DEVELOPMENT OF A DATA BASE OF COMMUNITY WATER-SUPPLY WELLS IN NEW JERSEY AND A METHOD TO EVALUATE THEIR SENSITIVITY TO CONTAMINATION

By Donald A. Storck, Kalman N. Isaacs, and Eric F. Vowinkel

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Bruce Babbitt, ***Secretary***

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, ***Director***

For additional information
write to:

District Chief
U.S. Geological Survey, WRD
Mountain View Office Park
810 Bear Tavern Road
Suite 206
West Trenton, NJ 08628

Copies of this report can be
purchased from:

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

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
gallon (gal)	0.003785	cubic meter
million gallons (Mgal)	3,785	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Transmissivity	
square foot per day (ft^2/d)[1]	0.09290	square meter per day

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.

Water-quality abbreviations:

pCi/L - picocurie per liter

mg/L - milligrams per liter

[1] This unit is used to express transmissivity, the capacity of an aquifer to transmit water. Conceptually, transmissivity is cubic feet (of water) per day per square foot (of aquifer area) times feet (of aquifer thickness), or $(ft^3/d)/ft^2$ x ft. In this report, this expression is reduced to its simplest form, ft^2/d.

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ABSTRACT

Well-construction and other well-attribute data for 2,598 community water-supply wells in New Jersey were compiled from existing data bases. The resulting data base is stored in a geographic information system and includes well-identification numbers, well-construction details and well characteristics, ratings of sensitivity to contamination, location data, and owner information. Information from this data base can be used by water managers to delineate wellhead-protection areas for water-supply wells.

Ground-water flow models were used to simulate ground-water contributing areas and the travel times of ground water from the water table to the open interval of wells in typical aquifer settings. From this information, the sensitivity to contamination of wells in three types of aquifers--glacial, Coastal Plain, and bedrock--was evaluated. Hydrogeologic variables that were considered in this assessment include the presence or absence of confining units above the open interval of the well, the location of the well relative to the outcrop area of the aquifer penetrated by the well, and the depth to the top of the open interval.

Wells with open intervals in glacial aquifers were considered to be sensitive to contamination from land surface because of (1) the absence of extensive confining units; (2) short ground-water travel times from the water table to the well; and (3) the typical construction characteristics of wells in glacial aquifers, which include shallow depth to the top of the open interval and shallow depth of the well. Wells screened in Coastal Plain aquifers were considered either (1) sensitive (wells in or less than 0.5 miles downdip from outcrop areas of confined aquifers and wells in unconfined aquifers, because the minimum travel time from land surface to the well likely is less than 12 years), or (2) insensitive (wells in confined aquifers greater than 0.5 miles downdip from the outcrop area, because the minimum travel time likely is greater than 12 years). Wells with open intervals in bedrock aquifers were considered sensitive to contamination because of (1) the geologic complexity of aquifer systems and absence of extensive confining units; (2) the relatively fast velocities of ground water in fractured zones within bedrock aquifers and the resulting short travel time of ground water from land surface to the wells; and (3) the typical construction characteristics of wells in bedrock aquifers, such as long open intervals and short casing lengths. All 245 wells in glacial and 1,002 wells in bedrock aquifers were considered sensitive to contamination because minimum travel times are most likely less than 12 years. In the Coastal Plain, 637 of 1,351 wells were considered sensitive to contamination because they are located in outcrop areas or less than 0.5 miles downdip from outcrop areas where minimum travel times are probably less than 12 years.

INTRODUCTION

The New Jersey Department of Environmental Protection (NJDEP) is responsible for ground-water protection and resource management within the State of New Jersey. The NJDEP developed a Wellhead Protection Program Plan as required by the 1986 Federal Safe Drinking Water Act Amendments (Section 1428). The purpose of the Wellhead Protection Program is to minimize the risk of water-supply-well contamination due to the discharge of ground-water contaminants at land surface. The Wellhead Protection Program was developed to enhance protection of three groups of potable-water-supply wells: public community supply wells, public noncommunity supply wells, and clusters of domestic supply wells. It provides this protection through the delineation of wellhead-protection areas and the implementation of regulations and other activities to minimize contamination from both point and nonpoint sources within these areas (New Jersey Department of Environmental Protection and Energy, 1991).

Wellhead-protection areas, as defined by the NJDEP, are portions of the wells' ground-water contributing areas that are close to the wells. A wellhead-protection area is defined by two criteria: the average time of travel for ground water to reach a well from the water table, and the presence of hydrologic boundaries, such as faults, surface-water bodies, and confining units. Each wellhead-protection area is divided into three sequential tiers. Management controls are most stringent nearest the well, because contaminant sources near a well pose the greatest threat to ground-water quality. Tier 1 is intended to prevent sources of bacteria and viruses from discharging near the well; the travel time from its outer boundary to the well is 200 days. Tier 2 is intended to prevent discharges of hazardous materials that do not degrade rapidly in ground water in areas so close to the well that remediation is not possible; the time of travel from its outer boundary to the well is 5 years. Tier 3 is designed to allow remediation of contaminant discharges before the well is contaminated if the discharge can be identified and responded to rapidly; the maximum time of travel from Tier 3 is 12 years. The time-of-travel criterion results in wellhead-protection areas that are tailored to individual wells and are based on the well's pumping capacity, the length of the well's open interval, the characteristics of the surrounding aquifer, and other variables specific to that well (New Jersey Department of Environmental Protection and Energy, 1991).

To effectively manage and protect the ground-water resources of the State, an understanding of the sensitivity of aquifers and wells to contamination is necessary. The sensitivity of wells to contamination is related to hydrogeologic factors that determine the time of travel of water recharged from land surface to the open interval of the well. Hydrogeologic variables that may affect the time of travel are soil type, depth to water, depth to the top of the open interval, hydraulic properties of aquifers, position of the well within the flow system, and the presence of confining units above the open interval.

The NJDEP Wellhead Protection Program establishes wellhead-protection areas on the basis of the assumptions that the recharge area of the well is in the immediate vicinity of the well, and that the protection area includes only those areas within a 12-year travel time of the well (New Jersey Department of Environmental Protection and Energy, 1991). Under this definition, community water-supply wells may be exempt from Wellhead Protection Program delineation regulations because the recharge area of the well is likely to be far from the well itself, and because ground-water travel time from the land surface to the well exceeds 12 years.

The NJDEP, Bureau of Safe Drinking Water (BSDW), currently monitors the quality of water in about 2,600 public community supply wells in New Jersey (fig. 1). Well-construction, well-location, and other well-attribute data for these wells reside in various locations and formats, and are associated with varying degrees of accuracy and completeness. Therefore, the U.S. Geological Survey (USGS), in cooperation with the NJDEP, conducted an investigation during 1992-95 to (1) compile and organize a data base of well-construction and other well-attribute data for community water-supply wells within the State of New Jersey, and (2) develop methods to determine the sensitivity of these wells to contaminants discharged at land surface. This information can be used by water managers to appropriately delineate wellhead-protection areas for water-supply wells that are contamination-sensitive, and to exempt from wellhead-protection delineation regulations those wells that withdraw water from parts of aquifer systems that are insensitive to contamination.

Purpose and Scope

This report describes the sources of well-construction and other well-attribute data that were compiled in, and components of, a data base of 2,598 community water-supply wells in New Jersey. It also describes the method used to evaluate the sensitivity to contamination of wells in three types of aquifers: glacial, Coastal Plain, and bedrock. Also included are examples of areas contributing water to wells and times of travel of ground water for selected wells in these types of aquifers determined by using available ground-water flow models. In addition, the report also presents guidelines for determining the sensitivity to contamination of wells screened in confined aquifers.

Description of the Study Area

New Jersey is divided into four well-defined physiographic provinces that trend from northeast to southwest: the Valley and Ridge, Highlands, Piedmont, and Coastal Plain Provinces. For this evaluation, aquifers and aquifer systems in these provinces are classified into three types --glacial, Coastal Plain, and bedrock--on the basis of similarities in hydrogeologic characteristics of the aquifers and typical well-construction characteristics. The stratigraphic and hydrogeologic characteristics of the geologic units in New Jersey are shown in table 1.

Previous Investigations

Previous investigations relevant to the current study are of four types: (1) evaluations of approaches and methods used to assess the sensitivity of aquifers and the vulnerability of ground water to contamination, (2) studies in which statistical and ground-water flow models were used to assess ground-water vulnerability and delineate ground-water contributing areas in New Jersey and hydrogeologically similar nearby areas, (3) studies in which ground-water flow models were developed to describe flow conditions in various parts of New Jersey, and (4) hydrogeologic investigations of various parts of New Jersey.

Many approaches and methods have been used to assess the sensitivity of aquifers and the vulnerability of ground water to contamination. These methods range in complexity from simple evaluations of available map data to complex models of physical, chemical, and biological

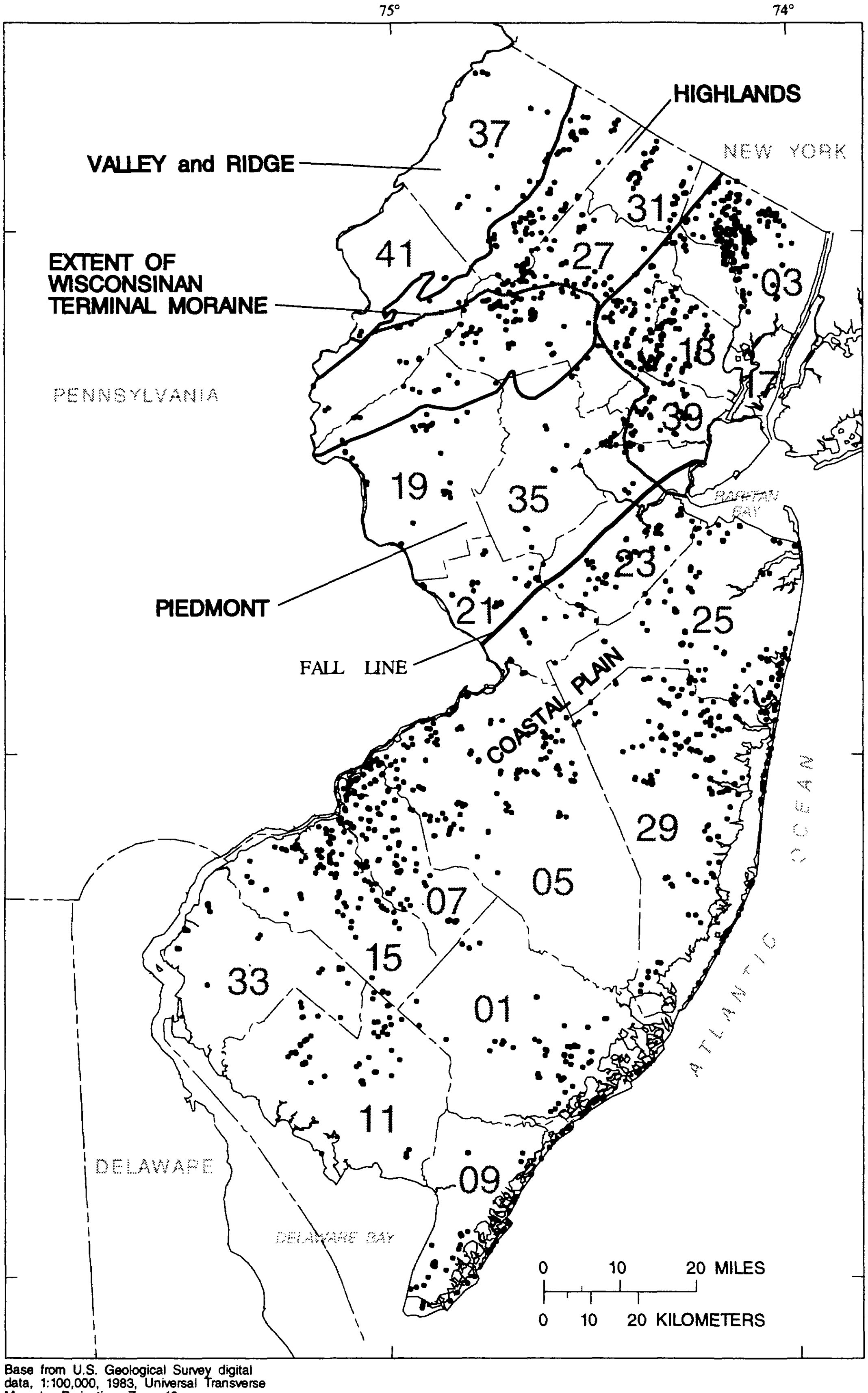

Figure 1. Physiographic provinces and distribution of community water-supply wells in New Jersey. (County names and codes are listed in table 1.)

processes that occur in ground-water systems and the unsaturated zone. The U.S. Environmental Protection Agency (1992) evaluated the methods currently available to assess aquifer sensitivity or ground-water vulnerability to pesticide contamination. The vulnerability of wells is determined on the basis of the sensitivity of the aquifer to contamination and the intensity of land use in areas where the aquifer is sensitive. The methods evaluated include aquifer-sensitivity methods, which consider hydrogeologic factors only; hybrid methods, which consider hydrogeologic and chemical factors; and ground-water-vulnerability assessment methods, which consider hydrogeologic, pesticide, and agronomic factors. The National Research Council (1993) evaluated assessment methods in three general categories, including overlay and index methods, methods employing process-based simulation models, and statistical models. Overlay and index methods are based on combining maps of various physiographic attributes by assigning a numerical index or score to each attribute. Process-based simulation model methods require the use of analytical or numerical solutions to mathematical equations that represent processes that control contaminant transport. Statistical methods incorporate data on known contaminant distributions and characterize contamination potential for the specific geographic area from which the data were collected.

Statistical models and ground-water flow models that incorporate hydrogeologic characteristics have been used to assess ground-water vulnerability. Vowinkel and others (1994) used a geographic information system (GIS) in conjunction with a numerical rating model to determine the vulnerability of community water-supply wells in New Jersey to contamination by pesticides. Nitrate was used as a surrogate for pesticide contamination, and the vulnerability rating was based on the sensitivity of the aquifer and the intensity of land use in sensitive areas. The results showed that only 1 of 134 wells more than 0.5 mi downdip from the outcrop of the Magothy Formation yielded water samples with nitrate concentrations greater than 0.5 mg/L. Vowinkel and Battaglin (1989) used nonparametric statistical procedures to determine significant hydrogeologic conditions, well-construction characteristics, and land-use variables that affect the presence and distribution of purgeable organic compounds in ground water. Risser and Madden (1994) used a numerical ground-water flow model to compare methods to delineate areas of diversion and contributing areas for wells screened in glacial-aquifer systems. They described and compared fixed-radius, uniform-flow, analytical, semianalytical, and numerical-modeling methods.

Many ground-water flow models developed to describe ground-water flow conditions in areas of New Jersey can be used to assess ground-water vulnerability and sensitivity. Navoy (1994) used a finely discretized ground-water flow model to show that the zone of nonpoint-source contamination extends a maximum of 0.5 to 2 mi downdip from the outcrop area of the Potomac-Raritan-Magothy system in Gloucester County. The areas contributing water to water-supply wells were determined by flow-path simulation by use of particle-tracking analysis. D.A. Pope and others (U.S. Geological Survey, written commun., 1994) simulated ground-water flow and the movement of the saltwater/freshwater interface in 10 aquifers and 10 confining units in the New Jersey Coastal Plain. They demonstrated that water moves vertically through a confining unit in less than 12 years only in the immediate vicinity of the aquifer outcrop. The maximum distance from the margin of the outcrop for a travel time of 12 years or less was similarly shown to be about 2 mi. Nicholson and others (1996) used a finite-difference model to simulate ground-water flow in three aquifers and two intervening confining units in a carbonate-rock and valley-fill aquifer system in the New Jersey Highlands. Particle-tracking analysis was used to

Table 1. Stratigraphic and hydrogeologic characteristics of geologic units in New Jersey

[Modified from New Jersey Department of Environmental Protection, 1990]

	Era	System	Series	Stratigraphic unit	Predominant lithology	Aquifer name or hydrogeologic characteristics
COASTAL PLAIN PROVINCE	CENOZOIC	Quaternary	Holocene	alluvial, coastal, marsh, and eolian deposits	sand, gravel, silt, mud, and peat	Under water-table conditions at most locations
			Pleistocene	COASTAL AREAS: Wisconsian alluvium, Cape May Formation, colluvium; INLAND, NORTHERN NEW JERSEY: Wisconsinan and pre-Wisconsinan alluvial, colluvial, glacial, lacustrine, and eolian deposits	sand, gravel, silt, clay (statewide), till and till-like deposits (northern New Jersey)	Includes glacial buried-valley aquifers and Cape May aquifer system/Holly Beach aquifer
		Tertiary	Miocene	Pensauken Formation	sand, clayey silt	Under water-table conditions at most locations
				Bridgeton Formation		
				Beacon Hill Gravel	gravel, sand	
				Cohansey Sand	sand, some clayey silt	Kirkwood-Cohansey aquifer system
				Kirkwood Formation	sand, gravel, clayey silt	confining unit
						Rio Grande water-bearing zone
						confining unit
						Atlantic City 800-foot sand
			Oligocene	ACGS beta unit	sand, some glauconitic sand	composite confining unit: Piney Point aquifer
				Mays Landing unit		
			Eocene	Shark River Formation	clayey silt, fine quartz sand, glauconitic sand	
				Manasquan Formation		
			Paleocene	Vincentown Formation	sand, clayey silt, glauconitic sand, calcarenite	Vincentown aquifer
				Hornerstown Formation	glauconitic sand	
	MESOZOIC	Cretaceous	Upper Cretaceous	Tinton Sand	sand, glauconitic sand	
				Red Bank Sand	sand, clayey, silt, some glauconitic sand	Red Bank Sand
				Navesink Formation	glauconitic sand	
				Mount Laurel Sand	sand	Wenonah-Mount Laurel aquifer
				Wenonah Formation	silty sand, some glauconite	Marshalltown-Wenonah confining unit
				Marshalltown Formation	clayey silt, glauconitic sand	
				Englishtown Formation	sand, clayey silt	Englishtown aquifer system
				Woodbury Clay	clayey silt	Merchantville-Woodbury confining unit
				Merchantville Formation	clayey silt, glauconitic sand	
				Magothy Formation	sand, clayey silt	Potomac-Raritan-Magothy aquifer system: upper aquifer
				Raritan Formation		confining unit
			Lower Cretaceous	Potomac Group	gravel, sand, silt, clay	middle aquifer; confining unit; lower aquifer
PIEDMONT PROVINCE		Jurassic	Lower Jurassic	Newark Supergroup, Brunswick Group: Boonton Formation	sandstone, siltstone, shale, conglomerate	Ground water is present along bedding surfaces, joints, faults, intergranular spaces, and other openings
				Hook Mountain Basalt	basalt	
				Towaco Formation	sandstone, siltstone, shale, conglomerate	
				Preakness Basalt	basalt, intercalated sedimentary rock	
				Feltville Formation	sandstone, siltstone, shale, conglomerate, limestone	
				Orange Mountain Basalt / diabase intrusives	basalt / diabase	
		Triassic	Upper Triassic	Passaic Formation	sandstone, siltstone, shale, conglomerate	
				Lockatong Formation	siltstone, mudstone, sandstone, shale	
				Stockton Formation	arkosic sandstone, siltstone, shale, conglomerate	

Table 1. Stratigraphic and hydrogeologic characteristics of geologic units in New Jersey—Continued

Province	Era	System	Group	Stratigraphic unit	Predominant lithology
VALLEY AND RIDGE PROVINCE	PALEOZOIC	Devonian			
				Marcellus Shale	shale, siltstone
				Buttermilk Falls Limestone	argillaceous limestone
				Schoharie Formation	calcareous siltstone
				Esopus Formation	siltstone, sandstone
			Oriskany Group	Ridgely Sandstone	sandstone, calcareous conglomerate
				Shriver Chert	shale, siltstone, chert
				Glenerie Formation	limestone
			Helderburg Group	Port Ewen Shale	calcareous shale, siltstone
				Minisink Limestone	limestone, calcareous shale
				New Scotland Formation	calcareous silty shale
				Coeymans Formation	limestone, standstone, conglomerate
				Rondout Formation	limestone, calcareous shale, dolomite
		Silurian		Decker Formation	calcareous sandstone, sandy limestone
				Bossardville Limestone	argillaceous, partly dolomitic limestone
				Poxono Island Formation	calcareous shale, dolomite
				Bloomsburg Red Beds	shale, siltstone, sandstone
				Shawangunk Formation	conglomeratic quartzite

GREEN POND MOUNTAIN REGION

Stratigraphic unit	Predominant lithology
Skunnemunk Conglomerate	conglomerate
Bellvale Sandstone	sandstone, siltstone, shale
Cornwall Shale	shale, siltstone
Kanouse Sandstone	conglomeratic sandstone, siltstone
Esopus Formation	siltstone, sandstone
Connelly Conglomerate	conglomeratic quartzite
Berkshire Valley Formation	calcareous siltstone, silty dolomite, sandstone
Poxono Island Formation	calcareous shale, dolomite
Longwood Shale	shale, siltstone
Green Pond Conglomerate	conglomeratic quartzite, siltstone

Hydrogeologic characteristics (Valley and Ridge Province and Green Pond Mountain Region): Ground water is present along bedding surfaces, joints, faults, intergranular spaces, solution cavities, and other openings

Province	Era	System	Series	Supergroup / Group	Stratigraphic unit	Predominant lithology	Hydrogeologic characteristics
HIGHLANDS PROVINCE	PALEOZOIC	Ordovician	Upper Ordovician		Beemerville intrusive complex	nepheline syenite, intrusive alkalic igneous rocks	Ground water is present along bedding surfaces, joints, faults, solution cavities, intergranular spaces, and other openings
					Martinsburg Formation	slate, siltstone, graywacke; shale, limestone, chert (Jutland)	
			Middle Ordovician		Jacksonburg Limestone	limestone, argillaceous limestone; shale, limestone, chert (Jutland)	
			Lower Ordovician	Kittatinny Supergroup; Beekman-town Group	Ontelaunee Formation	dolomite, limestone (Ontelaunee, Epler); shale, limestone, chert (Jutland)	
					Epler Formation		
					Rickenbach Dolomite	sandy dolomite (Rickenbach); shale, limestone, chert (Jutland)	
					Jutland klippe units (not part of Kittatinny Supergroup) (Martinsburg Formation through Rickenbach Dolomite)	shale, limestone, chert (Jutland)	
		Cambrian	Upper Cambrian	Kittatinny Supergroup	Allentown Dolomite	dolomite, calcareous sandstone	
			Middle Cambrian	Kittatinny Supergroup	Leithsville Formation	dolomite, calcareous shale	
			Lower Cambrian		Handyston Quartzite	arkosic quartzite, conglomerate (Hardyston)	
	?	Ordovician (?) Cambrian (?) Late Proterozoic (?)			Manhattan Schist, Wissahickon Formation, serpentinite, Chickies Quartzite	sillimanite-garnet-muscovite-biotite schist (Manhattan); schist, metagraywacke, amphibolite, altered ultramafics (Wissahickon); highly sheared serpentinite preserving few original igneous structures; quartz-sericite schist, conglomerate (Chickies)	Ground water is present in joints, faults, foliation surfaces, solution cavities, and other openings
	PROTEROZOIC	Late Proterozic (?)			Chestnut Hill Formation	greenschist-grade metasedimentary and metavolcanic (?) rock	
		Middle Proterozoic			Byram Intrusive Suite, Lake Hopatcong Intrusive Suite, Mount Eve Granite	granite, quartz syenite, syenite, quartz monzonite, monzonite, and granodiorite	
					metasedimentary rocks	quartzofeldspathic and calcareous metasedimentary rocks including the Franklin and Wildcat Marbles	
					Losee Metamorphic Suite	highly sodic gneissic and granitoid rocks; amphibolite	

This table is a generalized guide to stratigraphic and aquifer nomenclature in common usage in New Jersey as of 1990. Due to space limitations, it does not include member names, facies names, or less commonly used aquifer names.

delineate areas contributing water to wells. D.E. Rice and L.M. Voronin (U.S. Geological Survey, written commun., 1995) used a three-dimensional finite-difference model to simulate ground-water flow under steady-state pumping conditions in glacial and bedrock aquifers at Picatinny Arsenal, New Jersey. A particle-tracking, flow-path analysis of simulated results for selected pumping alternatives was used to determine contributing areas of water-supply wells and travel times of ground water from contributing areas to the wells. Hill and others (1992) used a three-dimensional numerical model to quantify hydrogeologic characteristics of the ground-water system and to evaluate the hydrologic relation between ground-water withdrawals and streamflow in valley-fill deposits in the Ramapo River Valley. In the northern part of the valley, a silt and clay layer locally confines a basal sand and gravel layer. Aquifer-test data were used to determine that recharge to the basal layer through the confining unit was less than recharge around its edges. Martin (1990) simulated ground-water flow in 10 aquifers and 9 intervening confining units of the New Jersey Coastal Plain by using a multilayer finite-difference model. Lacombe and Carleton (U.S. Geological Survey, written commun., 1995) present a detailed description of aquifers and confining units in Cape May County that includes maps of the tops of units, thickness of units, potentiometric surfaces, and areas affected by saltwater intrusion.

Many reports and maps have described the hydrology and hydrogeology of New Jersey. These reports were used to evaluate the sensitivity of wells to contamination and to determine the aquifers in which new wells compiled as part of this study were completed or are open. Zapecza (1989) described the hydrogeologic framework of the entire Coastal Plain of New Jersey. This investigation used borehole geophysical data to define the presence and configuration of 15 regional hydrogeologic units. Barton and Kozinski (1991) investigated the hydrogeology of Greenwich Township, in Gloucester County. Lewis and others (1991) studied the hydrogeology and ground-water quality of the Potomac-Raritan-Magothy aquifer system in the Logan Township area of western Gloucester and northern Salem Counties. Gronberg and others (1991) studied the hydrogeologic framework of the Potomac-Raritan-Magothy aquifer system in the northern part of the New Jersey Coastal Plain. Geologic maps and reports were used to determine geologic units and aquifer codes for new wells in non-Coastal Plain areas of the State that were compiled as part of this study. Aquifer codes stored in the water-supply-well data base represent the geologic unit in which the open interval of the well is found. The maps used include the Newark 1°x 2° Quadrangle, New Jersey, Pennsylvania, and New York (Lyttle and Epstein, 1987), Green Pond Mountain region from Dover to Greenwood Lake, New Jersey (Herman and Mitchell, 1991), Stanhope Quadrangle, Sussex and Morris Counties, New Jersey (Volkert and others, 1989), Franklin and parts of Hamburg Quadrangles, New Jersey (Buddington and Baker, 1961), Branchville Quadrangle, Sussex County, New Jersey (Drake and Monteverde, 1992), Bloomsbury Quadrangle, New Jersey (Drake, 1967a), Easton Quadrangle, New Jersey (Drake, 1967b), and Newton West Quadrangle, Sussex and Warren Counties, New Jersey (Drake, 1992). Miller (1974) presents the geology and ground-water resources of Sussex and parts of Warren Counties and includes a geologic and a depth-to-bedrock map.

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Jersey Geological Survey (NJGS), for their assistance with the data base and for supplying global-positioning-system location data for many of the wells. Thanks also to Richard Kropp, Jan Gheen, Gail Witkowski, and other personnel of the NJDEP, Bureau of Water Allocation for their guidance in the collection of well records and well permits from their data base of community water-supply wells, and for supplying computerized versions of their data base for these wells.

DEVELOPMENT OF THE WATER-SUPPLY-WELL DATA BASE

A data base containing well-construction and other well-attribute data for community water-supply wells in New Jersey was developed. Items stored in the data base include well-identification numbers, well-construction details and other well characteristics, rating of sensitivity to contamination, location data, and owner information. This data base is stored in a GIS as an ARC/INFO[1] point coverage and includes information from the USGS National Water Information System (NWIS) Ground Water Site Inventory (GWSI) data base stored in a point-attribute table. Information compiled from other data bases and files from various State agencies that is not in the GWSI data base is stored in related INFO data files. The water-supply-well data base ultimately will reside with, and be maintained by, the NJGS.

Sources of Well-Construction and Other Well-Attribute Data

The sources of well-construction and other well-attribute data in the water-supply-well data base are (1) the NJDEP Bureau of Safe Drinking Water (BSDW) SOURCE data base, (2) the NJDEP Bureau of Water Allocation data bases WATERA and WSOURCE, and (3) the USGS GWSI data base (fig. 2). Information also was compiled from survey questionnaires that were distributed by the BSDW to gather information on public water systems and were completed by purveyors or owners, and from BSDW field inspection reports. Additional information stored in the water-supply-well data base was compiled directly from well permits and well records.

Data were compiled for wells that meet the BSDW definition of a public community supply well--that is, any well that is used to supply water for human consumption on a year-round basis to 25 or more people, or that has 15 or more service connections. The water-supply-well data base was created from the list of active community water-supply wells in the BSDW SOURCE data base by adding new wells and additional data from GWSI, WSOURCE, and BSDW inspection reports, survey questionnaires, well permits and well records, and other minor sources. The BSDW definition includes many low-capacity wells that are used by trailer parks and homeowner associations, for example, that are not included in WSOURCE, the Bureau of Water Allocation data base for public community supply wells. Because the Bureau of Water Allocation defines a public community supply well as any well that supplies water for human consumption and produces at least 100,000 gal/d or 70 gal/min, WSOURCE includes only wells owned by major water companies, water departments, and some of the larger trailer parks and homeowner associations.

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[1] The use of brand or trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

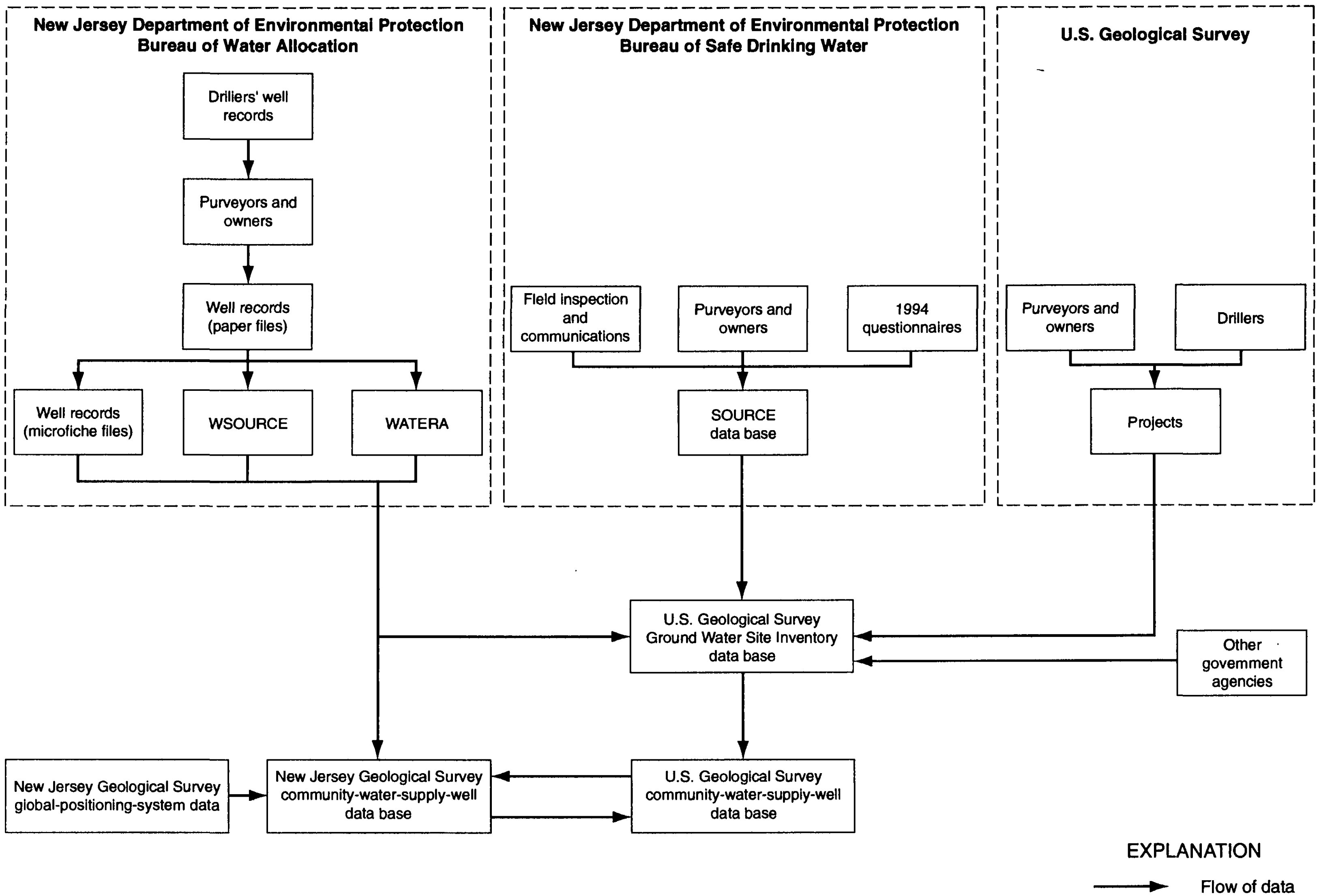


Figure 2. Sources of well-construction and other well-attribute data stored in the water-supply-well data base.

The BSDW SOURCE data base contains information about owners or purveyors, and well-construction and other well-attribute data for public water systems and treatment facilities. It consists of information collected from Bureau of Water Allocation data bases, from periodic field inspections, and from other sources.

The Bureau of Water Allocation WATERA and WSOURCE data bases contain information about the well owners or purveyors, and well-construction and other well-attribute data for individual wells, respectively. These data bases include information for several types of wells monitored by the Bureau, including public supply, industrial, irrigation, observation, and other types of wells. The source of much of the data for wells maintained in WATERA and WSOURCE data bases is well records and permits submitted by the driller, and correspondence between the purveyors and the Bureau during the water-allocation permitting process. When a new well is installed, the well driller is required to submit information about the well to the Bureau, including construction details, owner information, and location data.

The USGS GWSI data base, a National ground-water data storage and retrieval system, contains well-construction and other well-attribute data (Mathey, 1990). This data base contains information on all types of wells, including public supply, observation, domestic, industrial, and other types of wells. These data were collected over many years, from owners, drillers, State agencies, and other sources. Selected information for community water-supply wells was retrieved from the GWSI data base and transferred into the water-supply-well data base. When a well record and well permit were found for a new well, information from them was coded on a GWSI entry form. Other information, such as aquifer codes, elevation, and location data, was determined from existing published reports and maps described in the Previous Investigations section of this report. The form was then submitted to the USGS, New Jersey District, GWSI data-base administrator for verification and entry into the GWSI data base. Methods used to determine the sensitivity rating are described in a later section of this report.

Components of the Data Base

Information for all community water-supply wells in New Jersey was collected and compiled from the sources listed above. Most components of the water-supply-well data base--for example, well-identification numbers--were found in only one source, and are unique to that source. The information that appeared to be most accurate and reliable was entered into the water-supply-well data base when conflicting values were found in two or more sources.

Items that are stored in the water-supply-well data base for each community water-supply well in New Jersey, the sources of the data and the priorities of the sources used, if applicable, and a brief description of the item are presented in table 2. The NJGS maintains its own version of the water-supply-well data base, which is based on the USGS version. Items added to the data base and items modified by the NJGS are presented in table 3.

Table 2. Items stored in the water-supply-well data base for New Jersey, sources of data, and descriptions of items

[GWSI, Ground Water Site Inventory data base; BSDW, Bureau of Safe Drinking Water; BWA, Bureau of Water Allocation; NJGS, New Jersey Geological Survey]

Data-base item	Source(s) of data	Description of item
	Identification numbers and names, and well characteristics	
Unique identifier	GWSI	Six-digit number that identifies an individual well in GWSI. The first two digits represent the county in which the well is located; the last four are sequentially assigned when entered into GWSI. County codes are given in table 1.
Site identifier	GWSI	Fifteen-digit code used as the primary identifier of a well in GWSI.
Public water supply number	BSDW	Seven-digit number assigned by BSDW that identifies a public-water-supply system. The first four digits represent the county and municipality in which the well is located; the last three digits are sequentially assigned.
SF ID	BSDW	Number assigned by BSDW that identifies an individual well within a public-water supply system.
Water allocation number	BWA	Number assigned by BWA to identify a well or group of wells covered under a water-allocation permit.
Permit number	BWA, GWSI, BSDW	Number assigned by BWA prior to well installation that is the N.J. Department of Environmental Protection primary identifier of a well. The first two digits represent the State Atlas Map on which the well is located; the last five digits are assigned sequentially.
Owner	GWSI	The owner of the well in the GWSI data base.
Purveyor name	BSDW	The owner or purveyor of a public-water-supply system in the BSDW data base.
Local identifier - GWSI	GWSI	The local name by which the well is known in the GWSI data base.
Local identifier - BSDW	BSDW	The local name by which the well is known in the BSDW data base.
Aquifer code	GWSI	Eight-character abbreviation that represents the aquifer or hydrogeologic unit from which the well withdraws water. Aquifer codes are given in tables 1 and 2.
Aquifer type	GWSI	One-character code that represents the type of aquifer from which the well withdraws water.
Sensitivity rating	Determined	Single-character code that represents whether the well is sensitive to contaminants from the land surface, based on confinement near the well.
Well type	BSDW	Single-digit code that represents the type of water-supply well.
Well status	BSDW	Single-character code assigned by BSDW that represents the well's operational status.
Use of well	GWSI, BWA, BSDW, NJGS	Two-digit code that represents whether the well is sealed, capped, or abandoned, and the source of this information.
Use of water	GWSI	One-character code that represents the primary use of water from the well.

Table 2. Items stored in the water-supply-well data base for New Jersey, sources of data, and descriptions of items--Continued

Data-base item	Source(s) of data	Description of item
Purveyor address and contact information		
Street	BWA, BSDW	Street address of the owner or purveyor.
City	BWA, BSDW	City of the owner or purveyor.
State	BWA, BSDW	State of the owner or purveyor.
Zip code	BWA, BSDW	Zip code of the owner or purveyor.
Purveyor contact	BWA, BSDW	Owner or purveyor representative.
Purveyor phone number	BWA, BSDW	Phone number of the owner or purveyor representative.
Well-construction information		
Well depth	GWSI	The maximum depth of the well, in feet below land surface.
Top of open interval	GWSI	Depth of the top of the well screen or open interval, in feet below land surface.
Bottom of open interval	GWSI	Depth of the bottom of the well screen or open interval, in feet below land surface.
Top of casing	GWSI	Depth of the top of the well casing, in feet below land surface.
Bottom of casing	GWSI, BWA	Depth of the bottom of the well casing, in feet below land surface.
Casing diameter	GWSI, BWA	Diameter of the inner casing, screen, or borehole, in inches.
Type of open interval	GWSI	The type of opening that allows water to enter the well.
Number of openings	GWSI	The number of screened or open intervals of the well.
Date completed	GWSI	The construction-completion date of the well.
Pumping capacity	BWA, GWSI, BSDW	The pumping capacity of the well, in gallons per minute.
Capacity source		The agency that provided the well pumping-capacity data.
Well-location information		
Latitude	GWSI, BWA BSDW	Number that represents the latitude of the well's location, in degrees, minutes, and seconds.
Longitude	GWSI, BWA, BSDW	Number that represents the longitude of the well's location, in degrees, minutes, and seconds.
Latitude longitude accuracy	GWSI	One-character code that represents the accuracy of the latitude and longitude measurement.
Grid number	GWSI	Number assigned by BWA that represents the grid location of the well on the State Atlas Maps.
Altitude	GWSI	Altitude of land surface at the well, in feet above sea level.
Altitude method	GWSI	One-character code that represents the method by which the altitude was measured.
Altitude accuracy	GWSI	Number that represents the accuracy of the altitude measurement.
County	GWSI	Three-digit number that represents the county in which the well is located. County codes are given in table 1.
Township	GWSI	Township in which the well is located.
Map name	GWSI	Name of USGS 7.5-minute quadrangle map in which the well is located.

Table 3. Items added to the water-supply-well data base by the New Jersey Geological Survey
[USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983]

Data-base item	Description of item
Easting	Number that represents the x coordinate of the well location. Value is in U.S. Survey feet, in NAD 83 of State Plane Coordinate System.
Northing	Number that represents the y coordinate of the well location. Value is in U.S. Survey feet, in NAD 83 of State Plane Coordinate System.
FIPS number	Number that represents the county and municipality in which the well is located. First two digits represent the county; last three represent the municipality.
Quad number	Three-digit code that represents the USGS 7.5-minute quadrangle in which the well is located.
Water use code	Two-digit code that represents the primary use of water from the well.
Well status code	One-digit code that represents the operational status of the well.
Locational method	One-character code that represents the method used to determine the location of the well.
Total casing length	Total length of casing installed in the well, in feet.
Geologic formation code	Four-character code that represents the name of the primary geologic formation penetrated by the well.
Transmissivity	Hydraulic conductivity of the aquifer multiplied by the well's open-interval length, in feet squared per day.
Aquifer thickness	Length of the screen or open interval of the well, in feet.
Aquifer porosity	Effective porosity of the aquifer penetrated by the well (dimensionless).
Hydraulic gradient	Change in hydraulic head per unit distance in the direction of maximum change (dimensionless).
Azimuth	Measure of direction in which ground water flows, in degrees.
Pumping rate	Maximum pumping capacity of the installed pump, in cubic feet per day.
CFR 1 radius	Radius of a 200-day time of travel from the well, in feet, determined by using the Calculated Fixed Radius equation (N. J. Department of Environmental Protection and Energy, 1991).
CFR 2 radius	Radius of a 5-year time of travel from the well, in feet, determined by using the Calculated Fixed Radius equation (N. J. Department of Environmental Protection and Energy, 1991).
Date delineated	Date of generation of the wellhead-protection area.
Person performing delineation	Name of the person who generated the wellhead-protection area.
Comments	Comments regarding the well or wellhead-protection area.

Table 3. Items added to the water-supply-well data base by the New Jersey Geological Survey--Continued

Data-base item	Description of item
Lot	Lot designation of the property on which the well is located.
Block	Block designation of the property on which the well is located.
Reference elevation	Elevation of the well's measuring point, in feet above sea level.
Elevation comment	Comments or additional information about the reference elevation of the well.
Natural flow	Rate of flow from the well without pumping, in gallons per minute.
Test date	Date of tests of the well, listed on the well record.
Test type	Type of test conducted.
Ground-water elevation	Elevation of ground water measured in the well, in feet above sea level.
Static water level	Depth to water in the well prior to pumping, in feet below land surface.
Pumping water level	Depth to water in the well during pumping, in feet below land surface.
Drawdown	Drop in water level in the well during an aquifer test, in feet.
Test length	Duration of the aquifer test, in minutes.
Discharge rate	Rate of discharge during the aquifer test, in gallons per minute.
Specific capacity	Discharge rate divided by drawdown, in gallons per minute per foot.
Drilling contractor	Name of the well-drilling contractor who installed the well.
License number	The State license number of the drilling contractor.
Drilling method code	One-character code that represents the method used to install the well.
Driller's log	Driller's log of the installation of the well.
Geologist	Geologist who reviewed or supervised the installation of the well.
Geologist's log	Geologist's log of the well.
Geophysical log	One-character code that indicates whether geophysical logs are available.
Lithologic log	One-character code that indicates whether lithologic logs are available.
Samples	One-character code that indicates whether geologic samples are available.
Water quality	One-character code that indicates whether water-quality data are available.
Water level	One-character code that indicates whether water-level data are available.
Fossils	One-character code that indicates whether fossils were present in geologic samples.

METHOD TO EVALUATE THE SENSITIVITY OF WELLS TO CONTAMINATION

All wells for which information was sufficient were evaluated for their sensitivity to contaminants generated at land surface. Wells were considered to be sensitive if recharge moving along any flow path from the land surface would reach the well in less than 12 years. The minimum data required to make this determination include depth of the open interval, location of the well, and altitude of the top of the well. Wells in aquifers that are considered to be confined to the degree that contamination from land surface is unlikely to reach the well opening are exempt from wellhead-protection-area delineation regulations (N.J. Department of Environmental Protection, 1991). A well is considered sufficiently confined (and thus insensitive to contamination) when the vertical time of travel through a confining unit and the horizontal time of travel to the edge of a confining unit is equal to or exceeds 12 years at all points. The method used to determine the sensitivity of wells had to be (1) simple to use--the method had to be applicable to all wells with a minimum of data and to provide results that are easy to understand--and (2) conservative, meaning that the method had to provide for a well to be considered insensitive to contamination if the minimum time of travel of recharge water to the well was greater than 12 years. A schematic diagram that depicts the method used to determine the sensitivity or insensitivity of community water-supply wells to contamination is shown in figure 3. A summary showing the number of wells in the data base that are sensitive to contamination, listed by county and by aquifer, is presented in table 4 for glacial and Coastal Plain aquifers and in table 5 for bedrock aquifers.

Hydrogeologic variables that were used to assess sensitivity of wells to contamination from land surface include the depth to the top of the open interval below land surface, the presence or absence of confining units above the well's open interval, and the location of the well relative to the outcrop area of the aquifer penetrated by the well. Results of previous investigations of confined aquifers have shown that the distance of a well from the aquifer's outcrop area is the best predictor of contamination in the well (Vowinkel and Battaglin, 1989). Other variables, such as soil type, depth to water, recharge to the aquifer system, and ground-water withdrawals, were not used for this assessment because their effect on ground-water travel time is small compared to that of the three variables that were used. Results of previous investigations have shown that soil type is not significantly related to nitrate concentrations in ground water (Vowinkel and others, 1994). Recharge to surficial aquifers and the depth to water in aquifers in New Jersey does not vary significantly; the depth to water in wells open to unconfined aquifers in New Jersey typically is less than 25 ft. For the purposes of this report, the travel time of recharge from the land surface to the water table is assumed to be negligible.

Well-construction characteristics can significantly affect a well's sensitivity to contamination. Boxplots comparing well depth, depth to the top of the open interval, and length of the open interval for wells in glacial, Coastal Plain, and bedrock aquifers are shown in figure 4. Wells in glacial aquifers generally are constructed with short casing lengths and screens; well depths and depths to the top of the open interval are very shallow. Wells in bedrock aquifers typically are constructed with short casing lengths through the unconsolidated zone above the bedrock and long open boreholes through the bedrock that commonly exceed several hundred feet in length. Open intervals typically pass through many fracture zones to allow sufficient water to enter the

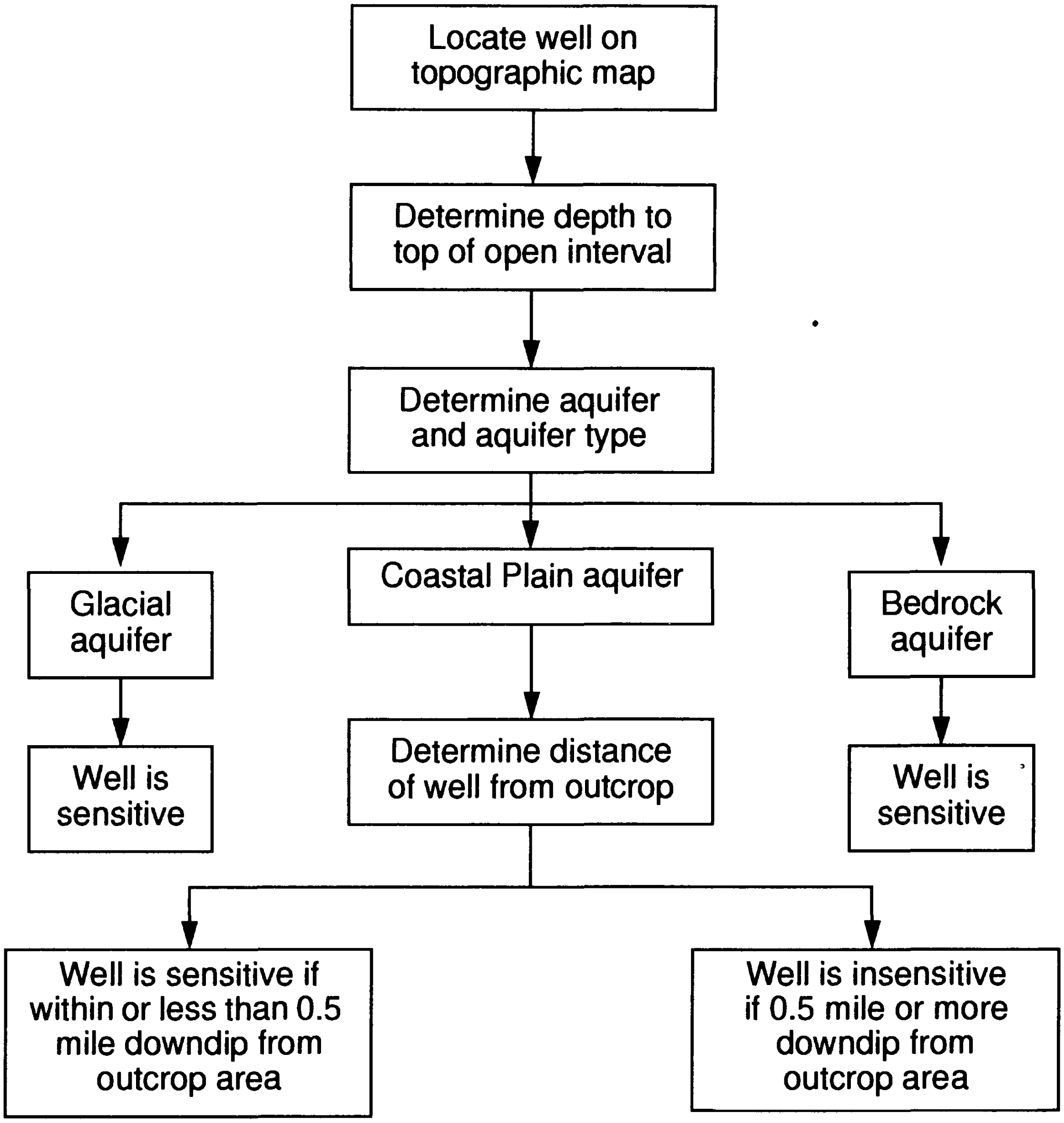


Figure 3. Method used to determine sensitivity of community water-supply wells in New Jersey to contamination from land surface.

Table 4. Number of wells in glacial and Coastal Plain aquifers in New Jersey in the water-supply-well data base, and number of wells that are sensitive to contamination, by county and by aquifer

[--, no wells in this aquifer in this county; stratigraphic and hydrogeologic characteristics of geologic units are shown in table 5]

		County code and name						
		01	03	05	07	09	11	13
Aquifer code [1]	Aquifer name	Atlantic	Bergen	Burlington	Camden	Cape May	Cumberland	Essex
	Glacial aquifers							
112SFDF	Stratified drift	--	30	--	--	--	--	39
	Sensitive	--	30	--	--	--	--	39
	Coastal Plain aquifers							
112HLBC	Holly Beach water-bearing zone	--	--	--	--	8	--	--
	Sensitive	--	--	--	--	8	--	--
112ESRNS	Estuarine sand facies	--	--	--	--	6	--	--
	Sensitive	--	--	--	--	0	--	--
121CNSY	Cohansey sand	--	--	--	--	29	--	--
	Sensitive	--	--	--	--	0	--	--
121CKKD	Kirkwood-Cohansey aquifer system	73	--	7	16	5	64	--
	Sensitive	73	--	7	16	0	64	--
122KRKDU	Rio Grande water-bearing zone	--	--	--	--	1	--	--
	Sensitive	--	--	--	--	0	--	--
122KRKDL	Atlantic City 800-foot sand	30	--	--	--	31	--	--
	Sensitive	0	--	--	--	0	--	--
124PNPN	Piney Point aquifer	2	--	2	4	--	--	--
	Sensitive	0	--	0	0	--	--	--
125VNCN	Vincentown aquifer	--	--	2	--	--	--	--
	Sensitive	--	--	2	--	--	--	--
211RDBK	Red Bank Sand	--	--	--	--	--	--	--
	Sensitive	--	--	--	--	--	--	--
211MLRW	Wenonah-Mount Laurel aquifer	--	--	40	18	--	--	--
	Sensitive	--	--	0	0	--	--	--
211EGLS	Englishtown aquifer system	--	--	6	3	--	--	--
	Sensitive	--	--	0	0	--	--	--
211MRPAU	Upper Potomac-Raritan-Magothy aquifer	--	--	32	35	--	--	--
	Sensitive	--	--	3	0	--	--	--
211MRPAM	Middle Potomac-Raritan-Magothy aquifer	--	--	40	18	--	--	--
	Sensitive	--	--	22	6	--	--	--
211MRPAL	Lower Potomac-Raritan-Magothy aquifer	--	--	17	85	--	--	--
	Sensitive	--	--	8	61	--	--	--
211MRPA	Undifferentiated Potomac-Raritan-Magothy aquifer system	--	--	10	3	--	--	--
	Sensitive	--	--	2	0	--	--	--
Unknown [2]	Sensitive[3]	30	--	24	2	14	15	--
County total	Coastal Plain aquifers	135	--	180	184	94	79	--
	Sensitive	103	--	68	85	22	79	--

[1] The first three numbers of the aquifer code represent the geologic age of the aquifer; the last four to five characters are an abbreviation of the aquifer name.

[2] Includes wells for which location of well, open interval, or well depth is unknown, or well is no longer used as community water-supply well. The sensitivity could not be determined due to insufficient information.

[3] All wells whose aquifer code is unknown are assumed to be sensitive to contamination.

Table 4. Number of wells in glacial and Coastal Plain aquifers in New Jersey in the water-supply-well data base, and number of wells that are sensitive to contamination, by county and by aquifer--Continued

Aquifer code[1]	15 Gloucester	19 Hunterdon	21 Mercer	23 Middlesex	25 Monmouth	27 Morris	29 Ocean	31 Passaic	33 Salem	35 Somerset	37 Sussex	39 Union	41 Warren	Aquifer total
						County code and name								
						Glacial aquifers								
112SFDF	--	--	--	8	--	122	--	10	--	--	18	12	6	245
	--	--	--	8	--	122	--	10	--	--	18	12	6	245
						Coastal Plain aquifers								
112HLBC	--	--	--	--	--	--	--	--	--	--	--	--	--	8
	--	--	--	--	--	--	--	--	--	--	--	--	--	8
112ESRNS	--	--	--	--	--	--	--	--	--	--	--	--	--	6
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
121CNSY	--	--	--	--	--	--	--	--	--	--	--	--	--	29
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
121CKKD	17	--	--	--	14	--	138	--	10	--	--	--	--	344
	17	--	--	--	14	--	138	--	10	--	--	--	--	339
122KRKDU	--	--	--	--	--	--	3	--	--	--	--	--	--	4
	--	--	--	--	--	--	0	--	--	--	--	--	--	--
122KRKDL	--	--	--	--	--	--	23	--	--	--	--	--	--	84
	--	--	--	--	--	--	0	--	--	--	--	--	--	--
124PNPN	--	--	--	--	--	--	19	--	--	--	--	--	--	27
	--	--	--	--	--	--	0	--	--	--	--	--	--	--
125VNCN	2	--	--	--	5	--	8	--	--	--	--	--	--	17
	0	--	--	--	0	--	0	--	--	--	--	--	--	2
211RDBK	--	--	--	--	--	--	2	--	--	--	--	--	--	2
	--	--	--	--	--	--	0	--	--	--	--	--	--	--
211MLRW	8	--	--	--	14	--	9	--	5	--	--	--	--	94
	1	--	--	--	0	--	0	--	0	--	--	--	--	1
211EGLS	--	--	--	--	34	--	23	--	1	--	--	--	--	67
	--	--	--	--	0	--	0	--	0	--	--	--	--	--
211MRPAU	43	--	3	37	50	--	10	--	9	--	--	--	--	219
	0	--	1	36	0	--	0	--	7	--	--	--	--	47
211MRPAM	19	--	12	30	25	--	4	--	4	--	--	--	--	152
	10	--	10	30	2	--	0	--	2	--	--	--	--	82
211MRPAL	11	--	--	--	--	--	--	--	2	--	--	--	--	115
	6	--	--	--	--	--	--	--	2	--	--	--	--	77
211MRPA	--	--	3	--	2	--	12	--	1	--	--	--	--	31
	--	--	3	--	0	--	0	--	1	--	--	--	--	6
Unknown[2]	10	--	1	1	14	--	31	--	10	--	--	--	--	152
County total	110	--	19	68	158	--	282	--	42	--	--	--	--	1,351
	44	--	15	67	30	--	169	--	32	--	--	--	--	714

Table 5. Number of wells in bedrock aquifers in New Jersey in the water-supply-well data base, by county and by aquifer

[--, no wells in this aquifer in this county; stratigraphic and hydrogeologic characteristics of geologic units are shown in tab'e 5; all wells in bedrock aquifers are considered to be sensitive to contamination from land surface]

		County code and name						
Aquifer code [1]	Aquifer name	01 Atlantic	03 Bergen	05 Burlington	07 Camden	09 Cape May	11 Cumberland	13 Essex
227BRCKS	Brunswick Group Sedimentary (undifferentiated)	--	28	--	--	--	--	22
227BNTN	Boonton Formation	--	--	--	--	--	--	2
227HKMN	Hook Mountain Basalt	--	--	--	--	--	--	1
227TOWC	Towaco Formation	--	--	--	--	--	--	5
227PRKS	Preakness Basalt	--	--	--	--	--	--	5
227FLVL	Feltville Formation	--	--	--	--	--	--	2
227PSSC	Passaic Formation	--	139	--	--	--	--	25
227BSLT	Basalt	--	--	--	--	--	--	4
231CGLMU	Unclassified conglomerate	--	--	--	--	--	--	--
230TRSC	Triassic System	--	--	--	--	--	--	--
231LCKG	Lockatong Formation	--	--	--	--	--	--	--
231QRCG	Quartzite conglomerate	--	--	--	--	--	--	--
231SCKN	Stockton Formation	--	--	--	--	--	--	--
341SKMK	Skunnemunk Conglomerate	--	--	--	--	--	--	--
344BLVL	Bellvale Sandstone	--	--	--	--	--	--	--
344CRNL	Cornwall Shale	--	--	--	--	--	--	--
344ESPS	Esopus Formation	--	--	--	--	--	--	--
344KNUS	Kanouse Sandstone	--	--	--	--	--	--	--
350GRPD	Green Pond Conglomerate	--	--	--	--	--	--	--
350HGFL	High Falls Formation (Bloomsburg Formation)	--	--	--	--	--	--	--
351BDVL	Bossardville Limestone	--	--	--	--	--	--	--
351DCKR	Decker Formation	--	--	--	--	--	--	--
360KTTN	Kittatinny Supergroup (undifferentiated)	--	--	--	--	--	--	--
360ODVC	Ordovician System	--	--	--	--	--	--	--
361BSKL	Bushkill Member of Martinsburg Shale	--	--	--	--	--	--	--
361MRBG	Martinsburg Shale	--	--	--	--	--	--	--
364JKBG	Jacksonburg Limestone	--	--	--	--	--	--	--
367EPLR	Epler Formation	--	--	--	--	--	--	--
367RCKB	Rickenbach Dolomite	--	--	--	--	--	--	--
371ALNN	Allentown Dolomite	--	--	--	--	--	--	--
374LSVL	Leithsville Formation	--	--	--	--	--	--	--
377HRDS	Hardyston Quartzite	--	--	--	--	--	--	--
400FRKL	Franklin Limestone	--	--	--	--	--	--	--
400PCMB	Precambrian Erathem (Proterozoic)	--	--	--	--	--	--	--
Unknown [2]		--	15	--	--	--	--	7
County total		--	182	--	--	--	--	73

[1] The first three numbers of the aquifer code represent the geologic age of the aquifer; the last four to five characters are an abbreviation of the aquifer name.

[2] Includes wells for which location of well, open interval, or well depth is unknown, or well is no longer used as community water-supply well.

Table 5. Number of wells in bedrock aquifers in New Jersey in the water-supply-well data base, by county and by aquifer--Continued

	County code and name													
Aquifer code[1]	15 Glou-cester	19 Hunter-don	21 Mercer	23 Middle-sex	25 Mon-mouth	27 Morris	29 Ocean	31 Passaic	33 Salem	35 Somerset	37 Sussex	39 Union	41 Warren	Aquifer total
227BRCKS	--	6	5	25	--	3	--	3	--	8	--	31	--	131
227BNTN	--	--	--	1	--	4	--	--	--	--	--	--	--	7
227HKMN	--	--	--	--	--	5	--	--	--	--	--	--	--	6
227TOWC	--	--	--	--	--	3	--	6	--	--	--	--	--	14
227PRKS	--	--	--	--	--	--	--	--	--	--	--	--	--	5
227FLVL	--	--	--	--	--	--	--	--	--	3	--	3	--	8
227PSSC	--	8	9	10	--	--	--	19	--	20	--	60	--	290
227BSLT	--	--	--	--	--	--	--	--	--	--	--	--	--	4
231CGLMU	--	1	--	--	--	--	--	--	--	--	--	--	--	1
230TRSC	--	2	--	--	--	--	--	--	--	--	--	--	--	2
231LCKG	--	--	1	--	--	--	--	--	--	--	--	--	--	1
231QRCG	--	1	--	--	--	--	--	--	--	--	--	--	--	1
231SCKN	--	5	24	1	--	--	--	--	--	1	--	--	--	31
341SKMK	--	--	--	--	--	--	--	1	--	--	--	--	--	1
344BLVL	--	--	--	--	--	5	--	--	--	--	--	--	--	5
344CRNL	--	--	--	--	--	2	--	3	--	--	--	--	--	5
344ESPS	--	--	--	--	--	--	--	2	--	--	--	--	--	2
344KNUS	--	--	--	--	--	--	--	1	--	--	--	--	--	1
350GRPD	--	--	--	--	--	3	--	--	--	--	--	--	--	3
350HGFL	--	--	--	--	--	--	--	--	--	--	1	--	--	1
351BDVL	--	--	--	--	--	--	--	--	--	--	1	--	--	1
351DCKR	--	--	--	--	--	--	--	--	--	--	1	--	--	1
360KTTN	--	1	--	--	--	--	--	--	--	--	19	--	3	23
360ODVC	--	3	--	--	--	--	--	--	--	--	--	--	--	3
361BSKL	--	2	--	--	--	--	--	--	--	--	--	--	1	3
361MRBG	--	--	--	--	--	--	--	--	--	--	3	--	--	3
364JKBG	--	--	--	--	--	--	--	--	--	--	1	--	1	2
367EPLR	--	1	--	--	--	--	--	--	--	--	--	--	3	4
367RCKB	--	--	--	--	--	--	--	--	--	--	--	--	4	4
371ALNN	--	2	--	--	--	1	--	--	--	--	5	--	10	18
374LSVL	--	2	--	--	--	11	--	--	--	--	1	--	2	16
377HRDS	--	1	--	--	--	--	--	--	--	--	--	--	--	1
400FRKL	--	--	--	--	--	--	--	--	--	--	2	--	--	2
400PCMB	--	15	--	--	--	75	--	29	--	--	71	--	2	192
Unknown[2]	--	16	2	--	--	38	--	11	--	11	78	8	24	210
County total	--	66	41	37	--	150	--	75	--	43	183	102	50	1,002

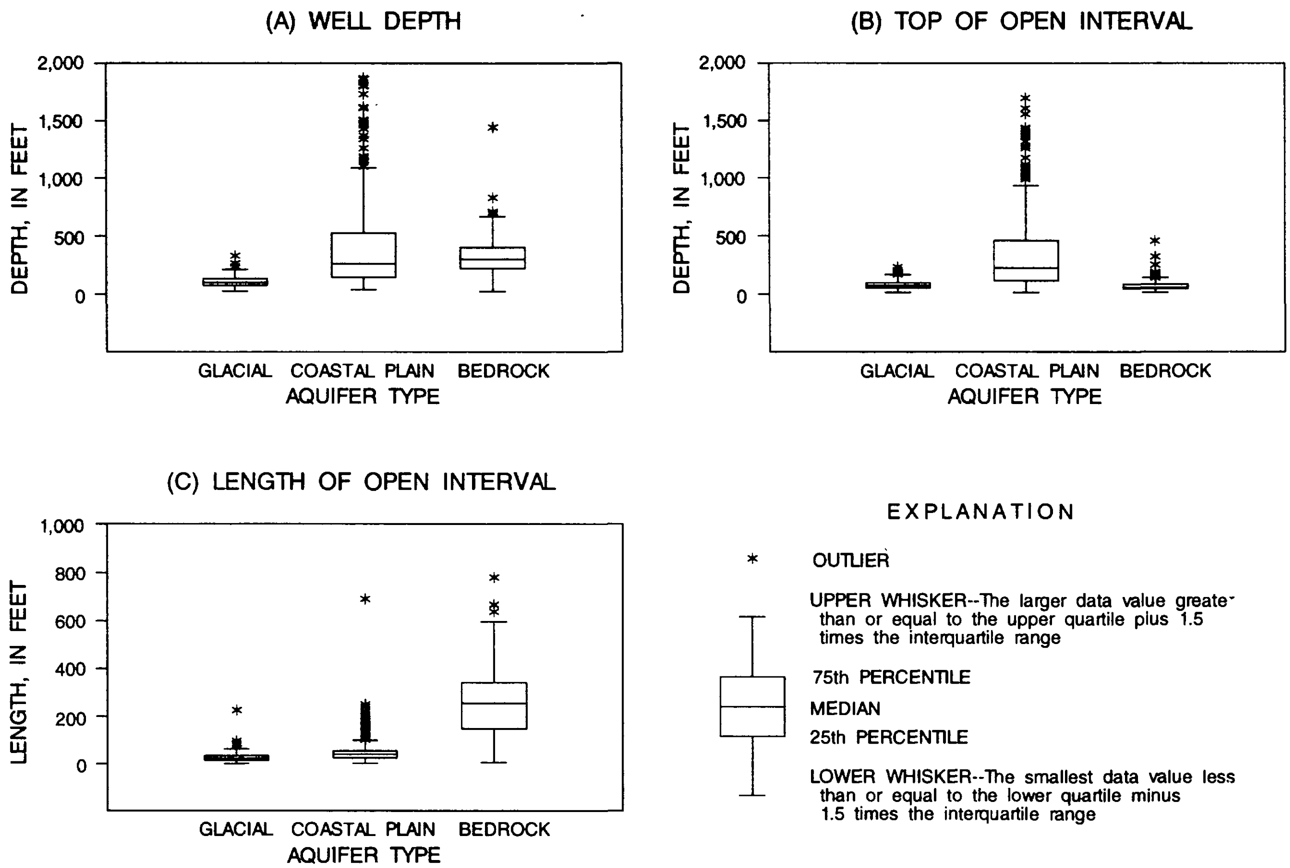


Figure 4. Distributions of well depth, depth to the top of the open interval, and length of the open interval for wells in glacial, Coastal Plain, and bedrock aquifers, New Jersey.

well. Wells in bedrock aquifers typically have the longest open intervals by far as well as the shallowest depth to the top of the open interval. Wells in Coastal Plain aquifers generally are constructed with long casing lengths and short screens in the unconsolidated sediments, although well depths and depths to the top of the open interval can vary significantly.

Confinement that protects wells from contaminants discharged at land surface is linked to thick, areally extensive, impermeable units, which are common in the Coastal Plain but rarely are found in glacial and bedrock aquifers in New Jersey. Confining units restrict the vertical and horizontal movement of ground water and reduce contaminant concentrations by processes of diffusion, adsorption, and biodegradation. (Reports documenting the location, extent, and thickness of such confining units in glacial and bedrock aquifers are rare.) Thin confining units of fine-grained sediments are probably present in most valleys in New Jersey; however, most confining units in glacial sediments probably are leaky so that travel times from the land surface to the well are small. For the purposes of this study, therefore, all wells with open intervals in glacial and bedrock aquifers are considered to be sensitive to contaminants discharged at land surface because no thick, areally extensive confining units have been documented in these aquifer types in New Jersey.

The concentration of tritium in ground-water samples can be used to indirectly assess the sensitivity of a well to contamination discharged at land surface by providing an indication of the length of time since the ground water was exposed to the atmosphere (Hendry, 1988). Although they were not directly used in this study to evaluate the sensitivity of community water-supply wells, tritium-concentration data can be used to (1) verify that the minimum time of travel is far greater than 12 years or (2) indicate that other methods are needed to accurately determine the minimum travel time.

Above-ground thermonuclear testing has caused large amounts of tritium to be injected into the atmosphere. Ground-water samples that contain high concentrations of tritium indicate that at least some of the water was deposited as precipitation after 1952, when atmospheric nuclear testing began. Samples that contain less than 0.64 pCi/L tritium indicate that the water was exposed to the atmosphere before 1952, when natural tritium concentrations were low (Hendry, 1988), and indicate that the likelihood that contaminants will enter the well within a 12-year period is small. Samples that contain more than 0.64 pCi/L tritium do not necessarily indicate that the well is sensitive to contamination, but that some of the water from the well was recharged from precipitation since 1952. Figure 5 shows boxplots of tritium concentrations in water samples from wells with open intervals in glacial aquifers, the Kirkwood-Cohansey aquifer system (an unconfined Coastal Plain aquifer system), and bedrock aquifers. The Kirkwood-Cohansey aquifer system is assumed to contain relatively young water because it is not overlain by any extensive confining units. Tritium concentrations in most samples from all three aquifer types are high, indicating that the water recharged the aquifers after 1952.

Glacial Aquifers

Wisconsinan glacial-drift material is present in the northern part of the Valley and Ridge, Highlands, and Piedmont Physiographic Provinces, generally occupying the valley areas (fig. 6). These nonmarine sediments comprise a discontinuous veneer that forms the floor of the northeast-

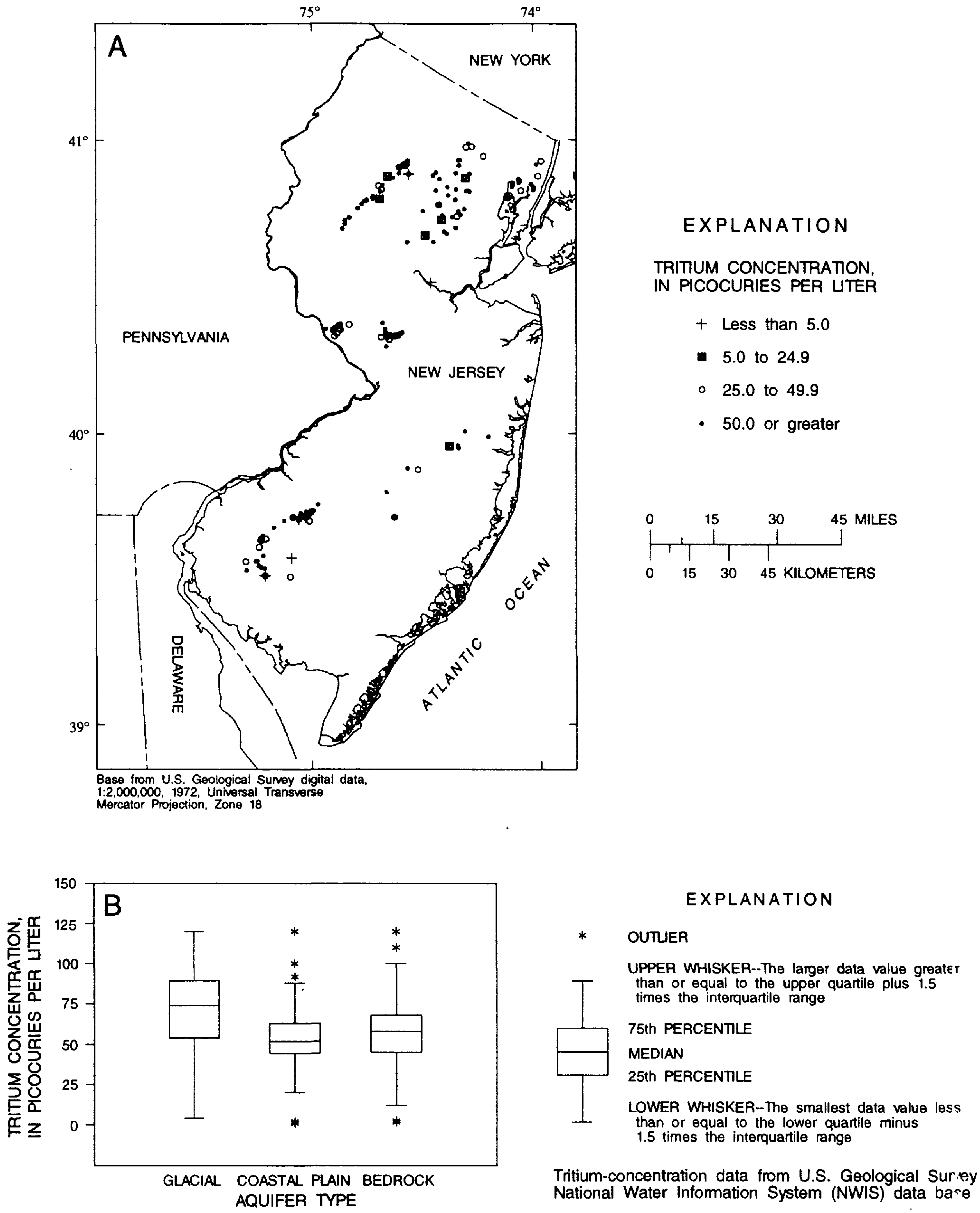


Figure 5. (A) Distribution of tritium concentrations in water samples from sampled wells, and (B) distributions of tritum concentrations in water samples from wells with open intervals in glacial aquifers, the Kirkwood-Cohansey aquifer system, and bedrock aquifers.

southwest-trending valleys between ridges of resistant bedrock. The glacial drift varies in thickness and lateral extent. Stratified sediments, which include lakebottom, fluvial, deltaic, and lacustrine deposits, consist of clay, silt, sand, and gravel that can be greater than 200 ft thick. Bedrock ridges commonly are overlain by discontinuous till deposits that generally are less than 20 ft thick. The terminal moraine trends northwest-southeast across the central part of the three provinces (fig. 6). Moraine deposits generally are present as ridges and knolls along former ice margins and can be as much as 200 ft thick.The materials comprising these deposits consist of poorly sorted sand, gravel, and boulders with interbedded silt and clay lenses (Stanford and others, 1990). A generalized cross-section showing aquifer and confining-unit geometry and ground-water flow patterns in this type of aquifer is shown in figure 7.

Two distinct types of aquifer systems--glacial and bedrock--are found in the Piedmont, Highlands, and Valley and Ridge Physiographic Provinces (fig. 1). Glacial drift in the scoured valleys is a source of abundant ground water in the northern half of New Jersey. Many community water-supply wells are completed in glacial sediment because yields from these wells typically are greater than those from wells in the surrounding bedrock aquifers. Water in glacial aquifer systems, like water in the Coastal Plain, typically enters a well from pore spaces in the aquifer material surrounding the well opening. Recharge to glacial aquifers typically enters the system as direct infiltration of precipitation and seepage from surface-water bodies through the valley floor and, near the base of the valley walls, of overland runoff from upland areas, because infiltration into the competent bedrock there is small as a result of low porosity (Risser and Madden, 1994).

Wells screened in glacial aquifer systems typically are less than 150 ft deep because glacial sediments are relatively thin. The depth to the top of the open interval of wells in glacial aquifers is commonly less than 100 ft below land surface (fig. 4). These wells typically have short open intervals because yields in glacial aquifers tend to be large. Median values determined from wells in the water-supply-well data base of the depth to the top of the open interval and the well depth for wells in stratified drift are 78 and 102 ft below land surface, respectively.

An available ground-water flow model was used to estimate the time of travel to, and evaluate the sensitivity to contamination of, selected wells in a "typical" glacial-aquifer setting. The contributing areas of three wells (27-82, 27-83, and 27-86) located in the Highlands Physiographic Province in a glacial aquifer are shown in figure 8. The contributing areas were delineated by use of a numerical ground-water flow model with a particle-tracking analysis to simulate flow paths and determine time of travel (D.E. Rice and L.M. Voronin, U.S. Geological Survey, written commun., 1995). Ground-water contributing areas associated with travel times less than or equal to 12 years are distinguished from those associated with travel times greater than 12 years. These wells were selected for this analysis because they represent a variety of conditions that are typical in glacial-valley aquifer systems in New Jersey. Selected well-construction and time-of-travel data for these wells are presented in table 6.

Picatinny Arsenal well 130 (27-82) is screened from 102 to 117 ft below land surface in stratified drift that is locally confined. Simulation results indicate that travel times from the water table to the well generally are less than 12 years. The well's contributing area is near the base of

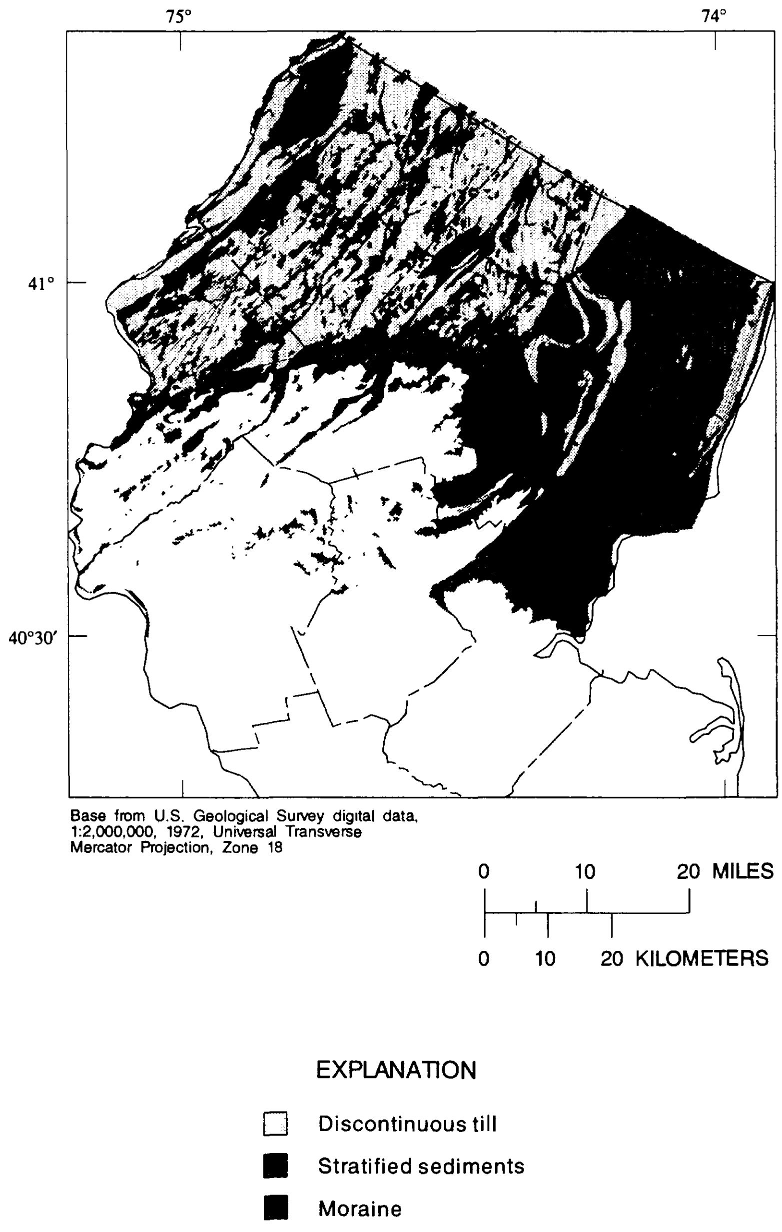


Figure 6. Extent of glacial sediments in northern New Jersey. (Modified from Stanford and others, 1990.)

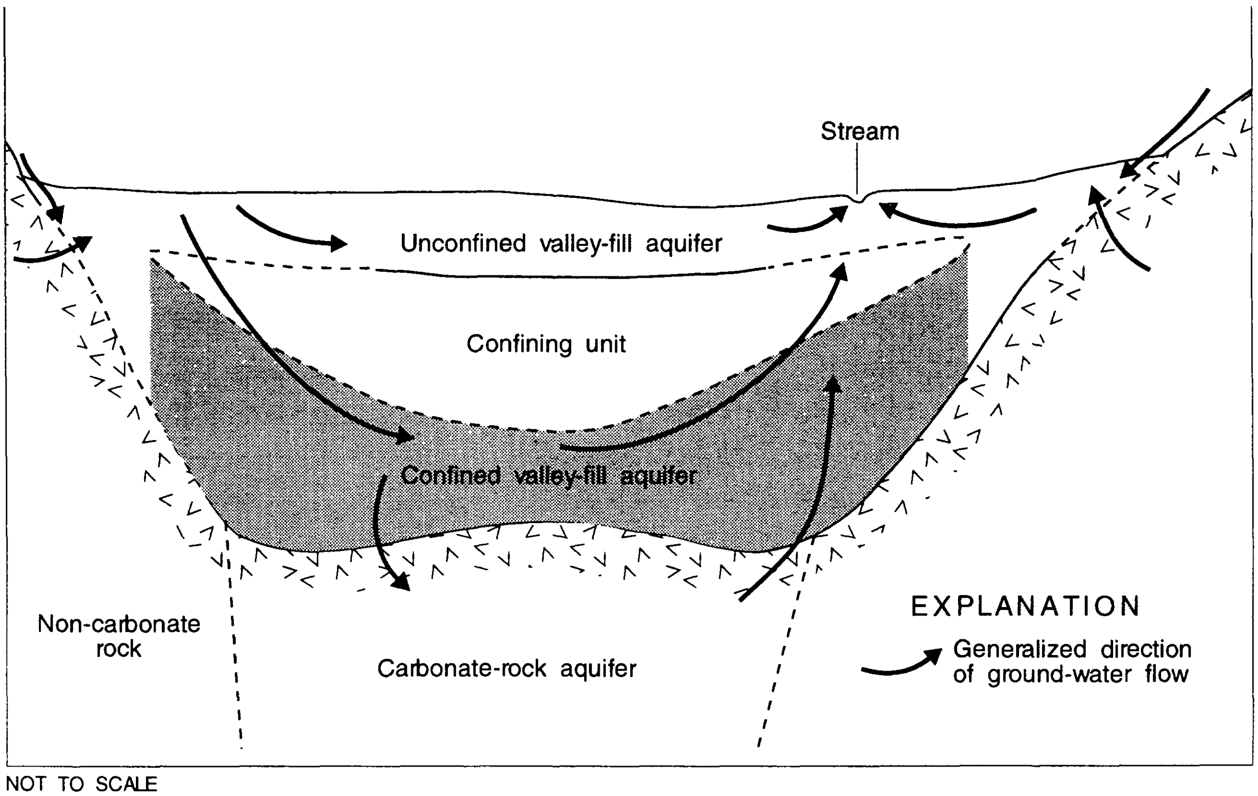


Figure 7. Generalized hydrogeologic section showing aquifer and confining-unit geometry and ground-water flow paths in glacial aquifers in northern New Jersey. (Modified from Sargent and others, 1990.)

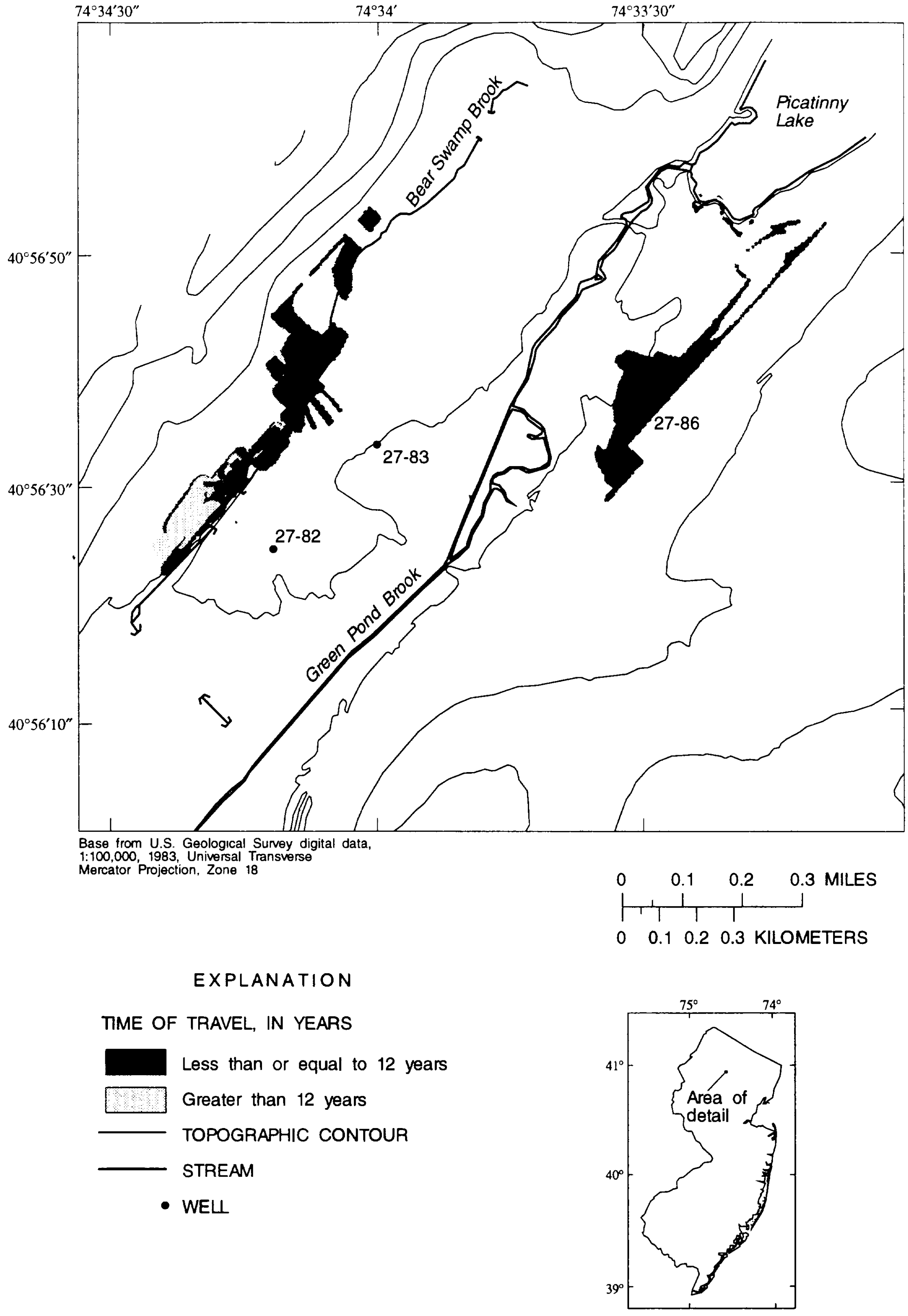


Figure 8. Simulated ground-water contributing areas and travel times for wells 27-82, 27-83, and 27-86 in a glacial aquifer at Picatinny Arsenal, Morris County, New Jersey. (Modified from D.E. Rice and L.M. Voronin, U.S. Geological Survey, written commun., 1995.)

Table 6. Selected well-construction data and simulated ground-water travel times for community water-supply wells screened in glacial and bedrock aquifers in Morris County, New Jersey

Well number	Depth of open interval, in feet below land surface	Aquifer type	Hydrogeologic characteristics	Travel time, in years		
				Minimum	Median	Maximum
27-82	102 - 117	Glacial	About 60 feet of alternating beds of very fine sand, silt, and clay	2	8	40
27-83	110 - 403	Glacial and bedrock	Screened partly in glacial sediments and partly in bedrock. Minimal confining material above open interval	1	10	619
27-86	75 - 85	Glacial	Minimal confining material above screened interval	1	2.3	150

the valley wall rather than around the well. Boxplots showing the distribution of simulated travel times are shown in figure 9. The median time of travel from the water table to the well is about 8 years. The minimum and maximum time of travel to well 130 are 2 and 40 years, respectively.

Well 410 (27-86) at Picatinny Arsenal also is completed in the glacial aquifer system (fig. 8). The well is screened from 75 to 85 ft below land surface in stratified drift. Only minimal confining material is present above the screened interval. The contributing area is partly around the well and partly in an area upvalley near Picatinny Lake. Most recharge enters the aquifer system near the valley wall. The time of travel from the water table to the well for nearly all of the contributing area is less than or equal to 12 years; therefore, the well is considered to be sensitive to contaminants discharged at land surface. The median simulated time of travel is 2.3 years (fig. 9), with minimum and maximum times of 1 and 150 years, respectively (table 6). Because some of the water in this well originates near the valley wall and near Picatinny Lake, about 0.5 mi upvalley from the well, a wellhead-protection area around the well would not protect it from contaminants originating at land surface in these areas.

Well 302D (27-83) at Picatinny Arsenal is open to both the glacial aquifer and the underlying bedrock aquifer. This well's open interval extends from 110 to 403 ft below land surface and only minimal confining material is present above the open interval. The contributing area (fig. 8) is near the base of the valley wall rather than around the well. The median simulated time of travel is 10 years; therefore, most of the recharge reaches the well in less than 12 years (fig. 9).

Ground-water flow in most glacial aquifer systems probably behaves similarly to that in the glacial aquifer system at Picatinny Arsenal. In this study, all wells with open intervals in glacial aquifers are considered to be sensitive to contamination discharged at land surface because of (1) the lack of mappable, extensive confining units; (2) the short travel times from land surface to the well; and (3) the typical construction characteristics of wells in glacial aquifers, which include shallow depth to the top of the open interval and shallow depth of the well.

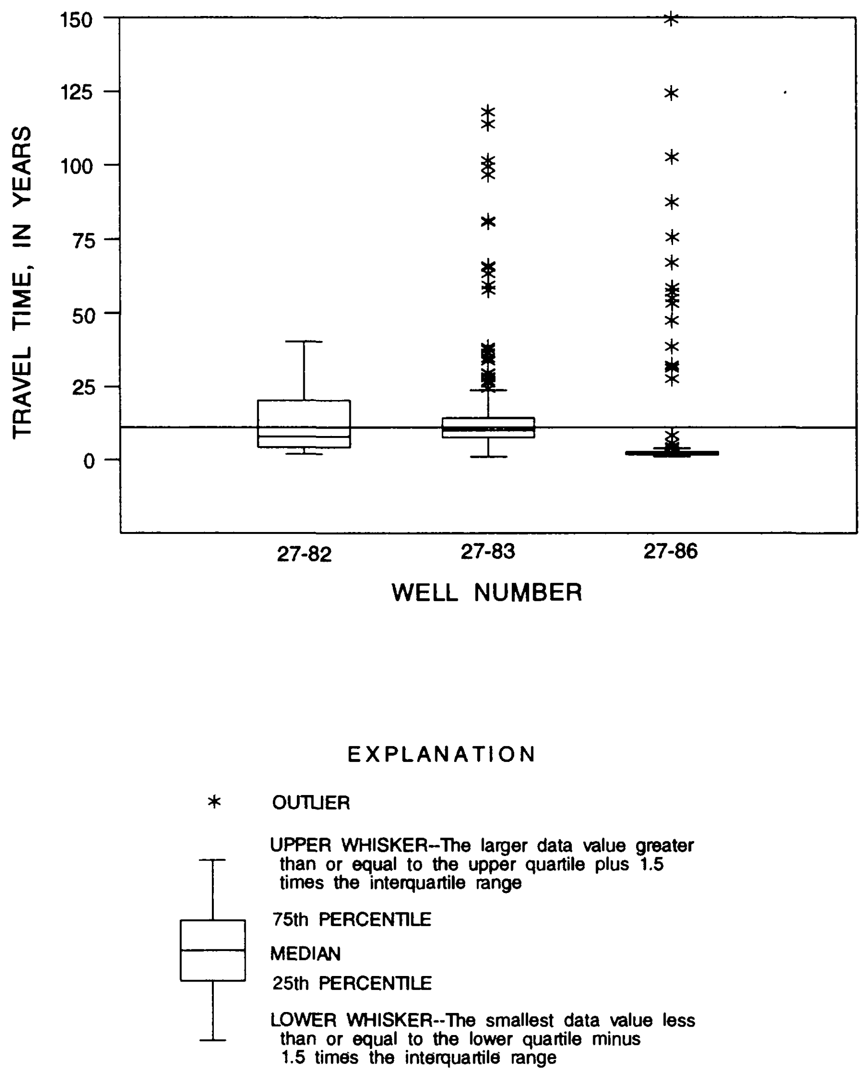


Figure 9. Distributions of simulated ground-water travel times for three wells at Picatinny Arsenal, Morris County, New Jersey. (Well locations are shown in fig. 8.)

Coastal Plain Aquifers

The New Jersey Coastal Plain Physiographic Province is located in the southern part of the State. It includes all of New Jersey south and east of a line between Raritan Bay and the Delaware River near Trenton, encompassing about 60 percent of the State (fig. 1). The Coastal Plain is structurally a monocline that dips southeastward at a very low angle. The Coastal Plain sequence strikes northeast-southwest, parallel to the lower reach of the Delaware River. The bedrock below the Coastal Plain sediments consists of a complex of pre-Cretaceous igneous and metamorphic rocks. Cretaceous sediments unconformably overlie the bedrock (table 1). These sediments consist mainly of continental, coastal, and shallow marine gravels, sands, silts, and clays. Glauconitic sands, generally indicative of marine transgression, are commonplace in the upper Cretaceous sediments. Above the Cretaceous sediments is a series of Tertiary sediments that range in age from Paleocene through Miocene. They include sands, silts, and gravels, with common glauconitic zones. Pleistocene sediments, mainly fluvial sands and gravels, form a discontinuous veneer across the Coastal Plain (Zapecza, 1989). The sedimentary section is about 6,700 ft thick in the southeasternmost part of Cape May County. These sediments comprise a series of layers of gravel and sand that function as aquifers and intervening layers of silt and clay that function as confining units.

The sediments of the New Jersey Coastal Plain are divided into a series of aquifers with intervening confining units that restrict the rate of movement and alter the direction of ground-water flow. Seven major aquifer systems are recognized, along with several that are of lesser importance and relatively limited extent. In many cases, hydrologic boundaries differ from the formal stratigraphic boundaries. For example, a geologic formation can act as an aquifer in one area and as a confining unit in another. A geologic formation can include more than one aquifer. A detailed description of the aquifers and confining units in the Coastal Plain, including maps of the altitude of the tops of units, thickness of units, outcrop areas of units, and extent of units is presented by Zapecza (1989).

In the Coastal Plain Physiographic Province (fig. 1), wells typically are screened in unconsolidated sediments consisting of gravel, sand, and silt. No community water-supply wells in the Coastal Plain are completed in bedrock aquifers. Water typically enters the well from pore spaces in the aquifer material surrounding the well opening. Ground water in wells with open intervals in aquifers in the Coastal Plain generally enters the system at land surface and flows downgradient through the unconfined system. In some cases, ground water flows underneath or through dense layers of fine sediments, where it becomes confined. A generalized hydrogeologic section through the major aquifers and confining units in the New Jersey Coastal Plain is shown in figure 10. Major aquifers within the Coastal Plain Province include (1) the Kirkwood-Cohansey aquifer system, (2) the Atlantic City 800-foot sand, (3) the Piney Point aquifer, (4) the Vincentown aquifer, (5) the Wenonah-Mount Laurel aquifer, (6) the Englishtown aquifer system, and (7) the Upper, Middle, and Lower Potomac-Raritan-Magothy aquifers. About 99 percent of community water-supply wells in the Coastal Plain Province tap these aquifers.

A confining unit is a formation or part of a formation in which ground-water flow is restricted relative to flow in the surrounding aquifers (Lohman and others, 1972). Hydraulic conductivities in confining units generally are distinctly lower than those in aquifers. Several major confining units are recognized within the Coastal Plain sediments in New Jersey. In order to

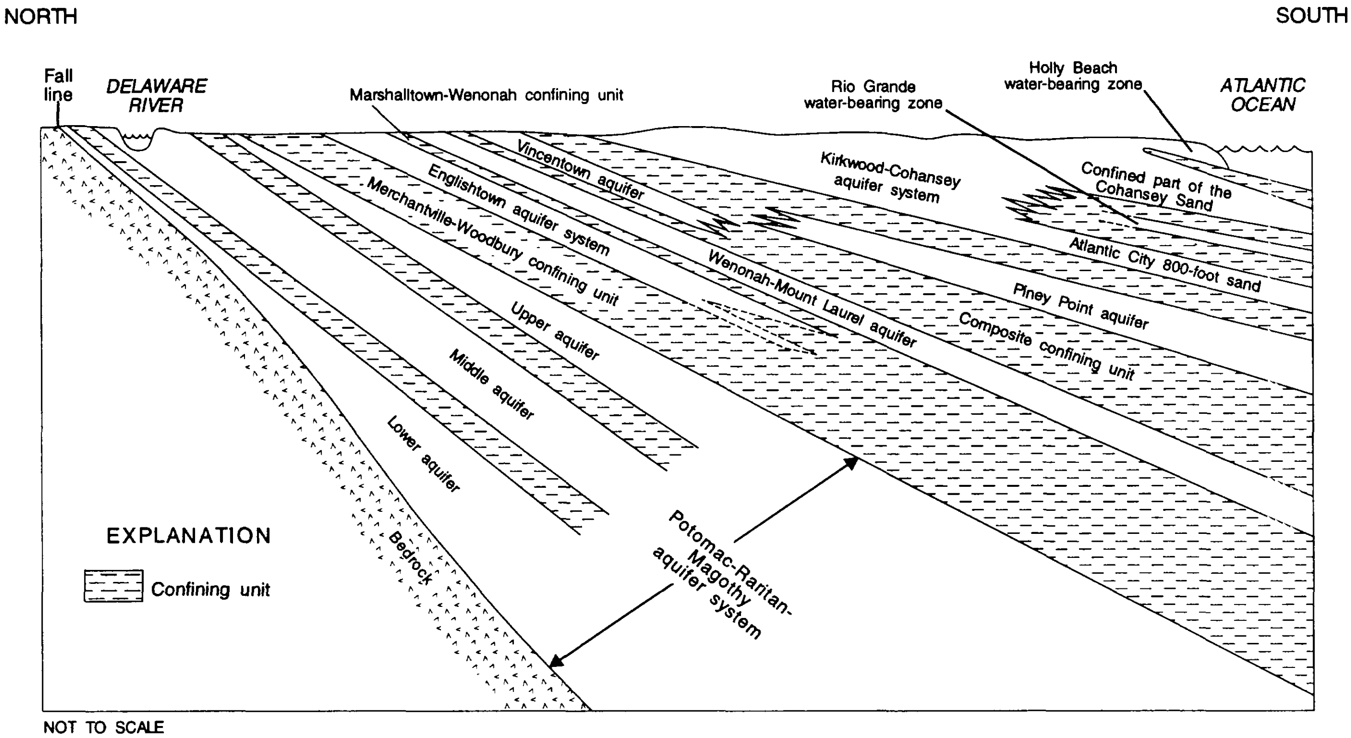


Figure 10. Generalized hydrogeologic section showing major aquifers and confing units in the New Jersey Coastal Plain. (Modified from Martin, in press.)

be considered adequate to restrict flow to the degree needed to protect a well from contaminants discharged at land surface, these layers must be fairly extensive areally, have appreciable thickness, and have relatively low hydraulic conductivities.

Confining units can restrict the vertical movement of ground water to the extent that the minimum time of travel from land surface to the well through the confining unit far exceeds 12 years. These units include (1) the confining unit overlying the estuarine sand facies in part of Cape May County, (2) the confining unit overlying the Atlantic City 800-foot sand, (3) the composite confining unit, (4) the Marshalltown-Wenonah confining unit, and (5) the Merchantville-Woodbury confining unit. Other less extensive and leaky confining units are present. In confined aquifers in areas near where confining units crop out, pinch out, thin, or become more permeable, ground water may flow around or through the confining unit and reach a well in less than 12 years. In these cases, a well screened in the confined aquifer may be sensitive to contamination discharged at land surface.

The time of travel of ground water through the Merchantville-Woodbury confining unit (fig. 11) was simulated with a finite-difference flow model of the New Jersey Coastal Plain (D.A. Pope and others, U.S. Geological Survey, written commun., 1995). This confining unit separates the Upper Potomac-Raritan-Magothy aquifer from the Englishtown aquifer system. For all areas far from the outcrop area, the time of travel through the confining unit exceeds 500 years. Near the outcrop of the confining unit, simulation results indicate that ground water flows upward from the Upper Potomac-Raritan-Magothy aquifer and, therefore, time of travel from land surface to the well also likely is greater than 12 years.

The time of travel of ground water through the composite confining unit (fig. 12) also was simulated (D.A. Pope and others, U.S. Geological Survey, written commun., 1995). This confining unit separates the Wenonah-Mount Laurel aquifer from the Vincentown, the Piney Point, and other aquifers, depending on location within the Coastal Plain. The model grid was too coarse near the outcrop to accurately determine the time of travel from land surface to a well and, consequently, to determine whether wells are sensitive to contamination from land surface. The time of travel through the confining unit exceeds 100 years in all areas except near the confining-unit outcrop area. Similar travel times were simulated for the remaining three confining units listed above (D.A. Pope and others, U.S. Geological Survey, written commun., 1995). Wells screened in aquifers below all five of these confining units that are located far from the confining-unit outcrop area most likely are adequately confined and, therefore, insensitive to contaminants discharged at land surface.

A ground-water contributing area for a shallow well located in the outcrop area of the Potomac-Raritan-Magothy aquifer system is shown in figure 13. The contributing area was simulated with a finely discretized ground-water flow model by use of a particle-tracking analysis (Navoy, 1994). The figure distinguishes between areas where travel times from the water table to the well exceed 12 years and areas where they are less than or equal to 12 years. The well, Greenwich Township well 4 (15-69), is screened from 108 to 168 ft below land surface in the Middle Potomac-Raritan-Magothy aquifer and is partly confined locally above the open interval. All water that enters the well within a radius of about 0.4 mi reaches the well within a 12-year period. The maximum distance that the contributing area extends from the well is about 0.8 mi, although the travel time to the well is greater than 12 years. Results of this simulation indicate that

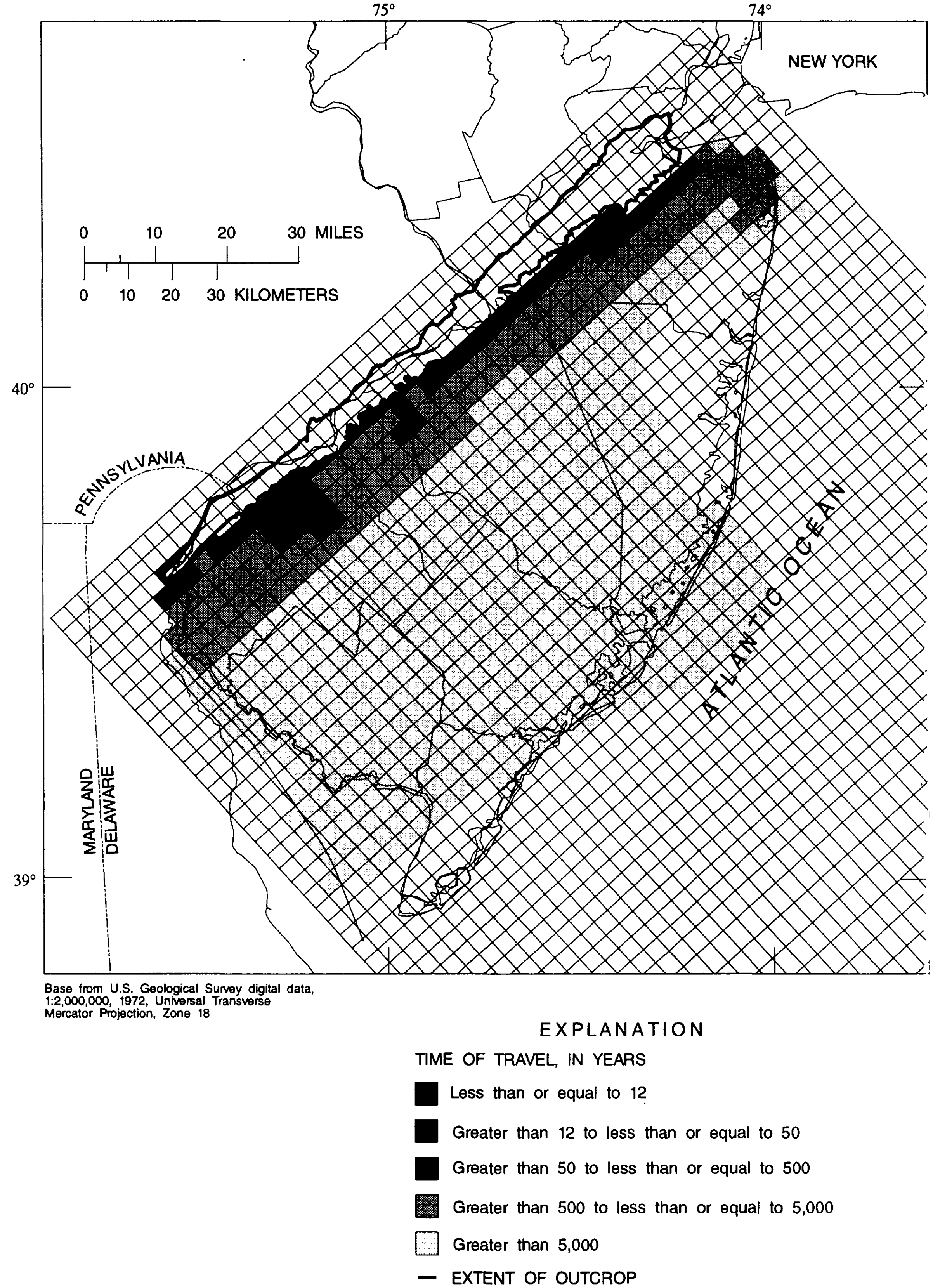


Figure 11. Ground-water travel time through the Merchantville-Woodbury confining unit in the New Jersey Coastal Plain. (Modified from D.A. Pope and others, U.S. Geological Survey, written commun., 1995.)

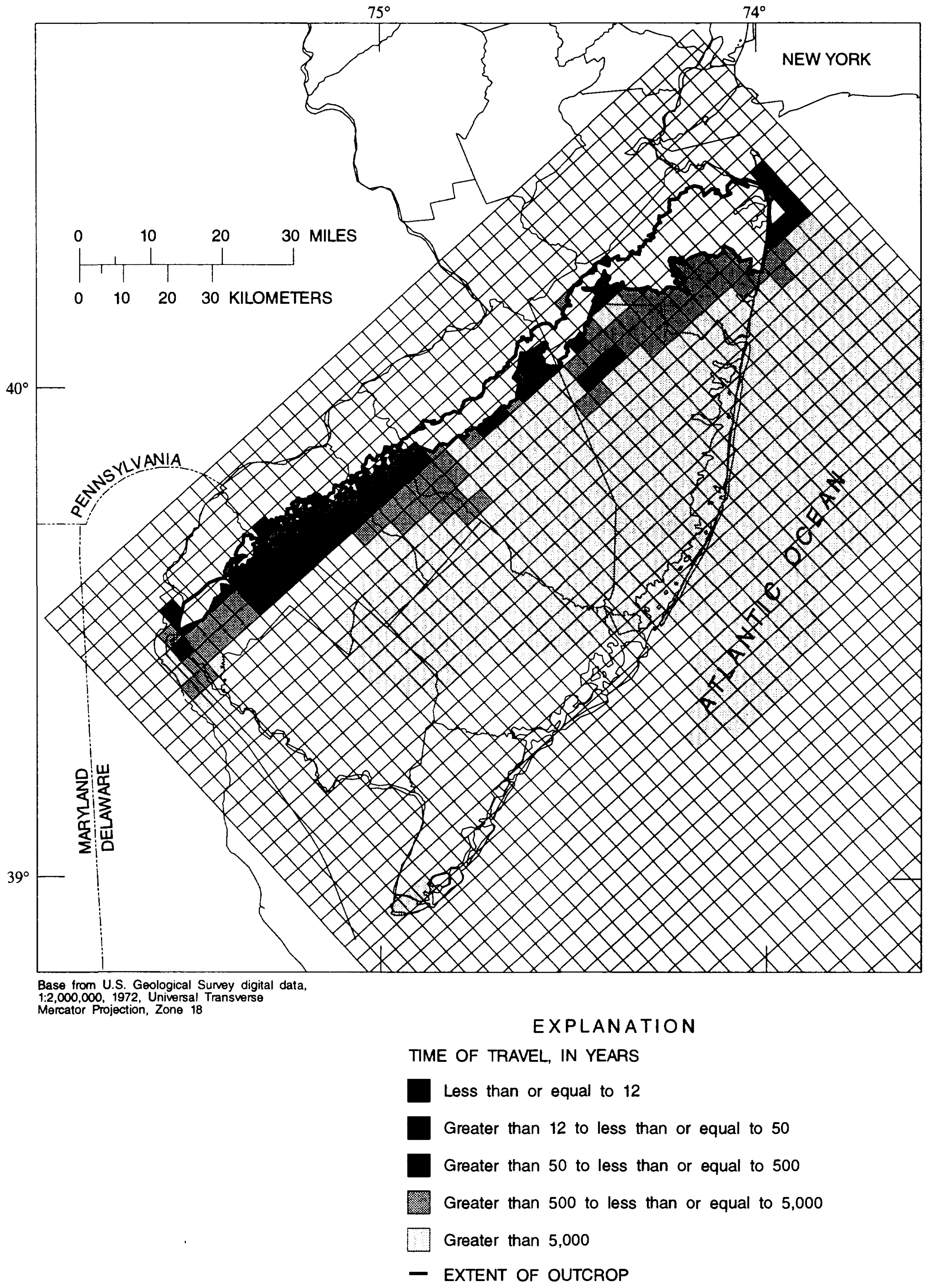


Figure 12. Ground-water travel time through the composite confining unit in the New Jersey Coastal Plain. (Modified from D.A. Pope and others, U.S. Geological Survey, written commun., 1995.)

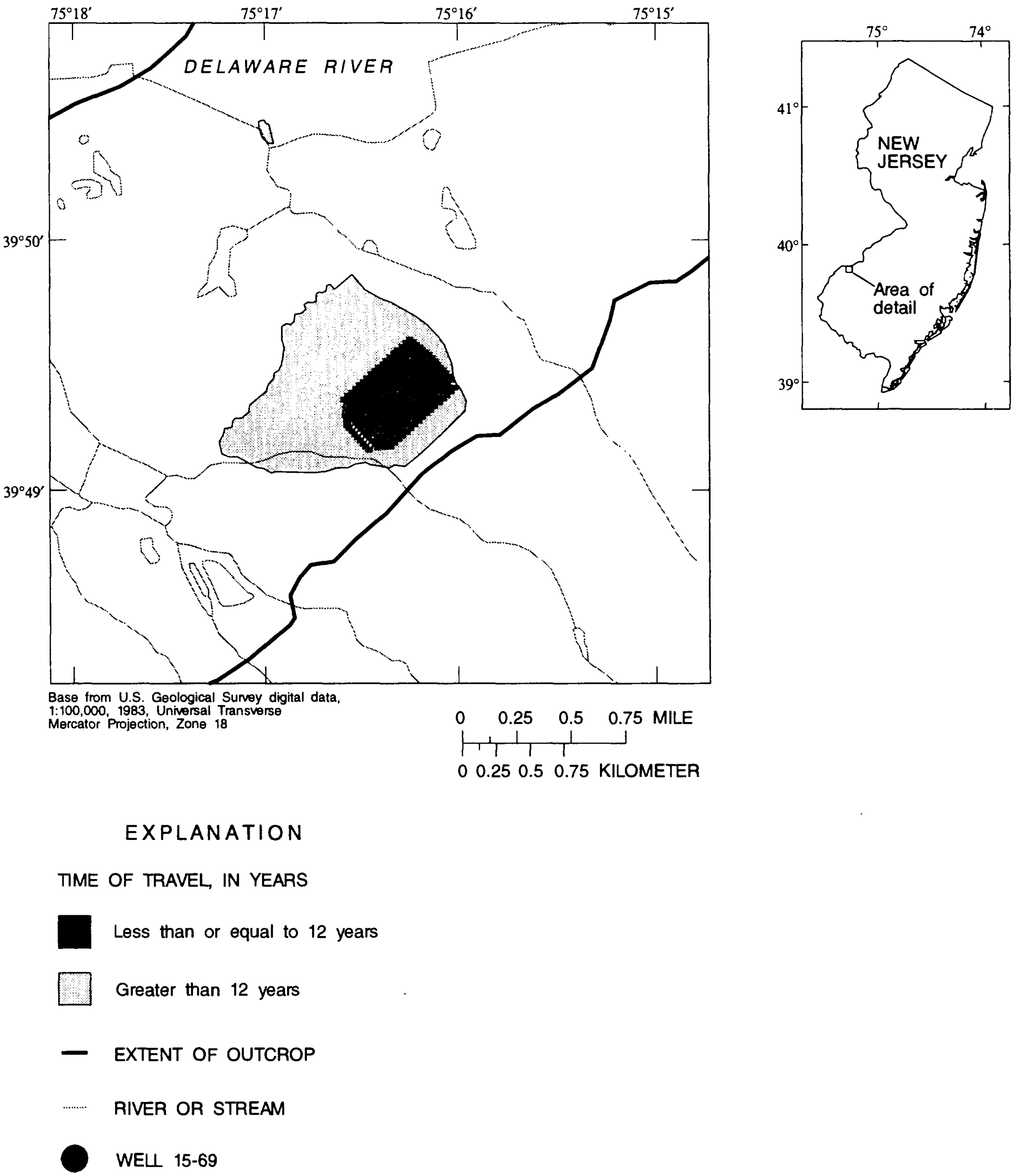


Figure 13. Simulated ground-water contributing area and travel time to well 15-69 in a Coastal Plain aquifer system, Gloucester County, New Jersey. (Modified from Navoy, 1994.)

about 17 percent of the flow to the well travels from land surface through the leaky confining unit between the Upper and Middle Potomac-Raritan-Magothy aquifers to the well in less than 12 years.

A ground-water contributing area for a well downdip from the outcrop area of the Potomac-Raritan-Magothy aquifer system is shown in figure 14. The contributing area was delineated with the numerical model described above (Navoy, 1994). This well, Paulsboro Water Department well 4 (15-212), is screened in the Middle Potomac-Raritan-Magothy aquifer from 192 to 220 ft below land surface. However, because a confining unit is present between the well's open interval and land surface, the contributing area does not surround the well, but is updip from the well in the outcrop area of the Potomac-Raritan-Magothy aquifer system. The time of travel from the water table to the well exceeds 12 years at all points within the contributing area.

A ground-water contributing area for a well screened adjacent to the outcrop area of the Potomac-Raritan-Magothy aquifer system is shown in figure 15. The well, Greenwich Township well 6 (15-348), is screened from 105 to 135 ft below land surface in the Middle Potomac-Raritan-Magothy aquifer. The contributing area was delineated with the same numerical model (Navoy, 1994). Results of the simulation indicate that the contributing area is greatly affected by the large volume of water withdrawn from this aquifer through well 15-69 (fig. 13). A statistical analysis of the 2,400 particles used in the model to represent ground-water flow paths indicates that the time of travel of all ground water flowing to the well is greater than 12 years.

A statistical analysis of travel times of 2,400 ground-water particles simulated with the numerical model (Navoy, 1994) was conducted for 10 wells in and near the outcrop of the Potomac-Raritan-Magothy aquifer system. The locations of the wells used in this simulation are shown in figure 16. The distribution of travel times indicates that although a well is located in the outcrop area, if it is sufficiently deep, the minimum time of travel may be greater than 12 years, as is the case for well 15-207, which is screened in the lower Potomac-Raritan-Magothy aquifer (fig. 17). Minimum travel time to other wells downdip from the outcrop, such as well 15-312, which is screened in the Middle Potomac-Raritan-Magothy aquifer about 0.4 mi downdip from the outcrop of the aquifer system, also may be greater than 12 years. Water traveled from the water table through or around the leaky confining unit between the Upper and Middle aquifers to this well in a minimum of about 30 years. Selected well-construction and time-of-travel data are presented in table 7.

Wells screened in Coastal Plain aquifers were determined to be either (1) sensitive (wells in or less than 0.5 mi downdip from outcrop areas of confined aquifers and wells in unconfined aquifers, where the minimum time of travel likely is less than 12 years) and (2) insensitive (wells in confined aquifers more than 0.5 mi from the outcrop area, where the minimum time of travel likely is greater than 12 years). All wells screened in aquifers that do not crop out can be considered to be insensitive to contamination because the time of travel exceeds 12 years. These aquifers include the Atlantic City 800-foot sand, the Rio Grande water-bearing zone, the Piney Point aquifer, and, in Cape May County, the estuarine sand facies and the Cohansey Sand.

A zone between 0 and 0.5 mi downdip from an outcrop area of an aquifer was considered to be an area of uncertainty where wells may be sensitive to contaminants discharged at land surface despite the presence of overlying confining units. In this area of local confinement, time of

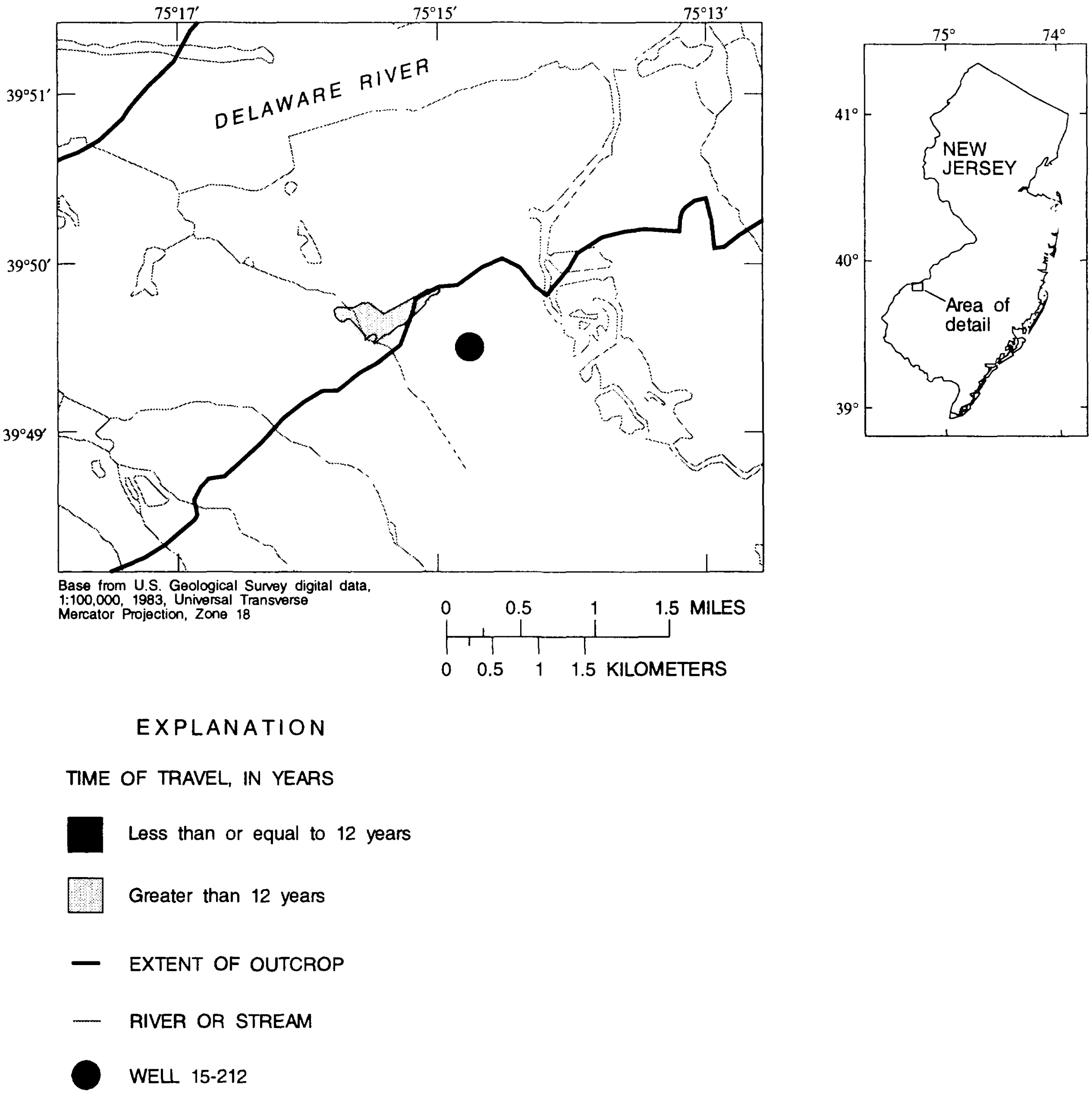


Figure 14. Simulated ground-water contributing area and travel time to well 15-212 in a Coastal Plain aquifer system, Gloucester County, New Jersey. (Modified from Navoy, 1994.)

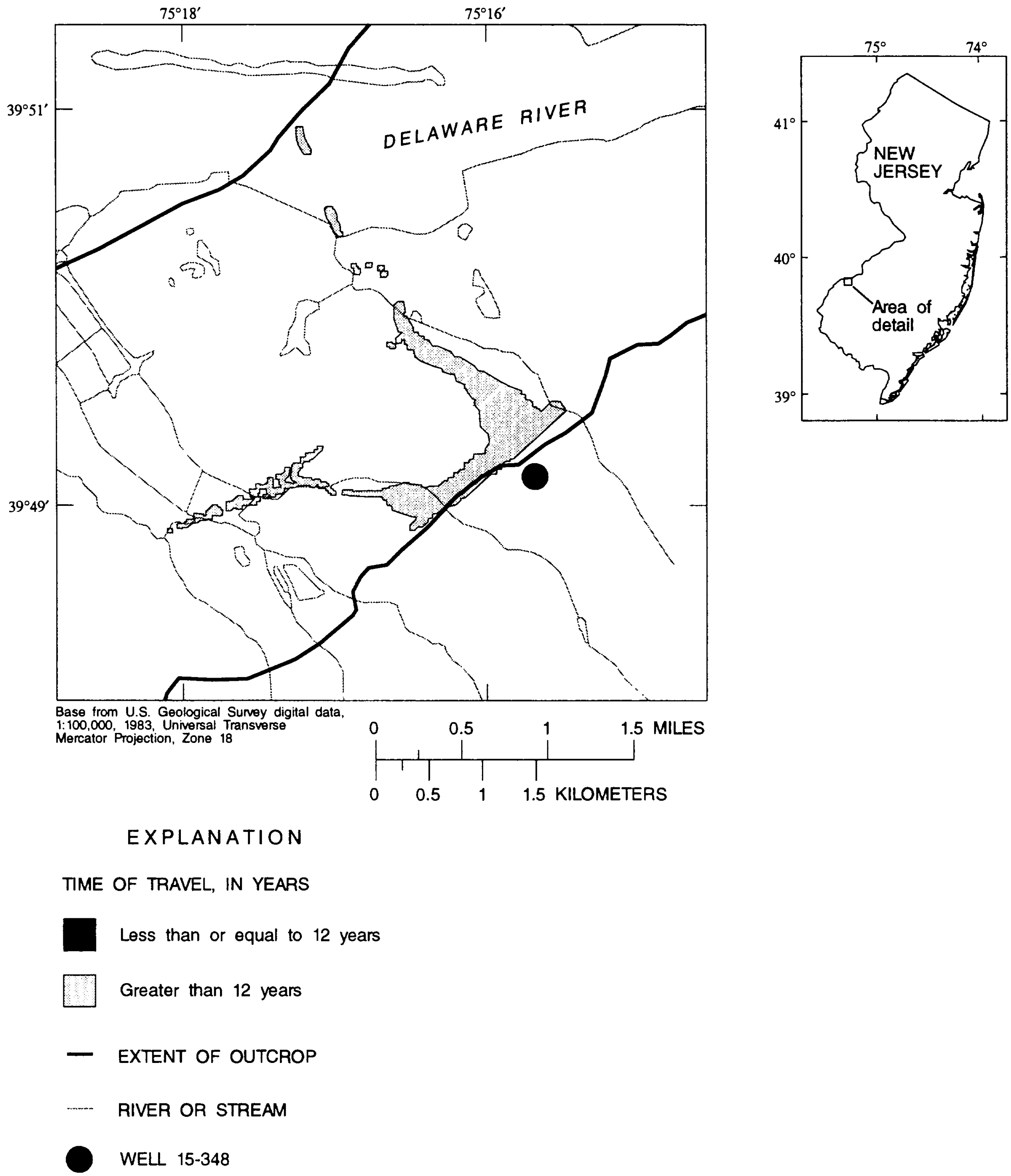


Figure 15. Simulated ground-water contributing area and travel time to well 15-348 in a Coastal Plain aquifer system, Gloucester County, New Jersey. (Modified from Navoy, 1994.)

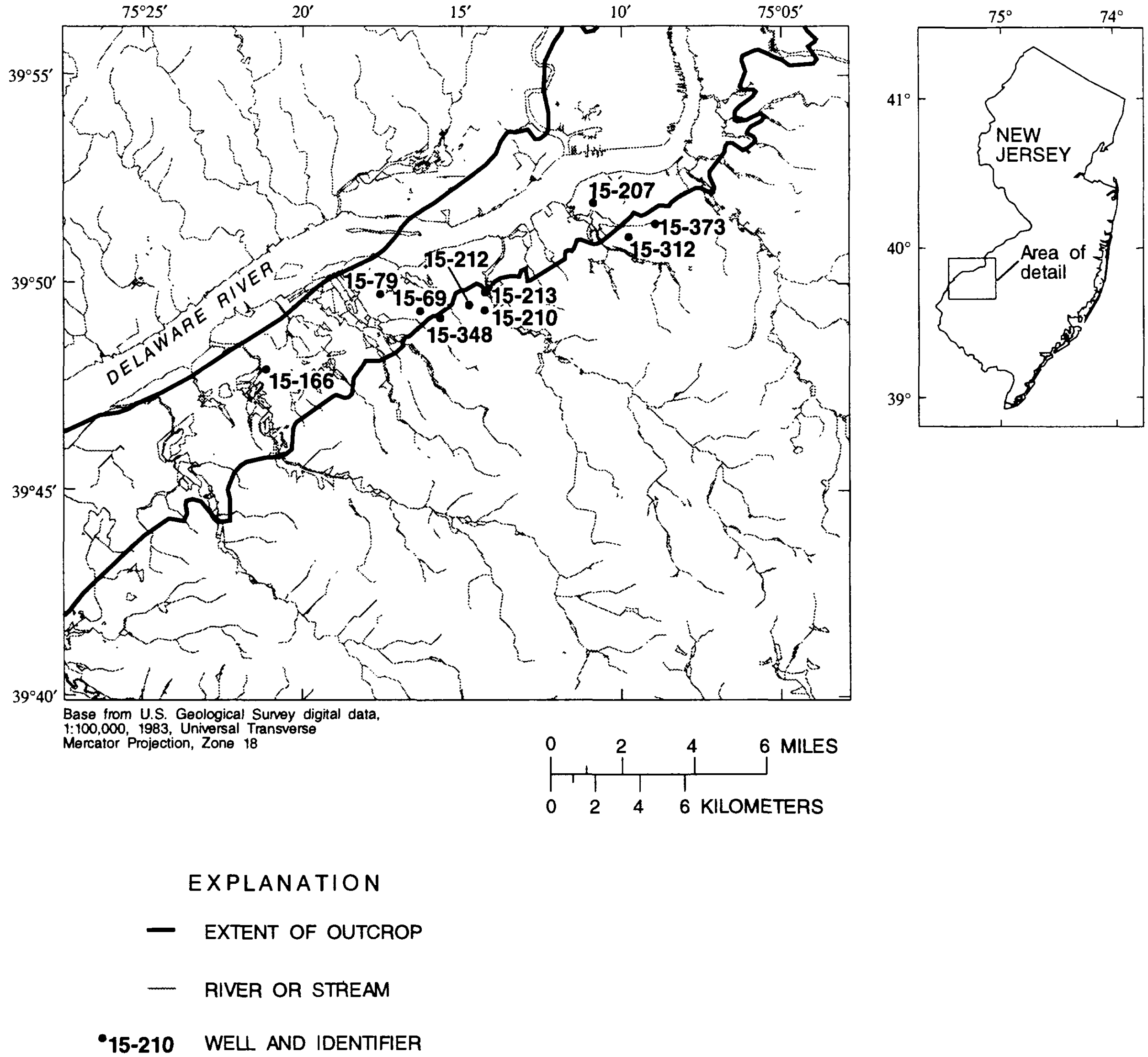


Figure 16. Locations of selected wells in and downdip from the outcrop of the Potomac-Raritan-Magothy aquifer system in Gloucester County, New Jersey.

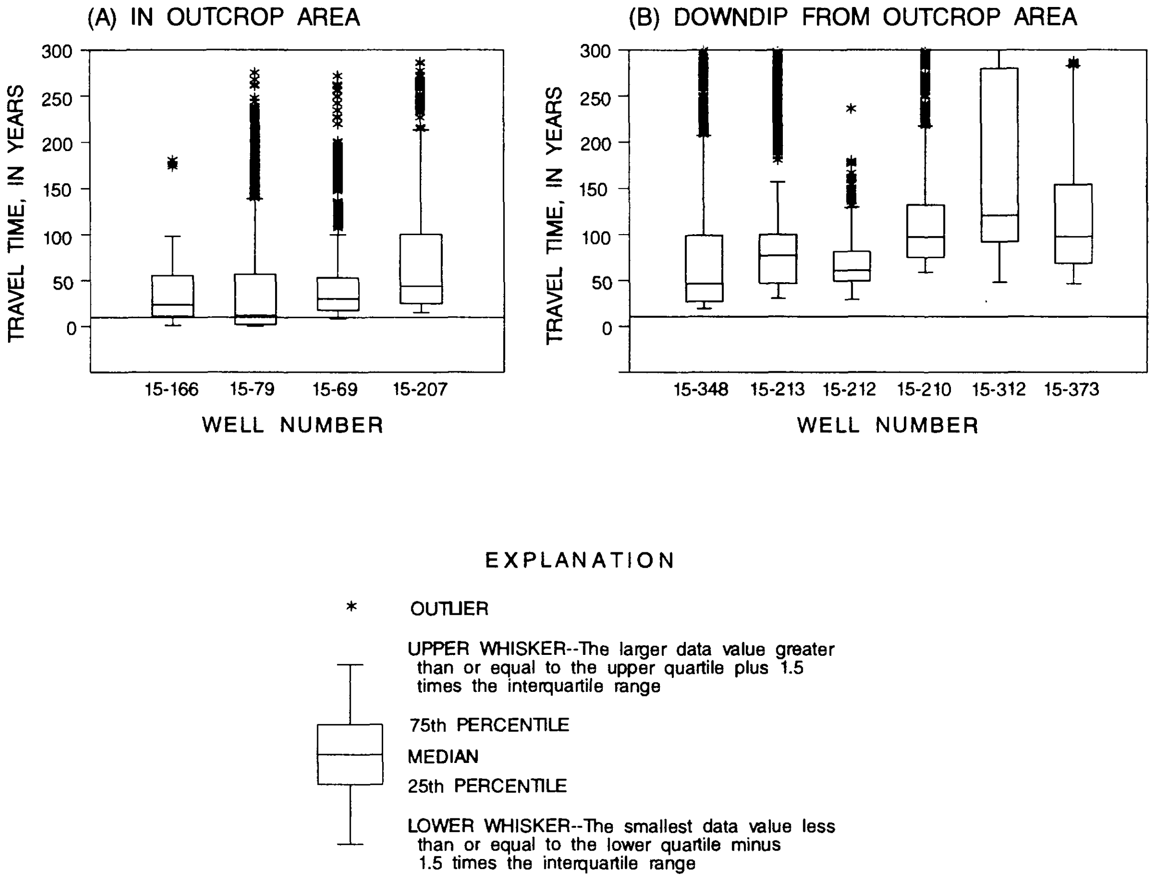


Figure 17. Distributions of ground-water travel times to selected wells in and downdip from the outcrop of the Potomac-Raritan-Magothy aquifer system, New Jersey. (Well locations are shown in fig. 16.)

Table 7. Selected well-construction data and simulated ground-water travel times for community water-supply wells screened in the Potomac-Raritan-Magothy aquifer system in Gloucester County, New Jersey

[<, less than]

Well number	Well owner and local identifier	Depth of open interval, in feet below land surface	Aquifer	Distance from outcrop area, in miles	Travel time, in years		
					Minimum	Median	Maximum
15-166	PENNS GROVE WSC #2	65 - 88	Middle	0	<1	23	180
15- 79	EI DUPONT REPAUNO #6	84 - 109	Middle	0	<1	12	781
15- 69	GREENWICH WD #4	108 - 168	Middle	0	8	30	272
15-207	NATIONAL PK WD #5	241 - 282	Lower	0	15	44	774
15-348	GREENWICH WD #6	105 - 138	Middle	.11	19	46	634
15-213	PAULSBORO WD #5	135 - 175	Middle	.04	30	77	314
15-212	PAULSBORO WD #4	192 - 220	Middle	.42	29	61	962
15-210	PAULSBORO WD #6	185 - 230	Middle	.51	58	97	1,763
15-312	W DEPTFORD WD #6	322 - 372	Lower	.38	48	121	10,562
15-373	W DEPTFORD WD #7	323 - 366	Lower	.38	47	98	10,600

travel to the well may be less than 12 years. In this situation, however, regulation of activities in the area surrounding the well would not protect the well from contaminants discharged at land surface because the area contributing water to the well is not near the well. Nevertheless, because of this uncertainty, the well is considered to be sensitive to contamination. A more detailed investigation in which site-specific information is examined would be needed to determine the sensitivity of this type of well.

For most aquifers in the Coastal Plain, any well in the outcrop area is considered to be sensitive to contamination, because confining units typically are thin or absent. In more complex aquifer systems, such as the Potomac-Raritan-Magothy aquifer system, where several aquifers are separated by thin, leaky confining units in the outcrop area, wells in the lowest aquifer may be confined to the degree that water from land surface may not reach the well within 12 years. However, a detailed investigation is usually needed to determine areas contributing water to wells and corresponding travel times. In areas near the Atlantic Ocean or Delaware Bay, such as Cape May County, the lateral movement of saltwater resulting from the pumping of freshwater from the aquifer system may be more important than the introduction of contaminants from the land surface to the aquifer.

Bedrock Aquifers

The Piedmont Physiographic Province trends northeast-southwest across the north-central and northeastern part of New Jersey (fig. 1). The southeastern edge of the province extends from the Delaware River near Trenton northeastward to Raritan Bay. The northwestern edge of the province is defined by a complex system of faults, beginning near Riegelsville and extending across the State. Structurally, the Piedmont Province is a monoclinal basin that strikes northeast-southwest and dips irregularly to the northwest (Lewis and Kummel, 1912). The sedimentary section consists of upper Triassic and lower Jurassic rocks, mainly nonmarine sandstones, shales, and conglomerates (table 1). Within the sedimentary section are three series of basalt flows, which crop out and form an arcuate series of ridges in north-central New Jersey called the Watchung Mountains, and thick diabase sills that crop out in Hunterdon and Mercer Counties and along the western bank of the Hudson River (Lyttle and Epstein, 1987). The Triassic and Jurassic sequence is collectively known as the Newark Supergroup. Geologic units that function as major aquifers in the Piedmont Province include the Passaic Formation and other members of the Brunswick Group, and the Stockton Formation. Ground water is present in joints, faults, and intergranular spaces and along bedding surfaces in this system of rocks.

The Highlands Physiographic Province consists of a belt of exposed Precambrian igneous and metamorphic rocks that extend northeast-southwest across the north-central part of New Jersey (fig. 1). The boundary between the Highlands and Piedmont Provinces is an intricate system of faults, with the Highlands Province Precambrian rocks forming the uplifted side. Middle Proterozoic igneous rocks, including alaskite, albite-oligoclase granite, and amphibolites, and a broad range of metamorphic rocks such as gneiss and marble are found in the province (table 1). Locally, small areas of overlying lower Paleozoic rocks are present (Lyttle and Epstein, 1987). Geologic units that function as major aquifers in the Highlands Province are the Allentown dolomite, Leithsville Formation, and various components of the faulted Precambrian crystalline rock. Wells in these and other geologic units are developed along bedding surfaces and in joints, faults, and solution cavities characteristic of these rock units.

The Valley and Ridge Physiographic Province is west of the Highlands Province in the northwestern part of the State (fig. 1). In New Jersey it is bounded on the northwest by the Delaware River. The rocks of the province consist of tightly folded lower and middle Paleozoic sediments that strike northeast-southwest, parallel to the Delaware River (table 1). Typically, the folds are overthrown to the west, with inclined axial planes (Lewis and Kummel, 1912). Reverse faulting and thrusting in the regional strike direction has further complicated the geology of the province. The ages of the rocks that crop out in the New Jersey Valley and Ridge Province range from Cambrian to Devonian. The lower Paleozoic formations (Cambrian and Ordovician) are limestone and dolomite. Higher in the section, the middle Paleozoic (Silurian and Devonian) rocks tend to be shales and sandstones (Lyttle and Epstein, 1987). Geologic units that function as major aquifers in the Valley and Ridge Province include the Allentown dolomite and other members of the Kittatinny Supergroup. Ground water is present in joints, faults, intergranular spaces, and solution cavities, and along bedding surfaces in this system of rocks.

Bedrock aquifers are a source of public-water supply in the Valley and Ridge, Highlands, and Piedmont Provinces. Bedrock aquifer systems include all types of consolidated material and include sandstones, limestones, crystalline rocks, and other types of rock. These aquifers coincide with geologic units. Their capacity to produce water varies widely depending on the type of material present in the unit. Water typically enters the well through fractures, faults, solution cavities, and other openings within the geologic unit. Fracturing in bedrock generally is greatest near land surface and decreases with depth; therefore, much of the water available to wells comes from shallow depths within the bedrock. Due to the complexity of the geology in northern New Jersey, however, extensive aquifers and confining units similar to those in the Coastal Plain generally are not present, and local confinement is documented in only a few areas in this part of the State.

A cross-section through a typical bedrock aquifer system is shown in figure 18. Water enters the bedrock aquifer system at land surface and flows toward discharge areas in valleys. Flow paths in the shallow weathered zone generally are relatively short. In the deeper rock layers, however, ground water flows through extensively fractured zones in the bedrock, and flow paths are much longer. The unconsolidated material above the bedrock may function locally as a confining unit. Similarly, competent unfractured bedrock strata also may act as confining units because flow through these zones in most cases is very slow. However, confinement does not necessarily protect the well from contaminants because the velocity of flow through fractures and faults typically is very high, and travel times can be very short. This characteristic, coupled with the fact that most bedrock wells have very long open intervals, indicates that the minimum travel time of ground water from land surface to the well typically is less than 12 years.

A ground-water contributing area for a well open to a carbonate-rock aquifer in the Highlands Physiographic Province is shown in figure 19. This bedrock aquifer is below a glacial aquifer system that consists of stratified drift. The well, Morris County Municipal Utility Authority Flanders well 2 (27-1727), is open to the Leithsville Formation from 164 to 288 ft below land surface. The contributing area was delineated with a discretized ground-water flow model by using a particle-tracking analysis to simulate flow paths (R.S. Nicholson, U.S. Geological Survey, written commun.,1996). The particles were started on the top face of the uppermost model layer and were forward-tracked to the discharge location. The distribution of travel times of particles from the water table to the well is shown in figure 20.

Results of this simulation indicate that recharge to the well originates in several areas, including near the valley walls and in upvalley areas, rather than near the well. Surface runoff that originates in upland areas may contribute to recharge near the valley walls. The location of the contributing area depends on several factors, including degree of local confinement, location of the well relative to the valley walls, and depth of the open interval. Ground water can flow through the glacial aquifer system and enter the underlying bedrock aquifer system. This well represents a situation in which a well in a bedrock aquifer can almost certainly be considered to be insensitive to contamination as a result of the presence of local confining layers above the well's open interval. In this case, the open interval is overlain by 164 ft of stratified drift, till, weathered bedrock residuum, and low-permeability rock. The open intervals of most wells in New Jersey open to bedrock aquifers are overlain by relatively little confining material. Figure 9 shows that the time of travel of ground water to this well is an outlier and is not typical of travel times to wells in bedrock aquifers. Even though the median time of travel of ground water from the water

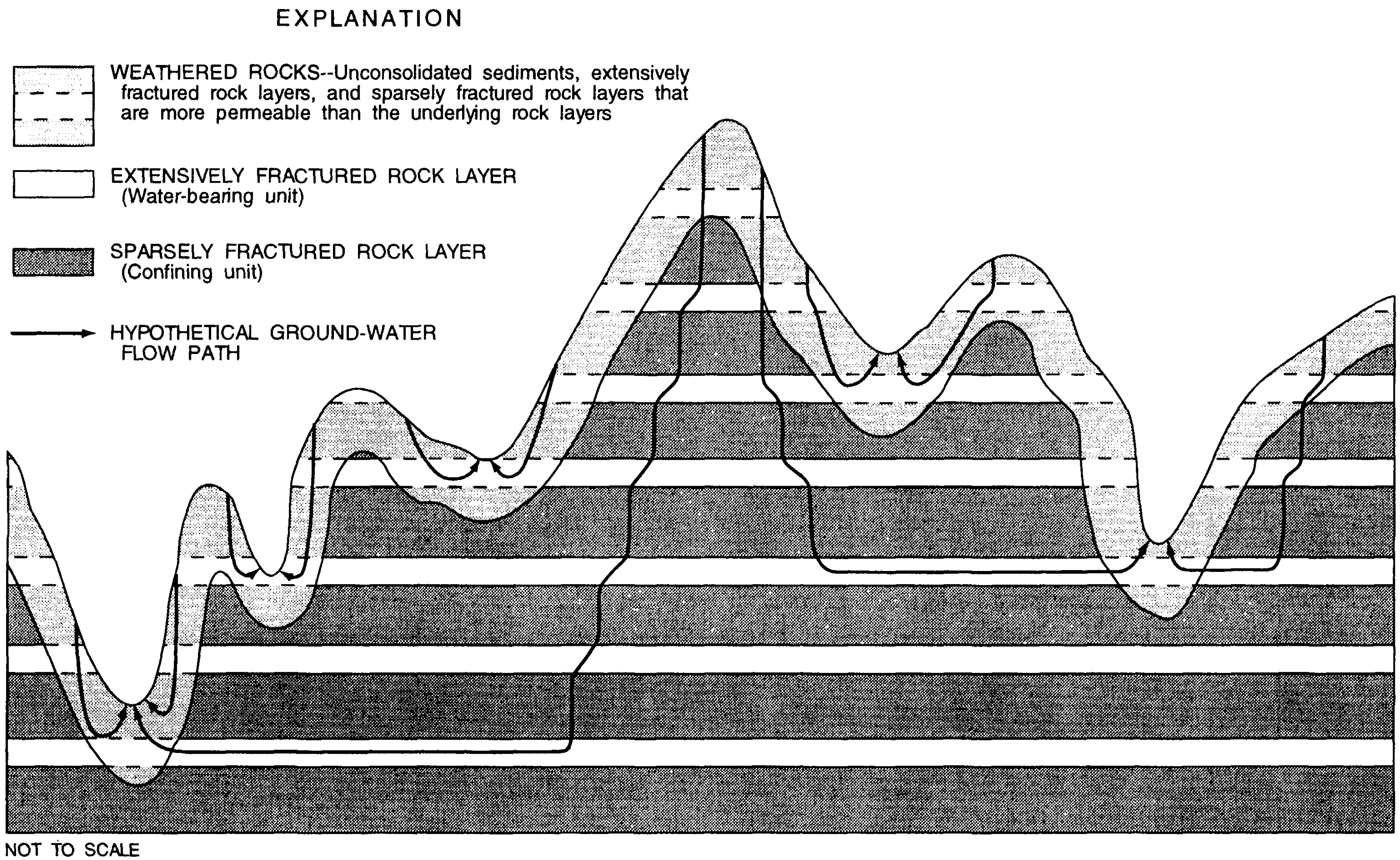


Figure 18. Generalized hydrogeologic section showing ground-water flow paths in bedrock aquifers. (From Lewis-Brown and Jacobsen, 1995.)

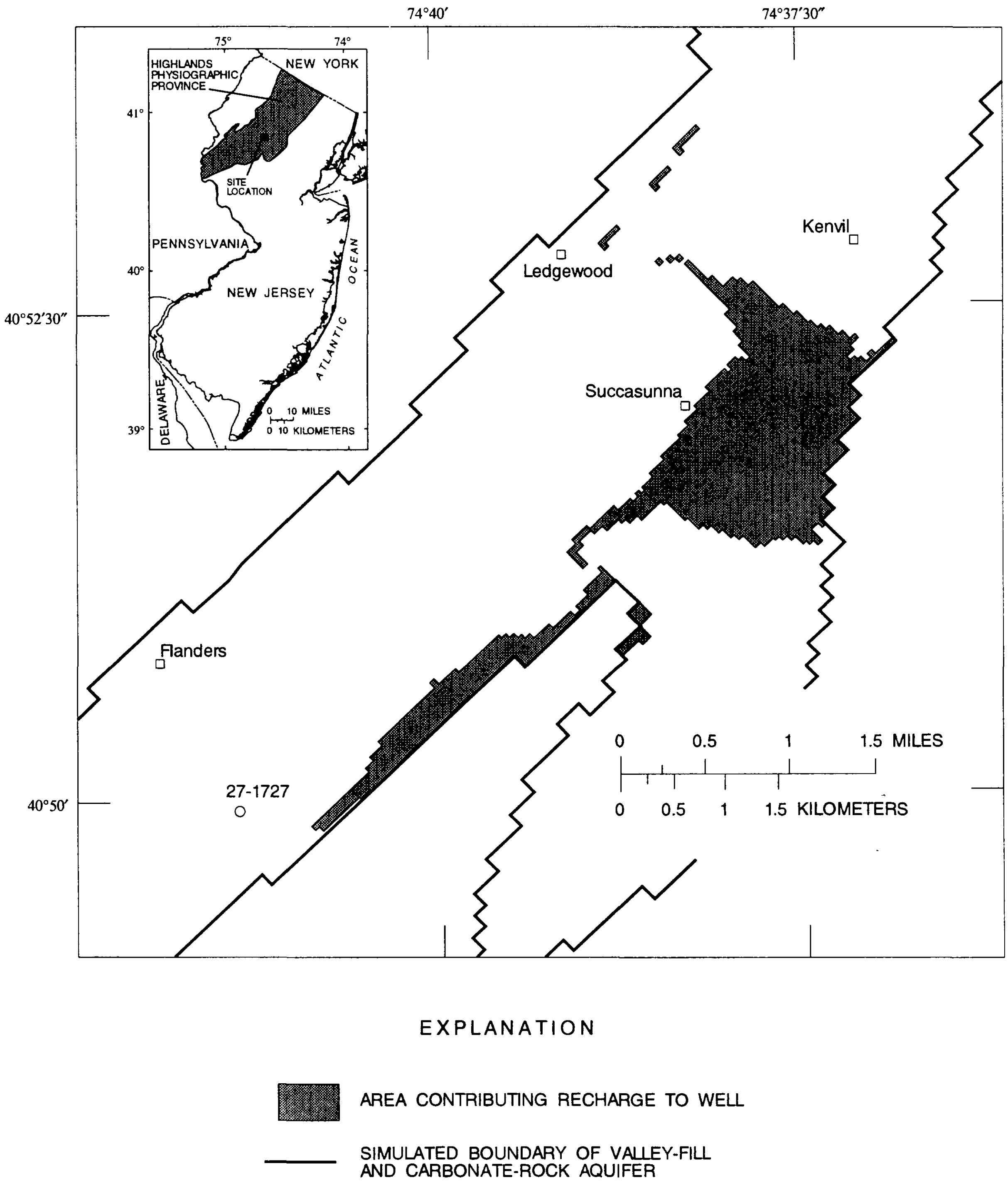
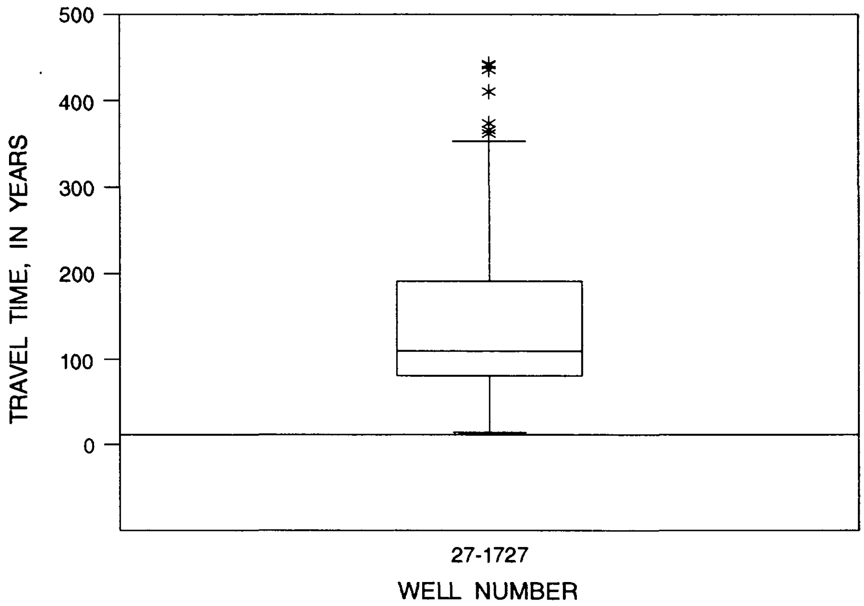


Figure 19. Simulated ground-water contributing area for well 27-1727 in a bedrock aquifer system, Morris County, New Jersey. (From R.S. Nicholson, U.S. Geological Survey, written commun., 1996.)



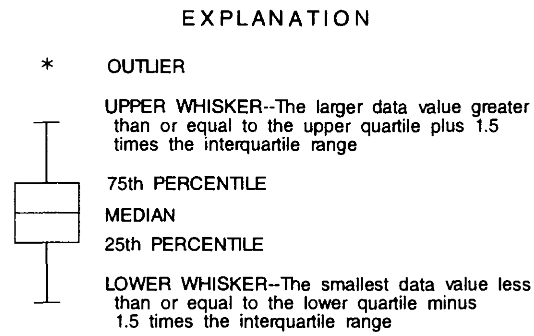


Figure 20. Distribution of ground-water travel times to a well in a bedrock aquifer system in Morris County, New Jersey.

table to the well's open interval is 109 years, the minimum time of travel is 14 years, slightly greater than the 12-year criterion. Selected well-construction characteristics and time-of-travel data for this well are presented in table 8.

Table 8. Selected well-construction data and simulated ground-water travel times for a community water-supply well open to a bedrock aquifer in Morris County, New Jersey

Well number	Depth of open interval, in feet below land surface	Aquifer type	Hydrogeologic characteristics	Travel time, in years		
				Minimum	Median	Maximum
27-1727	164 - 288	Bedrock	Open interval is overlain by 98 feet of glacial sediments	14	109	764

All wells whose open intervals are in bedrock aquifer systems are considered to be sensitive to contamination discharged at land surface because of (1) the geologic complexity of the aquifer systems and the lack of mappable, extensive confining units; (2) the relatively fast velocities of ground water in fractured zones within bedrock aquifers and the resulting short travel times from land surface to wells; and (3) the typical construction characteristics of wells in bedrock aquifers, which include long open intervals and short casing lengths.

SUMMARY AND CONCLUSIONS

An understanding of the sensitivity of wells to contamination from land surface is necessary to effectively manage New Jersey's ground-water resources and to protect its potable-water supply. The sensitivity of wells is related to hydrogeologic factors that determine the time of travel of water recharged from land surface to the open interval of the well. Hydrogeologic variables that were used for this assessment that can affect the time of travel are the presence of confining units above the open interval of the well and the depth to the top of the open interval. Sensitivity to contamination was evaluated for wells in three types of aquifer systems: glacial, Coastal Plain, and bedrock. Results of this evaluation can be used to delineate wellhead-protection areas. The report also presents guidelines for determining the sensitivity to contamination of wells screened in confined aquifers.

The U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection (NJDEP), compiled well-construction and other well-attribute data for 2,598 community water-supply wells in New Jersey from existing data bases and files. A data base containing this information was developed and stored in a geographic information system as an ARC/INFO point coverage. The data base includes information from the USGS National Water Information System, Ground Water Site Inventory, data base stored in a point-attribute table. Information compiled from other data bases and files from various State agencies is stored in related INFO data files. Items stored in the data base include well-identification numbers, well-construction characteristics, sensitivity ratings, location data, and owner information.

All wells for which sufficient information was available were evaluated for their sensitivity to contaminants discharged at land surface. The minimum data required to determine sensitivity or insensitivity to contamination include depth of the open interval, location of the well, and altitude of the top of the well. The sensitivity of 362 wells could not be determined either because one or more of these items was unknown or because the well was no longer used as a community water-supply well. Available ground-water flow models were used to simulate ground-water contributing areas, estimate the time of travel, and determine the sensitivity or insensitivity of wells in typical aquifer settings to contamination. Hydrogeologic variables that were used for this assessment include the presence or absence of confining units above the well's open interval, the location of the well relative to the outcrop area of the aquifer penetrated by the well, and the depth of the top of the open interval below land surface. Wells were grouped into three categories--those in glacial, Coastal Plain, and bedrock aquifers. Aquifer confinement, which protects ground water from contaminants discharged at land surface, is associated with the presence of overlying thick, areally extensive, impermeable units, which are common in the Coastal Plain but rarely are found in glacial and bedrock aquifer systems in New Jersey. A well is considered sufficiently confined to be designated insensitive when the vertical time of travel through a confining unit and the horizontal time of travel to the edge of a confining unit equals or exceeds 12 years at all points.

Simulated contributing areas of three wells in a typical glacial aquifer indicate that the minimum travel time of ground water from the water table to these wells generally is less than 12 years. Ground water in most glacial aquifer systems probably behaves similarly to that in these examples. Although thin confining units composed of fine-grained sediments are probably present in most valleys in New Jersey, most confining units in glacial sediments probably are leaky and, therefore, travel times from the land surface to the well most likely are small. All 245 wells open to glacial aquifers are considered to be sensitive to contamination discharged at land surface because of (1) the lack of mappable, extensive confining units; (2) the short travel times from land surface to the well; and (3) the typical construction characteristics of wells in glacial aquifers, which include shallow depth to the top of the open interval and shallow depth of well.

Coastal Plain sediments consist of a series of aquifers with intervening confining units that alter the direction of ground-water flow. Virtually all of the 1,351 community water-supply wells in the Coastal Plain Province withdraw water from these aquifers. For this analysis, two designations were possible for wells screened in Coastal Plain aquifer systems: (1) sensitive (wells in or less than 0.5 mi downdip from outcrop areas of confined aquifers and wells in unconfined aquifers, where the minimum time of travel from land surface to the well likely is less than 12 years), or (2) insensitive (wells in confined aquifers greater than 0.5 mi from the outcrop area where the minimum time of travel likely is greater than 12 years). All wells screened in aquifers that do not crop out were considered to be insensitive to contamination because the time of travel probably exceeds 12 years. These include wells screened in the Atlantic City 800-foot sand, the Rio Grande water-bearing zone, the Piney Point aquifer, and other minor aquifers. Some areas between 0 and 0.5 mi downdip from the outcrop area of an aquifer were considered to be areas of uncertainty where wells may be sensitive to contaminants discharged at land surface because travel time likely is less than 12 years despite the presence of overlying confining units. Ground water in such an area cannot be protected from contaminants discharged at land surface by establishing a wellhead-protection area because the ground-water contributing area is not adjacent to the well. Of the 1,351 water-supply wells in the Coastal Plain, 714 are considered to be insensitive to contamination because they are more than 0.5 mi downdip from outcrop areas where travel times are likely greater than 12 years.

Because the geology in northern New Jersey is complex, extensive aquifers and confining units similar to the those found in Coastal Plain generally are not present in bedrock, and local confinement is documented in only a few areas in this part of the State. Ground water that flows through fractures and faults typically has very high velocities, and travel times can be very short despite local confinement. Short travel times coupled with the very long open intervals found in most bedrock wells indicate that the minimum travel time of ground water from land surface to the well is most often less than 12 years. All 1,002 wells with open intervals in bedrock aquifers are considered to be sensitive to contamination discharged at land surface because of (1) the geologic complexity of the aquifer systems and the lack of mappable, extensive confining units; (2) the relatively fast velocities of ground water in fractured zones within bedrock aquifers and the resulting short travel time from land surface to wells; and (3) the typical construction characteristics of wells in bedrock aquifers, which include long open intervals and short casing lengths.

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