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

GROUND-WATER FLOW AND DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS, RUTGERS UNIVERSITY BUSCH CAMPUS AND VICINITY, PISCATAWAY TOWNSHIP, NEW JERSEY

Rec'd
9/6/00

Water-Resources Investigations Report 99-4256

Prepared in cooperation with

RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY

GROUND-WATER FLOW AND DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS, RUTGERS UNIVERSITY BUSCH CAMPUS AND VICINITY, PISCATAWAY TOWNSHIP, NEW JERSEY

By Jean C. Lewis-Brown and Vincent T. dePaul

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 99-4256

Prepared in cooperation with

RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY

West Trenton, New Jersey

2000

USGS

science for a changing world

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY

Charles G. Groat, *Director*

For additional information
write to:

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

Copies of this report can be
purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

Page

Abstract 1
Introduction 2
Purpose and scope 3
Acknowledgments 3
Methods of data collection 3
Geologic coring 3
Borehole geophysical logging 3
Well installation 7
Measurement of water levels and streamflow 9
Aquifer testing 9
Collection and analysis of water-quality samples 10
Hydrogeology 11
Geologic setting 11
Hydrogeologic framework 11
Estimates of hydraulic properties 14
Ground-water flow 16
Conceptual model 16
Simulated ground-water flow system 18
Description of digital model 18
Model area and grid 18
Model boundaries 22
Assumptions, limitations, and appropriate uses of the model 22
Model calibration 25
Hydraulic parameters 25
Areal recharge 25
Transmissivity 26
Vertical hydraulic conductivity and vertical leakance 27
Streambed hydraulic conductance 28
Specific yield and storage coefficient 29
Pumpage 29
Calibration criteria 29
Simulated ground-water budget 31
Ground-water quality and distribution of volatile organic compounds 31
Ground-water quality 31
Quality assurance procedures 33
Distribution of volatile organic compounds 33
Carbon tetrachloride and tetrachloroethylene 33
Other volatile organic compounds 34
Relation of distribution of contaminants to ground-water flow paths 35
Carbon tetrachloride 36
Tetrachloroethylene 40
Summary and conclusions 46
References cited 50

ILLUSTRATIONS

Page

Figure 1. Map showing location of the study area, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey 4
2. Map showing location of wells and coreholes in the study area 5
3. Generalized section along dip of bedding showing transmissivity measured at wells and interpreted location of hydrogeologic units in the study area 13
4. Map of area of ground-water flow model showing horizontal discretization and lines of hydrogeologic section 19
5. Section B-B' along strike of bedding showing interpreted hydrogeologic framework in the study area and assumed framework outside the study area in the area of the ground-water flow model 20
6. Section C-C' along dip of bedding showing interpreted hydrogeologic framework in the study area and assumed framework outside the study area in the area of the ground-water flow model 21
7. Section C-C' showing vertical discretization of ground-water flow model 23
8. Simulated ground-water budget 32
9. Map showing concentration of carbon tetrachloride in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with no pumpage from the irrigation well 37
10. Map showing concentration of carbon tetrachloride in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with average annual pumpage from the irrigation well 38
11. Map showing concentration of carbon tetrachloride in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with maximum pumpage from the irrigation well 39
12. Section A-A' showing hydrogeologic framework, concentration of carbon tetrachloride in water samples collected from wells in 1995, and simulated area containing ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with no pumpage from the irrigation well 41
13. Section A-A' showing hydrogeologic framework, concentration of carbon tetrachloride in water samples collected from wells in 1995, and simulated area containing ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with both average annual and maximum pumpage from the irrigation well 42
14. Map showing concentration of tetrachloroethylene in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed tetrachloroethylene source area under steady-state conditions with no pumpage from the irrigation well 43

ILLUSTRATIONS--Continued

Page

Figure 15. Map showing concentration of tetrachloroethylene in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed tetrachloroethylene source area under steady-state conditions with average annual pumpage from the irrigation well 44

16. Map showing concentration of tetrachloroethylene in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed tetrachloroethylene source area under steady-state conditions with maximum pumpage from the irrigation well 45

17. Section A-A' showing hydrogeologic framework, concentration of tetrachloroethylene in water samples collected from wells in 1995, and simulated area containing ground-water flow paths from the assumed tetrachloroethylene source area under steady-state conditions with no pumpage from the irrigation well 47

18. Section A-A' showing hydrogeologic framework, concentration of tetrachloroethylene in water samples collected from wells in 1995, and simulated area containing ground-water flow paths from the assumed tetrachloroethylene source area under steady-state conditions with both average annual and maximum pumpage from the irrigation well 48

TABLES

Table 1. Borehole geophysical logs collected in wells and coreholes at the Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey 6

2. Construction information for wells and piezometers at the Rutgers University Busch Campus and vicinity 8

3. Transmissivity and horizontal hydraulic conductivity at selected wells, Rutgers University Busch Campus and vicinity 15

4. Transmissivity in the weathered zone, water-bearing units, and confining units, Rutgers University Busch Campus and vicinity 16

5. Hydraulic parameters used in digital model of ground-water flow, Rutgers University Busch Campus and vicinity 25

6. Measured and simulated water levels on October 28, 1996, and drawdown on October 29, 1996, in wells in the study area, Rutgers University Busch Campus and vicinity 30

7. Concentrations of selected volatile organic compounds in, and chemical and physical properties of, water samples from wells, Rutgers University Busch Campus and vicinity, 1993-96 52

APPENDIXES

Page

Appendix 1. Water-level altitudes in wells, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey, 1992-96 56
2. Volatile organic compounds determined in ground-water samples, Rutgers University Busch Campus and vicinity 63
3. Selected chemical constituents in ground-water samples collected at the Rutgers University Busch Campus and vicinity, 1993-94 64
4. Maximum contaminant levels for selected organic compounds and inorganic constituents, New Jersey 66
5. Results of analyses of quality-assurance blank samples for selected organic compounds, 1993-96 67

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

Multiply	By	To obtain
	Length	
inch	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
gallon (gal)	0.003785	cubic meter
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
foot per day (ft/d)	0.3048	meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day

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

Multiply	By	To obtain
	Transmissivity	
square foot per day (ft^2/d)[1]	0.09290	square meter per day

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

Water-quality abbreviations:

mg/L - milligrams per liter
µg/L - micrograms per liter
mS/cm - microsiemens per centimeter at 25 degrees Celsius
VOC - volatile organic compound
µm - micrometer

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

GROUND-WATER FLOW AND DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS, RUTGERS UNIVERSITY BUSCH CAMPUS AND VICINITY, PISCATAWAY TOWNSHIP, NEW JERSEY

By Jean C. Lewis-Brown and Vincent T. dePaul

ABSTRACT

Volatile organic compounds, primarily carbon tetrachloride and tetrachloroethylene (PCE), were detected in shallow ground water near the Chemical Engineering building--also called the C-Wing building--at the Rutgers University Busch Campus in Piscataway Township, Middlesex County, New Jersey. The C-Wing building overlies the Passaic Formation, which comprises a water-supply aquifer, and is about 2,500 feet north-northeast of several domestic wells.

In the area of the Busch Campus, the Passaic Formation consists of dipping layers of extensively fractured coarse-grained siltstone and sandstone alternating with layers of sparsely fractured finer grained siltstone and mudstone. Ground water is primarily stored in and transmitted through interconnected fractures in these rocks. The extensively fractured layers comprise water-bearing units; the sparsely fractured layers comprise confining units. The rock layers dip 11° to the northwest. Near land surface, the rocks are weathered. Clay and silt derived from the weathering process fills many of the fractures in the weathered zone, causing it to be less permeable than the underlying water-bearing units. Four water-bearing units, alternating with confining units, are present in the study area. The median transmissivity of the water-bearing units and confining units, respectively, is 84 and 3.7 ft^2/d (feet squared per day). The median transmissivity of the weathered zone is 4.8 ft^2/d.

Recharge to the ground-water flow system is by downward leakage of infiltrated precipitation. The transmissivity contrasts and the dipping hydrogeologic units of the multiunit aquifer system cause large-scale anisotropic flow. Ground-water flow through the system is predominantly southwest, parallel to the strike of the rock layers. Ground-water discharges predominantly to the Raritan River and its tributaries; minor amounts flow to a pumped irrigation well and several domestic wells. The northeastern half of the study area is a recharge area and the southwestern half, which is nearer to the Raritan River, is a discharge area.

A digital model was developed to simulate both steady-state and transient ground-water flow in the study area.The configuration of simulated ground-water flow paths from the vicinity of the C-Wing building are primarily horizontal in the water-bearing units and vertical in the confining units. Horizontal flow generally is parallel or subparallel to the strike of the rock layers. When the irrigation well is not being pumped, all water that passes through the vicinity of the C-Wing building discharges to the Raritan River and its tributaries. Pumping from the irrigation well causes flow lines to shift toward the well and away from the nearby domestic wells.

Water samples were collected from 25 wells in the study area at least once during 1993-96. The spatial distributions of the two primary contaminants at Busch Campus--carbon tetrachloride and PCE--differ from each other. The carbon tetrachloride plume is localized near the C-Wing building, although trace amounts were detected in wells as far as 750 feet from the building. The occurrence of PCE, in contrast, is discontinuous. This compound

was detected in concentrations greater than the New Jersey maximum contaminant level of 1.0 microgram per liter at several locations in the study area. Concentrations were highest in shallow wells less than 10 feet from the C-Wing building and in the irrigation well, which is 2,370 feet from it. PCE was not detected in samples from nine wells between the C-Wing building and the irrigation well, however.

All wells in which carbon tetrachloride was detected are within the area encompassed by the simulated flow lines from the assumed carbon tetrachloride source area at the C-Wing building, and the concentration of carbon tetrachloride decreases along the flow lines. Therefore, the flow-path analysis supports the hypothesis that all of the carbon tetrachloride detected in the study area originated in the C-Wing area. Some wells that contained PCE, however, are outside the area encompassed by the flow lines from the assumed PCE source area at the C-Wing building. Consequently, both the simulated flow paths and the discontinuous distribution of PCE are inconsistent with the hypothesis that all of the PCE detected in the study area originated at the broken pipe near the C-Wing building. Because actual ground-water flow paths through the fractured-rock aquifer system are undoubtedly more complex than the simulated paths, however, the possibility that all of the PCE originated at the broken pipe cannot be conclusively ruled out.

INTRODUCTION

In 1988, during a renovation in the basement of the Chemical Engineering building (hereafter called the C-Wing building) at the Rutgers University Busch Campus, volatile organic compounds (VOC's) were detected in excavated soils surrounding a former laboratory. Concentrations of total VOC's as great as 125,000 µg/L subsequently were detected in ground-water samples collected near the C-Wing building (ENSR Consulting and Engineering, 1989). The contaminants may have originated from a damaged sump piping system in the basement of the building (ENSR Consulting and Engineering, 1989). This piping system served as a drain for acid wastes and organic solvents used in the C-Wing building. The major compounds identified in the ground-water samples are carbon tetrachloride and tetrachloroethylene (PCE). The C-Wing building overlies the Passaic Formation, which comprises a regional water-supply aquifer, and is about 2,500 ft north-northeast of several domestic wells.

In 1991, the U.S. Geological Survey, in cooperation with Rutgers, the State University of New Jersey, began an investigation of the hydrogeology and extent of contamination in the vicinity of the C-Wing building. The study was conducted in two phases. The first phase, which was conducted during 1991-92, consisted of reconnaissance of contamination in the unsaturated zone and shallow ground water near the C-Wing building, including collection and analysis of soil-gas samples, ground-water samples, water-level data, and electrical-resistivity data (dePaul, 1996). In the second phase of the investigation, which was conducted during 1993-97, the study area was expanded to include areas potentially affected by contaminated ground-water flowing from the C-Wing building. This report describes the second phase of the investigation.

The study area is within the Newark Basin, which extends from southeastern New York, through New Jersey, and into Pennsylvania. The Newark Basin comprises a fractured-rock aquifer composed of layered sedimentary rocks. Methods used in this investigation to characterize the hydrogeologic framework and to simulate ground-water flow using a digital model may be applicable to other areas in the Newark Basin where site-specific ground-water flow patterns are of concern.

Purpose and Scope

This report describes the hydrogeologic framework, the development of and results of simulations made with a digital model of ground-water flow, and the extent of VOC contamination in the vicinity of the Rutgers University Busch Campus, Piscataway Township, northwestern Middlesex County, New Jersey (fig. 1). The study area comprises 0.3 mi^2, including parts of the Rutgers University Busch Campus and the Rutgers University Golf Course. Results of field investigations conducted in the study area from May 1993 to October 1996 are presented, including collection of geologic cores, borehole video surveys, and geophysical logs; installation of 19 monitor wells; collection and analysis of water samples from 25 wells; aquifer testing; and measurement of ground-water levels and streamflow.

Acknowledgments

The authors thank Michael Quinlan and Martin Costello of the Rutgers Environmental Health and Safety Department for providing facilities for the storage of equipment and supplies, coordinating site safety during drilling, and providing equipment for removal of hazardous waste during drilling and sampling. The assistance of Joseph Spang in providing access to the Rutgers University Golf Course also is appreciated. The authors also thank Michael Ayres of Rutgers University Grounds Operation and Facilities Maintenance Services for allowing access to Busch Campus grounds during field work. The assistance of Nicholas Smith and Eric Jacobsen of the U.S. Geological Survey during collection of water samples and installation of monitor wells also is appreciated.

METHODS OF DATA COLLECTION

Most of the data used in this study were collected in accordance with procedures approved by the U.S. Geological Survey, the U.S. Environmental Protection Agency, or the New Jersey Department of Environmental Protection. Types of data collection for which these agencies have not issued approved procedures were performed according to established practices of the U.S. Geological Survey.

Geologic Coring

In order to determine the hydrogeologic framework, three coreholes were drilled in the study area. Corehole sites were chosen to encompass sediments overlain by the C-Wing building, while presumably lying outside the contaminant plume (fig. 2). Coreholes CH-1 and CH-2 were aligned approximately along strike; corehole CH-3 was approximately 600 ft downdip from the other two coreholes. The overburden at each site was stabilized by installing temporary casing to 10 or 15 ft below land surface. Continuous 10-ft lengths of 2-inch-diameter core were collected at each site by the wireline method. CH-1, CH-2, and CH-3 were cored to 110, 100, and 221 ft below land surface, respectively. Upon removal from the core barrel, the rock cores were placed in wooden boxes and catalogued on site. After all borehole geophysical logs were collected and borehole video surveys were completed, each corehole was sealed with cement grout to land surface.

Borehole Geophysical Logging

Geophysical logs were collected in nine boreholes in the study area. These logs provide information on the physical characteristics of the formation intersected by the well bore as well as the borehole fluid. The geophysical logs, together with borehole video surveys, were used to help determine the three-dimensional hydrogeologic framework in the study area. A summary of the logs collected in each borehole and the principal application of each log are presented in table 1.

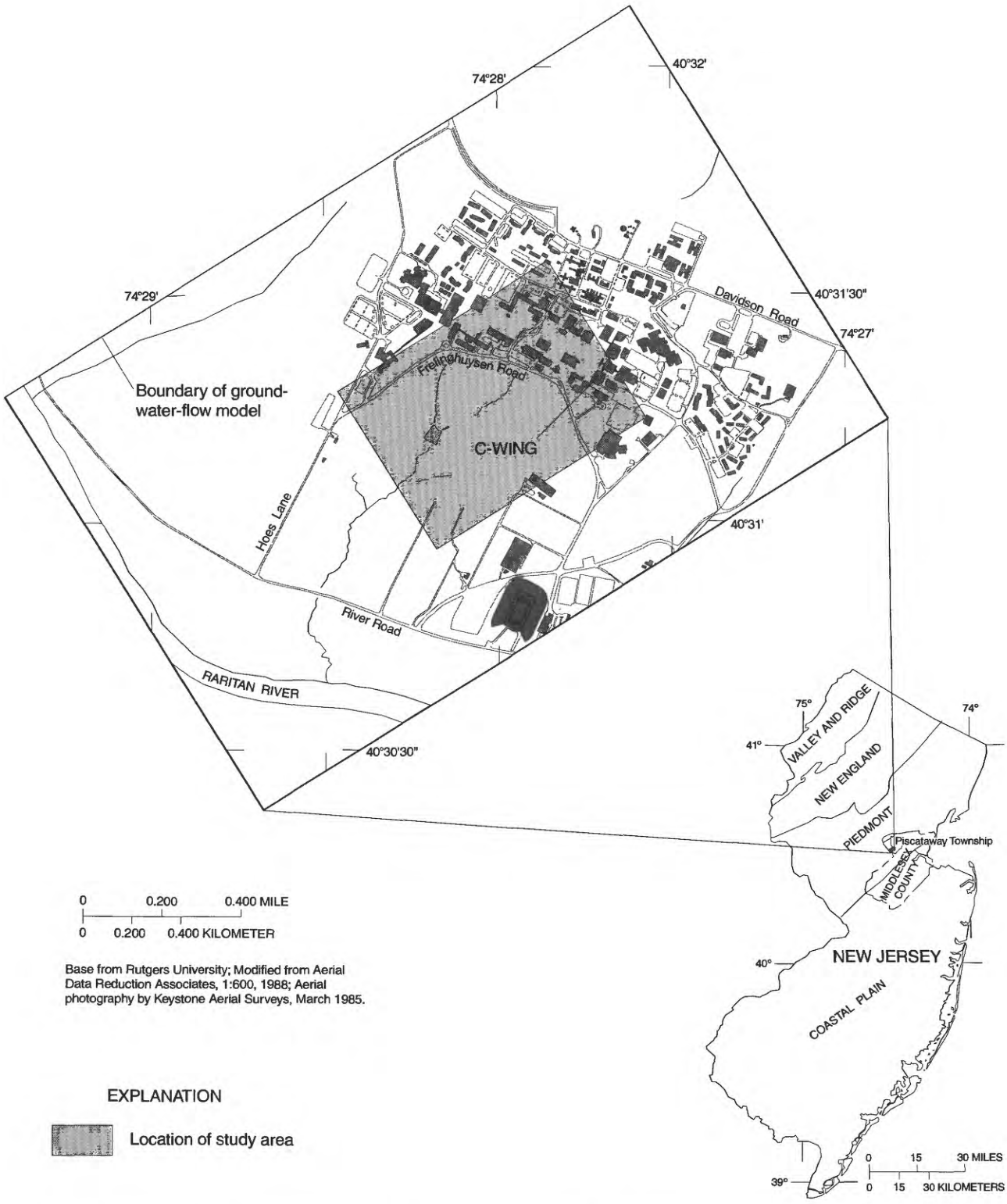


Figure 1. Location of the study area, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

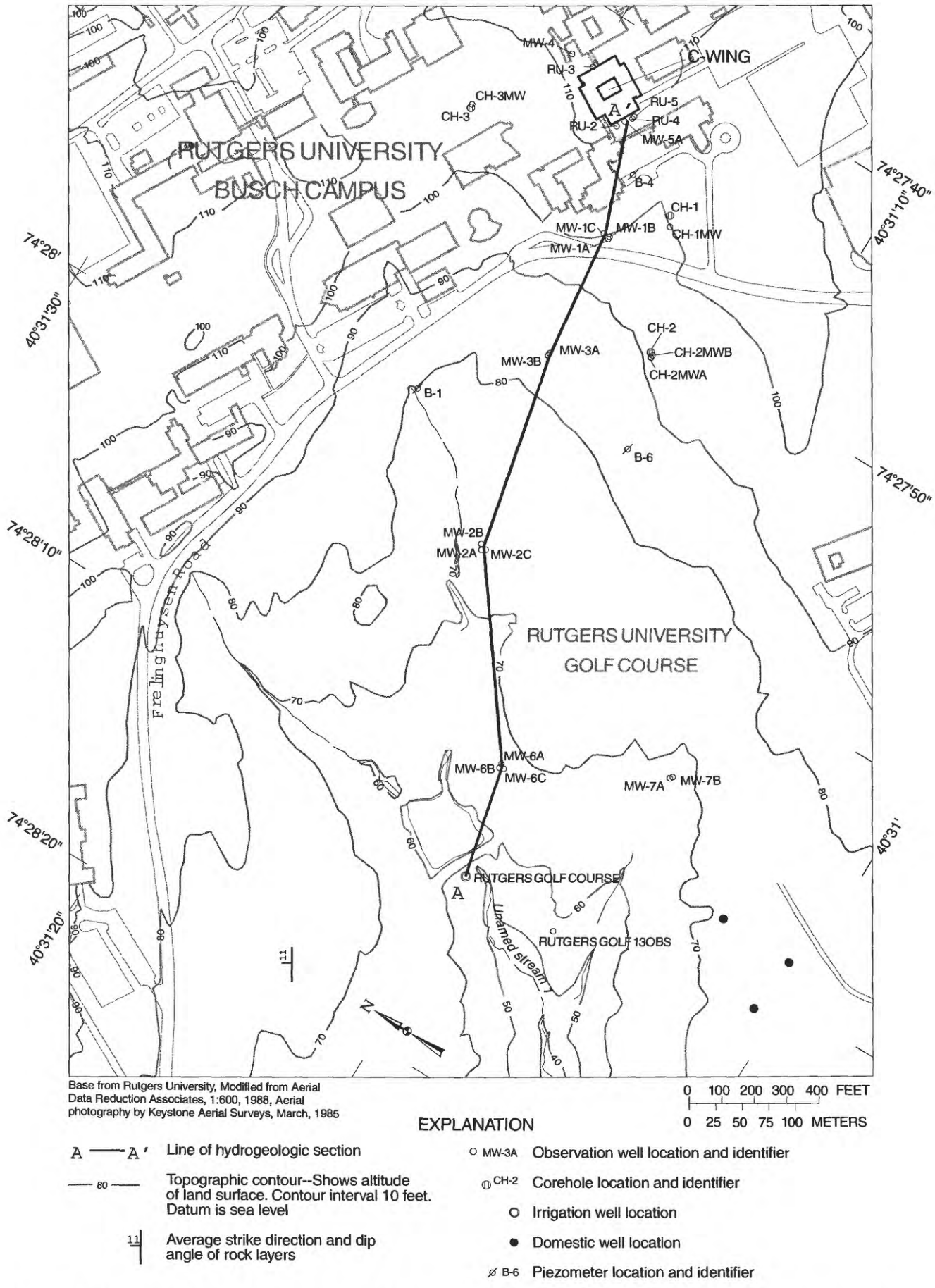


Figure 2. Location of wells and coreholes in the study area, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

Table 1. Borehole geophysical logs collected in wells and coreholes at the Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey

[X, log collected; - log not collected]

Log type	Property measured[1]	Principal application[1]	Local well name								
			CH-1	CH-2	CH-3	MW-2A	Rutgers Golf Course (Irrigation well)	Rutgers Golf 13 Obs	MW-5A	MW-6A	MW-7A
Caliper	Borehole diameter	Casing or borehole diameter, fracture locations	X	X	X	X	X	X	X	X	X
Electromagnetic induction	Electrical conductivity of rock and fluid surrounding borehole	Lithology, stratigraphic correlation, location of fractures	-	-	-	-	X	-	-	-	X
Fluid resistivity	Electrical resistance of borehole fluid	Water quality, identification of water producing zones	X	X	X	-	X	X	X	X	X
Fluid temperature	Temperature of borehole fluid	Location of water-producing zones, identification of intervals of vertical flow within the borehole	X	X	X	-	X	X	X	X	X
Gamma (natural)	Natural gamma radiation	Lithology, stratigraphic correlation	X	X	X	X	X	X	X	X	X
Single-point resistance	Electrical resistance of rock and borehole fluid	Lithology, fracture location	X	X	X	X	-	X	-	-	-
Spontaneous potential	Electrical potential between borehole fluid and surrounding earth materials	Lithology, changes in water quality	X	X	X	X	-	X	-	-	-
Video	Borehole recorded on videotape	Lithology, location of fracture zones, seeps above standing water level, stratigraphic correlation, well-casing inspection	X	X	X	-	X	X	-	-	-

[1] Keys and MacCary, 1971.

Well Installation

In order to refine the description of the hydrogeologic framework and to provide a monitor-well network to observe changes in contaminant concentrations and ground-water levels over time, nineteen 4-inch-diameter wells were installed in the study area. Well installation was completed during two phases of drilling from 1993 to 1995. Six wells and three piezometers that had been installed prior to 1993 also were used during this study. Locations of all wells and piezometers are shown in figure 2. Construction information for all wells and piezometers in the study area is presented in table 2.

During the first phase of drilling, May-June 1993, 13 wells were installed. Wells were grouped at sites and screened at different depths to facilitate determination of hydraulic characteristics, vertical-flow gradients, and water quality in discrete water-bearing units. Open and screened intervals were selected on the basis of a framework derived from measured strike and dip and previous identification of water-bearing units at well RU-5 (fig. 2). Some well positions and depths were altered during the drilling process as interpretation of new data (geophysical logs and drilling observations) warranted. These monitor wells ranged in depth from 30 to 170 ft below land surface.

Six monitor wells were installed during the second phase of drilling, August-September 1995. A cluster of three wells--MW-6A, MW-6B, and MW-6C--was installed approximately 350 ft northeast of the Rutgers Golf Course well (hereafter referred to as the irrigation well) to provide additional information regarding the source and distribution of contaminants near the irrigation well. Open intervals were chosen to intersect three discrete water-bearing units that contribute to the irrigation well. Two wells--MW-7A and MW-7B--were installed approximately 470 ft northeast of the nearest domestic well. This site was chosen to provide a detection point between the C-Wing building and downgradient domestic wells. These wells are open to the same water-bearing units as the nearest domestic well. Well MW-5A was completed between existing monitor wells along the southwestern wall of the C-Wing building in order to provide a deeper sampling point in the area where contaminant concentrations are highest. The monitor wells installed during the second phase of drilling range in depth from 90 to 265 ft below land surface.

All drilling and well construction were performed by private contractors under the supervision of a New Jersey-licensed well driller. The air-rotary method was used. Occasionally, potable water was injected to control dust and to cool the bit until sufficient water was produced in the formation.

Three types of wells were installed. Shallow wells were completed by lowering 4-inch-diameter black carbon-steel casing attached to 10 ft of stainless-steel continuous-slot wire-wound screen with 0.020 slotted openings into a nominal 8-inch-diameter borehole. A fine gravel pack was placed around the screen. One to 2 ft of fine-grained sand and then 2 ft of bentonite pellets were placed above the gravel pack to prevent infiltration of the casing seal. The remaining annular space was sealed from the bottom up by pressure grouting through a tremie pipe with either a neat cement slurry or a portland cement/bentonite mixture.

Most deeper wells were completed by installing 4-inch-diameter black carbon-steel casing in a nominal 8-inch diameter borehole from land surface to the top of the proposed open interval. The annular space was sealed with either a neat cement slurry or a portland cement/bentonite mixture as described above. After the annular seal had set, the proposed open interval of the well was drilled through the casing with a 3-7/8-inch bit. No screens were installed in these deeper wells because the bedrock surrounding the open intervals is assumed to be sufficiently competent to preclude collapse of the aquifer material.

Table 2. Construction information for wells and piezometers at the Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey

[PVC, polyvinylchloride; SS, stainless steel; W, weathered zone; CU, confining unit]

U.S. Geological Survey well number	Local well name	Latitude (degrees)	Longitude (degrees)	Layer number	Date of well construction	Altitude of land surface (feet above sea level)	Depth of screened or open interval (feet below land surface)	Diameter of screen or open interval (inches)	Casing material	Type of opening or screen material
23-1191	B-1	403118	742757	W	11-16-91	79.47	14 - 15	.5	PVC	PVC
23-1190	B-4	403117	742743	W	12-17-91	96.14	2 - 4	.5	PVC	PVC
23-1187	B-6	403112	742754	W	06-23-92	84.01	14 - 16	.75	PVC	PVC
23-1221	CH-1MW	403115	742746	W	06-21-93	99.75	30 - 40	4	Steel	SS
23-1218	CH-2MWB	403114	742751	W	06-28-93	91.31	30 - 40	4.	Steel	SS
23-1219	CH-2MWA	403114	742751	CU9	06-28-93	91.03	70 - 90	4	Steel	Open hole
23-1232	CH-3MW	403123	742746	9	06-28-93	103.98	140 - 160	4	Steel	Open hole
23-1226	MW-1A	403117	742748	CU9	06-24-93	96.29	80 - 100	4	Steel	Open hole
23-1227	MW-1B	403117	742748	CU9	06-24-93	97.00	120 - 140	4	Steel	Open hole
23-1228	MW-1C	403117	742748	W	06-24-93	97.82	30 - 40	4	Steel	SS
23-1223	MW-2A	403115	742801	CU9	06-24-93	72.80	150 - 170	4	Steel	Open hole
23-1224	MW-2B	403115	742801	9	06-24-93	72.43	90 - 110	4	Steel	Open hole
23-1225	MW-2C	403115	742801	CU8	06-24-93	72.51	60 - 80	4	Steel	Open hole
23-1229	MW-3A	403117	742753	CU9	06-25-93	83.16	120 - 140	4	Steel	Open hole
23-1230	MW-3B	403117	742753	9	06-25-93	83.06	70 - 90	4	Steel	Open hole
23-1231	MW-4	403121	742742	W	06-24-93	110.84	20 - 30	4	Steel	SS
23-1268	MW-5A	403118	742743	11	08-30-95	107.70	178 - 204	4	Steel	SS
23-1265	MW-6A	403111	742808	12	09-13-95	65.51	239 - 265	4	Steel	SS
23-1266	MW-6B	403111	742808	11	09-18-95	65.22	190 - 215	4	Steel	Open hole
23-1267	MW-6C	403111	742808	9	09-20-95	65.42	75 - 100	4	Steel	Open hole
23-1263	MW-7A	403107	742805	11	09-22-95	67.73	110 - 136	4	Steel	SS
23-1264	MW-7B	403107	742805	10	09-23-95	67.92	65 - 90	4	Steel	Open hole
23-1184	RU-2	403118	742743	W	08-25-88	108.67	7 - 27	4	PVC	PVC
23-1186	RU-3	403120	742742	W	08-25-88	110.93	7 - 27	4	PVC	PVC
23-1185	RU-4	403118	742743	W	08-30-88	107.45	7 - 27	4	PVC	PVC
23-1183	RU-5	403118	742743	9	09-06-88	107.59	55 - 75	4	PVC	PVC
23-1165	Rutgers golf 13 obs	403108	742812	9-11	06-29-89	58.8	50 - 200	6	Steel	Open hole
23-1053	Rutgers golf course (irrigation well)	403110	742812	9-12	06-30-80	55.71	55 - 300	8	Steel	Open hole

Three of the deeper wells--MW-5A, MW-6A, and MW-7A--were completed with 25 ft of stainless-steel screen instead of an open hole so that the entire borehole could be geophysically logged at one time. The continuous geophysical logs from these deep boreholes were used to select open intervals of proposed shallower wells at the same sites. A large slot size of 0.10 was used so as not to restrict the natural flow through the fractured bedrock.

Wells MW-1A, MW-1B, and MW-5A were constructed with an 8-inch-diameter outer casing set in a 12-3/4-inch-diameter borehole to 40, 40, and 80 ft, respectively. This was done in order to reduce the risk of downward migration of contaminants during drilling.

All wells were finished to land surface with a concrete collar and a water-resistant flush-mounted cover. After completion, wells were developed by surging and pumping with a stainless-steel submersible pump until the water was relatively clear and free of debris. Wells that had low yields--CH-1MW and MW-4--were later redeveloped by use of a surge block and a centrifugal pump. Altitudes of land surface and top of casing were surveyed to the nearest hundredth of a foot, and the location was determined to the nearest tenth of a second.

In order to reduce the possibility of introducing foreign contaminants and of cross-contamination during well installation, all well casings and screens were washed with laboratory-grade detergent and potable water, then steam-cleaned inside and out. All other equipment (drill rod, bits, pumps, and hoses) including the drill rig was steam-cleaned prior to use at each site. At sites near the C-Wing building, drill cuttings and borehole water were assumed to be hazardous. The water and cuttings were collected in a portable basin and subsequently removed and placed in containers for testing and proper disposal. At sites farther away from the C-Wing building, drill cuttings and borehole water were not expected to contain significant contamination. Water encountered during drilling was allowed to discharge to the ground in the vicinity of the well. Drill cuttings were removed from the well sites and stockpiled at a location designated by Rutgers University.

Measurement of Water Levels and Streamflow

Water levels in all wells and piezometers were measured synoptically 12 times during September 1993-October 1996 to determine head gradients and to provide data for calibration of the digital ground-water flow model used in this study. In addition, water levels in each well were recorded during routine site visits. Water-level data are presented in appendix 1.

Water levels were measured manually with either with a steel or an electric tape that was decontaminated with laboratory soap and deionized water at each well site. The water level in the irrigation well, a flowing artesian well, was measured by attaching a clear plastic extension to a fitting near the well head and measuring the height of the water column above land surface.

On March 13, 1995, and October 28, 1996, base-flow discharge measurements were made on unnamed stream 1. (The location of these measurements is shown in figure 4, farther on.) The measurement was made volumetrically, because all flow was concentrated in two culverts and could easily be diverted into a container. This is the most accurate method for measuring small discharges (Rantz and others, 1982, p. 262).

Aquifer Testing

Slug tests were chosen as a means of estimating the transmissivity and horizontal hydraulic conductivity of the aquifer because slug tests do not require the handling and disposal of large volumes of potentially contaminated water, and testing can be completed in a

relatively short period of time. The main limitation of slug tests is that the results can be applied only to a small area surrounding the well and are dependent on well construction in addition to the formation characteristics.

The slug tests were conducted by using a solid polyvinyl chloride (PVC) cylinder that was decontaminated between sites. Water levels were measured by using a 2.5-psi pressure transducer and a data logger. At each well, several static-water-level measurements were made; then a transducer was placed in the well and allowed to stabilize to water temperature. A static-water-level measurement was then made with the transducer in the well. The PVC cylinder was then quickly lowered into the well, and the decline in water level was measured. Measurements were made at 1-, 2-, or 5-second intervals on the basis of expected response time for a particular well. The cylinder was then removed and the rise in water level recorded. The static water level was measured again at the end of the test.

Collection and Analysis of Water-Quality Samples

Water-quality samples were collected from 25 wells in the study area during four rounds of sampling from August 1993 to October 1996. No newly installed monitor wells were sampled until at least 30 days after development. Wells were purged by pumping three to five casing volumes of water whenever possible, and samples were collected after water temperature, pH, specific conductance, and dissolved-oxygen concentration had stabilized to ensure that the sample was representative of aquifer water. For low-yielding wells that were slow to recover, standing water was evacuated at a low pumping rate to the top of the open interval one to two times, then allowed to recover sufficiently before sampling. Well purging at most sites was accomplished by using a variable-pumping-rate stainless-steel submersible pump attached to 1/2-inch-diameter polyethylene hose. In shallow wells in which the static water level was less than 20 ft below land surface, a peristaltic pump outfitted with silicone and polyethylene hose was used. All samples except that from the irrigation well were collected with Teflon bailers attached to Teflon-coated stainless-steel wire. Water in the irrigation well was evacuated by using its high-volume pump, and the sample was drawn through a stainless-steel fitting attached to a sampling spigot near the wellhead. Samples to be analyzed for dissolved constituents were filtered in the field with an 0.45-μm filter. Immediately following collection, samples were preserved and prepared for shipment to the laboratory.

In order to reduce the potential for cross-contamination during sampling, wells were sampled in ascending order of known or expected total-VOC concentration. The hose used for well purging was flushed with deionized water prior to use and disposed of after one use. Submersible pumps used for purging were decontaminated between uses by an external wash with laboratory-grade detergent and tap water, an internal flush with a detergent-and-water solution, a cold tap-water rinse and flush, and, finally, a deionized-water rinse and internal flush. When pumps were used to purge wells in which total-VOC concentrations were 500 μg/L or greater, the final step was preceded by an external methanol rinse and internal flushing with a methanol/deionized-water solution. In addition, several times during each sampling event, the pumps were disassembled in the laboratory and thoroughly cleaned. Bailers were dedicated to one well per sampling day and returned to the laboratory for cleaning. Bailers and bailer parts were decontaminated by scrubbing with a solution of tap water and laboratory-grade detergent, rinsing with tap water, rinsing with deionized water, rinsing with reagent-grade methanol, purging with pure nitrogen or allowing them to thoroughly air-dry, rinsing with deionized water, and then

air-drying. Equipment used to collect water to be analyzed for organic constituents was wrapped in aluminum foil; equipment used to collect water to be analyzed for inorganic constituents was sealed in polyethylene until use.

During the initial round of sampling in 1993, purge and equipment-cleaning water from all wells except the irrigation well and Rutgers golf 13 obs was placed in containers. Thereafter, all purge and equipment-cleaning water only from wells known or suspected to have significant contamination was pumped directly into 55-gallon drums for proper disposal.

VOC's in ground-water samples were determined by gas chromatography-mass spectrometry according to U.S. Environmental Protection Agency method 524.2 (U.S. Environmental Protection Agency, 1991, 1992, and 1994). Compounds measured and their respective reporting limits are listed in appendix 2. All VOC analyses were performed by two laboratories certified by the New Jersey Department of Environmental Protection: Quanterra-East of Somerset, New Jersey, and Analab Inc., of Edison, New Jersey. All other analyses were performed by Quanterra-East.

HYDROGEOLOGY

Geologic Setting

The study area is within the Piedmont Physiographic Province. In New Jersey, this province coincides with the Newark Basin, which is the largest of a series of fault-block basins that extend from Nova Scotia to South Carolina (Froelich and Olsen, 1985). The basins were formed during initial continental rifting during the Triassic Period (Van Houten, 1969). The Newark Basin consists of Triassic- and Jurassic-age red shales, siltstones, mudstones, sandstones, argillites, and intrusive and extrusive igneous rock. The Passaic Formation, which is part of the Newark Supergroup (Olsen, 1980), forms the bedrock in the study area.

Hydrogeologic Framework

In the study area, the Passaic Formation consists of interbedded layers of reddish-brown mudstone and siltstone with a few thin zones of reddish-brown shale and sandstone. Two zones of fine-grained purple siltstone about 10 ft thick also are present. The uppermost of these purple beds was observed in rock cores and cuttings from 10 boreholes throughout the study area. The orientation of the plane formed by the top of this bed in the 10 boreholes indicates that bedding consistently strikes N. 57° E. and dips 11° to the northwest throughout the study area. This bedrock orientation is consistent with the findings of dePaul (1996), which are based on measurements at outcrops. The pervasiveness of the purple marker bed in the study area also indicates that each rock stratum probably is continuous throughout the study area.

The Passaic Formation is a gently dipping, multiunit leaky aquifer system that consists of thin water-bearing units and thick intervening confining units, all of which are parallel to bedding. The rock has little primary porosity or permeability as a result of compaction and cementation; therefore, the principal means of ground-water movement is through a network of interconnected fractures.

Rock fractures in the study area are either parallel or perpendicular to bedding. Fractures perpendicular to bedding are near-vertical. Most of these near-vertical fractures are either parallel to the strike of bedding or perpendicular to it. On the basis of observations of 29 near-vertical fractures in outcrops in and near the study area, these two vertical sets contain a similar number of fractures. A few vertical fractures oriented in other directions also are present (dePaul, 1996). Fractures parallel to bedding are more continuous and extensive than vertical fractures (Michalski, 1990). Many

vertical fractures terminate at contacts between rock types (Houghton, 1990).

Two types of water-bearing units are present in the Passaic Formation. One type is formed by major fractures parallel to bedding. The other type consists of thin geologic strata that are intensely fractured both parallel and perpendicular to bedding. All water-bearing units are bounded by confining units that are only sparsely fractured. Widely spaced vertical fractures through confining units allow water to leak from one water-bearing unit to another (Michalski, 1990).

Rocks near land surface are weathered. Clay and silt from the weathering process have partly filled the fractures in these rocks and reduced their permeability. Consequently, the framework of dipping water-bearing units and confining units is draped by a shallow weathered zone that is less permeable than deeper water-bearing units. Hydraulic-conductivity data from three sites in the Newark Basin indicate that the transition from the weathered zone to the unweathered zone occurs at a depth of about 50 to 60 ft (Michalski, 1990). For purposes of this study, the base of the weathered zone was assumed to be at 50 ft below land surface.

The upper part of the aquifer system is unconfined because the well-connected fractures in this material are open to the atmosphere and contain water under atmospheric pressure. At increasing depth, fractures are increasingly isolated from the atmosphere by confining units. Below a certain depth, which varies from about 50 to about 150 ft, the aquifer system is semiconfined (Houghton, 1990). For purposes of this study, the base of the unconfined zone was assumed to be at the same position as the base of the weathered zone--50 ft below land surface.

At least 23 fracture zones are present in the strata penetrated by boreholes and coreholes in the study area. These zones were identified on the basis of observations of rock cores and borehole video logs and interpretations of geophysical logs. Transmissivity data from wells completed in these boreholes, however, indicate that only four of these fracture zones are capable of transmitting significant volumes of water. The interpreted position of these four water-bearing units in a section through the study area along the dip of bedding is shown in figure 3. The open intervals of all wells in which transmissivity was measured are projected onto this section. Mean transmissivity is shown for wells in which transmissivity was measured more than once. Confining units were delineated on the section by connecting the open intervals of wells in which the measured transmissivity is relatively low (less than 11 ft^2/d). Water-bearing units were delineated likewise by connecting the open intervals of wells in which the measured transmissivity is relatively high (greater than 43 ft^2/d). The lines delineating the units are drawn along the dip of the bedding--11°. During this process, water-bearing units and confining units were assumed to be continuous throughout the study area. In addition, it was recognized that a water-bearing unit probably intersects only part of the open interval of a well where high transmissivity was measured, whereas a confining unit probably spans the entire open interval of a well where low transmissivity was measured. Consequently, the lines separating water-bearing units from confining units are not necessarily coincident with the tops and bottoms of open intervals of wells. The transmissivity data used in this analysis are discussed in detail later in the report.

Two anomalies are present in the section (fig. 3). The transmissivity measured in well CH-2MWA is relatively high although this well appears to be open to the same strata as four wells (MW-2A, MW-3A, MW1A, and MW1B) in which the measured or estimated transmissivity was less than 11 ft^2/d. The anomalously high transmissivity in the immediate vicinity

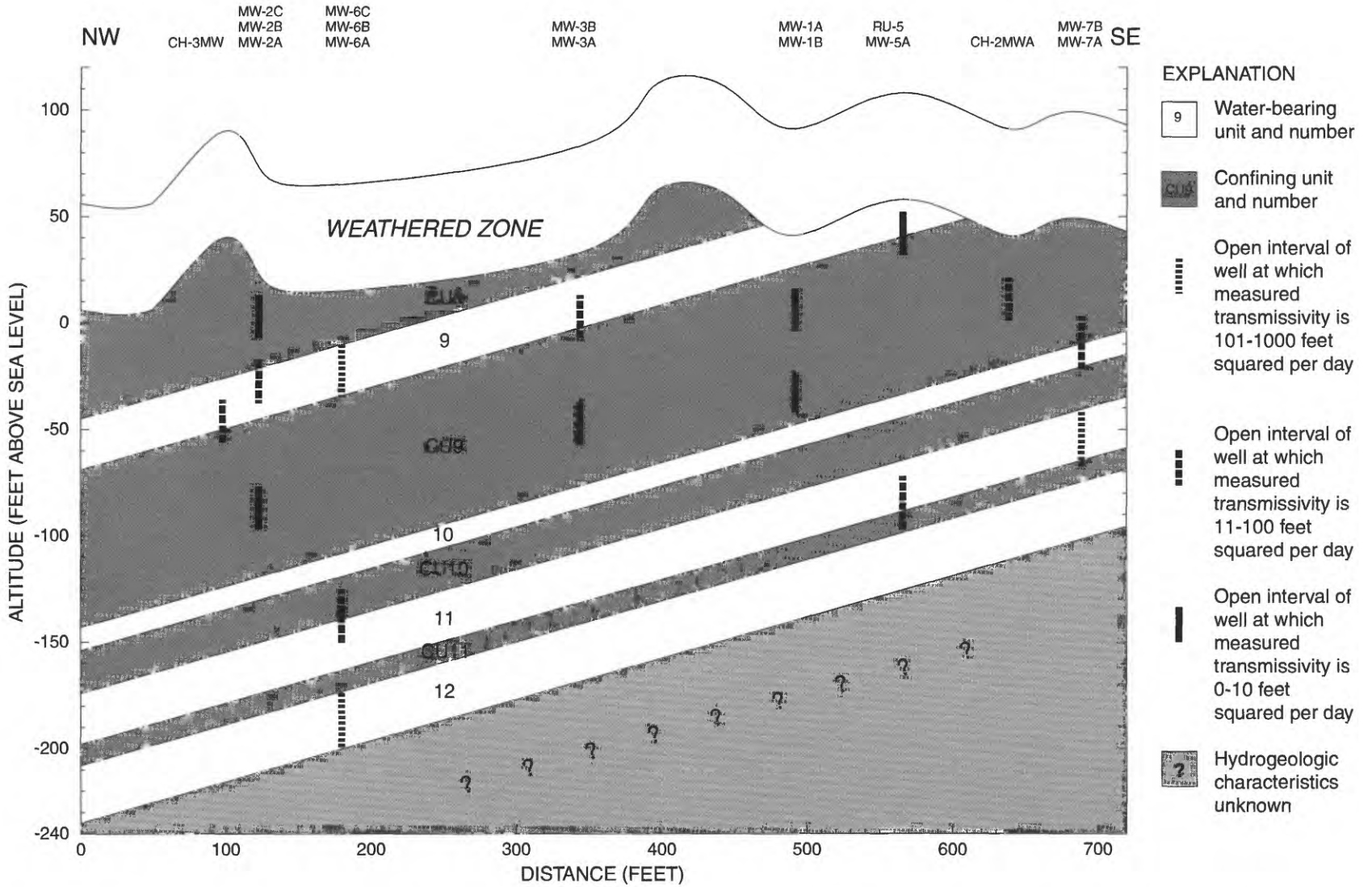


Figure 3. Generalized section along dip of bedding showing transmissivity measured at wells and interpreted location of hydrogeologic units in the study area, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

of well CH-2MWA probably is caused by a vertical fracture. A vertical fracture is present in cores from the adjacent corehole at the same depth as that of the screen in well CH-2MWA. The vertical fracture probably is one of the widely spaced fractures that are present in confining units.

The other anomaly is at well RU-5, where the measured transmissivity is relatively low--2 ft^2/d--although the transmissivity at four other wells in the same stratum (CH-3MW, MW2B, MW6C, and MW3B) is greater than 40 ft^2/d. The reason for this anomaly is unknown.

Data from drilling and geophysical logs indicate that the four water-bearing units in the study area are relatively coarse-grained. Zones where loss or gain of water was significant in boreholes during drilling and zones where drilling rods were observed to drop quickly during drilling are coarse-grained siltstone and, in some cases, sandstone. Low natural-gamma-radiation counts measured in these zones also indicate that these water-bearing units are relatively coarse-grained. On the basis of these findings, it is assumed that the four water-bearing units identified in the study area comprise sandstone and coarse-grained siltstone strata whereas the confining units comprise fine-grained siltstone and mudstone. In the water-bearing units, fractures oriented both parallel and perpendicular to bedding are observed in rock cores and borehole video logs. Whether one or both types of fractures actually transmit water in these water-bearing units is unknown.

Estimates of Hydraulic Properties

The hydraulic properties of the rocks in the study area were estimated for use in determining the location and thickness of hydrogeologic units (described earlier) and in developing the ground-water flow model. Horizontal hydraulic conductivity and transmissivity, which are measures of the ability of a permeable medium to transmit water in the horizontal direction, were determined at wells in the study area by slug testing. The methods of Bouwer and Rice (1976) and Hvorslev (1951) were used to analyze data from slug tests conducted in wells open to the unconfined weathered zone. The method of Cooper and others (1967) was used to analyze data from slug tests conducted in the deeper wells considered to be open to confined parts of the aquifer system.

At the time of testing, the water level in some wells was recovering or being drawn down in response to recent pumping at the irrigation well. If interference was minimal, data from these tests were adjusted to remove the effects of this pumping. Otherwise, the test was repeated at a later time.

The methods used to analyze slug-test data from wells in the unconfined zone provide an estimate of horizontal hydraulic conductivity of the tested aquifer, whereas the method used to analyze slug-test data from wells in the confined zone provides an estimate of transmissivity of the tested aquifer. The transmissivity of an aquifer is equal to its horizontal hydraulic conductivity multiplied by its saturated thickness. Hydraulic conductivity in the unconfined zone ranges from 0 to 1.2 ft/d, with a median of 0.12 ft/d. If this zone is assumed to be 40 ft thick (the distance from the water table, which is approximately 10 ft below land surface, to the base of the unconfined zone at 50 ft below land surface), then the median transmissivity of this zone is 4.8 ft^2/d. The median transmissivity measured in wells in the confined water-bearing and confining units, respectively, is 84 and 3.7 ft^2/d. Detailed results of slug testing are listed in table 3 and summarized in table 4.

Table 3. Transmissivity and horizontal hydraulic conductivity at selected wells, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey

[CU, the confining unit below the indicated layer; W, weathered zone; NA, not applicable; C, Cooper and others, 1967; E, estimate based on extremely low recovery after insertion or removal of slug; B, Bouwer and Rice, 1976; H, Hvorslev, 1951. Well locations shown in fig. 2]

Local well name	Layer number	Depth of screened or open interval (feet below land surface)	Date of test	Transmissivity (feet squared per day)	Hydraulic conductivity (feet per day)	Analytical method
CH1-MW	W	30 - 40	09-08-94	NA	0	E
CH-2MWA	CU9	70 - 90	09-01-94 11-20-96	140 54	NA	C
CH-2MWB	W	30 - 40	08-30-94	NA	.065	B, H
CH-3MW	9	140 -160	08-31-94	94	NA	C
MW-1A	CU9	80 - 100	08-24-94	1.4	NA	C
MW-1B	CU9	120 - 140	08-24-94	0	NA	E
MW-1C	W	30 - 40	09-02-94	NA	0.12	B, H
MW-2A	CU9	150 - 170	08-23-94	0	NA	E
MW-2B	9	90 - 110	08-23-94 11-20-96	110 65	NA	C
MW-2C	CU8	60 - 80	08-23-94	6.0	NA	C
MW-3A	CU9	120 - 140	09-01-94	10	NA	C
MW-3B	9	70 - 90	09-01-94	44	NA	C
MW-5A	11	178 - 204	11-19-96	70	NA	C
MW-6A	12	239 - 265	11-20-96	910	NA	C
MW-6B	11	190 - 215	11-18-96	58	NA	C
MW-6C	9	75 - 100	11-18-96	210	NA	C
MW-7A	11	110 - 136	11-19-96	150	NA	C
MW-7B	10	65 - 90	11-19-96	79	NA	C
RU-3	W	7 - 27	08-31-94	NA	1.2	B, H
RU-4	W	7 - 27	09-08-94	NA	.54	B, H
RU-5	9	55 - 75	09-08-94	2.0	NA	C

The transmissivity contrasts and the dipping hydrogeologic units of the aquifer system cause large-scale anisotropic flow. The predominant direction of ground-water flow through the aquifer system is the direction of strike of the bedding units, although minor variations from that direction attributable to topography, flow boundaries, and pumping are possible (Michalski, 1990). Because of this anisotropy, no attempt was made to derive flow directions from hydraulic-head gradients.

Vertical head gradients are useful in delineating ground-water recharge and discharge areas. Water-level altitudes measured on October 28, 1996, were used for this purpose because they include data from all wells on the campus and golf course. During the 8-day period preceding the measurements, only 0.08 inch of rain was recorded in the vicinity of the study area, and the irrigation well had not been pumped for at least 3 days. Water-level data indicate that these time lapses allow water levels to return to static conditions after being stressed by precipitation or by pumping the irrigation well. The irrigation well is the only well that affects water levels in wells on the campus and golf course. Therefore, these water levels represent steady-state, nonpumping conditions.

A downward vertical gradient (decreasing head with depth) was observed at well clusters at relatively high altitudes in the study area--clusters MW-1, MW-2, MW-3, CH-2, and the cluster composed of wells RU-4, RU-5, and MW-5A (fig. 2). An upward vertical gradient was observed, however, at the MW6 and MW7 well clusters, which are at lower altitudes and closer to the Raritan River than the other clusters. Water in both Rutgers golf 13 obs and the irrigation well flows under artesian pressure when water levels are high. Water levels as high as 3.0 and 17.6 ft above land surface, respectively, have been observed at these wells. These wells are the closest to the Raritan River. The upward gradients and flowing wells near the Raritan River are indicative of an area of ground-water discharge. Therefore, the transition from a recharge area to a discharge area apparently occurs somewhere between well clusters MW2 and MW6.

Drawdowns in water levels resulting from pumping are useful in determining the effectiveness of confining units in this multiunit aquifer system. To obtain drawdown data, the pump in the irrigation well was turned on after water levels were measured on October 28, 1996. After the well was pumped continuously for 19 hours and 11 minutes, water levels were measured again. Water levels continued to decline after these measurements were made. Therefore, this data set represents transient conditions.

In the weathered zone, drawdown was greatest (1.96 ft) in well MW1C; drawdown in 8 of the 10 wells in the weathered zone was less than 0.5 ft. Drawdown in the confined water-bearing units was much greater. Drawdown in water-bearing unit 9 ranged from a minimum of 6.81 ft in well RU-5 to a maximum of 18.98 ft in well MW-6C, and in water-bearing unit 11 ranged from a minimum of 13.08 ft in well MW-7A to a maximum of 29.52 ft in well MW-6B.

The relatively minor drawdown in the weathered zone compared to drawdown in the confined water-bearing units indicates a lack of hydraulic connection between the weathered zone and the confined water-bearing units. The irrigation well is cased through the weathered zone and open to water-bearing units 9 through 12. Another reason for the relatively minor drawdown in the weathered zone may be that the sediments that fill the fractures in the weathered zone increase ground-water storage.

The wide range in drawdown in the confined water-bearing units is caused partly by the difference in the distance of the wells from the irrigation well. The unit to which the well is open appears to be a more important factor, however. For example, drawdown in wells

Table 4. Transmissivity in the weathered zone, water-bearing units, and confining units, Rutgers University Busch Campus and vicinity Piscataway Township, New Jersey

[ft^2/d, feet squared per day]

	Median (ft^2/d)	Range (ft^2/d)
Weathered zone	4.8	0 - 48
Water-bearing units	84	2 - 910
Confining units	3.7	0 - 97

The vertical hydraulic conductivity of rocks similar to those in the study area was estimated at four locations in previous studies by model calibration. The vertical conductivity of the Passaic Formation at a site in northern Mercer County, New Jersey, is on the order of 0.0001 ft/d (Carleton and others, 1999). In parts of Mercer, Somerset, and Hunterdon Counties, New Jersey, the vertical conductivity of the Passaic Formation is about 32 ft/d in rocks less than 75 ft below land surface and 0.032 ft/d in rocks at depths between 75 and 500 ft below land surface (Lewis-Brown and Jacobsen, 1995). Gerhart and Lazorchick (1988) report vertical conductivities ranging from 0.13 to 3.34 ft/d in fractured sedimentary rocks in the Gettysburg Triassic rift basin in Pennsylvania and Maryland. Chichester (1996) reports a range of 0.1 to 0.6 ft/d in the vertical conductivity of rocks in the Cumberland Valley of Pennsylvania, which includes parts of the Gettysburg Triassic rift basin. The overall range in vertical hydraulic conductivity at these locations is 0.0001 to 32 ft/d.

Estimates of vertical hydraulic conductivity made on the basis of calibration of digital models of ground-water flow rely on the premise that the values of other parameters in the model are much better known because they are based on field measurements. The value of vertical hydraulic conductivity is then solved for by adjusting this value until the simulated ground-water system closely matches the real system. The ground-water system in most of these models, however, was reported to be relatively insensitive to the value of vertical hydraulic conductivity. Consequently, the wide range of reported values is not unexpected.

GROUND-WATER FLOW

Ground-water flow in the study area is controlled primarily by the distribution of water-bearing fractures in the dipping strata that make up the hydrogeologic framework and by contrasts in transmissivity within the aquifer system. Both a conceptual and a digital model were used to analyze the flow system in the study area and its effect on the distribution of contaminants.

Conceptual Model

Recharge to the ground-water system is by downward leakage of precipitation. After passing vertically through the unsaturated zone, water reaches the top of the weathered zone. Because the weathered zone is much less permeable than the underlying water-bearing units, water probably flows only a few hundred feet laterally before reaching the bottom of the weathered zone and flowing into one of the underlying confined water-bearing units.

Water that reaches one of the confined water-bearing units water typically flows in that unit for some distance before reaching the contact between the water-bearing unit and a confining unit. The water then typically passes through a vertical fracture in the confining unit and into the next water-bearing unit. Flow through confining units generally is vertical as a result of head differences between the water-bearing units. Ground water discharges primarily to the Raritan River and its tributaries. Smaller amounts of water discharge to the irrigation well and 11 domestic wells in the study area.

MW-6A, MW-6B, and MW-6C, all of which are equidistant from the irrigation well, was 63.68, 29.52, and 18.98 ft, respectively. These wells are open to water-bearing units 12, 11, and 9, respectively (fig. 3). The irrigation well is open to all of these units. The large differences in drawdown among these wells probably result from effective separation of these units from one another by the intervening confining units.

Water levels and drawdowns in wells on October 28 and 29, 1996, are shown in table 6 (farther on). All water-level data for wells in the study area are presented in appendix 1.

Simulated Ground-Water Flow System

A digital model of the ground-water flow system was developed for three purposes: (1) to test hypotheses developed in the conceptual model concerning the movement of ground water, (2) to help guide the placement of new monitor wells, and (3) to estimate potential paths of contaminated water from the vicinity of the C-Wing building. The model was used to simulate both steady-state and transient flow conditions, although the transient simulation was used only for calibration.

Description of digital model

A three-dimensional, finite-difference Fortran code (MODFLOW) developed by McDonald and Harbaugh (1988) was used. No modifications were made to the published code.

Model area and grid

The model area was extended beyond the study area to include natural hydrologic boundaries. It encompasses 2.3 mi^2, including McEttis Brook near its northwestern boundary and the Raritan River at its southwestern boundary (fig. 4). The model grid was oriented so that the columns are parallel to the strike of the rock layers. The model was discretized horizontally into 100 rows and 63 columns. Model cells are smallest in the part of the model that represents the study area, where each cell is 49 ft long and 49 ft wide. At the edges of the model, cells are 217 ft long and 217 ft wide.

The model is discretized vertically into 20 layers. Throughout the model area, layer 1 represents the 40-ft-thick unconfined weathered zone just below the water table. The other 19 model layers represent dipping water-bearing units. Confining units are represented by low rates of vertical leakance between water-bearing units, as described by McDonald and Harbaugh (1988).

Model layers 9-12 represent the four water-bearing units identified in the study area. Because the geologic strata dip to the north-northwest, these four units are increasingly deep in parts of the model area north-northwest of the study area and increasingly shallow south-southeast of the study area. Water-bearing units similar to these four units are assumed to be present stratigraphically above and below them in the northwestern and southeastern parts of the model area, respectively. Layers 2-8 and 13-20 represent these hypothetical water-bearing units that are stratigraphically above and below layers 9-12. These additional layers are assumed to have the same strike, dip, and hydraulic properties as those in the study area. Each hypothetical unit was assigned a thickness approximately twice the average thickness of the units in the study area to minimize the number of hypothetical units needed to fully represent the model area and, in turn, reduce computation time during model calibration. This assumed hydrogeologic framework in the model area is shown in sections B-B' (parallel to strike) and C-C' (parallel to dip) in figures 5 and 6, respectively.

Representation of water-bearing units as model layers is complicated by the fact that the units dip. The model code requires that each model layer be represented in some way over the full extent of the model area even though

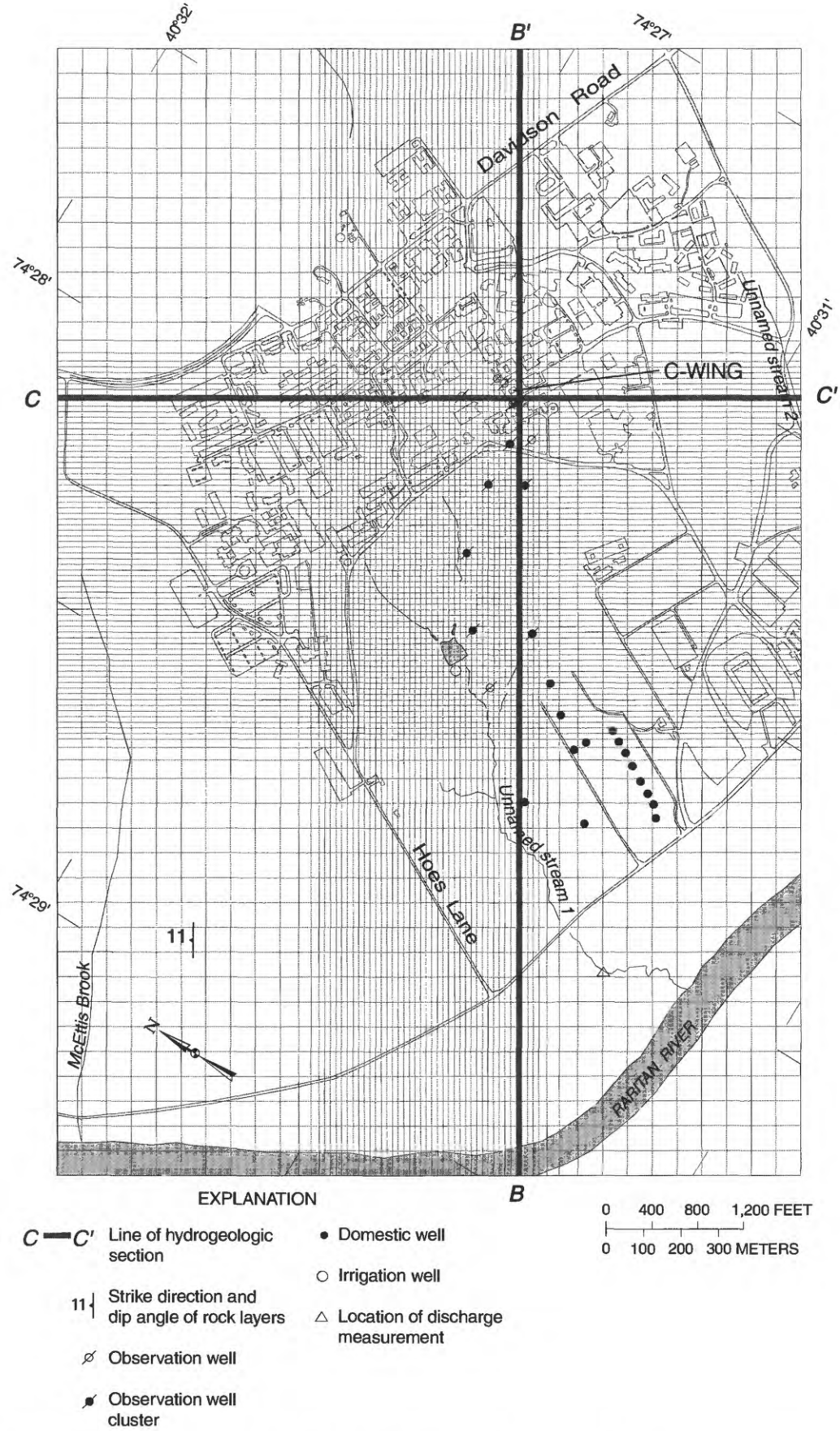


Figure 4. Area of ground-water flow model showing horizontal discretization and lines of hydrogeologic sections, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

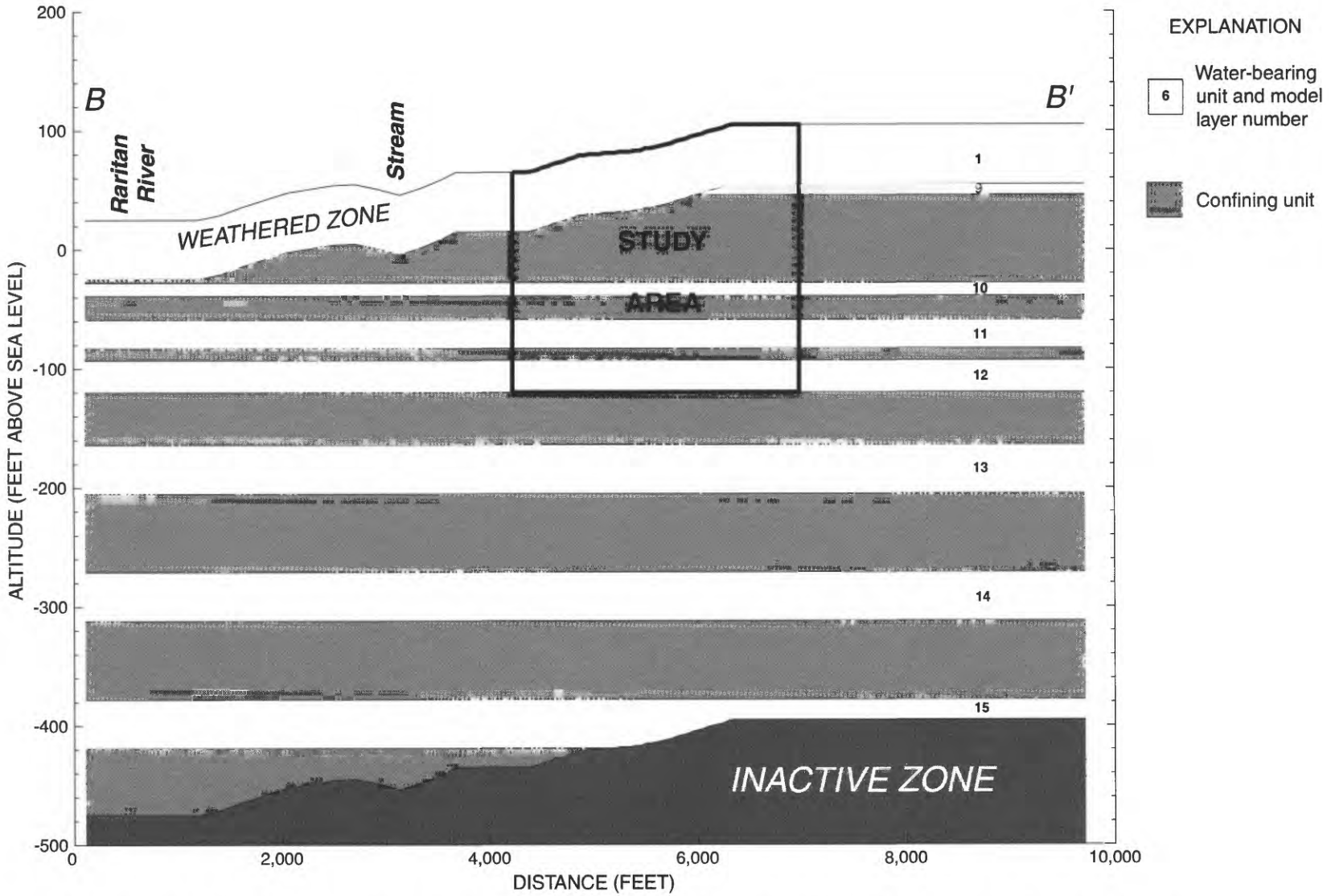


Figure 5. Section *B-B′* along strike of bedding showing interpreted hydrogeologic framework in the study area and assumed framework outside the study area in the area of the ground-water flow model of the Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

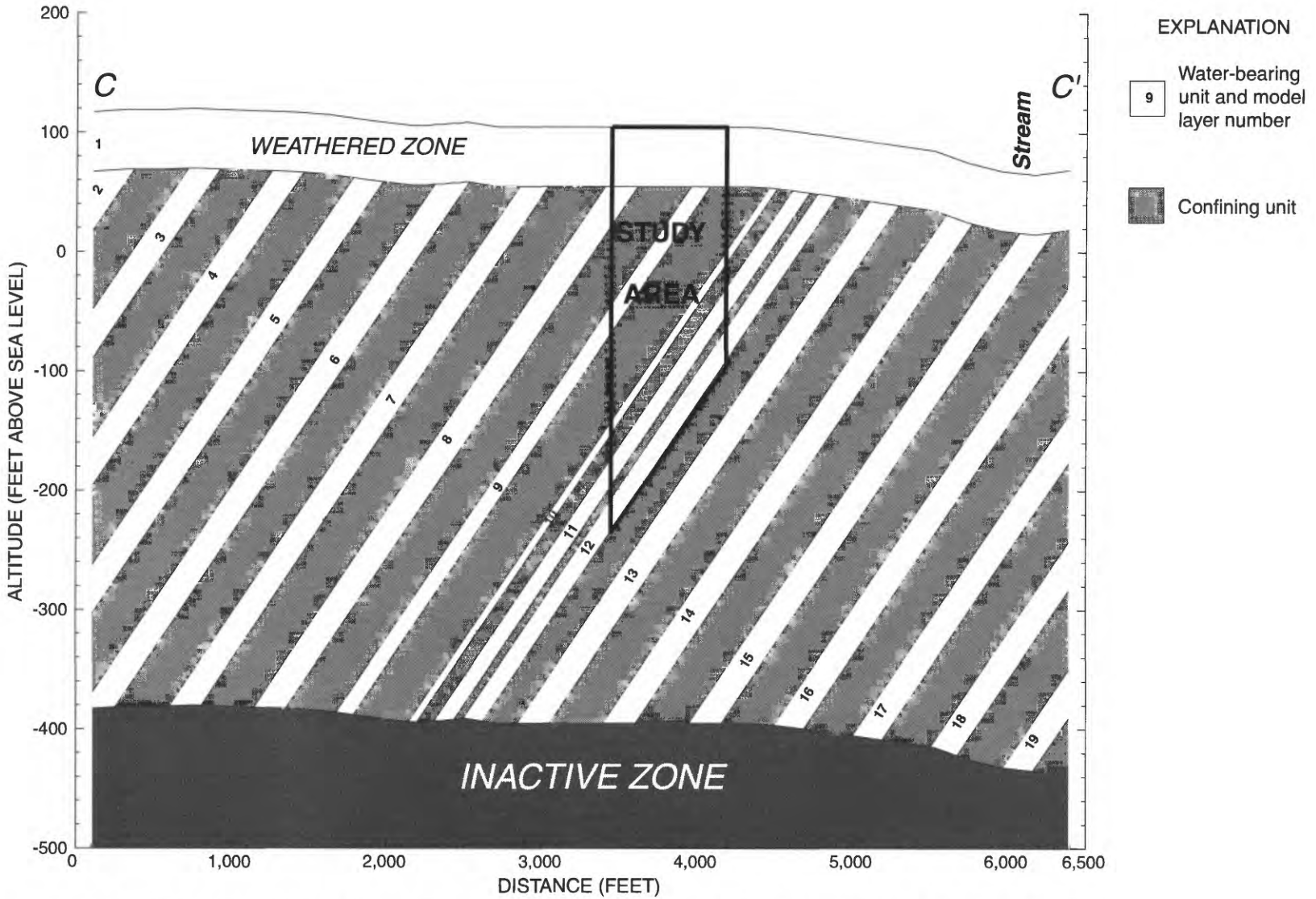


Figure 6. Section *C-C'* along dip of bedding showing interpreted hydrogeologic framework in the study area and assumed framework outside the study area in the area of the ground-water flow model of the Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

the actual water-bearing units are not present over the full area. Each water-bearing unit terminates updip at the base of the weathered zone. Although each water-bearing unit probably extends thousands of ft downdip, ground-water flow is assumed to be negligible at depths greater than 500 ft below land surface, as explained in the section on model boundaries (below). In order to represent these changes in the character of each water-bearing unit, each model layer is made up of three segments. These segments are illustrated for hydrogeologic section C- C', as represented in the model, in figure 7. The most downdip of these segments is an inactive zone and represents the part of the water-bearing unit that is deeper than 500 ft below land surface. The next segment is the active zone, representing the part of the water-bearing unit between the weathered zone and 500 ft. The next segment is pseudo-active and represents the imaginary extension of the water-bearing unit updip from its outcrop. Although this part of a model layer represents imaginary sediments above the weathered zone, the entire model layer is positioned below the weathered zone. Therefore, the pseudo-active segment is modeled as active in order to allow water to flow from the weathered zone, through the pseudo-active zone, to the first water-bearing unit that is actually beneath the weathered zone.

Model boundaries

The upper boundary of the model represents the water table and is the top of model layer 1, the weathered zone. A specified flux is applied to the top of this uppermost layer to represent areal recharge from precipitation. The northwestern and southeastern edges of the model area are bounded by no-flow cells. Because these boundaries are parallel to the strike of the rock layers, and ground water flows parallel or subparallel to the strike direction, it is assumed that these boundaries are parallel to flow lines and that a negligible amount of water crosses them.

The southwestern limit of the active model area coincides with the Raritan River. This boundary was simulated as a head-dependent flux boundary. In cells beneath the river, it was assumed that ground-water flow is vertically upward toward the river and that no horizontal flow occurs beneath the river. Model cells southwest of the river are inactive (no-flow boundaries).

The northeastern boundary of the model initially was placed at a surface-water drainage divide near the northeastern border of the study area. During model calibration, however, it became evident that some ground water probably crosses that boundary from the northeast, but a flow rate could not be determined. Therefore, a no-flow boundary was placed throughout row 1 of the model, which is 2,800 ft northeast of the study area. Although some flow probably crosses this boundary, it is assumed that any such flow is sufficiently far from the study area that its effect on simulated flow in the study area is minimal.

The bottom of the active model is 500 ft below land surface throughout the modeled area. All model cells that represent parts of water-bearing units deeper than 500 ft are inactive. This depth was chosen for two reasons: (1) The deepest well in the study area is 300 ft deep; therefore, no field data for depths greater than 300 ft are available. (2) It is assumed that any flow that may occur below 500 ft is separated by confining units from flow occurring in the 0-to-300-ft-depth zone and, therefore, ground-water flow and contaminant transport in the study area are not affected by any flow that may occur at depths greater than 500 ft.

Assumptions, limitations, and appropriate uses of the model

Ground-water flow in fractured rocks is too complex to be succinctly simulated with a digital model. If several necessary but simplifying assumptions are made, however, a model can be constructed that is capable of approximating flow through the fractured framework.

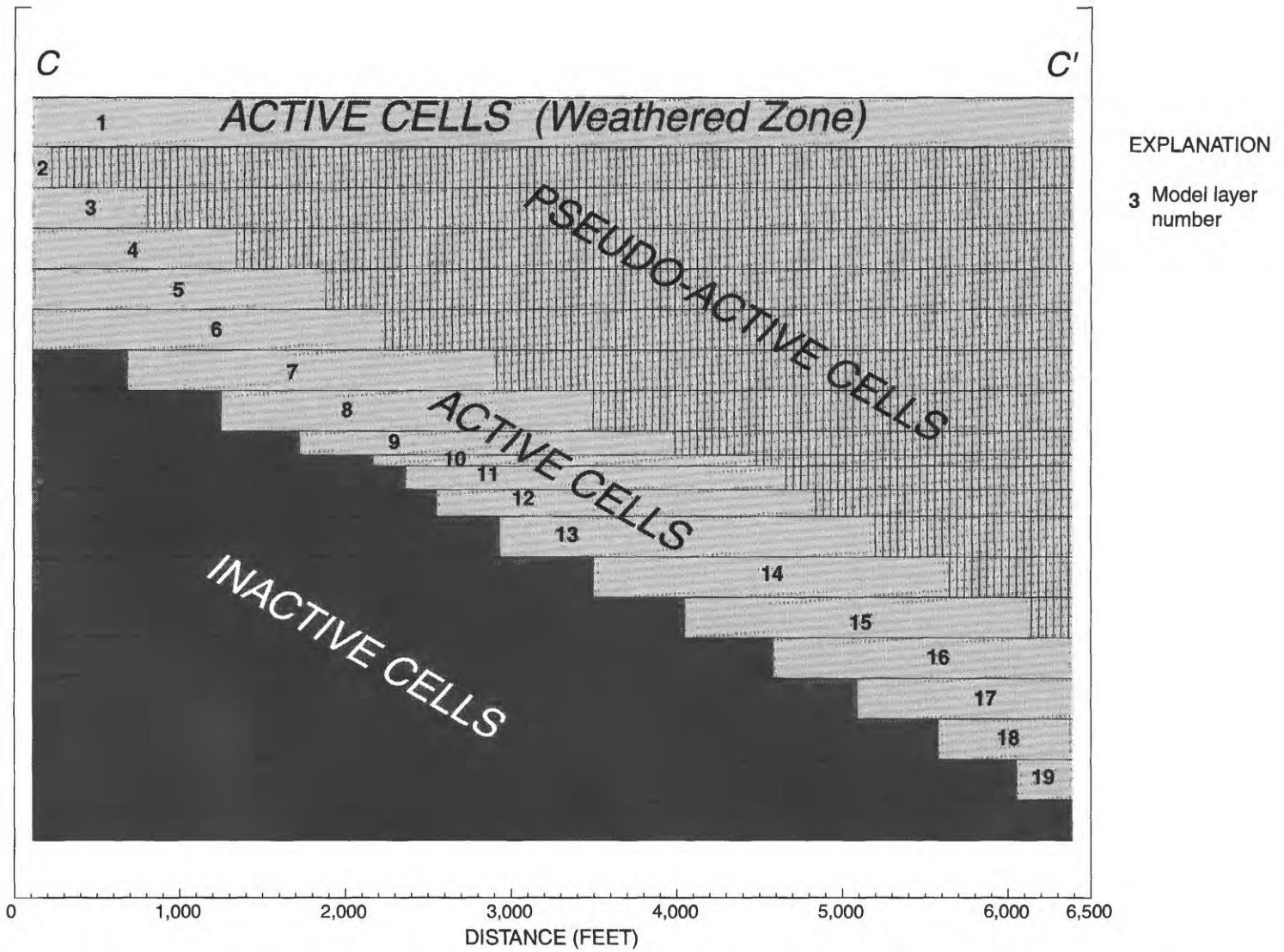


Figure 7. Section *C-C'* showing vertical discretization of ground-water flow model of the Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

The model structure is based on a simplified conceptualization of the ground-water flow system. The fractured rocks are modeled as equivalent porous media. Thus, we assume that ground-water flow can be described by using a standard three-dimensional flow equation based on Darcy's Law. In this approach, the hydraulic-conductivity and storativity values used in the model represent the bulk properties of the fractured rock represented by each model layer. Water flux, which in reality may occur in only a small fraction of the layer that is occupied by fractures, is simulated as being distributed throughout each layer. This assumption means that the model cannot be used to simulate local or small-scale ground-water flow paths that are controlled by a few discrete fractures. Each model cell represents a volume of aquifer material that contains many fractures. The model calculates the flow path from one cell to the next by simulating the net effect of all of the fractures in that interval. Therefore, the model cannot be used to simulate paths on a scale smaller than the cell size. In the study area, this means that paths on a scale that is smaller than a 49-ft by 49-ft square cannot be simulated.

The primary intended use of this model is simulation of ground-water flow and advective contaminant transport in the study area. Most of the data used to calibrate the model are from the study area. Therefore, use of the model to obtain detailed predictions of ground-water conditions outside the study area would be inappropriate.

The digital model used in this study simulates only the advective flow of ground water. Dilution and dispersion of dissolved contaminants, movement of dense non-aqueous phase liquids due to gravity effects, and mixing of variable-density fluids are not simulated in the model. The model can be used to estimate flowpaths; however, it cannot appropriately be used alone to identify or rule out suspected sources of contamination.

The model can be used to estimate the effects of stresses such as ground-water pumping, drought, or artificial recharge on the flow system. If the effects of simulated pumping extend beyond the model boundaries, however, drawdown within the model area will be overestimated.

The model was calibrated by using water levels measured in October 1996. Although water levels generally are low in early fall, 1996 was an unusually wet year. Precipitation during 1996 was the second highest of that in all years during 1968-97. Consequently, the water levels used to calibrate the model probably were somewhat higher than mean water levels under static conditions. Ideally, a steady-state model is calibrated to average conditions, when the amount of water entering the ground-water system equals the amount leaving it. Under wet conditions, more water is entering the system than leaving it.

The use of wet-condition water levels to calibrate the model probably has little effect on the simulated flow paths. The relatively high water levels probably caused the hydraulic-head gradient to be steeper than average, however, especially in the weathered zone. A steep gradient would cause more water to flow through the system at higher velocities than average, but flow paths would not be different.

The hydraulic parameters determined by model calibration probably are different than they would have been if average water levels had been used during calibration. Recharge and storativity may be overestimated, and the horizontal hydraulic conductivity, vertical hydraulic conductivity, and streambed conductivity may be underestimated in the model. These potential overestimates and underestimates need to be considered if these parameters are used in other applications.

Model Calibration

During calibration of the digital model, values of hydraulic parameters were varied within reasonable ranges until acceptable matches were achieved between measured and simulated static ground-water levels, drawdown, and base flow to unnamed stream 1.

Hydraulic parameters

The hydraulic parameters that were adjusted during calibration are areal recharge, transmissivity, vertical hydraulic leakance, streambed conductance, specific yield, and storage coefficient. Values that were relatively well known were adjusted over smaller ranges than values that were less well known. The value of each parameter used in the final calibrated model is listed in table 5.

Areal recharge

Areal recharge was considered to be one of the better known parameter values because an estimate of recharge to the Passaic Formation was available from a previous study (Lewis-Brown and Jacobsen, 1995). That estimate of 8.2 inches per year was derived from measurements of base flow, ground-water pumpage, and sewage inflows to streams in west-central New Jersey and was used as the starting value of recharge during calibration. Land use differs between the two areas, however. In the west-central New Jersey study area, most land is either undeveloped or farmed, whereas the Busch Campus has been extensively developed. Many buildings, roads, and parking lots intercept precipitation at the campus, and most of the intercepted precipitation flows to storm sewers. In addition, several drains have been installed in grassy areas of the campus and golf course to prevent these areas from becoming

Table 5. Hydraulic parameters used in digital model of ground-water flow, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey

[ft/d, feet per day; ft^2/d, feet squared per day]

Parameter	Value	Comments	Governing equation
Areal recharge	0.0017 ft/d		
Transmissivity			
-Layer 1 (weathered zone)	16 ft^2/d		
-Layers 2-8 and 13-20	110 - 440 ft^2/d	Decreases with depth	$4550/depth^{0.6}$
-Layers 9 and 12	120 - 500 ft^2/d	Decreases with depth	$5200/depth^{0.6}$
-Layers 10 and 11	470 - 1,900 ft^2/d	Decreases with depth	$19{,}500/depth^{0.6}$
Vertical hydraulic conductivity			
-Layer 1 (weathered zone)	4.0×10^{-3} ft/d		
-Confining units below layers 2-8 and 10-19	1.9×10^{-8} - 7.7×10^{-5} ft/d	Decreases with depth	$10^2/depth^{3.6}$
-Confining unit below layer 9	1.9×10^{-4} - 7.7×10^{-1} ft/d	Conductivity is high because confining unit is leaky	$10^6/depth^{3.6}$
-Streambeds and riverbed	1.0 ft/d		
Storage coefficient			
-Layer 1	3.0×10^{-2}		
-Layers 2-20	4.0×10^{-7}		

muddy. Therefore, the amount of areal recharge at the west-central New Jersey study area was considered to be the maximum reasonable value of recharge in the current study area. In the calibrated model, simulated water levels and base flow best matched the measured values when an areal recharge of 7.4 inches per year (0.0017 ft/d) was applied.

Transmissivity

Transmissivity was considered to be one of the better known parameter values in the model because estimates were available from analysis of slug-test data. The actual values of measured transmissivity were assumed to be subject to a potential error of about one order of magnitude because of uncertainty related to curve-matching and interference caused by pumping at the irrigation well.Therefore, adjustments of up to about one order of magnitude from the measured values were allowed during calibration.

In the digital model, the weathered zone was initially assigned a transmissivity of 4.8 ft^2/d--the mean transmissivity measured in this zone by slug testing. During model calibration, the transmissivity in this zone was adjusted to 16 ft^2/d.

The water-bearing units represented by model layers 2-20 were initially assigned a transmissivity of 84 ft^2/d--the mean transmissivity measured in water-bearing units 9-12. During model calibration, it was found that simulated water levels, drawdown, and base flow better matched the measured values if the transmissivity in each of these units decreased with depth. Although the transmissivity data obtained in the study area by slug testing do not indicate any trend as a function of depth, only 10 wells are open to water-bearing units; therefore, it is not surprising that no trend is indicated in so few data. In a previous study in west-central New Jersey, however, the specific capacity per foot of open hole of 709 wells in the Passaic Formation was found to decrease with depth (Lewis-Brown and Jacobsen, 1995). There the median specific capacity per foot of open hole in wells 76 to 100 ft deep is 0.00771, and the median specific capacity of deeper wells is increasingly smaller. The specific capacity per foot of open hole of the deepest wells (251-300 ft deep) is 0.00051. Specific capacity per foot of open hole is a parameter used to estimate transmissivity (Heath, 1983).

During model calibration, it was also determined that simulated conditions best match measured conditions when the transmissivity assigned to model layers 9 and 12 ranges from 120 ft^2/d at the greatest depths to 500 ft^2/d at the shallowest depths; the transmissivity assigned to model layers 10 and 11 ranges from 470 to 1,900 ft^2/d; and the transmissivity assigned to all of the hypothetical layers ranges from 110 to 440 ft^2/d. The depth-dependent transmissivity at each model cell was calculated by using a computer program separate from the model. The equations used to determine transmissivity at each cell are listed in table 5.

During model calibration, several model runs were made with anisotropy incorporated into each water-bearing unit by varying the ratio of horizontal hydraulic conductivity in the strike direction to that in the dip direction. Ratios varying from 1:2 to 1:10 were tested. The best model calibration was achieved when no anisotropy was incorporated into individual model layers; however, the large-scale anisotropy present in the study area, wherein water flows preferentially in the strike direction, is simulated by the model. The large-scale anisotropy is a result of transmissivity contrasts in the aquifer system. Water is impeded from flowing horizontally across units in the dip direction because of the low transmissivity of the confining units (fig. 6). Likewise, water is impeded from flowing any great distance downdip within a water-bearing unit because the transmissivity of each unit decreases with depth. Consequently, water flows along the path of least resistance (greatest transmissivity), which

is through a water-bearing unit and in the strike direction (into the page in figure 6). All of these transmissivity contrasts are represented in the model, with the result that simulated flow paths are predominantly along strike.

Pseudo-active cells were assigned a transmissivity of zero. The purpose of this zone, as described earlier, is to allow instantaneous vertical flow, but no horizontal flow, through parts of model layers that represent non-existent extensions of water-bearing units updip from their outcrops.

Vertical hydraulic conductivity and vertical leakance

All of the estimates of vertical hydraulic conductivity in rocks similar to those in the study area, which vary from 0.0001 to 32 ft/d, apply to the bulk vertical conductivity of aquifer systems composed of both water-bearing and confining units. Therefore, vertical hydraulic conductivity was allowed to vary over several orders of magnitude during model calibration.

Simulated heads, drawdown, and base flow best matched measured conditions when the vertical conductivity of the weathered zone was 4.0×10^{-3} ft/d and the vertical conductivity of each confining unit, like the horizontal transmissivity of the water-bearing units, decreased with depth. The best model calibration was achieved when all confining units except the one below water-bearing unit 9 were assigned vertical-conductivity values ranging from 1.9×10^{-8} to 7.7×10^{-5} ft/d. The confining unit below water-bearing unit 9 was assigned vertical-conductivity values four orders of magnitude higher than those of the other confining units. This is an indication that this confining unit is leakier than the others. Values of vertical hydraulic conductivity used in the model and the equations used to calculate the depth-dependent values are listed in table 5.

Vertical leakance, rather than vertical hydraulic conductivity, is the parameter actually incorporated into the model. Vertical leakance is the vertical conductivity of the depth interval between the center of a model cell and the center of the model cell beneath it divided by the length of that interval. The vertical leakance applied to model cells representing the weathered zone depends on the type of unit that is below the weathered zone. In some places, a water bearing unit is directly beneath the weathered zone, and in other places a confining unit is directly beneath the weathered zone (fig. 6). The case in which a water-bearing unit directly underlies the weathered zone is analogous to the situation described by McDonald and Harbaugh (1988) in which two adjacent model layers are used to represent two vertically adjacent hydrogeologic units. In this case, the vertical leakance assigned to the cell representing the weathered zone is defined as

$$Vcont = \frac{1}{\frac{m_w}{2K_{zw}} + \frac{m_{wb}}{2K_{zwb}}} \qquad (1)$$

where

Vcont is the vertical leakance,

m_w is the thickness of the weathered zone,

m_{wb} is the thickness of the water-bearing unit directly beneath the weathered zone,

K_{zw} is the vertical hydraulic conductivity of the weathered zone, and

K_{zwb} is the vertical hydraulic conductivity of the water-bearing unit directly beneath the weathered zone.

An analysis of the reasonable ranges of values of the parameters in equation 1 indicates that the vertical conductivity of the weathered zone controls the value of vertical leakance because the vertical conductivity of the weathered zone is orders of magnitude lower than that of the water-bearing units. Consequently, the terms for vertical conductivity and thickness of the water-bearing unit underlying the

weathered zone can be disregarded, and the resulting equation is

$$Vcont = \frac{2K_{zw}}{m_w} \quad . \tag{2}$$

The case in which a confining unit is present between the weathered zone and the underlying water-bearing unit is analogous to the situation described by McDonald and Harbaugh (1988) in which two adjacent model layers are used to represent two water-bearing units separated by an interbedded confining unit. In this case, the vertical leakance assigned to the cell representing the weathered zone is defined as

$$Vcont = \frac{1}{\frac{m_w}{2K_{zw}} + \frac{m_c}{K_{zc}} + \frac{mwb}{2K_{zwb}}} \tag{3}$$

where

m_c is the thickness of the confining unit, and

K_{zc} is the vertical hydraulic conductivity of the confining unit.

In this case, the vertical conductivity of both the weathered zone and the confining unit is much lower than that of the water-bearing unit, so the terms representing the thickness and conductivity of the water-bearing unit can be disregarded, and the resulting equation is

$$Vcont = \frac{1}{\frac{m_w}{2K_{zw}} + \frac{m_c}{K_{zc}}} \quad . \tag{4}$$

Model layers 2-19 each represent a water-bearing unit that is underlain by a confining unit which, in turn, is underlain by another water-bearing unit. In this situation, the vertical conductivity of the confining unit is orders of magnitude smaller than that of the water-bearing units, and the vertical leakance is defined by the equation:

$$Vcont = \frac{K_{zc}}{m_c} \quad . \tag{5}$$

A computer program separate from the model was used to calculate the leakance at each model cell according to equation 2, 3, or 4. Pseudo-active cells were assigned a vertical leakance of 100 ft/d to allow near-instantaneous vertical flow through these cells.

Streambed hydraulic conductance

Streams were simulated as head-dependent flux boundaries by using the "river module" of MODFLOW. In this module, the head in the stream is specified, and water flows between the aquifer and the stream through the streambed. The rate of flow between the aquifer and the stream is controlled by the head difference between the stream and the aquifer, and the hydraulic conductance of the streambed. McDonald and Harbaugh (1988) define this conductance according to the equation:

$$Criv = \frac{K_s LW}{m_s} \tag{6}$$

where

C_{riv} is the hydraulic conductance of the stream-aquifer interconnection;

K_s is the vertical hydraulic conductivity of the streambed material,

L is the length of the reach,

W is the width of the stream, and

m_s is the thickness of the streambed.

Streambed material in the study area consists of silt or fractured bedrock with silt filling the fractures. Heath (1983) estimated the horizontal hydraulic conductivity of silt to range from 0.003 to 10 ft/d. In the calibrated model, simulated heads, drawdown, and base flow were nearest measured conditions when a vertical conductivity of 1 ft/d was assigned to the bed material of the Raritan River and its tributaries.

The length of the tributaries to the Raritan River within each model cell was determined from topographic maps by means of a geographic information system. The width of these three streams was estimated to be 3 ft on the basis of measurements at a few representative sites. Because the Raritan River is about 300 ft wide in the model area, its area (L x W) within each model cell was determined by digital scanning of topographic maps. The thickness of the streambed was estimated to be 5 ft in the tributaries and 10 ft in the Raritan River.

Specific yield and storage coefficient

Specific yield is used to define the storage capacity of model layer 1, the weathered zone, which is assumed to be unconfined. Specific yield is defined as the ratio of the volume of water that can be drained from a rock to the volume of the rock. In the calibrated model, the specific yield of the weathered zone was set at 3.0×10^{-2}.

The storage term used in the model for confined water-bearing units below the weathered zone is storage coefficient--specific storage of the water-bearing unit multiplied by the thickness of the water-bearing unit. Specific storage is the amount of water released from or taken into storage per unit volume of aquifer material per unit change in head. Rima and others (1962) found that the storage coefficient of the upper part of the Stockton Formation in southeastern Pennsylvania is about 1.37×10^{-4}. Because the transmissivity of the Passaic Formation is lower than that of the Stockton Formation, it is assumed that the storage coefficient of the Passaic Formation is less than 10^{-4}. As a result of model calibration, specific storage in layers 2-20 was set at 4.0×10^{-7}.

Pumpage

In the study area, the only wells from which water is withdrawn are 11 domestic wells and the irrigation well. Pumpage at the domestic wells was estimated by assuming that each household includes four persons and that each person uses 75 gal of water per day. The pumping rate at the domestic wells was assumed to be constant over time.

Pumpage at the irrigation well initially was distributed equally among the four model layers intersected by the well opening (layers 9-12). During calibration of the transient model, the pumpage was redistributed until the best match between measured and simulated drawdown was achieved. In the calibrated model, 18, 17, 22, and 43 percent of the total pumpage is applied to layers 9, 10, 11, and 12, respectively. This distribution also was used in the steady-state simulations.

The total volume of water pumped over the 19-hour period simulated by the transient model was 40,561 ft^3. No records were kept of any changes in pumping rate over that period, but it is assumed that the rate decreased with time because of drawdown in the well. Therefore, in the transient model, the total pumping time is divided into five equal stress periods; the pumping rate decreases from each stress period to the next, and in the last stress period it is approximately one-half the pumpage in the first period.

Calibration criteria

The digital model was calibrated by adjusting values of hydraulic parameters until acceptable matches were achieved between measured and simulated static ground-water levels and drawdown. Base flow to unnamed stream 1 also was used in calibrating the model.

Water levels used in calibration of the steady-state model were measured on October 28, 1998. As explained earlier, these water levels are representative of steady-state conditions with no pumping from the irrigation well. Measured and simulated water levels at each well are listed in table 6. Simulated water levels in wells open to confining units are approximate because flow in confining units is not expressly

Table 6. Measured and simulated water levels on October 28, 1996, and drawdown on October 29, 1996, in wells in the study area, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey

[CU, confining unit]

Local well name	Model layer number	Static water level, October 28, 1996 (feet above sea level)			Drawdown, October 29, 1996 (feet)		
		Measured	Simulated	Simulated minus measured	Measured	Simulated	Simulated minus measured
B-1	1	75.64	83.64	8.00	0.15	0.04	-0.11
B-4	1	95.54	88.73	-6.81	.05	.09	.04
B-6	1	79.92	80.10	.28	.33	.10	-.23
CH-1MW	1	86.58	84.89	-1.69	.06	.09	.03
CH-2MWA	CU9	72.12	75.71	3.59	8.00	4.53	-3.47
CH-2MWB	1	84.89	82.49	-2.40	.56	.09	-.47
CH-3MW	9	71.97	70.67	-1.30	9.67	9.54	-.13
MW-1A	CU9	72.12	69.86	-2.26	7.70	9.28	1.59
MW-1B	CU9	71.83	69.86	-1.97	4.19	9.28	5.09
MW-1C	1	77.63	90.85	13.16	1.96	.06	-1.90
MW-2A	CU9	59.92	66.64	6.72	6.10	11.45	5.35
MW-2B	9	61.13	66.71	5.58	12.73	12.82	.10
MW-2C	CU8	68.21	70.76	2.55	3.61	6.43	2.83
MW-3A	CU9	67.91	68.79	.88	19.04	9.93	-9.11
MW-3B	9	68.66	68.95	.29	9.43	10.69	1.26
MW-4	1	92.96	99.80	6.84	.04	.05	.01
MW-5A	11	70.18	63.53	-6.65	15.51	17.58	2.07
MW-6A	12	64.28	64.50	.22	63.68	64.31	.63
MW-6B	11	62.24	60.32	-1.92	29.52	21.53	-7.99
MW-6C	9	58.44	64.24	5.80	18.98	16.32	-2.66
MW-7A	11	61.94	60.38	-1.56	13.08	20.43	7.35
MW-7B	10	61.92	64.30	2.38	8.50	10.36	1.86
RU-3	1	99.32	97.62	-1.70	.08	.05	-.03
RU-4	1	94.33	90.81	-3.52	0	.09	.09
RU-5	9	73.23	71.08	-2.15	6.81	9.20	2.39

simulated in the model. The approximated water level is the average of the water levels simulated in the water-bearing units above and below the confining unit. These approximations were made to provide additional data points for calibration purposes.

All simulated water levels were within 14 ft of the measured levels, and 60 percent were within 2.6 ft of the measured levels. All simulated head-gradient directions matched actual gradient directions.

Base flow of 0.407 ft^3/s (35,200 ft^3/d) was measured in unnamed stream 1 near its confluence with the Raritan River (fig. 4) on October 28, 1996, the same day the steady-state water levels were measured. Streamflow on that day was assumed to consist entirely of base flow because only a trace of precipitation had fallen during the 8-day period preceding the measurement and because streamflow in nearby gaged streams was at base-flow conditions (R.S. Schopp, U.S. Geological Survey, oral commun., 1996). Simulated base flow at the measurement site is 32,300 ft^3/d--92 percent of the measured base flow. Consequently, the model is considered to be adequately calibrated with respect to base flow.

The transient model was calibrated to the total drawdown observed in wells after the irrigation well had been pumped for 19 hours and 11 minutes. All simulated drawdowns were within 9.2 ft of the measured levels, and 60 percent were within 1.9 ft of the measured levels.

Simulated Ground-Water Budget

Data from the calibrated model can be used to estimate the ground-water-flow budget in the study area. Most of the inflow into the model area is areal recharge, and most of the outflow is discharge to the Raritan River and its tributaries. Regional flow into the model area across the northeastern boundary accounts for the rest of the inflow, and pumping from wells accounts for the rest of the outflow. When the irrigation well is pumped at its average annual rate, 78 percent of the water captured by the well is intercepted base flow to unnamed stream 1. The remainder is intercepted base flow to the Raritan River. Budgets for the simulations with no pumping and with average annual pumpage from the irrigation well are shown schematically in figure 8.

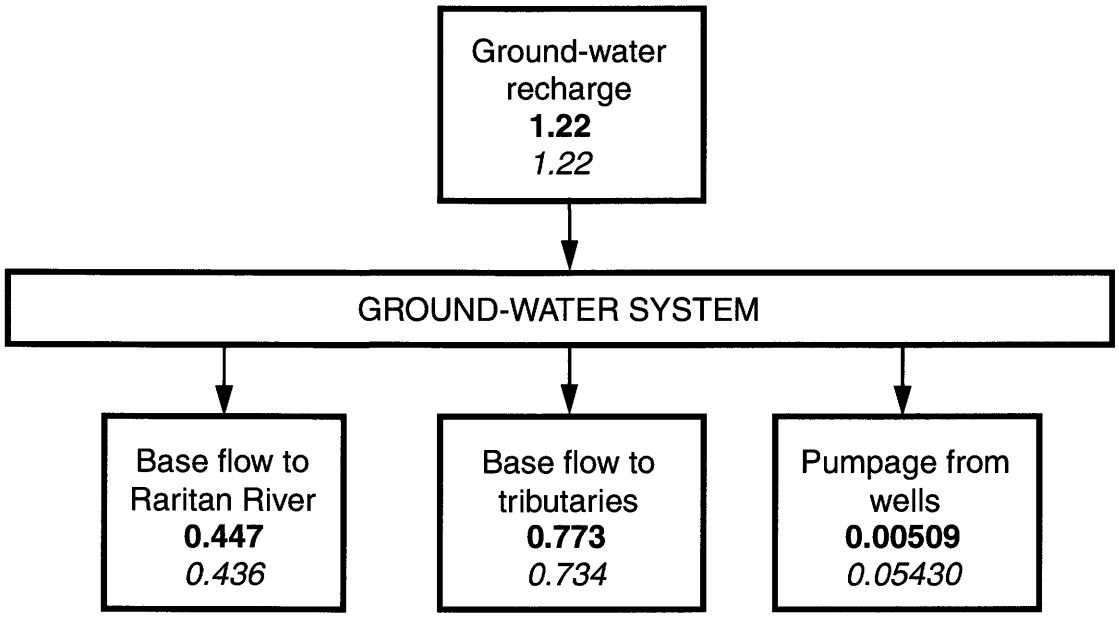
GROUND-WATER QUALITY AND DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS

Water samples were collected from each accessible well in the study area at least once during 1993-96 and analyzed for VOC's. Samples were collected from 15 wells during August-September 1993, from 17 wells during June-July 1994, from 24 wells in 1995, and from 25 wells in 1996. The shallow upgradient well (MW-4) was sampled twice in 1995 because attempts to sample this well in 1993 and 1994 were not successful because of its low yield.

Ground-Water Quality

All water samples were analyzed for VOC's. Eleven VOC's were present at concentrations above the reporting limit (table 7, at end of report). The reporting limits of these 11 compounds, as well as the 48 VOC's for which the samples were analyzed but were not detected in concentrations above the reporting limit, are listed in appendix 2. The areal distribution of VOC's in the study area did not vary greatly from 1993 to 1996.

Samples from 12 of the wells in the study area were analyzed for dissolved cations, anions, nutrients, metallic trace elements, and phenols, and samples from 11 wells were analyzed for polychlorinated biphenyls. Results of these analyses are listed in appendix 3. No primary maximum contaminant level (MCL) for any of these constituents was exceeded in any



EXPLANATION

1.22 No pumpage at irrigation well.
Value in cubic feet per second

1.22 Average annual pumpage at irrigation well.
Value in cubic feet per second

Figure 8. Simulated ground-water budget, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

of these samples, and no polychlorinated biphenyls were detected in any sample. The MCL is the maximum concentration of a constituent allowable in public drinking water. MCLs are generally based on health criteria. MCLs for selected inorganic constituents and organic compounds are listed in appendix 4.

Quality Assurance Procedures

VOC-concentration data were reviewed to verify the results of the laboratory analyses. Recoveries of the surrogate analyte added to all samples prior to analysis as well as the accuracy of the measurement of compounds of interest in the laboratory-fortified blanks were within accepted precision limits.

Twelve sequential replicate samples were submitted blind to the laboratory for analysis for VOC's during 1993-96. Results of analyses of these samples are included in table 7. Of the 708 sets of analyses (including those for compounds listed in appendix 2 that were not detected in any sample), 688 were duplicated exactly. Only two sets of analyses had relative percent differences greater than 27 percent; these two were analyses for methylene chloride, a common laboratory contaminant. For the purposes of this study, the quality of the replicate analyses are acceptable.

Thirty-one field blanks and 23 trip blanks also were submitted for VOC analysis. Results of these analyses are presented in appendix 5. Methylene chloride was the prevalent compound found in blanks; this compound was detected in concentrations up to 6.3 µg/L in 13 field blanks and up to 5.0 µg/L in 9 trip blanks. In most cases, methylene chloride was detected also in the associated laboratory method blank; therefore, occurrence of this compound in blanks is attributed to contamination originating in the analyzing laboratory. A concentration of 0.6 µg/L of chloroform was detected in the trip blank for September 19, 1995, and a concentration of 0.6 µg/L of 1,2-dichloropropane was detected in the trip blank for October 4, 1996, but neither of these compounds was detected in other samples in the same shipments. No other organic compounds were detected.

As a simple check on analyte loss during transportation and laboratory holding time and on GC/MS accuracy, samples collected from two wells (MW-2A and CH3-MW) in 1995 were spiked in the field with a known concentration of an organic compound. The only compound detected in these two samples was this field surrogate; percent recoveries for this surrogate were 100 and 87 percent, respectively.

Distribution of Volatile Organic Compounds

Carbon tetrachloride and tetrachloroethylene

Carbon tetrachloride was detected at higher concentrations than any other VOC and was detected in samples from 5 wells. Concentrations of this compound ranged from less than 0.5 µg/L to 24,000 µg/L and were highest in samples from wells less than 10 ft from the C-Wing building--RU-2, RU-4, and RU-5. These wells are 27, 27, and 75 ft deep, respectively. Concentrations of carbon tetrachloride in all samples from these wells greatly exceeded the MCL of 2.0 µg/L (New Jersey Administrative Code, 1990). Carbon tetrachloride also was detected consistently in samples from well MW-3B, which is 750 ft from the C-Wing building and 90 ft deep, and intermittently in samples from well MW-1A, which is 370 ft from the C-Wing building and 100 ft deep. The concentrations of carbon tetrachloride in all samples from these two wells were below the MCL. Trace amounts of carbon tetrachloride (below the reporting limit of 0.5 µg/L) were detected in water from wells MW-1A, MW-3A, MW-2B, and MW-2C in 1993. These wells are 330, 750, 1,380, and 1,380 ft from the C-Wing building and are 100, 140, 110, and 80 ft deep, respectively.

Well MW-5A, which was installed in 1995 to help define the vertical distribution of contaminants near the C-Wing building, is screened from 179 to 204 ft below land surface. It is more than 100 ft deeper than the adjacent well, RU-5, which is 75 ft deep. The sample from well MW-5A contained no detectable carbon tetrachloride although the samples from well RU-5 contained up to 8,500 µg/L of this compound.

The analytical data indicate that the carbon tetrachloride contaminant plume--as defined by points where this compound has been detected at concentrations exceeding the MCL--is localized in an area within 10 ft of the C-Wing building and to a depth of somewhere between 75 and 179 ft.

The areal distribution of PCE is very different from and much more discontinuous than the distribution of carbon tetrachloride. PCE, the most frequently detected compound, was present in 22 samples from nine wells in concentrations ranging from less than 0.5 to 1,300 µg/L. PCE was detected in concentrations exceeding the MCL (1.0 µg/L) in all samples from wells RU2, RU-4, RU-5, MW-5A, CH-2MWB, and the irrigation well. These wells are 5 to 2,370 ft from the C-Wing building and 27 to 300 ft deep.

Concentrations of PCE were highest in samples from wells less than 10 ft from the C-Wing building--RU-2, RU-4, and RU-5, which are 27, 27, and 75 ft deep, respectively. The sample from well MW-5A, the 204-ft-deep well near the C-Wing building, contained 1.4 µg/L of PCE. The presence of PCE, but not carbon tetrachloride, at this depth may be the result of an earlier release time for PCE or its slightly greater specific density (1.63 compared to 1.59) and lower viscosity.

The next highest concentrations of PCE were found in the irrigation well, which is 2,370 ft from the C-Wing building. PCE concentrations detected in this well range from 16 to 23 µg/L. The irrigation well is 300 ft deep and open to water-bearing units 9-12.

No PCE was detected in many wells between the C-Wing building and the irrigation well (all wells in clusters MW-1 and MW-3 and the deepest wells in clusters MW-2 and MW-6). Moreover, where PCE was detected in wells between the C-Wing building and the irrigation well, concentrations were low (at or below the MCL). At the well cluster closest to the irrigation well, PCE was detected at 0.5 µg/L in well MW-6C, which is open to water-bearing unit 9, but was not detected in samples from the two deeper wells open to water-bearing units 11 and 12.

PCE also was consistently present in samples from Rutgers golf 13 obs. This well is 200 ft deep, open to water-bearing units 9-11, and 2,500 ft from the C-Wing building--farther from the building than is the irrigation well. Concentrations of PCE in samples from this well are either slightly above or below the MCL.

Other volatile organic compounds

Four other VOC's were detected in concentrations exceeding their MCL's. Trichloroethylene (TCE) was detected in concentrations exceeding the MCL (1.0 µg/L) in water from well MW-5A in 1995 and 1996, from RU-4 in 1994, and from well CH-1MW in 1993. TCE was detected in a concentration below the MCL in water from well RU-5 in 1994. TCE in the study area commonly is associated with PCE and cis-1,2-dichloroethene. PCE degrades to TCE, to the 1,2-dichloroethenes, and finally to vinyl chloride by the process of reductive dehalogenation (Freedman and Gossett, 1989). Therefore, TCE in the study area probably is a degradation product of PCE.

Benzene was detected in samples from two wells in concentrations greater than the MCL of 1.0 µg/L--well CH-1MW in 1993 (2.9 µg/L) and well RU-4 in 1994 (3.4 µg/L). The 1994

water sample from well RU-4 also contained 36 µg/L of 1,2-dichloroethane, which exceeds the MCL of 2.0 µg/L. These results, however, were not duplicated in previous or subsequent sampling. The only water sample in which the MCL of 100 µg/L for total trihalomethanes was exceeded was collected from well RU-2 in 1994. Chloroform, one of the trihalomethanes, was detected in this sample at a concentration of 110 µg/L.

The only VOC's detected at the MW-7 well cluster were toluene and chloroform. These compounds were detected in concentrations of 29 and 0.6 µg/L, respectively, which are far below the MCL's of 1,000 and 100 µg/L. This well cluster is between the C-Wing building and the domestic wells but is much closer to the domestic wells. It was installed to serve as an early warning to detect any contaminants that may be moving from the C-Wing building area toward the domestic wells.

Relation of Distribution of Contaminants to Ground-Water Flow Paths

The digital model was used to approximate the configuration of ground-water-flow paths from the vicinity of the C-Wing building. These approximations were made to determine whether the broken sump pipe at the C-Wing building is a plausible source of all carbon tetrachloride and PCE detected in wells in the study area and to estimate the effects of pumping on flow paths. MODPATH, a particle-tracking post-processor for MODFLOW developed by Pollack (1994), was used to compute the paths. Actual ground-water flow paths through the fractured-rock aquifer system are undoubtedly more complex than the simulated paths; however, the simulated paths are considered the best available estimate of the general configuration of flow paths on the scale of the study area.

Both of the primary contaminants at the C-Wing building--carbon tetrachloride and PCE--are dense nonaqueous-phase liquids (DNAPLs). Although these compounds have been detected in the study area only in the dissolved phase, it is possible that undissolved masses of these DNAPLs are present near their assumed source area. Because undissolved DNAPLs are denser than water, they move in different directions and at different velocities than the surrounding water. Their density causes them to move more slowly and have a greater downward vertical component of flow than the surrounding water. As water flows past the DNAPLs, it dissolves the DNAPLs, which can then move advectively with the water. The digital model used in this study simulates only the advective transport of dissolved contaminants--it cannot predict the movement of the undissolved DNAPLs. Therefore, it is necessary to estimate the "assumed source area" over which undissolved DNAPLs are present in order to use the model to estimate advective flow paths beginning at the source area.

Kueper and McWhorter (1991) found that DNAPLs travel along dipping fracture planes at a speed directly proportional to the dip of the plane from the horizontal. They also found that DNAPLs tend to pool above confining units but that if a DNAPL encounters an open fracture in the confining unit it may move through the fracture to lower water-bearing units. These findings were used to estimate the potential movement of DNAPLs from the site of the broken sump pipe at the C-Wing building. If any DNAPL were present, it probably would move along bedding-plane fractures in the water-bearing units in the direction of the dip of the bedrock (northwest) and also downward through vertical fractures in confining units. Consequently, any DNAPLs that ever were present near the broken sump pipe probably have moved both to the northwest and vertically downward. The extent of this movement is unknown, but water-quality data for wells RU-5 and MW5-A indicate that the maximum depth of dissolved carbon tetrachloride is

somewhere between the bottom of water-bearing unit 9 and the top of water-bearing unit 11 and that the maximum depth of dissolved PCE is approximately at the bottom of water-bearing unit 11. Water-quality data from well CH3-MW indicate that both contaminants have moved less than 500 ft downdip. Consequently, the assumed source area of undissolved carbon tetrachloride was conservatively estimated to extend 130 ft below and 250 ft northwest from the broken sump pipe. Similarly, the assumed source area of PCE was estimated to extend 200 ft below and 250 ft northwest from the broken sump pipe.

The flow paths were estimated from simulations of the ground-water system under three hypothetical steady-state conditions. In all three simulations, 11 domestic wells in the model area are pumped. In Simulation 1, the irrigation well is not pumped; in Simulation 2, the irrigation well is pumped at the average yearly rate (22.1 gal/min); and in Simulation 3, the irrigation well is pumped at a rate equal to its maximum short-term yield (262 gal/min). It is not known, however, whether this pumping rate could actually be sustained in the well or whether the drawdown caused by the pumping would adversely affect yields in the domestic wells.

Three different pumping rates were simulated because actual pumping from the irrigation well is intermittent. The well is pumped only during late April through October, and during those months it is pumped only when precipitation is inadequate to maintain grass on the golf course. Even at those times, the well is pumped for a maximum of about 16 hours per day. Consequently, steady-state ground-water conditions probably occur only rarely during the spring, summer, and fall. The simulated flow paths under the two "end-member" conditions--no pumping and maximum pumping--provide a reasonable range of actual flow paths of water from the C-Wing building. The simulated flow paths under the average-yearly-pumpage condition provide an intermediate estimate of actual flow paths.

Carbon tetrachloride

Simulated paths of ground-water flow from the assumed carbon tetrachloride source area in the three simulated pumping conditions are shown in map view in figures 9-11. Only a few representative flow paths, including the two outermost paths, are shown. The two outermost flow paths enclose the entire simulated area through which water from the C-wing building could flow. In all three simulations, flow lines trend predominantly northeast to southwest--parallel to the strike of the water-bearing units. This predominant flow direction is consistent with the conceptual model and is a result of the dip of the water-bearing units and confining units that make up the hydrogeologic framework.

Pumping from the irrigation well affects the configuration of the simulated flow paths. When the well is not pumped, all water that passes through the assumed carbon tetrachloride source area flows generally southwest and discharges to unnamed stream 1. Water originating in the weathered part of the carbon tetrachloride source area flows nearly vertically from the weathered zone into the underlying water-bearing unit (unit 9). Most of the water flows through unit 9 to the unit's outcrop in unnamed stream 1, where it discharges to the stream, but some water from the southeastern-most part of the source area flows from unit 9 to unit 10 and back to unit 9 before discharging to the stream. It is unlikely that water reaching the stream from the C-wing building still contains carbon tetrachloride because this compound has not been detected in concentrations above the MCL at distances greater than 10 ft from the building.

In the model simulation in which the irrigation well is pumped at the average annual rate, all water from the assumed source area

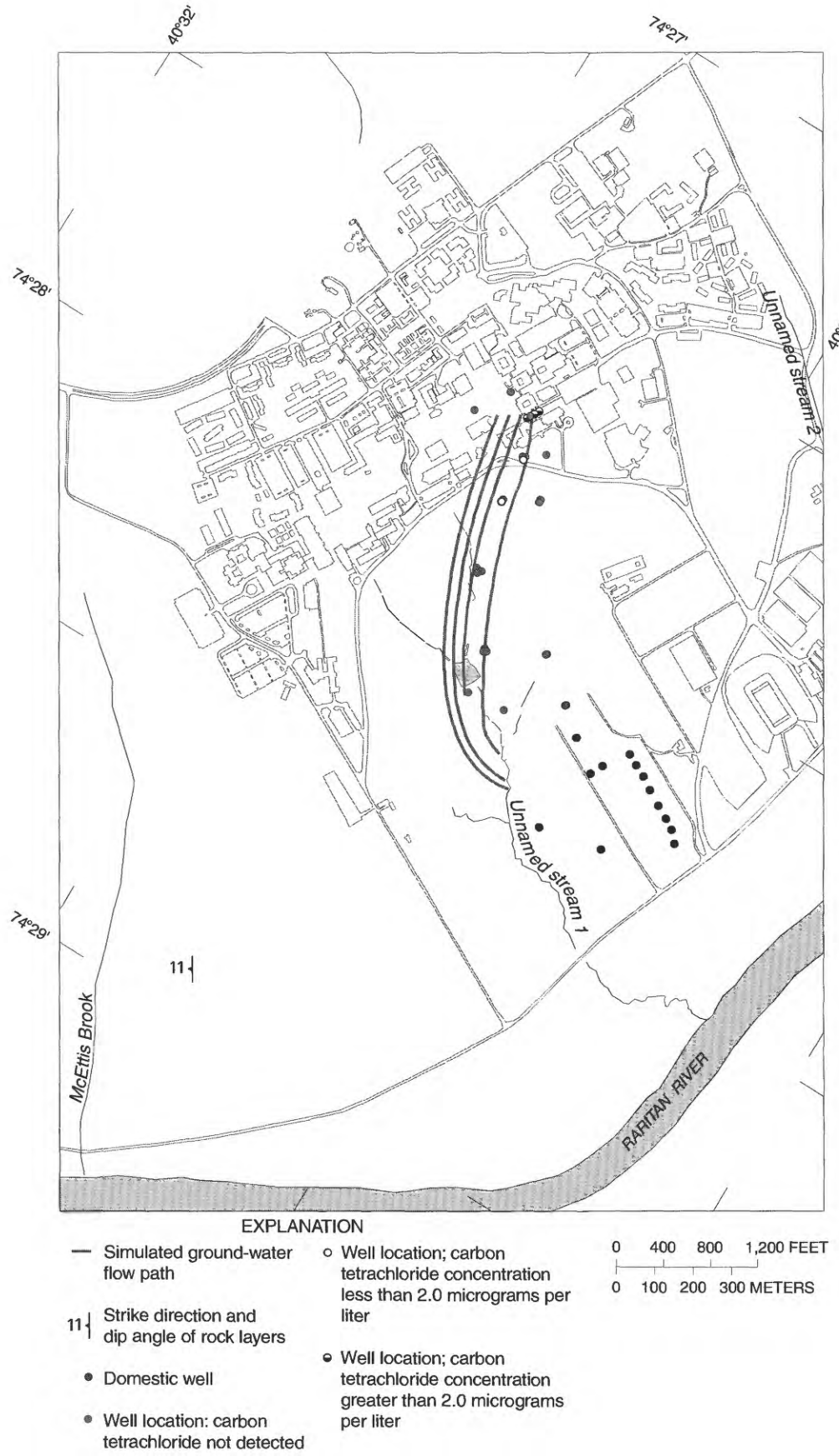


Figure 9. Concentration of carbon tetrachloride in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with no pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

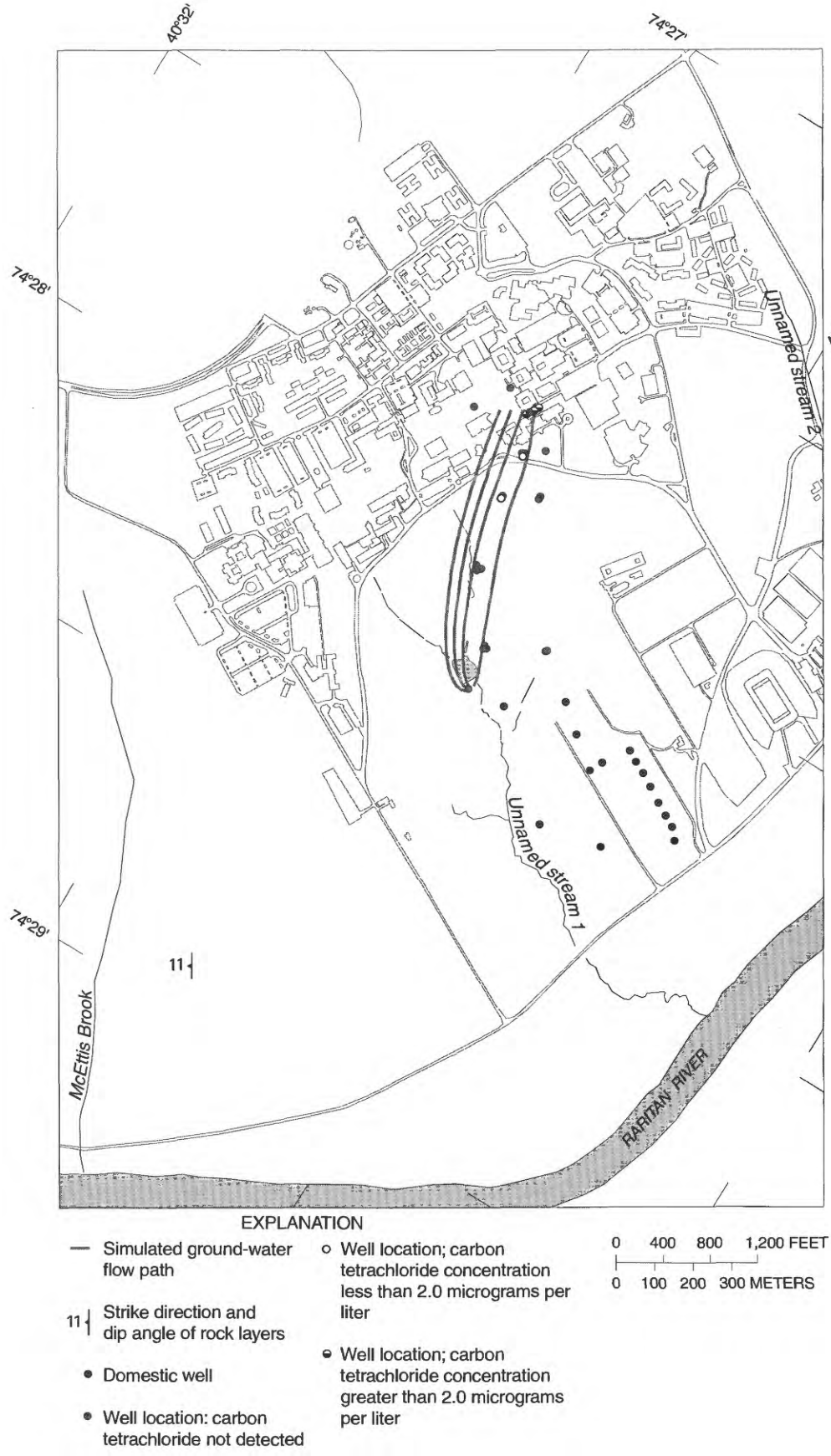


Figure 10. Concentration of carbon tetrachloride in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with average annual pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

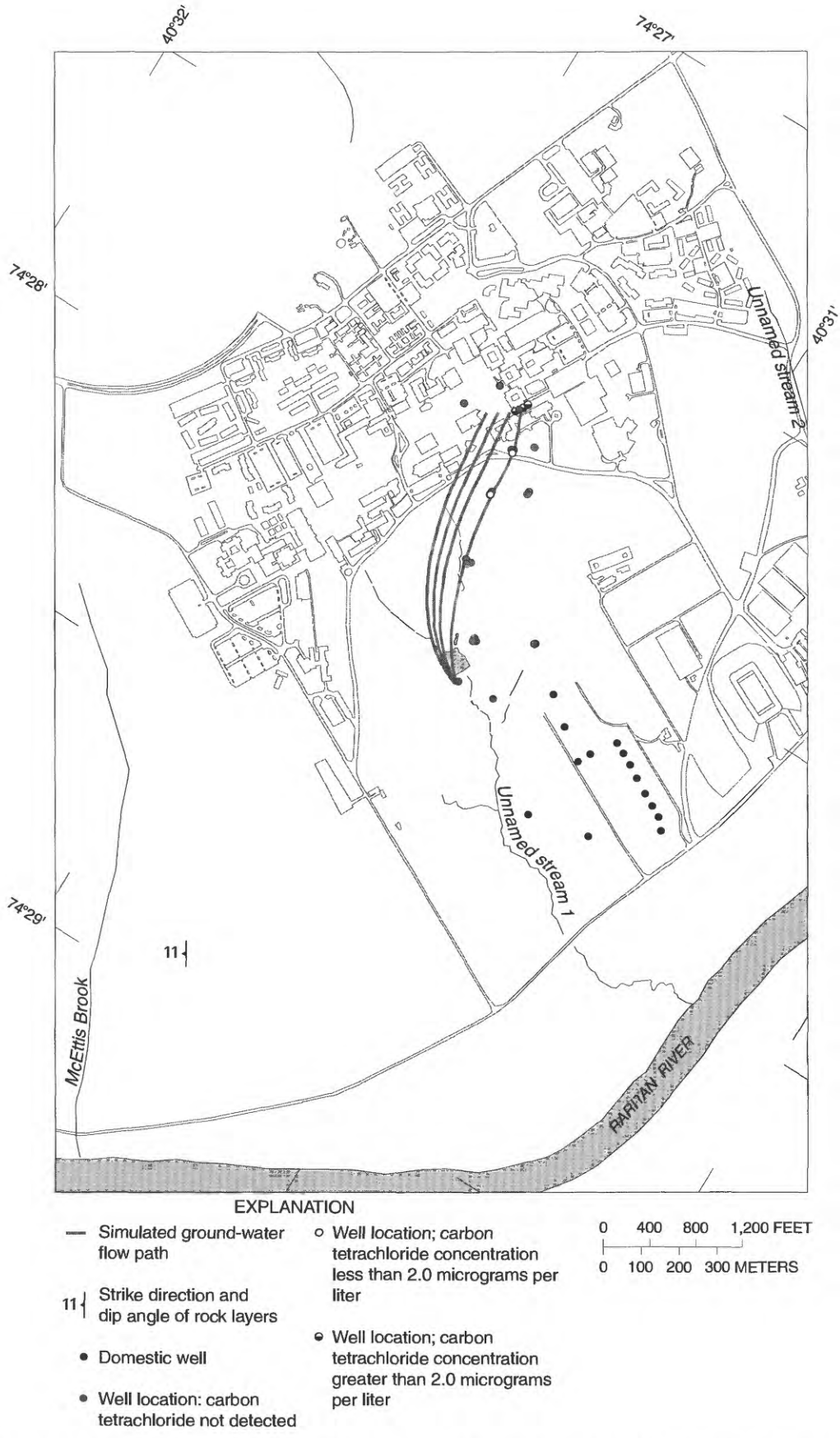


Figure 11. Concentration of carbon tetrachloride in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with maximum pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

discharges to the irrigation well, which is open to water-bearing units 9-12, and all paths remain in water-bearing unit 9. In the model simulation in which the irrigation well is pumped continuously at its maximum short-term yield, flow paths follow the same pattern but are farther downdip, toward the northwest, as a result of drawdown in the vicinity of the irrigation well.

The concentrations of carbon tetrachloride (greater than 2 µg/L, less than 2 µg/L, or not detected) in samples from wells also are shown in figures 9-11. All wells in which carbon tetrachloride was detected are within the area encompassed by the flow lines from the assumed carbon tetrachloride source area, and the concentrations of carbon tetrachloride decrease along flow paths. Consequently, the flow-path analysis supports the hypothesis that all the carbon tetrachloride detected in the study area originated at the broken pipe near the C-Wing building.

In all three pumping simulations, none of the flow paths from the assumed carbon tetrachloride source area (figs. 9-11) reaches any domestic well. The shortest distance between a flow path and a domestic well in any of the simulations is about 700 ft. That flow path was generated in the simulation with no pumping from the irrigation well. The simulation results show that pumping from the irrigation well widens the distance between flow paths of potentially contaminated water and the domestic wells.

A section view through the study area showing the extent of the simulated flow paths from the assumed carbon tetrachloride source area with no pumping from the irrigation well and concentrations of carbon tetrachloride in samples from wells are shown in figure 12. As in the map views (figs. 9-11), all wells in which carbon tetrachloride was detected are within the area encompassed by the flow lines from the carbon tetrachloride source area, and concentrations decrease along flow lines. The same information for both the average-annual-pumpage and maximum-pumpage simulations is shown in figure 13. The area that includes the flow lines is identical in these two simulations, and, as in the no-pumping simulation, all wells in which carbon tetrachloride was detected are located within this area.

Tetrachloroethylene

Simulated paths of ground-water flow from the assumed PCE source area in the three steady-state simulations are shown in map view in figures 14-16. Flow paths from the assumed PCE source area are more numerous than those from the assumed carbon tetrachloride source area because the PCE source area encompasses two additional water-bearing units--units 10 and 11. In the simulation with no pumping from the irrigation well (fig. 14), the discharge points of flow paths in units 10 and 11 are farther southwest than the discharge points of flow paths in unit 9 because these units crop out farther southwest than does unit 9; paths in unit 11 extend to the Raritan River (fig. 14).

When the irrigation well is pumped at its average annual rate, most of the flow paths originating in the assumed PCE source area are captured by the well (fig. 15); when the well is pumped at a rate equal to its maximum short-term yield, all of the flow paths are captured (fig. 16). Like the flow paths originating in the assumed carbon tetrachloride source area, paths originating in the PCE source area shift to the northwest as pumpage from the irrigation well increases.

The concentrations of PCE detected in samples from wells are also shown in figures 14-16. The distribution of PCE, unlike the distribution of carbon tetrachloride, is complex and discontinuous. PCE was detected in concentrations above the 1.0 µg/L MCL in samples from wells as far as 2,500 ft from the C-Wing building but not at several wells closer to the C-Wing building (fig. 14). In addition, simulated ground-water flow paths from the building area do not encompass all of the wells in which PCE was detected.

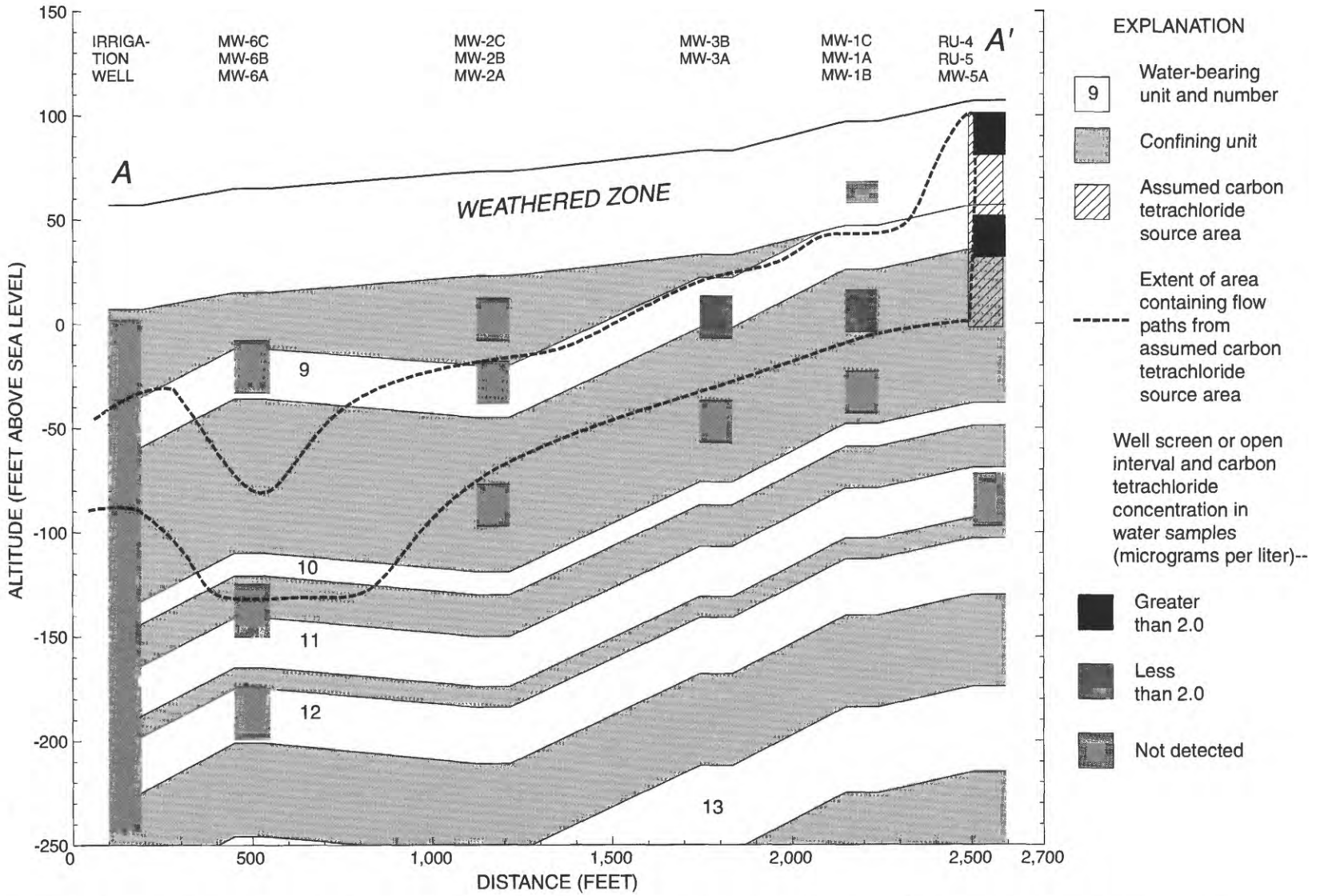


Figure 12. Section *A-A'* showing hydrogeologic framework, concentration of carbon tetrachloride in water samples collected from wells in 1995, and simulated area containing ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with no pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey. (Line of section shown in fig. 2)

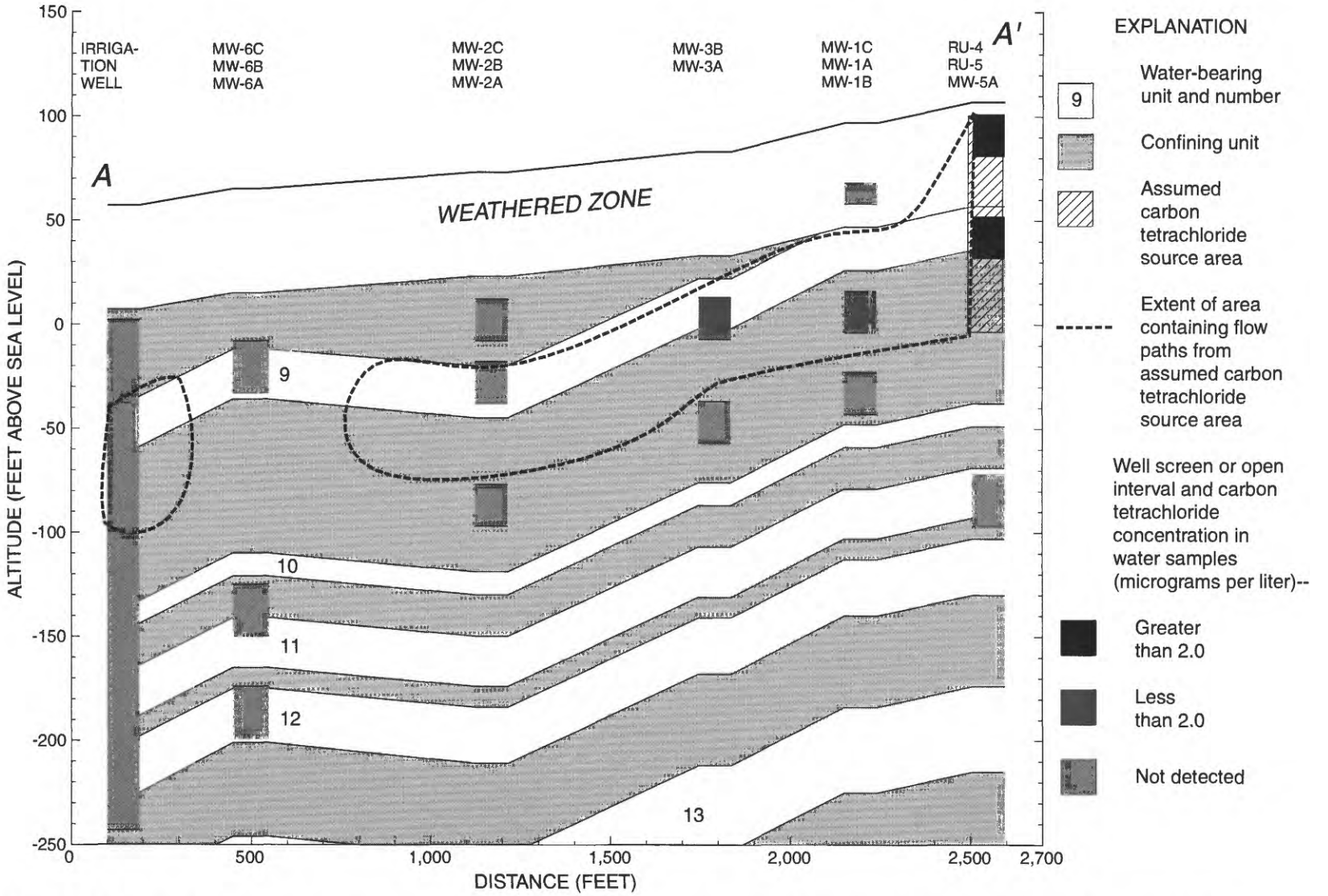


Figure 13. Section *A-A'* showing hydrogeologic framework, concentration of carbon tetrachloride in water samples collected from wells in 1995, and simulated area containing ground-water flow paths from the assumed carbon tetrachloride source area under steady-state conditions with both average annual and maximum pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey. (Line of section shown in fig. 2)

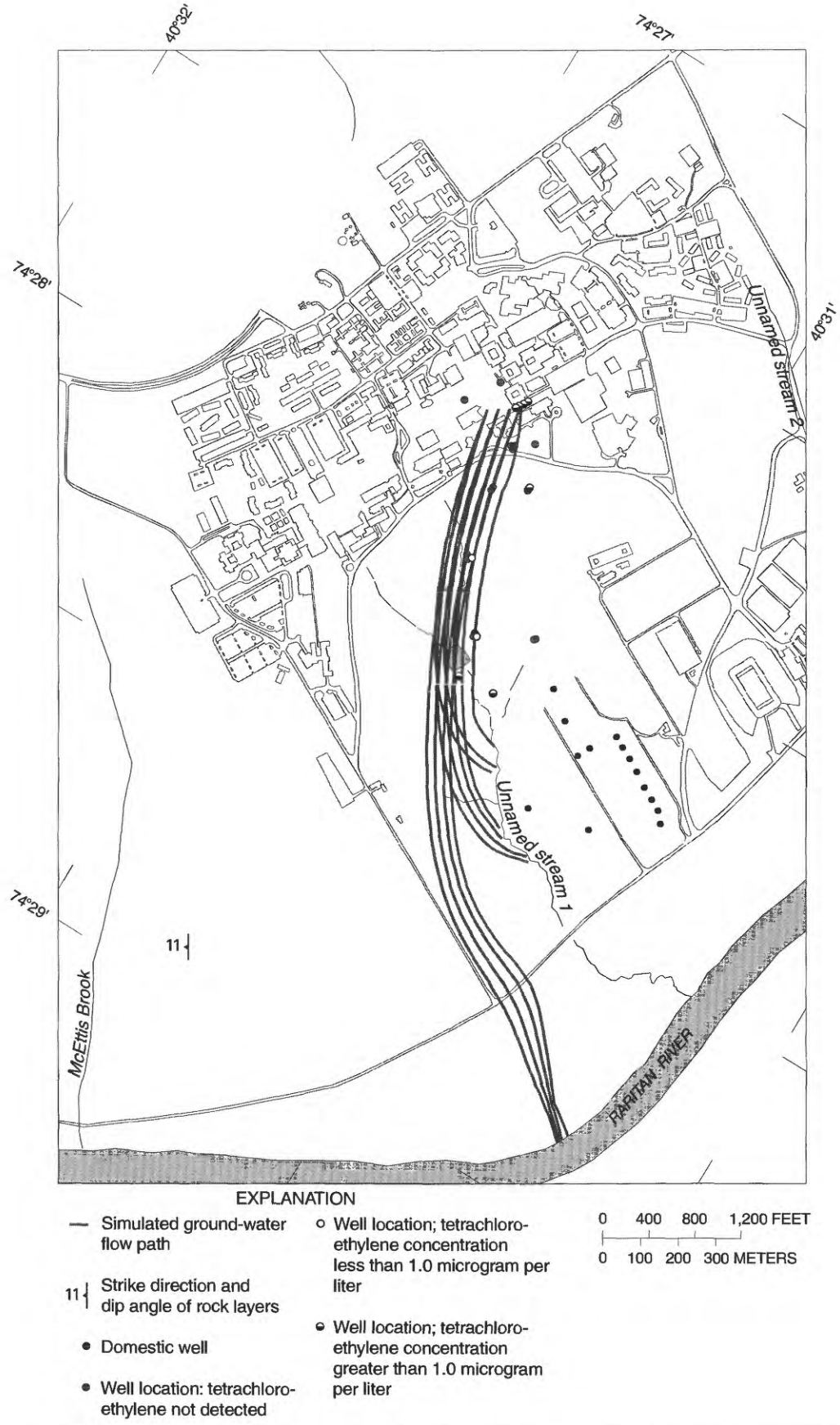


Figure 14. Concentration of tetrachloroethlyene in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed tetrachloroethlyene source area under steady-state conditions with no pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

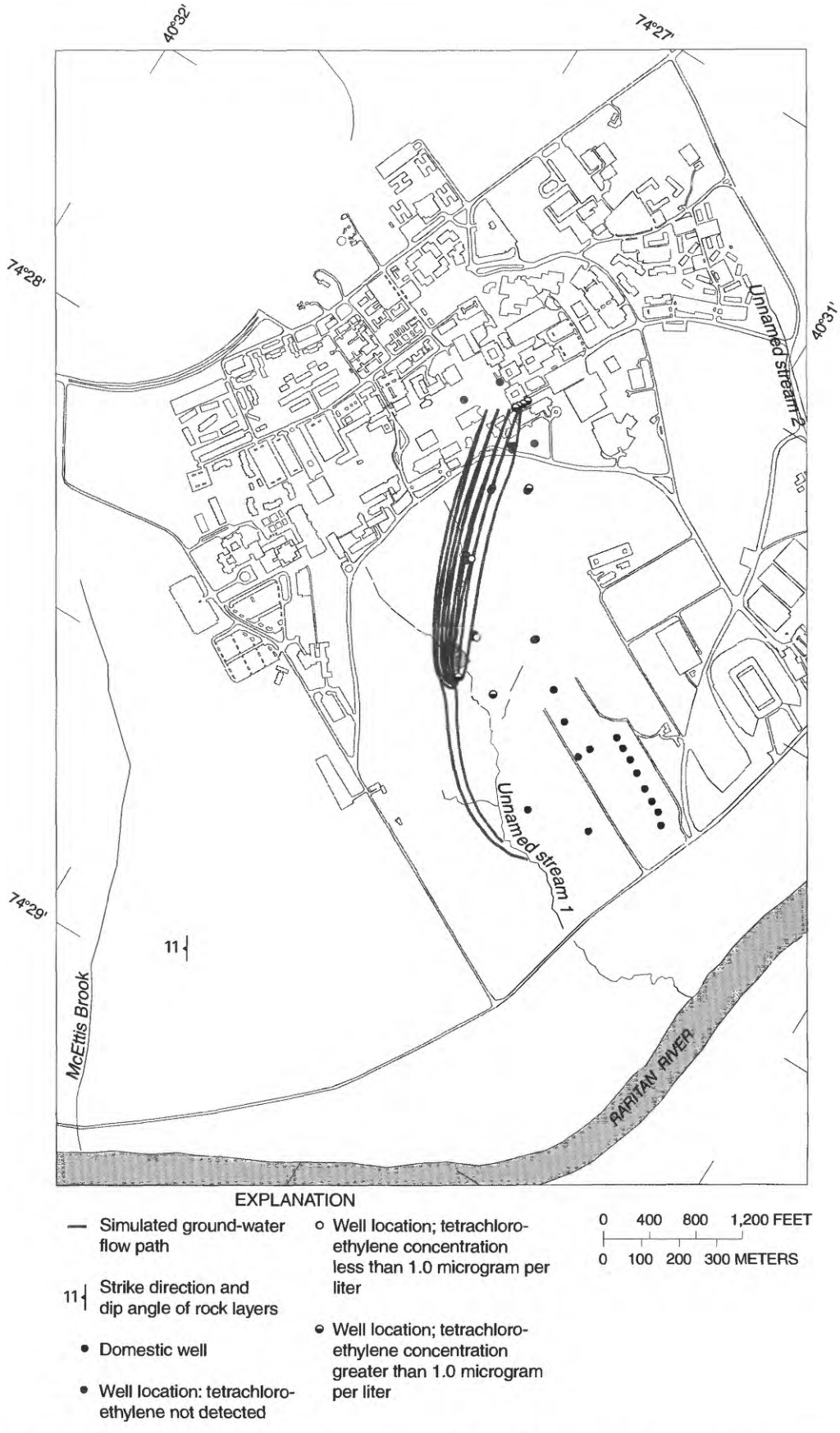


Figure 15. Concentration of tetrachloroethlyene in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed tetrachloroethlyene source area under steady-state conditions with average annual pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

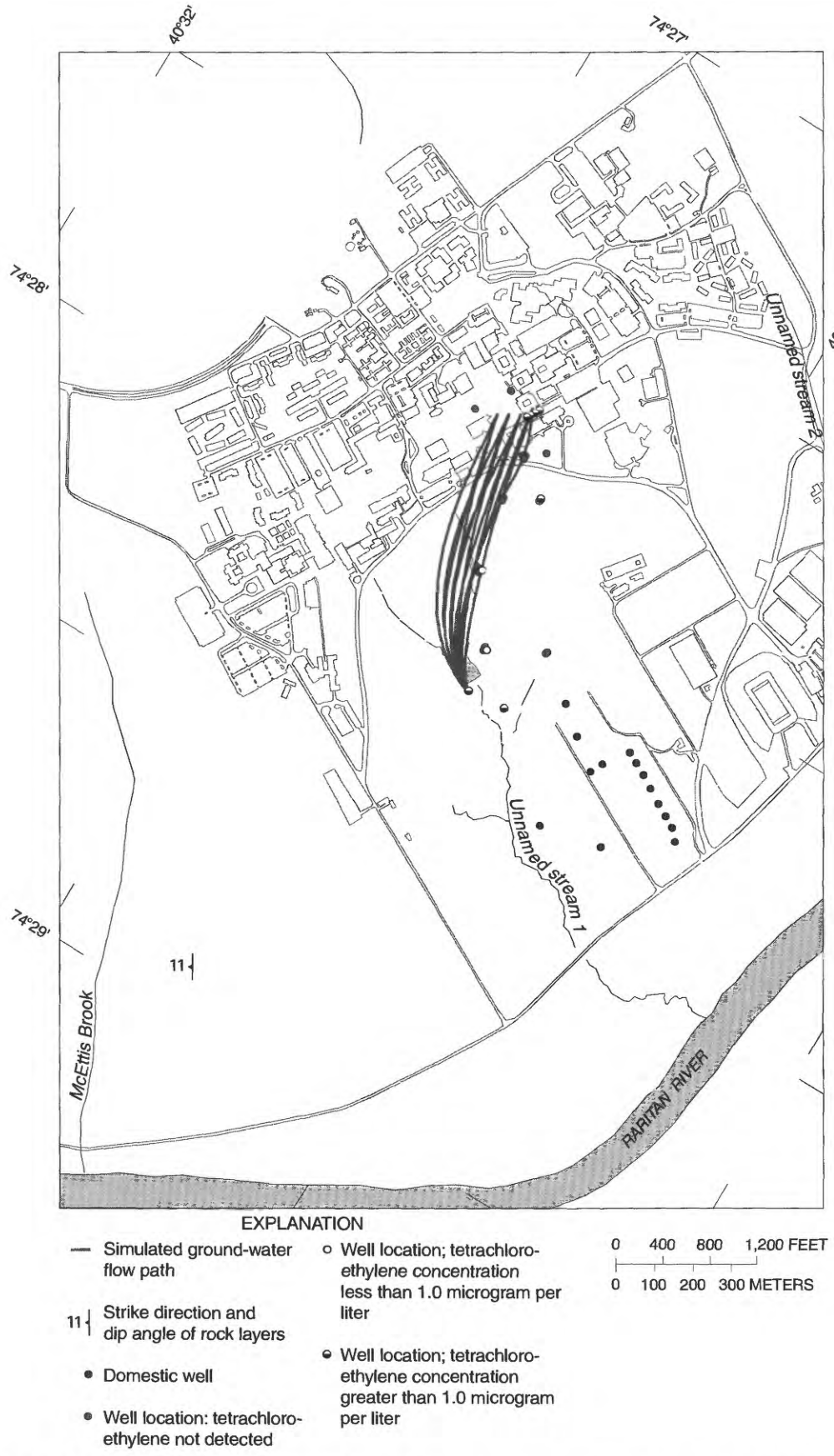


Figure 16. Concentration of tetrachloroethlyene in water samples collected from wells in 1995 and simulated ground-water flow paths from the assumed tetrachloroethlyene source area under steady-state conditions with maximum pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey.

A section view through the study area showing the area containing simulated flow paths from the assumed PCE source area in the no-pumping simulation and concentrations of PCE detected in samples from wells are shown in figure 17. The same information for both the average-annual-pumpage and maximum-pumpage simulations is shown in figure 18. As in the map views (figs. 14-16), some wells in which PCE was detected are outside the area encompassed by the flow lines from the assumed source area. Consequently, the distribution of PCE and the simulated flow paths are inconsistent with the hypothesis that all the PCE detected in the study area originated at the broken pipe near the C-Wing building. As described earlier, however, simulations of ground-water flow through fractured rocks cannot exactly duplicate the actual paths. Consequently, the possibility that all PCE found in the study area is derived from the C-Wing building area cannot be conclusively ruled out.

SUMMARY AND CONCLUSIONS

Volatile organic compounds, primarily carbon tetrachloride and tetrachloroethylene (PCE), were detected in shallow ground water near the Chemical Engineering building--also called the C-Wing building--at the Rutgers University Busch Campus in Piscataway Township, Middlesex County, New Jersey. The C-Wing building overlies the Passaic Formation, which comprises a water-supply aquifer, and is about 2,500 ft north-northeast of several domestic wells. During 1993-96, the U.S. Geological Survey, in cooperation with Rutgers, the State University of New Jersey, conducted field investigations and data analysis to determine the extent and distribution of contamination and characteristics of the ground-water flow system in a study area comprising 0.3 mi^2 in the vicinity of the Busch Campus. Field investigations included geologic coring, collection of borehole-geophysical logs, installation of monitor wells, measurement of ground-water levels and streamflow, aquifer testing, and collection of water-quality samples.

In the study area, the Passaic Formation consists of dipping layers of extensively fractured coarse-grained siltstone and sandstone interbedded with layers of sparsely fractured, finer grained siltstone and mudstone. Ground water is primarily stored in and transmitted through interconnected fractures in these rocks. The rocks are weathered near land surface. Clay and silt derived from the weathering process fills many of the fractures in the weathered zone, causing it to be less permeable than the underlying water-bearing units.

At least 23 fracture zones are present in the study area. Transmissivity data from wells completed in these zones, however, indicate that only four of these fracture zones are actually water-bearing units. No other fracture zones transmit significant volumes of water and all are within confining units. The median transmissivity of zones identified as water-bearing units and confining units, respectively, is 84 and 3.7 ft^2/d. The median transmissivity of the weathered zone is 4.8 ft^2/d.

Recharge to the ground-water system is by downward leakage of infiltrated precipitation. The transmissivity contrasts and the dipping hydrogeologic units of the multiunit aquifer system cause large-scale anisotropic flow. Ground-water flow through the system is predominantly southwest, parallel to the strike of the rock layers. Discharge is predominantly to the Raritan River and its tributaries; minor amounts flow to pumped wells. The northeastern half of the study area lies in a recharge area and the southwestern half--which is nearer to the Raritan River--lies in a discharge area.

A digital model was developed to simulate both steady-state and transient ground-water flow and to analyze ground-water flow in the study area. The digital model used in this inves-

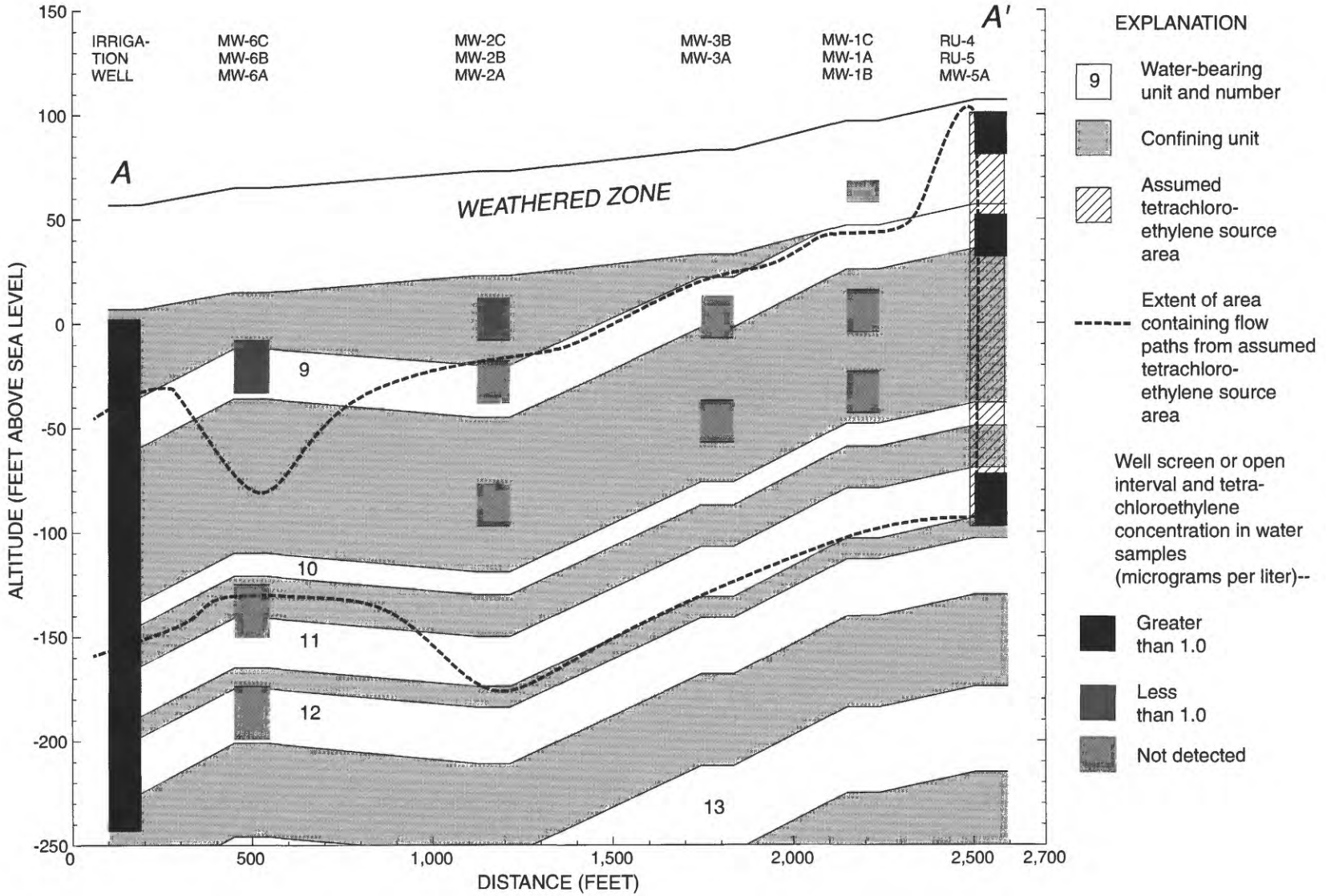


Figure 17. Section *A-A'* showing hydrogeologic framework, concentration of tetrachloroethylene in water samples collected from wells in 1995, and simulated area containing ground-water flow paths from the assumed tetrachloroethylene source area under steady-state conditions with no pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey. (Line of section shown in fig. 2)

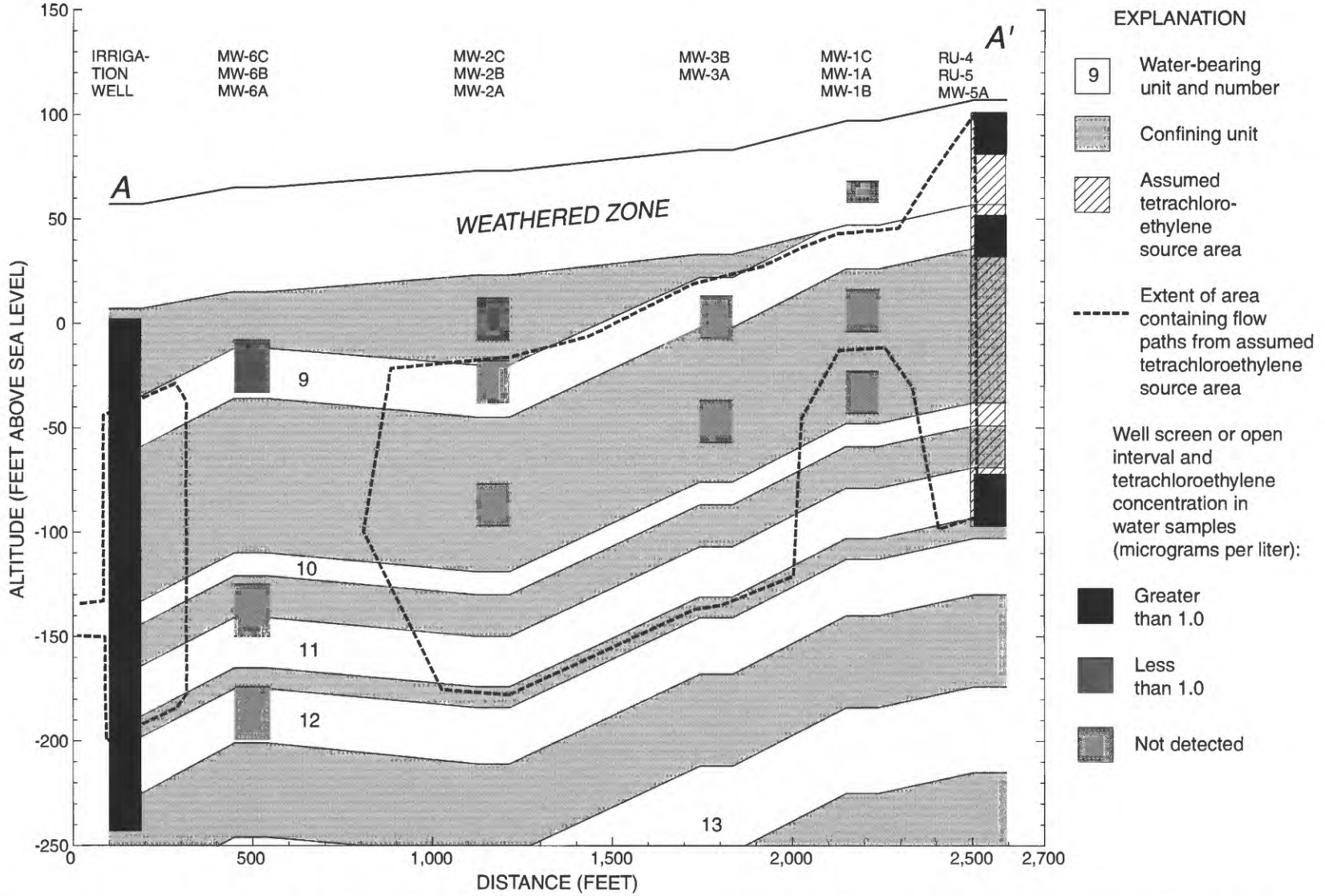


Figure 18. Section *A-A'* showing hydrogeologic framework, concentration of tetrachloroethylene in water samples collected from wells in 1995, and simulated area containing ground-water flow paths from the assumed tetrachloroethylene source area under steady-state conditions with both average annual and maximum pumpage from the irrigation well, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey. (Line of section shown in fig. 2)

tigation simulates only advective transport of constituents dissolved in the water; dilution and dispersion of dissolved contaminants and the movement of dense nonaqueous-phase liquids cannot be simulated. The model area, which encompasses 2.3 mi^2, was extended beyond the study area to natural hydrologic boundaries.

Areal recharge was represented in the model as specified flux of 7.4 inches per year applied to the uppermost active model layer. Surface-water bodies were simulated as head-dependent-flux boundaries. The value of vertical hydraulic conductivity of the streambed material used in the model is 1.0 ft/d.

In the calibrated model, the horizontal transmissivity of the weathered zone is 16 ft^2/d, and the transmissivity of the underlying water-bearing units ranges from 110 to 1,900 ft^2/d depending on lithology and depth. Vertical hydraulic conductivity in the calibrated model is 4.0×10^{-3} ft/d in the weathered zone and ranges from 1.9×10^{-8} ft/d to 7.7×10^{-1} ft/d in the confining units, depending on lithology and depth. Below the weathered zone, both the transmissivity of the water-bearing units and the vertical hydraulic conductivity of the confining units decrease with depth. Storage coefficients are 3.0×10^{-2} in the weathered zone and 4.0×10^{-7} in all of the water-bearing units.

Water samples were collected from each of the 25 wells in the study area at least once during 1993-96. The spatial distributions of the two primary contaminants in the study area--carbon tetrachloride and PCE--differ from each other. The carbon tetrachloride plume, as defined by the points where this compound has been detected at concentrations exceeding the MCL, is localized in the C-Wing building area, although trace amounts were detected in wells as far as 750 ft from the C-Wing building. The plume's vertical extent is somewhere between 75 and 179 ft below land surface.

The distribution of PCE, in contrast, is discontinuous. This compound was detected in concentrations above the New Jersey MCL of 1.0 µg/L at several locations in the study area. Concentrations were highest in shallow wells less than 10 ft from the C-Wing building. PCE was detected in samples from six additional wells in the study area. Of these six wells, the irrigation well, which is 2,370 ft from the C-Wing building, contained the highest concentration of PCE. PCE was not detected in samples from nine wells between the C-Wing building and the irrigation well, however.

The digital model was used to estimate the configuration of ground-water flow paths from the vicinity of the C-Wing building. Actual flow paths through the fractured-rock aquifer system undoubtedly are more complex than the simulated paths. The simulated flow paths are primarily horizontal in the water-bearing units and vertical in the confining units. Horizontal flow generally is parallel or subparallel to the strike of the rock layers. When the irrigation well is not being pumped, all water that passes through the vicinity of the C-Wing building discharges to the Raritan River and its tributaries. It is unlikely that water reaching the stream from the C-wing building still contains carbon tetrachloride because this compound has not been detected in concentrations above the MCL at distances greater than 10 ft from the building.

Pumping at the irrigation well causes flow lines to shift toward the well. Analysis of flow paths shows that if this well were pumped continually at its current maximum short-term yield, all water that originates at or passes through the C-Wing building area would discharge to the irrigation well. The simulated flow paths do not reach any domestic well when the irrigation well is not pumped, and the distance between the flow paths and the nearest domestic well increases as simulated pumping from the irrigation well increases.

All wells in which carbon tetrachloride was detected are within the area encompassed by the flow paths from the assumed carbon tetrachloride source area, and the concentration of

carbon tetrachloride decreases along flow paths. Therefore, the flow-path analysis supports the hypothesis that all of the carbon tetrachloride detected in the study area originated at the broken pipe near the C-Wing building.

Some wells in which PCE was detected, however, are located outside the area encompassed by the flow paths from the assumed PCE source area. Consequently, both the simulated flow paths and the discontinuous distribution of PCE are inconsistent with the hypothesis that all of the PCE detected in the study area originated at the broken pipe near the C-Wing building. Because of the complexity of actual ground-water flow paths through the fractured-rock aquifer system, however, it is not possible to state conclusively that an additional source of PCE must be present.

REFERENCES CITED

Aerial Data Reduction Associates, 1988, Topographic survey, Rutgers University, Middlesex County, N.J.: Pennsauken, New Jersey, Aerial Data Reduction Associates, scale 1:600.

Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, no. 3, p. 423-428.

Carleton, G.B., Welty, C., and Buxton, H.T., 1999, Design and analysis of tracer tests to determine effective porosity and dispersivity in fractured sedimentary rocks, Newark Basin, N.J.: U.S. Geological Survey Water-Resources Investigations Report 98-4126, 80 p.

Chichester, D.C., 1996, Hydrogeology of, and simulation of ground-water flow in, a mantled carbonate-rock system, Cumberland Valley, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 94-4090, 39 p.

Cooper, H. H., Jr., Bredehoeft, J.D., and Papadopoulos, I.S., 1967, Response of a finite-diameter well to an instantaneous charge of water: Water Resources Research, v. 3, no. 1, p. 263-269.

dePaul, Vincent, 1996, Reconnaissance of volatile organic compounds in the subsurface at Rutgers University, Busch Campus, Piscataway Township, New Jersey: U.S. Geological Survey Open-File Report 95-729, 26 p.

ENSR Consulting and Engineering, 1989, Preliminary ground water assessment for the engineering building C-wing basement, Piscataway, New Jersey: Somerset, New Jersey, ENSR Consulting and Engineering, 47 p., 4 app.

Freedman, D.L., and Gossett, J.M., 1989, Biological reductive dechlorination of tetrachloroethylene and trichloroethylene to ethylene under methanogenic conditions: Applied and Environmental Microbiology, v. 55, p. 2,144 to 2,151.

Froelich, A.J., and Olsen, P.E., 1985, Newark Supergroup, a revision of the Newark Group in eastern North America, *in* Robinson, G.R., and Froelich, A.J., eds, Proceedings of the second U.S. Geological Survey workshop on the Early Mesozoic basins of the eastern United States: U.S. Geological Survey Circular 946, p. 1-3.

Gerhart, J.M., and Lazorchick, G.J., 1988, Evaluation of the ground-water resources of the Lower Susquehanna River basin, Pennsylvania and Maryland: U.S. Geological Survey Water-Supply Paper 2284, 128 p.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Houghton, H.F., 1990, Hydrogeology of the early Mesozoic rocks of the Newark Basin, New Jersey, *in* Kroll, R.L., and Brown, J.O, comp., Aspects of ground water in New Jersey: Seventh Annual Meeting of the Geological Association of New Jersey, October 26-27, 1990, Kean College, Union, N.J., p. E1-E36.

Hvorslev, M.J., 1951, Time lag and soil permeability in ground water observations: U.S Army Corps of Engineers Waterway Experimentation Station, Vicksburg, Mississippi, Bulletin 36, 56 p.

Keys, W.S., and MacCary, L.M., 1971, Application of borehole geophysics to water-resources investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. E1, 126 p.

Keystone Aerial Surveys, Inc., 1985, Aerial photographs of Rutgers University: Philadelphia, Pennsylvania, Keystone Aerial Surveys, unpublished photographs.

Kueper, B.H., and McWhorter, D.B., 1991, The behavior of dense, nonaqueous phase liquids in fractured clay and rock: Ground Water, v. 29, no. 5, p 716-728.

Lewis-Brown, J.C., and Jacobsen, Eric, 1995, Hydrogeology and ground-water flow, fractured Mesozoic structural-basin rocks, Stony Brook, Beden Brook, and Jacobs Creek drainage basins, west-central New Jersey: U.S. Geological Survey Water-Resources Investigations Report 94-4147, 83 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 576 p.

Michalski, Andrew. 1990, Hydrogeology of the Brunswick (Passaic) Formation and implications for ground water monitoring practice: Ground Water Monitoring Review, v. 10, no. 4, p 134-143.

New Jersey Administrative Code, 1990, Safe drinking-water act: Secondary Drinking Water Regulations, Title 7, Chapter 10, Subchapter 7, p. 10-19 to 10-21.

Olsen, P.E., 1980, Triassic and Jurassic Formations of the Newark Basin, *in* Field studies of New Jersey geology and guide to field trips, 52nd annual meeting of the New York State Geological Association, p. 2-39.

Pollack, D.W., 1994, User's guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 94-464, 104 p., 6 app.

Rantz, S. E., and others, 1982, Measurement and computation of streamflow--Volume 1. Measurement of stage and discharge; Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Rima, D.R., Meisler, Harold, and Longwill, Stanley, 1962, Geology and hydrology of the Stockton Formation in southeastern Pennsylvania: A study of the effect of lithology upon the yield of wells: Pennsylvania Geological Survey, Fourth series, Bulletin W14, 46 p.

U.S. Environmental Protection Agency, 1991, Methods for the determination of organic compounds in drinking water: EPA 600/4-88/039.

_____1992, Methods for the determination of organic compounds in drinking water, Supplement II: EPA 600/R-92/129.

_____1994, Technical notes on drinking water methods: EPA 600/R-94/173.

Van Houten, F.B., 1969, Late Triassic Newark Group, north-central New Jersey and adjacent Pennsylvania and New York, in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and Pennsylvania and guidebook of excursions: New Brunswick, N.J., Rutgers University Press, p. 314-347.

Table 7. Concentrations of selected volatile organic compounds in, and chemical and physical properties of, water samples from wells, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey, 1993-96

[All concentrations in micrograms per liter, unless otherwise noted; <, less than; B, compound present in method blank; µS/cm, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter; E, compound was positively detected but the amount detected is below where it can be reliably quantified; --, no data; all volatile organic compounds analyzed are listed in Appendix 2]

U.S. Geological Survey well number	Local well name	Date sampled	Specific conductance (µS/cm)	pH, field (standard units)	Temperature, water (deg C)	Oxygen, dissolved (mg/L)	Benzene	Carbon tetrachloride	Chloroform	cis-1,2-Dichloroethylene
23-1190	B-4	09-23-96	727	6.76	21.1	--	< 0.5	100	4.6	< 0.5
23-1221	CH-1MW	09-13-93	5,390	11.52	15.0	.8	2.9	< .5	< .5	E .23
23-1221		07-14-94	921	11.88	16.0	.2	< .5	< .5	< .5	< .5
23-1221		07-14-94	921	11.88	16.0	.2	< .5	< .5	< .5	< .5
23-1221		09-28-95	1,133	11.64	12.5	1.1	< .5	< .5	< .5	< .5
23-1221		10-08-96	1,504	12.14	12.8	--	< .5	< .5	< .5	< .5
23-1219	CH-2MWA	08-24-93	342	7.12	14.5	6.3	< .5	< .5	.68	< .5
23-1219		07-14-94	324	7.89	13.0	6.6	< .5	< .5	< .5	< .5
23-1219		09-26-95	324	7.85	13.0	6.0	< .5	< .5	< .5	< .5
23-1219		10-07-96	328	8.04	13.0	5.49	< .5	< .5	< .5	< .5
23-1219		10-07-96	328	8.04	13.0	5.49	< .5	< .5	< .5	< .5
23-1218	CH-2MWB	08-23-93	423	7.17	14.5	6.0	< .5	< .5	.50	< .5
23-1218		07-14-94	458	7.53	13.0	--	< .5	< .5	< .5	< .5
23-1218		09-26-95	586	7.34	12.5	4.6	< .5	< .5	< .5	< .5
23-1218		10-08-96	637	7.75	13.1	5.31	< .5	< .5	< .5	< .5
23-1232	CH-3MW	08-19-93	510	6.77	17.0	2.5	< .5	< .5	1.4	< .5
23-1232		08-19-93	510	6.77	17.0	2.5	E .14	< .5	1.4	< .5
23-1232		07-06-94	525	7.48	16.5	1.7	< .5	< .5	E .44	< .5
23-1232		09-22-95	560	7.51	16.5	1.4	< .5	< .5	< .5	< .5
23-1232		09-17-96	553	7.51	17.0	1.18	< .5	< .5	< .5	< .5
23-1226	MW-1A	09-14-93	276	7.66	14.5	1.1	< .5	E .29	E .05	< .5
23-1226		07-08-94	286	8.15	16.5	1.0	< .5	< .5	< .5	< .5
23-1226		09-19-95	276	8.16	16.0	1.7	< .5	1.2	< .5	< .5
23-1226		10-03-96	307	8.04	14.5	2.86	< .5	< .5	< .5	< .5
23-1227	MW-1B	09-15-93	293	7.21	15.5	--	< .5	< .5	< .5	< .5
23-1227		07-06-94	288	8.64	14.0	<.1	< .5	< .5	< .5	< .5
23-1227		09-19-95	245	8.83	15.0	1.2	< .5	< .5	< .5	< .5
23-1227		10-04-96	283	8.31	14.3	3.00	< .5	< .5	< .5	< .5
23-1228	MW-1C	08-23-93	459	6.99	16.5	--	< .5	< .5	E .07	< .5
23-1228		07-06-94	513	7.43	16.5	2.8	< .5	< .5	E .066	< .5
23-1228		11-21-95	517	7.35	14.5	.9	< .5	< .5	< .5	< .5
23-1228		10-04-96	537	7.38	14.3	2.70	< .5	< .5	< .5	< .5
23-1223	MW-2A	08-17-93	745	7.26	15.5	1.9	< .5	< .5	< .5	< .5
23-1223		07-08-94	270	8.85	16.5	<.1	< .5	< .5	< .5	< .5
23-1223		09-20-95	443	8.10	16.0	.2	< .5	< .5	< .5	< .5
23-1223		09-26-96	409	8.05	17.0	.90	< .5	< .5	< .5	< .5
23-1224	MW-2B	08-18-93	411	6.91	14.0	1.2	< .5	E .17	E .25	< .5
23-1224		07-08-94	433	7.84	13.5	.5	< .5	< .5	< .5	< .5
23-1224		09-20-95	457	6.46	13.0	.5	< .5	< .5	< .5	< .5
23-1224		10-02-96	454	7.92	13.0	.6	< .5	< .5	< .5	< .5
23-1225	MW-2C	08-18-93	425	6.26	14.5	--	E .07	E .08	E .42	< .5
23-1225		07-08-94	574	7.11	15.0	1.6	< .5	< .5	< .5	< .5
23-1225		09-25-95	491	6.63	14.0	2.3	< .5	< .5	< .5	< .5
23-1225		09-26-96	535	6.76	14.5	1.36	< .5	< .5	< .5	< .5
23-1229	MW-3A	08-25-93	315	7.24	15.0	2.1	< .5	E .05	< .5	< .5
23-1229		08-25-93	315	7.24	15.0	2.1	< .5	E .06	< .5	< .5
23-1229		07-12-94	331	7.88	14.0	.5	< .5	< .5	< .5	< .5
23-1229		09-21-95	290	8.15	14.0	.3	< .5	< .5	< .5	< .5
23-1229		10-01-96	296	8.12	13.8	.55	< .5	< .5	< .5	< .5
23-1230	MW-3B	09-13-93	411	6.90	14.5	--	E .26	.80	E .21	< .5
23-1230		07-12-94	450	7.74	13.5	1.9	< .5	.57	< .5	< .5
23-1230		09-26-95	451	7.69	13.5	2.0	< .5	.8	0.5	< .5
23-1229		10-02-96	481	7.79	13.3	2.39	< .5	.8	< .5	< .5
23-1231	MW-4	01-19-95	240	9.16	16.5	--	< .5	< .5	< .5	< .5
23-1231		11-08-95	247	9.26	17.5	3.4	< .5	< .5	< .5	< .5
23-1231		09-24-96	230	9.53	17.0	--	< .5	< .5	< .5	< .5

Table 7. Concentrations of selected volatile organic compounds in, and chemical and physical properties of, water samples from wells, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey, 1993-96 -- Continued

[All concentrations in micrograms per liter, unless otherwise noted; <, less than; B, compound present in method blank; µS/cm, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter; E, compound was positively detected but the amount detected is below where it can be reliably quantified; --, no data; all volatile organic compounds analyzed are listed in Appendix 2]

U.S. Geological Survey well number	Local well name	Date sampled	Specific conductance (µS/cm)	pH, field (standard units)	Temperature, water (deg C)	Oxygen, dissolved (mg/L)	Benzene	Carbon tetrachloride	Chloroform	cis-1,2-Dichloroethylene
23-1268	MW-5A	11-28-95	347	7.97	14.0	2.4	< .5	< .5	< .5	1.3
23-1268		10-09-96	381	7.95	14.6	2.07	< .5	< .5	< .5	1.6
23-1268		10-09-96	381	7.95	14.6	2.07	< .5	< .5	< .5	1.5
23-1265	MW-6A	11-22-95	1,373	7.45	13.5	<.1	< .5	< .5	< .5	< .5
23-1265		09-25-96	1,414	7.48	13.2	.03	< .5	< .5	< .5	< .5
23-1266	MW-6B	11-21-95	597	7.64	13.0	<.1	< .5	< .5	< .5	< .5
23-1266		09-24-96	507	7.70	13.2	.09	< .5	< .5	< .5	< .5
23-1267	MW-6C	11-22-95	429	7.32	12.5	2.7	< .5	< .5	< .5	< .5
23-1267		09-24-96	449	7.29	12.7	2.11	< .5	< .5	< .5	< .5
23-1267		09-24-96	449	7.30	12.7	2.11	< .5	< .5	< .5	< .5
23-1263	MW-7A	11-08-95	427	7.92	12.5	2.5	< .5	< .5	.5	< .5
23-1263		11-08-95	427	7.92	12.5	2.5	< .5	< .5	< .5	< .5
23-1263		09-18-96	490	7.92	12.9	3.46	< .5	< .5	.6	< .5
23-1264	MW-7B	11-08-95	644	7.94	13.0	2.4	< .5	< .5	< .5	< .5
23-1264		09-18-96	574	7.73	13.3	1.28	< .5	< .5	< .5	< .5
23-1184	RU-2	08-20-93	954	6.47	24.5	1.4	< .5	150	14	< .5
23-1184		07-15-94	1,034	7.39	20.5	--	< .5	6,600	110	< .5
23-1184		11-28-95	569	7.29	19.0	6.3	<50	2,100	<50	<50
23-1184		10-09-96	462	7.10	21.0	5.57	< .5	300	12	< .5
23-1184		10-09-96	462	7.10	21.0	5.57	< .5	230	10	< .5
23-1185	RU-4	07-15-94	524	6.87	18.0	1.6	3.40	24,000	50	5.20
23-1185		11-28-95	268	6.60	18.5	--	<250	21,000	<250	<250
23-1185		11-28-95	268	6.60	18.5	--	<250	18,000	<250	<250
23-1185		10-10-96	630	6.85	18.4	5.96	<25	25,000	35	<25
23-1183	RU-5	07-15-94	364	7.46	18.0	6.3	< .5	6,000	25	< .5
23-1183		11-29-95	374	7.75	16.0	6.6	<50	8,500	<50	<50
23-1183		10-10-96	395	7.85	17.5	5.40	<25	6,400	<25	<25
23-1183		10-10-96	395	7.85	17.5	5.40	<25	5,600	28	<25
23-1165	Rutgers golf 13 obs	08-24-93	954	6.84	14.0	.4	< .5	< .5	E .13	< .5
23-1165		07-12-94	832	7.63	13.0	.5	< .5	< .5	< .5	< .5
23-1165		09-28-95	859	7.59	13.0	.2	< .5	< .5	< .5	< .5
23-1165		09-28-95	859	7.59	13.0	.2	< .5	< .5	< .5	< .5
23-1165		09-19-96	786	7.40	13.0	< .1	< .5	< .5	< .5	< .5
23-1053	Rutgers golf course (Irrigation well)	08-17-93	2,170	6.42	14.0	0.5	<0.5	<0.5	<0.5	<0.5
23-1053		06-01-94	2,080	7.49	16.0	<.1	< .5	< .5	< .5	< .5
23-1053		09-19-95	2,330	7.41	13.5	0.1	< .5	< .5	< .5	E .19
23-1053		09-25-96	2,120	7.43	13.4	<.1	< .5	< .5	< .5	< .5
23-1053		09-25-96	2,120	7.43	13.4		< .5	< .5	< .5	< .5

Table 7. Concentrations of selected volatile organic compounds in, and chemical and physical properties of, water samples from wells, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey, 1993-96--Continued

U. S. Geological Survey well number	Local well name	Date sampled	1,2 Dichloro-ethane	Hexachlor-obutadiene	Methylene chloride	Tetrachloro-ethylene	Toluene	Trichloro-ethylene	Trichloro-fluoro-methane
23-1190	B-4	09-23-96	< 0.5	< 0.5	< 0.5	1.7	< 0.5	< 0.5	< 0.5
23-1221	CH-1MW	09-13-93	< .5	< .5	< .5	< .5	1.5	1.1	< .5
23-1221		07-14-94	< .5	< .5	2.3B	< .5	< .5	< .5	< .5
23-1221		07-14-94	< .5	< .5	2.2B	< .5	< .5	< .5	< .5
23-1221		09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1221		10-08-96	< .5	< .5	1.2B	< .5	< .5	< .5	< .5
23-1219	CH-2MWA	08-24-93	< .5	< .5	.74B	E .21	E .22	< .5	< .5
23-1219		07-14-94	< .5	< .5	2.4B	< .5	< .5	< .5	< .5
23-1219		09-26-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1219		10-07-96	< .5	< .5	1.2B	< .5	< .5	< .5	< .5
23-1219		10-07-96	< .5	< .5	1.3B	< .5	< .5	< .5	< .5
23-1218	CH-2MWB	08-23-93	< .5	< .5	0.8	3.7	< .5	< .5	< .5
23-1218		07-14-94	< .5	< .5	2.1B	1.7	< .5	< .5	< .5
23-1218		09-26-95	< .5	< .5	< .5	4.2	< .5	< .5	< .5
23-1218		10-08-96	< .5	< .5	2.1B	1.4	< .5	< .5	< .5
23-1232	CH-3MW	08-19-93	< .5	< .5	E .23	< .5	E .30	< .5	< .5
23-1232		08-19-93	< .5	< .5	E .24	E .16	E .29	< .5	< .5
23-1232		07-06-94	< .5	< .5	E .37	< .5	< .5	< .5	< .5
23-1232		09-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1232		09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1226	MW-1A	09-14-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1226		07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1226		09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1226		10-03-96	< .5	< .5	6.1B	< .5	< .5	< .5	< .5
23-1227	MW-1B	09-15-93	< .5	< .5	< .5	< .5	E .09	< .5	< .5
23-1227		07-06-94	< .5	< .5	E .36	< .5	< .5	< .5	< .5
23-1227		09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1227		10-04-96	< .5	< .5	1.3	< .5	< .5	< .5	< .5
23-1228	MW-1C	08-23-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1228		07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1228		11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1228		10-04-96	< .5	< .5	1.3	< .5	< .5	< .5	< .5
23-1223	MW-2A	08-17-93	< .5	< .5	E .24	< .5	E .20	< .5	< .5
23-1223		07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1223		09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1223		09-26-96	< .5	< .5	2.1	< .5	< .5	< .5	< .5
23-1224	MW-2B	08-18-93	< .5	< .5	< .5	E .44	< .5	< .5	< .5
23-1224		07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1224		09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1224		10-02-96	< .5	< .5	3.7	< .5	< .5	< .5	< .5
23-1225	MW-2C	08-18-93	< .5	< .5	< .5	1.0	< .5	< .5	< .5
23-1225		07-08-94	< .5	< .5	< .5	.74	< .5	< .5	< .5
23-1225		09-26-95	< .5	< .5	< .5	.8	< .5	< .5	< .5
23-1225		09-26-96	< .5	< .5	3.8	.6	< .5	< .5	< .5
23-1229	MW-3A	08-25-93	< .5	< .5	.85B	< .5	< .5	< .5	< .5
23-1229		08-25-93	< .5	< .5	.82B	< .5	< .5	< .5	< .5
23-1229		07-12-94	< .5	< .5	.53B	< .5	< .5	< .5	< .5
23-1229		09-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1229		10-01-96	< .5	< .5	.5	< .5	< .5	< .5	< .5
23-1230	MW-3B	09-13-93	< .5	< .5	< .5	< .5	E .06	< .5	< .5
23-1230		07-12-94	< .5	< .5	.57B	< .5	< .5	< .5	< .5
23-1230		09-26-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1229		10-02-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1231	MW-4	01-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1231		11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1231		09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5

Table 7. Concentrations of selected volatile organic compounds in, and chemical and physical properties of, water samples from wells, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey, 1993-96--Continued

U. S. Geological Survey well number	Local well name	Date sampled	1,2 Dichloro-ethane	Hexachlor-obutadiene	Methylene chloride	Tetrachloro-ethylene	Toluene	Trichloro-ethylene	Trichloro-fluoro-methane
23-1268	MW-5A	11-28-95	< .5	< .5	< .5	1.4	< .5	1.6	< .5
23-1268		10-09-96	< .5	< .5	1.9	1.0	< .5	1.3	< .5
23-1268		10-09-96	< .5	< .5	2.2	.9	< .5	1.5	< .5
23-1265	MW-6A	11-22-95	< .5	< .5	< .5	< .5	0.8	< .5	< .5
23-1265		09-25-96	< .5	< .5	1.6	.5	< .5	< .5	< .5
23-1266	MW-6B	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1266		09-24-96	< .5	< .5	1.5	< .5	< .5	< .5	< .5
23-1267	MW-6C	11-22-95	< .5	< .5	< .5	.5	< .5	< .5	< .5
23-1267		09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1267		09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1263	MW-7A	11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1263		11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1263		09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1264	MW-7B	11-08-95	< .5	< .5	< .5	< .5	29	< .5	< .5
23-1264		09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5
23-1184	RU-2	08-20-93	< .5	< .5	E .16	5.1	< .5	< .5	E .15
23-1184		07-15-94	< .5	3.7	3.0B	34	< .5	< .5	< .5
23-1184		11-28-95	<50	<50	<50	<50	<50	<50	<50
23-1184		10-09-96	< .5	< .5	2.2	5.1	< .5	< .5	< .5
23-1184		10-09-96	< .5	< .5	4.4	4.4	< .5	< .5	< .5
23-1185	RU-4	07-15-94	36	.95	1.3B	1,000	2.0	9	.88
23-1185		11-28-95	<250	<250	<250	1,300	<250	<250	<250
23-1185		11-28-95	<250	<250	<250	990	<250	<250	<250
23-1185		10-10-96	<25	<25	100	1,200	<25	<25	<25
23-1183	RU-5	07-15-94	< .5	< .5	2.4B	100	< .5	0.81	1.6
23-1183		11-29-95	<50	<50	<50	130	<50	<50	<50
23-1183		10-10-96	<25	<25	94	96	<25	<25	<25
23-1183		10-10-96	<25	<25	89	99	<25	<25	<25
23-1165	Rutgers golf 13 obs	08-24-93	< .5	< .5	1.0B	1.7	< .5	< .5	< .5
23-1165		07-12-94	< .5	< .5	< .5	.86	< .5	< .5	< .5
23-1165		09-28-95	< .5	< .5	< .5	1.7	< .5	< .5	< .5
23-1165		09-28-95	< .5	< .5	< .5	1.6	< .5	< .5	< .5
23-1165		09-19-96	< .5	< .5	1.2	< .5	< .5	< .5	< .5
23-1053	Rutgers golf course (Irrigation well)	08-17-93	<0.5	<0.5	<0.5	21	<0.5	<0.5	<0.5
23-1053		06-01-94	< .5	< .5	< .5	16	< .5	E .13	< .5
23-1053		09-19-95	< .5	< .5	< .5	23	< .5	< .5	< .5
23-1053		09-25-96	< .5	< .5	.8	26	< .5	< .5	< .5
23-1053		09-25-96	< .5	< .5	2.1	26	< .5	< .5	< .5

Appendix 1. Water-level altitudes in wells, Rutgers University Busch campus and vicinity, Piscataway Township, New Jersey, 1992-96

[<, less than; >, greater than]

U.S. Geological Survey well number	Local well name	Depth of screened or open interval (feet below land surface)	Altitude of land surface (feet above sea level)	Date measured (YYMMDD)	Water-level altitude (feet above sea level)	Remarks
23-1191	B-1	14 - 15	79.47	920113	75.62	
				920404	75.73	
				921123	75.55	
				951019	75.23	
				961028	75.64	
				961029	75.49	
23-1190	B-4	2 - 4	96.14	920113	96.12	
				920404	95.96	
				921123	95.93	
				930930	95.93	
				931103	95.82	
				931202	95.98	
				940207	95.42	
				940324	95.91	Ice melt may cause non-static conditions
				940426	94.82	
				940601	94.40	
				940630	96.25	2" rain previous night
				940801	94.95	
				940913	94.71	
				951019	95.49	
				961028	95.54	
				961029	95.49	
23-1187	B-6	14 - 16	84.01	921123	76.40	
				930930	79.17	
				931103	80.01	
				931202	78.88	
				940207	76.79	
				940324	79.99	Ice melt may cause non-static conditions
				940427	79.24	
				940601	78.07	
				940630	76.80	2" rain previous night
				940801	78.40	
				940913	76.20	
				951019	78.17	
				961028	79.92	
				961029	79.59	
23-1221	CH-1MW	30 - 40	99.75	930913	79.46	
				930930	83.28	
				931103	85.53	
				931202	84.28	
				940207	86.24	
				940324	97.40	Ice melt may cause non-static conditions
				940426	87.86	
				940601	84.94	
				940630	80.16	2" rain previous night
				940801	82.20	
				940913	80.48	

Appendix 1. Water-level altitudes in wells, Rutgers University Busch campus and vicinity, Piscataway Township, New Jersey, 1992-96 --Continued

[<, less than; >, greater than]

U.S. Geological Survey well number	Local well name	Depth of screened or open interval (feet below land surface)	Altitude of land surface (feet above sea level)	Date measured (YYMMDD)	Water-level altitude (feet above sea level)	Remarks
				951019	82.62	
				961028	86.58	
				961029	86.52	
23-1219	CH-2MWA	70 - 90	91.03	930824	65.42	
				930930	68.69	
				931103	71.24	
				931202	71.52	
				940207	70.43	
				940324	72.56	Ice melt may cause non-static conditions
				940426	73.19	
				940601	65.07	
				940630	62.38	2" rain previous night
				940801	68.35	
				940913	69.79	
				951019	68.14	
				961028	72.12	
				961029	64.12	
23-1218	CH-2MWB	30 - 40	91.31	930823	80.73	
				930930	83.16	
				931103	84.27	
				931202	84.15	
				940207	83.88	
				940324	86.72	Ice melt may cause non-static conditions
				940426	84.73	
				940601	83.42	
				940630	83.13	2" rain previous night
				940801	83.47	
				940913	82.30	
				951019	83.75	
				961028	84.89	
				961029	84.33	
23-1232	CH-3MW	140 - 160	103.98	930819	63.56	
				930930	68.78	
				931103	71.21	
				931202	71.50	
				940207	70.39	
				940324	72.52	Ice melt may cause non-static conditions
				940426	72.24	
				940601	64.73	
				940630	62.84	2" rain previous night
				940801	68.50	
				940913	65.24	
				951019	68.32	
				961028	71.97	
				961029	62.30	
23-1226	MW-1A	80 - 100	96.29	930914	65.10	
				930930	68.86	
				931103	71.31	

Appendix 1. Water-level altitudes in wells, Rutgers University Busch campus and vicinity, Piscataway Township, New Jersey, 1992-96 --Continued

[<, less than; >, greater than]

U.S. Geological Survey well number	Local well name	Depth of screened or open interval (feet below land surface)	Altitude of land surface (feet above sea level)	Date measured (YYMMDD)	Water-level altitude (feet above sea level)	Remarks
				931202	71.62	
				940207	70.64	
				940324	72.70	Ice melt may cause non-static conditions
				940426	73.28	
				940601	66.82	
				940630	62.36	2" rain previous night
				940801	68.44	
				940913	64.95	
				951019	68.26	
				961028	72.12	
				961029	64.42	
23-1227	MW-1B	120 - 140	97.00	930915	65.44	
				930930	68.65	
				931103	71.09	
				931202	71.34	
				940207	70.43	
				940324	72.54	Ice melt may cause non-static conditions
				940426	73.62	
				940601	68.36	
				940630	65.60	2" rain previous night
				940801	68.22	
				940913	64.56	
				951019	68.11	
				961028	71.83	
				961029	67.64	
23-1228	MW-1C	30 - 40	97.82	930823	71.23	
				930930	74.40	
				931103	76.69	
				931202	77.06	
				940207	76.65	
				940324	78.54	Ice melt may cause non-static conditions
				940426	78.84	
				940601	74.97	
				940630	70.09	2" rain previous night
				940801	74.53	
				940913	71.50	
				951019	74.08	
				961028	77.69	
				961029	75.73	
23-1223	MW-2A	150 - 170	72.80	930817	49.03	
				930930	57.63	
				931103	58.79	
				931202	58.53	
				940324	66.95	Ice melt may cause non-static conditions
				940426	61.21	
				940601	57.69	May not be static--nearby irrigation well recently pumped
				940630	65.67	2" rain previous night
				940801	56.39	

Appendix 1. Water-level altitudes in wells, Rutgers University Busch campus and vicinity, Piscataway Township, New Jersey, 1992-96 --Continued

[<, less than; >, greater than]

U.S. Geological Survey well number	Local well name	Depth of screened or open interval (feet below land surface)	Altitude of land surface (feet above sea level)	Date measured (YYMMDD)	Water-level altitude (feet above sea level)	Remarks
				940913	52.56	
				951019	58.35	
				961028	59.92	
				961029	53.83	
23-1224	MW-2B	90 - 110	72.43	930818	55.00	
				930930	60.15	
				931103	61.18	
				931202	61.02	
				940324	61.21	Ice melt may cause non-static conditions
				940426	60.88	
				940601	51.97	May not be static--nearby irrigation well recently pumped
				940630	53.65	2" rain previous night
				940801	59.13	
				940913	55.94	
				951019	59.17	
				961028	61.13	
				961029	48.41	
23-1225	MW-2C	60 - 80	72.51	930818	63.63	
				930930	65.51	
				931103	64.09	
				931202	64.05	
				940324	68.71	Ice melt may cause non-static conditions
				940426	67.91	
				940601	63.97	May not be static--nearby irrigation well recently pumped
				940630	64.33	2" rain previous night
				940801	67.11	
				940913	64.90	
				951019	66.65	
				961028	68.21	
				961029	64.60	
23-1229	MW-3A	120 - 140	83.16	930825	61.38	
				930930	65.95	
				931103	67.52	
				931202	67.50	
				940324	69.46	Ice melt may cause non-static conditions
				940426	68.19	
				940601	57.55	
				940630	59.65	2" rain previous night
				940801	65.49	
				940913	62.31	
				951019	65.23	
				961028	67.91	
				961029	48.87	
23-1230	MW-3B	70 - 90	83.06	930913	62.85	
				930930	66.71	
				931103	68.35	
				931202	68.36	
				940324	68.93	Ice melt may cause non-static conditions

Appendix 1. Water-level altitudes in wells, Rutgers University Busch campus and vicinity, Piscataway Township, New Jersey, 1992-96 --Continued

[<, less than; >, greater than]

U.S. Geological Survey well number	Local well name	Depth of screened or open interval (feet below land surface)	Altitude of land surface (feet above sea level)	Date measured (YYMMDD)	Water-level altitude (feet above sea level)	Remarks
				940426	68.83	
				940601	60.80	
				940630	59.73	2" rain previous night
				940801	66.09	
				940913	62.28	
				951019	65.79	
				961028	68.66	
				961029	59.23	
23-1231	MW-4	20 - 30	110.84	930817	<80.21	Dry
				930819	<80.21	Dry
				930820	<80.21	Dry
				930823	<80.21	Dry
				930824	<80.21	Dry
				930825	<80.21	Dry
				930913	<80.21	Dry
				930914	<80.21	Dry
				930915	<80.21	Dry
				930930	90.69	
				931103	89.55	
				931202	88.61	
				940207	91.04	
				940324	91.78	Ice melt may cause non-static conditions
				940426	91.01	
				940601	89.81	
				940630	84.88	2" rain previous night
				940801	81.98	
				940913	85.16	
				951019	92.85	
				961028	92.96	
				961029	92.92	
23-1268	MW-5A	179 - 204	107.70	951019	66.69	
				951128	67.35	
				961028	70.18	
				961029	54.67	
23-1265	MW-6A	239 - 265	65.51	951019	62.74	
				961028	64.28	
				961029	.60	
23-1266	MW-6B	190 - 215	65.22	951019	60.33	
				961028	62.24	
				961029	32.72	
23-1267	MW-6C	75 - 100	65.42	951019	55.18	
				961028	58.44	
				961029	39.46	
23-1263	MW-7A	110 - 136	67.73	951019	59.75	
				951108	62.20	
				961028	61.94	
				961029	48.86	

Appendix 1. Water-level altitudes in wells, Rutgers University Busch campus and vicinity, Piscataway Township, New Jersey, 1992-96 --Continued

[<, less than; >, greater than]

U.S. Geological Survey well number	Local well name	Depth of screened or open interval (feet below land surface)	Altitude of land surface (feet above sea level)	Date measured (YYMMDD)	Water-level altitude (feet above sea level)	Remarks
23-1264	MW-7B	65 - 90	67.92	951019	59.48	
				951108	62.08	
				961028	61.92	
				961029	53.44	
23-1184	RU-2	7 - 27	108.67	920113	96.82	
				920404	96.82	
				921123	96.84	
				930820	96.75	
				930930	96.79	
				931103	96.80	
				931202	96.96	
				940207	96.85	
				940324	96.79	Ice melt may cause non-static conditions
				940426	96.78	
				940601	96.79	
				940630	96.95	2" rain previous night
				940801	96.82	
				940913	96.83	
				951019	96.95	
				961028	96.85	
				961029	96.66	
23-1186	RU-3	7 - 27	110.93	920113	98.71	
				920404	99.00	
				921123	101.65	
				930930	99.62	
				931103	99.52	
				931202	99.12	
				940207	98.52	
				940324	99.78	Ice melt may cause non-static conditions
				940426	98.31	
				940601	98.94	
				940630	101.90	2" rain previous night
				940801	98.96	
				940913	98.40	
				951019	99.24	
				961028	99.32	
				961029	99.24	
23-1185	RU-4	7 - 27	107.45	920113	92.19	
				931209	95.11	
				940324	95.15	Ice melt may cause non-static conditions)
				940426	94.26	
				940601	94.03	
				940630	94.90	2" rain previous night
				940801	94.13	
				940813	94.41	
				951019	95.10	
				961028	94.33	
				961029	94.36	
23-1183	RU-5	55 - 75	107.59	920404	73.35	
				931209	71.76	
				940207	71.66	
				940324	73.73	Ice melt may cause non-static conditions)
				940426	73.79	
				940601	66.99	

Appendix 1. Water-level altitudes in wells, Rutgers University Busch campus and vicinity, Piscataway Township, New Jersey, 1992-96 --Continued

[<, less than; >, greater than]

U.S. Geological Survey well number	Local well name	Depth of screened or open interval (feet below land surface)	Altitude of land surface (feet above sea level)	Date measured (YYMMDD)	Water-level altitude (feet above sea level)	Remarks
				940630	64.27	2" rain previous night
				940801	69.71	
				940813	66.50	
				951019	69.55	
				961028	73.23	
				961029	66.42	
23-1165	Rutgers golf 13 obs	50 - 200	58.8	920113	56.86	
				920404	58.06	
				930818	55.52	
				931202	60.36	
				940125	57.78	
				940324	60.27	Ice melt may cause non-static conditions
				940426	59.05	
				940601	48.20	May not be static--nearby irrigation well recently pumped
				940630	53.57	2" rain previous night
				940801	58.32	
				940913	55.76	
				951019	58.20	
				961028	61.56	
				961029	21.31	
23-1053	Rutgers golf course (irrigation well)	55 - 300	55.71	931202	> 55.71	Flowing ~ 19 gallons per minute
				940601	> 55.71	"Barely flowing" -- pumped 7 hours overnight
				951019	62.25	flowing about 9.2 gallons per minute

Appendix 2. Volatile organic compounds determined in ground-water samples, Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey

Compound	Reporting limit (micrograms per liter)	Compound	Reporting limit (micrograms per liter)
Benzene	0.50	1,3-Dichloropropane	.50
Bromobenzene	.50	2,2-Dichloropropane	.50
Bromochloromethane	.50	1,1-Dichloropropene	.50
Bromodichloromethane	.50	cis-1,3-Dichloropropene	.50
Bromoform	.50	trans-1,3-Dichloropropene	.50
Bromomethane	.50	Ethylbenzene	.50
n-Butylbenzene	.50	Hexachlorobutadiene	.50
sec-Butylbenzene	.50	1-Methylethylbenzene (Cumene)	.50
tert-Butylbenzene	.50	p-Isopropyltoluene (p-Cymene	.50
Carbon tetrachloride	.50	Methylene chloride	.50
Chlorobenzene	.50	Napthalene	.50
Chloroethane	.50	n-Propylbenzene	.50
Chloroform	.50	Styrene	.50
Chloromethane	.50	1,1,1,2-Tetrachloroethane	.50
2-Chlorotoluene	.50	1,1,2,2-Tetrachloroethane	.50
4-Chlorotoluene	.50	Tetrachloroethene	.50
Dibromochloromethane	.50	Toluene	.50
1,2-Dibromo-3-chloro-propane	.50	1,2,3-Trichlorobenzene	.50
1,2-Dibromomethane	.50	1,2,4-Trichlorobenzene	.50
Dibromomethane	.50	1,1,1-Trichloroethane	
1,2-Dichlorobenzene	.50	1,1,2-Trichloroethylane	.50
1,3-Dichlorobenzene	.50	Trichloroethene	.50
1,4-Dichlorobenzene	.50	Trichlorofluoromethane	.50
Dichlorodifluoromethane	.50	1,2,3-Trichloropropane	.50
1,1-Dichloroethane	.50	1,2,4-Trimethylbenzene	.50
1,2-Dichloroethane	.50	1,3,5-Trimethylbenzene	.50
1,1-Dichloroethene	.50	Vinyl chloride	.50
cis-1,2-Dichloroethene	.50	o-Xylene	.50
trans-1,2-Dichloroethene	.50	meta/para-Xylene	1.0
1,2-Dichloropropane	.50		

Appendix 3. Selected chemical constituents in ground-water samples collected at Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey, 1993-94

[Well locations are shown in figure 2; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data; PCB, polychlorinated biphenyl; <, less than; ANC, acid-neutralizing capacity; E, compound was positively detected but the amount detected is below where it can be reliably quantified]

U.S. Geological Survey well number	Local well name	Date sampled	Depth of well (feet below land surface)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	ANC, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
23-1219	CH-2MWA	08-24-93	90	17.3	4.1	10.4	<5.0	37.4	26.4
23-1218	CH-2MWB	08-23-93	40	50.8	10.9	12.4	E 1.4	130	14.5
23-1232	CH-3MW	08-19-93	160	5.3	3.0	26.8	25.7	55.0	31.3
23-1226	MW-1A	09-14-93	100	28.3	9.8	13.2	E 2.9	136	E 1.1
23-1227	MW-1B	09-15-93	140	27.9	13.1	12.9	E 4.1	140	11.2
23-1228	MW-1C	07-06-94	40	66.4	14.5	18.1	< 5.0	201	15
23-1223	MW-2A	08-17-93	170	39.6	21.3	41.1	7.2	79.2	346.0
23-1224	MW-2B	08-18-93	110	27.9	11.6	28.1	7.0	110	41.4
23-1225	MW-2C	08-18-93	80	48.4	12.6	16.0	E 2.2	114	43.1
23-1229	MW-3A	08-25-93	140	28.2	14.4	13.6	E 3.1	165	E 2.8
23-1230	MW-3B	09-13-93	90	44.5	14.0	14.9	E 2.9	170	E 2.7
23-1053	Rutgers golf course (irrigation well)	08-17-93	300	445	51.3	96.2	E 4.6	103	2,030

U.S. Geological Survey well number	Date sampled	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, ammonia dissolved (mg/L as N)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)
23-1219	08-24-93	13.3	0.12	.29	.16	<0.20	E 3.4	110	< 2.0	< 5.0
23-1218	08-23-93	45.8	E .05	.24	.86	< .20	< 5.0	540	< 2.0	< 5.0
23-1232	08-19-93	26.2	< .1	.085	.18	< .20	< 5.0	17	< 2.0	< 5.0
23-1226	09-14-93	5.3	< .1	.056	1.3	< .20	< 5.0	280	< 2.0	< 5.0
23-1227	09-15-93	2.1	< .1	E .016	.57	< .20	< 5.0	100	< 2.0	< 5.0
23-1228	07-06-94	13.0	E .053	E .049	.094	E .15	E 2.8	880	< 2.0	< 5.0
23-1223	08-17-93	6.7	< .1	E .016	.14	< .20	< 5.0	<10	< 2.0	< 5.0
23-1224	08-18-93	17.6	E .05	< .050	.27	< .20	< 5.0	23	< 2.0	< 5.0
23-1225	08-18-93	35.8	< .1	< .050	1.5	< .20	< 5.0	210	< 2.0	< 5.0
23-1229	08-25-93	4.1	< .1	E .023	.40	< .20	6.7	150	< 2.0	< 5.0
23-1230	09-13-93	26.4	< .1	.051	.93	< .20	< 5.0	390	< 2.0	< 5.0
23-1053	08-17-93	18.8	.11	< .050	E .02	<.20	E 3.9	<10	< 2.0	< 5.0

U.S. Geological Survey well number	Date sampled	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese dissolved (µg/L as Mn)	Nickel, dissolved (µg/L as Ni)	Zinc, dissolved (µg/L as Zn)	Mercury, dissolved (µg/L as Hg)	Phenols, total (µg/L)
23-1219	08-24-93	< 10	< 10	< 100	< 7.5	< 10	< 40	< 20	< 0.20	220
23-1218	08-23-93	< 10	< 10	E7.2	< 7.5	81	< 40	< 20	< .20	37
23-1232	08-19-93	< 10	< 10	< 100	--	< 10	< 40	< 20	< .20	46
23-1226	09-14-93	< 10	< 10	E 6.2	< 7.5	16	< 40	< 20	< .20	32
23-1227	09-15-93	< 10	< 10	< 100	--	49	< 40	< 20	< .20	20
23-1228	07-06-94	< 10	< 10	260	--	59	< 40	< 20	< .20	78
23-1223	08-17-93	< 10	< 10	< 100	< 7.5	81	< 40	< 20	< .20	<10
23-1224	08-18-93	< 10	< 10	< 100	--	21	< 40	< 20	< .20	20
23-1225	08-18-93	< 10	< 10	320	--	260	< 40	E 2.7	< .20	24
23-1229	08-25-93	< 10	< 10	E 9.9	< 7.5	16	< 40	< 20	< .20	33
23-1230	09-13-93	< 10	< 10	E 6.2	< 7.5	26	< 40	< 20	< .20	710
23-1053	08-17-93	< 10	< 10	260	< 7.5	350	< 40	310	<.20	17

Appendix 3. Selected chemical constituents in ground-water samples collected at Rutgers University Busch Campus and vicinity, Piscataway Township, New Jersey, 1993-94--Continued

U.S. Geological Survey well number	Date sampled	Aroclor 1016 PCB total (µg/L)	Aroclor 1221 PCB total (µg/L)	Aroclor 1232 PCB total (µg/L)	Aroclor 1242 PCB total (µg/L)	Aroclor 1248 PCB total (µg/L)	Aroclor 1254 PCB total (µg/L)	Aroclor 1260 PCB total (µg/L)
23-1219	08-24-93	< 0.50	< 0.50	< 0.50	< 0.50	< .50	< 1	< 1
23-1218	08-23-93	< .50	< .50	< .50	< .50	< .50	< 1	< 1
23-1232	08-19-93	< .50	< .50	< .50	< .50	< .50	< 1	< 1
23-1226	09-14-93	< .50	< .50	< .50	< .50	< .50	< 1	< 1
23-1227	09-15-93	< .50	< .50	< .50	< .50	< .50	< 1	< 1
23-1228	07-06-94	< .50	< .50	< .50	< .50	< .50	< 1	< 1
23-1223	08-17-93	< .50	< .50	< .50	< .50	< .50	< 1	< 1
23-1224	08-18-93	< .50	< .50	< .50	< .50	< .50	<1	< 1
23-1225	08-18-93	< .50	< .50	< .50	< .50	< .50	< 1	< 1
23-1229	08-25-93	< .50	< .50	< .50	< .50	< .50	<1	< 1
23-1230	09-13-93	--	--	--	--	--	--	--
23-1053	08-17-93	< .50	< .50	< .50	< .50	< .50	< 1	< 1

Appendix 4. Maximum contaminant levels for selected organic compounds and inorganic constituents, New Jersey

[Maximum contaminant levels from New Jersey Administrative Code, 1990]

Organic compound	Maximum contaminant level (micrograms per liter)
Benzene	1
Carbon tetrachloride	2
meta-Dichlorobenzene	600
ortho-Dichlorobenzene	600
para-Dichlorobenzene	75
1,2-Dichloroethane	2
1,1-Dichloroethylene	2
cis-1,2-Dichloroethylene	10
trans-1,2-Dichloroethylene	10
Methylene chloride	2
Polychlorinated biphenyls	.5
Tetrachloroethylene	1
Toluene	1,000
1,2,4-Trichlorobenzene	8
1,1,1-Trichloroethane	26
Trichloroethylene	1
Trihalomethanes	100
Vinyl chloride	2
Xylenes (total)	44
Inorganic constituent	
Arsenic	50
Barium	2,000
Beryllium	4
Cadmium	5
Chromium	100
Cyanide	200
Fluoride	4,000
Mercury	2
Nickel	100
Nitrate (as nitrogen)	10,000
Nitrite	1,000
Nitrate/nitrite	10,000
Selenium	50

Appendix 5. Results of analyses of quality-assurance blank samples for selected organic compounds, 1993-96

[All concentrations in micrograms per liter; <, less than minimum reporting limit]

Sample type	Date	Benzene	Bromo-benzene	Bromo-chloro-methane	Bromo-dichloro-methane	Bromoform	Bromo-methane (methyl bromide)	n-Butyl-benzene	sec-Butyl-benzene	tert-Butyl-benzene	Carbon tetrachloride
Field blank	08-19-93	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Field blank	08-25-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	08-19-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-14-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-15-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	01-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	01-18-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	08-23-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-29-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-25-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-07-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	09-11-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-23-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-25-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-02-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-08-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-10-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5

Appendix 5. Results of analyses of quality-assurance blank samples for selected organic compounds, 1993-96--Continued

Sample type	Date	Chloro-benzene	Chloro-ethane	Chloroform	Chloro-methane (methyl chloride)	2-Chloro-toluene (o-chloro-toluene)	4-Chloro-toluene (p-chloro-toluene	Chloro-dibromo-methane	1,2-Dibromo-3-chloro-propane (dibromo-chloro-propane)	1,2-Dibromo-ethane	Dibromo-methane
Field blank	08-19-93	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Field blank	08-25-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	08-19-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-14-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-15-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	01-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	01-18-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	08-23-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-29-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-19-95	< .5	< .5	.6	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-25-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-07-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	09-11-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-23-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-25-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-02-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-08-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-10-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5

Appendix 5. Results of analyses of quality-assurance blank samples for selected organic compounds, 1993-96--Continued

Sample type	Date	1,2-Dichloro-benzene (o-chloro-benzene	1,3-Dichloro-benzene	1,4-Dichloro-benzene	Dichloro-difluoro-methane	1,1-Dichloro-ethane	1,2-Dichloro-ethane	1,1-Dichloro-ethylene	cis-1,2-Dichloro-ethene	trans-1,2-Dichloro-ethene	1,2-Dichloro-propane
Field blank	08-19-93	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Field blank	08-25-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	08-19-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-14-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-15-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	01-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	01-18-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	08-23-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-29-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-25-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-07-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	09-11-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-23-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-25-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-02-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	.6
Field blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-08-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-10-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5

Appendix 5. Results of analyses of quality-assurance blank samples for selected organic compounds, 1993-96--Continued

Sample type	Date	1,3-Dichloro-propane	2,2-Dichloro-propane	1,1-Dichloro-propene	cis-1,3-Dichloro-propene	trans-1,3-Dichloro-propene	Ethyl-benzene	Hexachloro-butadiene	Isopropyl-benzene	4-Isopropyl-toluene (p-Isopropyl-toluene)	Methylene chloride
Field blank	08-19-93	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Field blank	08-25-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	.81
Trip blank	08-19-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-14-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	.54
Field blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	2.50
Field blank	07-15-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	1.20
Trip blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	2.40
Trip blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	1.40
Field blank	01-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	01-18-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	1.0
Equipment blank	08-23-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-29-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	.9
Trip blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-25-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-07-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	09-11-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	.7
Trip blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-23-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	1.5
Field blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	2.0
Field blank	09-25-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	6.3
Field blank	09-26-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	4.5
Trip blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	.8
Field blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-02-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	1.4
Trip blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	1.3
Field blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	2.6
Trip blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	.9
Field blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	1.0
Field blank	10-08-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	3.0
Trip blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	5.8
Field blank	10-10-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	3.9

Appendix 5. Results of analyses of quality-assurance blank samples for selected organic compounds, 1993-96--Continued

Sample type	Date	Naphthalene	N-propyl-benzene	Styrene	1,1,1,2-Tetrachloro-ethane	1,1,2,2-Tetra-chloro-ethane	Tetrachloro-ethene	Toluene	1,2,3-Trichloroben zene	1,2,4-Trichloro-benzene	1,1,1-Trichloro-ethane
Field blank	08-19-93	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Field blank	08-25-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	08-19-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-14-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-15-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	01-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	01-18-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	08-23-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	11-29-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-25-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-07-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Equipment blank	09-11-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-19-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-23-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-25-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	09-26-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-02-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-08-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	10-10-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5

Appendix 5. Results of analyses of quality-assurance blank samples for selected organic compounds, 1993-96--Continued

Sample type	Date	1,1,2-Trichloro-ethane	Trichloro-ethene	Trichloro-fluoro-methane	1,2,3-Trichloro-propane	1,2,4-Tri-methyl-benzene	1,3,5-Tri-methyl-benzene	Vinyl chloride	o-Xylene	meta/para-Xylene
Field blank	08-19-93	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Field blank	08-25-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	08-19-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	09-14-93	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	07-15-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-06-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-08-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-12-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Trip blank	07-14-94	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5
Field blank	01-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	01-18-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Equipment blank	08-23-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-26-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	11-08-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	11-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	11-29-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-19-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-20-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-22-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-25-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	11-07-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	11-21-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	11-28-95	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Equipment blank	09-11-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-17-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-19-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-18-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-23-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	09-24-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-25-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	09-26-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	10-01-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	10-02-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	10-04-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	10-07-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	10-08-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Trip blank	10-09-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0
Field blank	10-10-96	< .5	< .5	< .5	< .5	< .5	< .5	< .5	< .5	<1.0

☆ U.S. GOVERNMENT PRINTING OFFICE: 2000-511-472