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Vulnerability of Production Wells in the Potomac-Raritan-Magothy Aquifer System to Saltwater Intrusion from the Delaware River in Camden, Gloucester, and Salem Counties, New Jersey

Scientific Investigations Report 2004-5096

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

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Gale A. Norton, Secretary

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per year (gal/yr)	0.003785	cubic meter per day (m^3/yr)
million gallons per day (Mgal/d)	3785.	cubic meters per day
million gallons per year (Mgal/yr)	3785.	cubic meters per year

Vertical coordinate information is referenced to the *North American Vertical Datum of 1988 (NAVD 88).*

Horizontal coordinate information is referenced to the *North American Datum of 1927 (NAD 27).*

ABBREVIATIONS USED IN REPORT

mg/L	milligram per liter
µS/cm	microsiemens per centimeter at 25 degress Celsius

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Abstract

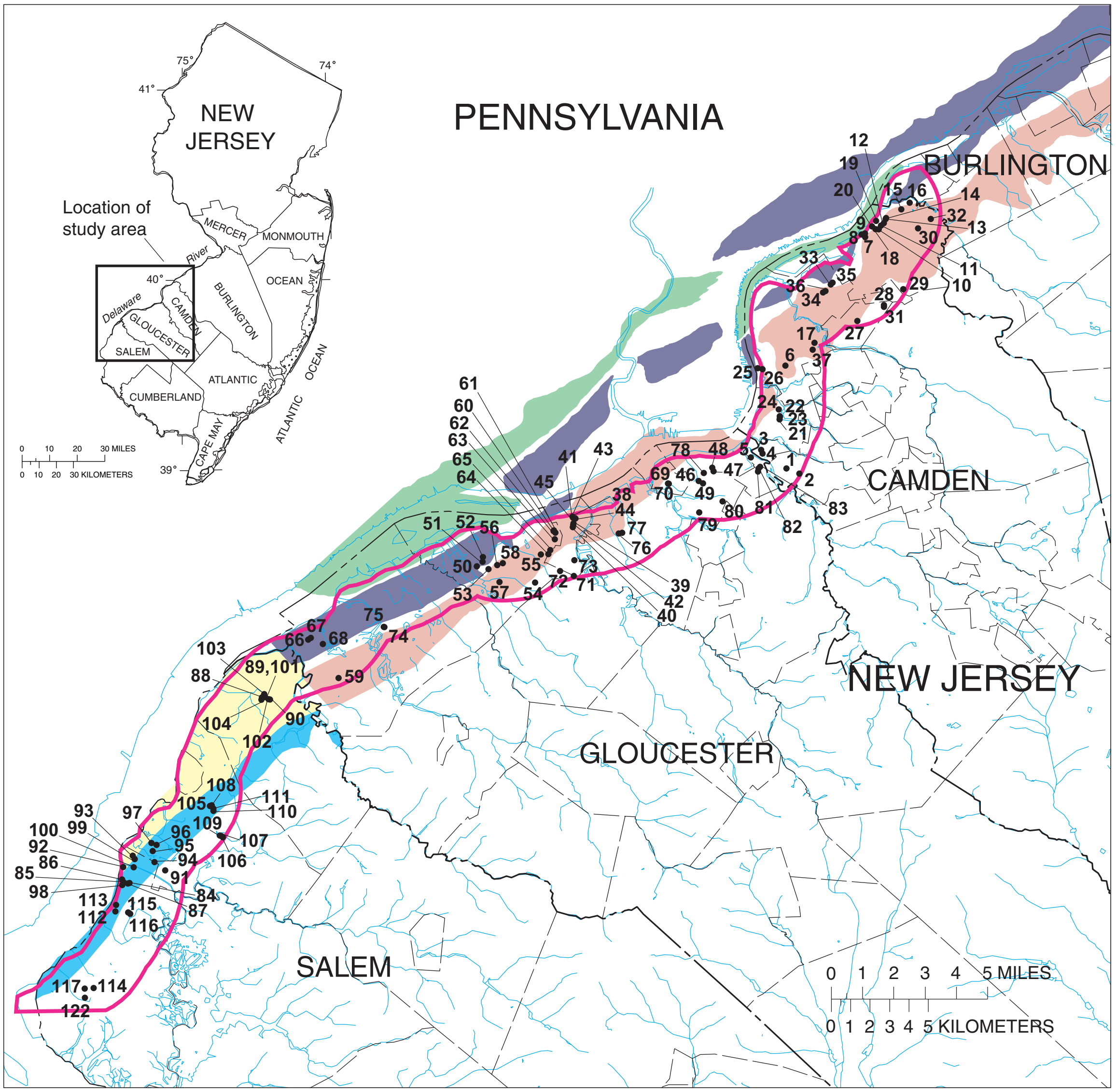
The Potomac-Raritan-Magothy aquifer system is hydraulically connected to the Delaware River in parts of Camden and Gloucester Counties, New Jersey, and has more limited contact with the river in Salem County, New Jersey. The aquifer system is used widely for water supply, and 122 production wells that are permitted by the New Jersey Department of Environmental Protection to pump more than 100,000 gallons per day in the three counties are within 2 miles of the river. During drought, saltwater may encroach upstream from the Atlantic Ocean and Delaware Bay to areas where the aquifer system is recharged by induced infiltration through the Delaware River streambed. During the drought of the mid-1960's, water with a chloride concentration in excess of potability standards (250 mg/L (milligrams per liter)) encroached into the reach of the river that recharges the aquifer system. The vulnerability of the major production wells in the area to similar saltwater encroachment in the future is a concern to water managers. This vulnerability was evaluated by investigating two scenarios: (1) a one-time recurrence of the conditions approximating those that occurred in the1960's, and (2) the recurrence of those same conditions on an annual basis.

Results of ground-water-flow simulation in conjunction with particle tracking and one-dimensional transport analysis indicate that the wells that are most vulnerable to saltwater intrusion are those in the Morris and Delair well fields in Camden County. A single 30-day event during which the concentration of dissolved chloride or sodium exceeds 2,098 mg/L or 407 mg/L, respectively, in the Delaware River would threaten the potability of water from these wells, given New Jersey drinking-water standards of 250 mg/L for dissolved chloride and 50 mg/L for dissolved sodium. This chloride concentration is about six times that observed in the river during the 1960's drought. An annually occurring 1-month event during which the concentrations of dissolved chloride or sodium in the river exceeds 1,818 mg/L or 358 mg/L, respectively, would threaten the potability of water from these wells. Wells outside the Morris and Delair well fields are substantially less vulnerable to the intermittent saltwater intrusion that was simulated.

Introduction

The Potomac-Raritan-Magothy aquifer system (locally referred to as the "PRM aquifer") is the primary source of potable water in southern New Jersey, especially in the Camden area. The outcrop of the aquifer system in southern New Jersey coincides with the course of the Delaware River, as shown in figure 1. Production wells near the river may derive part of their recharge from induced infiltration of river water (Navoy and Carleton, 1995). For a given well, the amount of recharge that originates in the river depends largely on the distance of the well from the river, assuming that other factors such as degree of confinement are equal. During drought, the lack of rainfall in the Delaware River Basin results in a decrease in the freshwater flow of the river. The lower reach of the Delaware River, downstream from Trenton, N.J., is tidal; river water is progressively more saline with proximity to the Atlantic Ocean. Any decrease in the freshwater flow of the river is offset by an upstream movement, or encroachment, of saltwater from the ocean into parts of the river that otherwise contain freshwater. This encroachment could allow saltwater to infiltrate into the aquifer system and subsequently flow toward production wells. Water managers are concerned that a severe drought could result in a degradation of the quality of ground water pumped from production wells near the river as a result of the intrusion of saltwater into the aquifer system. The possible effects of any potential rise in sea level amplify these concerns.

Storage reservoirs have been built in the upper Delaware River Basin to augment streamflow during drought to help prevent saltwater from moving upstream. The determination of the vulnerability of production wells near the river to saltwater intrusion is essential for the purposes of refining water-management policy to protect potable water supplies in the Delaware River Basin. The reach of the river that is intermittently exposed to saltwater is the riverfront of Camden, Gloucester, and Salem Counties. Generally, wells that are closest to the river in that reach and have large rates of withdrawal are those that are most vulnerable to saltwater intrusion. Because the factors differ from well to well that affect the amount of induced infiltration captured, individual wells must be evaluated to determine their



EXPLANATION

Hydrogeologic unit (Navoy and Carleton, 1995)
(Gloucester, Camden, and Burlington Counties)

- Outcrop area of the Upper Potomac-Raritan-Magothy aquifer
- Outcrop area of the Middle Potomac-Raritan-Magothy aquifer
- Outcrop area of the Lower Potomac-Raritan-Magothy aquifer

Geologic unit (U.S. Geological Survey, 1967)
(Salem County)

- Outcrop area of the Magothy Formation
- Outcrop area of the Potomac Group and Raritan Formation
- Boundary of the Delaware River buffer zone (within 2 miles of the Delaware River)
- 117• Well location--Number shown is map number in table 2

Figure 1. Location of study area, outcrop of the aquifers of the Potomac-Raritan-Magothy aquifer system, and location of wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden, Gloucester, and Salem Counties, N.J.

vulnerability to saltwater intrusion based on factors such as withdrawal rate, distance to the river, and local configuration of the aquifer system.

In this report, the term “encroachment” is used to refer to saltwater movement in the Delaware River (the surface-water system), whereas the term “intrusion” is used to refer to saltwater movement in the aquifers (ground-water system). This distinction facilitates the concurrent discussion of both processes when necessary.

Purpose and Scope

This report presents the results of an investigation of the vulnerability of production wells to contamination from induced infiltration of saltwater containing high concentrations of chloride and sodium from the Delaware River into the Potomac-Raritan-Magothy aquifer system, as might be expected during severe drought conditions. Wells completed in the aquifer system that are capable of withdrawing more than 100,000 gal/d, and that are within 2 miles of the Delaware River, are the focus of the study. The study area is limited to Camden, Gloucester, and Salem Counties, N.J., because management of water-storage reservoirs in the upper Delaware River Basin potentially can affect the salinity of the river in these three counties. Production wells in the counties upstream from the study area, such as Burlington and Mercer, were not included in the investigation because they were not affected by the 1960’s drought. The drought experienced in the Northeastern United States in the 1960’s (1963-66) is popularly considered to be the most severe on record. Production wells in Salem County near tidal creeks that are tributary to the Delaware River and are completed in aquifers other than the Potomac-Raritan-Magothy aquifer system were also not investigated. The assessment of ground-water conditions that may result from saltwater intrusion from the Delaware River does not include the determination of the likelihood of drought or of low freshwater flows in the river.

Previous Investigations

Several studies of the ground-water resources adjacent to the Delaware River in New Jersey have been conducted. Those that are most relevant to the current study are summarized here.

Navoy and Carleton (1995) developed a flow model that simulates the connection between the Potomac-Raritan-Magothy aquifer system and the Delaware River. That model provides the basis for the analyses done in this report. Navoy (1991) outlines the use of a flow model with particle tracking to test ground-water vulnerability to saltwater intrusion from the river. Simulations were conducted for five wells on the basis of 1980's water use. Lennon and others (1986) examine chloride concentrations in ground water during the 1960's drought and discuss the potential for saltwater intrusion due to sea-level rise.

The hydrogeology of the New Jersey Coastal Plain is described in several reports. Zapecza (1989) summarizes the hydrogeologic framework of these sediments. Duran (1986) used surface geophysical methods to determine the distribution and thickness of the riverbed sediments. Lacombe and Rosman (1997), Rosman and Lacombe (1995), Eckel and Walker (1986), and Walker (1983) provide potentiometric-surface data for the Coastal Plain aquifers, including the Potomac-Raritan-Magothy aquifer system, at 5-year intervals starting in 1978. Camp Dresser and McKee, Inc. (1984a, 1984b, and 1987), provide information on the ground-water-flow system and water management in the area, the connection of the aquifer system to the river, and the saltwater intrusion that occurred in the 1960’s.

Hydrogeology

A conceptual understanding of the hydrogeology of the Potomac-Raritan-Magothy aquifer system was developed on the basis of the results of the previous investigations. The framework of the aquifer system, the withdrawal stresses on the system (water use), and saltwater encroachment up the Delaware River and intrusion into the aquifer system during the 1960’s drought, historically the most severe, are described below and are used as the basis for the vulnerability analysis.

Hydrogeologic Framework

The Potomac-Raritan-Magothy aquifer system is part of a southeastward-dipping wedge of Coastal Plain sediments composed of gravels, sands, silts, and clays that range in age from Cretaceous to Holocene (Zapecza, 1989). The aquifer system, which consists primarily of fluvial-marginal marine sands and gravels that are the oldest of these deposits, overlies the pre-Cretaceous crystalline bedrock. The aquifer system is differentiated locally into three components--the Upper, Middle, and Lower aquifers. Intervening confining units, generally composed of clay and silt, separate these aquifers. The orientation of the aquifer system beneath the Delaware River in the Camden area is shown in figure 2.

About 90 Mgal/d per day is withdrawn from the aquifer system through wells in Camden, Gloucester, and Salem Counties (Hoffman and Lieberman, 2000). These withdrawals have caused a large cone of depression in the potentiometric surface (Lacombe and Rosman, 1997), and water levels in some parts of the aquifer system are below sea level. Because production wells are near the river, the reach in the vicinity of Camden provides substantial recharge to the aquifer. The amount of recharge leaking from the river would be difficult to measure directly. Qualitative analysis of ground-water levels near the river does not provide the means to distinguish between river leakage and recharge from the outcrop as the source of water to wells. A ground-water-flow model was therefore used to estimate the magnitude and extent of river leakage, and the relative importance of river leakage, recharge from the outcrop area, and flow from adjacent parts of the aquifer. This information is needed to determine the vulnerability of wells to saltwater intrusion from the river.

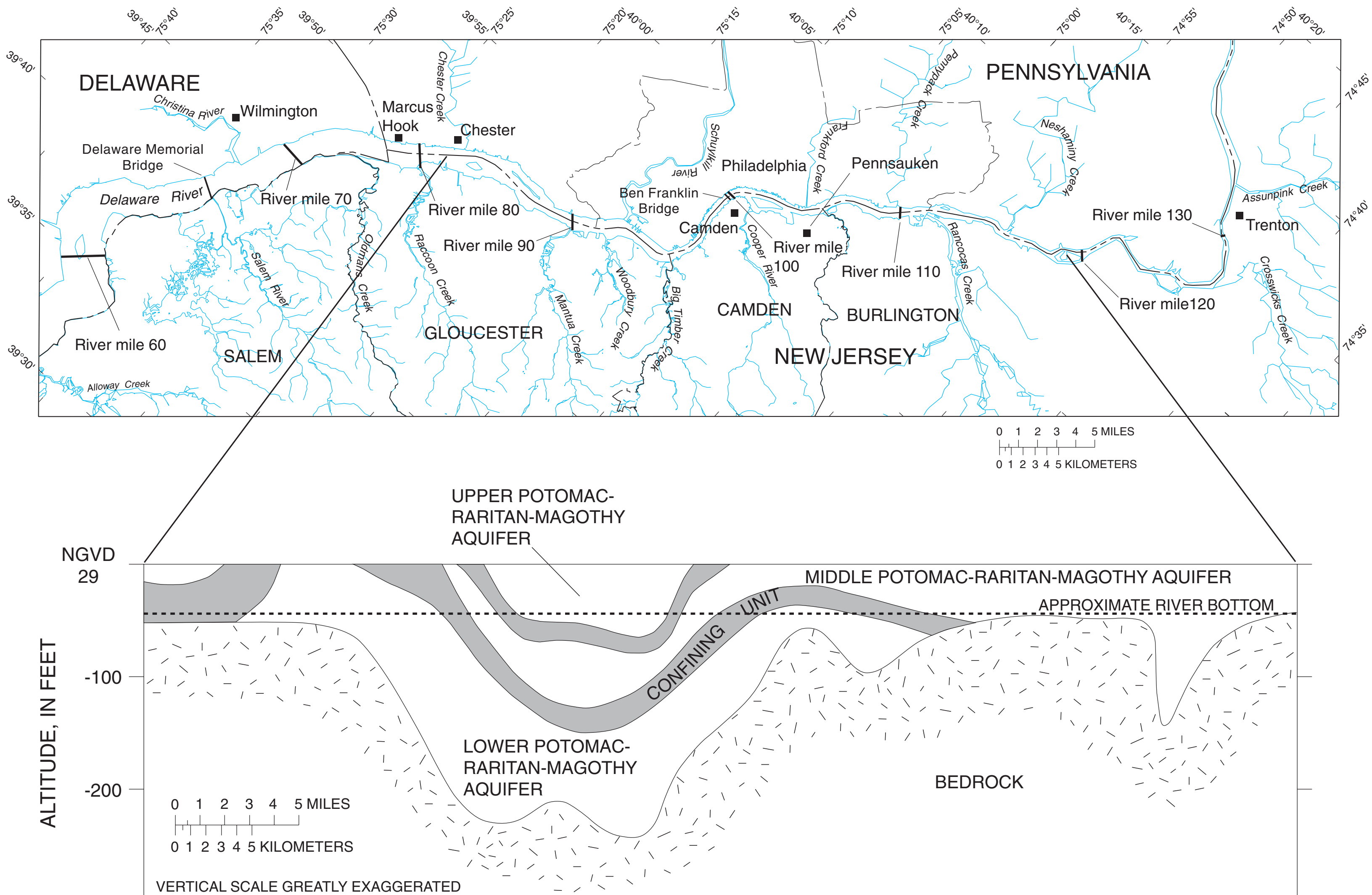


Figure 2. Generalized hydrogeologic section along the Delaware River, New Jersey and Pennsylvania.

Water Use

A water-use and well database was compiled from information in New Jersey Department of Environmental Protection (NJDEP) files. The database consisted of water-use data for permitted wells (capable of withdrawing more than 100,000 gal/d) from 1996, the most recent year for which withdrawal information was available by individual well at the time of the compilation. Wells within 2 mi of the river in Camden, Gloucester, and Salem Counties were identified from these data. Withdrawal data for and construction characteristics of these wells are listed in table 1 (at end of report); the wells are categorized by the magnitude of withdrawals in figure 3. Total water use in 1996 in the 2-mi-wide, three-county area was about 12,220 Mgal/yr (33.5 Mgal/d).

River Salinity in Fall 1964

The drought of the early to mid-1960's in the northeastern United States resulted in a period of low freshwater discharge in the Delaware River. During November and December 1964, the saltwater interface in the river, which normally is in the vicinity of Wilmington, Delaware, encroached upriver into the Camden area. The saltwater then was drawn into the Potomac-Raritan-Magothy aquifer system as induced infiltration from the river (Lennon and others, 1986). This intrusion of saline water into the aquifer system provides verification that the river and aquifer are hydraulically connected and that future saltwater-intrusion events may threaten the potability of ground-water supplies.

The Delaware River reach under consideration is affected by tides, and chloride concentrations vary through each cycle. Chloride concentration is related to specific conductance. The specific conductance of water in the Delaware River at the Benjamin Franklin Bridge in Philadelphia (station 01467200, river mile 100.16, fig. 2) typically is less than 500 μS/cm (Kolva and others, 1989). The maximum recorded specific conductance during November 1964 was slightly less than 1,500 μS/cm (U.S. Geological Survey, 1965, p. 43). For approximately 21 days, from November 16th to December 5th, the daily maximum and daily mean specific conductance of the river water exceeded 1,000 μS/cm. On the basis of a simple statistical correlation of monthly measurements of chloride concentrations and specific conductance of Delaware River water (U.S. Geological Survey, 1965, p. 42), the concentrations of dissolved chloride in water with specific conductances of 1,500 and 1,000 μS/cm were approximately 300 and 200 mg/L, respectively.

The river-monitoring site at the Benjamin Franklin Bridge is in the reach of the river where induced infiltration into the Lower aquifer occurs because the substantial water-supply withdrawals have lowered ground-water levels below the river level (Gill and Farlekas, 1976, sheet 2, map showing potentiometric surface for 1968). The saltwater that flowed into the aquifer in November and December 1964 was transported toward water-supply wells near the river. The concentration of dissolved chloride in water from wells near this river reach increased most likely as a result of the intrusion of saltwater into the aquifer. Lennon and others (1986, fig. 15) show that chloride concentrations in water-supply wells increased about 15 to 25 mg/L above background levels (concentrations had been about 8 to 10 mg/L) starting in 1965, roughly a year after the encroachment had occurred.

Vulnerability of Wells to Saltwater Intrusion

Not all wells screened within the Potomac-Raritan-Magothy aquifer system are hydraulically connected with the Delaware River. Navoy and Carleton (1995, fig. 53) show that river water that has been induced to flow into the aquifer system is not likely to be found more than 2 mi from the river in the Camden area. Thus, the investigation of vulnerability can be limited to this 2-mi-wide area, which is referred to in this report as the Delaware River buffer zone (fig. 1). The locations of important withdrawal wells (those with water-allocation permits from NJDEP to pump more than 100,000 gal/yr) within the 2-mi-wide area are also shown in figure 1. Wells with smaller withdrawals have very small cones of depression and are much less likely to induce recharge from the river. Therefore, they can be eliminated from consideration in this study. The wells shown in figure 1 and listed in table 1 are those that are most likely to capture water derived from induced infiltration of river water; therefore, these wells were selected for evaluation of their vulnerability to saltwater intrusion.

The Potomac-Raritan-Magothy aquifer system is a complex assemblage of multiple aquifer layers that have an irregular contact with the Delaware River, and from which many water-supply wells withdraw water. The ground-water-flow model developed by Navoy and Carleton (1995) is a tool that accounts for this complexity. The model cannot be used, however, to directly determine changes in chloride concentrations. This task can be accomplished by the use of particle tracking and concurrent, one-dimensional ground-water solute-transport analysis. In this manner, available tools can be used to assess vulnerability without the additional time and expense needed to develop an area-wide solute-transport model.

Because the ground-water-flow model of the Camden area developed by Navoy and Carleton (1995) does not include Salem County and therefore does not encompass the entire reach of the river that is within the current study area, the vulnerability of the wells in Salem County that are within 2 mi of the river was evaluated by means of other, albeit less sophisticated, methods. A comparison with simulation results for wells in Camden and Gloucester Counties, however, provided some confidence in the results of the analysis of the wells in Salem County.

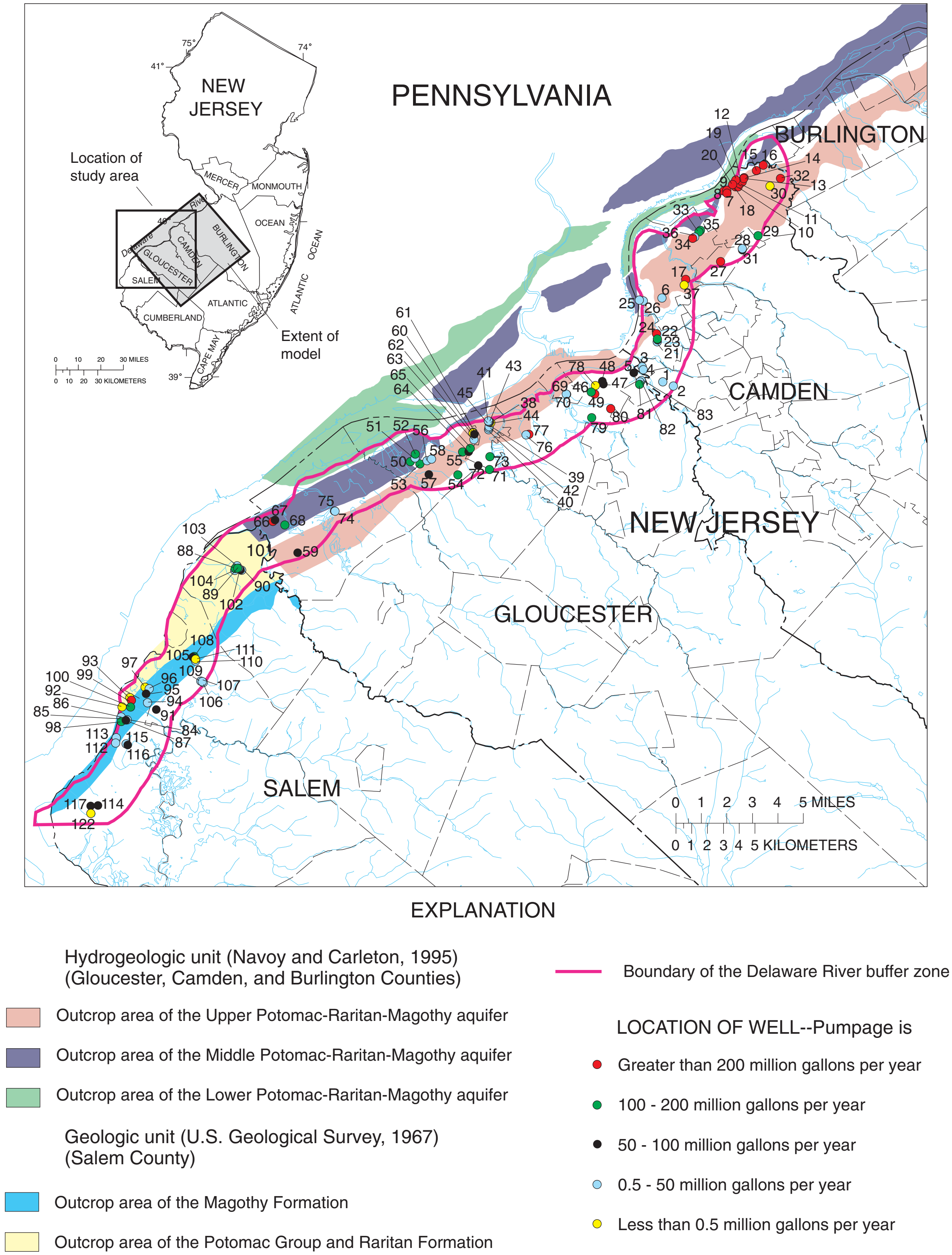


Figure 3. Ground-water withdrawals from wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden, Gloucester, and Salem Counties, N.J., 1996.

Wells in Camden and Gloucester Counties

Modeling Approach

The ground-water-flow model of the Potomac-Raritan-Magothy aquifer system in the Camden area developed previously by Navoy and Carleton (1995) by use of MODFLOW (McDonald and Harbaugh, 1988) as a tool for water-resources managers to use in evaluation of ground-water-withdrawal management strategies was used in this analysis. Detailed information on the design and calibration of the model is available in Navoy and Carleton (1995). Because the model is used to simulate the hydraulic interaction of the aquifer system with the Delaware River and its tributaries, it can be used to determine the potential for supply wells near the river to capture water from the river. The model consists of a five-layer, quasi-three-dimensional representation of the hydrogeologic units. The Upper, Middle, and Lower aquifers of the Potomac-Raritan-Magothy aquifer system are represented by three model layers; the two additional model layers represent stratigraphically younger aquifers that overlie the confined parts of the Potomac-Raritan-Magothy aquifer system. These aquifers are included to account for vertical boundary flow in downdip areas. Horizontal boundary flows were derived from the more coarsely discretized USGS Regional Aquifer Systems Analysis (RASA) model of the entire New Jersey Coastal Plain (Martin, 1998). A no-flow boundary represents the crystalline rocks underlying the aquifer system. The simulated aquifers were discretized horizontally into a variably spaced grid having 99 rows and 106 columns that is oriented approximately parallel to the Fall Line and the strike of the Potomac-Raritan-Magothy aquifer system. The extent of the model is shown in the inset map in figure 3. The smallest model cells are 880 ft by 1,650 ft and are near the Delaware River. These dimensions allow the span of river to be covered by three or more grid cells, providing for an accurate representation of the river's morphology and of the variability of riverbed permeability. The largest cells are 2,200 ft by 3,300 ft and generally are in the downdip, southeastern part of the model, farther from the river. The model was calibrated to historical water-level data (Navoy and Carleton, 1995).

The potential for each of the wells to induce infiltration of river water can be determined with a particle-tracking technique. The simulated movement of hypothetical particles as they travel through the ground-water-flow field is determined as a function of time, generating path lines and time-of-travel information (Pollock, 1988).

A steady-state simulation was performed with withdrawal rates for 1996, and ground-water-flow paths were determined by use of the MODPATH particle tracker (Pollock, 1989). Effective porosity values of 0.35 for the aquifers, a typical value for sand, and 0.45 for the confining units, a typical value for clays, were used (Freeze and Cherry, 1979, p. 37). A steady-state analysis is suitable because withdrawals from the Potomac-Raritan-Magothy aquifer system in the Camden area have been fairly stable over time, as shown by the annual withdrawal data in figure 4. Withdrawals from the aquifer system are not

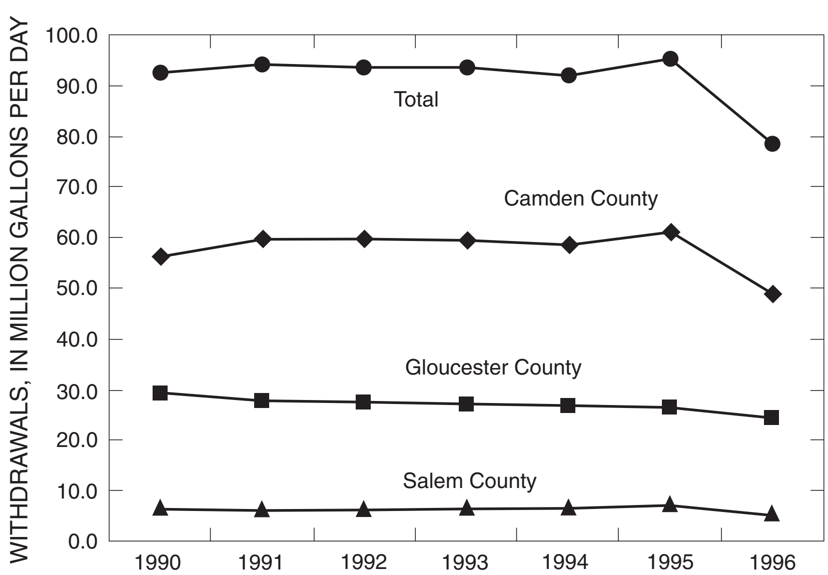


Figure 4. Withdrawals from the Potomac-Raritan-Magothy aquifer system in Camden, Gloucester, and Salem Counties, N.J., 1990-96. (From Hoffman and Lieberman, 2000, app. A, tables A4, A8, and A17)

likely to increase substantially in the future; the NJDEP has determined that the deep cones of depression in the aquifer system are indicative of conditions approaching over-pumping, and has initiated measures to restrict or curtail future increases in withdrawals (N.J. Department of Environmental Protection, 1986; New Jersey Administrative Code, 1995). Thus, the withdrawal rates used are likely to be representative of those in the Camden area in the foreseeable future.

The particle-tracking analysis supports a one-dimensional transport analysis using the advection-diffusion equation (Javandel and others, 1984, eq. 1, p. 9) to account for dispersive processes along each calculated flow path:

$$\frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right) - \frac{\partial}{\partial x}(Cv) = \frac{\partial C}{\partial t},$$

where

$v = \frac{-K}{n}\frac{\partial h}{\partial x}$

C = solute concentration,
D = dispersion coefficient,
K = hydraulic conductivity,
x = coordinate distance,
v = average pore-water velocity,
n = effective porosity,
h = hydraulic head,

and

t = time.

The velocity values needed to solve advective-diffusive transport are generated with the ground-water-flow model and particle-tracking software. A.L. Baehr (U.S. Geological Survey, written commun., 1989) developed a computer program to evaluate analytically the one-dimensional advection-diffusion equation over a semi-infinite domain in which a time-dependent input concentration boundary condition (of the first kind) is allowed by employing Duhamel's Principle (Carslaw and Jaeger, 1959, p. 30; Bear, 1979, p. 158). This approach was used to simulate the change in concentrations along flow paths and has been described in Navoy (1991, p. 113 and app. D).

The calibration of dispersivity needed for the one-dimensional transport analysis can be done with observed data. The chloride-concentration peak arrival in the wells during the mid-1960's drought as shown by Lennon and others (1986, fig. 15) fall into two groups. One group, with an apparent ground-water-flow velocity of 2,000 ft/yr, shows an increase in dissolved-chloride concentration to a peak of approximately 25 mg/L. The other group, with an apparent velocity of 4,000 ft/yr, also shows an increase to a peak of approximately 25 mg/L. (These apparent velocities are very high for ground water; however, these are conditions close to large-capacity water-supply wells and are not representative of natural or background conditions.) Because the data are sparse, a precise indication of the peak breakthrough concentration is not possible.

A range of dispersivities was used in the one-dimensional solute-transport model to produce chloride-breakthrough curves for velocities of 2,000 and 4,000 ft/yr to determine the dispersivity that best corresponds to the observed chloride peak arrival data. If the proportion of river water pumped by the monitored water-supply wells is estimated to be about 75 percent, a dispersivity of about 100 ft yields chloride concentrations of 0.75 times 40 and 55 mg/L (30 and 41 mg/L) for 2,000 and 4,000 ft/yr velocities, respectively. These values are consistent with the magnitude and timing of the observed data (Navoy, 1991, p. 114). Gillham and Cherry (1982, p. 46) and Anderson (1979, p. 126) suggest a range of longitudinal dispersivity of 10 to 200 ft for unconsolidated, saturated clastic aquifers. The dispersivity of 100 ft falls within this range, lending additional confidence to the estimate.

Two drought scenarios based on 1964 conditions were examined. The first scenario represents an isolated 1-month event in which saltwater encroaches upriver to a point adjacent to the recharge area for the wells. The second scenario represents intermittent saltwater encroachment in the river that recurs regularly for a 1-month period each year.

The approach used to determine the vulnerability of each well to saltwater intrusion is as follows. For each selected well, the lengths of the ground-water-flow paths between the river and the well and the ground-water velocity along each flow path (required to solve the advective-diffusion equation) were calculated with the particle tracker. This task was accomplished by specifying an array of particles at each model cell from which ground water is withdrawn and backtracking these particles to their point of recharge. The percentage of particles that was tracked to cells representing the Delaware River provides an estimate of the fraction of water withdrawn from the well that is derived from the river. Average flow-path length and velocity were calculated for a set of flow-path classes that consist of flow paths whose travel times fall into 5-year travel-time intervals. Breakthrough-curve concentrations then were determined with the one-dimensional transport model for each flow-path class on the basis of the velocity and flow-path length determined from the particle-tracking analysis. A composite breakthrough curve for each of the two scenarios then was made for each well by combining the concentrations determined for each flow-path class, weighted by the fraction of flow to the well it represents. This composite breakthrough curve is the concentration of a conservative solute through time at the well for the flow paths originating in the river. The peak concentration from the composite breakthrough curve, mixed proportionately with the water originating from nonriver sources (20 mg/L dissolved chloride or sodium), yields the maximum concentration expected at the well.

Flow Paths and Travel Times

Analysis of the results obtained by use of the ground-water-flow model, particle tracker, and one-dimensional solute-transport model indicates that the wells within 2 mi of the river in Camden and Gloucester Counties can be categorized into three groups on the basis of their vulnerability to saltwater intrusion from the Delaware River: a high-vulnerability group, a low-vulnerability group, and a group with virtually no vulnerability. Of the 122 wells located within 2 mi of the river, 83 are in Camden and Gloucester Counties (table 1). Fourteen percent of these wells are in the high-vulnerability group, 34 percent are in the low-vulnerability group, and 52 percent are in the no-vulnerability group. The results of the simulation of the two scenarios for each well are listed by vulnerability group in table 2 (at end of report).

The vulnerability categorization for each well is based on the travel time along the flow paths from the river to the well and the percent of well water derived from the river. All of the wells grouped in the low- and no-vulnerability classifications have the majority portion of their flow-path travel times in excess of 20 years. This criterion relates to a dilutive process. As travel time increases, in most cases related to increased distance from the river, the opportunity increases for dispersion and mixing to occur between water of varying flow paths that are converging at the well. For the intermittent intrusion scenarios tested, this substantially dilutes the peak concentration arriving at a well that originated at the river. For travel times longer than 20 years, simulated concentrations at such wells were much less than 1 percent of the starting concentration in the river for the intermittent intrusion scenarios tested. Additionally, the wells in the no-vulnerability classification have less than 40 percent of well water derived from the river. Correspondingly, the wells in the high-vulnerability classification have the majority portion of their flow-path travel times from the river shorter than 20 years and the majority of the water is derived from the river.

The high-vulnerability group contains only wells in the City of Camden well fields in Pennsauken. These wells generally have high withdrawal rates (200 to 500 Mgal/yr) and are very close to the river (typically within 0.5 mile). The aquifer layer in which these wells are screened is hydraulically well-connected with the river adjacent to the well field; therefore, it is not surprising that these wells are the most vulnerable. Some of the wells in the Camden well fields, as well as some in the other groups, are near enough to each other to be included in the same cell of the ground-water-flow model. In such cases, the pumpage is combined in the one model cell (table 2). The percentage of the pumpage from each of the wells in the group that is derived from the river, as simulated with the model, ranges from 54 to 93 percent.

Results of the simulation of the single, 1-month-duration saltwater-encroachment event indicate that a pulse of saltwater arriving at the high-vulnerability wells contained between 2 and 13 percent of the initial concentration in the river. In this type of analysis, the transport process is assumed to be conservative; that is, no significant chemical or physical reactions occur between the dissolved constituents and the aquifer materials along the flow path. For chloride, this assumption is valid. For sodium, this assumption does not include the potential for ion exchange with clay minerals, which could lower the concentration along a given flow path. Depending on the percentage of river water comprising the water pumped from the well (table 2), these data indicate that the critical concentrations in the river that would cause water in the well to be nonpotable range from 2,098 to 22,269 mg/L for dissolved chloride and from 407 to 3,777 mg/L for dissolved sodium. These thresholds are based on the New Jersey drinking-water standard of 250 mg/L for dissolved chloride and 50 mg/L for dissolved sodium (New Jersey Administrative Code, 1989).

Results of the simulation of the annually recurring, 1-month-duration saltwater-encroachment event indicate that a pulse of saltwater arriving at the high-vulnerability wells contained between 2 and 15 percent of the initial concentration in the river. For this scenario, the critical concentrations in the river that would render the water from the well nonpotable range from 1,818 to 22,296 mg/L for dissolved chloride and from 358 to 3,777 mg/L for dissolved sodium. The thresholds in this scenario are lower than those in the previous scenario because the recurrent saltwater encroachment has an additive affect through time that increases the amount of saltwater that reaches each well.

The locations, contributing areas, and arrival-concentration data for the individual wells in the high-vulnerability group are plotted in figures 5 through 10. These figures also indicate, by histogram, the range in travel times of the flow paths from the river to the wells. In the high-vulnerability group, most of the flow-path travel times are less than 5 years. The graphs of the concentration of conservative solute arriving at each well (“breakthrough plots”), shown in figures 5 (c and d), 6 (c and d), and 7 (c and d) for the Morris 11 and 13 wells, the Morris 12 well, and the Delair wells, respectively, indicate that the peak concentration can arrive within 1 year of the encroachment event in the river. This is consistent with the observations made from the mid-1960's event (Lennon and others, 1986, fig. 15). Ground-water velocities play an important role in the mechanical dispersion of solutes, such as those in saltwater (sodium and chloride). Water withdrawn from a well has traveled along flow paths of varying lengths because the recharge, or source of water to a well, generally is distributed over a large area or reach of stream that is hydraulically connected to the aquifer. Consequently, the travel times of ground water that flows to a single well vary. Where a well is located near a source of recharge, flow paths and, therefore, travel times to the well will be relatively short. Because the solute is not transported far, mechanical dispersion is small, resulting in the movement of relatively large concentrations of solute toward the well. In contrast, ground-water-flow paths to a well that is distant from its source of water are relatively long and have long travel times. Water traveling along long flow paths has a lower average ground-water velocity, greater dispersion, and lower arrival concentration of solute at the well than water traveling along short flow paths.

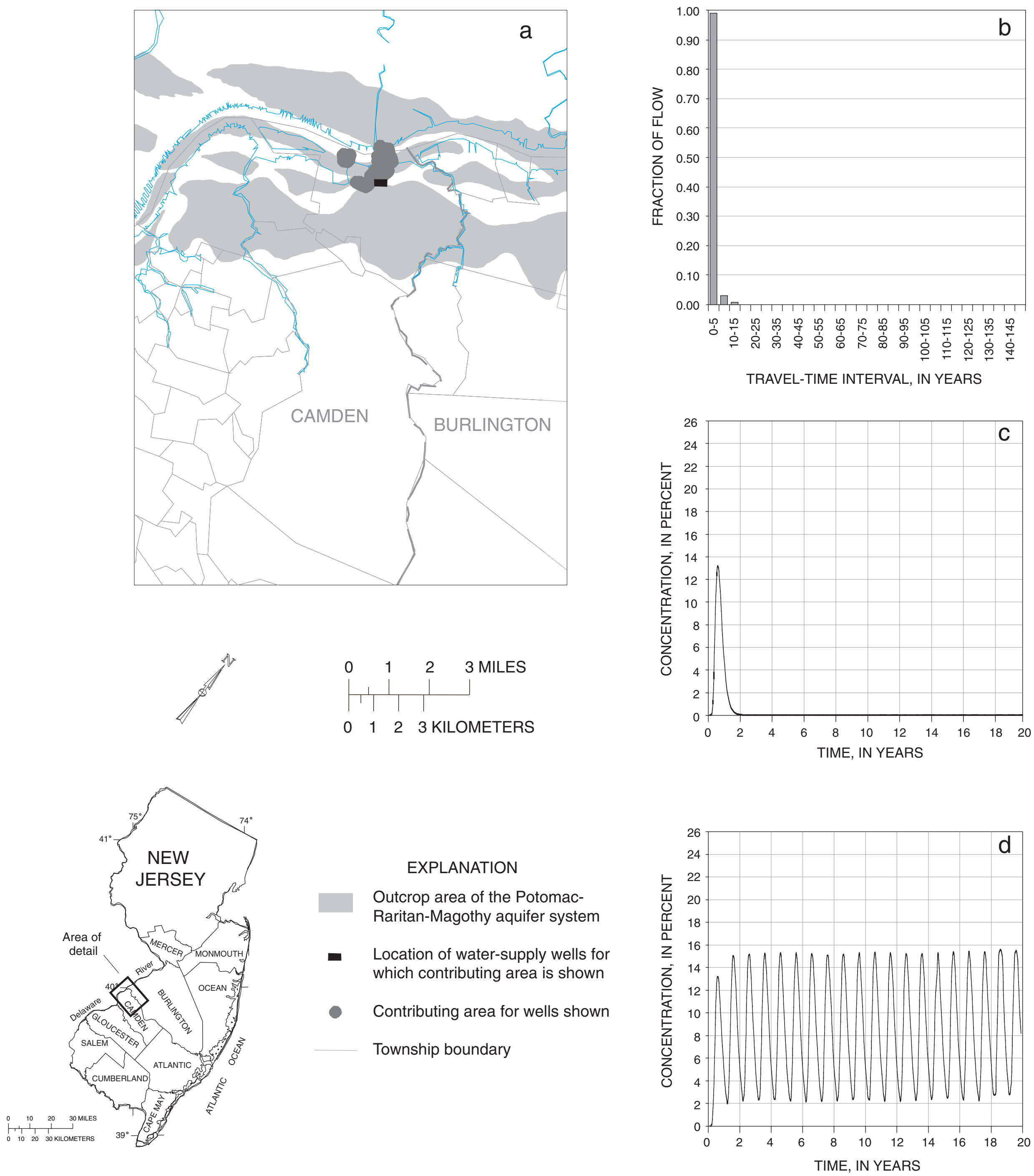


Figure 5. (a) Location of and contributing area for wells Morris 11 and 13; (b) travel-time frequency along flow paths from the Delaware River to the wells; (c) breakthrough concentration for a single 1-month saltwater-intrusion event; and (d) breakthrough concentration for an annually recurring 1-month saltwater-intrusion event.

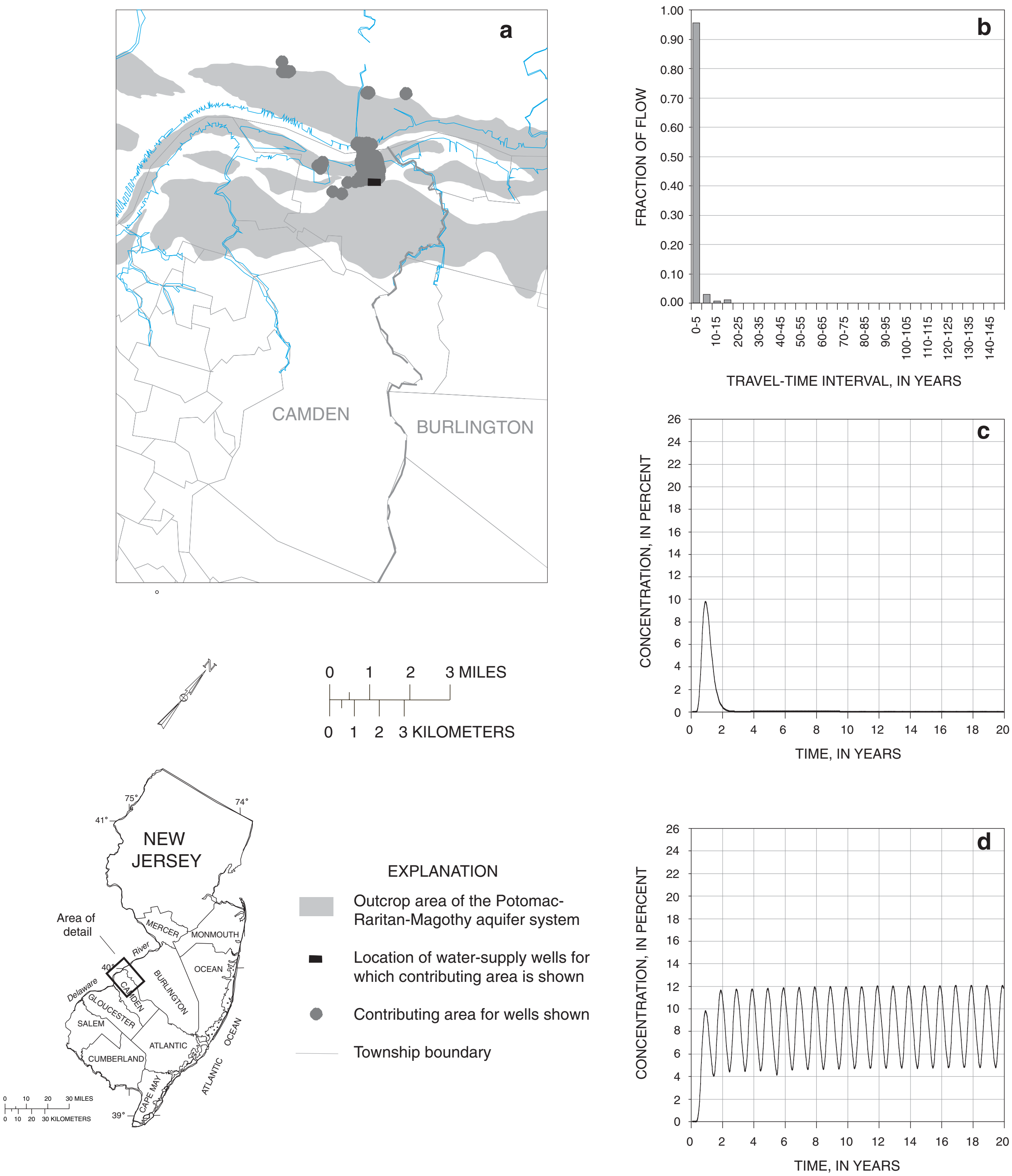


Figure 6. (a) Location of and contributing area for well Morris 12; (b) travel-time frequency along flow paths from the Delaware River to the well; (c) breakthrough concentration for a single 1-month saltwater-intrusion event; and (d) breakthrough concentration for an annually recurring 1-month saltwater-intrusion event.

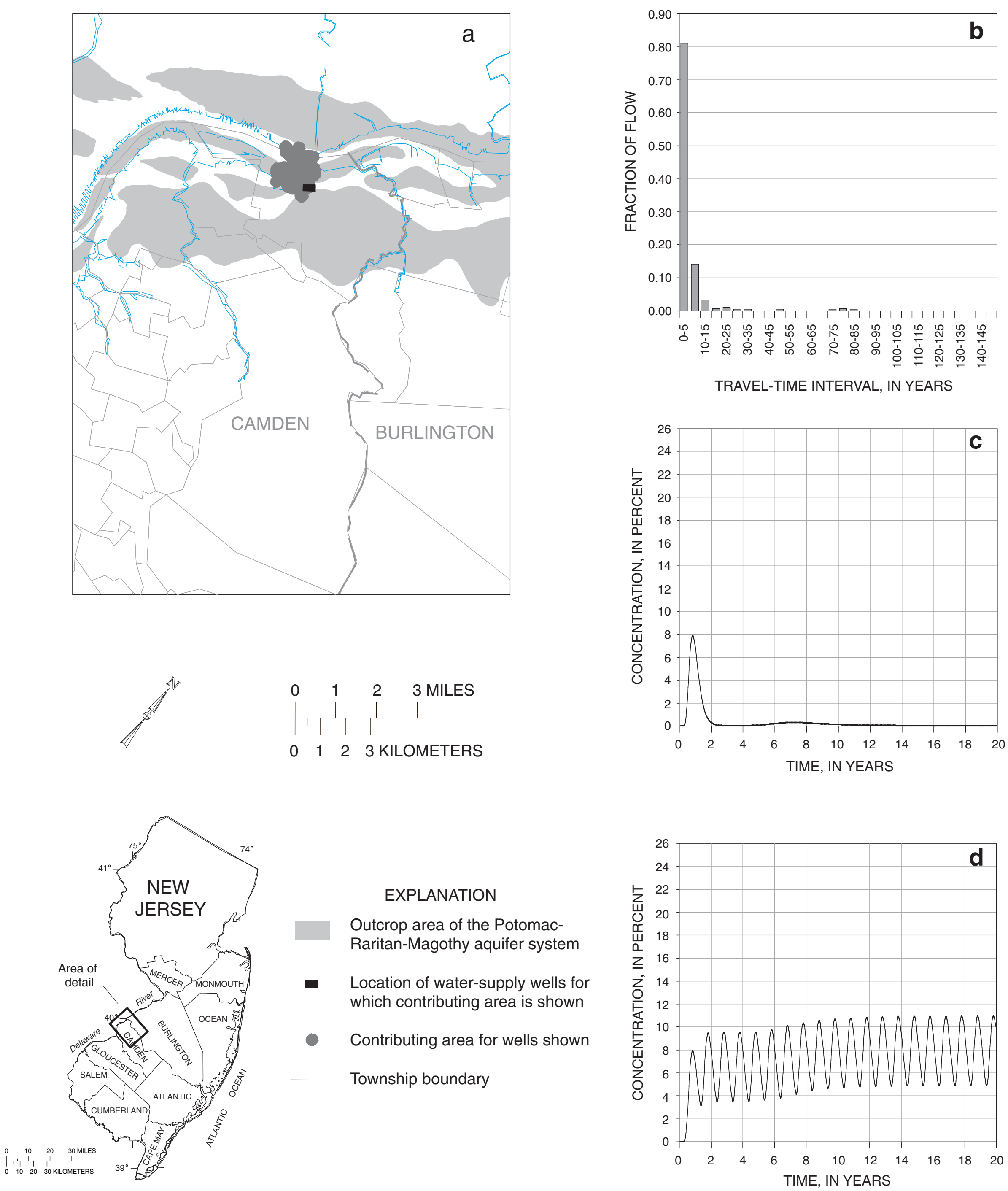


Figure 7. (a) Location of and contributing area for wells Delair 1, 2, and 3; (b) travel-time frequency along flow paths from the Delaware River to the wells; (c) breakthrough concentration for a single 1-month saltwater-intrusion event; and (d) breakthrough concentration for an annually recurring 1-month saltwater-intrusion event.

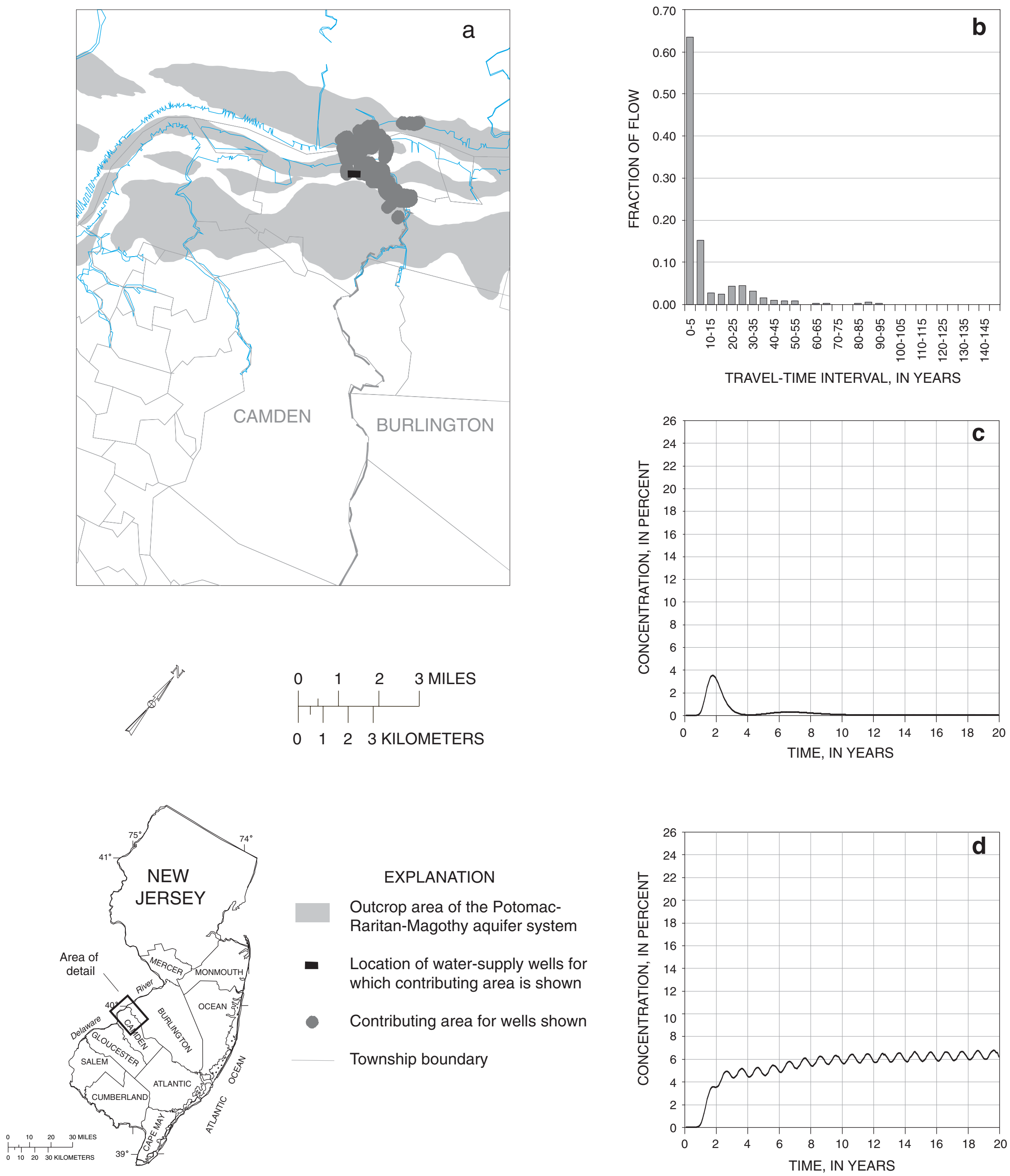


Figure 8. (a) Location of and contributing area for wells Morris 7 and 10; (b) travel-time frequency along flow paths from the Delaware River to the wells; (c) breakthrough concentration for a single 1-month saltwater-intrusion event; and (d) breakthrough concentration for an annually recurring 1-month saltwater-intrusion event.

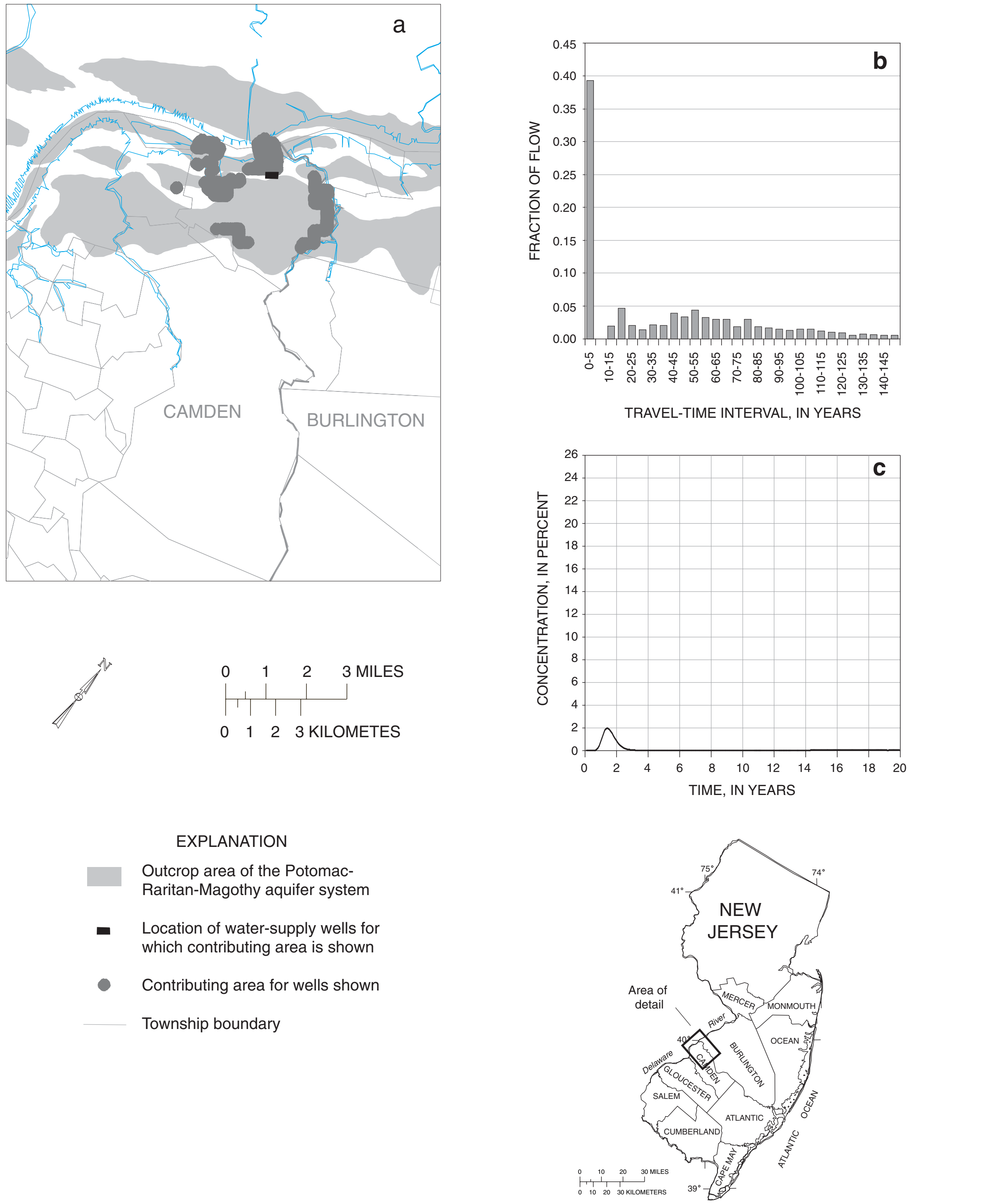


Figure 9. (a) Location of and contributing area for wells Morris 6, 8, and 9; (b) travel-time frequency along flow paths from the Delaware River to the wells; and (c) breakthrough concentration for a single 1-month saltwater-intrusion event.

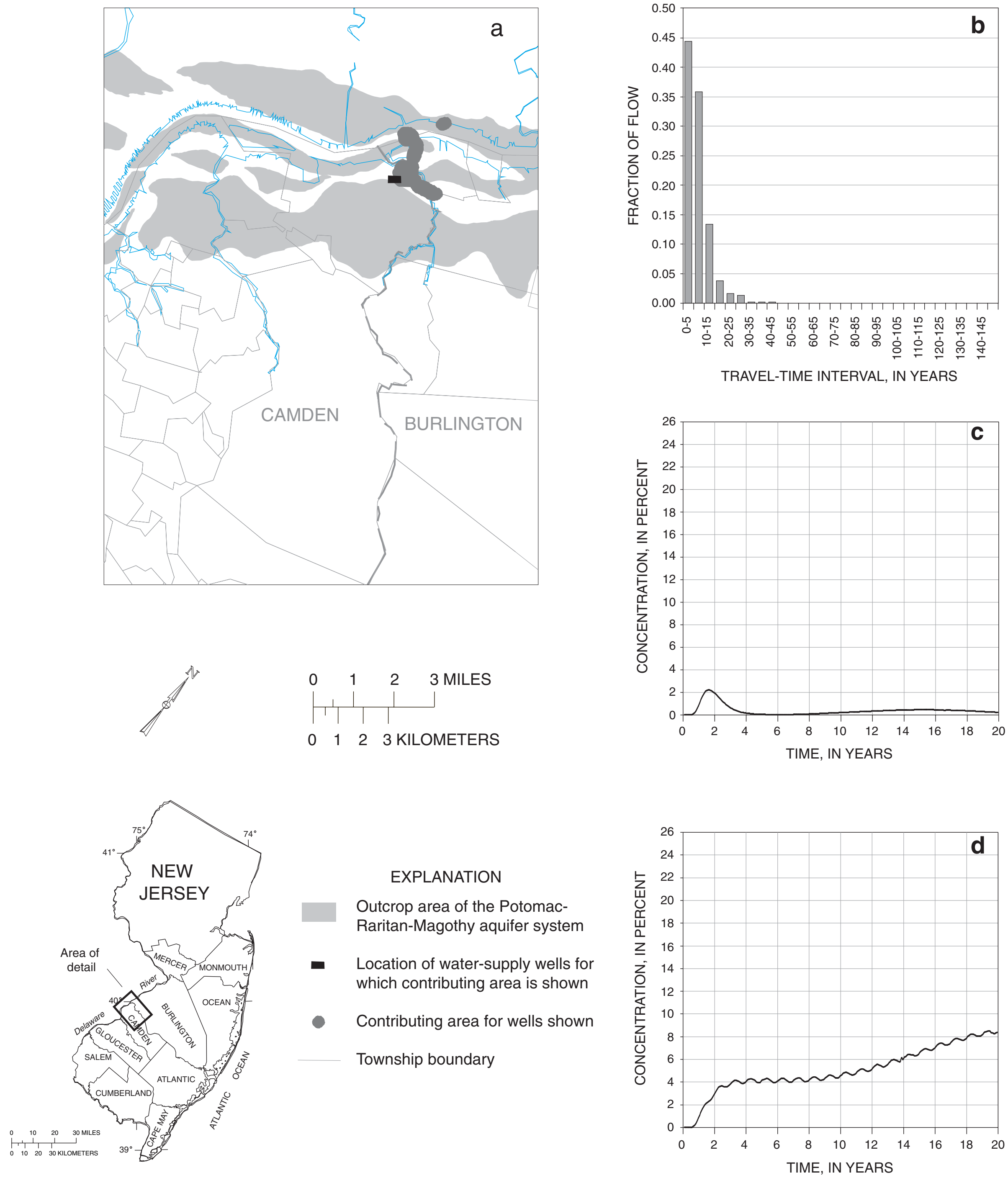


Figure 10. (a) Location of and contributing area for well Morris 3A; (b) travel-time frequency along flow paths from the Delaware River to the well; and (c) breakthrough concentration for a single 1-month saltwater-intrusion event; and (d) breakthrough concentration for an annually recurring 1-month saltwater-intrusion event.

The second group of wells listed in table 2 is substantially less vulnerable to saltwater intrusion than the first group. These wells are characterized by flow-path travel times from the river to the well that generally exceed 10 years. Whereas the percentage of river water in the withdrawals from some of these wells is high, the long travel time allows for substantial dilution of the saltwater from the river. Two examples of wells from this group are shown in figures 11 and 12. The travel times to both wells greatly exceed 10 years (figs. 11b and 12b), and the arrival-concentration graphs (figs. 11c and 12c) show virtually no response. Generally, water flowing to these wells from the river has to pass through a confining unit or units, which accounts for the increase in travel time. Although these wells do receive recharge from the river, they have a low vulnerability to intermittent saltwater intrusion. Because virtually no chloride arrived at the wells in this group, no calculation was made (in table 2) to determine the threshold concentrations of dissolved chloride and dissolved sodium in the river for nonpotability conditions to occur in these wells.

The third group of wells listed in table 2 is characterized by withdrawals that contain less than 40 percent river water and by generally small withdrawal rates. Travel times of ground-water flow from the river to wells in this group generally are long because the wells are far from the river. On the basis of the simulation, these wells will not be affected by intermittent saltwater intrusion from the Delaware River.

Limitations of Modeling

In general, results of ground-water-flow model and particle-tracking analyses are expected to give reasonable approximations of the percentage of ground-water withdrawals that is derived from the river and a good indication of the variations in ground-water travel-time with distance from the river to the well. From these factors alone, wells that are especially vulnerable to saltwater intrusion can be identified.

Although the use of the flow model is appropriate for determining regional ground-water-flow patterns and hydrologic budgets, the model may not represent ground-water flow near wells precisely because of its relatively coarse discretization (the smallest model cells are more than 800 ft on a side). Under pumping conditions, large volumes of ground water travel from a widely distributed source area to a well. Flow converges toward the well and large head gradients develop. Flow models that assign withdrawals to large cells cannot represent adequately these small-scale head gradients that develop near a pumped well. Consequently, estimates of flow-path lengths and ground-water velocities may reflect, in part, coarse model discretization, especially for short flow paths.

The estimate of the fraction of flow from each recharge source, such as the river, was determined from the proportion of total particles and is based on the assumption that an equal flow rate is associated with each particle. This is not strictly true. Flow conditions associated with each particle can differ. To minimize the deviation from this assumption, a large number of particles can be used. Flow-path analysis results for several wells were tested by formulating model runs in which 20, 200, 2,000, and 20,000 particles were distributed evenly around the walls of the cell containing the well and comparing the resulting contributing areas for each run. The 2,000- and 20,000-particle contributing areas were nearly identical, so 2,000 particles were used in each particle-tracking simulation in backtracking mode.

A one-dimensional analysis of solute transport cannot entirely approximate dispersion in a three-dimensional ground-water-flow system. Transverse dispersivities need to be specified to characterize mechanical dispersion along a path in a three-dimensional flow system more closely. Therefore, the arrival concentrations, or breakthrough curves, produced in this study probably underestimate the full measure of dispersion. This underestimate can be viewed as a “safety factor” in the analysis, because additional dispersion would lower arrival concentrations.

Wells in Salem County

Because water-supply wells within 2 mi of the Delaware River in Salem County are outside the model area used for Camden and Gloucester Counties, their vulnerability to saltwater intrusion was determined separately. For this analysis, historical chloride-concentration data, water levels, and lithologic logs of wells adjacent to the Delaware River in Salem County were compiled and reviewed. Reports on water quality and the hydrogeology of areas near or including the part of Salem County near the river also were reviewed.

The hydrogeologic framework of the Potomac-Raritan-Magothy aquifer system adjacent to the Delaware River in Salem County has not been investigated in detail, but available data are sufficient to determine a generalized (preliminary) hydrogeologic framework. The generalized section shown in figure 13 is based on a previous investigation of the sediments below the Delaware River (Duran, 1986), lithologic logs for wells 33-137 and 33-127, and the geophysical log for well 33-302 (Zapecza, 1989, pl. 4). Duran determined that a clay layer at least 50 ft thick underlies the Delaware River in the vicinity of the Delaware Memorial Bridge (fig. 2) and extends upstream about 9 mi. Duran also determined that bedrock is within 10 ft of the Delaware River channel in an area that extends from 2 mi downstream from the Salem-Gloucester County border to about 8 mi above it. The lithologic logs for wells 33-137 and 33-127 indicate a clay layer about 80 ft below land surface. This clay layer may extend under the Delaware River and merge with the clay layer under the Delaware River mapped by Duran. The outcrop area of the confining unit overlying the Middle Potomac-Raritan-Magothy aquifer is closer to the Delaware River in Gloucester County (Lewis and others (1991, pl. 6) than in Camden County. This trend continues downstream and into Salem County, but the outcrop area becomes deeper with distance downstream and eventually crops out beneath the Delaware River as shown in figure 13. This clay layer also may be continuous downdip with the clay layer overlying the Middle Potomac-Raritan-Magothy aquifer at well 33-302 shown by Zapecza (1989, pl. 4).

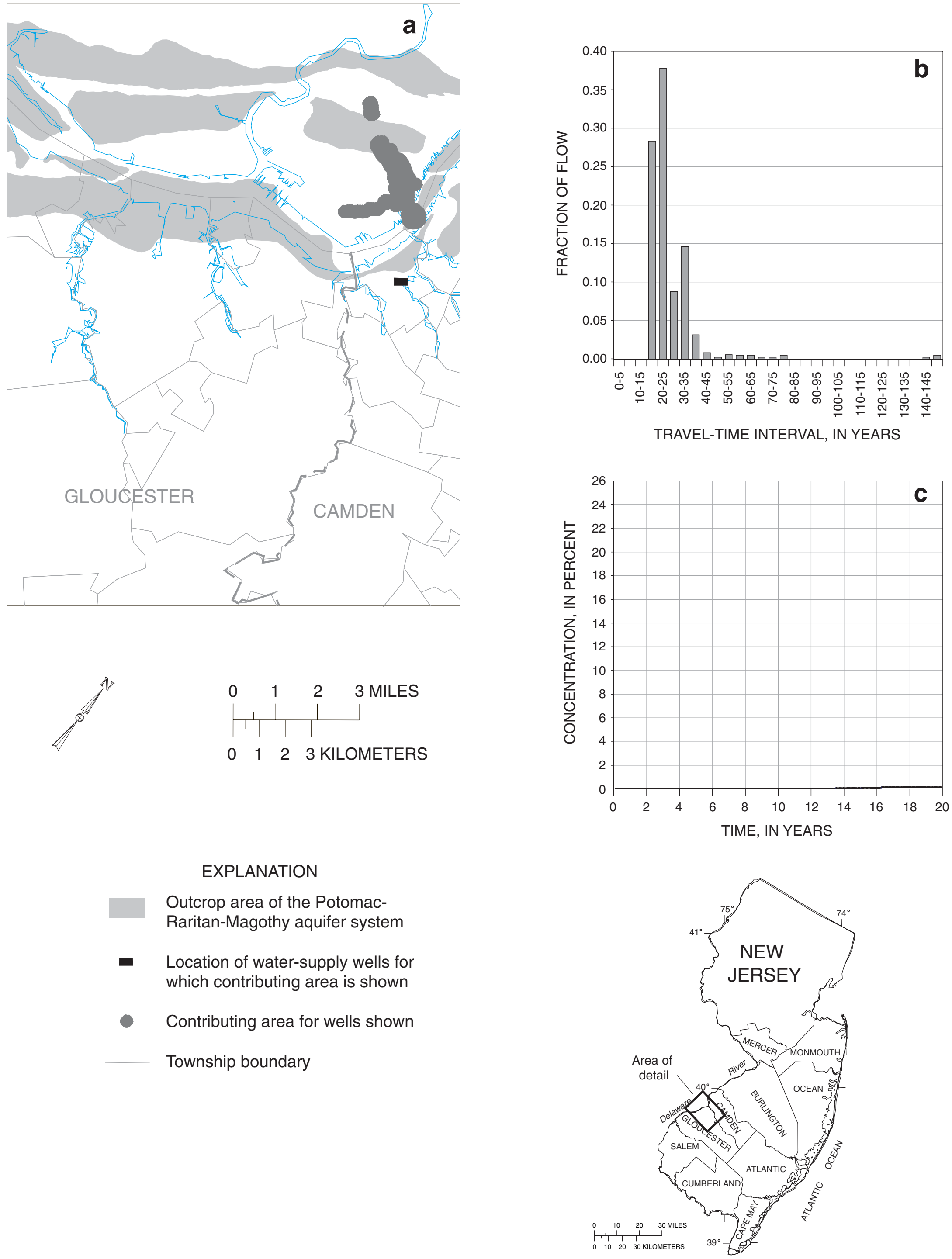


Figure 11. (a) Location of and contributing area for wells GCWD 40, 42, and 43; (b) travel-time frequency along flow paths from the Delaware River to the wells; and (c) breakthrough concentration for a single 1-month saltwater-intrusion event.

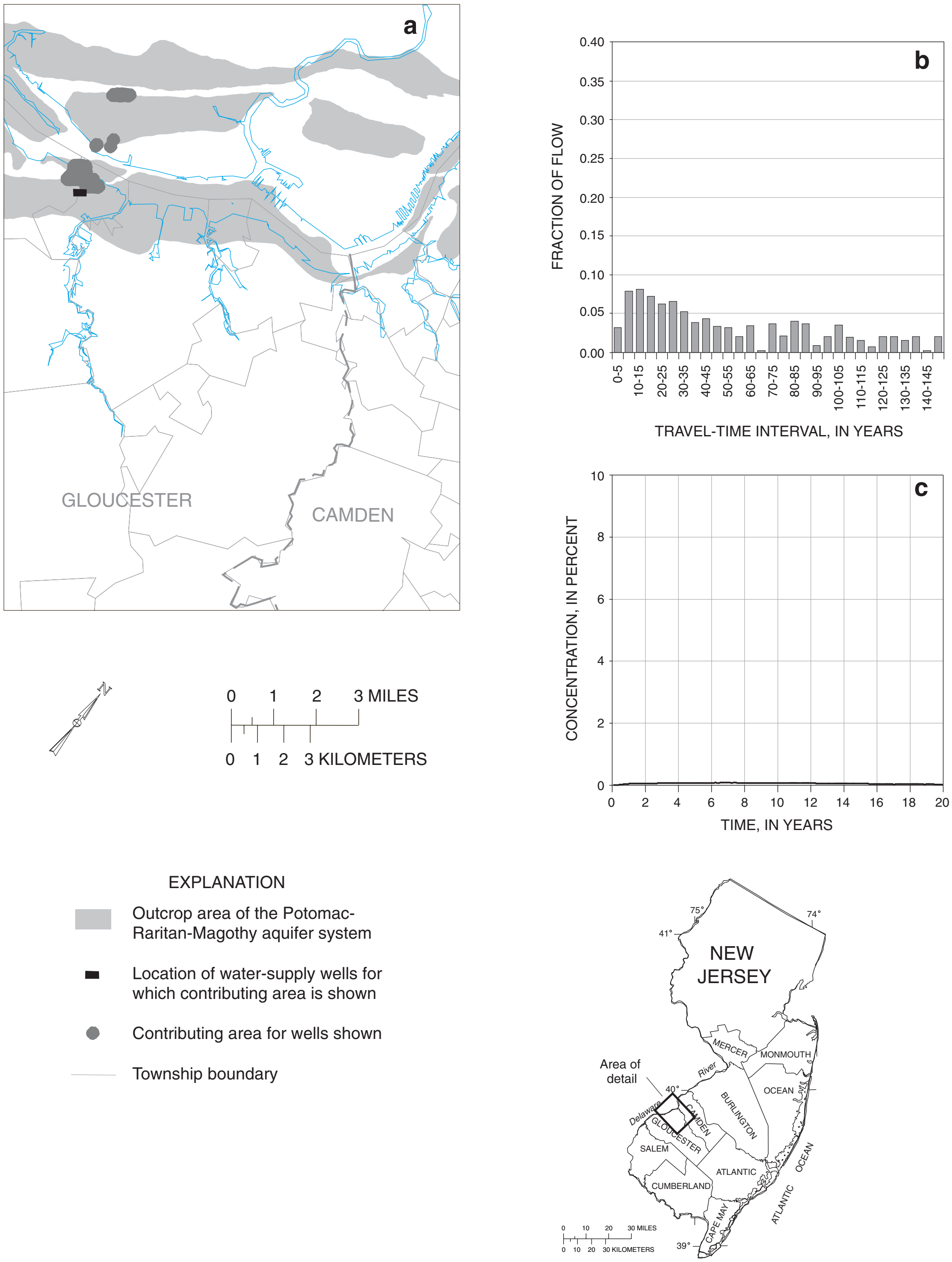


Figure 12. (a) Location of and contributing area for wells RW-5, RW-6, and Mobil 47; (b) travel-time frequency along flow paths from the Delaware River to the wells; and (c) breakthrough concentration for a single 1-month saltwater-intrusion event.

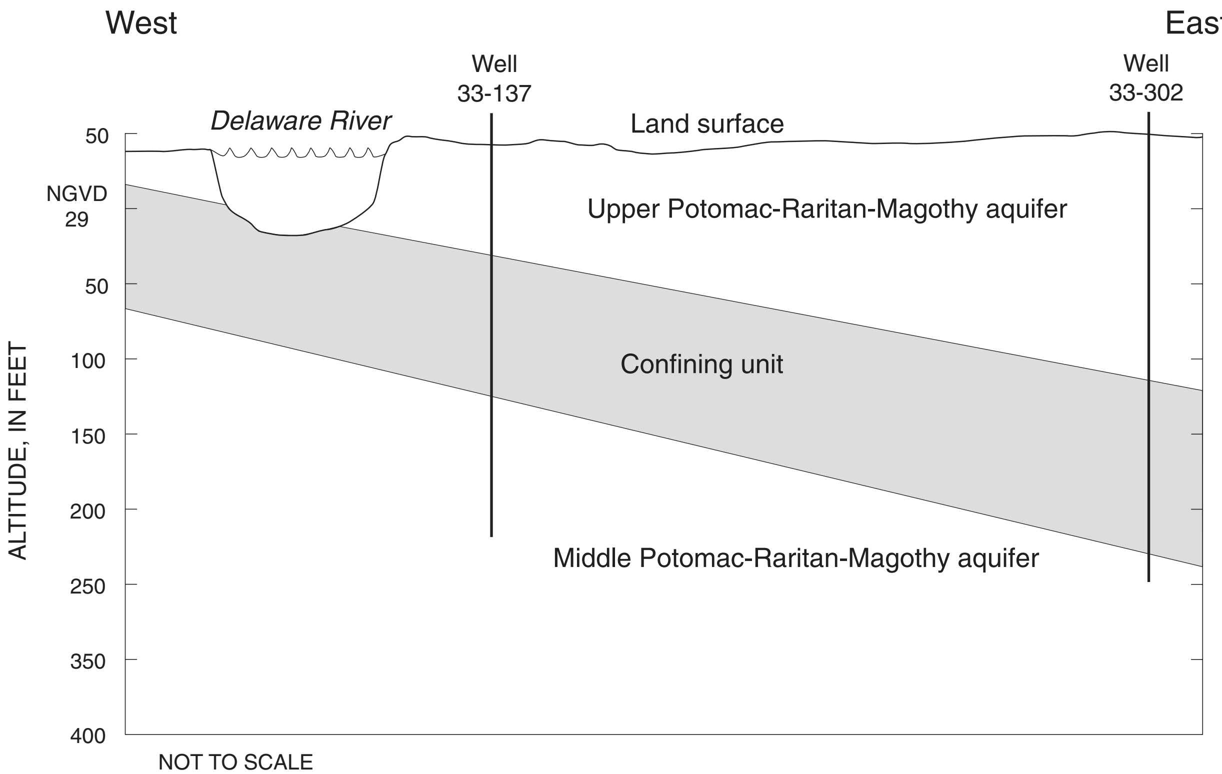


Figure 13. Generalized hydrogeologic section through Salem County, N.J.

The wells in Salem County with the greatest withdrawals are clustered in one area and generally withdraw water from the Middle Potomac-Raritan-Magothy aquifer near the Delaware River. The potentiometric surface of the Middle Potomac-Raritan-Magothy aquifer in this area, shown in figure 14, was determined from water levels measured in nine wells in 1988 (Rosman and Lacombe, 1995). The water levels are similar to those measured in 1973 (Walker, 1983) and may indicate that the ground-water-flow system in this area has stabilized with respect to ground-water withdrawals. Fewer water levels were measured in this area during the Coastal Plain-wide synoptic water-level measurement conducted in 1993 (Lacombe and Rosman, 1997) than in previous measurements. The water level in well 33-119 in 1993 was 44 ft below NGVD 1929 (“sea level”); this value is similar to those measured in 1973 (-46 ft) and 1988 (-43 ft). The similarity of these water levels is additional evidence that the ground-water-flow system in this area has stabilized with respect to ground-water withdrawals.

Water levels in wells within 1,000 ft of the Delaware River in Salem County are about 25 to 43 ft lower than those in wells within 1,000 ft of the Delaware River in Camden County. Ground-water withdrawals from wells within 2 mi of the Delaware River in 1996 in Salem County totaled 2,230 Mgal/yr (table 1) and in Camden County totaled 6,529 Mgal/yr. Therefore, water levels in Salem County are lower than those in Camden County, not as a result of greater ground-water withdrawals, but likely because the hydraulic connection of the aquifer system with the Delaware River is more limited in this area than in places upstream from Salem County, such as Pennsauken in Camden County (fig. 2).

Chloride concentrations as high as 2,000 mg/L have been measured in the Delaware River at the Salem-Gloucester County line (Hardt and Hilton, 1969). If the hydraulic connection between the Delaware River and the Middle Potomac-Raritan-Magothy aquifer was good, chloride concentrations in wells in this area would be high. Although the background

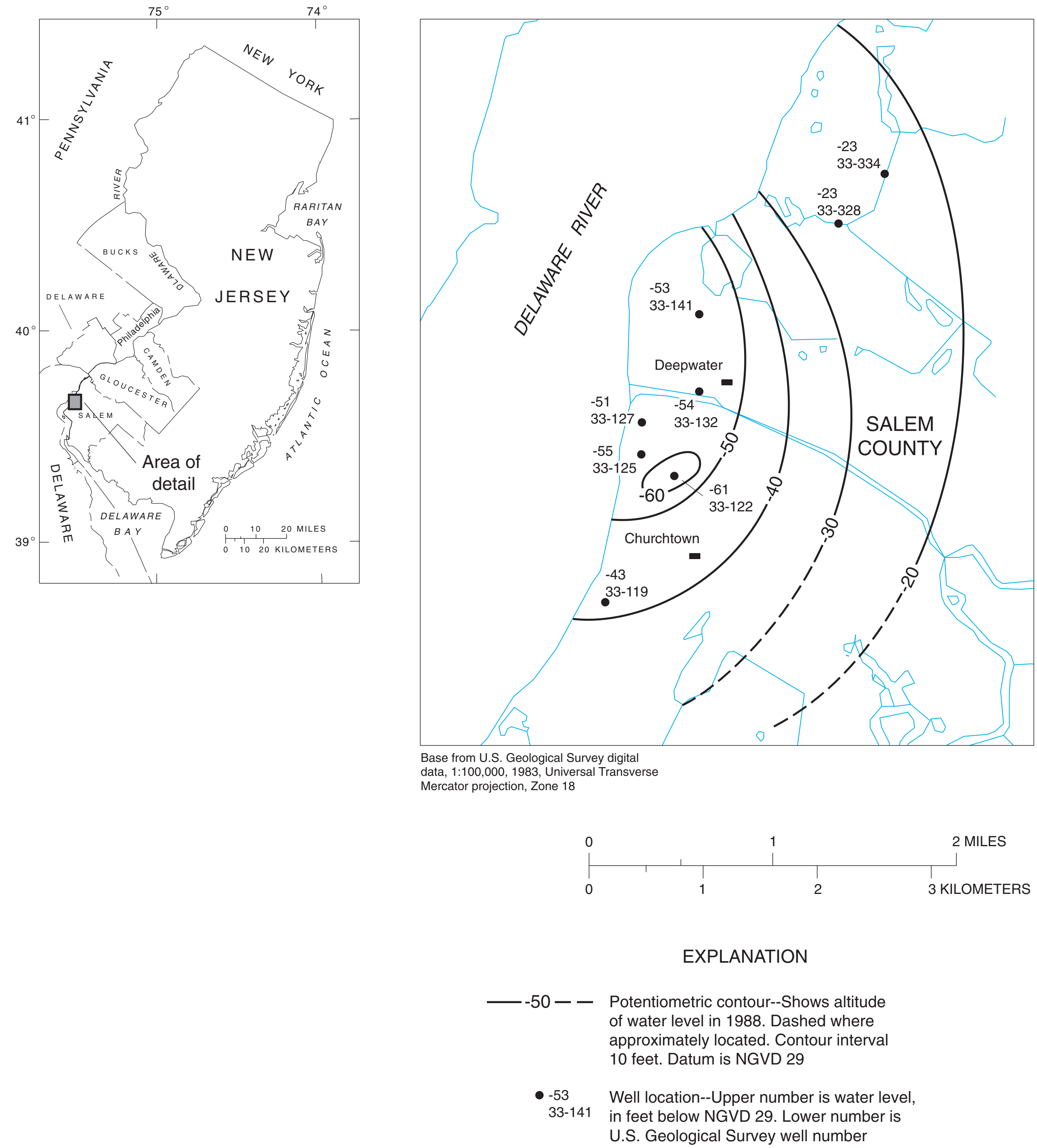


Figure 14. Potentiometric surface of the Middle Potomac-Raritan-Magothy aquifer, Salem County, N.J., 1988.

values are higher in Salem County than in Camden or Gloucester County, chloride concentrations in water from 12 wells in this area, shown in figure 15, ranged only from 55 to 317 mg/L.

On the basis of results of previous hydrogeologic investigations, lithologic logs, water levels, and low chloride concentrations in wells within 2 mi of the Delaware River in Salem County, the Middle and Lower Potomac-Raritan-Magothy aquifers appear to be confined in this area and to have only a limited hydraulic connection with the Delaware River.

An estimate of the travel time of ground water from the Delaware River through the confining unit to wells near the Delaware River can be made by means of Darcy’s law. Estimated hydraulic conductivities of the confining unit in this area can be calculated from Martin (1998) and range from 0.12775 to 0.2555 ft/yr. If porosity is assumed to be 35 percent and the minimum water level in the Middle Potomac-Raritan-Magothy aquifer is assumed to be 60 ft below sea level, the travel-time calculation indicates that it would take 100 to 225 years for river water to travel from the river, through the confining unit, to water-supply wells in this area. This travel time is substantially longer than that calculated for wells in the part of the study area in Camden and Gloucester Counties. These data suggest that the vulnerability of the Salem County wells to saltwater intrusion from the Delaware River under current pumping conditions is low.

Summary and Conclusions

The Potomac-Raritan-Magothy aquifer system is hydraulically well connected with the Delaware River in parts of Camden and Gloucester Counties, New Jersey, and has a more limited contact with the river in Salem County, New Jersey. The aquifer system is used widely for water supply, and about 122 production wells (wells with New Jersey Department of Environmental Protection (NJDEP) water-allocation permits) in the three counties are within 2 miles (mi) of the river and withdraw about 12,220 million gallons per year (Mgal/yr). During drought, saltwater may threaten to encroach upstream from the Atlantic Ocean and Delaware Bay to areas that recharge the aquifer system. Additionally, consideration of any sea-level-rise effects amplifies these concerns. During the drought of the mid-1960's, chloride concentrations in the reach of the river that recharges nearby water-supply wells temporarily exceeded the drinking-water (potability) standard of 250 mg/L. Intrusion of this water into the aquifer caused chloride concentrations in some wells to increase temporarily, but these concentrations did not exceed the drinking-water standard.

To address the concern about the potential for saltwater intrusion in the future, a ground-water-flow model, particle tracking, and a one-dimensional ground-water transport model were used to assess the vulnerability of wells in Camden and Gloucester Counties to saltwater intrusion from the Delaware River. Analysis of the ground-water-flow model simulation using particle tracking yielded flow paths, the proportion of flow originating from the river, and velocities for production wells near the river. The path lengths and velocities were used as input to the one-dimensional transport model to determine simulated breakthrough times and concentrations, in terms of percent of initial river concentrations, of induced flow from the Delaware River to the wells. In this manner, the chloride concentration in the Delaware River that would be necessary to render the water in production wells near the river nonpotable was estimated for two scenarios--a single encroachment event lasting 1 month, and intermittent, recurring encroachment events that last 1 month during each year.

A suitable ground-water-flow model for similar use in the Salem County area was not available. Accordingly, an analysis of the hydrogeologic framework and potentiometric surface in the vicinity of production wells in Salem County near the river indicates that the effect of induced infiltration of saltwater from the river on wells can vary greatly depending on the distance of the wells from the river, ground-water withdrawal rates, and the local hydrogeologic framework.

The following conclusions pertaining to the vulnerability of water-supply wells in the Potomac-Raritan-Magothy aquifer system in Camden, Gloucester, and Salem Counties, New Jersey, to saltwater intrusion from the Delaware River can be drawn from the findings of this investigation:

1. There are 122 production wells (wells for which water-allocation permits have been issued by NJDEP) within a 2-mi distance of the Delaware River in Camden, Gloucester, and Salem Counties.

2. The production wells in Camden and Gloucester Counties can be divided into three categories with respect to their vulnerability to saltwater intrusion from the Delaware River during a drought resulting in an intermittent saltwater intrusion event lasting about 1 month (similar to that experienced in the drought of the mid-1960's). The categories are “high,” “low,” and “no vulnerability.”

3. Wells in the high-vulnerability group are those in the Morris and Delair well fields in Camden County (14 percent of the 83 wells investigated in Camden and Gloucester Counties). These wells receive a large percentage of their recharge (50 percent or more) from the Delaware River, have large withdrawals, and are sufficiently close to the river that the travel time from the river to the wells generally is less than 20 years and for several wells is less than 5 years. Because dilution occurs along ground-water-flow paths, however, concentrations of dissolved chloride or dissolved sodium in the river would have to exceed 2,098 mg/L or 407 mg/L, respectively, for a single 1-month encroachment event, or 1,818 mg/L or 358 mg/L, respectively, for an annually recurring 1-month encroachment event to threaten the potability of the water in these wells (if drinking-water standards are assumed to be 250 mg/L for dissolved chloride and 50 mg/L for dissolved sodium). The single one-month encroachment event chloride concentration exceeds that measured in the river during the 1960's drought by more than six times.

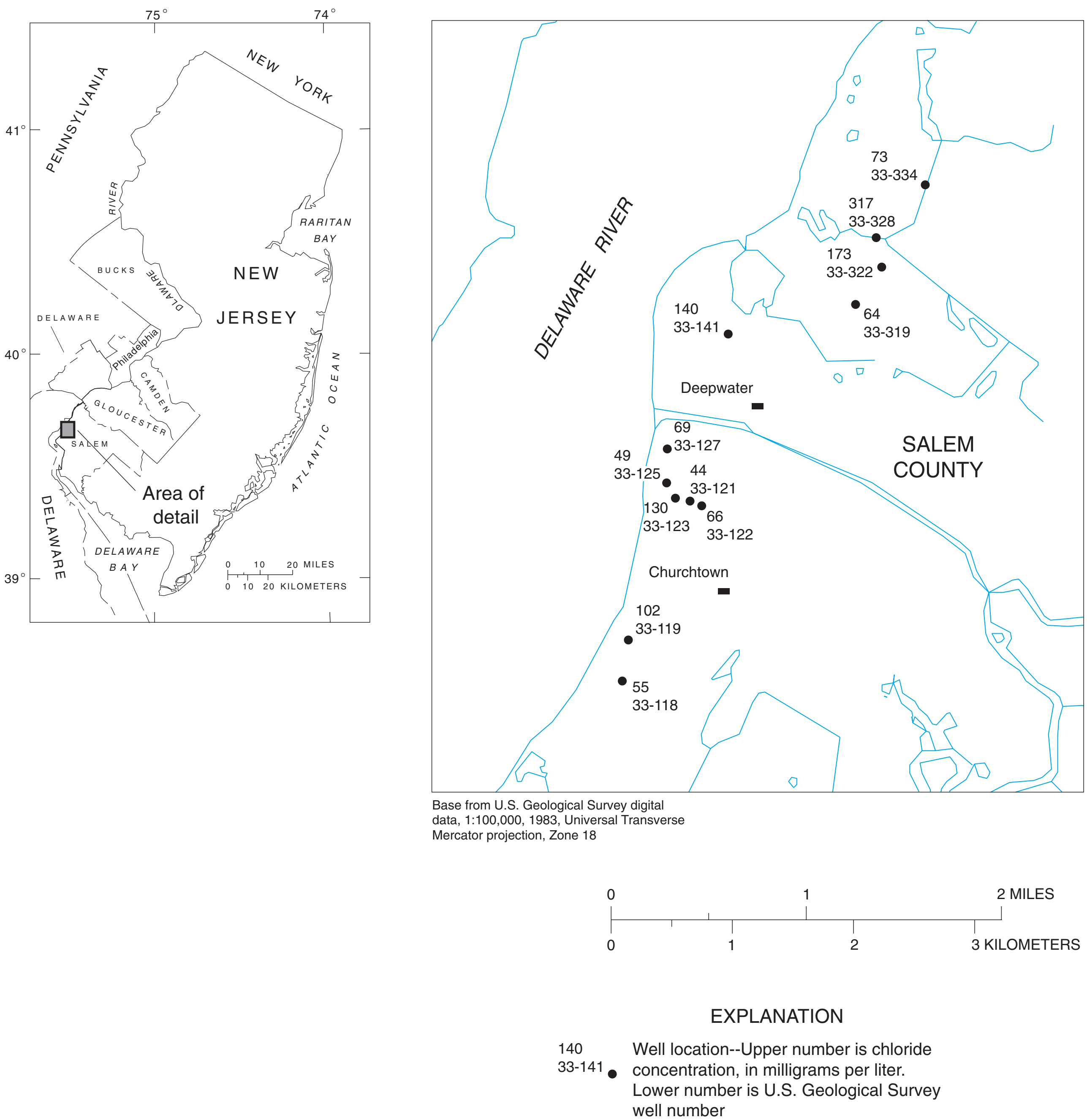


Figure 15. Concentration of dissolved chloride from water samples from the Middle Potomac-Raritan-Magothy aquifer, Salem County, N.J., 1968-95.

4. Wells in the low-vulnerability category include 28 of the 83 wells investigated in Camden and Gloucester Counties. These wells receive a large percentage of their recharge (40 percent or more) from the river, but the effects of intermittent intrusion of saltwater from the river are minimized because the travel time from river to well is longer than that for the high-vulnerability wells as a result of smaller withdrawal rates or greater distance from the river. The longer travel time, in turn, allows additional dilution to occur. Therefore, concentrations of dissolved chloride or dissolved sodium in the river would have to be substantially higher than the level that would affect the wells in the high-vulnerability category (1,818 mg/L or 358 mg/L, respectively) to cause water in these wells to become nonpotable. Consequently, these wells are not considered to be vulnerable to drought-related saltwater intrusion.

5. Wells that have a long travel time from river to well (greater than 20 years) and receive only a small amount of their recharge (less than 40 percent) from the river are in the no-vulnerability category. This includes 43 of the 83 wells investigated in Camden and Gloucester Counties. Based on the simulations, these wells do not receive enough recharge from the river to be vulnerable to saltwater intrusion from the river.

6. Analyses of the hydrogeology and potentiometric surface of the Salem County part of the study area indicate that water from the Delaware River flows to the wells through a confining unit. This pathway results in long travel times similar to those associated with wells in the low-vulnerability category in Camden and Gloucester Counties. Although these wells receive recharge from the river, the long travel time substantially reduces the peak constituent concentrations as a result of dilution and dispersion. Because the Salem County wells are farther downstream than those in Camden and Gloucester Counties, chloride concentrations in the adjacent river reach tend to be higher than those in the upstream wells under any given circumstance; therefore, their “baseline” vulnerability is higher. A detailed flow model of the part of Salem County near the river would be needed to assess accurately the vulnerability of these wells to saltwater intrusion.

7. Based on the simulations, if the saltwater-encroachment conditions experienced in the drought of the mid-1960's were to recur, it is unlikely that the potability of water from production wells within 2 mi of the Delaware River that are completed into the Potomac-Raritan-Magothy aquifer system in the Camden/Gloucester/Salem County area would be threatened by the intrusion of saltwater from the river.

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Table 1. Locations of, construction data for, and withdrawals from wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden, Gloucester, and Salem Counties, N.J.

[NJDEP, New Jersey Department of Environmental Protection; Mgal/yr, million gallons per year; --, no data; Aquifer codes: QRNR, Quaternary deposits; HPPN, undifferentiated Holocene, Pleistocene, Pliocene, and (or) Miocene deposits; MLRW, Wenonah-Mt. Laurel aquifer; MRPA, Potomac-Raritan-Magothy undifferentiated; MRPAU, Upper Potomac-Raritan-Magothy aquifer; MRPAM, Middle Potomac-Raritan-Magothy aquifer; MRPAL, Lower Potomac-Raritan-Magothy aquifer]

Map number of well in figure 1	Well owner	Local well name	Well number	Aquifer code	Altitude of land surface (feet above NGVD 1929)	Open interval (feet below land surface)		NJDEP permit number	1996 withdrawals (Mgal/yr)
						Top	Bottom		
			Camden County						
1	BELLMAWR B W D	BBWD 3	7-12	MRPAL	35	334	359	31-02687	28.919
2	BELLMAWR B W D	BBWD 6	7-601	MRPAL	40	330	381	31-19218	45.456
3	BROOKLAWN B W D	BBWD 3	7-520	MRPAL	10	307	327	31-04325	23.367
4	BROOKLAWN B W D	BBWD 5(OW 3)	7-531	MRPAL	10	300	320	31-14471	25.492
5	BROOKLAWN B W D	BBWD 4	7-596	MRPAL	10	263	293	31-19765	58.2
6	CAMDEN CITY W D	CITY 11	7-46	MRPAM	13	124	154	51-00061	11.81
7	CAMDEN CITY W D	DELAIR 1	7-368	MRPAL	10	106	126	51-00053	333.875
8	CAMDEN CITY W D	DELAIR 2	7-369	MRPAL	5	111	141	51-00054	333.875
9	CAMDEN CITY W D	DELAIR 3	7-370	MRPAL	6	87	127	51-00055	333.875
10	CAMDEN CITY W D	MORRIS 6	7-373	MRPAL	5.9	98	133	51-00051	333.875
11	CAMDEN CITY W D	MORRIS 9	7-374	MRPAL	6.8	99	118	51-00076	333.875
12	CAMDEN CITY W D	MORRIS 8	7-375	MRPAL	6	89	124	31-00944	333.875
13	CAMDEN CITY W D	MORRIS 7	7-377	MRPAL	6	85	120	51-00052	333.875
14	CAMDEN CITY W D	MORRIS 10	7-379	MRPAL	8.7	75	115	31-04251	333.875
15	CAMDEN CITY W D	MORRIS 3A	7-386	MRPAL	10	73	103	31-00945	333.875
16	CAMDEN CITY W D	MORRIS 1	7-390	MRPAL	6	93	118	51-00050	333.875
17	CAMDEN CITY W D	PARKSIDE 18	7-527	MRPAL	40	258	288	31-09574	201.84
18	CAMDEN CITY W D	MORRIS 11	7-545	MRPAL	15.3	102	144	31-15745	333.875
19	CAMDEN CITY W D	MORRIS 12	7-586	MRPAL	10	86	117	31-16814	333.875
20	CAMDEN CITY W D	MORRIS 13	7-587	MRPAL	10	90	130	31-16813	333.875
21	GLOUCESTER C WD	GCWD 42	7-210	MRPAL	15	--	--	31-05242	17.547
22	GLOUCESTER C WD	GCWD 40	7-220	MRPAL	10	221	261	31-04306	149.51

Table 1. Locations of, construction data for, and withdrawals from wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden, Gloucester, and Salem Counties, N.J.—Continued

[NJDEP, New Jersey Department of Environmental Protection; Mgal/yr, million gallons per year; --, no data; Aquifer codes: QRNR, Quaternary deposits; HPPN, undifferentiated Holocene, Pleistocene, Pliocene, and (or) Miocene deposits; MLRW, Wenonah-Mt. Laurel aquifer; MRPA, Potomac-Raritan-Magothy undifferentiated; MRPAU, Upper Potomac-Raritan-Magothy aquifer; MRPAM, Middle Potomac-Raritan-Magothy aquifer; MRPAL, Lower Potomac-Raritan-Magothy aquifer]

Map number of well in figure 1	Well owner	Local well name	Well number	Aquifer code	Altitude of land surface (feet above NGVD 1929)	Open interval (feet below land surface)		NJDEP permit number	1996 withdrawals (Mgal/yr)
						Top	Bottom		
				Camden County--Continued					
23	GLOUCESTER C WD	GCWD 43	7-516	MRPAL	10	220	260	31-18822	53.152
24	GLOUCESTER C WD	GCWD 41/AKA 3104903 RD	7-902	MRPAU	10	225	265	31-27737	207.447
25	MACANDREWS & FORBES CO	M&F IND 3R	7-825	MRPAM	10	86	146	31-42789	33.402
26	MAFCO	MAFCO 4R/1	7-43	MRPAM	12	82	103	31-00290	10.061
27	MCHVIL PNSK WCM	1R	7-319	MRPAM	15	132	152	31-05641	277.867
28	MCHVIL PNSK WCM	WOODBINE 1	7-320	MRPAL	69	245	285	31-04642	47.744
29	MCHVIL PNSK WCM	MARION 1	7-335	MRPAL	61	243	278	31-02915	139.934
30	MCHVIL PNSK WCM	NATIONAL HWY 1	7-372	MRPAL	68	195	230	31-05110	0.271
31	MCHVIL PNSK WCM	WOODBINE 2	7-560	MRPAL	58	196	226	31-14563	66.769
32	MCHVIL PNSK WCM	NATIONAL HWY 2	7-602	MRPAL	35	182	206	31-19207	306.04
33	NEW JERSEY WATER CO	CLEVELAND AVE PW 53	7-724	MRPAL	32	154	194	31-18947	120.404
34	NJ/AMERICAN WATER CO	CAMDEN DIV 52	7-98	MRPAL	18	147	198	31-04847	204.04
35	NJ/AMERICAN WATER CO	54	7-547	MRPAL	35	155	195	31-18944	154.655
36	NJ/AMERICAN WATER CO	55	7-597	MRPAL	11	136	176	31-20270	5.498
37	OUR LADY HOSP	STAND BY WELL	7-57	MRPAL	30	237	258	31-04620	0.01
								Total	6,529.81
				Gloucester County					
38	BP OIL CO	BP R-6-A	15-1120	MRPAM	14	6	72	30-07032	40.234
39	BP OIL CO	BP R-8-A	15-1121	MRPAM	14	39	85	30-07014	16.489
40	BP OIL CO	BP R-9-A	15-1122	MRPAM	14	45	90	30-07015	17.349
41	BP OIL CO	BP R-7-A	15-1124	MRPAM	32	95	40	30-07012	16.022
42	BP OIL COMPANY - PAULSBORO TERMINAL	BP R-4A	15-1378	HPPM	20	11	82	30-06920	19.921
43	BP OIL COMPANY - PAULSBORO TERMINAL	BP R-10A	15-1383	HPPM	15	9	39	30-07028	7.204

Table 1. Locations of, construction data for, and withdrawals from wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden, Gloucester, and Salem Counties, N.J.—Continued

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Map number of well in figure 1	Well owner	Local well name	Well number	Aquifer code	Altitude of land surface (feet above NGVD 1929)	Open interval (feet below land surface)		NJDEP permit number	1996 withdrawals (Mgal/yr)
						Top	Bottom		
			Gloucester County--Continued						
44	BP OIL COMPANY - SOHIO PAULSBORO	BP 51-1	15-1381	HPPM	13.89	8	28	30-05153	.178
45	BP OIL COMPANY - SOHIO PAULSBORO	BP RECOVERY 2	15-1382	HPPM	15	4	24	30-05183	7.004
46	COASTAL EAGLE POINT OIL COMPANY	EAGLE POINT 7	15-317	MRPAL	10	261	301	31-06834	140.319
47	COASTAL EAGLE POINT OIL COMPANY	EAGLE POINT 1	15-320	MRPAL	20	248	288	31-00007	85.453
48	COASTAL EAGLE POINT OIL COMPANY	EAGLE POINT 3	15-322	MRPAL	20	258	288	31-00008	73.697
49	COASTAL EAGLE POINT OIL COMPANY	EAGLE POINT 6A	15-430	MRPAL	15	256	328	31-17788	222.526
50	E I DUPONT	REPAUNO 3	15-72	MRPAM	6	91	101	30-00037	151.512
51	E I DUPONT	REPAUNO 6	15-79	MRPAM	10	84	109	30-01145	25.648
52	E I DUPONT	INTERCEPTOR 46	15-692	MRPAM	5	96	136	30-03594	162.461
53	GREENWICH T W D	GTWD 5 (2-A)	15-347	MRPAM	20	82	117	30-01545	137.675
54	GREENWICH T W D	GTWD 6	15-348	MRPAM	20	105	135	30-01776	103.554
55	GREENWICH T W D	MEMORIAL AVE 4R	15-1364	MRPAM	15	98	166	30-09345	107.177
56	HERCULES CHEMICAL	4 1970	15-76	MRPAM	15	90.5	120.5	30-01224	25.389
57	HERCULES INC	HERCULES PW 11	15-1034	MRPAM	10	90	120	30-04319	51.364
58	HERCULES INC - HIGGINS PLANT	HERCULES PW-10	15-1373	MRPAM	12	14.7	45	30-04426	9.773
59	LOGAN WELLS WATER CO	LWWC BIRCH CK RD 4	15-1362	MRPAM	19	56	91	30-09444	85.095
60	MOBIL OIL COMPANY	MOBIL 47	15-118	MRPAL	18	220	240	30-00198	3.405
61	MOBIL OIL COMPANY	RW-5	15-823	QRNR	25.4	18	53	30-01909	22.869
62	MOBIL OIL COMPANY	RW-6	15-824	QRNR	18.8	13.5	48.5	30-01905	50.047
63	MOBIL OIL COMPANY	RW-8	15-826	QRNR	19	15	50	30-01906	5.973

Table 1. Locations of, construction data for, and withdrawals from wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden, Gloucester, and Salem Counties, N.J.—Continued

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Map number of well in figure 1	Well owner	Local well name	Well number	Aquifer code	Altitude of land surface (feet above NGVD 1929)	Open interval (feet below land surface)		NJDEP permit number	1996 withdrawals (Mgal/yr)
						Top	Bottom		
				Gloucester County--Continued					
64	MOBIL OIL COMPANY	MOBIL 48 DWTA	15-1039	MRPAM	7	100	153	30-05060	90.081
65	MOBIL OIL COMPANY	MOBIL RW-19	15-1374	MRPAM	5	15	55.7	30-05642	140.96
66	MONSANTO CHEM	BRIDGEPORT W2	15-158	MRPAM	12	57	82	30-00873	200.006
67	MONSANTO CHEM	BRIDGEPORT E1	15-159	MRPAM	11	56	81	30-00872	59.579
68	MONSANTO CHEM	MONSANTO 1	15-167	MRPAM	10	64	94	30-01170	107.841
69	NATIONAL PK W D	NPWD 2/NPWD 5	15-207	MRPAL	30	241	282	31-02555	48.195
70	NATIONAL PK W D	NPWD 6	15-533	MRPAL	22	240	272	31-17938	66.433
71	PAULSBORO W D	1973-6	15-210	MRPAM	15	185	227	30-01348	111.811
72	PAULSBORO W D	PWD 4	15-212	MRPAM	25	192	220	30-00069	53.828
73	PAULSBORO W D	PWD 5	15-213	MRPAM	10	135	175	30-00602	114.423
74	PENNS GROVE WSC	BRIDGEPORT BACKUP-2	15-697	MRPAM	8	69	84	30-03332	4.899
75	PENNS GROVE WSC	BRIDGEPORT 2	15-166	MRPAM	5	65.4	85.4	30-00410	31.818
76	PENNWALT CORP	418	15-304	MRPAL	10	237	289	30-01173	7.29
77	PENNWALT CORP	417	15-306	MRPAL	10	234	276	30-01174	288.57
78	TEXAS OIL CO	EAGLE POINT 4A	15-410	MRPAL	5	256	296	31-10647	1.908
79	W DEPTFORD T WD	6 RED BANK AVE	15-312	MRPAL	20	322	372	51-00063	135.476
80	W DEPTFORD T WD	WDTWD 7	15-373	MRPAL	28	323	363	31-17452	216.473
81	WESTVILLE W D	WWD 5	15-326	MRPAL	12	243	277	31-05689	141.34
82	WESTVILLE W D	WWD 4	15-327	MRPAL	16	286	313	31-03418	45.884
83	WESTVILLE W D	WWD 6	15-434	MRPAL	15	265	317	31-17923	5.277
								Total	3,460.43

Table 1. Locations of, construction data for, and withdrawals from wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden, Gloucester, and Salem Counties, N.J.—Continued

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Map number of well in figure 1	Well owner	Local well name	Well number	Aquifer code	Altitude of land surface (feet above NGVD 1929)	Open interval (feet below land surface)		NJDEP permit number	1996 withdrawals (Mgal/yr)
						Top	Bottom		
			Salem County						
84	ATL CITY ELEC	DEEPWATER 3R	33-122	MRPAM	10	165	235	30-01234	8.294
85	ATL CITY ELEC	DEEPWATER 2	33-123	MRPAM	10	157	234	50-00001	15.351
86	ATL CITY ELEC	DEEPWATER 5	33-125	MRPAM	10	149	219	30-00151	11.403
87	ATLANTIC CITY ELEC CO - DEEPWATER STA	AC ELEC IW-3R	33-897	MRPAM	5	189	229	30-08099	59.371
88	B F GOODRICH CO	6 (PW-2)	33-85	MRPAM	10	109	129	30-01141	186.336
89	B F GOODRICH CO	4 (PW-3)	33-86	MRPAL	13	169	189	30-01139	123.259
90	B F GOODRICH CO	3	33-432	MRPAL	10	180	195	50-00079	7.261
91	E I DUPONT	CHAMBERS INJ 1	33-129	MRPAM	8	--	--	30-01018	73.98
92	E I DUPONT	DRINKWATER 8	33-137	MRPAL	14	317	347	50-00003	.009
93	E I DUPONT	CHAMBERS INJ 3	33-138	MRPAL	5	314	462	30-01049	.018
94	E I DUPONT	102	33-316	MRPAU	5	--	--	30-02322	8.053
95	E I DUPONT	104	33-319	MRPAM	5	--	--	30-01272	59.738
96	E I DUPONT	CARNEY PT 2	33-322	MRPAM	5	169	219	50-00004	17.87
97	E I DUPONT	CARNEY PT 4	33-326	MRPAU	5	--	--	30-00423	4.505
98	E I DUPONT	CHAMBERS 108	33-602	MRPAM	5	43.1	86.2	30-03368	164.032
99	E I DUPONT	DUPONT REPL 103A	33-857	MRPAM	5	49	81	30-03367	204.242
100	E I DUPONT	CHAMBERS 5-R	33-898	MRPAM	5	81	119	30-04667	189.264
101	GEON COMPANY	BFG SHALLOW WELL 10	33-784	MRPAM	10	76	102	30-06023	13.406
102	PEDRICKTOWN COGENERATION LTD	PEDRICKTOWN PW-3	33-899	MRPAL	15	170	195	30-08172	94.044
103	PEDRICKTOWN COGENERATION LTD	PEDRICKTOWN PW-1	33-901	MRPAL	15	207	248	30-07176	46.141
104	PEDRICKTOWN COGNERATION LTD	PEDRICKTOWN PW-2	33-900	MRPAL	10	215	235	30-07824	5.159
105	PENNS GROVE WATER CO	RF 3A	33-750	MRPAU	20	36	56	30-03535	84.277
106	PENNS GROVE WATER SUPPLY CO	LAYTON 2	33-697	MRPAU	12	47	62	30-01113	88.69

Table 1. Locations of, construction data for, and withdrawals from wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden, Gloucester, and Salem Counties, N.J.—Continued

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Map number of well in figure 1	Well owner	Local well name	Well number	Aquifer code	Altitude of land surface (feet above NGVD 1929)	Open interval (feet below land surface)		NJDEP permit number	1996 withdrawals (Mgal/yr)
						Top	Bottom		
			Salem County--Continued						
107	PENNS GROVE WSC	LAYTON 11	33-330	MRPAL	16	--	--	50-00098	53.839
108	PENNS GROVE WSC	LAYNE 1	33-346	MRPAL	19	317	357	30-00563	169.989
109	PENNS GROVE WSC	SCHULTES 4	33-361	MRPAU	13	44	54	30-01815	88.69
110	PENNS GROVE WSC	PGWSC 1A/RF2A	33-460	MRPAU	19	41	61	30-03310	65.303
111	PENNS GROVE WSC	RTE 48 & DUPONT RD RF2B	33-767	MRPAU	20	50	65	30-08511	0.332
112	PENNSVILLE T WD	PTWD 1	33-118	MRPAM	8	213	238	50-00041	31.925
113	PENNSVILLE T WD	PTWD 2	33-119	MRPAM	7	210	230	30-00018	46.987
114	PENNSVILLE T WD	PTWD 5	33-360	MRPAU	10	101	117	28-10466	87.094
115	PENNSVILLE T WD	PTWD 6	33-453	MRPAU	10	99	114	30-03013	9.299
116	PENNSVILLE T WD	PTWD 3A	33-671	MRPAU	7	87	102	30-05148	79.827
117	PENNSVILLE TWP	PTWD 4A RPL	33-686	MRPAU	10	110	130	30-08335	68.79
118	PUBLIC SERV E-G	PW 3	33-32	MLRW	12	242	293	34-00758	.054
119	PUBLIC SERV E-G	PW 2	33-35	MLRW	9	230	281	34-00757	.009
120	PUBLIC SERV E-G	PW 5	33-364	MRPAM	17	765	840	34-01031	38.475
121	PUBLIC SERV E-G	HOPE CREEK	33-452	MRPAM	10	746	817	34-01074	20.925
122	SIEGFRIED CHEM	1973-1	33-109	MRPAU	5	116	131	30-01322	4.454
								Total	2,230.695
							TOTAL		12,220.935

Table 2. Saltwater-intrusion vulnerability characteristics of wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden and Gloucester Counties, N.J.

[Mgal/yr, million gallons per year; mg/L, milligrams per liter; Aquifer codes: QRNR, Quaternary deposits; HPPN, undifferentiated Holocene, Pleistocene, Pliocene, and (or) Miocene deposits; MLRW, Wenonah-Mt. Laurel aquifer; MRPA, Potomac-Raritan-Magothy undifferentiated; MRPAU, Upper Potomac-Raritan-Magothy aquifer; MRPAM, Middle Potomac-Raritan-Magothy aquifer; MRPAL, Lower Potomac-Raritan-Magothy aquifer.]

Map number of well in figure 1	Well owner	Local well name	Aquifer	Model row	Model column	1996 withdrawals (Mgal/yr)	Percent of well water derived from river	Isolated 1-month event			Annually recurring 1-month		
								Percent of initial river concentration at well	Concentration threshold in river resulting in nonpotability		Percent of initial river concentration at well	Concentration threshold in river resulting in nonpotability	
									Chloride (mg/L)	Sodium (mg/L)		Chloride (mg/L)	Sodium (mg/L)
						High-vulnerability wells							
7	CAMDEN CITY W D	DELAIR 1	MRPAL	19	67	333.875	81	8	3,799	713	11	2,763	519
8	CAMDEN CITY W D	DELAIR 2	MRPAL	19	67	333.875	81	8	3,799	713	11	2,763	519
9	CAMDEN CITY W D	DELAIR 3	MRPAL	19	67	333.875	81	8	3,799	713	11	2,763	519
10	CAMDEN CITY W D	MORRIS 6	MRPAL	20	69	333.875	54	2	22,296	3,778	2	22,296	3,778
11	CAMDEN CITY W D	MORRIS 9	MRPAL	20	69	333.875	54	2	22,296	3,778	2	22,296	3,778
12	CAMDEN CITY W D	MORRIS 8	MRPAL	20	69	333.875	54	2	22,296	3,778	2	22,296	3,778
13	CAMDEN CITY W D	MORRIS 7	MRPAL	19	70	333.875	76	3.5	9,218	1,699	7	4,609	850
14	CAMDEN CITY W D	MORRIS 10	MRPAL	19	70	333.875	76	3.5	9,218	1,699	7	4,609	850
15	CAMDEN CITY W D	MORRIS 3A	MRPAL	20	71	333.875	93	2	13,366	2,613	2	13,366	2,613
18	CAMDEN CITY W D	MORRIS 11	MRPAL	19	68	333.875	91	13	2,098	407	15	1,818	353
19	CAMDEN CITY W D	MORRIS 12	MRPAL	19	69	333.875	86	10	2,874	549	12	2,395	457
20	CAMDEN CITY W D	MORRIS 13	MRPAL	19	68	333.875	91	13	2,098	407	15	1,818	353
						Low-vulnerability wells							
1	BELLMAWR B W D	BBWD 3	MRPAL	42	45	28.919	40						
21	GLOUCESTER C WD	GCWD 42	MRPAL	34	48	17.547	42						
22	GLOUCESTER C WD	GCWD 40	MRPAL	34	48	149.51	42						
23	GLOUCESTER C WD	GCWD 43	MRPAL	34	48	53.152	42						
25	MACANDREWS & FORBES CO	M&F IND 3R	MRPAM	24	51	33.402	42						
26	MAFCO	MAFCO 4R/1	MRPAM	25	51	10.061	43						

Table 2. Saltwater-intrusion vulnerability characteristics of wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden and Gloucester Counties, N.J.—Continued

[Mgal/yr, million gallons per year; mg/L, milligrams per liter; Aquifer codes: QRNR, Quaternary deposits; HPPN, undifferentiated Holocene, Pleistocene, Pliocene, and (or) Miocene deposits; MLRW, Wenonah-Mt. Laurel aquifer; MRPA, Potomac-Raritan-Magothy undifferentiated; MRPAU, Upper Potomac-Raritan-Magothy aquifer; MRPAM, Middle Potomac-Raritan-Magothy aquifer; MRPAL, Lower Potomac-Raritan-Magothy aquifer.]

Map number of well in figure 1	Well owner	Local well name	Aquifer	Model row	Model column	1996 withdrawals (Mgal/yr)	Percent of well water derived from river	Isolated 1-month event			Annually recurring 1-month		
								Percent of initial river concentration at well	Concentration threshold in river resulting in nonpotability: Chloride (mg/L)	Concentration threshold in river resulting in nonpotability: Sodium (mg/L)	Percent of initial river concentration at well	Concentration threshold in river resulting in nonpotability: Chloride (mg/L)	Concentration threshold in river resulting in nonpotability: Sodium (mg/L)
Low-vulnerability wells--Continued													
32	MCHVIL PNSK WCM	NATIONAL HWY 2	MRPAL	25	73	306.04	46						
35	NJ/AMERICAN WATER CO	54	MRPAL	22	62	154.655	75						
38	BP OIL CO	BP R-6-A	MRPAM	22	26	40.234	89						
39	BP OIL CO	BP R-8-A	MRPAM	22	26	16.489	89						
40	BP OIL CO	BP R-9-A	MRPAM	23	25	17.349	41						
41	BP OIL CO	BP R-7-A	MRPAM	21	26	16.022	95						
42	BP OIL COMPANY - PAULSBORO TERMINAL	BP R-4A	HPPM	23	25	19.921	41						
43	BP OIL COMPANY - PAULSBORO TERMINAL	BP R-10A	HPPM	22	26	7.204	89						
44	BP OIL COMPANY - SOHIO PAULSBORO	BP 51-1	HPPM	22	26	0.178	89						
45	BP OIL COMPANY - SOHIO PAULSBORO	BP RECOVERY 2	HPPM	22	26	7.004	89						
46	COASTAL EAGLE POINT OIL COMPANY	EAGLE POINT 7	MRPAL	32	38	140.319	60						
49	COASTAL EAGLE POINT OIL COMPANY	EAGLE POINT 6A	MRPAL	33	38	222.526	70						
60	MOBIL OIL COMPANY	MOBIL 47	MRPAL	21	24	3.405	50						
61	MOBIL OIL COMPANY	RW-5	QRNR	21	24	22.869	50						
62	MOBIL OIL COMPANY	RW-6	QRNR	21	24	50.047	50						
69	NATIONAL PK W D	NPWD 2/NPWD 5	MRPAL	29	35	48.195	90						

Table 2. Saltwater-intrusion vulnerability characteristics of wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden and Gloucester Counties, N.J.—Continued

[Mgal/yr, million gallons per year; mg/L, milligrams per liter; Aquifer codes: QRNR, Quaternary deposits; HPPN, undifferentiated Holocene, Pleistocene, Pliocene, and (or) Miocene deposits; MLRW, Wenonah-Mt. Laurel aquifer; MRPA, Potomac-Raritan-Magothy undifferentiated; MRPAU, Upper Potomac-Raritan-Magothy aquifer; MRPAM, Middle Potomac-Raritan-Magothy aquifer; MRPAL, Lower Potomac-Raritan-Magothy aquifer.]

Map number of well in figure 1	Well owner	Local well name	Aquifer	Model row	Model column	1996 withdrawals (Mgal/yr)	Percent of well water derived from river	Isolated 1-month event: Percent of initial river concentration at well	Isolated 1-month event: Concentration threshold in river resulting in nonpotability: Chloride (mg/L)	Isolated 1-month event: Concentration threshold in river resulting in nonpotability: Sodium (mg/L)	Annually recurring 1-month: Percent of initial river concentration at well	Annually recurring 1-month: Concentration threshold in river resulting in nonpotability: Chloride (mg/L)	Annually recurring 1-month: Concentration threshold in river resulting in nonpotability: Sodium (mg/L)
						Low-vulnerability wells--Continued							
70	NATIONAL PK W D	NPWD 6	MRPAL	29	35	66.433	90						
73	PAULSBORO W D	PWD 5	MRPAM	28	23	114.423	43						
76	PENNWALT CORP	418	MRPAL	30	28	7.29	74						
77	PENNWALT CORP	417	MRPAL	30	29	288.57	56						
80	W DEPTFORD T WD	WDTWD 7	MRPAL	38	38	216.473	61						
81	WESTVILLE W D	WWD 5	MRPAL	39	43	141.34	50						
						Wells with no vulnerability							
2	BELLMAWR B W D	BBWD 6	MRPAL	44	46	45.456	33						
3	BROOKLAWN B W D	BBWD 3	MRPAL	36	45	23.367	0						
4	BROOKLAWN B W D	BBWD 5(OW 3)	MRPAL	37	45	25.492	11						
5	BROOKLAWN B W D	BBWD 4	MRPAL	36	43	58.2	19						
6	CAMDEN CITY W D	CITY 11	MRPAM	27	52	11.81	0						
16	CAMDEN CITY W D	MORRIS 1	MRPAL	20	73	333.875	0						
17	CAMDEN CITY W D	PARKSIDE 18	MRPAL	28	56	201.84	34						
24	GLOUCESTER CITY	GCWD 41/AKA 3104903 RD	MRPAU	33	49	207.447	15						
27	MCHVIL PNSK WCM	1R	MRPAM	30	61	277.867	3						
28	MCHVIL PNSK WCM	WOODBINE 1	MRPAL	31	64	47.744	14						
29	MCHVIL PNSK WCM	MARION 1	MRPAL	31	66	139.934	11						
30	MCHVIL PNSK WCM	NATIONAL HWY 1	MRPAL	25	72	0.271	0						
31	MCHVIL PNSK WCM	WOODBINE 2	MRPAL	31	64	66.769	14						
33	NEW JERSEY WATER CO	CLEVELAND AVE PW 53	MRPAL	22	61	120.404	24						

Table 2. Saltwater-intrusion vulnerability characteristics of wells capable of withdrawing more than 100,000 gallons per day that are within 2 miles of the Delaware River in Camden and Gloucester Counties, N.J.—Continued

[Mgal/yr, million gallons per year; mg/L, milligrams per liter; Aquifer codes: QRNR, Quaternary deposits; HPPN, undifferentiated Holocene, Pleistocene, Pliocene, and (or) Miocene deposits; MLRW, Wenonah-Mt. Laurel aquifer; MRPA, Potomac-Raritan-Magothy undifferentiated; MRPAU, Upper Potomac-Raritan-Magothy aquifer; MRPAM, Middle Potomac-Raritan-Magothy aquifer; MRPAL, Lower Potomac-Raritan-Magothy aquifer.]

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						Wells with no vulnerability--Continued							
34	NJ/AMERICAN WATER CO	CAMDEN DIV 52	MRPAL	22	60	204.04	3						
36	NJ/AMERICAN WATER CO	55	MRPAL	22	60	5.498	3						
37	OUR LADY HOSP	STAND BY WELL	MRPAL	28	55	0.01	0						
47	COASTAL EAGLE POINT OIL COMPANY	EAGLE POINT 1	MRPAL	33	40	85.453	14						
48	COASTAL EAGLE POINT OIL COMPANY	EAGLE POINT	MRPAL	32	40	73.697	1						
50	E I DUPONT	REPAUNO 3	MRPAM	16	16	151.512	0						
51	E I DUPONT	REPAUNO 6	MRPAM	16	17	25.648	0						
52	E I DUPONT	INTERCEPTOR 46	MRPAM	16	17	162.461	0						
53	GREENWICH T W D	GTWD 5 (2-A)	MRPAM	18	17	137.675	0						
54	GREENWICH T W D	GTWD 6	MRPAM	26	19	103.554	0						
55	GREENWICH TWP WATER DEPT	MEMORIAL AVE 4R	MRPAM	23	21	107.177	0						
56	HERCULES CHEMICAL	4 1970	MRPAM	18	17	25.389	0						
57	HERCULES INC	HERCULES PW 11	MRPAM	21	17	51.364	0						
58	HERCULES INC - HIGGINS PLANT	HERCULES PW-10	MRPAM	19	18	9.773	0						
59	LOGAN WELLS WATER CO	LWWC BIRCH CK RD 4	MRPAM	14	3	85.095	0						
63	MOBIL OIL COMPANY	RW-8	QRNR	22	23	5.973	0						
64	MOBIL OIL COMPANY	MOBIL 48 DWTA	MRPAM	23	22	90.081	8						
65	MOBIL OIL COMPANY	MOBIL RW-19	MRPAM	23	22	140.96	8						

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						Wells with no vulnerability--Continued							
66	MONSANTO CHEM	BRIDGEPORT W2	MRPAM	7	3	200.006	17						
67	MONSANTO CHEM	BRIDGEPORT E1	MRPAM	7	3	59.579	17						
68	MONSANTO CHEM	MONSANTO 1	MRPAM	8	3	107.841	0						
71	PAULSBORO W D	Jun-73	MRPAM	30	22	111.811	3						
72	PAULSBORO W D	PWD 4	MRPAM	27	21	53.828	0						
74	PENNS GROVE WATER CO	BRIDGEPORT BACKUP-2	MRPAM	13	8	4.899	0						
75	PENNS GROVE WSC	BRIDGEPORT 2	MRPAM	13	8	31.818	0						
78	TEXAS OIL CO	EAGLE POINT 4A	MRPAL	32	39	1.908	3						
79	W DEPTFORD T WD	6 RED BANK AVE	MRPAL	37	36	135.476	36						
82	WESTVILLE W D	WWD 4	MRPAL	38	43	45.884	22						
83	WESTVILLE W D	WWD 6	MRPAL	38	43	5.277	22						

For additional information, write to:

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Water Resources Division
New Jersey District
Mountain View Office Park
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West Trenton, NJ 08628

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http://nj.usgs.gov/