ARTIFICIAL RECHARGE OF GROUND WATER BY WELL INJECTION FOR STORAGE AND RECOVERY, CAPE MAY COUNTY, NEW JERSEY, 1958-92

By Pierre J. Lacombe

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNIT

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
gallon (gal)	0.1337	cubic foot
gallon per minute (gal/min)	1,440	gallon per day
million gallons per day (Mgal/d)	3,785	cubic meters per day
million gallons per year (Mgal/yr)	3,785	cubic meters per year

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

Abbreviated water-quality unit used in this report:
mg/L (milligram per liter)

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ABSTRACT

Artificial recharge is used for storage and recovery of ground water in the estuarine sand and Cohansey aquifers in southern Cape May County and in the Kirkwood-Cohansey aquifer system in northern Cape May County, New Jersey.

Wildwood Water Utility has injected ground water for public-supply storage since 1967 and in 1992 operated four injection wells. The storage and recovery program began as a way to ensure an adequate supply of water during the summer tourist season. From 1967 through 1992, about 3.8 billion gallons was injected and about 3.3 billion gallons (about 85 percent of the injected water) was recovered.

An electric company has injected ground water for industrial-supply storage since 1965 and in 1992 operated one injection well. The purpose of the storage and recovery program is to prevent saltwater encroachment and to ensure sufficient supply during times of peak demand. From 1967 through 1988 the company injected 100.1 million gallons and withdrew 60.6 million gallons, or 61 percent of the injected water.

INTRODUCTION

In 1958, a consultant hired by the managers of Wildwood Water Utility, Cape May County, N.J. (fig. 1), investigated the effectiveness of artificial recharge of ground water by well injection for storage and recovery as a practical solution to the summer water-supply shortage of the Wildwood communities (Schultes, 1959). At that time, Wildwood's public water supply was withdrawn from about 10 to 13 wells located 4.5 mi northwest of the communities, and was supplemented by water from 2 wells located on the barrier islands. Average water demand during the 3 summer months in 1958 ranged from 6 to 7 Mgal/d and hourly peak water demand ranged from 10 to 12 Mgal/d. To meet the large water demand of the Wildwood communities during the 3-month summer tourist season, 10 to 15 wells, a large pumping facility, and large transmission lines were needed. The massive water-supply system, which is critical to the economic viability of the Wildwood communities, and the health of its residents, would be unused, for the most part, about 9 months of the year. Schultes (1959) suggested that a practical and economical solution was to design a well field, pumping facility, and transmission line from the well field to the Wildwood communities so that water could be pumped throughout the year and transmitted to the island wells to be stored until needed during the summer. By analyzing the annual and seasonal water budgets of the Wildwood communities, Schultes calculated that storage of 200 Mgal/yr of water on the island would eliminate a large part of the summer water-supply problems. Schultes determined that the only practical place to store this large volume of water was underground, in the aquifers.

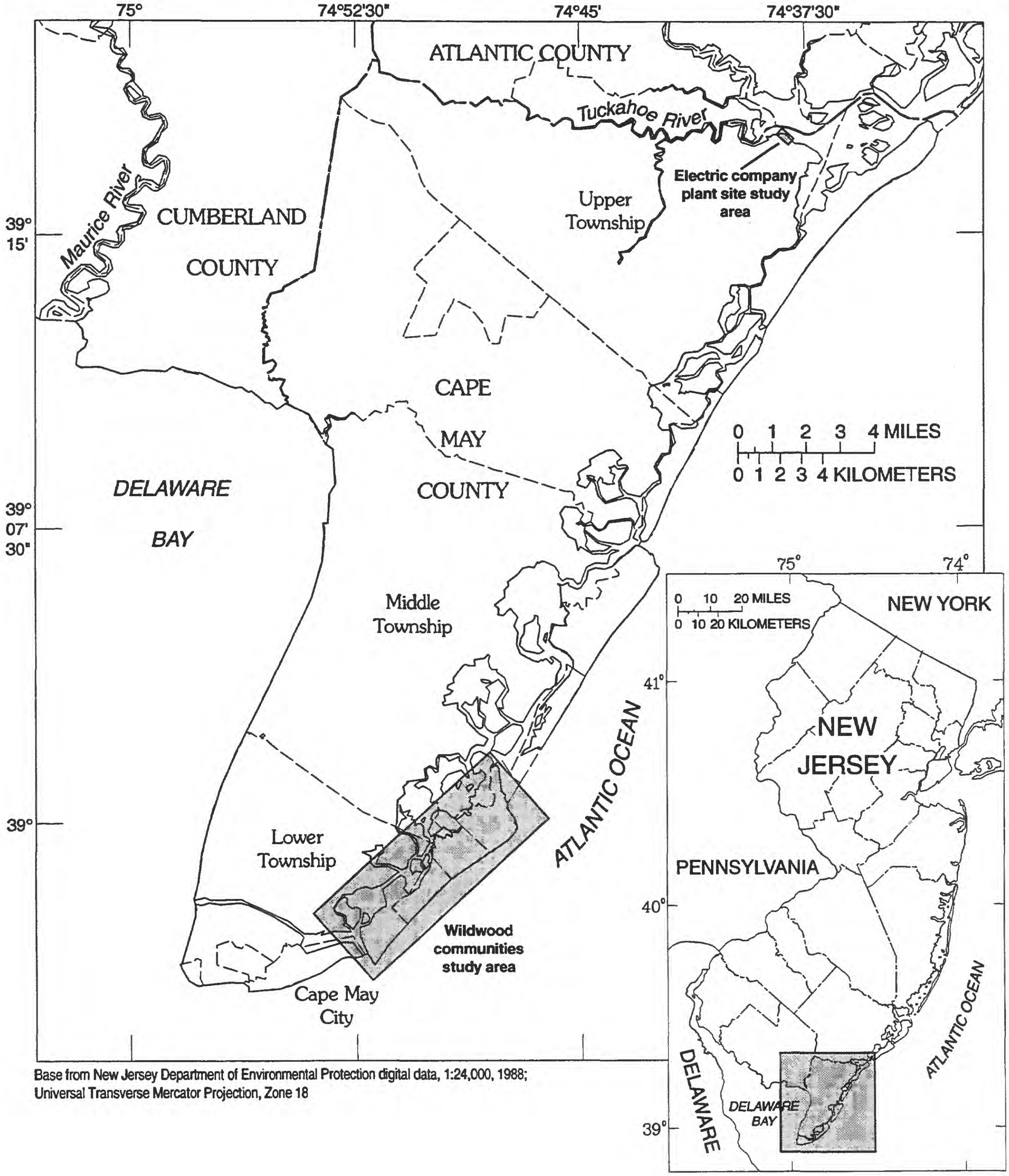

Figure 1. Location of the study areas, Cape May County, New Jersey.

In 1967, Wildwood Water Utility began artificial recharge on a regular basis. The water utility has operated six recharge wells but has abandoned two of them because an abandoned supply well near one recharge well provided a conduit for the recharge water to escape to land surface during injection, and a casing or screen failed in the second well. The Wildwood Water Utility injected 3,849 Mgal of water and recovered 3,286 Mgal, or 85 percent of the injected water, during 1967-92.

In 1965, the Atlantic Electric Company[1] began artificial recharge for storage and recovery at the B.L. England Electric Generating Plant in Upper Township (fig. 1). During the first year of injection (1965), the electric company reported injecting 19.331 Mgal; during 1967-88, from 1.406 to 9.031 Mgal/yr was stored. About 100.144 Mgal of water has been stored since injection began and 60.6 Mgal, or 61 percent of the stored water has been recovered.

During 1989-92, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corp of Engineers (COE), the New Jersey Department of Environmental Protection (NJDEP), and the Cape May County Planning Board, conducted a study to determine the effects of artificial recharge for storage and recovery on ground-water levels and water quality in Cape May County, New Jersey.

Purpose and Scope

This report describes the programs of artificial recharge by well injection for storage and recovery that were developed by Wildwood Water Utility and Atlantic Electric Company. Methods of injection and recovery and changes in ground-water levels and water quality that result from the injection and recovery program are described. Maps are included to show the locations of injection wells and changes in water levels. Tables are included to show monthly and annual rates of injection and recovery. The hydrostratigraphy of the aquifers used for storage is illustrated and calculations of the extent of the aquifer that is affected by the injection of water are included.

Location and Hydrostratigraphy of the Study Area

The Wildwood Water Utility injection-recovery wells are located on the barrier island of Five Mile Beach in the municipalities of North Wildwood, Wildwood City, Wildwood Crest, and Lower Township (fig. 2). Section A-A' (fig. 3) shows the hydrostratigraphy of the aquifers and confining units underlying the Wildwood communities and vicinity on Five Mile Beach. The section is interpreted from geophysical and driller's logs of wells and boreholes on the island. The hydraulic characteristics of the aquifers and confining units are described in Gill (1962) and Zapecza (1989). The data on screen intervals of the injection-recovery wells were obtained from well records on file at the NJDEP office in Trenton, N.J.

The Atlantic Electric Company B.L. England Electric Generating Plant is located on about 70 acres in Upper Township, Cape May County (fig. 1). The locations of the plant site, injection-recovery wells, industrial-supply wells, and section B-B' are shown in figure 4. Section B-B' (fig. 5) shows the hydrostratigraphy beneath the plant site. The section is

[1] The use of firm names in this report is for identification purposes only and does not impute responsibility for any past, present, or potential effect on water resources in the study area.

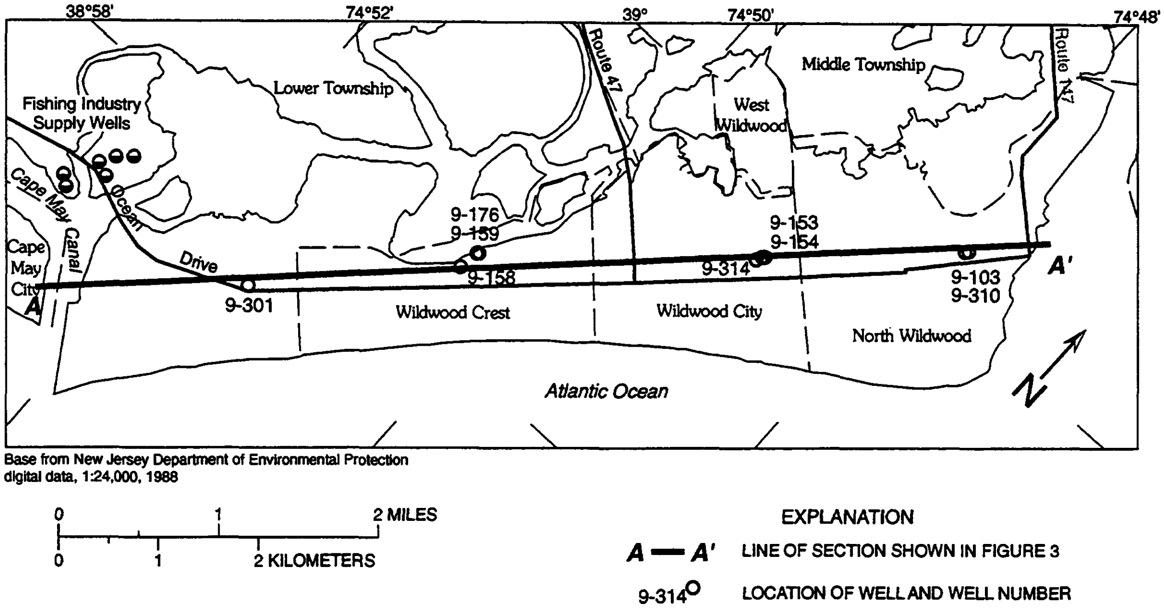

Figure 2. Wildwood communities study area on Five Mile Beach showing the locations of section A-A', injection-recovery wells, and selected operating and abandoned supply wells.

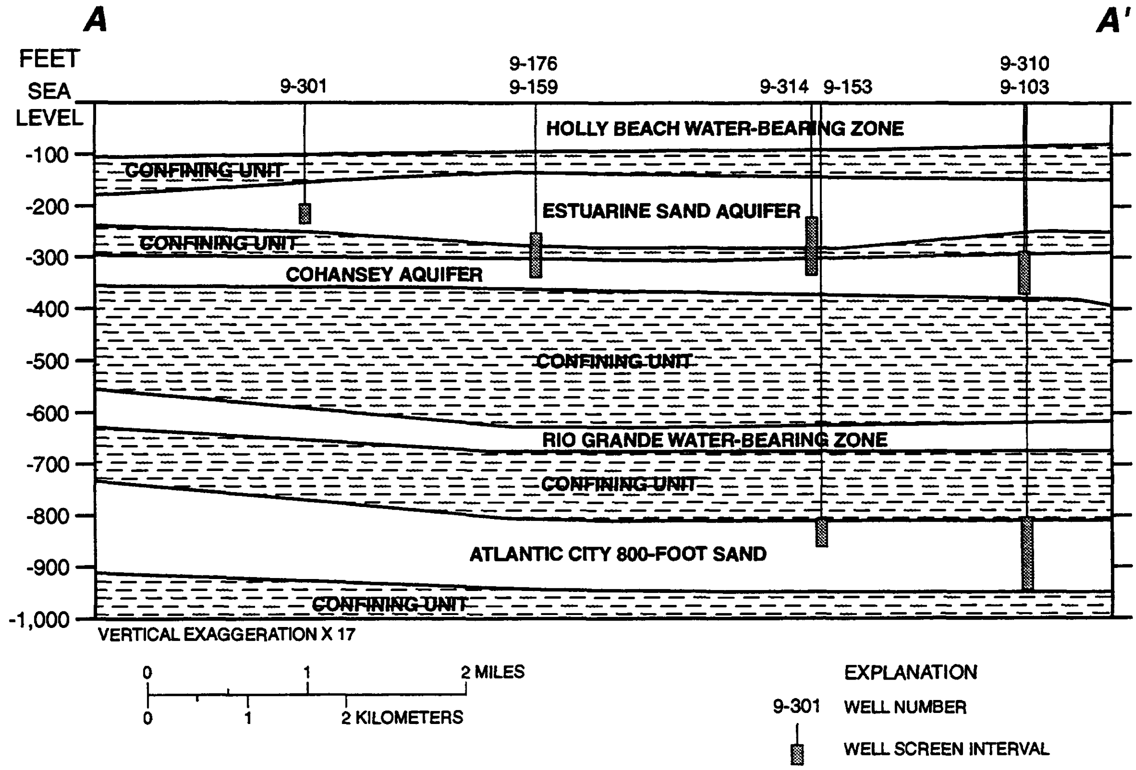

Figure 3. Generalized hydrostratigraphy along section A-A' and the locations of the screen intervals of the injection-recovery wells in the Wildwood communities.

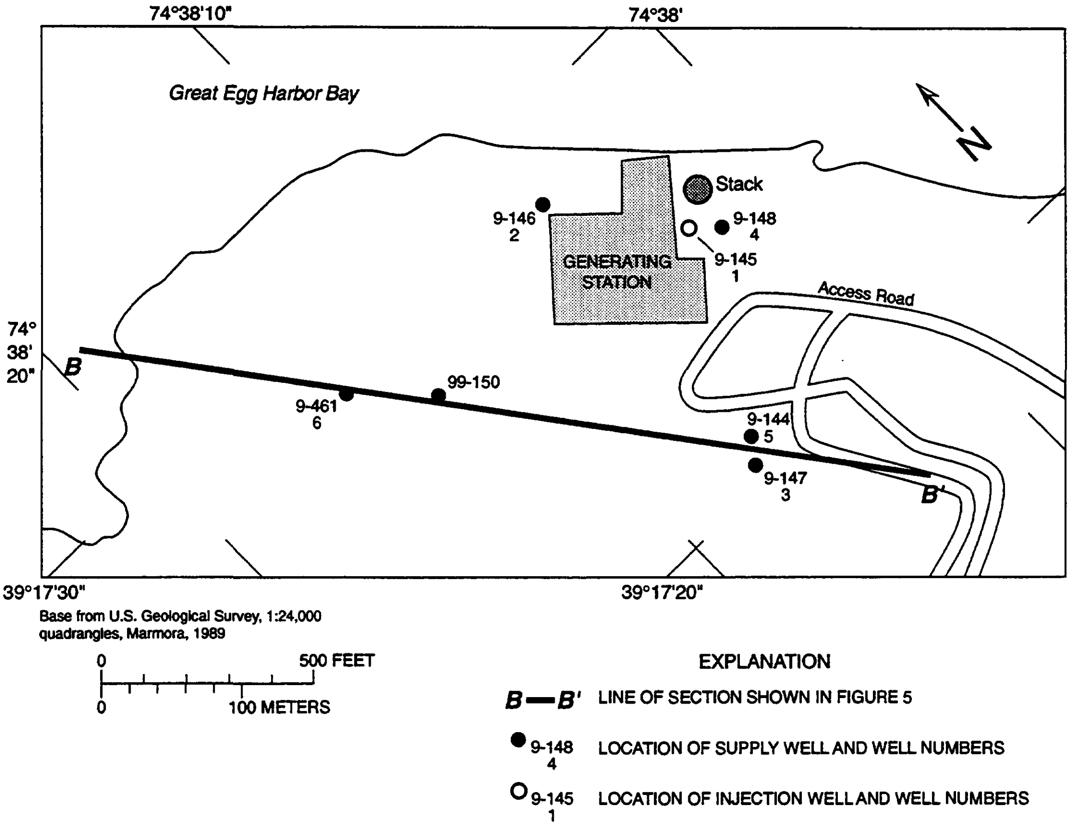

Figure 4. Electric comapany plant site in Upper Township showing the locations of section B-B', the injection-recovery well, and the industrial-supply wells.

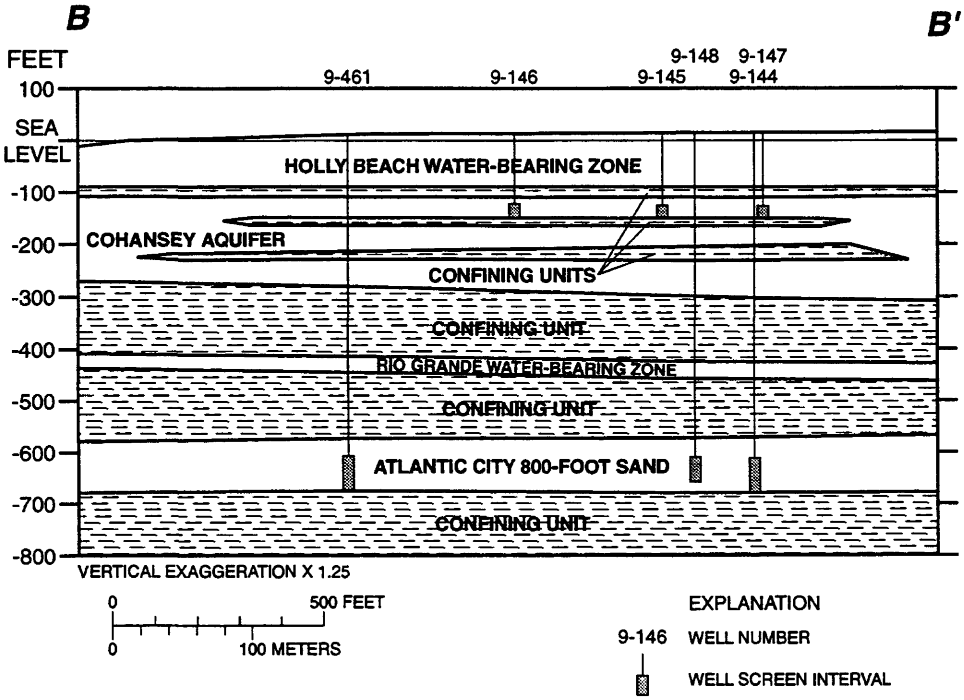

Figure 5. Generalized hydrostratigraphy along section B-B' and the locations of the screen interval of the injection-recovery well and industrial-supply wells at the electric company plant site.

interpreted from geophysical and drillers' logs of supply wells located at the plant. Data on the screen intervals of the injection-recovery and supply wells were obtained from well records on file at the NJDEP office in Trenton, N.J.

Previous Studies

Schultes (1959) conducted the first water-budget and system analyses and the first test of artificial recharge for storage and recovery at the Wildwood Water Utility. The test was run during an 8-day period in December 1958, and approximately 231,300 gallons of water was injected and withdrawn. Water-quality and injection-pressure analyses were conducted during the test. Atlantic Electric Company developed the artificial-recharge program with the assistance of the NJDEP.

Geraghty and Miller, Inc. (1971), O'Hare and others (1986), Hydrologic Engineering Center (1984), and Epstein (1988) note that Wildwood Water Utility has injection wells for artificial recharge for storage and recovery but provides no details or data about the system. May (1985) discusses the feasibility of artificial recharge into the deep aquifers in the Atlantic City, N.J., area. Aronson (1978), Aronson and Beyth (1980) and Vecchioli and others (1980) investigated artificial recharge of wastewater and storm runoff through shallow wells into Coastal Plain sediments on Long Island, N.Y. Fleming and Speitel (1980) and Sniegocki and others (1965) describe several studies of artificial recharge by use of pressure recharge systems that are similar to the systems used in the Wildwood communities and at the electric plant.

Well-Numbering System

The well-numbering system in this report has been used by the USGS, New Jersey District, since 1978. The well number consists of a county code (9 for Cape May County) and a sequence number assigned to each recorded well within the county. A representative well number is 9-159 for the 159th well inventoried by the USGS in the county.

Acknowledgments

The author thanks Earl "Bud" Moyer, Thurmon Thompson, Gregory Lanze, and Eugene Comisky of the Wildwood Water Utility and Norris Justic and Wayne Adamson of Atlantic Electric Company for information on operations at, and tours of, their storage and recovery facilities.

ARTIFICIAL RECHARGE BY WELL INJECTION FOR STORAGE AND RECOVERY

Artificial recharge by well injection for storage and recovery is the technique whereby freshwater is pumped into an aquifer through a well, is stored in the aquifer material, and ultimately is recovered from the aquifer by pumping it out through the same well or a nearby well. Since the mid-1960's, Wildwood Water Utility and Atlantic Electric Company have injected water into aquifers beneath Cape May County as a means of artificial recharge for storage and recovery. Wildwood Water Utility began ground-water injection in 1967 to store water for use during the summer tourist season. In 1965, Atlantic Electric Company began ground-water injection to store water beneath the electric generating plant in Upper Township for use during peak demand times.

Storage and recovery data, well-construction data, and historical information concerning methods and problems of injection and recovery were collected from records of the NJDEP. Well-construction data are stored in the USGS Ground Water Site Inventory data base and injection and recovery data are stored in the USGS State Water Use Data System data base. Information about the daily operations of the storage and recovery system and water-quality data were obtained from Wildwood Water Utility and Atlantic Electric Company. Wells used for artificial recharge and recovery and supply wells are described in table 1. Monthly and annual injection and recovery data for the Wildwood Water Utility beginning in 1967 and for the Atlantic Electric Company beginning in 1965 are listed in tables 2 and 7.

Wildwood Water Utility

Wildwood Water Utility serves the municipalities of North Wildwood, West Wildwood, Wildwood, and Wildwood Crest, as well as the part of Lower Township on the barrier island of Five Mile Beach (fig. 2). The water utility also serves some of the businesses and residences in southern Middle Township (fig. 1). The water utility obtains its water from 10 wells in southern Middle Township (fig. 1).

History of Storage and Recovery Program

In 1894, Wildwood Water Utility drilled the first public-supply well (9-153) on the barrier island of Five Mile Beach (fig. 2). By 1910, two or possibly three additional supply wells had been drilled in the North Wildwood area, but the utility did not use the wells extensively because of high concentrations of chloride in the water. It appears that the utility determined at the time that it could not supply the large volume of freshwater needed by their communities during the summer. In 1910, Wildwood Water Utility installed about 10 supply wells on the mainland, 4.5 mi northwest of Five Mile Beach in southern Middle Township (fig. 1). The utility used the wells on the mainland for water supply but maintained the island supply wells for use during the summer peak demand and fire emergencies. Water containing high concentrations of chloride from the island wells was blended with freshwater from the mainland wells before it was allowed to enter the water-supply distribution system. In 1926, Wildwood Water Utility installed two additional wells on the island for use during periods of peak demand. Water from the well in Wildwood Crest (9-158) had a chloride concentration of 340 mg/L; therefore, it was abandoned in 1927. Water from the well in Wildwood City (9-154) had water with a chloride concentration of 130 mg/L, and this water was blended into the system. By 1936, the utility had abandoned the supply wells in North Wildwood, possibly because of the high concentrations of chloride or iron. Thereafter, the water supply was derived primarily from the mainland wells and was augmented at times of peak demand in the summer with water from the two supply wells in Wildwood City (9-153 and 9-154).

During summers in the late 1950's, Wildwood Water Utility occasionally exceeded the 5.0 Mgal/d withdrawal allotment permitted by the NJDEP (Schultes, 1959). In June 1958, a 20-in.-long break was found in the 4.5-mi transmission line that carried water from the mainland

Table 1. Records of wells used for injection and recovery and other selected wells

[SS, stainless steel; PVC, polyvinyl chloride; ESRNS, estuarine sand aquifer; CNSY, Cohansey aquifer; KRKDL, Atlantic City 800-foot sand; N/A, not applicable; --, data not available; ~, about; USGS, U.S. Geological Survey; present is 1992]

Injection-well number	USGS well number	Local name	Location	Screen: Interval (feet)	Screen: [1]Length (feet)	Screen: Diameter (inches)	Screen: Material	Screen: Slot size (inches)	Borehole diameter (inches)	Aquifer	Period of use
				Wildwood Water Utility injection and recovery wells							
1	9-159	35	Wildwood Crest	249-360	70	12	SS	0.060	--	ESRNS-CNSY	1967-1977
2	9-103	39	North Wildwood	807-969	105	12	SS	.030	32	KRKDL	1970-1985
3	9-176	35A	Wildwood Crest	251-338	51	12	SS	.045	36	ESRNS-CNSY	1978-present
4	9-314	3	Wildwood City	212-328	94	12	SS	.045	36	ESRNS-CNSY	1982-present
5	9-301	44	Lower Township	190-245	55	12	PVC	--	--	ESRNS	1985-present
6	9-310	39A	North Wildwood	279-357	73	12	SS	.045	36	CNSY	1986-present
				Wildwood Water Utility island supply wells							
Test	9-153	1	Wildwood City	887-931	44	3	--	--	--	KRKDL	1894-~1970
N/A	9-154	2	Wildwood City	293-354	61	8	--	--	--	CNSY	1926-~1970
N/A	9-158	old well	Wildwood Crest	810-937	100	6	--	--	--	KRKDL	1926-1927
				Atlantic Electric Company injection and recovery well							
1	9-145	1	Upper Township	130-150	20	--	--	--	--	CNSY	1961-present
				Atlantic Electric Company industrial-supply wells							
N/A	9-146	2	Upper Township	100-120	20	--	--	--	--	CNSY	1961-1962
N/A	9-147	3	Upper Township	125-145	20	--	--	--	--	CNSY	1962-1964
N/A	9-148	4	Upper Township	645-675	30	--	--	--	--	KRKDL	1964-present
N/A	9-144	5	Upper Township	650-690	40	--	--	--	--	KRKDL	1975-present
N/A	9-461	6	Upper Township	639-710	71	8	SS	.045	26	KRKDL	1992-present

[1]Screen length is shorter than screen interval in some wells because blanks were installed in the screen interval.

wells to the island communities. The line could not be shut down at the time because the water demand was high (Schultes, 1959). Schultes conducted an analysis of the utility's system -- particularly the seasonal water demand, water-supply source area, water-distribution area, and delivery system. He pointed out that the utility withdrew water from 10 wells on the mainland and pumped it through a 4.5-mi transmission line at the summer peak demand rate of 10 to 12 Mgal/d, which overloaded the transmission line. He speculated that another break would leave the island communities with little or no water for public use or to fight fires. Schultes contrasted the large summer demand that was needed for less than 3 months to the small non-summer demand that was needed for about 9 months. He noted that winter water demand was 1 to 2 Mgal/d and the winter hourly peak demand was equivalent to 2 to 3 Mgal/d. Schultes suggested that a new transmission line with additional pumping facilities would be needed at the mainland well field.

Schultes also recommended that the utility consider ground-water storage by injection on the barrier island because of the seasonal fluctuation in water demand and in use of the mainland facilities. He analyzed the monthly and annual water budget of the service area and suggested that by storing 50 percent of the summer demand during the off-season and recovering it when needed would reduce the summer load on the pumping station and transmission line by 50 percent. Schultes provided calculations to show that three wells, each injecting water at a rate of 200 gal/min, could supply 50 percent of the water that was used in summer 1958. He itemized the economic and hydrologic components of a seasonally based storage and recovery plan to demonstrate its viability. Schultes concluded his report by citing the methods used in and the results of an 8-day injection test and a 2-day recovery test conducted at a supply well (9-153) in Wildwood City.

In 1964, the NJDEP initially approved further investigation and tests of underground storage to solve the water problems of the area (A.B. Cyphers, N.J. Bureau of Water Resources, written commun., 1964). In 1966, Wildwood Water Utility's application for additional withdrawals was approved by the NJDEP (A.B. Cyphers, witten commun., 1966) with the following condition:

> Condition 16: In recognition of need for additional capacity to meet peak daily demand the applicant is hereby authorized to utilize one or more recharge wells in any of the water bearing formations and at any available location on the island for off-peak recharge and storage of fresh water for withdrawal during the said peak demand. (NJDEP, written commun., 1964)

In 1967, the NJDEP authorized the drilling of a 1,110-ft exploratory borehole that was developed as Injection Well 1 (9-159) with an estimated recharge rate of 1,000 gal/min. The well was drilled in Wildwood Crest and the 70-ft screen was placed in the estuarine sand and Cohansey aquifers (fig. 3). Water was injected into the well at rates ranging from 9 to 14 Mgal/mo (220 to 340 gal/min) from 1968 through 1976.[2] In 1977, water began to flow out of the ground under a utility building about 20 ft north of Injection Well 1, and the injection well

[2] To convert Mgal/mo to gal/min, the author assumed that a month is 30 days and that injection occurs for 23 hours per day. This allows for a 1-hour "shutdown" period each day for well maintenance.

was abandoned. In 1990, after studying a map of the well site prepared in the 1930's, the USGS and utility personnel determined that Injection Well 1 was located about 20 ft south of an old supply well (9-158) that was drilled in 1926, abandoned, and reportedly sealed in 1927. The injected water probably flowed from the well screen of Injection Well 1 (9-159) through the aquifer material and continued up either the ungrouted annular space outside the casing of well 9-158 or flowed into the casing of well 9-158 at a point of corrosion or at a casing joint and then up the inside of the well.

In 1970, the utility installed Injection Well 2 (9-103) in North Wildwood, and the 105-ft screen was placed in the Atlantic City 800-foot sand. From 1971 to 1976 water was injected into the well at a rate ranging from about 10 to 12 Mgal/mo (240 to 290 gal/min). From 1978 to 1984 injection decreased because of progressive screen clogging, and ranged from 4 to 8 Mgal/mo (90 to 195 gal/min). In 1985, a large quantity of sand was being withdrawn during water recovery, and the sand was destroying the pump. Because utility personnel believed the source of the sand was the supply water, they installed a filter to remove the sand from the supply water before injection, but the problem continued. The well was televiewed in 1985 to determine if a crack in the casing or screen was allowing sand to flow into the well, but no crack was found. The well was abandoned and sealed to land surface with cement. (Thurmon Thompson, Assistant Water Superintendent, Wildwood Water Utility, oral commun., 1990.)

In 1978, the utility installed Injection Well 3 (9-176) in Wildwood Crest about 30 ft from Injection Well 1 (9-159). The well's 51-ft-long screen was placed at about the same altitude as the screen of Injection Well 1. Water was injected into the well at rates that typically ranged from about 5 to 9 Mgal/mo (120 to 220 gal/min). Injection Well 3 is about 25 ft from the abandoned old well (9-158) drilled in 1926. In 1992, no evidence of upwelling of ground water near the abandoned old well (9-158) was observed when injection was occurring.

In 1982, the utility installed Injection Well 4 (9-314) in Wildwood, and a 94-ft screen was placed in the estuarine sand and Cohansey aquifers. Water is injected into the well at rates ranging from about 7 to 10 Mgal/mo (170 to 240 gal/min). The well was still active in 1992.

In 1986, the utility installed Injection Well 5 (9-301) in Lower Township, and a 55-ft screen was placed in the estuarine sand aquifer. Injection rates typically range from 3 to 8 Mgal/mo (75 to 195 gal/min). The well was still active in 1992.

In 1987, the utility installed Injection Well 6 (9-310) in North Wildwood, about 10 ft from the abandoned and sealed Injection Well 2 (9-103). The 73-ft screen was placed in the Cohansey aquifer and water is injected at rates that typically range from 5 to 8 Mgal/mo (120 to 195 gal/min).

Operation of Injection-Recovery Wells

The following description of the yearly operation of the injection-recovery wells is based on numerous conversations with Earl Moyer, Thurmon Thompson, and Eugene Comisky of the Wildwood Water Utility and an inspection of the utility's injection wells. From mid-September until mid-May, each well is used as an injection well for storage. From mid-May to mid-September, each well is used primarily as a ground-water withdrawal well for recovery of the stored water. During fall, winter, and spring, chlorinated water from the mainland well field is piped to the injection wells through the transmission lines, and then passes through a set of check valves, which adjust the line pressure optimally to 16 psi (pounds per square inch), or about 72 to 290 gal/min, depending on the well-construction characteristics (screen length, borehole diameter, and gravel pack) and aquifer characteristics (hydraulic conductivity and porosity). Each morning during fall, winter, and spring, injection is stopped and the pump is turned on to backflush the well screen. All of the backflushed water is discarded. During the first 2 min of backflushing, the water is clear; then, for the next 3 to 4 min, the water is red as a result of the removal of rust buildup in the screen, gravel pack, and aquifer material. After 6 to 8 min, the water becomes clear again. The pump is shut off for about 1 min, then is turned on again to repeat the backflushing. After the second backflushing the pump is turned off, and valves are adjusted to allow injection to continue. The entire backflushing process requires about 1 hour each day. The backflushing operation is necessary because the pressure needed to inject water increases as rust and sediments clog the screen, gravel pack, and aquifer. During the late 1970's, the Wildwood Water Utility attempted to solve a clogging and sand problem in Injection Well 2 (9-103) by filtering the water prior to injection. The results of the filtering are unclear; however, Eugene Comisky (Wildwood Water Utility, oral commun., 1990) and James Schultes (W.C. Services, Inc., oral commun., 1990) report that the filters became dirty each day.

Injection and Recovery Data

Monthly and annual injection and recovery data for 1967-91 are listed in table 2. Reported and total annual injection and recovery data for the six injection-recovery wells for the period of record are summarized in table 3. The total annual injection and recovery and the difference between them are listed in table 4. Reported annual injection from 1968 through 1991 ranges from about 71 to 275 Mgal, and reported annual recovery ranges from about 62 to 269 Mgal. Wildwood Water Utility has recovered about 85 percent of the water injected. In 1975, 1979, 1985, and 1991, Wildwood Water Utility withdrew more water than it had injected during each of those years.

Extent of Effect of Recharge

The radius of the theoretical cylinder of aquifer material used for storage can be calculated from the volume of water that was injected. Injection is assumed to take place from the top to the bottom of the screen interval. Injection is assumed to be isotropic within the aquifer, and the injected water is assumed to form a cylinder around the well screen. The porosity of the aquifer is assumed to be 30 percent. The following formula is used to calculate the radius of the theoretical cylinder of injected water that forms around each well:

$$r = \sqrt{\frac{Vi}{\eta \pi 7.48 b}} \quad ,$$

where r is the radius of the cylinder formed during injection;
Vi is injected volume, in gallons;
η is porosity, in percent;
b is the screen length, in feet; and
7.48 is the factor used to convert gallons to cubic feet.

Table 2. Monthly and annual storage and recovery at the six Wildwood Water Utility recharge wells

[Data from U.S. Geological Survey, State Water Use Data System; storage and recovery in million gallons; --, no reported storage or recovery]

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
							Well 1 USGS well number 9-159						
							Water storage						
1967	27.232	--	--	--	--	--	--	--	--	--	3.287	12.585	11.360
1968	99.457	1.565	11.863	14.822	14.679	14.721	11.064	--	--	--	8.619	11.551	10.573
1969	92.277	8.075	7.959	11.388	11.168	11.658	8.164	--	--	--	11.565	11.003	11.297
1970	90.792	11.336	10.687	11.770	9.640	10.128	4.250	--	--	--	11.410	10.664	10.907
1971	75.779	11.070	10.166	10.584	7.985	--	--	--	--	5.385	10.807	9.860	9.922
1972	71.374	9.779	8.926	9.478	9.175	9.470	5.829	--	--	--	1.377	6.096	11.244
1973	80.918	10.877	9.688	10.201	9.156	10.106	3.587	--	--	--	5.617	10.683	11.003
1974	84.672	10.916	9.900	11.048	10.550	5.437	8.398	--	--	--	5.854	11.106	11.463
1975	75.021	11.302	10.067	11.422	11.217	10.692	--	--	--	--	--	8.805	11.516
1976	78.097	11.598	10.754	7.144	4.461	8.948	6.809	--	--	4.350	8.681	6.357	8.995
1977	36.543	7.494	8.489	8.382	9.168	3.010	--	--	--	--	--	--	--
							Water recovery						
1968	79.274	--	--	--	--	--	1.737	31.489	35.417	6.815	3.816	--	--
1969	91.219	--	--	--	--	--	--	38.630	41.373	11.216	--	--	--
1970	61.552	--	--	--	--	1.355	.331	21.938	26.384	11.544	--	--	--
1971	102.387	--	--	--	--	.085	6.936	42.193	37.713	15.460	--	--	--
1972	69.158	--	--	--	--	--	4.443	28.844	26.776	9.095	--	--	--
1973	78.400	--	--	--	--	--	16.649	26.680	26.904	8.167	--	--	--
1974	89.414	--	--	--	--	--	6.655	31.463	32.108	19.188	--	--	--
1975	72.050	--	--	--	--	--	4.447	27.015	25.725	14.863	--	--	--
1976	51.017	--	--	--	.561	--	1.224	22.035	20.198	6.042	--	.957	--
1977	87.139	--	--	--	--	--	--	39.026	38.295	9.818	--	--	--
							Well 2 USGS well number 9-103						
							Water storage						
1970	23.212	--	--	--	--	--	--	--	--	--	--	11.606	11.606
1971	50.269	10.233	10.460	11.175	11.485	6.916	--	--	--	--	--	--	--
1972	--	--	--	--	--	--	--	--	--	--	--	--	--
1973	72.163	--	5.156	10.245	10.439	9.507	8.229	--	--	--	5.781	11.291	11.515
1974	85.057	11.797	10.866	11.663	10.920	8.106	4.172	--	--	--	2.255	12.626	12.652
1975	60.728	11.876	11.990	11.280	11.313	4.349	--	--	--	--	--	8.805	1.115
1976	75.795	--	10.147	12.135	10.622	10.506	6.209	--	--	6.079	7.614	5.072	7.411
1977	38.252	8.093	7.613	7.938	7.540	4.316	2.752	--	--	--	--	--	--
1978	27.837	--	--	--	--	--	--	--	--	--	9.049	9.227	9.561
1979	82.271	9.153	7.130	9.469	9.313	8.767	6.954	--	--	3.884	10.056	8.846	8.699
1980	72.431	8.120	7.052	7.772	4.936	7.489	5.649	--	--	4.600	9.266	8.695	8.852
1981	65.175	1.586	7.904	5.615	7.604	11.023	11.515	--	--	3.264	6.361	5.526	4.777
1982	54.451	4.239	2.399	7.614	5.427	0.993	2.097	--	--	5.174	8.955	9.349	8.204
1983	42.823	9.233	4.142	0.845	1.998	2.573	2.191	--	--	1.370	2.481	8.286	9.704
1984	58.266	6.298	5.794	6.268	6.282	5.847	5.142	--	--	2.668	7.073	6.269	6.625
1985	14.537	6.185	3.701	3.422	--	--	--	--	--	--	--	.785	.444
							Water recovery						
1970	--	--	--	--	--	--	--	--	--	--	--	--	--
1971	--	--	--	--	--	--	--	--	--	--	--	--	--
1972	--	--	--	--	--	--	--	--	--	--	--	--	--
1973	34.116	--	--	--	--	--	1.241	11.902	11.852	9.171	--	--	--
1974	79.430	--	--	--	--	--	--	25.405	34.644	19.381	--	--	--
1975	85.991	--	--	--	--	--	.296	32.628	34.830	18.237	--	--	--
1976	68.433	--	--	--	--	--	2.530	35.754	22.607	6.640	--	.902	--
1977	62.643	--	--	--	--	--	--	28.675	29.609	4.359	--	--	--
1978	57.286	--	--	--	--	--	5.405	22.687	25.414	3.780	--	--	--
1979	58.933	--	--	--	--	--	1.193	27.190	23.892	--	6.658	--	--
1980	54.147	--	--	--	--	--	3.214	20.754	20.909	9.270	--	--	--
1981	66.172	--	--	--	--	--	13.243	24.085	23.490	5.354	--	--	--
1982	43.598	--	--	--	--	--	--	15.799	20.124	7.675	--	--	--
1983	48.667	--	--	--	--	--	--	22.582	22.424	3.661	--	--	--
1984	38.092	--	--	--	--	--	2.443	14.047	16.363	5.239	--	--	--
1985	22.601	--	--	--	--	--	--	9.528	10.454	2.619	--	--	--

able 2. Monthly and annual storage and recovery at the six Wildwood Water Utility recharge wells--Continued

Well 3 USGS well number 9-176

Water storage

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1978	56.682	–	–	–	–	9.378	15.248	–	–	–	9.454	11.911	10.691
1979	66.471	6.406	1.435	7.942	8.681	8.024	6.156	–	–	3.905	8.872	7.649	7.401
1980	55.540	6.694	5.618	6.497	6.504	5.565	4.396	–	–	5.346	6.318	5.123	3.479
1981	69.181	8.535	7.141	7.939	7.684	6.447	2.740	–	–	4.821	8.692	7.647	7.535
1982	54.335	7.374	7.005	6.704	5.644	1.367	4.143	–	–	2.402	7.024	6.568	6.104
1983	48.973	6.510	5.086	3.596	–	4.722	5.309	–	–	3.272	7.090	6.774	6.614
1984	65.088	9.759	7.407	7.362	7.081	5.828	5.663	–	–	3.075	7.155	5.856	5.902
1985	45.682	5.634	4.936	5.688	5.346	5.275	5.399	–	–	–	3.580	5.074	4.750
1986	51.660	4.207	3.251	4.601	3.053	11.123	6.896	–	–	2.289	6.082	5.370	4.788
1987	40.854	4.119	3.072	4.143	3.963	4.021	–	–	–	3.796	6.340	5.892	5.508
1988	61.490	5.316	6.454	7.483	7.310	6.453	3.632	–	–	4.105	8.283	6.879	5.575
1989	60.694	5.175	6.317	8.456	7.155	5.396	–	–	–	2.937	10.515	7.761	6.982
1990	70.518	7.070	6.564	6.618	7.164	6.388	4.031	–	–	3.717	10.033	9.614	9.319
1991	70.460	7.806	9.461	9.160	9.077	7.103	–	–	–	–	10.962	7.454	9.437
1992	40.647	7.107	9.907	9.539	11.570	2.524	–	–	–	–			

Water recovery

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1978	20.179	–	–	–	–	0.982	–	2.094	13.593	3.510	–	–	–
1979	68.420	–	–	–	.507	–	–	24.546	31.948	–	11.419	–	–
1980	51.752	–	–	–	–	–	2.713	23.316	23.545	2.178	–	–	–
1981	48.928	–	–	–	–	–	–	22.197	20.669	6.062	–	–	–
1982	59.805	–	–	–	–	2.130	2.531	25.109	25.203	4.832	–	–	–
1983	53.905	–	–	–	–	–	–	25.045	25.098	3.762	–	–	–
1984	53.342	–	–	–	–	–	5.663	21.703	20.188	5.788	–	–	–
1985	35.919	–	–	–	–	–	–	15.979	18.178	1.762	–	–	–
1986	35.919	–	–	–	–	–	–	15.979	18.178	1.762	–	–	–
1987	45.721	–	–	–	–	–	4.958	18.030	18.922	3.811	–	–	–
1988	49.031	–	–	–	–	–	–	21.361	23.208	4.462	–	–	–
1989	48.035	–	–	–	–	–	.879	21.264	20.831	5.061	–	–	–
1990	56.871	–	–	–	–	–	3.127	19.948	20.723	13.073	–	–	–
1991	84.271	–	–	–	–	–	12.480	19.115	24.617	28.059	–	–	–
1992	57.526	–	–	–	–	–	3.599	22.276	23.510	8.141	–	–	–

Well 4 USGS well number 9-314

Water storage

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1982	83.109	–	4.321	6.527	12.780	11.873	8.480	–	–	6.548	11.673	10.938	9.969
1983	69.380	10.794	9.486	9.628	9.098	6.813	2.863	–	–	–	.168	11.441	9.089
1984	61.906	9.861	8.060	8.090	–	–	–	–	–	3.653	12.567	10.191	9.484
1985	42.351	9.238	8.630	9.109	7.138	5.590	–	–	–	–	2.646	–	–
1986	78.794	10.037	10.793	10.449	8.477	7.669	4.718	–	–	3.652	9.032	7.276	6.691
1987	68.579	6.204	5.640	7.724	7.725	7.736	1.396	–	–	3.294	10.108	9.468	9.284
1988	79.593	8.135	8.063	8.433	9.340	7.905	4.824	–	–	3.814	10.115	9.473	9.491
1989	66.985	9.071	7.285	9.890	9.269	6.151	–	–	–	–	10.341	7.955	7.023
1990	72.717	7.585	7.127	7.643	9.098	7.229	1.654	–	–	–	12.041	9.579	10.761
1991	66.668	9.786	8.607	7.791	10.443	4.705	–	–	–	–	9.585	7.840	7.911
1992	38.002	9.105	8.746	7.904	9.787	2.460	–	–	–	–	–	–	–

Water recovery

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1982	29.059	–	–	–	–	–	–	17.542	11.061	0.456	–	–	–
1983	47.610	–	–	–	–	–	–	20.739	20.342	6.529	–	–	–
1984	51.841	–	–	–	–	–	–	23.611	22.336	5.894	–	–	–
1985	46.244	–	–	–	–	2.220	7.778	15.357	15.953	4.936	–	–	–
1986	59.874	.474	–	–	–	1.164	6.641	21.532	24.035	6.028	–	–	–
1987	44.522	–	–	–	–	–	–	16.817	19.984	7.721	–	–	–
1988	44.829	–	–	–	–	1.168	3.797	19.793	16.497	3.574	–	–	–
1989	45.194	–	–	–	–	2.042	4.162	17.169	14.397	7.424	–	–	–
1990	60.972	3.104	1.956	.865	–	1.542	4.986	18.419	18.183	10.133	–	–	1.784
1991	70.354	1.253	2.550	2.257	2.669	6.290	9.870	17.268	18.539	9.057	.383	.218	–
1992	50.525	–	–	–	–	1.937	2.314	20.047	20.121	6.106	–	–	–

Table 2. Monthly and annual storage and recovery at the six Wildwood Water Utility recharge wells--Continued

Year	Annual	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
							Well 5 USGS well number 9-301						
							Water storage						
1986	45.394	--	--	--	--	--	--	9.240	15.010	--	9.316	6.972	4.856
1987	48.573	4.326	3.560	3.176	5.533	5.849	4.480	--	--	4.564	7.136	5.404	4.545
1988	51.260	5.919	5.978	5.604	4.988	4.476	2.818	--	--	3.489	7.539	5.651	4.798
1989	47.459	4.255	3.985	7.277	5.871	3.881	--	--	--	4.053	8.184	4.656	5.297
1990	64.432	6.760	6.260	5.917	7.544	6.144	3.126	--	--	5.151	8.412	7.688	7.430
1991	55.663	6.987	6.243	7.013	7.185	5.344	.179	--	--	--	8.874	5.854	7.984
1992	26.189	5.578	6.644	6.280	6.355	1.332	--	--	--	--	--	--	--
							Water recovery						
1986	35.668	--	2.671	7.020	8.003	7.506	6.846	--	--	3.622	--	--	--
1987	46.715	--	--	--	--	--	--	19.284	21.603	5.828	--	--	--
1988	45.080	--	--	--	--	--	.573	18.937	21.054	4.516	--	--	--
1989	51.055	--	--	--	--	--	2.070	20.483	20.302	8.200	--	--	--
1990	52.869	--	--	--	--	--	1.969	20.593	22.487	7.820	--	--	--
1991	71.878	--	--	--	--	--	7.168	19.872	21.445	23.393	--	--	--
1992	54.260	--	--	--	--	1.490	2.545	21.062	22.799	6.364	--	--	--
							Well 6 USGS well number 9-310						
							Water storage						
1986	24.372	--	--	--	--	--	--	--	--	3.046	7.207	7.134	6.985
1987	47.030	6.398	5.593	5.239	5.069	5.225	--	--	--	2.330	6.258	5.664	5.254
1988	52.815	5.021	5.292	5.603	5.475	5.771	3.902	--	--	2.935	7.117	6.139	5.560
1989	44.028	5.198	5.272	7.310	6.176	4.977	--	--	--	.938	--	7.037	7.120
1990	67.755	6.653	7.487	7.019	7.851	6.947	5.077	--	--	4.161	8.389	7.100	7.071
1991	64.220	8.518	6.495	8.458	7.729	6.785	2.026	--	--	--	8.560	7.242	8.407
1992	34.092	6.538	7.148	9.131	9.218	2.057	--	--	--	--	--	--	--
							Water recovery						
1986	--	--	--	--	--	--	--	--	--	--	--	--	--
1987	59.362	--	--	--	--	--	5.190	20.785	25.313	8.074	--	--	--
1988	45.036	--	--	--	--	--	--	22.511	19.708	2.817	--	--	--
1989	66.228	--	--	--	--	--	.945	21.343	21.195	14.075	8.670	--	--
1990	55.624	--	--	--	--	--	3.106	23.147	24.560	4.811	--	--	--
1991	42.805	--	--	--	--	--	2.553	21.490	18.145	.617	--	--	--
1992	34.004	--	--	--	--	1.675	3.073	21.572	22.739	6.445	--	--	--

Table 3. Annual and total storage and recovery at the six Wildwood Water Utility recharge wells

[Data from U.S. Geological Survey, State Water Use Data System; storage and recovery in million gallons; -- indicates no data]

Year	USGS well number 9-159	9-103	9-176	9-314	9-301	9-310	Total
			Water storage				
1967	27.232	--	--	--	--	--	27.232
1968	99.457	--	--	--	--	--	99.457
1969	92.277	--	--	--	--	--	92.277
1970	90.792	23.212	--	--	--	--	114.004
1971	75.779	50.269	--	--	--	--	126.048
1972	71.374	--	--	--	--	--	71.374
1973	80.918	72.163	--	--	--	--	153.081
1974	84.672	85.057	--	--	--	--	169.729
1975	75.021	60.728	--	--	--	--	135.749
1976	78.097	75.795	--	--	--	--	153.892
1977	36.543	38.252	--	--	--	--	74.795
1978	--	27.837	56.682	--	--	--	84.519
1979	--	82.271	66.471	--	--	--	148.742
1980	--	72.431	55.540	--	--	--	127.971
1981	--	65.175	69.181	--	--	--	134.356
1982	--	54.451	54.335	83.109	--	--	191.895
1983	--	42.823	48.973	69.380	--	--	161.176
1984	--	58.266	65.088	61.906	--	--	185.260
1985	--	14.537	45.682	42.351	--	--	102.570
1986	--	--	51.660	78.794	45.394	24.372	200.220
1987	--	--	40.854	68.579	48.573	47.030	205.036
1988	--	--	61.490	79.593	51.260	52.815	245.158
1989	--	--	60.694	66.985	47.459	44.028	219.166
1990	--	--	70.518	72.717	64.432	67.755	275.422
1991	--	--	70.460	66.668	55.663	64.220	257.011
*1992	--	--	40.647	38.002	26.189	34.092	138.930
			Water recovery				
1968	79.274	--	--	--	--	--	79.274
1969	91.219	--	--	--	--	--	91.219
1970	61.552	--	--	--	--	--	61.552
1971	102.387	--	--	--	--	--	102.387
1972	69.158	--	--	--	--	--	69.158
1973	78.400	34.116	--	--	--	--	112.516
1974	89.414	79.430	--	--	--	--	168.844
1975	72.050	85.991	--	--	--	--	158.041
1976	51.017	68.433	--	--	--	--	119.450
1977	87.139	62.643	--	--	--	--	149.782
1978	--	57.286	20.179	--	--	--	77.465
1979	--	58.933	68.420	--	--	--	127.353
1980	--	54.147	51.752	--	--	--	105.899
1981	--	66.172	48.928	--	--	--	115.100
1982	--	43.598	59.805	29.059	--	--	132.462
1983	--	48.667	53.905	47.610	--	--	150.182
1984	--	38.092	53.342	51.841	--	--	143.275
1985	--	22.601	35.919	46.244	--	--	104.764
1986	--	--	35.919	59.874	35.668	--	131.461
1987	--	--	45.721	44.522	46.715	59.362	196.320
1988	--	--	49.031	44.829	45.080	45.036	183.976
1989	--	--	48.035	45.194	51.055	66.228	210.512
1990	--	--	56.871	60.972	52.869	55.624	226.336
1991	--	--	84.271	70.354	71.878	42.805	269.308
1992	--	--	57.526	50.525	54.260	34.004	196.315

* September through December data not included.

Table 4. Total annual storage, recovery, and difference between storage and recovery, at the Wildwood Water Utility recharge wells

[Data from U.S. Geological Survey, State Water Use Data System; storage, recovery, and difference in million gallons; --, no reported storage or recovery; negative sign indicates that recovery exceeded storage; I, incomplete data]

Year	Storage	Recovery	Difference
1967	27.232	--	27.232
1968	99.457	79.274	20.183
1969	92.277	91.219	1.058
1970	114.004	61.552	52.452
1971	126.048	102.387	23.661
1972	71.374	69.158	2.216
1973	153.081	112.516	40.565
1974	169.729	168.844	.885
1975	135.749	158.041	-22.292
1976	153.892	119.450	34.442
1977	74.795	149.782	-74.987
1978	84.519	77.465	7.054
1979	148.742	127.353	21.389
1980	127.971	105.899	22.072
1981	134.356	115.100	19.256
1982	191.895	132.462	59.433
1983	161.176	150.182	10.994
1984	185.260	143.275	41.985
1985	102.570	104.764	-2.194
1986	200.220	131.461	68.759
1987	205.036	196.320	8.716
1988	245.158	183.976	61.182
1989	219.166	210.512	8.654
1990	275.422	226.336	49.086
1991	257.011	269.308	-12.297
1992	*138.930	196.315	I
Total	3,849.8	3,286.6	442.27

* September through December data not included.

The minimum and maximum amounts of water injected into each of the six recharge wells of Wildwood Water Utility during years in which water was injected for 9 or more months are shown in table 5. The minimum and maximum radii of the cylinder of injected water, calculated by using the minimum and maximum amounts of injected water and the screen length, also are listed. Estimates of the radius of the cylinder of water range from 215 to 492 ft.

Water-Level Changes

Water levels in the Cohansey aquifer in Cape May County were above sea level before development (about 1900) (Gill, 1962, p. 112) (fig. 6a). The water-level map (fig. 6a) shows that water flowed from the center of the peninsula toward the bay and ocean. The first large withdrawal wells tapping the Cohansey aquifer were installed in southern Cape May County about 1928. The water-level map of the Cohansey aquifer in 1958 (fig. 6b) shows three cones of depression in southern Cape May County (Gill, 1962, p. 108). The largest and deepest cone, centered in southern Lower Township, resulted from pumping of public-supply wells that serve Cape May City and industrial-supply wells that serve the fishing industry. Water levels at the center of the cone of depression were about 21 ft below sea level during the non-tourist season. In southern Middle Township, a second cone of depression was centered at the public-supply wells of Wildwood Water Utility. Water levels were about 10 ft below sea level during the non-tourist season. The third small cone of depression with water levels about 7 ft below sea level formed in the Wildwood communities as a result of ground-water withdrawals from public- and industrial-supply wells located on the island. In 1967, Wildwood Water Utility began ground-water injection for storage and recovery. The USGS measured ground-water levels in southern Cape May County in 1978, 1983, 1988, and 1991 (Walker, 1983; Eckel and Walker, 1986; Rosman and others, 1995; Lacombe and Carleton, 1992). Water levels measured in April 1991 (fig. 6c) indicate that the cones of depression in southern Lower Township and southern Middle Township remain and are joined by a third cone of depression centered over the public-supply wells of the Lower Township Municipal Utilities Authority in western Lower Township. Water levels in southern Lower Township have remained constant since 1958 at about 20 ft below sea level. The cone of depression in southern Middle Township has increased in depth from about 10 ft below sea level in 1958 to about 20 ft below sea level in 1991. The cone of depression on Five Mile Beach has been filled and replaced by a water mound that is about 5 ft above sea level. The water mound is caused by the injection of ground water by the Wildwood Water Utility.

Injection well 5 (9-301) is located 6,000 ft from a group of industrial-supply wells that serve the fishing industry in eastern Lower Township (fig. 2). A cone of depression centered on the fishing-industry wells extends to Well 5 (9-301). Well 5 is the only well of the utility that is used to inject water in an existing cone of depression. As a result, the injected water is not creating a water mound that is above sea level like water levels found around the other three injection wells.

The presence of the water mound on the eastern side of the peninsula decreases the likelihood of lateral saltwater intrusion from the east toward the mainland. The cone of depression in southern Middle Township has increased in depth and width in part because of increased withdrawals of ground water that is used for storage and recovery. This larger cone of depression will increase lateral movement of ground water toward the Wildwood Water Utility

Table 5. Minimum and maximum amounts of water injected for storage, and radius of the theoretical cylinder of water that forms around each well screen

Well number	Volume of water (million gallons per year)		Well-screen length (feet)	Radius of cylinder (feet)	
	Minimum	Maximum		Minimum	Maximum
9-159	71,374	99,457	70	380	492
9-103	42,823	85,057	105	215	303
9-176	45,682	70,518	51	353	434
9-314	42,351	83,109	94	252	354
9-301	48,573	64,432	55	353	363
9-310	47,030	67,755	73	302	320

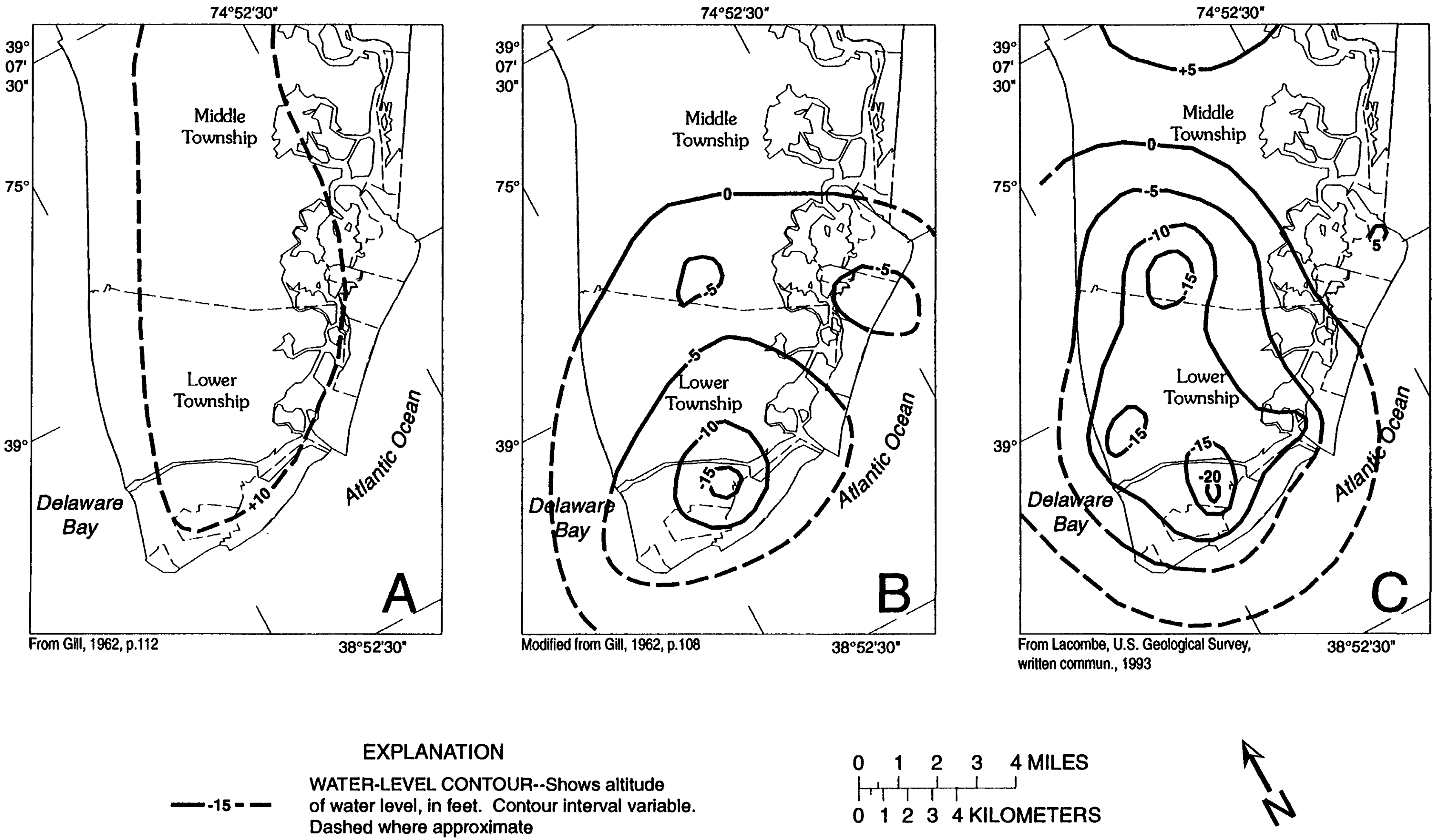

Figure 6. Altitude of water levels in the Cohansey aquifer in southern Cape May County, New Jersey, (A) before 1900, (B) January 1958, (C) April 1991.

supply wells because of the increased hydraulic gradient. Ground water moving from the north, east, and south will not adversely affect the water supply because the water in the vicinity of the Wildwood Water Utility supply wells is fresh, but ground water moving from the west could contain chloride and sodium in concentrations greater than the NJDEP recommended secondary drinking-water standards.

Water-Quality Changes

The quality of the injected water is altered while it is stored in the aquifers of Five Mile Beach. Water that is used for injection is withdrawn from the estuarine sand aquifer, Cohansey aquifer, and Rio Grande water-bearing zone through 10 public-supply wells in southern Middle Township. Schultes (1959) reported that the chloride concentration of the blended water from the mainland was 38 mg/L. During the initial injection test, this water was stored in the Atlantic City 800-foot sand, where the chloride concentration of the water was 300 mg/L (Schultes, 1959). A total of 231,300 gallons was injected during 8 days and was recovered during 2 days. During the first 11 hours of recovery, 156,000 gallons was withdrawn, and the chloride concentration was relatively constant at about 38 mg/L. As additional water was withdrawn, the chloride concentration gradually increased. After 50 hours of recovery, 229,800 gallons had been withdrawn, and the chloride concentration was about 135 mg/L.

In 1992, the Wildwood Water Utility measured the chloride concentration of the injected water and the recovered water (table 6) (Gregory Lanze, Wildwood Water Utility, oral commun., 1992). From mid-September 1991 to the beginning of the Memorial Day weekend in 1992, 49 to 69 Mgal was injected into each of the four wells. The chloride concentration of the water used for injection fluctuated during the injection season but typically ranged from 30 to 35 mg/L. Ground-water recovery began on May 29, 1992, for the holiday weekend. The chloride concentration of the water recovered from each well measured July 28 was found to be nearly the same as that of the injected water (table 6). The concentration of chloride in the recovered water was measured again on August 30 and September 4; it had increased to 40 to 64 mg/L. Recovery ceased and injection was resumed about September 11, 1992.

Injection Well 3 (9-176) was used to inject 68.5 Mgal during the 1991-92 injection season. Nearly 11 Mgal was left in storage; therefore, only 84 percent of the water was recovered by the end of the summer. The chloride concentration of the recovered water increased from 35 mg/L during injection to 40 mg/L on August 30, and to 44 mg/L on September 4. The chloride concentration increased only 9 mg/L during the recovery period because a large volume (11 Mgal) of the injected water was left in the storage.

Injection Well 4 (9-314) was used to inject 62.737 Mgal during the 1991-92 injection season, but 12 Mgal was left in storage. Therefore, only 81 percent of the water was recovered. The chloride concentration remained constant at 35 mg/L during recovery. The well is screened in the part of the estuarine sand and Cohansey aquifers on Five Mile Beach in which the chloride concentration is quite low (less than 100 mg/L) (Gill, 1962, p. 123; Lacombe and Carlton, 1992, p. 291). Because the well screen is located in the part of the aquifer with a low chloride concentration and because 12.262 Mgal was left in storage, the chloride concentration of the recovered water is more similar to that of the injected water in this well than in the other three injection-recovery wells.

Table 6. Chloride concentration of injected and recovered water, and amount of water available in storage from four of the Wildwood Water Utility wells, April-September 1992

[Chloride data from Gregory Lanza (Wildwood Water Utility, oral commun., 1992); total water available in million gallons; percent, percentage of water that remains in storage; --, no data]

1992 Date	USGS well number 9-176		9-314		9-301		9-310	
April - June	chloride concentration of injected water ranged from 30 to 35 milligrams per liter							
	Chloride concentrations of recovered water (milligrams per liter)							
July 28	34		35		32		32	
August 28	40		--		44		51	
September 4	44		35		47		64	
	Water available in storage							
	Total	Percent	Total	Percent	Total	Percent	Total	Percent
April 30	65.973	--	60.277	--	47.569	--	56.244	--
May 28	68.500	--	62.737	100	48.901	100	58.301	100
May 31	68.500	100	60.800	97	47.411	97	56.626	97
June 30	64.901	95	58.486	93	44.866	92	53.553	92
July 31	42.625	62	38.439	61	23.804	49	31.981	55
August 31	19.115	28	18.318	29	1.005	2	9.242	16
September 11	10.974	16	12.262	20	-5.359	-11	2.797	5

Injection Well 5 (9-301) was used to inject 48.901 Mgal during the 1991-92 injection season and 54.260 Mgal was recovered. Therefore, the utility withdrew either a previous year's excess injected water or the ambient water from the aquifer or a mixture of both. During withdrawal, the chloride concentration of the recovered water increased from 32 to 47 mg/L. This small increase could be the result of a low chloride concentration in the ambient water as reported by Gill (1962, p. 123) and Lacombe and Carleton (1992, p. 291).

Injection Well 6 (9-310) was used to inject 58.301 Mgal during the 1991-92 injection season, and 2.797 Mgal was left in storage. Therefore, 95 percent of the water was recovered. During withdrawal the chloride concentration of the recovered water increased from 32 to 64 mg/L (fig. 7). This is the largest increase in chloride concentration measured at the four wells. Well 6 taps that part of the aquifer on Five Mile Beach in which the chloride concentrations is highest (Gill, 1962, p. 123; Lacombe and Carleton, 1992, p. 291). The increase in the chloride concentration during the water recovery probably resulted from the high chloride concentration of the ambient water in the aquifer in the northern part of Five Mile Beach.

The iron concentration of the blended water withdrawn from the 10 public supply wells in southern Middle Township was about 0.35 mg/L, and the iron concentration of the water recovered from injection-recovery wells 3, 4, and 5 (9-176, 9-314, and 9-301) also was about 0.35 mg/L. The iron concentration of the water recovered from Well 6 (9-310) increased steadily and by mid-summer had increased to 0.9 mg/L (Earl Moyer, Wildwood Water Utility, oral commun., 1991.) As a result, water recovered from Well 6 contains higher concentrations of iron than water recovered from the other injection-recovery wells. Gill (1962a, p. 63) shows higher concentrations of iron in water from the Cohansey aquifer in the North Wildwood area than from the Cohansey aquifer in any other part of Five Mile Beach, possibly as a result of the presence of more iron or a more easily mobilized source of iron in the aquifer material in this area than elsewhere on the island.

Electric Company Plant

The B.L. England Electric Generating Plant, in Upper Township on Great Egg Harbor Bay, is owned by Atlantic Electric Company. The company operates two industrial-supply wells that are screened in the Atlantic City 800-foot sand. All freshwater supplies for the company are obtained from the two wells. One artificial-recharge well screened in the Cohansey aquifer is used for storage and recovery (fig. 4).

History of Storage and Recovery Program

In 1961, Atlantic Electric Company drilled Supply Wells 1 and 2 (9-145 and 9-146), which are screened in the Cohansey aquifer, for its proposed fossil-fuel, steam-power electricity-generating station. The wells are about 300 ft apart and about 200 ft from the saltwater in Great Egg Harbor Bay (fig. 4). In 1961, the chloride concentrations of water withdrawn from Supply Well 1 and 2 were about 14 and 38 mg/L, respectively. The chloride concentration of water from Supply Well 2 (9-146) was too high for economical steam generation. As a result, Supply Well 2 was abandoned and sealed in 1962, and Supply Well 3 (9-147) was installed about 700 ft from the bay. From 1962 to 1964 the chloride concentration of water from Supply Well 1 (9-145) increased to about 85 mg/L, and the company applied to the NJDEP for permission to

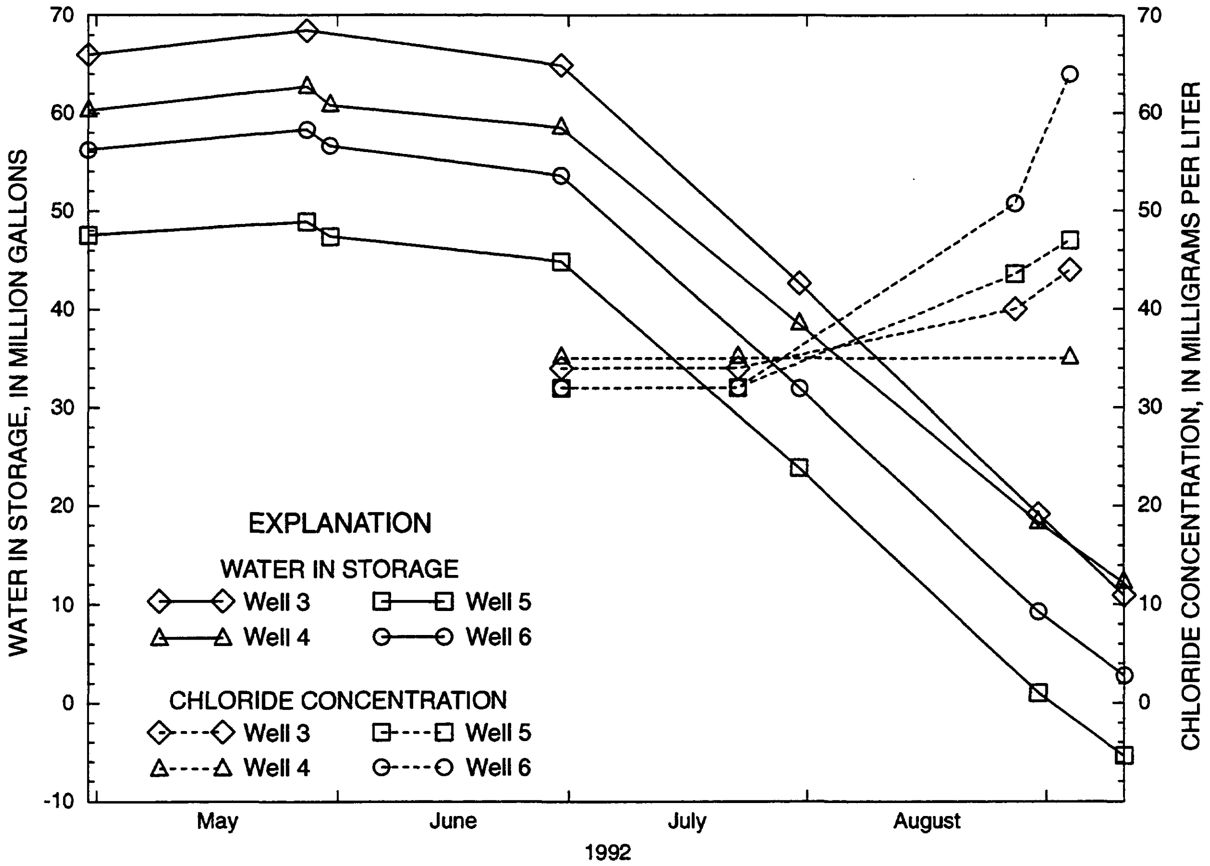

Figure 7. Volume of water in storage, May-September 1992, and chloride concentration of recovered water, July-September 1992, Wildwood Water Utility injection-recovery wells, Cape May County, New Jersey.

(1) drill a new well (Supply Well 4 (9-148)) to be screened in the Atlantic City 800-foot sand, (2) make Supply Well 1 a "standby" well, and (3) abandon Supply Well 3 and use it as an observation well. NJDEP granted the request and Supply Well 4 was completed in late 1964. A few months later, Supply Well 1 (9-145) was put on standby; the pump in Supply Well 3 (9-147) was removed, and the well became an observation well. In February 1965, Atlantic Electric Company planned to conduct a 2-mo. long performance test on Supply Well 4 (9-148). The performance test required pumping about 100 gal/min more than the plant typically would use. Because southern New Jersey was experiencing a severe drought (Wayne Adamson, Atlantic Electric Company, oral commun., 1992), the company requested permission to divert the unused water from the performance test into Supply Well 1 rather than waste the water by pumping it into the bay. The company calculated that about 4 Mgal/mo would be injected into the Cohansey aquifer during the performance test. This temporary arrangement would conserve water, and it also would make Supply Well 1 a short-term backup for Supply Well 4. NJDEP accepted the proposal, and the performance test on Supply Well 4 was conducted. In October 1965, NJDEP granted the electric company's request for a permit to continue injecting water from Supply Well 4 into Supply Well 1 and thereby maintain Supply Well 1 as a viable backup well.

In 1975, Atlantic Electric Company drilled Supply Well 5 (9-144), which is screened in the Atlantic City 800-foot sand. In 1992, Supply Well 6 (9-461) was drilled and screened in the Atlantic City 800-foot sand; this well is to be used in 1993 or 1994 for a planned scrubber unit (Environmental Consulting and Technology, Inc., 1992).

Operation of the Injection-Recovery Well

Water is injected into the Cohansey aquifer through a 3/4-in. feed line that is placed inside the well casing. Typically water is injected for about 8 hours, but it may be injected for as long as 4 days if water is available (Norris Justic and Wayne Adamson, Atlantic Electric Company, oral commun., 1992). The injected water is obtained by pumping the two supply wells that tap the Atlantic City 800-foot sand. The chloride concentration of the water from the two supply wells typically is 5 or 6 mg/L. The water is injected at a line pressure of 60 psi, which can be set lower if injection continues for more than 8 hours. Water is injected on an "as available" basis and when personnel are available to monitor the operation.

Water is recovered from the well as needed. The well pump is turned on, and the water is added to the supply system. Withdrawals and chloride concentration are monitored daily. After about 1 Mgal of water has been withdrawn, the operators of the plant consider injecting additional water for storage. Withdrawals cease if the chloride concentration exceeds 7 or 8 mg/L, and plans are then made to inject additional water.

Injection and Recovery Data

Monthly ground-water storage and recovery data for 1965 through 1988 are listed in table 7. Table 8 lists the total annual amounts of water stored and recovered, and the difference between the two. These tables were compiled from data provided by Atlantic Electric Company to the NJDEP and stored in the USGS State Water Use Data System (SWUDS).

Table 7. Monthly and annual storage and recovery at the electric company plant injection well at Beesley's Point, Cape May County

[Data from U.S. Geological Survey, State Water Use Data System; storage and recovery in million gallons; --, no reported storage or recovery]

Year	Annual	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
							Well 1 USGS well number 9-145						
							Water storage						
1965	19.332	--	--	--	3.754	3.132	--	--	--	2.649	4.153	4.476	1.168
1966	--	--	--	--	--	--	--	--	--	--	--	--	--
1967	3.654	--	.206	.918	.447	.922	.765	.378	.018	--	--	--	--
1968	5.243	--	--	.364	.682	.658	.531	.065	.467	.834	.284	.441	.917
1969	2.768	1.017	.251	--	--	--	--	--	--	.423	1.001	.073	--
1970	8.473	--	--	.533	.744	1.063	.789	.459	.382	.380	1.077	1.970	1.076
1971	6.126	.162	--	--	--	--	1.089	.500	1.602	.066	.942	.830	.935
1972	9.031	1.031	1.009	.252	.318	1.024	.810	.760	.759	.969	.814	.246	1.039
1973	1.811	.483	.362	.189	--	--	.164	.484	.129	--	--	--	--
1974	4.705	.248	.622	.910	.585	.711	1.193	.254	.149	--	--	--	.033
1975	2.082	.138	.612	.316	.414	--	--	--	.256	--	.346	--	--
1976	4.864	--	--	.910	.513	.301	3.14	--	--	--	--	--	--
1977	3.949	--	--	1.184	--	--	--	.492	.526	.807	.908	.032	--
1978	5.304	--	--	--	.102	1.115	.590	.367	.202	.279	.859	1.538	.252
1979	8.803	.963	.670	.787	.555	1.087	.525	.942	.210	.557	.735	.871	.901
1980	5.696	.838	.296	.177	1.119	--	--	.612	.636	.455	.298	.397	.868
1981	3.074	.868	.710	--	--	.026	.001	--	.164	.311	.080	.356	.558
1982	2.987	.111	.383	--	.683	--	.022	.018	.073	.459	.625	--	.613
1983	3.107	.572	.532	.602	.619	.092	.631	.448	.030	.494	.717	.749	.733
1984	5.059	.297	.008	.783	.646	.665	.411	--	.036	.491	.463	.660	.599
1985	6.525	.774	.710	.847	1.086	.764	.134	.753	.042	--	--	.546	.869
1986	4.058	.035	.627	--	--	--	1.445	.537	.425	.008	.139	.228	.614
1987	1.406	.260	.023	--	--	--	--	--	.001	1.122	--	--	--
1988	1.427	--	.076	--	--	.207	.371	.149	--	.614	.010	--	--
							Water recovery						
1962	4.680	--	--	--	--	--	--	--	--	4.680	--	--	--
1963	21.360	--	2.750	2.450	1.860	2.110	3.000	3.320	1.540	2.290	2.040	--	--
1964	22.892	3.500	1.300	1.370	.127	--	1.100	5.890	5.000	4.580	.021	.004	--
1965	4.472	.051	.052	--	--	--	--	1.420	.998	--	--	--	1.950
1966	1.090	--	--	.014	.007	.003	.033	.222	.572	.142	.016	--	.080
1967	3.544	--	1.870	--	.217	.199	.009	.558	--	.451	.032	.175	.033
1968	4.13	1.730	.578	.029	.948	--	--	.407	--	--	.441	--	--
1969	1.740	.134	--	.046	.358	--	--	.612	--	1.002	.580	.006	--
1970	6.101	.461	--	1.500	1.270	--	.021	2.340	.094	.030	.385	--	--
1971	3.787	.414	--	.050	.464	.033	.139	2.530	.012	.019	.116	--	--
1972	.453	.408	.045	--	--	--	--	--	--	--	--	--	--
1973	2.807	--	--	.210	.868	.503	.110	--	.200	.225	.414	.277	--
1974	1.440	.160	--	--	.744	.025	.031	.038	.029	.069	.325	--	.019
1975	.496	--	--	--	.074	--	--	.326	--	.096	--	--	--
1976	.955	--	.011	--	--	--	--	.171	.089	--	.426	.028	.230
1977	.941	--	--	--	.422	--	--	.413	--	--	--	.106	--
1978	2.083	.286	--	--	.597	--	--	--	--	.200	--	--	--
1979	1.073	.038	.056	--	.024	.010	--	.360	.050	--	.535	--	--
1980	3.556	--	.149	.126	.517	--	--	.357	1.240	.461	.502	.104	.100
1981	3.793	.166	.101	.100	.468	.461	.432	.453	.245	.149	.728	--	.490
1982	4.171	.273	.361	.423	.620	--	.225	.149	.224	.479	.476	.378	.563
1983	4.346	.254	.715	.124	.075	.693	.785	.158	.229	.377	.458	.096	.382
1984	5.889	.461	.387	.454	.462	1.410	.442	--	.448	--	1.435	--	.390
1985	2.600	.140	.400	.750	.490	.060	--	.520	--	.030	.040	.050	.120
1986	4.644	.258	2.362	--	.456	.009	.744	--	.160	.386	.003	.117	.035
1987	.681	.043	.056	.003	.102	.039	.132	.019	.088	.042	.155	.001	.001
1988	1.382	.001	.019	--	.108	.046	.094	.046	.196	.130	.203	--	.539

Table 8. Total annual storage, recovery, and difference between storage and recovery at the electric company plant injection well at Beesley's Point, Cape May County

[Data from U.S. Geological Survey, State Water Use Data System; storage, recovery, and difference in million gallons per year; --, no reported storage or recovery; negative sign indicates that recovery exceeded storage; total is for 1967 through 1988]

Year	Storage	Recovery	Difference
1965	19.332	4.472	14.860
1966	--	1.090	-1.090
1967	3.654	3.544	.110
1968	5.243	4.133	1.110
1969	2.768	1.740	1.028
1970	8.473	6.101	2.372
1971	6.126	3.787	2.339
1972	9.031	.453	8.578
1973	1.811	2.807	-.996
1974	4.705	1.440	3.265
1975	2.082	.496	1.586
1976	4.864	.955	3.909
1977	3.949	.941	3.008
1978	5.304	2.083	3.221
1979	8.803	1.073	7.730
1980	5.696	3.556	2.140
1981	3.074	3.793	-.719
1982	2.987	4.171	-1.184
1983	3.107	4.346	-1.239
1984	5.059	5.889	-.830
1985	6.525	2.600	3.925
1986	4.058	4.644	-.586
1987	1.406	.681	.725
1988	1.427	1.382	.045
Total	100.144	60.610	39.534

From 1967 to 1988, the electric company injected 100.14 Mgal and withdrew 60.61 Mgal, resulting in a net gain to the Cohansey aquifer of 39.53 Mgal.

SUMMARY

Artificial recharge of ground water by well injection for storage and recovery has proven to be a viable means of water management for the Wildwood Water Utility and Atlantic Electric Company in Cape May County, New Jersey. In the late 1950's, Wildwood Water Utility was unable to meet seasonal water demand. In 1958, the Wildwood Water Utility supply system was analyzed and injection-recovery tests were conducted to evaluate the feasibility of injection of ground water for storage and recovery. Artificial recharge by well injection for storage and recovery began in 1967, and has been in use since then. Wildwood Water Utility has injected from about 71 to 275 Mgal/yr and has recovered from about 62 to 269 Mgal/yr. Since 1976, about 85 percent of injected water has been recovered. As a result of injection, water levels in the Cohansey aquifer have increased in the Wildwood communities and a water mound that is 5 ft above sea level is formed during the non-tourist season. The chloride concentration of water used for injection is about 35 mg/L. During the 1992 recovery season, the chloride concentration of the recovered water was about 35 mg/L at the beginning of the recovery season but increased to a maximum of 64 mg/L at the end of the season.

The electric company began artificial recharge by well injection in 1965 and stored 19 Mgal that year. Since 1967, the electric company has stored from about 1.406 to 9.031 Mgal/yr and recovered from 0.453 to 6.101 Mgal/yr. From 1965 through 1988, the electric company injected 100.144 Mgal and recovered 60.610 Mgal, thereby recovering 61 percent of the water that was stored.

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