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With a section on
Modeling Ground-Water Flow in the Rockaway River Valley

logical Survey
esources Investigations Report 96-4086

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CONTENTS

CONTENTS (continued)

FIGURES

TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
feet per day (ft/d)	0.3048	meters per day
feet per day per foot (ft/d/ft)	1.0	meters per day per meter

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 units used in this report:

- Chemical concentrations are given in milligrams per liter (mg/L) or micrograms per liter (µg/L). 1,000 µg/L is equivalent to 1 mg/L. For concentrations less than 7,000 mg/L, the numerical values are the same as for concentrations in parts per million.

- Isotope values for deuterium (δD) and ^{18}Oxygen ($\delta^{18}O$) are given in parts per thousand (permil).

- Tritium activity is given in tritium units, equal to one tritium atom per 10^{18} hydrogen atoms.

- Specific conductance of water is expressed in microsiemens per centimeter (µS/cm) at 25°C, equivalent to micromhos per centimeter at 25°C.

- Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\,(°C) + 32$$

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Abstract

The vertical hydraulic conductivity per unit thickness (streambed leakance) of unconsolidated sediment immediately beneath the channel of the Rockaway River near a municipal well field at Dover, N.J., is between 0.2 and 0.6 feet per day per foot and is probably near the low end of this range. This estimate is based on evaluation of three lines of evidence: (1) Streamflow measurements, which indicated that induced infiltration of river water near the well field averaged 0.67 cubic feet per second; (2) measurements of the rate of downward propagation of diurnal fluctuations in dissolved oxygen and water temperature at three piezometers, which indicated vertical Darcian flow velocities of 0.6 and 1.5 feet per day, respectively; and (3) chemical mixing models based on stable isotopes of oxygen and hydrogen, which indicated that 30 percent of the water reaching a well near the center of the well field was derived from the river. The estimated streambed-leakance values are compatible with other aquifer properties and with hydraulic stresses observed over a 2-year period, as demonstrated by a set of six alternative ground-water flow models of the Rockaway River valley. Simulated water levels rose 0.5 to 1.7 feet near the well field when simulated streambed leakance was changed from 0.2 to 0.6 feet per day per foot, or when a former reach of the Rockaway River valley that is now blocked by glacial drift was simulated as containing a continuous sand aquifer (rather than impermeable till). Model recalibration to observed water levels could accommodate either of these changes, however, by plausible adjustments in hydraulic conductivity of 35 percent or less.

The ground-water flow models incorporate a new procedure for simulating areal recharge, in which water available for recharge in any time interval is accepted as recharge only where the water level in the uppermost model layer is below land surface. Water rejected as recharge on upland hillsides is allowed to recharge aquifers at the base of the hillsides. Inclusion of uplands in models of valley-fill aquifers and use of the new procedure increases model complexity and data requirements, but automates the simulation of recharge to those aquifers from the uplands, even in transient-state simulations with multiple periods of varied stresses, and facilitates delineation of upland areas that contribute water to well fields. The area from which ground water flowed toward the Dover well field decreased with an increase in simulated streambed leakance or an increase in simulated hydraulic conductivity of upland till.

Concentrations of solutes in ground water near the Dover well field reflect the mixing of native ground water with water infiltrated from the Rockaway River. Chemical reactions in the aquifer, chiefly the weathering of carbonate minerals by dissolved carbon dioxide, affect the pH and the concentrations of both solutes and dissolved gases. Concentrations of sodium, chloride, and sulfate appear to be related to man's activities, such as road deicing, or to decay of organic matter in the aquifer.

INTRODUCTION

Nationwide concern about the availability of water, especially during periods of drought, prompted the U.S. Geological Survey (USGS) in 1978 to begin a program of ground-water studies to provide information for evaluating and managing major aquifer systems. The program was referred to as Regional Aquifer-System Analysis (RASA) (Bennett, 1979; Sun, 1986; Sun and Johnston, 1994). The Northeast Glacial Aquifers RASA (Lyford and others, 1984) was a study of the hydrology of stratified-drift aquifers, which consist largely of unconsolidated sand and gravel and were formed by glacial meltwater. The study covered the northeastern part of the United States (fig. 1). Most of the aquifers are crossed by streams that receive ground-water discharge and can be major sources of recharge. To help quantify the potential for stream-aquifer interaction, six localities (fig. 1) were selected for detailed study. This report gives results from one of these localities, along the Rockaway River at Dover, N. J.

Purpose and Scope

The principal purpose of this report is to evaluate the water-transmitting properties of sediments that immediately underlie the channel of the Rockaway River at Dover, N.J., a locality selected because the ratio of pumpage from riverbank wells to low streamflow was larger here than in most river reaches. Several methods of determining rates or velocities of induced infiltration were applied at this locality, including (a) simultaneous precise streamflow measurements upstream and downstream to determine seepage losses, (b) chemical mixing models to determine the ratio of river water to native ground water, and (c) use of dissolved oxygen and temperature as natural tracers to determine vertical flow velocities through the streambed. The dissolved-oxygen method is described in some detail in this report; the other methods have been described elsewhere and are only summarized herein. Pertinent data from all methods are tabulated, and results are evaluated. A comparison of these results with similar

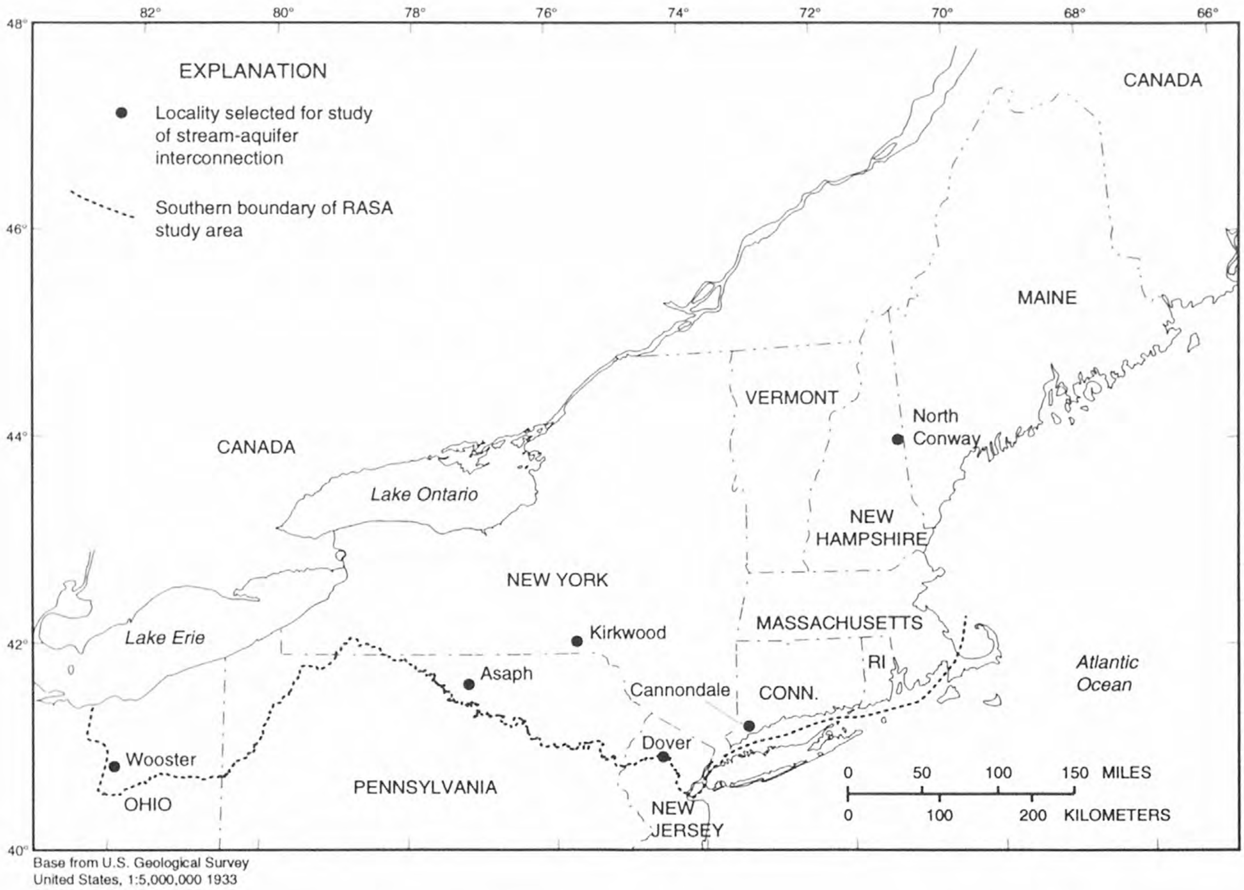


Figure 1. Location of Northeast Glacial Aquifers Regional Aquifer-System Analysis study area and localities selected for detailed study.

determinations made in other localities in the glaciated Northeast is incorporated in a summary report on the Northeast Glacial Aquifers RASA (Kontis and others, USGS, written commun., 1995) and may lead to a synthesis that could be applied in the construction of ground-water flow models of stratified-drift aquifers for which suitable local data are unavailable.

Six ground-water flow models of a 2.5-mi reach of the Rockaway River valley were constructed to verify whether the estimated water-transmitting properties of the riverbed are consistent with other known or estimated aspects of local hydrogeology. The models were also used to test a new procedure for simulating recharge to stratified-drift aquifers in valleys that was developed by Northeast Glacial Aquifers RASA and accounts for recharge from precipitation on the adjacent uplands as well as on the valley itself. This report describes the new procedure, documents the data and assumptions on which the modeling was based, and presents sensitivity analyses to help explain hydrologic conditions at Dover.

Finally, because the data collected for the chemical mixing models also proved useful in evaluating the chemical evolution of ground water through weathering reactions, an analysis of this process is presented here as a contribution to regional geochemistry.

Previous Studies

Low-flow characteristics and flow duration of New Jersey streams were described by Gillespie and Schopp (1982). The availability and chemical quality of ground water in Morris County, N.J. was described by Gill and Vecchioli (1965). The thickness and extent of stratified drift in northern Morris County was mapped by Canace and others (1983) to determine the feasibility of withdrawing ground water to augment flow of the Rockaway River. Ground-water resources in Wharton and Dover were investigated by Geraghty and Miller (1968 and 1969). Bedrock geology of areas that include Dover was described by Sims (1958) and by Lyttle and Epstein (1987); the surficial geology by Stanford (1989). Soils of Morris County have been mapped by Eby (1976). Water-table and streamflow fluctuations, gains and losses of water from successive stream reaches, water chemistry, and stream biology in the upper Rockaway River valley, which includes Dover, were described by Schaefer and others (1993). The hydrology of the Rockaway River valley upstream from Dover was described by Hill and Pinder (1981), who constructed a ground-water flow model that simulated interchange of water between streams and aquifers. The stratified-drift aquifers of the upper Rockaway River basin, including the area described in this report, were modeled by Gordon (1993).

Acknowledgments

Thanks are expressed to Mr. Andrew Du-Jack, Superintendent of the Town of Dover Water Department, who provided his time, personnel, and equipment throughout the study. Scott Stanford, Geologist, New Jersey Geological Survey, provided well records, lithologic data, and a preliminary map and description of surficial deposits in the Dover 7 1/2-minute quadrangle. Jean Brown of the USGS did preliminary digital modeling of the aquifer system. Vincent W. Uhl of Geraghty and Miller Inc. provided water-level and lithologic data. Pierre Lacombe of the USGS performed geophysical studies to delineate configuration of the bedrock surface.

DESCRIPTION OF STUDY AREA

The study area is in north-central Morris County, N.J., along the Rockaway River valley (fig. 2). This part of Morris County is characterized by broad, northeast-trending bedrock ridges and narrow valleys. The ridges are generally 200 to 300 ft above the valley floor and have maximum altitudes of about 1,000 ft.

The Rockaway River valley has become increasingly urbanized in recent years. The combined population of Dover and Wharton was 14,345 in 1940 (Summers and others, 1979) and 20,520 in 1990 (U.S. Census Bureau, 1992).

Climate

Average annual precipitation at Split Rock Pond, 8 mi northeast of the Dover well field (fig. 2), was 50.14 in. for 1951-80 (U.S. National Oceanic and Atmospheric Administration, 1982). Mean monthly precipitation ranges from 3 to 5 in.; the higher values occur generally during the summer (fig. 3). Monthly precipitation from May 1984 though September 1985, when most of the data used in this study were collected, commonly departed significantly from long-term monthly averages (fig. 3).

Air temperature averaged 10.2° C during 1951-80 (National Oceanic and Atmospheric Administration, 1982). Monthly averages range from -2.6° C in January to 22.4° C in July. Average annual evapotranspiration has been estimated from climatic data and evapotranspiration formulas to be 25.8 in. (Summers and others, 1978), and comparison of a runoff map by Hely and Nordenson (1961) with precipitation at Split Rock Pond also indicates annual evapotranspiration to be about 25 in.

Streamflow

The Rockaway River has a drainage area of about 47 mi^2 at Dover. Green Pond Brook, a major tributary with a drainage area of 15 mi^2, enters the Rockaway River about 4,000 ft upstream from the Dover well field (fig. 2). Streamflow in the Rockaway River normally varies seasonally from peaks in the spring to minimum flows in early fall. The Rockaway River has been gaged since 1938 at Boonton, N.J., about 12 mi downstream from the Dover well field. Daily and

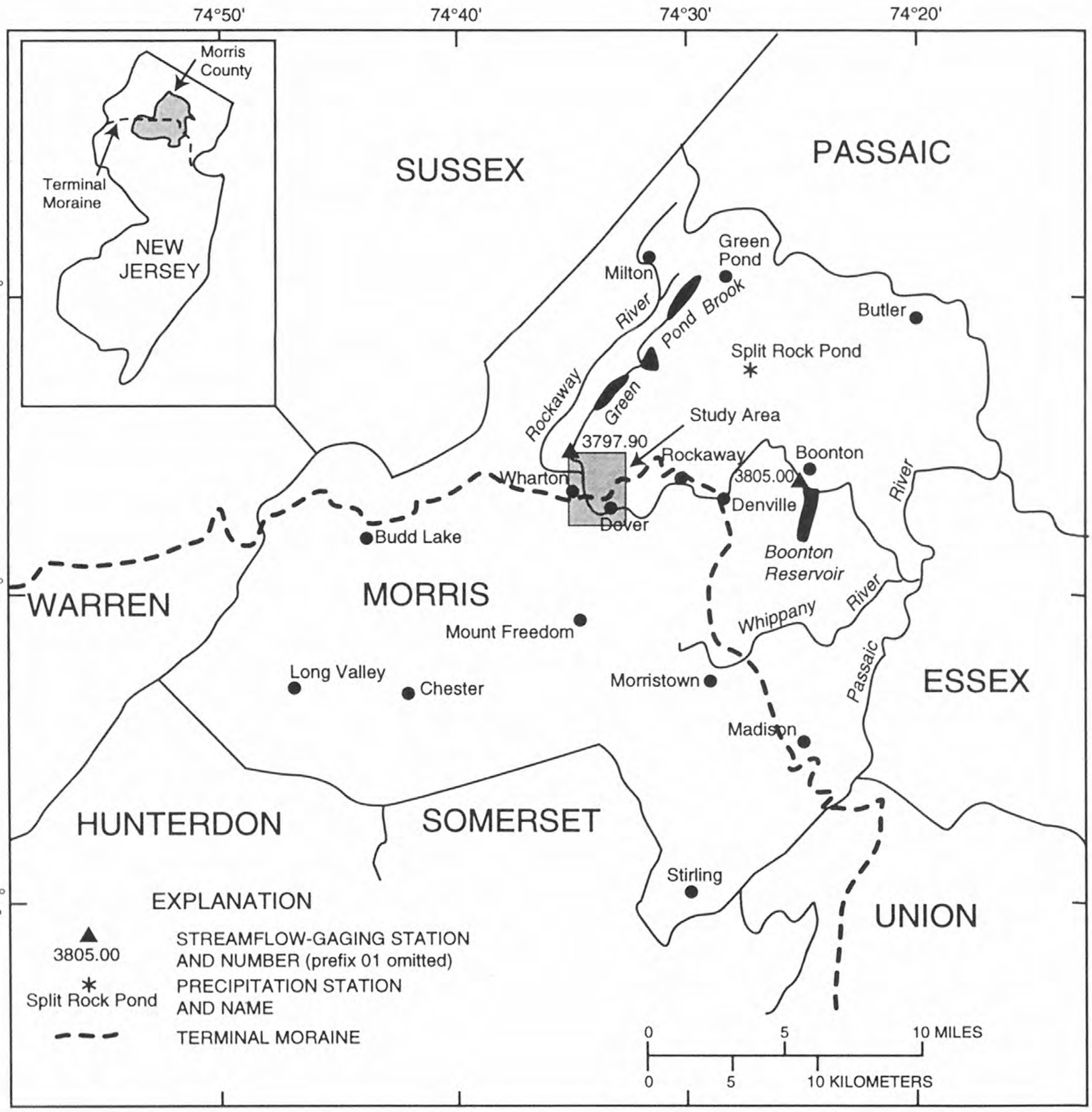


Figure 2. Location of Dover study locality and nearby geographic features, Morris County, N.J.

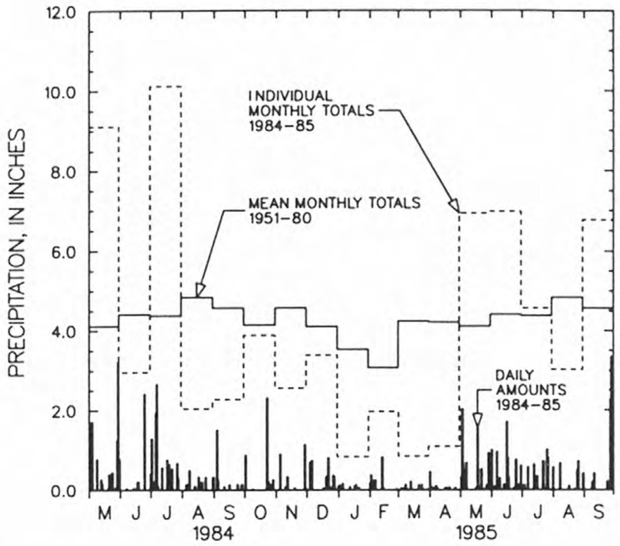


Figure 3. Precipitation at Split Rock Pond, N.J., May 1984-September 1985. (Location is shown in fig. 2.)

monthly mean flows at Boonton during this study, and long-term monthly means, are shown in figure 4. If streamflow per unit area at Dover were the same as that measured at Boonton, then flow at Dover for 1938-84 would have equaled or exceeded 62 ft^3/s about 50 percent of the time, 16 ft^3/s 90 percent of the time, and 7 ft^3/s 99 percent of the time.

Geology

The bedrock beneath the study area was identified by Sims (1958) as mainly granitoid gneisses with some pegmatites, and by Lyttle and Epstein (1987) as quartz diorite and alaskite composed principally of oligoclase, perthite, quartz, and hypersthene. The bedrock is generally capable of yielding only a few gallons per minute to wells, from fractures (Gill and Vecchioli, 1965). A map of the bedrock surface, based on available well records and on seismic-refraction surveys conducted for this study (fig. 5), shows a relatively deep valley outlined by the 450-ft altitude contour. This valley, which lies about 1,500 ft east of the Dover well field, probably was the preglacial course of the Rockaway River.

Unconsolidated materials mantle the bedrock nearly everywhere in and near the study area. They range in thickness from zero to at least 150 ft (Gill and Vecchioli, 1965; Stanford, 1989). Most unconsolidated materials are products of the last glaciation of this region and can be classified as either morainal deposits or stratified drift. The distribution of unconsolidated materials at land surface is shown in figure 6. The Dover municipal well field lies just east of the Rockaway River (fig. 6) where the terminal moraine

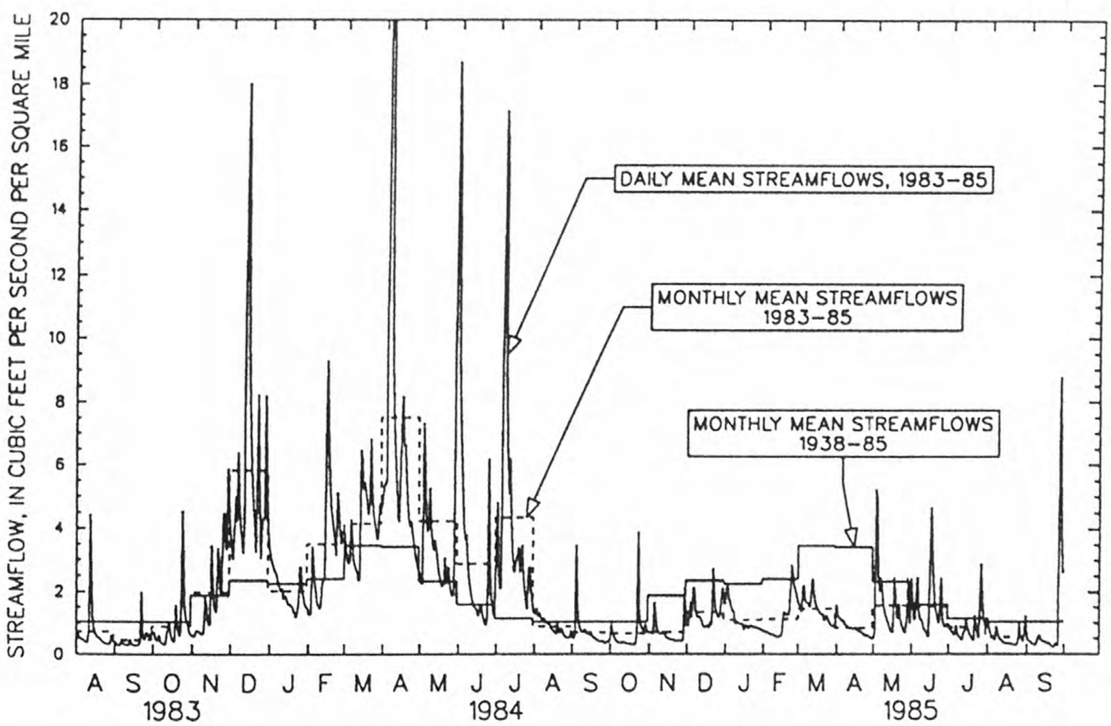


Figure 4. Flow of Rockaway River above reservoir at Boonton, N.J. for 1983-85 and 1938-85.

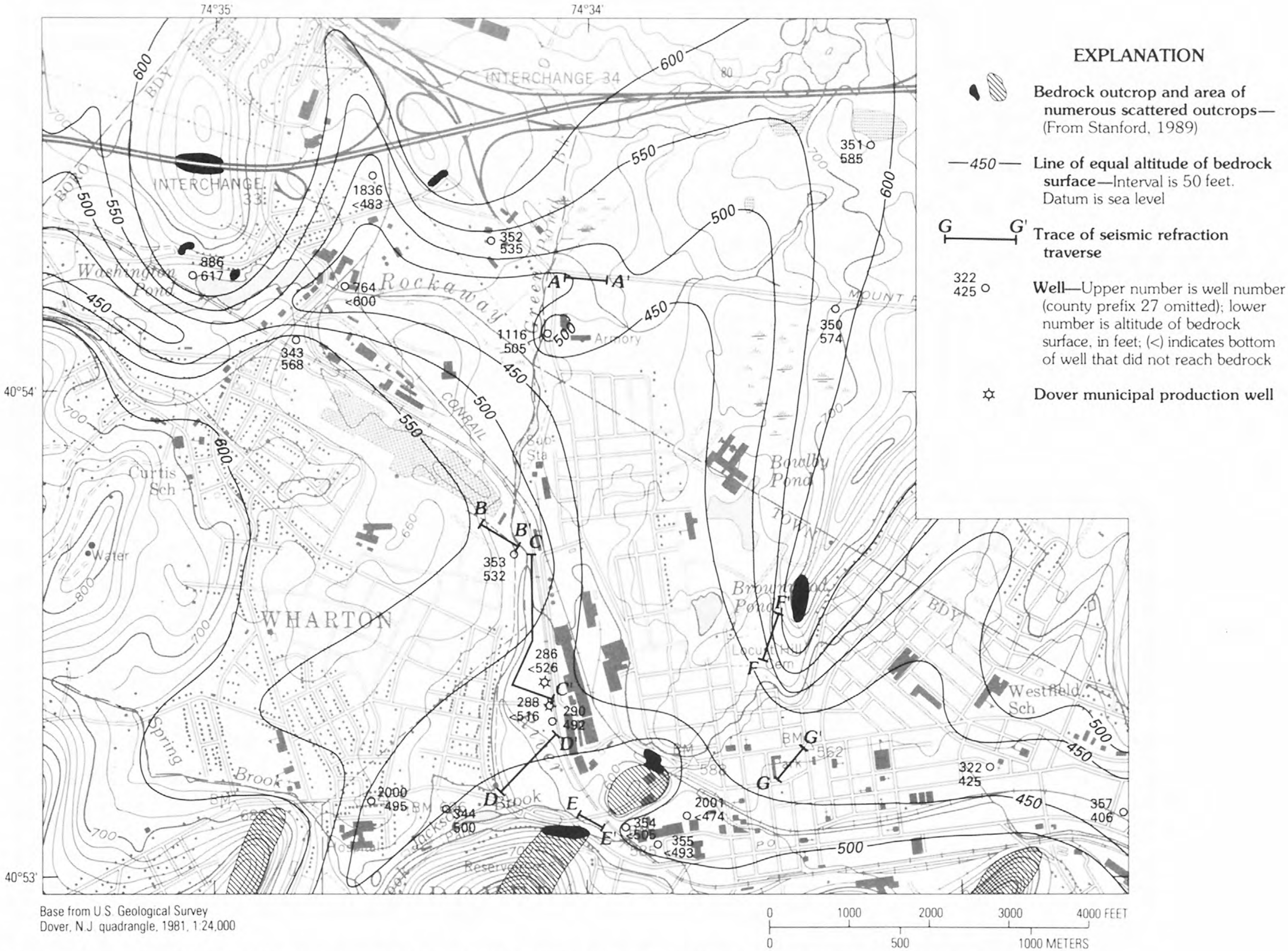


Figure 5. Generalized configuration of the bedrock surface near Dover, N.J. Logs and records of wells are given in tables 20 and 21. Seismic-data interpretation by P. Lacombe (U.S. Geological Survey, written commun., 1985). Interpretation of bedrock surface in part after Stanford (1989). (Location is shown in fig. 2.)

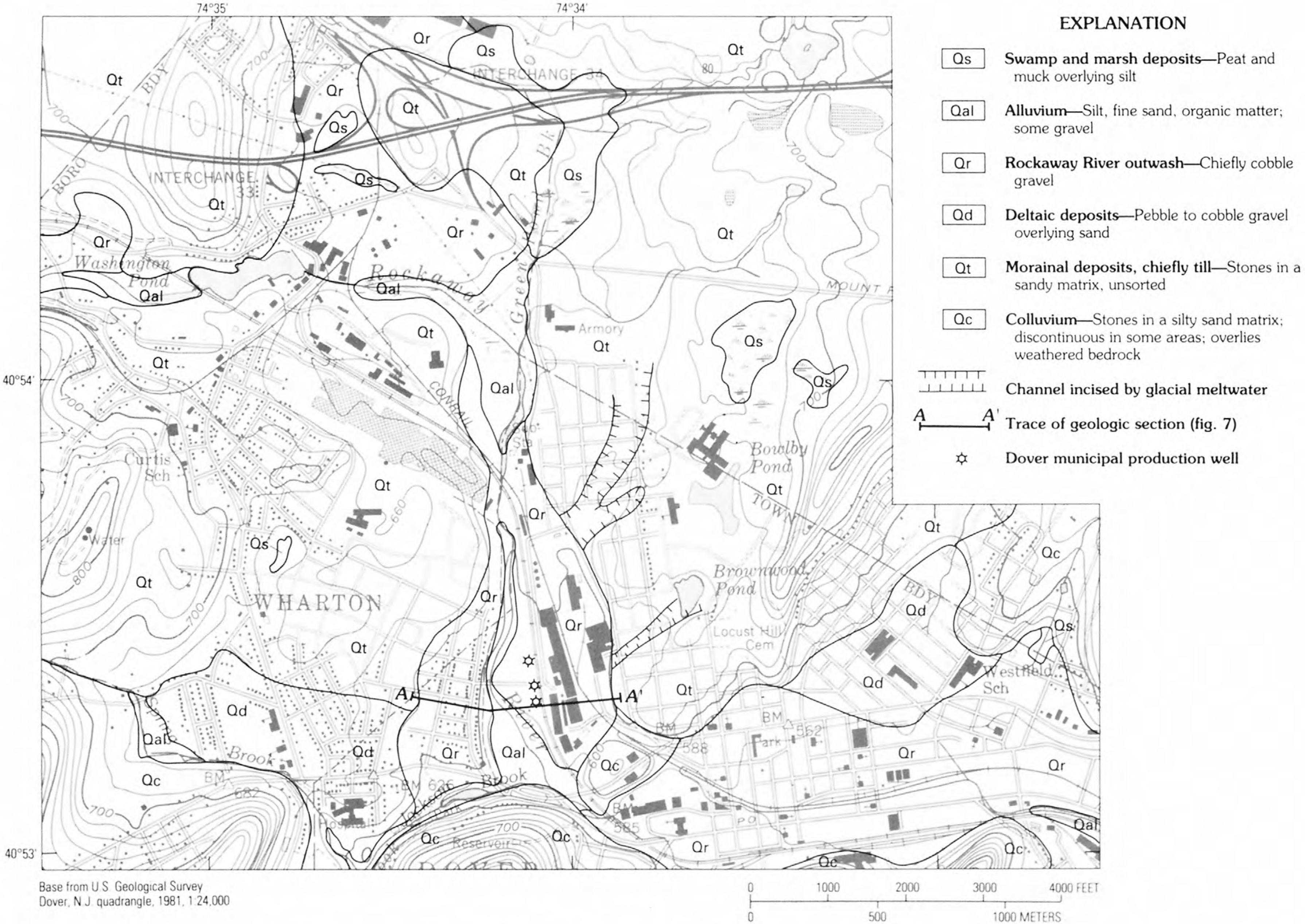


Figure 6. Surficial geology near Dover, N.J. (Modified from Stanford, 1989). (Location is shown in figure 2.)

that marks the southern extent of the last glaciation (fig. 2) crosses the Rockaway River valley. The hills and low rolling uplands northeast and northwest of the well field are mantled by morainal deposits that consist mostly of till, a heterogeneous mixture of material that is predominantly sandy but ranges in size from clay to boulders. South of the well field, hillsides are mantled by colluvial aprons derived from weathered bedrock and from an older till that formerly covered the bedrock (Stanford, 1989).

Stratified drift fills the Rockaway River valley to a depth of about 100 ft near the Dover well field (fig. 7). The lower 35 to 50 ft consists of silt, very fine sand, and some clay. These lake-bottom sediments are overlain by 60 to 70 ft of sand and gravel that constitutes the aquifer tapped by the Dover municipal wells. Near the well field, the aquifer consists of two layers– an upper layer of outwash gravel 20 to 30 ft thick and a lower layer of deltaic sand and gravel (fig. 7). The outwash is coarser than the deltaic deposits, contains a wider range of grain sizes, and is probably somewhat less permeable. Proglacial lakes formed in the Rockaway River valley when the advancing late Wisconsinan ice blocked its lower reaches (Stanford, 1989), and the fine-grained lake-bottom sediments and sandy deltas accumulated in these lakes. The ice eventually advanced across the Rockaway valley at Dover, perhaps eroding the deltas and lake-bottom deposits to some extent, then capping them with morainal deposits . When the ice retreated, meltwater cut through the morainal deposits along a route now followed by the Rockaway River and deposited the coarse gravel outwash (fig. 6). A ridge of morainal deposits, east of the Dover well field and south of Brownwood Pond (fig. 6), blocks a short reach of the deep preglacial bedrock valley (fig. 5; also see Stanford, 1989, section D). The geologic history suggests that the morainal deposits may overlie deltaic sand and lake-bottom fines in this reach, but no well logs are available to confirm this hypothesis.

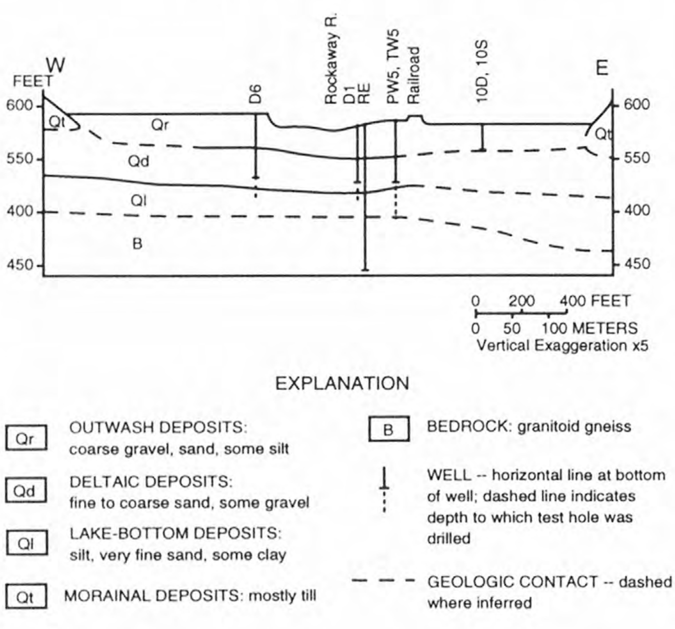
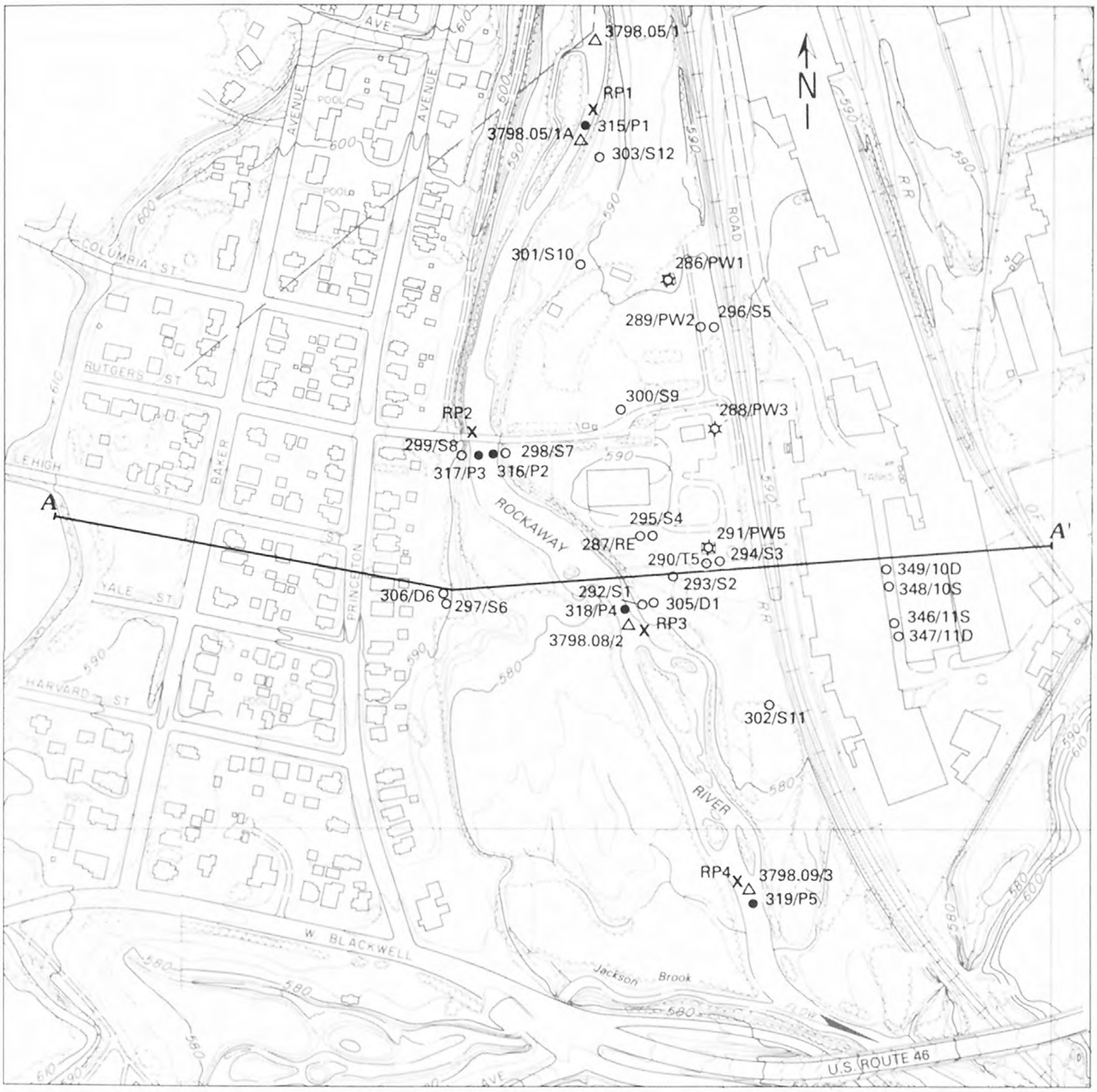


Figure 7. Geologic section across Rockaway River valley through Dover well field. (Line of section is shown in figs. 6 and 8.)

The bed of the Rockaway River consists mostly of gravel, although mud, sand, and organic debris occur in a few places near the banks. At four of five locations where well points were driven through the streambed, driving became easier 2 to 2.5 ft below the top of the streambed; this change in resistance may reflect less coarse and(or) less silty gravel below river-channel alluvium. A backhoe trench about 25 ft long and 4 ft deep across the river channel just south of the bridge near well S7 (fig. 8) revealed a heterogeneous mixture of coarse sand and gravel, the top few inches of which were muddy or silty, although no clay or silt layers were observed. Upstream from Dover production well PW5 (fig. 8), the channel was characterized in 1988 by several manmade riffles or cobble dams, some built by local youths for recreation, others by Water Department personnel to enhance trout habitat (D. Warner, Dover Water Department., oral commun., 1988). Much of the channel consisted of shallow pools between these temporary structures. From PW5 downstream to Route 46 (fig. 8), the channel lacked such pools; the flood plain was considerably wider than that upstream and was incised by natural floodwater channels.

Ground-Water Recharge and Discharge

Much of the recharge to the stratified-drift aquifer in the Rockaway River valley is derived from local precipitation, including that which falls on the aquifer surface or the till that overlies it locally and that which falls on adjacent upland hillsides and flows downslope on and beneath land surface. (The concept of recharge to stratified-drift aquifers in valleys from upland runoff is discussed at length by Morrissey and others, 1988.) In urban or suburban areas, infiltration of precipitation can be appreciably reduced by large buildings or paved surfaces, and some of the natural downslope flow on till-mantled hillsides may be



Base from U.S. Army Corps of Engineers, Passaic River Basin Study, 1978, 1:24,000 Sheets B17, C17

0 100 200 300 400 FEET
0 50 100 METERS

EXPLANATION

A——A' **Line of geohydrologic section in figure 7**

3798.05/1 △ **Streamflow-measurement site**—Number is U.S. Geological Survey station number (prefix 01 omitted) followed by site number used in this report

RP1 X **Stream-stage reference point**

286/PW1 ✡ **Production well**

293/S2 ○ **Observation well**

315/P1 ● **Streambed piezometer**

Number is U.S. Geological Survey sequential number (county prefix 27 omitted) followed by local number assigned by well owner. Well records are given in table 21

Figure 8. Locations of wells and streamflow-measurement sites near Dover well field.

diverted to streams by roadside ditches and storm sewers. Leakage from water mains and sewers is an additional possible source of recharge. None of these possible effects of urbanization was studied at Dover, however. Water-level measurements indicate an upward gradient from bedrock to the stratified drift, but the lacustrine silt and clay beneath the aquifer presumably limits recharge from this direction. Some ground water flows downvalley through the aquifer toward the Dover well field. Induced infiltration from the Rockaway River near the well field is an additional source of recharge, evaluated in detail further on.

Water is discharged from the aquifer by evapotranspiration, seepage to the river, ground-water underflow downvalley, and pumping. Evapotranspiration of ground water might be as great as 25 in/yr in a few low-lying areas of flood plain downstream from the well field, where the water table is near land surface. Ground-water underflow downvalley through sand and gravel is probably negligible 1,500 ft downstream from the well field, where the Rockaway River flows through a narrow gorge whose bedrock walls are only 400 ft apart and whose bedrock floor rises eastward to about 20 ft below river level, according to a seismic survey (P. Lacombe, U.S. Geological Survey, written commun., 1985). Therefore, substantial ground-water discharge to the river and its tributaries is likely between the well field and the gorge, as observed upstream from bedrock gorges elsewhere in the glaciated Northeast (for example, Ku and others, 1975, p. 70). Ground-water underflow might, however, bypass the gorge by flowing southeastward through the preglacial bedrock valley reach east of the Dover well field (fig. 5), if that preglacial valley reach were to contain deltaic sand as hypothesized earlier in the section, "Geology." Large quantities of water are removed from the aquifer by pumping. The Dover well field has three production wells whose individual yields range from 1,000 to 1,700 gal/min. Annual withdrawal increased from about 2.1 ft^3/s in 1975 to about 4.7 ft^3/s in 1981-85 (fig. 9). Withdrawals have varied widely from day to day (fig. 9) but only modestly from month to month (table 1). In the early 1970's and in 1988-89, an additional 1.6 ft^3/s was withdrawn intermittently from a municipal well owned by the Wharton Water Department and located along the Rockaway River 1,300 ft upstream from the Dover well field (well 27-353, table 21, fig. 5).

Table 1. Ground-water withdrawals from municipal well field, Dover, N.J., 1984-85

[Values are in millions of gallons]

Year and local well number	Total for year	Mean Monthly	Mean Daily	Highest Month	Lowest Month
1984					
PW-1	617.740	51.476	1.687		
PW-3	172.340	14.361	.470		
PW-5	363.175	30.264	.992		
For year	1,153.255			101.985 (June)	90.070 (Feb)
1985					
PW-1	757.305	63.108	2.075		
PW-3	14.851	12.340	.400		
PW-5	330.385	27.523	.754		
For year	1,102.441			98.910 (Jan)	78.085 (Dec)

DATA COLLECTION

Most of the data used in this study was collected from July 1984 through September 1985; some additional data were collected during the summers of 1986, 1987, and 1988. Data include lithology, water levels, stream stage, streamflow, temperature, and water chemistry, and were collected at sites shown in figure 8.

Thickness and lithologic characteristics of glacial deposits penetrated by several wells were determined from drillers' logs or from examination of drill cuttings and are given in table 20 (at end of report); records of wells in the project area are given in table 21. Wells inventoried by the USGS in New Jersey are identified by a county code followed by a sequential number assigned at the time the well was inventoried. All wells cited in this report are in Morris County; thus, all numbers begin with the county code 27. Well number 27-343, for example, is the 343rd well inventoried in Morris County. Wells in or near the Dover well field also have local well numbers, generally assigned by the well owners. The local numbers are included in tables 20 and 21 and figure 8 and are used for convenience throughout this report.

Fourteen observation wells (S1 through S12, D1, and D6, fig. 8) were drilled in 1984 to define the distribution of hydraulic head, lithology, and water quality in the stratified-drift aquifer along the Rockaway River valley near the Dover well field. Screened well points

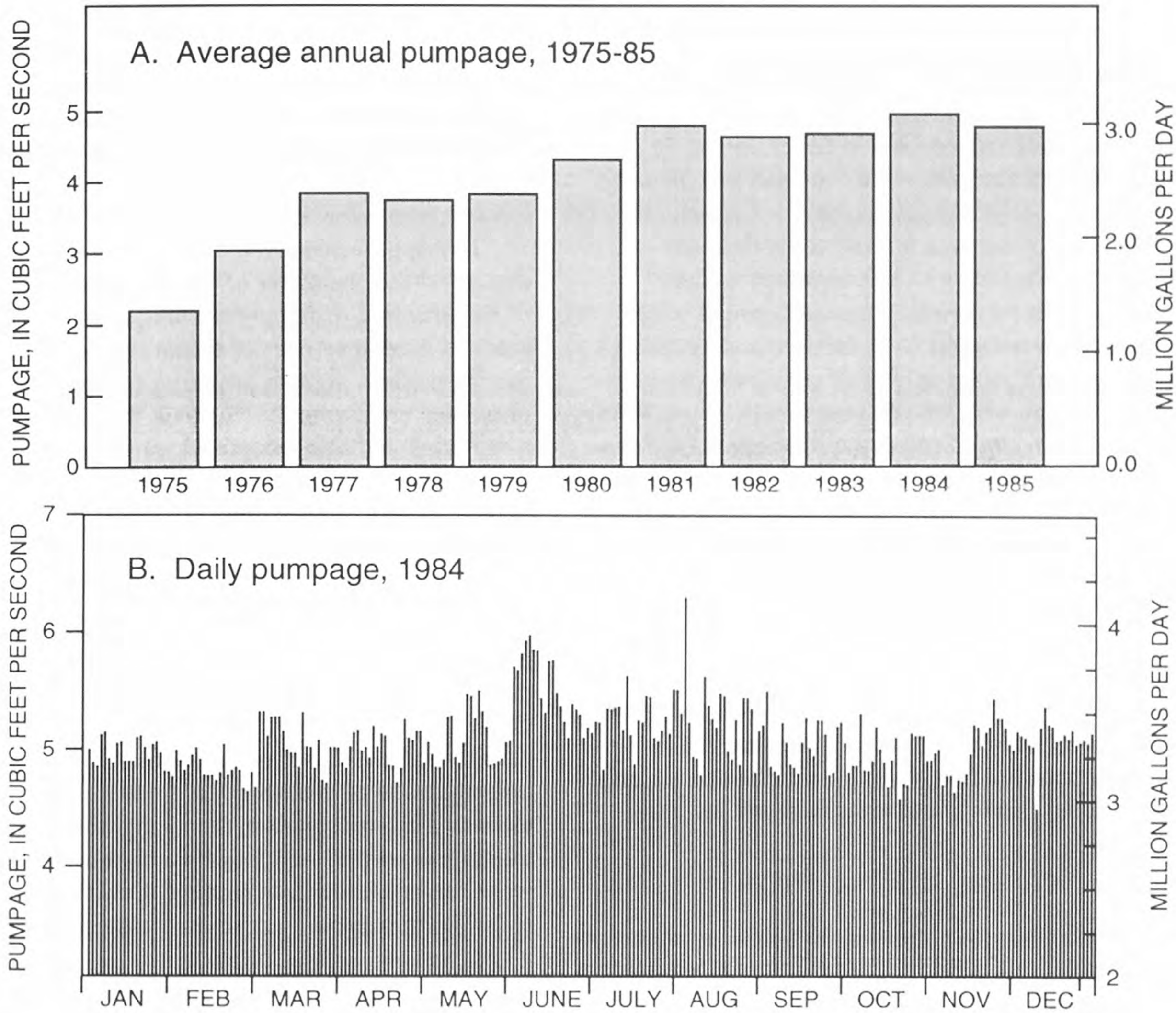


Figure 9. Pumpage from municipal well field at Dover, N.J., 1975-85 and 1984.

were driven manually into the streambed in 1985 at five locations (P1 through P5 in fig. 8) so that hydraulic head in materials immediately below the stream could be measured. Bentonite was tamped around the pipes as they were driven to reduce the possibility of leakage along the pipes. The screens in these piezometers are 0.5 ft long and were generally placed from about 3 to 3.5 ft below the top of the streambed (table 21). Water levels in all accessible wells and piezometers and in the Rockaway River were measured during visits to collect water samples or to measure streamflow and on a few other occasions; results are reported in table 22 (at end of report).

Pumpage is monitored continuously by the Dover Water Department. Figure 9 and table 1 are based on Water Department records. Temperatures were measured at 2-ft depth increments in three wells at about 2-month intervals; the data are given in table 23 (at end of report).

Water samples were collected from the Rockaway River, seven wells, and one piezometer about monthly from September 1984 through August 1985. Samples from the deep wells, all at least 4 in. in diameter, were collected with a portable submersible pump set just above the screened or uncased interval. A peristaltic pump was used to collect samples from streambed piezometer P4 (fig. 8) and shallow wells S1 through S12, all of which were 1 or 2 in. in diameter, and from the river. Ground-water samples were collected after pumping out an amount equal to at least three casing volumes. River samples were collected near P4 from about the centroid of streamflow. While water was being pumped, several water-quality characteristics were monitored with an inline flow chamber connected to the pump-discharge hose. Specific conductance, pH, dissolved-oxygen concentration, and temperature were recorded at 2- to 4-minute intervals; the records appear in table 24 (at end of report).

Water samples were analyzed for major inorganic constituents, selected trace metals, and(or) isotopic content; results are reported in tables 25 and 26 (at end of report). Samples were collected and prepared according to techniques described by Classen (1982). If necessary, water was filtered at the field site through membranes with a 0.45-µm pore size.

More than 80 surface-water and ground-water samples were analyzed for deuterium and oxygen-18. Deuterium analysis consisted of conversion to hydrogen by reaction with zinc (Kendall and Coplen, 1985) and measurement with an isotope-ratio mass spectrometer. Water for oxygen-isotope analysis was prepared by equilibrating a 2-mL aliquot with carbon dioxide (Epstein and Mayeda, 1953) for subsequent analysis on a double-focusing, double-collecting mass spectrometer (Coplen, 1973).

Values reported for either of these isotopes represent the enrichment or depletion of that isotope in the water sample analyzed relative to its abundance in an international standard, SMOW (Standard Mean Ocean Water). Isotope values are expressed in parts per thousand (permil) and are calculated as:

$$\delta(\mathrm{D\ or\ }^{18}\mathrm{O}) = \left(\frac{R_{\mathrm{sample}}}{R_{\mathrm{smow}}} - 1\right)1000,$$

where: δD = delta deuterium,
$\delta^{18}O$ = delta oxygen-18, and
R = ratio $^2H/^1H$ (deuterium to protium) or ratio $^{18}O/^{16}O$ (oxygen-18 to oxygen-16).

The 1-sigma precision of δD values is 1.0‰ (permil) and of $\delta^{18}O$ is 0.1‰.

About 50 samples were obtained for tritium (^3H) analysis. The samples were predistilled and counted by liquid scintillation with electrolytic enrichment (Ostlund and Werner, 1962). Tritium activity is reported in tritium units (T.U.), equal to one tritium atom per 10^{18} hydrogen atoms. The precision for analyses of tritium ranges from 0.4 to 3.0 T.U.

WATER CHEMISTRY IN THE STRATIFIED-DRIFT AQUIFER AT DOVER

The ranges and median concentrations of dissolved solids and nine individual solutes at several sampling sites within the Dover well field are shown in table 2. Three solutes–calcium, magnesium, and bicarbonate–constitute from 80 to 60 percent of the dissolved solids in these analyses. Five others—sodium, potassium, chloride, sulfate, and silica—are also present in appreciable amounts. All sampling sites listed in table 2 are on or close to an east-west transect across the well field (line A-A' in fig. 10).

Two approaches were used to evaluate processes that affect the chemistry of ground water in this part of the stratified-drift aquifer. First, the relative importance of several sources of recharge was evaluated by mixing models, applied primarily to data for isotopes of oxygen and hydrogen. Second, the effects of weathering and solution processes on ground-water chemistry was evaluated by reaction models, applied to data for inorganic solutes.

Appraisal of Recharge Sources

Water in the Rockaway River and water in the bedrock differ chemically and isotopically from water that recharges the stratified-drift aquifer from precipitation and upland runoff. The following sections describe the evidence for infiltration of river water and migration of ground water from the bedrock into the stratified-drift aquifer, then apply that evidence to estimate what percentages of water at particular sites were derived from these sources. Contribution of chloride from human activities is also considered.

Infiltration of River Water

Near the Dover well field, water infiltrates from the Rockaway River into the stratified-drift aquifer and migrates eastward toward the production wells, as indicated by water-level, temperature, and chemical data. Water levels measured in wells on the riverbanks and in piezometers P1 through P4 beneath the riverbed (fig. 10) were consistently lower than river stage (table 22), an indication that the river was losing water to the aquifer in this reach. By contrast, water levels beneath the riverbed slightly downstream from the well field, in piezometer P5 (fig. 10), were higher than river stage on some dates (table 22), an indication that the southern limit of the losing reach fluctuates but is generally near P5. Ground water moves toward the municipal wells from surrounding areas in the aquifer, as shown by the potentiometric contours in figure 10. These contours indicate that water near wells S6 and D6 flows eastward toward the river, then under the river, on its way toward the municipal wells. High river stages might reverse the potentiometric gradient and cause some water from the river to flow westward toward wells S6 and D6, but measurements during this

Table 2. Range and median concentration of major inorganic solutes and dissolved solids in water from Rockaway River, piezometer, and wells at Dover, N.J., July 1984 through August 1985

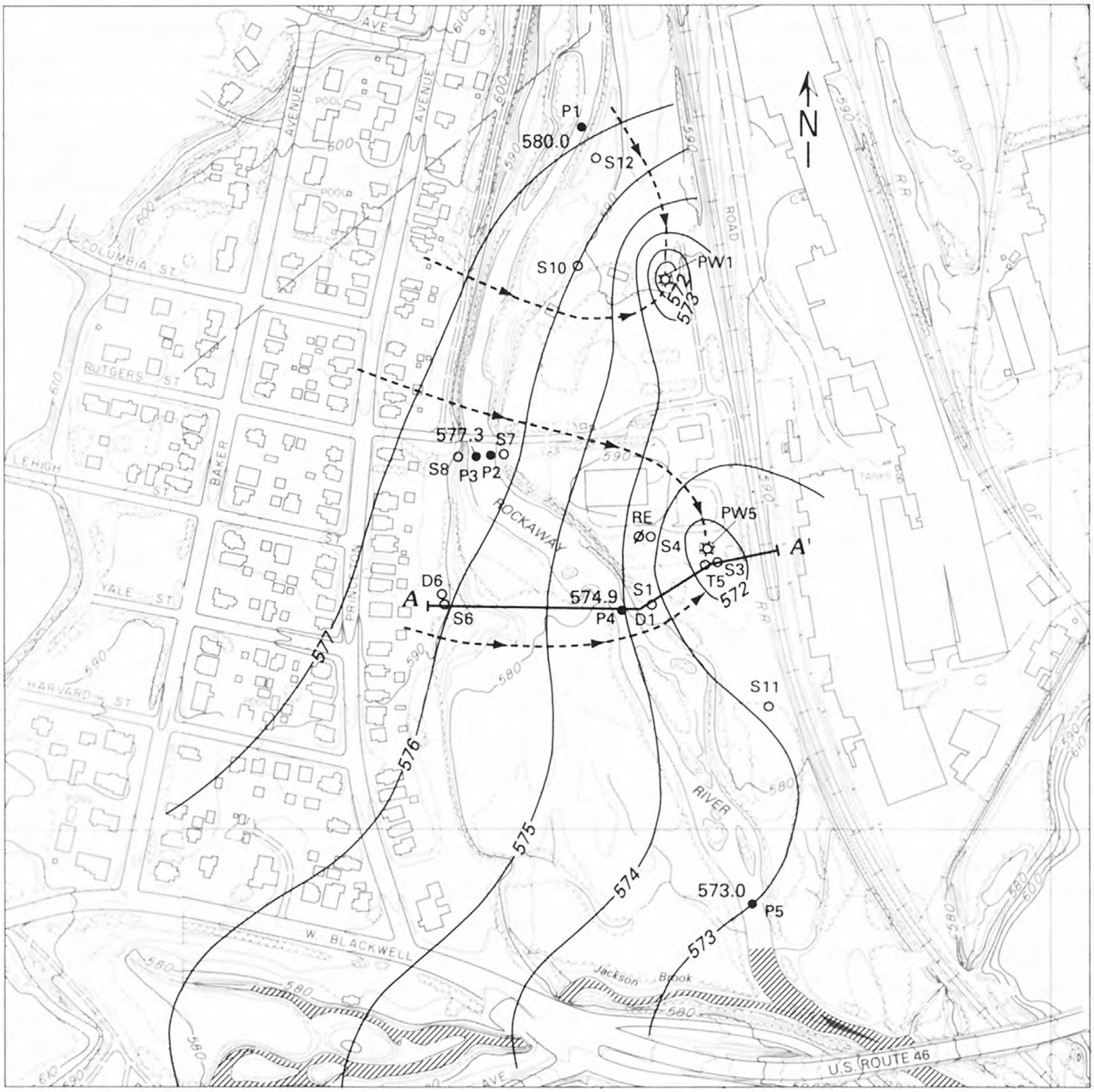
[Concentrations are in milligrams per liter; median values are in parentheses. Site locations are shown in fig. 8. Concentrations of fluoride were either 0.1 or 0.2 milligrams per liter in all samples.]

Site	No. samples	Sodium	Potassium	Calcium	Magnesium	Chloride	Bicarbonate	Sulfate	Silica	Total dissolved solids
S6	5	31-36	2.1-2.5	40-58	15-22	64-86	139-180	23-28	15-16	260-340
		(32.0)	(2.2)	(44.0)	(16.0)	(70.0)	(156)	(21.5)	(16.0)	(280)
D6	4	17-28	1.3-1.6	54-62	22-24	56-77	191-210	29-31	16-17	290-340
		(22.0)	(1.4)	(58.5)	(23.0)	(66.0)	(202)	(29.5)	(16.5)	(315)
River at P4	7	12-19	0.7-1.1	14-23	5.1-8.6	22-35	49-85	11-22	2.0-8.7	98-150
		(16.0)	(1.0)	(20.0)	(7.4)	(31.0)	(71.9)	(17.0)	(8.7)	(130)
P4	4	18-22	1.0-1.2	16-28	6.2-17	31-40	55-107	17-19	7.6-8.3	130-180
		(19.0)	(1.1)	(23.5)	(8.9)	(38.5)	(87.8)	(18.5)	(8.0)	(160)
S1	4	14-19	0.9-1.1	20-25	7.2-9.8	30-39	62-83	16-19	6.6-11	130-160
		(17.0)	(1.0)	(21.0)	(8.0)	(35.5)	(73.8)	(17.0)	(9.0)	(145)
D1	4	7.6-8.2	0.8-1.0	28-32	9.7-10	5.7-5.9	123-133	21-25	12-12	150-160
		(7.8)	(0.9)	(30.5)	(10.0)	(5.8)	(128)	(21.5)	(12.0)	(150)
RE	3	6.5-8.5	0.9-8.3	12-12	2.7-5.1	2.2-4.2	76-82	1.6-3.1	2.8-19	79-90
		(7.2)	(0.9)	(12.0)	(5.0)	(2.9)	(76.8)	(3.0)	(19.0)	(86)
S4	6	20-25	1.1-2.1	25-36	9.9-13	41-53	82-132	18-27	9.1-16	17-230
		(22.5)	(2.0)	(33.0)	(12.5)	45.5	(127)	(19.5)	(15.0)	(210)
T5	8	22-28	1.3-1.7	34-55	14-21	49-67	134-200	18-29	5.7-15	210-310
		(24.0)	(1.6)	(46.0)	(18.0)	(58.0)	(177)	(25.0)	(13.0)	(270)

toward wells S6 and D6, but measurements during this investigation never indicated such a reversal of gradient. Therefore, water collected from wells S6 and D6 is considered "native" –that is, representative of the background chemical and isotope composition of water in the aquifer.

Studies elsewhere have revealed large seasonal temperature fluctuations in ground water derived from river infiltration (Winslow and others, 1965; Yager, 1986, Randall, 1970, 1986; Lapham, 1989). At the Dover well field, temperature near the water table fluctuates widely at wells D1 and RE, which lie between the river and production well PW5 (fig. 10), but fluctuates only slightly west of the river at well D6 (fig. 11). This pattern indicates that induced infiltration constitutes a plume just below the water table as it begins its journey from the river to the production well. Nevertheless, some downward propagation of temperature fluctuations is evident at altitudes of 540-550 ft in D1 and RE, presumably due to temperature conduction, dispersion, and a downward component of flow. At well T5, 18 ft from PW5, temperature fluctuates widely over the entire aquifer thickness (fig. 11), and seasonal temperature extremes are observed first in the bottom 30 ft of the aquifer (minimum in March, maximum in September), before they reach the zone near the water table (minimum in June, maximum in November). These patterns could not be duplicated by radial flow of native ground water influenced by temperature conduction from land surface; they demonstrate that river water has reached the base of the aquifer. Downward potentiometric gradients toward the production-well screen, and water-level fluctuations of 3 ft or more when PW5 cycles on and off (see fig. 28) presumably enhance dispersion near PW5.

Solute concentrations were about the same in water from the river, streambed piezometer P4, and shallow streambank well S1 (table 2). Solute concentrations in water from well T5 (screened from 48 to 68 ft) and shallow well S4 were intermediate between those of the river and the native ground water at wells S6 and D6. For example, the maximum concentrations of all solutes listed in table 2 at wells S4 and T5 were greater than those in river water but less than or equal to those at S6 and D6. Generally, the isotope values of water from well T5 were more negative ("lighter") than those of water from the river and piezometer P4, but heavier than those of native ground water from wells S6 and D6 (fig. 12, table 26). Therefore, ground water in the vicinity of wells S4



Base from U.S. Army Corp of Engineers,
Passaic River Basin Study, 1978,
Sheets B17, C17, 1:2,400

0 100 200 300 400 FEET
0 50 100 METERS

EXPLANATION

Gaining reach of Rockaway River and tributary

—577— **Potentiometric contour**—Shows altitude of water level in shallow wells open in upper part of aquifer between 9 and 11 AM July 7, 1988, after PW1 and PW5 had been operating several hours; contour interval 1 foot; datum is sea level

A——A' Trace of section (fig.14)

----► Direction of ground-water flow

PW5 **Production well**

S6 **Observation well**—Finished in stratified drift

RE **Observation well**—Finished in bedrock

P1 **Piezometer**—Screen is 3 or 4 feet below top of streambed

573.0 **Altitude of water level in streambed piezometer between 9 and 11 AM July 7, 1988 (table 22)**

Figure 10. Generalized potentiometric contours and ground-water flow paths near the Dover well field. (Modified from Dysart, 1988, fig. 2).

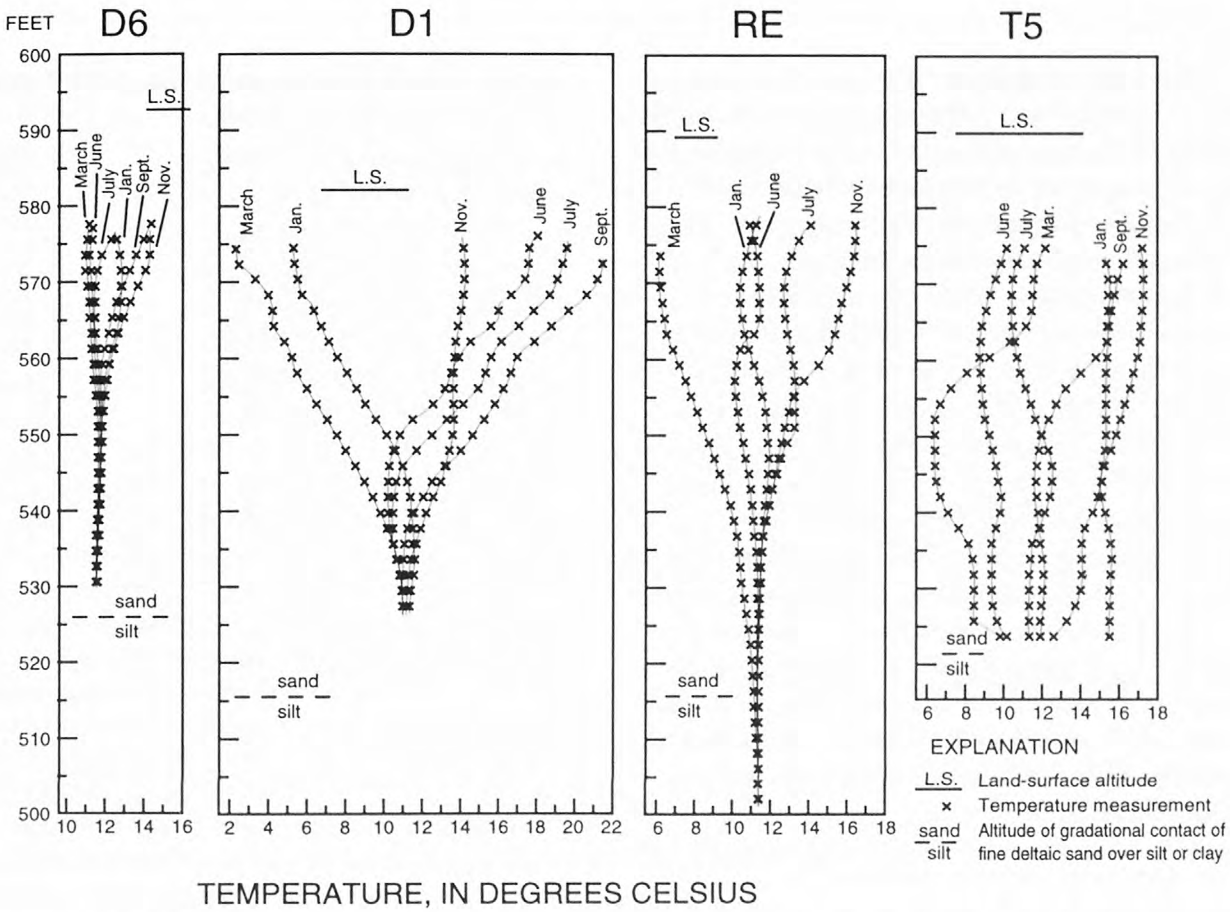


Figure 11. Temperature profiles in selected wells at Dover well field, September 1984 to July 1985. (Locations are shown in fig. 10.)

and T5 (fig. 10) is interpreted to be a mixture of infiltrated river water and native aquifer water.

Mass-balance analysis was used to estimate the percentage of water near well T5 that was derived by infiltration from the Rockaway River. The percentage was calculated by the following equation (Dysart, 1988):

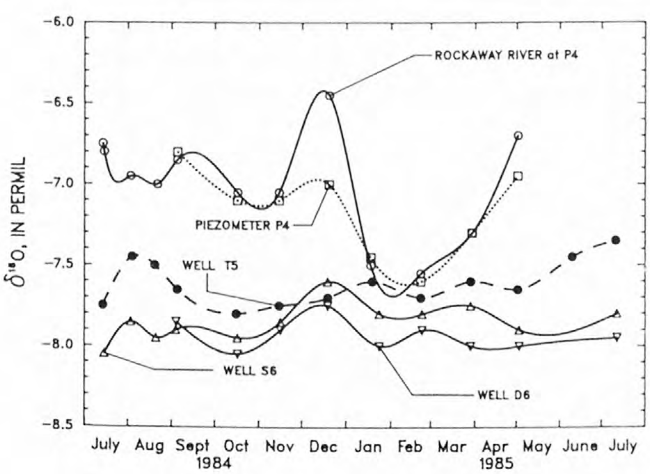


Figure 12. $\delta^{18}O$ at six sites near Dover well field. (From Dysart, 1988, fig. 4.) Locations of sites are shown in fig. 10. Each curve is a spline interpolation between points.

$$Q_r/Q_{pw} = [C_{i(pw)} - C_{i(gw)}]/[C_{i(r)} - C_{i(gw)}], \qquad (1)$$

where: Q_{pw} = total volume of water pumped from a production well or flowing through an observation well during a specified time,

Q_r = part of the total volume that was derived from losing reaches of the river, and

$Ci(gw, r, pw)$ = concentration of conservative constituent i (one that is not chemically altered in the streambed or aquifer), or isotope value of deuterium or oxygen-18 in one of the following:

gw, native ground water;

r, induced river infiltration;

pw, water from production well or observation well.

Mass-balance analyses based on solute concentrations or isotope values of two constituents generally yield more precise estimates of the ratio Q_r/Q_{pw} than those based on a single constituent. In this report, mass-balance analyses based on a single constituent are termed "single-constituent mixing models,"and those based on two constituents are termed "paired-constituent mixing models." Paired-constituent mixing models can be analyzed by solution of simultaneous equations (Dysart, 1988) or by a graphical approach that involves plotting one constituent against the other. If two types or sources of water that have differing isotope values are plotted on a graph of δD versus $\delta^{18}O$, any sample formed by mixing of water from the two sources will lie along a straight line (mixing line) that connects the two sources, and the data-point location on the line indicates the percentage of water derived from each source. Stable oxygen and hydrogen isotopes in water are particularly suitable for these models because they are unaffected by chemical reactions with earth materials; they have been widely used to evaluate interaction between ground water and surface water (McCarthy and others, 1992; Dysart, 1988; and references in each).

The percentage of river infiltration in the aquifer near well T5 was readily estimated from mixing models. Arithmetic mean values of δD and $\delta^{18}O$ in river water, native ground water, and water at T5 were calculated from samples collected from each source on 11 dates between July 1984 and May 1985 (table 26). A paired-constituent model whose mixing line is based on these averages indicates that about 30 percent of the water at T5 was river water (fig. 16, p.20). If the 95-percent confidence limits for well T5 are considered, the model indicates that 20 to 35 percent of the water at T5 was river water (fig. 13). Ideally, isotope values for river water and ground water on a particular date should be compared with values for water at T5 on some later date, when the water from these sources actually reaches T5. Several trial calculations were undertaken in an attempt to determine average traveltime from the river to T5. First, the percentage of river water at T5 on individual dates was calculated by comparing, in single-constituent and paired-constituent mixing models, the isotope content of water at T5

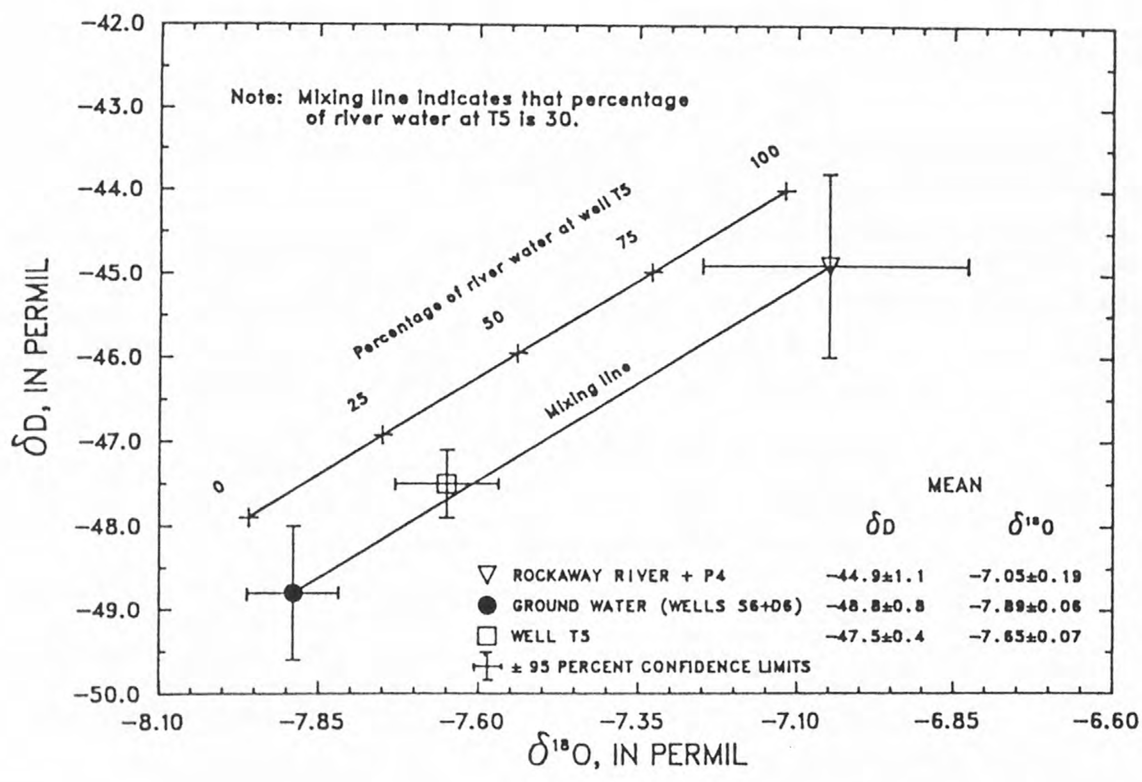


Figure 13. Mixing relation between Rockaway River and ground water, July 1984 through May 1985, based on paired-constituent mass-balance analysis using annual mean isotope values. (From Dysart, 1988, fig. 5.) (Locations of sites are shown in figs. 8 and 10.)

on those dates with isotope content of river water and native ground water on the same dates (a valid comparison only if traveltime from the river to T5 were just a few days). Then, the percentage of river water at T5 on individual dates was recalculated by comparing isotopic content of water at T5 with that of river water and ground water 4, 8, and 12 weeks earlier (valid if average traveltime from river to T5 were the number of weeks assumed in each comparison). If any of these sets of calculations had yielded roughly the same percentage of river water at T5 on each measurement date, that would have been taken as evidence that the assumed travel time was correct. In each trial, however, the variation in calculated percentage of river water from one sampling date to another was implausibly large (Dysart, 1988). Nevertheless, the average percentage of river water at T5 estimated in each trial was 30 to 35 percent, similar to the relation shown in figure 13.

Infiltration of Water from Bedrock

Heads in the bedrock at well RE and in the lower part of the stratified-drift aquifer at D1 and D6 were higher than heads in nearby shallow wells (table 22). Therefore, some water must be flowing upward from bedrock into the aquifer. Concentrations of chloride and tritium in water from deep well D1 are low, about the same as in bedrock well RE (table 24). By contrast, concentrations of these constituents at D6 are nearly equal to those in the upper part of the aquifer at S6 and much higher than those at D1. These results suggest that most of the water in D1 could be derived from bedrock, but if so, upward leakage near S6 and D6 is much smaller. Substitution of tritium concentrations from samples collected during 1984 into the mass-balance equation (eq. 1) indicates that about 12 percent of the water at well D6 is derived from bedrock:

$$Q_{RE}/Q_{D6} = [C_{i(D6)} - C_{i(S6)}]/[C_{i(RE)} - C_{i(S6)}].$$

Thus, for tritium:

$$Q_{RE}/Q_{D6} = [23.4 - 26.5]/[1.2 - 26.5]$$

$$= 0.12 \text{ or } 12 \text{ percent } RE \text{ (bedrock water).}$$

Substitution of tritium values for well T5 into the same equation indicates that the percentage of bedrock water at T5 is zero. Substitution of chloride concentrations for T5 and D6 into the equation gives slightly different results—about 15 percent of the water at T5 and less than 5 percent of the water at D6 is derived from bedrock. Thus, bedrock water apparently is only a minor component of ground water at D6, T5 and S6, even though it is the predominant component at D1. The large percentage of bedrock water at D1 might result from localized discontinuities in the lacustrine clay that underlies the aquifer; that is, the clay might grade into fine sand somewhere near D1. Such discontinuities could allow greater upward percolation of bedrock water to D1 than to D6 and T5. In general, however, upward percolation of water from bedrock in this area is negligible compared to the other sources of recharge–induced infiltration from the river, and natural recharge from precipitation on the aquifer and from upland runoff.

Chloride Contributed by Human Activities

The Dover well field is a small area of wooded parks, lawns, and playgrounds controlled by the Dover Water Department, but it is surrounded by residential and industrial development, a railroad, and a major highway (fig. 8). Although this study was not designed to appraise the effect of human activities in areas surrounding the well field on water chemistry in the stratified-drift aquifer, the analytical data (table 2) indicate that water from several wells contained higher concentrations of chloride and sodium than would be expected under natural conditions. Chloride is only a minor component of rock-forming minerals, and shallow ground water in northeastern United States probably contained little chloride under purely natural conditions. Motts and Saines (1969) report that the Cl content of ground water was 5 mg/L or less in 1890 throughout Massachusetts, where climate and bedrock lithology are reasonably similar to conditions at Dover, N.J. Water from wells RE and D1 contained less than 6 mg/L Cl in 1985 and may represent recharge that occurred before or beyond the influence of urban development. Chloride concentrations in water from S6, D6, and T5 ranged from 49 to 86 mg/L, similar to the range that has been reported for some wells in urban areas throughout the Northeast and interpreted as elevated due to road deicing and other activities of man (Rogers, 1989; Randall, 1977; Motts and Saines, 1969). Sodium concentrations are less variable and generally smaller in magnitude than chloride concentrations at Dover (table 2), probably because Na in ground water has exchanged with Ca or Mg on mineral surfaces in the aquifer.

Weathering Reactions in Stratified Drift

The mixing of induced infiltration from the river with native ground water largely explains the water-quality characteristics in the stratified drift near the center of the Dover well field but does not explain the large variations in CO_2 (carbon dioxide) pressures and pH. These variations, along with an appraisal of the saturation state of the water with respect to various minerals, suggest that weathering reactions in the aquifer affect water chemistry.

The distribution of aqueous species and the saturation state of the water with respect to selected minerals was calculated with the computer program WATEQF (Plummer and others, 1976). The results are given in table 3 in terms of the saturation index (*SI*), which indicates the tendency for a mineral to dissolve in or precipitate from the water analyzed. The index is calculated as follows:

$$SI = \log IAP / \log KT,$$

where: IAP = ion-activity product of mineral/water reaction, and

KT = equilibrium constant for the selected mineral at temperature of sample.

Thus, minerals with large negative *SI* values would be dissolving, as explained in table 3, and those with large positive *SI* would be precipitating.

Dissolved-oxygen concentrations and pH are generally greater in river water than in the shallow wells and piezometer P4 (fig. 14). CO_2 pressures calculated for river water are roughly an order of magnitude lower than those calculated for ground water in shallow wells and P4 (table 3). These contrasts indicate that rain water or river water becomes enriched with carbon dioxide as it infil-

Table 3. Carbon dioxide pressure and saturation indices for selected mineral phases in water from Rockaway River, piezometer, and wells at Dover, N.J.

[Suffix D indicates a negative saturation index whose absolute value is greater than 5 percent of log *KT* (logarithm of solubility equilibrium constant for selected mineral at sampling temperature); the indicated mineral phase tends to dissolve in these samples. Other mineral phases are either in equilibrium or tend to precipitate. Site locations are shown in fig. 8.]

Site	Date sampled (mo-d-yr)	log pCO_2 (atm)[1]	Saturation index			
			Calcite	Dolomite	Chalcedony	Kaolinite
S6	9-5-84	-1.57	-1.12**D**	-2.53**D**	-0.43**D**	+3.73
D6	9-4-84	-2.29	-0.04	-0.37	+0.12	+4.27
River at P4	9-5-84	-2.69	-0.83**D**	-1.90**D**	-0.23**D**	+3.60
	2-22-85	-3.12	-1.11**D**	-2.65**D**	-0.10	+4.41
P4	9-5-84	-1.83	-1.53**D**	-3.29**D**	-0.28**D**	+3.25
	2-22-85	-2.66	-1.45**D**	-3.31**D**	-0.09	+4.70
S1	9-5-84	-1.65	-1.74**D**	-3.70**D**	-0.15	+2.84
	1-18-85	-2.01	-1.89**D**	-4.16**D**	-0.20**D**	+2.55
D1	11-15-84	-2.99	-0.07	-0.46	-0.02	+3.18
RE	8-4-84	-2.88	-0.87**D**	-1.99**D**	+0.16	+3.06
S4	9-5-84	-1.45	-1.39**D**	-3.05**D**	+0.03	+3.13
	3-30-85	-2.39	-1.18**D**	-2.72**D**	-0.07	+4.60
T5	9-5-84	-1.97	-0.35	-0.94**D**	+0.03	+4.37
	5-2-85	-2.55	-0.04	-0.44	+0.06	+3.93

[1] Logarithim of carbon dioxide pressure, in atmospheres

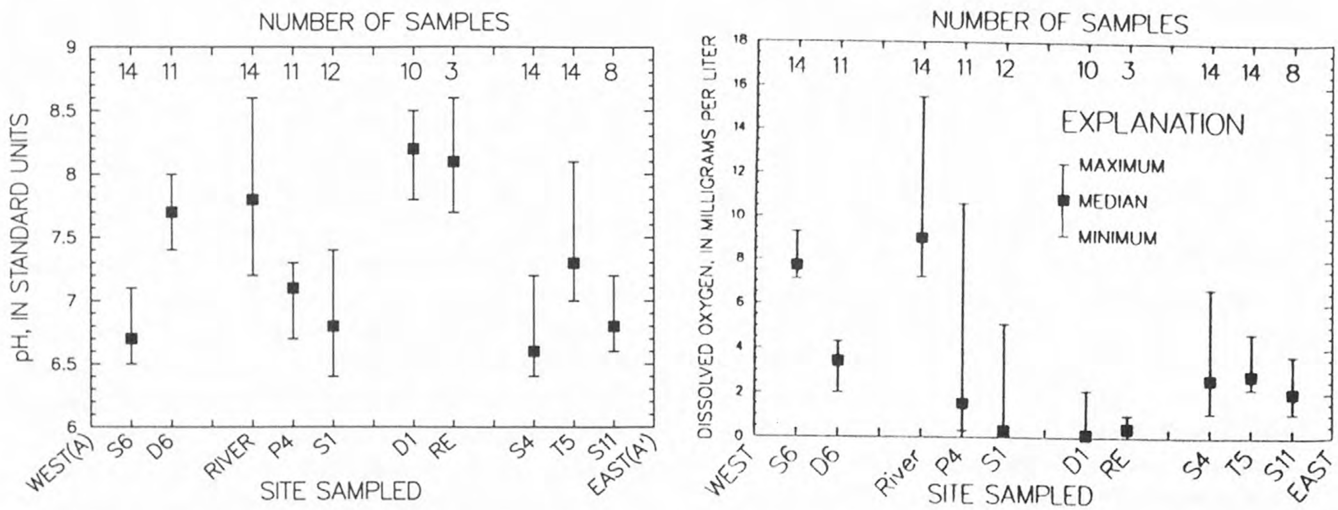


Figure 14. Distribution of pH (left) and dissolved oxygen (right) at selected sites at Dover, N.J. Site sequence corresponds to that along section A-A′ (fig. 10) but is not to scale.

trates into the aquifer or streambed. Oxidation of organic matter in the soil or streambed consumes the oxygen in the infiltrating water, as indicated by reaction 1b in table 4, and bacterial action produces additional CO_2; both processes result in increased CO_2 pressures. Increases in dissolved CO_2 lower the pH and increase HCO_3^- concentrations in shallow zones of the aquifer (fig. 15 and reaction 1c). CO_2 also dissolves carbonate minerals in the aquifer, and as a result, concentrations of Ca^{+2} and Mg^{+2} increase (reactions 2a and 2b).

CO_2 pressures are lower and pH is higher in deep wells D6 and T5 than in shallow wells (table 3 and fig. 15); concentrations of Ca^{+2}, Mg^{+2} and HCO_3^- also are greater in wells D6 and T5 than in shallow wells. Concentrations of these solutes and pH could be limited by the solubility of calcium and magnesium carbonates (reactions 2a-2f in table 4) because waters from D6 and T5 are at or approaching equilibrium with respect to these carbonates (table 3). By contrast, water from well S6 is undersaturated with respect to these carbonate minerals, and dissolution is expected to result.

Table 4. Chemical reactions that control solute chemistry near Dover, N.J.

[aq, aqueous; g, gas. Each reaction was tested by applying WATEQ data (table 3) to computer program BALANCE (Parkhurst and others, 1982).]

1. Carbon - Oxygen - Water system

a. $H_2O + O_2(g) \longleftrightarrow O_2(aq) + H_2O$

b. $CH_2O + O_2\ (aq) \longleftrightarrow CO_2\ (aq) + H_2O$
(organics)

c. $CO_2\ (aq) + H_2O \longleftrightarrow HCO_3^- + H^+$

2. Weathering involving carbonate dissolution and precipitation

a. $CaCO_3 + CO_2\ (aq) + H_2O \longleftrightarrow Ca^{+2} + 2\ HCO_3^-$
(calcite)

b. $CaMg(CO_3)_2 + 2CO_2\ (aq) + 2H_2O \longleftrightarrow Ca^{+2} + Mg^{+2} + 4\ HCO_3^-$
(dolomite)

c. $CaCO_3 + H^+ \longleftrightarrow Ca^{+2} + HCO_3^-$

d. $CaMg(CO_3)_2 + H^+ \longleftrightarrow Ca^{+2} + Mg^{+2} + 2HCO_3^-$

e. $CaCO_3 + H_2O \longleftrightarrow Ca^{+2} + CO_2\ (aq) + 2\ (OH)^-$

f. $CaMg(CO_3)_2 + 2\ H_2O \longleftrightarrow Ca^{+2} + Mg^{+2} + 2\ CO_2\ (aq) + 4\ (OH)^-$

3. Weathering involving silicate dissolution and precipitation

a. $SiO_2 + 2\ H_2O \longleftrightarrow H_4SiO_4$
(chalcedony)

b. $Al(OH)_3 + H_4SiO_4 \longleftrightarrow 0.5\ Al_2\ Si_2O_5(OH)_4 + 2.5\ H_2O$
(gibbsite) (kaolinite)

c. $1.15\ Al_2\ Si_2O_5(OH)_4 + 0.6\ K^+ + 0.25\ Mg^{+2} + 1.2\ H_4SiO_4 \longleftrightarrow K_{0.6}Mg_{0.25}Al_{2.30}Si_{3.50}O_{10}(OH)_2 + 1.1\ H^+$ (illite)$+ 3.15\ H_2O$

d. $7\ Al_2\ Si_2O_5(OH)_4 + Ca^{+2} + 8\ H_4SiO_4 \longleftrightarrow 6\ Ca_{0.167}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 2\ H^+ + 23\ H_2O$
(Ca-smectite)

e. $7\ Al_2\ Si_2O_5(OH)_4 + Mg^{+2} + 8\ H_4SiO_4 \longleftrightarrow 6\ Mg_{0.167}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 2\ H^+ + 23\ H_2O$
(Mg-smectite)

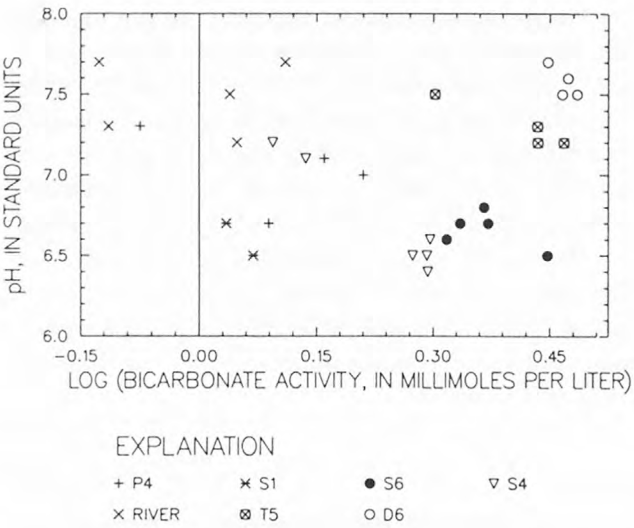


Figure 15. Bicarbonate activity in relation to pH at selected sites at Dover. (Locations are shown in fig. 10.)

Concentrations of Ca^{+2} and Mg^{+2} as well as pH in the aquifer at Dover are probably controlled by carbonic acid weathering reactions (reactions 2a-2b) rather than by mineral acid weathering (reactions 2c-2d) or hydrolysis (reactions 2e-2f). This conclusion is justified by figure 16, in which representative ground-water samples plot near the line for weathering of alkaline sediments by carbonic acid rather than near the lines for weathering by mineral acids or by hydrolysis. Also, shallow zones in the stratified drift are open to CO_2; that is, they can readily receive additional CO_2 from soil gas and infiltrating precipitation. Silicate minerals may also undergo weathering in the aquifer, but this process is probably insignificant relative to carbonate weathering. Saturation indices suggest that chalcedony may be dissolving in parts of the aquifer (table 3), and precipitation of the clay mineral kaolinite is plausible (reaction 3b). Kaolinite could be the mineral that limits alumina concentration in the aquifer. Reactions involving potassium-aluminosilicate minerals such as illite (reaction 3c) may occur but must be insignificant because potassium concentrations are nearly constant at all wells (table 2). Reactions 3d and 3e, which represent the weathering of Ca and Mg smectites (clay minerals), must also be insignificant because they would result in higher activities of H_4SiO_4 than those determined in water samples.

None of these silicate reactions are necessary to explain variations in other solute concentrations within the aquifer.

Sulfate concentrations are about the same in water from the stratified-drift aquifer, represented by wells S6 and D6, as in water from the underlying lacustrine unit, represented by well D1 (table 2). These concentrations could result from organic reactions. Decay of organic matter would increase solute concentrations, pH, and CO_2 pressures (Drever, 1988, p. 220-222; also see table 4, reactions lb, 1c, and 2e). The leaching of about 30 mg/L of SO_4^{-2} from the biomass to ground water would not drastically affect carbonate mineral solubilities, which are controls on concentrations of Ca^{+2}, Mg^{+2}, and HCO_3^{-}, but would cause increases in concentrations of organic solutes, including dissolved organic carbon or organic nitrates and phosphates. Assessment of the process of organic decay was not completed because samples for analysis of organic constituents were unavailable.

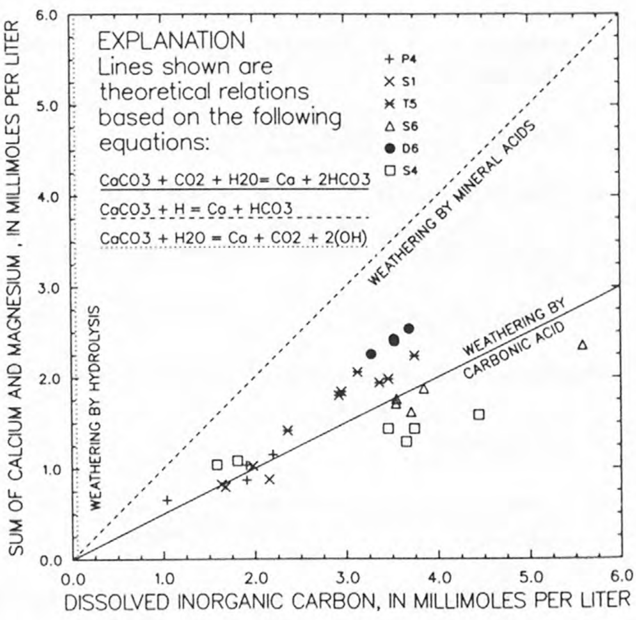


Figure 16. Relation of calcium, magnesium, and carbon concentrations in water at Dover to results expected from theoretical weathering reactions. (Site locations are shown in fig. 10.)

Derivation of Chemistry of Water at Dover Well Field

The mixing and weathering processes described previously account for the chemistry of water that reaches the Dover well field, as shown by the following example computation. A geochemical mixing model and a set of weathering reactions were used to compute water chemistry at well T5, near production well 5 at the center of the well field (fig. 10).

Computation. The computation was done by the computer program BALANCE (Parkhurst and others, 1982) and is summarized in table 5. Samples from piezometer P4 and well D6 were taken as representative of water infiltrated from the river and native ground water, respectively. The reason for using P4 to represent water from the river is that carbon dioxide is added to the river water as it infiltrates through the riverbed, resulting in CO_2 pressures 0.5 to 1.5 orders of magnitude greater than those in the river itself (table 3), and these CO_2 pressures affect weathering of carbonate minerals in the aquifer. The program first computed the mixing proportions indicated in row 2 of table 5 by comparing the activity of conservative solutes in water from P4 and D6 on Sept. 4 or 5, 1984, with those in water from T5 on Sept 5. Isotope data confirm the validity of that computation in that mixing of water from P4 and D6 in the proportions thus computed produce an isotope content identical to that observed at T5 (table 5, rows 8-9). The program then computed the changes in solute chemistry that would result from five weathering reactions that were judged appropriate to conditions at Dover (table 5, rows 3-7). Weathering of calcite and dolomite added calcium, magnesium, and bicarbonate ions (table 5, rows 3-4). Activities of man and dissolution of organic matter added sodium, chloride, and sulfate (rows 5- 6). Finally, calcium and magnesium were exchanged with sodium on clay surfaces to achieve calcium, magnesium, and sodium balance (row 7).

Table 5. Computed and observed solute chemistry and isotope content of water at center of Dover well field (well T5), September 1984

Row	Computation step	Activity of solutes, computed by WATEQF from analysyses in table 24 (millimoles per liter)							Isotope content (permil)	
		Ca^{+2}	Mg^{+2}	Na^{+}	HCO_3^-	Cl^-	SO_4^{-2}	H_4SiO_4	δD	$\delta^{18}O$
(1)	Input data: solute concentrations and isotope content September 4-5, 1984 at :									
	- Piezometer P4 (water infiltrated from river)	0.41	0.24	0.73	1.23	0.82	0.13	0.13	-43.0	-6.80
	- Well D6 (native ground water)	1.02	0.66	1.10	3.06	1.97	0.19	0.28	-49.5	-7.85
(2)	Mixing of 22.3% water from P4 with 77.7% water from D6	0.88	0.56	1.02	2.65	1.71	0.18	0.25	-48.0	-7.62
(3)	Dissolution of calcite									
	$0.02\ CaCO_3 + 0.02\ CO_2 + 0.02\ H_2O = 0.02\ Ca^{+2} + 0.04\ HCO_3^-$	0.02			0.04					
(4)	Dissolution of dolomite									
	$0.03\ CaMg(CO_3)_2 + 0.06\ CO_2 + 0.06\ H_2O = 0.03\ Ca^{+2} + 0.03\ Mg^{+2} + 0.12\ HCO3^-$	0.03	0.03		0.12					
(5)	Addition of NaCl from man's activities									
	$0.01\ NaCl = 0.01\ Na^+ + 0.01\ Cl^-$			0.01		0.01				
(6)	Addition of hydrated sodium sulfate, a surrogate for man's activities or dissolution of organic matter									
	$0.03\ Na_2SO_4 \bullet 7H_2O = 0.06\ Na^+ + 0.03\ SO_4^{-2} + 0.21\ H_2O$			0.06			0.03			
(7)	Exchange of Ca and Mg in ground water with Na on clay surfaces (CS in equation = clay surfaces)									
	$0.02(Na)CS + 0.01\ Ca^{+2} + 0.01\ Mg^{+2} = 0.02\ Na^+ + 0.02(0.5Ca, 0.5Mg)\ CS$	-0.01	-0.01	0.02						
(8)	Total calculated at T5 (sum of rows 2 through 7)	0.92	0.58	1.11	2.81	1.72	0.21	0.25	-48.0	-7.62
(9)	Total observed at T5 on September 5, 1984*	0.92	0.58	1.11	2.94	1.72	0.20	0.25	-47.5	-7.65

* Total values in row 9 are equal to those in row 8 if a precision of ±5 percent is used for solutes, ±1.0 permil for δD, and ±0.1 permil for $\delta^{18}O$

Rationale for presence of source minerals. The reactions in rows 3 and 4 of table 5 assume the presence of calcite and dolomite in the aquifer. No data are available on the mineralogy of the stratified drift, and no carbonate minerals have been identified in the bedrock units that underlie the Dover well field (Lyttle and Epstein, 1987). Several units of dolomite, calcitic dolomite, and calcareous siltstone are mapped within the Rockaway River watershed less than 5 mi upstream from Dover, however (Lyttle and Epstein, 1987). Therefore, some carbonate minerals are likely to be present in the stratified drift, particularly in the outwash that constitutes the upper part of the aquifer. Water collected in September 1984 from well D6 was at equilibrium with calcite (table 3) and contained 1 mmol/L of calcium (table 5, row 1). Because each mole of calcite produces 1 mole of calcium in solution, about 1 mmol (0.10 g) of calcite must dissolve in each liter of water to achieve equilibrium. If the granular aquifer materials are saturated and have a porosity of 25 percent and a specific gravity of 2.65, the volumetric ratio of water-filled pores to solid grains is 1:3 and the mass of solid per liter of water is 7,950 g. If 0.10 g of calcite dissolves from the solid mass of 7,950 g, the water would be saturated with respect to calcite. Thus, the amount of calcite remaining in the aquifer at present could be as little as 0.1 g/ 7,950g or 0.001 percent by weight of sediment and still allow saturation with respect to calcite. Similar reasoning can be applied to justify the assumption that dolomite is present in the aquifer.

Sodium chloride and hydrated sodium sulfate are invoked as source minerals (table 5, rows 5, 6) as a computational device to account for solutes whose presence is assumed to result from man's activities and (or) decay of organic matter. Their solubilities are given by Weast (1973, B-133 and B-140). Neither of these highly soluble minerals would actually exist under natural conditions in stratified-drift aquifers. If gypsum, which does occur naturally in shallow bedrock and drift in parts of the glaciated Northeast, is invoked as a source mineral instead of hydrated sodium sulfate, the BALANCE program calculates the same proportions of water from P4 and D6 at T5.

Cation exchange on clay mineral surfaces was incorporated in the computations (table 5, row 7). The aquifer is composed largely of sand and gravel, but clay-sized sediment of unknown mineralogy is present near the base of the aquifer, in small amounts, and in the underlying lacustrine deposits. Mass balance could have been attained by allowing the weathering of small amounts of clay minerals such as calcium or magnesium smectites (table 4, reactions 3d and 3e) rather than by cation exchange; the mixture at well T5 would then be 25 percent water from P4 and 75 percent water from D6. This alternative was rejected because thermodynamic restraints indicate kaolinite, rather than the smectites, to be the stable clay mineral in this aquifer.

Evaluation. The foregoing analysis explains the water chemistry observed at well T5 in September, 1984 as a mixture of 22 percent river water with 78 percent native ground water, modified slightly by reaction of carbon dioxide in the water with small amounts of calcite and dolomite in the aquifer and by addition of even smaller amounts of sodium, chloride, and sulfate derived presumably from human activities, ion exchange, and(or) decay of organic matter in the aquifer. The mixing and weathering reactions specified in table 5 are not the only possible way to derive the water chemistry observed at well T5, but are believed reasonable in that they satisfy known constraints for isotope content, thermodynamics, and mineralogy of the aquifer. Water at well D6, taken as representative of native ground water, could, in turn, have been derived by allowing the same weathering reactions (table 5, rows 3-7) to modify native ground water like that at well S6 as it flowed through the aquifer toward well D6 from a ground-water divide further west. Because water chemistry fluctuates during the year at P4, D6, and T5 (tables 24-26), and because the water chemistry at T5 on any given date must actually result from mixing of water that flowed past P4 and D6 sometime earlier, as explained in the section on "Infiltration of river water", the computation summarized in table 5 should not be construed as exactly defining the average mixing proportions nor weathering rates. Use of solute concentrations observed on other dates would result in somewhat different mixing proportions and weathering rates. Nevertheless, mixing of the two sources and carbonate weathering controlled by CO_2 would still explain water chemistry at well T5.

Infiltration of river water at Dover probably began about 1940, when production wells PW2 and PW3 were constructed (table 21). If the carbonate content of the stratified drift is indeed minimal, saturation indices for Ca and Mg could be expected to decrease over time as large volumes of river water and precipitation, both unsaturated with respect to Ca and Mg, leaches more and more of these ions from the aquifer.

INDUCED INFILTRATION FROM THE ROCKAWAY RIVER

The principal focus of this study was on the water-transmitting properties of sediments immediately below the channel of the Rockaway River, in a reach where pumping from municipal wells induced water to infiltrate from the river into the underlying aquifer. Three approaches were used to obtain information. The first, geochemical mixing models, was discussed earlier in the section "Infiltration of river water" and led to an estimate of the proportions of river water and native ground water at an observation well adjacent to one of the municipal wells, averaged over a year. The other two approaches are discussed below. The next section describes how dissolved oxygen concentrations and water temperature were used as tracers to measure the rate of vertical flow through the streambed at one or more points. The subsequent section explains how streamflow measurements upstream and downstream from the losing river reach were used to calculate the net loss in river flow from that reach. Results of all these approaches are used further on to calculate the vertical water-transmitting capacity of the streambed.

Vertical Flow Rates through the Streambed

Several water-quality characteristics, including dissolved-oxygen concentrations, pH, and water temperature, fluctuate diurnally in surface water as a result of diurnal cycles in solar radiation that affect air pressure and temperature. These water-quality characteristics were monitored continuously for several days in the Rockaway River and in piezometers screened a short distance below the river, in the hope that the rate at which diurnal fluctuations prograde downward into the streambed could be determined and could be used, in conjunction with head measurements, to calculate the water-transmitting properties of the streambed.

Measurement Procedures

Ground-water temperature, ground-water level, river level, and river temperature were measured every 2 hours at piezometers P2, P3, and P4 (locations are shown in fig. 10) from the afternoon of June 2 through the morning of June 6, 1986. Ground-water temperature was measured at 0.5-ft depth intervals by a thermistor lowered through the water column in each piezometer. River temperature was measured just above the riverbed, generally with the same instrument. Water level was measured with a steel tape.

During the same 92-hour period, water temperature, pH, dissolved oxygen, and specific conductance in water pumped from streambed piezometer P2 and from the river at P2 were monitored for at least 10 min every 2 hours. The monitoring at P2 consisted of three steps. First, water was pumped from the river at P2 for 10 to 30 min through plastic tubing to an inline flow-through cell, within which water-quality probes measured temperature, pH, dissolved oxygen and specific conductance continuously. Values were recorded at 2-minute intervals. Next, water levels and temperatures within the river and the piezometer were measured, as described in the previous paragraph. Then, the pump was connected to tubing from piezometer P2, and water from this source was monitored for 15 to 70 min; values were again recorded at 2-minute intervals. These three steps were repeated every 2 hours. The pumping rate was about 0.13 gal/min. Computations presented further on assume that vertical head gradient and flux near the piezometer were not significantly affected by this small withdrawal.

Sampling procedures were designed to ensure representative data. The open end of the tubing from the river at P2 to the peristaltic pump was placed about 0.1 ft above the riverbed. Sampling traverses across the river on a line through P2 showed only slight variation in water quality with depth or horizontal position. The open end of the tubing in piezometer P2 was placed near the top of the screen, and data collection commenced only after three or more casing volumes were pumped from the piezometer. The use of an inline flow cell connected directly to the pump discharge line ensured that measurements of dissolved oxygen and pH would not be significantly affected by exchange of oxygen and carbon dioxide between the water pumped and the atmosphere. The discharge line was fitted inside an opaque tubing to retard equilibration of water temperature to that of the ambient air.

The data are listed in tables 27 through 29 (at end of report) and summarized in figures 18 through 20 and table 6.

Observed Fluctuations in Water Quality

The stage of the Rockaway River at P2 decreased gradually a total of 0.1 ft over the first 3 days of observation (table 28, fig. 17). Heavy rain during the early hours of June 6 resulted in a rapid increase in river stage of 0.3 ft. Water levels in P2 fluctuated over a range of about 0.4 ft in response to the frequent changes in pumping rate at the Dover well field but remained about 2 ft below river stage and seemed to show a downward trend comparable to that in the river (fig. 17).

The four water-quality characteristics monitored in the Rockaway River varied in nearly diurnal cycles (fig. 18). Similar cycles were suggested by data from piezometer P2, which is screened 3 to 3.5 ft below the top of the streambed. Each plot in figure 18 includes all pertinent data from table 27 or 29A; several successive identical observations at nearly the same time result in slightly enlarged data points. Each plot also includes a curve developed from regression of the data against time, the sine or cosine of time, and (for some curves) water temperature or hydrogen-ion activity, as explained in table 6. The curves show the extent to which the independent variables considered (table 6) explain data fluctuations within the period of observation.

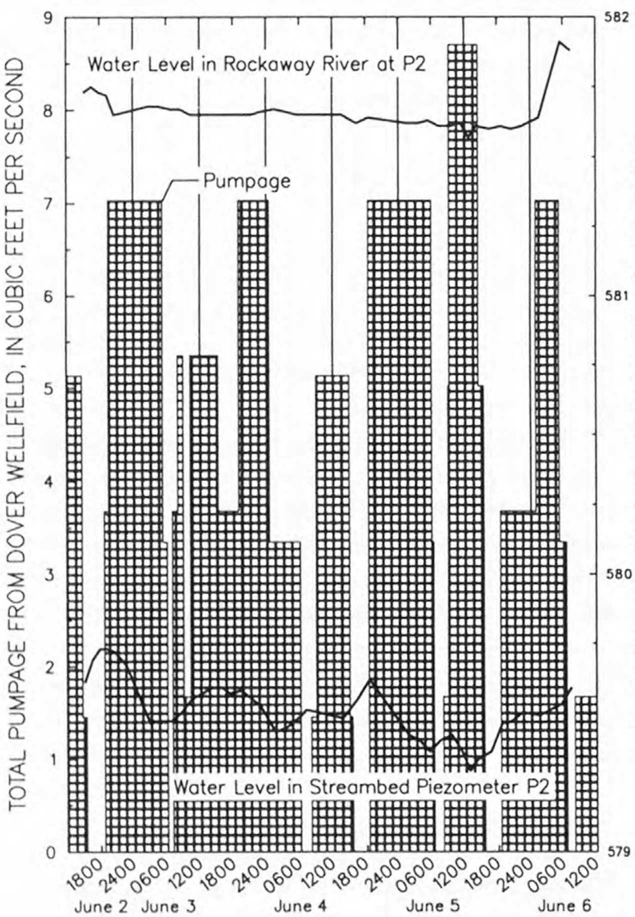


Figure 17. Water level in piezometer P2 in relation to river level and pumpage from Dover well field, June 2-6, 1986.

In the river, minima for temperature and pH and maxima for specific conductance occurred in early morning; maxima for temperature and pH and minima for specific conductance were observed in the early afternoon (fig. 18). Dissolved oxygen (DO) concentrations (fig. 18 and table 27) reached minima and maxima during the late evening and late morning, respectively. The diurnal cycles in river temperature would be expected to control diurnal cycles in DO concentrations and pH.

In the piezometer, temperature and DO reached minima in late morning and maxima in late evening (fig. 18). Consistent diurnal cycles of pH could not be objectively discerned from the observed data for P2; only one 24-hour cycle is suggested in figure 18. Reactions involving carbon dioxide (table 4, reactions 1b and 1c) probably control DO concentrations and pH within the streambed.

Diurnal fluctuations in specific conductance were detected in piezometer P2 as well as in the river (fig. 18) but were generally small. The decrease in specific conductance in the river from 270 to 250 μS/cm early on the morning of June 6, followed by an increase to 304 μS/cm, is probably a result of heavy rain at that time. No similar fluctuations were detected in P2 over the next 5 hours; this evidence suggests either that the time of travel from the river to P2 was greater than 5 hours or that the volume of infiltration was small. Values observed at both sites over an 80-minute period in the early evening of June 3 were much lower than all other values recorded June 2-6; these anomalous values are unexplained and may be invalid, but were used in the regression analysis (table 6) that generated the curves in figure 18.

Diurnal temperature cycles in the river at P2 had an amplitude of 3 to 4°C (fig. 18). Amplitude decreased with depth beneath the top of the streambed, to about 1°C at a depth of 1.8 ft (fig. 18) and to less than 0.5°C at a depth of 4 ft (table 29). Similarly, total observed ranges in water temperature decreased with depth at piezometers P3 and P4, although the rate of decrease was small at depths greater than 3 ft below the top of the streambed (fig. 19 and table 29).

Diurnal cycles for DO concentrations in the river have a periodicity of about 24 hours with an amplitude of about 2 mg/L (fig. 18). Concentrations of DO in P2 were much smaller but also varied in nearly diurnal cycles with a periodicity of about 24 hours and an amplitude as much as 1.5 mg/L. Both maximum and minimum DO concentrations in the

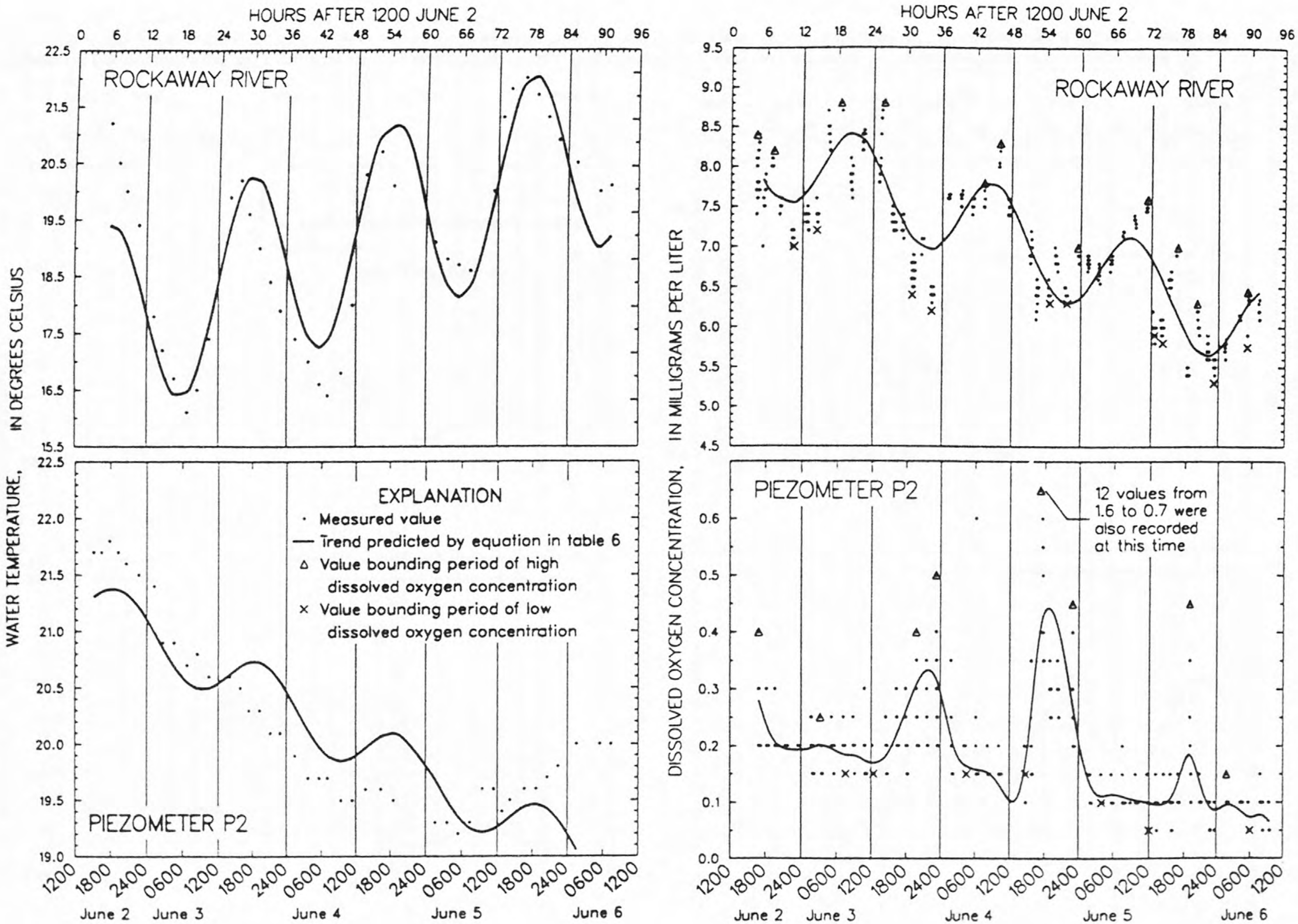


Figure 18. Specific conductance, pH, water temperature, and dissolved oxygen concentration in Rockaway River and in piezometer P2, June 2-6, 1986. Temperature shown for P2 was measured at a depth of 1.8 feet below top of streambed (table 29); all other data for P2 were measured in water that entered P2 3 to 3.5 feet below top of streambed.

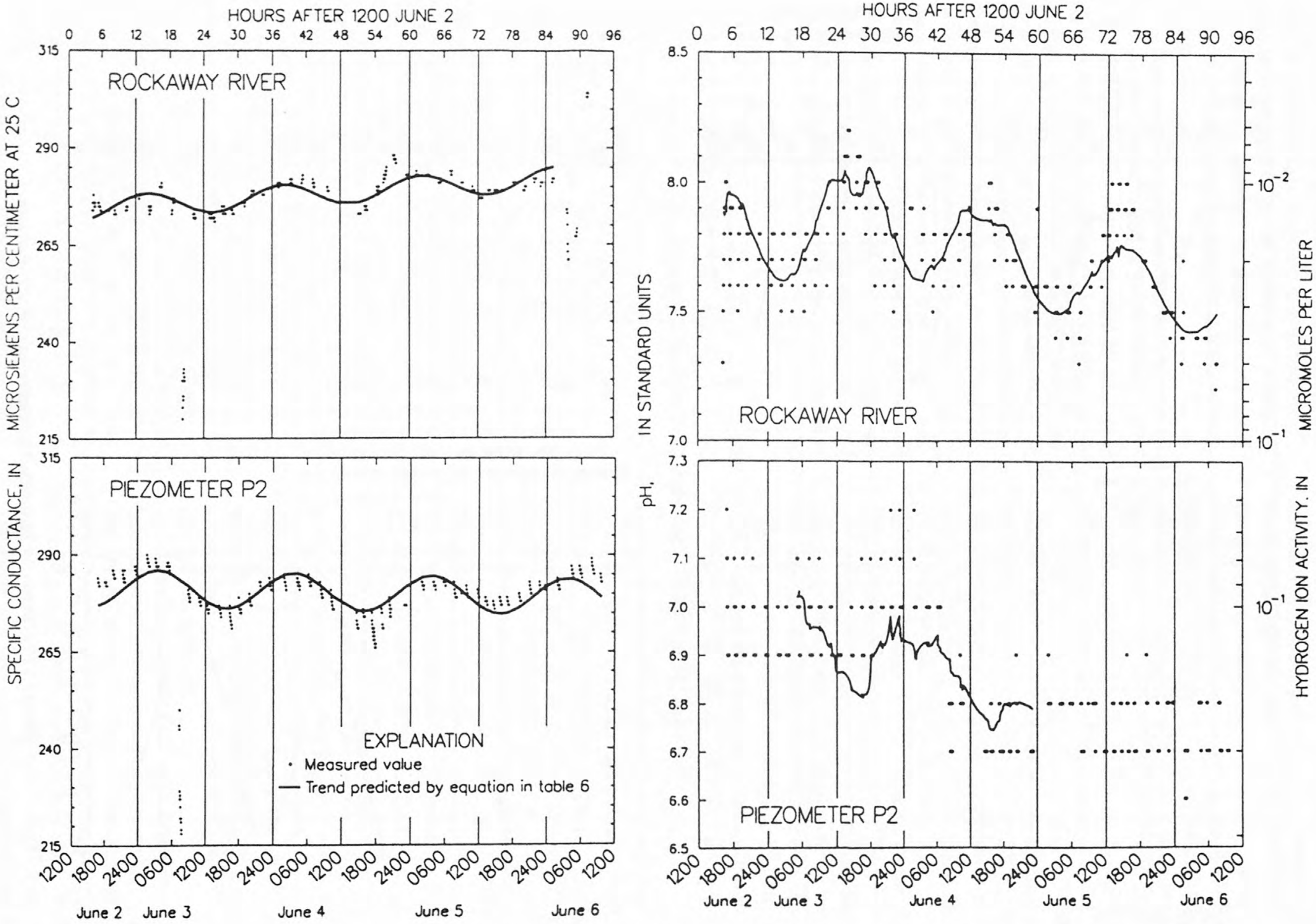


Figure 18 (continued). Specific conductance, pH, water temperature, and dissolved oxygen concentration in Rockaway River and in piezometer P2, June 2-6, 1986. Temperature shown for P2 was measured at a depth of 1.8 feet below top of streambed (table 29); all other data for P2 were measured in water that entered P2 3 to 3.5 feet below top of streambed.

river decreased gradually during the period of data collection, and a gradual decrease in minimum DO concentrations was also apparent in piezometer P2. Maxima in P2 were quite variable, ranging as high as 1.6 mg/L on June 4 (fig. 18 and table 27), and coincided to some extent with increases in aquifer head that resulted from reduced pumping (fig. 17).

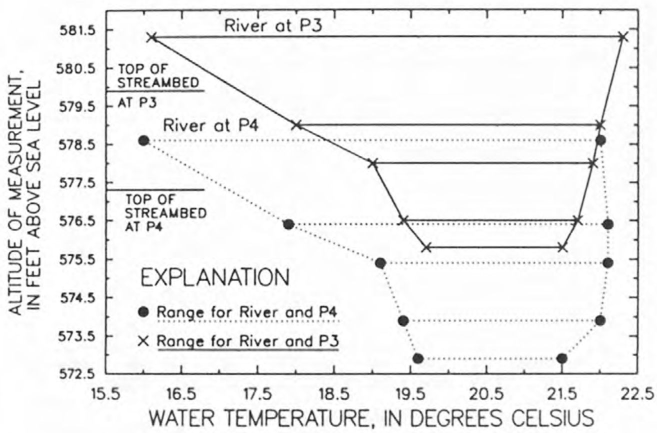


Figure 19. Range in water temperature at piezometers P3 and P4 as a function of altitude relative to streambed, June 2-6, 1986. (Locations shown in fig. 10.)

Computation of Vertical Flow Rates from Dissolved-Oxygen Concentrations

The approach used to compute downward velocity from dissolved-oxygen concentrations is conceptually simple. It assumes that microbial activity and chemical reactions within the streambed do not impose patterns of dissolved-oxygen concentration on infiltrating river water, but instead allow the diurnal fluctuations inherited from the river to progress downward, greatly diminished in magnitude but unaltered in timing. Accordingly, the timing and magnitude of dissolved-oxygen fluctuations in river and piezometer were delineated in detail and compared to estimate the time required for maxima and minima in the river to reach the piezometer.

Procedure and results. The analytical procedure described here has no theoretical rationale but proved useful. First, several pairs of DO concentrations measured in the river were selected, such that one pair represented a period of high dissolved oxygen in the river's diurnal cycle and the next pair represented the subsequent period of low dissolved oxygen. Each individual member of a pair of high values is the

Table 6. Regression equations developed to represent diurnal cycles of water-quality characteristics in Rockaway River and piezometer P2 at Dover, N.J., June 2-6, 1986

[Site location is shown in fig. 10. *T*, number of hours after 1200 on June 2; $T' = T \times (2\pi/24)$; Ha, hydrogen ion activity, in micromoles per liter; WT, water temperature, in degrees Celsius; R', coefficient of determination × 100; SC, specific conductance, in microsiemens per centimeter; and DO, dissolved oxygen concentration, in milligrams per liter. Equations in this table were developed only for trend analysis of water-quality characteristics; they are fitted to the observed data but are not proposed to predict values beyond the period of observation.]

		Equation terms[a]						
			Coefficients for independent variables indicated					
Site	Dependent variable	Intercept	*T*	Sine *T'*	Cos *T'*	WT	Ha	R'
River at P2	SC	274.1	+0.093	-1.355				67
P2	SC	281.7	-0.030	-3.884	-2.688			56
River at P2	Ha	-0.0335	+0.0008	-0.0101	-0.0075	0.0026		62
P2	Ha	0.4286	+0.0010	-0.0102	-0.0090	0.0263		64
River at P2	WT	17.68	+0.0330	+1.8090	+0.1326			74
P2[b]	WT	21.30	-0.02616	+0.2312	-0.1274			78
River at P2	DO	8.82	-0.0250	-0.3961	+0.4308	-0.0274		84
P2[c]	log (base 10) of DO	0.7834	0.0033	+0.0876			+0.7959	69
P2[d]	log (base 10) of DO	-0.3092	-0.0562	+1.1495			+0.1916	95

[a] Each equation has the form:
Dependent variable = Intercept + *T* (coefficient for *T*) + (next independent variable for which coefficient is listed) × (coefficient for that variable) + . . .

[b] Temperature in P2 at a depth of 1.8 feet below top of streambed (table 29).

[c] *T* used in this equation was from 4.9 to 47.7 hours and from 58.8 to 93.6 hours.

[d] *T* used in this equation was from 47.8 to 58.7 hours.

maximum value recorded during one sampling episode (a set of several successive observations at 2-minute intervals that plot as nearly vertical lines in fig. 18.) Each selected pair of high values brackets a time period that contains two or more sampling episodes in which dissolved oxygen was higher than average, and is followed by a pair of low values selected similarly. This procedure was repeated with DO data from piezometer P2. The selected pairs of high and low values from the river and from P2 are shown in figure 18. During each episode of sampling from P2, DO concentrations declined for the first few minutes, then either declined very slowly or held constant for the remainder of the episode; therefore, the high values selected from P2 are invariably the first observations recorded in particular sampling episodes. By contrast, DO in the river fluctuated somewhat but did not change systematically during most sampling episodes.

If each period of high (or low) DO in the river were the cause or source of the first period of high (or low) DO observed subsequently in the piezometer, average traveltime from river to piezometer would be about 12 hours (table 7). This is the minimum traveltime that is plausibly consistent with the array of dissolved-oxygen data. If each period of high values in the river were the source of the second subsequent high in the piezometer, however, average traveltime would be about 34 hours (table 7). If each period of high values in the river were reflected as the third or fourth subsequent high in P2, travel time would be 57 hours or 79 hours, respectively. To determine which of these four possible traveltimes is most likely to be correct, differences in the magnitudes of highs and lows were compared in graphs such as figure 20. Each river value was shifted ahead in time just enough to place it directly above the value in P2 with which it would correspond if the average traveltime calculated in table 7 were correct. In figure 20, which represents a 34-hour traveltime, the largest diurnal high concentration detected in the river during the 92 hours of study (8.8 mg/L) corresponds to the largest high concentration detected in P2 (1.6 mg/L), and magnitudes of other extremes in the river were judged to correspond to those detected in P2 at least as well as when alternative traveltimes were tested. In summary, the dissolved-oxygen data indicate that the minimum plausible traveltime from the river to the screen in P2, a distance of 3.25 ft, is about 12 hours. If so, the average linear water velocity is 6.3 ft/d and, if effective porosity is 0.25, Darcian velocity is 1.6 ft/d. The data further suggest, however, that an average traveltime of about 34 hours is somewhat more likely than 12 hours; if so, the average linear velocity is only 2.3 ft/d, and Darcian velocity 0.6 ft/d.

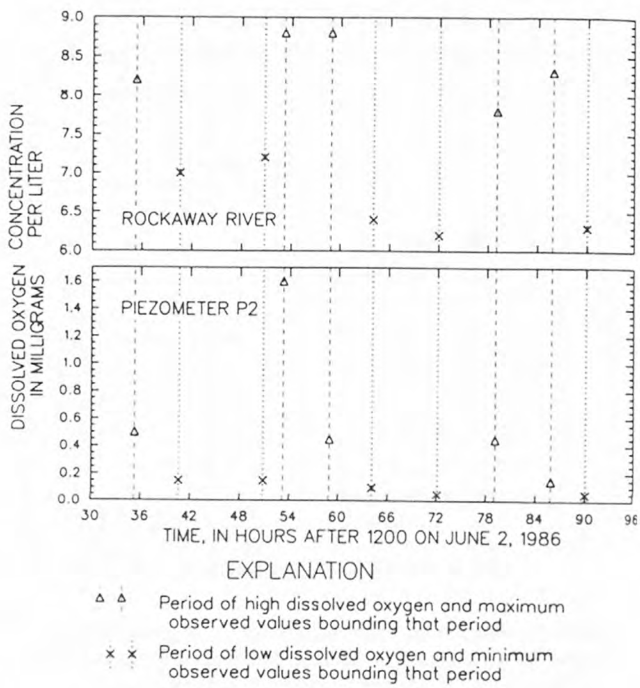


Figure 20. Magnitudes of corresponding diurnal maximum and minimum dissolved oxygen concentrations in Rockaway River and piezometer P2, assuming 34.4-hour traveltime from river to piezometer. Piezometer data are plotted at the times of observation; river data are displaced an average of 34.4 hours (table 7).

Suggestions for application elsewhere.—The foregoing analysis has shown that downward water velocity beneath losing reaches of a river can be calculated from measurement of diurnal fluctuation in DO concentrations in river and streambed. Results at Dover suggest that:

1. Correlation of diurnal fluctuations in DO concentration in river and streambed requires precise observations every 2 to 4 hours over several days. Data were collected at this site November 19-21, 1985, in much the same manner as in June 1986 except that monitoring was suspended in late evening and resumed early the next morning. A total of 426 DO observations in river and piezometer were recorded (as compared with 1,258 in June 1986). The long overnight gaps between observations hindered delineation of the magnitude and timing of diurnal cycles, and more than one traveltime from river to piezometer seemed equally plausible.

Table 7. Alternative estimates of time required for diurnal dissolved-oxygen cycles to travel through streambed of Rockaway River at Dover, N.J., June 2-6, 1986

[Dissolved oxygen concentrations are in milligrams per liter, mg/L]

	Values bounding period of high or low dissolved oxygen in river (fig. 18)		Values bounding corresponding period of high or low dissolved oxygen at P2		Difference between river and P2	
	Time, in hours after 1200 noon, June 2	Dissolved oxygen concentration	Time, in hours after 1200 noon, June 2	Dissolved oxygen concentration	Traveltime, in hours	Depletion of dissolved oxygen concentration
Earliest Alternative *						
High	7.20	8.20	15.20	0.25	8.00	7.95
Low	10.58	7.00	19.63	0.15	9.05	6.85
	14.40	7.20	24.43	0.15	10.03	7.05
High	18.47	8.80	31.82	0.40	13.35	8.40
	25.88	8.80	35.25	0.50	9.37	8.30
Low	30.80	6.40	40.57	0.15	9.77	6.25
	34.17	6.20	50.77	0.15	16.60	6.05
High	43.30	7.80	53.18	1.60	9.88	6.20
	45.97	8.30	58.88	0.45	12.91	7.85
Low	54.58	6.30	64.03	0.10	9.45	6.20
	57.60	6.30	72.03	0.05	14.43	6.25
High	59.50	7.00	79.03	0.45	19.53	6.55
	71.30	7.60	85.82	0.15	14.52	7.45
Low	72.52	5.90	89.97	0.05	17.45	5.85
				Mean:	12.4 hours	6.9 mg/L
Second Alternative**						
High	7.20	8.20	35.25	0.50	28.05	7.70
Low	10.58	7.00	40.57	0.15	29.99	6.85
	14.40	7.20	50.77	0.15	36.37	7.05
High	18.47	8.80	53.18	1.60	35.71	7.20
	25.88	8.80	58.88	0.45	33.00	8.35
Low	30.80	6.40	64.03	0.10	33.23	6.30
	34.17	6.20	72.03	0.05	37.86	6.15
High	43.30	7.80	79.03	0.45	35.73	7.35
	45.97	8.30	85.82	0.15	39.85	8.15
Low	54.58	6.30	89.97	0.05	35.39	6.25
				Mean:	34.4 hours	7.1 mg/L

* Assumes each period of high dissolved oxygen in the river is the source of the first subsequent period of high dissolved oxygen in P2
**Assumes each period of high dissolved oxygen in the river is the source of the second subsequent period of high dissolved oxygen in P2

2. Diurnal fluctuations are generally small and can be similar from one day to the next. Therefore, regular calibration of the water-quality probes and continuous monitoring of concentrations during periods of data collection are needed to determine whether apparent fluctuations in concentrations are true signals or "noise" caused by instrument or observer error.

3. DO cycles longer than diurnal could also prove useful. For example, diurnal cycles observed in the river June 2-6, 1986 were superimposed on a trend of rising water temperature and therefore declining DO (fig. 18). Temperature changes associated with the passage of weather fronts might reverse such trends and thus cause distortion in diurnal DO cycles that might be useful in matching river and piezometer data.

4. Suitable data probably could be collected at any time or season. Measurable differences in DO concentrations between the river and streambed piezometers were detected during all months of data collection at Dover (fig. 21). DO concentrations in small streams such as the Rockaway River at Dover are largely controlled by ambient air temperature, however, and diurnal fluctuation in DO is therefore likely to be most pronounced

during prolonged periods of warm days and cool nights, which are more probable in spring or fall than in summer or winter.

5. Low, constant river stage and steady pumping rates are advantageous. High river stage could result in vertical stratification of DO concentrations in the river. Abrupt changes in vertical gradient between river and streambed could cause DO stratification in the streambed and unsteady rates of downward water movement that would complicate matching of river and piezometer data.

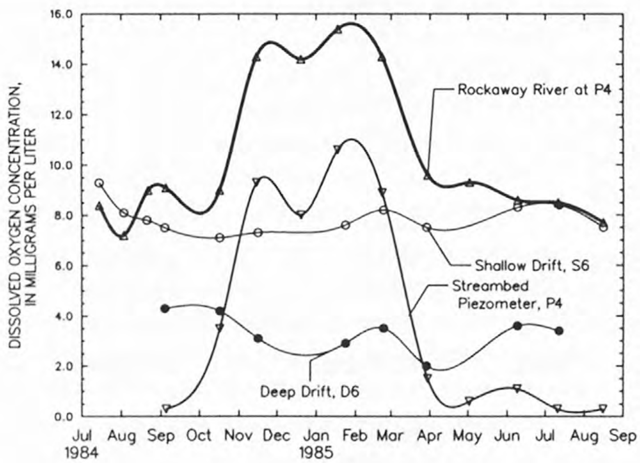


Figure 21. Dissolved-oxygen concentrations at selected sites at Dover, N.J., 1984-85. (Locations shown in fig. 10.)

Computation of Vertical Flow Rates from Water Temperatures

The temperature data in table 29 were analyzed by Lapham (1989, p. 25-9), who computed several theoretical profiles of temperatures beneath the river at Dover for a 24-hour period on June 4-5, 1986. Each theoretical profile was based on river temperatures recorded on those dates, wet-bulk density and thermal properties typical of coarse-grained sediments, and one of several alternative downward water velocities. Lapham (1989, p. 29) then compared temperatures measured at 0.2-ft depth intervals and 2-hour time intervals in piezometers P2, P3, and P4 (table 29) to the theoretical profiles, and concluded that the measured temperature profiles most nearly matched those theoretical profiles that incorporated a downward Darcian velocity of 1.5 ft/d, which would be equivalent to an average linear water velocity of about 6 ft/d. Conditions at Dover were less than ideal for application of this technique, however, for four reasons: (1) Water temperatures in the upper part of the riverbed could not be measured because the water level within each piezometer was about 1 ft below the bottom of the river. (2) At depths greater than about 1.5 ft below the bottom of the river, a lateral ground-water flow component toward the well field is likely, in addition to the vertical flow assumed in deriving the theoretical profiles. (3) The sinusoidal diurnal temperature cycle was superimposed on a cycle of several days duration in which air and river temperatures were warm through June 2, cooler June 3-4, and warm again thereafter (fig. 18); this influence could not be incorporated in the theoretical profiles. (4) Frequent changes in rates of withdrawal from municipal wells caused fluctuations in head at P2 (fig. 17), and therefore temporary acceleration and perhaps reversal of downward flux. Diurnal temperature minima at depths of 0.9 to 1.5 ft below the top of the riverbed in piezometers P3 and P4 generally preceded minima in the river (table 29), which suggests that they represent the previous day's river minima migrating downward. If so, the average time required for those minima (and intervening maxima) to reach depths of 1.5 to 2 ft was about 28 hours (table 29), much greater than the 15 hours shown in the theoretical profiles by Lapham (1989, fig. 31) for a Darcian velocity of 1.5 ft/d. Thermal conductivity contributes to the downward propagation of temperature extremes, and heat exchange delays those extremes as well as decreasing their magnitude, so water velocity cannot be simply equated to travel rates of temperature minima. Nevertheless, the foregoing comparison suggests that the true downward Darcian velocity is appreciably less than 1.5 ft/d. If so, vertical hydraulic conductivity of the streambed is appreciably less than the 2.2 to 2.5 ft/d calculated by Lapham (1989, table 6).

Measured Loss of River Flow

Flow of the Rockaway River was measured upstream and downstream from the Dover well field on two occasions in the summer of 1988. The net decrease in flow is assumed to result from infiltration through the streambed into the aquifer and, thus, is termed "seepage loss." Stream stage and water levels in streambed piezometers were also measured so that the downward gradient in this reach could be used with the measured seepage loss to calculate hydraulic properties of the streambed. All measurements and calculations were done with more than usual care because seepage losses were expected to be only a small percentage of streamflow (and were, in fact, about 5 percent).

Several steps were taken to improve measurement precision:

1. Measurements were delayed until the Rockaway River was at low flow so that the ratios of seepage loss to streamflow and to measurement error would be as large as possible. Flow of the river at Dover was estimated from stage monitored at a gaging station several miles downstream.
2. Three measurement sites were selected (fig. 8) that were suitably located with respect to the well field, similar in water depth and flow conditions, and characterized by fairly uniform flow distribution across the width of the stream.
3. The cobble-bottom streambed near each measurement site was regraded to produce a smooth, level surface and uniform flow distribution. This entailed removing the large stones at each measurement site, filling indentations between the remaining stones with fine gravel and coarse sand, and removing or rearranging many stones upstream from each measurement site.
4. One or more float-activated analog recorders were installed to obtain a continuous and precise record of stream stage during the period of measurement.
5. Tapes, stopwatches, and current meters were checked for consistency.
6. Arrangements were made for municipal wells PW1 and PW5 to be pumped continuously during the days when streamflow was measured, to eliminate the possibility that seepage loss might vary in response to large changes in vertical gradient beneath the stream that occur whenever pumping is started or stopped. The pumps were turned on at least 4 hours before the start of streamflow measurement each day. Average daily withdrawal was about 6.9 ft^3/s, somewhat greater than normal.
7. Three hydrographers were employed on each date and instructed to make two successive measurements at each site. Each measurement was to include depth and velocity in about 30 verticals. Tag lines (measuring tapes) were left in place at each site so that all measurements on a given date would be at the same location.

Streamflow was computed from each measurement by standard procedures. Minor differences of opinion between hydrographers were reconciled to ensure consistent estimates of unmeasured velocity at ends of measurement sections and consistent estimates of angles (all 1 degree or less) that were observed in a few places between flow and a perpendicular to the measurement section. Then, three adjustments were made to improve the precision with which seepage loss would be determined:

1. A constant amount was added to or subtracted from all six measurements (two at each site) by a particular hydrographer on a particular date, such that sets of six measurements on the same date by different hydrographers would all have the same mean. This adjustment ensured that subsequent computations would not be distorted by differences between hydrographers in determining the absolute magnitude of flow. Such differences, which were not important to this study, could have resulted from meter sensitivity or measurement technique. The adjustment preserved the differences in flow between sites recorded by each hydrographer.
2. Streamflow declined gradually during each day of measurement, presumably as a result of changing conditions upstream. Therefore, the difference between measured flows at any two sites reflects not only seepage loss in the intervening reach but also the decline in streamflow in the time interval between the two measurements. To eliminate the effect of declining flow, all measurements on a particular date were adjusted to a single uniform stage by use of rating curves (fig. 22) in which flow is plotted as a function of stage. First, each adjusted measurement at site 2 (from step 1, above) was plotted as a function of the average stage recorded at that site during the measurement. Then, the measurements at sites 1 and 3 were plotted as a function of stage recorded at site 2 sufficiently later or earlier, respectively, to allow for traveltime of perturbations in stage between sites. A low dam of stones was hastily constructed upstream from site 1, resulting in a temporary decrease in flow that took about 40 min to travel from site 1 to site 2. Therefore, measurements at site 1 are plotted in figure 22 as a function of the site-2 stage which was recorded 40 min after the time of measurement at site 1. Because the distance between sites 2 and 3 was half as great as the distance between sites 1 and 2 (fig. 8), measurements at site 3 were plotted as a function of the site-2 stage which was recorded 20 min earlier than the time of measurement at site 3. Plotting the rating curves in this manner virtually eliminated the effect of traveltime. The rating curves were then used to adjust all measurements on a particular date to a single representative river stage. Each measurement on July 6 was adjusted to

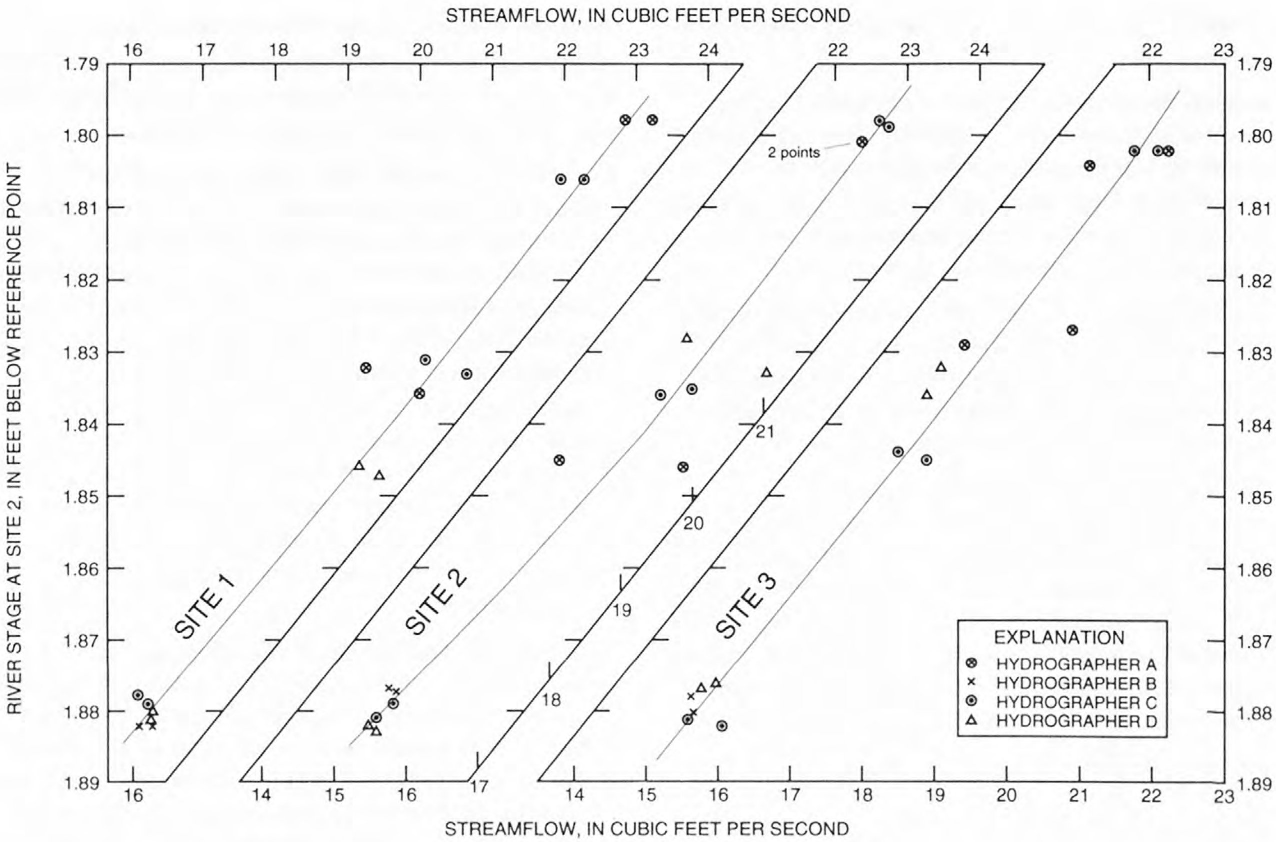


Figure 22. Rating curves of streamflow in the Rockaway River at three measurement sites in relation to stage at measurement site 2. (Site locations are shown in fig. 8.)

a stage of 1.80 ft, each measurement on July 7 to 1.84 ft, and each measurement on Aug. 23 to 1.88 ft, by means of the following ratios, which were determined from the slopes of the rating curves at those stages.

Stage at site 2 (ft below reference point)	Decline in streamflow, in cubic feet per second per 0.01 foot of decline in stage at site 2		
	Site 1	Site 2	Site 3
1.80	0.76	0.75	0.70
1.84	.83	.87	.80
1.88	.87	.95	.82

3. Finally, a correction was made for a constant flow of 0.04 ft^3/s from a pipe into the Rockaway River between sites 2 and 3.

The final adjusted flows and decreases in flow from site to site are shown in table 8. Decreases in flow averaged 0.26 ft^3/s in the upper reach and 0.41 ft^3/s in the lower reach. Most of the loss was calculated to be in the lower reach on July 6-7 and in the upper reach on August 23. Such a shift seems unlikely, though, inasmuch as the rates and distribution of pumping and the depths to water in observation wells were similar on both dates. One way to interpret these results is to ignore site 2 at first and limit analysis to losses over the entire reach studied, which were fairly consistent: 0.77 ft^3/s on July 6, 0.69 ft^3/s on July 7, and 0.58 ft^3/s on August 23, with a weighted average of 0.67 ft^3/s and a standard deviation (based on all 16 measurement pairs) of 0.46 ft^3/s. A maximum plausible loss of 1.13 ft^3/s from the entire reach can then be estimated in two ways—by adding the maximum loss in the lower reach (0.63 ft^3/s, July 7) to that in the upper reach (0.50 ft^3/s, August 23), or by adding the standard deviation (0.46 ft^3/s) to the average loss (0.67 ft^3/s) for the entire reach.

Many reports dealing with streamflow measurements offer estimates of the reliability of those measurements. An exhaustive literature review by Pelletier (1988) cites numerous studies that have shown how one or more factors affect accuracy or precision of current-meter measurements. Only three fairly comprehensive studies of the subject have been published, however. Two of these indicated that

Table 8. Seepage losses calculated from measurements of streamflow in the Rockaway River at Dover, N.J.

[Stage values are in feet below reference point at measurement site 2. Streamflows are in cubic feet per second. Site locations are shown in fig. 8.]

Date, stage, and hydrographer (from fig. 22)	Indices of measurement precision: Average number of verticals per site	Average number of non-zero velocity measurements per square foot of stream cross section	Adjusted streamflow: Site 1	Site 2	Site 3	Net change in streamflow: From site 1 to 2	From site 2 to 3	Average from site 1 to 3
July 6 1.80 feet								
C	32	1.15	22.72	22.69	22.20	-0.03	-0.49	
			22.39	22.45	21.86	+ .06	-.59	
A	27	1.0	23.08	22.46	22.35	-.62	-.11	
			22.68	22.40	21.35	-.28	-1.05	
					Average	-.22	-.55	-0.77
July 7 1.84 feet								
C	33	1.3	20.08	19.53	19.23	-0.55	-.30	
			19.30	19.18	18.76	-.12	-.42	
D	31	1.2	20.01	20.39	18.52	+.38	-1.87	
			19.69	18.88	18.41	- .81	-.47	
A	27	1.05	19.67	20.40	19.83	+.73	-.67	
			18.55	18.57	18.50	+.02	-.07	
					Average	-.06	-.63	-0.69
August 23 1.88 feet								
C	33	1.35	16.09	15.75	16.15	-.34	+.40	
			15.89	15.74	15.58	-.15	-.16	
D	31	1.3	16.31	15.90	15.59	-.41	-.31	
			16.25	15.69	15.45	-.56	-.24	
B	36	1.5	16.46	15.69	15.62	-.77	-.07	
			16.25	15.50	15.40	-.75	-.10	
					Average	-.50	-.08	-0.58
			Average for all 16 sets of measurements			-.26	-.41	-0.67

the uncertainty of single streamflow measurements can be as low as 4 percent at the 95-percent confidence level, given 30 or more vertical subdivisions of the section, water velocity of at least 0.8 ft^3/s, measurements at two depths in each vertical subdivision, and other favorable conditions in moderately large streams. Much larger errors are easily possible given lower velocities, fewer vertical subdivisions, turbulence, etc. Apparently no study has developed a means of predicting the uncertainty of single measurements over the wide range in channel shape and hydraulic properties of streams, particularly small streams. The International Organization for Standardization (1979) recommended that users determine independently the values of uncertainty that apply to their particular cases. The foregoing calculation of standard deviation and maximum plausible seepage loss, based on 16 rigorously adjusted measurement pairs, constitutes such a determination of uncertainty.

Water-Transmitting Properties of the Streambed

The several measurements of induced infiltration, described previously, were used to compute the water-transmitting properties of the bed of the Rockaway River. Results of each method are summarized in table 9. The accuracy and significance of each method is limited to some extent by imprecision in measurement or analysis, as explained earlier, and by the scope of data collection, as discussed below.

The dissolved-oxygen and temperature methods yield point data, namely the velocity at which infil-

Table 9. Water-transmitting properties of the bed of the Rockaway River at Dover, N.J., as computed by four methods

[A dash indicates value not required or not pertinent to that method. ft, foot; d, day; ft^3/s, cubic feet per second.]

			Terms of equation 2 ($K/m = [\Delta D / L\ W] / \Delta h$)				
			ΔD	LW	$\Delta D/LW$	Δh	K/m
Method	Pertinent dates	Approximate river flow (ft^3/s)	Decrease in river flow from induced infiltration (ft^3/s)	Length x width of losing reach (ft)	Downward specific flux or Darcian velocity (ft/d)	Average difference in head between river and piezometer(s) (ft)	Streambed leakance (vertical hydraulic conductivity per unit thickness) [(ft/d)/ft]
Paired streamflow measurements	July 6-7 and August 23, 1988	16-22	0.67 average (1.13 maximum plausible)	2,600 x 40	--	2.7	0.21 (0.35 maximum plausible)
Dissolved oxygen tracer	June 2-6, 1986	45	--*	--	at P2: 0.6 (1.6 maximum plausible)	2.15	0.28 (0.73 maximum plausible)
Temperature depth profile	June 2-6, 1986	45	--*	--	at P2, P3, P4: 1.5	2.20	0.68
Geochemical mass balance for δD and $\delta^{18}O$	July 1984 through May 1985	variable	1.47**	2,650 x 40	--	1.75	0.68

* Induced infiltration not determined as part of this method but can be back-calculated through equation 1 to be 0.74 ft^3/s, from dissolved oxygen method, or 1.8 ft^3/s, from temperature method.

** Derived by assuming that the water pumped from production wells contains the same percentage of water from the Rockaway River as that in well T5, as determined from mass-balance analysis.

trating river water flowed downward through the streambed at one to three points at which piezometers were located. Similar observations at more points distributed over the losing reach would be needed to characterize the areal variability of downward velocity and compute a representative average. Downward gradients and, thus, velocities are probably greater at the piezometer locations studied, which are close to the center of the cone of depression around production wells, than near the upstream and downstream ends of the losing reach. Furthermore, inconsistencies between theoretical and observed temperatures also suggest that velocities computed by the temperature method may be greater than actual velocities, as explained earlier.

The geochemical mass-balance method, based on isotopes of oxygen and hydrogen, indicates that an average of 30 percent of the water moving past well T5 toward production well 5 was derived from the Rockaway River. If the same percentage were assumed to apply to all water pumped from production wells 1, 3, and 5, then the average rate of induced infiltration would be 1.5 ft^3/s (0.3 times average annual pumpage of 4.9 ft^3/s). This extrapolation may overestimate seepage loss, however, because it is based only on water that approaches the production wells from the west and contains induced infiltration; in actuality, flow from the west presumably mixes at the production wells with some flow from the east that does not contain induced infiltration (fig. 10).

The streamflow-measurement method has the advantage of providing directly an integrated average value of induced infiltration for approximately the entire losing reach. Seepage losses were measured at Dover when river stage was close to its annual minimum; at higher stages, lateral seepage away from the river through the banks could increase more than downward seepage through the bed, in which case the water-transmitting capacity of the streambed would be somewhat larger than the value in table 9.

The vertical water-transmitting capacity of the Rockaway River bed is expressed in table 9 as the "streambed leakance," K/m, which is the hydraulic conductivity per unit thickness of streambed. It is computed as:

$$(2\ \frac{K}{m} = \frac{\Delta D/LW}{(\Delta h)}, \qquad (2)$$

where:

ΔD = decrease in river flow in losing reach, caused by induced infiltration [L^3/T],

L = length of losing reach [L],

W = average width of losing reach [L],

$\Delta D/LW$ = downward Darcian velocity or specific flux [L/T], and

Δh = head in the stream minus head in the aquifer below the streambed, averaged from measurements in piezometers [L].

Average width of stream reach was estimated to be 40 ft, from examination of large-scale topographic maps and field inspection. For the streamflow-measurement method, the value of Δh in table 9 is the average of maximum head differences recorded at piezometers P1 through P5 on two dates of streamflow measurement (table 10). The losing reach was taken as the distance between the upstream and downstream measurement sites (fig. 8). For the mass-balance method, the losing reach was taken as the distance between points 600 ft upstream from piezometer P1 and 600 ft downstream from piezometer P4, and Δh was obtained by calculating the average head differences at piezometers P1 through P4 over the period of study, summing these four values, then dividing by 5 to allow for a zero head difference at the ends of the reach. Any error in these estimates of average head difference would result in an equal percentage error in calculated streambed leakance; however, the relatively uniform differences in head along most of the losing reach on July 6-7, 1988 (table 10) and the modest changes from one date to another in head difference at individual piezometers (table 22) suggest that the estimates of average Δh for the streamflow-measurement and mass-balance methods in table 9 are likely to be approximately correct.

The data in table 9 and the foregoing discussion indicate that streambed leakance (K/m) for the bed of the Rockaway River at Dover is probably between 0.2 and 0.6 (ft/d)/ft. The most likely representative value is interpreted to be about 0.3 (ft/d)/ft, for periods of low or moderately low flow. If streambed thickness (m) is taken as the average depth to the midpoint of the screen in piezometers P1 through P5, namely about 3.3 ft, then average streambed hydraulic conductivity (K) is about 1 ft/d. Observations of an excavation in the streambed and of resistance to driving piezometers, described earlier, suggest that the upper 1 to 2.5 ft is siltier than underlying sediment, in which case hydraulic conductivity in the silty depth interval would be somewhat less than 1 ft/d.

In the ground-water model code by McDonald and Harbaugh (1988), which is applied to the Rockaway River valley at Dover in the next section of this report, flow between a stream and an aquifer is conceptualized as moving upward or downward through a leaky confining layer. In the notation of McDonald and Harbaugh (1988), the flow ($QRIV$) over a stream reach within model node i, j, k is described by:

$$QRIV = \frac{K}{m}LW(HRIV - h_{ijk}),\ h_{ijk} > RBOT\ \ [L^3/T], \qquad (3a)$$

$$QRIV = \frac{K}{m}LW(HRIV - RBOT),\ h_{ijk} \le RBOT, \qquad (3b)$$

where:

K/m = streambed leakance,

LW = streambed area (length $\times$ width),

$HRIV$ = stream-surface altitude,

$h_{i,j,k}$ = head or potentiometric-surface altitude in the aquifer, and

$RBOT$ = altitude of the bottom of the streambed confining layer.

If streambed leakance can be specified, model operation does not depend on the existence of a distinct confining layer nor on its hypothesized thickness, as long as aquifer head remains above the hypothesized bottom elevation of such a layer, in which case only equation 3a applies. Aquifer head at Dover, as measured in piezometers P1 through P4 (table 22) averaged about a foot below the bottom of the Rockaway River under the conditions of moderately

Table 10. Maximum head differences across the streambed of the Rockaway River at Dover, N.J., measured July 6-7, 1988

[Head difference (Δh) is stream stage minus water level in piezometer. Piezometer locations shown in fig. 8. P2 and P3 are upstream and downstream, respectively, from a small riffle that angles across the Rockaway River.]

Piezometer	Maximum Δh (feet)	Depth of piezometer screen below top of streambed (feet)
P1	4.0	3.0 - 3.5
P2	3.5	do
P3	2.5	do
P4	3.5	3.5 - 4.0
P5	0.2	3.0 - 3.5

low flow and the 1983-88 pumping regimen that were simulated for this report. If the model were used to estimate the effects of larger withdrawals, the hydraulic conductivity and thickness of the streambed would become critical; that is, if the uppermost 1 ft or less of alluvial sediment were notably less permeable than that below, withdrawals that exceeded 1983-88 rates would lower aquifer head below the bottom of that streambed layer, but induced infiltration would generally remain constant (as expressed by eq. 3b). Additional infiltration would occur only at the ends of the losing reach, as the cone of depression expanded upstream and downstream. If the sediment beneath the river were generally uniform in hydraulic properties to a depth of 3 ft or more, however, the same decline in head would cause significant increases in induced infiltration all along the losing reach (as expressed by eq. 3a).

MODELING GROUND-WATER FLOW IN THE ROCKAWAY RIVER VALLEY

Ground-water flow in the stratified-drift aquifer in the Rockaway River valley at Dover was modeled to determine whether the water-transmitting properties of the riverbed calculated from the induced-infiltration studies described previously are commensurate with other aspects of local hydrology, and to test a new method of simulating recharge and boundaries of stratified-drift aquifers.

Modeling Approach

At Dover, as in most localities in the glaciated northeastern United States, a ground-water flow model could not be used to determine streambed leakance with certainty because knowledge of other aspects of hydrology is insufficient to rigidly constrain the model. Consequently, the approach used in this study was to design a set of similar models that encompassed the range of streambed leakance values calculated from induced infiltration studies (table 9) and determine whether each model could replicate the measured spatial and temporal head distribution without simulating implausible values for other hydraulic properties of the system. Also, because the nature of the glacial deposits in some localities outside the Dover well field but within the model area was unknown, the effects of alternative hypotheses as to the presence of absence of continuous permeable stratified drift in these localities was tested by constructing additional models in which hydraulic conductivity in these localities was simulated differently. In all, six separate calibrated transient-state models with differing hydraulic properties were developed to represent the period September 23, 1983 to September 19, 1985.

The uplands east and west of the Dover well field were included in the models to allow investigation of alternative ways of simulating recharge from uplands to a stratified-drift aquifer. The modular ground-water flow model code of McDonald and Harbaugh (1988) was modified by adding a module that incorporates a new procedure, developed as part of the Northeast Glacial Aquifers RASA, for simulating recharge from precipitation on the aquifer and adjacent uplands. This new procedure is termed Variable Recharge, and the modified code was used to implement the six Dover models.

The discussion of the Dover models that follows includes a brief description of the Variable-Recharge procedure and a complete account of model design, assignment of hydraulic properties, and the calibration process. It also includes model results pertaining to seepage loss, and sensitivity analyses of several model properties. Results of a more general nature are given in a summary report on the Northeast Glacial Aquifers RASA (Kontis and others, U.S. Geological Survey, written commun., 1995).

Variable-Recharge Procedure

The Variable-Recharge procedure is designed primarily for simulation of a valley-fill aquifer bounded by uplands that are an active part of the model. In the ground-water flow-model code of McDonald and Harbaugh (1988), an areal distribution of recharge is specified and applied to active model nodes, irrespective of the head distribution in the model. The basic premise of the Variable-Recharge procedure is that (a) recharge can occur only when the hydraulic head in shallow earth materials is below land surface and (b) when the hydraulic head is at or above land surface, recharge cannot occur, any ensuing precipitation will be rejected, and outward seepage may occur as well. In the Variable-Recharge procedure, the areal distribution of water available for recharge is specified, but the water available is accepted as recharge only in nodes where simulated head in the top model layer is below land surface. Thus, the procedure is conceptually similar to the variable-source-area overland-flow concept (Dunne and Black, 1970), which postulates that overland flow occurs when soils are saturated by a rising water table. It is also conceptually similar to the ground-water flow-model code of Potter and Gburek (1987), wherein outward seepage is calculated when the water table reaches land surface. When the Variable-Recharge procedure simulates rejected recharge and(or) outward seepage on upland hillsides, it treats these quantities as surface runoff that can recharge a valley-fill aquifer either as channeled runoff in streams that can lose water as they cross the valley fill, or as unchanneled runoff that moves downslope as sheet flow, small rills, or shallow subsurface flow and infiltrates the valley fill at the base of the hillside. Morrissey and others (1988) show that channeled and unchanneled runoff from upland hillsides can be a significant component of recharge to valley-fill aquifers.

The Variable-Recharge procedure uses the following information:

1. Average land-surface elevation for each active model node of the top model layer.

2. Division of the entire modeled area into (1) a set of upland topographic subbasins for which surface runoff is calculated and redistributed to other parts of the model, and (2) a set of topographically low areas in which surface runoff is not redistributed. The topographically low areas typically include the main valley-fill aquifer being evaluated. They may also include some upland valleys where surface runoff enters streams whose flow does not cross the aquifer being evaluated or is not treated quantitatively in the model. Each upland subbasin is assigned a unique nonzero zone number, and all topographically low areas are collectively designated zone zero; these numbered zones constitute the Variable-Recharge zone array.

3. For each upland subbasin, an estimate of the percentage of upland runoff (rejected upland recharge plus outward seepage) that reaches the valley floor as channeled flow.

4. Where upland runoff reaches the valley floor as channeled flow, specification of the model node location, streambed conductance, stream stage, and elevation of the top and bottom of the streambed for each node along the valley floor that contains a stream reach.

5. Where upland runoff reaches the valley floor as unchanneled runoff, specification of the model location of nodes along the valley wall that receive the unchanneled runoff.

6. Estimates of the quantity of water available for recharge (*WAFR*) for each time period simulated, which may be computed from the following relation (modified from Lyford and Cohen, 1988)

$$WAFR = P - ET + SN_m - SN_s \pm SM \qquad [\mathrm{L}], \quad (4)$$

where: P = precipitation,
ET = evapotranspiration of moisture above the saturated zone,
SN_m = snowmelt,
SN_s = snow stored on the land surface, and
SM = change in soil moisture in the unsaturated zone.

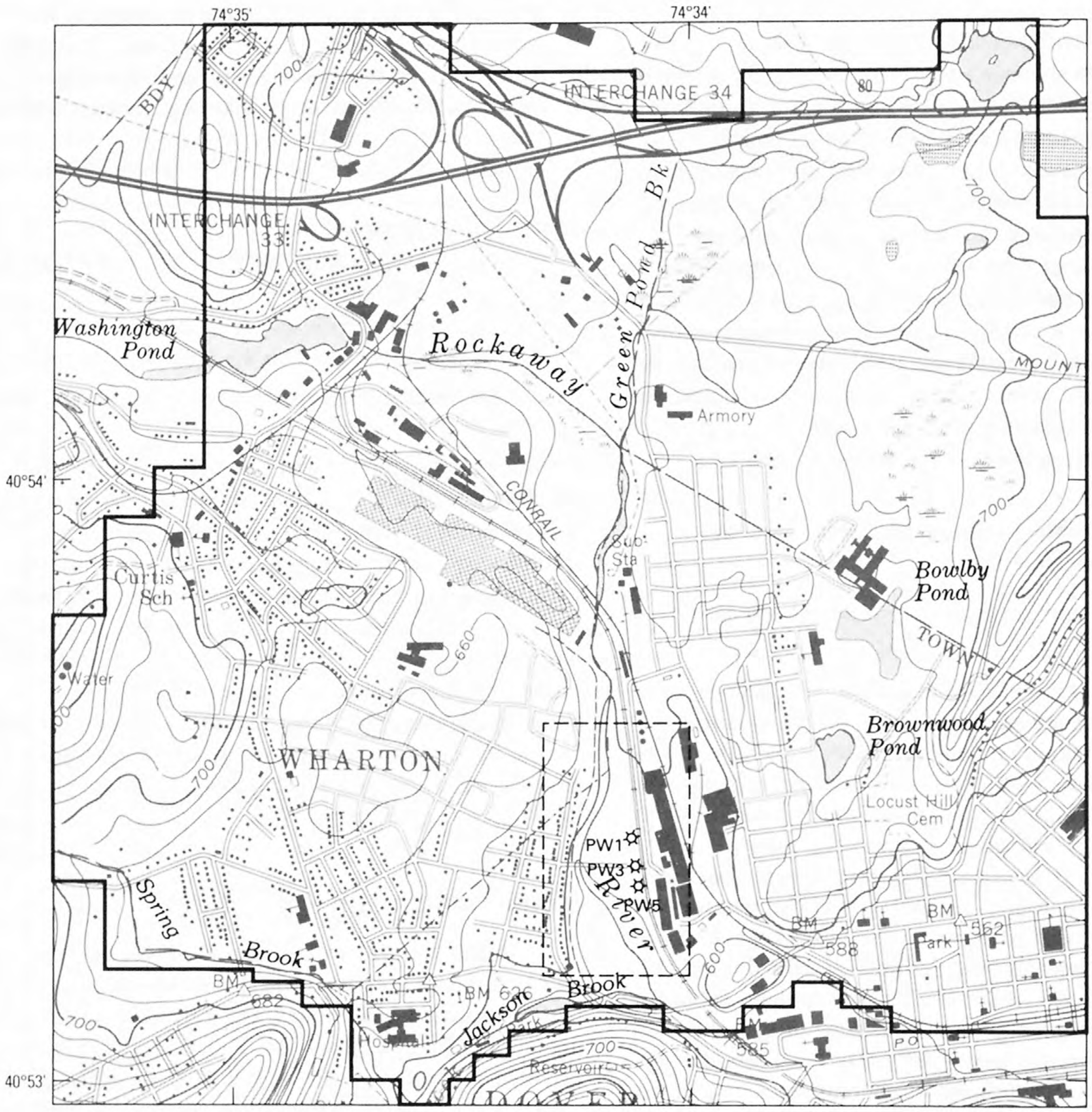
If evapotranspiration of soil moisture exceeds precipitation, water available for recharge is zero, and soil moisture is depleted. If precipitation exceeds evapotranspiration, soil moisture increases, but this addition cannot become water available for recharge until any soil moisture deficit accumulated over time has been replenished. The formulation and implementation of finite-difference equations that partition water available for recharge into recharge and surface runoff are explained in a report on another locality that was modeled with the Variable-Recharge procedure (Breen and others, 1995).

Model Design and Procedures

The unequally spaced model grid, which contains 34 rows and 41 columns, and the locations of river nodes, specified-head nodes, and zero-flow nodes are depicted in figures 23 and 24. The model grid is oriented generally parallel to the Rockaway River valley in the vicinity of the Dover well field. Model cell dimensions range from 500 to 75 ft. The river nodes correspond to reaches of the Rockaway River, Green Pond Brook, Spring Brook, and Jackson Brook (fig. 23). The specified-head nodes represent upland ponds east of the Rockaway River.

Geologic Discretization

Each model consists of two layers. Along the Rockaway River valley, the surficial coarse sand and gravel deposited as Rockaway River outwash and alluvium (fig. 6) is represented by layer 1; elsewhere, layer 1 represents other surficial geologic units—till, bedrock, and proglacial deltaic deposits (fig. 25). This top layer is treated as unconfined, and its thickness is taken to be 30 ft in outwash, 40 ft in the



Base from U.S. Geological Survey
Dover, N.J. quadrangle, 1981, 1:24,000

0 1000 2000 FEET
0 500 METERS

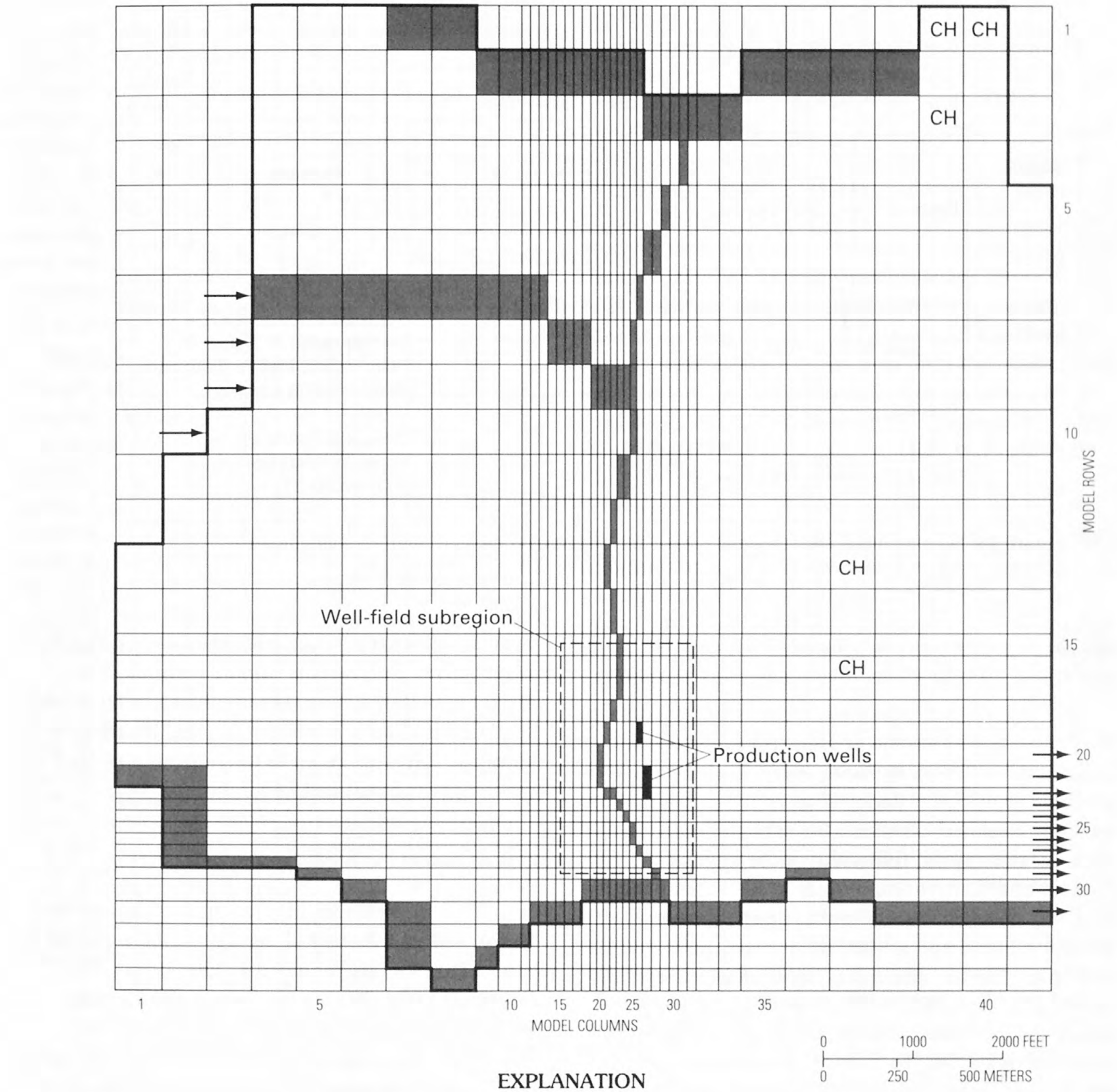
EXPLANATION

—— Boundary of active model

– – – – – Boundary of Dover well-field subregion

PW5 ✡ Dover municipal production well

Figure 23. Extent of modeled area. (General location is shown in fig. 2.)



EXPLANATION

CH Specified head nodes (layer 1)

River nodes (layer 1)

Boundary of active model (layers 1 and 2)

Boundary flux into or out of indicated nodes (layers 1 and 2)

Figure 24. Dover model grid and locations of constant-head and river nodes.

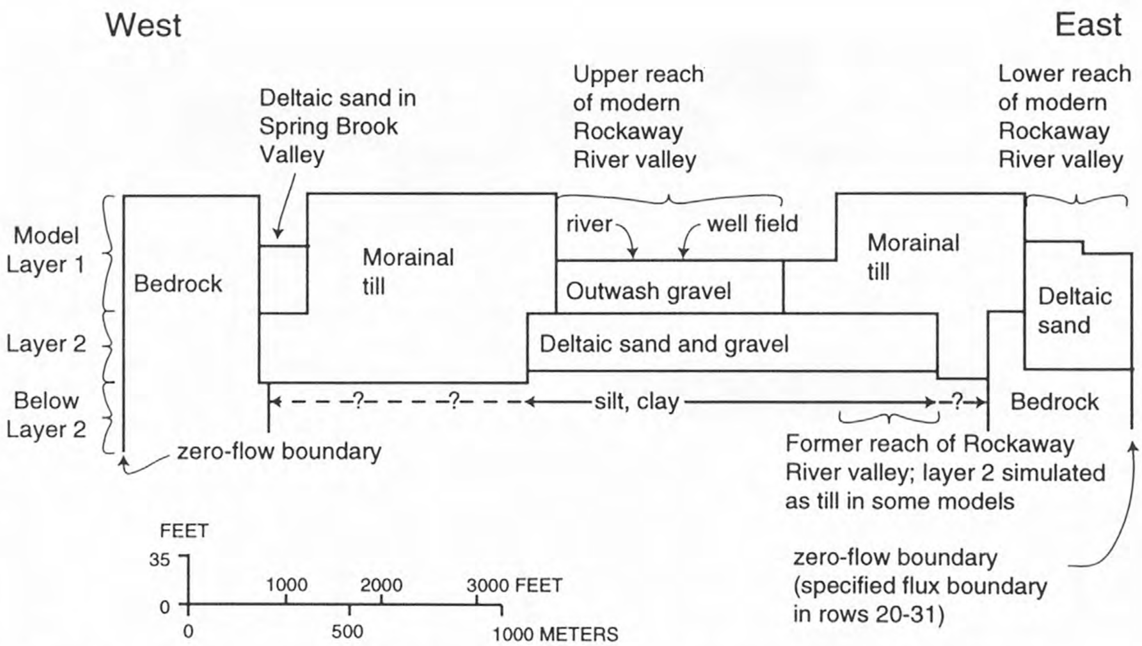


Figure 25. Diagrammatic section along model row 19 showing geologic materials simulated in layers 1 and 2 and below layer 2. (Location of model row 19 is shown in fig. 24.)

deltaic deposits, 35 ft in till-mantled areas of low relief, and 70 ft in till-mantled areas of high relief.

Layer 2, which is treated as confined, represents the fine to coarse deltaic or lacustrine-fan sand and gravel that underlies surficial outwash along much of the Rockaway River valley (fig. 7) and is inferred to underlie morainal till where the surficial outwash does not occupy the full width of the valley. The number and distribution of deep wells in the modeled area (fig. 5) are not sufficient to define the extent of the layer 2 sand and gravel everywhere, however. For example, whether this unit is continuous beneath the morainal till that blocks the former Rockaway River valley reach southeast of the Dover well field (figs. 5 and 6) is unknown. To evaluate the effect of this uncertainty on the ground-water flow system, two alternative model designs were developed. In some models, the lower sand and gravel unit is assumed to be continuous eastward from the well field, beneath the till. In other models, this unit is assumed to have been eroded or never deposited east of the well field, in which case till directly overlies fine-grained lake deposits and the aquifer is discontinuous. (The section in fig. 25 depicts the former valley reach at the eastern side of the upper Rockaway valley, where model row 19 intersects it; further south, in model rows 24 through 30, the former reach is separated by bedrock from the upper reach of the modern valley but merges with the lower reach.) Outside the Rockaway River valley, layer 2 represents till and bedrock. For purposes of developing transmissivity of layer 2 from specified hydraulic conductivity, the thickness of stratified drift was taken to range from 2 to 30 ft and the thickness of till and bedrock to be 35 ft.

Model Boundaries

The east-west trending reaches of Green Pond Brook and its tributary along the northern part of the model (fig. 23) are modeled as lateral zero-flow boundaries (fig. 24), as are Spring and Jackson Brooks and the east-west trending reach of the Rockaway River along the southern part of the model. These stream reaches constitute natural lows in the water table and are generally bordered by till and bedrock outside the model boundaries; accordingly, ground-water flow across these boundaries is probably quite small or nil. Most of the western edge of the model coincides with upland surface-drainage divides, so is also treated as a zero-flow boundary; a specified nonzero-flow boundary in the vicinity of Washington Pond represents eastward underflow within the Rockaway River valley. The northern two-thirds of the eastern edge of the model also generally coincides with an upland surface-drainage divide and is treated as a zero-flow boundary.

The lower reach of the modern Rockaway River valley, in the southeastern corner of the modeled area, is separated from the Dover well field by a surface-drainage divide but is included as an active part of the model because the sand and gravel of layer 2 might be continuous beneath the divide, along the former valley reach. Nodes along the southeastern model boundary that represent stratified drift are assigned eastward-directed specified nonzero flows. These flows were computed by Darcy's law from assumed representative values of hydraulic conductivity and head gradient and are given in table 11.

The base of layer 2 was treated as a zero-flow boundary. Layer 2 generally overlies fine-grained lacustrine sediment beneath the modern Rockaway River valley and some adjacent areas; beneath the bordering hills the base of this layer lies within the bedrock (fig. 25). A sensitivity analysis (A.L. Kontis and others, USGS, written commun., 1995) showed that the assumption of a zero-flow boundary beneath layer 2 is reasonable, given probable values of hydraulic conductivity and vertical leakance of underlying materials.

Table 11. Boundary fluxes specified for models of ground-water flow in the Rockaway River valley at Dover, N.J.

[Fluxes are in cubic feet per second. Positive flux values represent flow into model, minus (-) sign denotes flow out of model. Locations of nodes where fluxes are applied are shown in fig. 24. Fluxes are the same in all stress periods and in all six models except as footnoted.]

Location in model		Boundary flux	
Row	Column	Layer 1	Layer 2
7	4	0.40	0.40*
8	4	0.02	0.40*
9	4	0.02	0.40*
10	3	0.02	0.02
20	41	-0.05	-0.05
21	41	-0.05	-0.05
22	41	-0.04	-0.04
23	41	-0.04	-0.04
24	41	-0.04	-0.04
25	41	-0.04	-0.04
26	41	-0.04	-0.04
27	41	-0.04	-0.04
28	41	-0.04	-0.04
29	41	-0.04	-0.04
30	41	-0.04	-0.04
31	41	-0.075	-0.04

* 0.02 in models 5 and 6

Time Discretization

Each of the six Dover models was designed to simulate the period from September 23, 1983 through September 19, 1985, during which several sets of water-level measurements had been obtained. Initial conditions for this 2-year transient-state simulation were obtained from a typical-year transient-state simulation that terminated at the end of summer and incorporated estimates of long-term average pumping rates, recharge rates, and stream-surface altitudes for each season. Long-term average end-of-summer conditions were successfully simulated by repeated cycling through the four seasons until the heads at the end of summer were essentially the same for two successive cycles, thereby achieving an approximate state of equilibrium. Stresses applied were the same for all models and are given in table 12.

Water levels in 16 observation wells, all in the vicinity of the Dover well field (fig. 8) were measured at intervals ranging from several weeks to several months from May 1984 through November 1985 (table 22). Sets of water levels measured on six dates (May 18, July 7, and September 20, 1984; January 24, May 28, and September 19, 1985) were selected for calibration of the 2-year transient-state simulations. Each of the time intervals between successive selected dates of water-level measurement was divided into a relatively long stress period followed by one or two relatively short stress periods, resulting in a total of 14 stress periods (table 12) for the 2-year period. Discretizing the interval between calibration times into long and short stress periods can be useful if stresses occurring shortly before and during the time when measurements were made differ significantly from the average stresses that prevailed during the long stress period. Stresses that could be varied from one period to the next include (1) rates of withdrawal from the three Dover production wells (PW1, PW3, and PW5, fig. 8), (2) amounts of water available for recharge, and (3) altitudes of stream surfaces.

Corrections for Effects of Pumping Cycles on Water Levels

A typical procedure for simulating intermittent withdrawals from wells is to calculate an average withdrawal rate for each stress period by dividing the total volume of water pumped by the length of the stress period. Withdrawal rates for each of the long stress periods in the 2-year transient simulation (table 12) were calculated in this manner. Water-level

Table 12. Stress periods and hydraulic stresses applied to models of Rockaway River valley at Dover, N.J.

[ft, feet; ft/s, feet per second; ft^3/s, cubic feet per second. For models 1-5, specific yield in layer 1 is 0.05 for till and 0.2 for stratified drift. For model 6, specific yield is 0.05 for till and 0.1 for stratified drift. Shading denotes short stress periods used in model calibration. Well locations shown in fig. 8.]

Stress Period					Water available for recharge		Pumping rate at wells (ft^3/s)		
No.	No. time steps	End date	Duration (days)	River stage* (ft)	Rate (10^{-7} ft^3/s)	Amount (inches)	PW1	PW3	PW5
A. Long-term average annual cycle									
1	1	Dec 30 (fall)	92	+0.3	1.06	10.11	2.63	0.74	1.41
2	1	Mar 31 (winter)	90	+0.5	1.16	10.82	2.57	0.83	1.48
3	1	Jun 30 (spring)	91	+0.5	0.45	4.25	2.56	0.85	1.62
4	1	Sep 30 (summer)	92	+0.1	0	0	2.48	0.83	1.63
B .Two-year simulation (September 23, 1983 through September 19, 1985)									
1	5		237	+0.7	1.34	32.92	2.57	0.74	1.46
2	1	May 18, 1984	1	+0.7	1.34	0.14	2.72	0.37	1.90
3	2		48	+0.7	1.23	6.12	2.65	0.82	1.72
4	2	July 7, 1984	2	+2.4	24.10	5.00	2.72	0.37	1.90
5	3		74	+0.4	0.40	3.06	2.48	0.83	1.61
6	1	Sept 20, 1984	1	0	0.40	0.04	2.72	0.37	1.90
7	5		107	0	0.45	4.99	2.89	0.42	1.41
8	2		18	-0.1	0	0	2.89	0.42	1.41
9	1	Jan 24, 1985	1	-0.1	0	0	2.72	0.37	1.90
10	5		123	+0.2	0.33	4.21	3.33	0.16	1.43
11	1	May 28, 1985	1	+0.2	0.33	0.03	2.72	0.37	1.90
12	5		95	0	0.46	4.52	3.31	0	1.41
13	2		18	-0.1	0	0	3.31	0	1.41
14	1	Sept 19, 1985	1	-0.1	0	0	2.72	0.37	1.90

measurements in observation wells at Dover often do not correlate well with average withdrawal rates over a period of weeks, however, because the production wells were turned on and off frequently, and water levels in observation wells responded to each start or cessation of pumping with substantial short-term fluctuations. These fluctuations are most prominent in wells close to PW5 (fig. 26) and correspond primarily to changes in pumping status of PW5. (PW1 was usually on when water levels were measured; PW3 was pumped only infrequently and at a smaller rate than PW5). In early June, 1986, the water level in S1, about 200 ft from PW5, fluctuated more than 1.5 ft, and the water level in piezometer P4 fluctuated nearly 1.5 ft, primarily in response to the pumping status of PW5 (fig. 27). Water levels in the other observation wells also responded to the status of the production wells, in amounts proportional to their distance from the production wells. Therefore, water-level measurements in different wells on the same date, or in the same well on successive dates, commonly represent different times since a recent change in pumping status at the nearest production well.

The aquifer models could be calibrated accurately to measured water levels if actual rates and durations of pumping in each production well were simulated for at least several hours before and during the time when each set of water-level measurements was made. This approach would require a separate stress period for each change in pumping-well status,

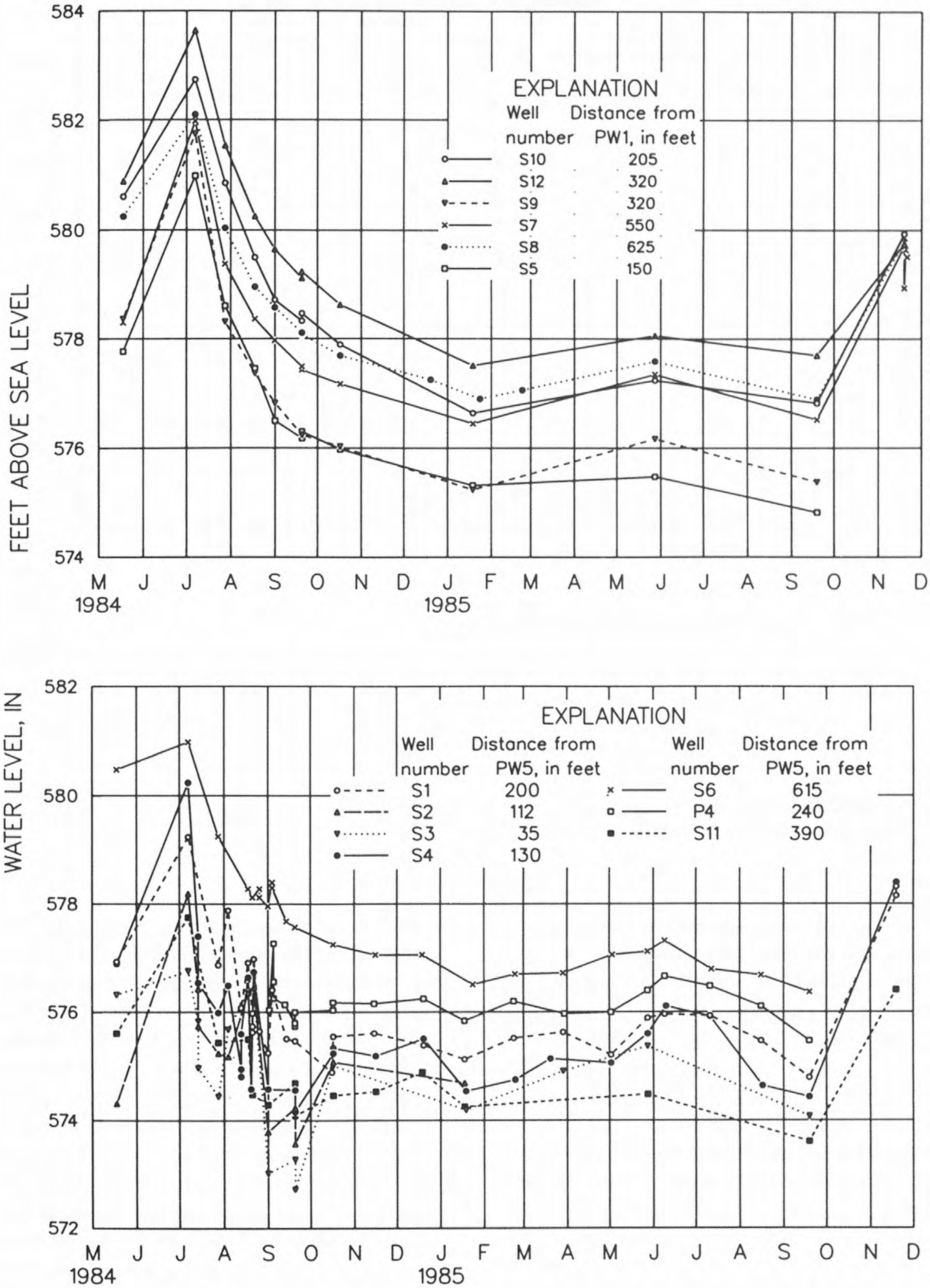


Figure 26. Water levels observed in selected wells at Dover, N.J. well field, 1984-85. (Locations are shown in fig. 8.)

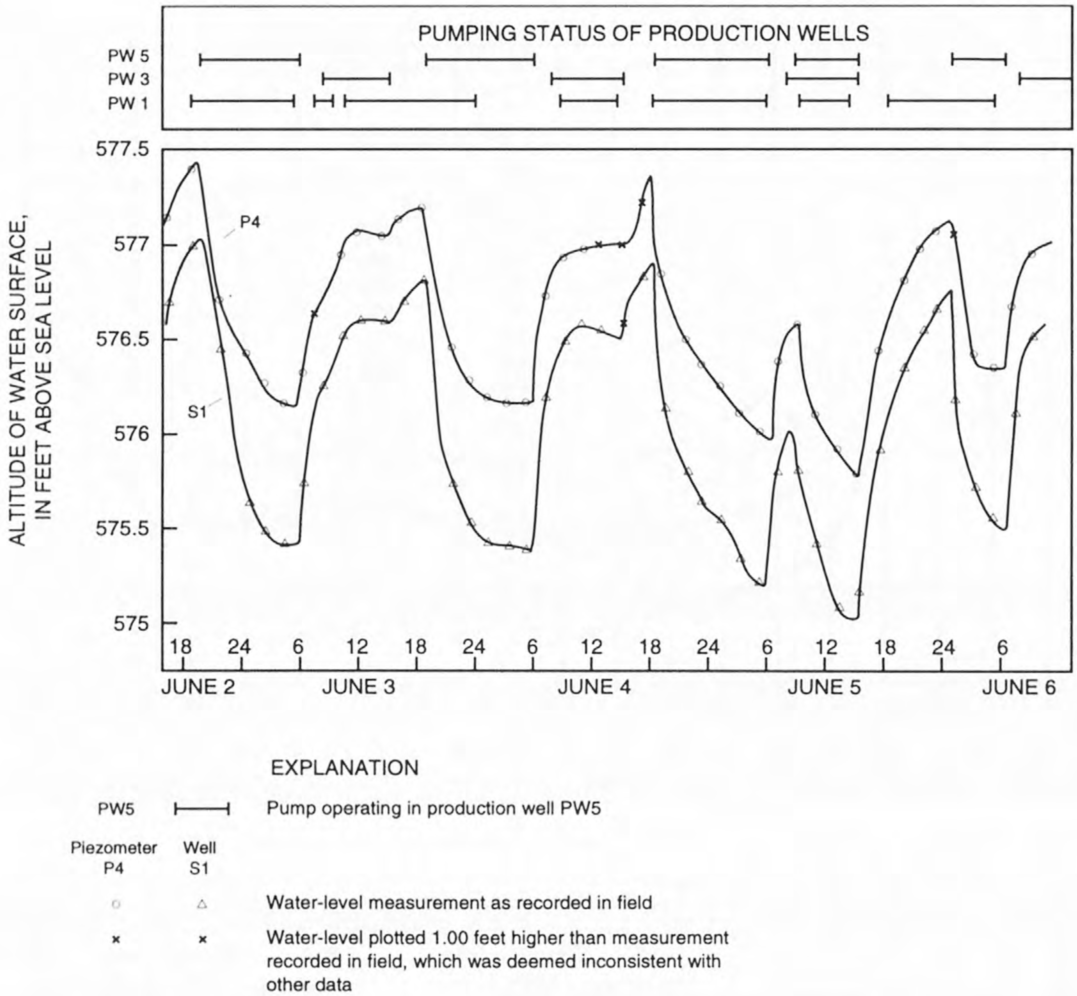
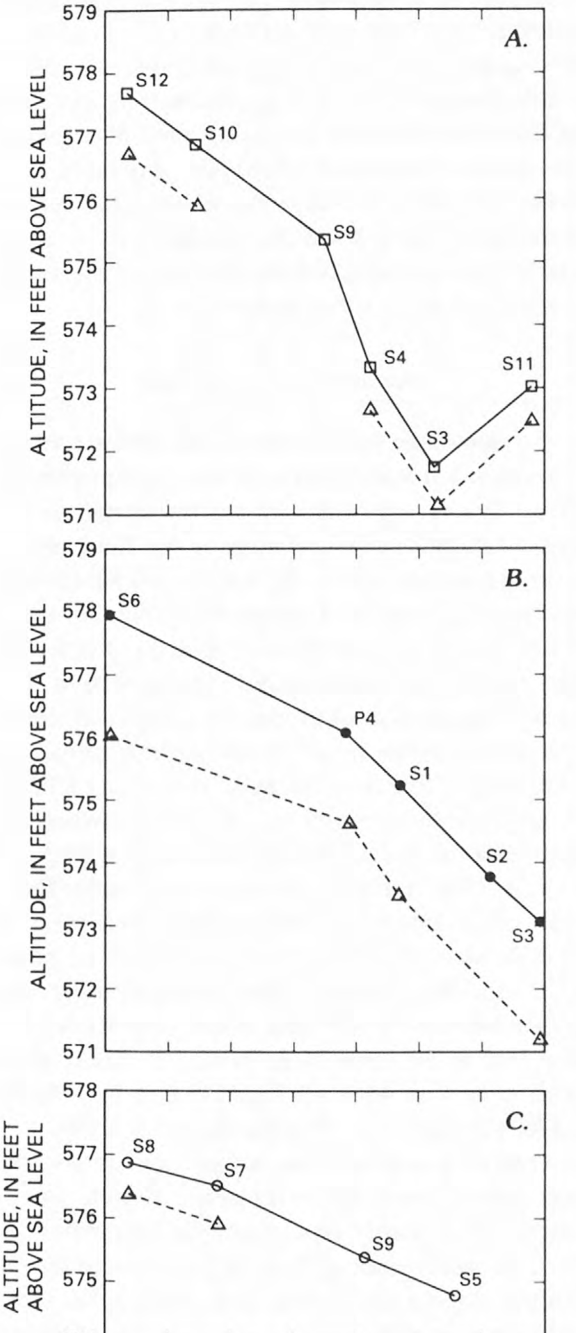


Figure 27. Water levels in well S1 and piezometer P4 in relation to pumping status of Dover production wells, June 2-6, 1986. (Locations are shown in fig. 8.)

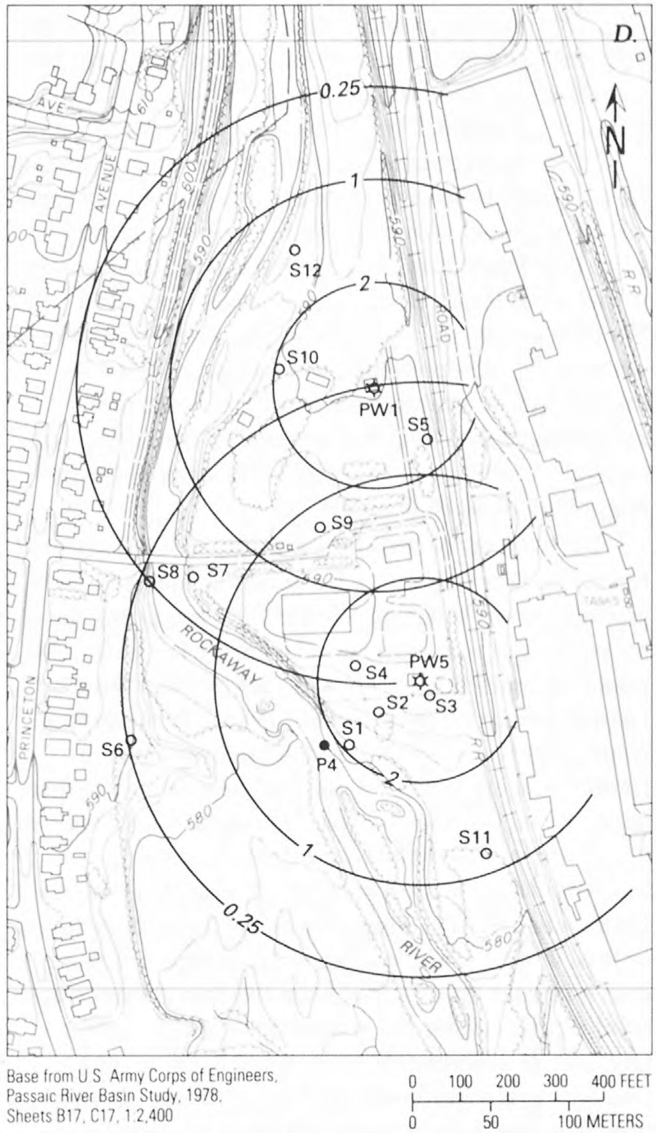
however, and the resulting simulation would be quite complex because the three production wells at Dover were commonly turned on and off at least once a day.

An alternative approach, which was used in this study, requires information on the short-term response of each observation well to the initiation or cessation of pumping of nearby production wells. Observed water levels can then be adjusted with reasonable accuracy to represent water levels corresponding to some standard pumping condition. The standard pumping condition chosen for the Dover models was that the production wells had been pumped for a sufficiently long period before the time of measurement that water levels had essentially reached equilibrium.

Two relations were developed to guide the adjustment of water levels. The first is a set of three water-level profiles through the well field (fig. 28A-C) that define the approximate shape of the water table under standard-pumping conditions. These profiles were plotted from water levels measured on Sept. 1 and 20, 1984 and Sept. 19, 1985, when nearby production wells were in a standard or near standard-pumping condition. Although the water table may rise and fall throughout the well field in response to long-term hydrologic stresses, the differences between water levels in adjacent observation wells for standard pumping conditions should remain essentially constant. The shape of the profiles was somewhat validated by measurements made on July 6-7, 1988, when PW1 and PW5 were both pumped, although PW3 was idle. The July 1988 profiles are nearly parallel to the profiles developed from the earlier data (fig. 28).



A, B, C. Profiles drawn through selected observation wells, based on water-level measurements after production wells PW1 and PW5 had been pumped for several hours. (Well locations shown in *D*.)



D. Contours of equilibrium drawdown or recovery (Map area approximately coincides with well-field subregion, fig. 23.)

EXPLANATION

o——o September 1, 1984

□——□ September 20, 1984

■——■ September 19, 1985

△- - -△ July 6–7, 1988

EXPLANATION

—2— Approximate equilibrium drawdown (or recovery) of water level, in feet, in response to initiation (or cessation) of pumping at production wells PW1 and PW5

S8 o Observation well

PW5 ✡ Production well

P4 ● Streambed piezometer

Figure 28. Water-table slope near production wells at Dover, N.J.

The second relation is a set of response contours (fig. 28D) that show the estimated difference between equilibrium water levels for nonpumping conditions and those for standard-pumping conditions as a function of distance from production wells PW1 and PW5. These response contours provide an upper limit on the magnitude of adjustment of a particular observation-well measurement. The response contours were developed primarily from time-series measurements of water levels in several wells near PW5. Because production well PW1 was usually on when water-level measurements were made, data were insufficient to establish the response to startup or shutdown of that well. Consequently, the relation of response to distance from PW5 was assumed to be applicable to wells near PW1.

For each set of water-level measurements selected for calibration (table 12), the pumping status of the production wells during the 24 hours preceding the measurement was determined from Dover well field pump-operation charts (A. Du-Jack, Dover Water Department, written commun., 1986). The pumping status, together with the 1984-85 hydrographs in figure 26, were used as a guide to determine whether adjustments were warranted. Measured water levels in any given well were adjusted if, at the time of measurement, the nearest production well had been off for about an hour or longer, or on for about three hours or less, and the observed water level departed more than a few tenths of a foot from the equilibrium water-level profiles under the standard pumping condition (fig. 28). If adjustments were applied, the response contours and equilibrium profiles of figure 28 were used as criteria for determining their magnitude. Application of adjustments to some of the data points in figure 26 resulted in hydrographs that approximately represent the standard-pumping condition (fig. 29). Model calibration to these adjusted water levels allows simulation of a single uniform pumping rate at each production well throughout each short stress period and thereby simplifies the simulation and calibration process. Because the effects of short-term changes in pumping have been largely eliminated, the remaining fluctuation is a function of change in river stage, recharge, and average pumping rate.

Model Input

Information on the hydrogeology of valley-fill aquifer systems is almost never complete, so the modeler must estimate some hydrogeologic properties of the area to be modeled. The following sections describe the procedures and assumptions used to develop the spatial and temporal magnitude and distribution of hydrogeologic characteristics used in the Dover simulations, including streambed properties, stream-surface elevation, pumping rates, land-surface elevation, recharge rates, storage properties, lateral and vertical hydraulic conductivity of aquifer material and till, and factors that control the amount of water available for recharge.

Stream-Surface Altitude

Stream-stage data for the model nodes containing a stream reach were derived from: (1) topographic maps, (2) a survey of stream-surface altitude, (3) periodic measurements of stage in the Rockaway River at four sites (RP1, RP2, RP3 and RP4, fig. 8 and table 22), and (4) a rating curve (fig. 30) that relates stream-surface altitudes measured at RP3 to daily flow at the Boonton, N.J. gaging station. To expedite generation of model input for each stress period, a reference set of stream-surface altitudes was developed as follows. The node containing RP3 was assigned a reference altitude of 578.5 ft, which is the altitude of the stream surface measured at RP3 on May 28, 1985 (table 22). Reference altitudes for nodes containing RP1, RP2, and RP4 were then calculated as the sum of the reference altitude for the node at RP3 and the average difference between stream-surface altitudes at RP3 and at the other RP as measured on the same dates (table 22). These average differences were +5.5, +2.7, and -5.0 ft, for RP1, RP2, and RP4 respectively. For the few river nodes between RP1 and RP4 that did not contain a stream-stage measurement site, a reference altitude was assigned by linear interpolation. On November 9-10, 1987, stream-surface altitude was measured by spirit-leveling along a reach extending about 2,000 ft upstream from RP1 (fig. 8), and a profile of stream-surface altitude with respect to distance and model-node location was drawn (fig. 31). The profile indicates that the Rockaway River surface in this reach declines in a steplike manner, as alternating pools and riffles. Thus, if the river surface were assumed to slope linearly between widely spaced measurement points, interpolations might be in error. For example, if river stage had been measured only at the middle of model rows 13 and 18, and assumed to slope linearly between these points, the interpolated altitudes in model rows 16 and 17 would be in error

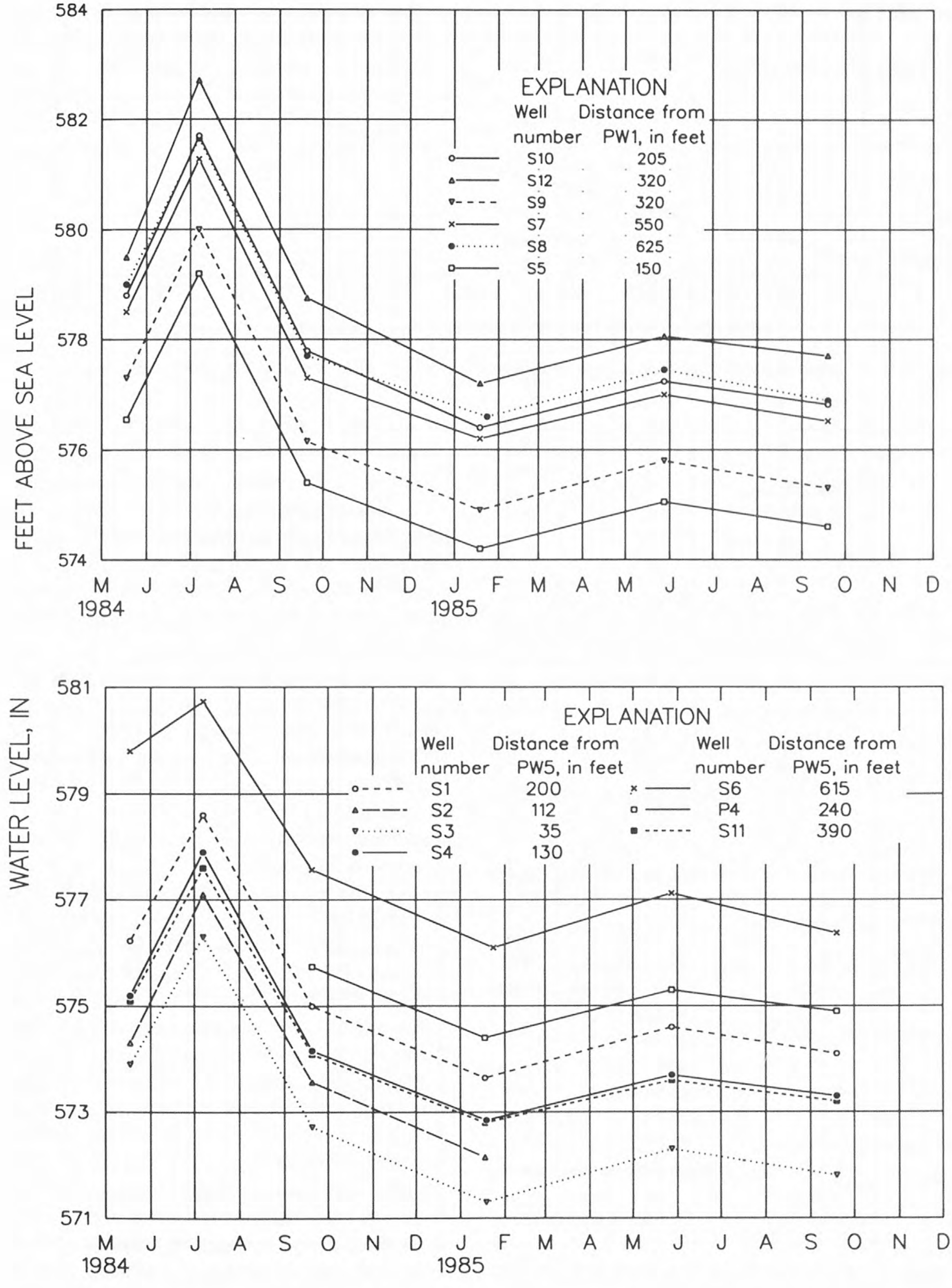


Figure 29. Water levels observed in selected wells after adjustment to standard pumping conditions, on dates in 1984-85 selected for model calibration. (Well locations are shown in fig. 8.)

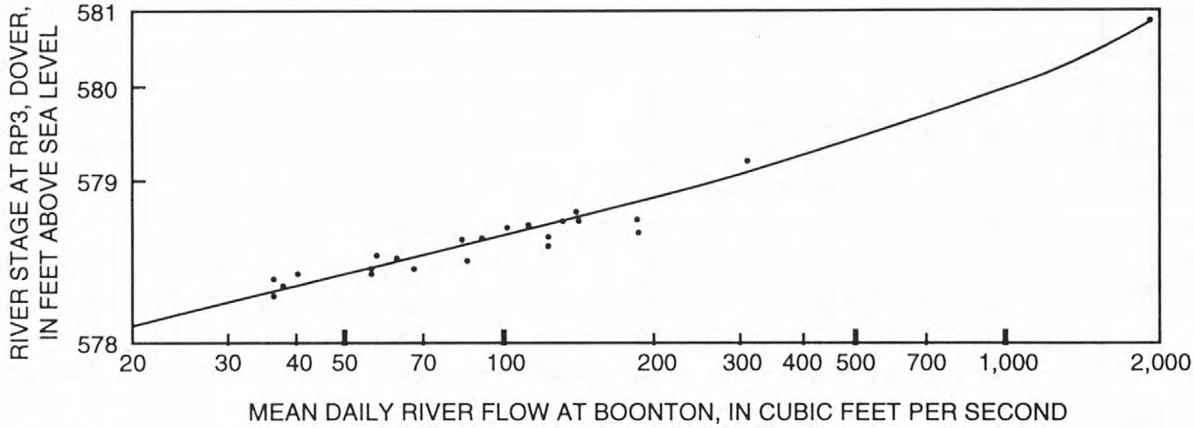


Figure 30. Relation of mean daily flow of Rockaway River at Boonton, N.J., to river stage at RP3 at Dover.

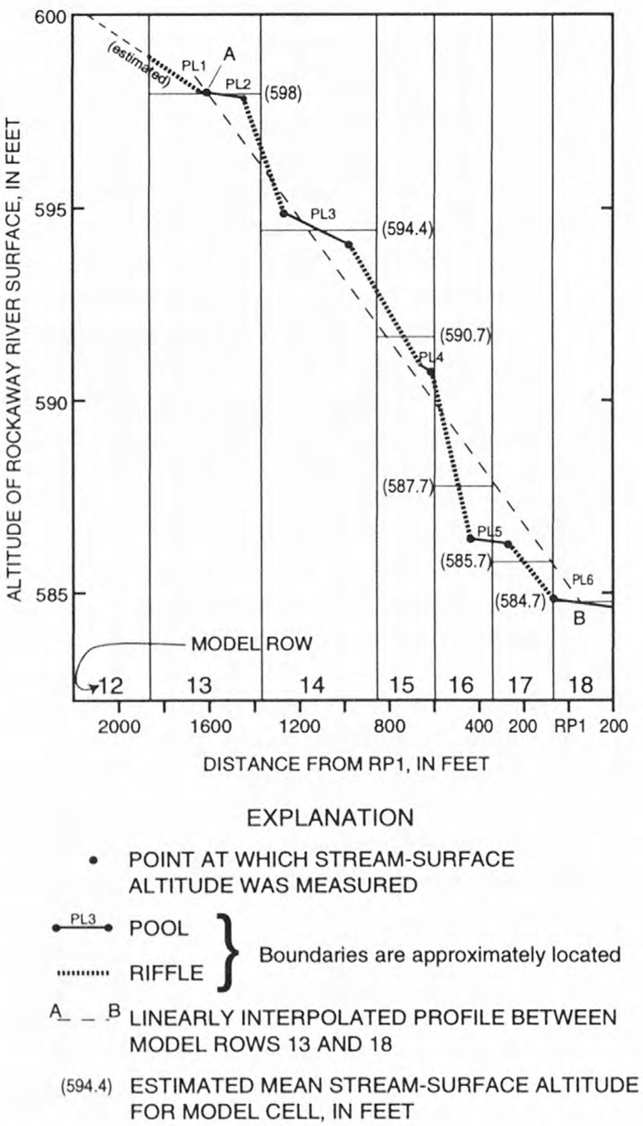
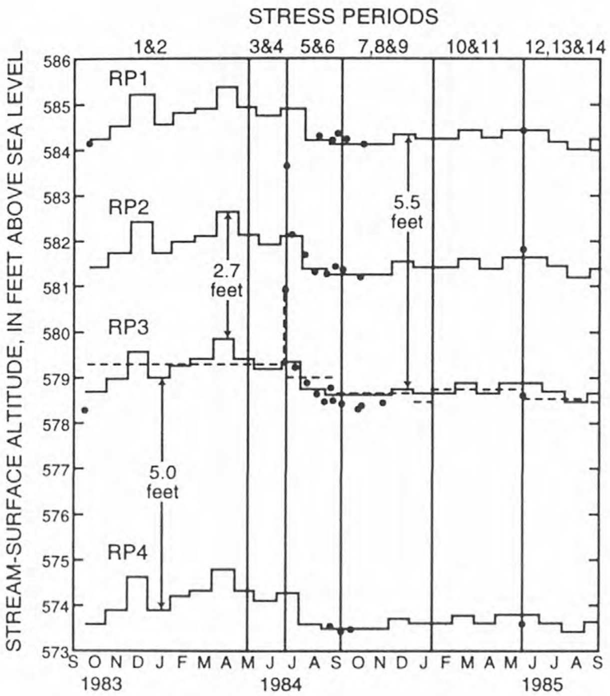


Figure 31. Profile of Rockaway River surface upstream from RP1 at Dover, N.J., measured November 9-10, 1987. (Location of RP1 shown in fig. 8, model cells in fig. 24.)

by more than 1 ft. The data of figure 31 were used to develop the reference altitudes over the extent of the measured profile. For the remainder of the model area, reference altitudes for the Rockaway River and its tributaries were estimated from a flood-plain topographic map with a 2-ft contour interval (U.S. Army Corps of Engineers, 1978) and from the 1981 edition of the USGS Dover Quadrangle topographic map with a 20-ft contour interval.

Mean river-surface altitude at RP3 was generated for each month from September 1983 through September 1985 (fig. 32) by entering the rating curve (fig. 30) with mean streamflow at Boonton for the same month (fig. 4). Mean river-surface altitude at RP3 for each stress period was then estimated either from actual measurements during that period (table 22) or from the monthly mean altitudes (fig. 32). The difference between the reference altitude and mean river-surface altitude at RP3 for each stress period was applied to reference altitudes for all other stream nodes to obtain the array of river-surface altitudes required as model input for that stress period. Thus, stage was assumed to rise and fall the same amount at all points along the Rockaway River. The estimated river-surface altitude at RP3 for each stress period in the 2-year transient simulation is also shown in figure 32. River stage during most short stress periods did not differ appreciably from the average stage estimated for the preceding long stress period. Therefore, no change in river stage was specified for short stress periods except for short stress period 4, which encompassed a high-flow event, and short stress period 6, which followed a long summer period during which river stage declined substantially.

The average seasonal river stages at RP3 for the long-term average four-season simulation were obtained by entering the rating curve (fig. 30) with seasonal average flows at Boonton that had been computed from the 1938-85 monthly values in figure 4. River-surface altitudes required as model input were then obtained from the reference altitudes in the same manner as for the 2-year transient-state simulation.



EXPLANATION

• MEASURED STREAM-SURFACE ALTITUDE

ESTIMATED MEAN MONTHLY STREAM-SURFACE ALTITUDES. Altitudes at RP3 from Fig. 37. Altitudes at other sites are a constant height above or below those at RP3, as indicated by vertical arrows.

--- ESTIMATED STREAM-SURFACE ALTITUDE AT RP3 USED IN 2 YEAR TRANSIENT-STATE SIMULATION OF 14 STRESS PERIODS

Figure 32. Altitude of Rockaway River surface at four measurement sites, September 1983 through September 1985. (Site locations are shown in fig. 8; stress-period dates in table 12.)

Streambed Properties

In the River Package of the ground-water flow-model code by McDonald and Harbaugh (1988) streambed conductance must be specified for each node containing a river or stream. Streambed conductance, *CRIV*, is defined as follows:

$$CRIV = (K/m)LW \qquad [L^2/T], \qquad (5)$$

where: K = vertical hydraulic conductivity of streambed [L/T],
m = thickness of streambed [L], and
LW = area (length × width) of streambed [L^2].

The area of the streambed can readily be determined, but the streambed leakance (*K/m*) is less easily measured. Several estimates of *K/m*, based on different kinds of data, are presented in table 9, and the text that accompanies the table concludes that *K/m* is probably between 0.2 and 0.6 (ft/d)/ft. Accordingly, models were constructed to simulate the midpoint and the lower and upper ends of this range. The altitude of the base of the streambed in each node (RBOT, eq. 3) was taken to be 5 ft below the reference stream-surface altitude in that node. This assumption is approximately equivalent to assuming a streambed thickness of 3.3 ft, equal to piezometer screen depth.

Properties That Control Recharge

The amount of water available for recharge during each stress period was estimated by a procedure given in Lyford and Cohen (1988). The calculation is based on equation 4 and is summarized in tables 13 and 14. Water available for recharge for any particular time period was considered to be precipitation minus evapotranspiration minus any water required to satisfy soil-moisture deficits accumulated from previous time periods. Storage of moisture as snow is incorporated in equation 4, but because it is usually small at Dover, it is ignored in table 13.

Land-surface altitude is needed as model input, because the Variable-Recharge procedure partitions water available for recharge in each node into recharge and rejected recharge on the basis of whether simulated aquifer heads are above or below land surface (Breen and others, 1995). The required array of land-surface altitudes was obtained by estimating the average land-surface altitude within each model cell from topographic maps, including maps at a 2-ft contour interval (U.S. Army Corps of Engineers, 1978; Geod Corporation, Oakridge, N.J., written commun., undated) and the USGS Dover quadrangle map at a 20-ft contour interval. A contour representation of the data array (fig. 33, p. 52) was produced that closely resembles the source maps, thereby verifying the node-by-node estimates of land-surface altitude. To facilitate contouring, a one-dimensional cubic spline interpolation procedure (Davis and Kontis, 1970) was used to

Table 13. Calculation of water available for recharge at Dover, N.J., September 23, 1983 through September 19, 1985
[ft/s, feet per second; col, column]

Stress period		Precipitation and soil-moisture conditions					Water available for recharge			
No.	Dates	Precipitation (inches)[1]	Evapotranspiration (inches)[2]	Soil-moisture depletion or addition (-) (inches)[3]	Accumulated soil-moisture deficit (cumulative total of col. 5) (inches)	Duration of stress period (days)	Calculated amount available (col.3 +4 +5) (inches)	Calculated rate for stress period (ft/s)[4]	Simulated rate for stress period (ft/s)[5]	Difference between calculated and simulated rates (inches)[6]
1	2	3	4	5	6	7	8	9	10	11
1	1983 Sept. 23-30	1.50	-0.66	0	0	8	0.84			
	October	5.91	-1.74	0	0	31	4.17			
	November	6.02	-1.09	0	0	30	4.93			
	December	8.13	0	0	0	31	8.13			
	1984 January	1.38	0	0	0	31	1.31			
	February	4.42	0	0	0	28	4.42			
	March	5.24	-1.58	0	0	31	3.66			
	April	6.90	-2.75	0	0	30	4.15			
	May 1-17	3.35	-1.99	0	0	17	1.36			
					Sum	237	33.04	1.34×10^{-7}	1.34×10^{-7}	0
2	May 18	0	-0.12	0.12	0.12	1	0	0	1.34×10^{-7}	0.14
3	May 19-31	6.77	-1.52	-0.12	0	13	5.13			
	June	2.90	-3.90	1.00	1.00	30	0			
	July 1-5	1.60	-0.66	-0.94	0.06	5	0			
					Sum	48	5.13	1.03×10^{-7}	1.23×10^{-7}	1.0
4	July 6-7	5.0	-0.27	-0.06	0	2	4.67	22.5×10^{-7}	24.1×10^{-7}	0.33
5	July 8-31	4.24	-3.19	0	0	24	1.05			
	August	2.30	-3.73	1.43	1.43	31	0			
	Sept. 1-19	2.08	-1.56	-0.52	0.91	19	0			
					Sum	74	1.05	0.15×10^{-7}	0.40×10^{-7}	1.9
6	Sept. 20	0	-0.08	0.08	0.99	1	0	0	0.40×10^{-7}	-0.04
7	Sept. 21-30	0.35	-0.82	0.47	1.46	10	0			
	October	3.35	-1.74	-1.46	0	31	0.15			
	November	2.36	-1.09	0	0	30	1.27			
	December	3.65	0	0	0	31	3.65			
	1985 Jan. 1-5	0.88	0	0	0	5	0.88			
					Sum	107	5.95	0.54×10^{-7}	0.45×10^{-7}	1.0

Table 13. Calculation of water available for recharge at Dover, N.J., September 23, 1983 through September 19, 1985 (continued)

Stress period		Precipitation and soil-moisture conditions					Water available for recharge			
No.	Dates	Precipi-tation (inches)[1]	Evapo-transpira-tion (inches)[2]	Soil-moisture depletion or addition (-) (inches)[3]	Accumulated soil-moisture deficit (cumulative total of col. 5) (inches)	Duration of stress period (days)	Calculated amount available (col.3 +4 +5) (inches)	Calculated rate for stress period (ft/s)[4]	Simulated rate for stress period (ft/s)[5]	Difference between calculated and simulated rates (inches)[6]
1	2	3	4	5	6	7	8	9	10	11
8	1985 Jan. 6-23	0.30	0	0	0	18	0.30	0.16×10^{-7}	0	0.23
9	Jan. 24	0	0	0	0	1	0	0	0	0
10	Jan. 25-31	0	0	0	0	7	0			
	February	1.96	0	0	0	28	1.96			
	March	1.59	-1.58	0	0	31	0.01			
	April	1.13	-2.75	1.62	1.62	30	0			
	May 1-27	6.05	-3.16	-1.62	0	27	1.27			
					sum	123	3.24	0.25×10^{-7}	0.33×10^{-7}	1.0
11	May 28	0.23	-0.12	0	0	1	0.11	1.06×10^{-7}	0.33×10^{-7}	0.08
12	May 29-31	0.46	-0.35	0	0	3	.11			
	June	7.46	-3.90	0	0	30	3.56			
	July	4.97	-4.12	0	0	31	0.85			
	August	2.67	-3.73	1.06	1.06	31	0			
					sum	95	4.52	0.46×10^{-7}	0.46×10^{-7}	0
13	Sept. 1-18	0.40	-1.48	1.08	2.14	18	0	0	0	0
14	Sept. 19	0	-0.08	0.08	2.22	1	0	0	0	0

1 From record of daily precipitation at West Wharton, N.J. (National Oceanic and Atmospheric Administration, 1983-85).

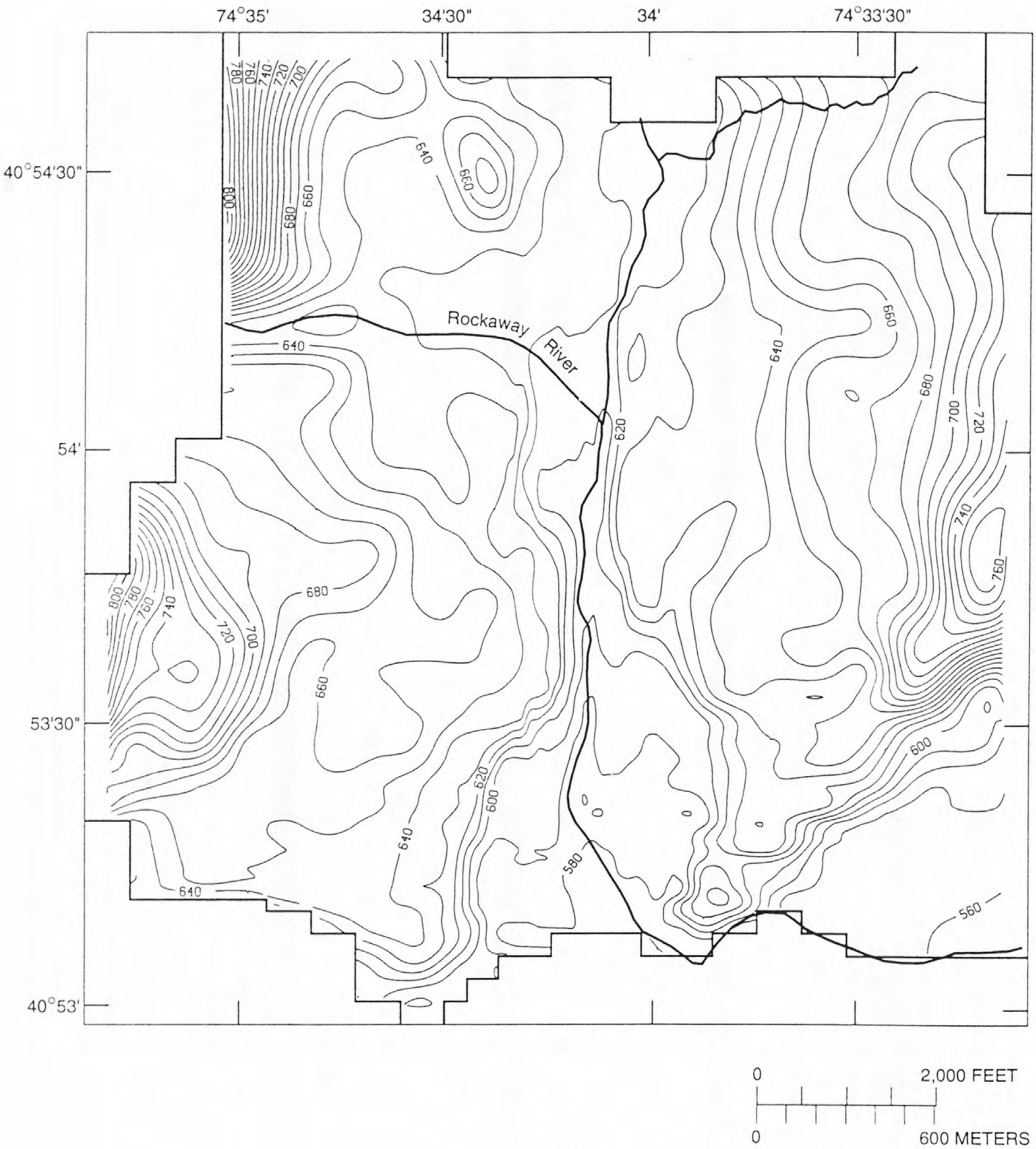
2 From table 14. For fractional months, evapotranspiration is proportioned linearly among number of days.

3 If the absolute value in column 4 exceeds that in column 3, the difference appears as a positive number in column 5. If the absolute value in column 3 exceeds that in column 4, all or part of the difference appears as a negative number in column 5, to the extent it can be subtracted from column 6 in the previous row without reducing the new cumulative total in column 6 to less than zero.

4 Obtained by dividing column 7 by column 8 and converting units to ft/s.

5 Simulated rate is that which facilitated model calibration.

6 Difference between calculated rate (column 9) and simulated rate (column 10), expressed in inches; can generally be interpreted as the amount by which evapotranspiration or precipitation would have to depart from values in columns 3 or 4 to account for this difference.



EXPLANATION

—660— LAND-SURFACE CONTOUR--Shows altitude of land surface, based on a data array of average land surface in each model cell as estimated from topographic maps. Contour interval 10 feet. Datum is sea level

——— BOUNDARY OF ACTIVE MODEL

Figure 33. Land-surface altitude as simulated in Dover models. (Area within model boundary is identical to that shown in figs. 23, 34, and similar figures.)

Table 14. Calculation of monthly evapotranspiration at Dover, N.J.

	Long-term average values		
	Evaporation	Evapotranspiration	
Month	(percent) [1]	(percent) [2]	(inches) [3]
January	2.6	0	0
February	3.1	0	0
March	5.8	6.33	1.58
April	10.1	11.00	2.75
May	13.3	14.51	3.63
June	14.3	15.59	3.90
July	15.1	16.46	4.12
August	13.7	14.95	3.73
September	9.0	9.82	2.46
October	6.4	6.97	1.74
November	4.0	4.36	1.09
December	2.5	0	0
Total	99.9	99.99	25.0

1 Class A average monthly pan evaporation at Hartford, Conn., which is the nearest station to Dover within the same climatic region cited by Lyford and Cohen (1988, table 2).

2 Recalculated from monthly evaporation in column 1, assuming that monthly evapotranspiration values are actually zero from December through February (Lyford and Cohen, 1988, p. 41).

3 Mean annual evapotranspiration is estimated to be about 25 inches–the difference between estimated mean annual runoff of 25.1 inches at Dover (pl. 6 of Hely and Nordenson, 1961) and mean annual precipitation of 50.1 inches at Split Rock Pond (National Oceanic and Atmospheric Administration, 1982). Data in this column are the product of the percentages in the previous column expressed as a decimal and multiplied by 25 inches.

convert data from the unequally spaced model nodes to a uniform grid spacing of 100 ft.

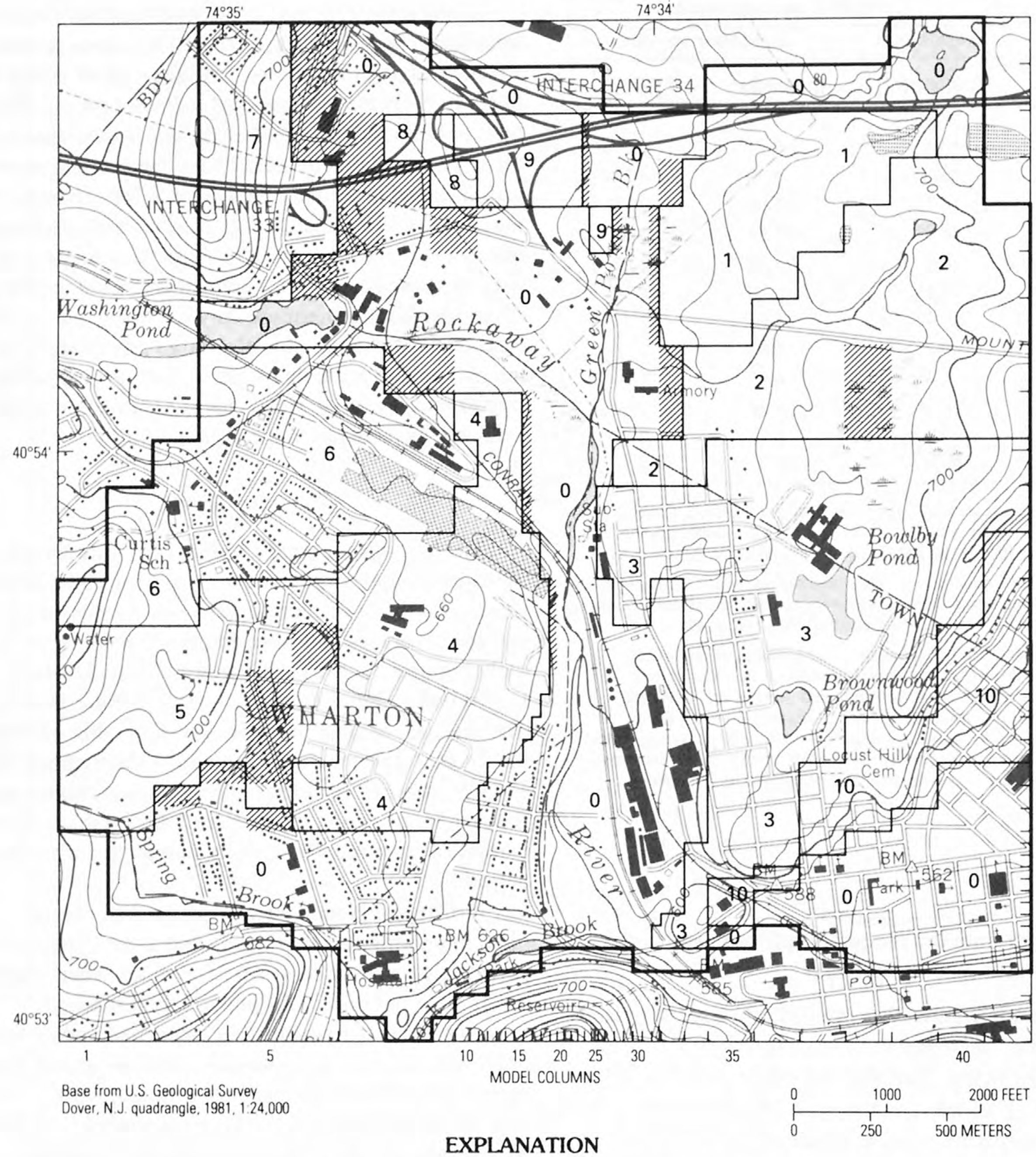
The modeled area was divided into a set of upland topographic subbasins and topographically low areas, as specified in the "Variable-Recharge procedure" section. Any rejected recharge or ground-water seepage within the upland subbasins (zones 1-10, fig. 34) was assumed to be unchanneled runoff and was applied as additional water available for recharge to specified nodes (fig. 34) that are chiefly along the edge of the valley fill adjacent to each subbasin. Several hillslopes in upland subbasins 2 and 5 are distant from the valley fill; therefore, part of the unchanneled runoff generated within these subbasins was distributed to topographically low upland areas at the base of those hillslopes. Any rejected recharge or seepage in the topographically low areas (zone zero, fig. 34) is assumed to flow to major streams and is not reapplied to other model nodes.

Many areas near the Dover well field have become urbanized (fig. 35) and are crossed by storm sewers, streets, and other impervious surfaces, all of which are likely to decrease recharge and intercept runoff. Therefore, only 50 to 75 percent of the water available for recharge calculated in table 13 for these urban areas was assumed to actually be available for recharge; the remainder was assumed to be collected and discharged through storm sewers. The 75-percent estimate was used in stress period 4; 50 percent was used in other stress periods. Furthermore, any unchanneled runoff calculated by the Variable-Recharge procedure from the two upland areas that were most intensely urbanized (zones 3 and 10, fig. 34) was assumed not to be available as recharge to the adjacent valley.

Pumping Rates

The long-term average four-season simulation used seasonal average pumping rates for 1984, which were assumed to be representative of long-term seasonal averages and were computed from records of daily pumpage at the Dover well field (A. Du-Jack, Dover Water Department, written commun., 1986). The seasonal average rates are given in table 12. For the 2-year transient-state simulations (September 23, 1983-September 19, 1985), the average pumping rate for each stress period longer than 2 days (table 12) was computed from records of daily pumpage during that period.

A different procedure was adopted to obtain model pumping rates for the 1- and 2-day stress periods that were used to simulate dates when water levels were measured. As previously discussed, water-level measurements that were made when the nearest production well was idle, or when it had been turned on within the previous few hours, were adjusted to approximately represent water levels that would have occurred under an idealized standard-pumping condition. The water-table configuration on three dates when pumping conditions were standard (September 1, 1984, September 20, 1984 and September 19, 1985) was used, in part, to guide adjustment of water levels measured on other dates under nonstandard pumping conditions (fig. 28). Therefore, to be consistent, an average of the pumping rates that prevailed over the 24 hours prior to measurements on these three dates was specified as the simulated pumping rate for every short stress period (table 12).



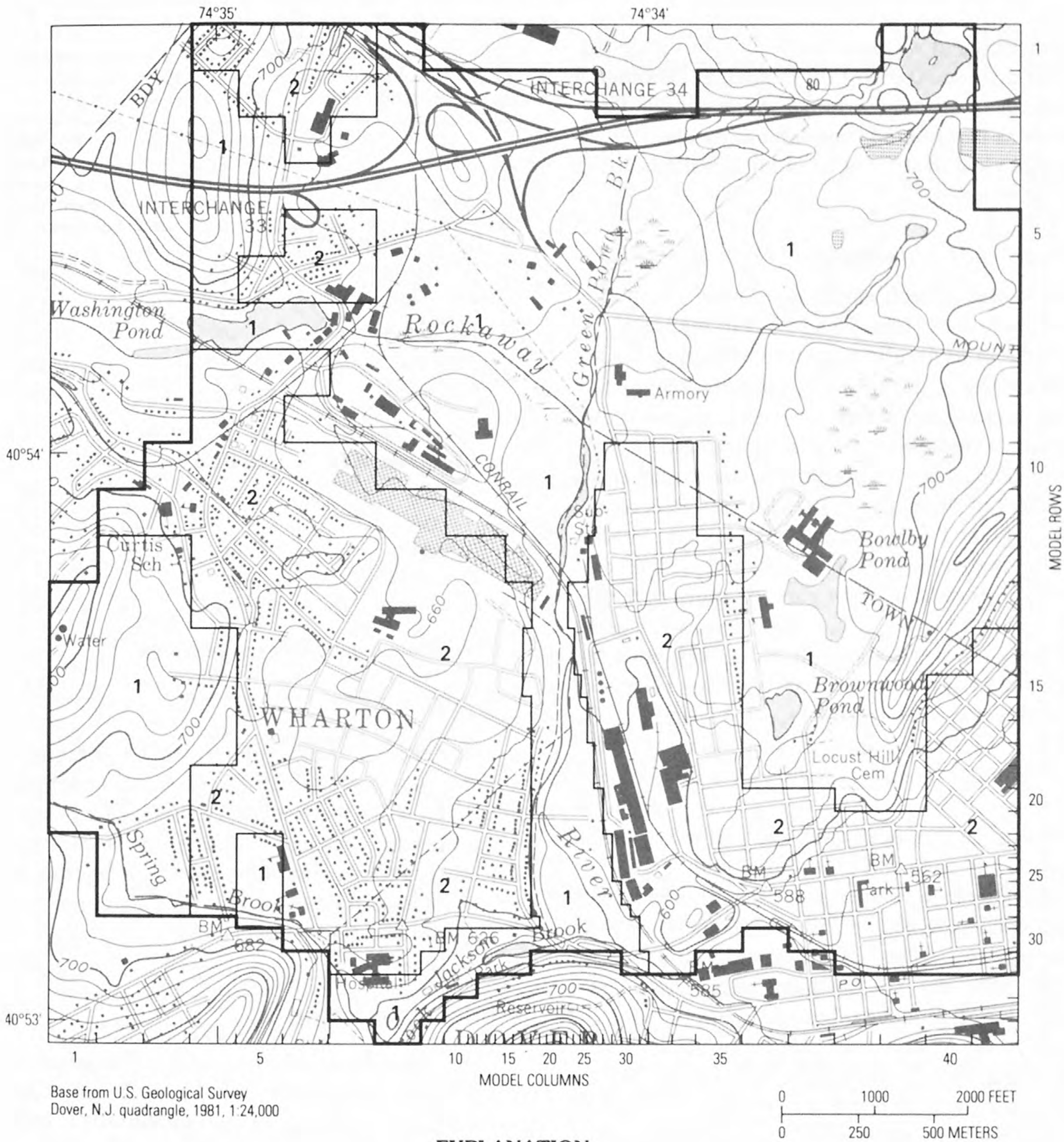
EXPLANATION

Nodes receiving unchanneled upland runoff

Boundary of active model

0 / 7 **Boundary of Variable-Recharge zones within active model**—Numbers are: (1–10) individual upland zones from which runoff is redistributed; each zone represents a subbasin; (0) low area from which runoff is not redistributed

Figure 34. Variable-recharge zones in Dover models. (General location is shown in fig. 2.)



EXPLANATION

—— Boundary of active model

1/2 —— Boundary between (1) nonurbanized areas, in which the entire calculated amount of water available for recharge was applied, and (2) urbanized areas, in which only 50 percent of the calculated amount was applied

Figure 35. Urbanized zones wherein water available for recharge was reduced in Dover models.

Storage Properties

Specific yield was taken to be 0.2 for valley-fill stratified drift and 0.05 for till in models 1 through 5, on the basis of reported average values for similar materials as determined from laboratory analyses. A specific yield of 0.1 was used for stratified drift in model 6.

Hydraulic Conductivities of Earth Materials

The nodes in each model layer were grouped into several zones (figs. 36 and 37) to facilitate adjustment of hydraulic conductivity during model calibration. All nodes in each zone were assigned the same hydraulic conductivity and were adjusted as a unit. Zone boundaries were placed at geologic contacts insofar as feasible. As explained earlier, the areal extent of the various surficial materials represented by layer 1 is reasonably well known, but the geologic identity of deeper materials represented by layer 2 is uncertain in all or parts of zones 0, 6, 10, 11, 12, 13, and 16 (fig. 37). These zones were generally assumed to consist of sand and gravel, but a few models had hydraulic conductivity values typical of upland till assigned to zones 11, 12, 13, and 16. Model response to the change in hydraulic conductivity of zone 16 was significant and is discussed further on.

The estimates of horizontal and vertical hydraulic conductivity of sand and gravel used in the initial simulations were developed from specific capacity of 10 wells (table 15), extrapolated on the basis of surficial geology (fig. 6) and lithologic descriptions of well logs (table 20). The estimates were subsequently modified during model calibration to improve the fit of model heads to adjusted observed heads. The specific capacity information is entirely from zones 1, 2, 3, 5, and 8 (figs. 36 and 37) in which surficial outwash, locally mantled by alluvium, is believed to overlie deltaic sands. Elsewhere, no local data were available to constrain estimates of hydraulic conductivity of sand and gravel.

Little information was available on hydraulic conductivity of the till and bedrock in the upland (zones 4, 6, 10-13, and 15, fig. 36 and zones 7 and 15, fig. 37). The hydraulic conductivity of bedrock was taken to be 0.25 ft/d for all models. A range of hydraulic conductivity values representative of sandy till were applied as follows: 0.25 ft/d for models 1 and 2; 4 ft/d for models 3 and 4; and 6 ft/d for models 5 and 6.

Table 15. Hydraulic conductivity values estimated from specific capacity of wells at Dover, N.J.

[Hydraulic conductivity values obtained from computerized procedure of Bradbury and Rothschild (1985), assuming a storage coefficient of 0.1. Locations are shown in fig. 5 or 8.]

Well number	Specific capacity (gallons per minute per foot of drawdown)	Estimated hydraulic conductivity (feet per day)
Dover well field		
286 (PW1)	127	872
288 (PW3)	96	570
289 (PW2)	109	753
290 (T5)	88	694
291 (PW5)	102	715
	Average	721
Southeast of Dover well field		
322	8.9	80
354	7.4	82
357	40	233
355	23.3	237
	Average	158
Wharton, north of Dover well field		
353	120	713

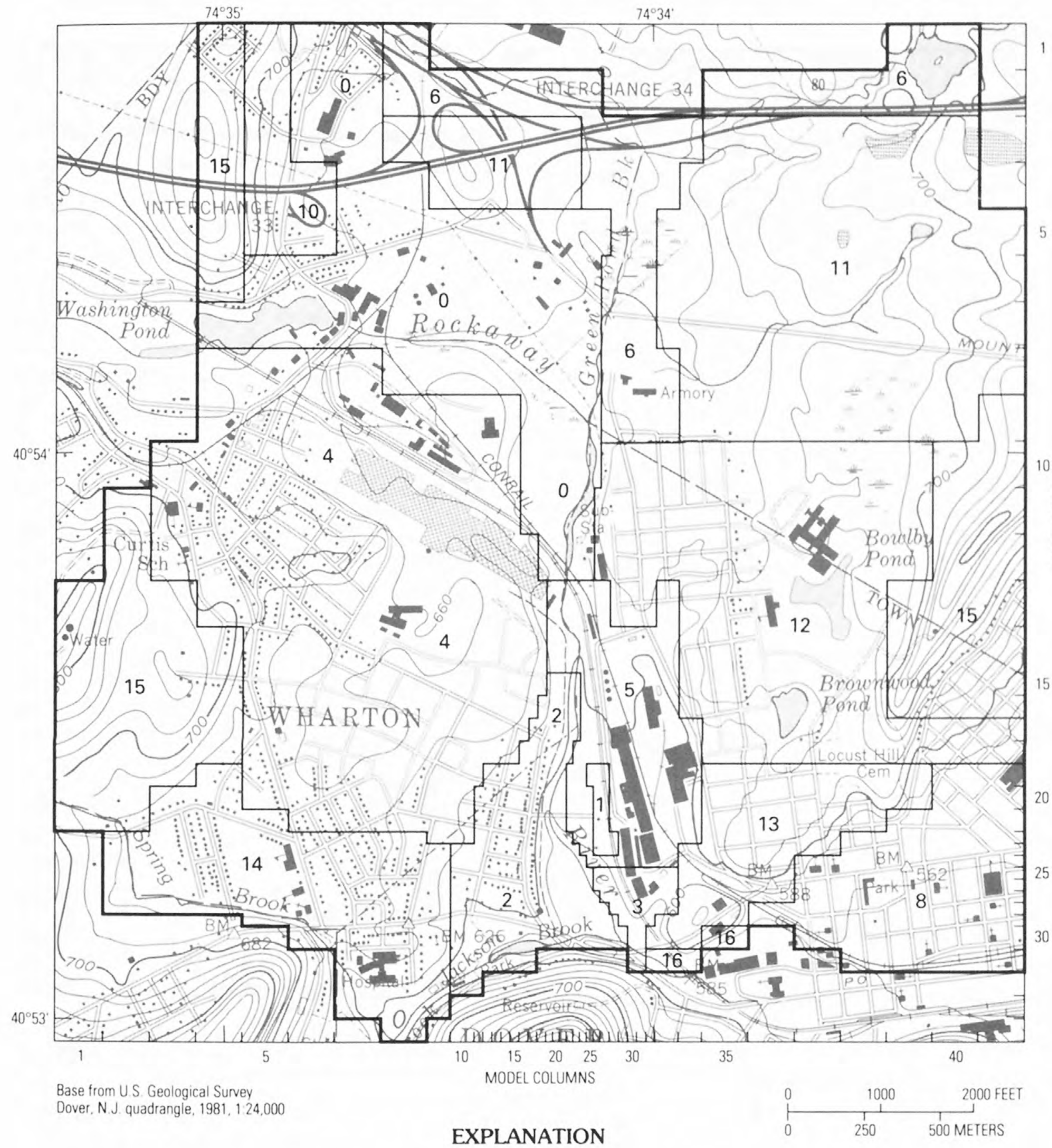
The ratio of vertical to horizontal hydraulic conductivity was estimated to be 0.01 in the uplands and 0.1 or 0.2 in the Rockaway River valley (see table 17, further on). Vertical leakance values, used by the model code to compute flow from one layer to the other, could then be computed from equation 51 of McDonald and Harbaugh (1988).

Model Calibration

Differences between observed and model-simulated heads can generally be attributed to erroneous hydraulic properties. During calibration, hydraulic properties are modified until the differences between observed and simulated heads are judged to be sufficiently small. Several procedures used to improve the accuracy of calibration and to illustrate the results of the Dover models are described in the next several sections, followed by a summary of what modifications were made during calibration, and why.

Interpolation of Simulated Heads

The simplest approach to model calibration entails minimizing the difference between observed head in each observation well and model-simulated



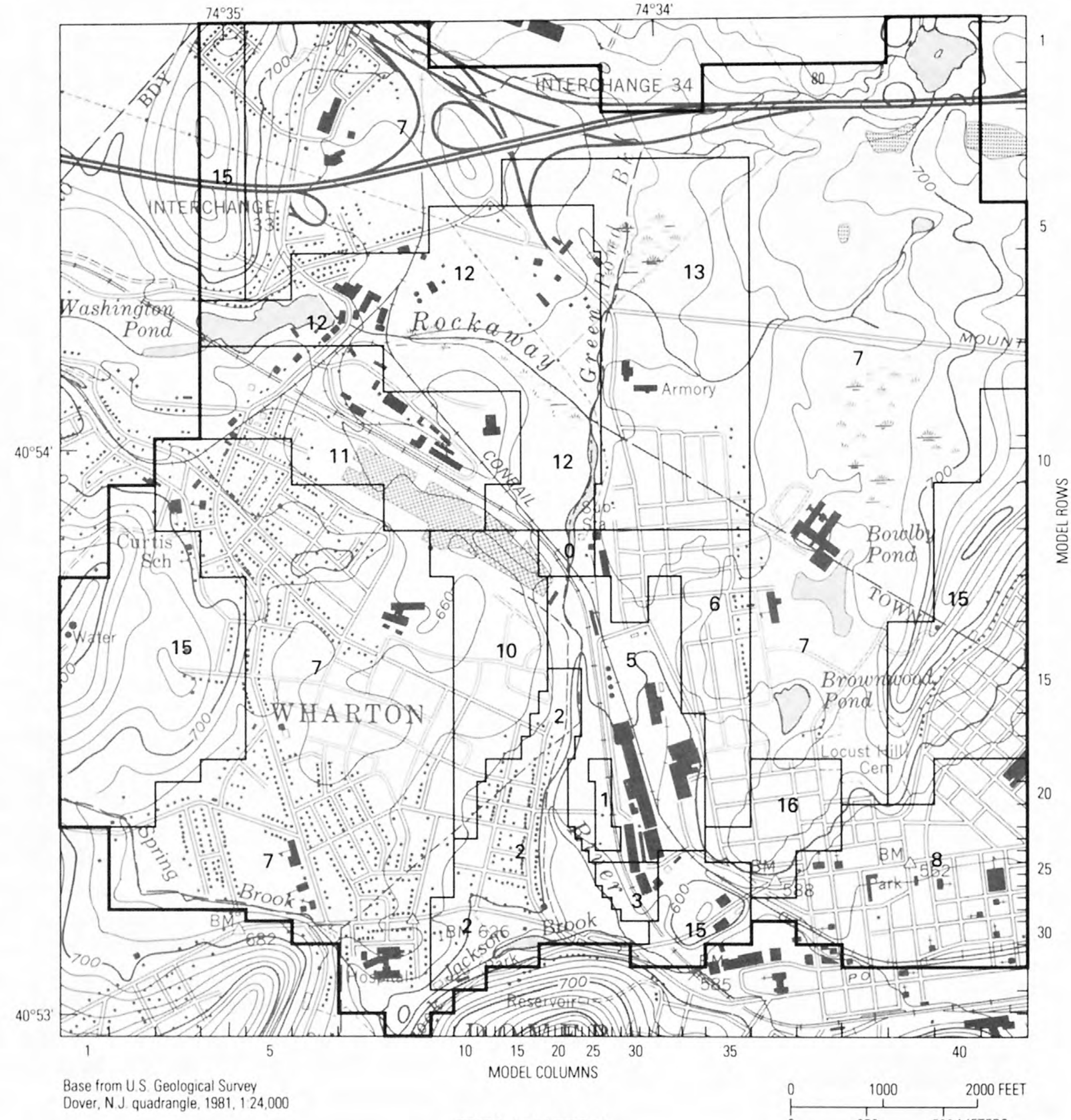
EXPLANATION

——— Boundary of active model

——— Boundary of hydraulic-conductivity zones

ZONE NUMBERS	MATERIAL SIMULATED
15	**Bedrock**
4, 6, 10, 11, 12, 13	**Moraine deposits**—Chiefly till
0, 1, 2, 3, 5, 8, 16	**Sand and gravel**— Predominantly fluvial outwash and alluvium
14	Deltaic and lacustrine-fan deposits

Figure 36. Hydraulic conductivity zones in layer 1 of Dover models.



EXPLANATION

——— Boundary of active model

——— Boundary of hydraulic-conductivity zones

ZONE NUMBERS	MATERIAL SIMULATED
15	Bedrock
7	Till
0, 1, 2, 3, 5, 6, 8, 10	Sand and gravel
11, 12, 13, 16	Zones simulated as sand and gravel in some models and as till in other models

Figure 37. Hydraulic conductivity zones in layer 2 of Dover models.

average head for the cell that encloses that observation well. Where several observation wells are located within one cell, an average of the observed heads can be used as an estimate of the true average head in that cell. If the head gradient is relatively large and the observation well(s) not centrally or uniformly distributed within the cell, however, the observed values commonly will not accurately represent the true average head. More exact calibration can be achieved by decreasing the model grid spacing. Alternatively, if the model-grid spacing is already sufficiently fine to define the essential form of the head surface, the goal of more exact calibration can be achieved more efficiently by merely interpolating the model-simulated heads at some finer grid spacing, such that the observed head in each well can be compared with an interpolated head that represents only a small area close to that well. Because most potentiometric surfaces are relatively smooth, any appropriate interpolation procedure will usually produce an accurate representation of the simulated surface. Hill (1992) discusses interpolation of hydraulic head at the exact location of observation wells using linear, triangular, or quadrilateral finite-element basis functions.

All data available for calibration of the Dover models, including water levels in streambed piezometers and observation wells, were collected in the area encompassed by model rows 15 through 29 and columns 15 through 32. This area has been termed the "Dover well field subregion." To facilitate calibration, model heads within this subregion were interpolated at a uniform spacing of 50 ft, through a one-dimensional cubic-spline interpolation procedure (Davis and Kontis, 1970). The locations of observation wells with respect to the 50-ft interpolated grid and the variably spaced model grid are shown in figure 38.

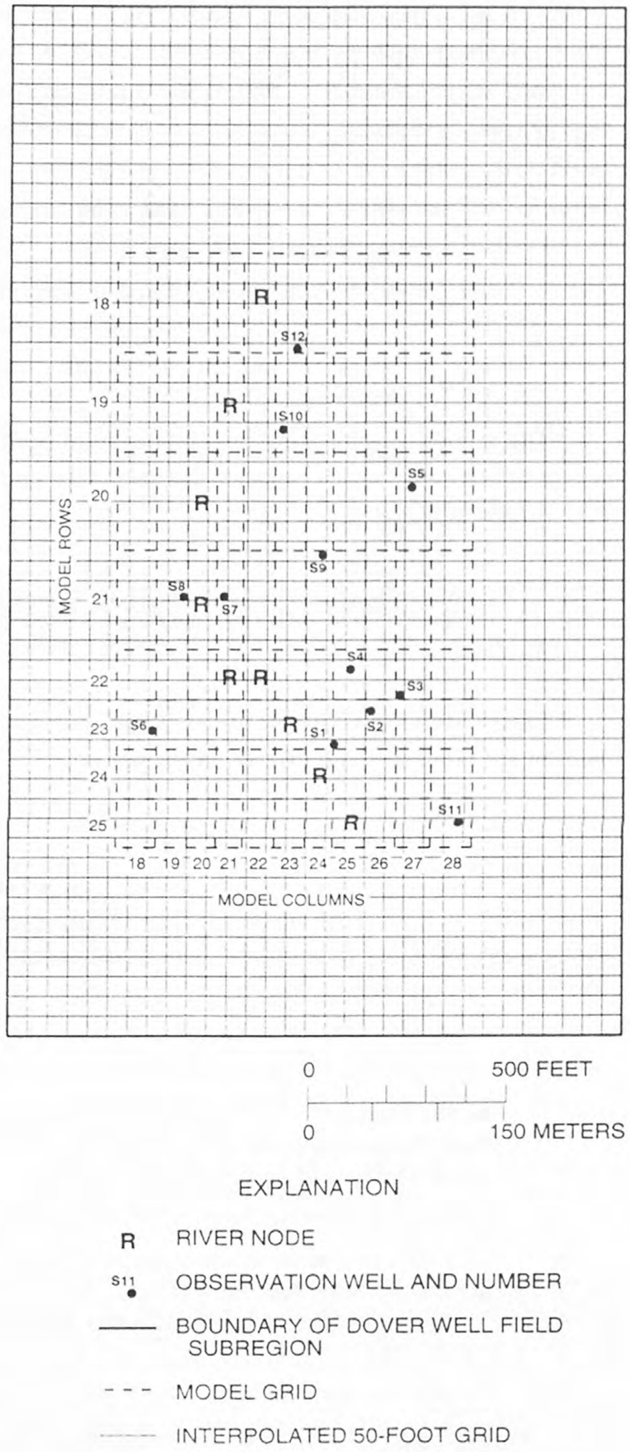


Figure 38. Locations of observation wells in relation to model grid and to a uniformly spaced interpolated grid within Dover well-field subregion. (Subregion location is shown in fig. 23.)

Goodness of Fit

Every time one of the Dover models was modified and rerun during the calibration process, a postprocessor routine computed two versions of the mean absolute difference (MAD) between simulated and observed heads. Together, these two MAD versions provided a comprehensive indication of model fit. The first version measures model fit for each stress period; that is, for N observation wells, the MAD for the ith stress period is:

$$MAD\langle i\rangle = \frac{\sum_{n=1}^{N} |h_m - h_o|_n}{N} \qquad i = 1, 2, \ldots 6 \text{ stress periods,} \quad (6)$$

where: h_o = adjusted observed head in an observation well, and

h_m = model head, interpolated as described in the previous section, for a cell 50 ft on a side that contains the observation well (fig. 38).

The second version measures model fit at each observation well over all 6 stress periods. That is, for the *n*th observation well,

$$MAD\langle n\rangle = \frac{\sum_{i=1}^{6} |h_m - h_o|_i}{6} \qquad n = 1, 2, \ldots N \text{ observation wells.} \quad (7)$$

The final MAD statistics for each calibrated model are tabulated and discussed further on.

Simulation of Flow Paths

As a means of approximately delineating lateral flow paths, the direction of lateral flow within each node was calculated from model flow components by the relation

$$A_{ijk} = \tan^{-1} (QX_{ijk} / QY_{ijk}), \quad (8)$$

where: $QX_{i,j,k}$ is the lateral flow parallel to row i, at node *i,j,k*, taken as the average of flows across the left and right faces of the node (eqs.10 and 11 of McDonald and Harbaugh, 1988);

$QY_{i,j,k}$ is the lateral flow parallel to column j, at node i,j,k, taken as the average of flows across the back and front faces of the node (eqs. 12 and 13 of McDonald and Harbaugh, 1988); and

$A_{i,j,k}$ is the angle of lateral-flow direction, at node *i, j, k*, relative to the orientation of model columns.

The angles of flow thus calculated were plotted on maps, from which flow paths could be approximately sketched.

Calibration of Six Alternative Models

Six different models of the Dover area were developed and calibrated. Hydraulic stresses (tables 11, 12) were the same for all six models, but the models differed significantly in four properties—streambed leakance, specific yield, hydraulic conductivity of upland till, and hydraulic conductivity of particular zones in layer 2 whose geologic character was uncertain. Each of these properties was constrained to a preset value in each model, as specified in table 16. During calibration, hydraulic conductivity was adjusted in all zones that represent stratified drift, other than the constrained zones listed in table 16, until reasonably close agreement between model heads and adjusted observed heads was obtained. The final distribution of hydraulic conductivity for each model is given in table 17. Large differences in hydraulic conductivity among the six models were preset in zones 11, 12, 13, and 16 of layer 2 and were required in zone 14 of layer 1 to achieve calibration. Calibrated hydraulic conductivity values for stratified drift in other zones varied by no more than 43 percent from the average values in the same zones in all six models (table 17). Variations of 35 percent or less were generally enough to compensate for the specified differences in streambed leakance or hydraulic conductivity of zone 16 in layer 2. This degree of variation is within the typical accuracy of hydraulic conductivity estimates and is therefore plausible.

Table 16. Specified hydraulic properties that distinguish ground-water flow models 1 through 6 of Rockaway River valley at Dover, N.J.

[Streambed leakance (*K/m*) is vertical hydraulic conductivity per unit streambed thickness, in feet per day per foot. Locations of hydraulic conductivity zones are shown in fig. 37.]

Model	Streambed leakance (*K/m*)	Relative hydraulic conductivity[1] of certain zones in model layer 2: Zone 16	Relative hydraulic conductivity[1] of certain zones in model layer 2: Zones 11, 12, 13	Hydraulic conductivity of till (feet per day)	Specific yield of stratified drift
1	0.2	high	high	4	0.2
2	0.2	low	high	4	0.2
3	0.6	high	high	0.25	0.2
4	0.6	low	high	0.25	0.2
5	0.4	high	low	6	0.2
6	0.4	high	low	6	0.1

[1] "High" indicates values typical of sand and gravel; "low" indicates values equal to or slightly greater than those for upland till. Specific numerical values are given in table 17.

During the calibration process, simulation of differences in water level between some successive stress periods was improved by modifying water available for recharge from the rates initially calculated (table 13, columns 9 and 10). The difference between the calculated rate and the final simulated rate for each stress period, converted to inches, is given in column 11 of table 13. The difference could generally be interpreted as the amount by which the calculated evapotranspiration rate (table 13, column 4) would have to be increased or decreased over the duration of a stress period to account for the implemented change in water available for recharge. In that evapotranspiration is a complex phenomenon and that the estimates (table 14) are an approximation of actual conditions, the adjustments of less than 2 inches (table 13, column 11) are within the probable range of uncertainty of this parameter.

Table 17. Hydraulic conductivity distribution in ground-water flow models of Rockaway River valley at Dover, N.J.

[Hydraulic conductivity values are in feet per day. *K/m* is streambed leakance (vertical hydraulic conductivity per unit streambed thickness), in feet per day per foot. Percent departures are in parentheses. Shading denotes properties that were preset and not varied during model calibration. Locations of hydraulic conductivity zones are shown in figs. 36 and 37].

Hydraulic conductivity zone[1]	Material[2]	Ratio of vertical to horizontal conductivity	Horizontal hydraulic conductivity and percent departure from average[3]					Average of previous 5 columns
			Model 1	Model 2	Model 3	Model 4	Models 5, 6	
			K/m = 0.2	K/m = 0.2	K/m = 0.6	K/m = 0.6	K/m = 0.4	
Layer 1								
0	SG	0.1	325 (18)	250 (9)	250 (9)	200 (27)	350 (27)	275
1*	SG	0.2	375 (14)	300 (9)	300 (9)	300 (9)	375 (14)	330
2*	SG	0.1	375 (23)	300 (2)	275 (10)	200 (34)	375 (23)	305
3*	SG	0.1	250 (9)	250 (9)	200 (13)	150 (35)	300 (30)	230
5*	SG	0.1	375 (17)	300 (7)	300 (6)	250 (22)	375 (17)	320
8	SG	0.1	150 (0)	150 (0)	150 (0)	150 (0)	150 (0)	150
14	SG	0.1	350 (56)	275 (22)	100 (56)	50 (78)	350 (56)	225
16	SG	0.1	250 (9)	250 (8)	200 (13)	200 (13)	250 (9)	230
4, 6, 10, 11, 12, 13	T	0.01	4	4	0.25	0.25	6[4]	
15	B	0.01	0.25 (0)	0.25 (0)	0.25 (0)	0.25 (0)	0.25[4] (0)	0.25
Layer 2								
0	SG	0.1	375 (12)	325 (3)	300 (10)	275 (18)	400 (19)	335
1*	SG	0.2	600 (3)	500 (14)	600 (3)	600 (3)	600 (3)	580
2*	SG	0.1	450 (14)	375 (5)	400 (1)	300 (24)	450 (14)	395
3*	SG	0.1	300 (7)	275 (2)	225 (20)	200 (29)	400 (43)	280
5*	SG	0.1	450 (6)	375 (12)	450 (6)	400 (6)	450 (6)	425
6	SG	0.1	400 (11)	325 (10)	350 (3)	300 (17)	425 (18)	360
10	SG	0.1	400 (16)	325 (6)	300 (13)	275 (20)	425 (23)	345
11	SG or T	0.1	400	325	300	275	25	
12	SG or T	0.1	375	325	300	275	25	
13	SG or T	0.1	400	325	350	300	25	
8	SG	0.1	200 (0)	200 (0)	200 (0)	200 (0)	200 (0)	200
16	SG or T	0.1	300	4[5]	250	4[5]	300	
7	T	0.01	4	4	0.25	0.25	6[4]	
15	B	0.01	0.25 (0)	0.25 (0)	0.25 (0)	0.25 (0)	0.25[4] (0)	0.25

1 Asterisk denotes zone in Dover well-field subregion

2 SG = sand and gravel. T = till. B = bedrock

3 Percent departures (in parentheses) are the difference, in percent, between hydraulic conductivity of indicated zone in a particular model and the average for that zone in all models. Average and percent departure not computed for zones whose hydraulic conductivity was fixed for each model, as specified in table 16.

4 Ratio of vertical to horizontal hydraulic conductivity is 0.1

5 Ratio of vertical to horizontal hydraulic conductivity is 0.01

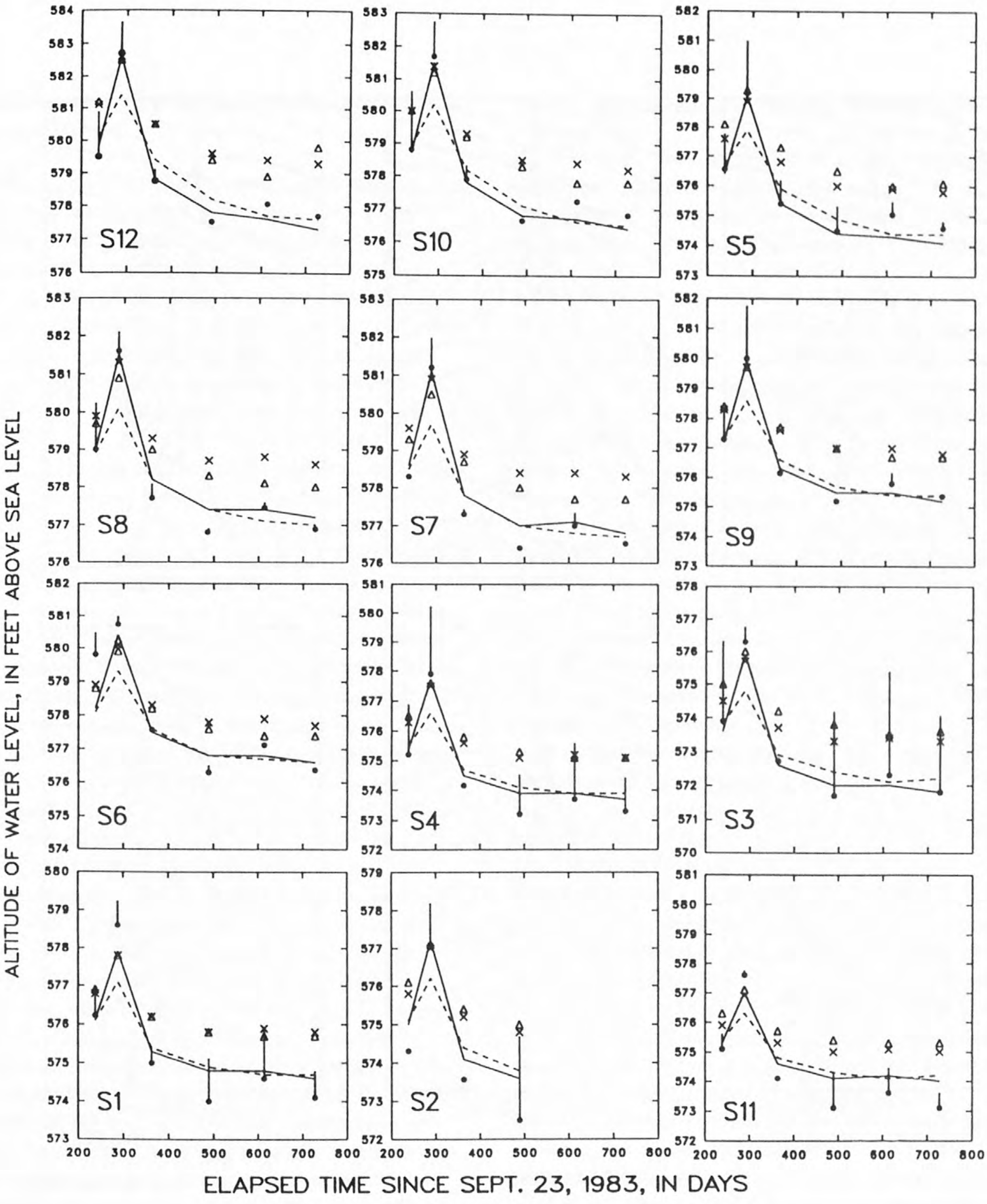
The mean absolute difference (MAD) for each of 13 observation wells, averaged over the six transient-state stress periods used in calibration, are given for each model in table 18. The MAD averaged 0.6 ft for models 1 through 5 and 0.3 ft for model 6. The MAD for each of the six stress periods, averaged over all 13 observation wells, are also given for each model in table 18. Except for stress period 4, the MAD is no more than 0.9 ft. Stress period 4 is characterized by a large rise in water levels (fig. 29) and stream-surface altitudes (fig. 32) in response to a 2-day rainfall of 5 in. (table 13). In models 1 through 5, the simulated water levels for stress period 4 were 1.5 to 2 ft lower than the adjusted observed water levels. Model 6 had a much better fit than models 1 through 5 for stress period 4 and generally a slightly better fit for the other stress periods. Figure 39 illustrates the fit of water levels simulated by models 1 and 6 to observed water levels in 12 shallow observation wells in all six stress periods and also illustrates how far the observed water levels were adjusted to conform to the assumed standard-pumping condition. The superior fit of model 6, particularly during the high-rainfall event (stress period 4), results primarily from of a specific yield of 0.1 rather than 0.2 (table 16). A specific yield of 0.1 is near the low end of the range of published values for medium to coarse stratified drift as obtained from laboratory measurements (0.13 to 0.46, Morris and Johnson, 1967) and near the upper end of the range of values typically derived from aquifer tests (about 0.03 to 0.13, Nwankwor and others, 1984). Although the distribution of simulated head is a function of many factors, the improved model fit obtained with the lower specific yield supports the view that in the analysis of aquifer response to changes in stress, except for long time periods, lower values obtained from aquifer tests are likely to be more appropriate than values based on laboratory measurements (Rasmussen and Andreasen, 1959; Neuman, 1987).

Table 18. Model fit as indicated by mean absolute difference between interpolated model heads and adjusted observed heads at observation wells along Rockaway River at Dover, N.J.

[All values are in feet. Well locations are shown in fig. 8; complete records of stress periods are given in table 12.]

Well, or stress period and end date	Model					
	1	2	3	4	5	6
A. By well, averaged for all stress periods (computed by eq. 7)						
S1	0.6	0.6	0.7	0.7	0.7	0.4
S2	0.9	0.8	0.7	0.8	0.9	0.6
S3	0.5	0.6	0.7	0.6	0.5	0.2
S4	0.6	0.5	0.6	0.6	0.6	0.3
S5	0.6	0.6	0.6	0.5	0.6	0.3
S6	0.7	0.7	0.8	0.8	0.7	0.5
S7	0.5	0.5	0.7	0.9	0.5	0.3
S8	0.5	0.5	0.6	0.8	0.5	0.3
S9	0.5	0.5	0.5	0.5	0.4	0.2
S10	0.5	0.6	0.5	0.4	0.5	0.3
S11	0.8	0.9	0.7	0.9	0.8	0.6
S12	0.6	0.7	0.5	0.6	0.5	0.3
T5	0.6	0.6	0.6	0.6	0.5	0.2
Mean	0.6	0.6	0.6	0.6	0.6	0.3
B. By stress period, averaged for all wells (computed by eq. 6)						
1984						
2 (May 18)	0.3	0.4	0.5	0.4	0.3	0.3
4 (July 7)	1.4	1.5	1.7	1.5	1.4	0.3
6 (Sept 20)	0.4	0.4	0.3	0.3	0.4	0.2
1985						
9 (Jan 24)	0.7	0.7	0.6	0.9	0.7	0.5
11 (May 28)	0.4	0.5	0.3	0.4	0.3	0.4
14 (Sept 19)	0.3	0.3	0.4	0.6	0.4	0.3

The potentiometric surface simulated in layer 1 of model 6 within the Dover well field subregion is depicted in figure 40, along with water levels in observation wells. The length of the losing reach is also indicated. In stress periods 2 and 4, the Rockaway River loses to the underlying aquifer throughout its length within the subregion, whereas in stress periods 6, 9, 11, and 14, the model indicates a gain at the extreme downstream end of the subregion. The simulated heads rise or fall from one stress period to the next in response to changes in applied stress (table 12), but the general flow pattern remains nearly the same except in stress period 4, when simulated heads rose to land surface in several topographically low areas in response to an increase in water available for recharge of 22.8×10^{-7} ft/s and an increase in stream stage of 1.7 ft relative to stress period 2 (table 12). Where this happens, the Variable-Recharge procedure sets each node to a constant head, equal to land-surface altitude (fig. 33), and treats net flow into the node as outward seepage. Such nodes are the cause of the sink in the flow system for stress period 4 south of observation well S11 (fig. 40).



EXPLANATION

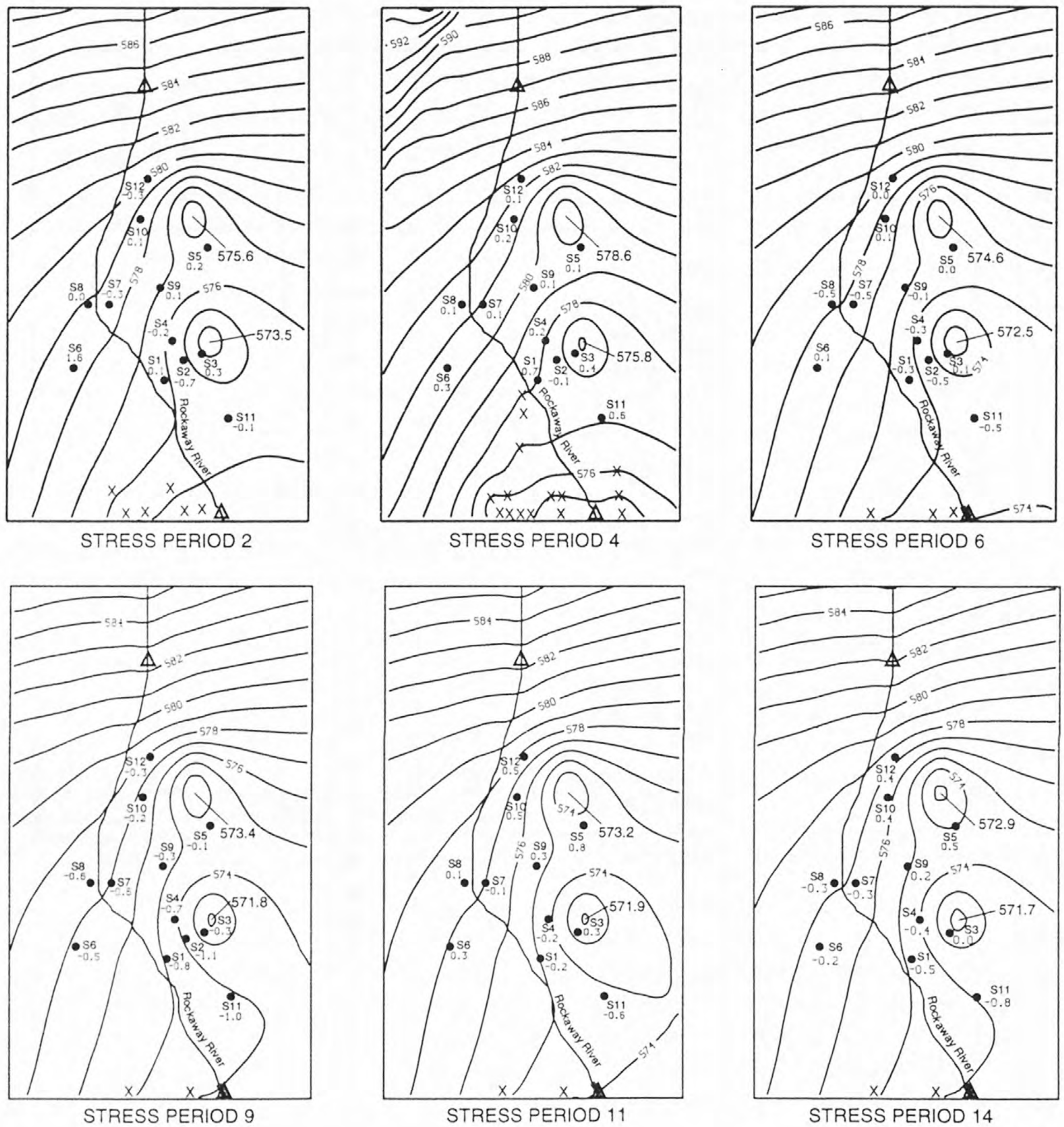
WATER LEVELS IN WELLS

- ● Adjusted water level used in calibration
- | Magnitude of adjustment to conform to standard pumping condition; top of line is observed water level

WATER LEVELS SIMULATED IN MODEL LAYER 1

- - - - - Model 1
- × Model 1, *K/m* increased from 0.2 to 0.6 feet per day per foot
- △ Model 1, *K* in zone 16 of layer 1 decreased from 300 to 4 feet per day
- ——— Model 6

Figure 39. Observed and adjusted water levels in individual wells on dates used for model calibration, and corresponding water levels simulated by models 1 and 6. Also shown is sensitivity of model 1 to an increase in streambed leakance (*K/m*), and to a decrease in hydraulic conductivity (*K*), within a former reach of the Rockaway River valley (zone 16, layer 2). Upper six wells are near production well PW1; lower six wells are near PW5.



0 500 FEET
0 150 METERS

EXPLANATION

—574— CONTOUR OF SIMULATED HYDRAULIC HEAD--Contour interval 1 foot. Datum is sea level

ROCKAWAY RIVER--Streamflow loss occurs along entire reach shown except near south edge of some maps where heavy line denotes simulated gaining reach

• S11 / -1.0 OBSERVATION WELL FINISHED IN MODEL LAYER 1--Upper number is local identifcation number, lower number is interpolated model head minus adjusted observed head in well, in feet

x LOCATION OF GROUND-WATER DISCHARGE AT LAND SURFACE--As simulated by the Variable-Recharge procedure

△ STREAMFLOW-MEASUREMENT SITE--Simulated stream loss from intervening reach is given in table 19

—571.7 SIMULATED HEAD AT PRODUCTION WELL

Figure 40. Simulated heads in layer 1 of model 6 within the Dover well-field subregion, for six transient stress periods. (Location of subregion is shown in fig. 23.)

Model Sensitivity to Selected Hydraulic Properties

Although the six Dover models were calibrated to water levels and stresses measured over a 2-year period within the Dover well field subregion, the models cover a much larger area (fig. 23) within which they were constrained only by geohydrologic plausibility. Therefore, they should not be considered an accurate representation of the entire study area without further calibration. Models 1 through 5 fit the adjusted observed-data base with about the same accuracy. The fit of model 5 was improved by decreasing storage coefficient of stratified drift from 0.2 to 0.1, resulting in model 6. An equally good fit could probably have been obtained from models 1 through 4 if a storage coefficient of 0.1 had been used instead of 0.2. Thus, the process of model calibration to the localized data base available through 1989 was incapable of distinguishing which of the alternative specifications of models 1 to 5 is most nearly correct. Nevertheless, useful information regarding hydrologic conditions at Dover was obtained by analysis of the sensitivity and response of the models to a range in values of streambed leakance, hydraulic conductivity of upland till, and hydraulic conductivity of layer 2 in the bedrock valley east of the well field, as discussed in the following sections.

The inclusion of the uplands and application of the Variable-Recharge procedure in a ground-water flow model of a valley-fill aquifer can be viewed as one way of simulating the lateral boundary of the aquifer along the valley wall. If the uplands are not included in a model, then subsurface flow and unchanneled surface flow across that lateral boundary can be simulated by assigning appropriate flows at the perimeter of the valley fill, usually in the form of specified fluxes that may vary spatially and with time. If the uplands are included in the model and the Variable-Recharge procedure is applied, then flows into the aquifer along the valley wall depend on the manner in which the uplands are simulated and the specifications of the Variable-Recharge input data (items 1 through 6 of the "Variable-Recharge Procedure" section). Kontis and others (U.S. Geological Survey, written commun., 1995) discuss and illustrate with water budgets the effects of hydraulic conductivity and other properties of the uplands on the magnitude of each component of upland runoff that is simulated by the Variable-Recharge procedure and on recharge to the valley-fill aquifer.

Streambed Leakance and Stream Loss

The sensitivity of simulated heads to a change in streambed leakance is illustrated in figure 39. If the streambed leakance in model 1 is increased threefold from 0.2 to 0.6 (ft/d)/ft while all other hydraulic properties (table 17) are held constant, heads at observation wells throughout the Dover well field subregion rise by 0.5 to 1.7 ft, depending on location and stress period (fig. 39). With the increased streambed leakance, the difference between stream stage and head beneath the streambed must decrease to maintain the stream-loss (induced-recharge) component of the model mass balance; hence, head in the aquifer rises. Conversely, if the properties of model 3 (table 17) are held constant except for a threefold decrease in streambed leakance from 0.6 to 0.2 (ft/d)/ft, simulated aquifer heads drop 1.2 to 4 ft, depending on location and stress period. Because models 1 and 3 had both been calibrated to the same stream-surface profile and aquifer heads, the initial simulated downward gradients across the streambed in both models were nearly the same. These sensitivity tests caused the downward head gradients in both models to change by roughly a factor of 3, as required by the inverse relation between gradient and streambed leakance in Darcy's law. The decline in head required to increase the calibrated gradient threefold is, however, necessarily a greater distance than the rise in head required to decrease that gradient threefold. The numerically greater sensitivity in the second test might also be caused in part by simulated aquifer heads falling below the base of the streambed (RBOT, eq. 3) in some model cells in response to decreased streambed leakance. When this occurs, inflow from the stream to the aquifer ceases to increase and is controlled by the difference in head between the stream surface and the base of the streambed; thus, other sources of water would be needed to balance the discharge to the production wells, such as water from storage or from more distant recharge, and aquifer head would decline further. Similar results could be expected from a change in streambed leakance in any model whose head-dependent inflows and outflows are primarily through the streambed.

The tests described above show that simulated heads are potentially quite sensitive to streambed leakance. Because all six Dover models were calibrated to the same array of adjusted observed heads, however, the models differ in the rate at which water infiltrates from the river into the aquifer rather than in simulated head or gradient beneath the river. Simulated streamflow losses near the well field were consistently proportional to the streambed leakance specified for each model (table 19). That is, in models 3 and 4, which incorporated a threefold increase in streambed leakance relative to models 1 and 2, the streamflow losses were nearly three times those in models 1 and 2. Likewise, the simulated streamflow losses in models 5 and 6 were about twice those of models 1 and 2 because streambed leakance was twice as great in models 5 and 6. Moderately small changes in hydraulic conductivity were needed throughout the modeled area (table 17) to calibrate the six models to adjusted observed heads near the well field and to the specified differences in streambed leakance and certain other properties (table 16).

The fact that all models can be calibrated with comparable accuracy (table 18) indicates that, even though pumpage is known and the amount of water available for recharge is fixed, model calibration to the array of measured heads in wells near the Dover well field is insufficient to define the magnitude of streambed leakance (eq. 3) or conductance (eq. 5). Calibration to accurately measured streamflow loss as well as measured heads would allow the calibration process to define streambed conductance. Differences in induced infiltration among models 1 through 6 (table 19) are necessarily balanced by differences in the extent of the cone of depression and, thus, in the capture of water available for recharge derived from precipitation on the aquifer and bordering uplands; perhaps careful calibration to heads in a more extensive array of observation wells and streambed piezometers would constrain the extent of the losing stream reach and the cone of depression enough to indirectly constrain streambed leakance as well.

Table 19. Simulated streamflow loss between model nodes that correspond to upstream and downstream measurement sites along Rockaway River at Dover, N.J.

[All values are in cubic feet per second. *K/m*, ratio of vertical hydraulic conductivity of streambed (*K*) to streambed thickness (*m*). Dates and duration of stress periods are given in table 12.]

Stress period	Date at end of stress period	Model 1 (*K/m* = 0.2)	2 (*K/m* = 0.2)	3 (*K/m* = 0.6)	4 (*K/m* = 0.6)	5 (*K/m* = 0.4)	6 (*K/m* = 0.4)
2	5/18/84	0.52	0.50	1.56	1.41	1.07	1.06
4	7/07/84	0.65	0.64	1.86	1.72	1.28	0.95
6	9/20/84	0.50	0.49	1.53	1.38	1.02	1.08
9	1/24/85	0.62	0.62	1.73	1.57	1.26	1.30
11	5/28/85	0.71	0.72	1.84	1.69	1.39	1.40
14	9/19/85	0.67	0.67	1.78	1.63	1.34	1.37
	Mean loss	0.61	0.61	1.72	1.57	1.23	1.19

The paired-streamflow-measurement method directly determined stream seepage loss, whereas application of other methods to estimate seepage loss at Dover (table 9) involved several assumptions that are not necessarily valid, and for some methods also involved extrapolation from one or a few sites to the entire losing reach. Consequently, the most likely value of induced infiltration for low-flow conditions at Dover is about 0.7 ft^3/s, as determined by paired streamflow measurements. If so, the simulated stream losses of models 3, 4, 5, and 6 (table 19) are too high. If the actual seepage loss from the Rockaway River is in fact about 0.7 ft^3/s, then streambed leakance, assuming uniform conditions, is about 0.2 (ft/d)/ft.

Hydraulic Conductivity of Bedrock Valley East of Dover Well Field

Zone 16 of model layer 2 (fig. 37) represents the unconsolidated sediment that underlies surficial morainal till in the former Rockaway River gorge southeast of the Dover well field. As previously explained, the geologic identity of this sediment is in doubt. In model 1, the hydraulic conductivity of zone 16 was set to 300 ft/d (table 17) to simulate continuity of deltaic sand and gravel through the gorge from the vicinity of the well field to the southeast corner of the model. The resulting average end-of-summer head distribution is shown in figure 41. If all hydraulic properties of model 1 as calibrated are held constant except that zone 16 is simulated as till with a hydraulic conductivity of 4 ft/d, flow that was formerly directed southeastward through zone 16 is diverted toward the well field, and simulated heads upvalley from zone 16 rise—by 0.6 to 1.7 ft in the Dover well field subregion on most dates used for calibration during the 2-year transient-state simulation (fig. 39). The magnitude of the rise in head decreases with distance from zone 16 and is somewhat smaller in stress periods when the amount of water available for recharge is relatively large than when the amount is smaller.

Hydraulic conductivity values that were preset in model 2 were nearly identical to those in model 1 (tables 16, 17), except in zone 16 of layer 2, where model 2 was assigned a low hydraulic conductivity of 4 ft/d, typical of till. Calibration of model 2 to adjusted observed heads was achieved by decreasing hydraulic conductivities in the Dover well-field subregion below those in model 1 by as much as 20 percent (table 17), thereby increasing drawdown near the well field enough to compensate for the higher heads that resulted from the low hydraulic conductivity in zone 16 of layer 2. The head distribution and flow pattern in layer 2 of model 2 (fig. 42) is similar to that in model 1 except near zone 16, where the flow line that bounds flow toward the well field is shifted south from its position in model 1 (compare figs. 41 and 42). Similar differences in hydraulic conductivity of zone 16 between models 3 and 4 cause a similar contrast in flow pattern within layer 2.

Models 1 and 2 were both calibrated to available data with comparable accuracy (table 18), so the models as defined for this study are incapable of distinguishing which interpretation of the geologic identity and hydraulic conductivity of sediments in the former Rockaway River gorge is correct. Comparison of figures 41 and 42 suggests, however, that the hydraulic conductivity of these sediments would be greatly constrained if head could be measured within the bedrock gorge, near model row 21, column 36, even if no record of materials penetrated by the borehole were available.

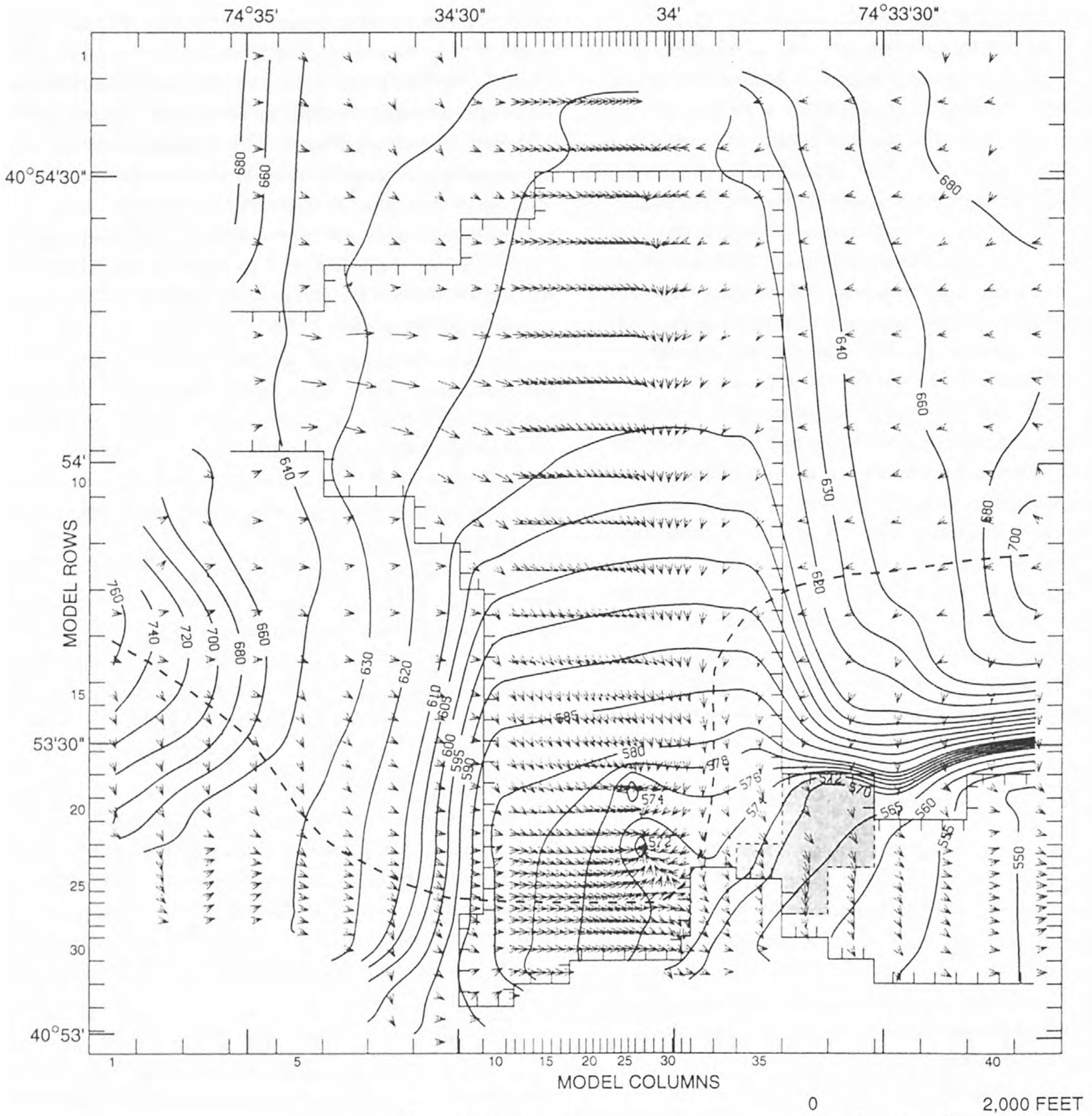
Hydraulic Conductivity of Upland Till

The simulated head distribution in the uplands bordering the Rockaway River valley varies significantly as a function of hydraulic conductivity of till. If the hydraulic conductivity of till is assumed to be only 0.25 ft/d (models 3 and 4, table 17), simulated heads in layer 1 are a slightly subdued replica of land surface, whereas simulated hydraulic conductivities of 4 to 6 ft/d (models 1, 2, 5, and 6, table 17) result in lower heads and gentler head gradients near the valley wall. These relations are illustrated by profiles of head in layer 1 along model row 14 (fig. 43) and by maps of head and flow directions in layer 1 in models 3 and 1 (figs. 44, 45). All these illustrations represent long-term average conditions at end of summer, after 3 months without recharge. The low hydraulic conductivity of model 3 results in a head distribution with short-wavelength features that mimic topographic knolls and minor valleys in the uplands (fig. 45; compare with fig. 33), whereas such features are significantly attenuated at the higher hydraulic conductivity of model 1 (fig. 44).

Because the uplands are an integral part of the ground-water flow system, upland hydraulic properties affect the shape or extent of the area from which ground water flows toward the Dover municipal wells. For example, the position of the ground-water divide in layer 1 that separates flow toward the well field from flow that bypasses the well field on the south side differs considerably between model 3 and model 1 (figs. 44, 45). The differences are due in part to the lower hydraulic conductivity of the valley fill in model 3 (table 17) that was needed to compensate for higher assumed streambed leakance, and also in part to the steeper, less regular hydraulic gradients within the upland that result from the lower simulated hydraulic conductivity of till.

In all six models, lateral flow is generally from the uplands toward the Rockaway River valley, then primarily downvalley. Vertical flow is downward from layer 1 to layer 2 in most places, but upward near gaining reaches of the Rockaway River, near the valley wall, and in a few topographic depressions in the uplands.

The availability of measured heads in the till at a few peripheral upland locations would greatly constrain the plausible range of options for hydraulic conductivity of upland till.



EXPLANATION

Boundary between stratified drift and till or bedrock in layer 2, as simulated in model 1; ticks point to stratified drift

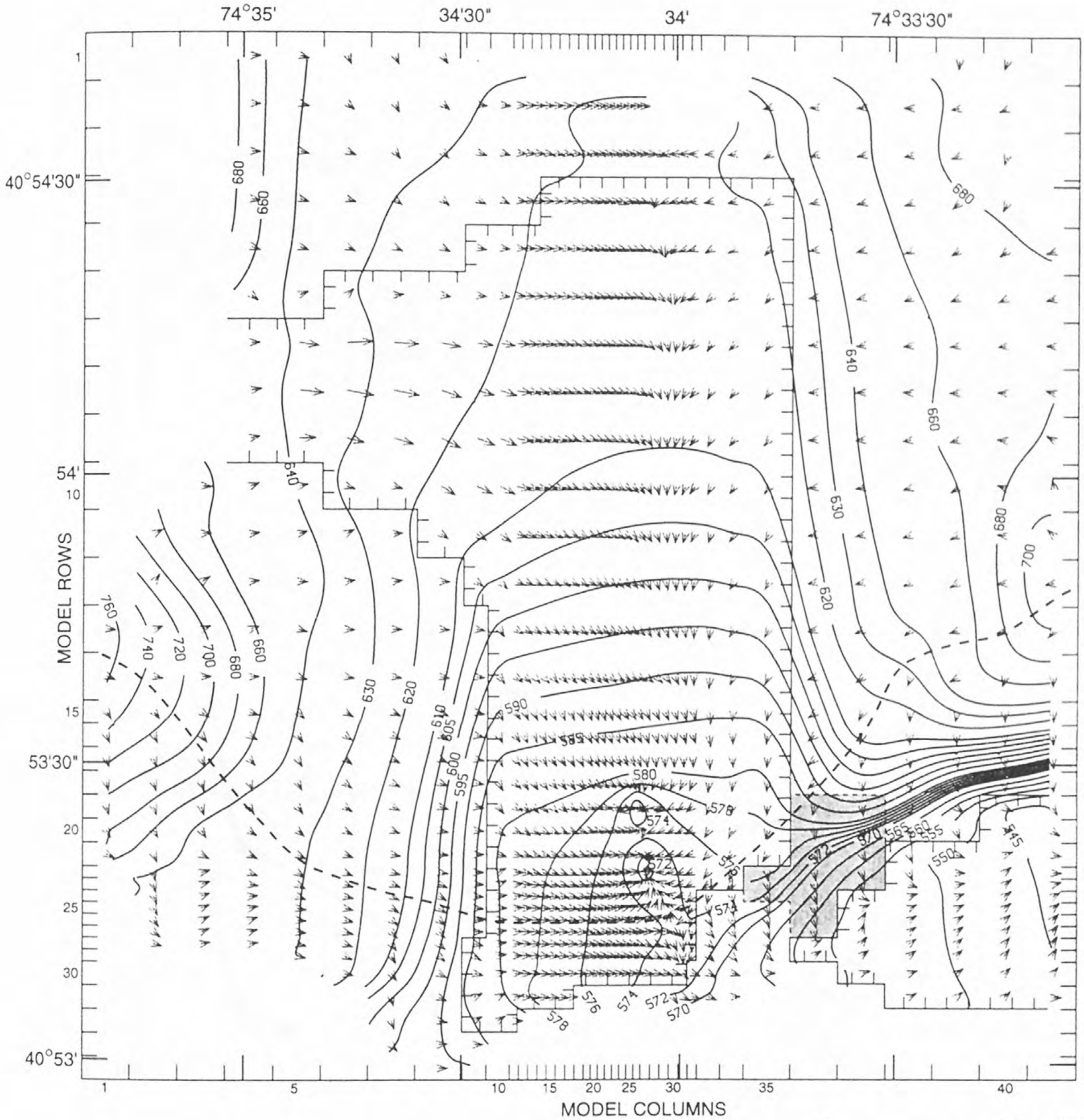
— 660 — Line of equal simulated head in model layer 2, in feet. Contour interval is variable. Datum is sea level

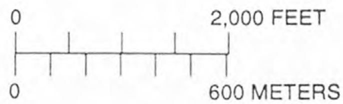
– – – – Approximate ground-water divide separating lateral flow toward Dover well field from flow toward Rockaway River downstream from well field

Zone 16

Average lateral flow direction in model cell, as calculated from equation 8. Length of vector is proportional to rate of flow, except that a vector length 25 percent of the maximum length is used for all flows less than 25 percent of the maximum flow

Figure 41. Simulated long-term average end-of-summer head and lateral flow direction in layer 2 of Dover model 1.





EXPLANATION

Boundary between stratified drift and till or bedrock in layer 2, as simulated in model 2; ticks point to stratified drift

—660— Line of equal simulated head in model layer 2, in feet. Contour interval is variable. Datum is sea level

- - - - Approximate ground-water divide separating lateral flow toward Dover well field from flow toward Rockaway River downstream from well field

Zone 16

Average lateral flow direction in model cell, as calculated from equation 8. Length of vector is proportional to rate of flow, except that a vector length 25 percent of the maximum length is used for all flows less than 25 percent of the maximum flow

Figure 42. Simulated long-term average end-of-summer head and lateral flow direction in layer 2 of Dover model 2.

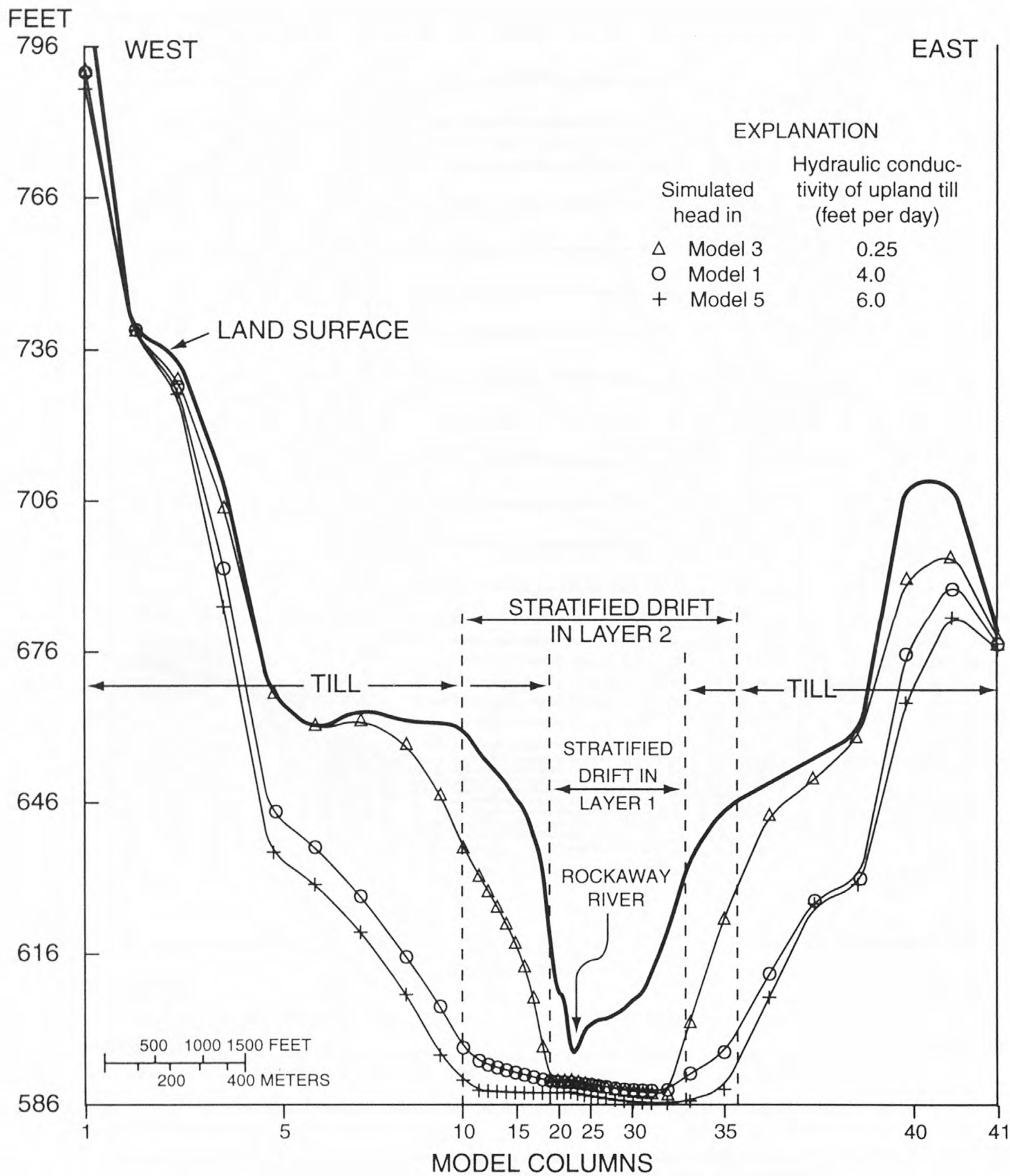
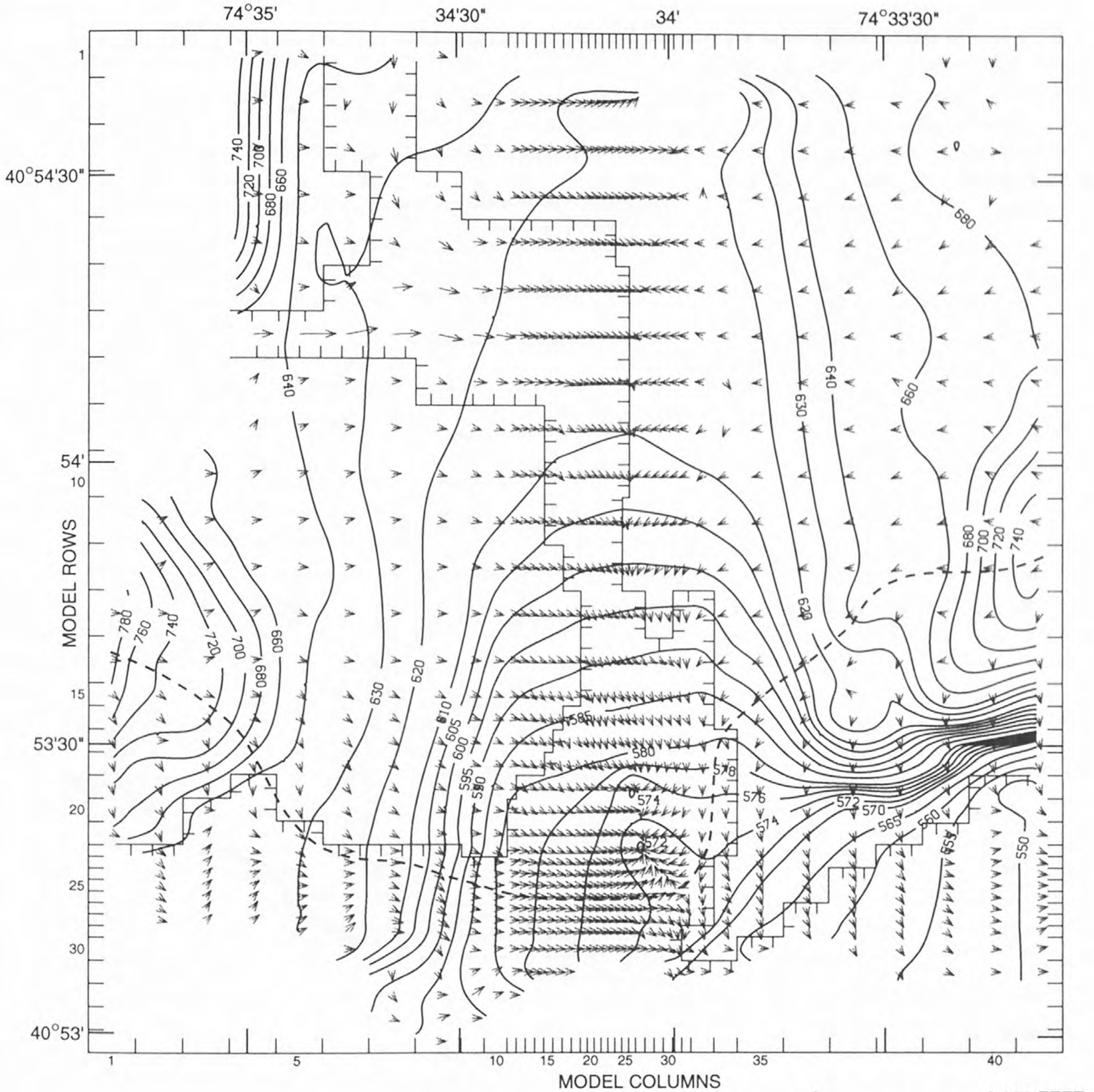


Figure 43. Profiles along model row 14 showing effect of hydraulic conductivity of upland till on simulated end-of-summer heads under long-term average conditions. (Location of row 14 is shown in fig. 24.)



EXPLANATION

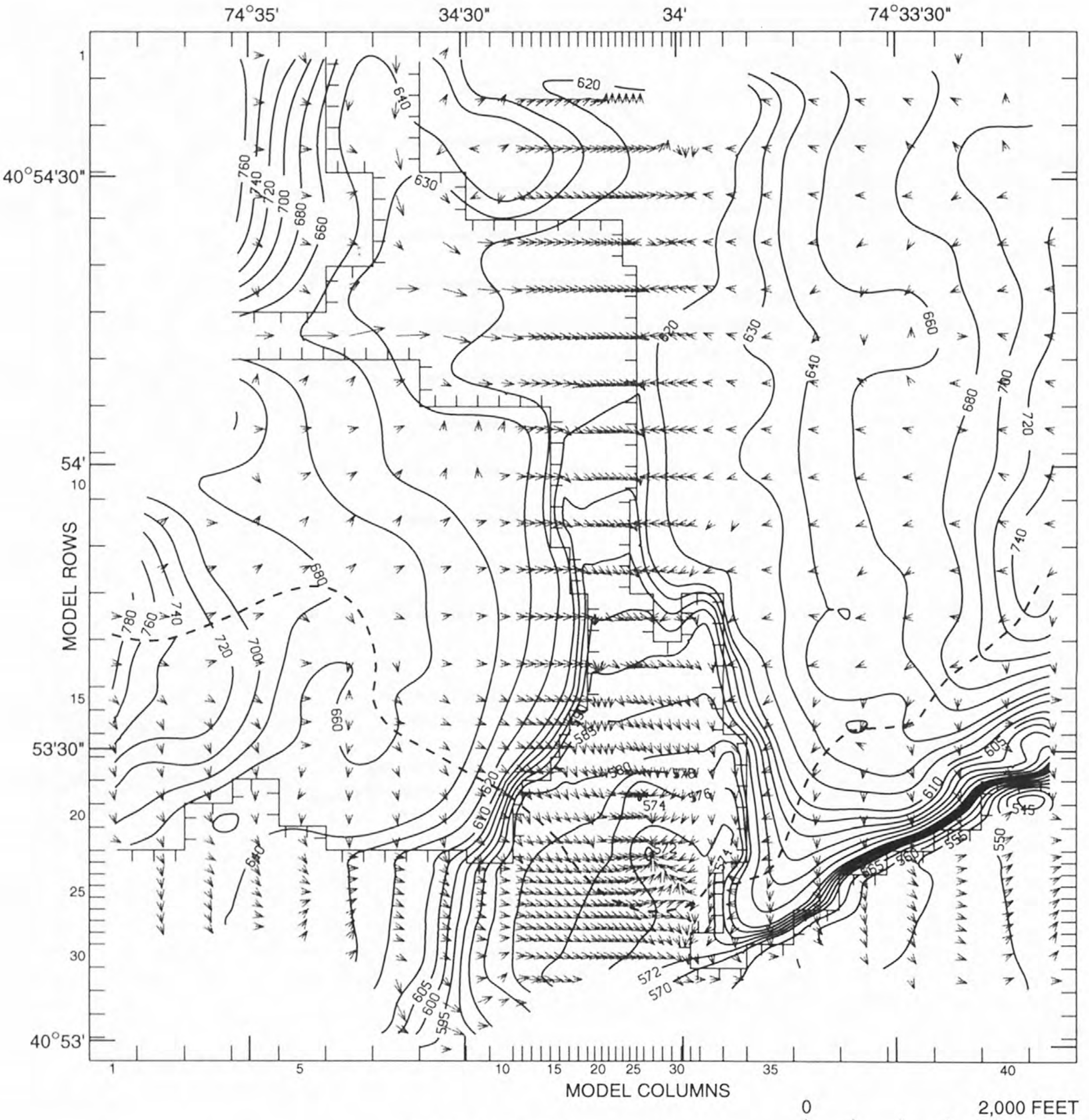
Boundary between stratified drift and till or bedrock in layer 1, as simulated in model 1; ticks point to stratified drift

— 660 — Line of equal simulated head in model layer 1, in feet. Contour interval is variable. Datum is sea level

- - - - Approximate ground-water divide separating lateral flow toward Dover well field from flow toward Rockaway River downstream from well field

Average lateral flow direction in model cell, as calculated from equation 8. Length of vector is proportional to rate of flow, except that a vector length 25 percent of the maximum length is used for all flows less than 25 percent of the maximum flow

Figure 44. Simulated head and flow directions in layer 1 of model 1 at end of summer under long-term average conditions. Streambed leakage is simulated as 0.2 feet per day per foot, and hydraulic conductivity of upland till as 4 feet per day.



EXPLANATION

Boundary between stratified drift and till or bedrock in layer 1, as simulated in model 3; ticks point to stratified drift

—660— Line of equal simulated head in model layer 1, in feet. Contour interval is variable. Datum is sea level

- - - - Approximate ground-water divide separating lateral flow toward Dover well field from flow toward Rockaway River downstream from well field

Average lateral flow direction in model cell, as calculated from equation 8. Length of vector is proportional to rate of flow, except that a vector length 25 percent of the maximum length is used for all flows less than 25 percent of the maximum flow

Figure 45. Simulated head and flow direction in layer 1 of model 3 at end of summer under long-term average conditions. Streambed leakage simulated as 0.6 feet per day per foot, and hydraulic conductivity of upland till as 0.25 feet per day.

SUMMARY

The rate or velocity of induced infiltration from the Rockaway River to a stratified-drift aquifer tapped by municipal wells at Dover, N.J., was determined by several methods. Ground-water flow in the Rockaway River valley at Dover was simulated with a new modeling procedure that incorporates the bordering uplands and computes recharge from upland runoff along the boundary of the aquifer. These studies were undertaken to develop estimates of streambed properties and quantitative techniques that could be used in appraising stratified-drift aquifers throughout the glaciated northeastern United States, rather than to thoroughly appraise the local hydrology. Although Dover is on the terminal moraine at the southern limit of the last glaciation, the Rockaway valley is typical of many valleys further north in that it contains a surficial stratified-drift aquifer several tens of feet thick that is crossed by a large stream (a potential source of induced infiltration) and is bordered by uplands of gneissic bedrock mantled by sandy till. Downstream from the Dover well field, the preglacial bedrock valley is blocked by drift, and the river is diverted through a bedrock gorge. Temperatures and concentrations of solutes and environmental isotopes in ground water indicate that induced infiltration is taking place at Dover. Chemical weathering, chiefly the dissolution of carbonate minerals by carbon dioxide, increases the bicarbonate content of ground water, and man's activities in this urban region presumably account for chloride concentrations 10 times the natural background level.

At Dover, the Rockaway River flows across alluvium and gravelly outwash about 30 ft thick that occupies a broad channel incised through the terminal moraine and overlies earlier deltaic sand that grades down into lake-bottom silt. The streambed leakance (vertical hydraulic conductivity per unit thickness of the unconsolidated sediment immediately underlying the river) is probably between 0.2 and 0.6 (ft/d)/ft, as indicated by the following evidence:

1. Streamflow measurements at carefully prepared sites upstream and downstream from the Dover well field were replicated and adjusted to eliminate differences due to measurement by different individuals at different times during periods of gradually declining low flow. Induced infiltration averaged 0.67 ft^3/s from a reach 2,600 ft in length, from which streambed leakance of 0.21 (ft/d)/ft was calculated.
2. Diurnal water-temperature fluctuations were measured every 2 hours in the river and at 0.5-ft depth intervals below the river at three sites over 4 days in June, 1986; results resemble theoretical temperature profiles that imply a downward Darcian velocity of 1.5 ft/d and a streambed leakance of 0.68 (ft/d)/ft, although the timing of temperature minima suggests that the actual values might be smaller.
3. Dissolved-oxygen concentration was monitored in the river and in a streambed piezometer every 2 hours over the same 4 days; comparison of fluctuation patterns suggests that diurnal dissolved-oxygen extremes required 34 hours to travel the 3.25 ft from riverbed to piezometer, in which case streambed leakance would be 0.28 (ft/d)/ft at that location.
4. Stable isotopes of oxygen and hydrogen in river water and ground water were sampled on 11 dates over the course of a year; chemical mixing models based on these data indicated that about 30 percent of the water reaching an observation well near the center of the Dover well field was derived from the river. If the same percentage of river water were assumed to apply to all water pumped from the nearby wells, then induced infiltration over the year would have averaged 1.5 ft^3/s, and streambed leakance would be 0.68 (ft/d)/ft; the pattern of flow lines relative to these wells suggests that the actual values might be somewhat smaller.

Ground-water flow models of the Rockaway River valley are sensitive to streambed leakance values; a decrease in leakance from 0.6 to 0.2 (ft/d)/ft, with all other hydraulic properties held constant, caused simulated heads near the Dover well field to decline 1.2 to 4 ft. The models can be calibrated to either leakance value, however, primarily through adjustments in hydraulic conductivity of stratified drift that average about 25 percent. The changes in hydraulic conductivity and streambed leakance result in compensating changes in the extent of the simulated area from which ground-water moves laterally to production wells.

The actual leakance of the Rockaway River bed at Dover is probably near the low end of the range generated from field measurements, inasmuch as the application of methods that yielded higher estimates involved assumptions that may not necessarily be valid or extrapolation of data from a few sites to the entire losing reach. All computations are based in part on differential head between river and aquifer measured in only one to five piezometers. If streambed leakance is about 0.3 (ft/d)/ft and streambed thickness is taken to be the average screen depth in the five piezometers (3.3 ft), then vertical hydraulic conductivity of the streambed is about 1 ft/d.

A set of six 2-layer ground-water flow models of the Rockaway River valley aquifer and adjacent uplands near Dover were designed to represent a 2-year period from September 1983 to September 1985. Because water levels near the Dover well field fluctuate in response to multiple starts and shutdowns of municipal wells each day, the models were calibrated to observed water levels that had been adjusted to represent a standard pumping regimen. The 2-year simulation was divided into successive long stress periods (in which average withdrawals over several months were simulated) followed by 1-day or 2-day stress periods on dates of water-level measurement (in which the standard pumping regimen was simulated). River stage in each river node was initially determined from spirit levels or topographic maps and was adjusted to particular stress periods on the basis of frequent measurements at two sites. Transmissivity was estimated from specific capacity of municipal wells. For each model, the 2-year transient-state simulation began with September heads from a four-season transient-state simulation of long-term average conditions that had been cycled repeatedly until heads reached equilibrium. The criterion for model calibration was to minimize the mean absolute difference between heads at observation wells (adjusted to the standard pump regimen) and heads interpolated from the unevenly spaced model grid to a 50-ft grid spacing.

Thickness and hydraulic properties of the stratified drift in a short reach of the Rockaway valley near the Dover well field could readily be characterized from several well logs, seismic surveys, and specific-capacity data; periodic water-level measurements also were available for model calibration. Instead of limiting the models to this small subregion and specifying boundary conditions and fluxes along its periphery, the models were expanded to include the bordering uplands and adjacent reaches of the Rockaway River valley, where the only sources of information were a surficial geology map and scattered well records. Thus, flux across the subregion perimeter was dependent on the manner in which areas peripheral to the subregion were simulated. A new model subroutine, termed the Variable-Recharge procedure, was developed to simulate recharge and runoff in uplands bordering a valley-fill aquifer and to allocate upland runoff as recharge along the margins of the aquifer. Water that was available for recharge from precipitation, computed from climate records, was partitioned by the Variable-Recharge procedure; the water was accepted as recharge in upland model cells where head was below land surface but was rejected where head was at or above land surface. The rejected recharge was then combined with simulated seepage discharge and treated as surface (or near-surface) runoff. The simulated surface runoff was reapplied as water available for recharge to selected nodes at the base of the hillsides; its magnitude was arbitrarily decreased in urbanized upland areas to account for presumed diversion of some runoff to storm sewers. Upland hillsides at Dover lack obvious stream channels, but if some had been identified, the Variable-Recharge procedure would have treated this form of upland runoff separately. Recharge accepted by upland model cells generally moved laterally as ground water into valley-fill stratified drift. In some localities, however, especially during periods of abundant precipitation, the combination of lateral ground-water flow and recharge from unchanneled runoff raised the simulated head at the edge of the valley to land surface; therefore, some recharge was again rejected and assumed to run off to streams.

Inclusion of the uplands in a simulation of a valley-fill system and use of the Variable-Recharge procedure increases the amount of required model input data and the overall complexity of the model. Once the Variable-Recharge input data are established, however, minimal effort is required to generate data for transient-state simulations with multiple stress periods. Although the hydraulic properties of uplands typically are poorly known, the Variable-Recharge procedure can be a viable simulation alternative in investigations where contributing area to wells or hydraulic interaction between the uplands and the valley fill is of interest.

Most hydraulic stresses and properties were the same for all Dover models, except that significant differences were imposed in hydraulic conductivity of upland till, streambed leakance, and hydraulic conductivity of specific zones in layer 2 whose geologic character was uncertain. When till was assigned a low hydraulic conductivity, 0.25 ft/d, the simulated upland water table was a slightly subdued replica of land surface that included several short-wavelength features. By contrast, when till was assigned a hydraulic conductivity of 4 ft/d, the result was lower heads and gentler, smoother water-table gradients in the uplands, with far fewer nodes saturated to land surface and an increase in recharge to the valley fill from upland sources. When the drift that blocks a former reach of the Rockaway River valley near the Dover well field was simulated as till (hydraulic conductivity 4 ft/d) rather than sand and gravel (hydraulic conductivity 300 ft/d), calibration resulted in higher heads in the former valley reach and a substantial change in flow paths and contributing area to the Dover well field. A change in simulated streambed leakance from 0.2 to 0.6 (ft/d)/ft was accompanied by a proportional change in induced infiltration and a compensating change in well-field contributing area. The five models that incorporated these imposed differences in hydraulic properties were calibrated by modifications of hydraulic conductivity of the valley fill near the Dover well field that deviated from average hydraulic conductivities of corresponding areas in all five models by less than a few tens of percent, which is within the typical range of accuracy of estimates of hydraulic conductivity. Therefore, model calibration solely to heads near the Dover well field could not be used to judge which set of hydraulic properties of peripheral areas or which value of streambed leakance was most likely.

When the storage coefficient of stratified drift was decreased from 0.2 to 0.1, the mean absolute deviation of simulated heads from observed heads over all stress periods decreased from 0.6 to 0.3 ft; much of the improvement resulted from a far better fit in stress period 4, when water levels rose several feet in response to a 2-day rainfall of 5 inches, but fit was better in other stress periods as well. A storage coefficient of 0.1 is compatible with values typically derived from aquifer tests, which are generally considered more appropriate for simulating short-term water-level fluctuations than the larger values typically derived from laboratory measurements.

For each of the six models discussed in this report, the simulated hydrogeologic properties are based on limited data, simplifying assumptions, and the process of calibration . They are a particular combination of properties that produced simulated heads that closely match the spatial and temporal distribution of water levels at a limited number of observation wells. As in all ground-water flow models, other combinations of properties would produce analogous results. Thus, the sets of properties arising from the simulations are not to be taken as being definitive, but rather as approximations of actual hydrogeologic conditions.

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Table 20.—Logs of selected wells near Dover, N.J.

[Well owner: DTWD, Dover Water Dept.; WBWD, Wharton Water Dept.; USGS, U.S. Geological Survey. Well locations are shown in figs. 5 or 8.]

USGS well number, local number, and well owner	Lithology	Depth (feet)
27-286 PW1 DTWD	Till and boulder	0-25
	Sand and silt	25-35
	Sand and gravel	35-45
	Sand and gravel (coarse)	45-55
	Sand and gravel (very coarse, clean)	55-60
	Sand (fine) and clay	60-64
	Clay, sand (hardpan)	64-68
27-290 T5 DTWD	Artificial fill	0-4
	Sand (very fine to medium), silt (grayish brown), trace of gravel and pebbles	4-20
	Sand (very fine to coarse, grayish-brown), trace of gravel and cobbles	20-40
	Sand (very fine to coarse, poorly sorted, grayish brown), some gravel, pebbles, and silt	40-50
	Sand (very fine to very coarse, grayish-brown), gravel (fine to medium)	50-60
	Sand (very fine to coarse, grayish-brown), cobbles and silt	60-68
	Clay (light grayish-brown) and cobbles	68-92
	Gravel, pebbles, and cobbles	92-95
	Clay (grayish-brown)	95-98
	Crystalline bedrock (weathered)	98-101
27-291 PW5 DTWD	Till and silt	0-15
	Cobbles (small), sand (brown), and silt	15-25
	Cobbles (small) and gravel	25-40
	Cobbles (big) and gravel	40-65
	Sand (fine) and silt	65-67
	Clay (green)	67-73
27-305 D1 USGS	Top soil	0-2
	Sand and gravel (yellowish-brown)	2-8
	Cobbles, sand, and gravel. Boulder zone.	8-12
	Sand and gravel (medium to coarse)	12-20
	Boulder zone	20-22
	Sand (fine to coarse, brightly colored)	22-30
	Cobbles (hard drilling)	30-32
	Gravel (coarse)	32-33
	Sand (fine to coarse, brightly colored)	33-45
	Sand (fine to coarse) and some silt	45-50
	Sand (fine to coarse) and some gravel	50-60
	Sand (same as above)	60-66
	Clayey silt (yellowish-brown, soft)	66-70

Table 20.—Logs of selected wells near Dover, N.J. (continued)

USGS well number, local number, and well owner	Lithology	Depth (feet)
27-306 D6 USGS	Top soil	0-2
	Sand and gravel	2-6
	Sand and gravel (medium to coarse)	6-8
	Sand, gravel, cobbles, and some silt	8-15
	Organic silt (black organic-rich layer)	15-16
	Sand (fine to coarse)	16-25
	Sand (fine to very coarse)	25-30
	Boulder zone	30-32
	Gravel	32-33
	Sand (very fine to medium, yellowish brown)	33-45
	Sand (very fine to fine), gravel, and some silt	45-65
	Silty sand (very fine)	65-70
	Silt and sand (very fine), some clay stringers	70-80
27-322 T2 DTWD	Sand (fine to medium, light brown)	0-15
	Sand (fine, light gray)	15-20
	Sand (fine to coarse, light brown)	20-25
	Sand (medium, salt and pepper color)	25-40
	Sand and gravel (coarse to very coarse, light brown)	40-50
	Sand and gravel (medium)	50-65
	Sand (fine to medium) and some silt	65-80
	Clayey silt (light gray)	80-90
	Sand (fine) and silt	90-95
	Silt (light gray)	95-130
	Crystalline bedrock	at 130
27-343 TW4 WBWD	Fill	0-7
	Clay, sand, and gravel	7-17
	Gravel, sand, and boulders	17-33
	Till	33-36
	Sand and gravel, some clay	36-40
	Sand (fine) and some silt	40-51
	Sand (medium, dark brown) and some silt	51-63
	Clay and sand	63-71
	Sand and some clay	71-79
	Sand, some silt, and streaks of clay	79-84
	Clay, sand and gravel	84-87
	Bedrock (weathered)	87-104
	Bedrock (hard)	104-114

Table 20.—Logs of selected wells near Dover, N.J. (continued)

USGS well number, local number, and well owner	Lithology	Depth (feet)
27-351 Rockaway	Overburden	0-25
Shop Center	Clay, gravel, sand	25-130
	Granite (brown, weathered)	130-160
	Granite (green-white)	160-171
27-353 PW3 WBWD	Sand and gravel, boulders	0-10
	Sand and gravel, pebbles	10-18
	Sand and gravel (coarse)	18-30
	Sand (coarse), gravel, pebbles	30-40
	Gravel (coarse) with pebbles and cobbles	40-50
	Sand (fine), gravel (coarse), and cobbles	50-60
	Sand (fine to coarse), some cobbles and boulders	60-64
27-357 PW4 DTWD	Stones (large)	0-12
	Silt (very fine)	12-30
	Sand (fine)	30-95
	Sand (coarse)	95-103
	Sand and gravel (medium to coarse)	103-135
	Gravel (coarse)	135-138
	Sand (fine)	138-149
	Bedrock	at 149
27-764 L.E. Carpenter Co.	Pavement, fill	0-2
	Silt (clayey, brown), little coarse to fine sand	2-5
	Gravel (coarse, decomposed)	5-10
	Sand (coarse to fine), some gravel (fine to medium), trace silt, saturated, chemical odor	10-20
	Gravel (coarse to fine), some sand (coarse), occasional cobbles and boulders	20-30
	Sand (coarse to fine), and gravel (coarse to fine), little silt, brown	30-35
	Sand (coarse to fine), and gravel, trace silt, gray	35-40
27-1836 TW1 WBWD	Soil	0-3
	Sand (fine to medium), silty	3-15
	Sand (medium to coarse), trace of gravel and pebbles	15-20
	Gravel (fine to coarse), trace of sand and silt	20-30
	Sand (fine to medium), trace of gravel and silt	30-41
	Sand (coarse) and gravel (fine)	41-52
	Silt	52-53
	Sand (coarse), trace gravel and silt	53-56
	Gravel (fine to coarse), trace clay silt and sand, compact	56-60
	Gravel (fine to coarse), clay, compact	60-70

Table 20.—Logs of selected wells near Dover, N.J. (continued)

USGS well number, local number, and well owner	Lithology	Depth (feet)
27-1836 TW1 WBWD (cont.)	Sand and gravel, trace silt and clay	70-80
	Sand (medium), trace clay to pebbles, very compact	80-100
	Sand (fine), trace silt and clay, compact	100-106
	Silty sand with clay	106-121
	Clay (firm), trace silt and sand	121-130
	Sand (fine to medium), trace clay and pebbles	130-135
	Sand and silt, trace clay and gravel, very compact	135-157
27-886 TW2 WBWD	Sand (medium), to gravel (fine), trace clay and boulders	0-5
	Sand (fine), to gravel (fine), trace clay	5-15
	Sand (fine to coarse) with clay, trace boulders	15-32
	Gravel with trace sand and clay	32-33
	Sand to pebbles, trace silt and clay	33-38
	Bedrock, granitic rock	38-39
27-915 TW3 WBWD	Silty sand, peat	0-2
	Sand (fine to very coarse), trace of silt, trace of gravel (fine to coarse) and cobbles	2-21
	Sand (fine to very coarse), trace of gravel and cobbles	21-30
	Clay, trace of silt (fine) to sand (very fine)	30-33
	Sand (coarse to very coarse), gravel (coarse), trace of cobbles	33-61
	Sand and gravel (fine to very coarse)	61-64.5
	Crystalline bedrock	at 64.5
27-1116 Townsquare	Fill with dirt and boulders	0-16
Nursery	Sand and silt (fine, dirty)	16-90
	Sand (fine), heaving	90-110
	Sand (coarse), little gravel	110-115
	Granite	at 115
27-2001 M. Ehrlich	Overburden	0-22
	Sand (fine) and gravel (dry)	22-40
	Clay, sand, gravel mix	40-72
	Coarse gravel mix	72-95
	Fine gravel	95-97
27-2000 S.T. Smith	Sand, cobbles, boulders	0-45
	Quicksand	45-125
	Potter's clay (blue)	125-133
	Quicksand	133-135
	Bedrock	at 135

Table 20.—Logs of selected wells near Dover, N.J. (continued)

USGS well number, local number, and well owner	Lithology	Depth (feet)
27-351 Rockaway	Overburden	0-25
Shop Center	Clay, gravel, sand	25-130
	Granite (brown, weathered)	130-160
	Granite (green-white)	160-171
27-353 PW3 WBWD	Sand and gravel, boulders	0-10
	Sand and gravel, pebbles	10-18
	Sand and gravel (coarse)	18-30
	Sand (coarse), gravel, pebbles	30-40
	Gravel (coarse) with pebbles and cobbles	40-50
	Sand (fine), gravel (coarse), and cobbles	50-60
	Sand (fine to coarse), some cobbles and boulders	60-64
27-357 PW4 DTWD	Stones (large)	0-12
	Silt (very fine)	12-30
	Sand (fine)	30-95
	Sand (coarse)	95-103
	Sand and gravel (medium to coarse)	103-135
	Gravel (coarse)	135-138
	Sand (fine)	138-149
	Bedrock	at 149
27-764 L.E. Carpenter Co.	Pavement, fill	0-2
	Silt (clayey, brown), little coarse to fine sand	2-5
	Gravel (coarse, decomposed)	5-10
	Sand (coarse to fine), some gravel (fine to medium), trace silt, saturated, chemical odor	10-20
	Gravel (coarse to fine), some sand (coarse), occasional cobbles and boulders	20-30
	Sand (coarse to fine), and gravel (coarse to fine), little silt, brown	30-35
	Sand (coarse to fine), and gravel, trace silt, gray	35-40
27-1836 TW1 WBWD	Soil	0-3
	Sand (fine to medium), silty	3-15
	Sand (medium to coarse), trace of gravel and pebbles	15-20
	Gravel (fine to coarse), trace of sand and silt	20-30
	Sand (fine to medium), trace of gravel and silt	30-41
	Sand (coarse) and gravel (fine)	41-52
	Silt	52-53
	Sand (coarse), trace gravel and silt	53-56
	Gravel (fine to coarse), trace clay silt and sand, compact	56-60
	Gravel (fine to coarse), clay, compact	60-70

Table 20.—Logs of selected wells near Dover, N.J. (continued)

USGS well number, local number, and well owner	Lithology	Depth (feet)
27-1836 TW1 WBWD (cont.)	Sand and gravel, trace silt and clay	70-80
	Sand (medium), trace clay to pebbles, very compact	80-100
	Sand (fine), trace silt and clay, compact	100-106
	Silty sand with clay	106-121
	Clay (firm), trace silt and sand	121-130
	Sand (fine to medium), trace clay and pebbles	130-135
	Sand and silt, trace clay and gravel, very compact	135-157
27-886 TW2 WBWD	Sand (medium), to gravel (fine), trace clay and boulders	0-5
	Sand (fine), to gravel (fine), trace clay	5-15
	Sand (fine to coarse) with clay, trace boulders	15-32
	Gravel with trace sand and clay	32-33
	Sand to pebbles, trace silt and clay	33-38
	Bedrock, granitic rock	38-39
27-915 TW3 WBWD	Silty sand, peat	0-2
	Sand (fine to very coarse), trace of silt, trace of gravel (fine to coarse) and cobbles	2-21
	Sand (fine to very coarse), trace of gravel and cobbles	21-30
	Clay, trace of silt (fine) to sand (very fine)	30-33
	Sand (coarse to very coarse), gravel (coarse), trace of cobbles	33-61
	Sand and gravel (fine to very coarse)	61-64.5
	Crystalline bedrock	at 64.5
27-1116 Townsquare	Fill with dirt and boulders	0-16
Nursery	Sand and silt (fine, dirty)	16-90
	Sand (fine), heaving	90-110
	Sand (coarse), little gravel	110-115
	Granite	at 115
27-2001 M. Ehrlich	Overburden	0-22
	Sand (fine) and gravel (dry)	22-40
	Clay, sand, gravel mix	40-72
	Coarse gravel mix	72-95
	Fine gravel	95-97
27-2000 S.T. Smith	Sand, cobbles, boulders	0-45
	Quicksand	45-125
	Potter's clay (blue)	125-133
	Quicksand	133-135
	Bedrock	at 135

Table 21.—Records of wells near Dover, N.J.

[ft, feet; in, inches; gal/min, gallons per minute. Footnotes listed on p. 84]

USGS well no.[1]	Local well no. (or name) and well owner[2]	Latitude	Longi-tude	Sequence no.[3]	Type of well[4]	Aquifer code[5]	Altitude of land surface (ft)[6]	Well depth below land surface (ft)	Depth to bedrock below land surface(ft)
Dover Town									
27-286	PW1 DTWD	405326	743405	01	P	SFDF	590.7	65.0	—
27-287	RE DTWD	405318	743407	02	O	GRGN	589.0	154.0	—
27-288	PW3 DTWD	405321	743404	01	P	SFDF	590.1	74.0	—
27-289	PW2 DTWD	405325	743405	02	PA	SFDF	589.2	72.0	—
27-290	T5 DTWD	405317	743404	03	T	SFDF	589.6	68.0	98
27-291	PW5 DTWD	405317	743404	02	P	SFDF	590.1	64.0	—
27-292	S1 USGS	405316	743405	01	O	SFDF	581.2	17.7	—
27-293	S2 USGS	405317	743405	01	O	SFDF	586.1	28.5	—
27-294	S3 USGS	405317	743404	01	O	SFDF	589.7	28.4	—
27-295	S4 USGS	405318	743407	01	O	SFDF	588.6	28.6	—
27-296	S5 USGS	405325	743405	01	O	SFDF	588.8	28.9	—
27-297	S6 USGS	405316	743412	01	O	SFDF	591.4	28.4	—
27-298	S7 USGS	405321	743411	01	O	SFDF	586.0	18.6	—
27-299	S8 USGS	405321	743412	01	O	SFDF	584.1	18.8	—
27-300	S9 USGS	405325	743405	03	O	SFDF	586.5	27.4	—
27-301	S10 USGS	405326	743408	01	O	SFDF	591.0	28.8	—
27-302	S11 USGS	405313	743402	01	O	SFDF	583.1	28.0	—
27-303	S12 USGS	405328	743408	01	O	SFDF	586.7	22.9	—
27-305	D1 USGS	405316	743405	02	O	SFDF	582.2	59.5	—
27-306	D6 USGS	405316	743412	02	O	SFDF	591.5	59.5	—
27-315	P1 USGS	405330	743409	01	O	SFDF	582.3	4.0	—
27-316	P2 USGS	405321	743411	02	O	SFDF	580.9	4.0	—
27-317	P3 USGS	405321	743412	02	O	SFDF	579.3	4.0	—
27-318	P4 USGS	405316	743405	03	O	SFDF	577.1	4.5	—
27-319	P5 USGS	405310	743404	01	O	SFDF	572.2	4.0	—
27-322	T2 DTWD	405314	743253	a	T	SFDF	555.	62.0	130
27-344	Hurd Park DTWD	405308	743419	01	T	SFDF	590.	90.0	90
27-345	W3 NJDOT	405307	743358	01	B	GRGN	586.8	18.0	7
27-346	11S DNHC	405315	743402	01	O	SFDF	582.9	12.4	—
27-347	11D DNHC	405315	743402	02	O	SFDF	582.9	24.3	—
27-348	10S DNHC	405317	743402	01	O	SFDF	583.1	10.4	—
27-349	10D DNHC	405317	743402	02	O	SFDF	583.1	23.6	—
27-354	Food Fair 1	405306	743351	01	IA	SFDF	577.	72.0	—
27-355	JC Penny 1	405304	743346	01	IA	SFDF	570.	77.0	—
27-357	PW4 DTWD	405307	743231	b	PA	SFDF	555.	138.0	149
27-2000	S.T. Smith	405308	743434	c	—	—	630.	135.0	135
27-2001	M. Erlich	405307	743343	c	—	SFDF	570.	96.0	—
Rockaway Township									
27-350	Parkwood 1	405409	743321	01	D	GRGN	680.	107.0	106
27-351	Rockaway Shop Ctr	405432	743308	01	D	GRGN	715.	171.0	130
27-1116	Townsquare Nursery	405407	743405	d	—	GRGN	620.	120.0	115
Wharton Borough									
27-343	T 4 WBWD	405406	743447	01	T	SFDF	655.	87.0	87
27-352	Shamrock 1	405419	743413	01	D	GRGN	625.	98.0	—
27-353	PW3 WBWD	405339	743408	01	P	SFDF	597.3	65.0	65
27-764	L.E. Carpenter Co.	405412	743439	e	T	SFDF	640.	37.5	—
27-1836	TW1 WBWD	405427	743435	01	T	—	640.	157.0	—
27-886	TW2 WBWD	405416	743503	01	T	—	655.	39.0	38
27-915	TW3 WBWD	405339	743408	02	T	SFDF	597.3	65.0	65

Table 21.—Records of wells near Dover, N.J. (continued)

USGS[1] well no.	Date completed	Casing diameter (in)	Open interval below land surface[7] (ft)	Well Acceptance Test[8]: Water level below land surface: Static (ft)	Pumping (ft)	Yield [9] (gal/min)	Specific capacity (gal/min per ft)	Length of test (hours)	Remarks[10]
Dover Town									
27-286	4/1/66	18	45.0-65.0	11.20	25	1711	126.70	72.0	L.W.G&M 238
27-287	—	8	152.0-154.0	11.25	25	10	0.75	3.0	W.R
27-288	9/6/40	18	52.0-74.0	8.35	25	1625	95.59	12.0	W.
27-289	9/1/39	12	52.0-72.0	11.00	22	1200	109.09	12.0	W.
27-290	8/11/71	8	48.0-68.0	13.03	19	525	87.94	24.0	L.W.
27-291	9/10/71	18	44.0-64.0	14.00	29	1529	101.93	72.0	L.W.
27-292	5/15/84	2	12.7-17.7	4.30	—	6	—	0.5	W.R.
27-293	5/8/84	2	18.5-28.5	8.62	—	4	—	0.5	W.
27-294	5/9/84	2	18.4-28.4	11.10	—	6	—	0.5	W.
27-295	5/10/84	2	18.6-28.6	10.69	—	6	—	0.5	W.
27-296	5/10/84	2	18.9-28.9	10.07	—	6	—	0.5	W.
27-297	5/10/84	2	18.4-28.4	11.40	—	6	—	0.5	W.R
27-298	5/15/84	2	13.6-18.6	7.65	—	4	—	0.5	W.
27-299	5/16/84	2	13.8-18.8	5.79	—	6	—	0.5	W.
27-300	5/14/84	2	17.4-27.4	8.16	—	6	—	0.5	W.
27-301	5/15/84	2	18.8-28.8	10.41	—	4	—	0.5	W.
27-302	5/16/84	2	18.0-28.0	6.98	—	6	—	0.5	W.
27-303	5/16/84	2	17.9-22.9	5.20	—	9	—	0.5	W.
27-305	8/13/84	4	50.5-59.5	6.21	—	2	—	1.0	L.W.R.
27-306	8/14/84	4	50.5-59.5	12.96	—	3	—	1.0	L.W.R.
27-315	9/8/84	1	3.0-3.5	—	—	—	—	—	W.P.
27-316	9/8/84	1	3.0-3.5	—	—	—	—	—	W.P.
27-317	9/8/84	1	3.0-3.5	—	—	—	—	—	W.P.
27-318	9/2/84	1	3.5-4.0	—	—	—	—	—	W.P.
27-319	9/8/84	1	3.0-3.5	—	—	—	—	—	W.P.
27-322	8/9/60	8	47.0-62.0	2.75	46	383	8.91	24.0	L.G&M 106
27-344	-/-/62	6	—	—	—	150	—	—	G&M 239
27-345	11/27/78	3	—	—	—	—	—	—	
27-346	3/22/85	4	5.4-12.4	6.10	—	—	—	—	W.
27-347	3/22/85	4	14.3-24.3	6.90	—	—	—	—	W.
27-348	3/21/85	4	5.4-10.4	6.80	—	—	—	—	W.
27-349	3/21/85	4	13.6-23.6	6.80	—	—	—	—	W.
27-354	2/12/57	10	60.0-72.0	15.00	69	400	7.40	24.0	G&M 240
27-355	4/5/52	10	66.0-77.0	17.00	60	1000	23.30	5.0	G&M 241
27-357	8/3/62	18	118.0-138.0	5.50	42	1455	39.90	72.0	L. G&M 127
27-2000	1886	—	—	—	—	—	—	—	L. NJ 45-263. Location approx.
27-2001	8/22/56	6	82-96	17.00	54	144	3.90	8.0	L. NJ 5545
Rockaway Township									
27-350	9/8/77	6	106.0-107.0	—	—	20	—	—	Location approx.
27-351	3/1/79	6	132.0-171.0	—	—	20	—	—	L.
27-1116	5/21/85	6	113-120	40.00	90	5	0.1	1.5	L. NJ 25-24,993 Location approx.
Wharton Borough									
27-343	-/-/59	8	—	—	—	290	97.00	—	L.
27-352	6/21/60	5	90.0-98.0	10.00	60	15	0.30	2.0	
27-353	4/16/71	18	40.0-65.0	5.00	18	1500	120.00	72.0	L.
27-764	5/14/80	2	7-37	9.00	12	20	6.70	—	L. NJ 21,326
27-1836	6/15/70	8	—	—	—	—	—	—	NJ 25-15,571
27-886	6/17/70	8	—	—	—	—	—	—	NJ 25-15,570
27-915	6/25/70	8	40-65	5.80	10	495	118.00	48.0	

Table 21.—Records of wells near Dover, N.J. (continued)

NOTES

[1] Well number consists of a county code number followed by a sequential number assigned at the time the well was originally inventoried. In the U.S. Geological Survey's Ground-Water Site Inventory data base for New Jersey, well numbers are stored in component C5 ("project number") with a zero replacing the dash used in this table.

[2] DTWD, Dover Water Department
DNHC, Dayco National Hose Company

NJDOT, New Jersey Department of Transportation
USGS, U.S. Geological Survey
WBWD, Wharton Water Department

[3] Each well in the U.S. Geological Survey's Ground-Water Site Inventory data base is identified by a 15-digit number stored in component C1 ("site number"). Each number consists of latitude, a zero, longitude, and the sequence number listed in this column. For a few wells, indicated by lettered footnotes in this column, site-identification numbers do not exactly correspond to latitude or longitude, generally because the locations of those particular wells had been plotted or measured somewhat differently by different individuals at different times.

a site number 405314074325001
b site number 405309074322901
c these wells not in U.S. Geological Survey data base in 1994
d site number 4054110743556
e site number 405415074343701

[4] A, no longer in use; B, test boring; D, domestic; I, industrial; O, observation; P, public water supply; T, test well.

[5] Symbols: SFDF, stratified drift; GRGN, granite and gneiss.

[6] Altitudes reported to the nearest tenth of a foot were measured by standard survey techniques and are accurate to ±0.1 ft.
Altitudes reported to the nearest foot were estimated from topographic maps and are accurate to ±10 ft.
For piezometers beneath the Rockaway River (27-315 to 319), altitude is top of streambed.

[7] Open interval is the uncased area in the well, either screened or open hole, where ground water enters.

[8] Generally measured within 2 weeks of well-completion date.

[9] Maximum short-term yield commonly exceeds reported value. Reported values are rounded to the nearest gallon.

[10] W, Water levels measured periodically during this study and reported in table 22.
R, Water-level recorder installed, generally 8/1/84 to 10/1/84.
L, Log in table 20.
P, Screened well point driven into bed of Rockaway River. Altitude of land surface is top of streambed.
G&M __, Well number in Geraghty and Miller (1969).
NJ __, New Jersey Division of Water Resources permit number.

Table 22. Measurements of water level in wells and in the Rockaway River at Dover, N.J.

[MP alt, altitude of measuring point, which is top of well casing except for measurements by air line. RP alt, altitude of reference point on bridge or river bank. Altitudes are in feet above sea level. Locations shown in fig. 8.]

Date	Time	Water-surface altitude
Well 27-286 PW1		**MP alt 592.70***
05-18-84		576.70
07-07-84	1035	574.70
08-04-84	1020	567.70
08-18-84	1315	575.70
09-01-84	1503	568.70
09-20-84	1351	574.70
09-20-84	1500	574.70
10-17-84	1430	572.70
05-28-85	1110	562.70
Well 27-287 RE		**MP alt 589.43**
05-18-84	1300	580.30
07-07-84	0720	580.89
07-14-84	0950	581.24
07-28-84	1601	580.81
08-04-84	0834	580.56
08-13-84	1248	580.28
08-13-84	1404	580.25
08-13-84	1510	580.22
08-13-84	1650	580.20
08-18-84	1220	580.05
08-22-84	0831	579.88
08-26-84	1539	579.83
09-01-84	1544	579.68
09-08-84	0945	579.73
09-14-84	1539	579.62
09-20-84	1157	579.41
10-17-84	1222	578.92
11-15-84	1057	578.75
01-19-85	1110	579.34
03-29-85	1000	578.34
05-28-85	1057	578.65
06-10-85	1008	578.71
07-11-85	1015	578.49
09-19-85	1220	578.07
11-19-85	0853	579.74
07-06-88	1318	577.83
07-06-88	1616	577.78
07-07-88	0941	577.86
07-07-88	1443	577.83
Well 27-289 PW2		**MP alt 589.16****
05-18-84	1330	577.85
07-07-84	1015	580.47
07-28-84	1615	578.46
08-18-84	1300	577.32
09-01-84	1459	576.14
09-20-84	1344	576.09
09-20-84	1511	576.19
10-17-84	1229	575.38
01-19-85	1310	574.30
05-28-85	1015	575.27
Well 27-290 T5		**MP alt 590.49**
05-18-84	1230	576.46
07-07-84	0820	576.71
07-14-84	1020	574.69
07-14-84	1254	573.87
07-28-84	1605	573.39
08-04-84	0822	574.21
08-04-84	1236	572.74
08-18-84	0815	576.37
08-20-84	1530	572.16
08-22-84	0818	576.46
09-01-84	1558	572.09
09-20-84	1146	572.25
09-20-84	1438	571.79
10-17-84	1119	575.04
11-15-84	0913	575.09
12-19-84	1000	575.44
01-19-85	0900	574.21
02-22-85	0955	574.85
03-29-85	1000	574.48
05-02-85	0925	573.44
05-28-85	1205	575.41
06-10-85	0829	575.37
07-11-85	0940	572.42
08-17-85	0801	575.42
09-19-85	1230	574.20
11-19-85	0923	578.07
Well 27-292 S1		**MP alt 583.63**
05-18-84	1030	576.93
07-07-84	0900	579.24
07-28-84	1343	576.87
08-04-84	0922	577.88
08-13-84	1223	576.08
08-18-84	0857	576.91
08-21-84	1131	575.98
08-21-84	1244	575.74
08-21-84	1336	575.63
08-22-84	0859	576.98
08-26-84	1605	575.65
09-01-84	1635	575.25
09-04-84	1550	576.41
09-14-84	1555	575.51
09-20-84	1131	575.47
10-17-84	1102	575.55
11-15-84	1201	575.61
12-20-84	0845	575.39
01-18-85	1011	575.13
02-22-85	1156	575.52
03-30-85	1520	575.63
05-02-85	1145	575.21
05-28-85	1230	575.89
06-09-85	1106	575.96
07-11-85	1200	575.93
08-16-85	1032	575.47
09-19-85	1235	574.79
11-19-85	0805	578.15†
11-19-85	1226	578.32†
11-04-86	1588	574.75
07-06-88	1253	573.57
07-06-88	1606	573.45
07-07-88	0927	573.93
07-07-88	1427	573.56
07-07-88	1740	573.45
Well 27-293 S2		**MP alt 588.08**
05-18-84	1100	574.31
07-07-84	0840	578.19
07-14-84	1030	576.43
07-14-84	1300	575.74
07-28-84	1530	575.24
08-04-84	1008	575.18
08-18-84	0832	576.36
08-22-84	0842	576.45
09-01-84	1623	573.79
09-20-84	1106	574.23
09-20-84	1428	573.57
10-17-84	1108	575.08
01-18-85	1613	574.69
Well 27-294 S3		**MP alt 591.47**
05-18-84	1200	576.32
07-07-84	0825	576.76
07-14-84	1022	575.83
07-14-84	1257	574.97
07-28-84	1547	574.44
08-04-84	0809	575.68
08-18-84	0810	576.37
08-22-84	0822	576.43
09-01-84	1602	573.02
09-20-84	1143	573.28
09-20-84	1435	572.72
10-17-84	1121	575.01
01-19-85	0930	574.19
03-29-85		574.91
05-28-85	1200	575.37
09-19-85	1225	574.07
07-06-88	1314	571.30
07-06-88	1612	571.15
07-07-88	0939	571.72
07-07-88	1435	571.29
Well 27-295 S4		**MP alt 590.44**
05-18-84	1250	576.89
07-07-84	0805	580.24
07-14-84	1015	577.40
07-14-84	1250	576.54
07-28-84	1555	575.99
08-04-84	0839	576.49
08-13-84	1417	574.95
08-13-84	1513	574.81
08-13-84	1654	575.60
08-18-84	0956	576.64
08-20-84	1538	574.58
08-22-84	0827	576.74
09-01-84	1529	574.58
09-20-84	1203	574.56
09-20-84	1445	574.16
10-17-84	1050	575.24

* Measurements by air line, recorded on chart in pumphouse.

** All water levels adjusted for column of oil in well.

† Well PW5 idle

Table 22. Measurements of water level in wells and in the Rockaway River at Dover, N.J. (continued)

Date	Time	Water-surface altitude
11-16-84	0840	575.19
12-20-84	1300	575.51
01-19-85	1054	574.54
02-23-85	0829	574.75
03-30-85	1054	575.14
05-02-85	1342	575.06
05-28-85	1140	575.61
06-10-85	1119	576.11
07-11-85	1414	576.92
08-17-85	0912	574.64
09-19-85	1220	574.43
11-19-85	0904	578.40†
07-06-88	1317	572.74
07-06-88	1615	572.60
07-07-88	0940	573.09
07-07-88	1442	572.70
Well 27-296 S5	**MP alt 590.32**	
05-18-84	1316	577.77
07-07-84	1006	580.99
07-28-84	1611	578.61
08-18-84	1254	577.46
09-01-84	1452	576.50
09-20-84	1348	576.18
09-20-84	1515	576.30
10-17-84	1232	575.98
01-19-85	1300	574.54
05-28-85	1020	575.48
09-19-85	1140	574.82
Well 27-297 S6	**MP alt 593.26**	
05-18-84	1532	580.48
07-07-84	0730	580.98
07-28-84	1659	579.25
08-18-84	1420	578.28
08-21-84	1620	578.12
08-26-84	1153	578.28
08-26-84	1445	578.12
09-01-84	1335	577.96
09-04-84	1730	578.40
09-04-84	1856	578.30
09-14-84	1440	577.68
09-20-84	1254	577.57
10-17-84	1152	577.25
11-16-84	1044	577.06
12-19-84	1257	577.06
01-24-85	1113	576.51
02-23-85	0943	576.70
03-29-85		576.72
05-03-85	0845	577.06
05-28-85	1315	577.12
06-09-85	1444	577.32
07-12-85	0815	576.79
08-16-85	1322	576.68
09-19-85	1340	576.37†
11-04-86	1605	576.62
07-06-88	1429	576.02
07-06-88	1646	575.98
07-07-88	1013	576.12
07-07-88	1512	575.98
Well 27-298 S7	**MP alt 587.85**	
05-18-84	1500	578.30
07-07-84	710	581.98
07-28-84	1639	579.38
08-18-84	742	578.37
09-01-84	1445	577.97
09-20-84	1219	577.49
09-20-84	1458	577.43
10-17-84	1135	577.17
01-19-85	1200	576.45
05-28-85	1337	577.35
09-19-85	1100	576.52
11-09-85	1056	579.70
11-09-85	2139	578.94
11-20-85	1611	579.64
11-21-85	0841	579.51
11-04-86	1515	576.71
07-06-88	1416	576.01
07-06-88	1633	575.97
07-07-88	0947	576.15
07-07-88	1448	575.98
Well 27-299 S8	**MP alt 585.99**	
05-18-84	1517	580.25
07-07-84	0705	582.10
07-28-84	1646	580.04
08-18-84	1353	578.96
09-01-84	1440	578.58
09-20-84	1227	578.11
09-20-84	1504	578.08
10-17-84	1144	577.69
01-24-85	1355	576.90
05-28-85	1300	577.59
09-19-85	1122	576.89
11-19-85	1107	579.80
11-04-86	1545	577.15
07-06-88	1418	576.47
07-06-88	1639	576.43
07-07-88	1005	576.53
07-07-88	1502	576.41
Well 27-300 S9	**MP alt 589.53**	
05-18-84	1445	578.37
07-07-84	0750	581.75
07-28-84	1633	578.32
08-18-84	1230	577.37
09-01-84	1450	576.82
09-20-84	1214	576.24
09-20-84	1453	576.24
10-17-84	1129	576.03
01-19-85	1220	575.24
05-28-85	1030	576.17
09-19-85	1056	575.38
Well 27-301 S10	**MP alt 592.52**	
05-18-84	1402	580.61
07-07-84	1055	582.74
07-28-84	1621	580.86
08-18-84	1326	579.50
09-01-84	1508	578.72
09-20-84	1356	578.33
09-20-84	1523	578.47
10-17-84	1240	577.89
01-19-85	1247	576.64
05-28-85	1110	577.24
09-19-85	1150	576.82
11-19-85	1137	579.93
11-04-86	1448	577.23
07-06-88	1356	576.09
07-06-88	1626	576.02
07-07-88	1020	576.07
07-07-88	1525	575.92
Well 27-302 S11	**MP alt 585.44**	
05-18-84	1130	575.61
07-07-84	0930	577.75
07-28-84	1540	575.44
08-18-84	0929	575.50
08-21-84	1406	574.48
09-01-84	1610	574.29
09-20-84	1031	574.69
09-20-84	1424	574.09
10-17-84	0955	574.46
11-16-84	0955	574.53
12-19-84	1205	574.89
01-18-85	1501	574.25
05-28-85	1215	574.48
09-19-85	1300	573.61
11-19-85	0838	576.41
07-06-88	1452	572.56
07-06-88	1713	572.50
07-07-88	0934	572.94
07-07-88	1432	572.61
Well 27-303 S12	**MP alt 589.16**	
05-18-84	1417	580.89
07-07-84	1105	583.64
07-28-84	1628	581.54
08-18-84	1335	580.26
09-01-84	1515	579.65
09-20-84	1405	579.12
09-20-84	1529	579.24
10-17-84	1248	578.63
01-19-85	1235	577.51
05-28-85	1120	578.06
09-19-85	1155	577.70
11-19-85	1125	579.75
11-04-86	1440	578.07
07-06-88	1405	576.88
07-06-88	1630	576.83
07-07-88	1026	576.84
07-07-88	1530	576.67
Well 27-305 D1	**MP alt 584.57**	
08-18-84	0915	576.70
08-21-84		576.57
08-22-84	0851	573.23
08-26-84	1607	575.83
08-26-84	1705	575.91
09-01-84	1653	575.64
09-02-84	0820	575.66
09-04-84	1545	574.70
09-14-84	1615	575.78
09-20-84	1136	576.31
10-17-84	1057	575.74
11-15-84	1213	575.86
12-20-84	0840	575.39

Table 22. Measurements of water level in wells and in the Rockaway River at Dover, N.J. (continued)

Date	Time	Water-surface altitude
01-18-85	1100	575.32
02-22-85	1107	575.37
03-30-85	1540	574.74
05-02-85	1049	575.11
05-28-85	1230	575.97
06-09-85	0952	575.89
07-11-85	1103	575.96
08-16-85	1035	575.70
09-19-85	1247	575.36
11-19-85		577.08
07-06-88	1300	574.01
07-06-88	1607	573.87
07-07-88	0930	574.39
07-07-88	1428	573.99
07-07-88	1739	573.88
Well 27-306 D6	**MP alt 594.26**	
08-18-84	1406	578.50
08-21-84	1600	578.36
08-22-84	1458	578.39
08-26-84	1146	578.50
08-26-84	1443	578.42
09-01-84	1408	578.22
09-04-84	1719	578.69
09-04-84	1920	578.52
09-14-84	1510	577.96
09-20-84	1332	577.90
10-17-84	1159	577.96
11-16-84	1042	577.28
12-19-84	1317	577.29
01-24-85	1110	576.74
02-23-85	0946	576.90
03-29-85	1430	576.93
05-03-85	0845	577.14
06-09-85	1404	577.55
07-12-85	0820	577.03
08-17-85	0912	577.46
05-28-85	1310	577.34
09-19-85	1346	576.62
11-19-85	1038	579.04
07-06-88	1428	576.35
07-06-88	1645	576.35
07-07-88	1012	576.59
07-07-88	1511	576.36

Date	Time	Water-surface altitude	
		Piezometer	River
Well 27-315 P1	**MP alt 584.92**		
09-08-84	1600	582.54	584.17
09-13-84	1015	581.17	584.15
09-20-84	0938	580.82	584.07
09-20-84	1122	580.87	584.07
09-20-84	1230	580.90	584.07
09-20-84	1546	581.13	584.08
10-17-84	1302	580.63	584.00
05-28-85	1131	580.49	584.18
09-19-85	1202	580.18	
11-04-86	1329	580.41	584.06
07-07-88	1535	579.92	584.03
07-07-88	1655	579.94	
Well 27-316 P2	**MP alt 583.57**		
09-08-84		580.39	581.01
09-13-84	1210	580.48	581.01
09-20-84	1253	580.27	580.90
09-20-84	1810	580.30	580.90
09-21-84	1115	580.28	580.90
09-21-84	1302	580.27	580.94
10-17-84	1203	580.09	580.93
05-28-85	1137	580.08	581.55
09-19-85	1110	579.02	
11-04-86	1511	578.90	581.37
07-07-88	0952	578.62	581.12
07-07-88	1452	578.57	581.10
Well 27-317 P3	**MP alt 582.48**		
09-08-84		578.89	581.02
09-13-84	1231	578.77	581.01
09-20-84	1302	578.50	580.95
09-20-84	1810	578.63	580.95
09-21-84	0905	578.69	580.95
09-21-84	1118	578.56	580.95
09-21-84	1302	578.53	580.95
10-17-84	1156	578.19	580.93
01-24-85	1512	577.50	581.26
05-28-85	1141	578.09	581.23
09-19-85	1115	577.36	
11-04-86	1507	577.73	581.17
07-07-88	0959	577.37	581.02
07-07-88	1459	577.28	581.01
Well 27-318 P4	**MP alt 579.59**		
09-02-84	1200	576.04	578.45
09-05-84	0840	577.27	578.69
09-05-84	1200	576.56	578.69
09-05-84	1413	576.26	578.67
09-13-84	1336	576.14	578.49
09-20-84	1330	575.80	578.40
09-20-84	1447	575.74	578.40
09-20-84	1502	576.00	578.40
10-17-84	0812	576.04	578.28
10-17-84	1214	576.18	578.33
11-15-84	1420	576.16	578.41
12-20-84	1100	576.25	578.68
01-18-85	1346	575.84	578.64
02-22-85	1305	576.20	578.74
03-30-85	1100	575.97	578.59
05-02-85	1258	576.00	578.59
05-28-85	1057	576.40	578.57
06-09-85	1300	576.66	578.69
07-11-85	1240	576.48	578.45
08-16-85	1017	576.11	578.36
09-19-85	1245	575.47	
11-04-86	1524	575.44	578.39
07-06-88	1130	574.76	578.40
07-06-88	1400	574.66	578.40
07-07-88	1055	574.90	578.36
07-07-88	1104	574.89	578.35
07-07-88	1400	574.76	578.35
Well 27-319 P5	**MP alt 575.20**		
09-16-84		573.32	573.32
09-20-84	1054	573.42	573.30
09-20-84	1428	573.35	573.30
09-20-84	1745	573.36	573.29
05-28-85	1040	573.46	573.39
11-04-86	0905	573.25	573.23
07-06-88	1500	572.99	573.23
07-06-88	1600	572.96	573.22
07-07-88	1000	573.05	573.22
07-07-88	1130	572.96	573.21
07-07-88	1429	572.97	573.19

Date	Time	Water-surface altitude
Well 27-346 11S		
05-28-85	1400	576.11
Well 27-347 11D		
05-28-85	1401	575.61
Well 27-348 10S		
05-28-85	1355	575.76
Well 27-349 10D		
05-28-85	1350	575.77
Rockaway River RP1		**RP alt 588.66**
09-29-83	1500	584.04
07-07-84	1115	587.01
08-18-84	1342	584.19
09-01-84	1521	584.14
09-13-84	1055	584.16
09-20-84	1021	584.08
10-16-84	1555	584.00
05-28-85	1129	584.28
Rockaway River RP2		**RP alt 593.31**
07-07-84	0721	583.77
07-15-84	1456	581.97
08-03-84	0936	581.57
08-18-84	0727	581.27
09-01-84	1435	581.22
09-13-84	1233	581.34
09-20-84	1253	581.25
09-21-84	1130	581.25
10-17-84	1330	581.14
05-28-85	1111	581.64
Rockaway River RP3		**RP alt 580.95**
09-29-83	1700	578.23
07-07-84	1300	580.90
08-04-84	1121	578.72
08-18-84	0850	578.49
08-21-84		578.49
09-01-84	1626	578.41
09-05-84	1000	578.63
09-08-84		578.46
09-20-84	1330	578.38
10-16-84	1320	578.27
10-17-84	1114	578.32
11-15-84	1535	578.37
05-28-85	1055	578.52
Rockaway River RP4		**RP alt 576.40**
09-13-84	1508	573.52
09-20-84	1643	573.47
05-28-85	1040	573.54

Table 23. Temperature-profile data for wells near Dover, N.J.

Well 27-305 (D1 USGS)
Altitude of measuring point 584.57 feet

Depth of probe below measuring point (feet)	Temperature, in degrees Celsius					
	1984		1985			
	Sept 5	Nov. 15	Jan. 1	Mar. 30	June 9	July 11
10.0		14.1	5.4	2.6	17.7	19.6
12.0	21.4	14.2	5.5	2.7	17.5	19.4
14.0	21.4	14.3	5.6	3.5	17.4	19.2
16.0	20.9	14.2	5.8	4.1	17.0	18.6
18.0	20.0	14.1	6.4	4.5	16.0	18.1
20.0	19.2	13.9	6.7	4.3	15.8	17.3
22.0	18.2	13.8	7.2	4.8	14.8	16.4
24.0	17.2	13.6	7.6	5.3	14.1	15.8
26.0	16.8	13.5	8.0	5.5	13.7	15.4
28.0	16.5	13.5	8.4	5.9	13.4	15.1
30.0	16.1	13.5	8.9	6.4	12.9	14.5
32.0	15.4	13.5	9.4	6.8	12.0	13.6
34.0	14.8	13.5	9.9	7.4	11.2	12.9
36.0	14.3	13.4	10.4	7.8	10.6	12.0
38.0	13.6	13.2	10.7	8.4	10.3	11.3
40.0	13.6	13.0	11.1	8.9	10.2	10.7
42.0	12.2	12.6	11.2	9.2	10.2	10.5
44.0	11.6	12.2	11.4	9.6	10.1	10.4
46.0	11.2	11.9	11.4	10.0	10.2	10.4
48.0	11.1	11.6	11.5	10.2	10.2	10.4
50.0	10.9	11.4	11.5	10.4	10.3	10.4
52.0	10.9	11.2	11.4	10.6		10.4
54.0	10.9	11.0	11.3	10.8		
56.0		10.9	11.2	10.8		
58.0		10.9	11.2	11.0		

Well 27-306 (D6 USGS)
Altitude of measuring point 594.26 feet

Depth of probe below measuring point (feet)	Temperature, in degrees Celsius					
	1984		1985			
	Sept. 4	Nov. 16	Jan. 24	Mar. 29	June 9	July 12
18.0	14.0	14.1	12.4	11.4	11.1	12.4
20.0	13.7	14.1	12.6	11.2	11.0	11.8
22.0	13.3	14.0	12.6	11.2	11.0	11.6
24.0	12.9	13.6	12.7	11.3	11.0	11.5
26.0	12.5	13.2	12.7	11.4	11.1	11.4
28.0	12.2	12.9	12.6	11.5	11.1	11.4
30.0	12.0	12.6	12.5	11.6	11.2	11.4
32.0	11.9	12.4	12.4	11.7	11.3	11.5
34.0	11.8	12.2	12.3	11.7	11.4	11.5
36.0	11.8	12.0	12.2	11.8	11.4	11.5
38.0	11.7	11.9	12.1	11.8	11.5	11.5
40.0	11.6	11.8	12.0	11.8	11.5	11.5
42.0		11.7	11.9	11.8	11.6	11.5
44.0	11.6	11.6	11.8	11.8	11.6	11.6
46.0		11.5	11.7	11.8	11.6	11.6
48.0		11.5	11.6	11.7	11.6	11.5
50.0	11.6	11.4	11.6	11.6	11.6	11.5
52.0		11.4	11.6	11.6	11.6	11.5
54.0	11.6	11.4	11.6	11.6	11.6	11.5
56.0		11.4	11.5	11.6	11.5	11.4
58.0		11.4	11.5	11.5	11.5	11.4
60.0	11.5	11.4	11.5	11.5	11.5	11.4
62.0	11.5	11.4				

Table 23. Temperature-profile data for wells near Dover, N.J.

Well 27-287 (RE DTWD)
Altitude of measuring point 589.43 feet

Depth of probe below measuring point (feet)	Temperature, in degrees Celsius 1984 Nov. 15	1984 Jan. 19	1985 Mar. 29	1985 June 10	1985 July 11
12.0	16.5	11.1		11.5	14.4
14.0	16.6	11.3		11.0	13.7
16.0	16.5	11.4	6.1	10.7	13.2
18.0	16.3	11.4	6.0	10.6	13.0
20.0	16.2	11.5	6.1	10.5	12.9
22.0	15.9	11.6	6.1	10.5	12.9
24.0	15.7	11.6	6.4	10.6	12.9
26.0	15.5	11.4	6.6	10.7	13.0
28.0	15.2	10.7	6.9	10.9	13.0
30.0	14.7	10.4	7.2	11.1	13.2
32.0	14.0	10.3	7.6	11.4	13.3
34.0	13.3	10.3	7.9	11.7	13.4
36.0	13.1	10.4	8.3	11.8	13.4
38.0	12.9	10.4	8.4	11.9	13.4
40.0	12.7	10.6	8.8	12.0	13.2
42.0	12.5	10.7	9.0	12.0	12.7
44.0	12.4	10.8	9.2	12.0	12.5
46.0	12.3	11.0	9.4	12.0	12.3
48.0	12.1	11.1	9.8	11.9	12.0
50.0	12.0	11.2	9.9	11.7	11.8
52.0	11.8	11.3	10.1	11.6	11.6
54.0	11.7	11.3	10.3	11.4	11.5
56.0	11.6	11.3	10.4	11.4	11.4
58.0	11.4	11.4	10.5	11.3	11.3
60.0	11.4	11.4	10.6	11.3	11.3
62.0	11.4		10.7		11.4
64.0	11.3	11.4	10.8	11.3	11.4
66.0	11.3		10.9		11.4
68.0	11.3	11.4	10.9	11.3	11.4
70.0	11.3		11.0		11.4
72.0			11.1		11.4
74.0	11.3	11.4	11.1	11.3	11.4
76.0			11.2		
78.0	11.3		11.2		11.4
80.0		11.4	11.2	11.4	
82.0	11.3		11.2		11.4
84.0			11.4		
86.0	11.3		11.3		11.4
88.0			11.3		
90.0	11.4	11.4	11.3	11.4	11.4
92.0			11.3		
94.0	11.4		11.3		11.4
96.0			11.4		
98.0	11.4	11.5	11.4	11.4	11.4

Well 27-290 (T5 DTWD)
Altitude of measuring point 590.49 feet

Depth of probe below measuring point (feet)	Temperature, in degrees Celsius 1984 Sept. 5	1984 Nov. 15	1985 Jan. 19	1985 Mar. 29	1985 June 10	1985 July 11
16.0		16.9		12.0	10.2	11.1
18.0	15.9	17.1	15.2	11.6	9.7	10.5
20.0	15.8	17.1	15.4	11.6	9.4	10.4
22.0	15.6	17.1	15.4	11.6	9.2	10.4
24.0	15.3	17.1	15.5	11.5	8.9	10.4
26.0	15.2	17.0	15.5	11.1	8.8	10.4
28.0	15.1	16.9	15.3	10.2	8.8	10.5
30.0	15.1	16.8	14.6	9.2	8.7	10.7
32.0	15.1	16.5	13.9	8.1	8.7	10.9
34.0	15.1	16.3	13.1	7.1	8.8	11.2
36.0	15.1	16.1	12.7	6.8	8.9	11.4
38.0	15.1	15.9	12.3	6.4	9.0	11.7
40.0	15.1	15.6	11.9	6.5	9.2	12.0
42.0	15.1	15.3	11.6	6.5	9.4	12.1
44.0	15.0	15.0	11.5	6.5	9.5	12.3
46.0	14.9	14.7	11.5	6.5	9.7	12.4
48.0	14.9	14.6	11.5	6.8	9.8	12.5
50.0	15.2	14.5	11.6	7.1	9.8	12.2
52.0	15.3	14.1	11.8	7.6	9.5	11.4
54.0	15.4	14.0	11.9	8.0	9.5	11.3
56.0	15.4	14.0	12.0	8.3	9.4	11.3
58.0	15.4	14.0	12.0	8.4	9.4	11.2
60.0	15.3	13.9	12.0	8.5	9.4	11.2
62.0	15.3	13.6	12.0		9.4	11.1
64.0	15.2	13.4	11.8	8.4	9.5	11.2
66.0	15.2	12.7	11.8	9.6	10.0	11.2

Table 24. Field measurements of temperature, specific conductance, pH, and dissolved oxygen in water at sites near Dover, N.J., July 1984 through August 1985

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no measurement on this date; site locations are shown in figs. 8 and 10; River is Rockaway River at site P4]

Site	Date of measurement	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
River	07-15-84	24.5	7.3	8.4	183
	08-03-84	22.0	7.2	7.2	240
	08-22-84	19.0	7.7	9.0	270
	09-05-84	17.0	7.5	9.1	245
	10-17-84	11.4	7.8	9.0	336
	11-15-84	7.2	8.6	14.3	304
	12-20-84	5.4	8.2	14.2	252
	01-18-85	0.8	7.9	15.5	247
	02-22-85	3.9	7.7	14.3	230
	03-30-85	10.4	7.8	9.6	245
	05-02-85	14.0	7.9	9.3	380
	06-09-85	17.7	7.9	8.6	245
	07-11-85	25.0	8.5	8.5	296
	08-16-85	24.4	8.0	7.7	287
D1	09-05-84	13.0	8.3	0.0	225
	11-15-84	11.9	8.0	0.1	243
	12-20-84	10.4	7.8	2.1	267
	01-18-85	10.1	7.9	0.7	257
	02-22-85	10.3	7.9	0.1	258
	03-30-85	9.0	8.3	0.0	254
	05-02-85	10.0	8.3	0.0	267
	06-09-85	11.4	8.2	0.4	278
	07-11-85	13.0	8.5	0.3	288
	08-16-85	13.5	8.3	0.0	282
D6	09-04-84	12.5	7.5	4.3	605
	10-17-84	12.0	7.6	4.2	587
	11-16-84	11.8	7.7	3.1	525
	12-19-84	11.4	7.4	--	538
	01-24-85	11.3	7.6	2.9	539
	02-23-85	11.9	7.5	3.5	582
	03-29-85	12.6	8.0	2.0	510
	05-03-85	11.5	7.8	--	555
	06-09-85	12.2	7.9	3.6	546
	07-12-85	12.1	7.9	3.4	535
	08-16-85	12.1	8.0	--	468
P4	09-05-84	19.0	6.7	0.3	255
	10-17-84	13.0	7.0	3.5	335
	11-15-84	7.7	7.1	9.3	302
	12-20-84	5.9	7.3	8.0	267
	01-18-85	0.4	7.3	0.6	254
	02-22-85	4.4	7.3	8.9	242
	03-30-85	10.4	7.2	1.5	250
	05-02-85	15.7	7.1	0.6	287
	06-09-85	18.5	7.0	1.1	248
	07-11-85	24.5	7.1	0.3	291
	08-16-85	25.0	6.9	0.3	283
S1	08-03-84	19.5	6.4	0.2	195
	08-21-84	20.0	6.7	0.3	240
	09-05-84	19.5	6.5	0.1	255
	10-16-84	16.7	6.7	0.3	285
	11-15-84	14.1	6.5	0.1	307
	12-20-84	7.1	6.8	3.7	305
	01-18-85	5.4	6.7	3.8	267
	02-22-85	3.5	6.9	5.1	298
	03-30-85	4.7	7.4	2.9	225
	05-20-85	9.8	7.1	0.6	265
	06-09-85	16.3	7.0	0.3	245
	07-11-85	18.5	7.1	0.2	249
S4	07-14-84	13.0	6.5	3.2	365
	08-03-84	14.0	6.4	2.0	389
	08-20-84	15.0	6.6	3.0	410
	09-05-84	15.5	6.5	2.3	410
	10-17-84	16.0	6.5	2.2	450
	11-16-84	15.1	6.5	2.2	439
	12-20-84	13.5	6.4	4.4	421
	01-19-85	9.7	6.5	4.7	350
	02-23-85	7.7	6.6	6.7	369
	03-30-85	6.1	7.2	5.4	312
	05-02-85	7.5	7.1	3.2	334
	06-10-85	11.4	6.9	1.9	345
	07-11-85	13.9	7.1	1.6	362
	08-17-85	15.4	6.8	1.1	375

Table 24. Field measurements of temperature, specific conductance, pH, and dissolved oxygen in water at sites near Dover, N.J., July 1984 through August 1985 (continued)

Site	Date of measurement	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)
S6	07-15-84	12.5	6.6	9.3	440
	08-03-84	13.5	6.7	8.1	512
	08-21-84	13.5	6.8	7.8	525
	09-04-84	14.0	6.7	7.5	540
	10-17-84	15.0	6.6	7.1	621
	11-16-84	14.3	6.6	7.3	654
	12-19-84	13.1	6.5	--	661
	01-24-85	12.3	6.6	7.6	654
	02-23-85	11.8	6.5	8.2	648
	03-29-85	12.0	7.1	7.5	647
	05-03-85	10.5	7.0	--	676
	06-09-85	11.4	7.0	8.3	626
	07-12-85	12.0	7.0	8.4	581
	08-16-85	13.1	7.0	7.5	618
S7	07-15-84	17.5	6.6	0.8	240
	08-03-84	17.5	6.7	0.6	240
S8	12-20-84	10.4	6.3	1.2	315
	01-24-85	9.8	6.6	2.9	402
S9	08-03-84	14.0	6.9	5.2	520
S11	07-14-84	10.0	6.8	3.7	386
	08-03-84	11.0	6.8	2.4	453
	08-21-84	11.0	6.9	2.1	455
	09-05-84	11.5	7.0	1.7	440
	10-17-84	12.0	6.9	1.7	452
	11-16-84	12.9	--	--	453
	12-19-84	12.9	6.7	2.0	466
	01-18-85	12.8	6.6	1.1	438
T5	07-14-84	14.2	7.5	2.2	400
	08-04-84	15.0	7.2	2.7	514
	08-20-84	15.5	7.3	2.5	510
	09-05-84	16.0	7.2	2.6	565
	10-16-84	15.6	7.3	2.8	594
	11-15-84	14.5	7.0	3.5	566
	12-19-84	13.3	7.2	3.8	566
	01-19-85	11.8	7.2	4.0	540
	02-22-85	10.2	7.2	4.7	544
	03-29-85	12.6	8.1	--	450
	05-02-85	8.0	7.7	3.9	525
	06-10-85	10.6	7.7	2.7	492
	07-11-85	13.0	7.7	2.3	496
	08-17-85	14.8	7.5	--	526
RE	07-14-84	13.5	8.6	1.0	145
	08-04-84	13.0	7.7	0.4	135
	06-10-85	12.4	8.1	0.4	140

Table 25. Chemical analyses of major inorganic solutes and selected trace metals in water samples from sites at Dover, N.J., July 1984 through August 1985

[dis, dissolved; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; ALK, alkalinity as calcium carbonate; Cl, chloride; SO_4, sulfate; SiO_2, silica; TDS, total dissolved solids; Fe, iron; Mn, manganese; and Al, aluminum. Analyses by U.S. Geological Survey laboratory at Denver, Colo. Site locations shown in figs. 8 and 10. A dash indicates no analysis. River is Rockaway River at site of piezometer P4]

Site	Date of sample collection (m-d-yr)	Inorganic solutes, in milligrams per liter									Trace metals, in micrograms per liter					
		Ca	Mg	Na	K	ALK	Cl	SO_4	SiO_2	TDS	Fe dis	Fe total	Mn dis	Mn total	Al dis	Al total
River	07-15-84	14	5.1	12	0.7	41	22	11	8.1	98	370	690	32	80	40	60
	08-03-84	20	7.4	15	0.9	60	29	15	8.7	130	300	540	32	70	<10	70
	08-22-84	23	8.5	16	1.0	70	31	22	8.4	150	170	610	23	50	10	50
	09-05-84	21	7.8	16	1.1	59	31	20	8.5	140	150	510	31	50	50	70
	02-22-85	16	6.1	19	1.0	40	35	17	8.0	130	160	280	53	60	30	40
	06-09-85	18	7.1	18	0.7	53	32	15	7.0	130	310	690	36	40	<10	<10
	07-11-85	22	8.6	18	1.1	66	33	20	7.0	150	190	340	17	20	30	70
D1	11-15-84	28	9.7	7.6	0.9	101	5.7	21	12	150	14	9,200	220	570	30	3,000
	01-18-85	30	10	7.9	1.0	103	5.9	21	12	150	14	3,900	130	270	20	1,100
	03-30-85	31	10	7.7	0.8	107	5.7	22	12	150	6	1,600	70	220	20	700
	05-20-85	32	10	8.2	0.9	109	5.8	25	12	160	3	180	11	80	20	150
D6	09-04-84	62	24	28	1.6	172	77	31	17	340	6	17,000	58	620	30	1,200
	10-17-84	58	23	23	1.5	167	68	29	17	320	3	15,000	38	550	50	6,000
	11-16-84	54	22	17	1.3	157	56	29	16	290	6	8,500	36	330	30	2,400
	02-23-85	59	23	21	1.4	164	64	30	16	310	7	25,000	39	1,100	20	2,900
P4	09-05-84	22	7.8	18	1.0	66	31	18	8.1	150	54	650	28	40	30	160
	10-17-84	28	11	20	1.2	88	40	19	7.8	180	58	300	9	20	<100	30
	11-15-84	25	10	18	1.1	78	40	19	7.6	170	72	450	12	40	60	60
	02-22-85	16	6.2	22	1.1	45	37	17	8.3	130	29	360	3	<10	30	40
S1	08-21-84	20	7.2	14	1.1	58	30	16	11	130	4	120	6	10	30	100
	09-05-84	22	8.0	17	1.1	63	33	17	11	150	5	100	8	10	20	70
	12-20-84	25	9.8	19	0.9	68	39	19	7.1	160	7	150	<1	10	<10	<10
	01-18-85	20	7.9	17	0.9	51	38	17	6.6	140	7	190	<1	20	10	60

Table 25. Chemical analyses of major inorganic solutes and selected trace metals in water samples from sites at Dover, N.J., July 1984 through August 1985 (continued)

Site	Date of sample collection (m-d-yr)	Inorganic solutes, in milligrams per liter									Trace metals, in micrograms per liter					
		Ca	Mg	Na	K	ALK	Cl	SO_4	SiO_2	TDS	Fe dis	Fe total	Mn dis	Mn total	Al dis	Al total
S4	07-14-84	32	12	21	2.0	102	41	19	15	200	3	70	<1	10	<10	30
	08-03-84	34	13	22	2.1	107	45	20	16	220	10	80	<1	<10	10	20
	08-20-84	36	13	24	2.1	108	51	27	15	230	13	170	<1	<10	60	80
	09-05-84	36	13	25	2.1	107	53	20	15	230	3	290	<1	<10	20	70
	03-30-85	25	9.9	20	1.1	67	43	18	9.1	170	10	80	<1	<10	30	40
	05-02-85	27	10	23	1.3	74	46	19	9.8	180	<3	110	<1	10	30	90
S6	07-15-84	40	15	31	2.1	114	64	25	15	260	7	80	<1	10	10	20
	08-03-84	42	16	31	2.2	119	69	25	16	270	25	160	<1	<10	10	60
	08-21-84	44	16	32	2.1	128	70	23	16	280	4	110	<1	<10	10	70
	09-04-84	47	17	34	2.2	130	76	27	16	300	5	100	<1	<10	20	40
	02-23-85	58	22	36	2.5	156	86	28	15	340	6	20	<1	<10	30	30
S11	07-14-84	34	13	23	1.5	105	45	23	12	210	6	100	<1	10	10	30
	08-03-84	39	15	26	1.6	121	55	24	13	250	8	100	1	<10	<10	40
	08-21-84	40	15	28	1.6	127	56	31	13	260	5	130	<1	<10	10	80
	09-05-84	41	16	31	1.6	126	53	25	13	260	<3	90	<1	<10	20	50
T5	07-14-84	34	14	22	1.6	110	49	20	7.3	210	20	4,800	160	230	<10	<10
	08-04-84	48	19	24	1.7	151	62	22	15	280	10	150	<1	<10	<10	50
	08-20-84	48	18	25	1.7	151	60	29	15	290	5	210	<1	<10	20	40
	09-05-84	55	21	28	1.7	164	67	23	15	310	4	730	<1	10	40	40
	03-29-85	37	18	23	1.5	123	56	18	5.7	230	12	3,200	92	80	20	10
	05-02-85	51	19	24	1.4	149	60	25	13	280	5	500	<1	10	20	50
	06-10-85	44	18	25	1.3	141	53	20	13	260	14	630	1	<10	<10	<10
	07-11-85	44	17	23	1.6	140	51	21	13	250	8	70	<1	10	10	30
RE	07-14-84	12	2.7	8.5	8.3	67	2.9	1.6	2.8	79	23	2,900	2	30	<10	80
	08-04-84	12	5.0	6.5	0.9	62	2.2	3.0	19	86	260	9,500	17	40	<10	--
	06-10-85	12	5.1	7.2	0.9	63	4.2	3.1	19	90	280	26,000	19	70	<10	<10

Table 26. Analyses for environmental isotopes in water samples from Dover, N.J., July 1984 through August 1985

[Site locations shown in figs. 8 and 10. Tritium activity expressed in tritium units (T.U.); analyses by Theodore Wyerman at U.S. Geological Survey laboratory in Reston, Va. unless otherwise footnoted. $\delta^{18}O$ and δD normalized to Standard Mean Ocean Water and expressed parts per thousand (o/oo); analyses by Carol Kendall at U.S. Geological Survey laboratory in Reston, Va.]

Site	Date of sample collection (mo-d-yr)	Isotope: Tritium activity, in T.U.	Isotope: $\delta^{18}O$ in o/oo	Isotope: δD in o/oo
Rockaway River at P4	07-14-84	27.7	-6.75	-42.0
	07-15-84	26.3	-6.80	-43.5
	08-03-84	29.2	-6.95	-44.5
	08-22-84	29.2	-7.00	-45.5
	09-05-84	27.1	-6.85	-42.5
	10-17-84	29.2	-7.05	-44.5
	11-15-84	28.2	-7.05	-46.0
	12-20-84	26.6	-6.45	-43.0
	01-18-85	28.8	-7.50	-48.0
	02-22-85	24.1[a]	-7.55	-47.5
	03-30-85	--	-7.30	-45.0
	05-02-85	--	-6.70	-43.0
	Number of samples	10	12	12
	Maximum	29.2	-6.45	-42.0
	Minimum	24.1	-7.55	-48.0
	Mean	27.6	-7.00	-44.6
	Median	28.0	-6.98	-44.5
P4	09-05-84	27.7	-6.80	-43.0
	10-17-84	28.5	-7.10	-46.0
	11-15-84	--	-7.10	-45.5
	12-20-84	--	-7.00	-45.5
	01-18-85	--	-7.45	-48.0
	02-22-85	--	-7.60	-46.5
	03-30-85	--	-7.30	-45.0
	05-02-85	--	-6.95	-43.5
	Number of samples		8	8
	Maximum		-6.80	-43.0
	Minimum		-7.60	-48.0
	Mean		-7.16	-45.4
	Median		-7.10	-45.5
Rockaway River and P4 combined	Number of samples	12	20	20
	Maximum	29.2	-6.45	-42.0
	Minimum	24.1	-7.60	-48.0
	Mean	27.7	-7.06	-44.9
	Median	28.0	-7.02	-45.0
S1	08-03-84	28.8	-6.80	-43.0
	08-21-84	29.8	-7.05	-45.0
	09-05-84	29.2	-7.00	-44.5
	10-16-84	27.7	-7.00	-44.5
	11-15-84	--	-6.95	-44.5
	12-20-84	--	-7.00	-44.0
	01-18-85	--	-7.15	-45.0
	Number of samples	4	7	7
	Maximum	29.8	-6.80	-43.0
	Minimum	27.7	-7.15	-45.0
	Mean	28.9	-6.99	-44.4
	Median	29.0	-7.00	-44.5
D1	09-05-84	1.6	-7.75	-49.5
	11-15-84	1.2	-7.80	-51.5
	12-20-84		-7.70	-48.5
	01-18-85	--	-7.90	-51.0
	Number of samples		4	4
	Maximum		-7.70	-48.8
	Minimum		-7.90	-51.5
	Mean		-7.79	-50.1
	Median		-7.78	-50.2
S4	07-14-84	26.6	-7.65	-48.5
	08-03-84	27.6	-7.50	-47.0
	08-20-84	28.0	-7.55	-48.0
	09-05-84	25.8	-7.40	-46.0
	10-17-84	27.2	-7.50	-46.0
	Number of samples	5	5	5
	Maximum	28.0	-7.40	-46.0
	Minimum	25.8	-7.65	-48.5
	Mean	27.0	-7.52	-47.1
	Median	27.2	-7.52	-47.0
S7	07-15-84	--	-6.90	-43.5
	08-30-84	28.8	-6.95	-43.0

a Tritium analysis by Tritium Laboratory, Rosensteil School of Marine and Atmospheric Science, Miami, Fla.

Table 26. Analyses for environmental isotopes in water samples from Dover, N.J., July 1984 through August 1985 (continued)

Site	Date of sample collection (mo-d-yr)	Isotope: Tritium activity, in T.U.	Isotope: $\delta^{18}O$ in o/oo	Isotope: δD in o/oo
S8	12-20-84	--	-6.9	-48.0
	01-24-85	--	-7.40	-47.5
S9	08-30-84	28.2	-7.7	-48.5
S6	07-15-84	25.5	-8.05	-50.0
	08-03-84	26.0	-7.85	-50.5
	08-21-84	26.5	-7.95	-50.0
	09-04-84	26.9	-7.90	-49.0
	10-17-84	26.0	-7.95	-48.5
	11-16-84	28.2	-7.85	-48.5
	12-19-84	--	-7.60	-48.5
	01-24-85	--	-7.80	-47.0
	02-23-85	--	-7.80	-46.5
	03-29-85	--	-7.75	-46.0
	05-03-85	--	-7.90	-47.5
	07-12-85	--	-7.80	-46.5
	Number of samples	6	12	12
	Maximum	28.2	-7.60	-46.0
	Minimum	25.5	-8.05	-50.5
	Mean	26.5	-7.85	-48.2
	Median	26.2	-7.85	-48.5
D6	09-04-84	25.8	-7.85	-49.5
	10-17-84	23.5	-8.05	-47.5
	11-16-84	21.0	-7.90	-50.5
	12-19-84	--	-7.75	-48.5
	01-24-85	--	-8.00	-48.5
	02-23-85	--	-7.90	-49.5
	03-29-85	--	-8.00	-48.0
	05-03-85	--	-8.00	-49.0
	06-09-85	18.5	--	--
	07-12-85	--	-7.95	-48.0
	Number of samples	4	9	9
	Maximum	25.8	-7.75	-47.5
	Minimum	18.5	-8.05	-50.5
	Mean	22.2	-7.93	-48.9
	Median	22.2	-7.95	-48.5
S6 and D6 combined	Number of samples	10	21	21
	Maximum	28.2	-7.60	-46.0
	Minimum	18.5	-8.05	-50.5
	Mean	24.8	-7.89	-48.6
	Median	25.9	-7.90	-48.5
S11	07-14-84	27.1	-8.10	-51.5
	08-03-84	27.1	-7.75	-49.5
	08-21-84	27.9	-7.75	-48.0
	09-05-84	25.6	-7.60	-46.5
	10-17-84	26.3	-7.65	-46.5
	11-16-84	26.0	-7.45	-48.0
	Number of samples	6	6	6
	Maximum	27.9	-7.45	-46.5
	Minimum	25.6	-8.10	-51.5
	Mean	26.7	-7.72	-48.3
	Median	26.6	-7.68	-47.5
RE	07-14-84	1.6	-8.25	-52.0
	08-04-84	0.9	-8.35	-52.0
	06-10-85	0.5[a]	--	--
T5	07-14-84	26.3	-7.75	-48.5
	08-04-84	27.2	-7.45	-47.0
	08-20-84	28.3	-7.50	-46.5
	09-05-84	27.7	-7.65	-47.5
	10-16-84	27.7	-7.80	-48.5
	11-15-84	25.6	-7.75	-48.0
	12-19-84	27.2	-7.70	-47.0
	01-19-85	25.7	-7.60	-47.5
	02-22-85	--	-7.70	-47.5
	03-29-85	--	-7.60	-47.0
	05-02-85	--	-7.65	-47.5
	06-10-85	--	-7.45	-46.0
	07-11-85	--	-7.35	-44.0
	Number of samples	8	13	13
	Maximum	28.3	-7.35	-44.0
	Minimum	25.6	-7.80	-48.5
	Mean	27.0	-7.61	-47.1
	Median	27.2	-7.65	-47.5

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986

[°C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25°C. Location of P2 is shown in fig. 8.]

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
River	4.28	22.8	7.3	7.70	274
River	4.32	22.7	7.5	8.10	276
River	4.35	22.8	7.6	8.00	276
River	4.38	22.8	7.7	8.40	276
River	4.42	22.8	7.8	7.80	274
River	4.45	22.9	7.8	8.00	276
River	4.48	22.9	7.9	7.60	278
River	4.52	22.8	7.9	8.10	278
River	4.55	22.7	7.9	8.20	276
River	4.58	22.7	7.9	7.80	276
River	4.62	22.7	7.9	8.20	275
River	4.65	22.7	8.0	8.40	276
River	4.68	22.7	8.0	8.30	275
River	4.72	22.7	8.0	8.40	275
River	4.75	22.7	8.0	8.30	276
River	4.78	22.5	8.0	7.70	275
P2	4.92	21.3	7.2	0.40	284
P2	4.95	21.3	7.1	0.30	283
P2	4.98	21.3	7.0	0.20	283
P2	5.02	21.3	7.1	0.20	283
P2	5.05	21.3	7.0	0.20	283
P2	5.08	21.2	6.9	0.20	283
P2	5.12	21.2	6.9	0.20	282
P2	5.15	21.0	6.9	0.20	282
P2	5.18	21.0	6.9	0.20	282
P2	5.22	20.9	6.9	0.20	282
River	5.42	21.5	7.6	7.00	276
River	5.45	21.5	7.7	7.60	276
River	5.48	21.5	7.8	7.60	275
River	5.52	21.5	7.9	7.60	275
River	5.55	21.5	7.9	7.50	275
River	5.58	21.5	7.9	7.50	275
River	5.62	21.5	7.9	7.50	275
River	5.65	21.4	7.9	7.50	275
River	5.68	21.4	7.9	7.50	275
River	5.72	21.4	7.9	7.70	274
River	5.75	21.4	7.9	7.80	274
River	5.78	21.3	7.9	7.80	274
River	5.82	21.3	7.9	7.90	274
P2	6.20	20.6	7.1	0.30	283
P2	6.23	20.6	7.0	0.30	283
P2	6.27	20.6	7.0	0.20	283
P2	6.30	20.5	7.0	0.20	283
P2	6.33	20.5	7.0	0.20	283
P2	6.37	20.5	7.0	0.20	283
P2	6.40	20.4	6.9	0.20	283
P2	6.43	20.4	6.9	0.20	282
P2	6.47	20.4	6.9	0.20	282
P2	6.50	20.4	6.9	0.20	282
P2	6.53	20.4	6.9	0.20	282
P2	6.57	20.4	6.9	0.20	282
River	6.78	20.6	7.5	8.00	274
River	6.82	20.6	7.6	8.00	274
River	6.85	20.5	7.7	8.00	274
River	6.88	20.6	7.8	8.10	274
River	6.92	20.5	7.8	8.00	274
River	6.95	20.5	7.8	8.10	274
River	6.98	20.5	7.8	8.10	274
River	7.02	20.5	7.8	8.00	274
River	7.05	20.5	7.9	8.00	274
River	7.08	20.5	7.9	8.20	274
River	7.12	20.4	7.9	8.20	274
River	7.15	20.4	7.9	8.20	274
River	7.18	20.4	7.9	8.20	274
River	7.22	20.4	7.9	8.20	274
River	7.25	20.4	7.9	8.20	274
River	7.28	20.4	7.9	8.20	274
River	7.32	20.3	7.9	8.20	274
P2	7.65	20.2	7.1	0.30	286
P2	7.68	20.2	7.0	0.20	286
P2	7.72	20.0	7.0	0.20	285
P2	7.75	20.2	7.0	0.20	285
P2	7.78	20.1	6.9	0.20	285
P2	7.82	20.2	6.9	0.20	285
P2	7.85	20.2	6.9	0.20	285
P2	7.88	20.2	6.9	0.20	284
P2	7.92	20.2	6.9	0.20	284
P2	7.95	20.2	6.9	0.20	284
P2	7.98	20.1	6.9	0.20	284
P2	8.02	20.2	6.9	0.20	284
P2	8.05	20.2	6.9	0.20	284
River	8.20	19.8	7.6	7.40	273
River	8.23	19.8	7.6	7.40	273
River	8.27	19.8	7.7	7.50	273
River	8.30	19.8	7.8	7.50	273
River	8.33	19.8	7.8	7.50	274
River	8.37	19.8	7.8	7.50	273
River	8.40	19.8	7.8	7.50	273
River	8.43	19.7	7.8	7.50	273
River	8.47	19.7	7.8	7.50	273
River	8.50	19.7	7.8	7.60	273
River	8.53	19.7	7.8	7.60	273
P2	9.38	19.8	7.1	0.20	286
P2	9.42	19.8	7.0	0.20	285

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
P2	9.45	19.8	7.0	0.20	285
P2	9.48	19.8	7.0	0.20	284
P2	9.52	19.8	7.0	0.20	284
P2	9.55	19.8	7.0	0.20	284
P2	9.58	19.8	6.9	0.20	283
P2	9.62	19.8	6.9	0.20	284
P2	9.65	19.8	6.9	0.20	284
P2	9.68	19.8	6.9	0.20	284
P2	9.72	19.8	6.9	0.20	284
P2	9.75	19.8	6.9	0.20	286
P2	9.78	19.8	6.9	0.20	283
P2	9.82	19.8	6.9	0.20	283
River	10.25	18.8	7.6	7.20	274
River	10.28	18.8	7.6	7.00	274
River	10.32	18.8	7.7	7.20	275
River	10.35	18.7	7.7	7.10	275
River	10.38	18.7	7.7	7.00	275
River	10.42	18.7	7.8	7.00	275
River	10.45	18.7	7.8	7.20	275
River	10.48	18.7	7.8	7.20	274
River	10.52	18.7	7.8	7.00	275
River	10.55	18.7	7.8	7.10	275
River	10.58	18.7	7.8	7.00	275
P2	11.53	19.2	7.0	0.20	287
P2	11.57	19.2	7.0	0.20	287
P2	11.60	19.1	7.0	0.20	286
P2	11.63	19.2	6.9	0.20	286
P2	11.67	19.1	7.0	0.20	286
P2	11.70	19.1	7.0	0.20	286
P2	11.73	19.0	6.9	0.20	286
P2	11.77	19.1	6.9	0.20	286
P2	11.80	19.1	6.9	0.20	286
P2	11.82	19.2	6.9	0.20	285
P2	11.87	19.3	6.9	0.20	286
P2	11.90	19.3	6.9	0.20	285
P2	11.93	19.3	6.9	0.20	285
River	12.57	17.9	7.6	7.40	278
River	12.60	17.9	7.7	7.50	277
River	12.63	17.9	7.7	7.30	278
River	12.67	17.8	7.7	7.40	278
River	12.70	17.8	7.8	7.40	278
River	12.73	17.9	7.8	7.40	278
River	12.77	17.8	7.8	7.30	278
River	12.80	17.8	7.8	7.30	278
River	12.83	17.8	7.8	7.50	278
River	12.87	17.8	7.8	7.30	278
River	12.90	17.8	7.8	7.40	278
River	12.93	17.8	7.8	7.40	278
River	12.97	17.8	7.8	7.20	278
River	13.00	17.8	7.8	7.20	278
P2	13.67	19.3	7.0	0.25	290
P2	13.70	19.3	7.0	0.25	289
P2	13.73	19.3	7.0	0.20	289
P2	13.77	19.2	7.0	0.20	288
P2	13.80	19.2	6.9	0.20	289
P2	13.83	19.3	6.9	0.20	288
P2	13.87	19.3	6.9	0.20	288
P2	13.90	19.1	6.9	0.20	288
P2	13.93	19.1	6.9	0.20	288
P2	13.97	19.2	6.9	0.20	288
P2	14.00	19.2	6.9	0.15	287
P2	14.03	19.2	6.9	0.15	287
P2	14.07	19.2	6.9	0.15	287
P2	14.10	19.2	6.9	0.15	287
P2	14.13	19.3	6.9	0.15	287
P2	14.17	19.3	6.9	0.15	287
River	14.30	17.4	7.5	7.60	275
River	14.33	17.4	7.6	7.40	275
River	14.37	17.3	7.6	7.40	274
River	14.40	17.2	7.7	7.20	273
River	14.43	17.2	7.7	7.40	273
River	14.47	17.2	7.7	7.30	273
River	14.50	17.2	7.8	7.30	274
River	14.53	17.2	7.8	7.40	274
River	14.57	17.3	7.8	7.40	275
River	14.60	17.3	7.8	7.40	274
River	14.63	17.2	7.8	7.40	275
River	14.67	17.2	7.8	7.40	274
P2	15.17	19.1	7.0	0.25	289
P2	15.20	19.2	7.0	0.25	288
P2	15.23	19.1	7.0	0.25	288
P2	15.27	19.1	6.9	0.20	288
P2	15.30	19.2	6.9	0.20	287
P2	15.33	19.2	6.9	0.20	287
P2	15.37	19.2	6.9	0.20	287
P2	15.40	19.1	6.9	0.20	287
P2	15.43	19.1	6.9	0.20	287
P2	15.47	19.1	6.9	0.15	287
P2	15.53	19.1	6.9	0.20	287
P2	15.57	19.1	6.9	0.20	287
P2	15.60	19.1	6.9	0.15	287
P2	15.63	19.1	6.9	0.15	287
P2	15.67	19.1	6.9	0.15	287
River	16.20	16.5	7.5	8.70	280
River	16.23	16.7	7.6	8.50	280
River	16.27	16.7	7.7	8.50	280
River	16.30	16.7	7.7	8.40	280

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
River	16.33	16.7	7.7	8.50	280
River	16.37	16.7	7.8	8.40	280
River	16.40	16.6	7.8	8.40	280
River	16.43	16.6	7.8	8.50	280
River	16.47	16.6	7.8	8.40	280
River	16.50	16.7	7.8	8.30	280
River	16.53	16.7	7.8	8.20	281
River	16.57	16.7	7.8	8.20	280
P2	17.13	18.8	7.1	0.25	287
P2	17.17	18.8	7.1	0.20	287
P2	17.20	18.8	7.1	0.20	287
P2	17.23	18.8	7.0	0.20	287
P2	17.27	18.8	7.0	0.20	288
P2	17.30	18.8	7.0	0.20	288
P2	17.33	18.8	7.0	0.20	288
P2	17.37	18.8	7.0	0.20	288
P2	17.40	18.7	7.0	0.20	287
P2	17.43	18.7	7.0	0.20	287
P2	17.47	18.7	7.0	0.20	287
P2	17.50	18.8	7.0	0.20	287
P2	17.53	18.8	6.9	0.20	287
P2	17.57	18.8	6.9	0.20	286
P2	17.60	18.8	6.9	0.15	286
P2	17.63	18.8	6.9	0.15	287
P2	17.67	18.8	6.9	0.20	285
River	18.27	16.0	7.5	8.80	273
River	18.30	16.1	7.6	8.80	273
River	18.33	16.0	7.7	8.80	274
River	18.37	16.0	7.7	8.80	274
River	18.40	16.1	7.7	8.80	277
River	18.43	16.1	7.7	8.80	277
River	18.47	16.1	7.8	8.80	277
River	18.50	16.2	7.8	8.80	276
River	18.53	16.2	7.8	8.80	277
River	18.57	16.1	7.8	8.80	276
River	18.60	16.2	7.8	8.80	277
River	18.63	16.1	7.8	8.80	277
River	18.67	16.1	7.8	8.70	277
River	18.70	16.1	7.8	8.80	276
P2	19.20	19.4	7.1	0.25	
P2	19.23	19.4	7.0	0.20	
P2	19.27	19.4	7.0	0.20	246
P2	19.30	19.5	7.0	0.20	245
P2	19.33	19.5	7.0	0.20	250
P2	19.37	19.5	6.9	0.20	229
P2	19.40	19.5	6.9	0.20	227
P2	19.43	19.5	6.9	0.20	228
P2	19.47	19.5	6.9	0.20	227
P2	19.50	19.5	6.9	0.20	225
P2	19.53	19.5	7.0	0.15	222
P2	19.57	19.5	6.9	0.15	222
P2	19.60	19.5	6.9	0.15	222
P2	19.63	19.5	6.9	0.15	221
P2	19.67	19.5	6.9	0.15	219
P2	19.70	19.5	6.9	0.15	218
River	20.12	16.4	7.6	7.90	230
River	20.17	16.3	7.6	7.80	220
River	20.20	16.3	7.7	8.10	223
River	20.23	16.3	7.7	7.90	230
River	20.27	16.4	7.7	7.80	226
River	20.30	16.4	7.8	7.70	225
River	20.33	16.4	7.8	7.60	226
River	20.37	16.4	7.8	7.70	232
River	20.40	16.4	7.8	7.70	230
River	20.43	16.5	7.8	7.60	233
River	20.47	16.5	7.8	7.90	231
River	20.50	16.5	7.8	8.00	231
River	20.53	16.5	7.8	8.00	230
P2	20.90	19.6	7.1	0.25	281
P2	20.93	19.6	7.0	0.20	280
P2	20.97	19.7	7.0	0.20	280
P2	21.00	19.7	7.0	0.20	280
P2	21.03	19.7	7.0	0.20	280
P2	21.07	19.6	7.0	0.20	279
P2	21.10	19.6	7.0	0.20	279
P2	21.13	19.6	7.0	0.20	278
P2	21.17	19.6	7.0	0.20	278
P2	21.20	19.7	7.0	0.15	279
P2	21.23	19.7	6.9	0.20	278
River	22.13	17.2	7.6	8.40	273
River	22.17	17.2	7.8	8.20	272
River	22.20	17.2	7.8	8.30	272
River	22.23	17.2	7.8	8.30	272
River	22.27	17.3	7.9	8.20	272
River	22.30	17.3	7.9	8.40	272
River	22.33	17.4	7.9	8.40	272
River	22.37	17.4	7.9	8.40	273
River	22.40	17.4	7.9	8.45	272
River	22.43	17.4	7.9	8.45	272
River	22.47	17.4	7.9	8.40	272
River	22.50	17.5	8.0	8.45	272
River	22.53	17.5	8.0	8.40	272
River	22.57	17.5	8.0	8.40	272
P2	22.83	20.2	7.0	0.30	279
P2	22.87	20.2	7.0	0.20	279
P2	22.90	20.1	7.0	0.20	278
P2	22.93	20.1	7.0	0.20	278

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
P2	22.97	20.2	7.0	0.20	278
P2	23.00	20.2	7.0	0.15	278
P2	23.03	20.3	7.0	0.15	278
P2	23.07	20.3	6.9	0.15	278
P2	23.10	20.3	6.9	0.15	277
P2	23.13	20.3	6.9	0.15	278
P2	23.17	20.3	6.9	0.15	278
P2	23.20	20.4	6.9	0.15	277
P2	23.23	20.4	6.9	0.15	277
P2	24.17	20.9	6.9	0.20	278
P2	24.20	20.9	6.9	0.20	278
P2	24.23	20.9	6.9	0.15	278
P2	24.27	20.9	6.9	0.15	277
P2	24.30	20.9	6.9	0.15	277
P2	24.33	20.9	6.9	0.15	277
P2	24.37	20.9	6.9	0.15	276
P2	24.40	20.9	6.9	0.15	276
P2	24.43	20.9	6.9	0.15	276
P2	24.47	20.9	6.9	0.15	276
P2	24.50	20.9	6.9	0.15	276
P2	24.53	20.9	6.9	0.15	276
P2	24.57	20.9	6.9	0.15	276
P2	24.60	20.9	6.9	0.15	275
P2	24.63	20.9	6.9	0.15	276
River	24.98	19.9	7.8	7.80	273
River	25.02	19.8	7.9	7.80	272
River	25.05	19.9	8.0	7.80	272
River	25.08	19.8	8.0	7.90	272
River	25.12	19.8	8.0	7.90	272
River	25.15	19.9	8.0	7.90	272
River	25.18	19.9	8.1	8.00	272
River	25.22	19.8	8.1	8.00	272
River	25.25	19.8	8.1	8.00	272
River	25.28	20.0	8.1	8.10	273
River	25.32	20.0	8.1	8.40	273
River	25.35	20.0	8.1	8.60	273
River	25.38	20.1	8.1	8.60	272
River	25.42	20.1	8.1	8.60	272
River	25.45	20.2	8.1	8.70	273
River	25.48	20.2	8.1	8.70	272
River	25.52	20.2	8.1	8.70	272
River	25.55	20.2	8.1	8.80	272
River	25.58	20.2	8.1	8.80	272
River	25.62	20.2	8.1	8.80	272
River	25.65	20.3	8.1	8.80	272
River	25.68	20.4	8.1	8.80	272
River	25.72	20.4	8.1	8.80	272
River	25.75	20.4	8.2	8.80	272
River	25.78	20.4	8.2	8.80	272
River	25.82	20.4	8.2	8.80	272
River	25.85	20.4	8.2	8.80	272
River	25.88	20.4	8.2	8.80	272
River	25.92	20.5	8.2	8.80	271
River	25.95	20.5	8.2	8.80	272
River	25.98	20.5	8.2	8.80	271
River	26.02	20.6	8.2	8.80	271
P2	26.50	21.3	7.0	0.25	277
P2	26.53	21.4	7.0	0.25	276
P2	26.57	21.4	7.0	0.20	276
P2	26.60	21.3	7.0	0.20	276
P2	26.63	21.4	6.9	0.20	276
P2	26.67	21.4	6.9	0.20	276
P2	26.70	21.4	6.9	0.20	275
P2	26.73	21.4	6.9	0.15	275
P2	26.77	21.4	6.9	0.15	275
P2	26.80	21.4	6.9	0.15	275
P2	26.83	21.4	6.9	0.15	274
River	27.25	21.5	7.9	7.40	275
River	27.28	21.5	7.9	7.30	274
River	27.32	21.5	8.0	7.30	274
River	27.35	21.5	8.0	7.50	274
River	27.38	21.5	8.0	7.30	273
River	27.42	21.4	8.1	7.40	274
River	27.45	21.5	8.1	7.40	274
River	27.48	21.5	8.1	7.40	274
River	27.52	21.5	8.1	7.30	274
River	27.55	21.5	8.1	7.20	274
River	27.58	21.5	8.1	7.20	274
River	27.62	21.5	8.1	7.30	274
River	27.65	21.6	8.1	7.20	275
River	27.68	21.6	8.1	7.20	273
River	27.72	21.6	8.1	7.20	274
River	27.75	21.5	8.1	7.20	273
River	27.78	21.4	8.1	7.20	273
River	27.82	21.5	8.1	7.30	273
River	27.85	21.4	8.1	7.20	273
River	27.88	21.5	8.1	7.30	273
River	27.92	21.5	8.1	7.20	273
P2	28.35	21.5	7.1	0.30	277
P2	28.38	21.5	7.0	0.25	275
P2	28.42	21.5	7.0	0.25	275
P2	28.45	21.4	7.0	0.25	274
P2	28.48	21.5	6.9	0.20	274
P2	28.52	21.5	6.9	0.20	273
P2	28.55	21.5	6.9	0.20	273
P2	28.58	21.5	6.9	0.20	273
P2	28.62	21.5	6.9	0.20	272
P2	28.65	21.4	6.9	0.20	272
P2	28.68	21.4	6.9	0.20	272

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
P2	28.72	21.4	6.9	0.20	272
P2	28.75	21.4	6.9	0.20	271
River	28.95	20.6	7.8	7.20	274
River	28.98	20.6	7.9	7.20	274
River	29.02	20.6	7.9	7.20	274
River	29.05	20.5	8.0	7.20	274
River	29.08	20.4	8.0	7.20	274
River	29.12	20.2	8.0	7.20	273
River	29.15	20.2	8.0	7.30	273
River	29.18	20.2	8.0	7.30	273
River	29.22	20.2	8.0	7.40	273
River	29.25	20.1	8.0	7.40	273
River	29.28	20.1	8.0	7.10	273
River	29.32	20.1	8.0	7.30	273
River	29.35	20.0	8.0	7.30	273
P2	29.95	20.3	7.1	0.30	279
P2	29.98	20.4	7.0	0.25	277
P2	30.02	20.4	7.0	0.25	277
P2	30.05	20.4	7.0	0.20	276
P2	30.08	20.4	7.0	0.20	276
P2	30.12	20.4	7.0	0.20	276
P2	30.15	20.4	7.0	0.20	276
P2	30.18	20.3	6.9	0.20	275
P2	30.22	20.3	6.9	0.20	275
P2	30.25	20.3	6.9	0.15	275
P2	30.28	20.3	6.9	0.20	275
P2	30.35	20.2	6.9	0.15	276
P2	30.38	20.2	6.9	0.15	275
River	30.67	19.4	7.6	6.60	276
River	30.70	19.4	7.8	6.80	276
River	30.73	19.3	7.8	6.80	276
River	30.77	19.3	7.9	6.60	276
River	30.80	19.3	7.9	6.40	276
River	30.83	19.3	7.9	6.70	276
River	30.87	19.3	7.9	6.50	276
River	30.90	19.3	7.9	6.80	276
River	30.93	19.3	7.9	6.80	276
River	30.97	19.3	7.9	6.70	276
River	31.00	19.2	7.9	6.50	276
River	31.03	19.2	7.9	6.90	276
River	31.07	19.2	8.0	6.80	276
River	31.10	19.2	8.0	6.60	276
River	31.13	19.2	8.0	6.70	276
River	31.17	19.2	8.0	6.50	276
River	31.20	19.1	8.0	6.70	276
River	31.23	19.1	8.0	6.60	275
River	31.27	19.1	8.0	6.70	276
River	31.30	19.1	8.0	6.80	276
River	31.33	19.1	8.0	6.70	276
P2	31.82	19.7	7.1	0.40	280
P2	31.85	19.8	7.1	0.35	279
P2	31.88	19.8	7.0	0.30	278
P2	31.92	19.8	7.0	0.25	278
P2	31.95	19.8	7.0	0.25	278
P2	31.98	19.8	7.0	0.25	278
P2	32.02	19.7	7.0	0.20	277
P2	32.08	19.7	7.0	0.20	277
P2	32.12	19.7	7.0	0.20	277
P2	32.15	19.8	7.0	0.20	277
P2	32.18	19.7	7.0	0.20	277
P2	32.22	19.7	7.0	0.20	277
P2	32.25	19.7	7.0	0.20	277
River	32.42	18.3	7.6	6.90	278
River	32.45	18.3	7.7	7.10	279
River	32.48	18.3	7.8	7.10	278
River	32.52	18.2	7.8	7.10	279
River	32.55	18.2	7.8	7.10	279
River	32.58	18.2	7.8	7.20	279
River	32.62	18.2	7.8	7.10	279
River	32.65	18.2	7.9	7.10	279
River	32.68	18.2	7.9	7.10	279
River	32.72	18.1	7.9	7.10	279
River	32.75	18.1	7.9	7.10	279
River	32.78	18.1	7.9	7.10	279
River	32.82	18.1	7.9	7.10	279
P2	33.60	18.9	7.2	0.35	283
P2	33.63	19.0	7.1	0.30	283
P2	33.67	19.0	7.1	0.25	283
P2	33.70	19.2	7.0	0.25	283
P2	33.73	19.1	7.0	0.25	282
P2	33.77	19.2	7.0	0.20	281
P2	33.80	19.2	7.0	0.20	281
P2	33.83	19.2	7.0	0.20	281
P2	33.87	19.2	7.0	0.20	281
P2	33.90	19.3	7.0	0.20	281
River	34.07	17.6	7.5	6.40	279
River	34.10	17.5	7.6	6.50	279
River	34.13	17.5	7.7	6.40	279
River	34.17	17.5	7.7	6.20	279
River	34.20	17.5	7.7	6.20	279
River	34.23	17.5	7.8	6.30	279
River	34.27	17.4	7.8	6.40	279
River	34.30	17.4	7.8	6.40	278
River	34.33	17.3	7.8	6.40	278
River	34.37	17.4	7.8	6.40	278
River	34.40	17.4	7.8	6.40	278
River	34.43	17.4	7.8	6.40	278

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
River	34.47	17.3	7.8	6.50	278
River	34.50	17.3	7.8	6.40	278
River	34.53	17.3	7.8	6.40	278
River	34.57	17.3	7.8	6.40	278
P2	35.25	18.6	7.2	0.50	284
P2	35.28	18.8	7.1	0.40	284
P2	35.32	18.8	7.1	0.35	283
P2	35.35	19.0	7.0	0.30	282
P2	35.38	19.0	7.0	0.30	282
P2	35.42	18.9	7.0	0.25	282
P2	35.45	19.0	7.0	0.25	282
P2	35.48	19.0	7.0	0.20	282
P2	35.52	19.0	7.0	0.20	282
P2	35.55	19.1	7.0	0.20	281
P2	35.58	19.0	7.0	0.20	281
P2	35.62	19.0	7.0	0.20	281
River	37.00	16.7	7.9	7.60	281
River	37.03	16.7	7.9	7.60	281
River	37.07	16.8	7.9	7.60	280
River	37.10	16.8	7.9	7.60	280
River	37.13	16.8	7.9	7.65	281
River	37.17	16.8	7.9	7.65	281
River	37.20	16.8	7.9	7.60	281
River	37.23	16.8	7.9	7.60	280
River	37.27	16.8	7.9	7.65	281
River	37.30	16.8	7.9	7.60	281
River	37.33	16.8	7.9	7.65	281
River	37.37	16.8	7.9	7.65	281
River	37.40	16.8	7.9	7.65	281
P2	37.87	18.9	7.2	0.35	285
P2	37.90	19.0	7.1	0.25	285
P2	37.93	19.0	7.1	0.25	284
P2	37.97	19.1	7.0	0.20	283
P2	38.00	19.1	7.0	0.20	283
P2	38.03	19.1	7.0	0.20	283
P2	38.07	19.1	7.0	0.20	283
P2	38.10	19.1	7.0	0.20	283
P2	38.13	19.1	7.0	0.15	282
P2	38.17	19.1	7.0	0.15	282
P2	38.20	19.2	7.0	0.15	282
P2	38.23	19.2	7.0	0.15	281
P2	38.27	19.1	7.0	0.15	281
River	39.20	16.3	7.7	7.65	282
River	39.23	16.3	7.7	7.65	281
River	39.27	16.3	7.8	7.60	281
River	39.30	16.3	7.8	7.50	281
River	39.33	16.3	7.8	7.50	282
River	39.37	16.3	7.8	7.60	281
River	39.40	16.3	7.8	7.65	282
River	39.43	16.3	7.8	7.65	282
River	39.47	16.4	7.8	7.65	281
River	39.50	16.3	7.9	7.70	282
P2	40.17	18.7	7.0	0.20	284
P2	40.20	18.7	7.0	0.20	283
P2	40.23	18.7	7.0	0.20	283
P2	40.27	18.8	7.0	0.20	284
P2	40.30	18.7	7.0	0.20	282
P2	40.33	18.7	7.0	0.20	283
P2	40.37	18.8	7.0	0.20	283
P2	40.40	18.7	7.0	0.20	283
P2	40.43	18.7	7.0	0.20	283
P2	40.47	18.8	7.0	0.15	283
P2	40.50	18.8	7.0	0.15	283
P2	40.53	18.7	7.0	0.15	282
P2	40.57	18.8	7.0	0.15	282
P2	40.60	18.8	7.0	0.15	282
P2	40.63	18.8	7.0	0.15	281
P2	40.67	18.8	7.0	0.15	282
River	41.20	15.7	7.5	7.50	281
River	41.23	15.8	7.6	7.40	281
River	41.27	15.8	7.7	7.50	281
River	41.30	15.9	7.7	7.50	282
River	41.33	15.9	7.8	7.60	282
River	41.37	15.9	7.8	7.60	282
River	41.40	15.9	7.8	7.50	283
River	41.43	15.9	7.8	7.60	282
River	41.47	15.8	7.8	7.60	283
River	41.50	15.8	7.8	7.60	282
River	41.53	15.8	7.8	7.60	282
P2	42.17	18.6	7.0	0.60	284
P2	42.20	18.7	7.0	0.25	285
P2	42.23	18.8	7.0	0.20	284
P2	42.27	18.8	7.0	0.20	284
P2	42.30	18.8	7.0	0.15	283
P2	42.33	18.8	7.0	0.15	284
P2	42.37	18.9	7.0	0.15	284
P2	42.40	18.9	7.0	0.15	283
P2	42.43	18.9	7.0	0.15	282
P2	42.47	18.9	7.0	0.15	283
P2	42.50	18.9	7.0	0.15	282
P2	42.53	18.9	7.0	0.15	283
P2	42.57	18.9	7.0	0.15	282
P2	42.60	19.0	7.0	0.15	283
P2	42.63	19.0	7.0	0.15	282
P2	42.67	19.0	7.0	0.15	282
River	43.20	16.3	7.6	7.50	281

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
River	43.23	16.3	7.7	7.70	282
River	43.27	16.2	7.8	7.70	281
River	43.30	16.2	7.8	7.80	281
River	43.33	16.2	7.8	7.50	280
River	43.37	16.2	7.8	7.80	280
River	43.40	16.2	7.8	7.60	280
River	43.43	16.3	7.8	7.60	280
River	43.47	16.2	7.8	7.75	281
River	43.50	16.2	7.8	7.75	280
River	43.53	16.2	7.8	7.75	280
P2	44.20	19.3	6.8	0.20	283
P2	44.23	19.3	6.8	0.20	283
P2	44.30	19.4	6.8	0.15	282
P2	44.33	19.3	6.8	0.15	282
P2	44.37	19.4	6.8	0.15	281
P2	44.40	19.4	6.7	0.15	281
P2	44.43	19.5	6.8	0.15	281
P2	44.47	19.6	6.8	0.15	280
P2	44.50	19.6	6.8	0.15	280
P2	44.53	19.6	6.8	0.15	280
P2	44.57	19.6	6.8	0.15	280
P2	44.60	19.6	6.7	0.15	279
P2	44.63	19.6	6.7	0.15	279
P2	44.67	19.6	6.8	0.15	279
P2	44.70	19.7	6.7	0.15	279
River	45.77	17.3	7.6	8.00	280
River	45.80	17.2	7.7	8.05	280
River	45.83	17.2	7.7	8.05	279
River	45.87	17.3	7.7	8.00	279
River	45.90	17.3	7.8	8.30	279
River	45.93	17.2	7.7	8.20	279
River	45.97	17.3	7.8	8.30	279
River	46.00	17.3	7.8	8.25	279
P2	46.17	19.9	6.9	0.20	281
P2	46.20	20.0	6.8	0.15	279
P2	46.23	20.1	6.8	0.15	279
P2	46.27	20.2	6.8	0.15	278
P2	46.30	20.2	6.8	0.15	278
P2	46.33	20.1	6.8	0.15	278
P2	46.37	20.1	6.8	0.15	277
P2	46.40	20.2	6.8	0.15	277
P2	46.43	20.2	6.8	0.15	276
P2	46.47	20.1	6.8	0.15	276
P2	46.50	20.1	6.8	0.15	276
P2	46.53	20.2	6.8	0.15	276
P2	46.57	20.2	6.8	0.15	276
P2	46.60	20.3	6.8	0.15	276
P2	46.63	20.3	6.8	0.15	276
P2	46.67	20.2	6.8	0.15	276
River	47.37	18.8	7.8	7.60	276
River	47.40	18.8	7.8	7.40	276
River	47.43	18.9	7.8	7.40	276
River	47.47	18.9	7.8	7.40	276
River	47.50	18.9	7.8	7.40	276
River	47.53	18.9	7.8	7.50	276
River	47.57	18.9	7.8	7.40	276
River	47.60	19.0	7.8	7.40	276
River	47.63	19.1	7.9	7.40	276
River	47.67	19.2	7.8	7.60	276
P2	50.60	21.2	6.7	0.20	275
P2	50.63	21.2	6.7	0.15	273
P2	50.67	21.3	6.7	0.15	272
P2	50.70	21.3	6.7	0.15	272
P2	50.73	21.3	6.7	0.15	272
P2	50.77	21.3	6.7	0.15	271
P2	50.80	21.3	6.7	0.10	271
P2	50.87	21.3	6.7	0.10	271
P2	50.90	21.3	6.7	0.15	271
P2	50.93	21.3	6.7	0.15	271
River	51.12	21.8	7.9	6.90	273
River	51.15	21.8	7.9	6.90	273
River	51.18	21.8	8.0	6.90	273
River	51.22	21.9	8.0	6.80	273
River	51.25	21.9	8.0	7.00	273
River	51.28	21.9	8.0	7.00	273
River	51.32	21.9	8.0	6.90	273
River	51.35	21.9	8.0	7.20	273
River	51.38	21.9	8.0	7.00	273
River	51.42	21.8	8.0	6.90	273
River	51.45	21.8	8.0	7.10	273
River	51.48	21.8	8.0	7.10	273
River	51.52	21.9	8.0	7.00	273
P2	51.68	21.6	6.8	0.35	276
P2	51.72	21.6	6.8	0.25	276
P2	51.75	21.6	6.8	0.20	275
P2	51.78	21.6	6.7	0.20	275
P2	51.82	21.6	6.7	0.20	274
P2	51.85	21.6	6.7	0.15	274
P2	51.88	21.6	6.7	0.15	274
P2	51.92	21.6	6.7	0.15	274
P2	51.95	21.6	6.7	0.15	274
P2	51.98	21.6	6.7	0.15	274
P2	52.02	21.6	6.7	0.15	274
River	52.20	22.0	7.7	6.40	275
River	52.23	21.9	7.8	6.10	275
River	52.27	21.9	7.8	6.20	275
River	52.30	21.9	7.9	6.20	274

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)
River	52.33	21.9	7.9	6.60	274
River	52.37	21.9	7.9	6.50	274
River	52.40	21.9	7.9	6.50	275
River	52.43	21.9	7.9	6.30	275
River	52.47	21.9	7.9	6.40	275
River	52.50	21.9	7.9	6.50	275
River	52.53	21.9	7.9	6.50	274
River	52.57	21.9	7.9	6.50	274
River	52.60	21.9	7.9	6.40	274
River	52.63	21.8	7.9	6.50	274
River	52.67	21.8	7.9	6.50	274
P2	53.18	21.2	6.8	1.60	276
P2	53.22	21.2	6.8	1.45	276
P2	53.25	21.1	6.8	1.30	275
P2	53.28	21.1	6.8	1.25	273
P2	53.32	21.1	6.7	1.15	272
P2	53.35	21.0	6.7	1.00	271
P2	53.38	21.0	6.7	0.90	271
P2	53.42	21.0	6.7	0.85	271
P2	53.45	20.9	6.7	0.80	270
P2	53.48	20.9	6.7	0.80	269
P2	53.52	20.9	6.7	0.70	268
P2	53.55	20.9	6.7	0.70	271
P2	53.58	20.9	6.7	0.60	271
P2	53.62	20.8	6.7	0.55	270
P2	53.65	20.8	6.7	0.55	270
P2	53.68	20.8	6.7	0.55	269
P2	53.72	20.8	6.7	0.50	268
P2	53.75	20.8	6.7	0.40	267
P2	53.78	20.8	6.7	0.40	267
P2	53.82	20.8	6.7	0.40	266
P2	53.85	20.7	6.7	0.35	266
P2	53.88	20.7	6.7	0.35	266
P2	53.92	20.6	6.7	0.35	267
River	54.32	20.8	7.6	6.50	279
River	54.35	20.8	7.6	6.40	280
River	54.38	20.8	7.7	6.50	279
River	54.42	20.8	7.7	6.60	279
River	54.45	20.8	7.8	6.40	279
River	54.48	20.7	7.8	6.30	279
River	54.52	20.7	7.8	6.30	279
River	54.55	20.7	7.8	6.30	278
River	54.58	20.7	7.8	6.30	279
River	54.62	20.7	7.8	6.40	279
River	54.65	20.7	7.8	6.30	280
River	54.68	20.7	7.8	6.30	280
P2	54.92	20.5	6.8	0.35	276
P2	54.95	20.5	6.8	0.30	275
P2	54.98	20.5	6.8	0.30	275
P2	55.02	20.5	6.7	0.30	275
P2	55.05	20.5	6.7	0.30	272
P2	55.05	20.5	6.7	0.30	272
P2	55.08	20.5	6.7	0.30	271
P2	55.12	20.5	6.7	0.25	272
P2	55.15	20.4	6.7	0.30	271
P2	55.18	20.5	6.7	0.25	271
P2	55.22	20.4	6.7	0.25	271
P2	55.25	20.4	6.7	0.25	271
River	55.47	20.4	7.6	7.00	281
River	55.50	20.4	7.6	7.00	282
River	55.53	20.4	7.6	6.90	282
River	55.57	20.4	7.7	6.90	283
River	55.60	20.4	7.7	6.80	282
River	55.63	20.4	7.7	6.80	282
River	55.67	20.4	7.7	6.90	282
River	55.70	20.4	7.7	6.90	282
River	55.73	20.4	7.7	6.80	282
River	55.77	20.3	7.7	6.80	283
River	55.80	20.3	7.7	6.80	283
River	55.83	20.3	7.7	6.80	284
River	55.87	20.3	7.7	6.80	283
River	55.90	20.3	7.7	6.80	283
River	55.93	20.3	7.7	6.80	284
River	55.97	20.3	7.7	6.70	284
River	56.00	20.3	7.7	6.80	285
P2	56.25	20.2	6.9	0.35	279
P2	56.28	20.2	6.8	0.30	278
P2	56.32	20.2	6.8	0.30	277
P2	56.35	20.2	6.8	0.30	276
P2	56.38	20.2	6.8	0.30	274
P2	56.42	20.2	6.7	0.30	277
P2	56.45	20.2	6.7	0.30	275
P2	56.48	20.2	6.7	0.30	274
P2	56.52	20.2	6.7	0.25	274
P2	56.55	20.1	6.7	0.25	276
P2	56.58	20.1	6.7	0.25	276
River	57.17	19.9	7.6	6.30	288
River	57.20	19.9	7.6	6.50	288
River	57.23	19.9	7.6	6.30	288
River	57.27	19.9	7.6	6.30	288
River	57.30	19.9	7.6	6.30	287
River	57.33	19.9	7.6	6.50	287
River	57.37	19.9	7.6	6.30	288
River	57.40	19.9	7.6	6.40	287
River	57.43	19.9	7.6	6.30	287
River	57.47	19.9	7.6	6.40	287
River	57.50	19.9	7.6	6.40	287
River	57.53	19.8	7.6	6.30	287

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)
River	57.57	19.8	7.6	6.30	287
River	57.60	19.8	7.6	6.30	287
River	57.63	19.8	7.6	6.40	286
River	57.67	19.8	7.6	6.40	286
P2	58.88	19.9	6.7	0.45	277
P2	58.92	19.9	6.7	0.40	277
P2	58.95	19.9	6.7	0.30	277
P2	58.98	19.9	6.7	0.30	277
P2	59.02	19.9	6.7	0.25	277
P2	59.05	19.9	6.7	0.25	277
P2	59.08	19.9	6.7	0.25	277
P2	59.12	19.9	6.7	0.20	277
P2	59.15	19.9	6.7	0.25	277
P2	59.18	19.9	6.7	0.25	277
P2	59.22	19.9	6.7	0.25	277
P2	59.25	19.9	6.7	0.20	277
River	59.43	19.5	7.5	7.00	283
River	59.47	19.5	7.5	7.00	283
River	59.50	19.4	7.5	7.00	283
River	59.53	19.4	7.6	6.90	283
River	59.57	19.4	7.6	7.00	283
River	59.60	19.4	7.6	6.90	283
River	59.67	19.4	7.6	6.90	283
River	59.70	19.3	7.9	6.80	283
River	59.73	19.3	7.6	6.80	283
River	59.77	19.3	7.6	6.80	283
River	61.13	19.0	7.6	6.80	283
River	61.17	19.0	7.6	6.90	283
River	61.20	19.0	7.6	6.85	283
River	61.23	19.0	7.6	6.70	284
River	61.27	18.9	7.6	6.85	283
River	61.30	19.0	7.6	6.80	283
River	61.33	19.0	7.6	6.75	283
River	61.37	19.0	7.6	6.80	283
River	61.40	19.0	7.6	6.90	283
River	61.43	19.0	7.6	6.75	283
River	61.47	19.0	7.6	6.85	283
River	61.50	19.0	7.6	6.80	283
P2	61.93	19.5	6.9	0.15	283
P2	61.97	19.5	6.8	0.15	283
P2	62.00	19.5	6.8	0.15	283
P2	62.03	19.6	6.8	0.15	283
P2	62.07	19.6	6.8	0.15	282
P2	62.10	19.6	6.8	0.15	282
P2	62.13	19.6	6.8	0.10	282
P2	62.17	19.6	6.8	0.10	282
P2	62.20	19.6	6.8	0.10	282
P2	62.23	19.6	6.8	0.10	282
P2	62.27	19.6	6.8	0.10	282
P2	62.30	19.6	6.8	0.10	281
P2	62.33	19.6	6.8	0.10	282
River	63.03	18.8	7.4	6.60	283
River	63.07	18.8	7.5	6.60	283
River	63.10	18.8	7.5	6.70	283
River	63.13	18.8	7.6	6.80	283
River	63.17	18.8	7.6	6.75	283
River	63.20	18.4	7.6	6.75	283
River	63.23	18.4	7.6	6.70	283
River	63.27	18.4	7.6	6.65	283
River	63.30	18.8	7.6	6.60	283
River	63.33	18.8	7.6	6.55	283
P2	63.97	19.5	6.8	0.15	283
P2	64.00	19.5	6.8	0.10	283
P2	64.03	19.5	6.8	0.10	283
P2	64.07	19.5	6.8	0.10	282
P2	64.10	19.5	6.8	0.10	282
P2	64.13	19.5	6.8	0.10	282
P2	64.17	19.5	6.8	0.10	282
P2	64.20	19.5	6.8	0.10	282
P2	64.23	19.5	6.8	0.10	282
P2	64.27	19.5	6.8	0.10	282
P2	64.30	19.5	6.8	0.10	282
P2	64.33	19.5	6.8	0.10	282
P2	64.37	19.5	6.8	0.10	281
River	65.07	18.5	7.4	6.70	281
River	65.10	18.5	7.4	6.70	281
River	65.13	18.6	7.5	6.80	281
River	65.17	18.6	7.5	6.80	281
River	65.20	18.6	7.5	6.85	281
River	65.23	18.5	7.5	6.90	281
River	65.27	18.6	7.6	6.80	281
River	65.30	18.6	7.6	6.80	281
River	65.33	18.6	7.6	6.85	281
River	65.37	18.6	7.6	6.85	281
River	65.40	18.6	7.6	6.80	281
River	65.43	18.6	7.5	6.85	281
River	65.47	18.5	7.6	6.90	282
P2	65.70	19.3	6.8	0.15	284
P2	65.73	19.4	6.8	0.15	283
P2	65.77	19.4	6.8	0.15	283
P2	65.80	19.4	6.8	0.10	283
P2	65.83	19.4	6.8	0.10	283
P2	65.87	19.4	6.8	0.10	283
P2	65.90	19.4	6.8	0.10	283
P2	65.93	19.4	6.8	0.10	283
P2	65.97	19.4	6.8	0.10	283
P2	66.00	19.4	6.8	0.10	283

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
P2	66.03	19.4	6.8	0.10	283
P2	66.07	19.4	6.8	0.10	282
P2	66.10	19.4	6.8	0.10	282
River	67.13	18.6	7.3	7.15	284
River	67.17	18.7	7.4	7.15	284
River	67.20	18.7	7.4	7.15	284
River	67.23	18.7	7.4	7.20	284
River	67.27	18.7	7.4	7.20	283
River	67.30	18.7	7.4	7.20	283
River	67.33	18.7	7.5	7.10	283
River	67.37	18.7	7.5	7.20	283
River	67.40	18.7	7.5	7.20	284
P2	67.57	19.6	6.8	0.20	283
P2	67.60	19.6	6.8	0.15	282
P2	67.63	19.6	6.8	0.10	281
P2	67.67	19.6	6.8	0.10	281
P2	67.70	19.6	6.7	0.10	280
P2	67.73	19.6	6.7	0.10	280
P2	67.77	19.7	6.7	0.10	280
P2	67.80	19.7	6.7	0.10	280
P2	67.83	19.7	6.7	0.10	279
P2	67.87	19.7	6.7	0.10	279
P2	67.90	19.7	6.7	0.10	279
P2	67.93	19.7	6.7	0.10	279
P2	67.97	19.7	6.7	0.10	279
P2	68.00	19.8	6.7	0.10	279
P2	68.03	19.8	6.7	0.10	279
P2	68.07	19.8	6.7	0.10	279
P2	68.87	20.3	6.8	0.10	280
River	69.03	19.2	7.6	7.35	281
River	69.07	19.2	7.6	7.40	281
River	69.10	19.2	7.6	7.35	281
River	69.13	19.2	7.6	7.35	281
River	69.17	19.2	7.7	7.35	281
River	69.20	19.3	7.7	7.35	281
River	69.23	19.3	7.7	7.35	281
River	69.27	19.3	7.7	7.30	281
River	69.30	19.2	7.7	7.25	281
River	69.33	19.4	7.7	7.30	281
P2	69.73	20.2	6.8	0.15	282
P2	69.77	20.2	6.8	0.10	282
P2	69.80	20.3	6.8	0.10	281
P2	69.83	20.3	6.8	0.10	281
P2	69.90	20.3	6.8	0.10	280
P2	69.93	20.3	6.8	0.10	280
P2	69.97	20.3	6.8	0.10	280
P2	70.00	20.3	6.8	0.10	279
P2	70.03	20.3	6.8	0.10	279
P2	70.07	20.4	6.8	0.10	279
P2	70.10	20.4	6.7	0.10	279
P2	70.13	20.4	6.7	0.10	279
P2	70.17	20.3	6.8	0.10	279
River	71.00	20.5	7.6	7.45	280
River	71.03	20.5	7.7	7.45	279
River	71.07	20.6	7.7	7.45	279
River	71.10	20.6	7.7	7.50	279
River	71.13	20.6	7.8	7.50	279
River	71.17	20.7	7.8	7.50	279
River	71.20	20.7	7.8	7.45	279
River	71.23	20.7	7.8	7.55	279
River	71.27	20.8	7.8	7.50	279
River	71.30	20.9	7.8	7.60	279
River	71.33	20.9	7.8	7.60	279
P2	71.67	20.7	6.7	0.15	281
P2	71.70	20.7	6.7	0.15	281
P2	71.73	20.8	6.7	0.10	281
P2	71.77	20.7	6.7	0.10	280
P2	71.80	20.7	6.7	0.10	280
P2	71.83	20.8	6.7	0.10	280
P2	71.87	20.9	6.7	0.05	280
P2	71.90	20.9	6.7	0.10	279
P2	71.93	20.9	6.7	0.10	279
P2	71.97	20.8	6.7	0.05	279
P2	72.00	20.7	6.7	0.10	279
P2	72.03	20.7	6.7	0.05	279
River	72.18	21.4	7.7	6.20	277
River	72.22	21.4	7.8	5.90	277
River	72.25	21.7	7.8	6.20	277
River	72.28	21.8	7.8	6.20	277
River	72.32	21.8	7.8	5.90	277
River	72.35	21.8	7.8	6.00	277
River	72.38	21.8	7.9	6.00	277
River	72.42	21.7	7.9	6.00	277
River	72.45	21.8	7.9	5.90	277
River	72.48	21.8	7.9	6.00	277
River	72.52	21.8	7.9	5.90	277
River	72.55	21.8	7.9	5.90	277
River	72.58	21.8	7.9	5.90	277
River	72.62	21.8	7.9	5.80	277
River	72.65	21.9	7.9	6.00	277
River	72.68	22.1	7.9	5.90	277
River	72.72	22.2	8.0	5.90	277
River	72.75	22.1	8.0	6.00	277
P2	73.10	20.8	6.8	0.15	279
P2	73.13	20.8	6.8	0.10	279
P2	73.17	20.8	6.8	0.10	278

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
P2	73.20	20.8	6.8	0.10	278
P2	73.23	20.8	6.8	0.10	278
P2	73.27	20.7	6.8	0.10	278
P2	73.30	20.7	6.7	0.10	278
P2	73.33	20.8	6.7	0.05	278
P2	73.37	20.7	6.7	0.10	278
P2	73.40	20.7	6.7	0.10	277
P2	73.43	20.7	6.7	0.10	277
P2	73.47	20.7	6.7	0.10	277
River	73.58	22.1	7.8	6.10	278
River	73.62	22.0	7.8	6.10	278
River	73.65	22.0	7.9	6.10	278
River	73.68	22.1	7.9	6.00	278
River	73.72	22.1	7.9	6.00	278
River	73.75	22.2	7.9	5.90	278
River	73.78	22.4	7.9	6.00	279
River	73.82	22.4	7.9	6.00	278
River	73.85	22.5	7.9	6.00	279
River	73.88	22.5	7.9	6.00	279
River	73.92	22.6	8.0	5.90	279
River	73.95	22.8	8.0	5.80	278
River	73.98	22.8	8.0	6.10	278
River	74.02	22.7	8.0	6.00	279
River	74.05	22.5	8.0	6.00	279
River	74.08	22.3	8.0	6.00	279
River	74.12	22.2	8.0	6.00	279
P2	74.45	20.9	6.8	0.15	278
P2	74.48	21.0	6.8	0.10	278
P2	74.52	21.1	6.8	0.10	277
P2	74.55	21.2	6.8	0.10	277
P2	74.58	21.1	6.8	0.10	277
P2	74.62	21.0	6.8	0.10	277
P2	74.65	20.8	6.7	0.10	277
P2	74.68	20.8	6.7	0.10	276
P2	74.72	20.8	6.7	0.10	276
P2	74.75	20.8	6.7	0.10	276
River	74.92	22.5	7.8	6.60	279
River	74.95	22.6	7.9	6.60	279
River	74.98	22.6	7.9	6.40	279
River	75.02	22.6	7.9	6.60	279
River	75.05	22.6	7.9	6.60	279
River	75.08	22.6	7.9	6.50	279
River	75.12	22.6	7.9	6.60	279
River	75.15	22.6	7.9	6.60	279
River	75.18	22.6	7.9	6.60	279
River	75.22	22.6	8.0	6.60	279
River	75.25	22.6	8.0	6.60	279
River	75.28	22.7	8.0	6.60	279
River	75.32	22.7	8.0	6.70	279
River	75.35	22.7	8.0	6.50	279
River	75.38	22.7	8.0	6.70	279
River	75.42	22.7	8.0	6.60	279
P2	75.60	21.1	6.9	0.15	279
P2	75.63	21.0	6.8	0.10	279
P2	75.67	20.9	6.8	0.10	279
P2	75.70	20.8	6.8	0.10	278
P2	75.73	20.8	6.8	0.10	278
P2	75.77	20.8	6.8	0.10	278
P2	75.80	20.8	6.8	0.10	278
P2	75.83	20.9	6.7	0.10	277
P2	75.87	20.9	6.7	0.05	277
P2	75.90	20.8	6.7	0.10	277
P2	75.93	20.8	6.7	0.10	277
P2	75.97	20.7	6.7	0.05	277
P2	76.00	20.7	6.7	0.10	277
River	76.22	22.7	7.8	6.90	279
River	76.25	22.7	7.8	7.00	279
River	76.28	22.7	7.9	7.00	279
River	76.32	22.6	7.9	6.90	279
River	76.35	22.6	7.9	7.00	279
River	76.38	22.6	7.9	7.00	279
River	76.42	22.6	7.9	7.00	279
River	76.45	22.6	7.9	7.00	279
River	76.48	22.6	7.9	7.00	279
River	76.52	22.5	7.9	7.00	279
River	76.55	22.6	7.9	7.00	279
River	76.58	22.6	7.9	7.00	279
P2	76.92	20.6	6.8	0.15	279
P2	76.95	20.7	6.8	0.10	279
P2	76.98	20.7	6.7	0.10	278
P2	77.02	20.6	6.7	0.10	278
P2	77.05	20.6	6.7	0.10	278
P2	77.08	20.6	6.7	0.10	278
P2	77.12	20.6	6.7	0.10	277
P2	77.15	20.6	6.7	0.10	277
P2	77.18	20.6	6.7	0.10	277
P2	77.22	20.6	6.7	0.10	277
P2	77.25	20.6	6.7	0.10	277
River	78.20	22.2	7.7	5.40	281
River	78.23	22.2	7.7	5.40	281
River	78.27	22.2	7.7	5.50	281
River	78.30	22.2	7.7	5.20	281
River	78.33	22.2	7.7	5.40	281
River	78.37	22.2	7.7	5.50	281
River	78.40	22.2	7.7	5.40	281
River	78.43	22.2	7.7	5.40	281
River	78.47	22.2	7.7	5.40	281

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)
River	78.50	22.2	7.7	5.40	281
River	78.53	22.2	7.7	5.50	281
River	78.57	22.2	7.7	5.40	281
River	78.60	22.2	7.7	5.40	281
River	78.63	22.1	7.7	5.40	281
River	78.67	22.1	7.7	5.40	281
River	78.70	22.1	7.7	5.40	281
P2	79.03	20.5	6.9	0.45	280
P2	79.07	20.5	6.8	0.35	280
P2	79.10	20.5	6.8	0.35	280
P2	79.13	20.5	6.8	0.25	279
P2	79.17	20.4	6.8	0.25	279
P2	79.20	20.4	6.8	0.20	279
P2	79.23	20.4	6.7	0.20	278
P2	79.27	20.4	6.7	0.15	278
P2	79.30	20.4	6.7	0.15	278
P2	79.33	20.4	6.7	0.15	278
P2	79.37	20.3	6.7	0.10	278
P2	79.40	20.3	6.7	0.10	278
River	80.03	21.8	7.6	6.30	279
River	80.07	21.8	7.6	6.20	279
River	80.10	21.7	7.6	6.20	279
River	80.13	21.7	7.6	6.30	279
River	80.17	21.7	7.6	6.20	279
River	80.20	21.7	7.6	6.20	279
River	80.23	21.7	7.6	6.10	279
River	80.27	21.7	7.6	6.00	279
River	80.30	21.7	7.6	6.00	280
River	80.33	21.7	7.6	6.20	280
River	80.37	21.7	7.6	6.00	280
River	80.40	21.7	7.6	6.00	280
River	80.43	21.7	7.6	6.00	280
River	80.47	21.7	7.6	6.00	280
River	80.50	21.7	7.6	5.90	280
River	80.53	21.7	7.6	6.00	280
P2	80.92	20.4	6.8	0.15	283
P2	80.95	20.4	6.8	0.15	282
P2	80.98	20.4	6.8	0.10	282
P2	81.02	20.3	6.8	0.10	281
P2	81.05	20.3	6.7	0.10	281
P2	81.08	20.3	6.7	0.10	281
P2	81.12	20.3	6.7	0.10	281
P2	81.15	20.4	6.7	0.10	280
P2	81.18	20.3	6.7	0.10	280
P2	81.22	20.3	6.7	0.10	280
P2	81.25	20.3	6.7	0.10	280
River	81.87	21.4	7.5	5.60	282
River	81.90	21.4	7.5	5.70	282
River	81.93	21.4	7.5	5.70	282
River	81.97	21.4	7.5	5.90	282
River	82.00	21.4	7.5	5.80	281
River	82.03	21.4	7.5	5.70	282
River	82.07	21.4	7.5	5.60	282
River	82.10	21.4	7.5	5.70	282
River	82.13	21.4	7.5	5.90	282
River	82.17	21.4	7.5	5.90	282
River	82.20	21.3	7.5	5.90	282
River	82.23	21.3	7.5	5.80	282
River	82.27	21.3	7.5	5.70	282
River	82.30	21.3	7.5	5.70	282
River	82.33	21.3	7.5	5.60	282
P2	82.67	20.1	6.8	0.10	283
P2	82.70	20.1	6.8	0.10	282
P2	82.73	20.1	6.8	0.10	282
P2	82.77	20.1	6.8	0.10	282
P2	82.80	20.1	6.8	0.10	281
P2	82.83	20.1	6.8	0.05	281
P2	82.87	20.1	6.8	0.05	281
P2	82.90	20.1	6.8	0.05	281
P2	82.93	20.1	6.7	0.05	281
River	83.12	21.1	7.4	5.60	280
River	83.15	21.1	7.5	5.50	281
River	83.18	21.1	7.5	5.30	281
River	83.22	21.1	7.5	5.50	281
River	83.25	21.1	7.5	5.50	281
River	83.28	21.1	7.5	5.50	281
River	83.32	21.1	7.5	5.40	281
River	83.35	21.0	7.5	5.30	281
River	83.38	21.0	7.5	5.50	281
River	83.42	21.0	7.5	5.60	281
P2	83.62	20.0	6.8	0.10	282
P2	83.65	20.0	6.8	0.10	282
P2	83.68	20.0	6.8	0.05	281
P2	83.72	20.0	6.8	0.05	281
P2	83.75	20.0	6.8	0.05	281
P2	83.78	20.0	6.8	0.05	281
River	85.10	20.8	7.3	5.70	281
River	85.13	20.8	7.3	5.70	281
River	85.17	20.8	7.4	5.75	281
River	85.20	20.8	7.4	5.70	282
River	85.23	20.8	7.4	5.70	282
River	85.27	20.8	7.4	5.75	282
River	85.30	20.8	7.4	5.75	282
River	85.33	20.8	7.7	5.60	282
River	85.37	20.8	7.4	5.80	282
River	85.40	20.8	7.4	5.85	282

Table 27. Field measurements of temperature, pH, dissolved oxygen concentration, and specific conductance in water from streambed piezometer P2 and from Rockaway River at P2, June 2-6, 1986 (continued)

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
River	85.43	20.8	7.5	5.80	282
P2	85.78	19.9	6.7	0.15	284
P2	85.82	19.8	6.6	0.15	283
P2	85.85	19.8	6.6	0.10	283
P2	85.88	19.8	6.6	0.10	282
P2	85.92	19.8	6.7	0.10	282
P2	85.95	19.8	6.7	0.10	282
P2	85.98	19.8	6.6	0.10	282
P2	86.02	19.8	6.6	0.10	282
P2	86.05	19.8	6.7	0.10	282
P2	86.08	19.8	6.7	0.10	281
P2	86.12	19.8	6.7	0.10	282
P2	86.15	19.7	6.7	0.10	282
P2	86.18	19.7	6.7	0.10	281
P2	86.22	19.7	6.7	0.10	281
P2	86.25	19.7	6.7	0.10	281
River	87.67	20.2	7.4	6.10	274
River	87.70	20.2	7.4	6.15	274
River	87.73	20.2	7.4	6.20	274
River	87.77	20.3	7.4	6.15	273
River	87.80	20.3	7.4	6.10	270
River	87.83	20.3	7.4	6.10	265
River	87.87	20.3	7.4	6.15	263
River	87.90	20.2	7.4	6.10	261
River	87.93	20.3	7.4	6.15	261
River	87.97	20.2	7.4	6.10	261
River	88.00	20.2	7.4	6.15	261
P2	88.27	19.6	6.8	0.10	287
P2	88.30	19.6	6.8	0.10	286
P2	88.33	19.6	6.8	0.10	286
P2	88.37	19.6	6.8	0.10	285
P2	88.40	19.5	6.8	0.10	286
P2	88.43	19.5	6.8	0.10	285
P2	88.47	19.6	6.8	0.10	285
P2	88.50	19.6	6.8	0.10	285
P2	88.53	19.6	6.8	0.10	285
P2	88.57	19.6	6.8	0.10	285
P2	88.60	19.6	6.8	0.10	285
P2	88.63	19.6	6.7	0.10	285
P2	88.67	19.6	6.8	0.10	284
River	89.17	20.0	7.3	5.75	267
River	89.20	20.1	7.3	5.90	267
River	89.23	20.1	7.4	6.45	267
River	89.27	20.1	7.4	6.40	267
River	89.30	20.1	7.4	6.40	267
River	89.33	20.1	7.4	6.35	267
River	89.37	20.1	7.4	6.30	267
River	89.40	20.1	7.4	6.35	267

Source	Time (decimal hours after 1200 June 2)	Water temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
River	89.43	20.1	7.4	6.30	268
River	89.47	20.1	7.4	6.45	268
River	89.50	20.1	7.4	6.35	269
P2	89.70	19.4	6.8	0.10	287
P2	89.73	19.6	6.7	0.10	286
P2	89.77	19.6	6.8	0.10	286
P2	89.80	19.6	6.7	0.05	286
P2	89.83	19.6	6.7	0.05	286
P2	89.87	19.6	6.7	0.05	285
P2	89.90	19.6	6.7	0.05	286
P2	89.93	19.6	6.7	0.05	285
P2	89.97	19.6	6.7	0.05	285
P2	90.00	19.6	6.7	0.05	285
P2	90.03	19.6	6.7	0.05	285
P2	90.07	19.6	6.7	0.05	285
P2	90.10	19.5	6.7	0.05	285
P2	90.13	19.6	6.7	0.05	284
River	91.20	20.2	7.2	6.30	303
River	91.23	20.2	7.2	6.20	303
River	91.27	20.2	7.3	6.20	303
River	91.30	20.2	7.3	6.20	303
River	91.33	20.2	7.3	6.10	303
River	91.37	20.2	7.3	6.20	304
River	91.40	20.2	7.3	6.35	304
River	91.43	20.2	7.3	6.10	304
P2	91.83	19.8	6.8	0.15	289
P2	91.87	19.7	6.8	0.10	288
P2	91.90	19.7	6.8	0.10	287
P2	91.93	19.7	6.8	0.10	287
P2	91.97	19.7	6.8	0.10	287
P2	92.00	19.7	6.8	0.10	287
P2	92.03	19.7	6.8	0.10	286
P2	92.07	19.7	6.7	0.10	286
P2	92.10	19.7	6.7	0.10	286
P2	92.13	19.7	6.7	0.10	286
P2	92.17	19.7	6.7	0.10	286
P2	92.20	19.7	6.7	0.10	285
P2	92.23	19.7	6.7	0.10	285
P2	92.27	19.7	6.7	0.10	285
P2	92.30	19.7	6.7	0.10	285
P2	92.33	19.7	6.7	0.05	285
P2	93.40	20.0	6.7	0.10	285
P2	93.43	20.0	6.7	0.10	285
P2	93.47	20.0	6.7	0.10	284
P2	93.50	20.0	6.7	0.10	284
P2	93.53	20.1	6.7	0.05	283
P2	93.57	20.1	6.7	0.05	283
P2	93.60	20.0	6.7	0.05	283
P2	93.63	20.0	6.7	0.05	283

Table 28. Water levels in streambed piezometer P2 and Rockaway River at P2, Dover, N.J., June 2-6, 1986

Date (mo-d-yr)	Time	Hours since 1200 June 2	Water level, in feet above sea level		Water-level difference, in feet
			River	P2	
6-2-86	1510	3.17	581.73	579.61	2.12
	1632	4.53	581.75	579.69	2.06
	1752	5.87	581.73	579.73	2.00
	1918	7.30	581.72	579.73	1.99
	2036	8.60	581.65	579.72	1.93
	2240	10.67	581.66	579.67	1.99
6-3-86	0244	14.73	581.68	579.47	2.21
	0438	16.63	581.68	579.47	2.21
	0648	18.80	581.67	579.47	2.20
	0830	20.50	581.67	579.50	2.17
	1027	22.45	581.65	579.55	2.10
	1405	26.08	581.65	579.59	2.06
	1555	27.92	581.65	579.59	2.06
	1725	29.42	581.65	579.57	2.08
	1920	31.33	581.65	579.58	2.07
	2115	33.25	581.65	579.55	2.10
	2256	34.93	581.66	579.52	2.14
6-4-86	0130	37.50	581.67	579.43	2.24
	0345	39.75	581.66	579.45	2.21
	0539	41.65	581.65	579.48	2.17
	0728	43.10	581.65	579.51	2.14
	0926	45.43	581.65	579.50	2.15
	1123	47.38	581.65	579.49	2.16
	1345	49.75	581.65	579.48	2.17
	1625	52.42	581.62	579.55	2.07
	1835	54.58	581.64	579.62	2.02
6-5-86	0138	61.63	581.62	579.42	2.20
	0338	63.63	581.62	579.40	2.22
	0528	65.47	581.63	579.36	2.27
	0724	67.40	581.61	579.40	2.21
	0930	69.50	581.61	579.42	2.19
	1122	71.37	581.62	579.36	2.26
	1250	72.83	581.57	579.29	2.28
	1410	74.17	581.61	579.33	2.28
	1640	76.67	581.60	579.36	2.24
	1840	78.67	581.61	579.46	2.15
	2035	80.58	581.60	579.47	2.13
	2225	82.42	581.61	579.50	2.11
6-6-86	0134	85.57	581.64	579.49	2.15
	0531	89.52	581.91	579.53	2.38
	0724	91.40	581.88	579.59	2.29
Maximum			581.91	579.73	2.38
Minimum			581.60	579.29	1.93
Range			0.31	0.44	0.45
Mean					2.15

Table 29. Water temperatures in Rockaway River and in streambed piezometers at Dover, N.J., June 2-6, 1986

[Dashes indicate no measurement at that depth, commonly because water level in piezometer had dropped below that depth. Locations of piezometers shown in figs. 8 and 10.]

A. Piezometer P2 and Rockaway River at P2

Date (mo-d-yr)	Time	Hours since 1200 June 2	Water temperature, in degrees Celsius, in River or in piezometer at indicated depth												
				Depth in piezometer, in feet below top of streambed											
			River	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.0
6-2-86	1510	3.17	22.6	21.7	21.7	21.7	21.7	21.7	21.7	21.5	21.4	21.3	21.1	21.0	20.5
	1632	4.53	21.8	*21.6	---	21.7	---	21.6	---	21.5	---	21.3	---	21.1	---
	1752	5.87	21.2	21.7	21.8	21.8	21.7	21.7	21.6	21.5	21.4	21.2	21.1	21.0	20.5
	1918	7.30	20.5	21.6	21.7	21.7	21.7	21.5	21.4	21.3	21.2	21.1	21.0	20.8	20.4
	2036	8.60	20.0	21.0	21.5	21.6	21.6	21.5	21.4	21.3	21.2	21.1	21.0	20.8	20.4
	2240	10.67	19.4	20.8	21.4	21.5	21.5	21.5	21.4	21.3	21.2	21.1	21.0	20.8	20.4
6-3-86	0117	13.28	17.8	20.2	21.2	21.4	21.5	21.5	21.5	21.4	21.3	21.2	21.1	21.0	20.7
	0244	14.73	17.2	---	20.7	20.9	21.2	21.2	21.3	21.2	21.2	21.1	21.0	---	---
	0438	16.63	16.7	---	20.0	20.9	21.1	21.2	21.3	21.3	21.2	21.1	21.1	---	---
	0648	18.80	16.1	---	19.5	20.7	20.9	21.1	21.2	21.2	21.2	21.1	21.0	---	---
	0830	20.50	16.5	---	20.7	20.8	20.9	21.0	21.0	21.0	21.0	21.0	20.9	---	---
	1027	22.45	17.4	---	20.4	20.6	20.7	20.8	20.9	20.9	20.9	20.9	20.9	---	20.5
	1405	26.08	19.9	20.1	20.5	20.6	20.6	20.7	20.7	20.7	20.7	20.7	20.7	20.6	20.4
	1555	27.92	20.2	20.0	20.5	20.5	20.5	---	20.6	20.6	20.7	20.7	20.7	20.6	20.4
	1725	29.42	19.6	---	20.2	20.3	20.4	20.5	20.5	20.6	20.6	20.6	20.6	20.5	20.4
	1920	31.33	19.0	---	20.1	20.3	20.3	20.4	20.4	20.5	20.5	20.5	20.6	20.5	20.4
	2115	33.25	18.4	---	20.0	20.1	20.2	20.3	20.4	20.4	20.4	20.5	20.5	20.4	20.4
	2256	34.93	17.9	---	19.7	20.1	20.2	20.3	20.3	20.3	20.4	20.4	20.4	20.4	20.3
6-4-86	0130	37.50	17.4	---	19.7	19.9	20.0	20.1	20.1	20.2	20.2	20.3	20.3	20.3	20.3
	0345	39.75	17.0	---	19.3	19.7	19.8	20.0	20.0	20.1	20.2	20.2	20.3	20.3	20.2
	0539	41.65	16.6	---	19.4	19.7	19.8	19.9	20.0	20.1	20.1	20.2	20.2	20.2	20.2
	0728	43.10	16.4	---	19.4	19.7	19.8	19.9	20.0	20.0	20.1	20.1	20.1	20.1	20.1
	0926	45.43	16.8	---	19.3	19.5	19.6	19.8	19.9	19.9	20.0	20.0	20.1	20.0	20.1
	1123	47.38	18.0	---	19.3	19.5	19.6	19.7	19.8	19.8	19.9	19.9	20.0	20.0	20.0
	1345	49.75	20.3	---	19.5	19.6	19.6	19.7	19.8	19.8	19.8	19.8	19.9	19.9	19.9
	1625	52.42	20.7	---	19.6	19.6	19.6	19.7	19.7	19.7	19.7	19.8	19.8	19.8	19.9
	1835	54.58	20.1	---	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.7	19.8	19.8	19.8
6-5-86	0138	61.63	19.1	---	18.7	19.3	19.4	19.4	19.5	19.5	19.5	19.5	19.6	---	---
	0338	63.63	18.8	---	18.9	19.3	19.4	19.5	19.5	19.5	19.5	19.5	19.6	19.6	19.7
	0528	65.47	18.7	---	19.1	19.2	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.6	19.6
	0724	67.40	18.6	---	18.9	19.3	19.4	19.4	19.5	19.5	19.5	19.5	19.6	19.6	19.6
	0930	69.50	19.0	---	19.7	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.6	19.6
	1122	71.37	20.0	---	19.8	19.6	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.6
	1250	72.83	21.3	---	---	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.6
	1410	74.17	21.8	---	---	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.6
	1640	76.67	22.0	---	---	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.6
	1840	78.67	21.7	---	19.9	19.6	19.5	19.5	19.4	19.5	19.5	19.5	19.5	19.5	19.5
	2035	80.58	21.3	---	19.9	19.7	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5
	2225	82.42	20.9	---	20.1	19.8	19.7	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.5
6-6-86	0134	85.57	20.5	---	20.1	20.0	19.9	19.8	19.7	19.6	19.6	19.6	19.5	19.5	19.5
	0531	89.52	20.0	---	20.0	20.0	20.0	19.8	19.8	19.7	19.7	19.6	19.6	19.5	19.5
	0724	91.40	20.1	19.9	19.9	20.0	20.0	19.9	19.9	19.8	19.7	19.6	19.6	19.6	19.5
Number of observations			42	10	38	42	41	41	41	42	41	42	41	36	36
Maximum			22.6	21.7	21.8	21.8	21.7	21.7	21.7	21.5	21.4	21.3	21.1	21.1	20.7
Minimum			16.1	19.9	19.1	19.2	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5
Range			6.5	0.8	2.7	2.6	2.3	2.3	2.3	2.1	2.0	1.8	1.6	1.6	1.2

* All temperature measurements in piezometer P2 at 1632 June 2 were made 0.1 feet higher than depth indicated at head of column.

Table 29 (continued)

B. Piezometer P3 and Rockaway River at P3

Date (mo-d-yr)	Time	Hours since 1200 June 2	Water temperature, in degrees Celsius, in River or in piezometer at indicated depth														
				Depth in piezometer, in feet below top of streambed													
			River	0.9	1.1	1.4	1.6	1.9	2.1	2.4	2.6	2.9	3.1	3.4	3.6	3.9	4.1
6-2-86	1530	3.50	22.3	22.0	22.0	21.9	21.9	21.9	21.9	21.8	21.8	21.8	21.8	21.6	21.5	21.4	21.4
	1810	6.17	21.1	21.8	21.8	21.8	21.9	21.9	21.9	21.8	21.8	21.8	21.8	21.7	21.6	21.5	21.4
	1932	7.53	20.3	21.3	21.5	21.6	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.6	21.5	21.4
	2130	9.50	19.7	21.3	21.3	21.4	21.5	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.5	21.4
	2252	10.87	19.2	20.9	21.0	21.1	21.3	21.4	21.4	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5
6-3-86	0125	13.42	17.7	20.7	20.7	20.8	21.0	21.1	21.2	21.3	21.3	21.3	21.4	21.4	21.4	21.4	21.4
	0254	14.90	17.1	19.5	20.3	20.6	20.8	21.0	21.1	21.2	21.2	21.2	21.3	21.3	21.3	21.3	21.4
	0445	16.75	16.6	---	19.1	20.4	20.5	20.8	21.0	21.0	21.1	21.1	21.1	21.2	21.2	21.3	---
	0656	18.93	16.1	---	20.2	20.4	20.6	20.7	20.8	20.8	20.9	20.9	21.0	20.9	20.9	---	---
	0839	20.65	16.5	19.8	20.0	20.1	20.3	20.4	20.4	20.5	20.6	20.6	20.6	20.6	20.6	21.2	21.3
	1035	22.58	17.5	---	20.0	20.1	20.1	20.2	20.2	20.3	20.3	20.3	20.4	20.4	20.4	21.0	21.1
	1255	24.92	19.2	20.1	20.1	20.1	20.1	20.2	20.2	20.3	20.3	20.3	20.4	20.4	20.5	21.0	21.2
	1615	28.25	19.9	20.1	20.2	20.2	20.2	20.3	20.3	20.3	20.4	20.4	20.4	20.5	20.5	20.9	21.1
	1755	29.92	19.5	20.1	20.2	20.2	20.2	20.2	20.3	20.3	20.3	20.4	20.4	20.5	20.5	21.0	21.2
	1945	31.75	19.1	20.0	20.1	20.2	20.2	20.2	20.2	20.3	20.3	20.3	20.4	20.4	20.5	20.9	21.1
	2103	33.05	18.5	19.5	19.9	20.1	20.1	20.1	20.2	20.3	20.3	20.3	20.4	20.4	20.5	20.8	21.1
	2244	34.73	18.0	18.0	19.9	20.0	20.0	20.0	20.1	20.1	20.2	20.2	20.3	20.3	20.3	20.7	21.0
6-4-86	0138	37.63	17.4	18.6	19.3	19.4	19.5	19.5	19.7	19.8	20.0	20.0	20.1	20.1	20.2	20.4	20.8
	0355	39.92	17.0	19.0	19.2	19.3	19.4	19.7	19.7	19.9	20.0	20.0	20.0	20.0	---	20.2	20.7
	0549	41.82	16.6	17.3	18.7	19.2	19.4	19.5	19.6	19.7	19.7	19.7	19.8	19.8	19.8	20.3	20.6
	0736	43.60	16.4	16.8	18.6	19.0	19.3	19.3	19.4	19.4	19.4	19.5	19.6	19.6	19.6	20.2	20.6
	0933	45.55	16.8	18.6	18.6	18.7	18.9	19.0	19.1	19.3	19.3	19.4	19.4	19.5	19.5	20.1	20.4
	1130	47.50	18.3	18.6	18.7	18.9	19.1	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	20.0	20.2
	1335	49.58	20.2	19.5	19.3	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.6	20.1	20.2
	1610	52.17	20.5	19.9	19.6	19.5	19.5	19.4	19.4	19.4	19.5	19.5	19.5	19.6	19.6	20.1	20.3
	1820	54.33	20.1	19.9	19.7	19.6	19.5	19.5	19.5	19.5	19.5	19.6	19.6	19.7	19.7	20.1	20.3
	2005	56.08	19.9	19.8	19.7	19.7	19.6	19.6	19.6	19.5	19.6	19.6	19.6	19.7	19.7	20.0	20.3
	2245	58.75	19.4	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.7	19.7	20.0	20.2
6-5-86	0140	61.67	19.0	18.7	19.4	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.8	20.0
	0339	63.65	18.8	18.9	19.2	19.3	19.4	19.5	19.5	19.6	19.6	19.6	19.6	19.7	20.0	---	---
	0535	65.58	18.7	18.8	18.9	19.3	19.4	19.4	19.4	19.5	19.5	19.5	19.6	19.6	19.6	19.9	20.0
	0730	67.50	18.6	---	19.2	19.3	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.5	19.8	20.0
	0936	69.60	19.0	---	19.5	19.3	19.3	19.3	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.7	19.9
	1128	71.47	20.1	---	20.2	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.6	19.8
	1300	73.00	21.3	---	---	19.5	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.6	19.6	19.7	19.8
	1450	74.83	21.8	---	---	20.0	19.7	19.5	19.5	19.5	19.5	19.5	19.6	19.6	19.6	19.7	19.8
	1645	76.75	21.9	---	20.6	20.2	19.9	19.6	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.8	19.9
	1850	78.83	21.6	---	20.8	20.5	20.3	19.9	19.7	19.6	19.6	19.6	19.6	19.6	19.7	19.8	19.8
	2045	80.75	21.2	---	20.9	20.6	20.4	20.2	19.9	19.8	19.7	19.6	19.6	19.6	19.7	19.7	19.8
	2230	82.50	20.9	20.8	20.7	20.6	20.4	20.2	20.0	19.8	19.7	19.7	19.6	19.7	19.7	19.7	19.8
6-6-86	0139	85.65	20.5	---	20.8	20.7	20.6	20.5	20.3	20.1	20.0	19.8	19.8	19.7	19.7	19.7	19.7
	0539	89.65	20.0	---	20.4	20.4	20.4	20.3	20.2	20.2	20.1	20.0	19.9	19.8	19.8	19.7	19.7
	0731	91.52	20.2	20.5	20.4	20.4	20.3	20.3	20.2	20.2	20.1	20.0	19.9	19.8	19.8	19.8	19.8
	0920	93.33	20.4	20.7	20.6	20.5	20.4	20.3	20.2	20.2	20.1	20.0	19.9	19.9	19.8	19.8	19.8
Number of observations			44	32	42	44	44	44	44	44	44	44	44	44	43	42	41
Maximum			22.3	22.0	22.0	21.9	21.9	21.9	21.9	21.8	21.8	21.8	21.8	21.7	21.6	21.5	21.5
Minimum			16.1	18.0	18.6	18.7	18.9	19.0	19.1	19.3	19.3	19.4	19.4	19.4	19.4	19.6	19.7
Range			6.2	4.0	3.4	3.2	3.0	2.9	2.8	2.5	2.5	2.4	2.4	2.3	2.2	1.9	1.8

Table 29 (continued)

C. Piezometer P4 and Rockaway River at P4

Date (mo-d-yr)	Time	Hours since 1200 June 2	Water temperature, in degrees Celsius, in River or in piezometer at indicated depth															
			River	Depth in piezometer, in feet below top of streambed														
				0.9	1.2	1.4	1.7	1.9	2.2	2.4	2.7	2.9	3.2	3.4	3.7	3.9	4.2	4.4
6-2-86	1625	4.42	22.0	22.1	22.1	22.1	22.1	22.1	22.1	22.0	22.0	22.0	22.0	22.0	22.0	21.8	21.6	21.5
	1845	6.75	21.6	21.6	21.7	21.7	21.7	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.7	21.7	21.5
	2140	9.67	19.5	21.4	21.6	21.6	21.7	21.8	21.8	21.8	21.8	21.8	21.8	21.7	21.7	21.6	----	----
6-3-86	0036	12.60	17.9	17.9	21.3	21.5	21.6	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	----
	0216	14.27	17.4	18.5	20.8	21.2	21.4	21.5	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.7	21.7	----
	0413	16.22	16.5	----	19.5	20.8	21.1	21.3	21.4	21.5	21.5	21.6	21.6	21.6	21.6	21.6	21.6	----
	0610	18.17	16.0	----	20.7	20.9	21.0	21.1	21.1	21.2	21.3	21.3	21.3	21.4	21.4	21.4	21.5	----
	0816	20.27	16.4	----	----	----	20.9	20.9	20.9	20.9	21.0	21.0	21.0	21.0	21.3	21.5	21.6	----
	1007	22.12	17.3	19.6	19.7	20.0	20.2	20.3	20.4	20.4	20.5	20.5	20.6	20.6	20.6	20.6	21.4	----
	1150	23.83	18.6	19.7	19.8	19.9	20.0	20.2	20.3	20.3	20.3	20.3	20.3	20.4	20.6	20.8	21.3	21.4
	1425	26.42	20.0	20.2	20.2	20.2	20.3	20.3	20.4	20.5	20.5	20.6	20.6	20.6	20.6	20.9	21.3	21.4
	1625	28.42	20.0	20.4	20.4	20.4	20.4	20.5	20.5	20.5	20.6	----	20.6	----	20.7	20.9	21.2	21.4
	1835	30.58	19.4	20.2	20.2	20.3	20.3	20.3	20.4	----	20.4	20.4	20.5	20.5	20.6	20.7	21.2	21.3
	2135	33.58	18.3	20.1	20.1	20.2	20.2	20.3	20.4	20.4	----	20.5	20.6	20.6	20.6	20.7	21.0	21.2
	2325	35.42	17.7	----	19.9	20.1	20.2	20.3	20.3	20.4	20.4	20.5	20.5	20.5	20.6	20.6	20.9	21.2
6-4-86	0110	37.17	17.6	----	19.3	19.9	20.0	20.1	20.2	20.3	20.3	20.4	20.4	20.4	20.5	20.5	21.0	21.1
	0312	39.20	17.1	----	17.5	19.7	19.8	20.0	20.1	20.1	20.2	20.3	20.3	20.3	20.3	20.4	20.9	21.0
	0512	41.20	16.7	----	17.9	19.5	19.8	19.9	20.0	20.0	20.1	20.1	20.1	20.2	20.2	20.2	20.7	20.9
	0707	43.12	16.4	17.8	19.2	19.4	19.4	19.6	19.6	19.7	19.7	19.8	19.8	19.8	19.9	19.9	20.6	20.8
	0905	45.08	16.6	19.0	19.0	19.1	19.2	19.2	19.3	19.3	19.3	19.4	19.4	19.4	19.4	19.4	20.4	20.7
	1104	47.07	17.9	18.9	18.9	19.0	19.0	19.1	19.2	19.2	19.2	19.3	19.3	19.4	19.4	19.4	20.3	20.5
	1250	48.83	19.8	----	----	19.2	19.2	19.3	19.3	19.4	19.2	19.5	19.5	19.6	19.6	19.6	20.3	20.4
	1505	51.08	20.7	----	----	19.5	19.3	19.4	19.4	19.5	19.6	19.6	19.6	19.6	19.7	19.7	20.3	20.4
	1715	53.25	20.4	----	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.6	19.6	19.6	19.7	19.8	20.2	20.4
	1915	55.25	20.0	19.8	19.7	19.6	19.6	19.5	19.6	19.6	19.6	19.6	19.6	19.7	19.7	19.7	20.2	20.4
	2145	57.75	19.6	19.6	19.6	19.6	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.7	19.7	19.8	20.1	20.3
	2310	59.17	19.3	----	19.5	19.5	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.7	19.7	19.8	20.1	20.2
6-5-86	0107	61.12	19.1	----	19.3	19.4	19.4	19.5	19.5	19.5	19.5	19.6	19.6	19.6	19.7	19.7	20.0	20.1
	0306	63.10	18.8	----	18.9	19.2	19.3	19.4	19.5	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.9	20.1
	0505	65.08	18.7	----	----	19.4	19.4	19.5	19.5	19.5	19.5	19.5	19.5	19.6	19.6	19.6	19.8	20.0
	0702	67.03	18.6	----	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.8	19.9
	0904	69.07	18.9	19.4	19.3	19.3	19.3	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.7	19.8
	1100	71.0	19.9	----	19.8	19.5	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.7	19.8
	1320	73.33	21.5	----	----	----	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.7	19.8
	1515	75.25	21.9	----	----	----	19.7	19.5	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.5	19.6	19.7
	1730	77.50	21.9	21.1	20.8	20.6	20.3	19.9	19.7	19.5	19.5	19.4	19.5	19.5	19.5	19.5	19.6	19.7
	2005	80.08	21.4	21.0	20.7	20.5	20.1	19.8	19.7	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.6	19.7
	2150	81.83	21.0	20.9	20.7	20.6	20.3	20.1	19.8	19.7	19.6	19.5	19.5	19.5	19.5	19.5	19.6	19.7
	2320	83.33	20.8	20.8	20.6	20.5	20.3	20.1	19.9	19.7	19.6	19.5	19.5	19.5	19.5	19.5	19.6	19.6
6-6-86	0105	85.08	20.5	----	----	20.5	20.4	20.3	20.1	19.9	19.7	19.7	19.6	19.5	19.5	19.5	19.6	19.6
	0316	87.27	20.3	22.2	20.8	20.7	20.5	20.4	20.2	20.0	19.9	19.8	19.7	19.6	19.6	19.6	19.6	19.6
	0507	89.12	20.1	----	20.7	20.6	20.4	20.3	20.2	20.0	19.9	19.8	19.7	19.6	19.6	19.6	19.6	19.6
	0705	91.08	20.1	20.2	20.2	20.2	20.2	20.2	20.2	20.1	19.9	19.8	19.7	19.7	19.6	19.6	19.6	19.6
	0900	93.00	20.4	20.3	20.3	20.3	20.2	20.2	20.1	20.1	20.0	19.9	19.8	19.7	19.7	19.6	19.6	19.6
Number of observations			44	24	37	41	44	44	44	43	43	43	44	44	44	44	43	37
Maximum			22.0	22.1	22.1	22.1	22.1	22.1	22.1	22.0	22.0	22.0	22.0	22.0	22.0	21.8	21.7	21.5
Minimum			16.0	17.9	17.5	19.0	19.0	19.1	19.2	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.6	19.6
Range			6.0	4.2	4.6	3.1	3.1	3.0	2.9	2.8	2.8	2.7	2.7	2.6	2.6	2.4	2.1	1.9