

The Wildwood Scenario using the steady-state deep-aquifer-system coupled CMAC-NJCP Sharp models differs from the deep-aquifer-system Baseline Scenario by shifting withdrawals of two of the three deep-system WWU wells from the Rio Grande water-bearing zone to the Atlantic City 800-foot sand. WWU was granted an increase in allocation and in 2005 installed, two wells designed to be open to the Rio Grande water-bearing zone. Unanticipated local-scale variations in the depth of the confining unit separating the Rio Grande water-bearing zone (also known as the upper Kirkwood Formation) from the underlying Atlantic City 800-foot sand (also known as the lower Kirkwood Formation) resulted in the two new wells being open to the Atlantic City 800-foot sand. The total simulated withdrawals in the Wildwood Scenario are the same as the deep-aquifer-system Baseline Scenario except that the Wildwood Scenario withdrawals from the Rio Grande water-bearing zone are lower and withdrawals from the Atlantic City 800-foot sand are higher than the 2012 full-allocation withdrawals.

For the Avalon, Cape May Court House, and Strathmere Scenarios, coupled NJCP Sharp/CMAC model steady-state simulations are used to evaluate proposed full-allocation withdrawals for Avalon Borough Water Utilities and New Jersey American Water (NJAW) systems in Cape May Court House and Strathmere, respectively (table 2). The proposed rates are higher than 2012 full-allocation rates by 40, 64, and 58 percent, respectively. The simulated withdrawals are from the Atlantic City 800-foot sand. Withdrawal rates for all simulated deep-aquifer-system wells are shown in table 4. The Combined Scenario simulates all of the withdrawals described above for the Wildwood, Avalon, Cape May Court House, and Strathmere Scenarios.

All of the deep-aquifer-system scenarios are steady-state simulations and do not represent changes through time, instead representing conditions with steady withdrawals. Therefore, unlike the shallow-aquifer-system model, there is no specific date at which these full-allocation withdrawal rates and subsequent aquifer responses are reached.

Limitations of the Models

As with all numerical models, many simplifying assumptions and approximations are used in both the shallow-aquifer-system model and the deep-aquifer-system coupled models. Lacombe and others (2009) provide calibration statistics that indicate the simulations are good representations of the flow systems, but these calibrations are not unique; different results might be obtained with different values for hydrologic variables (such as hydraulic conductivity) that produced similar calibration statistics. No new calibrations were performed for this study because the only changes made to the models were adjustments of groundwater-withdrawal rates.

The shallow-aquifer-system model explicitly simulates the movement of variable-concentration/variable-density water. Lacombe and others (2009) did not show chloride concentrations of less than 250 mg/L, and that study predated the collection of data during 2010–12 at the WWU well field showing that chloride concentrations of 50 mg/L in the Cohansey aquifer had reached the well field. The simulated 50-mg/L isochlor in 2010 generated by the shallow-aquifer-system Baseline Scenario is about 3,400 ft from the well field rather than at the well field (fig. 6), yet chloride concentrations of 50 mg/L were detected in WWU Well 28 (090068) in 2010. Therefore, the simulated location of the Lower Township Scenario 50-mg/L isochlor near the Rio Grande well field in 2050 is not as far inland as would be expected at the simulated withdrawal rates. However, the magnitude of the difference between the shallow-aquifer-system Baseline Scenario and Lower Township Scenario 50-mg/L isochlor locations is considered to be relatively accurate, thus the effect of increasing LTMUA's allocation can be determined. The locations of the 50- and 250-mg/L isochlors offshore from the Lower Township well field currently (2018) are not known. The calibration of the shallow-aquifer-system model by Lacombe and others (2009) was based on setting the location of the 250-mg/L isochlor west of LTMUA wells in 1900 that resulted in simulated chloride concentrations near the mouth of Fishing Creek during 1980–2010 similar to measured concentrations. It is possible that the location of the 250-mg/L isochlor in 1900 should have been set closer or farther offshore west of the LTMUA wells and, therefore, that the simulated 250-mg/L isochlor in 2050 would be closer or farther, respectively, from the LTMUA wells in 2050.

The shallow-aquifer-system model does not include fluxes into or out of the model through the confining unit underlying the Cohansey aquifer because Lacombe and others (2009) found that the small changes to the heads and water budget were not important and greatly lengthened the time required for each simulation. Therefore, the effects of changes in allocation for deep-aquifer-system purveyors on the shallow-aquifer system were not simulated.

The deep-aquifer-system coupled CMAC-NJCP model uses simulated fluxes across CMAC model boundaries derived from the NJCP Sharp model (Lacombe and others, 2009). However, the NJCP Sharp model does not include the Rio Grande water-bearing zone so withdrawals from that aquifer are assigned to the Atlantic City 800-foot sand. Therefore, the simulation shifting WWU withdrawals from the Rio Grande water-bearing zone to the Atlantic City 800-foot sand may be limited by the fact that the boundary flows calculated by the NJCP Sharp model for the CMAC model are the same for the Baseline and Wildwood Scenarios. This approach is acceptable because the Rio Grande water-bearing zone is a minor aquifer compared to the Atlantic City 800-foot sand, and weighting of boundary flows from the NJCP Sharp model based on transmissivity reasonably allocates the boundary flows from the regional model (Daryll Pope, U.S. Geological Survey, written commun., 2012).

Simulated Effects of Proposed Groundwater Withdrawals

Lower Township Scenario (table 2) simulated water levels are 1 to 4 ft lower than water levels from the shallow-aquifer-system Baseline Scenario in an area about 3 miles across and approximately centered on the LTMUA airport well field in Lower Township, (fig. 8, table 5). The 50-mg/L isochlor is a maximum of 750 ft farther east in the Lower Township Scenario than in the shallow-aquifer-system Baseline Scenario (fig. 9, table 6) and is 700 ft northwest of the northwestern-most LTMUA airport well PW 9 (090662)). North of Fishing Creek and south and east of the Cape May Canal, the simulated 50- and 250-mg/L isochlor locations in 2050 are unchanged compared to the shallow-aquifer-system Baseline Scenario.

The location of the 50- and 250-mg/L isochlors in the Cohansey aquifer offshore from LTMUA PW 1 (090052) is not known, so the vulnerability of those wells cannot be estimated with confidence. The simulated 50-mg/L isochlor in 2010 is about 3,500 ft west of the WWU Rio Grande well field, but chloride concentrations in water from wells 28, 29, and 34 (090068, 090079, and 090065, respectively) were greater than 50 mg/L at least once during 2010–17 (Ed Cerrone, Wildwood Water Utility, written commun., 2017). Therefore, the actual location of the 50-mg/L isochlor northwest of the LTMUA airport wells may be farther inland than the simulated 50-mg/L isochlor, and those wells could be more vulnerable than shown by the Lower Township Scenario. However, water samples from observation well Cape May F-41 (090213) open to the Cohansey aquifer on the Delaware Bay coastline south of Fishing Creek, had low chloride concentrations (less than 15 mg/L) during 1966–2012. Therefore, it is possible that the more rapid than predicted saltwater intrusion towards the Rio Grande well field is caused by a local aquifer heterogeneity that is not a factor farther to the south and the simulated 50-mg/L isochlor location is accurate west of LTMUA wells.

Table 5. Simulated water levels in the Cohansey aquifer in 2050 near the Lower Township Municipal Utilities Authority and Wildwood Water Utility well fields, Cape May County, New Jersey.

[LTMUA, Lower Township Municipal Utilities Authority; WWU, Wildwood Water Utility]

Scenario	Location of simulated water-level altitude (altitude above NAVD88, in feet)			
	South of canal	LTMUA 1	LTMUA airport	WWU wells
Shallow-aquifer-system Baseline Scenario	–13	–12	–21	–15
Lower Township Scenario	–14	–13	–25	–17

Table 6. Simulated difference in location of the 50-milligram per liter isochlor near the Lower Township Municipal Utilities Authority and Wildwood Water Utility well fields, Cape May County, New Jersey, 2010–50.

[LTMUA, Lower Township Municipal Utilities Authority; WWU, Wildwood Water Utility; mg/L, milligrams per liter]

Scenario	Approximate location where simulated distance the 50 mg/L isochlor moves from 2010 to 2050 is recorded		
	West of WWU well field (feet)	West of airport (feet)	West of LTMUA well 2 (feet)
Shallow-aquifer-system Baseline Scenario	3,300	5,400	3,600
Lower Township Scenario	3,300	6,150	3,800

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

Figure 8. The difference between Lower Township Scenario and shallow-aquifer-system Baseline Scenario simulated water levels in the Cohansey aquifer in 2050, southern Cape May County, New Jersey.

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

EXPLANATION

- **Simulated isochlor** 250 milligrams per liter, Cohansey aquifer, 2050, Baseline Scenario
- **Simulated isochlor** 250 milligrams per liter, Cohansey aquifer, 2050, Lower Township Scenario
- **Simulated isochlor** 50 milligrams per liter, Cohansey aquifer, 2050, Baseline Scenario
- **Simulated isochlor** 50 milligrams per liter, Cohansey aquifer, 2050, Lower Township Scenario
- **Production well** Withdrawals, in millions of gallons per year
  - 4.0 to 49.9
  - 50 to 99.9
  - 100 to 149.9
  - 150 to 249

Figure 9. Lower Township Scenario and shallow-aquifer-system Baseline Scenario simulated isochlors in the Cohansey Aquifer in 2050, southern Cape May County, New Jersey. (WWU, Wildwood Water Utility; LTMUA, Lower Township Municipal Utilities Authority; CMCWD, Cape May City Water Department)

Wildwood Scenario

The WWU 2012 allocation allows withdrawals from the Holly Beach water-bearing zone, the estuarine sand, Cohansey aquifer, and the Rio Grande water-bearing zone (upper Kirkwood Formation). WWU Rio Grande well field wells 46 and 47 (090523 and 090522, respectively), installed in 2003, were intended to be completed in the lower part of the Rio Grande water-bearing zone but were inadvertently screened in the Atlantic City 800-foot sand (lower Kirkwood Formation). Water-level data from a nearby Atlantic City 800-foot sand observation well to the northwest along the Delaware Bay shoreline (Oyster 800 obs, 090306) and two wells to the southeast along the Atlantic Ocean shoreline (Coast Guard 800 obs, 090302 and N. Wildwood 800 obs--090337) show a distinct step-function drop in water levels in summer 2008 after wells Rio Grande 46 and Rio Grande 47 were brought into production (fig. 10). In contrast, water-level-altitude data from a nearby Rio Grande water-bearing zone well (Airport Rio Grande obs, 090304) do not show a similar drop in water levels during the same period (fig. 10), further indicating the withdrawal wells are not open to the Rio Grande water-bearing zone.

The only difference between the Wildwood Scenario and the deep-aquifer-system Baseline Scenario is that, in the Wildwood Scenario, wells Rio Grande 46 and Rio Grande 47 withdraw from the Atlantic City 800-foot sand rather than the Rio Grande water-bearing zone. Simulated Wildwood Scenario water levels in the Atlantic City 800-foot sand are 30–54 ft lower than the deep-aquifer-system Baseline Scenario water levels within about 4,500 ft of the WWU Rio Grande well field and are a maximum of 102 ft below sea level at the well field (fig. 11, table 7). Simulated water-level-differences between the two scenarios in the Atlantic City 800-foot sand are less than 5 ft lower in Woodbine, Upper Township and Ocean City, 5–10 ft lower in southern Dennis Township, northern Middle Township, Avalon Borough, and Sea Isle City, and 20–54 ft lower in southern Middle Township, Lower Township, Cape May City, and the Wildwoods (fig. 11). The maximum difference between the Baseline and Wildwood scenario water levels in the Rio Grande water-bearing zone is +111 ft at the WWU well field and +10–15 ft as far northeast as Cape May Court House and Stone Harbor. The maximum change in the Rio Grande water-bearing zone (+111 ft) is greater than the maximum change in the Atlantic City 800-foot sand (–54 ft) because of the higher transmissivity of the latter aquifer.

Avalon Scenario

The Avalon Scenario simulated an increase in Avalon Borough proposed full-allocation withdrawals from the Atlantic City 800-foot sand of 495 Mgal/yr, a 40-percent increase from the 2012 allocation of 354 Mgal/yr (table 2). The increased withdrawals are distributed among four Atlantic City 800-foot sand production wells at the same ratio as recent withdrawals.

Avalon Scenario simulated water levels (table 7) in the Atlantic City 800-foot sand are 5–8 ft lower than those from the deep-aquifer-system Baseline Scenario in an area approximately corresponding to Avalon Borough limits (fig. 12). Water levels are about 4 ft lower than in the deep-aquifer-system Baseline Scenario at Cape May Court House and about 2 ft lower at the WWU Rio Grande well field and Ocean City.

Court House Scenario

The Court House Scenario simulated proposed full-allocation withdrawals from the Atlantic City 800-foot sand for New Jersey American Water–Cape May Court House are 385 Mgal/yr, a 64-percent increase from the 2012 allocation of 235 Mgal/yr (table 2). The increased withdrawals were distributed among two Atlantic City 800-foot sand production wells at the same ratio as recent withdrawals.

The Court House Scenario simulated Atlantic City 800-foot sand water levels (table 7) are 10 to 12 ft lower than in the deep-aquifer-system Baseline Scenario in the immediate vicinity of the Court House wells. Water levels are 5–10 ft lower in about a 6-mile-diameter circle covering much of Middle Township and centered slightly to the east of the well field (fig. 13). Water levels are about 5 ft lower than those from the deep-aquifer-system Baseline Scenario in Avalon and about 3 ft lower in Ocean City and Cape May City.

Strathmere Scenario

The Strathmere Scenario simulated proposed full-allocation withdrawals from the Atlantic City 800-foot sand of 30 Mgal/yr, a 58-percent increase from the 2012 allocation of 19 Mgal/yr (table 2). The increased withdrawals were distributed among two production wells at the same ratio as recent withdrawals.

Strathmere Scenario simulated water levels (table 7) in the Atlantic City 800-foot sand are less than 2 ft lower than deep-aquifer-system Baseline Scenario water levels at all locations. Water levels are 1 ft lower in Cape May Court House and Ocean City and are less than 1 ft lower south and west of Cape May Court House.

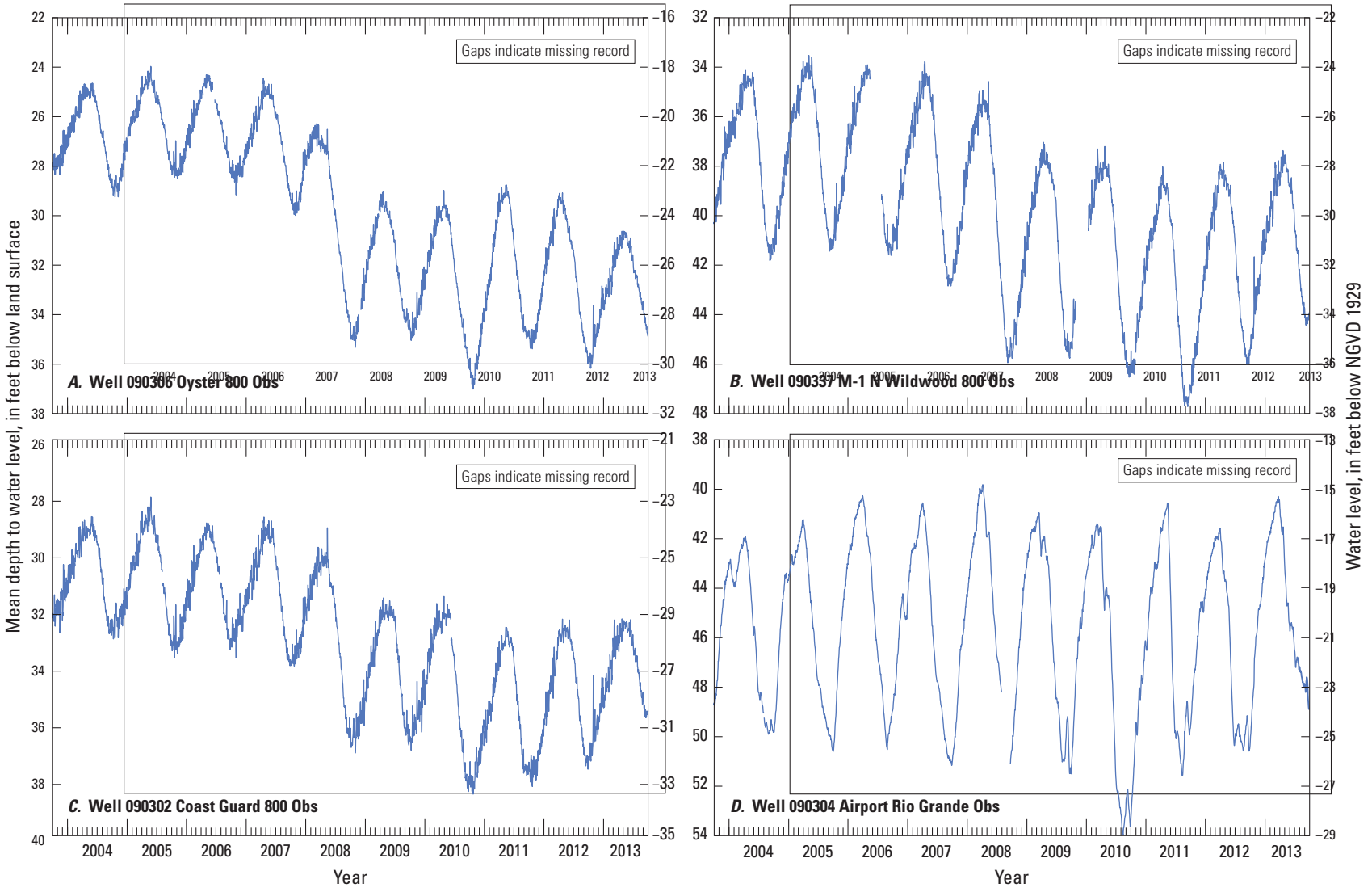
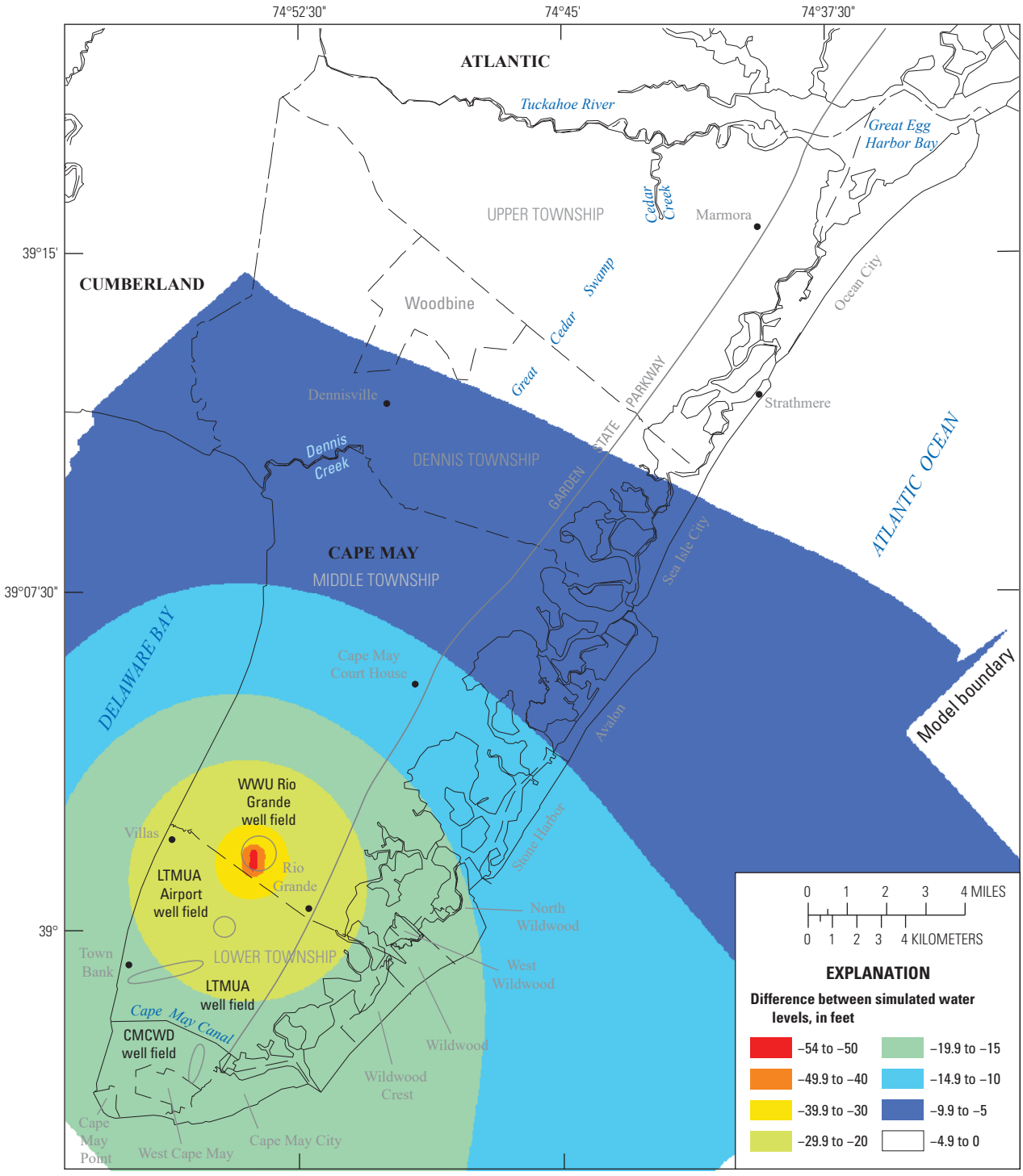


Figure 10. Water levels in three observation wells open to the Atlantic City 800-foot sand (*A*–*C*) and an observation well open to the Rio Grande water bearing zone (*D*), Cape May County, New Jersey, 2004–13.



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

Figure 11. The difference between the Wildwood Scenario and the deep-aquifer-system Baseline Scenario simulated water levels in the Atlantic City 800-foot sand in 2050, Cape May County, New Jersey.

Table 7. Simulated water levels in the Atlantic City 800-foot sand (lower Kirkwood Formation) and Rio Grande water-bearing zone (upper Kirkwood Formation) for the deep-aquifer-system Baseline, Wildwood, Avalon, Court House, Strathmere, and Combined Scenarios, Cape May County, New Jersey, 2050.

[WWU, Wildwood Water Utility; CMCH, Cape May Court House; CMCWD, Cape May City Water Department]

Scenario	Rio Grande water-bearing zone		Atlantic City 800-foot sand						
	WWU well field	Ocean City	Woodbine	Ocean City	Strathmere	Avalon	CMCH	WWU well field	CMCWD well field
Deep-aquifer-system Baseline Scenario	–180	–52	–26	–115	–70	–71	–61	–49	–68
Wildwood Scenario	–69	–50	–30	–118	–74	–79	–72	–102	–86
Avalon Scenario	–181	–54	–28	–117	–73	–78	–65	–51	–70
Court House Scenario	–181	–55	–29	–118	–74	–76	–70	–53	–71
Strathmere Scenario	–180	–53	–27	–116	–72	–71	–62	–49	–68
Combined Scenario	–69	–53	–36	–123	–81	–91	–84	–109	–92

Combined Scenario

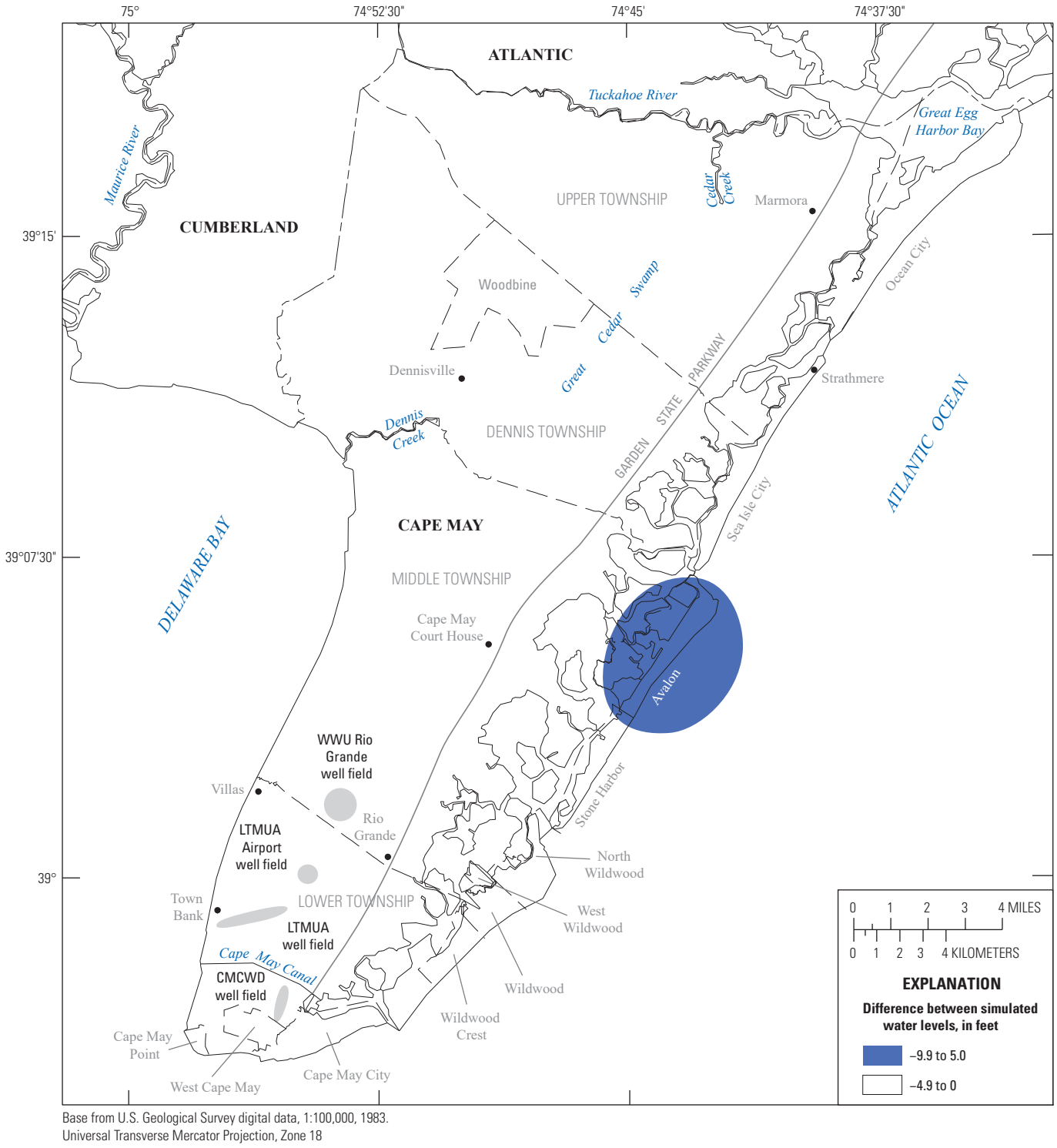
The Combined Scenario simulates a combination of a shift of WWU full-allocation withdrawals of 776 Mgal/yr from in two wells from the Rio Grande water-bearing zone to the Atlantic City 800-foot sand and proposed full-allocation withdrawals from the Atlantic City 800-foot sand by Avalon, Cape May Court House, and Strathmere of 495, 385, and 19 Mgal/yr, respectively (table 2). Because the increase in withdrawals by WWU is more than double the other three combined, the WWU withdrawals have the greatest effect on the results of the Combined Scenario, although effects of the Avalon and Court House withdrawals are also evident (fig. 14).

Combined Scenario simulated water levels (table 7) for the Atlantic City 800-foot sand are 40–61 ft lower than those for the deep-aquifer-system Baseline Scenario in the immediate vicinity of the WWU Rio Grande well field (fig. 14), at least 20 ft lower for the part of the county south of Cape May Court House, 15–20 ft lower in Avalon and northern Middle Township, and 5–15 ft lower in the part of the county north of Middle Township (fig. 14).

Summary and Conclusions

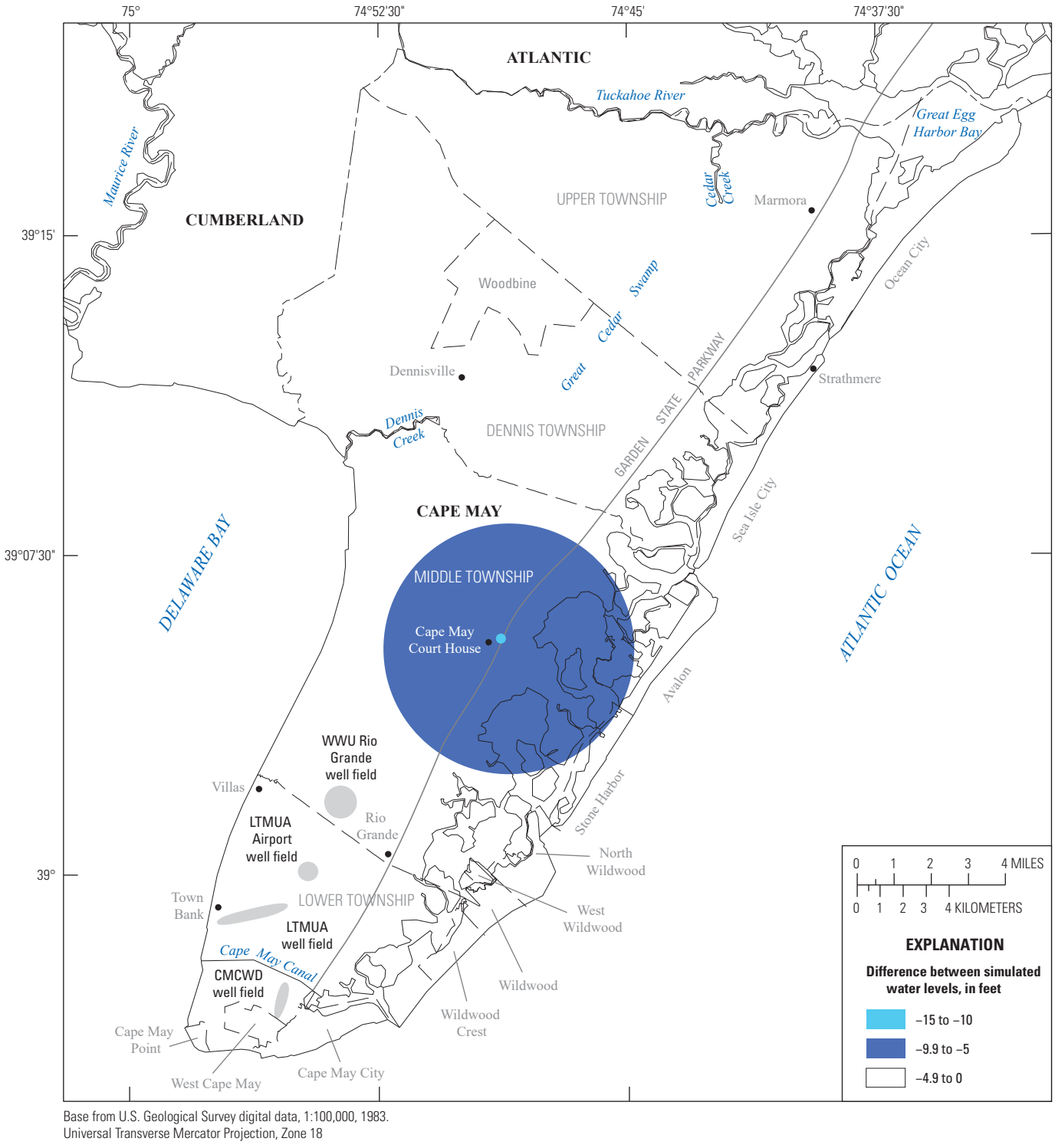
Several water purveyors in Cape May County requested changes to their allocation permits from the New Jersey Department of Environmental Protection (NJDEP). The U.S. Geological Survey, in cooperation with the NJDEP, simulated six water-supply scenarios to determine the effects of proposed full-allocation withdrawals on water levels and saltwater intrusion in the Cohansey aquifer and water levels in the Rio Grande water-bearing zone (upper Kirkwood Formation) and the Atlantic City 800-foot sand (lower Kirkwood Formation).

The Lower Township Scenario simulates effects on water levels and saltwater intrusion in the Cohansey aquifer with proposed full-allocation withdrawals of 1,079 Mgal/yr from the Cohansey aquifer for Lower Township Municipal Utilities Authority (LTMUA), 211 Mgal/yr (24 percent) greater than the 2012 full-allocation withdrawals. The effects of proposed full-allocation withdrawals on water levels and saltwater intrusion are simulated with a shallow aquifer system variable-density groundwater-flow model developed by Lacombe and others (2009). The Lower Township Scenario simulated water levels are 2–4 feet (ft) lower than shallow-aquifer-system Baseline Scenario simulated water levels in an area about 3 miles across, centered approximately on LTMUA withdrawal wells near the airport. The simulated 250-milligram per liter (mg/L) isochlor is a maximum of 750 ft farther east in the Lower Township Scenario than in the shallow-aquifer-system Baseline Scenario. Groundwater with chloride concentrations of 50 mg/L is simulated to be 700 ft northwest of the northwestern-most LTMUA well at the airport in 2050. North of Fishing Creek and south and east of the Cape May Canal, the simulated 250-mg/L isochlor is unchanged in the Lower Township Scenario compared to the shallow-aquifer-system Baseline Scenario. The current (2018) location of the 50-mg/L isochlor in the Cohansey aquifer offshore from LTMUA PW 1 (090052) and PW 2 (090054) is not known, so the accuracy of the simulated 50-mg/L isochlor location near those wells cannot be verified. Although chloride concentrations greater than 50 mg/L have been measured in water from several wells in the Wildwood Water Utility (WWU) Rio Grande well field, the simulated 50-mg/L isochlor had not reached the well



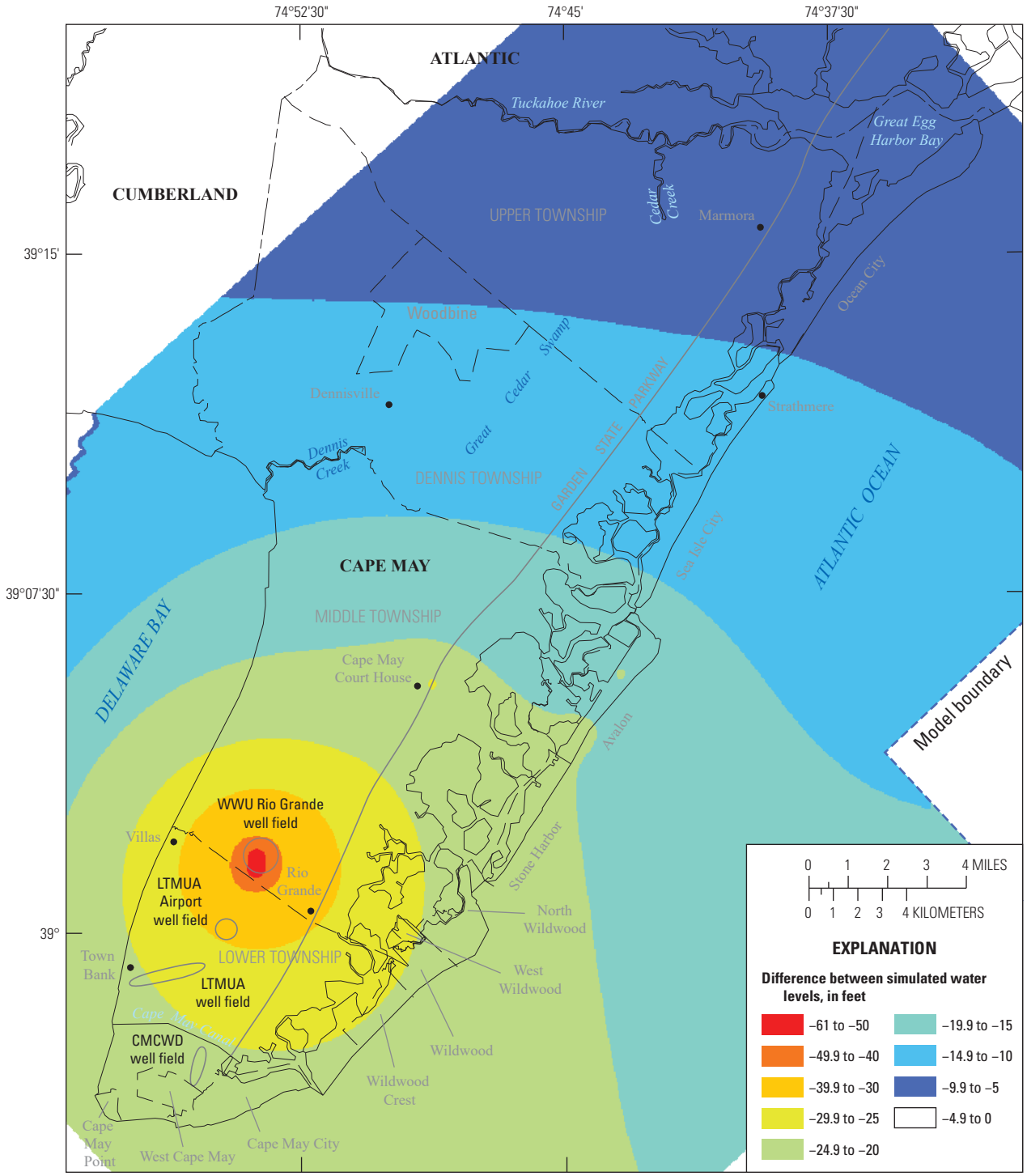
Base from U.S. Geological Survey digital data, 1:100,000, 1983.
Universal Transverse Mercator Projection, Zone 18

Figure 12. The difference between Avalon Scenario and deep-aquifer-system Baseline Scenario simulated water levels in the Atlantic City 800-foot sand in 2050, Cape May County, New Jersey.



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

Figure 13. The difference between Court House Scenario and deep-aquifer-system Baseline Scenario simulated water levels in the Atlantic City 800-foot sand in 2050, Cape May County, New Jersey.



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

Figure 14. The difference between Combined Scenario and deep-aquifer-system Baseline Scenario simulated water levels in the Atlantic City 800-foot sand in 2050, Cape May County, New Jersey.

field as of 2010. Therefore, the actual location of saline water northwest of the LTMUA airport wells might be closer than the simulated location.

Two production wells installed at the WWU Rio Grande well field that were intended to be open to the Rio Grande water-bearing zone (upper Kirkwood Formation) were later determined to be open to the Atlantic City 800-foot sand (lower Kirkwood Formation). The Wildwood Scenario simulation of withdrawals of 776 Mgal/yr from the two wells shows simulated water levels in the Atlantic City 800-foot sand to be 15–54 ft lower than the deep-aquifer-system Baseline Scenario in southern Middle Township, Lower Township, the Wildwoods, and Cape May City, 5–10 ft lower in southern Dennis Township, northern Middle Township, Avalon, and Sea Isle City, and less than 5 ft in Woodbine, Upper Township, and Ocean City.

The Avalon Scenario simulated proposed full-allocation withdrawals for Avalon Borough of 495 Mgal/yr, which is 141 Mgal/yr (40 percent) higher than 2012 full-allocation withdrawals from the Atlantic City 800-foot sand, the sole potable aquifer underlying Avalon. Water levels for the Avalon Scenario are 5 to 7 ft lower than those for the deep-aquifer-system Baseline Scenario within the Avalon Borough boundary and less than 5 ft lower beyond the borough.

The Court House Scenario proposed simulated full-allocation withdrawals for New Jersey American Water–Cape May Court House of 385 Mgal/yr, which is 150 Mgal/yr (64 percent) higher than 2012 full-allocation withdrawals. The Court House Scenario simulated water levels in the Atlantic City 800-foot sand are 10–12 ft lower than those for the deep-aquifer-system Baseline Scenario at the wells and 5–12 ft lower over a circular area about 6 miles in diameter approximately centered on the Court House wells. Water-levels are about 3–5 ft lower than the deep-aquifer-system Baseline Scenario in Avalon, Ocean City, and Cape May City.

The Strathmere Scenario simulated proposed full-allocation withdrawals for New Jersey American Water–Strathmere of 30 Mgal/yr, which is 11 Mgal/yr (58 percent) higher than 2012 full-allocation withdrawals. The Strathmere Scenario simulated water levels are less than 2 ft lower than those for the deep-aquifer-system Baseline Scenario in Strathmere, about 1 ft lower in Cape May Court House and Ocean City, and essentially unchanged south and west of Cape May Court House.

The Combined Scenario simulates withdrawals from the Atlantic City 800-foot sand by Wildwood, Avalon, Cape May Court House, and Strathmere of 776, 495, 385, and 30 Mgal/yr, respectively. Compared to the Baseline Scenario, the simulated water levels in the vicinity of the WWU Rio Grande well field are 40–60 ft lower, more than 20 ft lower south of Cape May Court House, and 5–15 ft lower north of Middle Township.

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For additional information, contact:

Director, New Jersey Water Science Center
U.S. Geological Survey
3450 Princeton Pike, Suite 110
Lawrenceville, NJ 08648

Or visit our website at: https://www.usgs.gov/centers/nj-water

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