GROUND-WATER CONTAMINATION IN EAST BAY TOWNSHIP, MICHIGAN

By F. R. Twenter, T. R. Cummings, and N. G. Grannemann

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DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
6520 Mercantile Way, Suite 5
Lansing, Michigan 48910

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

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 on 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.

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

Hydraulic conductance (L^2/t). Hydraulic conductivity multiplied by the area under consideration and divided by the length of the path through which water is flowing. It is the reciprocal of resistance to ground-water flow.

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.

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 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.

Steady-state ground-water flow. Indicates that, at any point in the flow field, the velocity and direction of ground-water flow is constant with time.

Strongly implicit procedure (SIP). A numerical iterative technique to approximate the solution of differential equations for which the exact solution is difficult or nonexistent.

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 the report can be converted to the metric system of units as follows:

Multiply inch-pound unit	By	To obtain metric unit
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.0386	liter per second per square kilometer [$(L/s)/km^2$]
degree Fahrenheit (°F)	(*)	degree Celsius (°C)

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

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ABSTRACT

Glacial deposits, as much as 360 feet thick, underlie the study area. The upper 29 to 118 feet, a sand and gravel unit, is the aquifer tapped for water by all wells in the area. This unit is underlain by impermeable clay that is at least 100 feet thick.

Ground-water flow is northeastward at an estimated rate of 3 to 6 feet per day. Hydraulic conductivities in the aquifer range from 85 to 150 feet per day; 120 feet per day provided the best match of field data in a ground-water flow model. The depth to water ranged from 1 to 20 feet.

Chemical anlayses indicate that ground water is contaminated with organic chemicals from near the Hangar/Administration building at the U.S. Coast Guard Air Station to East Bay, about 4,300 feet northeast. The plume, which follows ground-water flow lines, ranges from 180 to 400 feet wide. In the upper reach of the plume, hydrocarbons less dense than water occur at the surface of the water table; they move downward in the aquifer as they move toward East Bay. Maximum concentrations of the major organic compounds include: benzene, 3,390 micrograms per liter; toluene, 55,500 micrograms per liter; xylene, 3,900 micrograms per liter; tetrachloroethylene, 3,410 micrograms per liter; and bis (2-ethyl hexyl) phthalate, 2,100 micrograms per liter. Soils are generally free of these hydrocarbons; however, in the vicinity of past drum storage, aircraft maintenance operations, and fuel storage and dispensing, as much as 1,100 micrograms per kilogram of tetrachloroethylene and 1,500 micrograms per kilogram of bis (2-ethyl hexyl) phthalate were detected. At a few locations higher molecular weight hydrocarbons, characteristic of petroleum distillates, were found.

INTRODUCTION

The U.S. Geological Survey, at the request of the U.S. Coast Guard, began a study of geologic and hydrologic conditions in East Bay Township and adjacent areas in July 1982. The investigation was prompted by the suspicion that organic chemicals contaminating ground water north of the Coast Guard Air Station might have their origin on or in the vicinity of the station. Because preliminary data were inadequate to assess the extent of the problem, the Coast Guard requested that an investigation be undertaken to (1) determine the rate and direction of ground-water flow, (2) locate the source or sources of ground-water contaminants, (3) determine the extent and distribution of contaminants, and (4) evaluate hydrologically suitable locations for installing purge wells should that be necessary. This report describes the results of the investigation.

Description of Area

East Bay Township and the U.S. Coast Guard Air Station[1] are in Grand Traverse County in northwestern Lower Michigan (fig. 1). The station is an area of about 1,800 feet by 2,500 feet encompassing about 115 acres; its present boundaries are shown on plate 1.

The principal study area includes not only the Air Station but a slightly larger area to the northeast. This northeast area, about 1/2 mi^2 or 320 acres, is primarily residential and is bounded on the north by East Arm Grand Traverse Bay[2] (plate 1). It is mostly in East Bay Township.

The study area is southeast of, and adjacent to, Traverse City, which has a population of about 16,000 (U.S. Department of Commerce, 1982). The land surface at the Air Station is relatively flat, sloping gently to the northeast (fig. 2). North of the station, near East Bay, the land surface drops sharply from an altitude of 605 feet to 595 feet along on old beachline. From there, the surface slopes gently northward to East Bay. In July 1983, the water level in the Bay was 580.0 feet (U.S. Army Corps of Engineers, 1983).

South of the Air Station the land surface rises gently for about 2 miles until it reaches an altitude of about 700 feet (fig. 3). Farther south, 3 to 4 miles from the station, the surface rises sharply to an altitude of 900 feet.

Mitchell Creek drains the area to the south and east of the station. Much of its upper reach is swampy. Boardman River and Boardman Lake drain the area west of the station and flow to West Arm Grand Traverse Bay.

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[1] Referred to as "Air Station" or "station" in this report.

[2] Referred to as "East Bay" in this report.

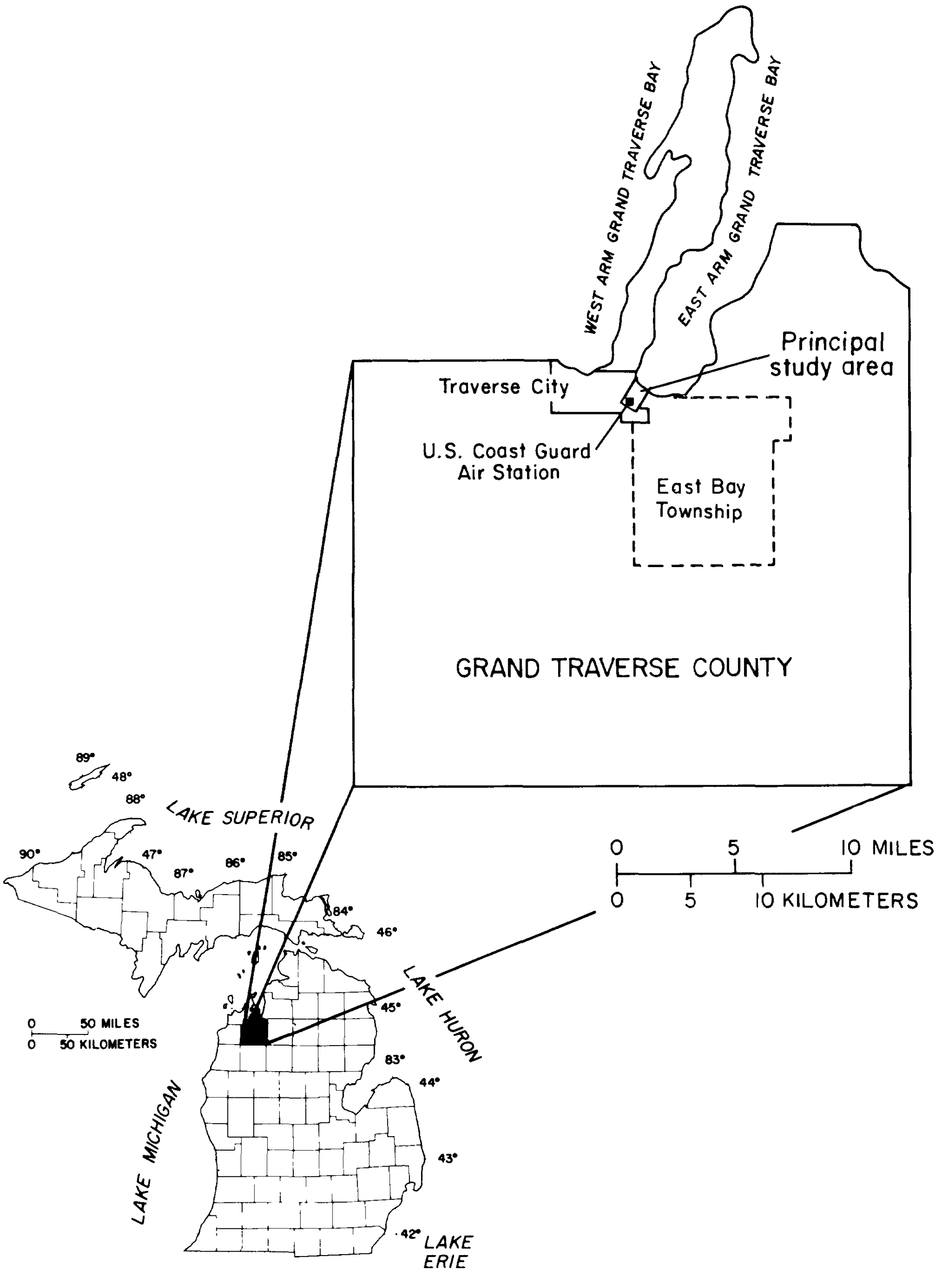
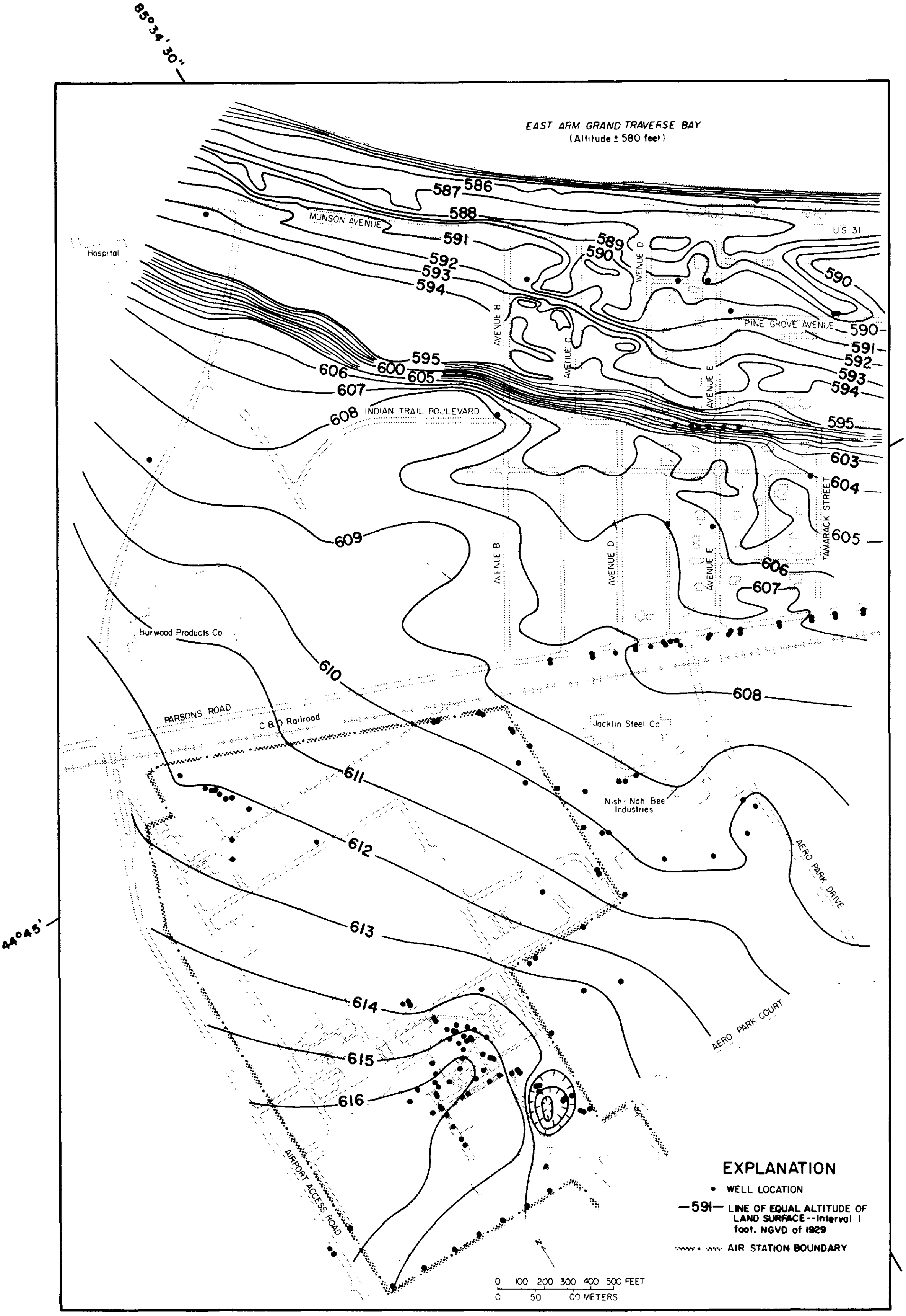
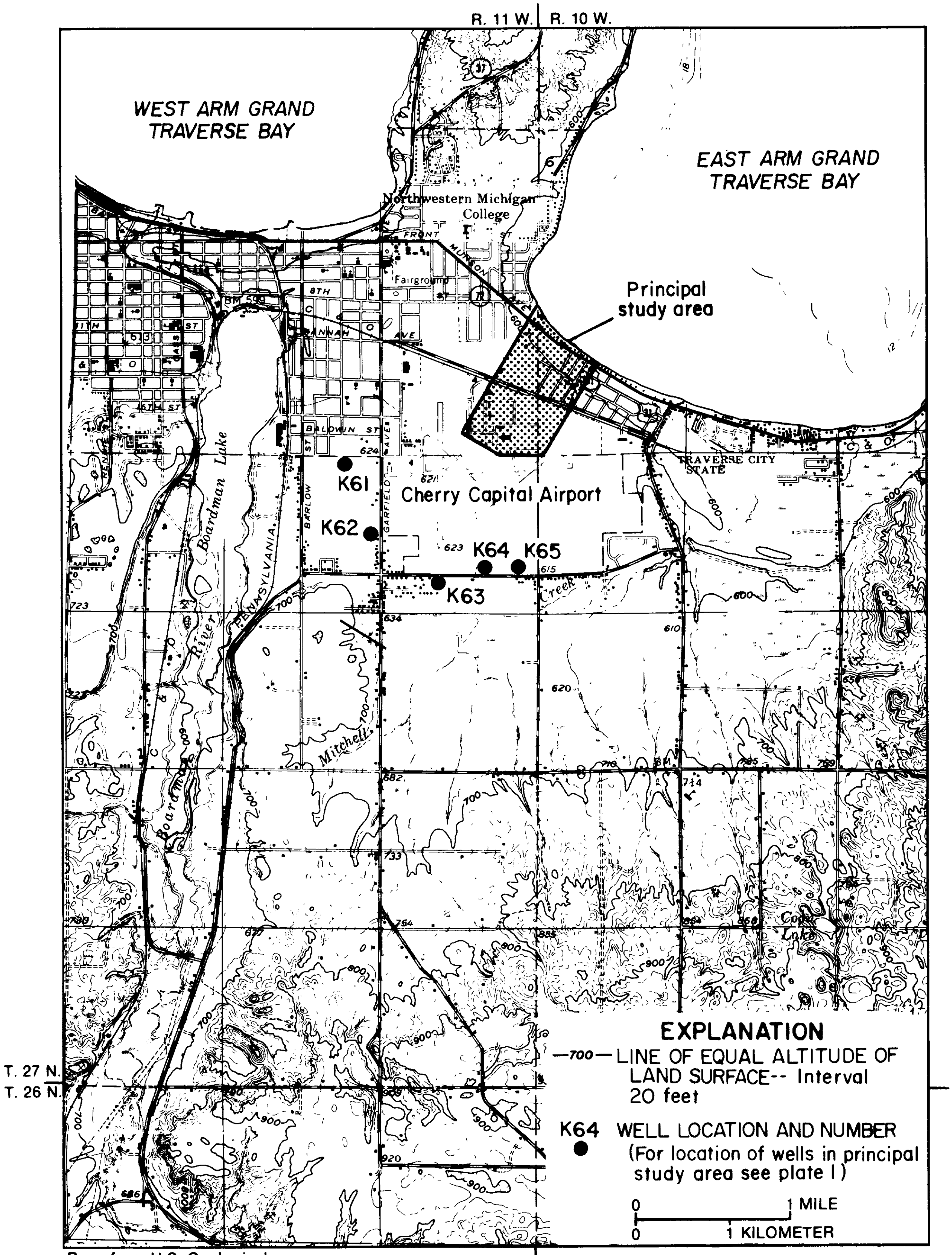


Figure 1.--Location of East Bay Township and U.S. Coast Air Station in Michigan.



Base adopted from U.S. Coast Guard map and maps by Gourdie-Fraser and Associates, Inc. Topography: north of Parsons Road from maps by Gourdie-Fraser and Associates, Inc.; south of Parsons Road based on altitude of land surface at wells and U.S Geological Survey topographic maps

Figure 2.--Configuration and altitude of land surface in study area.



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

Figure 3.--Physical setting and altitude of land surface in vicinity of study area.

Mean monthly temperatures range from 21°F in January to 69°F in July. The record low is -33°F; the record high is 105°F. Average annual precipitation is 30 inches. Potential pan evaporation is estimated to average about 28 inches (Michigan Department of Agriculture, 1971). Because of the cool temperatures in spring and early summer, the area is especially suited for the production of cherries and is the largest single cherry producing area in the world.

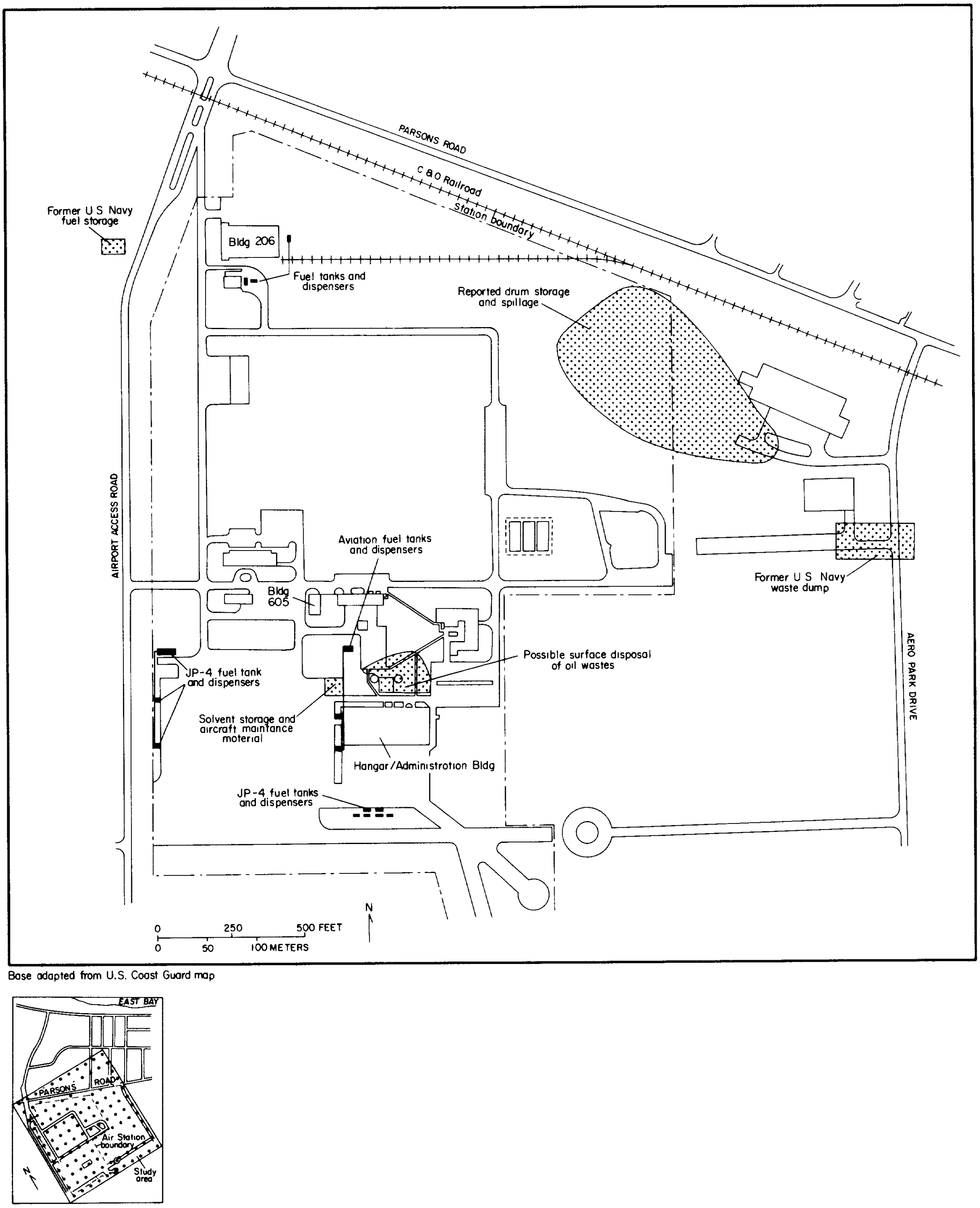
Nature and Scope of Problem

In 1980, residents along Avenue E in East Bay Township complained of odors and foaming of water withdrawn from domestic wells. Investigations by the Michigan Department of Public Health showed that several wells were contaminated with organic substances at levels that are believed to be harmful. A subsequent hydrogeological investigation by the Michigan Department of Natural Resources indicated that the origin of the chemicals was south of Parsons Road, in the vicinity of the U.S. Coast Guard Air Station, on land formerly owned and operated by the U.S. Navy. An old Navy waste dump, just to the east of current Coast Guard property, was strongly suspected to be a contributor to the problem.

Interviews conducted by the Michigan Department of Natural Resources solicited information from long-term residents of the area regarding past waste-disposal practices. Although some of the information was conflicting it nevertheless provided general guidance for an approach to the problem. The unpublished hydrogeological study of the Michigan Department of Natural Resources also provided valuable initial guidance. Information was also available in a U.S. Environmental Protection Agency photographic analysis of ground-water contamination in East Bay Township (Page, 1982). This study identified the location of the old Navy waste dump, and suggested other locations at which surface waste discharges may have occurred.

Lastly the U.S. Coast Guard searched old files and records, and assembled aerial photography of the Air Station from 1946 through 1982. Information on the past and present usage of fuel substances, primarily JP-4 fuel and aviation gasoline, were readily available from maps and current records. Locations of storage tanks, distribution lines, and dispensing units for these substances, as well as for motor and diesel fuel, were identified. The aerial photography, which showed areas where chemical substances had been used on the Air Station, was a principal basis for the initial, detailed design of this investigation.

Figure 4 shows the locations where release of contaminants to the environment was thought possible. Not all early speculative sites have been shown, particularly if information was imprecise or conflicting. In addition to possible fuel-related sources, prominent among possibilities were the old Navy waste dump, and the general area west and south of Jacklin Steel Company. Surface disposal of liquid organic chemicals was reported to have occurred in the northeast corner of Air Station property. Old aerial photographs showed a discolored area north of the current Hangar/Administration building which may have served, in part, as a waste oil pit. In an area near the northwest corner of the building



Base adapted from U.S. Coast Guard map

Figure 4.--Location of possible sources of ground-water contamination.

(now a rock garden), drums of solvents and other chemicals were stored. Aircraft maintenance was also conducted in this general area. Just north, paints were used in Building 605. West of Building 206 and west of Airport Access Road, fuel was once stored and dispensed by the Navy.

Chemicals and chemical compounds thought to have been stored and used at the Air Station were identified by the Coast Guard. Because a number of the compounds are commercial products, all components are difficult to identify. Most of the compounds fall into the broad categories of solvents and cleaning agents, paints and lacquers, paint removers or strippers, paint thinners, oils, and fuel substances.

Polyurethane, epoxy, and enamel paints, and lacquers contain a variety of chemicals depending on intended use and specific formulation. Toluene, benzene, and xylene are common ingredients, as are ketones, alcohols, ethers, esters, acetates, and metal chromates. Paint removers or strippers contain many of the same compounds, and frequently dichloromethane. Paint thinners have various compositions, ranging from those whose principal component is toluene to those that are complex mixtures of toluene, xylene, benzene, alcohols, ethers, ketones, and acetates. Primers used at the station are known to contain xylene, chromates, napthenates, and alkyl resins.

Solvents, degreasers, and cleaning compounds used at the Air Station contain many of the same chemicals contained in paints and related compounds. In a pure form, toluene, tetrachloroethylene, methyl ethyl ketone, trichloroethane, xylene, trichlorotrifluoroethane, as well as freon of unknown composition, have been used. Naptha, which contained benzene, toluene, and xylene, has also been used as a solvent. When naptha is distilled from coal-tar for use as a solvent, phenols are a likely component. Stoddard solvent, a petroleum distillate containing paraffinic and aromatic hydrocarbons, has also been stored and used. The composition of a cleaning compound for aircraft surfaces is unknown.

Adhesives, which contain toluene, xylene, benzene, naptha, and ketones, have been used, as well as lube and hydraulic oils, and linseed oil.

METHODS OF DATA COLLECTION AND ANALYSIS

The U.S. Geological Survey began collecting data in August 1982 by installing wells on U.S. Coast Guard property near the Hangar/Administration building, along Parsons Road, and at a few other locations to guide selection of future drilling. During the project additional wells were drilled surrounding the Air Station and at sites extending to East Bay. One hundred and thirty-eight wells were installed (pl. 1 and fig. 3). Eighty-four 4-inch diameter wells were installed to obtain geologic and lithologic data, and for water level measurements and the collection of water-quality samples. One 6-inch diameter well (KT) was installed in the northwest corner of the station for a pumping test. An additional forty-nine 2-inch wells ("S" wells and wells K39WT, K50.5, K61-K65, AH1, and AH2) were hand augered just to the water table to obtain water-quality samples, to obtain soil samples, or to measure water-levels for model development. Wells KT1-KT4, also 2-inches in diameter, were hand augered for the pumping test. Data for all wells is shown in tables 1, 2, 3, and 4.

At 38 sites, both deep[1] and shallow 4-inch wells were installed to detect vertical stratification of contaminants. In shallow wells, screens were set 17-30 feet below land surface, depending on location. The screen of well K48S was set 3 to 7 feet below the land surface, however. Deep wells were either drilled to the clay surface, or to a lesser depth, if it seemed more appropriate. During the drilling of 13 wells, multiple screens were set at 3 or 4 depths and water-quality samples collected prior to finishing the well. During drilling of many wells, lithologic logs were kept, and samples of materials collected. Water levels were measured on a monthly basis, and continuous water level recorders were installed at two locations. Discharge of Mitchell Creek was measured at three locations to aid in the development of the ground-water flow model.

Samples of water for chemical analysis were collected from 153 wells or zones within a well and at 9 locations in East Bay. In addition, water from 17 domestic wells ("E" and "M" wells) and state-drilled wells ("EB" wells) was analyzed.

Submersible pumps were used to collect samples from wells drilled by the Geological Survey and the State of Michigan. The order in which wells were sampled was chosen so that teams of samplers moved from wells of lower concentration to those known to have, 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 collecting a sample. At least two samples were collected from each well in order that duplicate analyses could be made if needed. In areas of significant contamination, water pumped from a well was passed through a carbon filtration system to prevent contaminants from being discharged on the land surface. 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 (Wershaw and others, 1983).

Data collected during the investigation, as well as information from other sources, were evaluated to determine the geologic and hydrologic conditions at the Air Station and to define the location, concentration, and movement of contaminants. A hydraulic model of the ground-water system was developed to better understand and predict ground-water flow.

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[1] Deep and shallow wells are designated in the report by "D" or "S" following the well number. At locations where multiple zones were sampled, the depth of the top of the screen has been incorporated in the well number.

The model was calibrated by duplicating water levels measured in the field. After calibration it was used to simulate hydrologic responses to past pumping activity and to simulate future responses to a variety of purge pumping conditions.

All water-quality data and summaries and representative examples of some of the geologic and hydrologic data collected by the Geological Survey are included in this report.

GEOLOGY

The U.S. Coast Guard Air Station and vicinity are underlain by thick glacial deposits. No wells are known to have penetrated the full thickness of the deposits in the study area. However, 1 mile northwest of the study area at Northwestern Michigan College, a 519-foot deep well penetrated bedrock (Antrim Shale) at 360 feet. The upper parts of the glacial deposits are of lacustrine origin. At depth, however, they may interfinger with materials of different origin. For this report, all materials underlying the study area are designated as lacustrine. An east-west line along the southern edge of the Cherry Capitol Airport marks the southern extension of the lacustrine deposits (fig. 3).

The low-lying area just south of Cherry Capitol Airport and along Boardman River is underlain by outwash (Martin, 1936). The 700-foot contour on figure 3 defines the southern extent of the outwash. Farther to the south, east, and west beyond the outwash are rolling hills formed by till of an end moraine. These hills rise 200 feet above the outwash plain. Kettles, some of which contain lakes, are numerous in the hilly area (fig. 3).

Lacustrine Glacial Deposits

Lacustrine glacial deposits consist of two units--an upper sand and gravel unit and an underlying clay unit.

Sand and Gravel Unit

The sand and gravel unit is mostly sand or a mixture of sand and gravel containing some silt and clay at places. It is commonly tan above the water table and gray to dark gray below. The sand is mostly fine to coarse or very-coarse grained, subrounded to rounded, clear quartz. Most gravel pebbles are 1 inch or less in diameter; however, pebbles from 1 to 2 inches are not uncommon and a few pebbles 2.5 to 4 inches are found. Composition of the gravel varies. Some beds are rich in igneous and metamorphic rocks, others are primarily sedimentary. Most larger pebbles are limestone or dolomite. A few fragments of black carbonaceous shale occur in most samples.

The upper 15 to 20 feet of this unit, the zone in which the water table occurs, is generally fine to medium grained sand. Below this, gravel and coarse to very coarse sand are more abundant. This is fairly common in the glacial deposits throughout the study area and may mark the top of a zone where outwash interfingers with lacustrine deposits. Horizontal definition of grain size or composition is not evident.

Based on wells installed for this study, the thickness of the sand and gravel ranges from 29 to 118 feet (table 1). Five test holes at the hospital in the northwest corner of the study area indicated the thickness of the unit to range from 22 to 33 feet (Gosling Czubak Associates, written communication, 1982). At Burwood Products Company just north of the Air Station the unit was about 35 feet thick (Fishback and others, 1980). The sand and gravel unit is thickest along the northeast part of the study area. Representative lithologic data are as follows:

Well no.	Lithologic description	Depth to bottom below land surface (feet)
K5D	Sand and gravel unit	
	Sand, medium to coarse, mostly clear quartz, few pebbles	19
	Sand, medium to very coarse, mostly clear quartz; some gravel, pebbles to ¼ inch	29
	Sand and gravel. Sand is medium to very coarse, mostly clear quartz. Pebbles to 1 inch and of variable composition; few clay balls at 35 feet	46
	Clay unit	
	Clay, gray to bluish gray	59
K9D	Sand and gravel unit	
	Sand, medium to coarse, mostly clear quartz, few pebbles to ¼ inch	20
	Sand and gravel. Sand is medium to very coarse, mostly clear quartz. Pebbles to 1 inch, few pebbles to 2 inches, varied composition	28
	Gravel, some sand. Most pebbles ¼ to 1 inch. Sand is coarse to very coarse, mostly clear quartz	30
	Sand and gravel. Sand is medium to very coarse, mostly clear quartz. Pebbles 1/8 to 1 inch	37
	Clay unit	
	Clay, gray to bluish gray, pure	50
K11D	Sand and gravel unit	
	Sand, fine to medium	10
	Sand, fine to medium; some gravel, pebbles to 3/4 inch	25
	Sand, medium to coarse; some gravel, mostly pea size, some pebbles to 1 inch	33

Well no.	Lithologic description	Depth to bottom below land surface (feet)
K11D (cont.)	Clay unit	
	Clay, gray	35
K18D	Sand and gravel unit	
	Sand, fine to medium, mostly clear quartz	20
	Sand, fine to coarse, mostly clear quartz; some gravel, pebbles ¼ to ½ inch	35
	Sand, medium to very coarse, mostly clear quartz; some gravel, pebbles to 1½ inches	50
	Sand and gravel. Sand is coarse to very coarse, mostly clear quartz; pebbles mostly ¼ to 3/4 inch, few to 2 inches	67
K29D	Sand and gravel unit	
	Sand, fine, mostly quartz	10
	Sand, fine to very coarse, mostly quartz; some gravel, pebbles to 3/4 inch	32
	Sand and gravel. Sand is fine to very coarse, pebbles to 2.5 inches	55
	Sand, fine to medium	64
	Silt and sand	66
	Sand, fine to very coarse; some gravel, pebbles to 2 inches. Thin (4 to 6 inches) clay layer and some clay mixed with silt and sand	80
	Sand, silt, and clay. Sand is very fine to fine	85
	Sand, fine to very coarse; some gravel, pebbles to 1.5 inches	90
	Clay, dark gray; some sand, very fine	93
	Sand, fine to medium	100
	Sand, medium to very coarse; some gravel, pebbles to 2.5 inches	110
	Clay unit	
	Clay, dark; some sand and silt	117

Clay Unit

The clay unit underlying the sand and gravel unit is gray to bluish gray and relatively impermeable. Its thickness in the study area is not known because it has never been fully penetrated. Wells K5D and K9D penetrated only about 12 feet of the unit; well K29D penetrated 6 feet. At Northwestern Michigan college, 1 mile northwest of the study area, the unit is 335 feet thick. About 1 mile to the southeast of the Air Station the unit is reported to be at least 225 feet thick. From this and other well data, the thickness of the clay unit is estimated to be at least 200 feet on the west side of the study area and 100 feet on the east. The altitude of the clay surface ranges from 575 to 585 feet along the west side of the area to 480 feet on the east (fig. 5). The upper surface of the clay unit slopes to the east at 45 ft/mi in the western part of the study area and slopes to the southeast at 500 ft/mi in the eastern part. As discussed below, the clay unit and the slope of its surface are significant to ground-water flow.

HYDROLOGY

Water Table and Ground-Water Flow

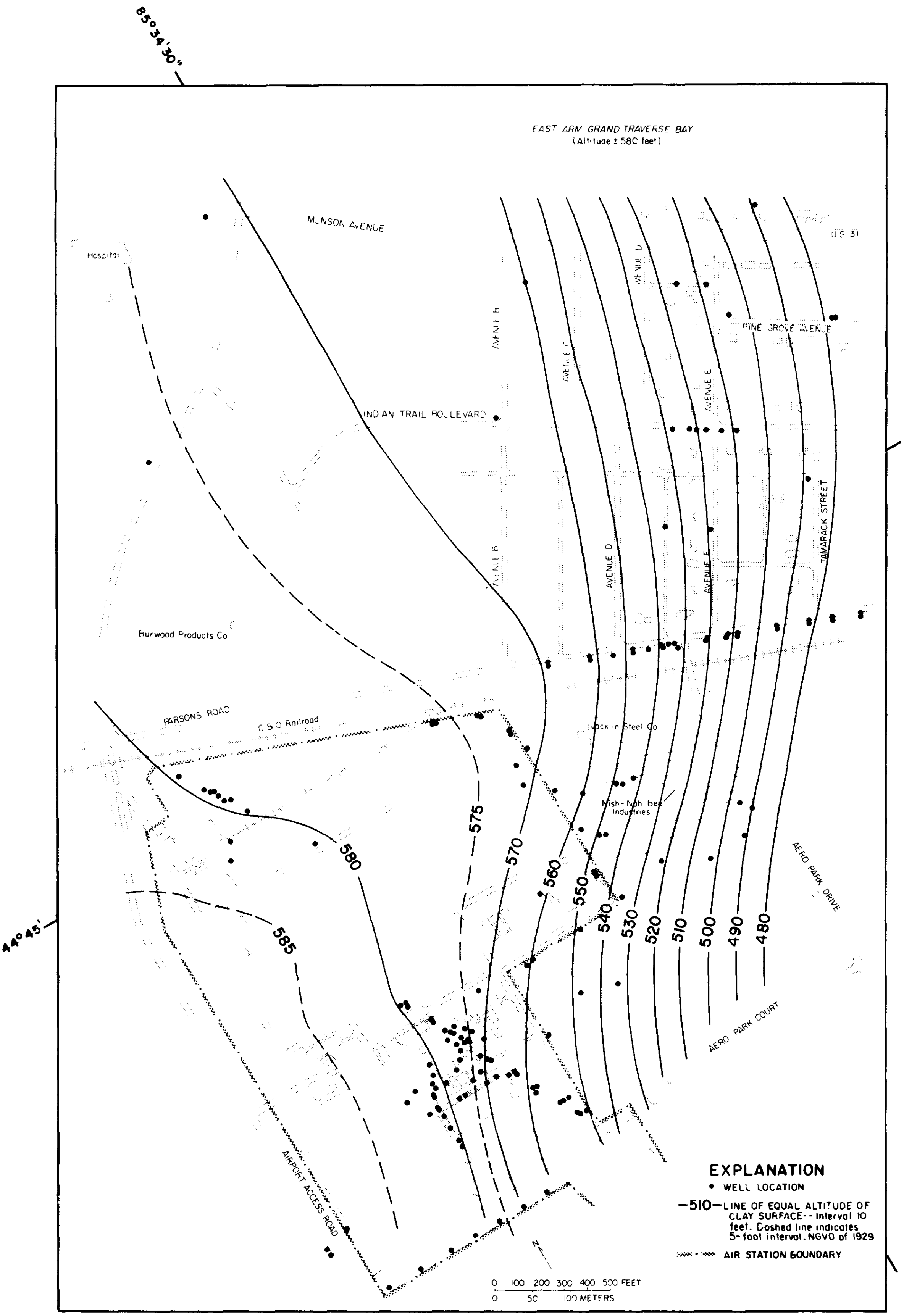
The general direction of horizontal ground-water flow is shown on figure 6. A major ground-water divide separates flow in Mitchell Creek basin from that in Boardman River basin. The location of the divide in the south and southwest part of the area is assumed to be along the topographic divide. From South Airport Road north the divide follows the crest of the underlying clay surface.

The altitude and configuration of the water table of the aquifer is a major factor in determining ground-water flow and, thus, indirectly, the movement of contaminants. Changes in the water-table altitude reflect changes in ground-water storage. The amount of water in storage, in turn, is controlled by differences in hydraulic properties of the aquifer and by recharge to, and discharge from, the aquifer.

The clay unit is an effective barrier to the vertical movement of water and its sloping surface seems to change the direction of ground-water flow. Water mounds on the clay where the depth to the clay surface is shallowest. Under this condition, one that may be common during periods of recharge, the direction of flow is diverted slightly eastward. This change in flow causes the west boundary of the major contaminant plume in the vicinity of Parsons Road to shift eastward reducing the width of the plume.

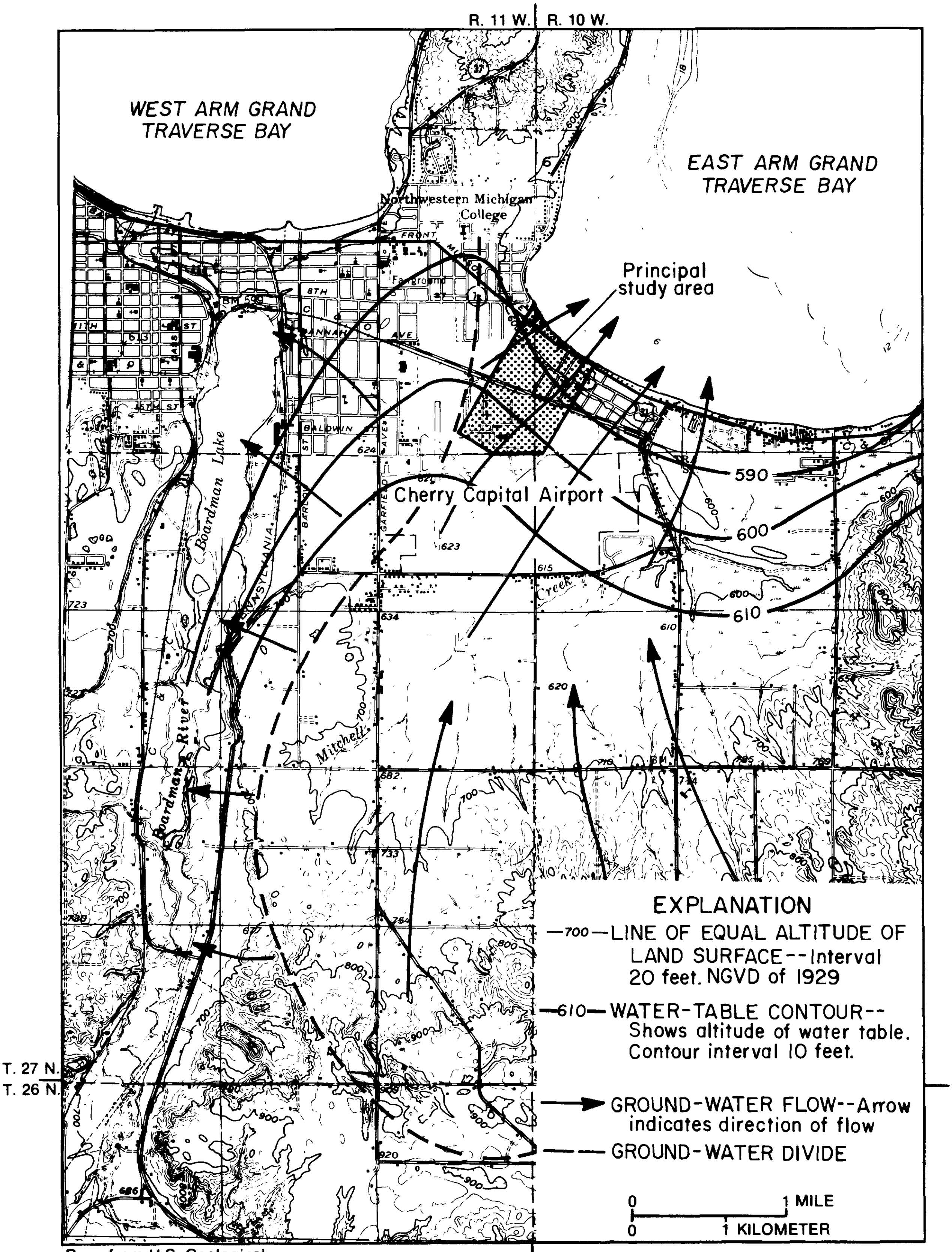
Water-level fluctuations in wells away from East Bay are typical of those of shallow unconfined aquifers in Michigan composed of coarse-grained materials. Levels are low in late fall or winter. They respond quickly to recharge, and, by late spring, after recharge has been augumented by water from snowmelt, levels are high. A typical example of water-level fluctuations is the hydrograph of well K4S (fig. 7). The change in water level in this well was 2 feet from November 1982 to July 1983.

Water levels in wells near East Bay fluctuate and respond to water level changes of the bay. The changes in levels shown by the hydrograph for well K48S (fig. 8) are typical. Water levels in this well changed about 1 foot during the period of record, which is similar to the change in the level of the bay. Many minor fluctuations in water levels occur in this well. Because there is no nearby pumping and because no other causes can be found for these minor water-level fluctuations, it seems probable that they result either from effects of tidal loading or from the mounding of bay water by wind along the beach.



Base adapted from U.S. Coast Guard map and maps by Gourdie-Fraser and Associates, Inc.

Figure 5.--Configuration and altitude of clay surface.



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

Figure 6.--General direction of ground-water flow.

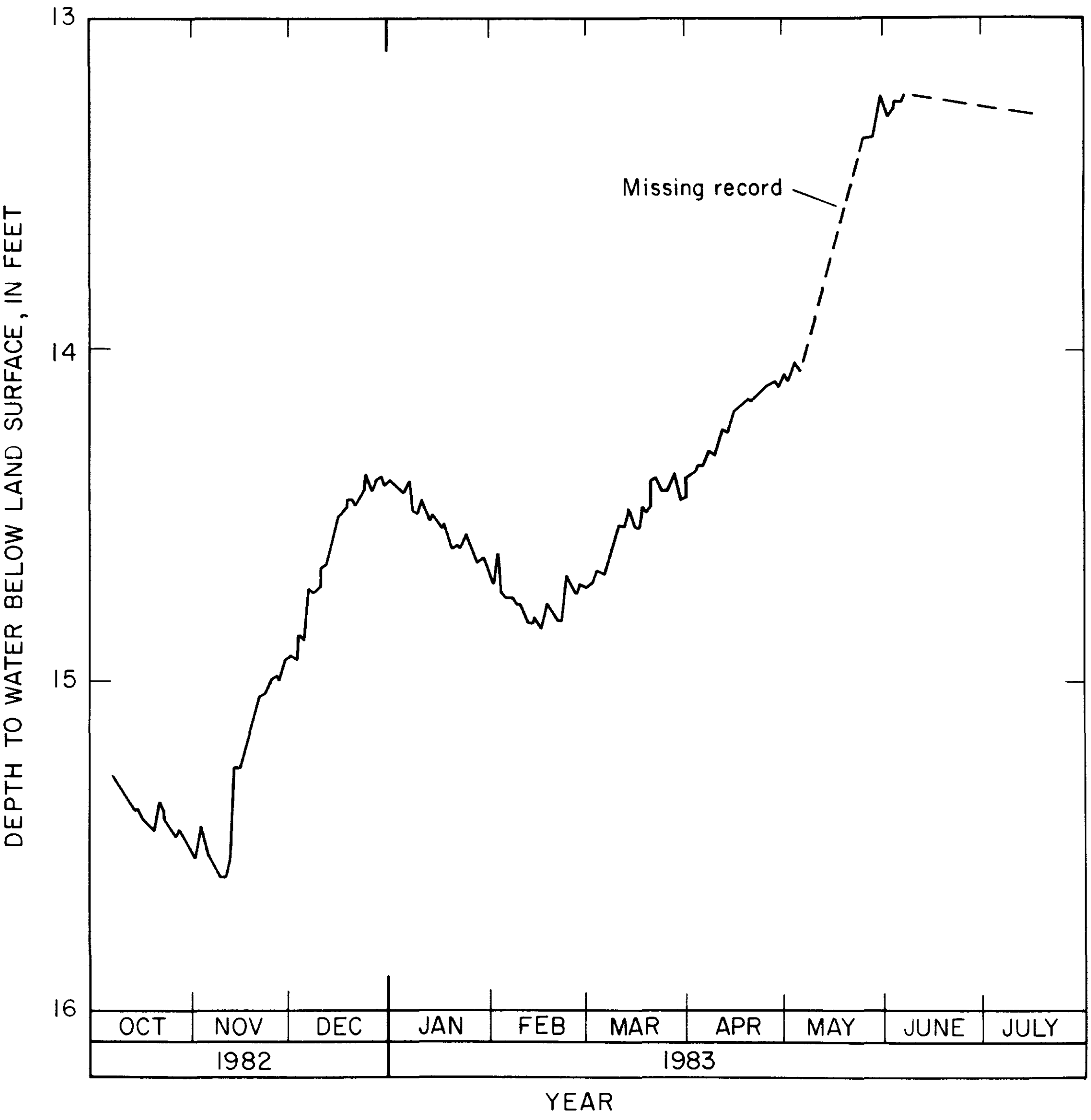


Figure 7.--Rise in water level in well K4S resulting from increased recharge.

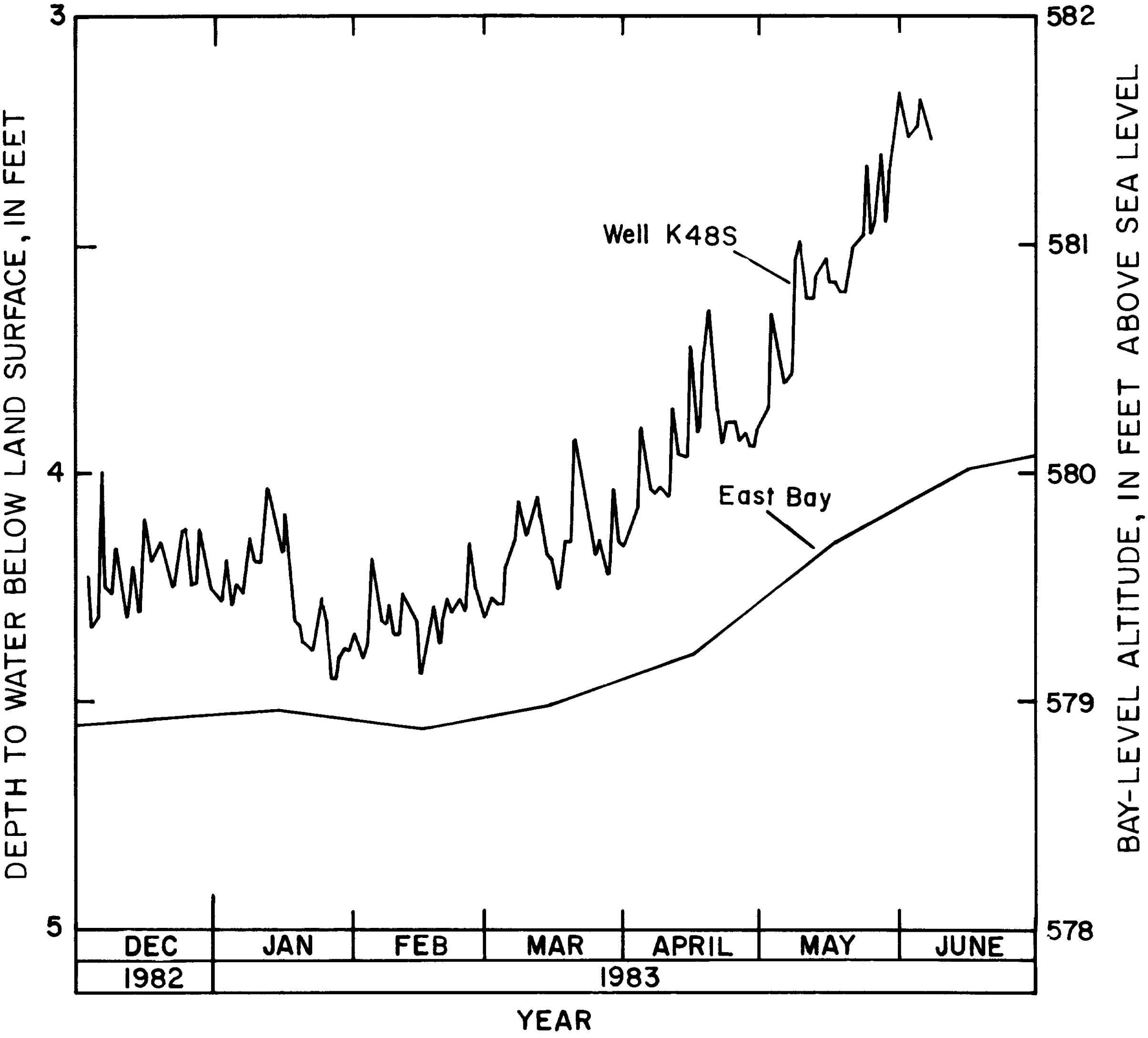


Figure 8.--Fluctuating water level in well K48S near East Bay.

A comparison of water-level data for April and July 1983, indicates that water levels in July were higher than those in April by about 1 foot in the vicinity of the clay crest and 0.4 to 0.7 feet away from the crest. Although the water-table maps for the two periods (figs. 9 and 10) do not differ appreciably, they do suggest that direction of the ground-water flow shifts slightly by about 150 feet downgradient from the Air Station, depending on recharge conditions. It is possible that an even greater shift would be recorded during a longer period. This would, of course, cause the position of the plume to shift from time-to-time.

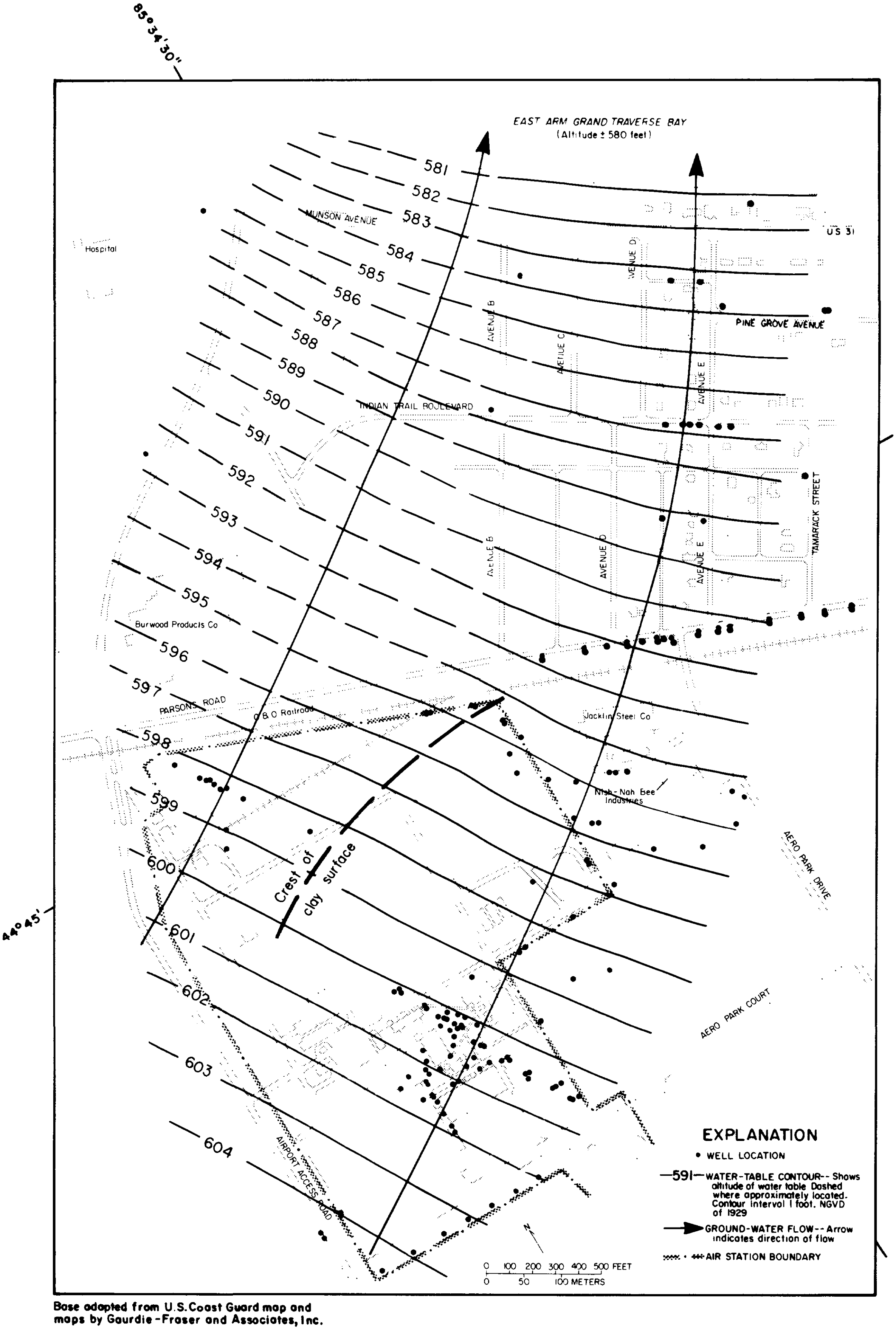
Initial estimates of hydraulic conductivity, transmissivity, and specific yield of the aquifer were based on pumping tests by the Geological Survey. For one pumping test a 6-inch well, KT, was installed. It was near the 4-inch wells K10S, K11D, K11S, and K12S. Four 2-inch observation wells were also installed for the test (fig. 11). Well KT was screened from 26 to 31 feet; the bottom of the screen was at the bottom of the aquifer. Well KT was pumped for 9 hours at a rate of 40 gal/min. Results of the test indicate that transmissivity of the aquifer ranges from 1,800 to 2,600 ft^2/d, and that hydraulic conductivity ranges from 100 to 150 ft/d. Specific yield ranged from 0.02 to 0.08. One-hour pumping tests of two other wells, K4D and K18D, indicated hydraulic conductivities of 85 and 150 ft/d, respectively.

Model simulations (discussed in a later section of this report) were used to refine estimates of average hydraulic conductivity of the sand and gravel aquifer. Simulations most accurately matched measured water-level data when values of hydraulic conductivity used in the model were 120 ft/d. This value is consistent with published values of hydraulic conductivity for sand and gravel (U.S. Bureau of Reclamation, 1977), and with values for similar materials in other areas in Michigan (McDonald, 1980; Stark and others, 1983).

Velocity of Ground-Water Flow

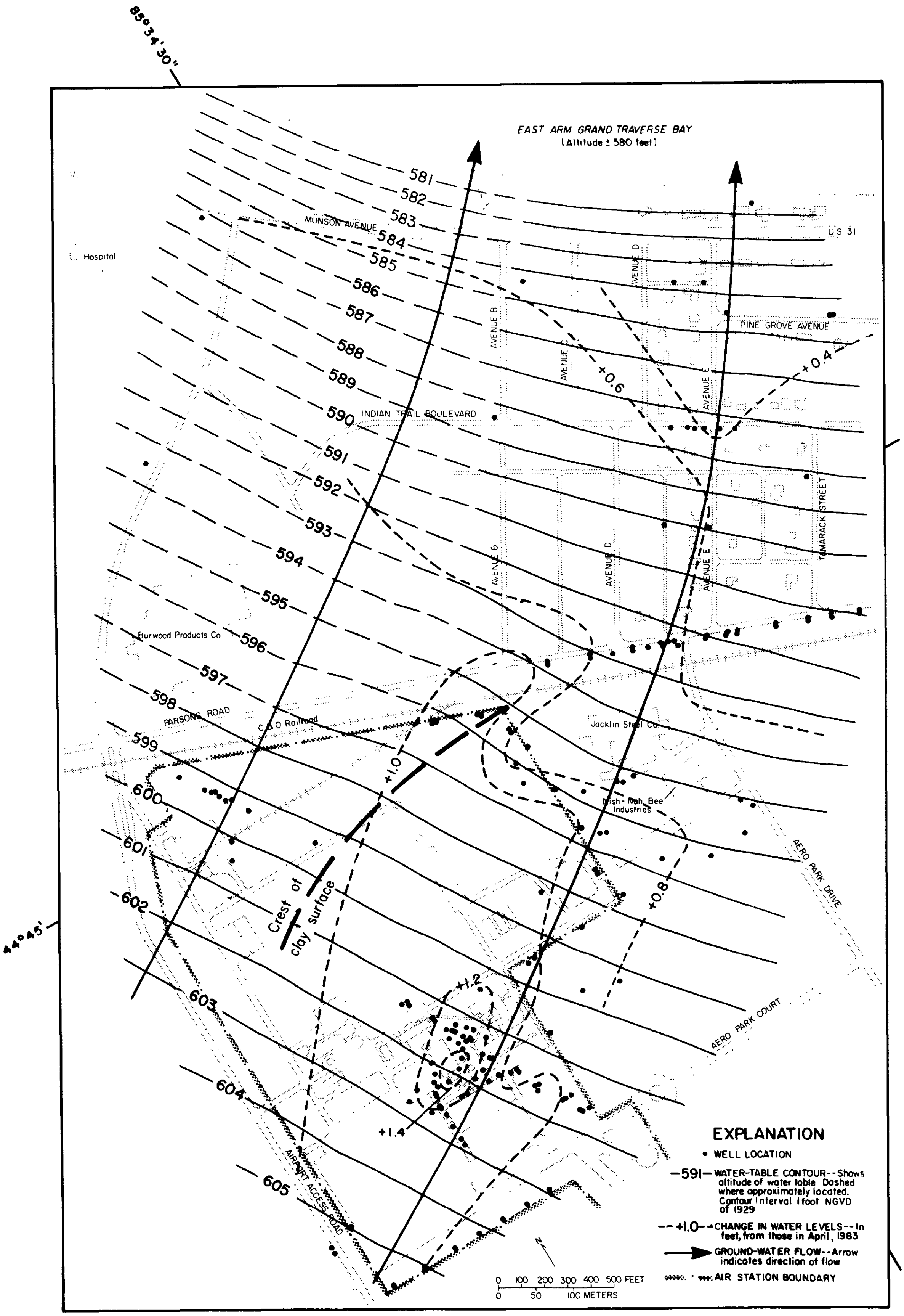
Average horizontal ground-water velocities are proportional to the hydraulic conductivity of the aquifer and the gradient of the water table and inversely proportional to porosity. On the basis of a hydraulic conductivity of 120 ft/d, gradients ranging from 0.004 to 0.007, and effective porosity of 0.15, velocities range from 3 to 6 ft/d. An independent evaluation, in which salt solutions were injected into the aquifer at two levels, one just below the water table and another about 10 feet below the water surface, suggested a velocity of 4 to 5 ft/d.

Attempts were made to determine the characteristics of vertical movement of water in the aquifer by use of paired observation wells. These wells consisted of a shallow well having a screen set about 10 feet below the water table and a deep well having a screen set near the base of the aquifer or at a depth of 40 to 50 feet below the water table. The vertical distance separating screens in individual pairs of wells ranged from 7 to 30 feet. Differences in the altitude of the water table in individual pairs of wells in the deeper of the paired wells was, depending on location, either slightly more or less than that



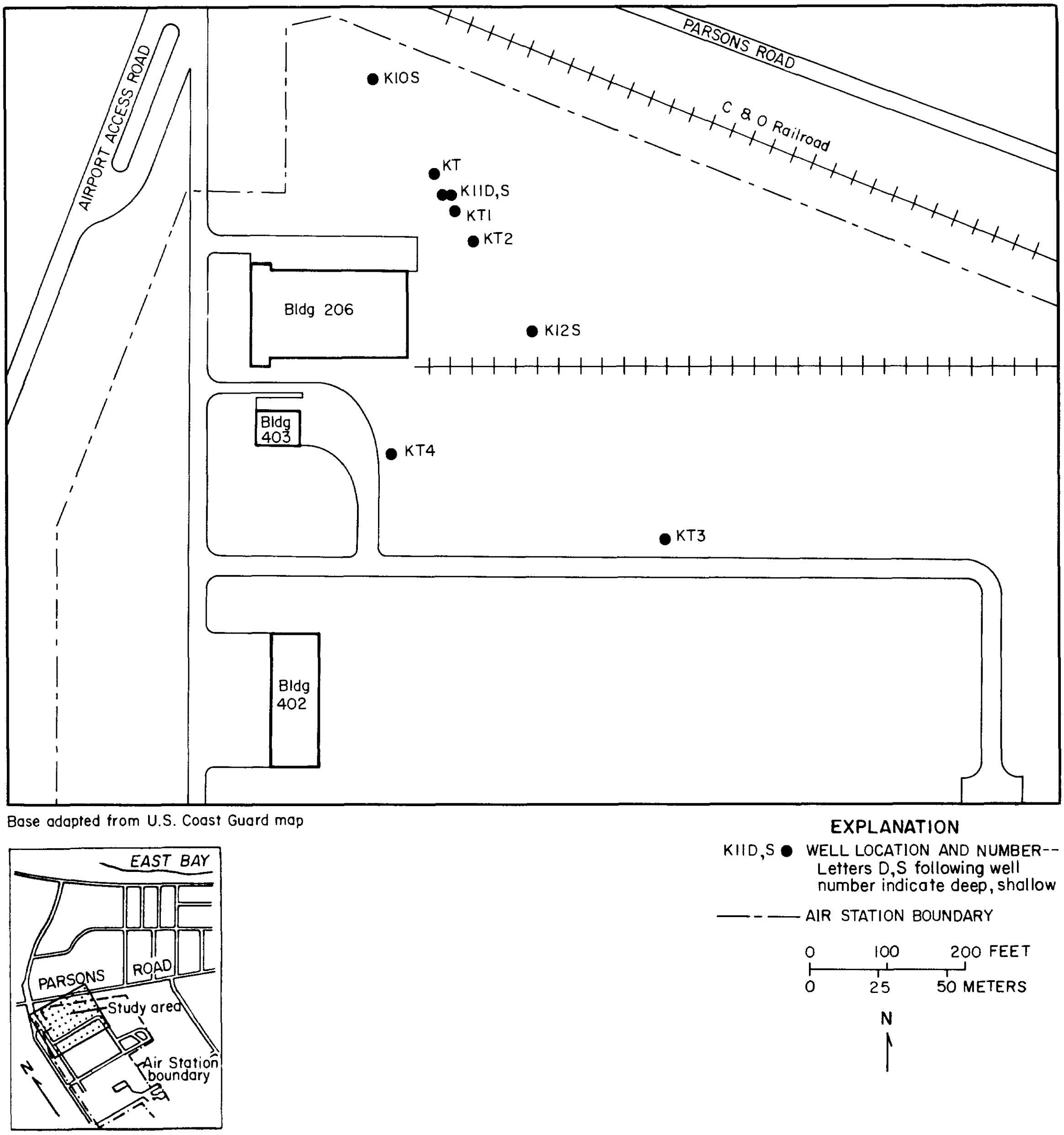
Base adapted from U.S.Coast Guard map and maps by Gourdie-Fraser and Associates, Inc.

Figure 9.--Water table and direction of ground-water flow on April 5-7, 1983.



Base adapted from U.S. Coast Guard map and maps by Gourdie-Fraser and Associates, Inc.

Figure 10.--Water table and direction of ground-water flow on July 19-20, 1983.



Base adapted from U.S. Coast Guard map

Figure 11.--Location of wells used for pumping test of well KT.

in the shallow well, but never exceeded 0.02 feet. Although these differences are within expected measurement error, some of the differences may indicate potential for vertical movement.

CONTAMINATION OF GROUND WATER

Nature and Significance of Organic Contaminants in Ground Water

Analyses of ground water in East Bay Township and adjacent areas are given in tables 2 and 4. Some of the major chemicals identified in the water include: benzene, toluene, xylene, ethyl benzene, trichloroethylene, 1,2 dichloroethylene, tetrachloroethylene, 1,2 dichloroethane, 1,1,1 trichloroethane, carbon tetrachloride, dichloromethane, chloroform, bromodichloromethane, bromoform, phthalate esters, and phenol. In industrial products, these substances most commonly occur in solvents and cleaning agents, paints and paint strippers, lacquers, enamels, adhesives, plastics, pharmaceuticals, and fuels. Many are used in a wide variety of chemical syntheses. In a pure or nearly pure form, some find use for specialized purposes. Eighteen of the compounds identified are on the current (1983) U.S. Environmental Protection Agency's list of 126 priority pollutants. Table 5 gives the chemical and physical properties of some of the organic compounds detected in highest concentration. In general, the water solubilities and densities of chlorinated ethylenes and ethanes are higher than those of unsaturated ring compounds. Benzene's solubility, and tetrachloroethylene's solubility and density, make each exceptions, however.

Analyses of soils at the Air Station identified numerous other organic compounds, typical of those found in petroleum and coal-tar distillates. Many were saturated hydrocarbons, both ring and straight chain, that are commonly less mobile in the subsurface environment than the major chemicals cited above.

The U.S. Environmental Protection Agency has issued a series of ambient water-quality criteria documents which are amended from time-to-time as new information on the environmental significance of substances becomes available. These documents suggest guidelines, including numerical concentration criteria, for judging the suitability of water for use by aquatic life and by humans. The guidelines also include a risk analysis for known or suspected carcinogens. For example, a risk level of 10^{-5} is one at which continuous ingestion of the substance in drinking water would theoretically result in one additional cancer death per 100,000 (10^5) people. For noncarcinogenic but toxic compounds, EPA has also suggested criteria for a number of compounds found in water. Concentrations suggested are estimates of levels below which no adverse response in humans is expected.

With respect to some of the substances found in water during this investigation, recommendations of the U.S. Environmental Protection Agency (1980) are as follows:

Substance	Maximum recommended level	Risk level
Benzene	0 μg/L	6.6 μg/L
Toluene	14,300 μg/L	--
Ethyl benzene	1,400 μg/L	--
1,1,2-Trichloroethylene	0 μg/L	27 μg/L
1,2-Dichloroethylene	[a]	[a]
Carbon tetrachloride	0 μg/L	4.0 μg/L
Chloroform	0 μg/L	1.9 μg/L
1,2-Dichloroethane	0 μg/L	9.4 μg/L
1,1,1-Trichloroethane	18,400 μg/L	--
1,1,1,2-Tetrachloroethylene	0 μg/L	8 μg/L
Dichloromethane	0 μg/L	1.9 μg/L
Napthalene	[a]	[a]
Phenol	300 μg/L	--

Origin and Distribution of Contaminants

General Characteristics of Ground-Water Contamination

Plate 1 shows the area of ground-water contamination in East Bay Township and at the Air Station. The movement and direction of contaminants follow ground-water flow lines (figs. 9 and 10). Delineation of the plume, which is about 4,300 feet long, is based on the concentrations of benzene, toluene, and xylene--the substances occurring in highest concentration. The plume encompasses all organic substances detected in ground water, however, with the exceptions of those thought to have their origin at locations other than in the area of the Hangar/Administration building. Near Munson Avenue the plume is estimated to be 260 feet wide; whereas, upgradient near the Hangar/Administration building, the width of the plume at the water table is about 400 feet. Concentrations decrease as the water moves toward East Bay, and downgradient some compounds were not detected. Maximum concentrations in water of the plume were 3,390 μg/L benzene (well K34S), 55,500 μg/L toluene (well S8), and 3,900 μg/L xylene (well S14) (table 2). Maximum concentrations of other substances include 310 μg/L phenol (well K50D-33'), 420 μg/L trichloroethylene (well S17), 295 μg/L dichloroethylene (well K40D-37'), 3,410 μg/L tetrachloroethylene (well S32), 2,100 μg/L bis (2-ethyl hexyl) phthalate (well S35), 374 μg/L chloroform (well S5), and 1,000 μg/L bromoform (well S17). Benzene tends to be absent along the northern and western side of the plume throughout its length; chlorinated and brominated hydrocarbons, however, tend to be highest in that part of the plume. Xylene tends to be absent along the southern and eastern margin of the plume.

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[a] No criteria established.

Vertical Profile of Contamination

Figure 12 is a generalized vertical profile of contaminants in the aquifer from the western edge of the Air Station to East Bay. From near the southwestern side of the Hangar/Administration building to a point about 125 feet east of the tennis courts, contaminants are principally at the surface of the water table; just east of the Hangar/Administration building, they are thought to be vertically distributed to the clay surface. The zone of contamination dips downward, generally following the decrease in elevation of the land and clay surfaces. Concentrations are not vertically uniform, however; based on maximum concentrations, dip is about 6 to 8 feet per 1,000 feet as far as Pine Grove Avenue. Near Pine Grove Avenue downward movement ceases, and upward movement to East Bay begins.

Model simulations indicate that pumping 1,000 gal/min for a period of 2 months (April-May, 1980) for installation of a sewage lift station at the intersection of Avenue E and Pine Grove Avenue caused the water table to be lowered by as much as 17 feet in the vicinity of the pumping wells. This may have caused contaminants entering the ground-water system upgradient to move deeper in the aquifer than they otherwise would have, and caused the distribution of contaminants in the plume to be different than they otherwise might have been. Two-thousand feet from these pumped wells the water table was lowered as much as 2 feet.

Lateral and Vertical Distribution of Contaminants

A generalized cross section of the vertical distribution of toluene, the substance in highest concentration, is shown in figure 13. Benzene, xylene, and other contaminants, in lesser concentration, are also within toluene distribution. The cross section of figure 13 extends from well S31 to well S23, a distance of 516 feet, and incorporates an area not considered part of the major plume. Highest concentrations at a site occur just at the water table. Detection of contaminants at the water surface extends over a much wider cross-sectional distance than either upgradient near the apparent origin of the plume, or downgradient where the plume is as little as 180 feet wide.

Toluene in water from well S23 (127 μg/L), at the surface of the water table, may not be part of the main body of the plume (fig. 13 and plate 1). Adjacent wells K2S and K2D, with screen settings of 7 to 11 feet and 37 to 41 feet below the water table, did not contain contaminants. Toluene in water of S23 may result from incidental spillage near the JP-4 fuel tanks and dispensers south of the Hangar/Administration building (fig. 4), which are upgradient along ground water flow lines from well S23.

Another possibility is that contaminants from a source adjacent to or just north of the Hangar/Administration building have moved laterally at the water surface to the southeast. Toluene, as do benzene and xylene, has a density less than that of water, and tends to "float" on the water surface until natural dispersion, recharge, and vertical ground-water flow causes movement to deeper parts of the aquifer. Lateral movement, if it occurs, could be related to variations in

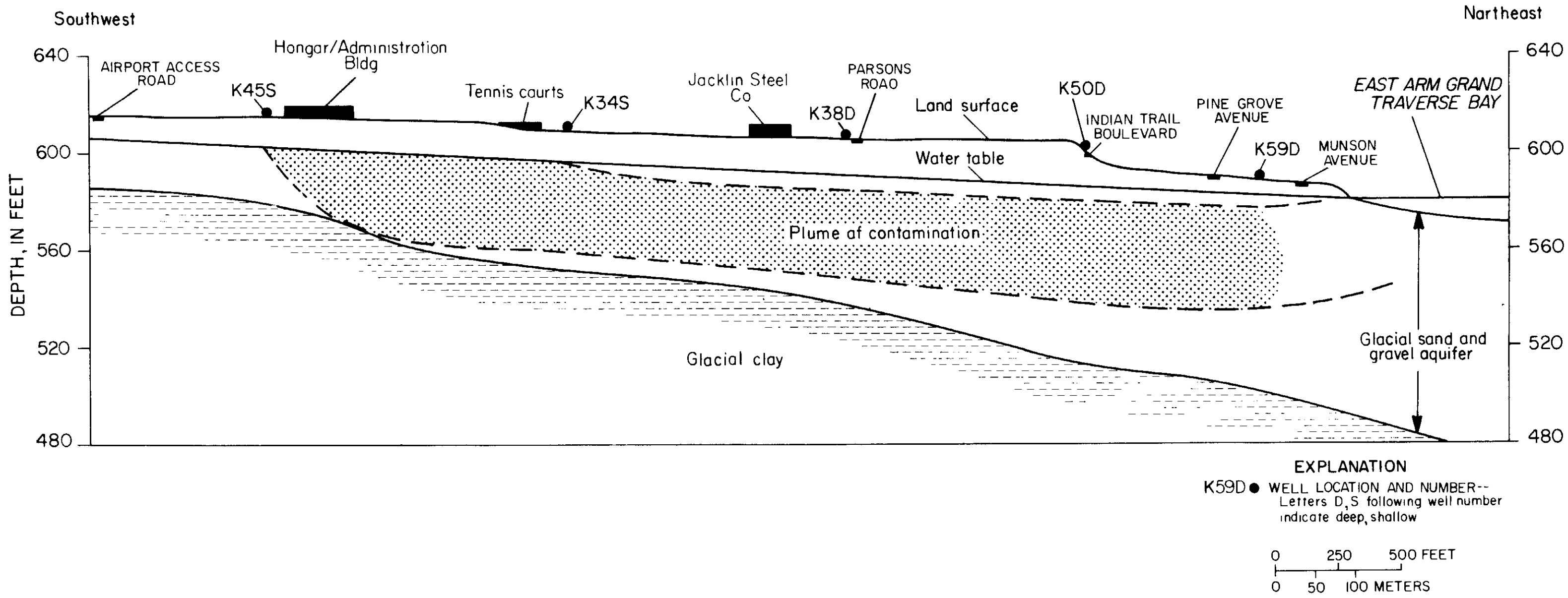

Figure 12.--Generalized longitudinal profile through the major ground-water contamination plume.

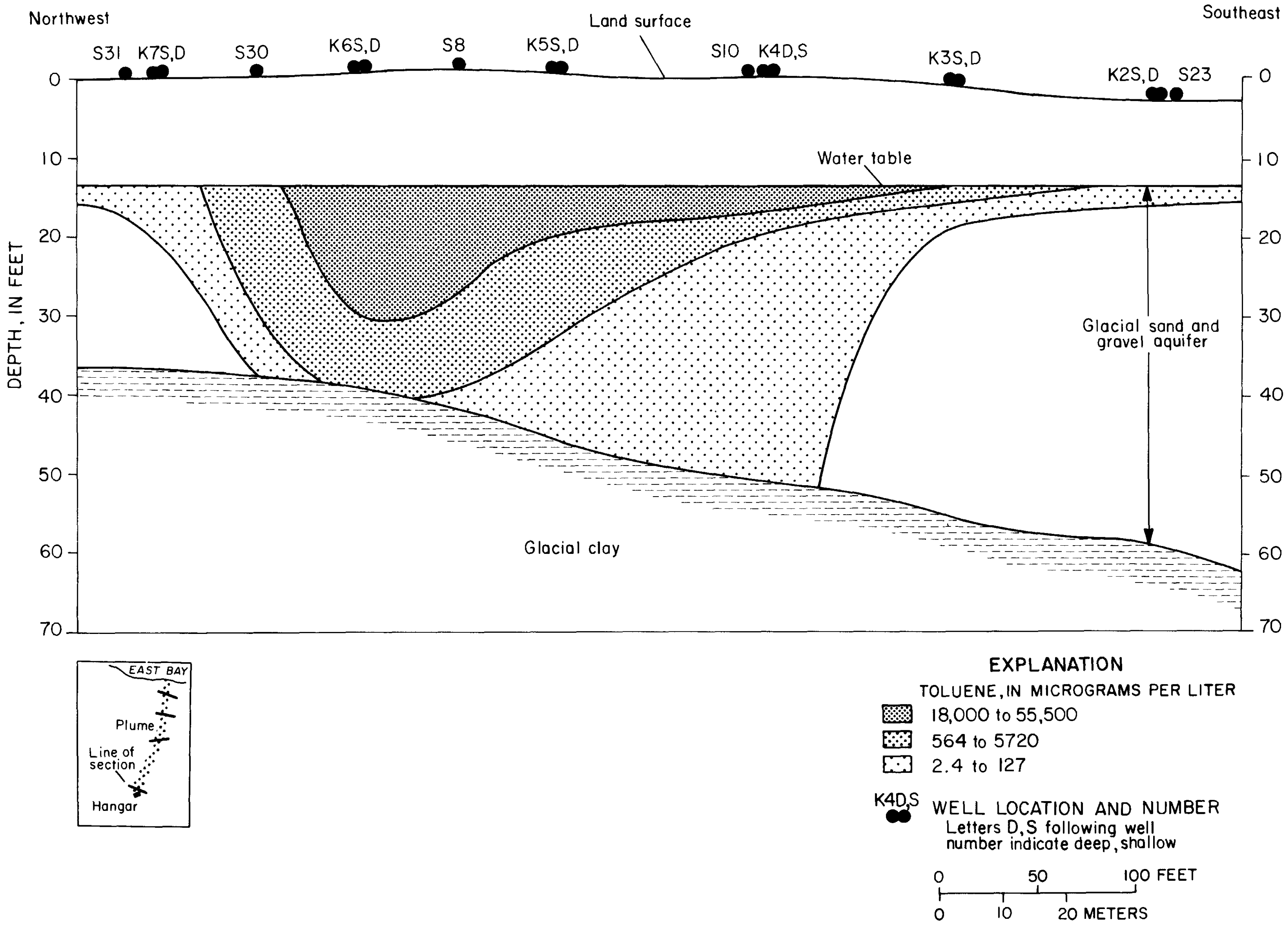

Figure 13.--Generalized vertical cross section of ground-water contamination near Hangar/Administration building.

recharge. Upgradient from well S23, recharge is restricted due to the Hangar/Administration building and concrete runways and aprons (plate 1). After heavy rains the water table is likely to be temporarily lower in the area of well S23 and along the normal path of ground-water flow from well S35 (34,580 µg/L toluene) to well S10 (31,000 µg/L toluene) (plate 2). Thus, there would be a tendency for less dense toluene to gradually move southeastward at the surface even though general movement was to the northeast along ground-water flow lines.

Toluene moving downgradient from the general vicinity of well S23 is probably the reason that wells K35, K36, K55, and K56 along Parsons Road had toluene ranging from 2.4 to 6.0 µg/L at depths 8 to 29 feet below the water surface. If this is true, then there is no evidence that the old U.S. Navy waste dump is contributing contaminants to the ground-water system.

Water from well S24, about 190 feet northwest of well S31 (plate 2), on an extension of the line of section on figure 13, contained 74 µg/L toluene. Toluene in water from this well is probably unrelated to the origin of contaminants in the major plume. Well S24 and adjacent wells K9S and K9D, which contained no contaminants, are downgradient from the former site of JP-4 fuel tanks near the west fence line. These wells are also downgradient from Building 605. Toluene in water from well S24 could have had its origin in either of these areas. Downgradient from well S24, water collected at the surface of the water table from wells S26, S27, K23D, K23S, K16D, and K57S contained no toluene with one exception. K57S, whose screen is set 9 to 13 feet below the water surface, contained 14 µg/L toluene.

Twenty-three deep and shallow wells were installed over a 1,400-foot distance along Parsons Road to determine the locations at which contaminants moved northward (plate 1). Wells drilled east of Aero Park Drive were installed primarily to determine if the old U.S. Navy dump (fig. 4) was a source of contaminants detected in domestic wells on Avenue E. Figure 14 is a cross section showing the occurrence of contamination in a 380-foot distance that includes wells K17, K37, K18, K38, and K19. The section indicates that contaminants move northward just west of Aero Park Drive in an area about 180 feet wide. At this location, and for about 600 feet downgradient, the plume seems to narrow. It is believed that this is related to a slight change in the direction of ground-water flow a few hundred feet to the west (fig. 10), and to the deepening of the clay surface to the east. Highest concentrations of benzene (1,270 µg/L) and toluene (3,410 µg/L) occur in well K38-33' about 17 feet below the water surface. Concentrations of benzene and toluene in water from this well decrease as depth within the plume increases. Analyses of water from well K37, about 100 feet west of K38, indicate a different vertical distribution. The concentration of benzene was comparatively uniform vertically; toluene was highest in water about 36 feet below the water surface. The highest concentrations of chlorinated hydrocarbons (trichloroethylene, dichloroethylene, tetrachloroethylene, dichloroethane, and dichloromethane) also occurred in the shaded areas on figure 14. The maximum concentration of a chlorinated hydrocarbon was 190 µg/L (1,2 dichloroethylene) in water from well K37-40'. Farther

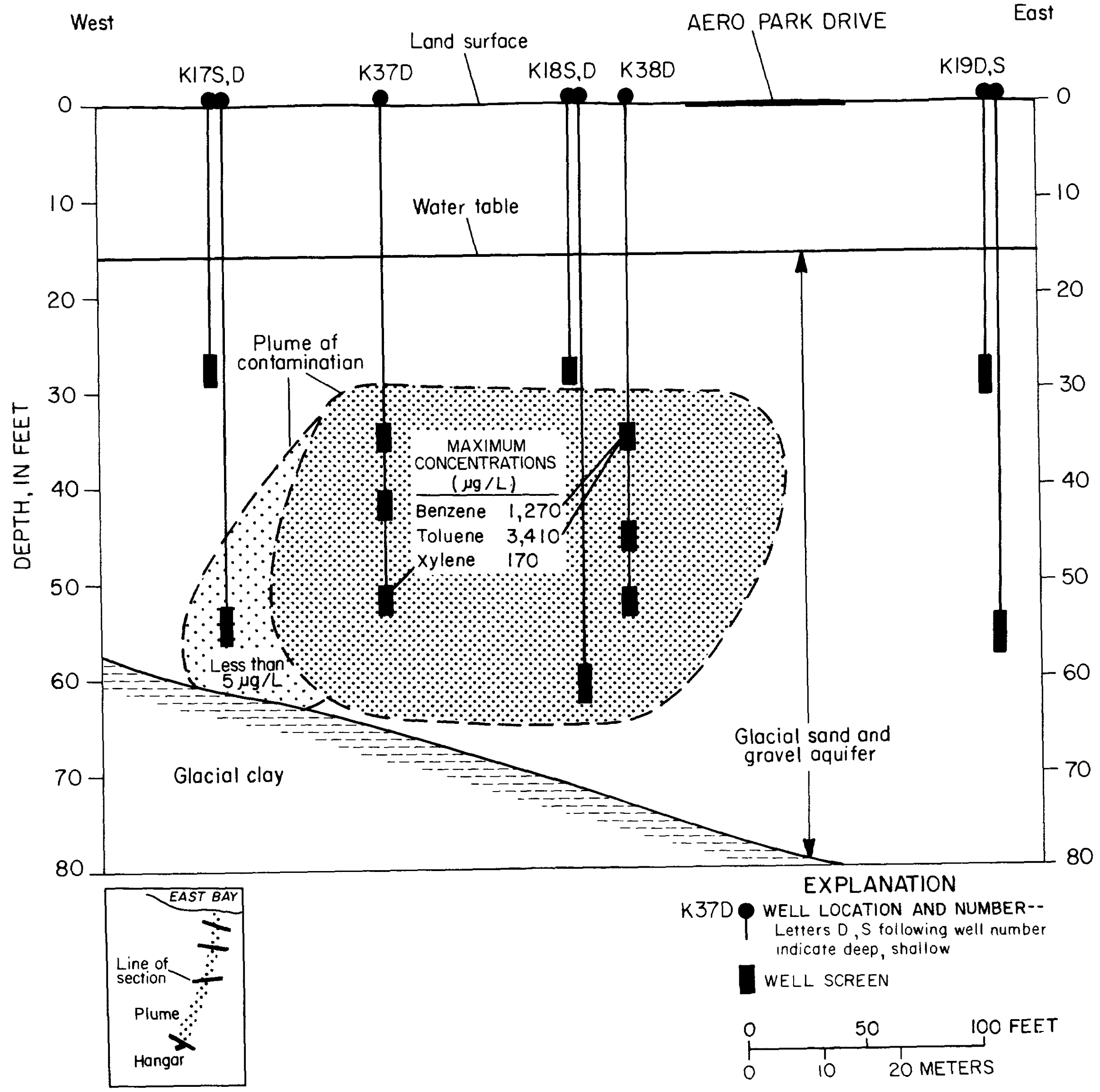

Figure 14.--Generalized vertical cross section of ground-water contamination at Parsons Road.

west, water from wells K57S and K16D had small amounts of trichloroethylene, 5.9 and 10 µg/L, respectively, and water from well K23S contained 7 µg/L of carbon tetrachloride.

To verify the direction of plume movement and the width of the plume, wells K53D and K54D were drilled near the residence at 934 Avenue E. K53D was drilled east of the residence near the street; K54D was drilled in the alley west of the residence. The distance between the two wells is 180 feet. Each well was sampled at three depths. Toluene was not detected; benzene was detected only in water from well K54D-48' (12 µg/L). Chloroform, trichloroethylene, and dichloroethylene were detected in water from wells K54D-38' and K54D-48'. The maximum concentration was that of trichloroethylene (107 µg/L). Water of well K53D also contained chloroform, trichloroethylene, and dichloroethylene in concentrations that did not differ greatly from those of K54D. A sample collected from the domestic well (E934) serving the residence, located about mid-way between the two wells, did contain benzene (85 µg/L) and toluene (19 µg/L) at a depth of 50 feet. These data, and those from other domestic wells on Avenue E (table 2), confirm the location and width of the plume in this area.

Figure 15 shows the occurrence of contaminants along Indian Trails Boulevard. The shaded area on the figure encompasses all of the benzene detected and all but traces of the toluene. Outside the shaded area concentrations of toluene ranging from 2.7 to 7.6 µg/L occurred in water from wells K51D-22', K50.5, K49D-22', K47D-33', and K47D-45'. At Indian Trails Boulevard the plume has widened to about 230 to 240 feet. The highest concentrations of benzene (3,030 µg/L), toluene (5,110 µg/L), and xylene (65 µg/L) occur near the central part of the plume about 22 to 25 feet below the water-table surface. With the exception of trace amounts, chlorinated hydrocarbons occurring in water along Indian Trails Boulevard also were found in the shaded area of the plume on figure 15. The concentration of dichlroethylene, 206 µg/L, was the highest found in water from wells in this section.

A cross section of the occurrence of contaminants between Pine Grove and Munson Avenues is shown in figure 16. The section is based on analyses of water from wells K59D and K60D drilled in a driveway and alley adjacent to a residence at 840 Avenue E, and on well K58D located on Pine Grove Avenue. The shaded area on the figure shows the width (about 260 feet) and the depth of the plume. The maximum concentration of benzene (1,970 µg/L) and maximum concentration of toluene (940 µg/L) occurred in the central part of the plume about 38 feet below the water-table surface. The base of the plume is believed to be about 20 feet below the bottom of the deepest well. Only traces of benzene and toluene were detected in well K60D. Within the shallow part of the plume, only small amounts of benzene and toluene were detected. About 13 feet below the water surface, water from well K59D-18' had 6.1 µg/L benzene. Water from well K58D-18' had 3.7 µg/L toluene.

At the surface of the water table, water from well K59D-5' had 22 µg/L of benzene and 3.2 µg/L of toluene. Trichloroethylene was detected at the water table in K59D-5' (1.0 µg/L) and in water from well K58D-18'

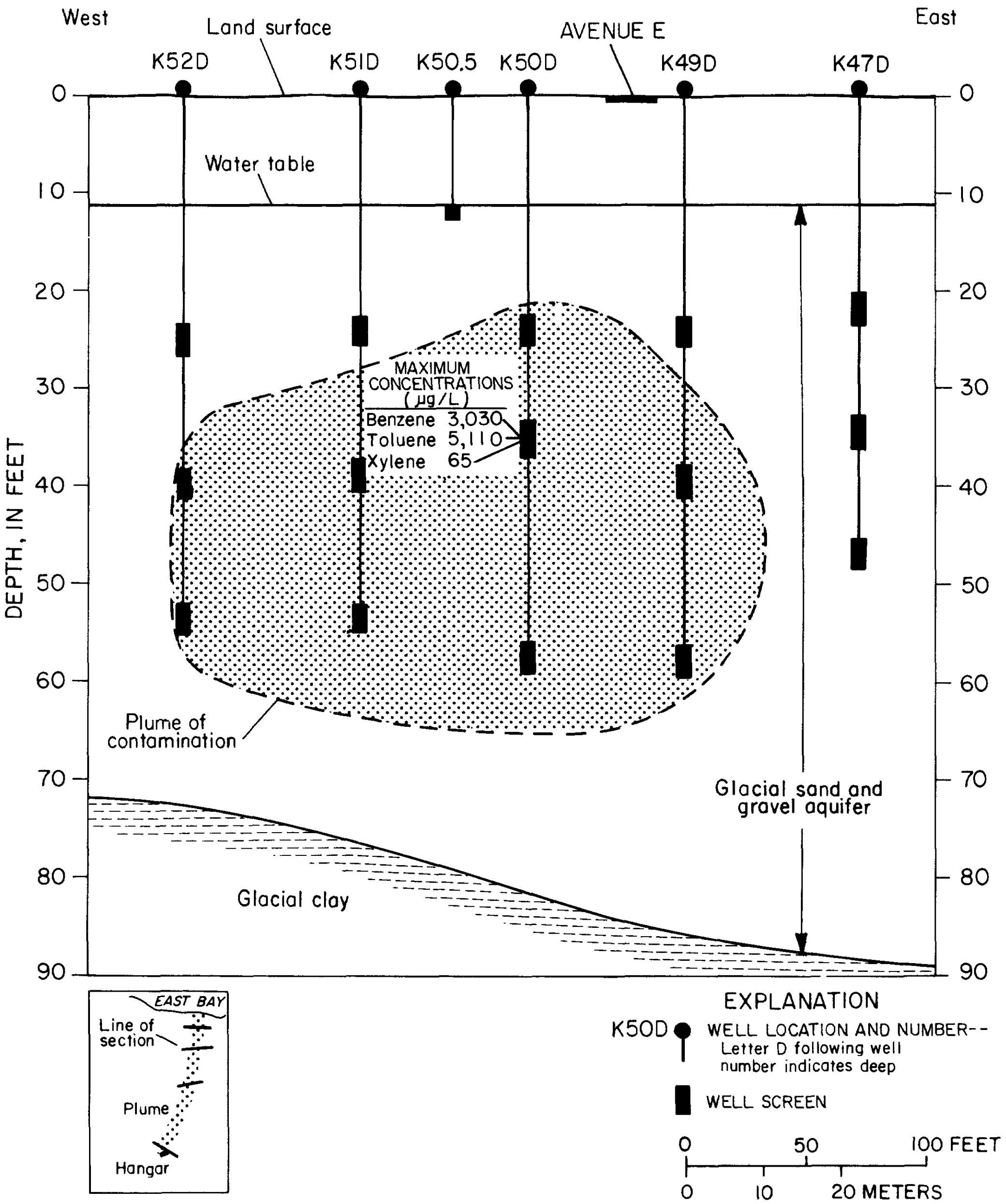

Figure 15.--Generalized vertical cross section of ground-water contamination at Indian Trails Boulevard.

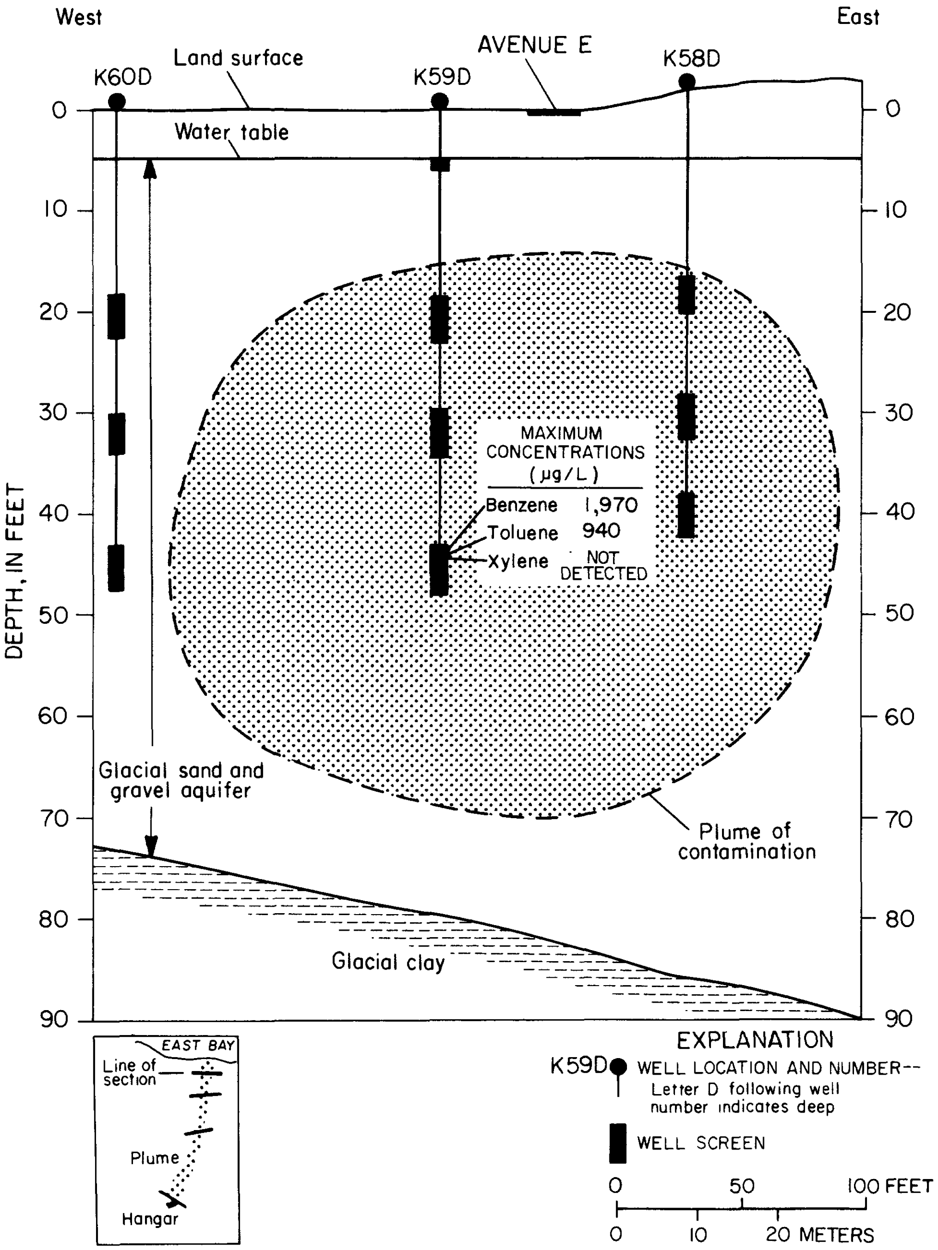

Figure 16.--Generalized vertical cross section of ground-water contamination near Pine Grove Avenue.

(29 μg/L). In view of the fact that well K59D had to be drilled in a dirt driveway, detection of contaminants in the upper part of the aquifer at this location may be unrelated to the plume. Near lakes, such as East Bay, ground water tends to have an upward component to its movement and these contaminants may be detected at comparatively shallow depths in this area. Traces of contaminants, however, may have remained at the surface of the water table even though this upper zone probably cannot be considered within the major part of the plume downgradient from the Air Station. Samples collected upgradient at the water table from wells S29 and K50.5, on Indian Trail Boulevard, also had small amounts of toluene.

Occurrence of Contaminants near Hangar/Administration Building

Benzene, toluene, xylene, and ethyl benzene.--Plate 2 shows the occurrence of benzene, toluene, xylene, and ethyl benzene in water near the Hangar/Administration building. Fifty-three wells were either drilled ("K" wells) or augered ("S" wells) to collect soil and water samples. Water from thirty of these wells was analyzed. As no significant concentrations of contaminants were found in water from wells K44S, K45S, K46S, S20, S25, S33, or S36, it seems that the origin of these contaminants is in the vicinity of, and just to the north of, the Hangar/Administration building. This is supported by the fact that contamination is greatest at the surface of the water table. Further, water from wells EB23 (30 feet deep), EB24 (30 feet deep), K33S (19 feet deep), and AH1 and AH2 (12.5 feet deep), 600 to 700 feet upgradient (plate 1), contained only small amounts of organic compounds compared to water near the Hangar/Administration building. Wells AH1 and AH2, drilled to the water surface west of Airport Access Road, contained water having 5.7 and 4.0 μg/L of toluene, respectively. Water from wells EB23 and EB24 contained no contaminants. K33S, however, contained 5.2 μg/L benzene and 64 μg/L toluene. Activity west of the Airport Access Road could be responsible for the benzene and toluene at this location, or alternatively, incidental spillage of a small amount of fuel in the southwestern corner of the station at some time in the past could be responsible.

Although plate 1 shows the boundary of a generalized, composite plume of contaminants near the Hangar/Administration building, benzene, toluene, and xylene are not uniformily distributed in the area. Figure 17 shows that benzene is not generally detected in the northwestern or southern part of the area either at the water table surface or in water from wells drilled to varying depths. The distribution of toluene, shown in figure 18, indicates that it is more broadly distributed in the area. Xylene distribution (fig. 19) is comparatively uniform, but less extensive than that of toluene. In water of two wells, S17 and S32, xylene was the only contaminant detected.

Chlorinated and brominated hydrocarbons.--Plate 3 shows the distribution of chlorinated and brominated hydrocarbons in water near the Hangar/Administration building. The highest concentrations occurred in, and to the north and northeast of, the rock garden. Maximum concentrations were 420 μg/L trichloroethylene (well S17), 207 μg/L dichloroethylene (well S32), 3,410 μg/L tetrachloroethylene (well S32), 1,000 μg/L bromoform

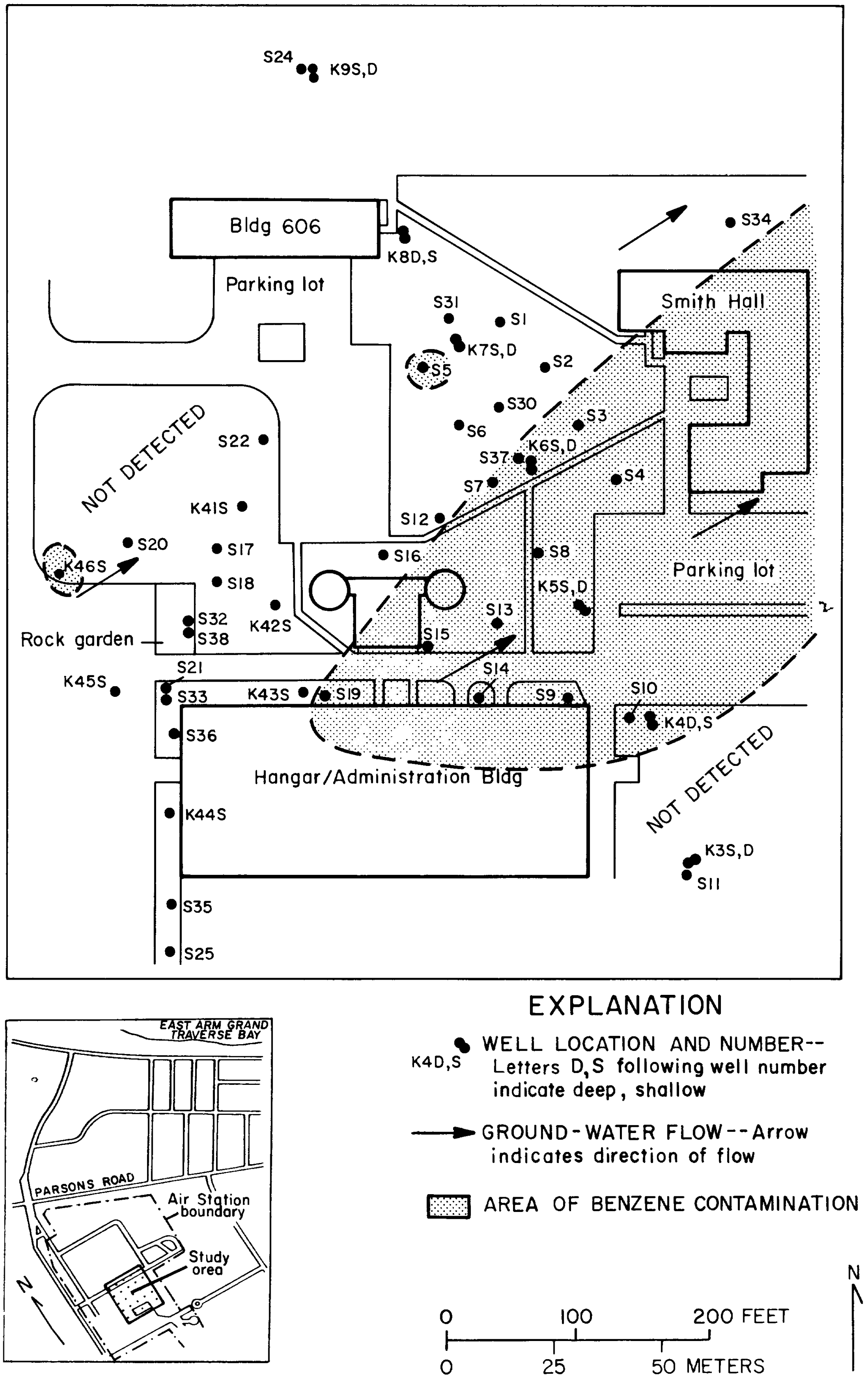

Figure 17.--Benzene in ground water near Hanger/Administration building.

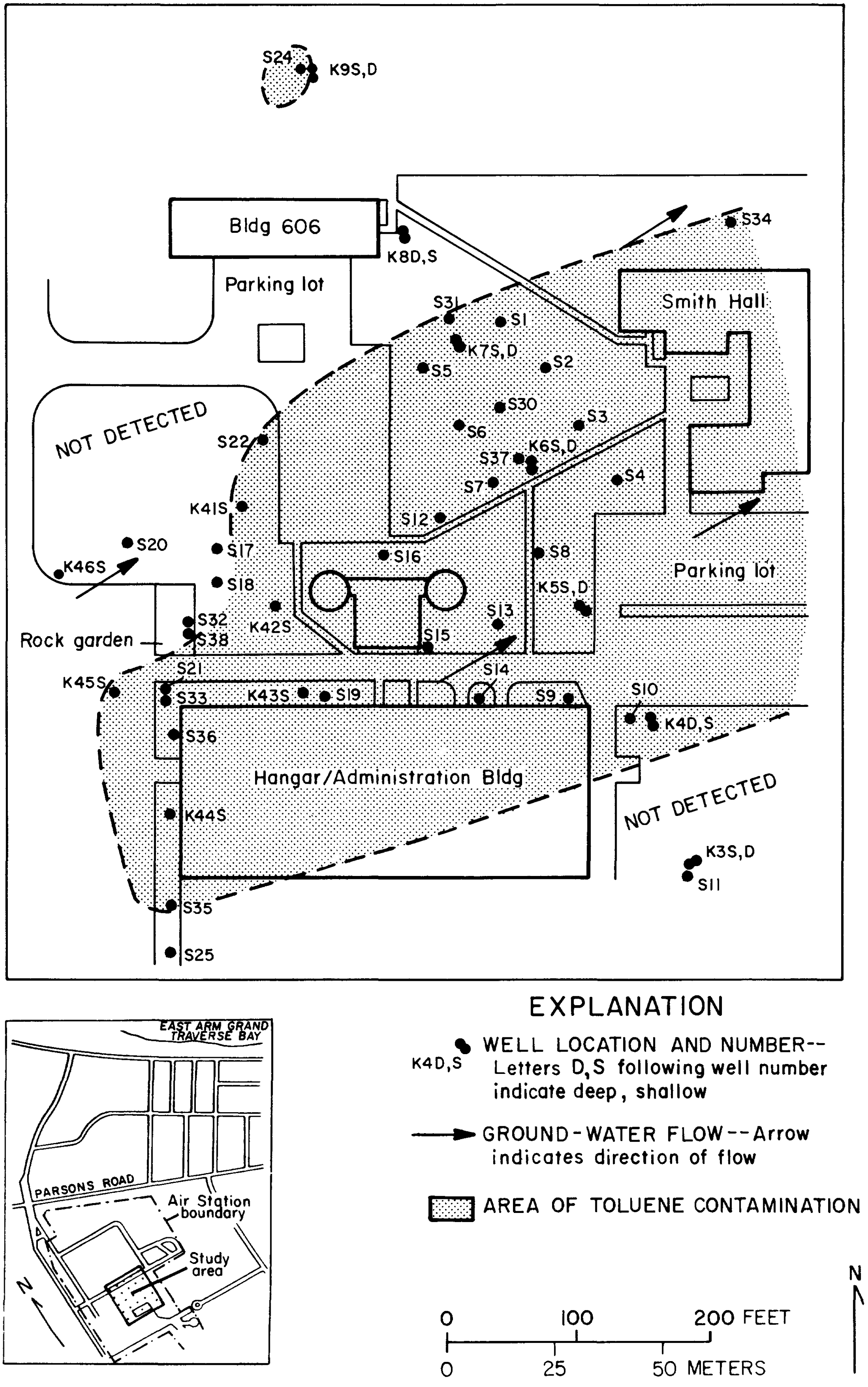

Figure 18.--Toluene in ground water near Hangar/Administration building.

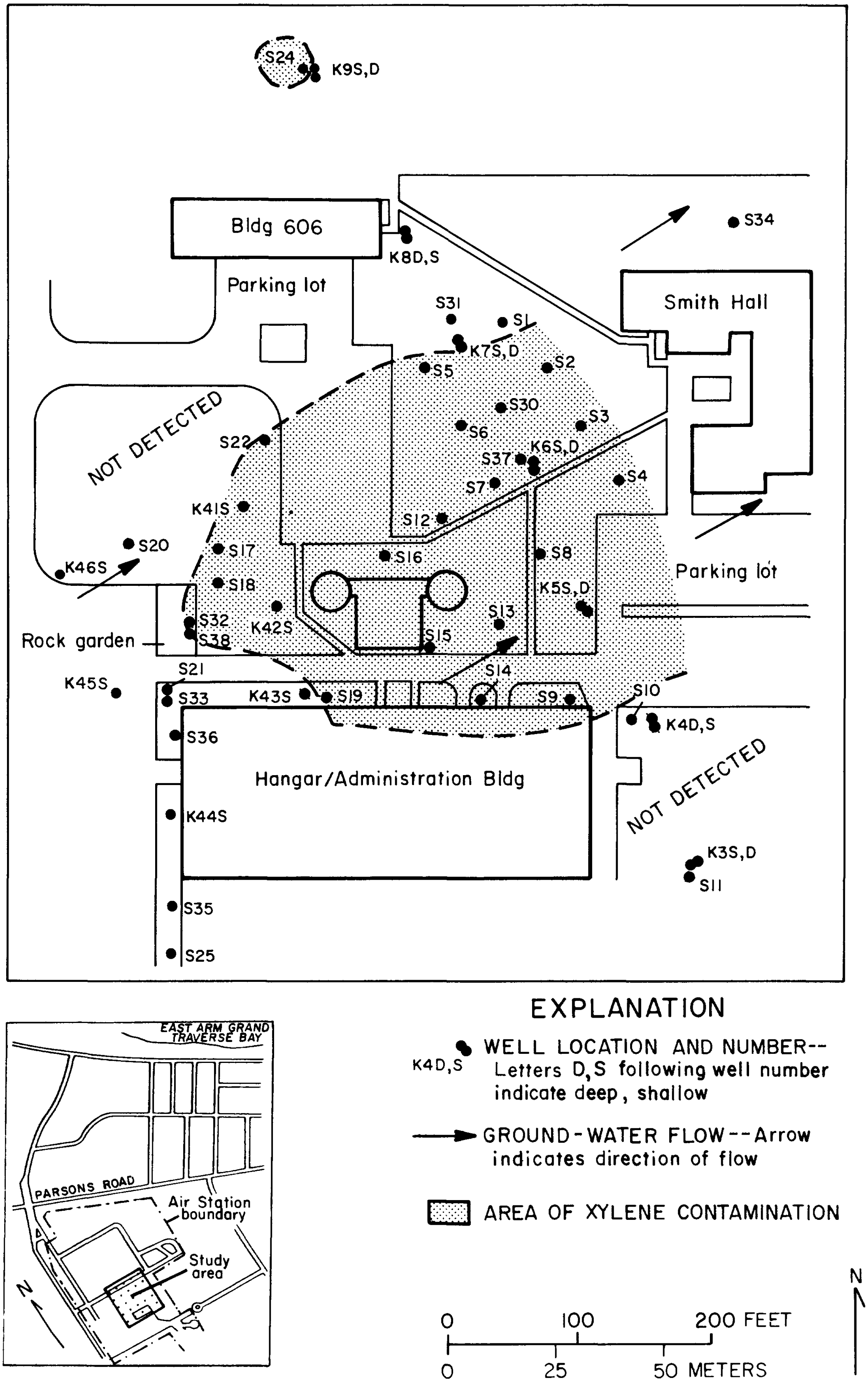

Figure 19.--Xylene in ground water near Hangar/Administration building.

(well S22), 374 μg/L chloroform (well S5), 90 μg/L bromodichloromethane (well S5), 5.6 μg/L dichloroethane (well K6D), and 6.8 μg/L trichloroethane (well K6D). Upgradient near Airport Access Road, chlorinated hydrocarbons were not detected in water from wells EB23, EB24, K33S, AH1, and AH2. This suggest that these hydrocarbons originate in the area just north of the Hangar/Administration building.

Figure 20 shows the distribution of chlorinated and brominated hydrocarbons in the Hangar/Administration building area, which differs from those of benzene, toluene, and xylene. Chlorinated and brominated hydrocarbons occur in the northern part of the plume (plate 1); this is undoubtedly the reason they tend to be found in the northern and northwestern part of the plume downgradient. Water of well S17, which is upgradient from well S22, contained 806 μg/L bromoform. Water from wells K16D and K57S, along Parsons Road but west of the major plume, contained trichloroethylene.

Base/Neutral compounds.--Base/neutral substances are primarily a series of semi-volatile and nonvolatile organic compounds extracted from water with methylene chloride. A number are regarded as priority pollutants due to known or suspected toxic effects. Water from six wells (S35, S36, S37, K39S, K39WT and K59D) was collected for base/neutral analyses (table 4). Nitrobenzene, napthalene, n-nitrosodi-n-propylamine, diethyl phthalate and di-n-butyl phthalate were found in concentrations ranging from 1 to 78 μg/L. Bis (2-ethyl hexyl) phthalate was present in high concentrations in water of S35 (2,100 μg/L) and in water of well S37 (1,000 μg/L).

ORGANIC SUBSTANCES IN WATER OF EAST BAY

Figure 21 shows locations at which samples of water were collected from East Bay; analyses are given in table 6. Sampling sites were located at 20 feet, 300 feet, and 600 feet northeast of the shoreline. Divers collected the samples as close to the lake bottom as possible. Of the volatile hydrocarbons, only benzene and toluene were detected. The highest concentration was that of benzene (20 μg/L) in the central part of the area, 300 feet from shore. Bis (2-ethyl hexyl) phthalate (1 μg/L) was also detected at the same location. No other base/neutral compounds were found.

ORGANIC SUBSTANCES ON SOILS

Organic substances adsorbed on soil were measured at 21 locations in the area of the Hangar/Administration building (plate 4 and table 3). Most soil samples were collected at a depth of 10 feet, 2 to 4 feet above the water table. Multiple depth samples were collected from wells S28, S30, and S32. Benzene and xylene were not detected; toluene was detected in low concentration[1] on soils from wells S7-10' (2.0 μg/kg), S8-10' (2.0 μg/kg), S9-10' (4.6 μg/kg), and S32-1' (5.7 μg/kg). Samples collected at 4 feet and at 11 feet from S32 did not contain benzene, toluene, and xylene, nor did samples collected at 5 and 10 feet in wells S30 and S35. In contrast, water just at the water table in these wells had high concentrations.

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[1] Results are reported in micrograms per kilogram (μg/kg) of soil material.

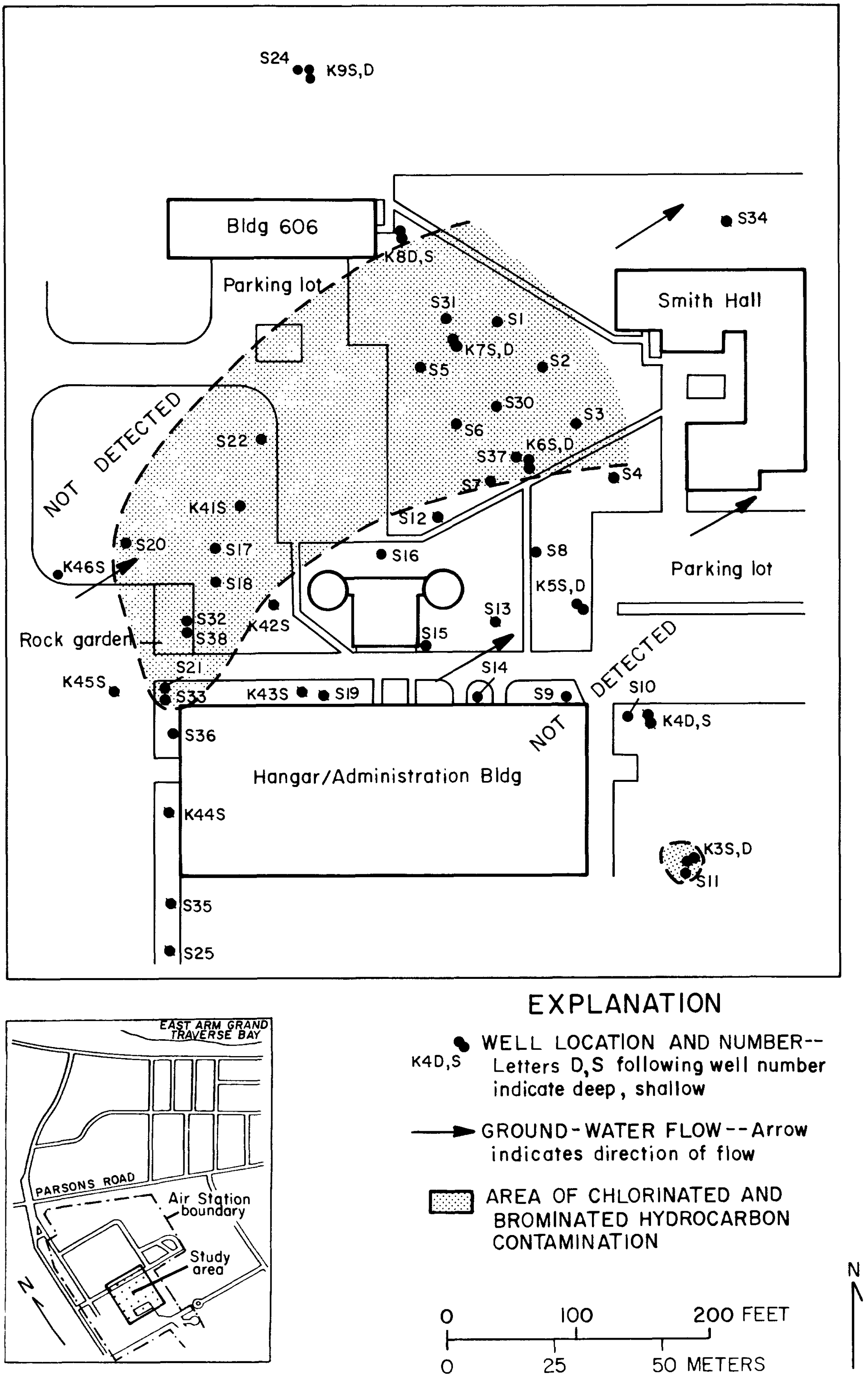
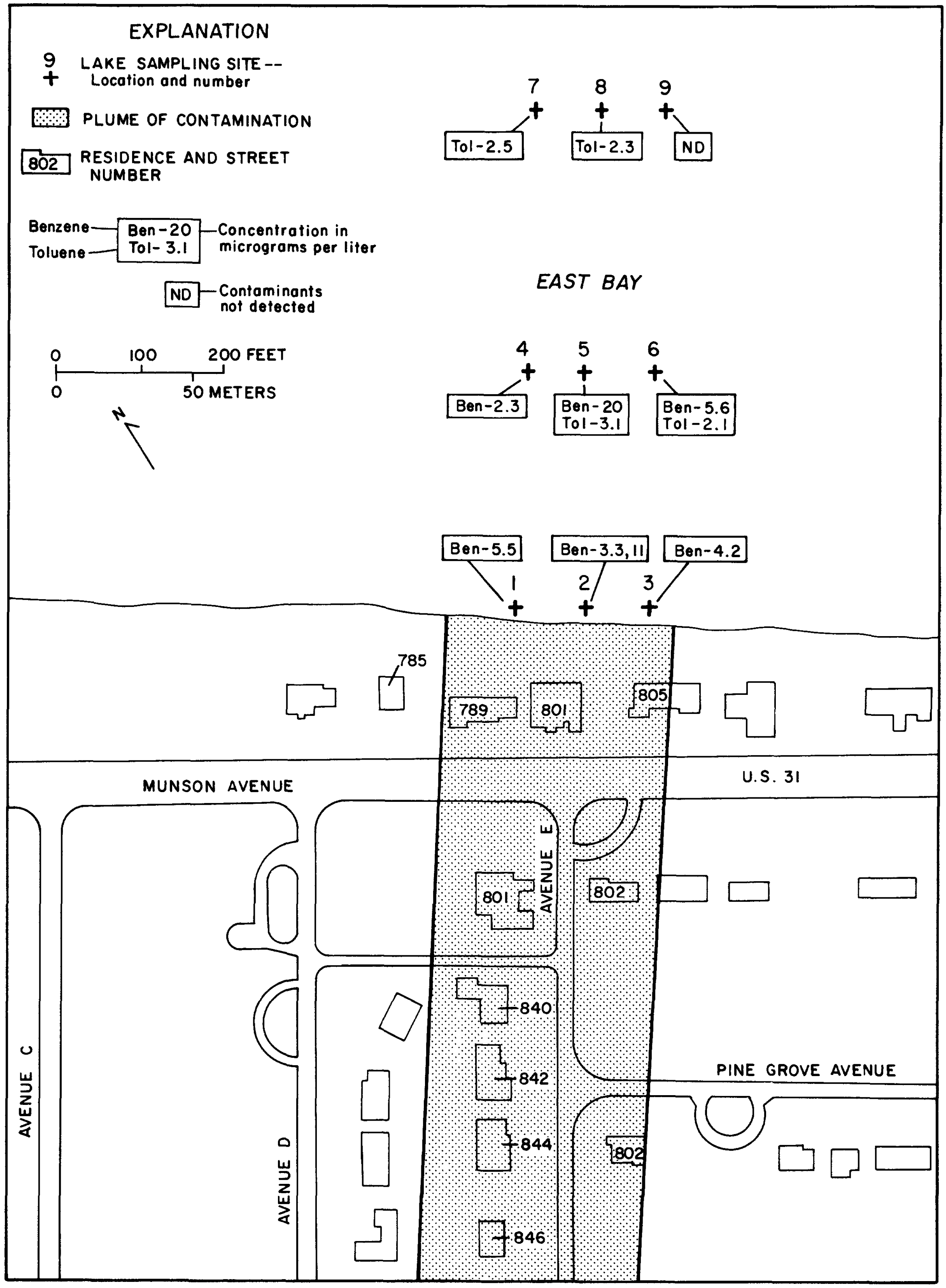


Figure 20.--Chlorinated and brominated hydrocarbons in ground water near Hangar/Administration building.



Base adapted from U.S. Coast Guard map and maps by Gourdie–Fraser and Associates, Inc.

Figure 21.--Benzene and toluene in water of East Bay.

Water from S30 contained 5,720 µg/L toluene; water from S35 contained 34,580 µg/L toluene. At the site of well S35-10' this is particularly significant because the well was installed adjacent to the former location of an aviation gasoline dispenser. Toluene was not detected in the soil sample about 3 feet above the water table. Soil of S35-10' did contain high concentrations of saturated hydrocarbons typical of petroleum distillates (Smith and others, 1981; written communication, U.S. Air Force, 1983). Soil samples from S36-10', located near the site of a second aviation gasoline dispenser, showed similar results although the total amount of hydrocarbons was not as great (table 2).

Chlorinated hydrocarbons were detected on soils collected from three wells--S18, S21, and S32. Concentrations of tetrachloroethylene are of most significance. Soils from well S32, in the rock garden, contained 1,100 µg/kg at 1 foot; 27 µg/kg at 4 feet; and 410 µg/kg at 11 feet. Soils from wells S26 and S27, in the northeast corner of the station, did not contain hydrocarbons at a depth of 4 feet.

Analyses of base/neutral compounds on soils from four wells were also made (table 4). Bis (2-ethyl hexyl) phthalate was found at all four locations. Highest concentrations (1,500 µg/kg) were found on soils from wells S35-10' and S36-10'. Diethyl phthalate, ranging from 300 to 370 µg/kg, and di-n-butyl phthalate, ranging from 190 to 870 µg/kg, were also detected. These compounds were not detected in water at the water table in these wells, nor were they detected downgradient in water of wells S37 and K39.

SOIL-WATER PARTITIONING OF CONTAMINANTS

Results of soil analyses are consistent with what little is known regarding the adsorption of the organic contaminants discussed above on soil or other geologic materials, and the adsorption isotherms of compounds on activated carbon. Although such isotherms vary, depending on the initial concentration of the substance being tested, the relative magnitudes of individual isotherms is probably indicative of how easily they are taken up by organic carbon in the environment. Benzene has an adsorption isotherm of 0.8[1], one of the lower values.[2] This fact, and the fact that organic carbon is low in soils[3] and underlying materials at the station, could be the principal reason benzene was not detected on soils. MacKay and Paterson (1981), in a study of mass distribution of selected organic substances in the environment, concluded that about 300 times as much benzene could be expected in water as on soils. Thus, benzene, if compared to many other

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[1] Percent adsorbed from solution.

[2] Adsorption isotherms used in this report are those of O. H. Materials, Inc., Findlay, Ohio.

[3] Samples collected from an uncontaminated area near well S1 showed the following results for total organic carbon: 3 feet, 0.6 grams per kilogram; 5 feet, 0.2 grams per kilogram; and 8 feet, 0.1 grams per kilogram.

organic compounds, would be expected to move rapidly to the water table. Once in the aquifer, dispersion would be a principal process accounting for a decrease in concentration. This seems to be the situation observed. In the upgradient part of the plume the maximum benzene concentration was 3,390 μg/L; in downgradient part, 1,970 μg/L. Most of the dispersion probably occurs vertically rather than horizontally.

Toluene has an adsorption isotherm of 3.19--higher than benzene, but comparatively low. Traces of toluene were found on soils from four wells. The maximum concentration of toluene in the upgradient part of the aquifer was 55,500 μg/L; in the downgradient part, 5,110 μg/L. Biodegradation of toluene in a shallow water-table aquifer has been cited by Wilson and others (1983).

Adsorption isotherms of other organic substances detected during this study include tetrachloroethylene, 11.2, and trichloroethylene, 6.6 to 38.9. The isotherm for tetrachloroethylene suggests that it should be adsorbed more strongly on organic carbon than are benzene or toluene. Data from well S32 indicate this to be true. Water from S32 contained 3,410 μg/L; soils from the same well contained tetrachloroethylene ranging from 27 to 1,100 μg/L. The highest value occurred at a depth of 1 foot where organic carbon would be expected to be higher. Although some existing literature suggests adsorption of tetrachloroethylene is probably not important, these data suggest otherwise. Significant concentrations of tetrachloroethylene were confined to the area of the northwest corner of the Hangar/Administration building near the rock garden; there was no detection in the downgradient part of the plume. Wilson and others (1983) found no detectable bacterial degradation of tetrachloroethylene.

According to Callahan and others (1979), the four phthalate esters detected in soils are adsorbed, and biodegradation is an important fate process. Even though water contained bis (2-ethyl hexyl) phthalate in the Hangar/Administration building area, only traces were detected downgradient in water from well K39S.

Soils of S35-10' and S36-10' both contained saturated and unsatured hydrocarbons typical of petroleum distillates (table 3). Many of these compounds have a comparatively low solubility (McAuliffe, 1966; Price, 1976), and tend to adsorb on soils. Transport is usually not great in ground-water systems. Soil at 10 feet from well S35 contained as much as 14,000 μg/kg; only traces were detected in water from wells K58D and K59D. Similar hydrocarbons were also detected in soil samples from well S28 at 1-, 4-, and 10-foot depths. Concentrations were comparatively low, however, and there is no evidence at downgradient sampling sites that the area around well S28 is a source of contamination at present, even though water of well EB14 contained 40,000 μg/L toluene. Upgradient from well EB14 water of well S8 contained 55,500 μg/L toluene.

RELATION OF CONTAMINANT OCCURRENCE TO POSSIBLE SOURCES OF CONTAMINATION

A comparison of data in the preceeding section of this report to the possible sources of contamination identified in figure 4, strongly suggests that origin of the plume is near the Hangar/Administration building, even though low concentrations of toluene were detected in upgradient wells K35S, AH1, and AH2. Existing contaminants in the area, both in water and on soils, are thought to be those remaining after discontinuance of fuel storage and aircraft maintenance operation in the area. Data suggest that the storage of solvents and other chemicals near the rock garden, and aircraft maintenance in the same general area, probably resulted in contamination of water and, at a few locations, contamination of soils. Leakage of aviation gasoline dispensers (now removed) and the connecting lines was also a possibility, particularly in view of the fact that higher molecular weight hydrocarbons characteristic of petroleum distillates were found on soils adjacent to the aviation gasoline dispenser near the southwest edge of the Hangar/Administration building. Evidence of fuel contamination is not conclusive, however, even though toluene in water at this site was high. Toluene and similar compounds used in aircraft maintenance operations in the same general areas may have entered the ground-water system. The detection of phthalate ester plasticizers in both water and soil at this site also suggest contamination other than by fuel.

Figure 4 also identifies an area north of the Hangar/Administration building where surface disposal of oil wastes may have occurred. Although organic compounds characteristic of such wastes were detected in water, high concentrations of these compounds also occur in water upgradient. Soils in the area were comparatively free from contaminants.

Contamination resulting from prior underground storage of aviation gasoline northeast of the rock garden does not seem to be extensive. A few feet downgradient from the storage site water at the water table contained a high concentration of toluene. About 140 feet farther downgradient, the toluene concentration at the water table was only about a fourth as great. Contaminants were not found at greater depths in this area or in the downgradient path of ground-water flow. Thus, it is believed that the existing organic compounds are those remaining in the system after removal of the storage tanks.

As suggested previously, the area along the western fence line that once contained JP-4 fuel tanks and dispensers does not seem to be a major source of contaminants. It is possible, however, that toluene (74 μg/L) detected in water of well S24 originated from the area of the JP-4 fuel tanks. The area of the former JP-4 fuel tanks and dispensers, however, does not contribute contaminants to the major plume, nor are significant concentrations detected downgradient in water other than that from S24. South of the Hangar/Adminsistration building, incidental spillage in the vicinity of present JP-4 storage tanks and dispensers could account for the occurrence of benzene, toluene, and xylene in water of well S23, although lateral movement to the area of well S23 is also a possibility. Whatever the origin, significant contamination does not exist downgradient; the JP-4 tanks and dispensers are not contributors to the major plume.

Other possible sources of contamination investigated include the former U.S. Navy fuel storage site west of Airport Access Road, fuel tanks and dispensers east of buildings 206 and 403, and the area west of Jacklin Steel Company where drum storage and spillage were reported. Data do not indicate that these areas are sources of contamination. The old U.S. Navy waste dump, located southeast of Nish-Nah-Bee Industries, does not seem to be presently contributing contaminants to the ground-water system.

GROUND-WATER FLOW MODEL

Digital simulation of ground-water flow was based on a two-dimensional form of a ground-water flow model developed by the U.S. Geological Survey (McDonald and Harbough, written commun. 1983). The model, which uses finite differences to approximate the partial differential equation for ground-water flow, was used to refine estimates of the aquifer's hydraulic parameters and to determine the effects of pumping on ground-water flow.

Modeling requires the ground-water flow system to be represented by 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 and ground-water runoff of streams. Calculated and measured water-levels and runoff were compared. If they matched, the model was considered calibrated. If not, hydraulc parameters were adjusted and new water levels and runoff were calculated. This procedure was repeated until the model was calibrated.

A conceptual model of the aquifer system of East Bay Township and adjacent areas was developed from the available hydrologic information. The conceptual model, using simplifying assumptions, makes it possible to use the digital model to simulate ground-water flow. These assumptions are:

(1) Ground-water flow is only in the sand and gravel aquifer.
(2) Flow is essentially horizontal and isotropic.
(3) The average stream stage remains constant.
(4) All pumping wells are considered to be screened through the full thickness of the aquifer and are 100 percent efficient.
(5) Ground water is discharged only by leakage to streams or lakes and by pumping from wells.
(6) The aquifer is recharged by precipitation and a small amount of inflow from Mitchell Creek.

The modeled area, about 8 mi^2 (plate 5), encompasses the Air Station and is bounded on the north by the east and west arms of Grand Traverse Bay, on the west by Boardman Lake and part of Boardman River, and on the south and east by Mitchell Creek and its tributaries. For the model, the area was divided into 4,200 rectangular cells. The strongly implicit procedure (SIP) was used to numerically solve the ground-water flow equation.

For model simulations, a hydraulic conductivity of 120 ft/d and recharge of 15 inches/yr was used. The recharge value is based on long-term estimates of ground-water runoff and represents 50 percent of the average annual rainfall. This percentage seems reasonable because most of the area is flat, sparsely vegetated, has sandy surface soil, and low surface runoff.

Lakes and streams bounding the modeled area were simulated as leaky confining layers. Hydraulic conductance of the leaky layers ranged from 0.04 and 2.0 ft^2/s. The depth used for all streams was 1 foot; the depth for lakes was 5 feet. Areas underlain by till, such as part of the peninsula that separates the east and west arms of Grand Traverse Bay, the area east of Mitchell Creek, and the model's southern boundary were simulated as no-flow boundaries (plate 5). In addition, the part of East Bay northeast of the leaky-layer cells was simulated as no-flow boundaries.

The model was calibrated using water-level data collected in April 1983 and streamflow data for Mitchell Creek collected in 1982-83. For calibration purposes, the April 1983 water levels were assumed to represent steady-state conditions because they are near the average for the period of record. The water table simulated by the steady-state, ground-water flow model for April 1983 (fig. 22) compares favorably with the water table defined by measured data for the same month (fig. 9).

Purging of Aquifer

Model simulations of the ground-water system under various pumping conditions were made to evaluate hydrologically suitable locations[1] for installation of purge wells, the rate at which purge wells could be pumped, and the effect of purging on the ground-water system. Evaluations of the effects of purging were made with purge wells located in the most highly contaminated area in the vicinity of the Hangar/Administration building as well as with wells along the plume north and south of Parsons Road. The simulations indicate the operation of 10 wells withdrawing a total of 300 gal/min installed along the plume of contamination, as shown in figure 23, would lower the water table by about 4 feet in the center of the plume. Purging under these conditions, however, would remove more uncontaminated water than necessary. Also, purging throughout the length of the plume may not be feasible because the area north of Parsons Road is densely residential making well installations very difficult.

Numerous model simulations were made with purge wells installed at various locations and pumping rates in the plume of contamination south of Parsons Road. Figure 24 shows the results of a simulation with 6 wells pumping a total of 200 gal/min. Again, as with the simulation above, removal of uncontaminated water was excessive.

Results of all the simulations indicate that four purge wells, pumping a total of 150 gal/min, would modify ground-water flow directions enough to withdraw water from within the plume south of Parsons Road. These wells are identified as P1, P2, P3, and P4 on figure 25. Wells P1

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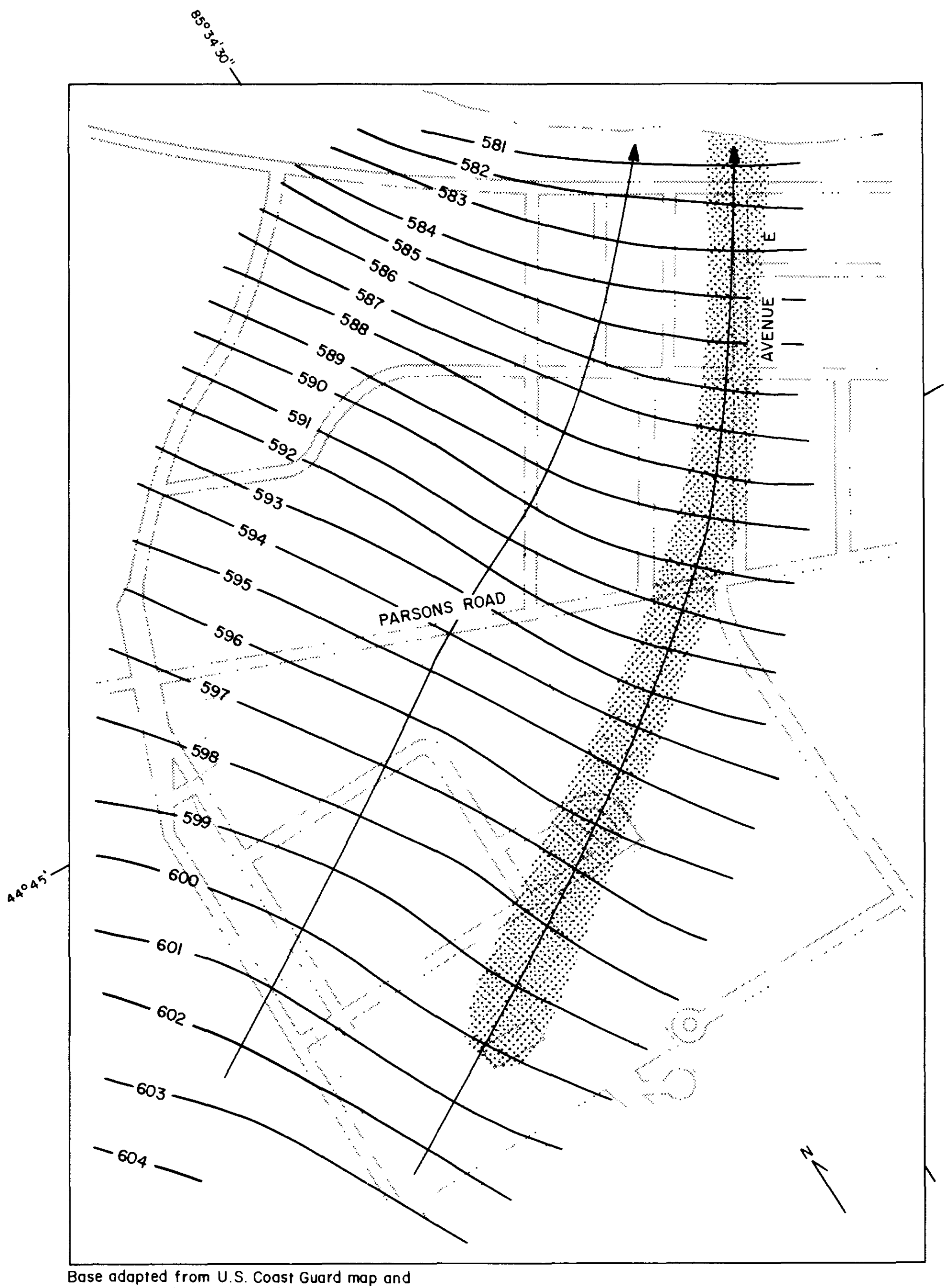
[1] Locations are based solely on hydrology; engineering feasibility has not been considered.



Base adapted from U.S. Coast Guard map and maps by Gourdie-Fraser and Associates, Inc.

EXPLANATION

—590— WATER-TABLE CONTOUR--Shows altitude of simulated water table April 1983. Contour interval 1 foot. NGVD of 1929

——► GROUND-WATER FLOW--Arrow indicates direction of flow

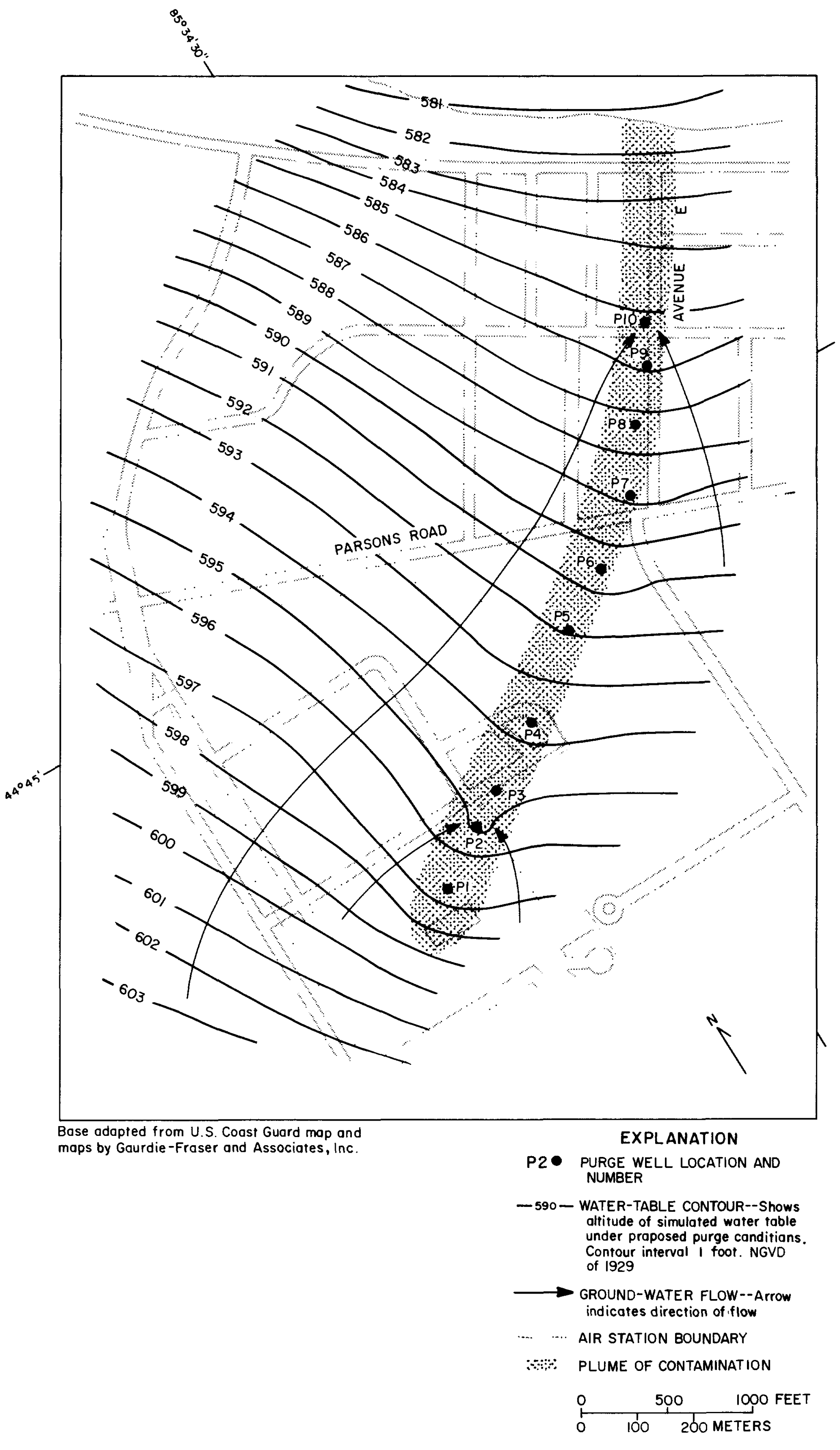
·····-····· AIR STATION BOUNDARY

∴∵ PLUME OF CONTAMINATION

0 500 1000 FEET

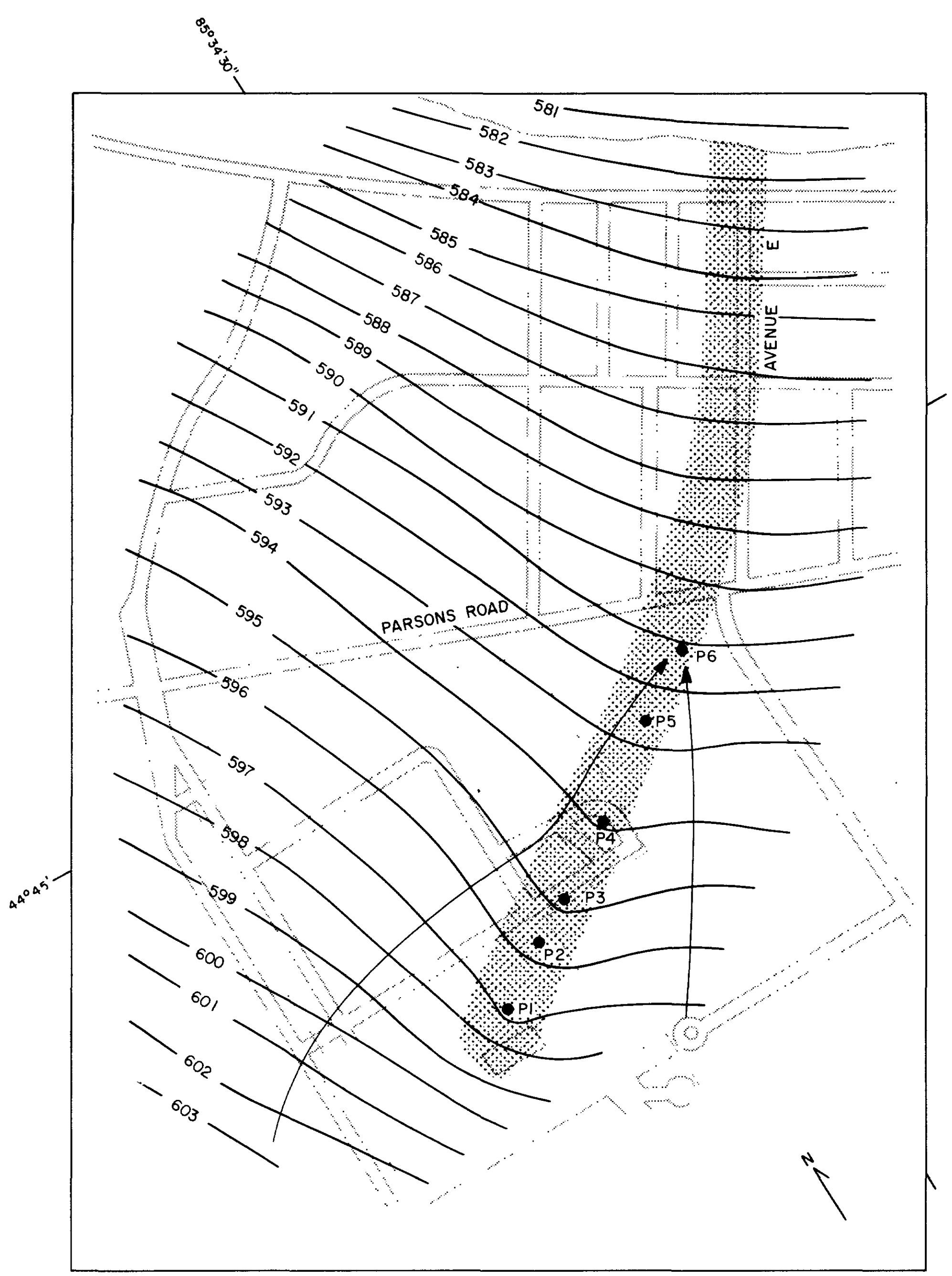
0 100 200 METERS

Figure 22.--Water table for April 1983, simulated by ground-water flow model.



Base adapted from U.S. Coast Guard map and maps by Gaurdie-Fraser and Associates, Inc.

Figure 23.--Model-predicted water-table altitudes as a result of pumping 300 gals/min from 10 wells.



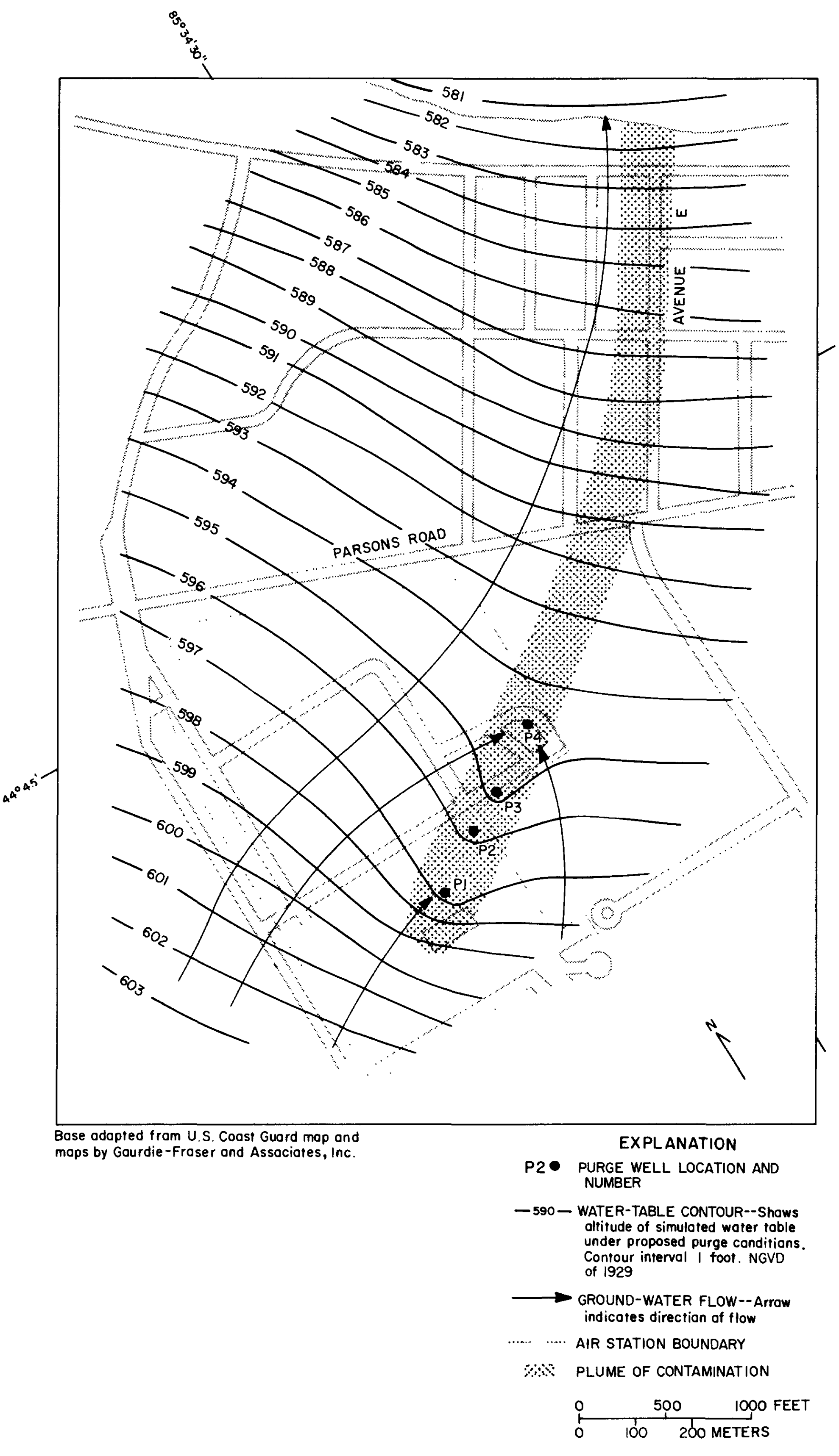
Base adapted from U.S. Coast Guard map and maps by Gourdie-Fraser and Associates, Inc.

EXPLANATION

P2 ●	PURGE WELL LOCATION AND NUMBER
—590—	WATER-TABLE CONTOUR--Shows altitude of simulated water table under proposed purge conditions. Contour interval 1 foot. NGVD of 1929
——▶	GROUND-WATER FLOW--Arrow indicates direction of flow
····· • ·····	AIR STATION BOUNDARY
⁘	PLUME OF CONTAMINATION

0 500 1000 FEET
0 100 200 METERS

Figure 24.--Model-predicted water-table altitudes as a result of pumping 200 gals/min from 6 wells.



Base adapted from U.S. Coast Guard map and maps by Gourdie-Fraser and Associates, Inc.

Figure 25.--Model-predicted water-table altitudes as a result of pumping 150 gals/min from 4 wells.

and P3 were simulated as pumping at 50 gal/min; well P2 and P4 were simulated as pumping at 25 gal/min. Under these simulated pumping conditions, the water table would be lowered by about 1 foot in the center of the plume at the pumping wells; a small cone of depression would be just to the north of the Hangar/Administration building. Contaminated ground water would be drawn to purge wells from all directions without removing significant amounts of surrounding uncontaminated water. Under this pumping scheme, contaminated water north of Parsons Road would, of course, continue to move northward until flushed from the system by natural ground-water flow.

SUMMARY AND CONCLUSIONS

The U.S. Coast Guard Air Station and the study area in East Bay Township are underlain by glacial deposits that are as much as 360 feet thick. The upper part of these deposits is a sand and gravel unit ranging in thickness from 29 to 118 feet. The unit is the source of water for all domestic wells in the study area. Underlying the sand and gravel is an impermeable, gray to bluish gray clay that is estimated to be at least 100 feet thick. The surface of this clay unit slopes sharply eastward.

Ground-water flow is from the Air Station northeastward toward East Bay and is estimated to be at 3 to 6 feet per day depending on hydraulic conductivity of the aquifer and gradient of the water table. Based on pumping tests, hydraulic conductivities ranged from 85 to 150 feet per day. A hydraulic conductivity of 120 feet per day, used in a ground-water flow model, provided the best match of field data. The depth to water ranges from about 1 foot near East Bay to about 20 feet about 1,000 feet south of the bay.

Organic chemicals, characteristic of solvents, cleaning agents, paints and related products, and fuel substances, occur in the ground-water system. Some of the chemicals and their maximum concentrations are: benzene, 3,390 µg/L; toluene, 55,500 µg/L; xylene, 3,900 µg/L; phenol, 310 µg/L; trichloroethyelene, 420 µg/L; dichloroethylene, 295 µg/L; tetrachloroethylene, 3,410 µg/L; and bis (2-ethyl hexyl) phthalate, 2,100 µg/L.

A plume of contamination, 4,300 feet long and ranging from 180 to 400 feet wide, extends from the Air Station to East Bay. In the vicinity of the Hangar/Administration building, hydrocarbons less dense than water (benzene, toluene, and xylene), tend to "float" on the ground-water surface before mixing and moving downward in the aquifer. Concentrations of contaminants generally decrease downgradient; some contaminants are not detected in the northern part of the plume. Upward movement of ground water north of Pine Grove Avenue results in as much as 20 µg/L benzene in East Bay 300 feet offshore.

Soils at most locations have not adsorbed benzene, toluene, and xylene. Higher molecular weight hydrocarbons, characteristic of petroleum distillates, were detected on soils near the Hangar/Administration building. Near the northwest corner of the building, as much as 1,100 µg/kg of tetrachloroethylene was detected. Also near the northwest corner and just west of the Hangar/Administration building, soils at 10 feet below the surface contained as much as 1,500 µg/kg bis (2-ethyl hexyl) phthalate, 870 µg/kg di-n-butyl phthalate, and 370 µg/kg diethyl phthalate.

A comparison of possible sources of contamination and past chemical usage with analyses of water and soils suggest that the origin of the plume is near the Hangar/Administration building. Upgradient from this area 600 to 700 feet, comparatively low concentrations of toluene were detected in water, but any upgradient source is not believed to be a significant contributor to the major plume. The old U.S. Navy waste dump does not seem to be contributing contaminants to the ground-water system.

Model simulations of the ground-water flow system indicate that water containing contaminants can be removed by purge wells either along the full length of the plume of contamination or in only the south part of the plume. The north part of the plume, however, is in a densely residential area; installation of purge wells could be difficult. Simulations for the south part of the plume indicate that four wells near the Hangar/Administration building, two pumping at 50 gal/min and two at 25 gal/min, could provide for hydrologically efficient purging of the system without removing significant amounts of uncontaminated water.

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TABLES OF DATA

Table 1.--Location and identification of wells in East Bay Township and at the U.S. Coast Guard Air Station

Local identifier	Altitude of measuring point (feet)	Drilled depth below land surface (feet)	Depth of screen below land surface (feet)	Casing diameter (inches)	Height of measuring point above land surface (feet)	Water level below measuring point (feet)	Depth to top of clay below land surface (feet)	Altitude top of clay (feet)	Date water level measured
K1D	615.70	59	54-57	4.00	2.0	14.14	58	556	July 20, 1983
K1S	615.04	24	21-24	4.00	1.5	13.43	--	--	Do.
K2D	611.98	55	51-55	4.00	1.5	10.48	--	--	Do.
K2S	612.33	25	21-25	4.00	1.3	10.85	--	--	Do.
K3D	613.98	55	47-51	4.00	1.5	12.53	55	557	Do.
K3S	613.83	26	22-26	4.00	1.4	12.30	--	--	Do.
K4D	616.55	50	46-50	4.00	1.8	15.11	50	565	Do.
K4S	616.36	25	21-25	4.00	1.6	14.89	--	--	Do.
K5D	616.71	59	39-42	4.00	1.6	15.16	46	569	July 19, 1983
K5S	616.52	25	22-25	4.00	1.4	14.92	--	--	Do.
K6D	617.53	38	34-38	4.00	1.5	15.88	38	578	Do.
K6S	617.27	25	21-25	4.00	1.7	15.61	--	--	Do.
K7D	615.58	36	30-34	4.00	1.5	13.95	36	578	Do.
K7S	615.57	25	21-25	4.00	1.6	13.93	--	--	Do.
K8D	616.17	33	28-32	4.00	1.8	14.62	33	581	Do.
K8S	615.78	25	21-25	4.00	1.5	14.22	--	--	Do.
K9D	615.22	50	31-34	4.00	1.6	13.74	37	577	Do.
K9S	615.10	24	21-24	4.00	1.5	13.63	--	--	Do.
K10S	613.83	24	21-24	4.00	1.9	14.71	--	--	July 20, 1983
K11D	614.41	35	29-32	4.00	2.1	15.10	33	579	July 19, 1983
K11S	613.92	24	21-24	4.00	1.6	14.62	--	--	July 20, 1983
K12S	614.18	24	21-24	4.00	2.1	14.71	--	--	Do.
K13D	611.80	37	31-34	4.00	2.4	16.17	37	572	Do.
K13S	611.68	24	21-24	4.00	2.0	15.99	--	--	Do.
K14D	612.06	37	32-35	4.00	2.7	16.29	36	573	Do.
K14S	611.40	24	21-24	4.00	1.8	15.55	--	--	Do.
K15D	611.81	35	30-33	4.00	1.9	15.35	34	576	Do.
K15S	611.75	24	21-24	4.00	1.8	15.25	--	--	Do.
K16D	610.96	49	42-46	4.00	1.9	17.68	48	561	Do.
K16S	610.21	30	27-30	4.00	1.4	16.96	--	--	Do.
K17D	609.44	62	52-56	4.00	1.9	16.70	--	--	Do.
K17S	608.26	29	26-29	4.00	1.3	15.56	--	--	Do.
K18D	609.07	67	58-62	4.00	1.9	16.67	--	--	Do.
K18S	608.45	29	26-29	4.00	1.5	16.06	--	--	Do.
K19D	609.06	57	53-57	4.00	1.9	16.93	--	--	Do.
K19S	608.75	30	26-30	4.00	1.5	16.67	--	--	Do.
K20D	609.24	57	53-57	4.00	2.1	17.40	--	--	Do.
K20S	608.70	30	26-30	4.00	1.5	16.90	--	--	Do.
K21S	621.27	32	25-28	4.00	1.5	16.53	--	--	Do.
K22S	611.37	32	23-26	4.00	1.5	14.99	--	--	Do.

Table 1.--Location and identification of wells in East Bay Township and at the U.S. Coast Guard Air Station--Continued

Local identifier	Altitude of measuring point (feet)	Drilled depth below land surface (feet)	Depth of screen below land surface (feet)	Casing diameter (inches)	Height of measuring point above land surface (feet)	Water level below measuring point (feet)	Depth to top of clay below land surface (feet)	Altitude top of clay (feet)	Date water level measured
K23D	610.45	41	34-37	4.00	2.0	16.63	39	569	July 20, 1983
K23S	609.97	24	21-24	4.00	1.5	16.05	--	--	Do.
K24D	612.82	65	55-58	4.00	2.1	15.28	--	--	Do.
K24S	611.91	25	22-25	4.00	1.5	14.42	--	--	Do.
K25S	595.53	42	21-25	4.00	4.0	11.27	32	560	Do.
K26S	611.28	27	24-27	4.00	2.4	17.83	--	--	Do.
K27S	609.51	34	31-34	4.00	1.5	21.23	--	--	Do.
K28S	606.33	29	25-28	4.00	2.3	18.24	--	--	Do.
K29D	588.88	117	49-52	4.00	1.5	6.02	110	477	Do.
K29S	588.70	20	17-20	4.00	1.4	5.84	--	--	Do.
K30S	595.90	23	19-22	4.00	2.0	9.48	--	--	Do.
K31D	616.47	39	25-28	4.00	2.0	12.18	32	582	July 19, 1983
K32D	612.27	118	54-57	4.00	2.0	17.12	118	492	Do.
K33S	618.51	30	19-22	4.00	2.2	13.47	29	587	Do.
K34S	614.26	30	27-30	4.00	2.7	15.86	--	--	July 20, 1983
K35D	610.01	46	42-45	4.00	2.9	18.41	--	--	Do.
K35S	610.09	27	24-27	4.00	3.0	18.56	--	--	Do.
K36D	608.76	45	42-45	4.00	2.3	17.40	--	--	Do.
K36S	609.41	30	27-30	4.00	2.9	18.07	--	--	Do.
K37D	608.60	53	40-43	4.00	1.9	16.08	--	--	Do.
K38D	609.61	53	43-46	4.00	2.2	17.21	--	--	Do.
K39S	611.05	32	29-32	4.00	1.8	15.74	--	--	Do.
K40D	612.06	50	28-31	4.00	2.6	16.27	--	--	Do.
K41S	617.92	23	20-23	4.00	2.5	15.40	--	--	July 19, 1983
K42S	619.23	26	23-26	4.00	2.5	16.67	--	--	Do.
K43S	618.48	23	20-23	4.00	2.3	16.00	--	--	Do.
K44S	618.11	23	20-23	4.00	2.3	15.22	--	--	Do.
K45S	616.0	34	23-26	4.00	0.0	14.32	34	582	Dec. 1, 1982
K46S	618.56	24	20-23	4.00	2.5	15.65	--	--	July 19, 1983
K47D	599.47	48	33-36	4.00	1.1	12.61	--	--	July 20, 1983
K48S	586.53	7	3-7	4.00	1.9	5.01	--	--	June 6, 1983
K49D	601.88	59	56-59	4.00	1.0	14.42	--	--	July 20, 1983
K50D	600.89	59	56-59	4.00	1.3	13.58	--	--	Do.
K51D	601.48	59	56-59	4.00	1.0	14.23	--	--	Do.
K52D	603.29	54	51-54	4.00	2.1	15.81	--	--	Do.
K53D	607.68	52	49-52	4.00	1.1	17.72	--	--	Do.
K54D	607.46	52	49-52	4.00	0.0	17.78	--	--	April 7, 1983
K55D	607.28	43	40-43	4.00	1.8	16.37	--	--	July 20, 1983
K55S	607.45	29	26-29	4.00	1.9	16.57	--	--	Do.
K56D	607.98	43	39-42	4.00	1.3	16.80	--	--	Do.

Table 1.--Location and identification of wells in East Bay Township and at the U.S. Coast Guard Air Station--Continued

Local identifier	Altitude of measuring point (feet)	Drilled depth below land surface (feet)	Depth of screen below land surface (feet)	Casing diameter (inches)	Height of measuring point above land surface (feet)	Water level below measuring point (feet)	Depth to top of clay below land surface (feet)	Altitude top of clay (feet)	Date water level measured
K56S	608.05	28	25-28	4.00	1.4	16.93	--	--	July 20, 1983
K57S	609.52	28	24-28	4.00	1.2	16.58	--	--	Do.
K58D	593.37	44	40-44	4.00	2.0	9.06	--	--	Do.
K59D	588.38	47	43-47	4.00	0.0	4.66	--	--	Do.
K60D	588.77	47	43-47	4.00	0.0	4.93	--	--	Do.
K61	627.47	29	26-29	2.00	4.1	30.43	--	--	June 10, 1983
K62	626.69	19	16-19	2.00	2.7	20.56	--	--	Do.
K63	626.63	8	5-8	2.00	1.3	5.99	--	--	Do.
K64	620.86	8	5-8	2.00	2.3	6.05	--	--	Do.
K65	614.65	8	5-8	2.00	1.4	6.20	--	--	Do.
KT	613.78	33	26-31	6.00	1.9	14.35	32	580	June 8, 1983
KT1	614.57	15	12-15	2.00	2.6	15.11	--	--	Do.
KT2	614.66	15	12-15	2.00	2.7	15.18	--	--	Do.
KT3	614.40	16	13-16	2.00	2.0	14.69	--	--	Do.
KT4	615.10	16	13-16	2.00	2.3	14.78	--	--	Do.
EB1	612.64	30	22.2-24.7	2.00	2.8	18.41	--	--	June 10, 1981
EB2	612.83	35	22.0-24.5	2.00	3.0	17.08	--	--	Do.
EB3	613.19	25	21.7-24.2	2.00	3.3	17.63	--	--	Do.
EB4	610.39	55	42.5-45.0	2.00	3.0	18.76	--	--	Do.
EB5	609.85	25	21.5-24.0	2.00	2.5	18.19	--	--	Do.
EB6	610.91	50	42.0-44.5	2.00	3.5	19.71	--	--	Do.
EB7	609.45	30	23.0-25.5	2.00	2.1	18.31	--	--	Do.
EB8	613.57	50	42.5-45.0	2.00	3.5	17.97	--	--	Do.
EB9	611.42	37	23.6-26.1	2.00	2.4	16.73	36	573	Do.
EB10	612.28	30	22.1-24.6	2.00	2.4	17.04	--	--	Do.
EB11	613.25	30	24.0-26.5	2.00	2.6	16.39	--	--	July 20, 1983
EB12	612.50	30	23.7-26.2	2.00	2.3	15.90	--	--	June 10, 1981
EB13	614.20	30	21.7-24.2	2.00	2.8	15.52	--	--	July 20, 1983
EB14	615.76	25	20.0-22.5	2.00	3.1	16.13	--	--	Do.
EB15	615.84	30	20.6-23.1	2.00	2.4	17.38	--	--	June 10, 1981
EB16	614.13	25	21.7-24.2	2.00	1.3	14.80	--	--	July 20, 1983
EB17	615.51	25	21.3-23.8	2.00	1.7	14.79	--	--	Do.
EB18	615.36	25	21.0-23.5	2.00	1.5	15.06	--	--	June 10, 1981
EB19	616.38	30	24.4-26.9	2.00	2.6	13.35	--	--	July 19, 1983
EB20	616.18	30	24.9-27.4	2.00	2.1	14.15	--	--	June 10, 1981
EB21	616.84	30	24.5-27.0	2.00	2.5	14.39	--	--	Do.
EB22	617.08	30	25.2-27.7	2.00	2.3	13.71	--	--	Do.
EB23	616.92	30	24.7-27.2	2.00	2.3	12.99	--	--	Do.
EB24	617.39	30	25.3-27.8	2.00	2.2	11.51	--	--	July 19, 1983

Table 2.--Analyses of volatile organic compounds in ground water
[Analyses by U.S. Geological Survey. ND indicates not detected.]

Well number	Date	Benzene (μg/L)	Toluene (μg/L)	Xylene (μg/L)	Ethyl benzene (μg/L)	Trichloro-ethylene (μg/L)	1,2 Di-chloro-ethylene (μg/L)	Tetra-chloro-ethylene (μg/L)	1,2 Di-chloro-ethane (μg/L)	1,1,1 Tri-chloro-ethane (μg/L)	Carbon tetra-chloride (μg/L)	Dichloro-methane (μg/L)	Phenol (μg/L)
K1D	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K1S	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
K2D	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K2S	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	13
K3D	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K3S	August 31, 1982	ND	ND	ND	ND	3.8	ND	ND	ND	ND	ND	ND	3
K4D	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
K4S	August 31, 1982	ND	2.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	4
K4D	March 3, 1983	ND	3.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K4S	March 3, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K5D	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3
K5S	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	52
K5D	March 3, 1983	ND	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K5S	December 3, 1982	2,040	3,880	3,400	68	ND	ND	ND	ND	ND	ND	ND	116
K6D	August 31, 1982	60	564	ND	ND	6.0	ND	25	5.6	6.8	ND	ND	5
K6S	August 31, 1982	90	18,000	696	ND	25	69	ND	ND	26	ND	ND	66
K7D	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K7S	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4
K8D	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K8S	August 31, 1982	ND	ND	ND	ND	11	ND	ND	ND	ND	ND	ND	3
K9D	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
K9S	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4
K10S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K11D	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K11S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K12S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K13D	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K13S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	6.6	ND	ND	ND	9
K14D	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K14S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4
K15D	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K15S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	19
K16D	September 1, 1982	ND	ND	ND	ND	10	ND	ND	ND	ND	ND	ND	<1
K16S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K17D	September 1, 1982	2.7	2.0	ND	ND	43	19	ND	2.9	ND	ND	ND	<1
K17S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
K18D[a/]	September 1, 1982	76	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
K18S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K19D	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K19S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K20D	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
K20S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K21S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K22S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K23D	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K23S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	7	ND	3
K24D	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K24S	September 1, 1982	131	1,400	106	12	ND	ND	ND	ND	ND	ND	ND	<1
K25S	September 1, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K28S	November 29, 1982	1.8	4.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K29S	November 29, 1982	ND	7.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	8
K29D	November 29, 1982	ND	Trace	ND	ND	ND	ND	ND	ND	ND	ND	ND	7
K33S	December 1, 1982	5.2	64	ND	ND	ND	ND	ND	ND	ND	ND	ND	7
K34S	December 2, 1982	3,390	ND	892	67	ND	92	ND	ND	ND	ND	ND	12
K35S	December 3, 1982	ND	5.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K35D	December 3, 1982	ND	3.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K36S	December 1, 1982	ND	3.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K36D	December 1, 1982	ND	2.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1

a/ Methyl hexanone - trace

Table 2.--Analyses of volatile organic compounds in ground water--Continued

Well number	Date	Benzene (μg/L)	Toluene (μg/L)	Xylene (μg/L)	Ethyl benzene (μg/L)	Trichloro-ethylene (μg/L)	1,2 Di-chloro-ethylene (μg/L)	Tetra-chloro-ethylene (μg/L)	1,2 Di-chloro-ethane (μg/L)	1,1,1 Tri-chloro-ethane (μg/L)	Carbon tetra-chloride (μg/L)	Dichloro-methane (μg/L)	Phenol (μg/L)
K37-33'	December 3, 1982	906	ND	ND	ND	11	28	ND	ND	ND	ND	26	--
K37-40'	December 3, 1982	399	147	ND	ND	39	190	ND	ND	ND	ND	30	<1
K37-50'	December 3, 1982	995	2,660	170	20	ND	32	ND	ND	ND	ND	32	--
K38-33'	December 3, 1982	1,270	3,410	88	18	ND	ND	ND	ND	ND	ND	32	--
K38-43'	December 3, 1982	30.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	28	<1
K38-50'	December 3, 1982	85.7	4.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K39S	December 3, 1982	1,620	13,020	1,610	65	ND	ND	ND	ND	ND	ND	19	284
K40D-21'	December 3, 1982	11	39	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K40D-29'	December 3, 1982	86	ND	ND	ND	10	209	ND	ND	ND	ND	ND	--
K40D-37'	December 3, 1982	960	ND	ND	ND	ND	295	ND	ND	ND	ND	ND	<1
K40D-47'	December 3, 1982	5.9	ND	ND	ND	16	31	ND	ND	ND	ND	11	--
K41S	December 3, 1982	ND	4.2	ND	ND	2.9	ND	17	ND	ND	ND	ND	<1
K42S	December 3, 1982	ND	Trace	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K43S	December 3, 1982	ND	9.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K44S	December 3, 1982	ND	4.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K45S	December 3, 1982	ND	5.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K46S	December 3, 1982	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K47D-20'	December 3, 1982	ND	ND	ND	ND	5.7	ND	ND	ND	ND	ND	ND	<1
K47D-33'	December 3, 1982	ND	7.6	ND	ND	3.5	ND	ND	ND	ND	ND	ND	<1
K47D-45'	December 3, 1982	ND	4.6	ND	ND	1.1	ND	ND	ND	ND	ND	ND	<1
K48S	June 7, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K49D-22'	March 29, 1983	ND	2.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	9
K49D-38'	March 29, 1983	1,340	1,640	ND	ND	18	ND	ND	ND	ND	ND	ND	74
K49D-56'	March 29, 1983	208	608	ND	ND	16	ND	ND	ND	ND	ND	ND	97
K50D-22'	March 30, 1983	187	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7
K50D-33'	March 30, 1983	3,030	5,110	65	11	ND	ND	ND	ND	ND	ND	ND	310
K50D-56'	March 30, 1983	362	25	ND	ND	ND	ND	ND	5.4	ND	ND	ND	7
K50.5	March 30, 1983	ND	4.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
K51D-22'	March 31, 1983	ND	4.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K51D-37'	March 31, 1983	360	ND	ND	ND	138	206	ND	5.9	ND	ND	ND	1
K51D-52'	March 31, 1983	352	ND	ND	ND	137	30	ND	ND	ND	ND	ND	1
K52D-23'	April 8, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K52D-38'	April 8, 1983	15	3.6	ND	ND	4.1	ND	ND	ND	ND	13	ND	<1
K52D-52'	April 8, 1983	111	ND	ND	ND	44	77	ND	ND	ND	ND	ND	<1
K53D-25'	April 6, 1983	ND	ND	ND	ND	59	ND	ND	ND	ND	ND	ND	<1
K53D-38'	April 6, 1983	ND	ND	ND	ND	65	ND	ND	ND	ND	ND	ND	<1
K53D-49'a/	April 6, 1983	ND	ND	ND	ND	37	ND	ND	ND	ND	ND	ND	<1
K54D-25'	April 7, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K54D-38b/	April 7, 1983	ND	ND	ND	ND	107	23	ND	ND	ND	ND	ND	<1
K54D-48'	April 7, 1983	12	ND	ND	ND	105	70	ND	ND	ND	ND	ND	<1
K55S	March 29, 1983	ND	6.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K55D	March 29, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K56S	April 8, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K56D	April 8, 1983	ND	5.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
K57S	March 30, 1983	ND	14	ND	ND	5.9	ND	ND	ND	ND	ND	ND	<1
K58D-18'	May 24, 1983	ND	3.7	ND	ND	29	ND	ND	ND	ND	ND	ND	<1
K58D-30'	May 24, 1983	400	3.0	ND	ND	110	ND	ND	ND	ND	ND	ND	8
K58D-40'c/	May 24, 1983	1,470	190	ND	ND	92	ND	ND	ND	ND	ND	ND	61
K59D-5'd/	May 23, 1983	22	3.2	ND	ND	1.0	ND	ND	ND	ND	ND	ND	--
K59D-18'	May 25, 1983	6.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K59D-30'	May 25, 1983	15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
K59D-43'e/	May 25, 1983	1,970	940	ND	ND	10	4.9	ND	10	ND	ND	ND	110
K60D-18'	May 24, 1983	Trace	Trace	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
K60D-30'	May 25, 1983	ND	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	3
K60D-43'	May 25, 1983	ND	Trace	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1

a/ Chloroform, 19 μg/L

b/ Chloroform, 6.2 μg/L

c/ Unknown hydrocarbon - best match is 2,2-dimethyldecane, 12 μg/L; unknown hydrocarbon - best match is 4-ethyl-2,2,6,6-tetramethylheptane, 420 μg/L

d/ 2,2-dimethylhexane, 4.1 μg/L; 3-heptanone, 4.8 μg/L

e/ Oxetane, 5.8 μg/L; 3-hydroxy-4-methyl-5-keto-2-heptene, 680 μg/L; 5,5-dimethyl-2-hexene, 6.1 μg/L

Table 2.--Analyses of volatile organic compounds in ground water--Continued

Well number	Date	Benzene (µg/L)	Toluene (µg/L)	Xylene (µg/L)	Ethyl benzene (µg/L)	Trichloro-ethylene (µg/L)	1,2 Di-chloro-ethylene (µg/L)	Tetra-chloro-ethylenc (µg/L)	1,2 Di-chloro-ethane (µg/L)	1,1,1 Tri-chloro-ethane (µg/L)	Carbon tetra-chloride (µg/L)	Dichloro-methane (µg/L)	Phenol (µg/L)
S5a/b/	March 3, 1983	49	8,400	920	53	ND	ND	ND	ND	ND	ND	ND	--
S8	March 3, 1983	441	55,500	3,800	216	ND	ND	ND	ND	ND	ND	ND	--
S10	March 3, 1983	1,100	31,000	1,960	ND	ND	ND	ND	ND	ND	ND	ND	--
S12	March 3, 1983	ND	10,200	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S14	March 2, 1983	1,500	33,600	3,900	ND	ND	ND	ND	ND	ND	ND	ND	--
S17c/	March 2, 1983	ND	ND	2,800	ND	420	ND	ND	ND	ND	ND	ND	--
S19	March 2, 1983	1,100	24,200	3,600	320	ND	ND	ND	ND	ND	ND	ND	--
S20	March 2, 1983	ND	ND	ND	ND	ND	ND	95	ND	ND	ND	ND	--
S22d/	March 2, 1983	ND	30,200	3,600	ND	ND	ND	ND	ND	ND	ND	ND	--
S23	March 3, 1983	5	127	15	ND	ND	ND	ND	ND	ND	ND	ND	--
S24	March 3, 1983	ND	74	5	ND	ND	ND	ND	ND	ND	ND	ND	--
S25	March 3, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S26	April 1, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S27e/	April 1, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S28f/	April 1, 1983	1,670	7,450	1,690	ND	ND	ND	ND	ND	ND	ND	ND	--
S29	April 1, 1983	ND	64	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S30	April 7, 1983	ND	5,720	439	ND	ND	ND	ND	ND	ND	ND	ND	--
S31	April 7, 1983	ND	5.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S32	April 7, 1983	ND	ND	197	ND	362	207	3,410	ND	ND	ND	ND	--
S33	April 7, 1983	ND	ND	ND	ND	ND	ND	113	ND	ND	ND	ND	--
S34	April 7, 1983	ND	9.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S35	May 6, 1983	ND	34,580	g/	24	ND	ND	ND	ND	ND	ND	ND	--
S36	June 8, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
AH1	June 8, 1983	ND	5.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
AH2	June 8, ,983	ND	4.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
EB2	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
EB10	August 31, 1982	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
EB11	August 31, 1982	1,300	12,000	3,600	102	ND	6.4	ND	5.9	ND	ND	ND	--
EB13	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
EB14	August 31, 1982	1,300	40,000	1,800	55	ND	ND	ND	ND	ND	ND	ND	--
EB16	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
EB21	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
EB22	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1
EB23	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
EB24	August 31, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
E918	November 3, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
E919	November 3, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
E934	April 7, 1983	85	19	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
E949	November 3, 1982	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
E954	November 3, 1982	30	ND	ND	ND	6.1	ND	ND	ND	ND	ND	ND	--
E962h/	November 3, 1982	1,471	1,260	100	ND	ND	ND	ND	ND	ND	ND	ND	--
M789	November 3, 1982	ND	ND	ND	ND	4.0	ND	ND	ND	ND	ND	ND	--

a/ Bromodichloromethane, 90 µg/L

b/ Chloroform, 374 µg/L

c/ Bromoform, 806 µg/L

d/ Bromoform, 1,000 µg/L

e/ Chloroform, 6,8 µg/L

f/ Chloroform, 133 µg/L

g/ Xylene present but diluted out during analysis

h/ Methyl hexanone detected in trace amount

Table 3.--Analyses of volatile organic compounds on soils
[Analyses by U.S. Geological Survey. ND indicates not detected.]

Well number	Date	Benzene (µg/kg)	Toluene (µg/kg)	Xylene (µg/kg)	Ethyl benzene (µg/kg)	Trichloro-ethylene (µg/kg)	1,2 Di-chloro-ethylene (µg/kg)	Tetra-chloro-ethylene (µg/kg)	1,2 Di-chloro-ethane (µg/kg)	1,1,1, Tri-chloro-ethane (µg/kg)	Carbon tetra-chloride (µg/kg)	Dichloro-methane (µg/kg)	Phenol (µg/kg)
S1-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S4-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S5-10'	March 3, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S7-10'	March 3, 1983	ND	2.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S8-10'	March 3, 1983	ND	2.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S9-10'	March 3, 1983	ND	4.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S13-10'	March 3, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S14-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S15-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S16-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S17-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S18-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	2.0	ND	ND	ND	ND	--
S20-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S21-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	16	ND	ND	ND	ND	--
S22-10'	March 2, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S26-4'	April 1, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S27-4'	April 1, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S28-1'a/	April 1, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S28-4'b/	April 1, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S28-10'c/	April 1, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S29-10'	April 1, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S30-5'	April 7, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S30-10'	April 7, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S32-1'd/	April 7, 1983	ND	5.7	ND	ND	29	ND	1,100	ND	ND	ND	ND	--
S32-4'	April 7, 1983	ND	ND	ND	ND	ND	ND	27	ND	ND	ND	ND	--
S32-11'e/	April 7, 1983	ND	ND	ND	ND	3.8	ND	410	ND	ND	ND	4.2	--
S35-10'f/	May 6, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--
S36-10'g/	June 7, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	--

a/ Ethanol, 0.6 µg/kg; 3,4-dimethylheptane, 0.7 µg/kg; 2,5,5-trimethyl-1-hexene, 4.4 µg/kg

b/ 2-propanone (acetone), 12 µg/kg; isobutyl alcohol, 4.1 µg/kg; 3,4-dimethylheptane, 7.4 µg/kg; 2,3,4-trimethylpentane, 6.1 µg/kg; 2,4,4-trimethyl-1-pentane, 3.2 µg/kg; 2,2,5-trimethylhexane, 4.8 µg/kg; 2,5,5-trimethyl-1-hexene, 14 µg/kg

c/ Ethanol, 0.7 µg/kg; tertiarybutyl alcohol, 4.4 µg/kg; 3,4-dimethylheptane, 8.5 µg/kg; 2,3,4-trimethylpentane, 4.1 µg/kg; 2,4,4-trimethyl-1-pentane, 3.1 µg/kg; 2,2,5-trimethylhexane, 6.6 µg/kg; 2,2,5-trimethyl-1-hexene, 18 µg/kg

d/ Ethanol, 0.9 µg/kg

e/ Ethanol, 0.7 µg/kg

f/ 3-methyl-2-propanol, 540 µg/kg; 2-propanone (acetone), 32 µg/kg; 2,3-dimethyl propane, 11 µg/kg; 2,2,3-trimethyl butane, 7.2 µg/kg; 2,4-dimethyl pentane, 240 µg/kg; 2,3-dimethyl pentane, 880 µg/kg; general hydrocarbons (substituted methyl pentanes, hexanes, etc.), 14,000 µg/kg

g/ 1-ethoxybutane, 41 µg/kg; 3-methyl-1-butene, 6.5 µg/kg; 3-methyl-2-pentene, 100 µg/kg; 2,2,6-trimethyloctane, 2.6 µg/kg; methylcycloheptane, 34 µg/kg; 5,5-dimethyl-2-hexene, 21 µg/kg; 3,4,4-trimethyl-2-pentene, 14 µg/kg; 2,2,4-trimethylhexane, 1.7 µg/kg; 4,4-dimethyl-2-hexene, 2.5 µg/kg; 2,5,5-trimethyl-2-hexene, 69 µg/kg; 1-ethyl-1-methylcyclopentane, 6.8 µg/kg

Table 4.--Analyses of base/neutral compounds in ground water and on soils
[Results of water analyses are in micrograms per liter (μg/L; results of soil analyses are in micrograms per kilogram (μg/kg). Analyses by U.S. Geological Survey.]

Well number	Sample	Date	Anthracene	2-Chloronaphthalene	Diethyl phthalate	Dimethyl phthalate	Di-n-butyl phthalate	Bis (2-Ethyl hexyl) phthalate	Fluoranthene	Fluorene	Naphthalene	Nitrobenzene	N-nitrosodi-n-propylamine	Phenanthrene	Pyrene
S35	Water	June 7, 1983	ND	ND	ND	ND	2	2,100	ND	ND	ND	55	78	ND	ND
S36	Water	June 7, 1983	ND	ND	ND	ND	2	ND	ND	ND	ND	ND	ND	ND	ND
S37	Water	June 7, 1983	ND	ND	ND	ND	1	1,000	ND	ND	2	6	ND	ND	ND
K39S	Water	June 8, 1983	ND	ND	1	ND	<1	1	ND	ND	18	ND	ND	ND	ND
K39WT	Water	June 8, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
K59D-43'	Water	July 20, 1983	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S-35-10'	Soil	June 7, 1983	ND	ND	300	ND	190	1,500	ND	ND	ND	ND	ND	ND	ND
S-36-10'	Soil	June 7, 1983	ND	ND	370	ND	200	1,500	ND	29	ND	ND	ND	ND	61
S-37-10'	Soil	June 7, 1983	ND	ND	310	43	540	740	ND	ND	ND	ND	ND	ND	ND
S-38-6'	Soil	June 7, 1983	14	41	330	29	870	400	31	ND	ND	ND	ND	92	58

Table 5.--Chemical and physical properties of organic compounds

Constituent	Boiling Point	Vapor Pressure	Specific Gravity	Density	Molecular Weight [a]	Solubility
Benzene	80.1°C[b]	76 mm at 20°C[c]	0.8786 [c]	0.8737 at -3.77°C[b]	78.11	1,800 mg/L at 25°C,[b] 1,780 mg/L at 20°C[c]
Toluene	110.6°C[d]	22 mm at 20°C[c]	0.867[c]	0.8669 at 20°C[d]	92.13	515 mg/L at 16°C[c]
O-Xylene	144.4°C[e]	5 mm at 20°C[c]	0.88[c]	0.8802 at 20°C[e]	106.17	175 mg/L as 20°C[c]
Ethyl Benzene	136.2°C[c]	7 mm at 20°C[c]	0.867[c]	0.8670 at 20°C[c]	106.17	152 mg/L at 20°C[c]
1,1;2-Trichloroethylene	86.7°C[f]	57.1 mm at 20°C[f]	1.465[f]	--	131.39	1,070 mg/L at 20°C[f]
Trans 1,2-Dichloroethylene	47.7°C[f]	267 mm at 20°C[f]	1.26[c]	1.2631 at 10°C[f]	96.95	6,300 mg/L at 25°C[f]
Carbon Tetrachloride	76.7°C[f]	89.6 mm at 20°C[f]	1.5947[f]	--	153.82	800 mg/L at 25°C,[f] 1,160 mg/L at 25°C[c]
1,2-Dichloroethane	83.7°C[f]	63.8 mm at 20°C[f]	1.25[c]	1.2529 at 20°C[f]	98.96	8.690 mg/L at 20°C[f]
1,1,2,2-Tetrachloroethylene	121.2°C[f]	10.0 mm at 13.8°C[f]	1.6226[f]	--	165.83	150 mg/L at 25°C[f]
1,1,1-Trichlorethane	74.0°C[f]	99.8 mm at 20°C[f]	1.35[c]	1.3249 at 20°C[f]	133.41	950 mg/L at 20°C,[f] 4,400 mg/L at 20°C[c]
Dichloromethane	39.8°C[f]	349 mm at 20°C[f]	1.320[f]	1.316 at 20°C[f]	84.93	13,200 mg/L at 20°C,[f] 20,000 mg/L at 20°C[c]
Phenol	181.8°C[g]	0.2 mm at 20°C[c]	1.07[c]	1.132 (solid) at 20°C[g]	94.11	83 mg/L at 15°C[c]
Methyl Isoamyl Ketone	144.9°C[h]	30 mm at 20°C[h]	.8127[h]	--	114.18	5,400 mg/L at 20°C[h]
Napthalene	217.9°C[c]	1 mm at 53°C[c]	1.152[c]	--	128.18	30 mg/L[c]

a/ Weast, 1968
b/ Kirk and Othmer, v. 3, 1979
c/ Verschveren, 1977
d/ Kirk and Othmer, 1969
e/ Kirk and Othmer, 1970
f/ Kirk and Othmer, v. 5, 1979
g/ Kirk and Othmer, 1982
h/ Kirk and Othmer, 1981

Table 6.--Concentrations of benzene and toluene in water of East Bay
[Analyses by U.S. Geological Survey. ND indicates not detected.]

Site	Date	Benzene (μg/L)	Toluene (μg/L)
1	July 20, 1983	5.5	ND
2	June 8, 1983	3.3	ND
	July 20, 1983	11	ND
3	July 20, 1983	4.2	ND
4	July 20, 1983	2.3	ND
[a]5	July 20, 1983	20	3.1
6	July 20, 1983	5.6	2.1
7	July 20, 1983	ND	2.5
8	July 20, 1983	ND	2.3
9	July 20, 1983	ND	ND

[a] Water also contained 1 μg/L bis (2-ethyl hexyl) phthalate.