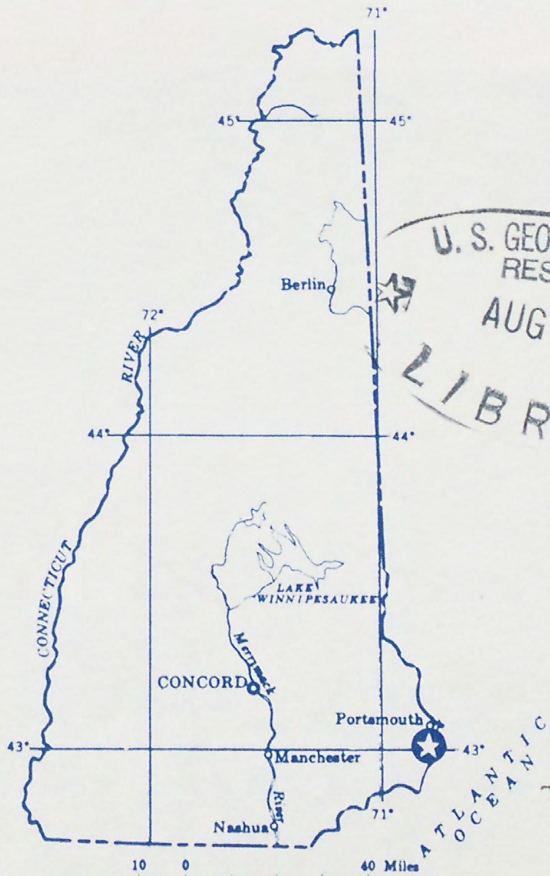
TRICHLOROETHYLENE IN THE GROUND-WATER SUPPLY OF PEASE AIR FORCE BASE, PORTSMOUTH, NEW HAMPSHIRE

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations
Open-File Report 80-557



INDEX MAP OF NEW HAMPSHIRE

STUDY AREA

Prepared in cooperation with the
U.S. AIR FORCE

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UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

Open-File Report

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

The following factors may be used to convert the inch-pound units to the International System of Units (SI):

Multiply inch-pound units	By	To obtain SI Units
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	.305	meter (m)
mile (mi)	1.61	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	.02832	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	.02832	cubic meter per second m^3/s
gallon per minute (gal/min)	.06309	liter per second (L/s)
million gallons per day (Mgal/d)	.04381	cubic meter per second (m^3/s)
	Temperature	
degrees Fahrenheit (°F)	°C = (°F-32)/1.8	degrees Celsius (°C)

TRICHLOROETHYLENE IN THE GROUND-WATER SUPPLY OF PEASE AIR FORCE BASE, PORTSMOUTH, NEW HAMPSHIRE

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ABSTRACT

TCE (trichloroethylene) in concentrations that may be hazardous to health occurs in the water of an ice-contact largely sand and gravel aquifer (called the main aquifer) underlying much of the PAFB (Pease Air Force Base). In 1977 and 1978, the highest TCE concentration was found surrounding the most productive well, Haven well. Large quantities of TCE were used for degreasing between 1955 and 1965 and, so far as is known, TCE was used extensively up until 1973. Data on how, where, and when TCE got into the aquifer are lacking, but geochemical evidence and TCE analyses show a strong relation between the high TCE concentrations near Haven well and the extensive storm-drain system that underlies the parking apron and runway. The drains help recycle some of the TCE-contaminated ground water from the Haven well area.

Sources of TCE-free ground water on PAFB may exist in the northern parts and do exist in the southern parts of the main aquifer; however, in the southern part, either the ground water is probably already being used nearly to capacity (Smith and Harrison production wells) or further development might adversely affect off-base ground-water use. In the northern part, available subsurface data indicate that only relatively small yields are likely at any one site; thus, to get sustained yields comparable to that of the Haven well would probably require an unreasonable number of wells.

This study locates TCE contamination in the main PAFB aquifer and discusses three possible water-use alternatives: (1) Abandonment of Haven well, (2) treatment of Haven well water to remove TCE, and (3) treatment of a portion of Haven well water for domestic consumption and use of the remainder for nondomestic uses. Continued use of the Haven well, with treatment of all or part of its yield for TCE removal, is advantageous, both because the Haven well is a high-yield source of water and because cessation of pumping from it might allow TCE-contaminated ground water to move downgradient (southward), endangering the Smith and Harrison production wells. Continued study and monitoring of the TCE contamination would help in predicting when the contamination problem will no longer be threatening.

INTRODUCTION

In April 1977, concentrations of TCE (trichloroethylene) high enough to be a health hazard were identified in the PAFB (Pease Air Force Base) water supply. Based on dose-response data extrapolated from laboratory studies on animals, the National Research Council, (1977, p. 779) concluded that a concentration of 10 parts per billion or 10 ug/L (micrograms per liter) in drinking water during a lifetime of exposure to a compound such as TCE would be expected to produce one excess case of cancer for every 50,000 persons exposed. At present, the U.S. Environmental Protection Agency has not established limits for TCE in domestic water supplies, but limits are expected to be established in the future.

The main source of water for the base is an aquifer consisting mainly of unconsolidated stratified sand and gravel that underlies parts of the base. In June 1977, the Air Force asked the U.S. Geological Survey in Boston for assistance in evaluating the water resources and ground-water contamination at PAFB. This report presents the results of the study, begun in late July 1977 to identify hydrocarbons and to define the nature and extent of contamination.

The first phase of the study included an intensive 3-day pumping and sampling of the PAFB principal supply wells (Haven, Smith, and Harrison, fig. 1) and analyses of water samples for volatile organic substances to determine if hydrocarbons other than TCE were also present in potentially dangerous amounts. Phase I established that TCE is the only hydrocarbon identified as being present in concentrations that could be a health hazard. Samples from the supply wells, available observation wells, and drains and ditches that are interconnected with the aquifer and receive relatively large contributions from ground water indicated that TCE is fairly widespread, at least in the central part of the sand and gravel aquifer.

During a second phase of the study, test holes were drilled, periodic water-level measurements were made, and water samples were collected from ditches, drains, and key observation wells; selected samples were analyzed for common chemical constituents and many for TCE. Test-drilling, water-level, and water-quality data are presented in tables 1, 2, and 3, respectively. Water-level data from recorder charts for selected test holes are available from the U.S. Geological Survey, Boston, Mass.

The data showed that TCE concentrations were highest in the aquifer near the Haven well. Also, the data suggest that a close relation exists between the TCE-contaminated ground water surrounding the Haven well and the major storm-drain system underlying the parking apron and runway (fig. 2). Sampling of both water and scum precipitate in the drains was, thus, added to the study plan.

Acknowledgments

The author thanks the many individuals who assisted in this study. Olin Braids, Geraghty and Miller, Inc., and W. D. Silvey, U.S. Geological Survey, made suggestions regarding the geochemical aspects of the investigation. Many PAFB personnel helped during the study, especially those in the Civil Engineering, Procurement, Health Unit, Water and Sewage Treatment Plant, Military Security units, and the Base Weather Station. Kelly Air Force Base laboratory personnel made many TCE analyses, and special assistance was provided by O. Thomas Love, U.S. Environmental Protection Agency, Cincinnati, Ohio, who analyzed two scum precipitate samples from storm drains and a sediment sample from TH 1A.

Most TCE analyses were made by the Kelly Air Force Base Occupational and Environmental Health Laboratory. Also, bioenvironmental engineers from that laboratory made a survey of possible sites where TCE was used and disposed of at PAFB.

TCE and TCE Use at PAFB

TCE is a nonflammable organic liquid compound whose water solubility is 1,100 mg TCE per liter of water (Hardie, 1978). It dissolves most fixed and volatile oils. Because liquid TCE has a density of about 1.5 between 17.6°C and 75°C, a discrete slug of it would tend to sink in water. Dissolved in water, however, TCE moves with the water molecules as would any normal chemical constituent. TCE evaporates rapidly when exposed to air; even dissolved in water in contact with air, it evaporates appreciably more rapidly than the water. For example, 90 percent of a solution in the microgram per liter range evaporates after 63-80 minutes in contact with the atmosphere (Verschueren, 1977, p. 609). TCE dissolved in ground water will persist for a long time owing to a lack of direct contact with the atmosphere, little or no adsorption by aquifer material, and ineffective microbial degradation.

Only small quantities of TCE have been used at PAFB since 1973. Before that, however, large amounts were used--particularly while B-47 aircraft were based there. In late July and early August 1977, Capt. John H. Pontier and Capt. William D. Christensen of Kelly Air Force Base, Texas, made a survey of the PAFB water supply and reported on the presence of TCE. Their findings included the following discussion of the past use of TCE (Pontier and Christensen, written commun. 1977):

An effort was made to identify areas in which trichloroethylene (TCE) had been used and the methods used for disposal. This work was accomplished by reviewing as-built drawings maintained by the Civil Engineer and through discussions with persons assigned to Pease AFB during the period that TCE was used and disposed of on Pease AFB.

During the period October 1955 through November 1965, unspecified quantities of TCE were used in maintenance of the B-47 weapons system. Two of the larger users were the vapor degreasers located in Buildings 113 and 244. Each building was equipped with a 1200 gallon underground holding tank to collect waste TCE. One tank, that at Building 113, was found, during the survey, to contain approximately 1000 gallons of liquid containing a chlorinated hydrocarbon. A sample was collected for analysis. The analysis revealed 79 percent TCE by volume and the balance, a silicone fluid similar to OS-45 Type III lubricating oil for aircraft weapons. If one assumes that these tanks did contain TCE and were pumped for disposal only once per year, there would be 24,000 gallons of TCE waste generated over a ten year period from these operations alone. This is considered to be a conservative estimate, but helps to place perspective on the magnitude of the waste disposal requirement.

During the period of TCE use, disposal practices included storage in underground tanks, burning[1] for fire fighting training purposes, and possible burial in landfill areas. No records of contract disposal were located. Areas in which TCE may have entered the ground water are identified on the attached diagram.

[1]TCE can be incinerated at higher temperatures.

Buildings 113 and 244 as well as other areas identified by Capts. Pontier and Christensen on their diagram are shown on figure 2.

PHYSICAL CONDITIONS, PAFB

Local Hydrogeology

The topography of PAFB varies from gently rolling or nearly flat in the eastern and southeastern parts to more sharply rolling along the western margin. Earth materials underlying the base consist of igneous and metamorphic bedrock formations that are overlain by unconsolidated glacial deposits; the latter contain the ground water that supplies the three major PAFB wells--Haven, Smith, and Harrison wells. Two wells in bedrock have much smaller yields and are not part of the main distribution system for the base.

Underlying the PAFB runway and much of the parking apron is a large elongate rather flat-topped deposit of unconsolidated stratified sand and gravel. The deposit, also called by geologists an ice-contact deposit, consists mainly of sand, gravel, pebbles, and cobbles in varying proportions, but it may contain silt in places. It is the main aquifer of the air base area and is locally a source of large ground-water yields. Its western edge is marked by a 25- to 55-foot drop. On the eastern side, it is bordered by bedrock, shallow glacial till, or marine silt and clay deposits that overlie bedrock.

Before and during construction of the air base, the U.S. Army Corps of Engineers obtained many soil borings and test holes. The Corps also prepared a map delineating the area within PAFB underlain by sand and gravel deposits. In this report, the main aquifer boundary (shown on fig. 1) has been taken, with only minor revisions, from the Corps map ("Water Supply Investigations on and near Base; Surficial and Subsurface Explorations 1951-1958; scale 1" = 500 feet, Plate X": Available for examination at the PAFB Civil Engineer's office).

In many places, the permeable sandy deposits extend in the subsurface beyond the limits shown in figure 1. For example, along the western and southwestern sides, the deposit may extend underneath marine and (or) outwash and shore deposits (Bradley, 1964, p. 57-58) for undetermined distances beyond the boundary shown. Also, along the eastern border, deposits may extend beyond the marked boundary, either beneath or interfingering with marine and (or) outwash and shore deposits.

The most permeable part of the main aquifer underlies the relatively narrow mid-section near the Haven production well (fig. 1). The total thickness of the deposits is 80 feet at test hole TH 3 (200 feet south of the Haven well), which is at one of the thickest parts of the deposit. (See figs. 3 and 4, and table 1.)

Table 1.--Logs of test holes, December 1977

(Drilled by Layne-New England Company;
Logs by U.S. Geological Survey.)

Locations of test holes are shown in figure 3 except for test hole TH 9 which is shown in figure 1.

	Depth (feet)
TH 1. 2-1/2-inch observation well. Screen: stainless steel, 5 foot, 30 mesh, 65-70 feet below land-surface datum. Drillers pumped with pitcher pump, water cloudy. Drillers reported static water level 18.4 feet below land-surface datum.	
Topsoil	0 - 1
Sand, fine to very fine, uniform, tan, micaceous,	1 - 32
Sand, fine and some medium-grained, tan	32 - 48
Sand, medium to coarse, mostly tan and some gray; gravel up to 1/4-inch diameter much of it tan, some dark gray (local bedrock color)	48 - 71
Refusal	71
TH 1A. 2-1/2-inch observation well. Screen: stainless steel, 3 foot, 10 mesh, 26-29 feet below land-surface datum. Not pumped by drillers. Drillers reported static water level 15.41 feet below land-surface datum.	
Topsoil	0 - 1
Sand, fine to very fine, uniform, micaceous, tan	1 - 32
TH 2. 2-1/2-inch observation well. Screen: stainless steel, 5 foot, 40 mesh, 63-68 feet below land-surface datum. Drillers reported static water level 18.3 feet below land-surface datum.	
Topsoil	0 - 1
Sand, fine, some medium and little coarse, brown	1 - 24
Sand and gravel; many pebbles up to 1-inch diameter; many angular to subangular pebbles and coarse gravel mixed with subrounded particles; very little fine sand and silt, gray and brown	24 - 48
Same as 24-48 except pebbles up to 3/4-inch diameter and contains more silt and very fine sand	48 - 60
Same as 24-48 except slightly more angular, darker (more gray), largest particles are about 1/2 inch	60 - 70
Refusal	70
TH 2A. 2-1/2-inch observation well. Screen: stainless steel, 5 foot, 40 mesh, 24-29 feet below land-surface datum. Drillers reported static water level 18.0 feet below land-surface datum.	
Topsoil	0 - 1
Sand, mostly fine, some medium, a little coarse; brown	1 - 24
Sand and gravel; contains a little silt and fine sand; brown and gray	24 - 29

Table 1.--Logs of test holes, December 1977 (Continued)

	Depth (feet)
TH 3. 2-1/2-inch observation well. Screen: stainless steel, 3 foot, 10 mesh, 77-80 feet below land-surface datum. Drillers reported static water level 22.1 feet below land-surface datum.	
Topsoil (or fill)	0 - 2
Sand, mostly fine, a little silt; occasional gravel and pebble particles, mostly subangular. Sand is brown; gravel usually gray	2 - 20
Same as 2-20 but more silt and smaller subrounded particles; light tan	20 - 30
Sand, very fine to fine; some silt; micaceous; tan (gravel particles absent)	30 - 40
Sand, very fine to fine; a little silt; tan	40 - 53
Sand, medium and some coarse, relatively uniform; tan	53 - 60
Sand, mostly coarse, some fine and medium and a few gravel particles; brown	60 -70±
Sand and gravel, silty; a few subrounded particles up to 1/3-inch diameter; subrounded; light tan	±70 - 80
Refusal	80
TH 4. 2-1/2-inch observation well. Screen: stainless steel, 3 foot, 10 mesh, 54-57 feet below land-surface datum. Drillers reported static water level 14.25 feet below land-surface datum.	
Topsoil	0 - 1
Sand, medium, a little fine sand; slightly micaceous; uniform textured; tan	1 - 20
Sand, medium less fine than above; becomes coarse sand near 40 feet; tan to brown where coarser	20 - 40
Sand, medium to coarse; some angular, dark gray, slaty gravel-size particles; tan except dark brownish-gray where an abundance of gravelly particles occurs	40 - 48
Sand and gravel; poorly sorted with some silt and small pebbles; dark brownish-gray. (Probably ice-contact deposits, but close to or mixed with a little till at bottom.)	48 - 58
Refusal	58
TH 5. 2-1/2-inch observation well. Screen: stainless steel, 5 foot, 60 mesh, 51-56 feet below land-surface datum. Drillers reported static water level 15.83 feet below land-surface datum.	
Topsoil	0 - 1
Sand, gravel with some pebbles and silt; poorly sorted; subrounded to subangular; tan with a few light gray pebbles and coarse gravel particles	1 - 35
Gravel, some poorly sorted sand, and pebbles up to 3/4-inch diameter. Tan, with some light gray particles	35 - 45
Sand and gravel, poorly sorted with many pebbles up to 1-inch diameter; mostly subrounded, brown to tan with a few light gray particles	45 - 56
Refusal	56

	Depth (feet)
TH 7. 2-1/2-inch observation well. Screen: stainless steel, 5 foot, 60 mesh, 65-75 feet below land-surface datum. Pumped by drillers. Drillers reported static water level 17.01 feet below land-surface datum.	
Topsoil	0 - 1
Sand, fine, a little very fine; uniform; tan	1 - 10
Sand, mostly fine, some medium and very fine; tan	10 - 35
Sand, mostly medium to coarse with scattered gravel particles, brown; gravel is subangular, brown and gray; a few particles up to 1/4-inch diameter	35 - 55
Sand and gravel, poorly sorted, brown and gray, a few particles up to 1/2-inch diameter; most larger particles are subangular, a few subrounded. (Two samples: 55-65 feet and 65-75 feet are approximately the same)	55 - 75
Refusal	75
TH 8. 2-1/2-inch observation well. Screen: stainless steel, 5 foot, 30 mesh, 51-56 feet below land-surface datum. Drillers reported static water level 9.01 below land-surface datum.	
Topsoil	0 - 1
Sand, mostly medium, poorly sorted and a little gravel; tan; scattered pebbles, subrounded; up to 1/2-inch diameter gray	1 - 25
Sand; mostly fine and very fine; some silt; micaceous; light tan	25 - 45
Sand; mostly fine to medium; a little silt; micaceous; brown	45 - 56
Refusal	56
TH 9. 2-1/2-inch observation well. Screen: stainless steel, 3 foot, 30 mesh, 40-43 feet below land-surface datum. Attempt was made to gravel-pack hole before setting screen because of fine-textured material and importance of trying to get water sample. Drillers reported static water level 7.1 feet below land-surface datum.	
Sand, mostly fine and very fine; tan	0 - 12
Silt and clay; a few gravel particles, subangular; gray. (Marine silt and clay overlying till?)	12 - 56
Refusal	56
TH 10. 2-1/2-inch observation well. Screen: stainless steel, 3 foot, 30 mesh, 32-35 feet below land-surface datum. Drillers reported static water level 23.8 feet below land-surface datum.	
Topsoil	0 - 1
Sand, fine and very fine; a little gravel including particles up to 1/4-inch diameter; brown	1 - 10
Sand, fine to medium; a little very fine sand; very few scattered pebbles up to 1/2-inch diameter; slightly micaceous; tan	10 - 20
Same as 10-20 except slightly less very fine sand and more dark-colored grains; brown	20 - 28
Sand and gravel; poorly sorted; some silt and many pebbles up to 1-1/4-inch diameter; pebbles are angular to subangular mostly dark gray; sample is dark brownish-gray. (May be till or very "dirty" ice-contact deposits.)	28 - 35
Refusal	35

As shown in figure 4, the deposits near the surface in the vicinity of the Haven well consist mostly of fine or fine to medium sand. These fine-grained materials occupy the unsaturated zone and also, in places, part of the saturated zone. Coarse, more permeable sand and gravel deposits constitute the aquifer material in the lower part of the saturated zone. The reverse situation is common in much of both the northern and the southern parts of the main aquifer; that is, coarse-grained stratified deposits in the unsaturated zone overlie fine sandy deposits in the saturated lower part of the aquifer. For example, test hole TH 9, west of the south end of the runway (fig. 1), is located at the bottom of a sand and gravel pit, where coarse materials are exposed in banks above the test hole, but the material drilled through to refusal at 56 feet is fine-grained, as shown by the log of the hole in table 1. Many borehole logs from prebase-construction and other testing show similar fine grained deposits in the saturated zone in other parts of the main aquifer.

Relation of Drainage to Ground Water and Changes Caused by Construction

The hydrologic regimen in the Air Base area has been modified because of construction of the runway, parking apron and associated buildings, roads, and storm drains. On this subject, Bradley (1964, p. 58) states:

> The yield from the deposits of the Newington-Portsmouth kame plain remains high despite changes caused by the construction of the Pease Air Force Base. The recharge area, which coincided with the exposed surface of the kame plain, was reduced somewhat by the construction of drained runways and parking aprons. However, the stripping of soil and trees has so reduced transpiration and soil-moisture retention in the present recharge area that recharge rates there probably are larger than before the construction of the base. The net effect of these opposing changes is unknown.

The storm-drain system that underlies the parking apron and runway areas (fig. 2) consists of interconnected concrete pipes of various diameters. They lie between about 3 and 20 feet below the surface and are accessible through manholes at more or less regular intervals. Under the apron (as shown on fig. 2), in general the pipes drain from the north and the south to the west side of the apron near Haven well. Here, at a point about 150 feet northeast of the well, a large drain from the northeast and one from the south join with the largest (108-inch) drain (hereafter referred to as the 108-inch storm drain); the latter drains westward into McIntyre ditch (also called Receiver Site Creek, see fig. 1). Figure 4 shows a 3-dimensional view of part of the 108-inch drain; figure 3 shows, in plan view, the principal storm drains in the Haven well area, and figure 2 shows the major drains of the system underlying the parking apron, except for those that drain elsewhere than through McIntyre ditch.

According to Bradley (1964, p. 57-58), before 1955 the saturated thickness of the main aquifer in the Haven well area was about 60 feet. Nearly continous pumping at Haven, together with construction of the parking apron and runway storm-drain system (figs. 2, 3, and 4), lowered the water table (the upper surface of the zone of saturation) about 30 feet. However, after construction was completed and removed earth materials were replaced, the water table probably recovered to near its previous position.

There are varying degrees of interconnection between storm drains and the ground-water reservoir. For instance, the 108-inch storm drain receives the runoff from the storm drains that underlie all except the northernmost parts of the runway, associated taxiways, and the northeast-trending extension of the parking apron; at times of little or no rain or snowmelt, however, ground water contributes nearly all the discharge of the 108-inch storm drain. Although data are too scant to show accurately where the drains are above or below the water table, the major storm drains underlying the parking apron itself are probably wholly above the water table. The drain entering the 108-inch storm drain from the northeast is also wholly above the water table; whereas, a part of the relatively large drain leading to the 108-inch storm drain from the south lies below the water table, at least for part of the time, when the water table is high.

Before 1974, when a fuel separator was constructed, all the flow through the 108-inch storm drain passed directly into the Great Bay estuary through McIntyre ditch. Since then, however, the flow (except for large flood discharges) has been diverted through the separator. Temperature and specific-conductance measurements at the entrance to the separator (table 4, McIntyre ditch 1) show a large influence from ground water that has leaked into the 108-inch storm drain, where it is below the water table.

The Water Table and Water-Level Fluctuations

Changes in ground-water levels are caused both by natural and man-induced factors. The principal causes of natural water-level fluctuations are related to changes in temperature and precipitation. Generally, the water table rises as a result of the addition of rainwater or melting snow that infiltrates through the soil and unsaturated zone. Infiltration is greatest in areas of coarse sandy soil and gentle topography, such as over the main aquifer at PAFB. The water table is normally highest in the spring, when the ground has thawed, allowing the spring rains to infiltrate. It is normally lowest in the fall after several months when infiltration is generally drastically reduced. High evapotranspiration during the summer increases natural discharge in vegetated areas, where the water table is close to the land surface. In and near ponds, streams, and swamps, both direct evaporation and transpiration lower ground-water levels, so that the water table declines also in upgradient areas between the streams, ponds, or swamps.

Figure 1 shows the altitude of the water table for the PAFB main aquifer and adjacent deposits during the fall of 1977. Figure 4 shows (in cross-section) the water table in the Haven well vicinity for more or less high water-table conditions. Close to the well, the water table fluctuates (between the approximate position as shown in the figure and a position 1 to 3 feet below it) in response to the intermittent pumping of the Haven well. (See below in this section.) Figure 3 shows also the range of water-level fluctuations in the Haven well test holes between January and May 1978.

Water-level measurements in selected nonsupply wells are shown in figure 5 and table 2. Goslin 1, Harrison 2, and B-101 each tap the main aquifer. The seasonal variation in water level ranges from only 1.5 feet in B-101 to 4 feet in the Harrison 2 well; Goslin 1 has an intermediate fluctuation range of 2.7 feet. CE 8-inch, which probably taps till, has a fluctuation range of almost 12 feet.

Man-made causes also produce water-level fluctuations. The water table surrounding wells pumping relatively large quantities of water is normally depressed into a shape that approximates an inverted cone. The seasonal variations and the intermittent pumping of Haven well caused the water table at the test holes to fluctuate over the ranges shown on figure 3. Figure 6 shows hydrographs for TH 1 and TH 1A taken from automatic water-level recorders. The hydrogeologic relation between the two test holes is shown in figure 4 and from the logs in table 1. After about a 36-hour nonpumping interval, the water-level difference between pumping and nonpumping levels for TH 1 (100 feet north of Haven well) was about 2.5 feet; TH 1A shows a smaller fluctuation (less than 1 foot) for the same interval.

A longer term man-induced water-level change results from significant changes in pumpage. The volume of aquifer material dewatered within the cone of depression may vary noticeably in accordance with the amount withdrawn. Figure 7 shows a gradual, but significant, rise in water levels in TH 1, TH 2, and TH 3 after a rather dramatic drop, about 0.5 Mgal/d (0.022 m^3/s) in the amount pumped from Haven well. This change also affected the other test holes in the Haven vicinity, as is shown by the January to May rise in water levels. (See fig. 3.) Part of the rise was due to the normal spring seasonal increase and part to a reduction in pumping, which resulted largely from isolation of a leaking water main. (See section, <u>TCE contamination outside the Haven well vicinity</u>.)

The natural and man-induced changes in water levels described above and illustrated in figures 3, 5, 6, and 7 result in an alternate submerging and emerging of part of the storm-drain system, especially in proximity to the Haven well. To some degree, this dynamic condition probably enhances both leakage and perhaps geochemical activity associated with the drains and the cone of depression.

Table 2.--Water-level fluctuations in selected observation wells, 1977-78
(Water levels are reported in feet below land-surface datum)

4305220704858.1. Local number CE 8-inch. Drilled test well in glacial till of Pleistocene age. Diameter 8 inches. Depth 40.9 feet cased. Land-surface datum 92.53 feet above mean sea level. Measuring point, top of casing, 0.0 feet above land-surface datum. Highest water level, 2.22 Dec. 12, 1977; lowest, 13.99 Sept. 13, 1977. Records available: 1977-78.

7-28-77	11.35	11- 1-77	6.78	11-28-77	4.22	1- 3-78	3.79
8-24-77	12.88	11- 7-77	6.86	12- 9-77	3.97	1- 9-78	3.88
9- 7-77	13.64	11-11-77	2.90	12-12-77	4.31	3-21-78	4.91
9-13-77	13.99	11-14-77	3.49	12-27-77	2.22	5-16-77	2.25
9-26-77	13.48	11-21-77	4.46				

4304540704850.1. Local number Goslin 1. Drilled observation well in sand (ice-contact deposits) of Pleistocene age. Diameter 2-1/2-inches. Depth 38.25 feet cased. Land-surface datum 64.31 feet above mean sea level. Measuring point top of casing 2.7 feet above land-surface datum. Highest water level, 1.33 May 16, 1978; lowest, 4.05 Sept. 12, 1977. Records available 1977-78.

8- 5-77	3.36	9-27-77	3.39	11-28-77	2.05	5-16-78	1.33
9-12-77	4.05	11- 7-77	2.55	1- 3-78	1.76		

4303580704818.1. Local number Harrison 2. Drilled test well in sand and gravel (ice-contact deposits) of Pleistocene age. Diameter 12 inches. Depth 43.5 feet cased. Land-surface datum 58.27 feet above mean sea level. Measuring point hole in casing cover 0.9 feet above land-surface datum. Highest water level, 12.90 Apr. 26, 1978; lowest, 17.16 Sept. 26, 1977. Records available: 1977-78.

8- 2-77	16.40	12-15-77	14.61	2- 2-78	13.01	3-28-78	13.16
9-12-77	17.10	12-27-77	13.79	2- 9-78	13.14	4-11-78	13.18
9-26-77	17.16	1- 3-78	13.64	2-16-78	13.39	4-19-78	13.31
11-15-77	15.18	1-10-78	13.56	3- 1-78	13.69	4-26-78	12.90
11-21-77	15.04	1-17-78	13.65	3- 7-78	13.90	5- 3-78	12.95
11-28-77	15.03	1-30-78	13.94	3-21-78	13.75	7-18-78	13.31
12-13-77	14.70						

4304070704916.1. Local number B-101. Drilled test well in sand and gravel (ice-contact deposits) of Pleistocene age. Diameter 3 inches. Depth 36.8 feet (measured in 1977; original reported depth, 38.3 feet) cased. Land-surface datum 78.73 feet above mean sea level. Measuring point top of casing (north side), 1.0 foot above land-surface datum. Highest water level, 26.43 Jan. 3, 1978; lowest, 28.39 Sept. 13, 1977. Records available 1977-78.

8-29-77	27.84	11- 7-77	27.58	11-28-77	27.03	12-27-77	26.78
9- 7-77	28.23	11-11-77	27.35	12- 5-77	26.94	1- 3-78	26.43
9-13-77	28.39	11-14-77	27.31	12-12-77	26.98	3-23-78	27.25
11- 1-77	27.78	11-21-77	27.09				

Ground-Water Movement

Water in the PAFB main aquifer moves at various rates, according to hydraulic conductivity variations and in response to head changes accompanying recharge, natural discharge, and withdrawals. Although the movement is 3-dimensional, in most parts of the aquifer horizontal flow is probably several times larger than vertical flow. Horizontal flow is approximately perpendicular to water table contour lines (fig. 1); locally, near the Haven well, horizontal flow is generally toward the pumping well, as shown by the small arrows in figure 3. It is emphasized, however, as is evident from the gradient of the water table, water--primarily from the north--is constantly moving toward Haven well from beyond the immediate areal extent of the cone of depression (only a few hundred feet).

Under nonpumping conditions, water in the main aquifer may move from less than a few feet per year in very silty and fine sand materials to several hundred feet per year in the more permeable parts of the aquifer. In contrast, ground water very close to Haven well, which pumps large amounts from a highly permeable part of the aquifer, can move as fast as several feet per minute.

The interconnection between storm drains and ground water (mentioned in the section "Relation of Drainage to Ground Water and Changes Caused by Construction) is particularly important in the Haven well area. The east end of the 108-inch drain and adjacent parts of the tributary drain from the south are located within the Haven well cone of depression. Haven well's daily intermittent pumping causes a water-level fluctuation that helps to increase the interchange of ground water and water in the drains affected by the cone.

GEOCHEMICAL CONDITIONS, PAFB

Table 3 shows that in general, ground water, drainage ditch, and storm drain samples were relatively low in dissolved-solids content, a common characteristic of most water in southeastern New Hampshire. Water from CE 8-inch is typical; it is relatively low in all dissolved constituents.

The most unusual chemical characteristic of many of the water samples is a considerably higher than normal concentration of bicarbonate and dissolved calcium, even though rocks in the area contain little or no calcium carbonate. Only the Golf Course spring[1], CE 8-inch, Newfields ditch, McIntyre ditch 2, Apron 1, and Dover Avenue 1 have bicarbonate concentrations lower than 100 mg/L, which is well above normal for the area; also water from these sites is relatively low in calcium content. The only source of lime to explain the high bicarbonate and calcium in the other samples is from recharge through concrete paving and (or) leakage through concrete storm drains. The recharge areas for both CE 8-inch and the spring are unaffected by large areas of concrete; whereas, most of the other wells sampled are at least partly influenced by recharge from or through the large parking apron. An intermediate bicarbonate concentration, 140 mg/L at Goslin 1 well, suggests some influence from concrete drains, but much less than at the Haven well area, which is close to the west side of the parking apron and near the major storm drains. (See figs. 2, 3 and 4, and chemical analyses for TH 2, TH 3, TH 4, and TH 5 in table 3.)

The highest bicarbonate, 300 mg/L, was found in water from the Harrison 2 test well (fig. 1 and table 3), which is about 220 feet north of Harrison production well and downgradient from the full length of the parking apron. (See water-table contours on fig. 1.)

The chemical analyses for TH 2, TH 3, TH 4 and TH 5 in table 3 are probably typical of water being pumped from the Haven well at present (1978). Chemical analyses of samples from the Haven, Smith, and Harrison production wells taken in 1974, 1975, and 1976 show more than 100 mg/L bicarbonate and relatively high calcium contents, but slightly less than the values shown in table 3 for the Haven test holes and Harrison 2. This difference is probably because the earlier samples were taken from the production wells, which draw water from a larger aquifer volume than the 2-1/2-inch test holes.

[1]Locally called a spring, it is a modified well with an underground gallery and stream.

Table 3.--Chemical quality data for water samples from selected sites, 1977-78

(Analyses by U.S. Geological Survey. Values are reported in milligrams per liter except dissolved iron which is reported in micrograms per liter.)

Local number	Location	Date of sample	Hardness (Ca,Mg)	Noncarbonate hardness	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Dissolved sodium (Na)	Bicarbonate (HCO_3)	Alkalinity as $CaCO_3$	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved iron (Fe)
CE 8-inch	4305220704858.1	9-26-77	90	12	25	6.7	4.4	95	78	13	7.2	0
Goslin 1	4304540704850.1	9-27-77	130	16	36	10	11	140	110	25	14	0
TH 2	4304330704909.2	3-23-78	210	23	65	12	9.1	230	190	33	12	0
TH 3	4304320704908.1	1-11-78	220	20	62	17	6.7	250	210	38	5.3	0
TH 4	4304340704907.1	3-23-78	200	34	63	10	9.0	200	160	30	24	90
TH 5	4304320704912.1	1-11-78	200	37	59	13	5.5	200	160	32	2.1	0
Harrison 2	4303580704819.1	9-26-77	250	8	67	21	9.1	300	250	20	6.4	30
Golf Course Spring	4303360704859.1	9-13-77	53	29	15	3.8	4.8	30	25	28	5.3	0
N. apron	4305450704908.1	9-13-77	140	0	41	8.0	8.2	170	140	8.9	4.6	10
McIntyre 1	4304250704925.1	9-27-77	180	22	53	11	9.2	190	160	32	12	10
		11- 1-77	180	28	54	12	7.7	190	160	31	12	10
McIntyre 2	4304100704955.1	11- 1-77	72	0	22	4.1	3.1	95	78	5.3	3.4	50
Newfields ditch	4304450704827.1	9-21-77	73	29	22	4.4	11	54	44	32	13	20
Grafton ditch	4304100704813.1	9-21-77	190	48	59	9.8	47	170	140	25	89	0
		9-27-77	190	38	61	10	38	190	160	25	66	--
Landfill ditch	4304120704738.1	11- 1-77	170	37	53	8.8	25	160	130	28	49	10
Parking apron 1	4304460704911.1	1-13-78	69	17	22	3.3	5.3	63	52	10	3.3	20
Parking apron 3	4304290704856.1	1-13-78	210	47	63	13	7.9	200	160	43	14	10
Dover Avenue	4304330704833.1	1-13-78	120	66	36	8.2	8.7	70	57	61	13	30

INTERPRETATIONS OF THE TCE CONTAMINATION

Interpretations of the TCE contamination are largely based on evaluation of the hydrogeologic conditions in conjunction with the data on TCE, bicarbonate, and calcium concentrations in water from key sampling sites. Although TCE analyses or laboratory measurements in themselves might vary, it is assumed that the TCE concentrations of water samples shown in tables 4 through 6 are all correlative. Data on TCE use and disposal for a quantitative assessment of the contamination problem do not exist. However, even though time and quantity figures for entry of TCE into the main aquifer are lacking, there are now (1978) sufficient data to demonstrate where TCE is most heavily concentrated and to indicate its behavior with reference to present and possible future water-use practices at PAFB. Some interpretations could be improved by further data collection and study. (See CONCLUSIONS.)

Figure 2 shows TCE concentrations, as determined from samples collected from wells, ditches or storm drains. It also shows an area of presumed highest TCE concentration in the main aquifer based on samples from all available wells within the area locally surrounding Haven well and Goslin I well area. In the fall of 1977, samples were collected from two downgradient wells south of the air base; TCE was not detected. Precise source(s) of TCE contamination are not known. More than one of the possible point sources shown on figure 2 may have contributed. Part may have originated elsewhere, perhaps spills on unpaved ground. The extent that infiltrating rainwater or snowmelt on TCE-soaked soil might dissolve TCE has not been studied, but probably any such contamination would be considerably less significant than that contributed through the storm drains and(or) parking apron described in the following section.

TCE Contamination in the Haven Well Vicinity

TCE concentrations in water collected from test holes in the area around Haven well are shown in figure 4. The samples are representative of water at the level of the screens in the test holes. Figure 4 also shows TCE concentrations in four samples collected from leaks in the 108-inch storm drain where it lies below the water table. On April 4, 1978, when the drain was sampled, 40 to 50 leaks from 1 to 25 gal/min into the drain were noted between 275 and 600 feet west of the east end of the drain. It is inconsistent with other data that samples DR 1 and DR 2 show only a TCE trace; whereas, water from DR 3, which is farther from the high TCE occurring in the Haven well cone of depression, has a TCE concentration of 3.8 ug/L. This apparent anomaly could possibly be resolved by further sampling in the drain.

Examination of figures 3 and 4 and table 6 shows that TCE in ground water in the Haven well area extends at least 500 feet north (upgradient to TH 7, 155 ug/L TCE concentration) but TCE concentration diminishes to only a trace at TH 8, which is 500 feet south of Haven well. TCE concentration also diminishes to a trace in water from TH 5, which is 265 feet west of Haven well. TH 5, 7, and 8 all show water-level changes in response to intermittent pumping of Haven well; the fact that TCE occurs in about the same concentration in TH 7 as in Haven well, but does not occur in either TH 5 or TH 8, is evidence that TCE comes from more or less directly upgradient (northward) from Haven well. Thus, the two most likely places for TCE to have leaked into the aquifer are: (1) At, or near, the 1200-gallon storage tank near Building 244; or (2) from waste TCE spills on the parking apron or into storm drains underlying the apron almost anywhere upgradient (north) of Haven well. Furthermore, table 5 and figure 8 show that TCE concentration in samples from Haven well varies considerably. Variations are partly due to sampling at random times in relation to the length of time that well has been pumping. For example, the data show a drop in TCE concentration during the nearly continuous pumping test (Aug. 2-5, 1977). The continuous pumping extended the pumping cone of depression so that it reached farther southwest of Haven well than during intermittent pumping ordinarily in operation for normal water demands. This southwestward extension of the cone of depression brought to the well a higher proportion of TCE-free water than during the normal pumping pattern. This is substantiated further by the lower TCE concentrations of samples from Haven well collected between August 1977 and early February 1978 while water use and pumping (table 9) had been increased because of a relatively large water-main leak. (See sections: The water table and water-level fluctuations and TCE contamination outside the Haven well vicinity.) Figure 8 and table 5 show that between mid-August 1977 and early February 1978 TCE concentration of Haven well samples was 160 ug/L or less; whereas, both before and after that period, concentration of all but a few samples was more than 160 ug/L.

Table 4.--TCE concentration and related field data from ditches, drains, and other special water samples
(ND, none detected; T, trace, sometimes reported as less than 1.5 ug/L.)

Date	TCE (ug/L)	Tempera-ture (°C)	Specific conduct-ance (umhos/cm)	Water discharge (estimated)	Remarks
				Spring	
8- 3-77	ND	--	--	--	
9-13-77	ND	14	120	15 gal/min	
10-25-77	ND	12	--	15 gal/min	
1-17-78	ND	6	150	12 gal/min	
				Grafton ditch	
8- 4-77	60.0	--	--	2 ft^3/s	Slight fuel scum where water moving very slowly
8-29-77	41.9	--	--	--	
9-20-77	12.2	14	135	7 ft^3/s	Fuel slicks
9-27-77	22.8	15	450	6 ft^3/s	
10-25-77	38.4	14	--	1 ft^3/s	Relatively clear
11-11-77	34.8	13	550	3 ft^3/s	
11-14-77	25.9	11	510	2 ft^3/s	A few fuel slicks
11-21-77	64.7	11	550	2 ft^3/s	
11-28-77	65.0	10.5	850	3 ft^3/s	Snow; roads may be salted
12-27-77	39.3	8.5	800	3 ft^3/s	
1- 3-78	46.0	10	590	3 ft^3/s	
1-13-78	55.9	9	600	2 ft^3/s	Dover Avenue storm drain sampled same day
1-17-78	60.7	9	590	2 ft^3/s	Appears clear
3-21-78	3.1	5	--	2 ft^3/s	Do.
4-19-78	5.7	7	740	1 ft^3/s	
				Landfill ditch	
8- 4-77	4.6	--	--	--	
9- 6-77	T	--	--	--	
1- 3-78	3.6	0.5	440	4 ft^3/s	Appears clear
1-17-78	5.2	3	500	4 ft^3/s	Do.
				McIntyre ditch 2	
8- 3-77	15.8	--	--	--	
				McIntyre ditch 1 (at "Separator")	
8-29-77	48.2	12	--	0.5 ft^3/s	Appears clear where flowing; scum on still water
8-30-77	46.1	12	--	.5 ft^3/s	Do.
9-20-77	T	13	100	15 ft^3/s	Heavy rains diluted TCE content
9-27-77	15.2	12.5	--	.8 ft^3/s	
10-11-77	40.7	11	--	.8 ft^3/s	
10-25-77	27.0	10.5	240	--	
11- 1-77	21.3	10.5	410	.8 ft^3/s	Fuel slicks present
11- 7-77	3.5	10.5	410	.8 ft^3/s	Fuel slicks and odor present
11-14-77	56.9	10	395	.7 ft^3/s	Sand washed into separator
11-21-77	51.8	10	400	.6 ft^3/s	
11-28-77	15.2	7.5	240	2.0 ft^3/s	Slight fuel odor
12- 5-77	36.3	8.5	400	1.0 ft^3/s	A few fuel slicks
12-27-77	33.0	7	400	65 gal/min	

Table 4.--TCE concentration and related field data from ditches, drains, and other special water samples (Continued)

Date	TCE (ug/L)	Temperature (°C)	Specific conductance (umhos/cm)	Water discharge (estimated)	Remarks
			McIntyre ditch 1 (at "Separator")--Continued		
1- 3-78	29.0	7	400	60 gal/min	
1-10-78	29.9	7	370	--	
1-13-78	42.8	7.5	410	--	
4- 4-78	24.1	8.5	390	1.5 ft^3/s	
5-31-78	16.4	--	--	.8 ft^3/s	
			Merrimac ditch		
9-20-77	ND	15	100	1 ft^3/s	Raining
			Newfields ditch		
8-29-77	21.2	17	--	1 ft^3/s	Water appears clear
8-30-77	29.3	17	--	1 ft^3/s	Do.
10-25-77	T	15	--	1 ft^3/s	
10-31-77	1.5	--	340	1 ft^3/s	
11- 7-77	T	15	330	1 ft^3/s	A few fuel slicks on slow-moving water
			N. Apron ditch		
9-13-77	ND	17	190	1 ft^3/s	Water has particles in it; streambed coated orange
			Spaulding Turnpike culvert		
1-17-78	2.8	1	550	5 ft^3/s	Broke ice cover to sample
			Dover Avenue (Drain 1)		
1-13-78	2.5	2	325	15 gal/min	
			Dover Avenue (Drain 2)		
1-13-78	4.7	14	350	5 gal/min	
			Parking apron 1		
1-13-78	T	7.5	230	17 gal/min	From northwest; drains apron only
			Parking apron 2		
1-13-78	9.2	9	400	2 gal/min	From northeast; drains apron and some hangar area
			Parking apron 3		
1-13-78	18.6	9	490	50 gal/min	Drains east side of apron and flow from building with wash rack

Table 5.--TCE concentration, Haven well water, for selected dates, 1977-78

(Most available analyses included.)

Date	Time	TCE (ug/L)	Date	TCE (ug/L)
6- 9-77	(a.m.)	216	9-14-77	42.7
6-29-77	--	260.4	9-20-77	61.2
7- 1-77	--	225	9-28-77	84.9
7- 1-77	--	261	10-18-77	145.5
7- 5-77	--	177.9	11- 1-77	160.2
7- 7-77	--	375.8	11- 8-77	61.3
7-11-77	--	210.6	11-15-77	48.5
8- 2-77	(0700)	350.0	11-22-77	132.6
8- 2-77	(0800)	340.0	11-29-77	151.0
8- 2-77	(0900)	333.0	12-13-77	148.8
8- 2-77	(1100)	354.0	12-29-77	148.0
8- 2-77	(1245)	275.0	1- 4-78	130.3
8- 2-77	(1855)	195.0	1-11-78	129.4
8- 3-77	(0100)	172.0	2- 2-78	116.6
8- 3-77	(0645)	155.0	2-16-78	169.7
8- 3-77	(1310)	213.4	2-23-78	*245.5
8- 3-77	(1900)	181.9	3- 2-78	159.4
8- 4-77	(0050)	163.3	3- 9-78	122.1
8- 4-77	(0800)	155.0	3-22-78	217.3
8- 4-77	(1315)	148.0	3-29-78	165.1
8- 4-77	(1935)	163.2	4- 6-78	180.5
8- 5-77	(0100)	168.0	4-12-78	201.5
8- 5-77	(0655)	138.0	4-19-78	273.5
8-31-77	--	96.5	4-26-78	223.9
9- 6-77	--	78.4	5- 3-78	202.1

*Haven well not operating for more than a 24-hour period March 21 and 22.

Table 6.--TCE concentration and related field data from ground water (nonsupply well and submerged storm drain) sources

(GW = ground water (the drain is below the water table and leaks occur under pressure; ND = not detected; T = trace.)

Date	TCE (ug/L)	Tempera-ture (°C)	Specific conduct-ance (umhos/cm)	Water discharge (gal/min)	Remarks
			CE 8-inch		
9-26-77	1.8	10.5	200	5	Pumped 51 minutes before sampled
			Goslin 1		
9-12-77	14.5	10	250	--	
			Goslin 2		
9-12-77	--	14.0	--	--	
			Harrison 2		
8-2-77	ND	--	--	2	Pumped 4-1/2 hours (with stops) before sampled
9-12-77	ND	10	410	5	Pumped 113 minutes before sampled
			TH 1		
1-10-78	159.4	10	450	4	Pumped ±1-1/2 hours before sampled.
			TH 1A		
1-10-78	310.7	9	490	1	Silt and very fine sand clogged pump; had to decant water sample after settling.
3-23-78	141.4	--	100 to 200	1	Sampled at 1400
3-23-78	193.4	--	100 to 200	--	Sampled at 1412 (pumps silt and very fine sand
			TH 2		
3-23-78	133.2	11.5	420	3	Pumped 40 minutes before sampled
			TH 3		
1-11-78	64.4	11	560	2	Pumped 100 minutes after water was clear before sampled
			TH 4		
3-23-78	451.8	--	--	1	Sampled at 1445
3-23-78	185.2	--	--	1	Sampled at 1503. Pump started at 1427; clogged easily with silt and very fine sand

Table 6.--TCE concentration and related field data from ground water (nonsupply well and submerged storm drain) sources (Continued)

(GW = ground water (the drain is below the water table and leaks occur under pressure); ND = not detected; T = trace.)

Date	TCE (ug/L)	Tempera-ture (°C)	Specific conduct-ance (umhos/cm)	Water discharge (gal/min)	Remarks
				TH 5	
1-11-78	ND	11	500	4	Pumped clear in 5 minutes; sampled at 35 minutes.
				TH 7	
1-10-78	155.3	10.5	440	3	Pumped clear in 5 minutes; sampled after 33 minutes.
				TH 8	
12-22-77	ND	10	415	3	Sampled at 1140 about 35 minutes after pumping clear.
12-22-77	ND	10	420	3	Sampled at 1255 (still pumping)
				TH 9	
12-22-77	ND	10	140	1	Sustained pumping difficult due to silt; sampled after 55 minutes.
				108-inch storm drain DR 1	
4- 6-78	T	--	--	13	GW leak about 350 feet west of east end of drain
				108-inch storm drain DR 2	
4- 6-78	T	--	--	10	GW leak about 400 feet west of east end of drain
				108-inch storm drain DR 3	
4- 6-78	*3.8	--	--	7	GW leak about 530 feet west of east end of drain
				108-inch storm drain DR 4	
5- 3-78	204.4	--	--	8	GW leak about 12 feet west of east end of drain

*Possibly confusion in bottle labelling occurred in the field; other related evidence suggests that this value belongs to 108-inch storm drain DR 1, and DR 3 should be T or ND.

The storm drains under the apron are, as far as is known, all above the water table; water and (or) TCE could leak out from the joints between the concrete sections in the same way that ground water leaks into the 108-inch storm drain where it lies below the water table. TCE contamination by leakage from the region of Building 244, or from the storage tank there, would have to move entirely through the aquifer--about 3,000 feet to the Haven well area. Assuming a rate of movement of 150 feet per year, it would take about 20 years to move water (and TCE) through the aquifer from the storage tank to the Haven well. Assuming further that the effective area of increased velocities in the cone of depression is 300 feet, it would take about 18 years to reach that point and perhaps less than a year more to reach the well. Finally, if it is assumed that the storage tank did not leak appreciably until 1960, TCE concentrations would just be showing up at the Haven well in 1978.

However, it seems nearly certain that TCE was already present in relatively high concentrations near the Haven well in the aquifer before the initial detection in April 1977. In addition to the possibility of leakage from Building 244, another source of the high TCE concentration in the Haven well area may be from spills and (or) leaks of used or waste TCE on, or near, parts of the parking apron or associated work areas anywhere north of the Haven well. Such spills or leaks would likely be washed into the storm-drain system that is tributary to the 108-inch storm drain from the northeast. (See storm drain, northeast branch on fig. 2.) Leaks through the concrete joints between sections of the drain pipes would allow TCE, either directly as a slug or already dissolved in water, to reach the aquifer at various intervals between the spill and the Haven well. Also, there is the possibility that leaks through the concrete apron itself could contribute to the contamination. It is also plausible that both TCE leakage from the tank near Building 244 and spills or leaks through the parking apron work areas combined to produce the high TCE concentrations in the Haven well area.

The probability that leakage from the storm drains and perhaps through the apron is related to TCE-contaminated ground water near the Haven well is most strongly substantiated by geochemical data. Relatively high bicarbonate and dissolved calcium in water samples from test holes TH 2, TH 3, TH 4, and TH 5 (table 3) is evidence of chemical solution of the concrete of the storm drains and (or) the parking apron. Because of the effective interconnection between ground water and the storm drains near the Haven well, TCE-contaminated water is being partly recycled by certain uses of Haven water on the base. For example, table 4 shows that a storm-drain sample collected January 13, 1978, from parking apron 3 had a TCE concentration of 18.6 ug/L, and that a storm-drain sample from parking apron 2 had a TCE concentration of 9.2 ug/L and a specific conductance of 400 umhos/cm. These concentrations suggest that water used for washing aircraft in Building 227 (WASH, fig. 2) flows to the storm drains under the apron and thence to the Haven well area through southeast branch. Water used for aircraft washing is exposed to air sufficiently for some TCE to evaporate, but how much loss this accounts for is unknown. Also unknown is the number of years TCE-contaminated ground water may have been being recycled. Washing of maintenance and other equipment may also contribute to recycling of TCE-contaminated ground water from the Haven well area. Although this recycling partly contributes to the present TCE concentrations in ground water, it is, obviously, only a byproduct or result of earlier more concentrated TCE-contamination sources.

To further study the relation between the storm drains and the high TCE concentrations within the cone of depression near the Haven well, samples of solid precipitate, a scumlike material adhering to the bottom walls of concrete sections of the storm drains, were collected and analyzed by the U.S. Environmental Protection Agency laboratories in Cincinnati. (See table 7.) Drain Scum 3 was collected from the east end of the 108-inch storm drain. Drain Scum 2 was collected in the storm drain entering the 108-inch drain from the south. The collection site was at the manhole shown in figure 8 about 75 feet south of Taxiway B. Drain Scum 3 showed 800 times as much TCE as Drain Scum 2; this can best be explained by assuming that in the past, large TCE spills or leaks came through the storm-drain system from the northeast branch (fig. 2) rather than from the south. In any case, this relatively high TCE from Drain Scum 3 relates the high TCE concentrations in nearby test holes to the proximity of the storm-drain system and the large withdrawals from the Haven well.

Table 7.--Relative TCE content of solids from drains and sediment from TH 1A

Date	TCE (ug/L)	Remarks
		TH 1A
3-23-78	2*	See table 1 for log. Sediment and water pumped at about 1/4 gal/min.
		Drain Scum 2
5- 3-78	1*	Scum scraped from bottom of storm drain south of Taxiway "B". Water flowing slowly; scum removed easily with paint scraper.
		Drain Scum 3
5- 3-78	800*	Scum scraped from bottom and lower sides of east end of 108-inch storm drain. Water flowing fast; scum removed only with difficulty using a razor blade scraper.

*Quantitative measurements of TCE on solid not possible; thus, blank water was added, shaken and allowed to stand overnight at 25°C. The supernate was then analyzed by gas chromatography using the purge and trap technique with an electrolytic detector. This provides only an estimate of the relative amounts of TCE associated with each sample.

Figure 4 and table 6 show that on January 10, 1978, shallow well TH 1A had a much higher TCE concentration (310.7 ug/L) than the deep hole TH 1 (159.4 ug/L) 2 feet away. The fine-grained sediment (table 1) of the screened interval in TH 1A allowed pumping at a rate of only about 1/4 gal/min; fine-grained sediment (very fine sand and silt) was collected with the water, and an analysis of the sediment (see table 7) showed a TCE content of only 2 ug/L. (See footnote of table 7.) Also, TH 4 (table 6) at Building 327 could be pumped only at a comparably slow rate (less than 1/4 gal/min). Water from it had an initial TCE concentration of 451.8 ug/L, which dropped after pumping 15 minutes to 185.2 ug/L. Probably concentrations of TCE were higher in the ground water when the test holes were drilled than when they were later sampled. This more contaminated water probably remained in the test-hole pipes until they were pumped, while the surrounding ground water received TCE-free replenishment by infiltration of rainwater, or melting snow. In the case of TH 1A, recharge from rains could have diluted the TCE concentration between the sampling January 10 (310.7 ug/L) and the sampling March 23 (141.4 and 193.4 ug/L, table 6). Ordinarily, because of the dilution by local recharge, it would be logical to expect that water in the upper part of the aquifer would become and would remain lower in TCE concentration than water in the lower part of the aquifer. That water in the shallow upper part is higher or at least as high in TCE concentration as water from the lower part, helps support the hypothesis that the storm-drains provide an avenue through which TCE-contaminated ground water is recycled from use sites on or near the parking apron back to the Haven well cone of depression. Additional evidence of the high TCE concentration in the upper part of the zone of saturation is provided by DR 4 (table 6), a sample taken May 3, 1978, from the east end of the 108-inch drain.

TCE Contamination Outside the Haven Well Vicinity

TCE concentrations in water are appreciable, or are present in at least detectable amounts, at places outside of the Haven well area. Notable examples are in two samples from Newfields ditch taken August 29 and 30, 1977, and in 13 samples from Grafton ditch collected between August 4, 1977, and January 17, 1978. (See figs. 4 and 8 and table 4.) Grafton ditch flows into Landfill ditch and then under the Spaulding Turnpike. Smaller amounts of TCE were detected in samples from Landfill ditch and Spaulding Turnpike culvert than from Grafton ditch because of dilution from ground-water inflow.

The Grafton ditch samples had a high TCE concentrations as a result of a large water-main leak next to Dover Avenue (fig. 2). Water from the leaking water main, composed of Haven well water, flowed into an adjacent storm drain which is part of the system flowing into the Grafton ditch. The leak was detected on Feb. 2, 1978, and a valve in the main was closed to bypass it. The bypass is indicated by a drop in pumpage and in base consumption (table 8) in Feburary 1978 after the leak was discovered, and the beginning of the leak is indicated by an appreciable increase in Haven well pumpage in mid-August 1977 (table 9). Total water use was particularly high in December 1977 and January 1978, and a large part of it came from the Haven well (tables 8 and 9). This lowered the water table in the Haven well cone of depression, as indicated in a general way by the 45-foot depression contour line and January low water levels in test holes. (See fig. 3.) The bypassing of the leak and the drop in pumpage was accompanied by a significant rise in water levels in observation wells in the Haven well area (fig. 7) and a significant drop in TCE concentrations in water samples from Grafton ditch in March and April 1978 (table 4). This substantiates that the Dover Avenue water-main break caused the high TCE content in Grafton ditch.

There is no satisfactory explanation for the August 29 and 30, 1977, TCE concentrations at Newfields ditch, which, like the Grafton ditch, receives some storm-drain runoff and some ground-water contribution. At Newfields ditch, however, temperature and specific-conductance measurements indicate a smaller ground-water contribution than at Grafton. Possibly the August 29 and 30 samples were contaminated during field collection or subsequent handling because other later samples had only a trace or no TCE (table 4).

The 1.8 ug/L TCE at CE 8-inch (table 6) may be explained on the basis of overflows of Haven well water from a nearby water-storage tank. The overflow water can leak into the aquifer in this area.

During Phase I of this study, the three major PAFB production wells (Haven, Smith, and Harrison wells) were pumped heavily, and samples were taken periodically for TCE analysis. During this testing, TCE, in relatively high concentrations, was found, at times, in both Smith and Harrison well samples. However, since that time, many samples from Smith well have shown only a trace or no TCE. The Harrison production well has not been in use, but sampling from Harrison 2 (about 220 feet northwest of the production well) shows no TCE in the ground water (table 6). Thus, at present (1978), the ground water around both Smith and Harrison wells is not contaminated with TCE.

CONCLUSIONS

The highest known concentrations of TCE in ground water are in the vicinity of the Haven well. The TCE-contaminated ground water probably originated from sources upgradient (north) of the Haven well. Some TCE-contaminated ground water has been recirculated by the pumping from Haven well and the discharging of some of the water, after use, into storm drains that pass through the area of influence of the Haven well. It is not known exactly where nor when TCE entered the aquifer nor is it known yet (1978) whether there is any long-term upward or downward trend in TCE concentrations.

Water-Use Alternatives

To alleviate (or eliminate) the use of the contaminated Haven well ground water, three alternatives are presented.

A) Abandon the Haven well supply and drill other wells on the air base. The disadvantages are that (1) wells having large yields that are not contaminated are already in use (Smith and Harrison wells area), (2) new ground-water development in the southern part of the base between the Smith well and the spring area (fig. 1) might interfere with off-base water supplies, (3) developing water in the noncontaminated but low yielding northern part of the main aquifer would require drilling many wells spaced some distance apart (some penetrating bedrock perhaps) to equal the Haven well yield, and (4) stopping the pumping of the Haven well might allow the contaminated water in the Haven area to move downgradient and contaminate the aquifer at the Smith and (or) Harrison wells as well as wells off base to the south.

Table 8.-- Total monthly water use, June 1977 through April 1978

(Values are given in thousands of gallons.)

Date	Total	Pease Air Force Base wells	Purchased water
6-77	--	--	1,277
7-77	--	--	17,011
8-77	38,561	31,740	6,821
9-77	29,220	23,763	5,457
10-77	30,789	23,005	7,784
11-77	31,291	27,232	4,059
12-77	37,194	34,697	2,497
1-78	40,227	35,161	5,066
2-78	24,557	20,236	4,321
3-78	25,902	23,630	2,272
4-78	23,621	18,343	5,278

Table 9.-- Selected total daily pumpage for Haven well, 1977-78

(Values are given in thousands of gallons.)

	1977		1978	
Day	July	August	January	February
1	--	55	--	875
2	--	*1,064	506	--
3	--	*1,157	Daily average	259
4	--	*1,001	for all of	388
5	--	203	January: 826	186
6	--	243	--	200
7	--	284	--	316
8	--	401	--	--
9	--	319	--	--
10	--	317	--	--
11	--	344	Daily average	
12	--	239	for all of	
13	--	257	February: 307	
14	--	302	--	--
15	--	297	--	--
16	--	282	--	--
17	--	749	--	--
18	--	846	--	--
19	--	885	885	--
20	882	810	885	--
21	727	776	885	--
22	749	792	459	--
23	354	715	949	--
24	399	897	949	--
25	367	884	574	--
26	395	869	1,162	--
27	153	822	1,200	--
28	400	823	723	--
29	323	1,000	764	--
30	335	964	805	--
31	251	432	829	--

*Continous pumping for Phase I of this study.

B) Treat Haven well water to remove TCE and use it on the base indiscriminately without modification of the water-distribution system. A first advantage is that the present distribution system would not need to be altered. A second advantage is that if Haven well water is used heavily, TCE content will probably become more and more diluted. A possible disadvantage is that, in the event of a TCE-removal process breakdown, water might have to be impor ıed to meet base needs until TCE removal equipment was repaired.

C) Treat a part of the Haven well water for removal of TCE, so that by mixing it with Smith and Harrison well waters, enough water of satisfactory quality will be available for domestic uses on the base; use the remainder of Haven water for uses other than human consumption. The re-use of some Haven water would aid in TCE dilution in the long run.

Alternatives B and C have in common the advantage over A that they would probably prevent (or delay until greater dilution has occurred) possible movement of TCE-contaminated water downgradient toward the Smith and Harrison wells.

Other alternatives or variations of the above can no doubt be considered. From the previously discussed alternatives and interpretations in this report, however, it would seem wise to include in any plan the continuation of pumping at Haven, even if only as a safety measure to avoid the TCE contamination moving downgradient.

Continued Monitoring and Study of the TCE Contamination

Quarterly or even bimonthly TCE sampling at McIntyre ditch 1 is suggested for continuance of monitoring. If the gradual downward trend between December 1977 and the end of May 1978 (fig. 8) continues or is not reversed during the remainder of the 1978 summer and fall season, it would be an indication that TCE is probably becoming more dilute under present water-use practices. This might influence the nature of possible proposed alternative water- use plans. Care should be taken to avoid sampling during or immediately after heavy rains or periods of rapid snowmelt. Also, annual checks of the distribution of leaks into the drain would determine whether the ratio of uncontaminated to contaminated ground water flowing out at the separator had changed.

Periodic TCE sampling, quarterly or semi-annually, in the Haven cone of depression would supplement the Haven well TCE monitoring. One of the best sampling sites would be at the east end of the 108-inch storm drain at site DR 4, but site McIntyre 1 at the fuel separator could give a rough estimate. Continuation of periodic sampling of the Harrison and Smith wells would alert health department officials of TCE contamination at these wells, should it occur in the future. Other aids to help study and perhaps even pinpoint sources of TCE are:

1) Sample the unsaturated zone and install shallow wells to sample the saturated zone near Buildings 113, 229 and 244, as well as near other sites (fig. 4) where significant amounts of TCE may have infiltrated.
2) Sample and analyze for TCE precipitate (scum) and liquids from parts of the storm-drain system, especially the section extending northeastward from the east end of the 108-inch storm drain, that were not sampled during this study.

The purpose of these steps would be to help establish a pattern of when, how, and where TCE has moved through the main aquifer to the Haven cone of depression. Given this evidence, as well as data from continued detailed TCE monitoring in the cone of depression, future predictions of the dilution of the TCE ground-water contamination may be possible.

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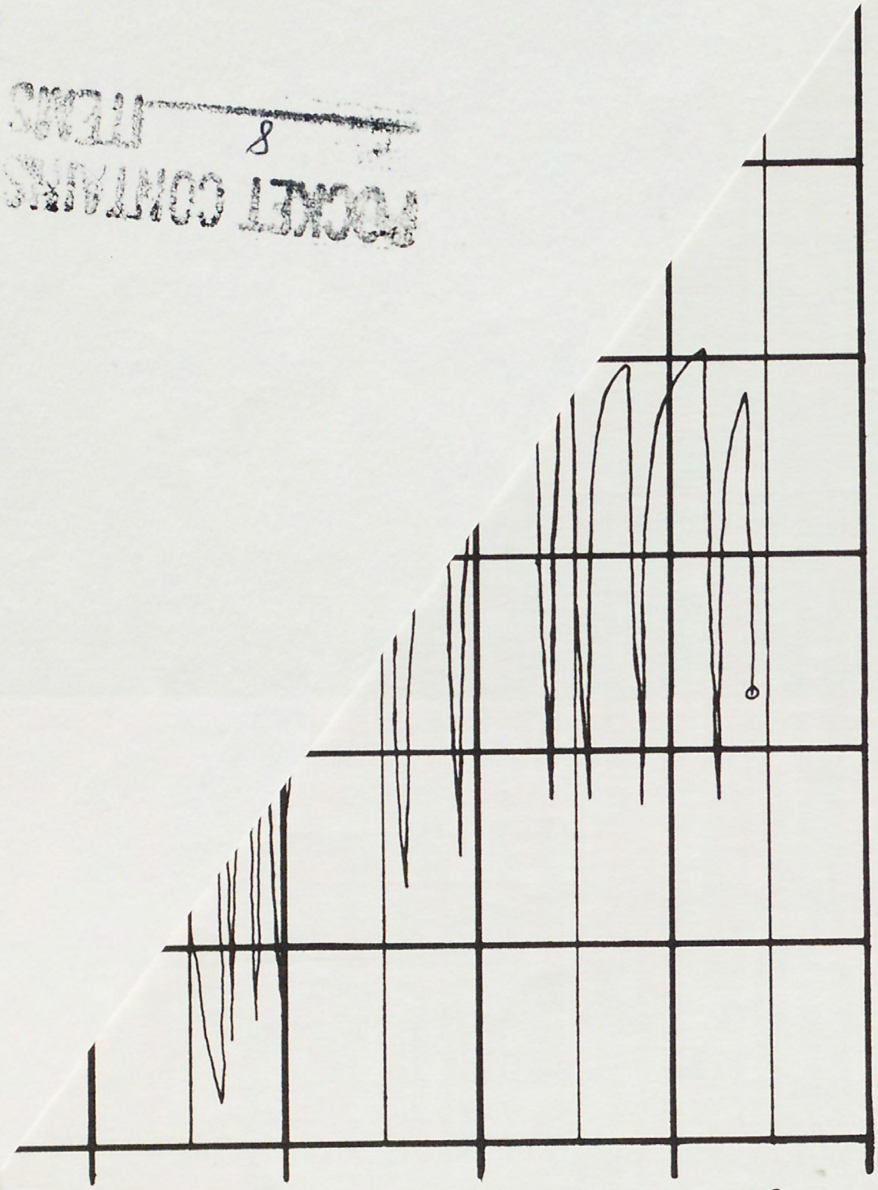
-NOTES-



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