GROUND-WATER CONTAMINATION AT WURTSMITH AIR FORCE BASE, MICHIGAN

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DEFINITION OF TERMS

Altitude. Vertical distance of a point or line above or below the National Geodetic Vertical Datum of 1929. The National Geodetic Vertical Datum of 1929 (NGVD of 1929) is a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. In this report, all altitudes are above NGVD of 1929.

Aquifer. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. It is also called a ground-water reservoir.

Bedrock. Designates consolidated rocks.

Concentration. The weight of dissolved solids or sediment per unit volume of water expressed in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Contour. An imaginary line connecting points of equal altitude, whether the points are on the land surface, on the clay surface, or on a potentiometric or water-table surface.

Divide. A line of separation between drainage systems. A topographic divide delineates the land from which a stream gathers its water; a ground-water divide is a line on a potentiometric or water-table surface on each side of which the potentiometric surface slopes downward away from the line.

Equipotential line. A line in an aquifer on which every point has the same potentiometric head. As used in this report, equipotential lines define the water table. The value identifying a given line is the altitude of all points on that line.

Ground water. Water that is in the saturated zone from which wells, springs, and ground-water runoff are supplied.

Hydraulic conductivity. The volume of water at the prevailing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. In general terms, hydraulic conductivity is the ability of a porous medium to transmit water.

Hydrograph. A graph showing the variations of stage, flow, velocity, discharge, or other aspect of water with respect to time.

Permeability, intrinsic. A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient. It is a property of the medium alone, and is independent of the nature of the fluid and of the force field.

Picocurie (pCi). One trillionth (1×10^{-12}) of the amount of radioactivity represented by a curie (Ci). A curie is the amount of radioactivity that yields 3.7×10^{10} radioactive disintegrations per second. A picocurie yields 2.22 dpm (disintegrations per minute).

Potentiometric surface. In aquifers, the levels to which water will rise in tightly cased wells. More than one potentiometric surface is required to describe the distribution of head. The water table is a particular potentiometric surface.

Recharge. The process by which water is infiltrated and is added to the zone of saturation. It is also the quantity of water added to the zone of saturation.

Runoff. That part of precipitation that appears in streams; the water draining from an area. When expressed in inches, it is the depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface.

Specific capacity. The rate of discharge of water from a well divided by the drawdown of water level within the well.

Specific conductance. A measure of the ability of water to conduct an electric current, expressed in micromhos (μmho) per centimeter at 25°C. Because the specific conductance is related to amount and type of dissolved material, it is used for approximating the dissolved-solids concentration of water. For most natural waters the ratio of dissolved-solids concentration (in milligrams per liter) to specific conductance (in micromhos) is in the range 0.5 to 0.8.

Specific yield. The ratio of the volume of water that the rock, after being saturated, will yield by gravity, to the volume of rock. It is used for water table aquifers.

Transmissivity. The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Water table. That surface in an unconfined water body at which the pressure is atmospheric. It is defined by levels at which water stands in wells.

CONVERSION FACTORS

The inch-pound units used in this report can be converted to the metric system of units as follows:

Multiply inch-pound unit	By	To obtain metric unit
inches	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons (gal)	3.785	liters (L)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
cubic feet per second (ft^3/s)	28.32	liters per second (L/s)
cubic feet per second per square mile [(ft^3/s)/mi^2]	0.0386	liters per second per square kilometer [(L/s)/km^2]
gallons per minute per foot [(gal/min)/ft]	0.207	liters per second per meter [(L/s)/m]
degrees Fahrenheit (°F)	(*)	degrees Celsius (°C)
micromhos	1.000	microsiemens (μs)

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* Temperature °C = (temperature °F -32)/1.8.

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ABSTRACT

A sand and gravel aquifer of glacial origin underlies Wurtsmith Air Force Base in northeastern lower Michigan. The aquifer overlies a thick clay layer at an average depth of 65 feet. The water table is about 10 feet below land surface in the western part of the Base and about 25 feet below land surface in the eastern part. A ground-water divide cuts diagonally across the Base from northwest to southeast. South of the divide, ground water flows to the Au Sable River; north of the divide, it flows to Van Etten Creek and Van Etten Lake. Mathematical models were used to aid in calculating rates of ground-water flow. Rates range from about 0.8 feet per day in the eastern part of the Base to about 0.3 feet per day in the western part. Models also were used as an aid in making decisions regarding purging of contaminated water from the aquifer.

In 1977, trichloroethylene was detected in the Air Force Base water-supply system. It had leaked from a buried storage tank near Building 43 in the southeastern part of the Base and moved northeastward under the influence of the natural ground-water gradient and the pumping of Base water-supply wells. In the most highly contaminated part of the plume, concentrations are greater than 1,000 micrograms per liter. Current purge pumping is removing some of the trichloroethylene, and seems to have arrested its eastward movement. Pumping of additional purge wells could increase the rate of removal.

Trichloroethylene has also been detected in ground water in the vicinity of the Base alert apron, where a plume from an unknown source extends northeastward off Base. A smaller, less well-defined area of contamination also occurs just north of the larger plume. Trichloroethylene, identified near the waste-treatment plant, seepage lagoons, and the northern landfill area, is related to activities and operations in these areas. Dichloroethylene and trichloroethylene occur in significant quantities westward of Building 43, upgradient from the major spill site. Benzene, indicative of ground-water contamination by a fuel substance, occurs in an area northeast of the bulk-fuel storage area. Analysis of a variety of chemical, physical, and biologic characteristics of water on the Base indicate that there is a measurable affect on ground-water quality from landfills, the seepage lagoon, and the waste-treatment plant.

INTRODUCTION

The U.S. Geological Survey, at the request of the U.S. Air Force, began an investigation of geologic and hydrologic conditions at Wurtsmith Air Force Base[1/] in September 1979. The investigation was prompted by the discovery that an underground storage tank containing trichloroethylene (TCE) had leaked, contaminating Base water-supply wells. Subsequent information suggested that the trichloroethylene had moved off-Base. A proposed plan of investigation by the Geological Survey was incorporated in a Statement of Work prepared by the Air Force. The major elements of the investigation were to include: (1) a determination of the rate and direction of ground-water movement, (2) a determination of the horizontal and vertical extent of trichloroethylene contamination, (3) an investigation of all suspected sources of ground-water contamination, including past and present landfill areas, (4) the development of a mathematical ground-water-flow model, and (5) a determination, for areas of contamination, of hydrologically suitable sites for installing purge wells, and a prediction of the quantities of water that could be withdrawn.

During the investigation, expansion of its scope was required. Trichloroethylene in ground water, once thought to be only the result of storage tank leakage, was found at some places on the Base to be unrelated to the initially identified spill site. Dichloroethylene was also detected. Contamination of ground water by a fuel substance, indicated by high concentrations of benzene, was found. Other organic compounds were detected at scattered locations.

Description of Area

Wurtsmith Air Force Base is in Iosco County in northeastern Lower Michigan (fig. 1). About 7,700 people live or work on the Base.

The Base is a 7-square-mile area adjacent to the community of Oscoda on the west shore of Lake Huron. The land surface is a 5-mile wide plain bounded on the west by 80-foot-high bluffs (fig. 2). Several small streams flow from the bluffs and discharge into a swampy area west of the Base.

The Au Sable River, which flows eastward and discharges into Lake Huron, is half a mile south of the Base. The land between the Base and the river is swampy. From the bluffs and extending 20 miles upstream, flow in the Au Sable River is controlled by a series of dams. Van Etten Lake, northeast of the Base, is 4 miles long and half a mile wide. The altitude of the land surface ranges from 580 to 750 feet (fig. 2).

Mean monthly temperatures range from 21°F in January to 68°F in July. The lowest recorded temperature is -22°F, the highest 102°F. Average annual precipitation is 30 inches; average snowfall is 44 inches.

1/ Referred to as the "Base" in this report.

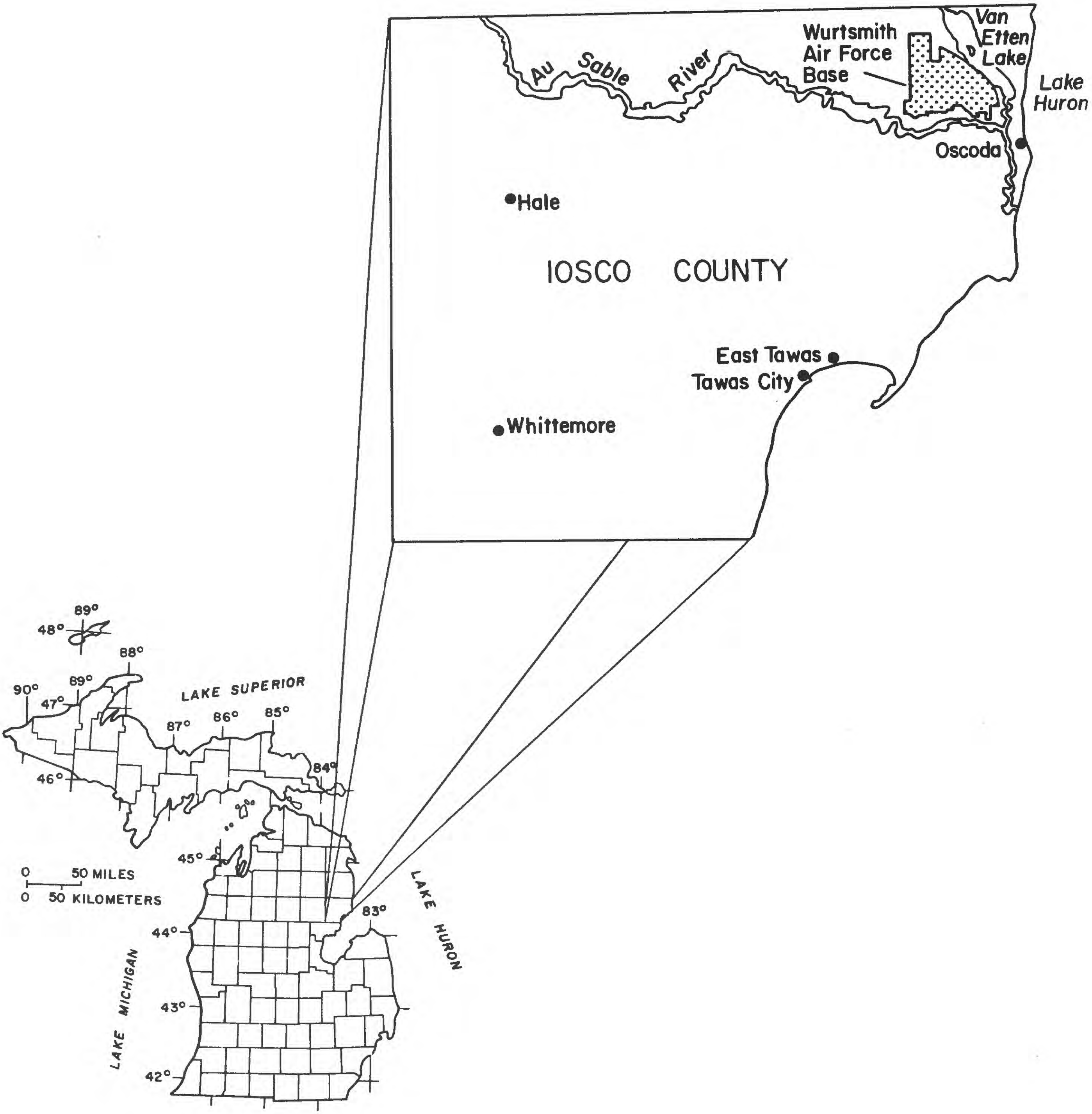
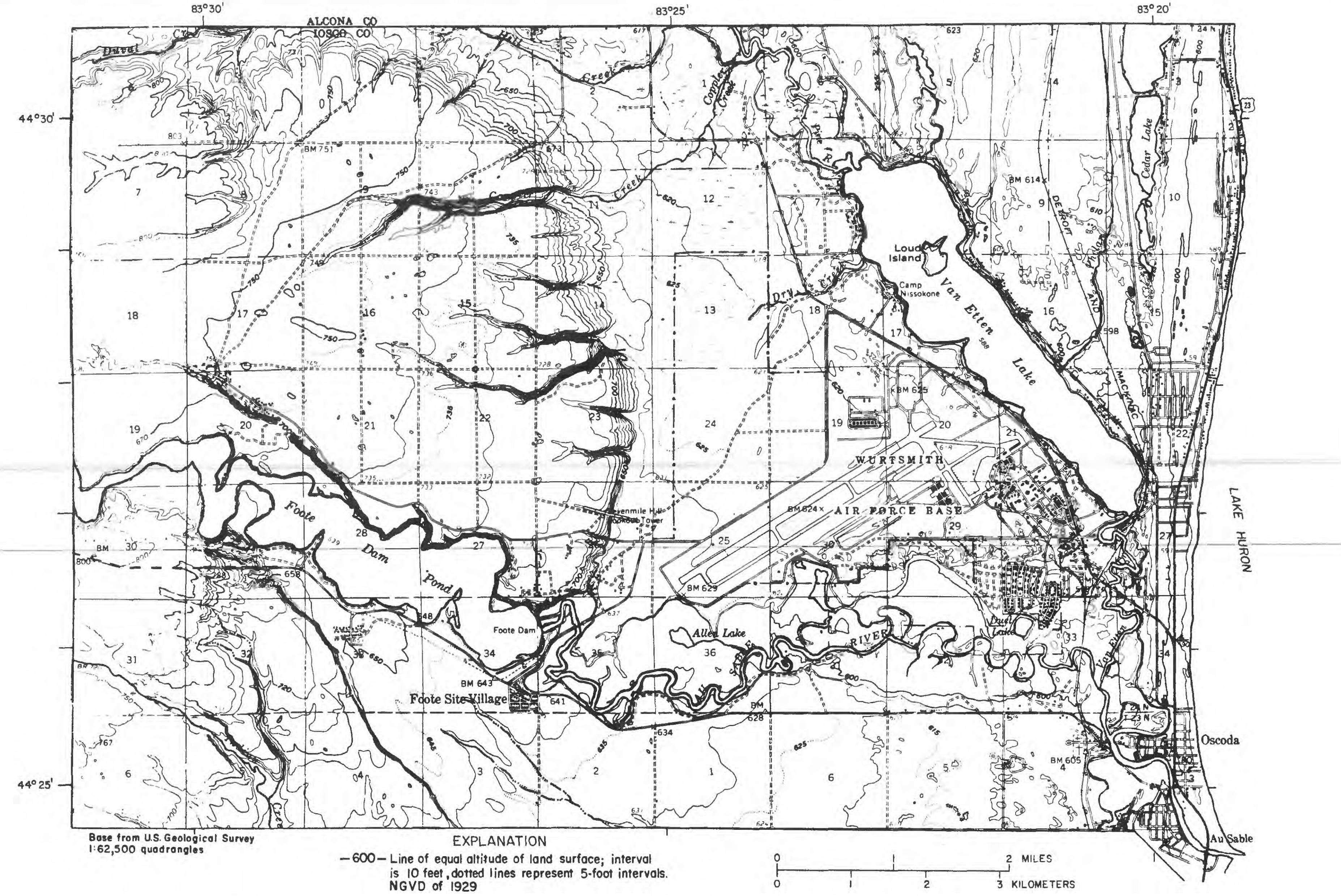


Figure 1.--Location of Wurtsmith Air Force Base in Michigan.



Base from U.S. Geological Survey
1:62,500 quadrangles

Figure 2.--Physical features in vicinity of Wurtsmith Air Force Base.

Nature and Scope of the Problem

Detection of Trichloroethylene in Water

In October 1977, complaints about a peculiar odor and taste of drinking water were received by the Civil Engineering Squadron, which oversees production and distribution of water on the Base. Analysis of water from a faucet in a Base-housing unit showed that it contained 1,100 µg/L (micrograms per liter) of trichloroethylene. Also, water from well AF3, a water-supply well in the eastern part of the Base, was found to contain about 6,700 µg/L of trichloroethylene.

The suspected source of contamination was near Building 43 (pl. 1), the jet engine repair shop, where a 500-gallon buried tank was used to store trichloroethylene temporarily after it had been used to degrease jet engine parts. Excavation of the tank indicated that the connection between the filler pipe and the tank had leaked, which seemed to confirm that the tank was the source of trichloroethylene in ground water.

Further investigations of Base water supplies by the Air Force indicated that water from well AF15, supplying the procurement office (Building 4004) in the southeastern part of the Base, also contained trichloroethylene. Trichloroethylene was also detected in other Base supply and observation wells at various locations. Analyses of water from private wells in the vicinity showed that water from all but one well was free of trichloroethylene. Water from the contaminated well, about 1,000 feet east of the Base near Pierce's Point on Van Etten Lake, contained enough trichloroethylene to make it unsuitable as a domestic supply.

Effect of Contamination on Water-Supply System

The primary water supply for Wurtsmith Air Force Base has been from wells AF1, AF2, AF3, AF4, and AF5, in the eastern part of the Base, and from AF18 and AF19, in the southern part (pl. 1). Individual wells at other locations supply water for a housing unit and several other buildings. All supply wells are less than 60 feet deep and tap a shallow sand and gravel aquifer.

Before 1977, the primary water supply was obtained from wells in the eastern part of the Base. After discovery of trichloroethylene in water from these wells in November 1977, their use was discontinued, and most water requirements were met by wells in the southern part of the Base. In January 1978, after it had been confirmed that only trace amounts of trichloroethylene occurred in water from wells AF4 and AF5, these two wells were again used. In March 1978, trichloroethylene was detected in water from well AF18, and its use was discontinued. Use of well AF19 was also discontinued when trichloroethylene was detected in August 1978. The present Base supply is from wells AF2, AF4, and AF5, although the current absence of trichloroethylene in water from wells AF18 and AF19 again permits their use if needed. Individual wells at other locations, with the exception of the contaminated well AF15, are still used and yield water that contains little or no trichloroethylene.

Initial Purging of Aquifer

In March 1978, the Air Force began efforts to purge trichloroethylene from the aquifer by pumping wells AF1 and AF3. An average of 280 gal/min from the two wells was pumped to an aeration reservoir just north of well AF3. Air was forced into the trichloroethylene-laden water in the reservoirs by large air blowers. In May 1978, three new purge wells, AF55, AF56, and AF57 were drilled near Building 43 (pl. 1) and included in the purge system. Three additional purge wells, AF58, AF59, and AF60, were installed near Building 43 in August 1979. Water from these six wells was pumped at an average rate totaling 125 gal/min to a newly constructed aeration reservoir close by. Water from both aeration reservoirs was then piped to the waste-treatment plant in the southeast part of the Base and subsequently to seepage lagoons in the southwest part. In the fall of 1979, carbon filtration was added to the system to remove trichloroethylene remaining after aeration.

METHODS OF DATA COLLECTION AND ANALYSIS

The U.S. Geological Survey began collecting data in late 1979 by installation of wells in areas of known contamination. Well installation continued throughout the study as information accumulated. Two-hundred-seventeen wells were installed on the Base and in the surrounding area (pl. 1 and fig. 3). One-hundred sixty-eight of the wells have 4-inch diameters and were used for pumping tests, water-level measurements, and collection of water samples for analysis. Forty-nine wells of 1¼-inch diameters were used exclusively for water-level measurements. Data for wells are shown in table 4. At 48 sites, both deep and shallow wells[1] were installed to detect vertical stratification of trichloroethylene. Most deep wells were finished by setting well screens just above the top of the clay unit. In shallow wells, screens were generally set 10 to 20 feet below the water table. During drilling, a log was kept, and samples of materials were collected. During 1980, water levels were measured, on a monthly or continuous basis, in 165 of the wells installed by the Geological Survey. From January to April 1981, levels continued to be measured in many of these wells and in 52 newly installed wells. Levels were measured monthly in 20 to 30 additional Air Force wells during 1980-81. Wells G4S, G9S, G16S, and G22M (pl. 1) were equipped with continuous recorders. A staff gage, to measure fluctuations in the level of Van Etten Lake, was installed at its mouth.

Samples of water for analysis of trichloroethylene and other hydrocarbons were collected from December 1979 to March 1981. Water from 197 wells was analyzed on one or more occasions. Water from Dry Creek, Van Etten Lake, and the carbon filtration system effluent was also analyzed.

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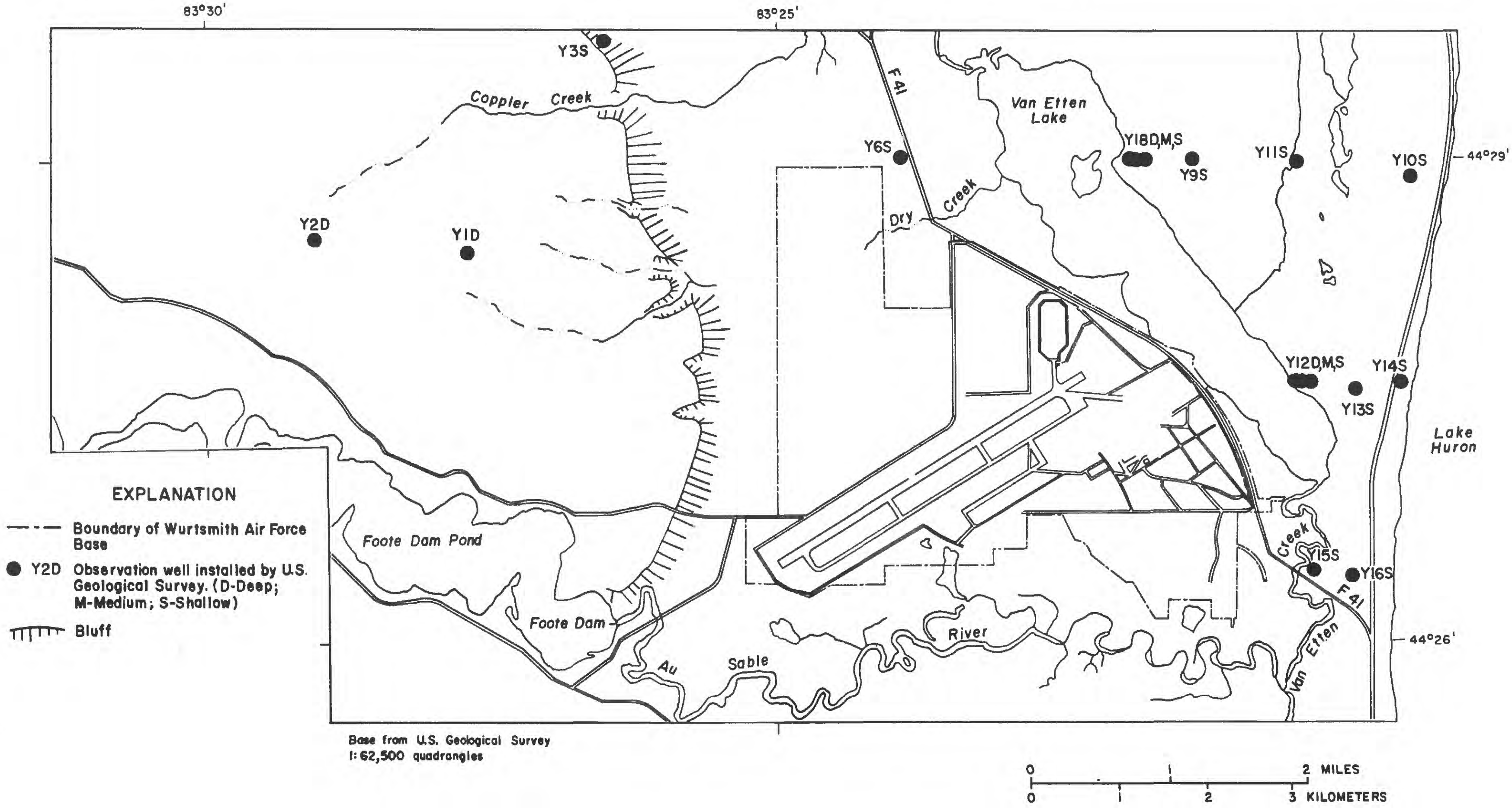
[1] Deep and shallow wells are designated in the report by "D" or "S" following the well number. At a few locations, wells of intermediate depth were also installed. These are designated by "M" following the well number.



Base from U.S. Geological Survey
1:62,500 quadrangles

Figure 3.--Location of wells installed by the U.S. Geological Survey in areas surrounding Wurtsmith Air Force Base.

Submersible pumps and R-3400 Tygon tubing from Norton Company[1] were used to collect samples. When appropriate, the order in which wells were sampled was chosen so that teams of samplers moved from wells of lower trichloroethylene concentration to those known or suspected of having a higher concentration. Before inserting the pump and tubing in a well, both were cleaned with methyl alcohol. All wells were pumped for 15 minutes before sampling. At least two samples were collected from each well in order that duplicate analyses could be made if needed. In areas of significant trichloroethylene contamination, water pumped from a well was discharged into a tanker, for subsequent disposal to an aeration reservoir. Immediately after collection, samples were chilled and prepared for shipment to the laboratory. Analyses were made by the U.S. Geological Survey with a gas chromotograph - mass spectrometer system. A selective ion-monitoring (SIM) technique was added when necessary.

Data obtained by the Geological Survey confirmed trichloroethylene levels found in preceding work by the U.S. Air Force, the State of Michigan, and the U.S. Environmental Protection Agency. Duplicate samples, collected by the Survey and analyzed by both Air Force and Survey laboratories for verification, gave results within the expected analytical error.

Data collected in this study as well as information from other sources were evaluated to determine the geologic and hydrologic conditions at the Base, and to define the location, concentration, and movement of trichloroethylene and other contaminants. Hydraulic models of the ground-water system were developed to better understand flow conditions. One model, referred to as the "Base model," simulates general ground-water flow on the Base. Two detailed models, termed the "Building 43 plume model" and the "Alert Apron plume model," were developed to simulate ground-water flow in those areas. The models were calibrated by duplicating conditions measured in the field. After calibration, they were used to simulate hydrologic responses to past water-supply and purge pumping and to simulate future responses to a variety of pumping conditions, including increased purge pumping. A description of the development and calibration of these models is given in the Appendix.

Only summaries of some of the geologic and hydrologic data collected by the Geological Survey are included in this report. Individual logs of most wells and records of water-level measurements are not included. Tabulations of all water-quality data, however, are given in the Appendix. Data obtained by the U.S. Air Force, such as analyses of water for trichloroethylene, have been cited as to source when used in evaluations and interpretations, but their bulk precludes inclusion in this report.

GEOLOGY

Wurtsmith Air Force Base is underlain by glacial deposits, consisting primarily of sand and clay, that are as thick as 225 feet. Underlying the glacial deposits are bedrock formations of sandstone, shale, and limestone.

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

Data indicate that water in the bedrock is salty. However, because a thick clay unit separates bedrock from the principal aquifer, water in bedrock probably has no effect on the quality of water in the glacial deposits. Thus, bedrock formations were not studied in detail.

Glacial Deposits

Glacial materials were deposited about 13,000 years ago, when ancestral Lake Huron was at a higher level. At that time, materials from receding glaciers were transported by meltwater in an ancestral Au Sable River (Burgis, 1977). Coarse materials were deposited at the river's mouth. Fine materials were carried farther into the lake. Bluffs near the west edge of Wurtsmith Air Force Base were formed by erosion when the lake was at a lower level. Glacial deposits consist of two distinct units--clay and overlying sand and gravel.

Clay Unit

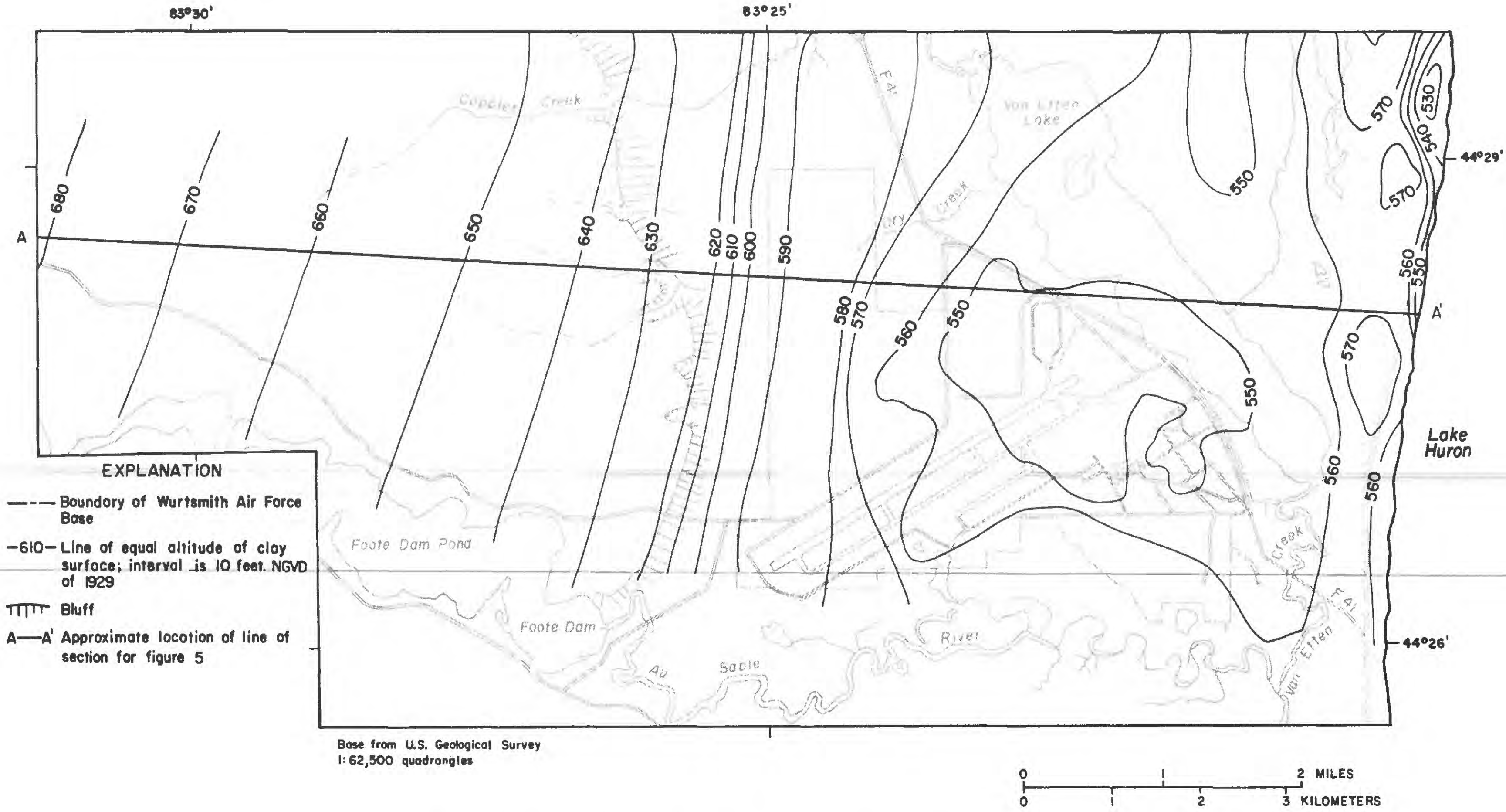
The clay unit is mostly brown to gray, relatively impermeable, and cohesive. Its thickness at the Base is not accurately known because it has never been fully penetrated by wells, but it is at least 13 feet thick at well R6D. At Oscoda and at places east and north of Van Etten Lake, the clay unit is at least 125 feet thick and may be as thick as 250 feet. Clay of such thickness is an effective barrier to the vertical movement of water between overlying and underlying aquifers.

Wells installed in the northern part of the Base penetrated thin (2 to 5 feet) beds of clay at depths ranging from 5 to 15 feet. Northeast of Van Etten Lake, beds of clay 5 to 20 feet thick lie at altitudes correlative with those of the shallow clay on Base; this may indicate that the sand and gravel unit interfingers northeastward with the clay unit.

The altitude of the top of the clay unit is high west of the Base (fig. 4). It slopes downward to the east at 10 to 30 feet per mile (fig. 5). In general, the surface of the unit dips inward to low points in the northeast part of the Base and in an area just northeast of Van Etten Lake (fig. 4). The unit is only 10 to 15 feet below land surface along the foot of the bluffs. Water moves along the top of this impervious layer and causes perennial flow in Coppler Creek and other nearby streams. Similarly, flow of Dry Creek may be the result of water moving from the swampy area along the top of a shallow clay lens.

Sand and Gravel Unit

The sand and gravel unit ranges in thickness from 80 feet in the northern part of the Base to 30 feet at the west edge; the average thickness is 65 feet. It is a brown to gray-brown medium to coarse sand containing some gravel. Beds of gravel and coarse sand are more frequent in the western part of the Base. The following lithologic data are representative of this unit.



Base from U.S. Geological Survey
1:62,500 quadrangles

Figure 4.--Altitude of top of clay unit.

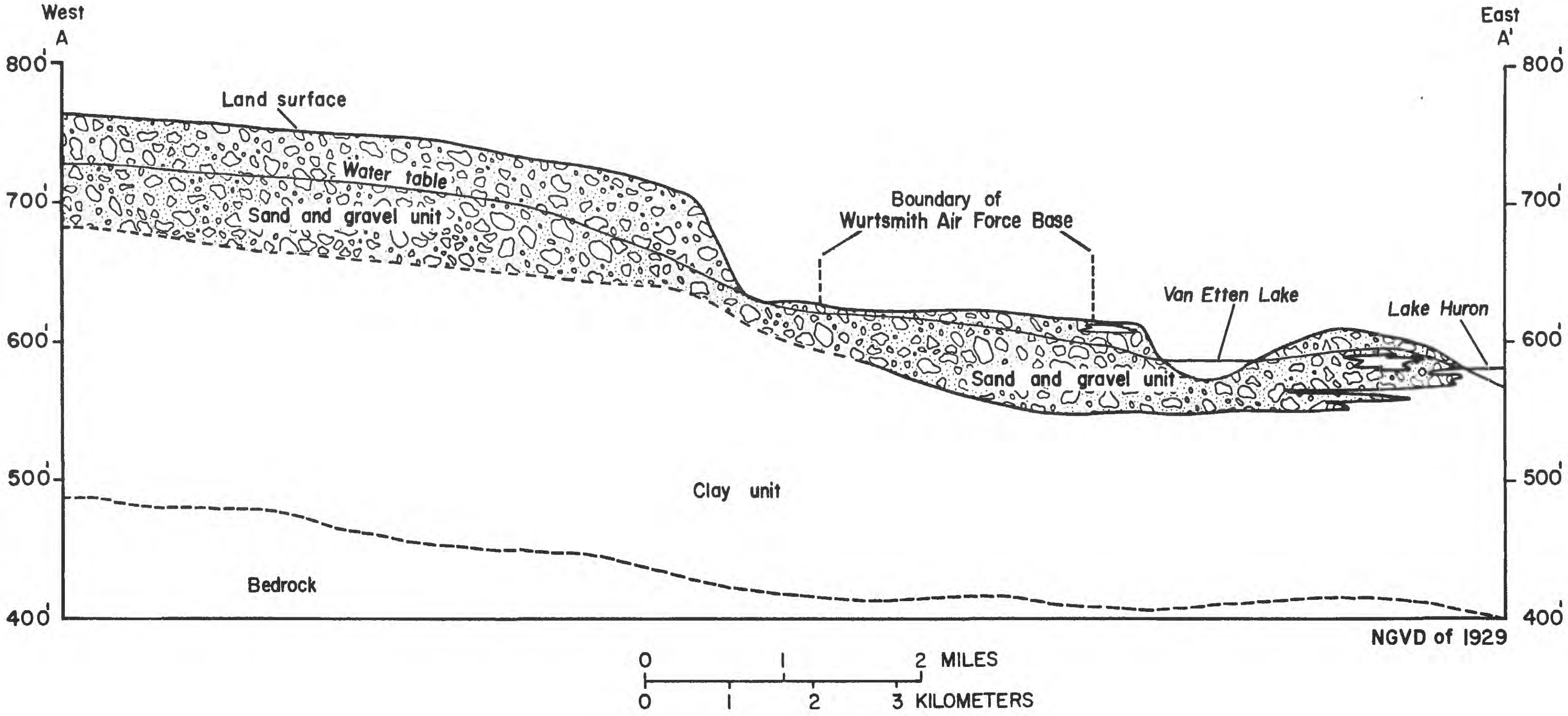


Figure 5.--Generalized geohydrologic section showing relation of sand and gravel unit to clay unit. Line of section shown in figure 4.

Well R8D
(South of Building 43)

	Depth to bottom, below land surface (feet)
Sand and gravel unit	
Sand, medium to coarse, mostly quartz	5
Sand, silty, fine to medium	10
Sand, medium to coarse, well sorted, rounded	20
Sand, medium to very coarse, some gravel	40
Sand and gravel, coarse to very coarse	55
Sand, fine to medium, mostly quartz, well sorted	60
Clay unit	
Sand, some clay	62
Clay, sandy	64

Well R36D
(East of alert apron)

	Depth to bottom, below land surface (feet)
Sand and gravel unit	
Sand, very fine to fine, mostly quartz, some clay	5
Sand and clay, very fine to fine	10
Sand, fine to medium, some clay	15
Sand, medium to very coarse, a few pebbles to ½-inch	20
Sand, coarse to very coarse, a few pebbles to ½-inch	35
Sand, medium to very coarse, mostly quartz	40
Sand, medium to coarse	45
Sand, medium to very coarse, mostly quartz, a few pebbles to ¼-inch	54

One-hundred seventy-seven lithologic samples of the sand and gravel unit from 19 wells were analyzed to determine grain-size distribution. About 80 percent had average grain sizes in the medium sand range (0.25-0.5 mm). Average grain sizes generally increase and are more variable to the west. Most material is moderately well sorted; the better sorted material occurs near the surface and in the eastern part of the Base.

HYDROLOGY

Flow in the sand and gravel aquifer[1] is generally eastward (fig. 6). Under hydrologic conditions during the study, a ground-water divide cut diagonally across the Base from northwest to southeast. South of the divide, ground water

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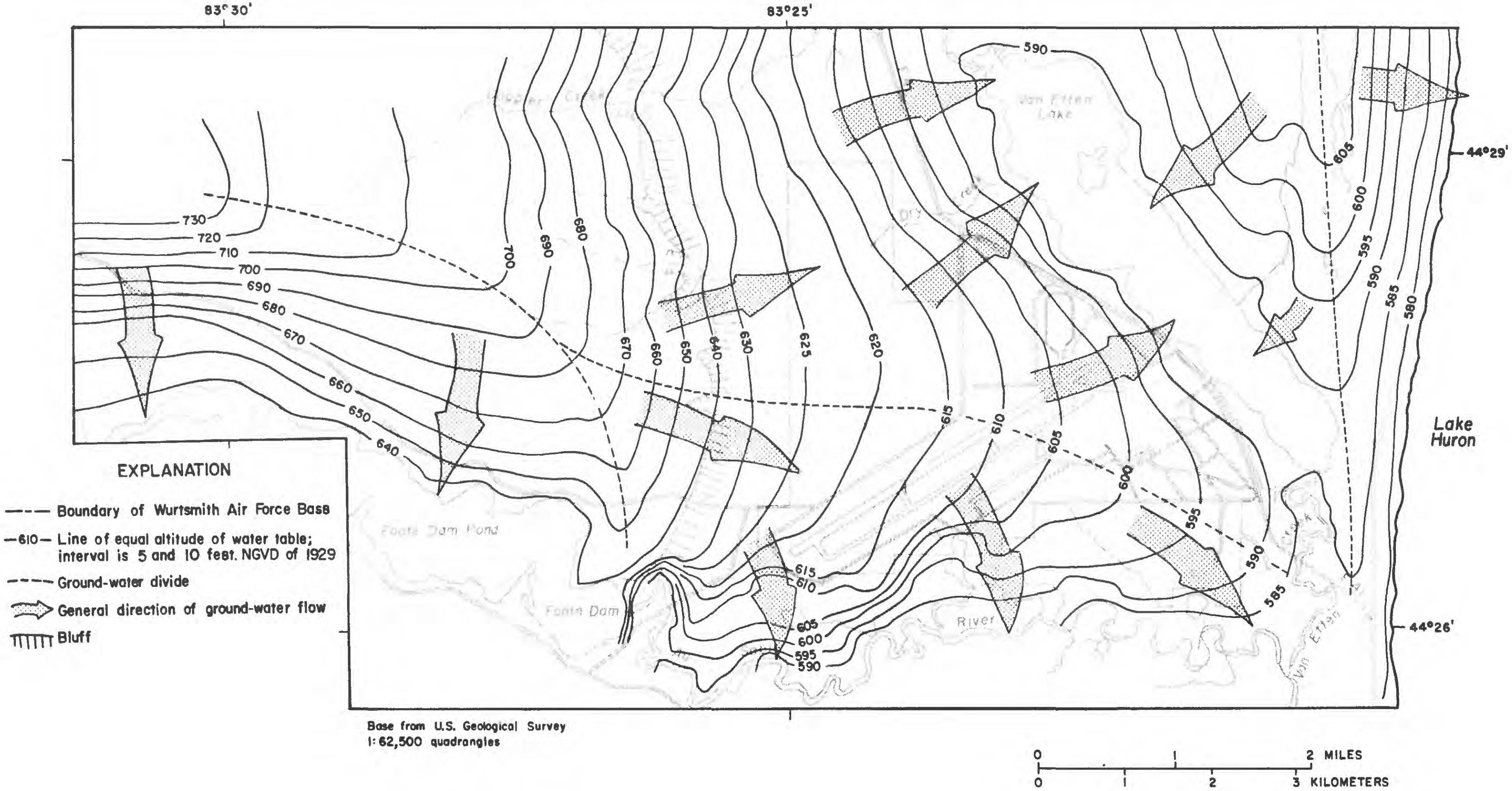
1/ Saturated part of sand and gravel unit of glacial deposits.



Base from U.S. Geological Survey
1:62,500 quadrangles

Figure 6.--Altitude of water table and direction of ground-water flow, September 1980.

flows toward the Au Sable River. North of it, water flows toward Van Etten Creek and Van Etten Lake. Ground-water flow at a given location is generally normal to the equipotential lines that define the water table. The general shape of the water table in areas not influenced by pumping did not change significantly during the study. At times when ground-water flow from the area of recharge to the west of the Base exceeded recharge from rainfall on the Base, the water table rose slightly along the west margin of the Base. In areas influenced by pumping, water levels were lowered and the direction of ground-water flow altered as water was drawn toward wells.

Water Table

The altitude and configuration of the water table in the sand and gravel aquifer is an important factor in determining ground-water flow and, thus, indirectly, in determining the movement of trichloroethylene and other contaminants. Changes in the water table, indicated by changes in water levels in wells, reflect changes in ground-water storage, which is controlled by precipitation; ground-water withdrawals; and the levels of nearby lakes, streams, and swamps.

Water levels in wells away from pumping centers and in wells near Van Etten Lake are typical of those of shallow unconfined aquifers composed of coarse-grained materials. Water levels are low in late fall or winter. However, they respond quickly to recharge, and, by late spring, after recharge has been increased by snowmelt, levels are high. Hydrographs of wells R9D and G22D (fig. 7) are typical. Water-level changes in these wells were less than 2 feet from January 1980 to April 1981.

Water levels in wells near Van Etten Lake vary with changes in levels of the lake. The hydrograph for well Y12S (fig. 8) on the southeast side of the lake is typical of those for wells near the lake. Water levels in this well changed 2.5 feet during the period of record. Lowest levels occurred in March and April and highest in May and June. These changes are related to similar changes in Van Etten Lake. A rapid rise or fall in the lake level, however, may not be immediately reflected in levels in nearby wells. Away from the shore of the lake, water-level changes in wells are smaller than near the shore. Maximum and minimum levels of the lake are legally controlled between the altitudes of 589.2 and 585.1 feet. Changes in lake levels do not significantly alter the direction of ground-water flow.

Water levels in wells in the vicinity of pumping wells are influenced by natural hydrologic changes and by pumping. As in other wells, levels are low in winter and high in late spring. However, because of variations in pumping patterns, fluctuations of water levels are much more frequent than fluctuations of water levels without pumping. The hydrograph for well Y19D (fig. 9) shows changes in levels over a 32-day period that are typical of wells in areas of pumping.

Hydrologic Properties of Aquifer

Hydraulic Conductivity, Transmissivity, and Specific Yield

Initial estimates of hydraulic conductivity, transmissivity, and specific yield of the sand and gravel aquifer were based on aquifer test data in Air

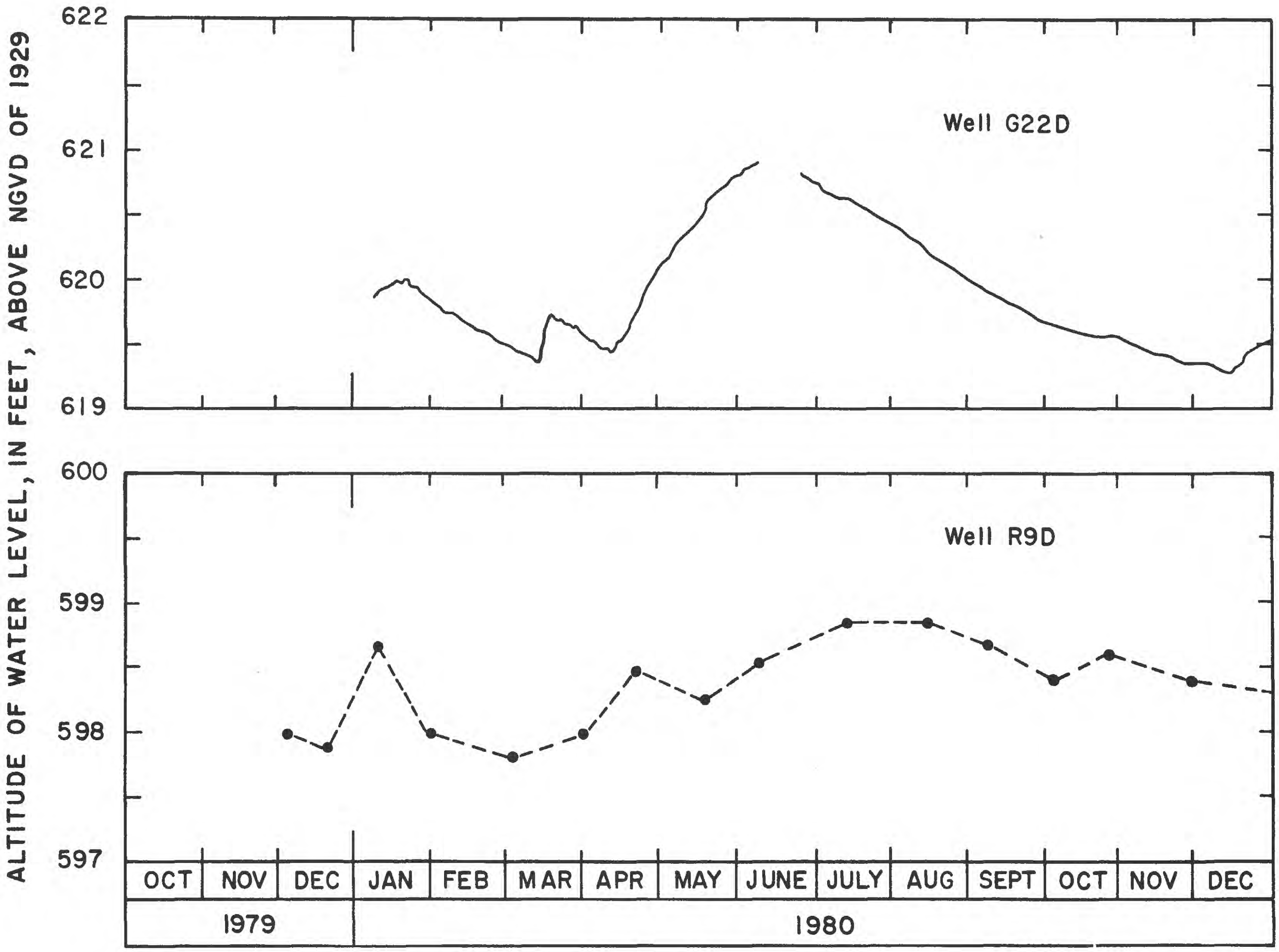


Figure 7.--Water levels in wells not significantly influenced by pumping or changes in levels of Van Etten Lake.

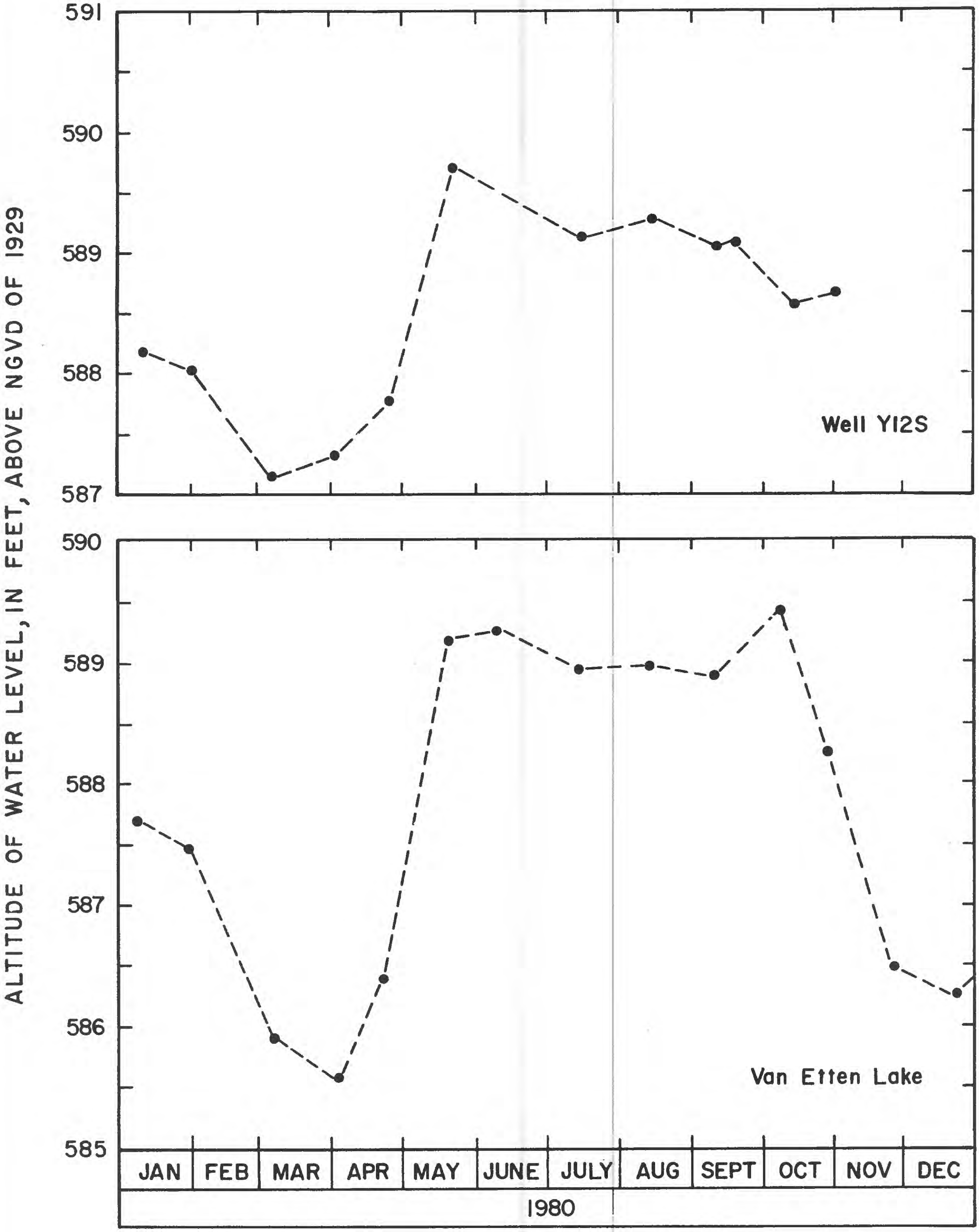


Figure 8.--Water levels of Van Etten Lake and a nearby well.

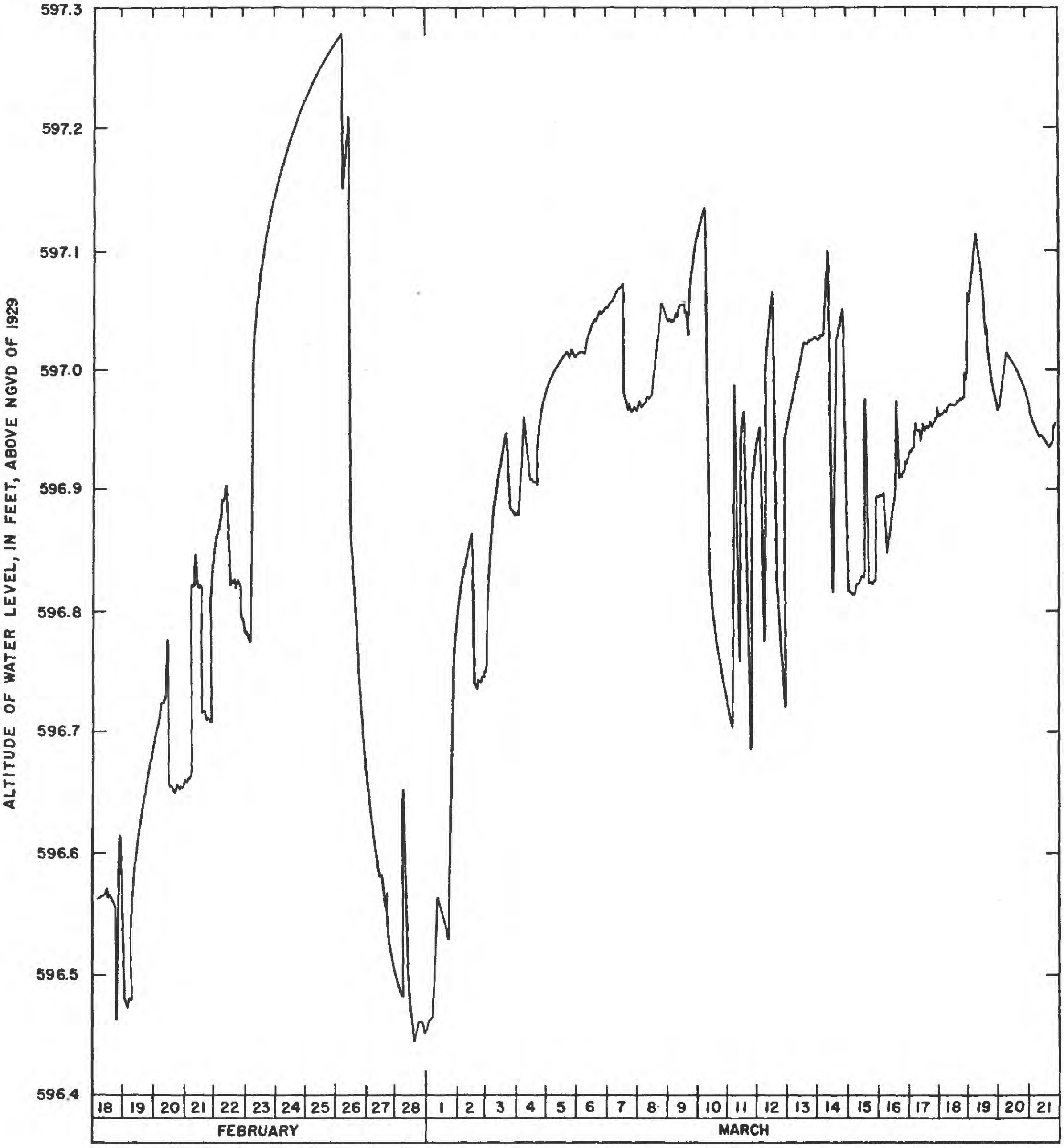


Figure 9.--Water levels in well Y19D in vicinity of pumping wells.

Force files and on an aquifer test and short-term, specific-capacity tests by the Geological Survey. Air Force test data indicate that transmissivity of the sand and gravel aquifer is about 5,000 ft^2/day. During the aquifer test by the Geological Survey, well AF57 was pumped for 48 hours at 34 gal/min. Eight observation wells were used to observe drawdown and recovery. Results of the test indicate that transmissivity of the aquifer ranges from 5,000 to 20,000 ft^2/day, depending on the location of the observation well, and that hydraulic conductivity ranges from 75 to 310 ft/day. Specific yield is about 0.2.

Specific-capacity tests at 37 sites were also used to estimate hydraulic conductivity. Each test consisted of pumping 10 to 15 gal/min from a well for about an hour. Data obtained from these tests were used to estimate hydraulic conductivity of that part of the aquifer surrounding the screen (Theis and others, 1963). Assuming that the wells were perfectly efficient, hydraulic conductivity ranged from 16 to 317 ft/day; the average was 140 ft/day. Generally, hydraulic conductivity increased from east to west. Also, hydraulic conductivity estimated from pumping tests of shallow wells tended to be greater than that estimated from pumping deep wells. A specific yield of 0.2 was used in all calculations.

Model simulations were used to refine estimates of hydraulic conductivity of the sand and gravel aquifer. Model results most accurately matched water-level data from wells when values of hydraulic conductivity assigned to the model were 100 ft/day in the eastern part of the Base and 150 ft/day in the west. These values are consistent with published values of hydraulic conductivity for sand and gravel (U.S. Bureau of Reclamation, 1977), with values for similar materials in other areas in Michigan (McDonald, 1980), and with the average value from specific-capacity tests at the Base.

Horizontal Hydraulic Gradients and Ground-Water Flow

Altitudes of ground-water levels range from 580 feet near Lake Huron to more than 730 feet in the highlands west of the Base (fig. 6). The water level fluctuates from 1 to 3 feet annually, depending on location and precipitation. The gradient of the water table ranges from less than 10 to about 25 feet per mile. In the bluff area west of the Base, gradients are as high as 50 feet per mile.

Ground-water flow is generally in three principal directions to: (1) Van Etten Lake, (2) the Au Sable River, and (3) Lake Huron. Eventually, all water from the Base reaches Lake Huron. The ground-water divide just east of Van Etten Lake (fig. 6) indicates, however, that ground water does not flow directly to Lake Huron.

Flow from the highlands west of the bluffs recharges the sand and gravel aquifer at the west edge of the Base and helps to maintain high ground-water levels in the swampy area at the foot of the bluff. It is also responsible for flow in several streams originating in the area.

Rates of horizontal ground-water flow (without consideration of porosity) are proportional to the hydraulic conductivity of the aquifer and the gradient of the water table. Model simulations showed that an inverse linear relationship between hydraulic conductivity and recharge would match field data better. For the simulations, values of ground-water recharge were varied from 8 to 18 inches per year. Using a hydraulic conductivity of 100 ft/day, which was determined to be reasonable for the eastern part of the Base, field data in parts of the Base influenced by ground-water withdrawal could be matched only by using a recharge rate of 15 inches per year. This rate is considered to be the best estimate possible. Model results, based on this value and on hydraulic conductivities determined previously, show that the rate of ground-water flow ranges from about 0.8 ft/day in the east part of the Base to about 0.3 ft/day in the west. Rates of flow within a few hundred feet of points of discharge, or pumping wells, are slightly higher.

Model simulations were used to estimate the range of flow that might result by varying values of recharge and hydraulic conductivity. Values of recharge were varied over a range of from 8 to 18 inches per year. Corresponding changes in hydraulic conductivity were made at each recharge rate in order to match field and model water-level values. Based on these simulations, flow rates as low as 0.1 ft/day and as high as 1.0 ft/day might be possible.

The effect of pumping on the direction and movement of ground-water flow is shown in figure 10. The effect of pumping water-supply and purge wells in the eastern part of the Base is to divert flow toward the wells and to cause drawdown in the east-central part of the Base.

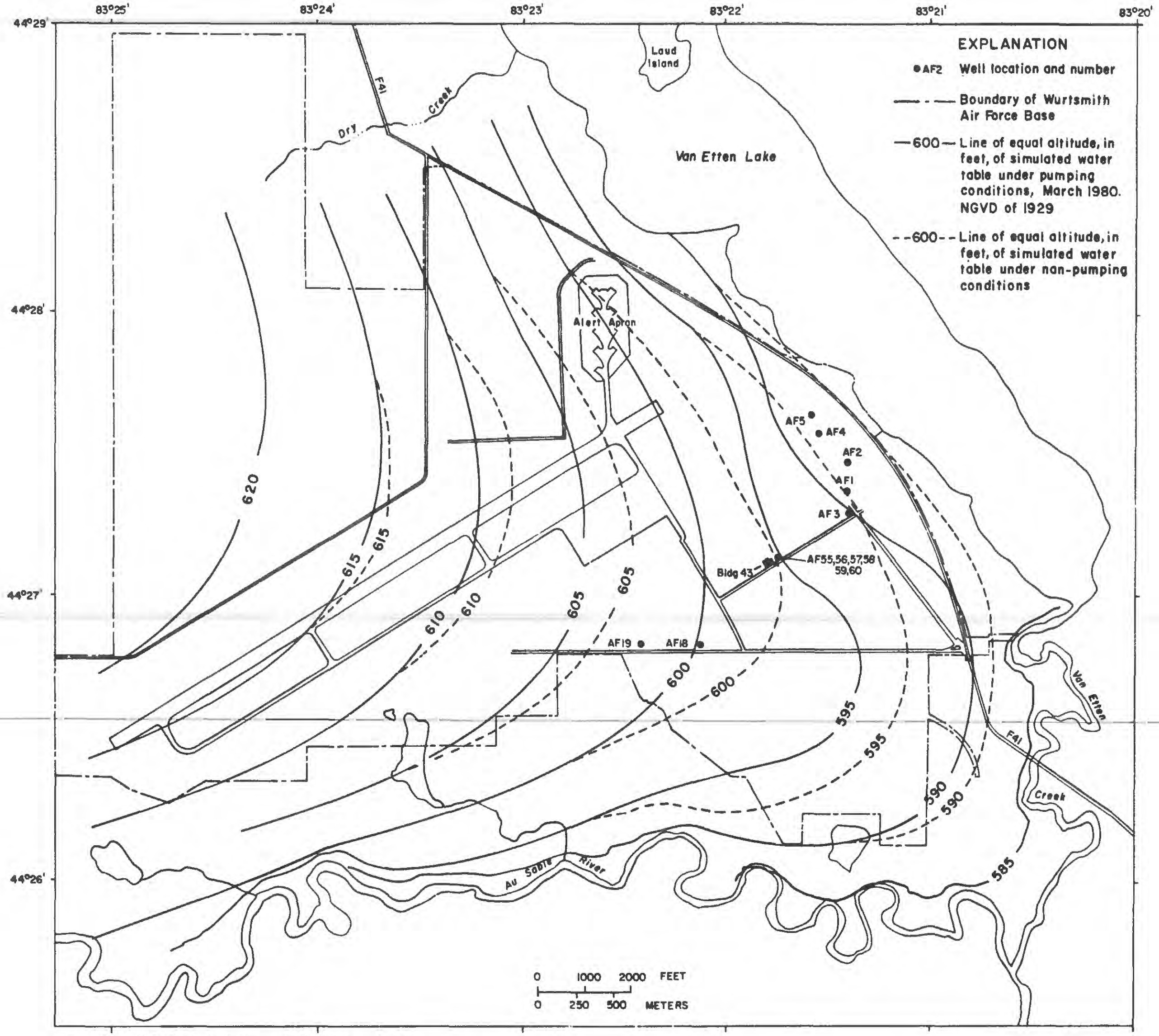
Vertical Hydraulic Gradient

Characteristics of the vertical component of flow in the sand and gravel aquifer were evaluated by use of paired observation wells. These wells consisted of a shallow well having a screen set 10 to 20 feet below the water table and a deep well having a screen set near the base of the aquifer. The vertical distance separating screens in individual pairs of wells ranged from 10 to 35 feet.

Differences in the altitude of the potentiometric surface in individual pairs of wells ranged from zero to as much as 0.33 foot in wells R2S and R2D. In most pairs of wells, the difference was less than 0.05 foot. Areas of highest vertical gradients are near pumping centers and surface-water bodies. The vertical component of flow is generally downward. However, pairs of wells within a few hundred feet of Van Etten Lake have upward vertical components. This is consistent with the conceptual view of ground-water movement in a flow system consisting of recharge and discharge areas (Freeze and Cherry, 1979).

CONTAMINATION OF GROUND WATER

The initial phase of this study dealt with the distribution and concentration of trichloroethylene in ground water arising from the spill at Building 43 in the eastern part of the Base. Although trichloroethylene has proven to be the principal organic contaminant, significant concentrations of dichloroethylene and benzene also have been detected on the Base. Other organic substances detected in water by the Geological Survey include toluene, tetrachloroethylene, and tetrachloroethane. Table 1 lists the results of laboratory analyses of organic compounds in ground water sampled by the Geological Survey. To evaluate general water-quality conditions, particularly with respect to



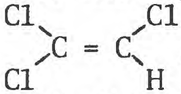
Base from U.S. Geological Survey 1:62,500 quadrangle
and Wurtsmith Air Force Base 1:7,200 map

Figure 10.--Simulated altitude of water table for pumping and nonpumping conditions.

landfills as a source of contaminants, analyses were also made for trace metals, nutrients, radiochemicals, chemical oxygen demand, biochemical oxygen demand, fecal coliform and streptococci, and oil and grease. These analyses are given in table 2.

Nature and Significance of Trichloroethylene, Dichloroethylene, and Benzene

1,1,2-Trichloroethylene

1,1,2-Trichloroethylene is a clear, colorless liquid having a boiling point of 86.7°C, a vapor pressure of 57.1 mm Hg at 20°C, a specific gravity of 1.465, and a solubility of 1,070 mg/L at 20°C (Kirk and Othmer, 1978). It has a molecular weight of 131.39 and empirically may be written C_2HCl_3. Its structural formula is  $\begin{matrix}\mathrm{Cl} & & & \mathrm{Cl}\\ & \mathrm{C} = & \mathrm{C} & \\ \mathrm{Cl} & & & \mathrm{H}\end{matrix}$, which is frequently indicated by writing $CHCl{=}CCl_2$. It is composed of 18.28 percent carbon, 0.77 percent hydrogen, and 80.95 percent chlorine by weight.

Concern over trichloroethylene in the environment is related primarily to as yet uncertain carcinogenic risks to human beings. According to the U.S. Environmental Protection Agency (1978a), the octanol/water partition coefficient (2.29) of trichloroethylene indicates it may bioaccumulate. However, Pearson and McConnell (1975) did not find significant bioaccumulation in marine food chains. Investigations by McConnell and others (1975) and Correia and others (1977), as well as analyses by the U.S. Environmental Protection Agency (1978a), suggest that trichloroethylene is present in trace amounts in food, water, and air in Europe and the United States. A drinking-water standard for trichloroethylene has not been set by the Environmental Protection Agency, but a Notice of Proposed Rule Making is in preparation (C. Vogt, oral communication, 1981). A recent review of toxicological data and a risk analysis by the National Academy of Sciences (1980) suggests a provisional maximum concentration of 270 µg/L in drinking water at U.S. Air Force bases.

Trichloroethylene is used principally as a degreasing solvent in metal industries, and has been used in drycleaning, as an extractive solvent for foods, and as an anesthetic. It is incorporated in several household cleaning agents. Most trichloroethylene is manufactured from 1,1,2,2-tetrachloroethane using ethlyene or acetylene as a base, and, in the 1960's, commercial trichloroethylene contained a substantial amount of 1,1,2,2-tetrachloroethane (Waters and others, 1976).

Trichloroethylene has been reported to resist hydrolosis at 100°C (Dilling and others, 1975), but it is known to break down in the presence of oxygen and light (Aviado and others, 1976; Dilling and others, 1975; and McConnell and others, 1975). Biochemical degradation is unknown by aerobic micro-organisms, but anaerobic degradation has been cited (Bouwer and others, 1981). Mammalian metabolism yields trichloroacetic acid, trichloroethanol, and trichloroethanol glucuronids (Waters and others, 1976). McConnell and others (1975) conducted experiments with sealed quartz flasks containing chlorine-substituted ethylenes exposed out-of-doors. Results indicated that these compounds have a mean half-life of 6 to 12 weeks. Breakdown products, determined after exposure of flasks to a xenon arc filtered so as to approximate tropospheric conditions, were primarily carbon monoxide (CO), carbon dioxide (CO_2), water, and hydrogen chloride (HCl). Trichloroethylene, however, yielded relatively stable chloro-organic intermediates, dichloroacetyl chloride and trichloroacetyl chloride. Minor amounts of phosgene ($COCl_2$) also occurred, which rapidly hydrolyzed to CO and HCl. The chloroacetyl chlorides react with water to form dichloroacetate and trichloroacetate anions, which have long chemical half-lives at normal environmental temperatures. In seawater and possibly other water, these compounds undergo microbial oxidation fairly rapidly to simple chemical species commonly present in the environment. Correia and others (1977) state, however, that once in the aqueous phase hydrolysis to dichloroacetic and trichloroacetic ions or to carbon dioxide is practically immediate. The dichloroacetate and trichloroacetate ions are then degraded to carbon dioxide and chloride ions by biological processes in a few weeks. Pearson and McConnell (1975) estimated the chemical half-life of trichloroethylene in water to be 2.5 years. After studying the decomposition of trichloroethylene in aerated water in the dark and in sunlight, Dilling and others (1975) concluded that the half-life of trichloroethylene was 10.7 months in the absence of light. They also concluded that dichloroacetic acid and hydrogen chloride were the likely products from the decomposition of trichloroethylene and, further, that addition of clay, limestone, sand, salt, peat moss, and kerosene had little effect on the disappearance of trichloroethylene from solution.

To verify the resistance of trichloroethylene to decomposition, the Geological Survey prepared solutions of trichloroethylene (about 4,000 µg/L) and added these solutions to peat moss, potting soil, and clean sand purchased at a garden supply store. Core materials from two uncontaminated wells at Wurtsmith Air Force Base were also obtained. One core sample contained sand and clay, the other sand only. Mixtures, about a third trichloroethylene solution and two-thirds solid material by volume, were placed in 1 liter bottles, aerated, and tightly sealed. Duplicate sets were prepared; one set was placed in the dark and the other in indirect sunlight. After about 5 weeks, these samples were analyzed for trichloroethylene and chlorinated hydrocarbon decomposition products. Only trichloroethylene was detected in the samples.

1,2-Dichloroethylene

1,2-Dichloroethylene is a mixture of the *trans* and *cis* isomers. Analyses of ground water at Wurtsmith Air Force Base have identified only the *trans* form. According to Kirk and Othmer (1978), *trans* 1,2-dichloroethylene has a solubility of 6,300 mg/L at 25°C, a vapor pressure of 265 mm Hg at 20°C, a boiling point of 47.7°C, and a specific gravity of 1.263. Corresponding values for the *cis* isomer are: solubility, 3,500 mg/L; vapor pressure, 180 mm Hg at 20°C, and boiling point, 60,2°C. Its molecular weight is 96.95. The U.S. Environmental Protection Agency (1978b) states that 1,2-dichloroethylene has an octanol/water partition coefficient of 5.37, which suggests that it should not bioaccumulate. No drinking water standards have been developed.

1,2-Dichloroethylene is used primarily as a solvent, to retard fermentation, as a refrigerant, as an additive to dye and lacquer, in organic synthesis, and as a constituent in various chemical compounds. Dichloroethylene is also used as an intermediate in preparing methylchloroform (1,1,1-trichlorothane) and producing polyvinylidene chloride copolymers. 1,1-dichloroethylene polymers are also used as interior coatings for ship tanks, railroad cars, fuel storage tanks, and for coating of steel pipes and structures.

McConnell and others (1975) concluded that one of the sources of dichloroethylene in the environment is from decomposition of 1,1,1-trichloroethane, which gives 1,1-dichloroethylene (vinylidene chloride). They also state that 1,1,1-trichloroethane is easily dechlorinated, but the rate is pH dependent. In seawater, 1,1,1-trichloroethane has a chemical half-life of 9 months; a minor amount of acetic acid is formed as a result of hydrolysis during decomposition. Degradation is rapid, however, in the presence of metallic iron.

Trichloroethane is known to have been used at Wurtsmith Air Force Base; however, records do not provide information regarding use of dichloroethylene. If 1,1,2-trichloroethane was used and entered the ground water system, and if decomposition analogous to that suggested by McConnell and others (1975) occurs, 1,2-dichloroethylene could be a decomposition product. Kirk and Othmer (1978) state that 1,2-dichloroethylene hydrolyzes slowly in the presence of water, producing hydrochloric acid.

To investigate the likelihood that decomposition of trichloroethane could account for dichloroethylene in ground water at Wurtsmith Air Force Base, approximately 1 cubic foot of core material, primarily sand, was collected from well R27D. Water from this well had shown only traces of trichloroethylene and dichloroethylene. Several liters of native ground water, which had passed through the carbon filtration system, were also collected and used to prepare solutions of 1,1,2-trichloroethane and 1,1,1-trichloroethane at a concentration of about 400 μg/L. Native water and core material were then used to prepare mixtures that were a third trichloroethane solution and two-thirds solid material by volume. Liter bottles containing these mixtures, as well as liter bottles containing only mixtures of native water and trichloroethane, were aerated and tightly sealed. Duplicate sets were prepared; one set was placed in the dark and the other in indirect sunlight. After about 10 weeks, the samples were analyzed for trichloroethane and chlorinated hydrocarbon decomposition products. Only trichloroethane was detected in the samples. Core material, however, did remove some of the trichloroethane from solution.

Benzene

Benzene is a clear, colorless liquid having a boiling point of 80.1°C, a vapor pressure of 76 mm Hg at 20°C, a specific gravity of 0.8786, and a solubility of 1,780 mg/L at 20°C (Verschueren, 1977). It has a molecular weight of 78.11 and empirically may be written C_6H_6. Benzene is used as an intermediate in synthesizing numerous organic chemicals and as a solvent and degreasing agent. It is a component of paints, lacquers, gasoline, and aviation fuels. A drinking-water standard has not been established for benzene, but the U.S. Environmental Protection Agency (1980) has estimated a 7-day SNARL (suggested no adverse response level) of 350 μg/L. No review of literature regarding benzene has been made for this study because, as a ground-water contaminant at Wurtsmith Air Force Base, it is probably only indicative of a fuel substance containing benzene.

Origin and Distribution of Trichloroethylene

Building 43 Plume

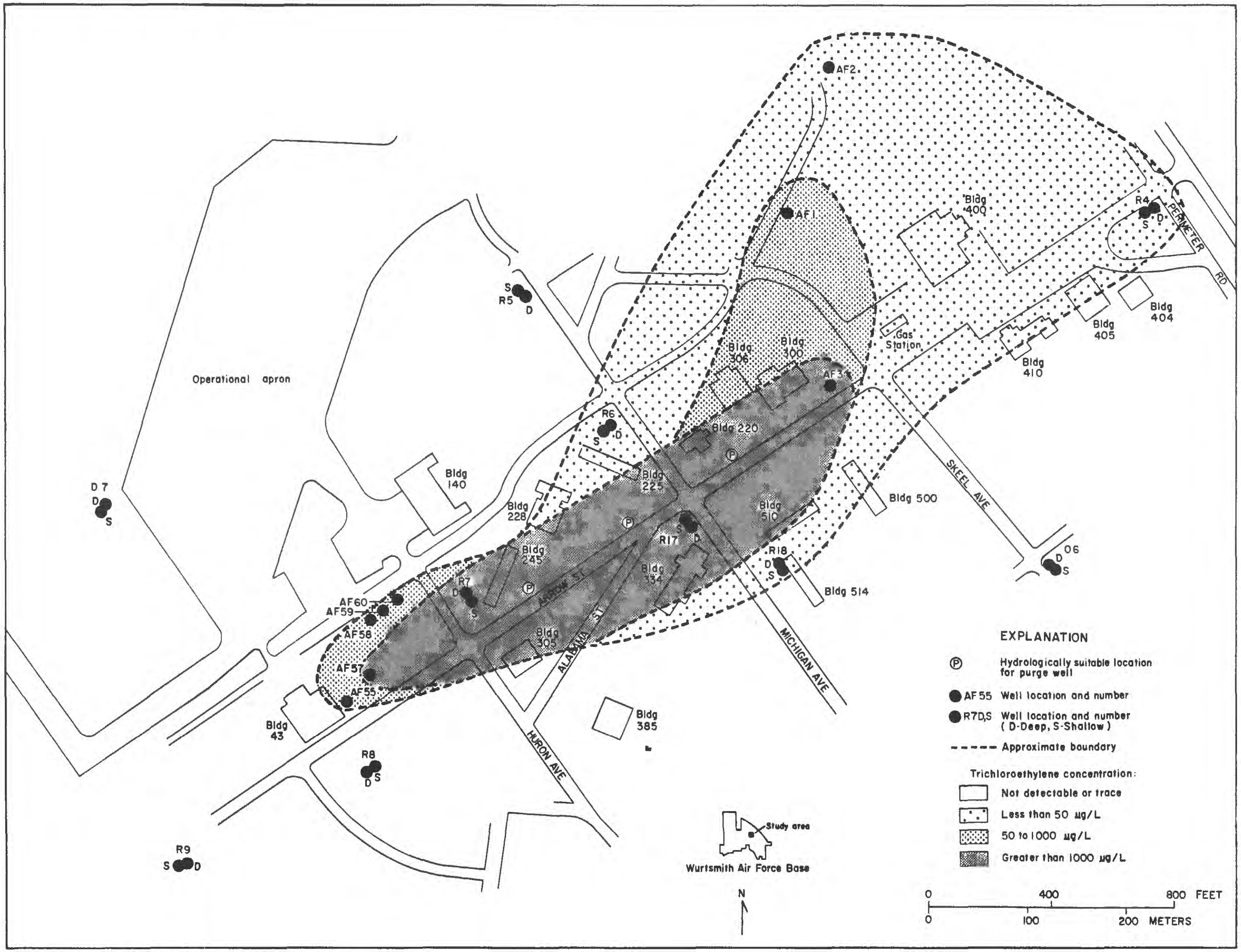
In 1962, a 500-gallon storage tank for waste trichloroethylene was installed underground just north of Building 43. Its contents were pumped out for disposal elsewhere when the tank became filled. From the time of installation until the tank was removed in 1977, Base officials estimate that about 5,000 gallons of trichloroethylene may have been added to the tank. It is not known when the tank first leaked, or how much was periodically removed from the tank, and thus no estimate can be made of the amount of trichloroethylene that entered the ground-water system. When removed from the ground, the tank appeared to have leaked near the filler pipe, suggesting that trichloroethylene may have escaped only during times when it was filled near capacity, or when trichloroethylene was added to or pumped from the tank. Thus, leakage to the ground-water system would not have been continuous. If substantial quantities leaked at any one time, trichloroethylene would have tended to move downward in the aquifer because it is denser than water. In the process, however, substantial amounts of trichloroethylene would have been taken into solution, to disperse and move with ground-water flow. Repeated discharges of trichloroethylene from the tank and localized variations in the permeability of aquifer material would have given rise to what is probably the situation in the major area of contamination at present; that is, trichloroethylene is not thoroughly mixed in the vertical, lateral, or horizontal dimensions of the plume. Although trends in concentration are evident in current purge wells, many "sub" plumes may exist which would account for the highly variable concentrations that are detected. Further, small and discrete areas containing water of high trichloroethylene concentration may lie at or near the clay surface at unidentified locations or at intermediate depths between the water surface and the clay layer.

Figure 11 shows the general distribution of trichloroethylene resulting from tank leakage at Building 43. The natural ground-water gradient and the pumping of water-supply wells AF1, AF2, and AF3 caused trichloroethylene to be drawn northeastward, roughly parallel to Arrow Street. A model simulation indicates that if wells AF1, AF2, AF3, AF4, and AF5 (pl. 1) were not pumped, ground water in the vicinity of Building 43 would move east toward the intersection of Skeel Avenue and Forest Street and not deviate northeastward.

After discovery of trichloroethylene in wells AF1 and AF3 in late 1977, pumping was terminated from these wells and also from wells AF2, AF4, and AF5. Wells AF18 and AF19 (on Perimeter Road, in the southern part of the Base) supplied water needs for a time (pl. 1). When trichloroethylene was detected in AF18 and AF19, major withdrawals were again made from wells AF2, AF4, and AF5. It is likely that these changes in pumping account, in part, for the dispersion of trichloroethylene in the northeastern portion of the plume.

A generalized cross section of the vertical distribution of trichloroethylene along a line between wells R5 and R18 near Michigan Avenue is shown in figure 12. The cross section indicates that the density of trichloroethylene is not a controlling factor in its distribution within the most highly concentrated part of the plume, although density may be a significant factor in localized variations.

Figure 13 shows the Building 43 spill area and the locations of past and present monitoring and purge wells. U.S. Air Force data indicate that in February 1978 well AF50, which is about 100 feet east of the storage tank, yielded water having the highest concentration of trichloroethylene (46,800 μg/L) detected on the Base (fig. 14). By October 1978, when sampling of AF50 was terminated, the concentration of trichloroethylene had decreased to less than 1,000 μg/L. Purge wells AF55, AF56, and AF57, which went into operation



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 11.--Building 43 trichloroethylene plume, 1979-80.

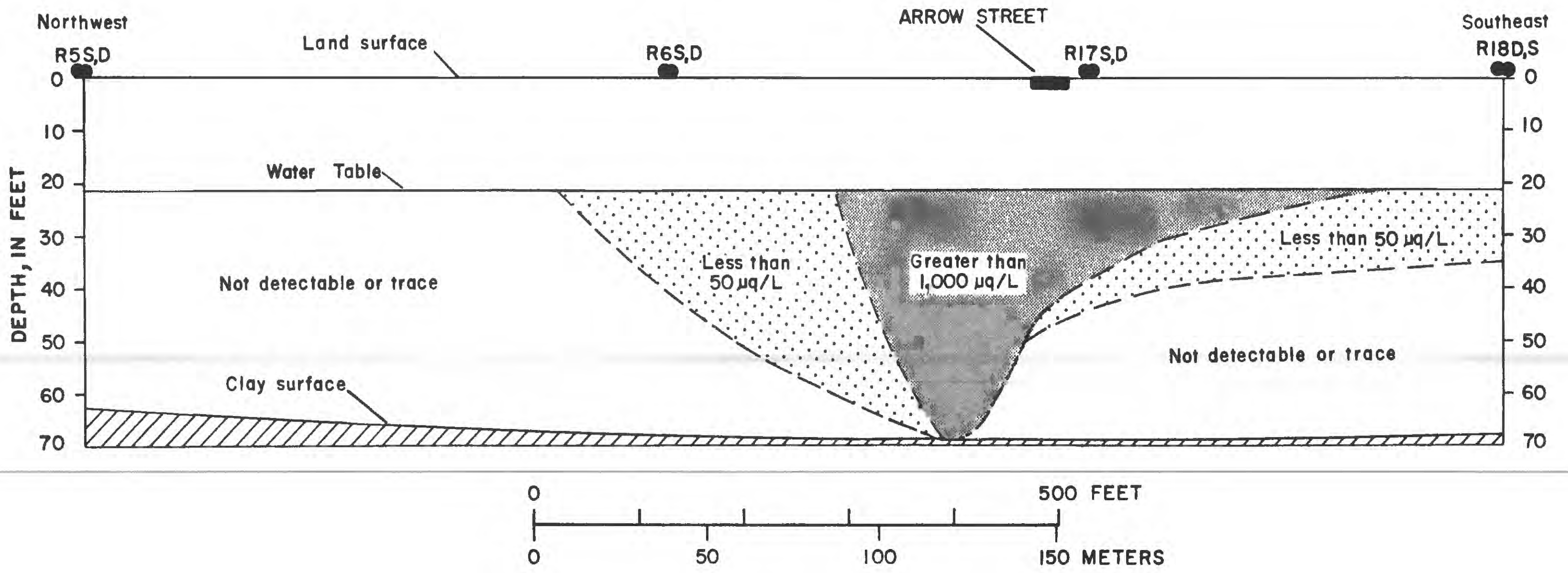


Figure 12.--Cross section showing generalized vertical distribution of trichloroethylene in Building 43 plume between wells R5D,S and R18D,S, 1979-80.

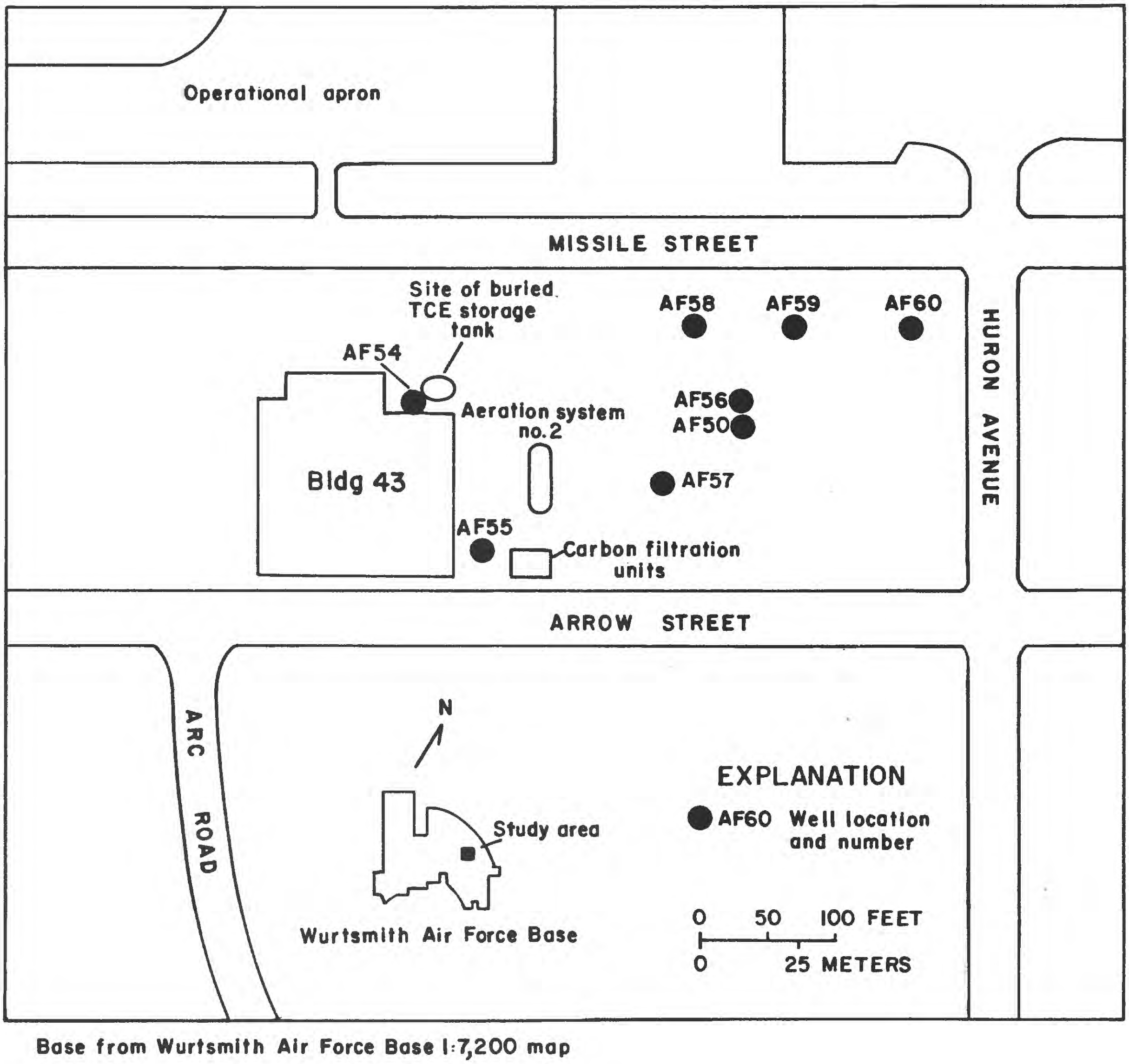


Figure 13.--Building 43 spill site and locations of wells.

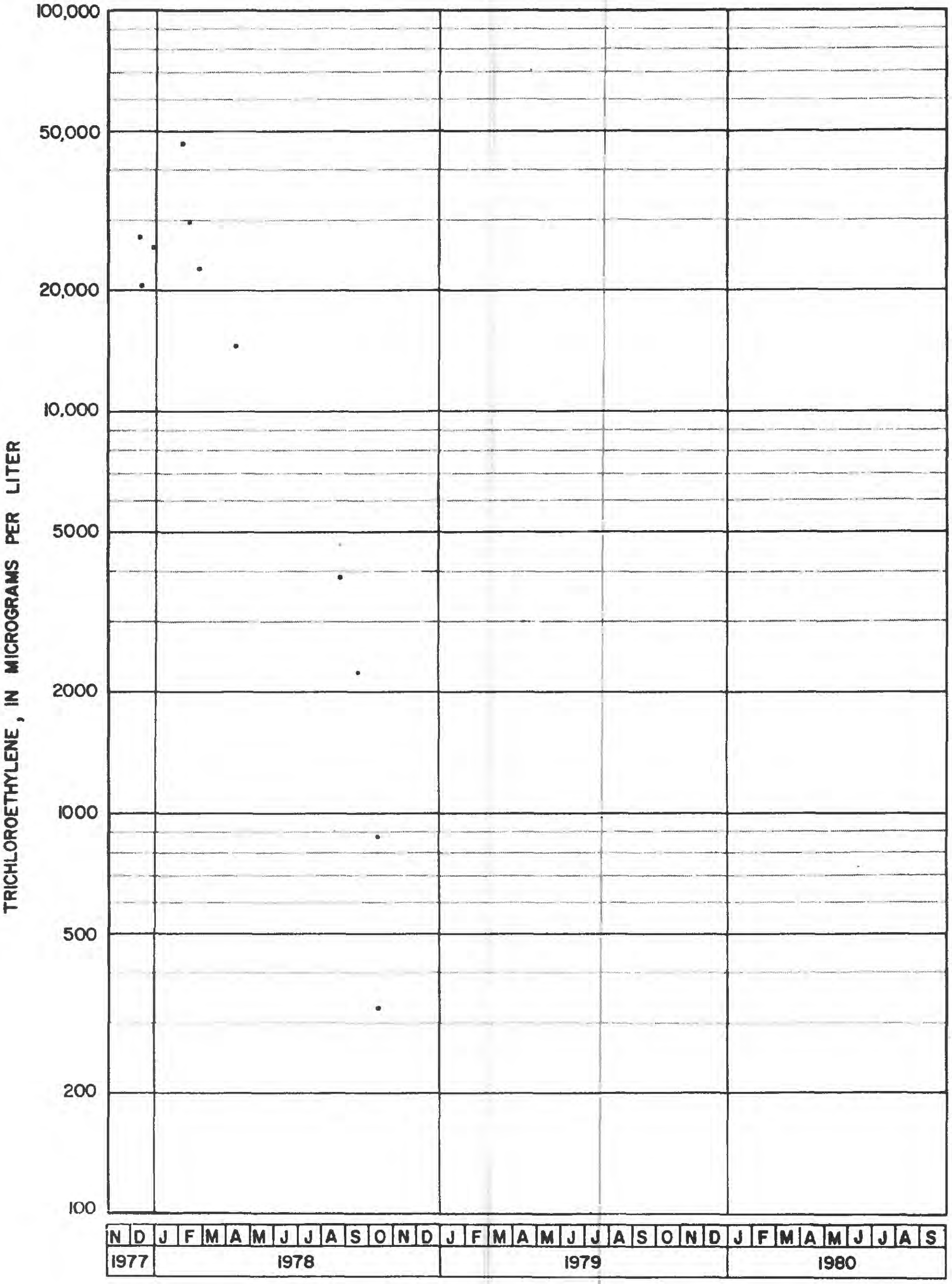


Figure 14.--Change in trichloroethylene concentration in water from well AF50.

in April 1978, may have drawn water away from AF50 before it ceased to be monitored. It is also possible that most of the highly contaminated water had passed eastward by the time purge pumping began, or that, because AF50 is a shallow well (32 feet), trichloroethylene moved to a depth below the well screen.

The trichloroethylene concentration of water from well AF57, just south of AF50, decreased from 15,000 µg/L in May 1978 to less than 1,000 µg/L in October 1978 (fig. 15). In November 1978, well AF57 became the dominant purge well near the spill site, and concentrations began to increase, generally ranging from 1,500 to 2,000 µg/L (average, 1,697 µg/L) during the first half of 1979. Concentrations decreased during the latter half of the year. During 1980, concentrations generally ranged from 500 to 1,500 µg/L (average, 870 µg/L) and did not differ appreciably during early 1981.

Increased pumping of well AF3, about 1,750 feet east of AF57, accelerated the movement of water eastward in early 1978. Concentrations of trichloroethylene in water from well AF3 decreased substantially (fig. 16), probably because greater amounts of less contaminated water were drawn to the well from the east and south. Most concentrations ranged from 1,500 to 3,000 µg/L (average 2,220 µg/L) during 1979 and early 1980. As pumping from well AF3 decreased in early 1980 and terminated for new pump installation in April, concentrations again increased. Resumption of pumping in September 1980 caused concentrations to decrease significantly.

Figure 17 indicates that utilization of well AF1 as a purge well, beginning in April 1978, drew contaminated water to the well. Trichloroethylene concentrations increased from less than 100 µg/L to about 900 µg/L in October 1978. Continued pumping of well AF1 and AF3, however, caused a progressive decrease in the trichloroethylene in water from well AF1. From April 1980 to March 1981, the average concentration in water from AF1 was 79 µg/L. A March 1981 sample contained only 16 µg/L.

Until pumping of wells AF4 and AF5 (pl. 1) became heavy in March 1978 and until purge pumping of AF2 increased in the summer of 1978, only trace quantities of trichloroethylene were detected in water from well AF2. Figure 18 shows that the trichloroethylene concentration increased until early 1980 and then decreased. Since May 1980, concentrations have been less than 5 µg/L.

Tricholoroethylene in water in wells AF4 and AF5 has been detectable since late 1977, although less frequently in AF4 than in AF5. Concentration levels have not increased, largely due to the substantial pumping of wells AF1, AF2, and AF3. In general, pumping has also retarded the movement of trichloroethylene eastward to Van Etten Lake; only low or trace amounts have been detected in wells R4D, R4S, and AF51, which are about 1,100 feet northeast of well AF3.

Trichloroethylene was detected in water-supply wells AF18 and AF19 in November 1977, shortly after the wells began to be pumped heavily in lieu of pumping the eastern supply wells. The maximum concentrations were 92 µg/L in water from well AF18, in February 1978, and 66 µg/L in water from well AF19, in December 1977. Concentrations decreased rapidly, however, as withdrawals were again made largely from the eastern supply wells. The Geological Survey analyses of water from well AF18, in December 1979 and January 1980, show nondetectable levels.

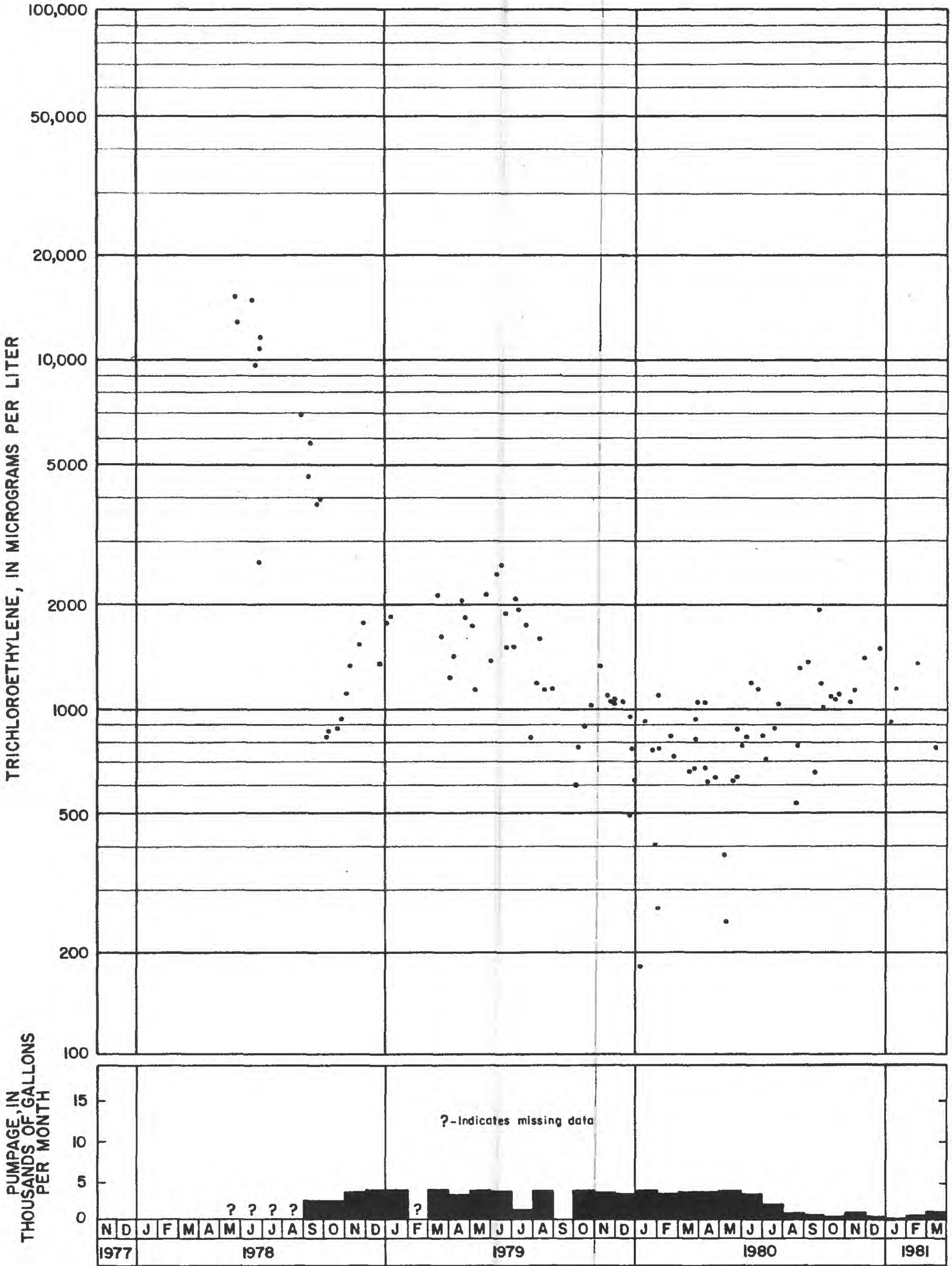


Figure 15.--Change in trichloroethylene concentration in water from well AF57.

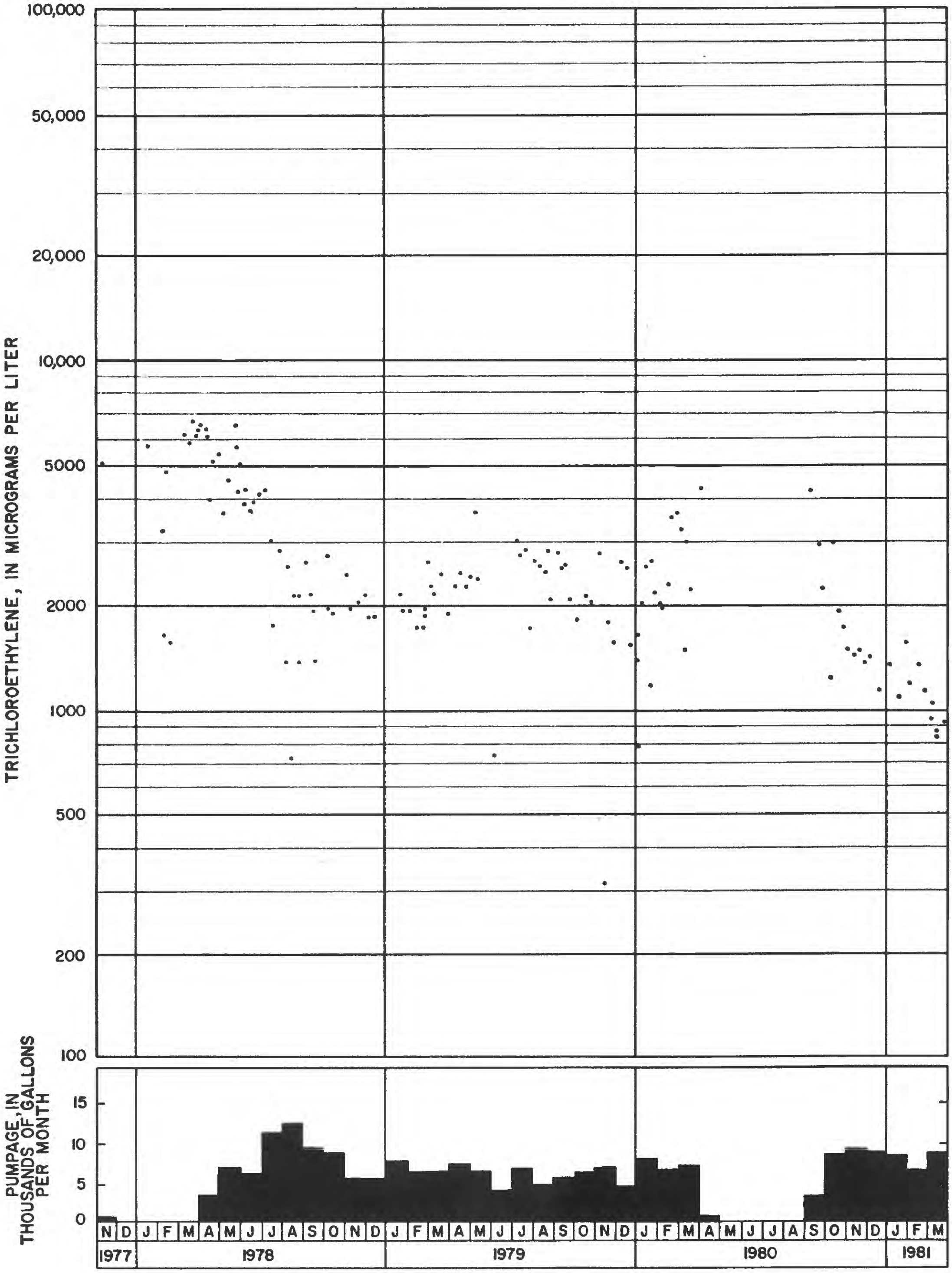


Figure 16.--Change in trichloroethylene concentration in water from well AF3.

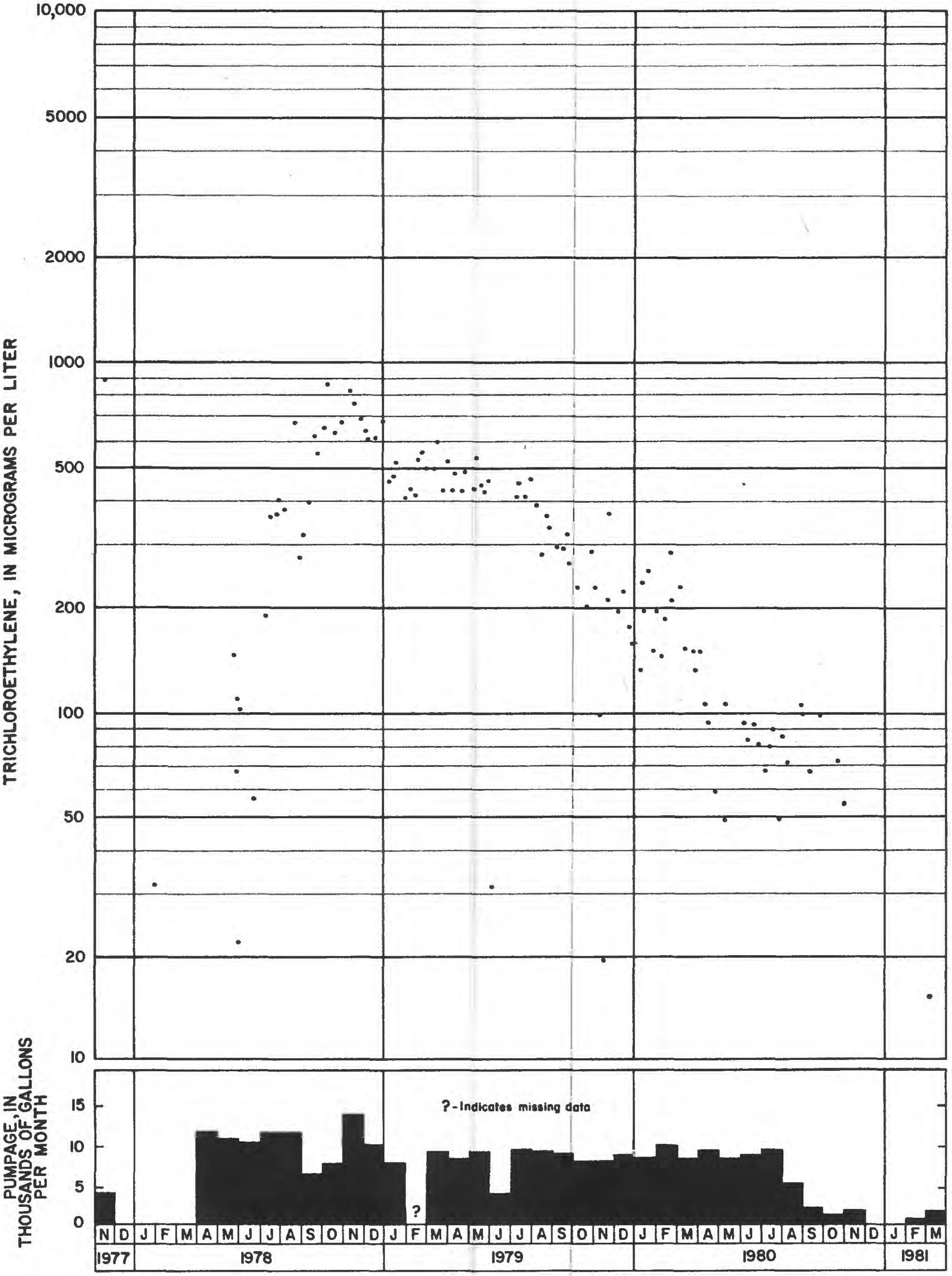


Figure 17.--Change in trichloroethylene concentration in water from well AF1.

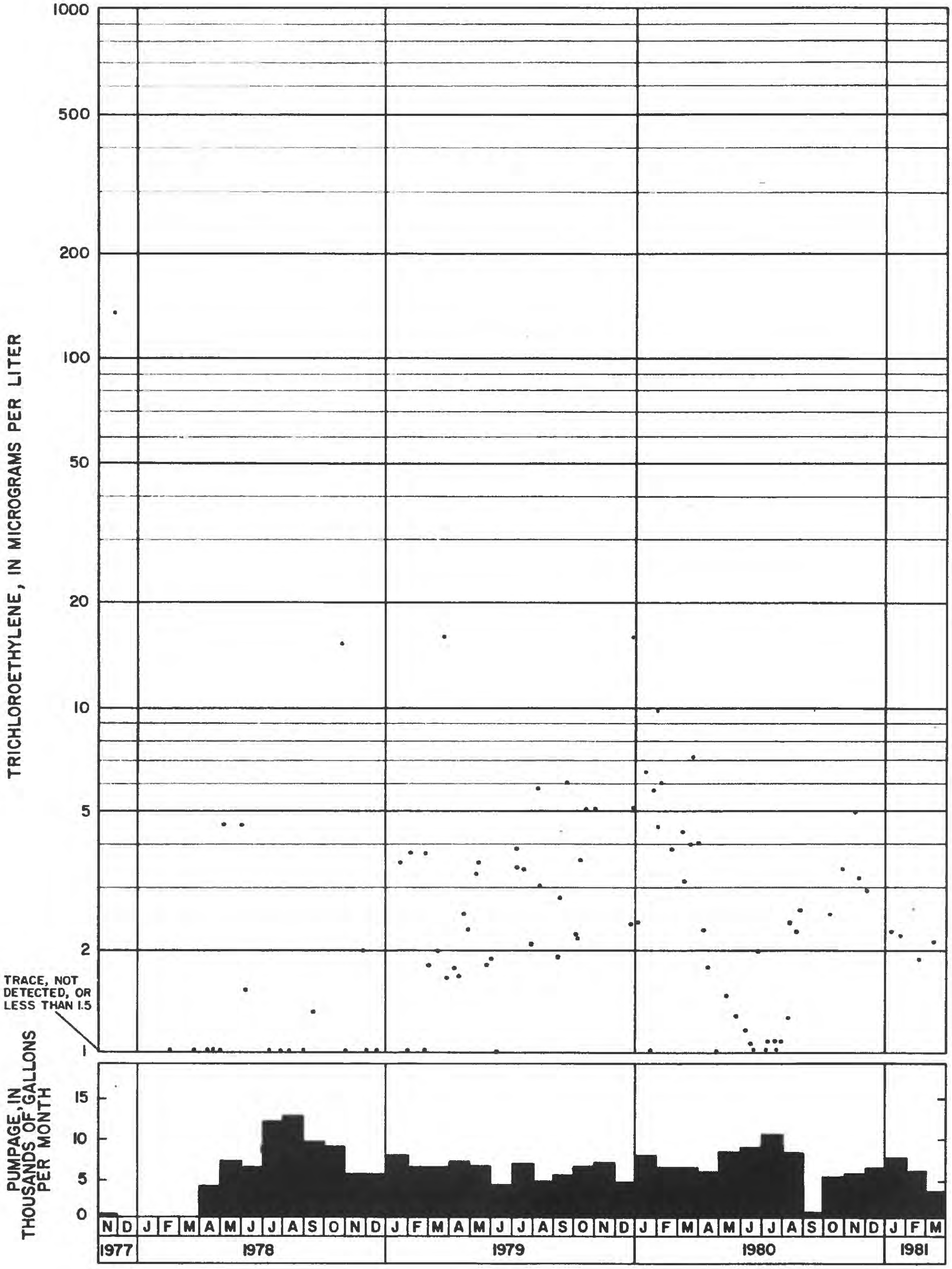


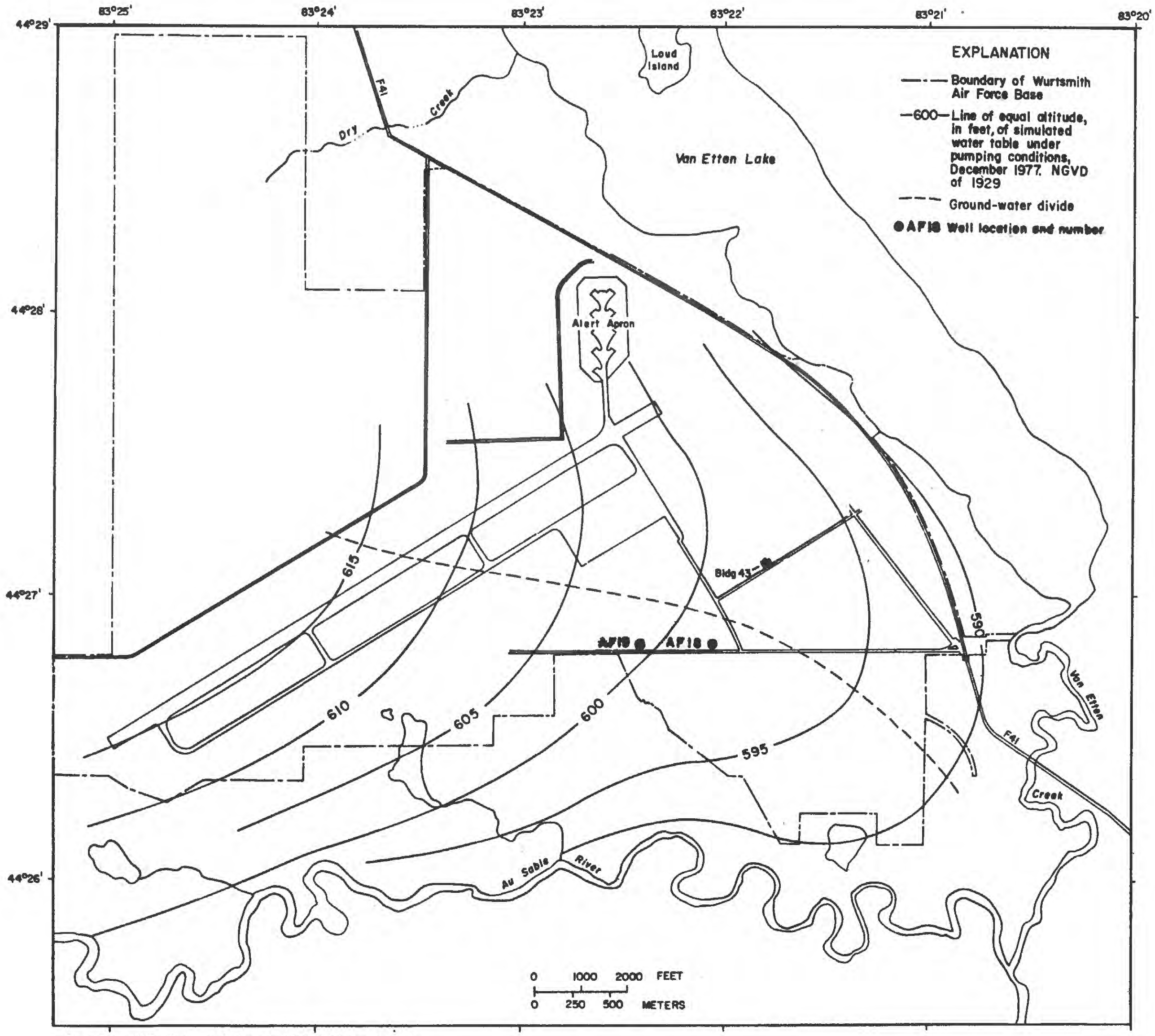
Figure 18.--Change in trichloroethylene concentration in water from well AF2.

Initial concern was that trichloroethylene from the spill site at Building 43 had been drawn to the southern water-supply wells AF18 and AF19. Water-level measurements, however, indicated that a ground-water divide running diagonally across the Base (fig. 6) made this improbable. To determine if extensive pumping from wells AF18 and AF19 could have diverted flow at Building 43 from its natural eastward course and caused contaminants to reach the southern supply wells near Perimeter Road, the Base ground-water flow model was used to simulate the period of heaviest pumping of wells AF18 and AF19, that of December 1977. Results of this simulation (fig. 19) show that pumping of wells AF18 and AF19 did not cause ground water to flow southwestward from the spill site at Building 43. The water at wells AF18 and AF19 remained 1 to 3 feet higher than the surface at the spill site. Because of this, contamination of these wells cannot be attributed to the spill. The only known potential source of trichloroethylene is the pipeline from the waste-treatment plant to the seepage lagoons, which may have been leaking slightly. This is supported somewhat by unpublished chemical analyses of water from these wells by the Geological Survey from 1966 to 1975, which indicate that chloride and nitrate concentrations have, at times, been higher than at many other locations on the Base.

The most highly contaminated part of the Building 43 plume (greater than 1,000 μg/L of trichloroethylene) seems to have been arrested by purge pumping. Near capacity purge pumping must be maintained to prevent eastward movement, however. Because purge well AF3 was not pumped from April to September 1980, a model simulation reflecting this decrease in pumping was made to investigate the effect on movement of the most highly contaminated part of the plume. The simulation indicates that, when well AF3 is not pumping, equipotential lines are shifted, so that ground-water flow near Building 43 is toward purge well AF1 rather than well AF3 and that the water table is about 0.5 foot higher between Building 43 and well AF3. Under this condition, the concentration of trichloroethylene in water near well AF1 would eventually increase. Eastward movement of the boundary of the most highly contaminated part of the plume is also possible, particularly between R18 and AF3. This will remain true until additional purge wells are installed in the central part of the plume.

Removal of trichloroethylene from the Building 43 area.--Based on purge pumping data and trichloroethylene analyses provided by the Air Force, and analyses made by the Geological Survey, 580 gallons of trichloroethylene is estimated to have been removed from the ground-water system betweem November 1977 and March 1981. About 84 percent of this amount has been pumped from wells AF3 and AF57. Pumping from wells AF1, AF56, and AF59 has accounted for 15 percent; the remaining 1 percent has been pumped from wells AF2, AF55, AF58, and AF60.

Figure 20 shows the effect of pumping on trichloroethylene removal. From early 1979 to the fall of 1980, a decrease in pumping from AF1, AF3, AF56, AF57, and AF59 substantially reduced the rate of trichloroethylene removal from the system. Most of the reduction cannot be accounted for by changes in concentrations. From September 1978 to August 1979, 215 gallons of trichloroethylene was purged; whereas, between September 1979 and August 1980, only about 75 gallons was removed from the system. Installation of a new pump in well AF3 in September 1980 increased the rate of trichloroethylene removal.



Base from U.S. Geological Survey 1:62,500 quadrangle
and Wurtsmith Air Force Base 1:7,200 map

Figure 19.--Simulated water table resulting from pumping from wells AF18 and AF19.

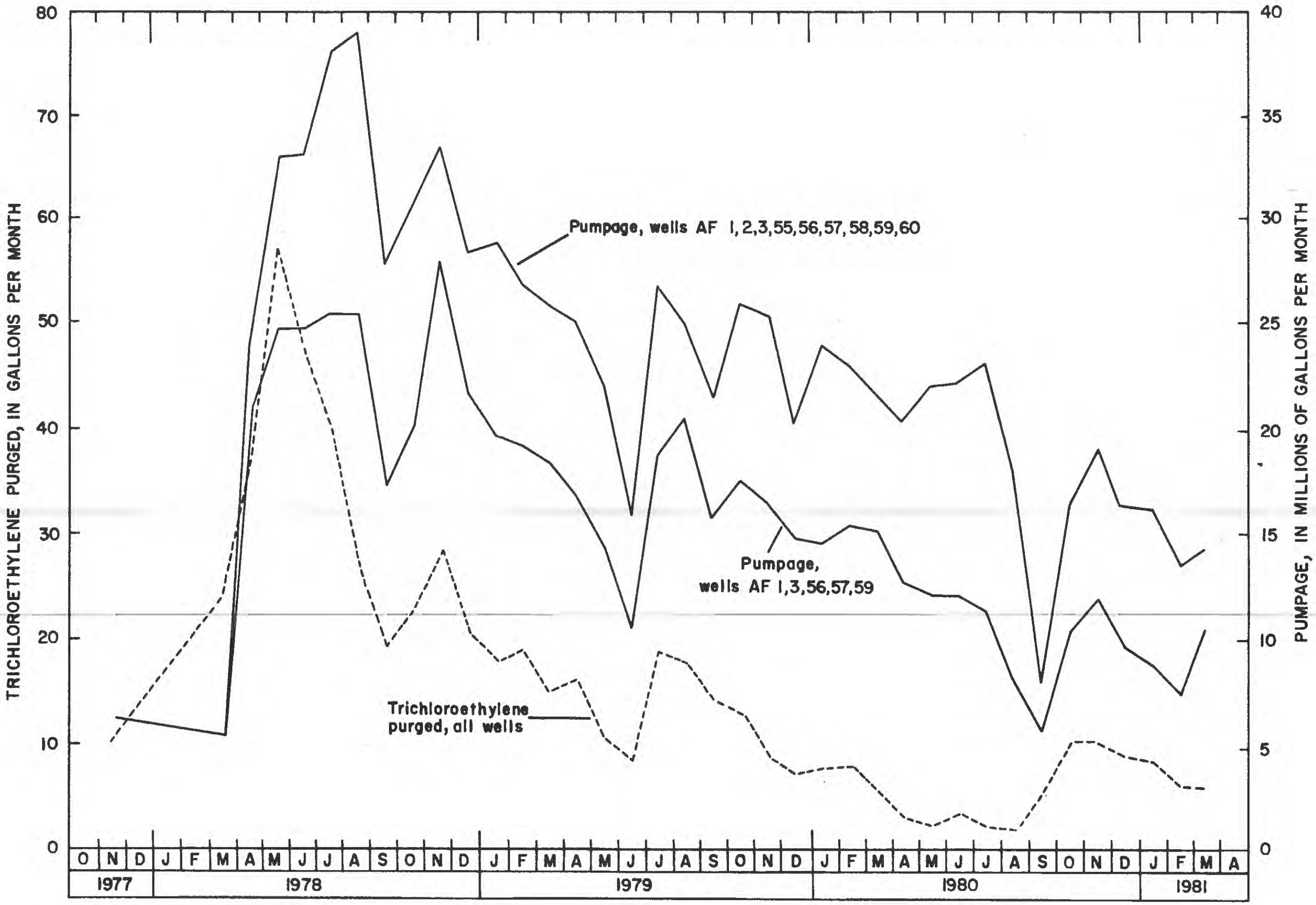


Figure 20.--Effect of pumping rate on trichloroethylene removal.

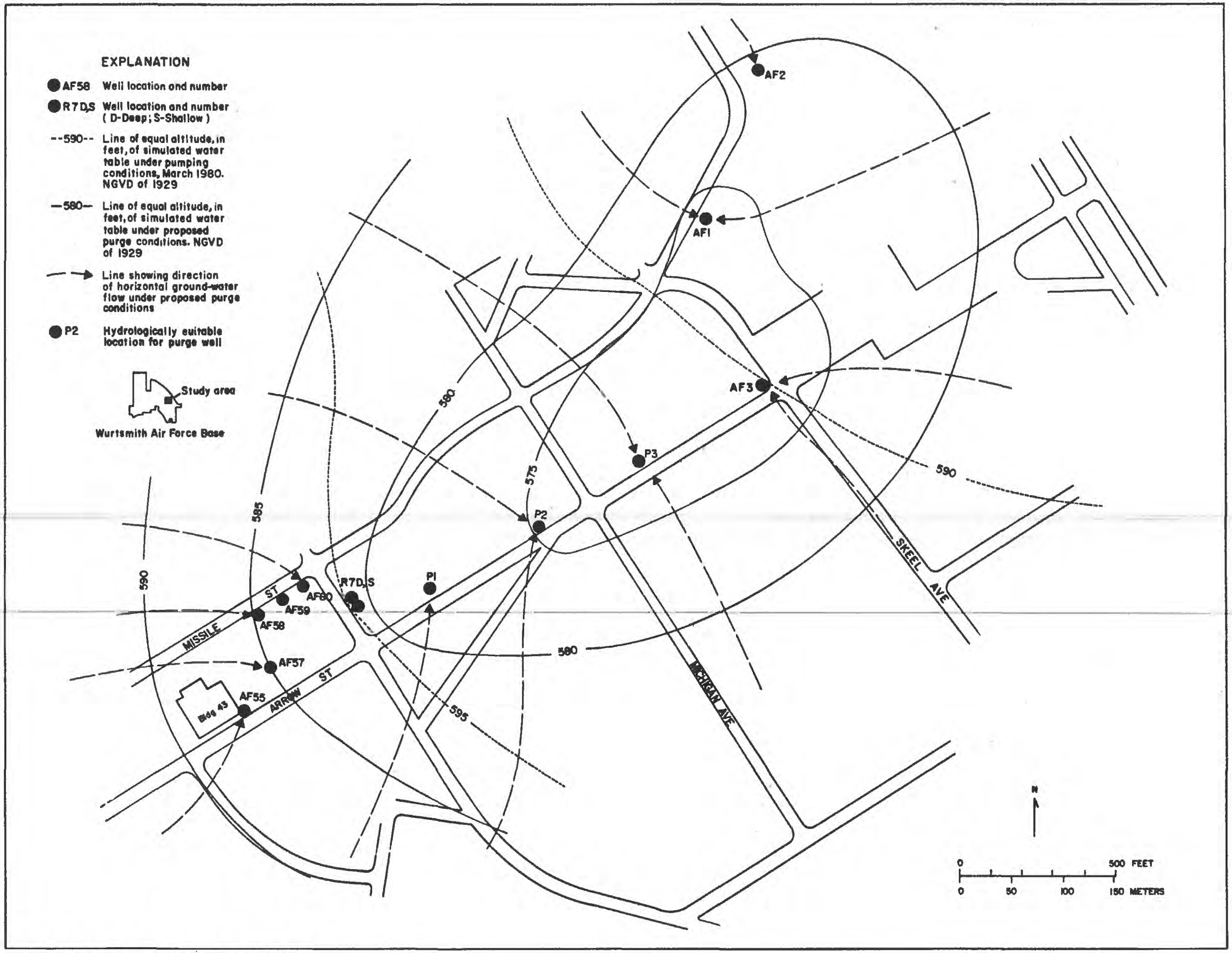
Model simulations were used to identify sites where substantial quantities of water could be removed from the most highly contaminated area. Results of these simulations suggested that, for most rapid and efficient purging of the ground-water system, three new purge wells, identified as P1, P2, and P3 on figure 21, could be drilled. Additional water could also be removed from the system by reconditioning well R7D, and pumping it as a purge well. In simulations, the assumption was made that pumping rates during 1979 would also be maintained for existing purge wells. In operation the purge system would include wells AF1, AF3, AF55, AF57, AF58, AF59, AF60, P1, P2, P3, and R7D. The most efficient removal of trichloroethylene might require either decreasing the rate of pumping from AF58, AF59, and AF60 or eliminating these wells from the system. Total pumpage from the wells could be as much as 1,200 gal/min, if a rate of 250 gal/min could be maintained from P1, P2, and P3.

To evaluate the effects of suggested purge pumping in the Building 43 plume area, a model simulation using estimated purge pumping rates was made. Because water-supply withdrawals have a significant impact on the water table, estimated rates for supply wells were also included, and the simulated water table compared with the water table in March 1980. The following pumping rates, in gallons per minute, were used:

Well	Model simulation pumping rate	March 1980 pumping rate	Well type
AF1	180	179	Purge
AF2	140	141	Supply
AF3	200	27	Purge
AF4	130	129	Supply
AF5	125	124	Do
AF55	44	43	Purge
AF57	36	77	Do
AF58	0	1	Do
AF59	36	15	Do
AF60	0	2.6	Do
R7D	100	0	Do
P1	200	0	Do
P2	200	0	Do
P3	300	0	Do

Figure 21 shows the simulated water table when all the wells are in operation. The simulation indicates that the water table in the central part of the plume will be lowered by about 15 feet and that contaminated ground water will be drawn to purge wells from the north, south and east of the most highly contaminated zone. Trichloroethylene will not escape eastward to Van Etten Lake.

Analyses of water from purge wells, made while the ground-water system is under stress, should provide a basis for determining if pumping rates need adjusting, and if any purge wells can or should be dropped from the system. It should also be possible to predict, after a few months, how rapidly trichloroethylene can be removed from the system.



Base from Wurtsmith Air Force Base 1 7,200 map

Figure 21.--Hydrologically suitable locations for purge wells in Building 43 trichloroethylene plume, and altitude of water table under March 1980 conditions and suggested purge conditions.

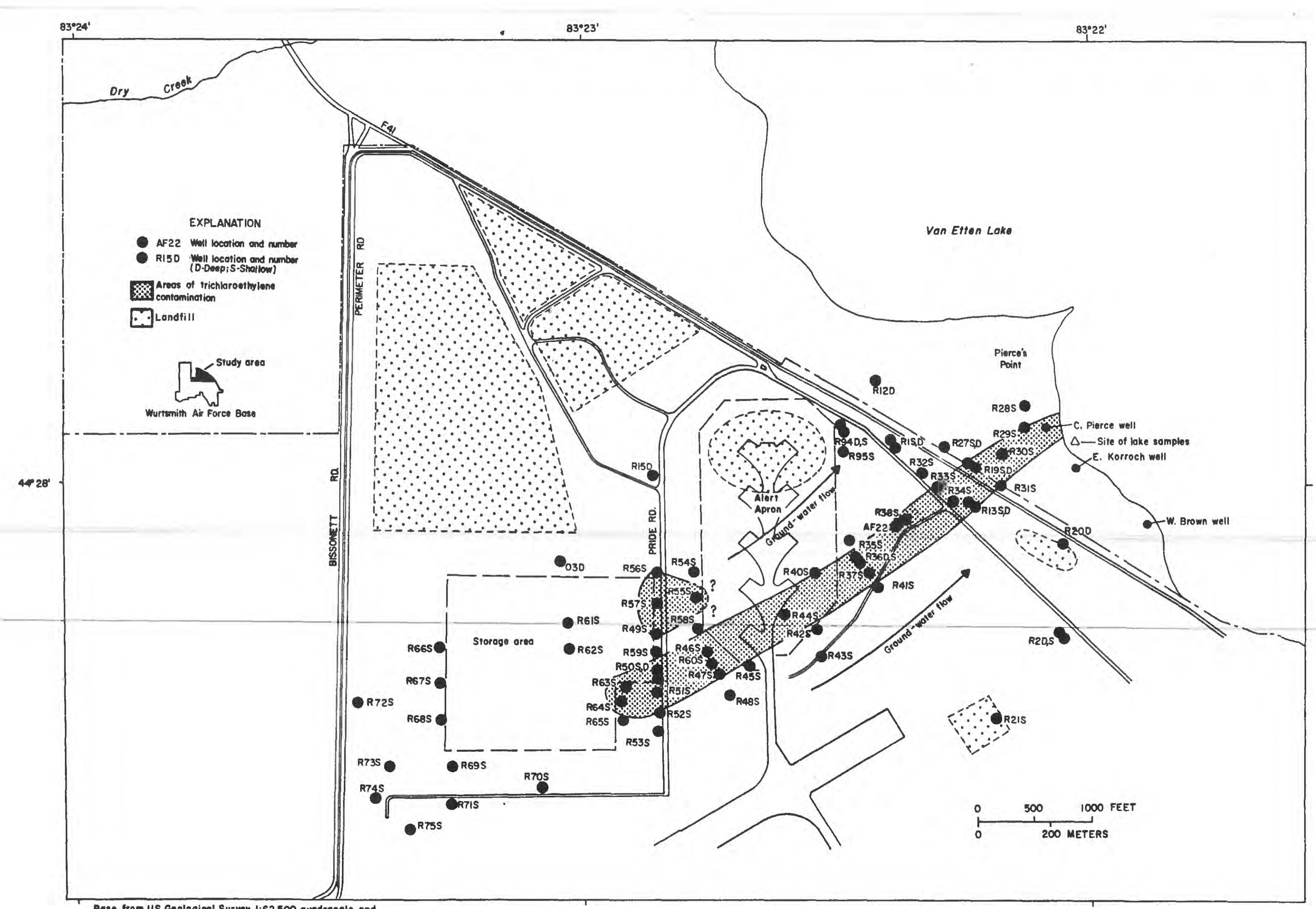
Evidence indicates that removal of trichloroethylene from the ground-water system will not be significantly retarded by absorption on organic material in the aquifer. Visual examination and sieve analysis of core samples from wells indicate that the amount of organic matter is very small. Chemical analyses of core samples have shown that the organic carbon content is less than 0.2 percent. Because the organic carbon is low, it probably does not act as a strong control on the movement of trichloroethylene in the aquifer. Analyses of core and soil samples (table 3) did not detect absorbed trichloroethylene, although associated water did contain low concentrations. These conditions are felt to be general over much of the Base, and thus purging of the ground-water system of trichloroethylene seems possible. The decrease in the trichloroethylene concentration in water from several Air Force wells, such as well AF2 (fig. 18), suggest that trichloroethylene can probably be purged to low levels.

Alert Apron Plumes

Geological Survey analyses of water from the domestic well of Charles Pierce, off Base near Van Etten Lake, have confirmed concentrations of trichloroethylene (400 to 800 μg/L) detected by the U.S. Air Force and State agencies. A preliminary evaluation of ground-water-flow data in the initial stages of the study concluded that the spill site at Building 43 was not the source of trichloroethylene in the Pierce well. Subsequent analyses of water from wells north and south of the Pierce well did not show trichloroethylene, which indicated that contamination was either very localized or that its source was southwest of the Pierce well. A low concentration of trichloroethylene (20 μg/L) was detected in shallow water of Van Etten Lake adjacent to the property of Charles Pierce. Installation of wells southwestward from the Pierce well and analyses of water demonstrated the existence of a major trichloroethylene plume extending to a point about 400 feet west of Pride Road on the Base. Figure 22 shows a generalized boundary of that plume, and a probable second plume, or area of contamination, immediately north of it.

Vertical distribution of the trichloroethylene within the southern, more extensive plume seems to vary. For example, concentrations in water from well R19D, 68 feet deep, ranged from "not detected" to 10 μg/L. Adjacent well R19S, 39 feet deep, had trichloroethylene concentrations ranging from 247 to 291 μg/L. Wells R36D and R36S, 54 and 35 feet deep, showed similar concentrations (372 and 323 μg/L) in August 1980. Well R50S, 24 feet deep, near the apparent origin of the major trichloroethylene plume, had a maximum concentration of 1,074 μg/L. In the area of contamination immediately north of the major plume, well R49S (24 feet deep) had a maximum concentration of 1,000 μg/L.

A precise northeastern boundary cannot be established for the small northern plume because of restricted drilling conditions near the alert apron area. To determine if trichloroethylene had moved east of the alert apron, wells R94S, R94D, and R95S were drilled near the eastern fence line at locations shown on figure 22. Trichloroethylene was not detected in water from these wells. This indicates that the northeastern boundary of the plume probably terminates under the alert apron, but at a location that cannot be determined.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 22.--Alert Apron trichloroethylene plume, 1980.

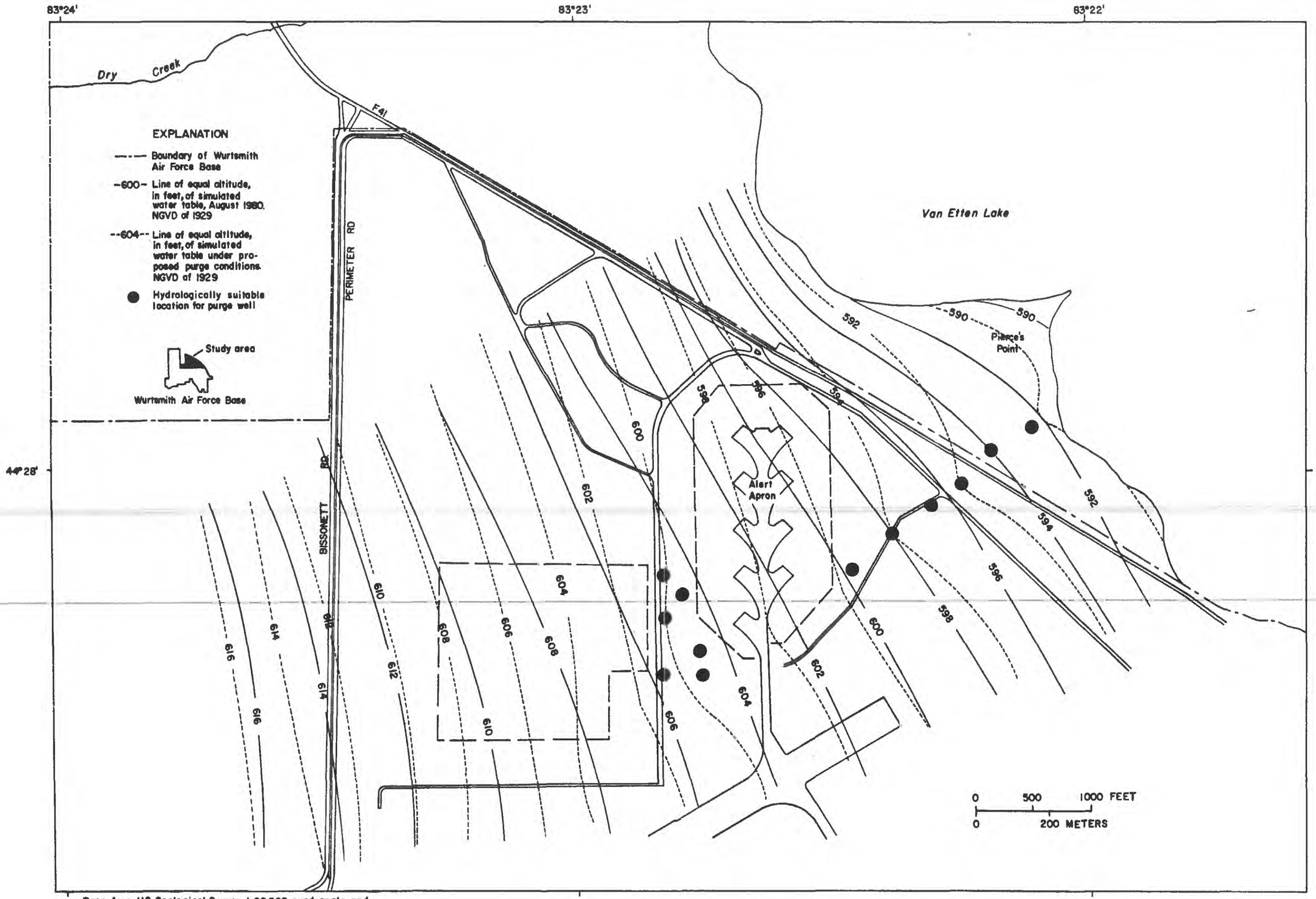
Information suggests that trichloroethylene may have been used 15 or more years ago in the storage area west of Pride Road, but use since that time is unknown. Along the path of ground-water movement, the distance from Pierce's well to the area of probable origin of the trichloroethylene is about 4,500 feet. Based on the hydrologic characteristics of the aquifer, and without consideration of porosity, the rate of water movement in the area is about 0.8 foot per day in the eastern part and about 0.4 foot per day in the western part. Thus, trichloroethylene found near Pierce's Point may have entered the aquifer about 20 years ago, a period of time that does not differ appreciably from the latest date trichloroethylene may have been used in the storage area. Considering the rate and direction of ground-water flow, the continuous nature of trichloroethylene contamination extending from the storage area to Pierce's well, and the possibility that trichloroethylene was used in the southwestward area of the plume, trichloroethylene found in the Charles Pierce well probably had its origin on the Base some years ago.

<u>Removal of trichloroethylene from the alert apron area</u>.--Model simulations were used to determine the most hydrologically suitable purging scheme in the alert apron area if purging is found to be desirable. The simulations indicate that installation of 12, 4- to 6-inch diameter wells, each having a capacity of 40 gal/min, will be most efficient and effective in rapidly removing water from the plume. Wells 30 to 45 feet deep will allow the top of the screen to be 5 to 10 feet below the water table. Figure 23 shows suitable locations of purge wells and the water-table altitude that would result from their operation. The water table resulting from the pumping simulation is compared to that of a nonpumping condition in August 1980. The simulation indicates that water would be withdrawn from the entire area of the major plume without removing significant amounts of surrounding uncontaminated water.

Three wells in the contaminated area north of the major plume should purge this area effectively. Because the location of the alert apron prevents accurate determination of the northeastern boundary of this contaminated area, wells R12D, R94S, and R95S (pl. 1) could be monitored to detect trichloroethylene that might migrate northeastward.

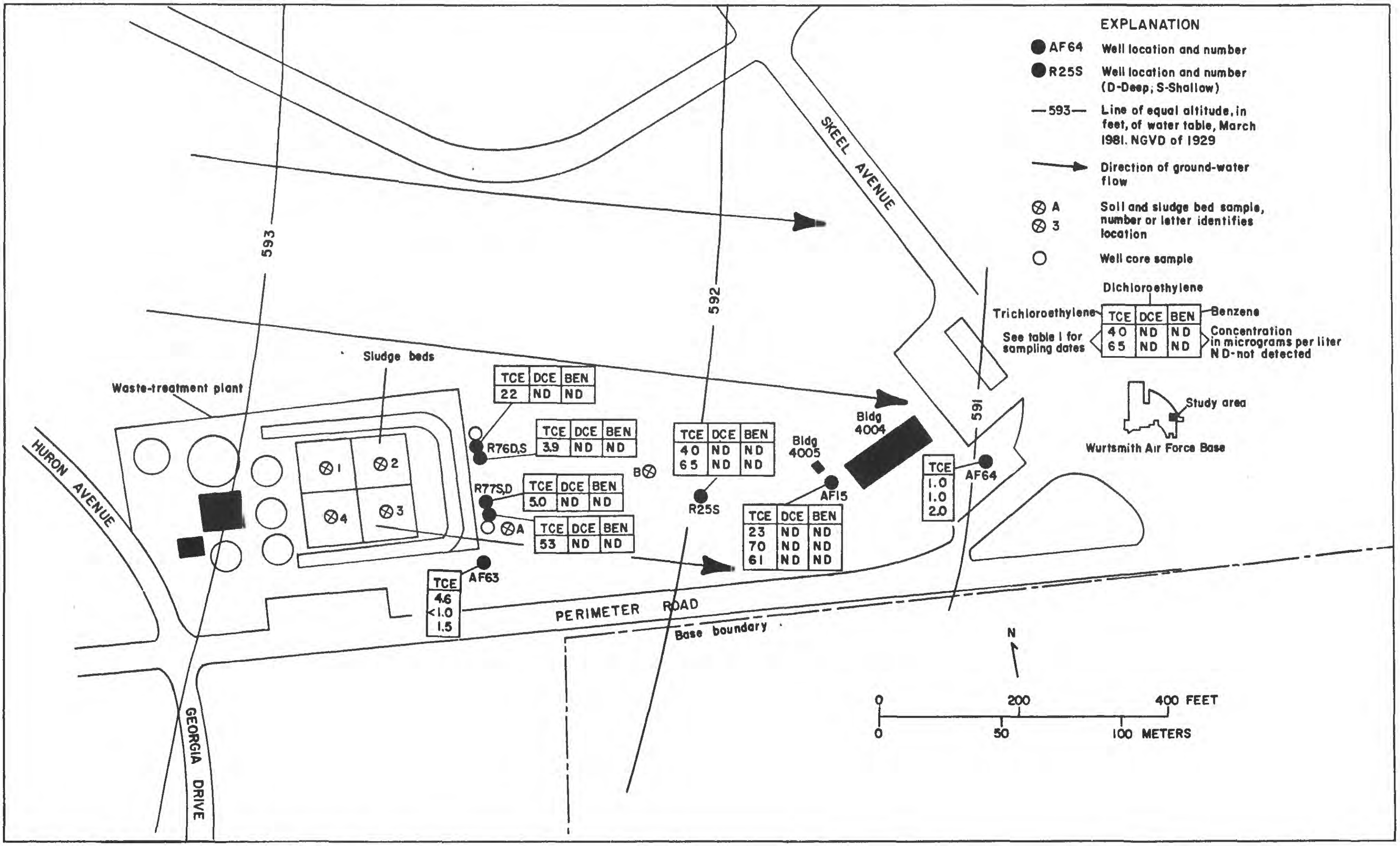
Waste-Treatment Plant Area

Water-level data indicates that trichloroethylene found east of the waste-treatment plant (fig. 24) did not come from leakage of the storage tank at Building 43. Trichloroethylene concentrations measured by the Geological Survey, which range from 23 to 70 μg/L in water from well AF15, confirm levels measured by the U.S. Air Force. From the time Air Force sampling began in late 1977 until February 1980, trichloroethylene concentrations in water from well AF15 generally ranged from about 50 to about 100 μg/L. Although concentrations were lower (average, 41 μg/L) from March to August 1980, no pattern of decline was evident. Water from well R25S, drilled in April 1980 about 200 feet west of well AF15, contains similar trichloroethylene concentrations. Air Force data have consistently shown trichloroethylene concentrations of less than 10 μg/L in water from well AF64, which is about 200 feet east of well AF15. Since March 1980, however, concentrations of water from AF64 have been less than 3 μg/L. From March to August 1980, well AF63, at the southeast corner of the



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 23.--Hydrologically suitable locations for purge wells in Alert Apron plume, and the effects of pumping on the water table.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 24.--Waste-treatment plant area.

waste-treatment plant, usually yielded water containing less than 2 µg/L. The comparatively stable levels of trichloroethylene in wells AF15 and R25S and the fact that ground-water flow is slightly southeastward from the treatment plant, suggested that the waste-treatment plant is the source of trichloroethylene.

Sludge placed in the drying beds at the waste-treatment plant were suspected of having adsorbed trichloroethylene at a time before water pumped to the plant was passed through carbon filters. A study of trichloroethylene adsorbed on sludge by Camisa (1975) indicated that as much as 3,030 mg of trichloroethylene could be adsorbed on a kilogram of solids. If sludge organic matter in the drying beds did contain a substantial amount of trichloroethylene, a slow release to the ground-water system would be expected.

Further investigation of the situation was made by drilling deep and shallow wells (R76D,S and R77D,S) at two locations just east of the waste-treatment plant. Core and water samples were collected from these wells, and soil samples were collected at sites A and B shown on figure 24. In addition, samples of sludge bed material were collected from each of the four beds. Analyses are given in table 3.

Results of analysis of water from deep wells R76D and R77D and shallow wells R76S and R77 indicate that levels of trichloroethylene previously found in wells AF15 and R25S extend westward to the waste-treatment plant. Trichloroethylene data obtained by the Air Force (wells AF63 and AF64) and the direction of ground-water flow indicate that most trichloroethylene contaminated water is north of well AF63 and south of well AF64. Dichloroethylene and benzene were not detected in water from any of the wells.

Trichloroethylene was not detected on the sludge bed soils, in surface sludge material, or on soils collected east of the treatment plant at sites A and B. This strongly suggests that trichloroethylene has not been adsorbed on soils or underlying materials and that release of trichloroethylene to the ground-water system from these materials is not occurring as once suspected. Sludge placed in the beds before the installation of carbon filtration equipment on the Base remains the most plausable origin of the trichloroethylene, however. In all probability, trichloroethylene in the sludge moved downward to the ground-water body beneath the beds, without significant adsorption.

Analyses of water from well AF15 by the Air Force and the Geological Survey suggest concentrations of trichloroethylene are decreasing slowly, which is consistent with discontinued use of the sludge beds and carbon filtration of purge water before piping to the treatment plant. Some decomposition may also be occurring, even though oxygen, which is probably essential to decomposition of trichloroethylene in the absence of light, is undoubtedly quite low in the ground water.

Support for a general improvement of water quality east of the waste-treatment plant is provided by nitrate plus nitrite data. Analyses of water from well AF15 showed nitrate plus nitrite concentrations of 25 and 28 mg/L as N (table 2) in the summer and fall of 1980; a concentration of 4.2 mg/L was measured in May 1981. The following table shows the results of May 7, 1981 sampling:

Well	Date	Nitrite plus Nitrate, total (mg/L as N)	Chloride, dissolved (mg/L as Cl)
R25	05/07/81	2.0	15
R76D	05/07/81	.10	15
R76S	05/07/81	<.1	15
R77D	05/07/81	.22	13
R77S	05/07/81	6.0	28
AF15	05/07/81	4.2	17
AF63	05/07/81	<.1	20
AF64	05/07/81	<.1	10

Once disposal of sludge at the treatment plant was terminated, the most likely source of nitrogen was eliminated. Natural flushing of the system in the waste-treatment plant area would be expected as ground water moved eastward.

Table 3 shows that dichloroethylene, benzene, toluene, methylene chloride, and tetrachloroethylene occurred on soils, sludge bed materials, and in well cores. Undifferentiated hydrocarbons (primarily straight chain) were also present. Benzene and undifferentiated hydrocarbons, detected on more than half of the 21 soils and cores, occurred most frequently. Soils of sludge beds 3 and 4 contained all the compounds except toluene and had the highest concentrations of undifferentiated hydrocarbons. Sludge bed 4 is known to have received hydrocarbon waste.

Benzene was associated with cores obtained from wells R76D and R77D at the 5- and 10-foot depths. Benzene occurred in core material from 50 feet in well R77D at a concentration of 43 μg/kg, the highest concentration of any single organic substance detected. The same core material also contained 32 μg/kg of other hydrocarbons calculated as benzene. Small amounts of toluene were also detected on the cores.

Hydrocarbons other than trichloroethylene have not been detected in water from wells east of the treatment plant. This suggests that these compounds, in contrast to trichloroethylene, are tightly bound to the soil and underlying material and thus do not seem to be potential ground-water contaminants in the waste-treatment-plant area.

Model simulations suggest that proposed purge pumping in the Building 43 plume area will have little effect on the direction of ground-water flow in the waste-treatment-plant area.

Northern (Perimeter Road) Landfill Area

Interest in the northern landfill area was related to the possibility that the landfills were a source of trichloroethylene found near Pierce's Point. Two tankers, known to contain trichloroethylene, also had been buried along the southern margin of one of the landfills. Initial well drilling and analysis of water by the Geological Survey indicated that trichloroethylene, dichloroethylene, and benzene were present in the water, although no conclusive pattern of contamination was evident. Trichloroethylene was either not detected or concentrations were less than 1 μg/L in wells R16D and R16S, which are at the former site of the buried tankers.

In an effort to better define the situation, additional deep and shallow wells were drilled on and off Base. Figure 25 shows the locations of wells and results of analyses. Water from Dry Creek (pl. 1) was also collected and analyzed[1/]. Analyses indicate that trichloroethylene does not occur in the deeper part of the aquifer; resampling of all wells in the area in March 1981 showed trichloroethylene only in water from shallow well 04S (152 μg/L). The source of trichloroethylene seems to be in the southeastern landfill, because water from wells R22D, R22S, and R93S along its west margin have nondetectable levels.

Benzene and dichloroethylene occur principally in shallow wells. However, water from a deep well off Base, R88D, had a dichloroethylene concentration of 155 μg/L, second highest found. Figure 26 illustrates the distribution of benzene, dichloroethylene, and trichloroethylene.

Figure 27 shows the altitude of the water table and the direction of ground-water flow in the northeast landfill area. Movement is northeastward toward Van Etten Lake. The altitude of the water table ranges from 585 to 610 feet. In the western part of the area, the water table is based on model simulation; in the central part, it is based on water levels measured in March 1981. Between Van Etten Lake and well R39S, the water table is approximate.

Based on ground-water-flow data, it seems that the source of both the benzene and dichloroethyene is in the western landfill area. The absence of dichloroethylene in well R89S, based on one analysis, may not be conclusive evidence that dichloroethylene does not exist in the shallow part of the aquifer in the area of the well, particularly because water from well R89D contained 5.7 μg/L.

Model simulations to assess the impact of proposed purge pumping in the Alert Apron plumes indicate that the effect on the direction of ground-water flow in the landfill area will be minimal. Flow may be shifted more eastward as a result of pumping, but water will continue to move to Van Etten Lake.

1,2-Dichloroethylene, Trichloroethylene, and Benzene West of Building 43

Initial sampling and analysis to define the extent of trichloroethylene contamination from the Building 43 spill also indicated that dichloroethylene was present in the area of the trichloroethylene plume (fig. 28). The highest concentration of dichloroethylene, however, was about 900 feet northwest of the trichloroethylene spill site in water from well 07D. The maximum concentration in water from this well, which is 64 feet deep, was 266 μg/L. In contrast, six samples from an adjacent shallow well, 07S (27 feet deep) showed nondetectable levels. The source of the dichloroethylene was presumed to be west of well 07 in the path of ground-water flow.

In an effort to locate the source of dichloroethylene, 23 deep and shallow wells were drilled westward to the vicinity of Skyway Street. Analyses of water from these wells indicated not only dichloroethylene, but traces of

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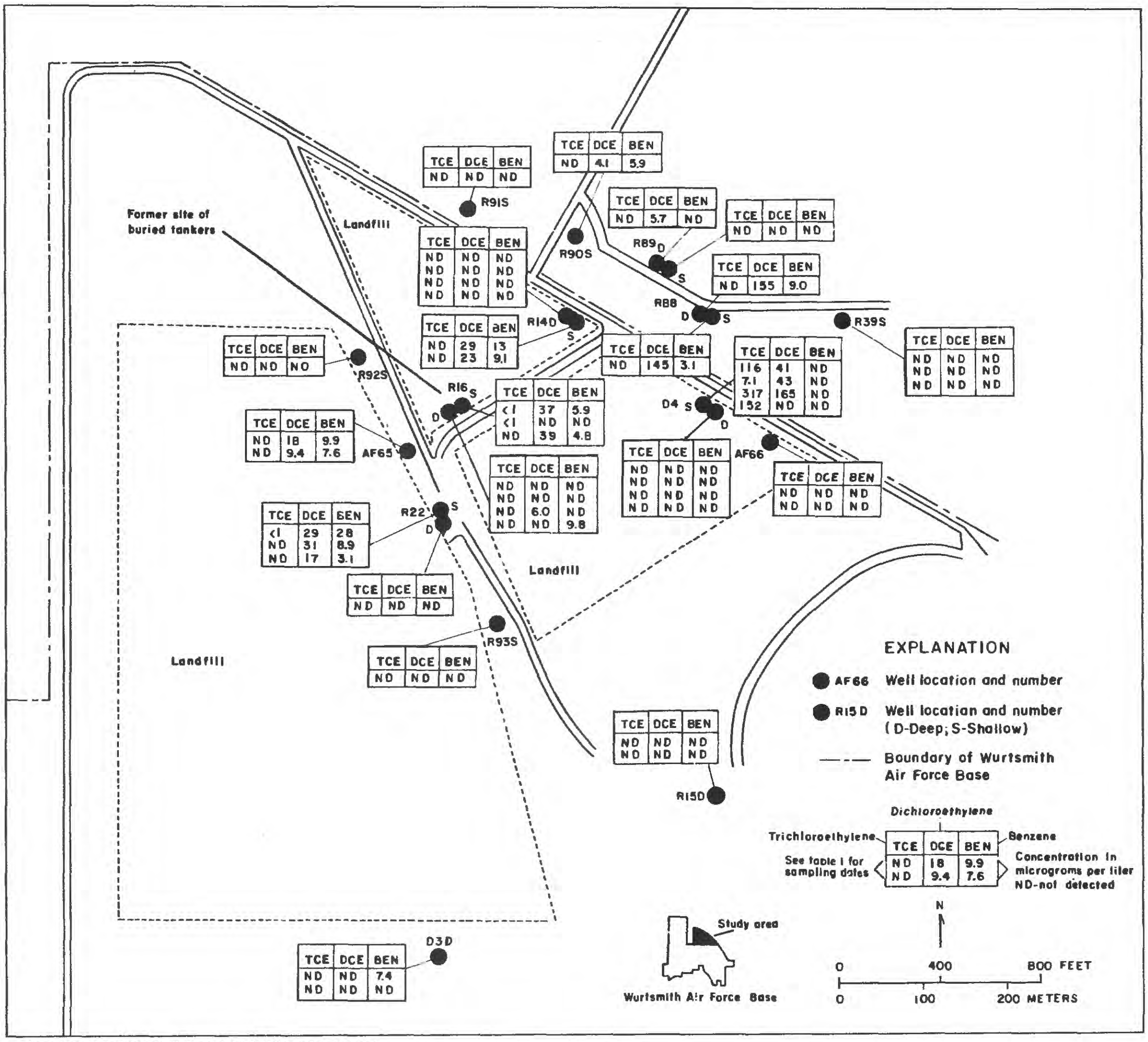
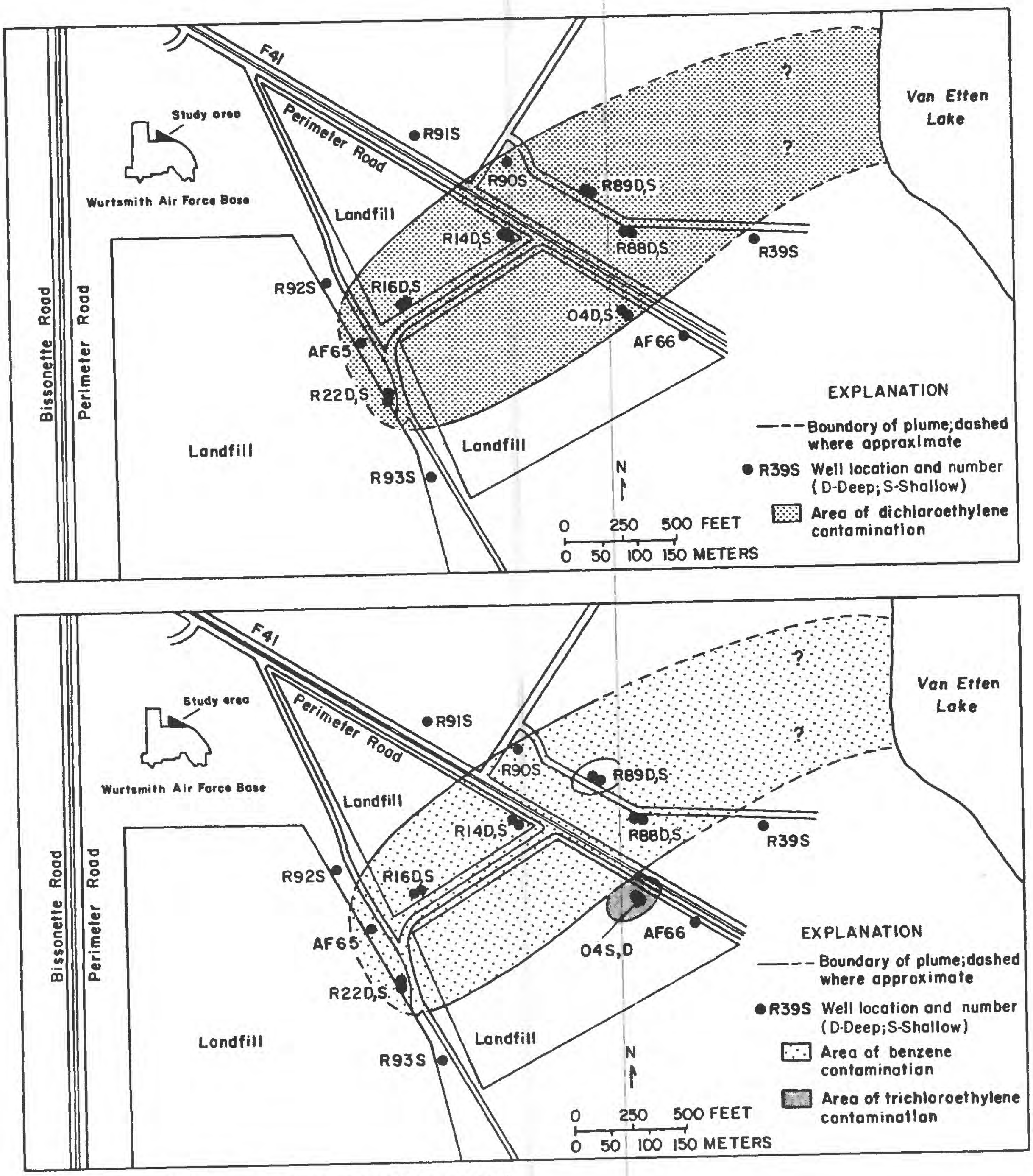
[1/] Samples collected December 20, 1979, and January 10, 1980, did not show detectable levels of trichloroethylene, dichloroethylene, or benzene.



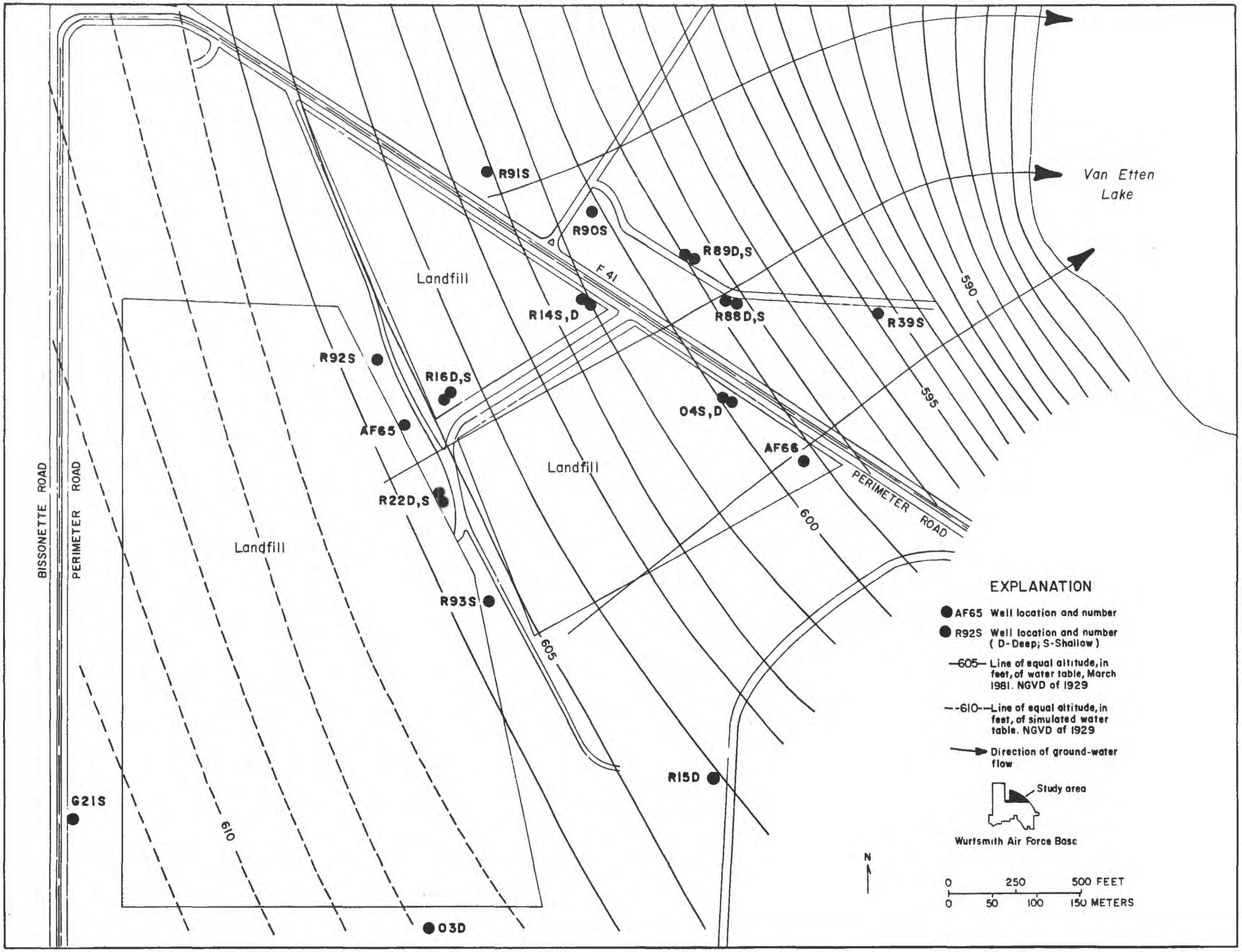
Base from US Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 25.--Concentrations of trichloroethylene, dichloroethylene, and benzene, and the location of wells in the northern landfill area.



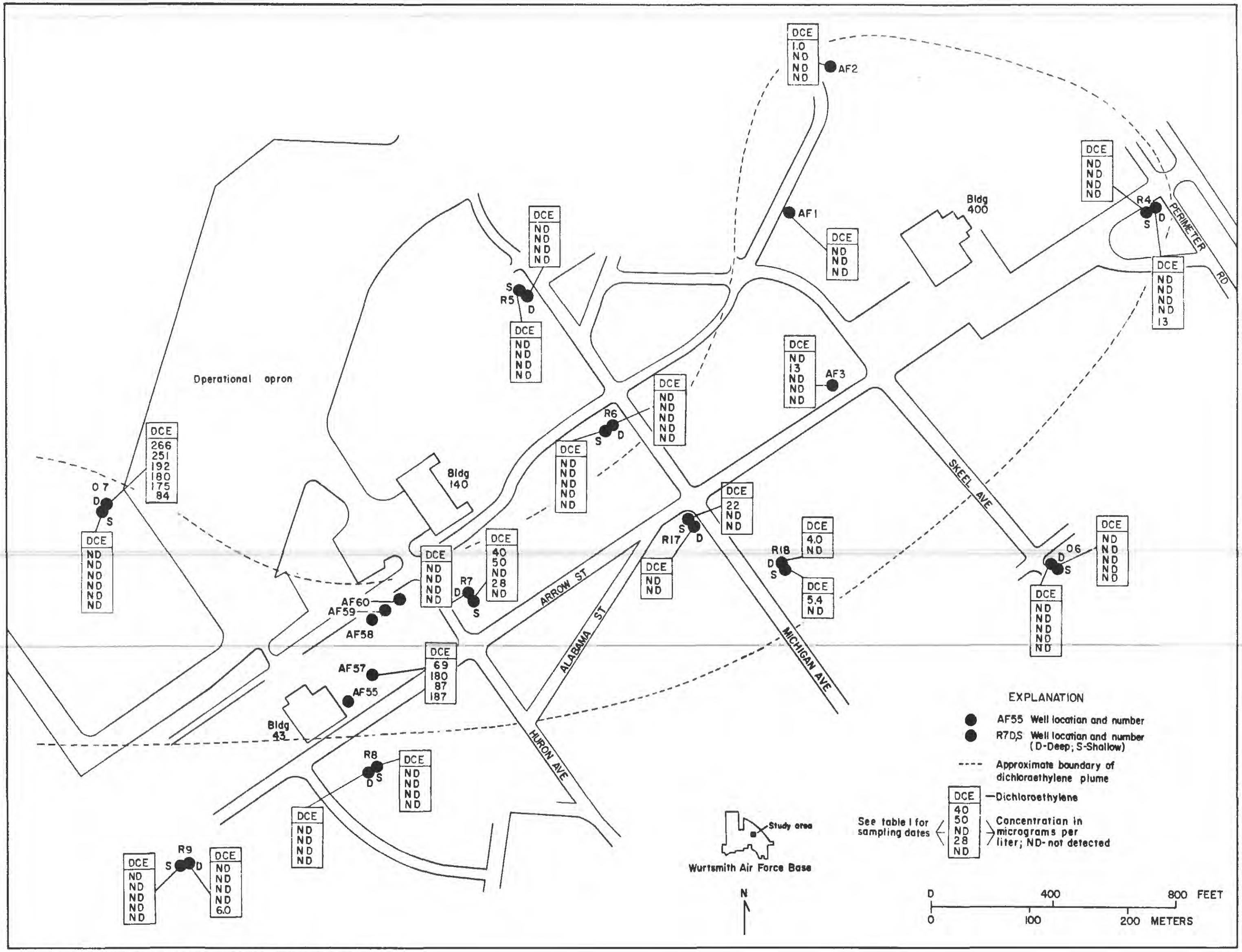
Base from US Geological Survey 1 62,500 quadrangle
and Wurtsmith Air Force Base 1 7,200 map

Figure 26.--Dichloroethylene, trichloroethylene, and benzene in shallow wells in the northern landfill area.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 27.--Water table and direction of ground-water flow in the northern landfill area, March 1981.



Base from U.S. Geological Survey 1:62,500 quadrangle and
Wurtsmith Air Force Base 1:7,200 map

Figure 28.--Dichloroethylene concentrations in ground water in the vicinity of Arrow Street.

trichloroethylene and benzene as well. Figure 29 shows the location of wells and the concentrations detected; figure 30 outlines the areas of detection.

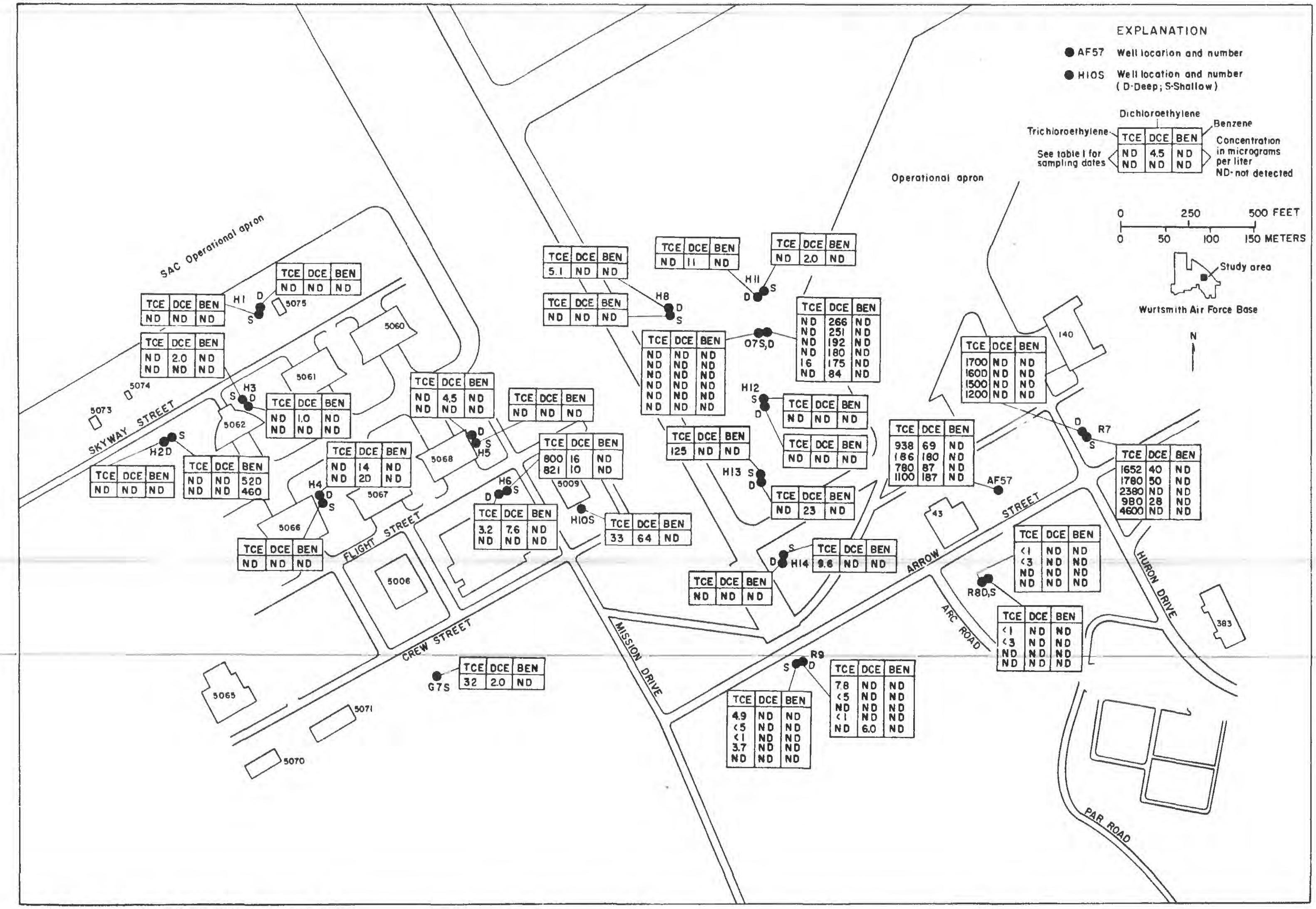
Ground-water flow in the area is generally eastward (fig. 31). In the past, most flow has been toward the area of drawdown produced by pumping of wells AF1, AF3, AF4, and AF5 and wells near Building 43. Model simulations show that these pumping conditions substantially altered the direction of ground-water flow. During December 1977, when supply wells AF18 and AF19 were pumped heavily, a more southerly component of flow was produced. In the future, additional purge pumping in the Building 43 area will increase the rate that ground water moves eastward.

Dichloroethylene occurs in both deep and shallow wells in the area outlined on figure 30 and in water from well G7S (2.0 µg/L) and well R9D (6.0 µg/L). Four previous determinations of dichloroethylene in water from well R9D, however, showed nondetectable levels. Shifting patterns of ground-water flow sometime in the past could account for dispersion of dichloroethylene southward to these areas. Data obtained from deep and shallow wells H8, H11, H12, and 07 suggest that a separate source of dichloroethylene may have existed at one time in the area of wells 07D,S. Dichloroethylene in this area is being drawn eastward toward Arrow Street by current purge pumping. Concentrations in well 07D decreased from 266 µg/L in December 1979 to 84 µg/L in March 1981.

Trichloroethylene was discovered in both deep and shallow wells as far west as Flight Street (fig. 30). Concentrations of trichloroethylene in water from well H6S were as high as 821 µg/L. Water from an adjacent deep well (H6D) had a maximum concentration of 3.2 µg/L. Water from well H10S had a concentration of 33 µg/L. Farther east, in the path of ground-water flow, well H13S showed 125 µg/L; well H13D showed a nondetectable level, however. This indicates that trichloroethylene is primarily in the shallow part of the aquifer. Nondetectable levels in wells H4D and H4S suggest that trichloroethylene entered the aquifer in the general vicinity of Building 5067. Trichloroethylene in water from wells G7S, R9D, and R9S indicates that a separate source of contamination may have existed at one time west of Crew Street. Movement of trichloroethylene from this area, rather than dispersion from the Building 43 spill may account for traces of trichloroethylene previously detected in wells R8D and R8S.

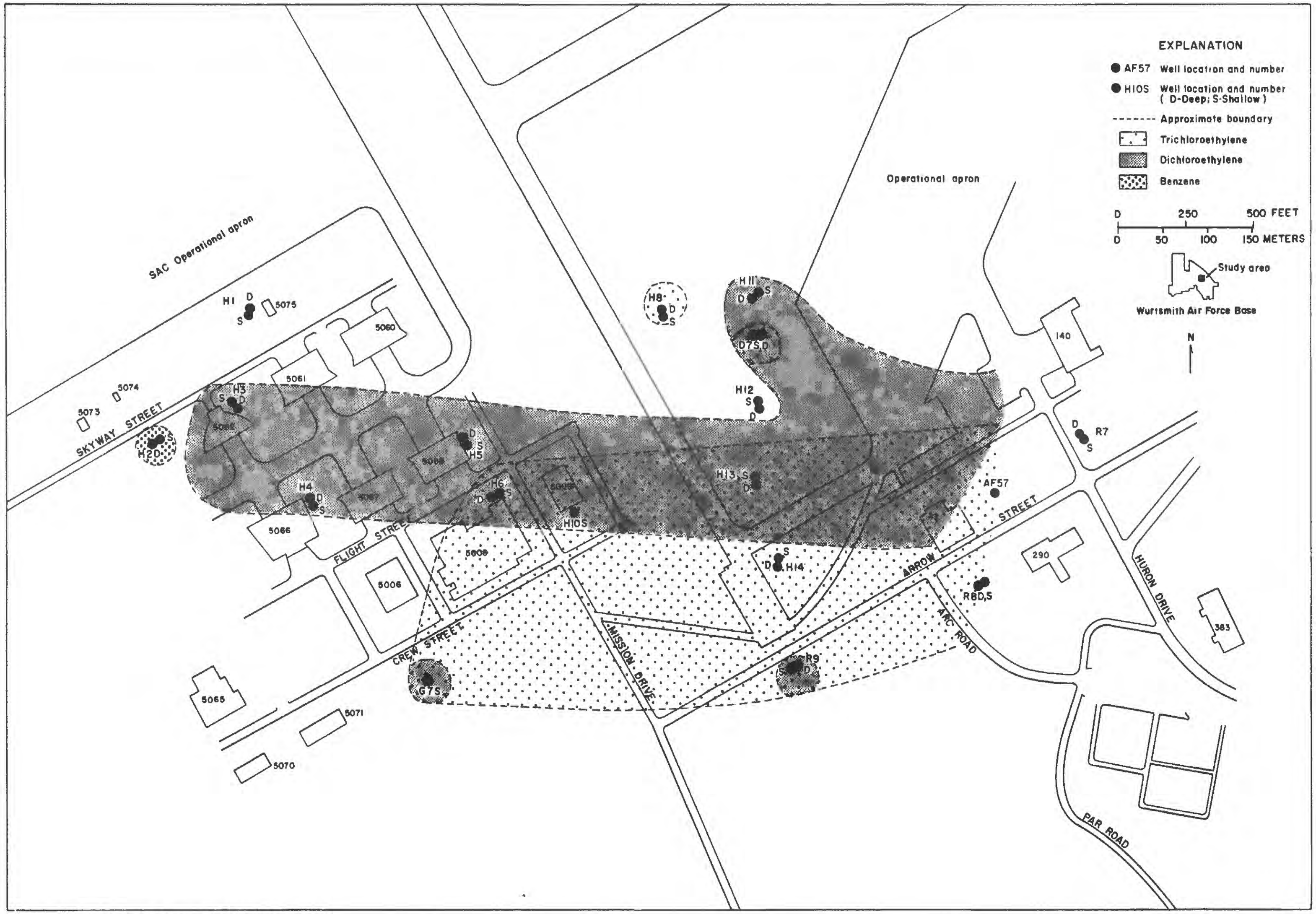
Although dichloroethylene and trichloroethylene occur in the same general area, their presence in the ground-water system is probably the result of separate uses. This is indicated, first, by the fact that trichloroethylene tends to be primarily in the shallow part of the aquifer; dichloroethylene, however, tends to be concentrated in the deeper part at some locations. Second, well water that has one of the substances may not have the other. For example, water from wells H3D, H3S, H4D, and H5D in the western part of the area contained small amounts of dichloroethylene but no trichloroethylene. Simiarly, water from wells H11D and H11S contained dichloroethylene but no trichloroethylene. Water from well R9D did not contain dichloroethylene on three occasions when trichloroethylene was detected; on a fourth occasion, dichloroethylene was detected, but trichloroethylene was not. Third, water from well H13D contained dichloroethylene but no trichloroethylene; the opposite was true for adjacent well H13S.

Benzene was detected in well H2S near Skyway Street. Water collected in March and April 1981 had concentrations of 520 µg/L and 460 µg/L, respectively.



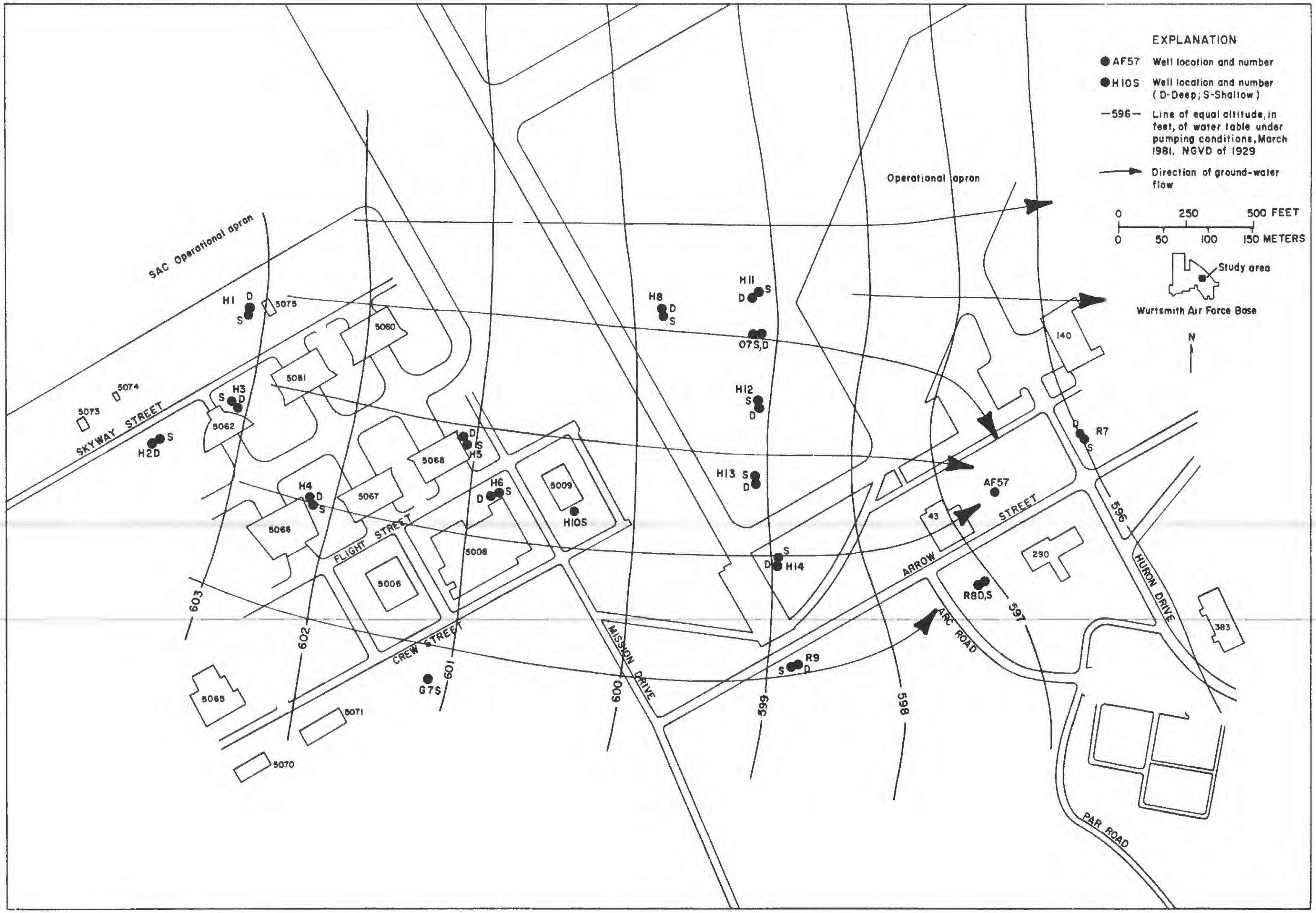
Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 29.--Concentrations of trichloroethylene, dichloroethylene, and benzene, and the locations of wells in the central part of the Base.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 30.--Distribution of trichloroethylene, dichloroethylene, and benzene, in the central part of the Base.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 31.--Water table and direction of ground-water flow in central part of the Base.

Benzene was not detected in an adjacent deep well (H2D), nor in any of the other wells drilled west of Building 43. This isolated occurrence suggests recent and local contamination. Based on the path of ground-water flow, spillage near Building 5073, which is a JP-4 fuel pump house, may have occurred.

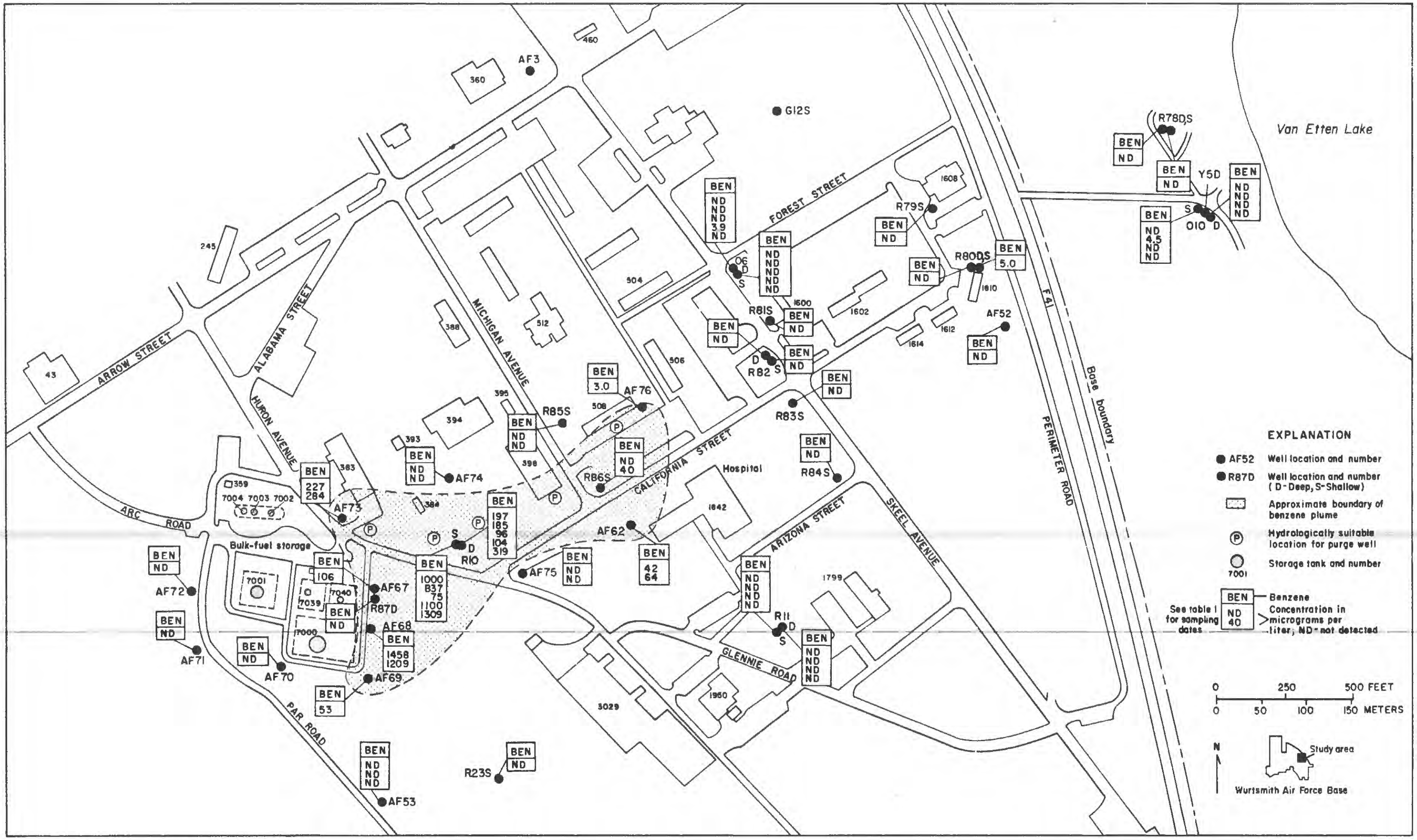
Benzene Near Bulk-Fuel Storage Area

Water from wells R10D and R10S southeast of Building 43 contained substantial amounts of benzene (fig. 32) when initially sampled in December 1979. Water from well R10S (28 feet deep) had a benzene concentration exceeding 1,000 µg/L. Traces of toluene, as well as other not easily identifiable organic compounds, were present in the water. Water from R10D (about 60 feet deep) contained 197 µg/L of benzene. Because of fuel storage facilities in the area, suspicion was cast on storage tanks and underground lines. JP-4 fuel, gasoline, heating fuel, and de-icer are all stored in the general area. Samples of gasoline and JP-4 fuel were sent to the laboratory for comparison with water from well R10S in an effort to identify which facility was the likely source. Results were inconclusive. Decomposition of the fuel substance contaminating the water made positive identification impossible, but a comparison of gas chromatograph spectra suggested JP-4 fuel to be the most likely contaminant.

Movement of ground water near the fuel storage area is influenced by pumping of Base supply and purge wells. The water table in late March 1981 shows this effect. Water from the southern part of the fuel storage area flows eastward toward Van Etten Lake, whereas that from the northern part flows northeastward toward Base purge wells. Figure 33 shows the water table and direction of ground-water flow.

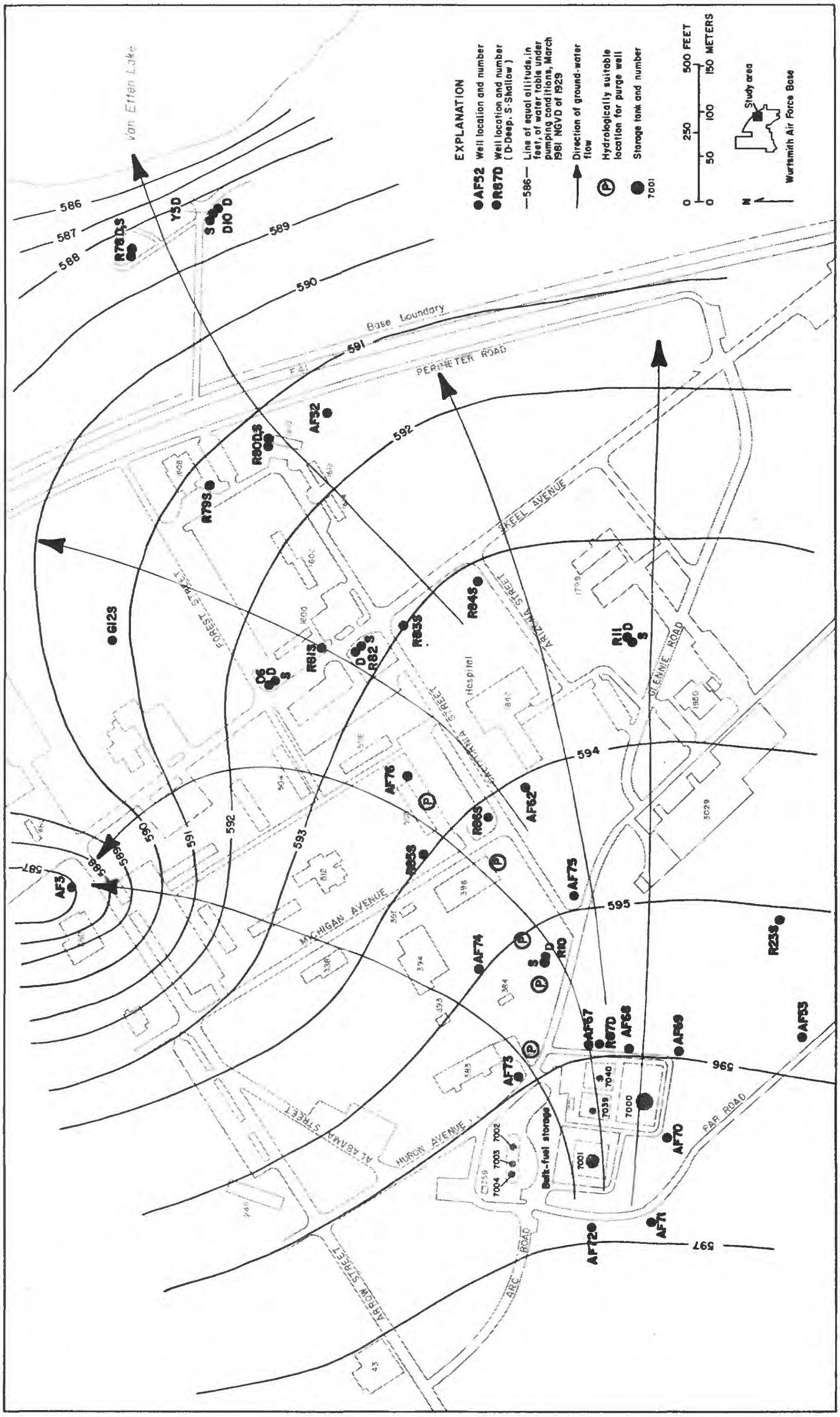
To investigate the movement and distribution of benzene, the Geological Survey drilled 13 additional deep and shallow wells between the bulk-fuel storage area and Van Etten Lake. The Air Force drilled 10 wells encircling the storage area. These 23 wells and 12 other wells formed the basis for further analysis of the problem. Table 1 gives the results of analyses for benzene, trichloroethylene, dichloroethylene, and other hydrocarbons. Figure 32 shows the extent of the benzene plume and concentrations found.

The absence of benzene in wells AF70, AF71, and AF72 south and west of the bulk-fuel storage area suggests that the benzene has its origin east of Par Road. Concentrations were greater than 1,000 µg/L only in shallow wells (R10S and AF68). Water from deep wells contained substantially less, suggesting that the benzene is primarily in the shallow part of the aquifer. Analyses of water from wells AF62, AF76, and R86S indicate that the benzene has reached the vicinity of the hospital. Analyses of water from wells O6S, R81S, R82S, R83S, and R84S indicate that benzene has not reached Skeel Avenue, although well O6D did have a concentration of 3.9 µg/L on January 31, 1980. Four other analyses of water from well O6D showed nondetectable levels, however. Benzene was detected in wells R80S and O10S east of Skeel Road. Water from well R80S had a concentration of 5.0 µg/L on December 17, 1980. Well O10S, off Base near Van Etten Lake, had a concentration of 4.5 µg/L benzene on January 10, 1980; three other analyses of water from the same well showed nondetectable levels. It does not seem likely that benzene found east of Skeel Road can be related conclusively to a source near the bulk-fuel storage area. Benzene in water from these wells may be due to other small but unidentified sources, or to contamination during well drilling.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 32.--Concentrations of benzene and location of wells near the bulk-fuel storage area.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 33.--Water table and direction of ground-water flow near the bulk-fuel storage area.

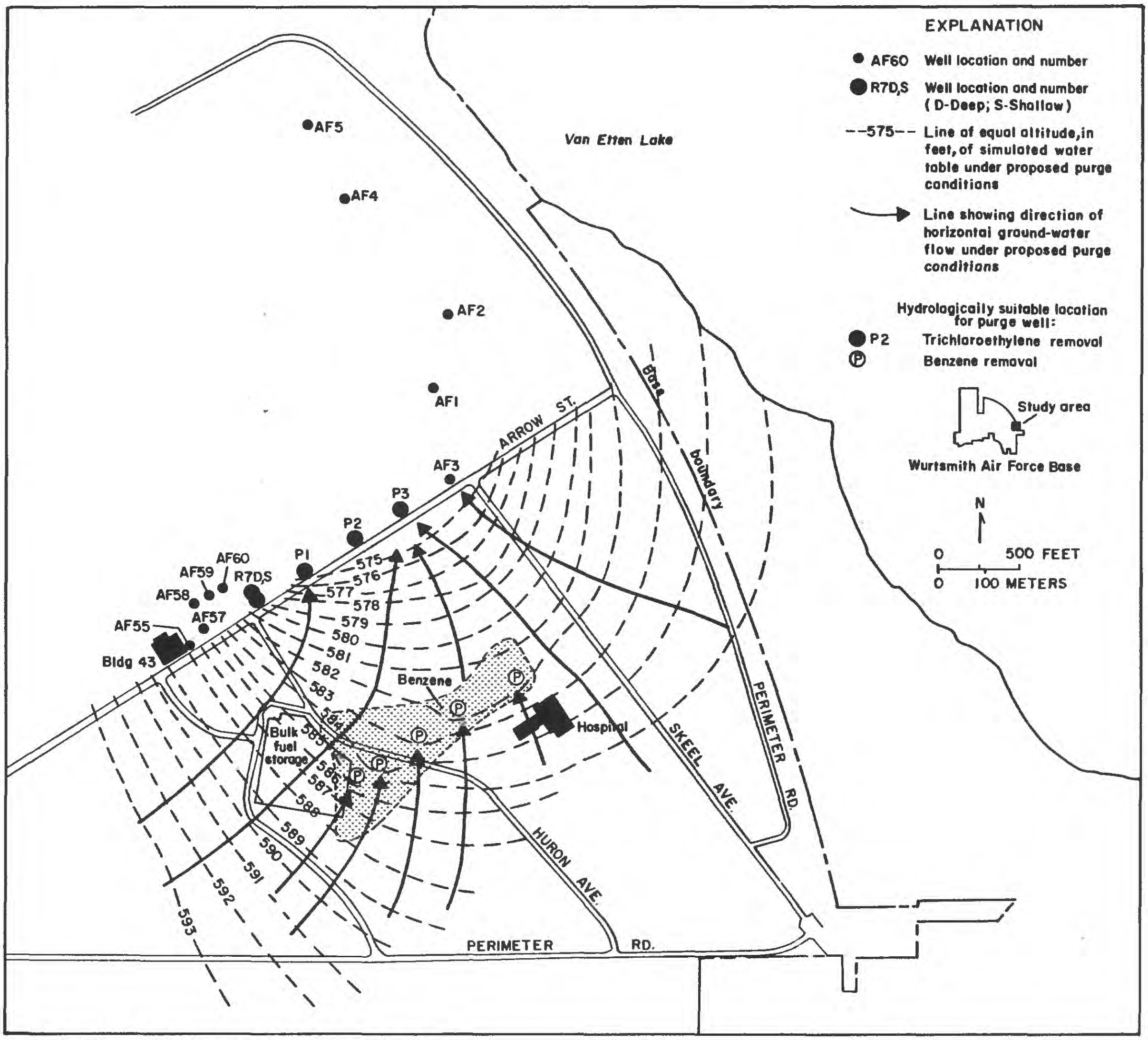
The direction of ground-water flow near the storage area and the occurrence of the highest benzene concentration (1,458 μg/L) in well AF68 suggest that the source is near JP-4 storage tank 7000. The source of benzene in wells R10S and R10D may be either near tank 7000, tank 7001 (JP-4 fuel), or tanks 7039 and 7040 (heating fuel). If no leaks in lines or tanks can be detected, spillage on the ground around the tanks at some time in the recent past might account for the contamination.

The amount of fuel substance in the ground-water system can only be estimated. The distance between well AF68 and wells R10D,S is about 450 feet. Assuming a width of 100 feet, and using available geologic, hydrologic, and concentration data, the ground-water system between the two wells is estimated to contain 1.8 gallons of benzene. Geological Survey analyses of JP-4 fuel for benzene suggest a content of 1 to 2 percent; Air Force data indicate a benzene content about 1 percent for JP-4 fuel, and 1.2 percent for gasoline. Thus, 1.8 gallons of benzene would indicate 150 to 200 gallons of fuel substance. If the remaining part of the plume area is considered, the amount in the plume might be twice as great.

Benzene in water from well AF73 is probably not derived from the area of JP-4 storage tank 7000. Ground-water flow to well AF73 is more likely to have been from the area of tanks 7002, 7003, and 7004, which contain gasoline and de-icer. Flow may also have been from the area of JP-4 storage tank 7001, depending on the pumping of water supply and purge wells. Spillage or leakage in these areas is a possible cause of benzene in water from this well. Benzene in water of well AF69 is probably from the area of the JP-4 storage tank 7000.

Model simulations show that the direction of ground-water flow in the fuel storage area is sensitive to drawdown produced by pumping. When all pumping was eliminated from simulations, ground-water flow from the storage area was nearly due east. Thus, variations in pumping of Base wells tend to shift flow between an east and northeast direction, dispersing contaminants in water near the storage area. This may be the reason that well AF62 contains benzene, but well AF75 (lying between wells AF62 and AF68) does not. Increased purge-pumping in the Building 43 plume area will tend to accelerate movement of ground water from the fuel storage area toward the purge wells.

Removal of benzene from the bulk-fuel storage area.--Installation of purge wells in the benzene plume near the fuel storage area was investigated by model simulations. From one to five wells were considered; a removal rate of 150 gal/min was assumed in each simulation. Figure 34 shows the altitude of the water table and the direction of ground-water flow for a five-well system that would be the most hydrologically efficient in removing benzene (or fuel substance). Altitudes and directions have been computed assuming new purge wells are operational in the Building 43 trichloroethylene plume area. Results of the simulations indicate that the altitude of the water table and the direction of ground-water flow would change only slightly if the number of purge wells were varied. Wells capable of pumping 30 gal/min, 6 inches in diameter with screens set at about 40 feet, could be installed.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 34.--Simulated water table and direction of flow when suggested purge wells are in operation near bulk-fuel storage area.

Seepage Lagoon Area

Seepage lagoons in the southwestern part of the Base (fig. 35) receive water from the waste-treatment plant by an underground pipeline. Because water in the lagoons is at a higher altitude than the surrounding water table, the lagoons leak in all directions. Of principal concern, however, is leakage to the south, which might reach the Au Sable River.

To monitor southern movement of contaminants from the lagoons, the Geological Survey installed deep (41 feet) and shallow (30 feet) wells 02D and 02S just off Base. Four additional Air Force observation wells along the northern and southern boundaries of the lagoons monitor trichloroethylene concentrations, and samples are obtained routinely from standing water in the lagoons.

Concentrations of trichloroethylene have decreased in water in all Air Force observation wells since monitoring began in January 1978. Since March 1980, water from observation wells 2 and 3 have consistently shown concentrations of less than 5 µg/L; generally, they have been either less than 1 µg/L, or nondetectable. Observation well 1, from which sampling was terminated in October 1979, yielded water containing less than 5 µg/L. Observation well 4, before January 1980, yielded water that had a concentration as high as 37 µg/L. From April 1980 to March 1981 the average concentration was about 8 µg/L.

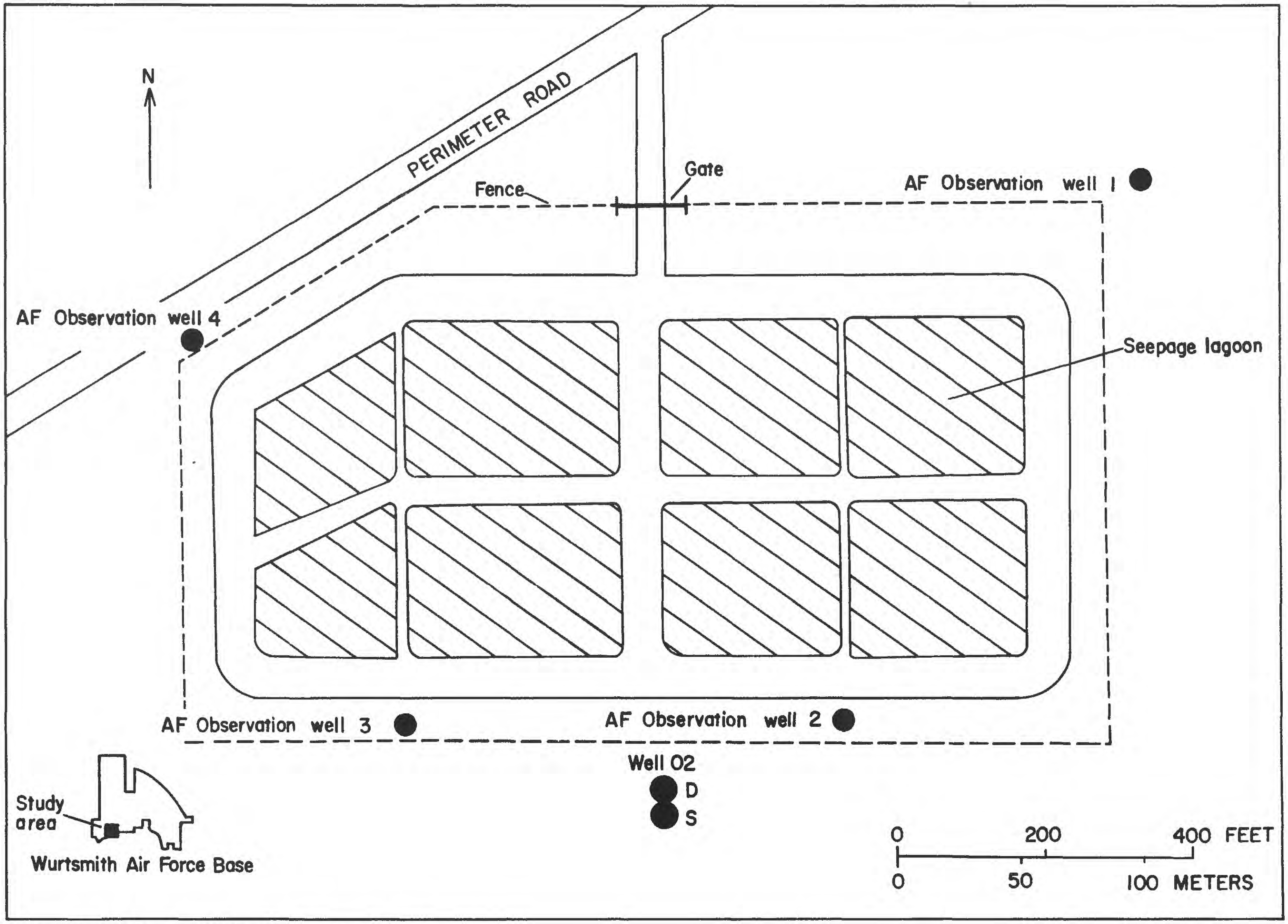
Well 02S yielded water containing as much as 9.4 µg/L trichloroethylene and as much as 17 µg/L dichloroethylene. Trichloroethylene and dichloroethylene were not detected in water from well 02D, but benzene (4.5 µg/L) was detected on one occasion.

U.S. Air Force analyses indicate that concentrations of trichloroethylene in standing water in the lagoons decreased rapidly from August 1979 to December 1979, primarily because the trichloroethylene concentration of water received from the treatment plant was decreasing. Carbon filtration of water from purge wells has generally reduced trichloroethylene to nondetectable levels. Thus, water piped to the waste-treatment plant from the carbon filtration system and subsequently to the lagoons now does not contain trichloroethylene. Dichloroethylene and benzene found in wells 02D and 02S were probably in purge water pumped to the waste-treatment plant before installation of carbon filtration and thus reached the lagoons in the same manner as trichloroethylene.

General Chemical, Physical, and Biologic Characteristics of Ground Water

Water from 35 wells installed by the Geological Survey and the Air Force were analyzed for a variety of constituents and properties. Table 2 lists the results of these analyses.

Data were obtained to (1) evaluate general water-quality characteristics and how they vary, and (2) assess the effects of landfills on ground-water quality. Thus, wells selected for sampling were either chosen for areal representation or because they were adjacent to landfills in the path of ground-water movement.



Base from Wurtsmith Air Force Base 1:7,200 map

Figure 35.--Seepage lagoon area.

Trace Metals

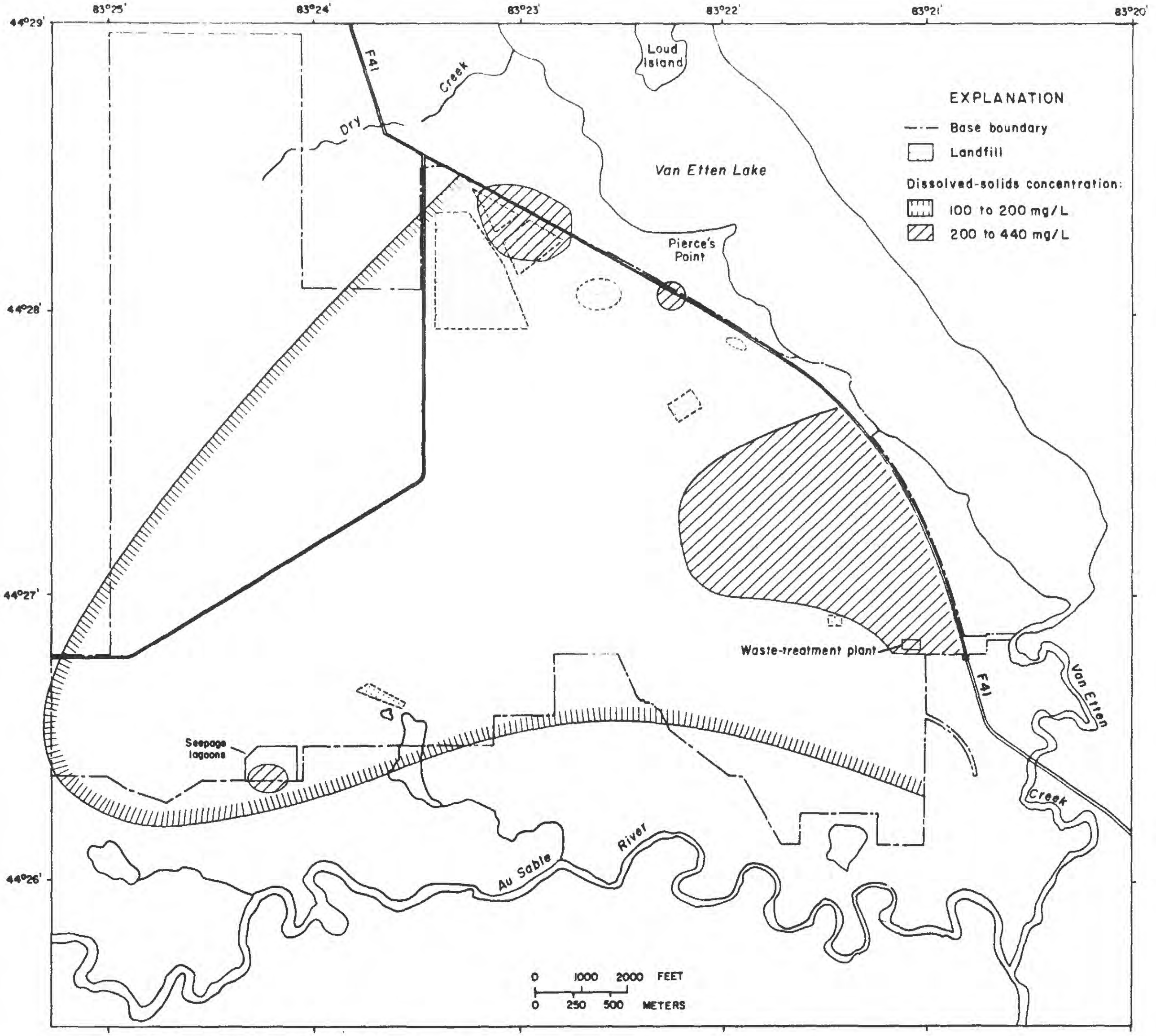
Cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc content of water from 31 wells was determined. With the exception of zinc, concentrations of each of these metals at all locations were low compared to drinking-water standards of the U.S. Environmental Protection Agency (1977). Standards have not been set for nickel. Although nickel was not detected in water from 29 of the 31 wells, water from wells 02S and R29S had a concentration of 100 µg/L. The fact that well 02S is near the seepage lagoon may be of significance; no explanation can be offered for the higher nickel concentration of water from well R29S.

Chloride, Nitrogen, Phosphorous, and Specific Conductance

Specific conductance, a measure of the ability of water to conduct an electric current, can be used to estimate dissolved-solids concentration. The relation of dissolved solids to specific conductance is determined by the amount and type of substances in solution. Most Michigan ground waters, in the mineralization range found at Wurtsmith Air Force Base, have a dissolved-solids/specific-conductance ratio of about 0.55 (Cummings, 1980). This ratio and specific-conductance values in table 2 have been used to compute and illustrate the general variation of dissolved-solids concentration in ground water at Wurtsmith Air Force Base (fig. 36). On much of the Base dissolved-solids concentrations range from about 100 to 200 mg/L. In the eastern part of the Base, the area of most intense operations and activity, dissolved-solids concentrations range from about 200 to about 440 mg/L. Levels are similar in the northern landfill area, where seepage probably increases dissolved solids downgradient. The dissolved-solids concentration of water from wells R27S near Pierce's Point and 02S at the seepage lagoons are also in the higher range. With respect to well 02S, seepage from the lagoons is probably the reason. No explanation can be given for the higher dissolved-solids concentration in water from well R27S. Water from well AF15 near the waste-treatment plant had the maximum dissolved-solids concentration on the Base, estimated to be 440 mg/L. It seems probable that seepage from sludge drying beds at the plant is responsible for this high concentration.

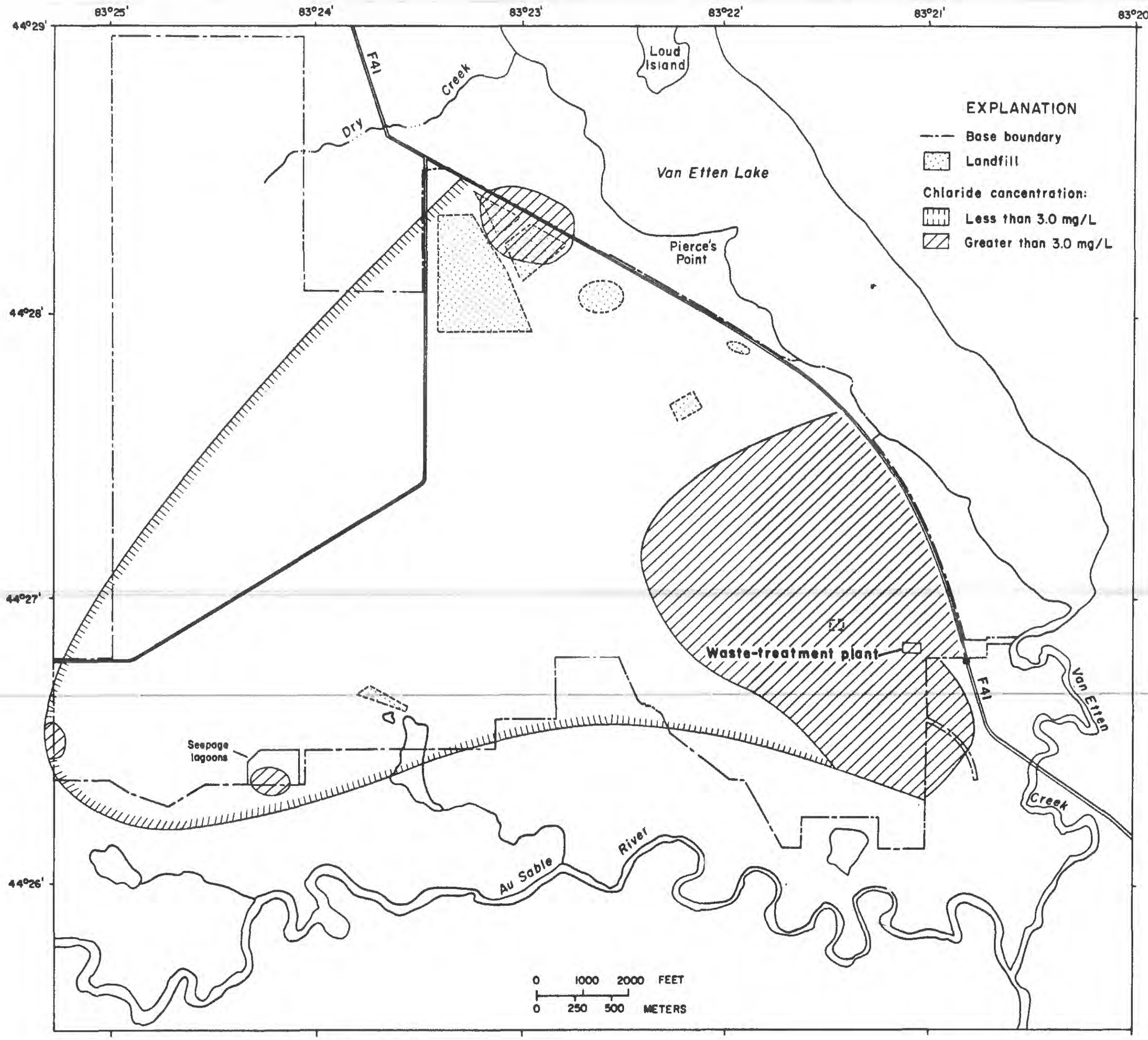
In general, chloride concentrations follow an areal pattern similar to that of dissolved-solids concentrations (fig. 37). Environmental and cultural influences, which determine these patterns, are likely to be similar.

Nitrate plus nitrite concentrations indicate less consistency in areal distribution than chloride and dissolved-solids concentrations. Concentrations exceeding 5 mg/L (computed as nitrogen) were found in water from wells R17S, R20D, R21S, R36S, and AF15. Water from wells R20D and R21S, which are adjacent to small landfills, has higher nitrate plus nitrite probably because of leaching of the landfill contents. The reason for comparatively high concentrations of nitrate plus nitrite in water from wells R17S (7.6 mg/L) and R36S (10 mg/L) is unknown. Water from well AF15 contained as much as 28 mg/L as N, which substantially exceeds the Environmental Protection Agency standard of 10 mg/L for drinking water. This high nitrogen concentration is attributed to sludge disposal at the waste-treatment plant. Phosphorous concentration (1.2 mg/L) was significant at only one location, near the seepage lagoons in the southwestern part of the Base (well 02S).



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 36.--Variation of dissolved-solids concentration in ground water.



Base from U.S. Geological Survey 1:62,500 quadrangle
and Wurtsmith Air Force Base 1:7,200 map

Figure 37.--Variation of chloride concentration in ground water.

Chemical Oxygen Demand, Biochemical Oxygen Demand, and Oil and Grease

Chemical oxygen demand (COD) is a measure of the chemically oxidizable material in water and generally indicates the minimum amount of organic and reducing material present. Biochemical oxygen demand (BOD) is a measure of the oxygen demand created by the bacterial decomposition of organic matter. Because COD and BOD measure demand of both contaminants and naturally occurring substances, low concentrations are not easily interpretable. COD concentrations greater than 20 mg/L occurred in the northern landfill area and in well 02S south of the seepage lagoons. These data support preceeding statements regarding the effect of the landfills and the lagoons. Water from wells 06D and R10S contained 39 mg/L and 66 mg/L COD, respectively. It seems certain that the higher COD concentration in water of well R10S is related to the benzene detected in the area.

BOD concentrations ranged from 0.0 to 14.2 mg/L; 27 of the 34 analyses fell in the 4.0 to 8.8 mg/L range. With the exception of well R22S (13.8 mg/L) in the northern landfill area and well 02S (14.2 mg/L) near the seepage lagoon, BOD concentrations are not particularly suggestive of ground-water contamination. Water from wells B4D, B5D, and B10D, in the western part of the Base, where activity is less, had concentrations that did not differ appreciably from those in the eastern part. Natural ground water in humid, vegetated areas sometimes contains as much as 5 mg/L BOD.

An oil and grease determination, because it is primarily a screening laboratory analysis, offers only a gross indication of possible contamination and cannot be relied on as most other laboratory procedures. Oil and grease concentrations, which ranged from 0 to 4 mg/L, are low. Only one correlation with known water-quality characteristics is suggested; water from well R10S, probably contaminated with a fuel substance, contained 3 mg/L. A reported concentration of 4 mg/L for well AF2 cannot be explained and may or may not be significant.

Fecal Coliform and Fecal Streptococci Bacteria

Fecal coliform bacteria are that part of the coliform group present in the intestines and feces of warm blooded animals. Fecal streptococci are normally found in the intestine of man and animals and are more specific indicators of fecal pollution. The Geological Survey used the membrane filter techniques for these determinations. When filters do not develop characteristic colonies, Geological Survey practice is to report results as "less than 1." Most determinations yielded this result. When colonies did develop, the number was low enough that the number counted was not considered statistically valid. Such values are reported as nonideal counts and are preceeded by "K" in table 2. In general, fecal coliform and fecal streptococci bacteria are low in ground water at Wurtsmith Air Force Base.

Gross Alpha and Gross Beta Activity

Analyses indicate that radioactivity in ground water at Wurtsmith Air Force Base is low. Most results in table 2 are reported as "less than" values, indicating that the count rate was too low to report more precisely than the maximum possible value. Drinking-water standards of the U.S. Environmental

Protection Agency (1977) require that if gross beta particle activity (referred to cesium-137 as a standard) exceeds 50 pCi/L (picocuries per liter), major radioactive constituents must be identified by analysis. No values approaching this level were detected.

Mathematical conversion of the measured gross beta activity as cesium-137 to gross beta activity as strontium-90 suggest that three wells (R16S, R22S, and AF15) could have strontium-90 levels that exceed the Environmental Protection Agency standard of 8 pCi/L. Because of this, specific analyses for strontium-90 were made. Results were as follows: well AF15, <0.4 pCi/L; well R16S, 0.9 pCi/L; and well R22S, 0.8 pCi/L. With respect to gross alpha activity, the Geological Survey reports results in μg/L as natural uranium. Conversion to pCi/L can be made by multiplying values given in table 2 by 0.68. Such a conversion indicates that the maximum gross alpha activity (<15), which was detected in water from well R16S, does not exceed the Environmental Protection Agency drinking-water standard of 15 pCi/L.

SUMMARY AND CONCLUSIONS

The principal aquifer in the Wurtsmith Air Force Base area is a sand and gravel unit that extends from land surface to a depth that averages 65 feet. The unit is mostly a medium to coarse sand containing some gravel. Thin beds of clay lie at depths ranging from 5 to 15 feet in the northern part of the Base. Underlying the sand and gravel unit, is a bed of relatively impermeable clay at least 125 feet thick.

The sand and gravel aquifer is mostly under water-table conditions. The depth to water ranges from about 25 feet near Van Etten Lake to less than 10 feet at places along the western part of the Base. Most ground-water flow is eastward toward Van Etten Lake and Van Etten Creek; a small part flows southward to the Au Sable River. In areas influenced by pumping, the natural direction of flow is significantly altered as water moves toward the pumped wells. Water levels fluctuate from 1 to 3 feet annually. The general configuration of the water table, however, does not change signficantly.

Two-dimensional finite-difference flow models were used to describe ground-water movement and to simulate water levels. Model simulations indicate that flow on the Base may be as low as 0.1 ft/day and as high as 1.0 ft/day, depending on location. Average flow ranges from 0.8 ft/day in the eastern part of the Base to 0.3 ft/day in the western part. Model simulations indicate that hydraulic conductivity is about 100 ft/day in the eastern part of the Base and about 150 ft/day in the western part.

Trichloroethylene that leaked from a buried storage tank near Building 43 moved northeastward under the influence of the natural ground-water gradient and the pumping of Base water-supply wells. The most highly contaminated water (greater than 1,000 μg/L) is found in a band along Arrow Street between well AF57 and AF3, although that part of the plume having less than 50 μg/L is broader and extends northeastward to Perimeter Road. Movement of the most highly contaminated part of the plume seems to have been arrested by pumping; however, eastward movement of the plume can be prevented only by near capacity pumping of existing purge well.

About 580 gallons of trichloroethylene was purged from the ground-water system between November 1977 and March 1981. Eighty-four percent of that amount has been pumped from wells AF3 and AF57. The rate of removal has been closely related to the rate of purge pumping. Removal of contaminated water could be more rapid if three additional purge wells were installed. A model simulation indicates that, with additional purge wells and supply wells pumping, water levels in the most highly concentrated part of the Building 43 plume will be lowered about 15 feet, and trichloroethylene will not escape to Van Etten Lake. Because trichloroethylene is not uniformly distributed in the aquifer, no prediction can be made of the time required to reduce concentrations to specified levels until new purge wells are in full operation.

Trichloroethylene in water from supply wells AF18 and AF19 in 1978 did not come from the Building 43 spill site. A ground-water divide observed during the study, which runs diagonally across the Base, indicates that migration of trichloroethylene southwestward is not possible.

Ground-water contaminated with trichloroethylene has been identified in the vicinity of the alert apron. No spill sites have been located, but concentrations of about 1,000 µg/L have been detected west of the alert apron near Pride Road. Data indicate two plumes exist. The major and southernmost plume extends off Base to the area of Pierce's Point. Trichloroethylene in the Charles Pierce well probably had its origin on the Base some years ago. A smaller, less well defined plume or area of contamination occurs immediately north of the major plume. The location of the alert apron prevents precise definition of its northeastern boundary. Water from well R94S, R94D, and R95S, just east of the alert apron, does not contain trichloroethylene; this suggests that the smaller plume terminates under the alert apron. Monitoring of these wells, and wells R1S, R1D, and R12D, could provide early warning of northeastward movement.

A simulation of ground-water flow in the area of the Alert Apron plume indicates that 12 small-diameter purge wells, each capable of pumping about 40 gal/min, are hydrologically suitable for most rapidly and efficiently removing trichloroethylene from the system.

Analysis of ground-water-flow data indicate that trichloroethylene detected in water east of the waste-treatment plant did not come from the leakage of the storage tank at Building 43. Sludge placed in the drying beds at the plant before installation of carbon filtration on the Base is the most plausable origin of trichloroethylene in the water. Trichloroethylene was not found to be adsorbed on soils, cores, or surface sludge material, although other organic compounds were detected.

Ground-water flow from the northern landfill area is northeastward toward Van Etten Lake. Dichloroethylene and benzene are more commonly detected in ground water than is trichloroethylene, although a higher concentration of trichloroethylene was detected. No evidence was found that leakage from the buried tankers containing trichloroethylene has contaminated ground water. Dichloroethylene and benzene occur primarily in the shallow part of the aquifer; the source seems to be in the western landfill area. The source of trichloroethylene seems to be in the southwestern landfill area.

Dichloroethylene occurs in ground water in the general area encompassed by the Building 43 trichloroethylene plume. Concentrations are highest, however, approximately 900 feet northwest of the Building 43 spill site. Investigation detected dichloroethylene westward as far as Skyway Street and disclosed traces of trichloroethylene and benzene. Dichloroethylene tends to be in the deeper part of the aquifer; trichloroethylene seems to be at more shallow depths. Benzene contamination is localized; a JP-4 fuel pump house is the likely source. Under the influence of the natural ground-water gradient and pumping in the vicinity of Arrow Street, contaminants are being drawn eastward to the Building 43 plume area.

Benzene, probably indicative of ground-water contamination by a fuel substance, was detected in concentrations exceeding 1,000 µg/L in water east of the bulk-fuel storage tanks. Data indicate that the benzene is primarily in the shallow part of the aquifer and that a plume extends northeastward from the bulk-fuel storage area to the vicinity of the hospital. Its source is likely one or more of the storage tanks or from spillage on the ground in the recent past. Ground-water movement is influenced by pumping of Base supply and purge wells. Based on model simulations, installing and pumping five purge wells, having a total capacity of 150 gal/min, seems to be the most hydrologically suitable scheme for rapid removal of the fuel substance from the aquifer.

Trichloroethylene, benzene, and dichloroethylene have been found in ground water in the immediate vicinity of the seepage lagoons. Concentrations have decreased, however, since 1978 largely because these substances are no longer contained in water pumped from the treatment plant.

Analyses by the Geological Survey for a variety of chemical, physical, and biologic characteristics of water were made to evaluate general water-quality conditions, with particular reference to landfills. Concentrations of trace metals, with the exception of zinc, were low at all locations. Water from wells O2S and R29S had nickel concentrations of 100 µg/L. Based on specific-conductance measurements, dissolved-solids concentration ranges from 100 to 200 mg/L over much of the Base. On the eastern part of the Base, in an area of concentrated operations and activity, the range is about 200 to 440 mg/L. Levels are similar in the northern landfill area, where seepage from the landfill probably increases dissolved-solids concentration. Concentration is highest in water from AF15 and is probably related to seepage from sludge drying beds at the waste-treatment plant. In general, chloride concentrations follow a pattern similar to dissolved solids. Nitrate plus nitrite concentrations show less consistent areal distribution than either chloride or dissolved-solids concentrations. Concentrations of nitrate plus nitrite exceeding 5 mg/L were found in water from several wells, some of which were adjacent to landfills. Water from well AF15 contained as much as 28 mg/L, an amount that considerably exceeds drinking-water standards of the Environmental Protection Agency. At most locations, biochemical oxygen demand and chemical oxygen demand concentrations are not particularly suggestive of ground-water contamination. However, well R22S in the northern landfill area had a BOD concentration of 13.8 mg/L. Well O2S, south of the seepage lagoons, had a BOD concentration of 14.2 mg/L. With respect to chemical oxygen demand, water from wells O6D and R10S contained 39 mg/L and 66 mg/L, respectively. It seems certain that the higher concentration of chemical oxygen demand in R10S is related to benzene detected in the area.

Gross beta activity and gross alpha activity in water did not exceed Environmental Protection Agency drinking-water standards. Standards were also met when specific analyses for strontium-90 were made.

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APPENDIX

Development and Calibration of Hydraulic Models

Mathematical simulation of ground-water flow was based on steady-state, two-dimensional finite-difference models. These models were developed using a computer program described by Trescott, Pinder, and Larson (1976). One model, referred to in this report as the "Base model," was used to describe general ground-water flow conditions for the entire Base. Models of two areas--the Building 43 plume area and the Alert Apron plume area--were developed for detailed evaluations. Each model was used to refine estimates of the aquifer's hydraulic parameters and to aid in calculating the rate and direction of ground-water flow.

Modeling required that the ground-water flow system be divided into discrete cells. Estimates of hydraulic parameters were initially assigned to each cell and boundary conditions were specified. The computer program was then used to calculate water levels. Calculated levels were compared to observed water levels. If the levels matched, the model was considered calibrated. If they did not match, the hydraulic parameters were adjusted and new water levels were calculated. This procedure was repeated until each model was calibrated.

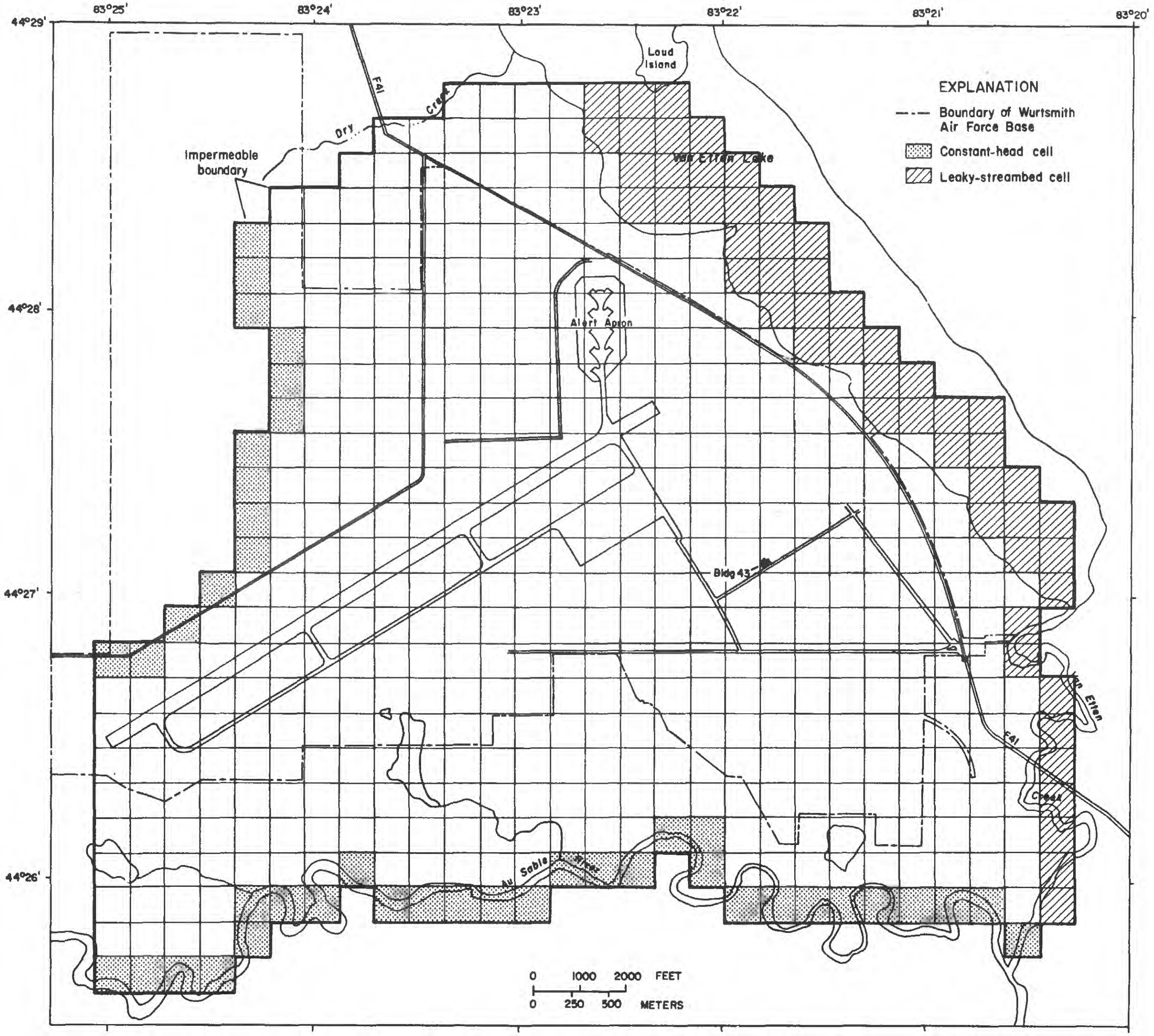
Hydraulic conductivity, determined by model calibration, is 100 ft/day in the eastern part of the Base and 150 ft/day in the western part. These values are within the range of hydraulic conductivities determined in the field. Ground-water recharge was determined to be 15 inches per year, which is about 50 percent of the annual precipitation. This seems reasonable because the Base is relatively flat, sparsely vegetated, has sandy surface soil, and low surface runoff.

Base Model

The Base model, enclosed by an impermeable boundary, covers an area of about 13 square miles (fig. 38). It encompasses the entire Base and an area to the east and south including Van Etten Lake, Van Etten Creek, and part of the Au Sable River. Flow in the sand and gravel aquifer that underlies the Base was simulated by dividing the area into 523 cells. All cells were represented by squares that measured 742 feet along a side.

The west side of the model area is bounded at some places by cells that represent constant heads (water levels) and at other places by cells that represent noflow conditions. Constant-head cells were located to coincide with the 620-foot equipotential line that was determined from field data. Noflow cells were located along ground-water flow lines.

The south side of the model area represents the Au Sable River. Because the river bed consists of permeable material, it is considered as a series of constant head cells and is set to the level of the water surface of the river. The east side of the model area represents Van Etten Lake and Van Etten Creek. The lake and creek bottoms are less permeable, and thus are considered as leaky streambed cells, that is, they simulate flow from the aquifer through confining beds to the lake and creek. Hydraulic head values for those parts of the leaky-streambed cells overlying the confining bed were set to a level that represented the water surface of the lake and stream. Use of leaky-streambed



Base from U.S. Geological Survey 1:62,500 quadrangle
and Wurtsmith Air Force Base 1:7,200 map

Figure 38.--Grid used for Wurtsmith Air Force Base model.

cells was justified because simulations showed that the hydraulic conductivity of the streambed and lakebed influenced the shape of the water table in the vicinity of the shores. The streambed and lakebed were simulated as having a uniform thickness of 1 foot. Model results best matched field data when the values of conductivities assigned the leaky-streambed cells were 0.02 ft/day for confining beds under Van Etten Creek and the southeast part of Van Etten Lake, and 0.07 ft/day for confining beds under the northwest part of the lake.

The north side of the model area is partly bounded by the leaky-streambed cells described above, and partly by noflow cells located along ground-water flow lines.

The Base model simulated conditions existing in March 1980. At that time, water-table fluctuations were minimal and were considered to represent steady-state conditions. Pumping rates of Base supply and purge wells used in the model were as follows:

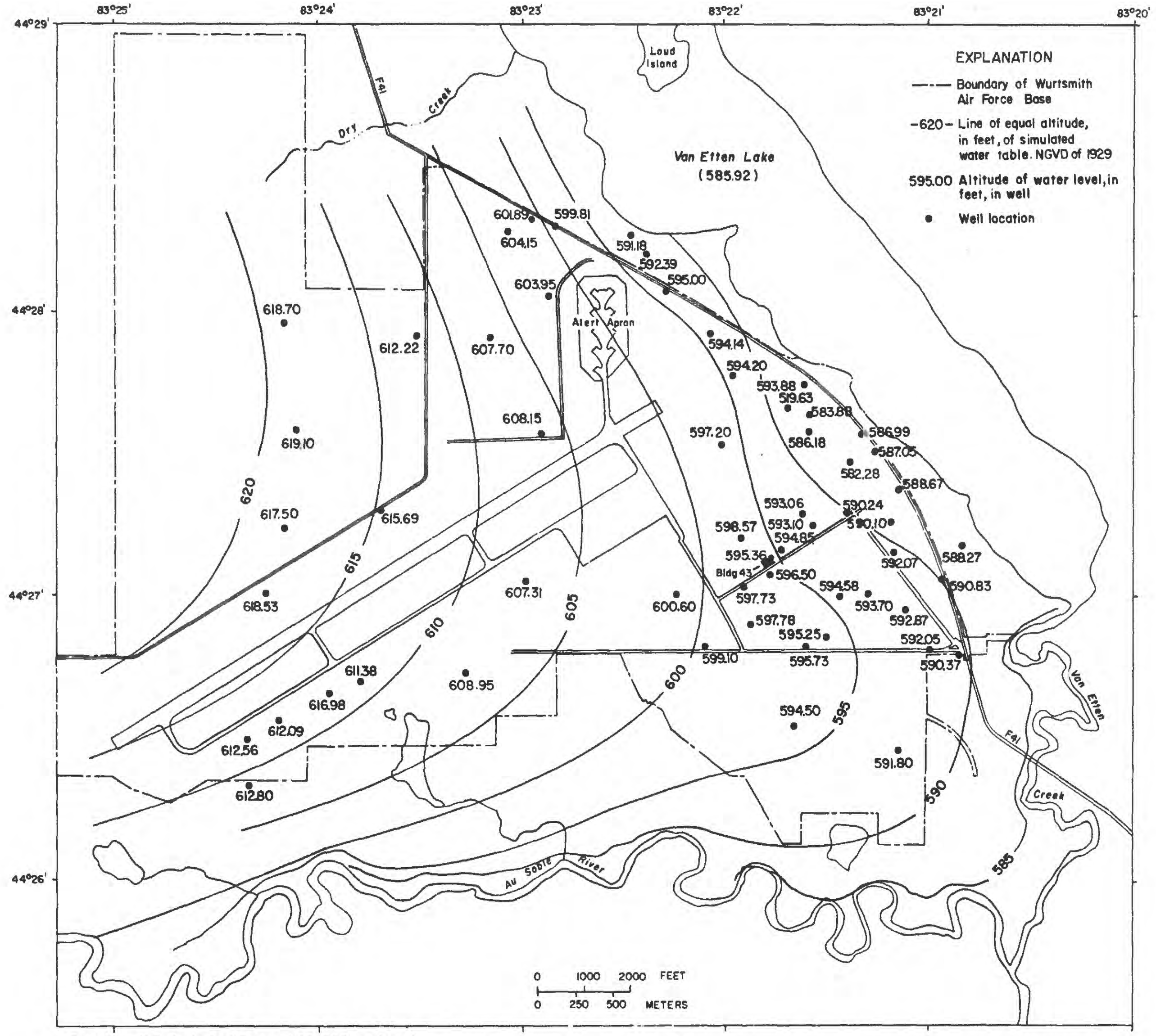
Well	Pumping rate (gal/min)
AF1	180
AF2	140
AF3	49
AF4	130
AF5	125
AF18	0
AF19	0
AF55	45
AF56	0
AF57	34
AF58	0
AF59	34
AF60	4

Figure 39 compares the water table simulated by the Base model with water levels in 57 wells in March 1980. The largest deviations between simulated levels and field measurements are at the seepage lagoons in the southwestern part of the Base. Because the lagoons were not simulated, the differences probably are due to induced recharge from the lagoons. Seepage lagoons were omitted from the model because the size of the lagoons is small compared to the size of the cell, and it was believed that the impact of the lagoons on ground-water levels would be negligible. Model simulation, however, indicates that the lagoons create a higher water table than would be expected under natural conditions.

Building 43 Plume Model

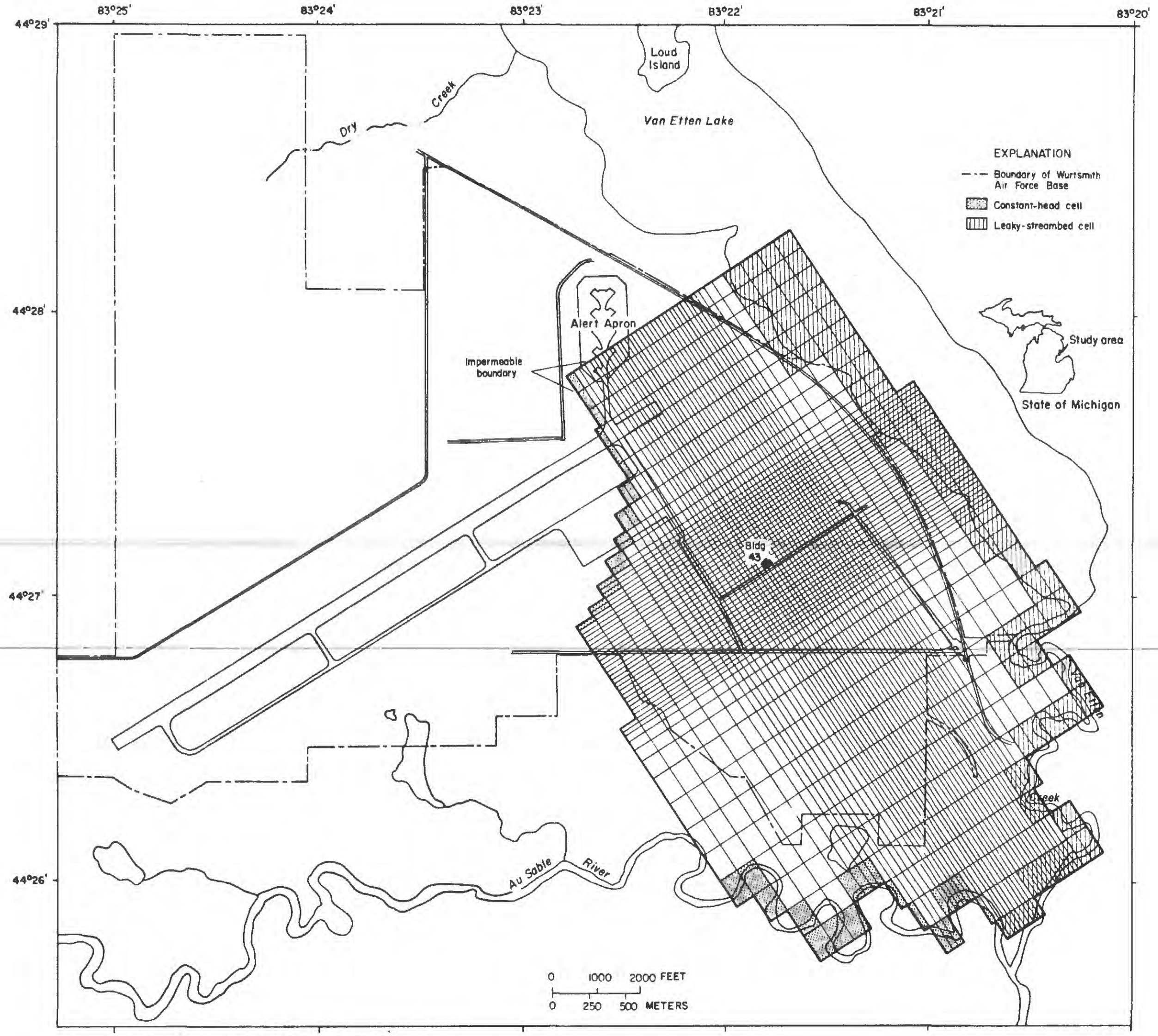
The Building 43 plume model was developed to study ground-water flow in the vicinity of and from the spill site. The area was divided by grid into 2,689 cells (fig. 40). The grid was designed so that the smallest cells, 100 feet on a side, represented the spill site and areas of heavy pumping.

Boundaries used for the model were similar in design to those used in the Base model. The south side of the model is bounded by constant-head cells representing the Au Sable River. The east side, representing Van Etten Lake and Van Etten Creek, is bounded by leaky-streambed cells. The north and west



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 39.--Water levels in wells and water table simulated by Wurtsmith Air Force Base model, March 1980.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

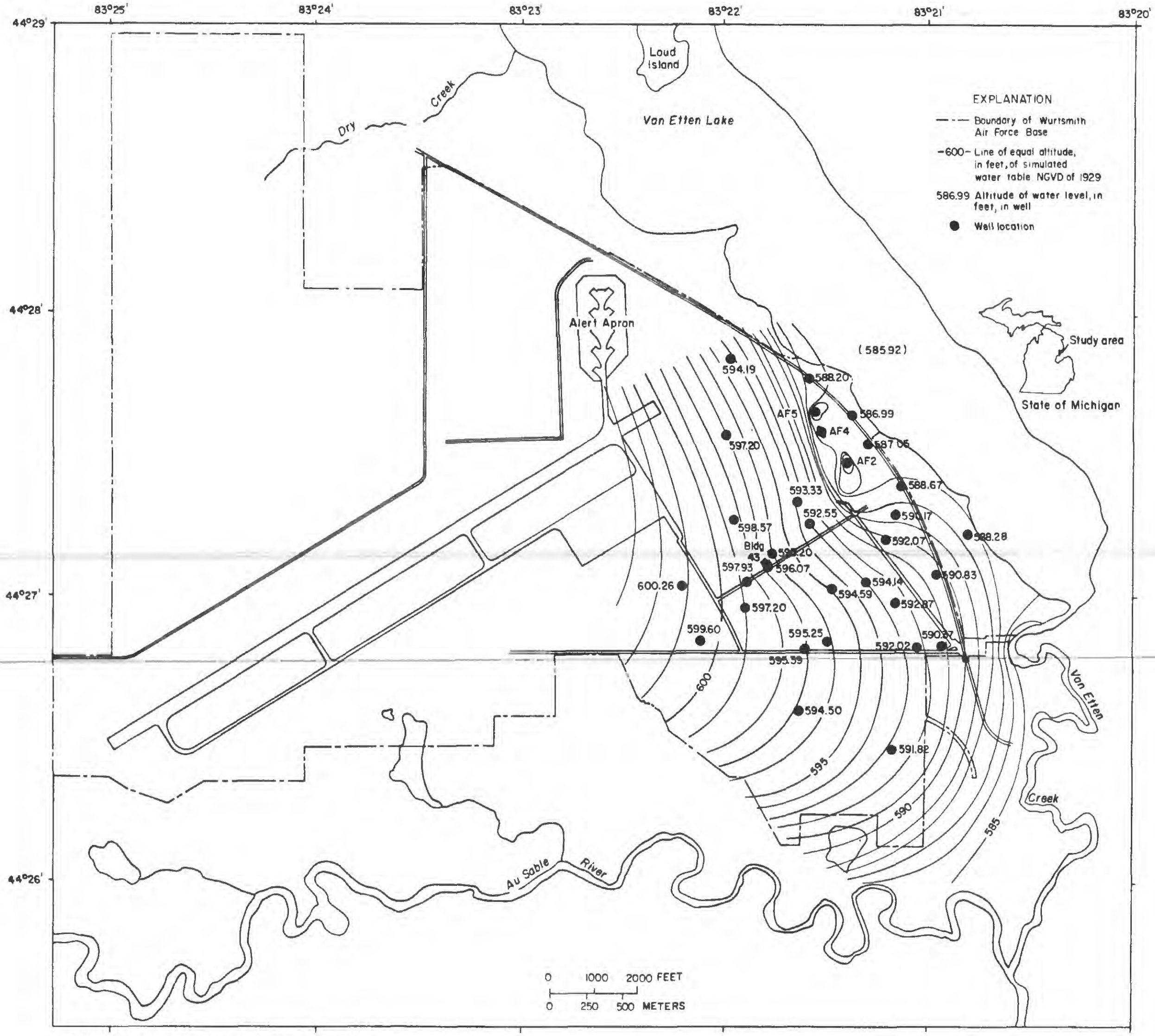
Figure 40.--Grid used for Building 43 plume model.

sides are bounded by constant-head and noflow cells located to coincide with equipotential lines and ground-water flow lines determined by the Base model. The Building 43 plume model was calibrated simultaneously with the Base model for the March 1980 period. Figure 41 compares the water table simulated by the model with water levels in 28 wells in March 1980.

Alert Apron Plume Model

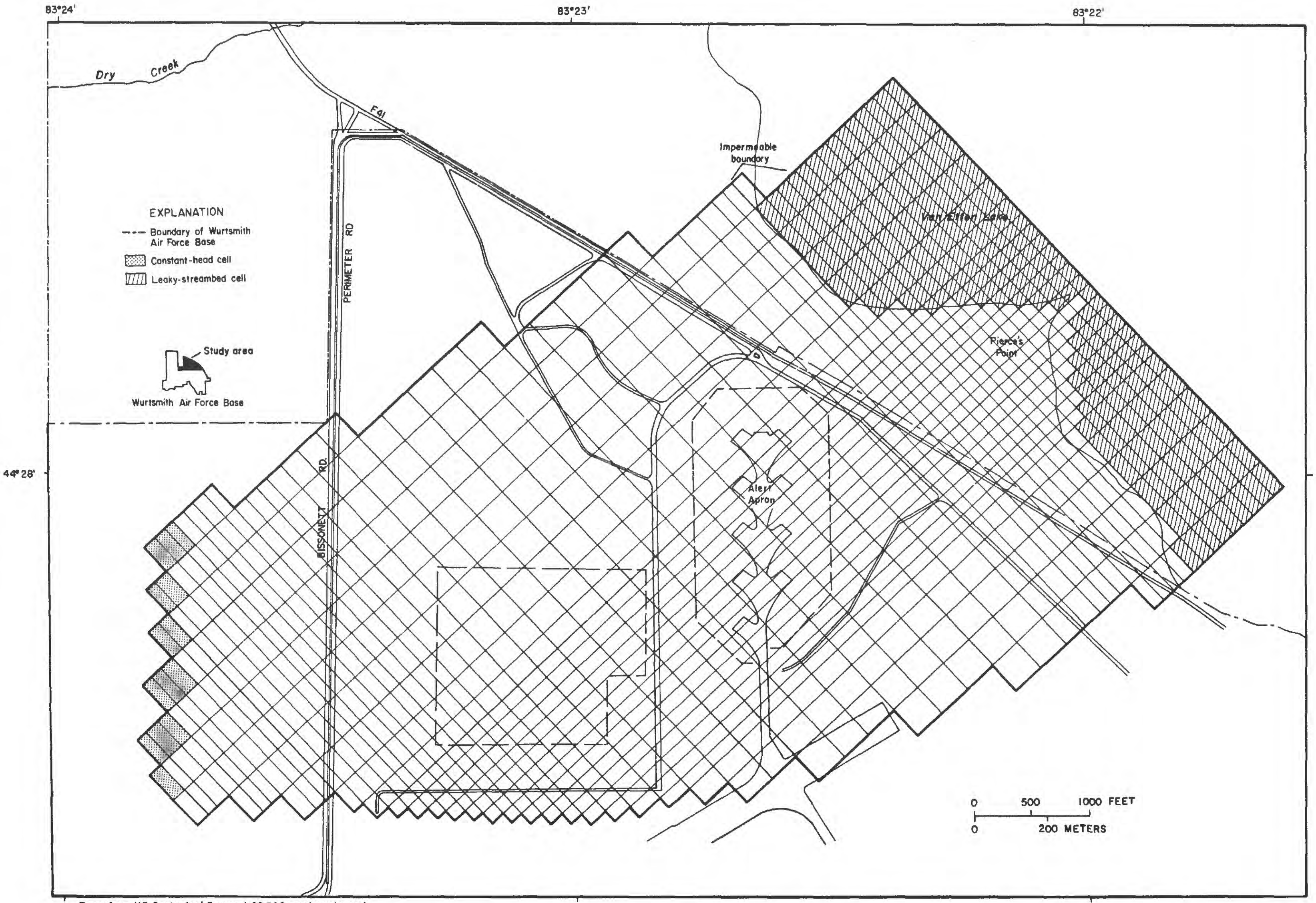
The Alert Apron plume model was developed to study ground-water flow from the storage area near Pride Road to Pierce's Point. The Alert Apron plume area was divided by a grid into 1,062 cells (fig. 42). The grid was designed so that the smallest cells, 120 feet on a side, represented the area near Pierce's Point.

Boundaries used for the model were similar to those used in the other models. The northeast side of the model is bounded by leaky-streambed cells representing Van Etten Lake. The south side is bounded by constant-head cells. The west and east sides are bounded by noflow cells. Constant-head and noflow cells are located along equipotential lines and streamflow lines, respectively. Figure 43 compares the water table simulated by the Alert Apron plume model with water levels in 36 wells in August 1980. The results of the simulation are comparable with water levels measured in the field.



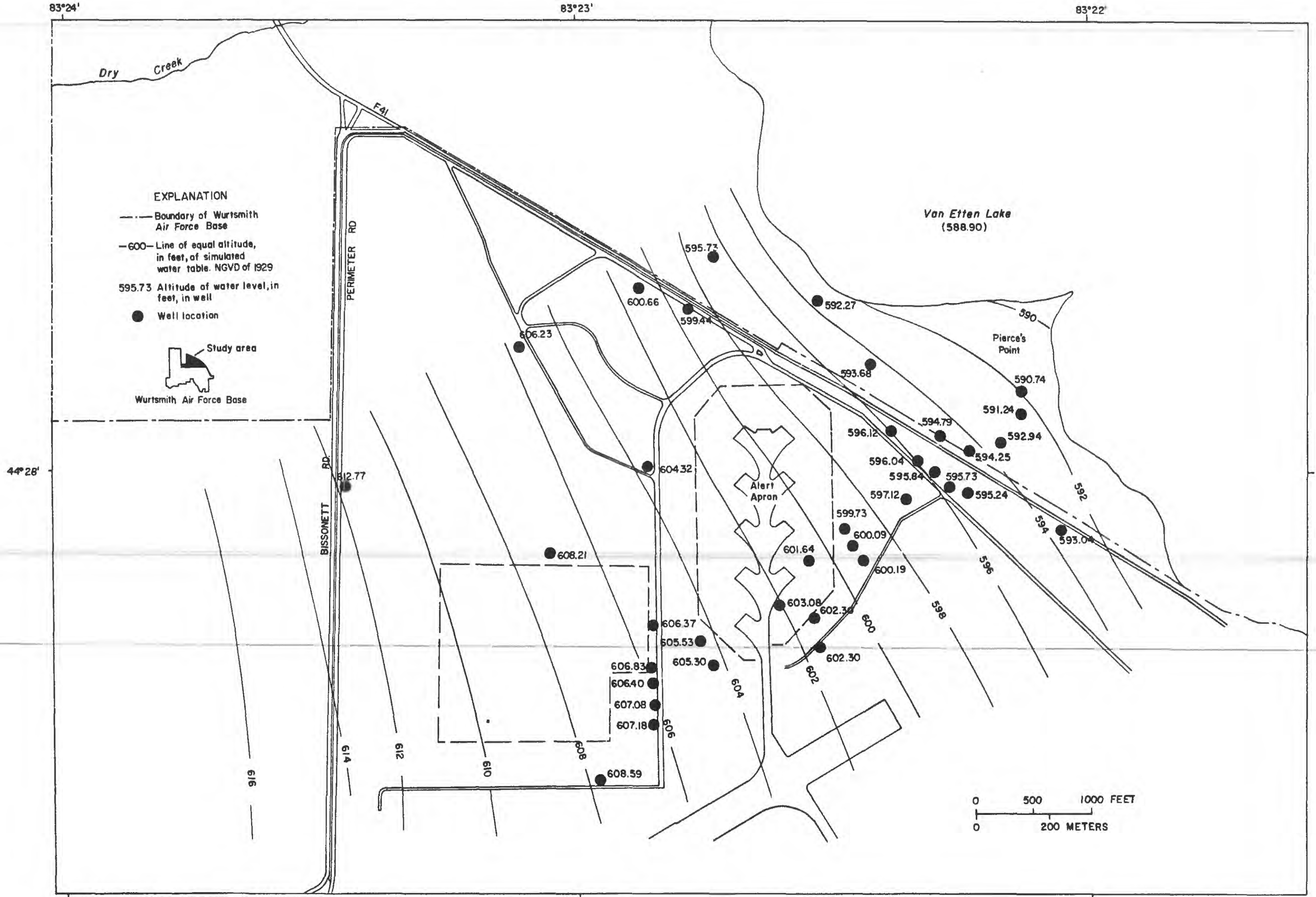
Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 41.--Water levels in wells and water table simulated by Building 43 plume model, March 1980.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 42.--Grid used for Alert Apron plume model.



Base from U.S. Geological Survey 1:62,500 quadrangle and Wurtsmith Air Force Base 1:7,200 map

Figure 43.--Water levels in wells and water table simulated by Alert Apron plume model, Augsut 1980.

TABLES OF DATA

Table 1.--Analyses of trichloroethylene, dichloroethylene, and benzene in ground water

[Analyses by U.S. Geological Survey. ND indicates not detected.]

Well number	Date	Trichloro-ethylene (μg/L)	Dichloro-ethylene (μg/L)	Benzene (μg/L)
AF1	January 10, 1980	235	ND	ND
	January 30, 1980	192	ND	ND
	September 18, 1980	66	ND	ND
AF2	December 20, 1979	16	1.0	ND
	January 10, 1980	6.5	ND	ND
	January 30, 1980	4.5	ND	ND
	September 18, 1980	ND	ND	ND
AF3	December 20, 1979	1,665	ND	ND
	January 10, 1980	1,194	13	13
	January 30, 1980	2,000	ND	4.9
	September 18, 1980	4,300	ND	ND
	October 7, 1980	3,000	ND	40
AF4	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 30, 1980	ND	ND	ND
AF5	December 20, 1979	<1	ND	ND
	January 10, 1980	3.5	ND	ND
	January 30, 1980	<1	ND	ND
AF15	December 20, 1979	23	ND	ND
	January 10, 1980	70	ND	ND
	January 30, 1980	61	ND	ND
AF18	December 20, 1979	ND	ND	ND
	January 30, 1980	ND	ND	ND
AF22	January 31, 1980	15	ND	ND
	May 22, 1980	12	ND	ND
AF52	December 16, 1980	ND	ND	ND
AF55	October 7, 1980	130	ND	ND
AF57	December 20, 1979	938	69	ND
	January 10, 1980	186	180	ND
	January 30, 1980	780	87	ND
	January 31, 1980	1,100	187	ND
AF58,59,60[1]	October 7, 1980	400	3.6	ND
AF62	December 16, 1980	ND	ND	42
	March 12, 1981	ND	ND	64
AF65	October 7, 1980	ND	18	9.9
	March 10, 1981	ND	9.4	7.6
AF66	October 7, 1980	ND	ND	ND
	March 10, 1981	ND	ND	ND
AF67[2]	December 17, 1980	ND	ND	106
AF68[3]	December 17, 1980	ND	ND	1,458
AF69	December 17, 1980	ND	ND	53
AF70	December 17, 1980	ND	ND	ND
AF71	December 17, 1980	ND	ND	ND
AF72	December 17, 1980	ND	ND	ND
AF73[4]	December 16, 1980	ND	ND	227
AF74[5]	December 17, 1980	ND	ND	ND
	March 5, 1981	ND	ND	ND
AF75	December 17, 1980	ND	ND	ND
	March 5, 1981	ND	ND	ND
AF76	December 16, 1980	ND	ND	3.0
B4D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
B5D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
B10D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
G7S	March 3, 1981	32	2.0	ND
H1S	March 3, 1981	ND	ND	ND
H1D	March 3, 1981	ND	ND	ND
H2S	March 4, 1981	ND	ND	520
	April 1, 1981	ND	ND	460
H2D	March 4, 1981	ND	ND	ND
H3S	February 6, 1981	ND	2.0	ND
	March 4, 1981	ND	ND	ND
H3D	February 6, 1981	ND	1.0	ND
	March 4, 1981	ND	ND	ND
H4S	March 3, 1981	ND	ND	ND
H4D	February 6, 1981	ND	14	ND
	March 3, 1981	ND	20	ND
H5S	March 3, 1981	ND	ND	ND
H5D	February 6, 1981	ND	4.5	ND
	March 3, 1981	ND	ND	ND
H6S	February 6, 1981	800	16	ND
	March 4, 1981	821	10	ND
H6D	February 6, 1981	3.2	7.6	ND
	March 4, 1981	ND	ND	ND
H8S	March 11, 1981	ND	ND	ND
H8D	March 11, 1981	5.1	ND	ND
H10S	March 4, 1981	33	64	ND
H11S	March 11, 1981	ND	2.0	ND
H11D	March 11, 1981	ND	11	ND
H12S	March 11, 1981	ND	ND	ND
H12D	March 11, 1981	ND	ND	ND
H13S	March 11, 1981	125	ND	ND
H13D	March 11, 1981	ND	23	ND
H14S[6]	March 11, 1981	9.6	ND	ND
H14D	March 11, 1981	ND	ND	ND
O1D	December 20, 1979	ND	ND	ND

1/ Composite of water from wells.

2/ Water also contained other undifferentiated hydrocarbons.

3/ A second sample of water also contained 1,209 μg/L benzene, 51 μg/L toluene, and 438 μg/L other undifferentiated hydrocarbons on December 17, 1980.

4/ A second sample also contained 284 μg/L benzene and other undifferentiated hydrocarbons.

5/ Water also contained 4.0 μg/L tetrachloroethylene on March 5, 1981.

6/ Water also contained 21 μg/L tetrachloroethylene and 3.0 μg/L toluene.

Table 1.--Analyses of trichloroethylene, dichloroethylene, and benzene in ground water--Continued

Well number	Date	Trichloro-ethylene (µg/L)	Dichloro-ethylene (µg/L)	Benzene (µg/L)
01D(Cont.)	January 10, 1980	ND	ND	ND
02S	December 20, 1979	9.4	13	ND
	January 10, 1980	6.6	17	ND
	October 7, 1980	1.0	ND	ND
02D	December 20, 1979	ND	ND	4.5
	January 10, 1980	ND	ND	ND
03D	December 20, 1979	ND	ND	7.4
	January 10, 1980	ND	ND	ND
04S	December 20, 1979	116	41	ND
	January 10, 1980	7.1	43	ND
	January 31, 1980	317	165	ND
	March 5, 1981	152	ND	ND
04D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
	March 5, 1981	ND	ND	ND
05S	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
05D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	3.9
06S	December 20, 1979	ND	ND	ND
	January 10, 1980	<1	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	<1	ND	ND
	December 17, 1980	ND	ND	ND
06D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	3.9
	December 17, 1980	ND	ND	ND
07S	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
	September 17, 1980	ND	ND	ND
	March 11, 1981	ND	ND	ND
07D	December 20, 1979	ND	266	ND
	January 10, 1980	ND	251	ND
	January 30, 1980	ND	192	ND
	January 31, 1980	ND	180	ND
	September 17, 1980	16	175	ND
	March 11, 1981	ND	84	ND
08S	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
08S (Cont.)	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
08D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
09S	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
09D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
010S	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	4.5
	January 31, 1980	12	ND	ND
	December 18, 1980	ND	ND	ND
010D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
	December 18, 1980	ND	ND	ND
R1S	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	August 13, 1980	ND	ND	ND
R1D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	August 13, 1980	ND	ND	ND
R2S	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
R2D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
R3S	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 30, 1980	1.3	ND	ND
	January 31, 1980	14	ND	ND
R3D	December 20, 1979	<1	ND	ND
	January 10, 1980	<3	ND	ND
	January 30, 1980	4.9	ND	ND
	January 31, 1980	13	ND	ND
R4S	January 10, 1980	<3	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
	May 22, 1980	ND	ND	ND
R4D	December 20, 1979	<1	ND	ND
	January 10, 1980	<3	ND	ND
	January 30, 1980	<1	ND	ND
	January 31, 1980	11	ND	ND

Table 1.--Analyses of trichloroethylene, dichloroethylene, and benzene in ground water--Continued

Well number	Date	Trichloro-ethylene (μg/L)	Dichloro-ethylene (μg/L)	Benzene (μg/L)
R4D (Cont.)	May 22, 1980	ND	13	ND
R5S	December 20, 1979	<1	ND	ND
	January 10, 1980	<3	ND	ND
	January 30, 1980	<1	ND	ND
	January 31, 1980	<1	ND	ND
R5D	December 20, 1979	<1	ND	ND
	January 10, 1980	<1	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
R6S	December 20, 1979	23	ND	ND
	January 10, 1980	34	ND	ND
	January 30, 1980	27	ND	ND
	January 31, 1980	22	ND	ND
	May 22, 1980	23	ND	ND
R6D	December 20, 1979	<1	ND	ND
	January 10, 1980	11	ND	ND
	January 30, 1980	<1	ND	ND
	January 31, 1980	6.2	ND	ND
	May 22, 1980	ND	ND	ND
R7S	December 20, 1979	1,652	40	ND
	January 10, 1980	1,780	50	ND
	January 30, 1980	2,380	ND	ND
	January 31, 1980	990	28	ND
	September 18, 1980	4,600	ND	ND
R7D	December 20, 1979	1,700	ND	ND
	January 10, 1980	1,600	ND	ND
	January 30, 1980	1,500	ND	ND
	January 31, 1980	1,200	ND	ND
R8S	December 20, 1979	<1	ND	ND
	January 10, 1980	<3	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
R8D	December 20, 1979	<1	ND	ND
	January 10, 1980	<3	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
R9S	December 20, 1979	4.9	ND	ND
	January 10, 1980	<5	ND	ND
	January 30, 1980	<1	ND	ND
	January 31, 1980	3.7	ND	ND
	March 3, 1981	ND	ND	ND
R9D	December 20, 1979	7.8	ND	ND
	January 10, 1980	<5	ND	ND
	January 30, 1980	ND	ND	ND
R9D (Cont.)	January 31, 1980	<1	ND	ND
	March 3, 1981	ND	6.0	ND
R10S[1/][2/][3/]	December 20, 1979	ND	ND	1,000
	January 10, 1980	<5	ND	837
	January 30, 1980	ND	ND	75
	January 31, 1980	ND	ND	1,100
	December 17, 1980	ND	ND	1,309
R10D[2/]	December 20, 1979	ND	ND	197
	January 10, 1980	71	ND	185
	January 30, 1980	ND	ND	96
	January 31, 1980	ND	ND	104
	December 17, 1980	ND	ND	319
R11S	December 20, 1979	<1	ND	ND
	January 10, 1980	<3	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
R11D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 30, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
R12D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
R13S[4/]	June 11, 1980	13	ND	ND
	August 13, 1980	12	ND	ND
R13D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	January 31, 1980	ND	ND	ND
	August 13, 1980	ND	ND	ND
R14S[5/]	May 2, 1980	ND	29	13
	March 5, 1981	ND	23	9.1
R14D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	May 2, 1980	ND	ND	ND
	March 5, 1981	ND	ND	ND
R15D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
R16S	May 2, 1980	<1	37	5.9
	May 22, 1980	<1	ND	ND
	March 5, 1981	ND	39	4.8
R16D	December 20, 1979	ND	ND	ND
	January 10, 1980	ND	ND	ND
	May 2, 1980	ND	6.0	ND
	March 5, 1981	ND	ND	9.8
R17S	April 29, 1980	1,848	22	ND

[1/] Water also contained toluene on January 31, 1980.

[2/] Water also contained other undifferentiated hydrocarbons on December 17, 1980.

[3/] Water also contained 21 mg/L total organic carbon on December 17, 1980.

[4/] Water also contained a trace amount of tetrachloroethane on June 11, 1980; a second sample also contained 12 μg/L of trichloroethylene on June 11, 1980.

[5/] Water also contained 3.8 μg/L toluene on March 5, 1981.

Table 1.--Analyses of trichloroethylene, dichloroethylene, and benzene in ground water--Continued

Well number	Date	Trichloro-ethylene (μg/L)	Dichloro-ethylene (μg/L)	Benzene (μg/L)
R17S (Cont.)	May 22, 1980	1,000	ND	ND
	September 17, 1980	2,100	ND	ND
R17D	April 29, 1980	<5	ND	ND
	May 22, 1980	ND	ND	ND
R18S	April 29, 1980	68	5.4	ND
	May 22, 1980	47	ND	ND
R18D	April 29, 1980	6.5	4.0	ND
	May 22, 1980	1.9	ND	ND
R19S	April 30, 1980	291	ND	ND
	May 22, 1980	247	ND	ND
	June 11, 1980	282	ND	ND
	August 13, 1980	250	ND	ND
R19D	April 30, 1980	10	ND	ND
	May 22, 1980	6.1	ND	ND
	August 13, 1980	ND	ND	ND
R20D	May 2, 1980	ND	ND	ND
R21S	May 2, 1980	ND	ND	ND
R22S	May 2, 1980	<1	29	28
	May 22, 1980	ND	31	8.9
	March 10, 1981	ND	17	3.1
R22D	March 10, 1981	ND	ND	ND
R23S	May 2, 1980	<1	ND	ND
R24D	May 1, 1980	<1	ND	ND
R25S	May 2, 1980	40	ND	ND
	May 22, 1980	65	ND	ND
R26D	May 1, 1980	<1	ND	ND
R27S	June 11, 1980	2.0	ND	ND
	August 13, 1980	ND	ND	ND
R27D	April 30, 1980	<1	ND	ND
	May 22, 1980	ND	3.0	ND
	August 13, 1980	2.0	ND	ND
R28S	June 11, 1980	ND	ND	ND
	August 13, 1980	ND	ND	ND
R29S	June 11, 1980	169	ND	ND
	August 13, 1980	265	ND	ND
R30S[1/]	June 11, 1980	13	ND	ND
	August 13, 1980	64	ND	ND
R31S	June 11, 1980	ND	ND	ND
	August 13, 1980	ND	ND	ND
R32S	June 11, 1980	ND	ND	ND
	August 13, 1980	ND	ND	ND
R33S	June 11, 1980	9.0	ND	ND
	August 13, 1980	ND	ND	ND
R34S	June 11, 1980	215	ND	ND
R34S (Cont.)	August 13, 1980	217	ND	ND
R35S	June 11, 1980	ND	ND	ND
	August 13, 1980	ND	ND	ND
R36S	June 11, 1980	387	ND	ND
	August 13, 1980	323	ND	ND
R36D	August 13, 1980	372	ND	ND
R37S[2/]	June 11, 1980	127	ND	ND
	August 13, 1980	169	ND	ND
R38S[3/]	June 11, 1980	3.3	ND	ND
	August 13, 1980	11	ND	ND
R39S	June 11, 1980	ND	ND	ND
	August 13, 1980	ND	ND	ND
	March 13, 1981	ND	ND	ND
R40S	August 13, 1980	30	ND	ND
R41S	August 13, 1980	ND	ND	ND
R42S	August 13, 1980	ND	ND	ND
R43S	August 13, 1980	ND	ND	ND
R44S	August 13, 1980	64	ND	ND
R45S	August 13, 1980	ND	ND	ND
R46S	August 13, 1980	186	ND	ND
R47S	August 13, 1980	33	ND	ND
R48S	August 13, 1980	ND	ND	ND
R49S	August 13, 1980	1,000	ND	ND
	September 17, 1980	526	ND	ND
R50S	August 13, 1980	1,074	ND	ND
	September 17, 1980	1,150	ND	ND
	October 30, 1980	867	ND	ND
R50D	October 30, 1980	1.0	ND	ND
R51S	August 13, 1980	21	ND	ND
R52S	August 13, 1980	19	ND	ND
R53S	August 13, 1980	ND	ND	ND
R54S	October 29, 1980	ND	ND	ND
R55S	October 29, 1980	274	ND	ND
R56S	October 28, 1980	6.7	ND	ND
R57S	October 28, 1980	2.4	ND	ND
R58S	October 28, 1980	ND	ND	ND
R59S	October 28, 1980	ND	ND	ND
R60S	October 28, 1980	12	ND	ND
R61S	October 28, 1980	ND	ND	ND
R62S	October 28, 1980	ND	ND	ND
R63S	October 29, 1980	10	ND	ND
R64S	October 29, 1980	5.5	ND	ND
R65S	October 29, 1980	ND	ND	ND
R66S	October 29, 1980	ND	ND	ND

1/ Water also contained 157 μg/L tetrachloroethylene on June 11, 1980; a second sample also contained 18 μg/L of trichloroethylene on June 11, 1980.

2/ Water also contained 16 μg/L tetrachloroethylene on August 13, 1980.

3/ A second sample also contained 3.9 μg/L trichloroethylene on June 11, 1980.

Table 1.--Analyses of trichloroethylene, dichloroethylene, and benzene in ground water--Continued

Well number	Date	Trichloro-ethylene (μg/L)	Dichloro-ethylene (μg/L)	Benzene (μg/L)
R67S	October 29, 1980	ND	ND	ND
R68S	October 29, 1980	ND	ND	ND
R69S	October 29, 1980	ND	ND	ND
R70S	October 29, 1980	ND	ND	ND
R71S	October 29, 1980	ND	ND	ND
R72S	October 30, 1980	ND	ND	ND
R73S	October 29, 1980	ND	ND	ND
R74S	October 30, 1980	ND	ND	ND
R75S	October 30, 1980	ND	ND	ND
R76S	March 12, 1981	3.9	ND	ND
R76D	March 12, 1981	22	ND	ND
R77S	March 12, 1981	5.0	ND	ND
R77D	March 12, 1981	53	ND	ND
R78S	December 18, 1980	ND	ND	ND
R78D	December 18, 1980	5.0	ND	ND
R79S	December 17, 1980	ND	ND	ND
R80S	December 17, 1980	17	ND	5.0
R80D	December 17, 1980	ND	ND	ND
R81S	December 17, 1980	5.0	ND	ND
R82S	December 18, 1980	ND	ND	ND
R82D	December 18, 1980	ND	ND	ND
R83S	December 18, 1980	8.0	ND	ND
R84S[1]	December 18, 1980	54	ND	ND
R85S[2]	December 18, 1980	ND	ND	ND
	March 5, 1981	48	ND	ND
R86S[3]	December 18, 1980	ND	ND	ND
	March 5, 1981	ND	ND	40
R87D	December 18, 1980	ND	ND	ND
R88S	March 2, 1981	ND	145	3.1
R88D	March 2, 1981	ND	155	9.0
R89S	March 2, 1981	ND	ND	ND
R89D	March 2, 1981	ND	5.7	ND
R90S	March 10, 1981	ND	4.1	5.9
R91S	March 10, 1981	ND	ND	ND
R92S	March 10, 1981	ND	ND	ND
R93S	March 10, 1981	ND	ND	ND
R94S	March 10, 1981	ND	ND	ND
R94D	March 12, 1981	ND	ND	ND
R95S	March 10, 1981	ND	ND	ND
C. Pierce well[4]	May 22, 1980	462	ND	ND
W. Brown well	May 22, 1980	ND	ND	ND
E. Korroch well	May 22, 1980	ND	ND	ND

[1] Water also contained 12 μg/L tetrachloroethylene.

[2] Water also contained 13 μg/L tetrachloroethylene on March 5, 1981.

[3] Water also contained 37 μg/L of other undifferentiated hydrocarbons calculated as benzene on March 5, 1981.

[4] A second sample also contained 642 μg/L trichloroethylene.

Table 2.--Chemical, physical, and biological characteristics of ground water

/Analyses by U.S. Geological Survey/

Well number	Date	Gross alpha, total (µg/L as U natural)a/	Gross beta, total (pCi/L as Cs 137)a/	Gross beta, total (pCi/L as Sr-90)a/	Biochemical oxygen demand, 5-day (mg/L)	Cadmium, total recoverable (µg/L as Cd)	Chemical oxygen demand (mg/L)	Chloride, dissolved (mg/L as Cl)	Chromium, total recoverable (µg/L as Cr)	Copper, total recoverable (µg/L as Cu)	Fecal coliform, 0.7 micron membrane filter (Cols./100 mL)
B4D	July 16, 1980	<2.7	<1.6	<1.5	6.1	0	0	8.8	10	20	<1
B5D	July 15, 1980	<3.6	<1.1	<1.0	7.5	0	7	.9	10	10	<1
B10D	July 16, 1980	<2.5	<1.2	<1.1	8.0	0	16	.9	10	0	<1
O2S	July 14, 1980	<6.1	<3.1	<3.0	14.2 b/	0	27	21	10	10	K1 c/
O3D	July 16, 1980	<3.3	<1.1	<1.0	7.5	0	4	1.0	10	10	<1
O4S	July 16, 1980	<10	<4.5	<4.4	7.1	0	12	3.6	10	10	<1
O6D	July 14, 1980	<8.5	<5.0	<4.8	7.4	0	39	8.5	10	0	<1
O7D	July 16, 1980	<10	<6.2	<5.9	8.1	0	4	3.4	10	10	K1 c/
O9D	July 15, 1980	<1.7	<.8	<.8	3.1	0	0	3.9	10	10	<1
R4D	July 15, 1980	<5.9	<2.2	<2.0	7.1	0	11	17	30	0	<1
R9S	July 15, 1980	<3.7	2.4	2.2	3.6	0	4	7.4	20	0	<1
R10S	July 15, 1980	<12	<6.2	<6.0	7.6 b/	0	66	4.3	10	0	<1
R12D	July 15, 1980	<2.9	<1.0	<.9	7.2	0	13	1.3	<10	0	<1
R14D	July 15, 1980	<9.9	<5.2	<5.0	7.8 b/	0	53	16	10	0	K2 c/
R14S	July 15, 1980	<7.9	5.8	5.6	4.8	0	20	14	10	10	<1
R15D	September 18, 1980	--	--	--	--	--	--	1.2	--	--	--
R16S	September 17, 1980	<15	<8.4	<8.1	4.8 b/	--	53	17	--	--	<1
R17S	July 15, 1980	<4.8	2.5	2.3	6.0	0	0	12	20	0	<1
R20D	July 16, 1980	<2.1	<1.3	<1.3	7.3	0	0	1.1	10	0	<1
R21S	July 16, 1980	<3.7	1.8	1.6	1.1	0	9	.9	10	0	<1
R22S	July 16, 1980	<13	11	11	13.8 b/	--	12	14	20	0	<1
R23S	July 14, 1980	<3.0	<1.0	<.9	.0	0	6	3.2	10	0	<1
R24D	July 16, 1980	<2.7	<1.3	<1.2	7.3	0	18	1.7	10	0	<1
R25S	September 18, 1980	--	--	--	4.9 b/	--	--	--	--	--	--
R27S	July 14, 1980	<5.2	<2.1	<2.0	6.8	0	1	1.1	10	10	1
R29S	July 16, 1980	<2.2	<1.2	<1.1	7.2	0	0	1.9	10	10	<1
R36S	July 16, 1980	<3.4	<1.2	<1.1	6.9	0	1	2.4	30	0	<1
R39S	September 17, 1980	<1.2	<.7	<.7	6.3 b/	--	39	1.3	--	--	<1
AF1	July 15, 1980	<5.5	<2.1	<2.1	4.7	0	6	7.0	10	0	<1
AF2	July 15, 1980	<5.8	<2.1	<2.0	7.2	0	9	7.0	<10	10	<1
AF4	July 15, 1980	<3.0	<1.8	<1.7	8.8 b/	0	21	2.8	20	0	<1
AF5	July 15, 1980	<2.3	<1.3	<1.2	7.2	0	7	1.7	10	10	<1
AF15	July 15, 1980	<12	9.0	8.6	7.2	0	8	18, 18d/	10	10	<1
AF18	July 15, 1980	<2.2	<1.6	<1.5	4.0	0	7	4.4	10	30	<1
AF57	July 15, 1980	<3.9	<2.2	<2.0	2.7	0	12	3.0	10	10	<1

a/ Samples collected September 17, 1980.
b/ Samples collected September 17 and 18, 1980.
c/ K - Non-ideal colony count (less than 20 colonies on filter).
d/ Samples collected September 18, 1980.

Table 2.--Chemical, physical, and biological characteristics of ground water--Continued

Well number	Date	Fecal streptococci, KF agar (Cols./100 mL)	Lead, total recoverable (µg/L as Pb)	Mercury, total recoverable (µg/L as Hg)	Nickel, total recoverable (µg/L as Ni)	Nitrite plus nitrate, total (mg/L as N)	Oil and grease (mg/L)	pH (units)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, total (mg/L as PO_4)	Selenium, total (µg/L as Se)	Specific conductance (micromhos)	Zinc, total recoverable (µg/L as Zn)
B4D	July 16, 1980	<1	0	<0.1	0	0.02	0.0	8.0	0.01	0.03	0	346	170
B5D	July 15, 1980	<1	0	<.1	0	.01	.0	7.9	.03	.09	0	290	560
B10D	July 16, 1980	K1 a/	0	<.1	0	.00	.0	7.8	.00	.00	0	278	1,300
02S	July 14, 1980	K5 a/	0	<.1	100	.01	.0	7.7	1.2	3.7	0	616	260
03D	July 16, 1980	<1	0	<.1	0	.00	2	7.7	.01	.03	0	293	500
04S	July 16, 1980	<1	0	<.1	0	.08	1	7.7	.00	.00	0	625	200
06D	July 14, 1980	<1	0	.1	0	.01	.0	7.7	.02	.06	0	732	320
07D	July 16, 1980	<1	0	<.1	0	.01	.0	7.8	.01	.03	0	592	390
09D	July 15, 1980	<1	0	<.1	0	1.8	1	7.9	.01	.03	0	219	120
R4D	July 15, 1980	<1	0	<.1	0	.00	1	7.8	.00	.00	0	652	450
R9S	July 15, 1980	<1	0	<.1	0	4.7	1	7.8	.00	.00	0	423	110
R10S	July 15, 1980	<1	0	<.1	0	.00	3	7.4	.01	.03	0	760	510
R12D	July 15, 1980	<1	0	<.1	0	.00	1	7.8	.01	.03	0	274	580
R14D	July 15, 1980	<1	0	<.1	0	2.6	1	7.5	.03	.09	0	794	370
R14S	July 15, 1980	K10 a/	0	<.1	0	.01	1	7.4	.01	.03	0	713	80
R15D	September 18, 1980	--	--	--	--	--	--	7.7	--	--	--	298	--
R16S	September 17, 1980	<1	--	<.1	--	.03	--	7.2	--	--	0	761	--
R17S	July 15, 1980	K1 a/	0	<.1	0	7.6	2	7.6	.00	.00	0	544	30
R20D	July 16, 1980	<1	0	<.1	0	5.9	2	8.0	.01	.03	0	298	20
R21S	July 16, 1980	<1	0	<.1	0	9.3	2	7.8	.01	.03	0	315	20
R22S	July 16, 1980	<1	--	<.1	--	.04	2	7.2	.01	.03	0	360	50
R23S	July 14, 1980	<1	0	<.1	0	.82	.0	7.8	.01	.03	0	247	50
R24D	July 16, 1980	K1 a/	0	<.1	0	.00	.0	7.9	.01	.03	0	276	40
R25S	September 18, 1980	--	--	--	--	--	--	--	--	--	--	--	--
R27S	July 14, 1980	K11 a/	0	<.1	0	.03	2	7.7	.01	.03	0	472	30
R29S	July 16, 1980	<1	0	<.1	100	.48	.0	8.0	.01	.03	0	274	40
R36S	July 16, 1980	<1	0	<.1	0	10	2	7.8	.00	.00	0	338	20
R39S	September 17, 1980	<1	--	<.1	--	.53	--	7.7	--	--	0	183	--
AF1	July 15, 1980	<1	0	<.1	0	3.5	1	7.6	.00	.00	0	475	10
AF2	July 15, 1980	<1	0	.1	0	3.1	4	7.8	.03	.09	0	466	10
AF4	July 15, 1980	<1	0	<.1	0	2.2	1	7.8	.00	.00	0	413	50
AF5	July 15, 1980	<1	0	<.1	0	2.3	1	7.9	.01	.03	0	295	10
AF15	July 15, 1980	K1 a/	0	<.1	0	28, 25 b/	1	7.7	.00	.00	0	798	40
AF18	July 15, 1980	K3 a/	0	<.1	0	.02	1	8.1	.01	.03	0	287	10
AF57	July 15, 1980	<1	0	.1	0	1.8	.0	7.8	.01	.03	0	468	100

a/ K - Non-ideal colony count (less than 20 colonies on filter).
b/ Samples collected September 18, 1980.

Table 3.--Analyses of well cores, soils, and sludge bed material for hydrocarbons

[Analyses by U.S. Geological Survey. ND indicates not detected.]

Location	Date	Depth (feet)	Tri-chloro-ethylene (µg/kg)	Di-chloro-ehtylene (µg/kg)	Benzene (µg/kg)	Toluene (µg/kg)	Total undifferentiated hydrocarbons, calculated as benzene (µg/kg)
Sludge Bed 1	May 6, 1981	1	ND	ND	ND	ND	ND
Sludge Bed 1	May 6, 1981	5	ND	ND	ND	ND	ND
Sludge Bed 2	May 6, 1981	1	ND	ND	9.0	ND	ND
Sludge Bed 2	May 6, 1981	5	ND	ND	ND	ND	13
Sludge Bed 3	May 6, 1981	1 a/	ND	10 b/	17	ND	82
Sludge Bed 3	May 6, 1981	5	ND	6.1 b/	4.1	ND	124
Sludge Bed 4	May 6, 1981	1 c/	ND	12 b/	7.6	ND	157
Sludge Bed 4	May 6, 1981	5 d/	ND	trace	ND	ND	93
Sludge Material, Bed 3	May 6, 1981	Surface	ND	ND	ND	34	18
Site A	May 6, 1981	1	ND	ND	ND	ND	ND
Site A	May 6, 1981	5	ND	ND	29	ND	54
Site B	May 6, 1981	1	ND	ND	5.5	ND	17
Site B	May 6, 1981	5	ND	ND	ND	ND	ND
Well R76D	March 12, 1981	5	ND	ND	6.0	2.7	13
Well R76D	March 12, 1981	10	ND	ND	10	3.1	10
Well R76D	March 12, 1981	20	--	-	--	--	--
Well R76D	March 12, 1981	40	ND	ND	ND	ND	ND
Well R76D	March 12, 1981	50	ND	ND	ND	ND	ND
Well R77D	March 12, 1981	5	ND	ND	2.0	ND	8.0
Well R77D	March 12, 1981	10	ND	ND	1.0	ND	6.0
Well R77D	March 12, 1981	15	--	--	--	--	--
Well R77D	March 12, 1981	30	ND	ND	4.7	ND	ND
Well R77D	March 12, 1981	50	ND	ND	43	5.7	32

a/ Sample also contained methylene chloride (12 µg/kg).
b/ trans 1,2-Dichloroethylene
c/ Sample also contained methylene chloride (68 µg/kg), and tetrachloroethylene (11 µg/kg).
d/ Sample also contained methylene chloride (26 µg/kg).

Table 4.--Location and identification of wells at Wurtsmith Air Force Base

Local identifier	Altitude of measuring point (feet)	Depth of well below land surface (feet)	Casing diameter (inches)	Height of measuring point above land surface (feet)	Water level below measuring point (feet)	Date water level measured
AF OBS 4	628.88	--	4.00	--	12.33	4-22-80
AF OBS 6	629.64	23.0	4.00	--	12.95	4-22-80
AF OBS 7	629.58	--	4.00	--	16.94	4-22-80
AF 1	--	65.2	12.00	--	--	--
AF 2	--	63.7	12.00	--	--	--
AF 2A	612.8	56.0	2.00	1.7	31.04	4-22-80
AF 3	--	67.0	12.00	--	--	--
AF 3A	615.5	70.0	2.00	--	28.44	10-27-80
AF 4	--	62.0	16.00	--	--	--
AF 4A	613.9	48.9	2.00	3.0	28.01	4-22-80
AF 5	--	62.0	16.00	--	--	--
AF 5A	611.5	50.2	2.00	2.5	25.55	4-22-80
AF 7	--	21.0	1.25	--	--	--
AF 8	--	23.0	1.25	--	--	--
AF15	--	35.0	4.00	--	--	--
AF18	--	66.5	12.00	--	--	--
AF18A	617.33	52.4	1.25	1.4	17.60	4-22-80
AF19	--	70.0	12.00	--	--	--
AF22	--	47.0	--	--	--	--
AF50	616.91	32.0	1.50	1.7	21.70	1-30-80
AF51	611.77	22.0	1.50	--	22.50	1-30-80
AF52	611.30	28.0	1.25	1.5	20.14	1-30-80
AF53	612.74	22.0	1.25	1.0	17.32	1-30-80
AF54	618.68	32.7	1.25	1.8	22.57	1-30-80
AF55	--	55.0	4.00	--	--	--
AF56	--	55.0	4.00	--	--	--
AF57	--	55.0	4.00	--	--	--
AF58	--	--	--	--	--	--
AF59	--	--	--	--	--	--
AF60	--	--	--	--	--	--
AF61	618.81	22.0	1.50	--	21.42	1-30-80
AF62	612.71	32.0	1.50	--	18.37	1-30-80
AF63	611.22	32.0	1.25	--	18.95	1-30-80
AF64	610.71	27.0	1.25	--	20.01	1-30-80
AF65	619.89	28.5	1.50	1.9	--	--
AF66	618.22	28.8	1.50	2.2	--	--
AF67	614.45	22.3	1.25	1.9	18.77	3-24-81
AF68	615.39	22.2	1.25	1.7	19.56	3-24-81
AF69	615.47	21.8	1.25	2.4	19.54	3-24-81
AF70	614.48	23.0	1.25	1.1	18.06	3-24-81
AF71	615.32	22.9	1.25	1.3	18.42	3-24-81
AF72	615.26	22.8	1.25	1.3	18.38	3-24-81
AF73	615.68	22.8	1.25	1.4	19.98	3-24-81
AF74	614.56	22.5	1.25	1.7	19.58	3-24-81
AF75	614.53	22.4	1.25	1.7	19.73	3-24-81
AF76	614.30	22.4	1.25	1.8	21.03	3-24-81
B 4D	636.52	39.6	4.00	2.4	16.83	1-30-80
B 5D	627.25	64.3	4.00	3.0	7.69	1-30-80
B10D	620.30	62.7	4.00	2.3	12.76	1-30-80
G 1S	630.04	20.1	1.25	3.0	11.45	1-30-80
G 2S	628.67	22.3	1.25	3.3	16.87	1-30-80
G 3S	627.64	22.9	1.25	3.0	19.37	1-30-80
G 4S	620.57	15.4	1.25	2.7	13.05	1-30-80
G 5S	623.98	14.8	1.25	3.2	15.36	1-30-80
G 7S	619.38	22.9	1.25	2.8	18.51	1-30-80
G 8S	616.33	23.4	1.25	3.4	24.44	1-30-80
G 9S	608.63	21.5	1.25	2.2	20.76	1-30-80
G10S	614.71	25.1	1.25	1.2	26.15	12-05-79
G11S	608.02	21.5	1.25	1.3	20.12	1-30-80
G12S	613.57	22.0	1.25	2.1	23.05	1-30-80
G14S	618.11	25.3	1.25	3.0	22.80	1-30-80
G15S	617.50	25.0	1.25	3.1	22.28	1-30-80
G16S	617.97	25.0	1.25	2.9	22.63	1-30-80
G17S	618.04	25.5	1.25	2.6	22.42	1-30-80
G18S	619.09	25.3	1.25	2.8	23.18	1-30-80
G19S	632	19.6	1.25	3.7	9.13	1-30-80
G20S	615.07	22.5	1.25	3.2	20.45	1-30-80
G21S	623.98	12.7	1.25	3.0	11.34	1-30-80
G22M	637.58	29.0	1.25	3.6	17.95	1-30-80
G22S	637.09	18.3	1.25	3.0	17.45	1-30-80
G23S	628	15.2	1.25	3.0	10.20	1-30-80
G24S	626	14.8	1.25	3.3	8.13	1-30-80
G25S	629	18.3	1.25	4.3	7.43	1-30-80
G26S	626	14.6	1.25	3.2	6.99	1-30-80
H 1D	--	65	4.00	1.9	16.91	3-03-81
H 1S	--	28	4.00	1.8	16.62	3-03-81
H 2D	620.99	65	4.00	2.0	17.70	3-23-81
H 2S	621.13	28	4.00	1.8	17.46	3-23-81
H 3D	621.46	60	4.00	2	18.09	3-23-81
H 3S	621.47	28	4.00	2	18.66	3-23-81
H 4D	621.28	65	4.00	1.9	19.08	3-23-81
H 4S	621.11	28	4.00	1.9	18.93	3-23-81
H 5D	621.32	65	4.00	1.9	20.05	3-23-81
H 5S	621.20	28	4.00	1.9	19.96	3-23-81
H 6D	620.53	65	4.00	2	19.57	3-23-81
H 6S	620.70	28	4.00	1.8	19.73	3-23-81
H 8D	617.59	65	4.00	1.8	17.75	3-23-81
H 8S	617.63	28	4.00	1.9	17.79	3-23-81
H10S	619.74	28	4.00	1.8	19.27	3-23-81
H11D	617.79	65	4.00	1.7	18.73	3-23-81
H11S	617.78	28	4.00	1.5	18.67	3-23-81
H12D	617.81	65	4.00	1.7	18.71	3-23-81
H12S	617.81	28	4.00	1.5	18.71	3-23-81
H13D	618.48	65	4.00	1.8	19.47	3-23-81
H13S	618.32	28	4.00	1.7	19.31	3-23-81
H14D	617.90	60	4.00	1.6	19.09	3-23-81
H14S	617.79	28	4.00	1.6	18.96	3-23-81
O 1D	627.48	60.5	4.00	3.0	11.42	1-30-80
O 2D	626.71	41.0	4.00	2.3	13.87	1-30-80
O 2S	626.21	29.5	4.00	2.6	13.17	1-30-80
O 3D	620.36	67.0	4.00	2.0	12.28	1-30-80
O 4D	617.70	59.9	4.00	2.6	17.73	1-30-80
O 4S	617.38	26.3	4.00	2.2	17.35	1-30-80
O 5D	616.93	65.4	4.00	3.1	19.07	1-30-80
O 5S	616.26	27.2	4.00	2.2	18.77	1-30-80
O 6D	615.43	54.8	4.00	3.0	23.24	1-30-80
O 6S	614.57	30.0	4.00	2.1	23.35	1-30-80
O 7D	618.58	63.5	4.00	3.2	19.91	1-30-80
O 7S	617.59	27.2	4.00	2.1	18.87	1-30-80
O 8D	614.58	56.5	4.00	2.3	18.73	1-30-80
O 8S	614.94	28.7	4.00	2.7	19.06	1-30-80
O 9D	611.23	50.0	4.00	2.2	19.21	1-30-80
O 9S	611.89	30.8	4.00	2.7	19.88	1-30-80
O10D	609.70	47.4	4.00	3.4	20.72	1-30-80
O10S	609.55	31.3	4.00	2.7	20.49	1-30-79
R 1D	617.67	68.8	4.00	3.0	22.41	1-30-80
R 1S	617.39	29.4	4.00	2.6	22.12	1-30-80
R 2D	616.34	67.8	4.00	2.7	21.77	1-30-80
R 2S	615.96	29.9	4.00	2.6	21.59	1-30-80
R 3D	609.22	53.9	4.00	3.1	20.33	1-30-80
R 3S	609.47	33.3	4.00	3.3	20.53	1-30-80
R 4D	612.69	57.4	4.00	3.1	23.52	1-30-80
R 4S	611.84	28.8	4.00	2.2	22.62	1-30-80
R 5D	615.53	58.5	4.00	2.0	22.12	1-30-80
R 5S	615.15	32.5	4.00	2.0	21.90	1-30-80
R 6D	616.17	60.7	4.00	2.3	23.17	1-30-80
R 6S	616.79	30.4	4.00	3.1	23.73	1-30-80
R 7D	616.12	58.3	4.00	1.7	21.16	1-30-80
R 7S	616.75	28.8	4.00	2.4	21.89	1-30-80
R 8D	616.43	57.0	4.00	3.0	20.28	1-30-80

Table 4.--Location and identification of wells at Wurtsmith Air Force Base--Continued

Local identifier	Altitude of measuring point (feet)	Depth of well below land surface (feet)	Casing diameter (inches)	Height of measuring point above land surface (feet)	Water level below measuring point (feet)	Date water level measured
R 8S	615.89	28.3	4.00	2.2	19.82	1-30-80
R 9D	618.80	62.9	4.00	2.1	20.68	1-30-80
R 9S	619.59	28.4	4.00	3.1	21.44	1-30-80
R10D	615.39	60.5	4.00	2.5	20.65	1-30-80
R10S	615.25	28.0	4.00	2.2	20.50	1-30-80
R11D	613.72	56.0	4.00	2.8	20.62	1-30-80
R11S	614.73	26.1	4.00	3.6	21.77	1-30-80
R12D	622.67	73.0	4.00	3.3	29.96	1-30-80
R13D	616.88	70.6	4.00	2.7	22.43	1-30-80
R13S	616.02	34.5	4.00	2.0	20.55	7-15-80
R14D	618.05	65.6	4.00	2.6	16.47	1-30-80
R14S	618.03	33.1	4.00	2.5	15.42	7-15-80
R15D	625.88	78.0	4.00	2.8	21.70	1-30-80
R16D	622.02	61.1	4.00	2.6	17.69	1-30-80
R16S	621.55	33.4	4.00	2.4	16.44	7-16-80
R17D	616.60	62.2	4.00	2.7	23.89	4-16-80
R17S	616.22	33.6	4.00	2.0	23.34	4-16-80
R18D	616.42	57.3	4.00	2.1	23.33	4-15-80
R18S	616.54	36.0	4.00	2.0	23.43	4-15-80
R19D	616.74	67.6	4.00	2.8	23.74	4-15-80
R19S	616.54	38.8	4.00	2.5	23.59	4-15-80
R20D	615.09	44.0	4.00	2.4	22.81	5-02-80
R21S	617.80	32.7	4.00	2.8	19.89	5-02-80
R22D	618.69	54.9	4.00	1.6	12.89	3-11-81
R22S	618.98	32.6	4.00	2.3	13.15	3-11-81
R23S	617.22	33.7	4.00	2.1	21.99	5-02-80
R24D	626.18	43.9	4.00	2.4	17.05	5-02-80
R25S	613.38	33.7	4.00	2.3	21.21	5-02-80
R26D	632.05	44.0	4.00	2.2	10.56	5-02-80
R27D	614.94	44.0	4.00	2.5	20.18	6-10-80
R27S	614.67	34.6	4.00	1.9	19.98	6-10-80
R28S	609.20	34.7	4.00	1.8	18.32	6-09-80
R29S	613.10	34.6	4.00	1.9	21.75	6-09-80
R30S	615.60	34.4	4.00	2.1	22.65	6-09-80
R31S	612.82	34.5	4.00	2.0	19.24	6-09-80
R32S	615.99	34.6	4.00	1.9	20.13	6-10-80
R33S	614.28	34.7	4.00	1.8	18.56	6-10-80
R34S	614.57	34.7	4.00	1.8	18.95	6-10-80
R35S	616.32	34.6	4.00	1.9	16.85	6-10-80
R36D	617.06	54.0	4.00	2.0	17.00	8-13-80
R36S	616.93	34.7	4.00	1.8	17.12	6-10-80
R37S	616.79	34.6	4.00	1.9	16.92	6-10-80
R38S	615.79	34.6	4.00	1.9	18.86	6-10-80
R39S	619.77	37.4	4.00	3.1	24.08	6-10-80
R40S	621.39	34.5	4.00	2.0	19.75	8-12-80
R41S	617.32	28.9	4.00	1.8	17.13	8-13-80
R42S	626.24	34.6	4.00	1.9	23.94	8-13-80
R43S	621.44	28.8	4.00	1.7	18.71	8-13-80
R44S	624.35	34.8	4.00	1.7	21.27	8-12-80
R45S	624.54	28.9	4.00	1.6	19.96	8-12-80
R46S	619.68	23.9	4.00	1.6	14.17	8-13-80
R47S	620.04	23.7	4.00	1.8	14.75	8-13-80
R48S	621.40	28.4	4.00	2.1	14.23	8-13-80
R49S	618.93	23.7	4.00	1.8	12.55	8-13-80
R50D	621.64	52.3	4.00	2.2	14.98	10-31-80
R50S	621.57	23.6	4.00	1.9	14.74	8-13-80
R51S	621.37	23.4	4.00	2.1	14.40	8-13-80
R52S	621.63	23.8	4.00	1.7	14.57	8-13-80
R53S	621.59	23.7	4.00	1.8	14.41	8-13-80
R54S	625.04	29.2	4.00	1.6	20.46	10-31-80
R55S	622.16	28.9	4.00	1.9	17.18	10-31-80
R56S	618.84	23.6	4.00	1.9	13.36	10-31-80
R57S	623.72	23.6	4.00	1.9	16.40	10-31-80
R58S	619.63	23.7	4.00	1.8	14.30	10-31-80
R59S	620.26	23.5	4.00	2.0	13.91	10-31-80
R60S	620.60	23.6	4.00	1.9	15.41	10-31-80
R61S	619.8	24.0	4.00	1.5	11.47	10-31-80
R62S	621.2	23.8	4.00	1.7	12.65	10-31-80
R63S	620.73	23.6	4.00	1.9	13.08	10-31-80
R64S	621.36	23.6	4.00	1.9	13.59	10-31-80
R65S	622.87	23.6	4.00	1.9	14.94	10-31-80
R66S	622.88	18.6	4.00	1.7	11.24	10-31-80
R67S	622.47	18.6	4.00	1.7	10.59	10-31-80
R68S	622.91	18.6	4.00	1.7	11.00	10-31-80
R69S	623.14	18.5	4.00	1.8	11.20	10-31-80
R70S	622.25	23.7	4.00	1.8	12.01	10-31-80
R71S	622.84	18.6	4.00	1.8	10.95	10-31-80
R72S	623.54	19.5	4.00	0.9	9.85	10-31-80
R73S	622.74	19.2	4.00	1.1	9.70	10-31-80
R74S	623.85	19.2	4.00	1.1	10.40	10-31-80
R75S	623.02	19.4	4.00	0.9	10.34	10-31-80
R76D	611.77	49	4.00	1.7	19.06	3-12-81
R76S	611.58	28	4.00	1.6	18.86	3-12-81
R77D	613.17	49	4.00	1.8	20.46	3-12-81
R77S	612.44	28	4.00	1.7	19.76	3-12-81
R78D	607.76	49.5	4.00	1.7	19.61	1-21-81
R78S	607.75	28.4	4.00	1.8	19.64	1-21-81
R79S	614.01	33.6	4.00	1.9	23.54	1-21-81
R80D	615.82	49.3	4.00	1.9	25.22	1-21-81
R80S	615.10	33.6	4.00	1.9	24.54	1-21-81
R81S	614.67	34.3	4.00	1.2	22.62	1-21-81
R82D	613.87	49.2	4.00	2.0	21.49	1-21-81
R82S	614.08	33.5	4.00	2.0	21.69	1-21-81
R83S	612.88	28.4	4.00	1.8	20.24	1-21-81
R84S	613.32	28.5	4.00	1.7	20.69	1-21-81
R85S	613.25	28.7	4.00	1.5	20.01	1-21-81
R86S	613.91	24.4	4.00	1.8	20.38	1-21-81
R87D	614.71	45.3	4.00	1.9	19.35	1-21-81
R88D	618.32	50.7	4.00	1.8	20.43	2-09-81
R88S	618.28	29.7	4.00	1.8	20.35	2-09-81
R89D	618.18	50.7	4.00	1.8	20.09	2-09-81
R89S	617.77	30.0	4.00	1.5	19.69	2-09-81
R90S	618.44	28	4.00	1.8	18.76	3-24-81
R91S	618.27	28	4.00	1.5	15.52	3-24-81
R92S	619.38	28	4.00	1.8	13.96	3-12-81
R93S	619.85	28	4.00	1.5	14.08	3-12-81
R94D	616.57	51	4.00	1.8	20.46	3-12-81
R94S	616.27	28	4.00	1.6	20.11	3-12-81
R95S	616.22	28	4.00	1.7	19.65	3-12-81
Y 1D	740	52.0	1.25	3.0	37.86	1-30-80
Y 2D	749	62.5	1.25	3.1	36.86	1-30-80
Y 3S	670	19.7	1.25	3.5	8.94	1-29-80
Y 4D	612.25	53.5	1.25	4.0	20.84	1-30-80
Y 4M	611.89	38.4	1.25	2.0	20.43	1-30-80
Y 4S	609.88	21.4	1.25	4.0	18.52	1-30-80
Y 5D	608.10	45.3	1.25	1.6	19.12	1-30-80
Y 6S	621	31.9	1.25	4.5	19.05	1-29-80
Y 7S	625	40.1	1.25	2.7	31.66	1-29-80
Y 9S	611	31.1	1.25	2.6	15.03	1-30-80
Y10S	595	15.5	1.25	2.4	6.50	1-30-80
Y11S	620	37.6	1.25	2.5	7.73	1-30-80
Y12D	596.78	39.3	1.25	1.9	8.49	1-30-80
Y12M	597.73	27.8	1.25	2.7	9.65	1-30-80
Y12S	597.79	18.0	1.25	2.8	9.70	1-30-80
Y13S	605	31.3	1.25	2.4	15.63	1-30-80
Y14S	584	10.6	1.25	2.0	5.26	1-30-80
Y15S	610	31.5	1.25	3.0	26.22	1-30-80
Y16S	608	31.0	1.25	2.4	23.38	1-30-80
Y17M	610.18	43.3	1.25	3.7	21.33	1-30-80
Y18D	607.68	49.5	1.25	2.6	18.06	1-30-80
Y18M	608.48	35.1	1.25	3.3	18.96	1-30-80
Y18S	608.22	25.2	1.25	3.2	18.63	1-30-80
Y19D	618.31	50.5	1.25	4.0	23.05	1-30-80