RECONNAISSANCE OF VOLATILE ORGANIC COMPOUNDS IN THE SUBSURFACE AT RUTGERS UNIVERSITY, BUSCH CAMPUS, PISCATAWAY TOWNSHIP, NEW JERSEY

By Vincent T. dePaul

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CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow	
gallon per minute (gal/min)	0.06308	liter per second
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)

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

Water-quality abbreviations:

mL - milliliter
mg/L - milligrams per liter
µg/L - micrograms per liter
µS/cm - microsiemens per centimeter at 25 degrees Celsius
VOC - volatile organic compound

Other symbols or abbreviations:

ohm-meter - a unit of electrical resistivity
mS/m - millisiemens per meter

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ABSTRACT

During 1991-92, the U.S. Geological Survey conducted a hydrogeologic reconnaissance at a site near the Rutgers University, Busch Campus, Chemical Engineering building, C-Wing. Results of analyses of the soil-gas samples, which were collected at 43 locations, indicated the presence of volatile organic compounds, primarily carbon tetrachloride, near the C-Wing building and about 550 feet downgradient from and southwest of the C-Wing building. Concentrations of the compound in soil-gas samples were highest (2.1 μg/L (micrograms per liter)) along the southwestern wall of the C-Wing building.

Ground-water samples were collected at depths as great as 55 feet from five wells and piezometers near the C-Wing building. Samples collected along the southwestern wall of the building also contained the highest concentrations of volatile organic compounds. Concentrations of carbon tetrachloride in the ground-water samples ranged from < 0.35 μg/L to 3,400 μg/L, and concentrations of tetrachloroethylene ranged from < 0.28 μg/L to 85 μg/L. Ground-water samples collected at depths of 55 feet or more from two wells located on the Rutgers University Golf Course about 2,400 feet downgradient from the C-Wing building contained concentrations of tetrachloroethylene as great as 17.7 μg/L. Water levels measured in six wells and six piezometers indicated that the general flow direction in the shallow part of the aquifer is to the southwest of the C-Wing building.

An electrical-resistivity survey was conducted by azimuthal resistivity techniques. The results of the survey were consistent with field measurements, and the dominant vertical fractures near the Busch Campus trend northeast. An electromagnetic survey was ineffective as a result of cultural interferences and could not be used to determine the hydrogeologic characteristics of the site.

INTRODUCTION

In 1988, during a renovation in the basement of the Chemical Engineering building, C-Wing (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 contamination may have originated in the basement of the C-Wing building from a damaged sump piping system located within the shallow aquifer (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 were carbon tetrachloride, tetrachloroethylene (PCE), and chloroform. The C-Wing building overlies a water-supply aquifer, the Passaic Formation, and is about 2,500 ft upgradient from several domestic wells. In 1991, the U.S. Geological Survey (USGS), in cooperation with Rutgers, the State University of New Jersey, began an investigation of the extent of contamination in the vicinity of the building. The study consisted of two phases--an initial reconnaissance of contamination in the unsaturated zone and shallow ground water near the C-Wing building, and observation-well drilling and ground-water-quality monitoring. This report describes the initial phase of the study, which was conducted during 1991-92.

Purpose and Scope

This report describes the results of a subsurface reconnaissance at a site near the C-Wing building at the Rutgers University, Busch Campus, to determine hydrogeologic conditions and the distribution of VOC's in the shallow subsurface. It includes results of a surface geophysical survey and of a qualitative investigation of soil gases. Water levels in 12 wells and piezometers and water-quality data for ground-water samples from 10 wells and piezometers within the study area also are included.

Previous Investigations

The Rutgers University, Busch Campus, overlies a water-supply aquifer, the Passaic Formation. Several regional studies of the geology and hydrology of the Passaic Formation have been conducted. Herpers and Barksdale (1951) reported on the ground-water resources of the Newark, New Jersey, area. Nemickas (1976) reported on the geology and hydrology of the Passaic Formation (formerly known as the Brunswick Formation) in Union County, New Jersey. Vecchioli (1967) described the results of an aquifer test near Flemington, New Jersey. Michalski and Gerber (1992) discussed flow velocities in the formation at a site in Piscataway Township, New Jersey. ENSR Consulting and Engineering (1989; 1990) reported the results of a preliminary ground-water investigation, which included geological coring; installation of observation wells near the C-Wing building; and ground-water sampling and analysis.

Well-Numbering System

The well-numbering system used in this report has been used by the USGS, New Jersey District, since 1978. The well number is a six-digit number, of which the first two digits are the county code. The last four digits in the number indicate the sequence in which that well was inventoried in that county. For example, well number 23-1165 is the 1,165th well inventoried in Middlesex County.

Acknowledgments

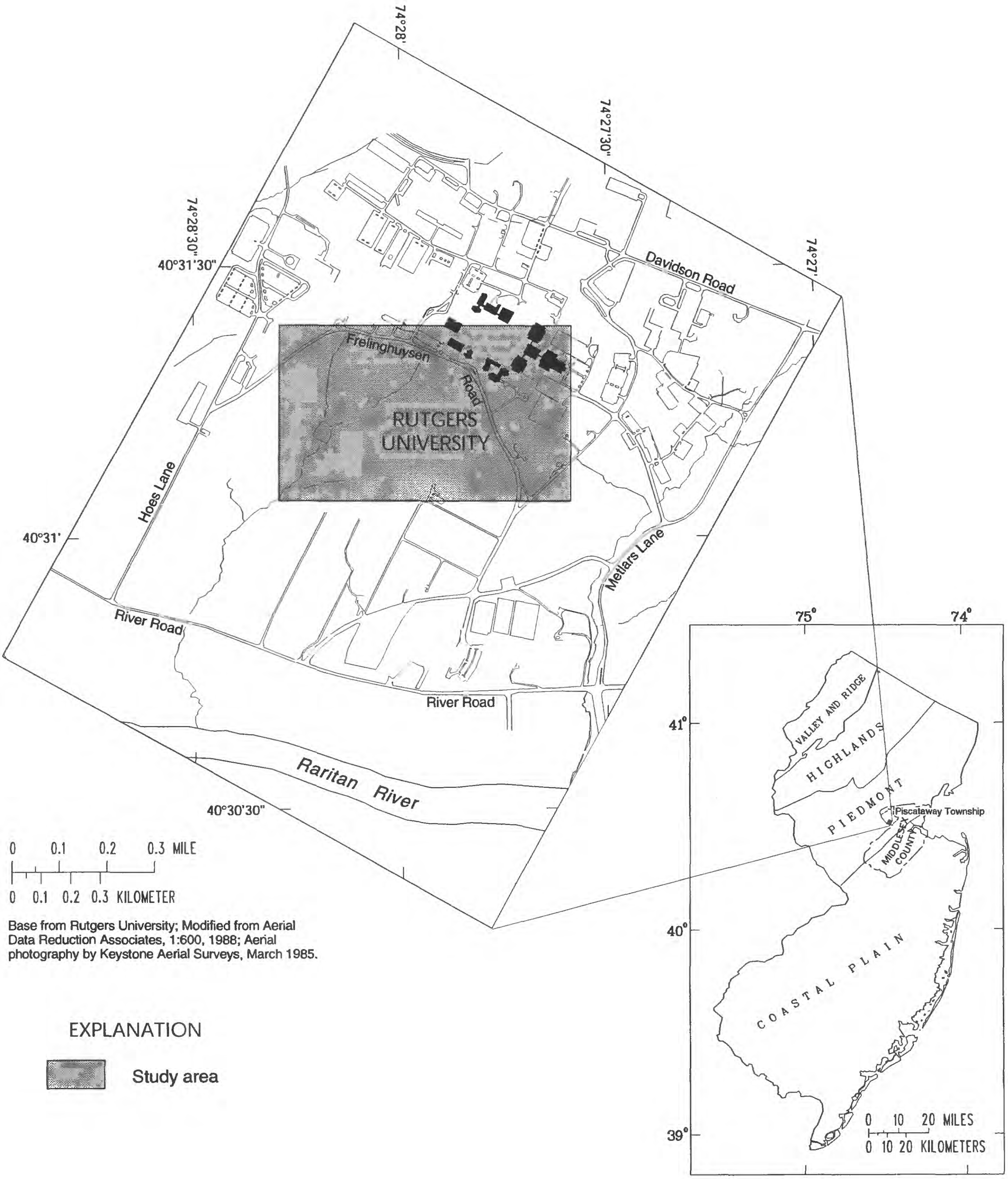
The author gratefully acknowledges Rutgers University personnel for their assistance and cooperation during this initial phase of study, particularly Martin Costello and Michael Quinlan of the Rutgers Environmental Health and Safety Department.

DESCRIPTION OF STUDY AREA

The study area comprises 0.23 mi^2 within the Rutgers University, Busch Campus, in Piscataway Township, northwestern Middlesex County, New Jersey (fig. 1). The physiography, geology, and hydrogeologic setting are described below.

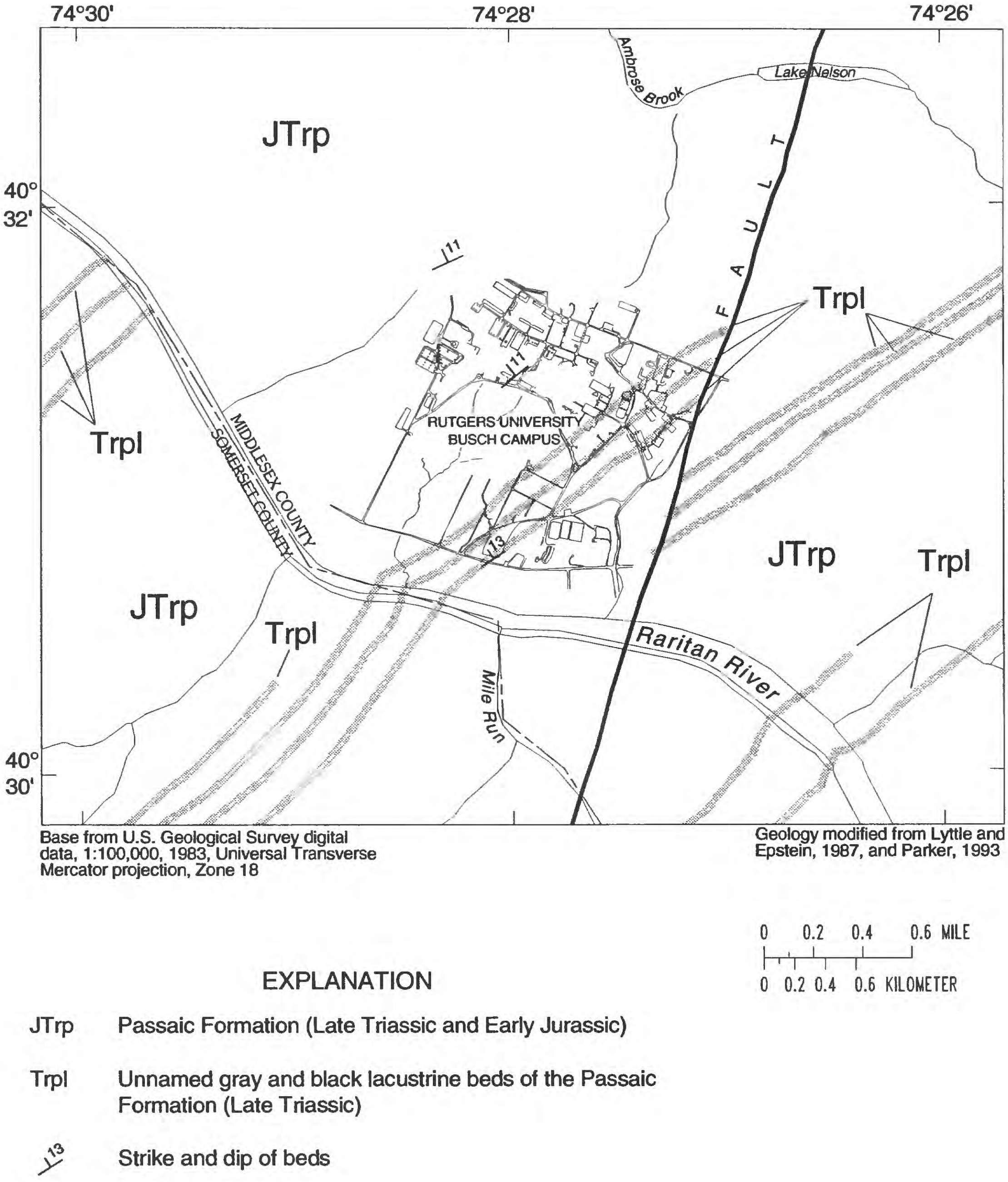
Physiography and Geology

The Busch Campus lies within the Piedmont Physiographic Province, which in New Jersey coincides with the Newark Basin. The Newark Basin is one in a series of fault-block basins formed during initial continental rifting during the Triassic Period and is the largest of these Triassic rift valleys that extend for nearly 1,000 mi from Nova Scotia to North Carolina (Van Houten, 1969). The Newark Basin consists of a thick series of red shales, interbedded sandstones, argillites, and intrusive and extrusive igneous rocks of Triassic and Jurassic age. The Passaic Formation, the thickest unit of the Newark Group, forms the bedrock at the Busch Campus (fig. 2). In this area, the formation is estimated to have a maximum thickness of about 7,800 ft (Houghton, 1990).



Base from Rutgers University; Modified from Aerial Data Reduction Associates, 1:600, 1988; Aerial photography by Keystone Aerial Surveys, March 1985.

Figure 1. Location of the Rutgers University, Busch Campus, Piscataway Township, New Jersey, and physiographic provinces.



Base from U.S. Geological Survey digital data, 1:100,000, 1983, Universal Transverse Mercator projection, Zone 18

Geology modified from Lyttle and Epstein, 1987, and Parker, 1993

EXPLANATION

JTrp	Passaic Formation (Late Triassic and Early Jurassic)
Trpl	Unnamed gray and black lacustrine beds of the Passaic Formation (Late Triassic)
13	Strike and dip of beds

Figure 2. Geology at the Rutgers University, Busch Campus, Piscataway Township, New Jersey and vicinity.

The Passaic Formation consists primarily of a nonmarine, reddish-brown mudstone interbedded with shale, siltstone, and sandstone. In the upper part of the formation, highly fractured mudstone is the predominant lithology (Houghton, 1990). The formation generally strikes northeast-southwest and dips slightly to the northwest. Two sets of near-vertical joints are present. The primary, more well-developed joint set trends nearly parallel to the strike of the bedding planes; a secondary joint set is oriented approximately perpendicular to the primary set. Other less well-developed joint patterns also are common. Depth to the top of competent bedrock in the area is generally less than 20 ft. Above the bedrock is a zone of highly fractured and weathered mudstone. Where the land surface is relatively undisturbed, soils that overlie the weathered zone are 1 to 2 ft thick. These soils generally are a reddish-brown shaly loam (U.S. Department of Agriculture, Soil Conservation Service, 1987).

Hydrogeologic Setting

The Passaic Formation is a major source of ground water in one of the most densely populated regions of New Jersey. The unfractured bedrock of the Passaic Formation has little primary porosity or permeability as a result of compaction and cementation; therefore, its ability to store and transmit water is negligible. The principal means of ground-water movement in the unweathered zone of the formation is through a complex, interconnected network of bedding-plane partings, fractures, and joints. The ability of these secondary openings to transmit water is a function of their size and density and, with increasing depth, these fractures become limited in size and number. In general, the formation has little water-bearing capacity below a depth of 500 ft.

Ground water in the Passaic Formation is present under unconfined and confined or semi-confined conditions. Shallow ground water is typically unconfined because of a zone of highly weathered and broken bedrock near land surface (Houghton, 1990), and ground-water flow is influenced by the topography of the land surface. Confined and semiconfined conditions are present in the deeper part of the ground-water system because of overlying beds that have low permeability. Shallow ground water typically discharges to local streams, whereas water from deeper zones generally moves toward regional discharge points, such as the Raritan River (fig.1).

Several studies of the Passaic Formation indicate that ground water moves primarily through extensively fractured layers of rock that are parallel to the strike. The water-bearing openings can be fairly continuous in the strike direction; in the dip direction, they may pinch out or be absent at depth. Vecchioli (1967), in describing aquifer tests at sites in Flemington and New Brunswick, New Jersey, reported that wells aligned along the strike in relation to a pumped well showed greater drawdown than those aligned in other positions. Herpers and Barksdale (1951) and Vecchioli and others (1969) observed similar anisotropy in the Passaic Formation.

METHODS OF INVESTIGATION

Field measurements of strike, dip, and joint orientation of bedrock, along with surface geophysical techniques, were used to define the general hydrogeologic framework in the study area. Electromagnetic (EM) and electrical-resistivity surveys were conducted at the site to map the subsurface structure and possible flowpaths of shallow ground water. A qualitative survey of soil gases was used to verify the presence of VOC's in the unsaturated zone and to estimate their areal distribution in the shallow aquifer. Six boreholes were drilled and completed as piezometers for the purpose of measuring water levels. Water samples were collected from observation wells, piezometers, and an irrigation well within the study area and were analyzed for VOC's and selected inorganic compounds.

Electromagnetic Survey

In July 1991, USGS personnel conducted an EM survey in an area southwest of the C-Wing building (fig. 3). The EM method is a surface geophysical technique that detects variations in the electrical conductivity of the subsurface. These variations result from differences in the soil or rock type, porosity, and the conductivity of ground water in pore spaces (Benson, 1991). The EM technique can be used in ground-water investigations to map ionic contaminant plumes because the electrical conductivity of the ground water typically increases with increased ionic concentrations. The EM method also can be used to map changes in the geology to indicate permeable pathways (such as highly fractured zones) through which ground water may move (Benson, 1991).

The EM instrument consists of two antennas, one of which is a transmitter and the other of which is a receiver. An alternating current is applied to the transmitting antenna, and a primary EM field perpendicular to the plane of the antenna is passed into the ground. The primary EM field causes a flow of electric current that is proportional to the conductivity of the earth materials and ground water. The electric current induces a secondary EM field in the subsurface, which is detected at the receiving antenna. Variations in the secondary field are perceived as anomalies that, in turn, can be interpreted as changes in the subsurface geology, the moisture content of the rock or soil, or the quality of the ground water.

The EM survey was conducted by using a Geonics[1] EM-31 Non- Contacting Terrain Conductivity meter. Field data were collected at 131 stations on a grid pattern with 50-ft spacings. The grid was oriented so that the rows and columns were aligned approximately along the strike and dip of the bedrock. Measurements were made with the instrument in the horizontal dipole position and with an intercoil spacing of 12 ft. Readings were taken at each station in directions facing both parallel and perpendicular to the strike in an effort to recognize false readings resulting from cultural interference. Locations of measuring stations and the distribution of apparent conductivities are shown in figure 3.

The apparent- conductivity values measured on the golf course were higher than those measured on the adjacent playing field. The higher values were attributed to the higher moisture content of the soil due to seasonal irrigation. Apparent conductivity readings greater than 67 mS/m (denoted by a 0 in figure 3) measured on the golf course coincided with the location of an underground pipe; these readings are attributed to metallic interference. Overhead power lines located between the golf course and playing field also could increase the conductivity readings in the area. Other factors that affected the EM-survey results include buried electrical lines along Frelinghuysen Road and automobiles in a parking lot near the playing field. When these interferences are considered, no obvious anomalies were evident in the remaining data set obtained from the survey. No meaningful interpretations concerning the hydrogeologic characteristics of, or water quality in, the area could be made.

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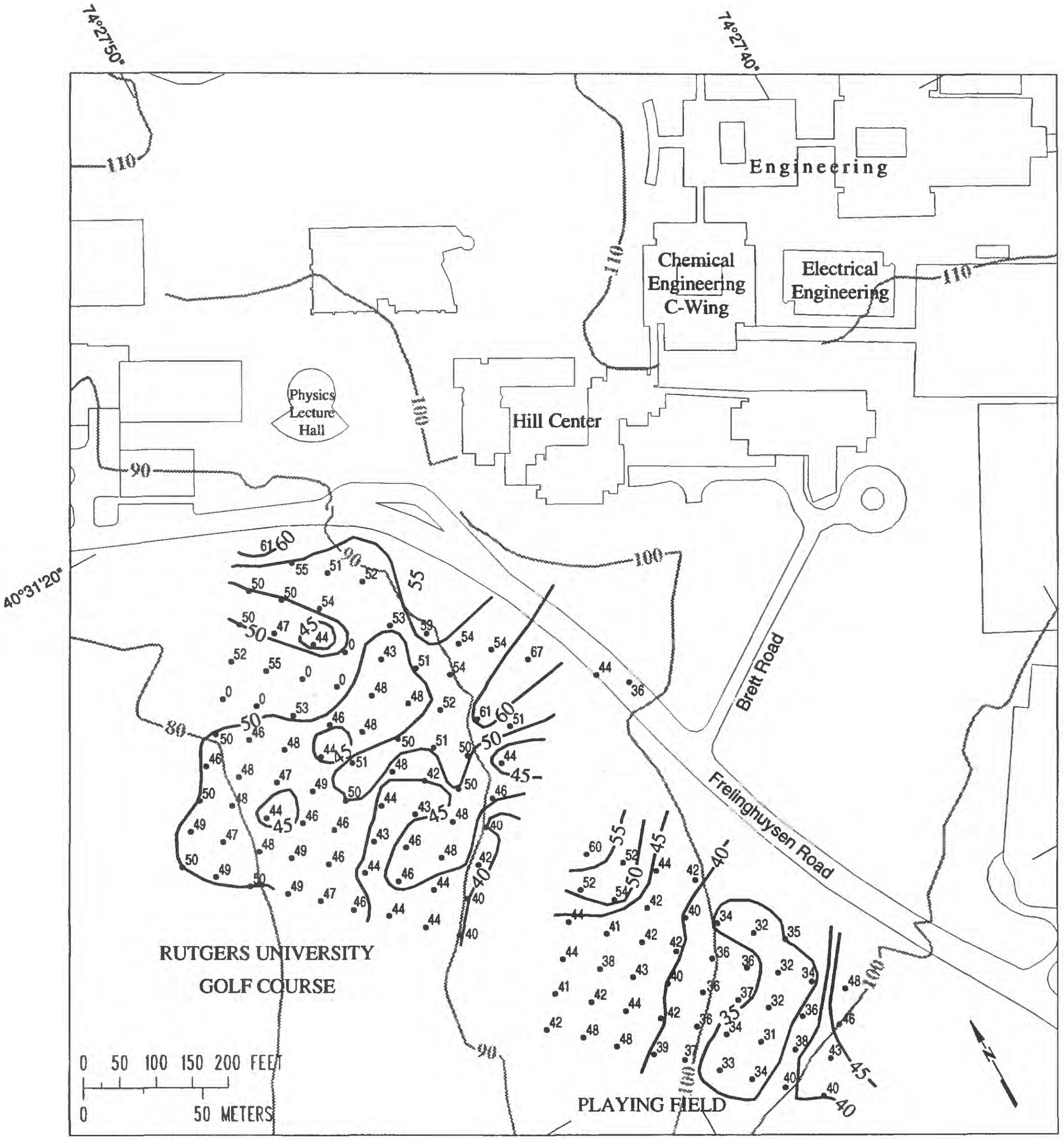
[1] Use of trade names is for identification purposes only and does not constitute endorsement by the U.S.Geological Survey.



Base from Rutgers University, Modified from Aerial Data Reduction Associates, 1:600, 1988, Aerial photography by Keystone Aerial Surveys, March 1985.

EXPLANATION

—45—	Line of equal apparent conductivity--Interval, in millisiemens per meter is variable
—100—	Topographic contour--Shows altitude of land surface. Contour interval 10 feet. Datum is sea level
•42	Measuring station--Number is apparent conductivity in millisiemens per meter. A zero denotes interference from buried pipe

Figure 3. Distribution of apparent-conductivity values, the Rutgers University, Busch Campus, New Jersey, June 1991.

Electrical-Resistivity Survey

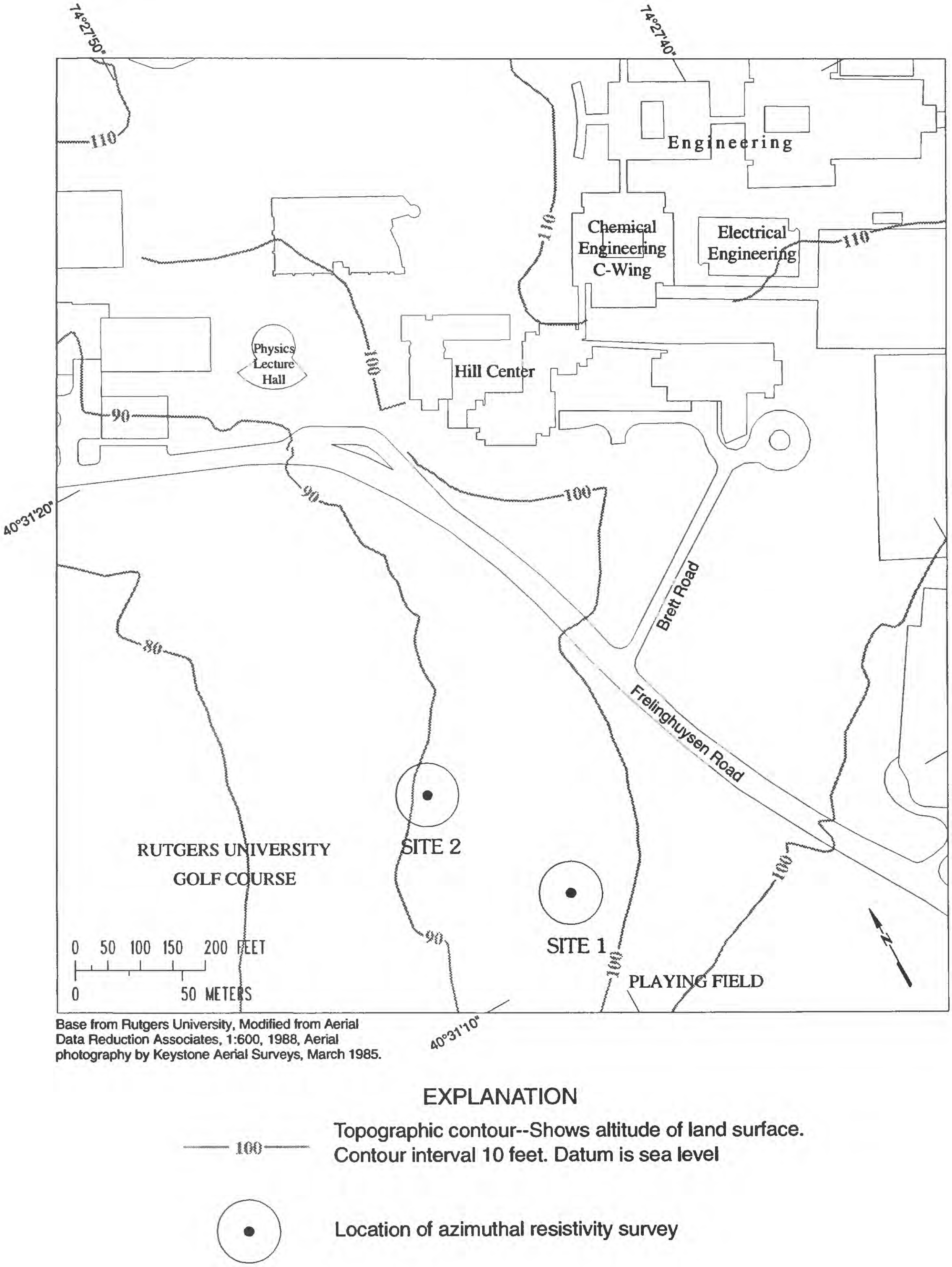
On January 16, 1992, an azimuthal resistivity survey was conducted at two sites southwest of the C-Wing building (fig. 4). The purpose of the survey was to determine the trend of the major joint sets in the study area. The azimuthal resistivity method is a surface geophysical technique that employs the basic principles of electrical resistivity. Electric current is introduced into the ground by two electrodes and the potential difference is measured between a second pair of electrodes. Resistivity is calculated on the basis of the array of the electrodes by using the current and potential difference measurements (Zohdy and others,1974). Resistivity data were collected by using a Schlumberger array in which the distance between the current electrodes was 30 m (98.4 ft) and the distance between the two potential electrodes was 6 m (19.7 ft). The center point of the array was held constant as the array was rotated at 30° intervals from 0°(North) to 360°. Readings were recorded at each 30° interval for each array.

Collection of Soil-Gas Samples

From October through December 1991, a soil-gas survey was conducted to determine the areal extent of VOC's in the vicinity of the C-Wing building. The presence of VOC's in soil vapors is indicative of their presence in the unsaturated zone or in the shallow ground water. Soil-gas analysis is most effective in detecting halogenated chemical solvents and petroleum hydrocarbons that have high vapor pressures, high gas/liquid partition coefficients, and low solubilities in water (Ballestero and others, 1991). These compounds readily evaporate from the ground water, migrate through the soil to land surface, and eventually dissipate in the atmosphere. Because the primary VOC of interest in this investigation, carbon tetrachloride, is suitable to soil-gas detection, this method was chosen as a cost-effective technique for estimating the presence of contaminants in the shallow ground water.

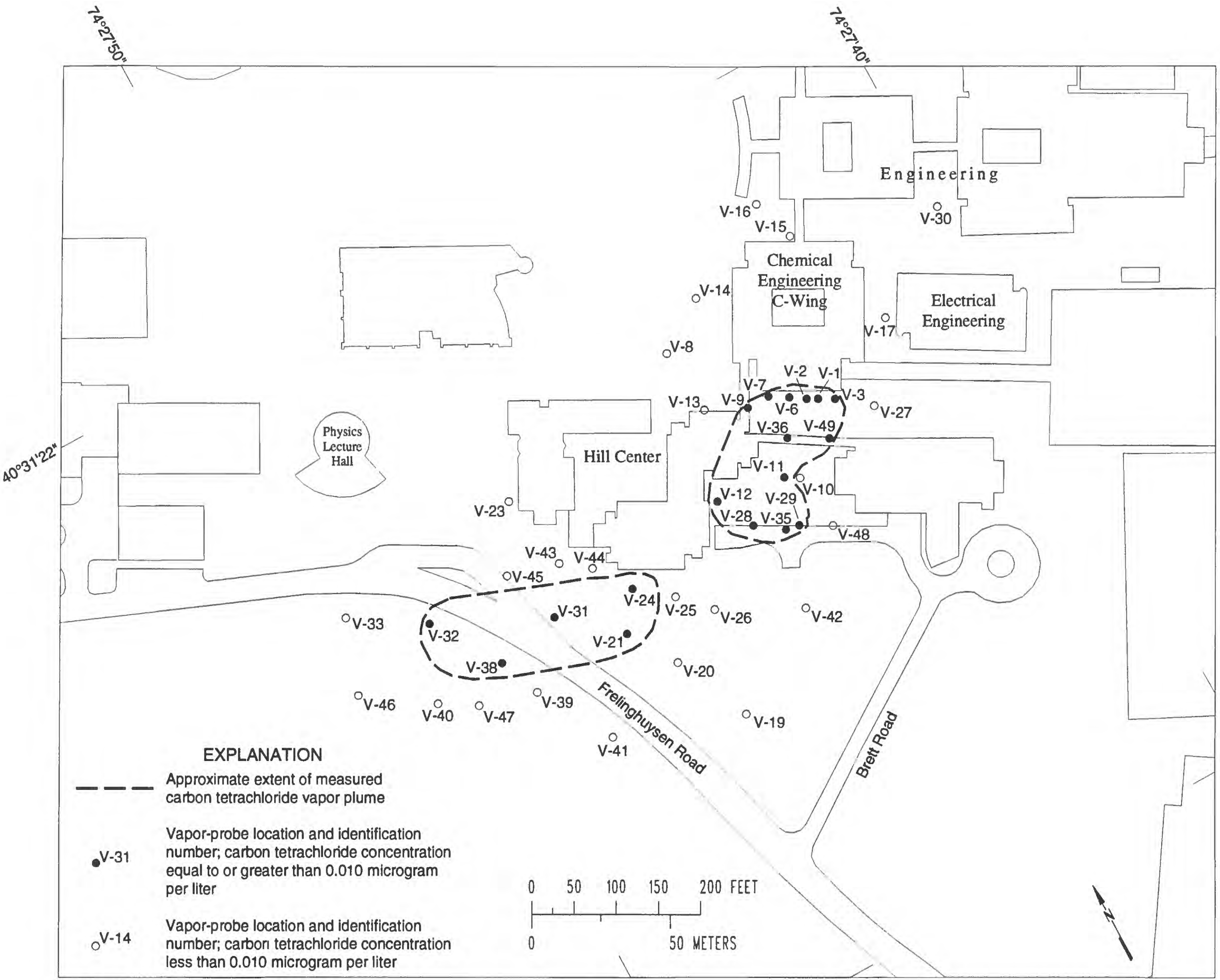
The sampling network, consisting of 43 vapor probes, was designed and installed to surround the suspected contamination source and continue downgradient along the most probable path of shallow-ground-water flow (fig. 5). The irregular pattern of the probe network, however, was a function of the urban nature of the site. Sidewalks, concrete courtyards, manhole covers, and shallow pipe and electrical lines prohibited an evenly spaced grid. The locations of the vapor probes were mapped by measuring with an engineer's tape the distance from existing, mapped structures such as buildings, and from other points of known location, such as observation wells, to the vapor probes.

Soil-gas samples were collected from the unsaturated zone by using probes constructed of 4.5-millimeter (0.18 in.) inside-diameter (i.d.) stainless-steel tubes cut in 5-ft lengths. The bottom 3 in. of each probe was slotted. The probes were installed by using a slam bar to drive a 0.5-in.-diameter hole. Vapor probes were set to depths from 3 to 4 ft below land surface, depending upon local conditions, such as depth to bedrock. After the probes were inserted into the hole, a fine-grained sand was poured in to surround the slotted part of the probe. Granular bentonite then was added above the sand to land surface to seal the annular space between the probe and the hole. Above land surface, Swagelok tube fittings and caps were fitted to the probes to ensure a gas-tight seal.



Base from Rutgers University, Modified from Aerial Data Reduction Associates, 1:600, 1988, Aerial photography by Keystone Aerial Surveys, March 1985.

Figure 4. Locations of azimuthal resistivity measuring stations, the Rutgers University, Busch Campus, New Jersey, January 1992.



Base from Rutgers University,Modified from Aerial
Data Reduction Associates, 1:600, 1988, Aerial
photography by Keystone Aerial Surveys, March 1985.

Figure 5. Distribution of vapor probes and approximate extent of measured soil-gas plume in the vicinity of the Chemical Engineering building, C-Wing, the Rutgers University, Busch Campus, New Jersey, 1991.

The soil-gas samples were collected in 125-mL glass sampling bulbs with Teflon stopcocks at both ends. The sampling bulb was connected to the vapor probe with a small section of silicone tubing such that only the bulb itself was in contact with the probe. The other end of the bulb was fitted with 0.19-in.-i.d. silicone hose leading to a peristaltic pump. Gas flow through the bulb then was induced at a rate of about 300 mL per minute. Flow rate was monitored during purging and sampling by the use of a bubble meter attached to the effluent end of the silicone hose. After 1,000 mL of soil gas had been purged through the bulb, the sample was collected by first closing the effluent stopcock and, 15 seconds later, the influent stopcock. This allowed the pressure inside the bulb to equalize with atmospheric pressure. A schematic diagram of the soil-gas-sampling configuration is shown in figure 6.

Following the collection of each soil-gas sample, each bulb was injected by syringe with a field surrogate (gaseous bromochloromethane) through its septum port for the purpose of monitoring sample loss during transportation. The bulbs were transported to the laboratory, where the samples were analyzed within 10 hours of collection. Replicate samples also were collected, and bulb and trip blanks were included with each set of samples to assure quality control.

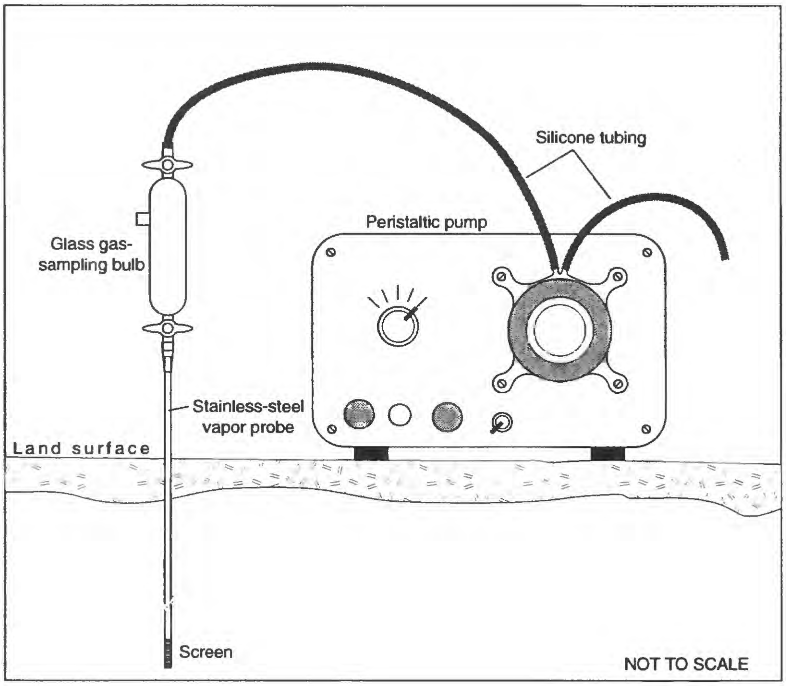


Figure 6. Soil-gas-sampling configuration. (Modified from Kammer and Smith, 1989)

Soil-gas samples were analyzed at the USGS, New Jersey District, laboratory for carbon tetrachloride, tetrachloroethylene, and benzene by purge-and-trap gas chromatography. The gas-sampling bulbs were directly attached to a modified purge-and-trap concentrator. Samples were purged with helium from the glass bulb onto an adsorbent trap. The contaminants were subsequently desorbed from the trap onto a capillary column where the chromatographic separations were made. A Tracor 540 gas chromatograph, configured in series with a Hall electrolytic conductivity detector and a photoionization detector, was used for the analyses. Compound retention times were compared against those of standards analyzed under the same conditions, and the compounds were identified.

The stability of soil-gas samples containing VOC's decreases with holding time (Kammer and Smith, 1989); therefore, interpretation of the chromatograms is semiquantitative. Recovery values for the field surrogate ranged from 30 to 100 percent as a result of transportation time and laboratory holding time. The use of an on-site portable gas chromatograph was not feasible, however, because the concentrations of the compounds in the soil vapors were low (≤ 2.1 μg/L). The large sample volume used in this method resulted in a lower analytical detection limit of 0.01 μg/L.

Installation of Piezometers

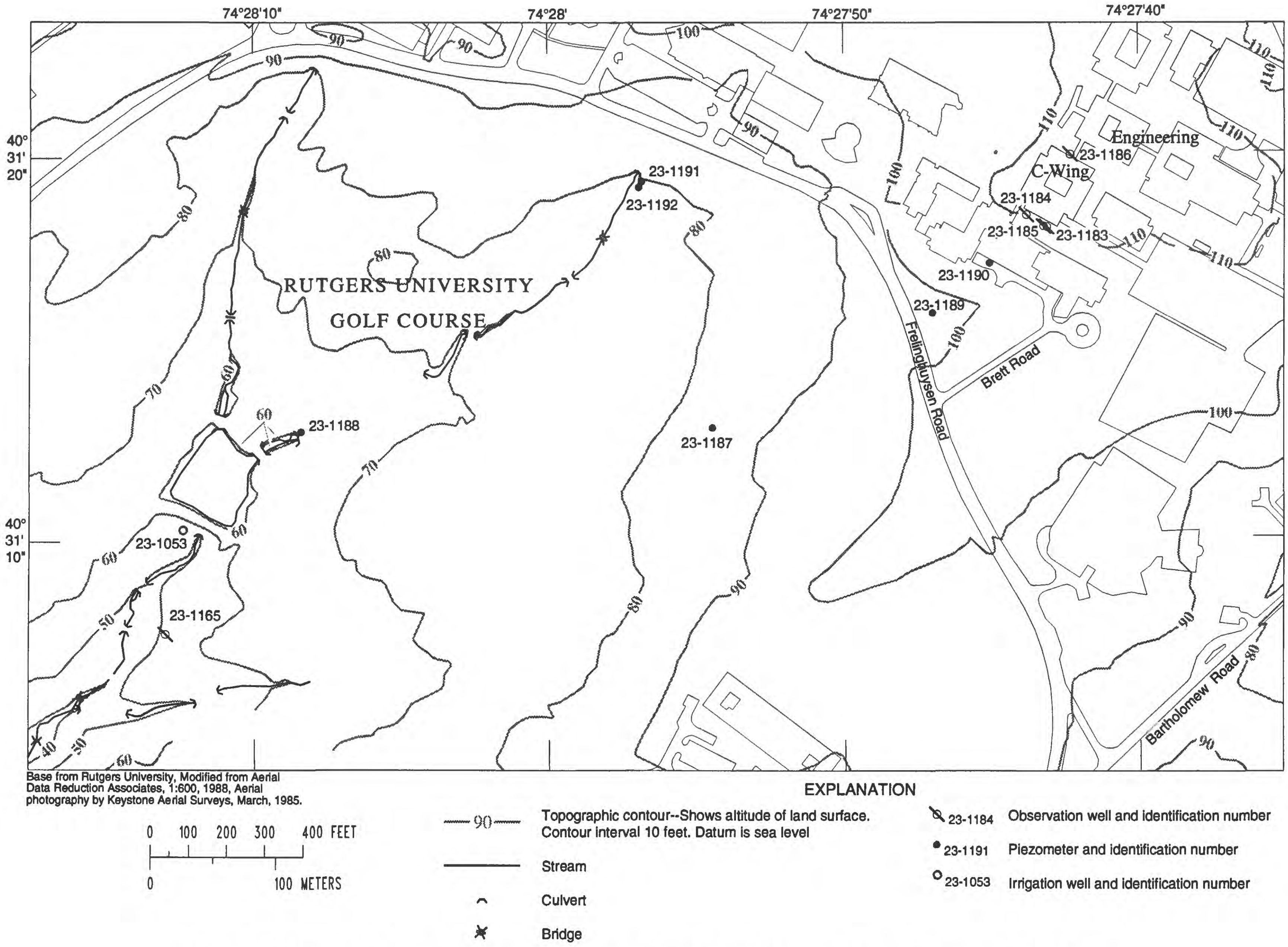
Six temporary piezometers, 23-1187 through 23-1192, were installed near the C-Wing building and on the Rutgers University Golf Course for the purpose of measuring water levels (fig. 7). The 3-in.-diameter boreholes were constructed by using a portable auger with solid-stem auger flights and a 3-in.-diameter rock bit. The shallow boreholes ranged in depth from 4 to 16 ft below land surface. The boreholes were advanced 3 ft beyond the water table, where possible, or until refusal in bedrock. No water was encountered in the overburden soil material during drilling. After removal of the auger string, a well screen and casing were set. The temporary piezometers were constructed of 0.5 or 0.75-in.-i.d. polyvinylchloride (PVC) riser pipe and 10-slot PVC screen. A gravel pack of uniform sand was funneled down the borehole from the bottom up to a depth of 2 to 3 ft above the top of the screen. Bentonite pellets were added above the sand, and a bentonite slurry was poured into the annulus to prevent surface leakage. After each borehole was completed, the rock bit was removed from the lead auger and was decontaminated by scrubbing with a solution of laboratory soap and deionized water, rinsing with deionized water, rinsing with methanol and air drying, and finally rinsing with deionized water. Fresh, uncontaminated auger flights were used in each subsequent borehole. Borehole 23-1185 was completed by using a 4-in.-diameter hand auger because of its proximity to a concrete wall and the looseness of the fill soil at that site. The screen and casing were set as described above.

Measurement of Water Levels

Water levels in the piezometers and previously installed observation wells at the site were measured during site visits. All water levels were measured manually with a steel tape that was decontaminated at each well site. All measuring-point altitudes were surveyed to the closest one-hundredth of a foot. Locations of wells and piezometers are shown in figure 7.

Collection and Analysis of Ground-Water Samples

Ground-water samples collected from the four observation wells during April 1992 were analyzed for dissolved cations, anions, nutrients, metals, polychlorinated biphenyls, and VOC's. Depths of wells sampled ranged from 27 ft to 200 ft below land surface. Wells were purged by pumping three casing volumes of water when possible, and field characteristics, such as temperature, pH, specific conductance, and dissolved-oxygen concentration, were allowed to stabilize to ensure that the sample was representative of



Base from Rutgers University, Modified from Aerial Data Reduction Associates, 1:600, 1988, Aerial photography by Keystone Aerial Surveys, March, 1985.

Figure 7. Locations of wells and piezometers, the Rutgers University, Busch Campus, New Jersey.

the aquifer water. Well purging was accomplished by using either a stainless-steel submersible pump or a peristaltic pump. Samples to be analyzed for inorganic constituents were collected with the peristaltic pump or by using a Teflon bailer lowered on Teflon-coated stainless-steel wire. All samples to be analyzed for organic constituents were collected with a Teflon bailer. Well 23-1183, the deepest well adjacent to the C-Wing building, was purged with a submersible pump that had become permanently lodged in the lower part of the screened interval during a previous investigation. After evacuating the casing down to the screened interval three times and allowing the water level to recover, all samples were collected with a Teflon bailer. All samples were preserved in accordance with the New Jersey Department of Environmental Protection specifications (New Jersey Department of Environmental Protection, 1980) and were prepared for shipment.

The wells were sampled in order of suspected increasing concentrations of VOC's to minimize cross-contamination. All sampling equipment was decontaminated at the USGS, New Jersey District, laboratory prior to use. Submersible pumps used for well-casing evacuation were field-decontaminated between use at each site. At sites known to have significant levels of contamination, purge and equipment-cleaning water was pumped directly into 55-gallon drums for proper disposal.

Samples collected from the irrigation well located on the Rutgers University Golf Course (well 23-1053) were analyzed for VOC's only. Because this well is a flowing artesian well and discharges about 10 gal/min of water, it was not necessary to engage the pump to evacuate standing water. After stabilization of field characteristics, samples were drawn through a Teflon tube connected to a sampling spigot near the wellhead. Samples from five temporary piezometers, 23-1187 to 23-1191, were collected and analyzed for VOC's only. Because the diameters of the piezometers are small ($\leq$ 0.75 in.), samples were withdrawn through fresh polyethylene tubing attached to a peristaltic pump at land surface. Piezometers typically were pumped dry twice before samples were collected. Because of the pressure gradient placed on the sample with this method, however, significant losses of VOC's can occur (Imbrigiotta and others, 1988); therefore, water-quality data from these sites can be interpreted qualitatively only. Because these samples were intended for reconnaissance purposes only, the results obtained were considered to be satisfactory.

Ground-water samples were analyzed by Accutest of Dayton, New Jersey, a NJDEP-certified laboratory. Duplicate samples for VOC's were analyzed at the USGS, New Jersey District, laboratory. Samples from the irrigation well (well 23-1053) and from piezometers also were analyzed for VOC's at the USGS, New Jersey District, laboratory.

RESULTS OF RECONNAISSANCE OF VOLATILE ORGANIC COMPOUNDS IN THE SUBSURFACE

Geologic maps that include the Rutgers University, Busch Campus (Parker, 1993), show the strike of the bedrock in the area to be about N. 59° E. This value is similar to those measured during this study. Several exposed outcrops of bedrock on and near the campus were measured for strike and dip of bedding planes and for joint orientation. Because the strike of the bedding planes varies locally, an average of N. 57° E. was used for the purpose of this study. The dip of the strata is typically 11° to the northwest. Additional observations at the outcrops show two major patterns of near-vertical joints with axes trending northeast and northwest.

Electrical Resistivity

Measurements recorded during the azimuthal resistivity survey at the two stations southwest of the C-Wing building indicated a resistivity low or, conversely, a conductivity high when the array was set in a northeast-southwest alignment. The long axes of the resistivity plots, oriented to the northwest, correspond to materials that are more resistant and, therefore, less conductive. These measurements correlated with mapped joint patterns at outcrops near the site, indicating a dominant joint set trending northeast-southwest subparallel to the strike of bedding that could affect ground-water flow (fig. 8).

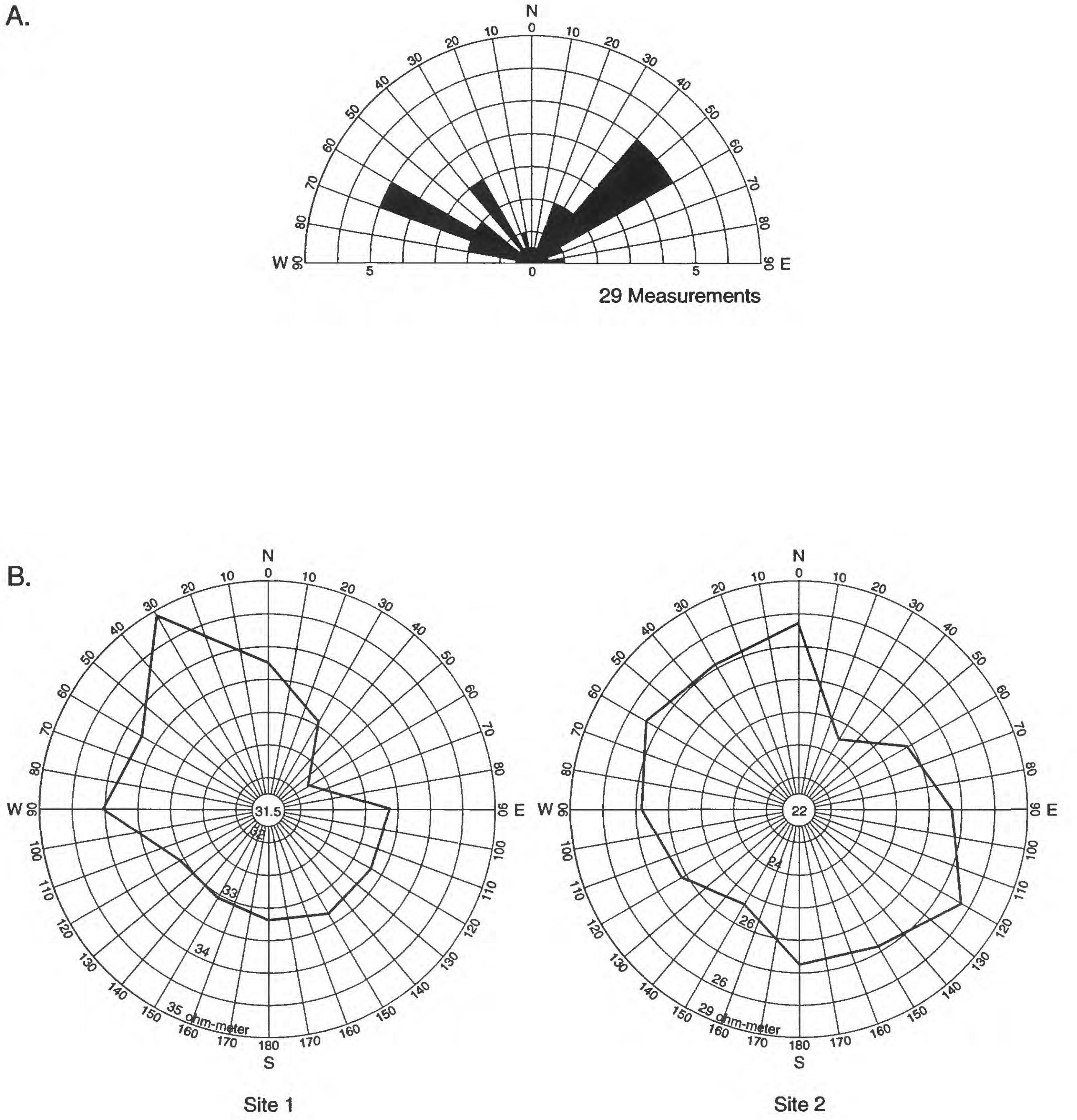
Distribution of Soil Gases

Results of analyses of the soil-gas samples indicate that carbon tetrachloride is the dominant compound in the unsaturated zone near the C-Wing building. Carbon tetrachloride was present in samples from 17 of the 43 vapor probes; tetrachloroethylene was present in samples from 4 sites (table 1). Trichlorofluoromethane was tentatively identified in samples at several sites; however, because a standard of this compound was not run prior to analysis, positive identification could not be made. Benzene, used in C-Wing laboratory operations from 1963 to 1979 (David Kosson, Rutgers University, written commun., 1991), was not detected in any of the samples. This could be attributed to benzene's susceptibility to biodegradation.

Those sites at which detectable quantities of carbon tetrachloride were identified are near the C-Wing building and to about 550 ft to the southwest (fig. 5). Disturbances in the shallow subsurface, such as building basements, ramps, and underground utilities, could affect shallow ground-water flow as well as the dispersal of contaminants. The highest concentrations of carbon tetrachloride (2.1 and 1.2 µg/L) were present in samples collected along the southwestern wall of the C-Wing building near the wells from which water contained high concentrations of carbon tetrachloride. The accuracy of the detection of soil gases is limited, however. Limitations include soil-moisture variability (Ballestero and others, 1991) and depth to the surface of the shallow ground water. Within the soil-gas-survey network, depth to ground water ranged from about 12 ft below land surface near the C-Wing building to about 5 ft below land surface near Frelinghuysen Road. Therefore, concentrations of VOC's measured in the soil gas may not always be proportional to concentrations that are present in the ground water, and the dispersal of contaminants in the ground water may not conform to the soil-gas plume.

Ground-Water Levels

Ground-water levels were measured in six wells and six piezometers in the study area during 1991-92 (table 2). Altitudes of water levels measured on October 22, 1991, in shallow wells near the C-Wing building ranged from 91.11 to 98.24 ft above sea level. Because of the difference in water levels between wells of similar construction, wells 23-1184 and 23-1185, it was suspected that the screen of well 23-1185 could be partially sealed. Subsequent water-level measurements produced the same discrepancy in water-level altitude and the water-level data from that well therefore are suspect. Because well 23-1183 is screened in a deeper water-bearing zone, the water level in this well, 70.79 ft, is considerably lower than those in the adjacent shallow wells. This indicates that this deeper zone probably is not well-connected to the shallow aquifer. Water levels, measured on November 23, 1992 in the observation wells and piezometers open to the shallow system, indicate that ground-water flow in this part of the system is generally to the southwest of the C-Wing building along the topographic gradient (fig. 9). Discharge in the shallow zone is probably to an unnamed creek on the Rutgers University Golf Course.



Site 1

Site 2

Figure 8. (A) Rose diagram showing preferred orientation of major joint sets at and near the Rutgers University, Busch Campus. (B) Azimuthal resistivity plots for two sites at the Rutgers University, Busch Campus, January 1992.

Table 1. Results of soil-gas analyses for selected volatile organic compounds in the vicinity of the Chemical Engineering Building, C-Wing, the Rutgers University, Busch Campus, New Jersey, 1991

[All concentrations are in µg/L (micrograms per liter); ND, concentration is less than minimum detection limit of 0.010 µg/L; --not determined as a result of analytical interference from unidentified compound]

Site-identification number	Sampling date	Depth below land surface in feet	Concentration	
			Carbon tetrachloride	Tetrachloro-ethylene
V-1	10/28/91	4.0	2.131	0.019
V-2	10/28/91	4.0	1.184	.072
V-3	10/29/91	4.0	.297	.017
V-6	10/28/91	4.0	.251	ND
V-7	10/28/91	4.0	.116	ND
V-7	10/28/91		.099	ND
V-8	10/30/91	4.0	ND	ND
V-9	10/28/91	4.0	.770	ND
V-10	10/29/91	4.0	ND	ND
V-10	10/29/91		ND	ND
V-11	10/29/91	4.0	.747	ND
V-12	10/30/91	4.0	.030	ND
V-13	10/29/91	4.0	ND	ND
V-14	10/31/91	4.0	ND	ND
V-15	10/31/91	4.0	ND	ND
V-16	10/31/91	4.0	ND	ND
V-17	11/20/91	3.5	ND	ND
V-17	11/21/91		ND	ND
V-19	11/05/91	3.0	ND	ND
V-20	10/31/91	4.0	ND	ND
V-21	11/04/91	4.0	.083	ND
V-23	10/31/91	4.0	ND	ND
V-24	10/30/91	4.0	.013	ND
V-24	10/31/91		.010	ND
V-25	10/30/91	4.0	ND	ND
V-25	12/19/91		ND	ND
V-26	10/30/91	4.0	ND	ND
V-27	10/29/91	3.0	ND	ND
V-27	11/21/91		ND	ND
V-28	11/05/91	4.0	.015	ND
V-29	11/05/91	4.0	.071	ND
V-30	11/20/91	3.4	ND	ND
V-31	11/04/91	2.7	.091	ND
V-32	11/04/91	3.0	.037	ND
V-33	11/05/91	2.6	ND	ND
V-35	11/04/91	4.0	.082	ND
V-36	11/04/91	3.2	.054	ND
V-38	11/20/91	3.0	.016	ND
V-39	11/20/91	3.7	ND	.013
V-40	11/21/91	3.8	ND	ND
V-41	11/20/91	3.0	ND	ND
V-42	11/21/91	3.2	ND	ND
V-43	11/21/91	4.0	ND	ND
V-44	12/19/91	3.0	ND	ND
V-45	12/20/91	2.3	ND	ND
V-45	12/20/91		ND	ND
V-46	12/20/91	3.0	ND	ND
V-47	12/20/91	3.5	ND	ND
V-48	12/19/91	4.0	ND	ND
V-49	12/19/91	3.1	--	--

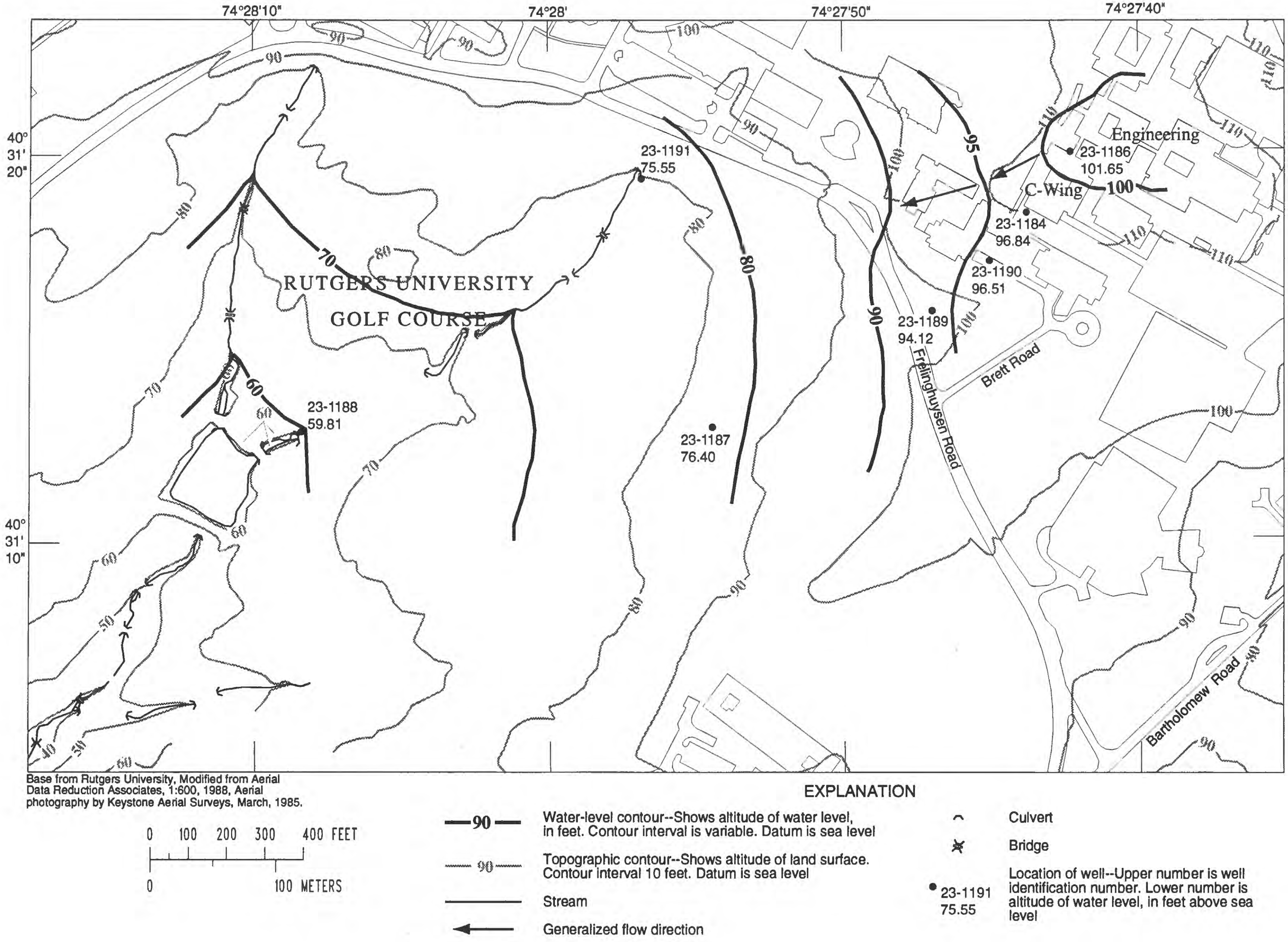
Because of the large open intervals, water levels in wells 23-1165 and 23-1053 are a composite of those in several water-bearing zones and, therefore, are not representative of any one zone. When water levels are high, both of these wells flow, probably because of the presence of alternating layers of rock of different permeability that can create semiconfined conditions within the aquifer system and because they are near the Raritan River. Ground-water flow in the deeper part of the system may not coincide with shallow flow because of geologic structural controls. Water in the deeper zones discharges to pumped and flowing wells; to upper, less well-confined zones of water; and probably to the Raritan River southwest of the campus.

Ground-Water Quality

The pH of the ground-water samples collected in the study area ranged from 7.3 to 7.8 with the exception of that of the sample from well 23-1186, which was 5.5 (table 3). Specific conductance ranged from 189 µS/cm to 2,330 µS/cm (table 3). Specific conductance is an indicator of ion concentration; as ion concentrations increase, conductance of the water increases (Hem, 1985). The higher specific conductances usually indicate the presence of older, more mineralized water; typically values increase with depth or near ground-water discharge areas. The specific conductance of the water sample from well 23-1194, a shallow well, was 1,090 µS/cm. This high specific conductance is a result of high concentrations of dissolved solids in the water, particularly sodium and chloride (92 mg/L and 280 mg/L, respectively). Water-quality data are presented in tables 3 and 4.

Results of analyses of ground-water samples indicated that the concentrations of beryllium and cadmium in water from well 23-1165 exceeded the New Jersey primary maximum contaminant level (MCL) for drinking water (4 µg/L and 5 µg/L, respectively) (New Jersey Administrative Code, 1990a). Because water samples were collected and analyzed for VOC's only, inorganic water-quality data for well 23-1053 determined from samples collected by the USGS on August 17, 1988, are included in table 3 and discussed in this section. Concentrations of dissolved sulfate in the sample from well 23-1053 and in the sample from well 23-1165 exceeded the secondary maximum contaminant level (SMCL) of 250 mg/L (New Jersey Administrative Code, 1990b). The elevated concentrations of sulfate in these two samples probably can be attributed to the dissolution of gypsum (a calcium sulfate mineral), which occurs at depth in the Passaic Formation. Samples from these two wells also were enriched in calcium and magnesium relative to concentrations in samples from shallower wells. The ground-water sample from well 23-1053 also contained dissolved manganese in concentrations greater than the SMCL of 0.05 mg/L and dissolved sodium in concentrations greater than the SMCL of 50 mg/L. Concentrations of sodium and chloride in the sample from well 23-1184 exceeded the SMCL's (50 and 250 mg/L).

Results of analyses of samples indicate that elevated concentrations of selected VOC's are present in the ground water near the C-Wing building to depths of at least 55 ft. Concentrations of carbon tetrachloride in samples from wells 23-1184 and 23-1183 were 340 µg/L and 3,400 µg/L, respectively, and greatly exceeded the MCL of 2 µg/L (New Jersey Administrative Code, 1990a). Concentrations of PCE in samples from both wells exceeded the MCL of 1 µg/L for this compound. PCE concentrations in samples from wells 23-1184 and 23-1183 were 5.4 µg/L and 85 µg/L, respectively. Results of analyses of duplicate samples collected from wells 23-1184 and 23-1183 that were analyzed at the USGS, New Jersey District, laboratory were similar to the results of the original analyses; however, concentrations of trichloroethylene in the duplicate sample from well 23-1183 exceeded the MCL of 1 µg/L (New Jersey Administrative Code, 1990a). VOC's were not present in ground-water samples collected from well 23-1186, which is upgradient from the C-Wing building; however, the temperature of the ground water from this well was 30.7°C, probably because of the presence of an underground steam line nearby. Because VOC's present in the ground water from this well probably would be affected by the elevated water temperature, VOC data for this site probably are unreliable.



Base from Rutgers University, Modified from Aerial Data Reduction Associates, 1:600, 1988, Aerial photography by Keystone Aerial Surveys, March, 1985.

Figure 9. Water levels in the shallow aquifer at the Rutgers University, Busch Campus, New Jersey, November 1992.

Table 2. Water levels in selected wells at the Rutgers University, Busch Campus, New Jersey, 1991-92

[MM/DD/YY, month/day/year]

Well number	Latitude	Longitude	Local well identifier	Elevation of land surface (feet above sea level)	Depth of screen or open interval (feet below land surface)	Altitude of water level (feet above sea level)	Date measured (MM/DD/YY)
23-1053	403110	742812	RUTGERS GOLF COURSE	55.71	55 - 300	73.31	4/29/92
23-1165	403108	742812	RUTGERS GOLF 13 OBS	58.80	50 - 200	57.27	11/12/91
23-1165						55.82	12/05/91
23-1165						56.86	1/13/92
23-1165						58.06	4/01/92
23-1165						59.13	4/29/92
23-1165						57.88	8/17/92
23-1165						56.52	11/23/92
23-1183	403118	742743	RU-5	107.59	55 - 75	70.79	10/22/91
23-1183						68.91	11/13/91
23-1183						73.35	4/02/92
23-1184	403118	742743	RU-2	108.67	7 - 27	96.77	8/23/91
23-1184						96.91	10/22/91
23-1184						96.85	11/13/91
23-1184						96.82	1/13/92
23-1184						96.82	4/02/92
23-1184						96.84	11/23/92
23-1185	403118	742743	RU-4	107.45	7 - 27	91.61	8/23/91
23-1185						91.11	10/22/91
23-1185						90.93	11/13/91
23-1185						92.19	1/13/92
23-1186	403120	742742	RU-3	110.93	7 - 27	98.24	10/22/91
23-1186						98.71	1/13/92
23-1186						99.00	4/01/92
23-1186						101.65	11/23/92
23-1187	403112	742754	B-6	84.01	14 - 16	77.52	6/26/92
23-1187						78.23	8/19/92
23-1187						76.40	11/23/92
23-1188	403114	742807	B-9	61.14	9.6 - 11.6	59.04	8/14/92
23-1188						59.09	8/19/92
23-1188						59.81	11/23/92
23-1189	403116	742745	B-5	97.32	5 - 8	94.83	1/13/92
23-1189						93.61	4/07/92
23-1189						94.12	11/23/92
23-1190	403117	742743	B-4	96.14	2 - 4	95.41	12/17/91
23-1190						96.12	1/13/92
23-1190						95.96	4/07/92
23-1190						96.51	11/23/92
23-1191	403118	742757	B-1	79.47	14 - 15	74.59	11/19/91
23-1191						75.52	12/05/91
23-1191						75.62	1/13/92
23-1191						75.73	4/07/92
23-1191						75.55	11/23/92
23-1192	403118	742757	B-3	78.66	5 - 6	75.84	12/17/91
23-1192						75.84	1/13/92
23-1192						76.04	4/07/92

Table 3. Chemical and physical properties of, and selected chemical constituents in, ground-water samples, the Rutgers University, Busch Campus, New Jersey, 1992

[All concentrations in milligrams per liter unless otherwise noted; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; -- no determination; (°C), degrees Celsius; MM/DD/YY, month/day/year]

Well number	Local well identifier	Sampling date (MM/DD/YY)	Temperature (°C)	Oxygen, dissolved	Field pH (standard units)	Specific conductance (µS/cm)	Lab alkalinity (as $CaCO_3$)
23-1184	RU-2	4/02/92	15.0	6.6	7.7	1,090	38.0
23-1186	RU-3	4/01/92	30.5	5.0	5.5	189	5.4
23-1183	RU-5	4/02/92	15.5	--	7.7	335	130
23-1165	RUTGERS GOLF 13 OBS	4/01/92	13.0	.2	7.6	937	130
23-1165		8/17/92	12.9	1.4	7.8	1,009	--
23-1053	RUTGERS GOLF COURSE	8/17/88	13.0	<.1	7.3	2,330	106
23-1053		4/01/92	13.5	.3	7.4	1,170	--
23-1053		8/19/92	13.6	.1	7.5	2,040	--

Well number	Ammonia, dissolved (as N)	Nitrate, dissolved (as N)	Nitrite, dissolved (as N)	Calcium, dissolved (as Ca)	Magnesium, dissolved (as Mg)	Sodium, dissolved (as Na)	Potassium, dissolved (as K)	Chloride, dissolved (as Cl)
23-1184	<0.10	4.3	<0.010	90	23	92	5.7	280
23-1186	< .10	4.8	< .010	11	5.7	21	<5.0	22
23-1183	< .10	2.1	< .010	50	9.0	13	<5.0	24
23-1165	.19	.21	< .010	170	30	45	5.4	2.0
23-1165	--	--	--	--	--	--	--	--
23-1053	.26	--	< .010	370	45	79	4.1	13
23-1053	--	--	--	--	--	--	--	--
23-1053	--	--	--	--	--	--	--	--

Well number	Sulfate, dissolved (as SO_4)	Fluoride, dissolved (as F)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)
23-1184	49	0.17	<5	130	<5	<5	<10	<20
23-1186	31	.18	<5	<100	<5	<5	<10	<20
23-1183	10	.14	<5	620	<5	<5	<10	<20
23-1165	430	.64	<5	<100	7	11	15	30
23-1165	--	--	--	--	--	--	--	--
23-1053	1,300	.10	6	--	--	<1	2	<1
23-1053	--	--	--	--	--	--	--	--
23-1053	--	--	--	--	--	--	--	--

Well number	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)	Polychlorinated biphenyls, total (µg/L)
23-1184	<150	<5	<30	<40	<50	<1	<50	<0.52
23-1186	<150	<5	<30	<40	61	<1	<50	< .52
23-1183	<150	<5	<30	<40	<50	<1	<50	< .52
23-1165	<150	<5	87	<40	81	<1	<50	< .52
23-1165	--	--	--	--	--	--	--	--
23-1053	170	<5	320	--	16	<0.1	--	--
23-1053	--	--	--	--	--	--	--	--
23-1053	--	--	--	--	--	--	--	--

Table 4. Concentrations of selected volatile organic compounds in ground-water samples, the Rutgers University, Busch Campus, New Jersey, 1992

[All concentrations in micrograms per liter unless otherwise noted; <, less than; -- no determination; MM/DD/YY, month/day/year; DUP, duplicate]

Well number	Local well identifier	Sampling date (MM/DD/YY)	Benzene total	Carbon tetra-chloride total	Chloroform total	cis-1,2-Di-chloro-ethylene total	Tetra-chloro-ethylene total	Trichloro-ethylene total	Trichloro-fluoro-methane total
23-1184	RU-2	4/02/92	<0.3	340	16	<0.3	5.4	<0.4	12
23-1184 (DUP)		4/02/92	< .5	310	66	--	10	--	--
23-1186	RU-3	4/01/92	< .3	< .4	< .2	< .3	< .3	< .4	< .4
23-1186 (DUP)		4/01/92	< .5	< .5	.4	--	< .5	< .5	--
23-1183	RU-5	4/02/92	< .3	3,400	24	.32	85	.83	.81
23-1183 (DUP)		4/02/92	< .5	2,467	11.6	--	74	28	--
23-1165	RUTGERS GOLF 13 OBS	4/01/92	< .3	< .4	< .2	< .3	1.4	< .4	< .4
23-1165		8/17/92	--	< .5	< .5	< .5	3	< .5	< .5
23-1053	RUTGERS GOLF COURSE	4/01/92	< .5	< .5	< .5	--	17.7	< .5	--
23-1053		8/19/92	--	< .5	< .5	< .5	15	< .5	< .5
23-1191	B-1	1/17/92	--	< .5	< .5	--	< .5	--	--
23-1190	B-4	4/07/92	--	112.9	6.5	--	1.8	1	--
23-1189	B-5	4/07/92	--	9.9	1.3	--	< .5	< .5	--
23-1187	B-6	8/19/92	--	< .5	< .5	--	< .5	--	--
23-1188	B-9	8/19/92	--	< .5	< .5	--	< .5	--	--

Concentrations of PCE in samples from wells 23-1165 and 23-1053 also exceeded the MCL. These wells are located on the University Golf Course about 2,400 ft downgradient from the C-Wing building. Because these wells have large open intervals (table 2), the samples represent composites of water from several water-bearing zones. Based on the open intervals of these wells, PCE is present in the ground water at these wells to depths of at least 50 and 55 ft, respectively. Because of the absence of other data-collection points of similar depths between these wells and those at the C-Wing building, however, it is inconclusive whether the presence of PCE in samples from these wells is associated with the presence of PCE in samples from wells adjacent to the C-Wing building.

Samples collected from piezometers 23-1189 and 23-1190 within and near the soil-gas plume indicate the presence of carbon tetrachloride in the shallow ground water in concentrations greater than the MCL. The sample from piezometer 23-1190 also contained concentrations of PCE greater than the MCL. Samples withdrawn from other piezometers beyond the soil-gas plume contained no detectable VOC's.

SUMMARY AND CONCLUSIONS

A zone of contaminated ground water is present adjacent to and downgradient from the Rutgers University, Busch Campus, Chemical Engineering building, C-Wing. Surface geophysical techniques were used with limited success to delineate the hydrogeologic framework of the site. The average strike of the bedrock in the study area is N. 57° E. and the dip is 11° to the northwest. Two major sets of near-vertical joints are present at the site; one set trends northeast subparallel to the strike of bedding, and the other set trends northwest approximately perpendicular to the first set. The electromagnetic-conductivity survey was inconclusive because of man-made interferences; however, the azimuthal resistivity method indicated that the dominant axis of joints was aligned in a northeast-southwest direction.

Results of a survey of soil gas in the unsaturated zone were used to estimate the extent of contaminants in the shallow subsurface. Carbon tetrachloride was the dominant volatile organic compound (VOC) in the unsaturated zone; it was present at 17 of the 43 sites sampled; concentrations of carbon tetrachloride in the soil gas were highest near the C-Wing building. Tetrachloroethylene was present in soil-gas samples from four sites. Both compounds were present in samples collected about 550 ft from the C-Wing building. Shallow contamination could have migrated southwest of the C-Wing building, following the topographic gradient. The orientation of the soil-gas plume indicates that VOC's may have migrated slightly downdip as well; however, this could result from an alteration of the flow path of the shallow ground water as a result of the presence of underground structures, such as sewer lines.

Ground-water samples from four observation wells, one irrigation well, and five piezometers at the study site were analyzed to determine concentrations of VOC's. Carbon tetrachloride was present in high concentrations (3,400 μg/L) in ground-water samples collected near the C-Wing building. Tetrachloroethylene was detected in ground-water samples collected from a well about 2,400 ft downgradient from the C-Wing building. Carbon tetrachloride and tetrachloroethylene were present in ground-water samples collected at screened intervals at least 55 ft below land surface near the C-Wing building. Tetrachloroethylene was present in samples collected at a depth of at least 55 ft in wells located on the Rutgers University Golf Course downgradient from the C-Wing building.

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Appendix 1. Maximum contaminant levels for selected organic compounds and inorganic constituents, New Jersey. (Maximum contaminant levels from New Jersey Administrative Code, 1990a)

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
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

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