DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS IN SOIL VAPOR IN THE VICINITY OF A DEFENSE FUEL SUPPLY POINT, HANAHAN, SOUTH CAROLINA

By J. Frederick Robertson, C. Marjorie Aelion, and Don A. Vroblesky

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ABSTRACT

Two passive soil-vapor sampling techniques were used in the vicinity of a defense fuel supply point near Hanahan, South Carolina, to identify areas of potential contamination of the shallow water table aquifer by volatile organic compounds, in particular benzene, toluene, ethylbenzene, and xylene, that are present in jet fuel. Both techniques involved the burial of samplers in the vadose zone and the saturated bottom sediments of a nearby stream and drainage ditch. One method, the empty-tube technique, allowed vapors to pass through a permeable membrane and accumulate inside an inverted empty test tube. A sample was extracted and analyzed on site using a portable gas chromatograph. As a comparison to this method, an activated-carbon technique also was used in certain areas. This technique uses a vapor collector consisting of a test tube containing activated carbon as a sorbent for VOC's. These samples were analyzed using Curie-point desorption mass spectrometry in the laboratory. Both techniques provided useful information concerning the areal distribution of volatile organic compounds.

The data from the empty-tube method were compiled using two approaches, 1) a total detector response (summation of chromatographic peak areas, measured in volt-seconds), and 2) tentative identification and concentrations of the individual targeted compounds toluene and ethylbenzene. The analyses of samples collected by the empty-tube technique identified several areas of potential contamination within the study area. Areas of relatively high total detector response in soil vapor were found northwest of the tank-farm facility, within the storage tank area, and along the southern boundary of the facility. The samplers placed in the bottom sediments of the stream and drainage ditch adjacent to the facility also detected the presence of volatile organic compounds at total response levels indicating potential contamination. The distribution of toluene detected by the empty-tube method was similar to that of the total response, with detection ranging from 1 part per billion to greater than 76,000 parts per billion (upper limit of calibration). The distribution of ethylbenzene was also similar to that of the total response, except for an absence of detection in most of the bottom-sediment samples. Ethylbenzene was detected at concentrations ranging from 10 parts per billion to greater than 76,000 parts per billion. The identification of toluene and ethylbenzene by portable gas chromatography is tentative.

The activated-carbon technique, though not used at all sample sites in the study area, showed a distribution of toluene that generally agreed with the distribution obtained by the empty-tube method. In addition to benzene, toluene, ethylbenzene, and xylene, the activated-carbon samplers also detected tetrachloroethylene, C_3 alkyl benzenes, and C_5-C_{10} cycloalkanes and alkenes. Analytical results from both methods showed a variable distribution of

volatile organic compounds in the bottom sediments of the stream and drainage ditch, which is possibly attributable to site hydrology, additional sources unrelated to the tank farm, or the transport and deposition of contaminated sediments.

INTRODUCTION

In 1975, tank 1 of a Defense Fuel Supply Point (DFSP)[1], near Hanahan, S.C., leaked a reported 83,000 gallons of JP-4 jet fuel. The leak contaminated water and sediment in the shallow water table aquifer beneath the facility with organic compounds, in particular, benzene, toluene, ethylbenzene, and xylene (collectively termed BTEX) (U.S. Army Environmental Hygiene Agency, 1975).

A hydrogeologic investigation carried out at the site in 1986 (McClelland Engineers, Inc., 1987) identified a BTEX-contamination plume extending north from the northern boundary of the DFSP facility (fig. 1). Further studies (RMT, Inc., 1988; 1989) suggested that additional plumes, probably unrelated to the 1975 spill, existed on the western side of the site near the truck-loading area, and on the eastern side of the site near the rail-loading area. Because the extent of contamination was not determined, the U.S. Geological Survey (USGS) in cooperation with the U.S. Navy, Southern Division Naval Facilities Engineering Command, initiated a soil-vapor survey to search for potential contamination in areas where additional contaminant plumes were suspected and the remaining areas of the facility where no data had been collected.

Purpose and Scope

This report describes the results of a reconnaissance study to identify areas of potential contamination of the water table aquifer by volatile organic compounds (VOC's) beneath a Defense Fuel Supply Point and adjacent properties near Hanahan, S.C. The results described in this report could be used to direct subsequent investigations of a more site-specific and quantitative nature. Six areas in and around the DFSP facility were investigated with soil-vapor techniques. The northern boundary area has been studied extensively and was, therefore, not included in this investigation.

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[1] The use of the facility name in this report is for descriptive or location purposes only and does not impute responsibility for any present or potential effects on the natural resources.

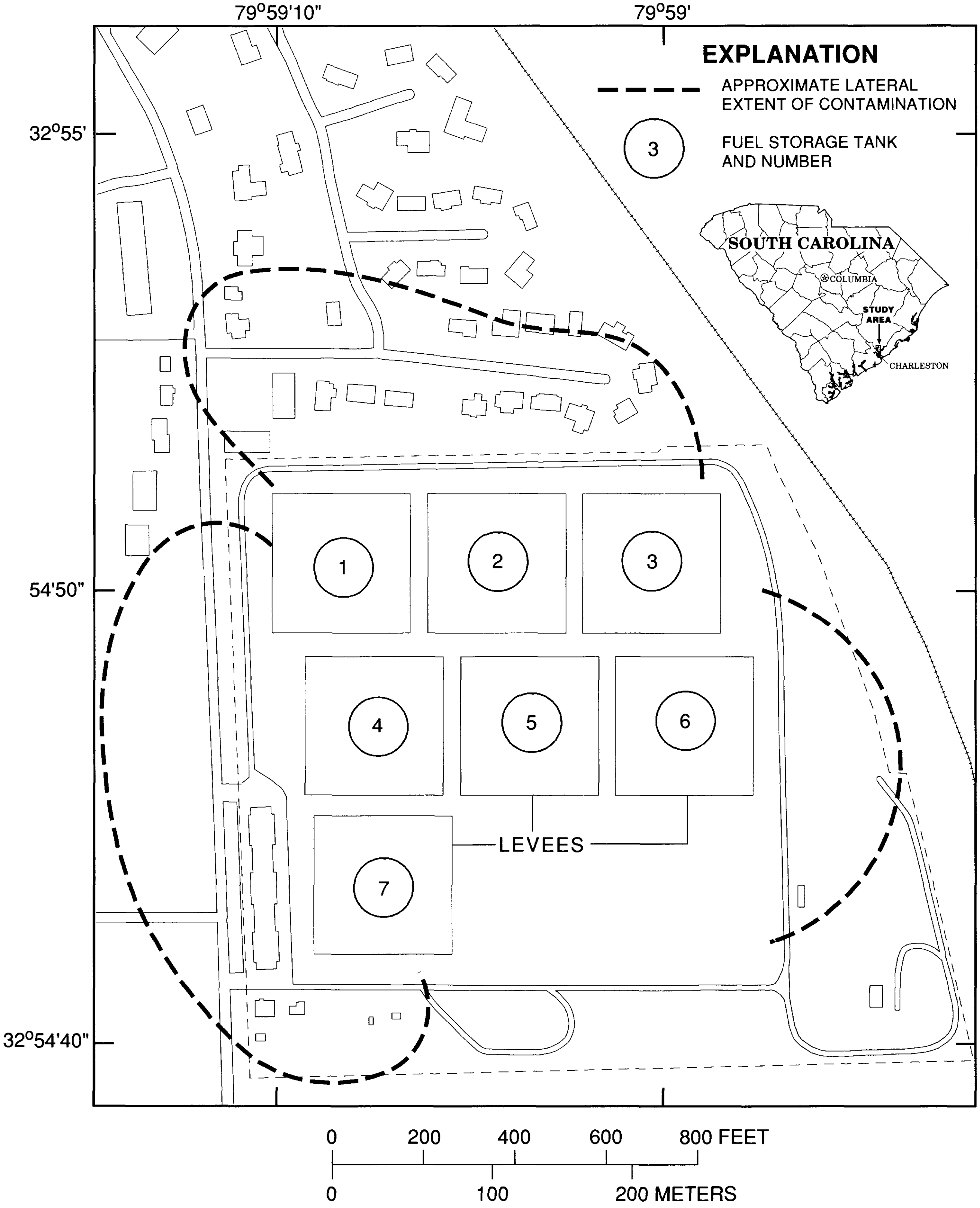

Figure 1.--Approximate lateral extent of possible contaminant plumes in the vicinity of a Defense Fuel Supply Point, near Hanahan, S.C., as determined by previous investigations (RMT, Inc., 1990).

<u>Approach</u>

A soil-vapor survey was made from mid-June to mid-July 1990 to aid in subsequent investigations of water table aquifer contamination beneath the facility and adjacent property. Two independent vapor collection techniques were used to make this reconnaissance of potential subsurface contamination by VOC's characteristic of petroleum products. Both soil-vapor techniques involved the burial of passive vapor collectors in the unsaturated zone and in the bottom sediments of streams. One technique, using empty test tubes, allowed vapors to pass through a permeable membrane and collect inside an inverted test tube, thereby reaching and maintaining equilibrium with the vapors of the soil. As a comparison of this technique to an independent method, Petrex[2] samplers that consisted of a test tube containing activated carbon as a sorbent for VOC's were placed with empty-tube samplers at selected sites.

Six areas in and around the DFSP facility were investigated with soil-vapor techniques (fig. 2): the western side of the site near the truck-loading area, the eastern side near the rail-loading area, the storage tank area, the southern side of the site, the stream located southwest of the facility, and the drainage ditch adjacent to the eastern boundary of the site. These areas are referred to as areas A, B, C, D, E, and F, respectively.

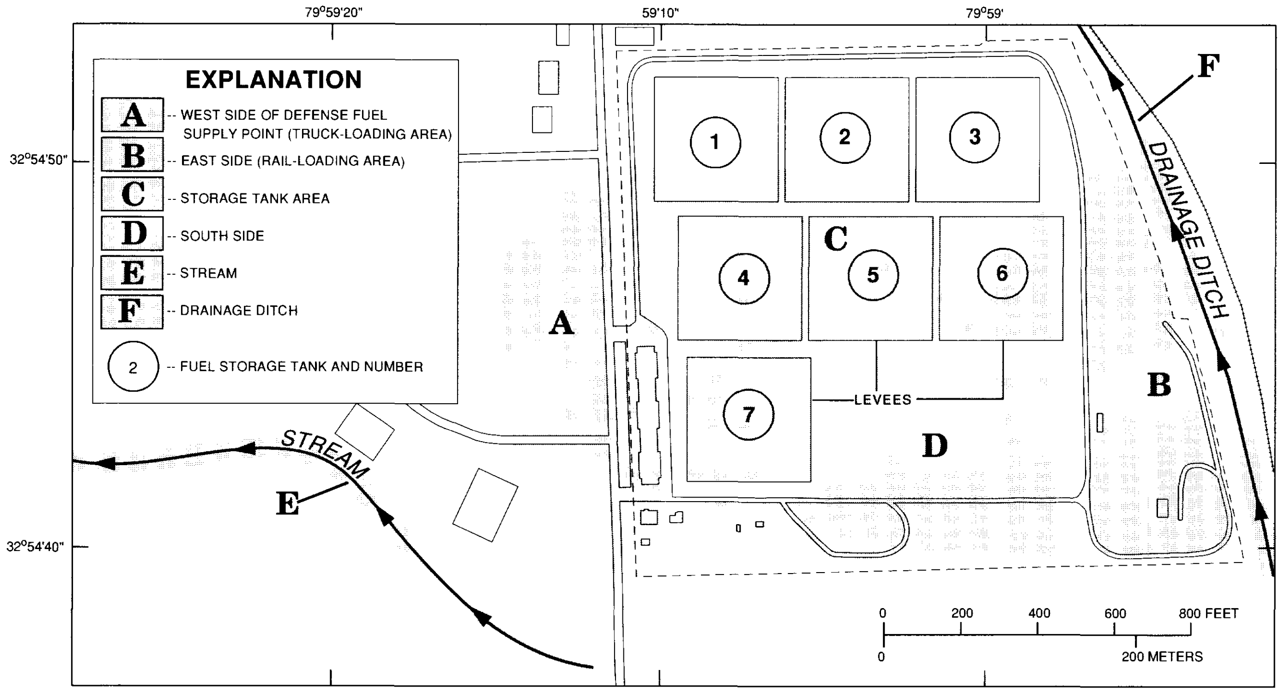

Figure 2.--Locations of study areas A through F in the vicinity of a Defense Fuel Supply Point, near Hanahan, S.C.

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[2] Use of trade, product, industry or firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

COLLECTION AND ANALYSES OF VOLATILE ORGANIC COMPOUNDS

The empty-tube technique was used in all six of the study areas (fig.2). The activated-carbon technique was used in areas A and E only. Vapors from the vadose zone were collected in areas A, B, C, and D and from the saturated stream-bottom sediment in areas E and F. The depth of the water table beneath areas A, B, C, and D was approximately 4 to 8 feet. Because the vapor samplers in areas E and F were buried in saturated bottom sediments of a gaining stream and drainage ditch, they were in contact with ground water prior to its discharge.

Empty-Tube Technique

An *in situ*, passive sampling technique modified from that used by Vroblesky and others (1991) was used in this study. The vapor sampler consisted of a 0.98 X 5.91 inch borosilicate glass test tube placed in a resealable, waterproof, polyethylene bag, of 1.15-mil thickness, configured so that the inverted open end of the test tube was covered by a single layer of polyethylene. The bags are permeable to organic vapors and allow these vapors to accumulate in the test tube (Vroblesky and others, 1991). Upon retrieval of the sampler, a sample of accumulated gases was immediately extracted by using a gas-tight syringe to penetrate the polyethylene bag. A layer of transparent tape was placed over the polyethylene prior to inserting the syringe to minimize tearing. The gas was slowly pulled into the syringe and pushed back out into the tube approximately three times before collecting the final sample. The effects of creating a slight vacuum in the tubes were considered to be unimportant, because the volume of the syringe was small relative to the volume of the test tubes. The gas in the syringe was then injected into the portable gas chromatograph (GC) and analyzed on site.

In general, the method for field GC analysis used during this investigation was consistent with the protocol described by Brock (1990). However, some site-specific variations with regard to sample collection and standard preparation as described in this report and by Vroblesky and others (1992) were incorporated.

The gas chromatograph was equipped with a capillary column, a photoionization detector, and an automatic integrator. Compound-specific retention times were determined by using a chromatographic-grade benzene, toluene, ethylbenzene and ortho-xylene gas standard. The individual BTEX compounds were tentatively identified by matching the retention times of sample peaks to the retention times of the standard peaks. Compound identification by portable gas chromatography must be considered tentative until confirmed by laboratory analysis. Three calibration ranges measured in volt-seconds for each compound were created to provide accurate peak quantification over concentrations of less than 90 ppb (low), from 90 to 730 ppb (medium), and from 730 to 76,000 ppb (high). This method of analysis allowed conversion of peak areas to compound concentrations for benzene, toluene, ethylbenzene, and ortho-xylene. Sample peaks which plotted off scale when using the highest calibration range could not be accurately quantified. These sample values were considered to be greater than 76,000 ppb, which was the upper limit of calibration. Sample peaks which were not off scale but exceeded the upper calibration limit were quantified, however, these values were considered as estimates. Areas of the remaining unidentified peaks were given in volt-seconds. For the remainder of this report, the use of the term xylene will refer to ortho-xylene.

Prior to placement of the samplers in the field, the test tubes were heated to 257 ^{0}F for a minimum of 76 hours to remove organic residues that may have been present on the tubes. The test tubes were then wrapped in aluminum foil for transport to the field. During installation, individual tubes were unwrapped and immediately placed inside the polyethylene bag so that only a single layer of polyethylene covered the opening of the tube. The bag was wrapped around the tube to remove excess air, then sealed and taped into place. A minimum of two samplers was placed at each location.

The samplers were buried at a depth of approximately 2 feet at 114 node points of a grid to encompass all areas of the site except the northern boundary area. Grid spacing was from 50- to 250-foot intervals in areas A, B, C, and D (fig. 3). Four- to six-inch diameter holes were dug with either a hand auger or post hole digger. The excavated soil was placed on a polyethylene sheet and was used as backfill for the respective hole. After the completion of each hole, the digging tool was rinsed with water to remove dirt and reduce cross contamination. At locations where a clay layer was encountered at the 2-foot depth, the samplers were buried below the clay at a depth of 3 feet. Samplers placed in areas E and F were buried approximately 6 inches into the saturated bottom sediments at from 50- to 100-foot intervals along the length of the stream that was studied.

The minimum burial time was based on laboratory analysis of the time necessary for benzene, toluene, and xylene to equilibrate across the polyethylene membrane, and was established prior to sampler burial. Laboratory experiments indicated that an equilibration period of 1 day was sufficient for benzene and toluene at concentrations of 50, 500, and 5,000 ppb (Aelion, C.M., U.S. Geological Survey, unpublished data, 1990). For xylene, an equilibration period of 1 day was sufficient at 50 and 500 ppb; however, only 60 percent of the ambient concentration was recovered in the test tubes after 7 days of incubation at the 5,000 ppb concentration. Although 1 day appears to be sufficient time to allow for vapors in the samplers to equilibrate with vapors at low concentrations in the soil, all tubes were left buried for a minimum of 5 days.

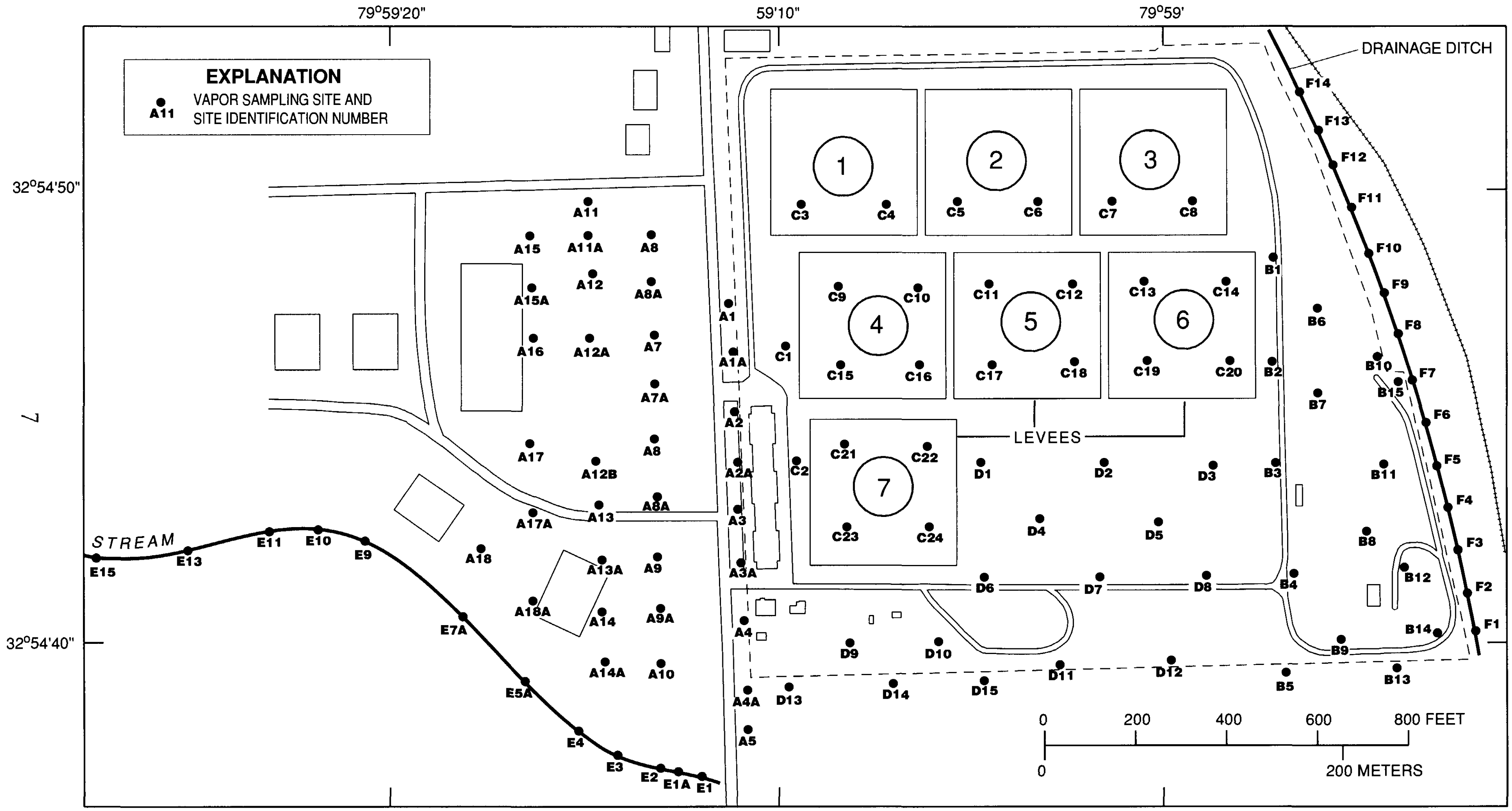

Figure 3.--Locations of soil-vapor sampling sites.

Several problems were encountered during empty-tube sample collection. These problems should be noted, because they could have affected sample integrity and were taken into account during the interpretation of the data. In many instances, particularly in area A, the polyethylene membrane covering the opening of the test tube had been torn or eaten while the samplers were in place. It was concluded that fire ants were responsible for the holes because of the coincidence of fire ants and holes at individual sampling sites. Supporting evidence to this conclusion was provided when a polyethylene bag buried in a fire-ant mound was retrieved the next day covered with holes similar to those found on the bags enclosing the samplers. It was assumed that samplers affected by fire ants could have lost a portion of the sample, therefore, these samples were considered to be underestimates of organic contamination. In those cases where sample integrity was compromised, the sample was discarded.

A less frequent problem involved small tears in the membrane where it touched the lip of the tube. These probably were caused by abrasion when the samplers were buried. Upon retrieval, samplers with small visible holes were immediately covered with tape. Samplers with large holes were discarded.

Another problem identified early in the collection process was sample cross contamination in area A caused by the adsorption of toluene onto the Teflon[2] coated syringe plunger. Samples thought to be affected by the cross contamination were discarded. Subsequently, gas-tight syringes were replaced by glass syringes in the remaining areas to avoid potential cross contamination. Comparison of vapor concentration changes in the glass syringes over the typical time interval required to transport samples from the field to the gas chromatograph (5-10 minutes) showed no identifiable vapor loss.

The data from the empty-tube analyses were compiled by using two approaches. The first method was a total detector response, which was a summation of the integration peak areas (in volt-seconds), of all detected VOC peaks, including BTEX and unidentified compounds, having retention times between 45 and 300 seconds. This time interval was chosen to closely bracket the retention times of the targeted compounds and to eliminate extraneous peaks. These values represent total flux response for each sample and are referred to as total response. Flux values of duplicate samples were averaged.

The total response values (in volt-seconds) of samples analyzed by using different calibration ranges cannot be directly compared. At different calibration ranges, the same peak area, or response, of an individual compound represents different compound concentrations. For example, at the low calibration range, a toluene response of 1.7 volt-seconds corresponds to a concentration of approximately 90 ppb; however, the same toluene response at the medium calibration range represents a concentration of approximately 730 ppb. At the high calibration range, a toluene response of 1.7 volt-seconds corresponds to a concentration of approximately 58,650 ppb. Most of the data used in plotting figure 4, however, were obtained by using the lowest calibration range. Data obtained by using other calibration ranges are identified by symbols. Duplicate sample values obtained using the same calibration range were generally comparable and were averaged.

The second method examined the concentrations (ppb) of the targeted compounds, benzene, toluene, ethylbenzene and xylene. By using chromatographic standards, these compounds can be tentatively identified, and their peak area response (volt-seconds) can be converted to concentrations. In this way, compound concentrations from various calibration ranges can be compared. The toluene and ethylbenzene peaks were the most reliable in terms of chromatographic quality, and therefore, these two compounds were used to assess individual compound concentrations.

Activated-Carbon Technique

As an independent comparison of the empty-tube technique, duplicate samples were taken at selected sites by using test tubes containing activated carbon as a sorbent for VOC's (Malley and others, 1985; Brower, 1987). The sampler consisted of a glass test tube filled with inert gas and contained a ferromagnetic wire to which activated carbon was chemically fused. The abundance of VOC's tested by using the activated-carbon samplers was analyzed by using Curie-point desorption mass spectrometry at a commercial laboratory. It is important to note that the results from the activated-carbon technique cannot be quantitatively compared to the results from the empty-tube method. The activated-carbon technique is a non-equilibrium approach in which residence time is a major factor influencing the detected concentration of VOC's, while the empty-tube technique is an equilibrium approach in which concentrations will no longer increase once equilibration is achieved.

An activated-carbon sampler was taped to empty-tube samplers and buried in the same hole at selected sites. Immediately prior to burial, the samplers were uncapped. Unlike the empty tubes, the activated-carbon tubes in the unsaturated zone were not put in polyethylene bags. Samplers in the stream-bottom sediments, however, were placed in polyethylene bags to keep sediment and water from entering the tubes.

A total of 20 activated-carbon samplers was installed; 15 in the unsaturated zone (area A) and 5 in the saturated bottom sediments (area E) (fig. 2). Five of the tubes contained duplicate samplers, an additional wire with activated carbon in the same tube. Two unopened field blanks, to detect possible contamination during transportation, accompanied the samplers from the laboratory to the field and were shipped back to the laboratory with the samples.

The samplers in the unsaturated zone were buried in the soil for 13 days, an amount of time bracketed by the recommended interval for samplers in the vadose zone (Malley and others, 1985). The samplers in the stream-bottom sediments were left undisturbed for 7 days, a period of time found to be sufficient for sorption of quantifiable amounts of VOC's from saturated bottom sediment onto the activated carbon (Vroblesky and others, 1991).

Upon retrieval of the activated-carbon samplers, the threads of the tube were wiped free of dirt with a clean towel, and the caps were securely replaced on the tubes. The samplers were then transported to an analytical laboratory where VOC's were thermally desorbed and analyzed by using mass spectrometry.

DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS

Although the results from the two vapor-collection techniques cannot be quantitatively compared, a comparison can be made between the distribution of relatively high and low concentrations of contaminants identified by each technique. Because the analysis of vapor from the empty tubes produced consistently good quality toluene peaks, this compound has been used to provide a comparison of the distributions derived by the two independent methods.

Empty-Tube Technique

The total response (volt-seconds), of VOC's having retention times between 45 and 300 seconds is shown in figure 4. A total response of 10 volt-seconds at the low calibration range appeared to delineate areas of elevated concentrations of VOC's in soil vapor. For the purpose of delineation, samples with a total response of less than 10 volt-seconds at the low-calibration range were considered to be relatively free of VOC's and are shown in figure 4 as a sampling point with no value given. Most samples were quantified by using the low calibration range, and these flux values were used to define areas of high concentrations. Values from samples analyzed by using higher calibration ranges are also plotted in figure 4 and identified according to calibration range. Sample values assumed to be minimal due to suspected loss of a portion of the sample also are denoted. Total response values along with calibration ranges for all samples are presented in table 1. Duplicate samples analyzed at different calibration ranges could not be averaged, therefore, both sample values are given in table 1. Concentrations, in parts per billion, of toluene and ethylbenzene are also listed in table 1.

The distribution pattern of the total flux values indicated that two areas contain relatively high amounts of VOC's in the soil vapor. The largest area of elevated VOC's in the soil vapor is in the northern part of area A (figs. 3 and 4) and extends from south of tank 1 in area C, west and south to the approximate center of area A. The second area containing relatively high amounts of VOC's in the soil vapor is in the storage tank area, from east of tank 5 to southeast of tank 2. In addition to these sites, several isolated areas of potential contamination generally were evident by using both the total detected VOC response and the concentrations of the targeted compounds toluene and ethylbenzene. These are at site C20, southeast of tank 6; at site D12, on the southern boundary of the DFSP; and at sites A3 and C2, both adjacent to the truck-loading facility, and at site C1, between tank 4 and the western boundary of the DFSP (fig. 3). The chromatographic signature of vapor samples from site C20 show a strong resemblance to the signature of JP-5 tank-water bottoms. JP-5 is a less volatile jet fuel than JP-4. JP-5 has been stored in tank 6 in the past, and previous disposal procedures involved draining the water bottoms into respective tank-containment areas. Therefore, contamination of the soil zone and ground water by tank-water bottoms is probable at site C20 and, perhaps, possible elsewhere in tank-containment areas. The sample from site C1 was off scale when analyzed at the high calibration range.

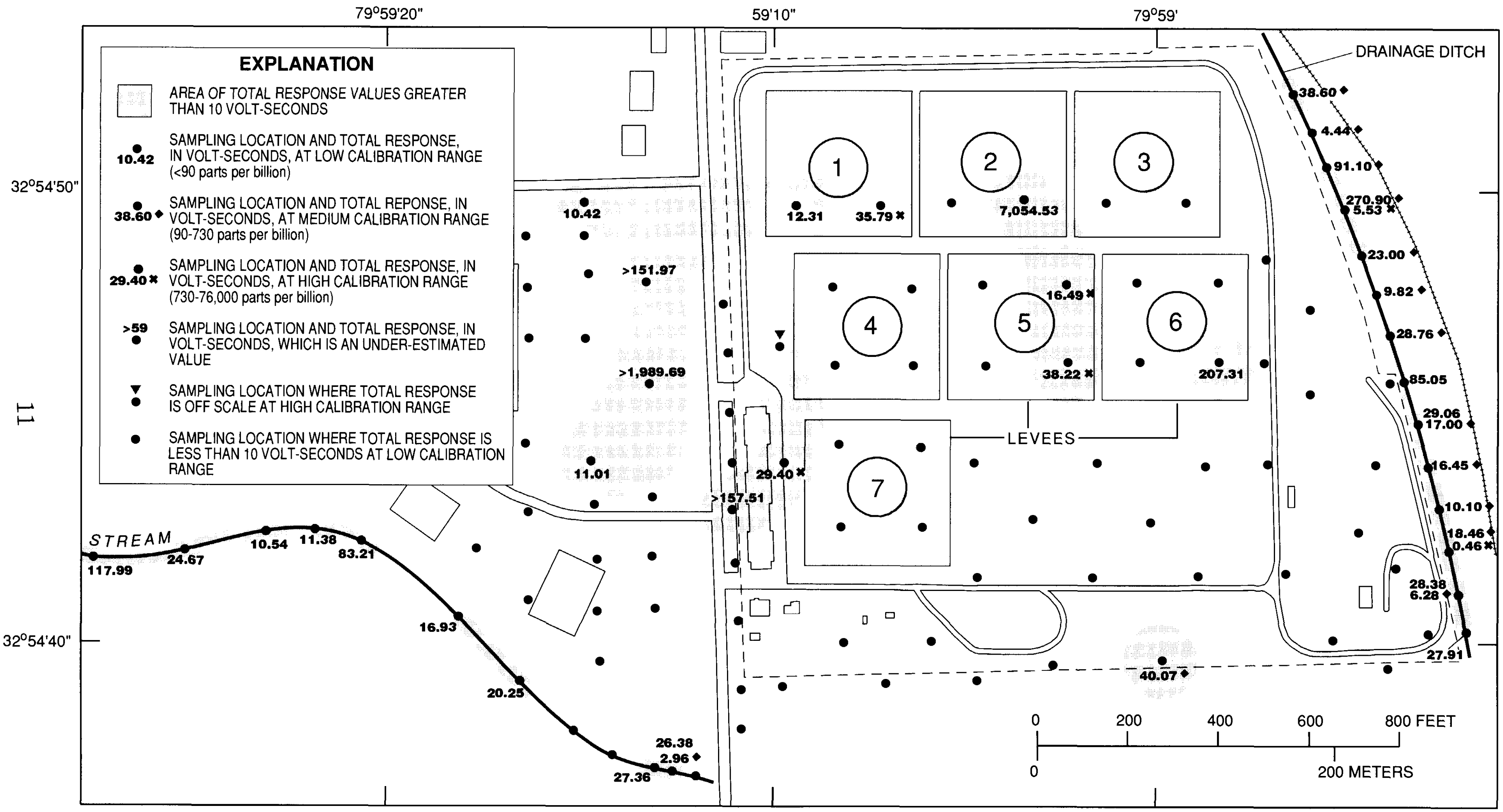

Figure 4.--The distribution of total response of volatile organic compounds having retention times between 45 and 300 seconds.

Table 1.--Total response of volatile organic compounds and toluene and ethylbenzene concentrations in samples collected using the empty-tube technique at the Defense Fuel Supply Point, Hanahan, S.C.

[>, greater than; --, not determined; values separated by semicolon (;) are from duplicate samples]

Sampling site (fig. 3)	Calibration range	Total response (volt-seconds)	Toluene (parts per billion)	Ethylbenzene (parts per billion)
A1	low	3.22	38	--
A1A	low	1.78	0	--
A2	low	1.73	164	0
A2A	low	1.55	0	--
A3	low	>157.51	--	--
A3A	low	2.38	0	0
A4	low	2.93	0;0	0;0
A4A	low	1.12	0	0
A5	low	1.37	1;2	0;0
A6A	low	>151.97	42,400	>59
A7A	low	>1,989.69	>6,300	>3,890
A8A	low	1.12	0	0
A9	low	1.24	0	0;0
A9A	low	.56	0	--
A11	low	10.42	0;382	0;89
A11A	low	2.18	0;0	0
A12	low	2.20	0;0	0
A12A	low	3.12	0;9	--
A12B	low	11.01	71	--
A13	low	4.40	0	--
A13A	low	1.34	--	--
A14	low	3.17	0;0	--
A14A	low	1.24	0	--
A15	low	1.59	0;0	0
A15A	low	1.89	0;0	0;0
A16	low	4.77	0;0	--
A17	low	3.94	0	0
A17A	low	1.12	0	0
A18	low	3.03	0;0	0;0
A18A	low	4.60	0	--
B1	low	1.20	0	0
B2	low	.00	0	0
B3	low	.00	0	0
B4	low	.13	0	0
B6	low	.48	0;0	0;0
B7	low	.51	0;0	0;0
B8	low	1.31	10	0;0
B9	low	.45	0	0

Table 1.--Total response of volatile organic compounds and toluene and ethylbenzene concentrations in samples collected using the empty-tube technique at the Defense Fuel Supply Point, Hanahan, S.C.--Continued

[>, greater than; --, not determined; values separated by semicolon (;) are from duplicate samples]

Sampling site (fig. 3)	Calibration range	Total response (volt-seconds)	Toluene (parts per billion)	Ethylbenzene (parts per billion)
B11	low	0.61	10;11	0;0
B12	low	.45	0	0
B13	low	.35	0	0
B14	low	.92	28;19	0;0
B15	low	1.01	0	0
C1	high	off scale	off scale	off scale
C2	high	29.40	201,000	24,300
C3	low	12.31	5;0	0;0
C4	high	35.79	off scale	0;488
C5	low	.62	0	0
C6	low	7,054.53	off scale	450,000
C7	low	2.05	0	0
C8	low	8.60	0	0
C9	low	1.08	0	0
C10	low	4.51	69	0
C11	low	.91	0	0
C12	high	16.49	170	--
C13	low	3.04	0	96
C14	low	2.20	0	23
C15	low	.73	16	0
C16	low	1.18	0	0
C17	low	1.46	0	0
C18	high	38.22	661,000	18,900
C19	low	.69	0	0
C20	low	207.31	--	8,970
C21	low	.91	13	0
C22	low	1.33	0	0
C23	medium	.00	0	0
C24	low	.13	0	0
D1	low	.42	0	0
D2	low	.55	0	0
D3	low	2.19	0	0
D4	low	.00	0	0
D5	low	.00	0	0
D6	low	.34	0	0
D7	low	.53	0	0
D8	low	1.10	0	0
D9	low	1.21	0;0	0;0

Table 1.--Total response of volatile organic compounds and toluene and ethylbenzene concentrations in samples collected using the empty-tube technique at the Defense Fuel Supply Point, Hanahan, S.C.--Continued

[>, greater than; --, not determined; values separated by semicolon (;) are from duplicate samples]

Sampling site (fig. 3)	Calibration range	Total response (volt-seconds)	Toluene (parts per billion)	Ethylbenzene (parts per billion)
D10	low	0.51	0	0
D11	low	.88	0	0
D12	medium	40.07	2,800;773	259;1,960
D13	low	.35	0	0
D14	low	.75	0	0
D15	low	.43	0	0
E1	low	7.81	14	42
E1A-1	low	26.38	222	0
E1A-2	medium	2.96	220	0
E2	low	27.36	1,540;59	0;0
E3	low	.72	9	0
E4	low	3.85	49	0
E5A	low	20.25	116	0
E7A	low	16.93	51;41	0;0
E9	low	83.21	1,640;293	0;0
E10	low	11.38	139	0
E11	low	10.54	0	0
E13	low	24.67	355	67
E15	low	117.99	3,230	135
F1	low	27.91	117	274
F2-1	low	28.38	261	62
F2-2	medium	6.28	63	0
F3-1	medium	18.46	319	0
F3-2	high	.46	0	0
F4	medium	10.10	801;347	10
F5	medium	16.45	44	0
F6-1	medium	17.00	0	0
F6-2	low	29.06	33	26
F7	low	85.05	19,900	2,090
F8	medium	28.76	5,820;6,080	0;0
F9	medium	9.82	208	0
F10	medium	23.00	3,550	0
F11-1	medium	270.90	14,400	--
F11-2	high	5.53	29,800	0
F12	medium	91.10	21,000;9,270	0;0
F13	medium	4.44	282;255	0;0
F14	medium	38.60	8,550;7,950	--

Total flux values of the stream-bottom-sediment vapor samples in areas E and F (figs. 3 and 4) were generally high. Samples from area E were analyzed by using the low calibration range (less than 90 ppb). Samples from area F, however, were better analyzed by using the medium calibration range (90-730 ppb). The elevated response of samples from area F is probably the result of higher concentrations of unidentified lower molecular weight organic compounds. No correlation was found between the distribution of VOC's in the unsaturated zone and in the bottom sediments of the stream and drainage ditch. The lack of correlation may be partly explained by site hydrology. Discharging ground water is derived from the water-table aquifer on both sides of the stream and drainage ditch. Thus, the stream and ditch are potential recipients of contaminated ground water from anywhere in the drainage basin. The reaches of the stream (area E) examined run through an industrial complex; therefore, the distribution of VOC's in the streambed may represent sources unrelated to the soil vapors closer to the facility. The streambed sediments in this area vary from well-sorted sands to dense clays, implying that ground-water discharge to the streambed may not be uniformly distributed along the reach of the stream. Thus, the distribution of contaminants discharging from the ground water to the stream is probably not uniform. Additionally, the transport and deposition of contaminated sediments in the streambed is possible and could also contribute to an irregular distribution of contaminants.

Toluene and ethylbenzene peaks were consistently well defined, and their concentrations are listed in table 1 and shown in figures 5 and 6. At sites where duplicate samples were taken, both concentrations are listed beside the sample location and were not averaged. The distribution of toluene (fig. 5) approximately resembled the distribution of total VOC's (fig. 4). Areas of relatively high toluene concentrations are located in the northeastern part of area A, near tanks 2 and 5 in area C, at an isolated site (D12) in the southern part of the facility, and at several sites in the streambed. Toluene concentrations in area F may be exaggerated due to coelution of lower molecular weight organic compounds. The toluene peaks of samples from sites C1, C4, and C6 were unquantifiable, because they greatly exceeded the highest calibration range, 76,000 ppb, and are denoted in figure 5 as off scale. Toluene peaks of samples from sites C2 and C18 were quantified; however, they must be considered as estimated values, because they exceeded the upper limit of calibration.

The distribution of ethylbenzene (fig. 6) was similar to that of total VOC's and toluene with a few exceptions. The exceptions were the absence of ethylbenzene at many sites where toluene was detected, particularly in the bottom-sediment samples in areas E and F. At site C1, the ethylbenzene peak was off scale (>76,000 ppb) and identified as such. At site C6, the ethylbenzene peak, though not off scale, exceeded the calibration limit; therefore, the value must be considered as an estimate.

Activated-Carbon Technique

The flux values (ion counts) from the activated-carbon samplers (areas A and E) were used to provide an independent qualitative measure of the areal distribution of contaminants. Unlike the empty-tube method, activated-carbon samplers will not maintain equilibrium but will continue to collect VOC's until saturation of the activated carbon is achieved. Based on this fact, it

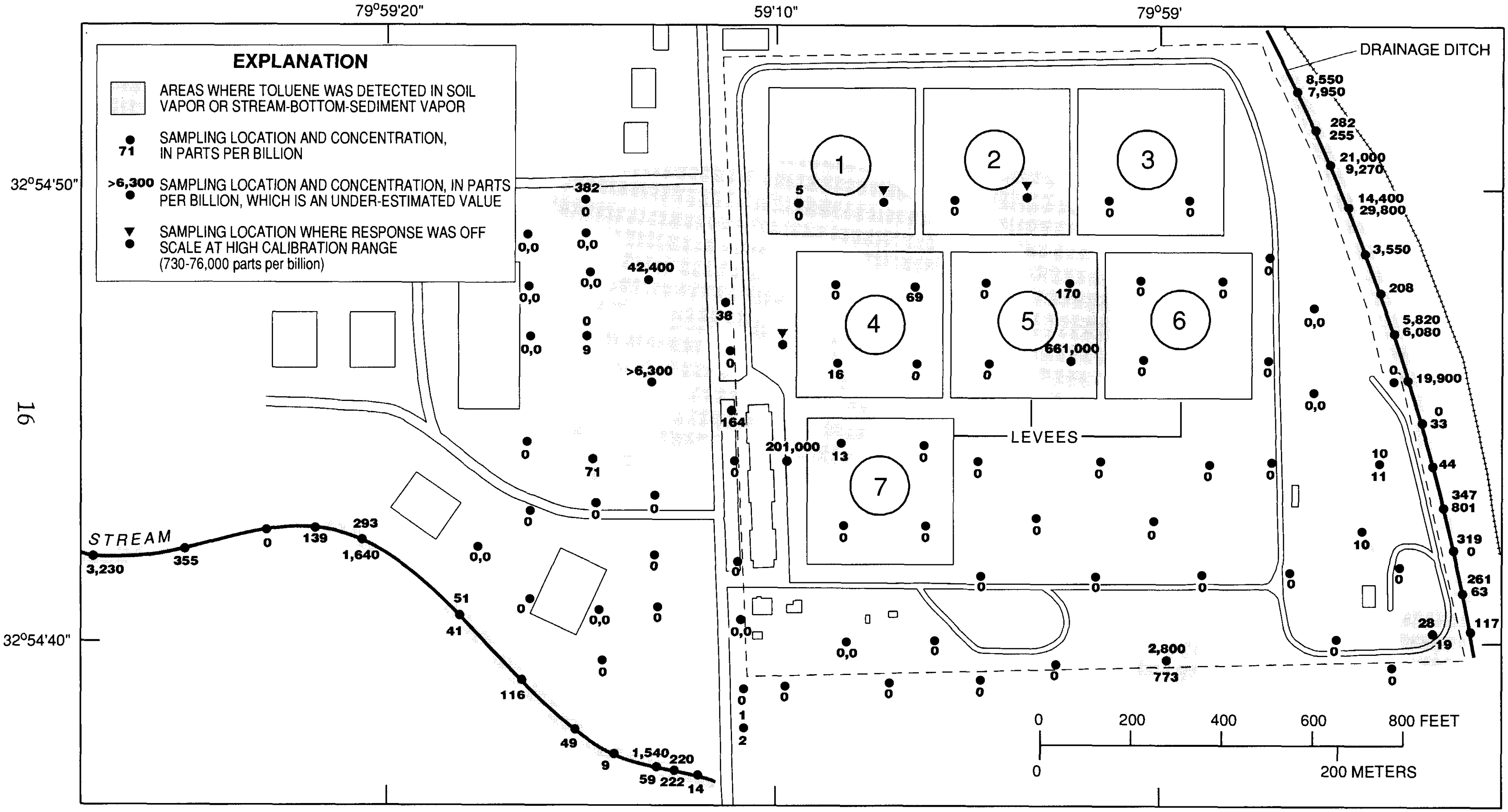

Figure 5.--The distribution of toluene as determined by the empty-tube technique.

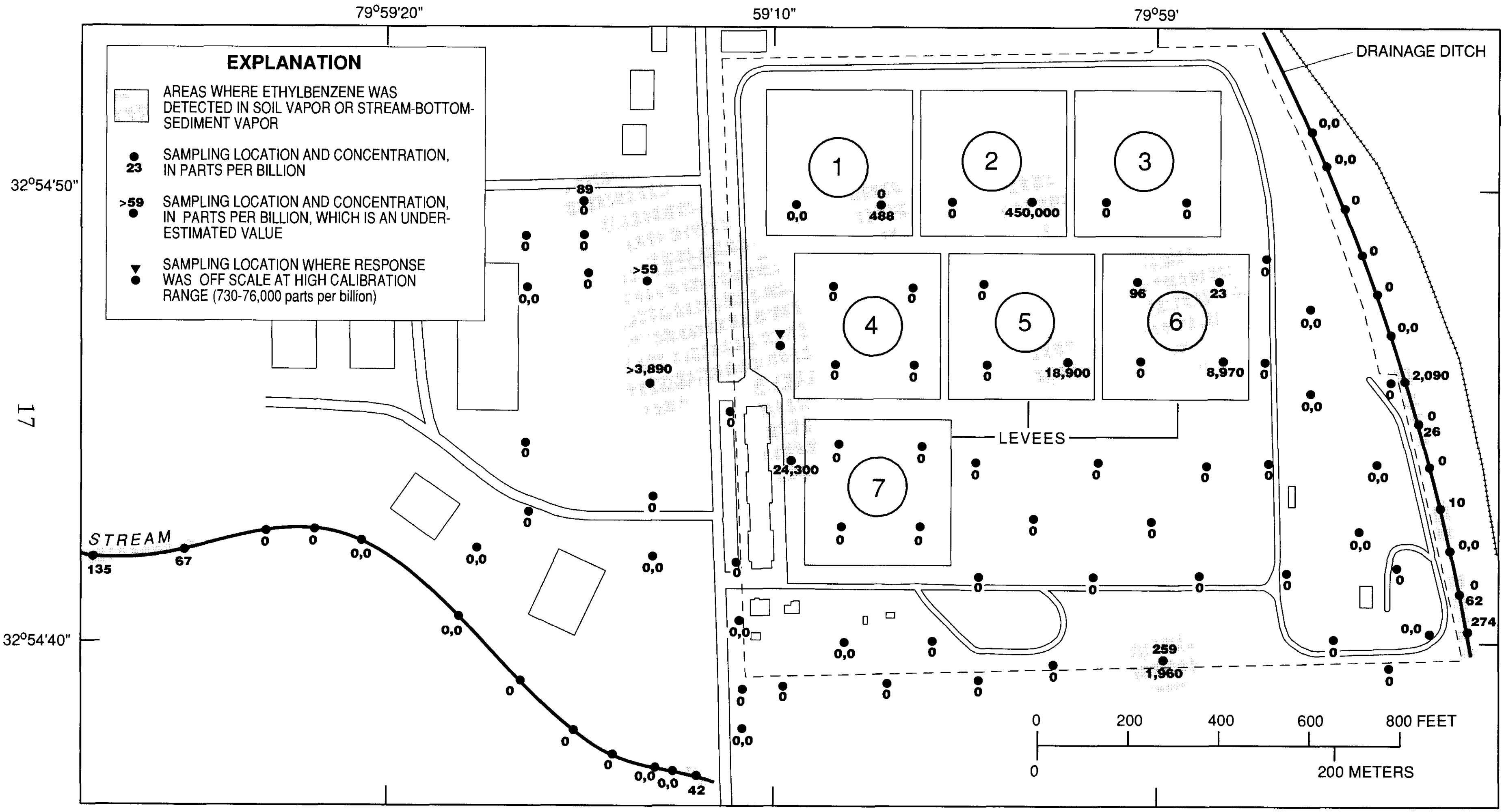

Figure 6.--The distribution of ethylbenzene as determined by the empty-tube technique.

is important to note that the concentrations obtained by the activated-carbon technique can be compared only in a qualitative way to concentrations found in the underlying ground water and sediments. Similarly, the flux values of the activated-carbon technique cannot be directly compared to the total response (volt-seconds) of the empty-tube method.

Activated-carbon sample results are reported in flux value, or ion counts, in figure 7 for toluene and table 2 for all detected compounds. Field blank values were averaged and subtracted from sample values. Duplicate samples were averaged. In addition to identification of BTEX compounds, other compounds and compound classes detected included C_3 alkyl benzenes, tetrachloroethylene (TeCE), C_5-C_{10} cycloalkanes and alkenes, and two compounds tentatively identified as methyl styrene and naphthalene.

A relatively high lateral distribution of toluene is prominent in the northern part of area A (fig. 7). Other compounds (benzene, ethylbenzene, xylene, TeCE, C_3 alkyl benzenes, methyl styrene, and C_5-C_{10} cycloalkanes and alkenes) (table 2) showed distribution patterns similar to that of toluene (highest values in the northern part of area A) and are, therefore, not presented as individual figures. Naphthalene was detected at 5 sites only.

As with the empty-tube samplers in areas A and E, the activated-carbon samplers showed no correlation between the distribution of VOC's in the unsaturated zone of area A and the stream-bottom sediments of area E. An area of relatively high toluene concentrations was noticed at sites E7A and E9. For reasons discussed previously, an irregular distribution in the stream-bottom sediments might be expected.

Generally, the distribution of toluene detected by the activated-carbon samplers in area A was similar to that of the empty-tube samplers. An area of relatively high soil-vapor concentrations in the northern part of area A was detected by both methods.

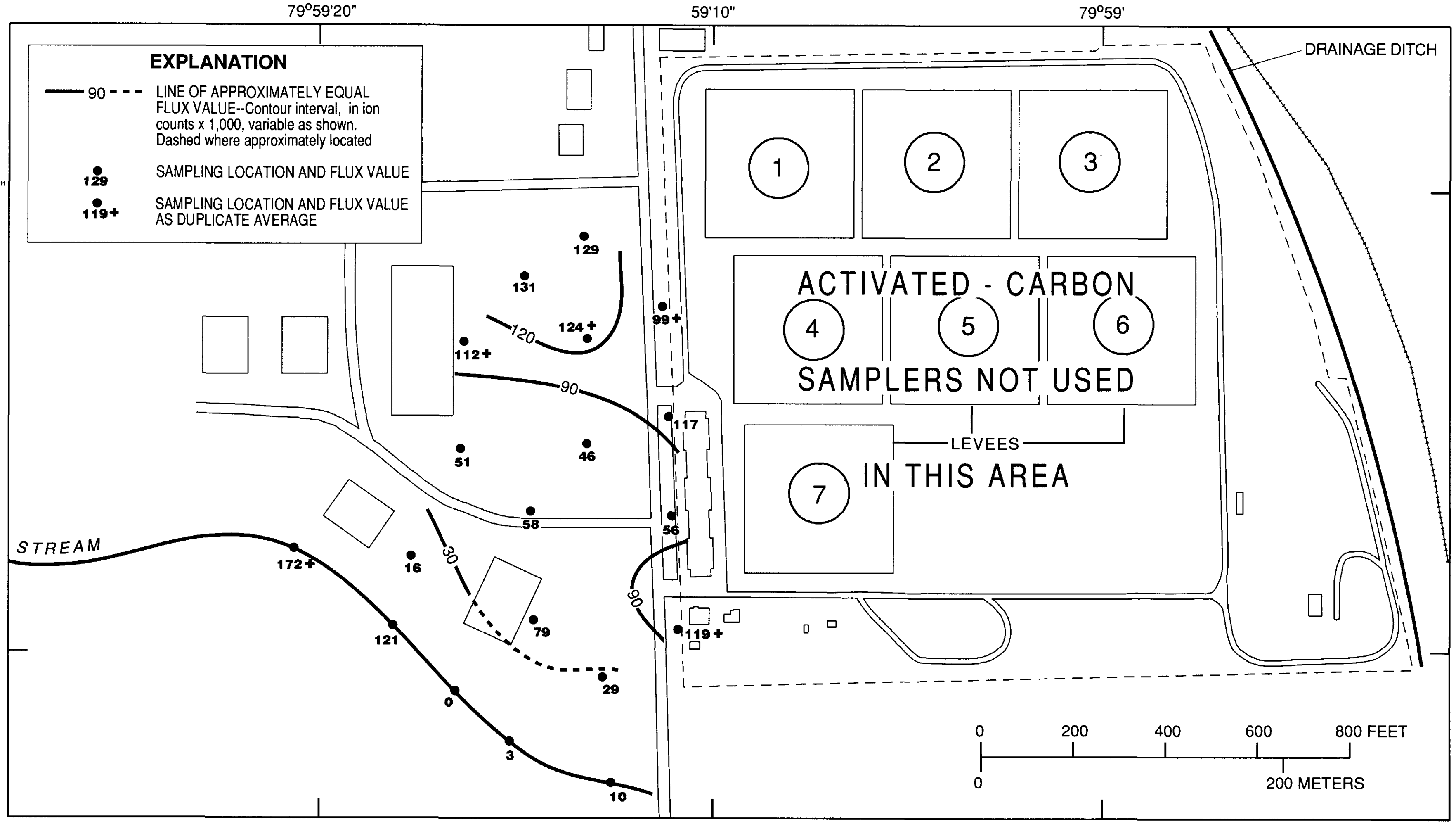

Figure 7.--The distribution of toluene as determined by the activated-carbon technique.

Table 2.--Flux values of volatile organic compounds detected at the Defense Fuel Supply Point, Hanahan, S.C., using the activated-carbon technique (in total ion counts)

[Eb/Xyl, Ethylbenzene and xylene; BTEX, Benzene, toluene, ethylbenzene and xylene; C, carbon; TeCE, Tetrachloroethylene; DUP, Duplicate sample; FB, Field blank]

Sampling site (fig. 3)	BTEX components			BTEX	Methyl styrene	C_3 alkyl benzenes	C_5-C_{10} cycloal-kanes and alkenes	TeCE	Naph-thalene	Total
	Benzene	Toluene	Eb/Xyl							
A1	821	85,207	11,416	97,444	10,064	13,413	0	10,094	0	131,015
A2	3,179	116,682	27,951	147,812	24,758	12,985	0	3,054	0	188,609
A3	9,037	55,516	55,117	119,670	75,525	28,347	5,455	6,412	0	235,409
A4	3,664	77,128	29,814	110,606	61,825	20,133	0	3,343	0	195,907
A6	49,821	128,610	137,998	316,429	216,847	209,847	1,367,178	73,874	4,735	2,188,910
A7	20,547	158,529	118,847	297,923	187,399	71,727	74,028	3,286	0	634,363
A8	33,605	46,413	121,739	201,757	214,472	174,185	161,452	22,780	0	774,646
A10	8,726	29,071	39,417	77,214	108,951	58,912	8,991	4,831	0	258,899
A12	22,135	131,467	130,365	283,967	174,471	85,938	54,970	11,970	0	611,316
A13	41,088	57,678	131,413	230,179	201,761	184,792	83,068	12,023	217	712,040
A14	31,141	79,071	112,671	222,883	193,521	163,428	103,722	12,047	0	695,601
A16	4,299	101,938	43,662	149,899	44,761	20,065	0	0	41,052	255,777
A17	8,589	51,368	57,137	117,094	79,735	37,488	4,231	3,221	1,758	243,527
A18	8,561	16,437	50,532	75,530	121,919	44,879	0	2,123	0	244,451
E2	0	10,060	3,131	12,748	4,719	4,972	22,746	1,051	0	46,236
E4	0	2,545	532	2,007	1,737	1,438	0	1,606	0	6,788
E5A	0	0	620	0	3,692	3,245	0	317	0	7,254
E7A	5,969	120,997	8,268	135,234	5,824	4,727	199,079	1,447	0	346,311
E9	3,363	146,165	8,252	157,780	3,312	2,412	101,789	623	0	265,916
A1(DUP)	0	112,164	10,517	122,390	4,952	1,879	0	0	0	129,221
A4(DUP)	8,923	161,139	68,512	238,574	81,894	25,414	2,501	800	0	349,183
A7(DUP)	11,125	90,394	59,782	161,301	153,273	49,891	13,017	2,964	0	380,446
A16(DUP)	5,426	122,693	50,500	178,619	53,293	23,979	0	0	50,535	306,426
E9(DUP)	6,969	197,356	9,220	213,545	4,913	3,685	172,241	497	0	394,881

Note: Data presented above reflect subtraction of field blank average values.

Table 2.--Flux values of volatile organic compounds detected at the Defense Fuel Supply Point, Hanahan, S.C., using the activated-carbon technique (in total ion counts)--Continued

[Eb/Xyl, Ethylbenzene and xylene; BTEX, Benzene, toluene, ethylbenzene and xylene; C, carbon; TeCE, Tetrachloroethylene; DUP, Duplicate sample; FB, Field blank]

Sampling site (fig. 3)	BTEX components			BTEX	Methyl styrene	C_3 alkyl benzenes	C_5-C_{10} cycloalkanes and alkenes	TeCE	Naphthalene	Total
	Benzene	Toluene	Eb/Xyl							
Duplicate sample averages										
A1	411	98,686	10,967	109,917	7,508	7,646	0	5,047	0	130,118
A4	6,294	119,134	49,163	174,590	71,860	22,774	1,251	2,072	0	272,547
A7	15,836	124,462	89,315	229,612	170,336	60,809	43,523	3,125	0	507,405
A16	4,863	112,316	47,081	164,259	49,027	22,022	0	0	45,794	281,102
E9	5,166	171,761	8,736	185,663	4,113	3,049	137,015	560	0	330,400
Field blank values										
FB1	2,762	6,397	542	9,683	0	0	68,689	339	447	79,158
FB2	2,827	1,339	0	4,166	0	0	13,149	681	201	18,197

SUMMARY

Two soil-vapor sampling techniques were used to detect the presence of volatile organic compounds (VOC's) beneath a defense fuel supply point and adjacent property near Hanahan, S.C. Analyses of samples indicated levels of VOC's that suggest contamination of the water table aquifer or the soil zone. As a preliminary screening study, the soil-vapor survey also identified several areas that are potentially contaminated with VOC's.

The empty-tube technique identified several areas in and around the DFSP facility that could be investigated further. The most extensive area where VOC's were detected in soil vapor at total response levels implying potential contamination is located in the northern part of area A, extending from south of tank 1 in area C, west and south to the approximate center of area A. Other extensive areas of elevated total response in soil vapor include the storage tank area, from east of tank 5 extending to the southeast of tank 2, and an area adjacent to the truck-loading facility extending from site A3 to site C2 and north to site C1, immediately west of the tank 4 containment area. Other isolated sites of elevated total response are located at sites C20, southeast of tank 6, and at site D12, on the southern boundary of DFSP. The empty-tube technique also detected elevated VOC content in the bottom-sediments of the drainage ditch, east of the facility, and to a lesser extent, in the bottom-sediments of the stream, southwest of the facility. The distribution of toluene was found to be similar to that of the total response, with detection ranging from 1 ppb to greater than 76,000 ppb, the upper limit of calibration. The distribution of ethylbenzene was also similar to that of the total response except for the lack of detection in bottom-sediments of most reaches of the stream and drainage ditch. Ethylbenzene was detected at concentrations ranging from 10 ppb to greater than 76,000 ppb. The identification of toluene and ethylbenzene must be considered tentative.

As a qualitative comparison to the empty-tube technique, the activated-carbon technique showed a distribution of toluene in area A similar to that obtained by the empty-tube method, with the highest concentrations found in the northern part of the area. Other compounds and compound classes detected by the activated-carbon samplers included benzene, ethylbenzene, xylene, tetrachloroethylene, C_3 alkyl benzenes, and C_5-C_{10} cycloalkanes and alkenes. Activated-carbon samplers at sites E7A and E9 in area E (stream-bottom-sediments) detected relatively high toluene concentrations. Both methods showed an irregular distribution of VOC's in the stream-bottom-sediments. This could be attributable to site hydrology, sources unrelated to soil vapors, and the transport and deposition of contaminated sediments.

From the results of this investigation, it can be concluded that further investigation of contamination in the water-table aquifer beneath the facility is needed. These areas need additional investigation of a more site-specific and quantitative nature to characterize the contamination. The detection of compounds tentatively identified by this investigation may be confirmed by subsequent investigation.

Considering that this entire area is industrialized, and there are many possible contaminant sources in and around the DFSP facility, it is difficult to identify the origin of the VOC's detected by this soil-vapor survey. In order to determine sources of contamination, verification of soil-vapor results and a better understanding of ground-water flow patterns is needed. The results of this investigation will be valuable to subsequent assessment of water-table aquifer contamination beneath the facility.

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CONVERSION FACTORS AND ACRONYMS

Multiply	By	To obtain
inch	25.40	millimeter
foot	0.3048	meter
parts per billion (ppb)	1.00	micrograms per liter

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows: $^{\circ}C = 5/9 \times (^{\circ}F - 32)$

ACRONYMS

BTEX, benzene, toluene, ethylbenzene and xylene
TeCE, tetrachloroethylene
VOC, volatile organic compound