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LEACHATE MIGRATION FROM A PESTICIDE WASTE DISPOSAL SITE IN HARDEMAN COUNTY, TENNESSEE

BY

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ABSTRACT

Between 1964 and 1972, approximately 300,000 drums (55-gallon steel barrels) of wastes derived from the manufacturing of pesticides were buried on 45 acres of land in northern Hardeman County, Tennessee. Leachates from these wastes are migrating from the disposal site, 1) in surface runoff, 2) through shallow perched water zones, and 3) through the local water-table aquifer. Compounds identified in the leachates included: dieldrin, endrin, chlordene, heptachlor, heptachlor epoxide, pentachlorocyclopentadiene, and hexachlorobicycloheptadiene. The rate of migration of some of the leachate compounds in the water-table aquifer was found to be at least 80 feet per year.

INTRODUCTION

Background Information

During the period October 1964 to June 1972, a 300-acre tract of land in northeastern Hardeman County, Tennessee, was used as a disposal site for wastes associated with the manufacturing of pesticides (Figure 1). An estimated 300,000 drums (55-gallon steel barrels) of liquid and solid wastes were buried in shallow trenches covering 45 acres on the site.

Upon learning that shallow burial of the pesticide manufacturing wastes was occurring, public health officials became concerned about potential health hazards associated with the highly toxic wastes. The officials were especially concerned that the wastes might contaminate the local and contiguous water supplies. Thus, in 1966, the Federal Water Pollution Control Administration (now the U.S. Environmental Protection Agency) asked the U.S. Geological Survey to study the potential contamination effects of waste disposal at the site.

The study by Rima and others (1967) reached the following conclusions:

1. Contaminated surface materials had washed from the site into a nearby stream (Pugh Creek North).

2. Vertical percolation of leachates had contaminated the shallow perched water zone.

3. The water-table aquifer beneath the site would soon become contaminated.

4. Attenuation of the leachates was prominent in both surface and subsurface movement.

5. At the time of the study, no local domestic well was close enough to the disposal pits to be affected by the contaminants.

After the 1967 study, the area of the disposal was enlarged from approximately 20 acres to 45 acres (Figure 2). Burial of wastes also occurred near the Pugh Creek South drainage divide near the southern boundary of the property. These changes plus questions about the extent and direction of migration of the pesticide leachates in the ground-water system caused the Tennessee Department of Public Health, Division of Water Quality Control (TDWQC) and the U.S. Geological Survey to begin a cooperative study in 1976 to reexamine the site and check on the validity of the conclusions of the 1967 study.

Use of trade names in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

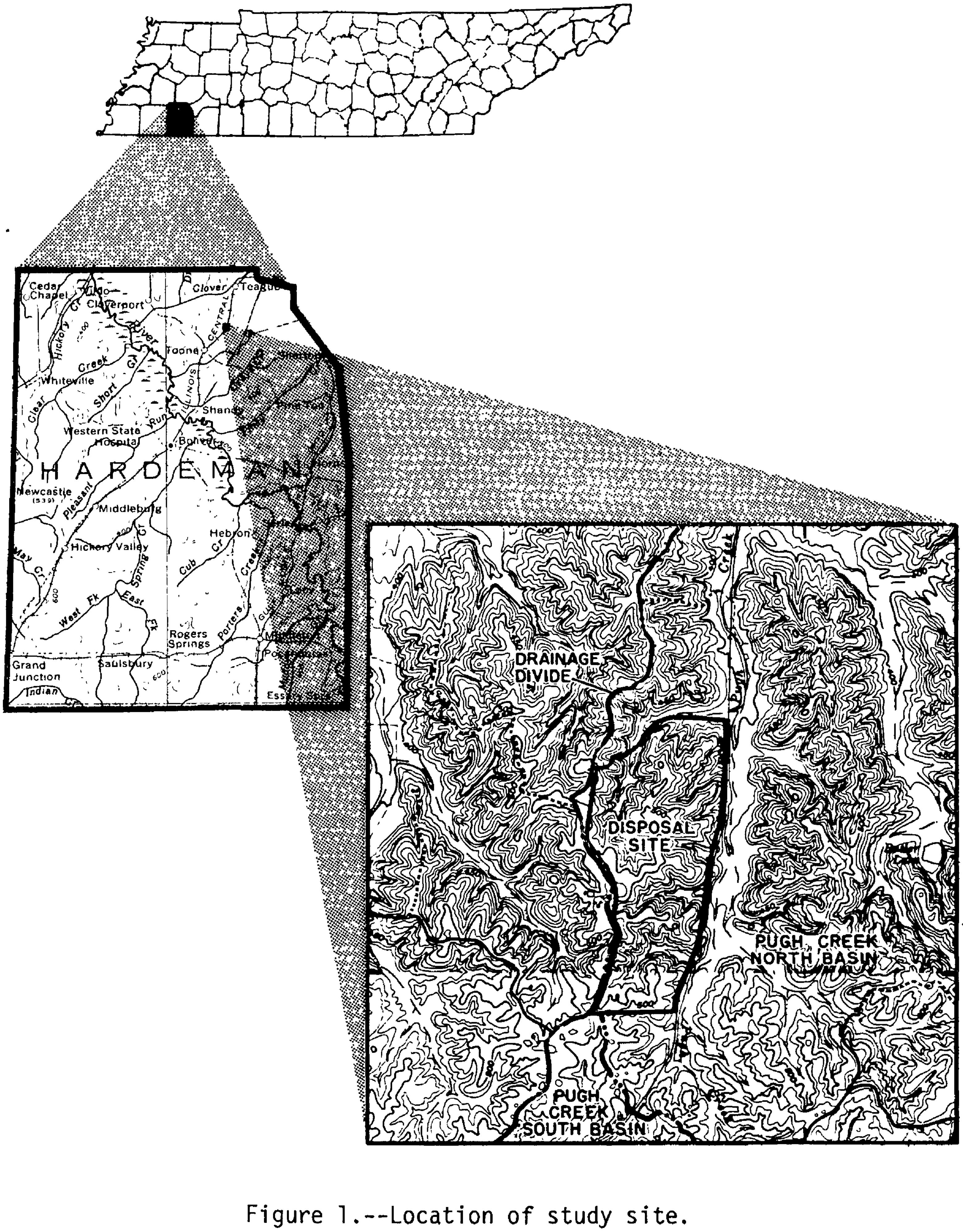
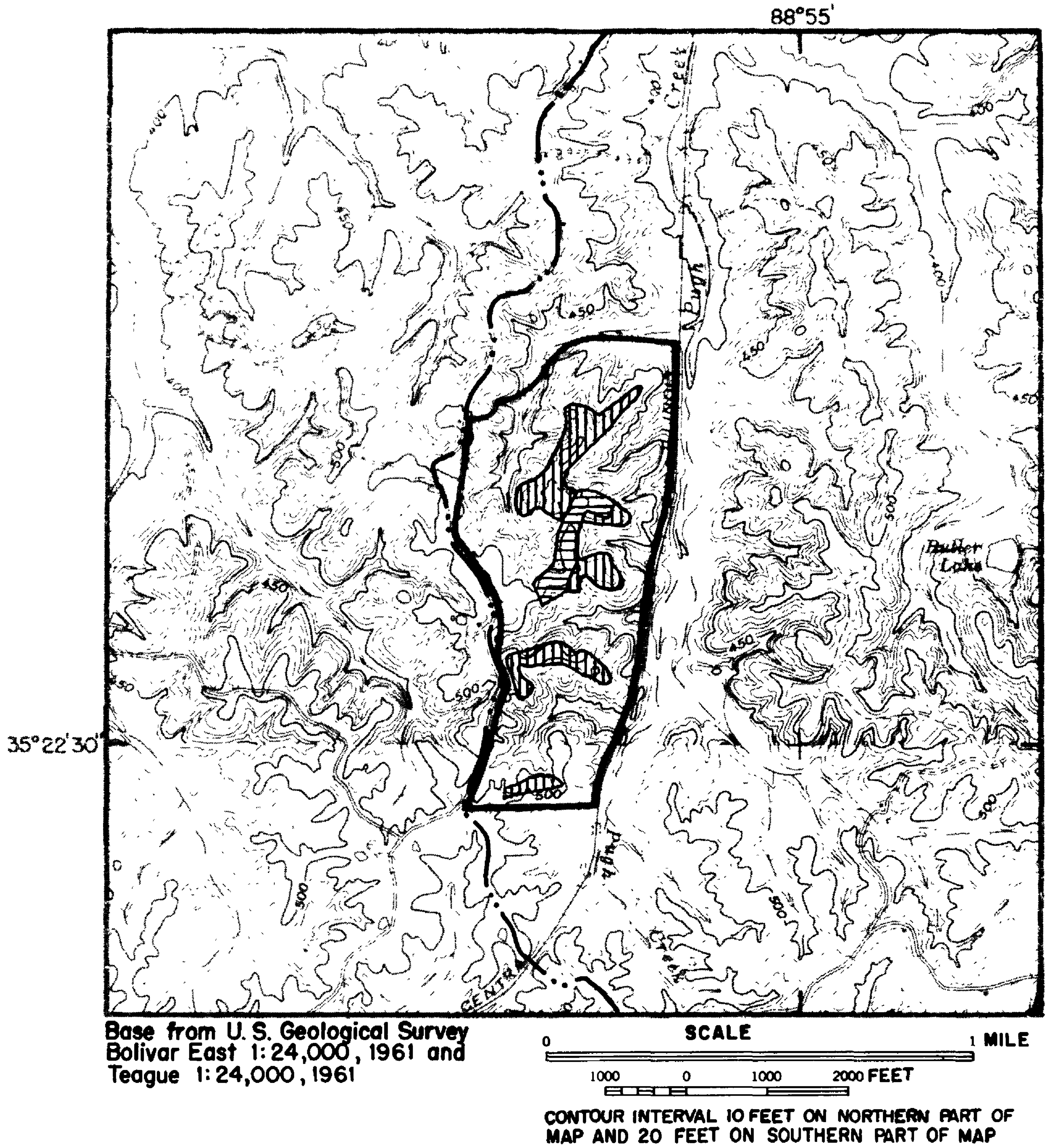


Figure 1.--Location of study site.



EXPLANATION

Burial area in 1967

Burial area determined from NASA high altitude photography (1975) and field visits (1976)

Boundary of Pugh Creek North drainage basin

Figure 2.--Expansion of burial grounds from 1967 to 1972.

Purpose and Scope

The objective of this report is to present additional information on the extent and direction of leachate migration from the pesticide waste disposal site. This report describes 1) the hydrologic setting of the site, 2) the methods used to obtain soil, earth core, and water samples from the site, 3) the results of chemical analysis of those samples, and 4) the inferred extent of contaminant migration from the site. The reports include suggestions for further study of the site.

Acknowledgments and Cooperation

Collection, analysis, and interpretation of the data were made possible by a cooperative agreement between the U.S. Geological Survey and the Tennessee Department of Public Health, Division of Water Quality Control. Wilton Burnett, formerly with the Tennessee Department of Public Health, aided materially in the planning and initiation of this study; his continuing interest and encouragement during the progress of the study are gratefully acknowledged. The able assistance and advice of D.M. (Mike) Robinson and other personnel with the Division of Water Quality Control were instrumental in the completion of this study and are greatly appreciated.

SITE DESCRIPTION

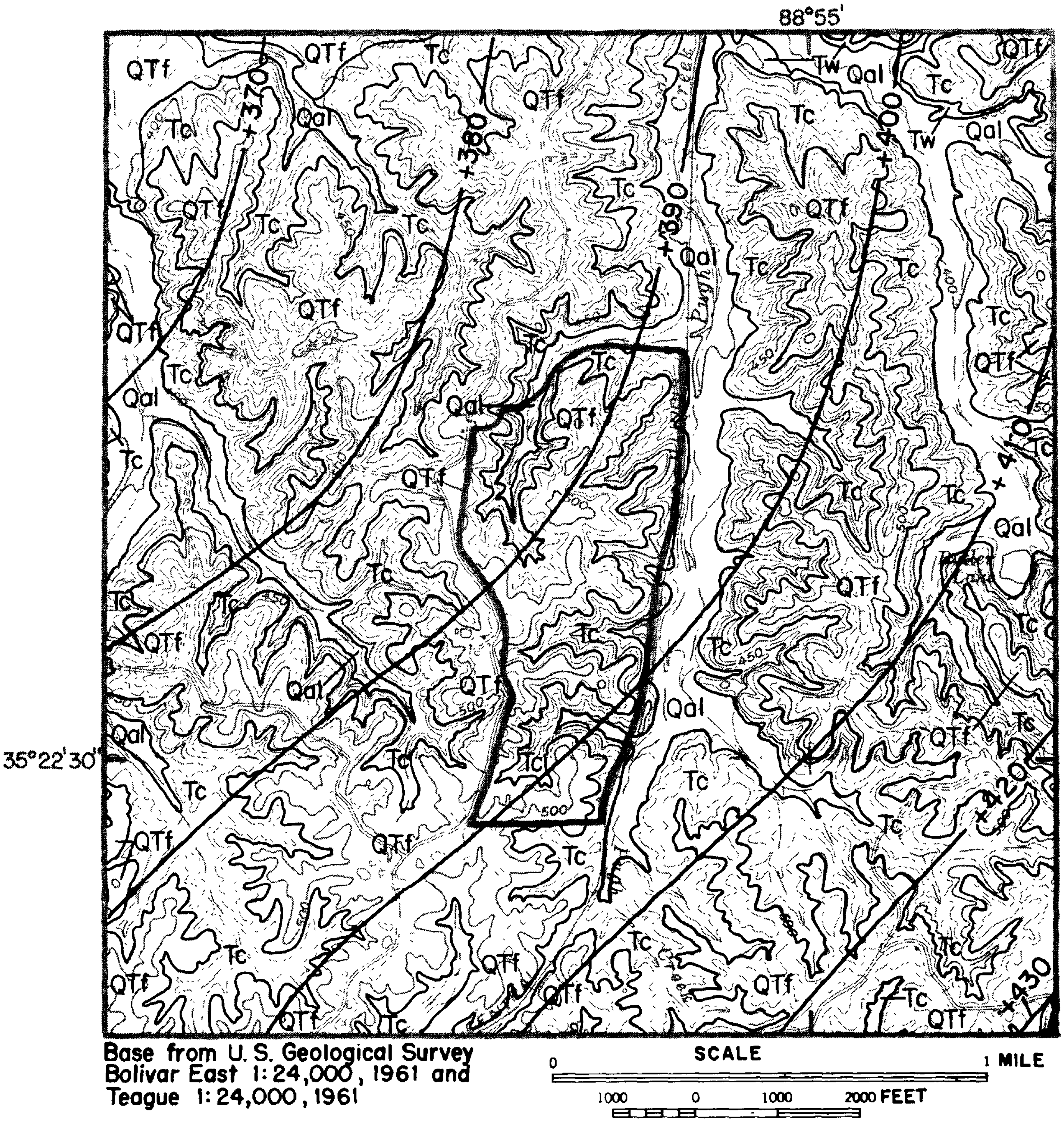
Topography

The disposal site is located within the drainage basin of Pugh Creek North, a tributary to Clover Creek. The drainage divide for Pugh Creek North lies on the western side of the site, thus surface drainage flows from the site to the east and northeast.

Topographically, the disposal site is situated on the upland remnant of a naturally dissected, fluvial terrace. The burial trenches are located on long, narrow ridges which are separated from the flood plain of Pugh Creek North by fairly steep-side gullies and ravines. The maximum relief on site is about 110 feet.

Geology

Beneath the disposal site lie nearly horizontal beds of unconsolidated sand, silt, and clay. These deposits are non-homogeneous and consist primarily of sand, with thin interbedded silt and clay lenses. Below a depth of about 115 feet, silt and clay predominate, with the sand occurring as lenses or beds. The following description of the geology and lithology of the disposal site was summarized from Russell and Parks (1975) and Parks (1974 and 1977). Surficial geology is shown in Figure 3.



EXPLANATION

Qal Aluvium

Tc Claiborne Formation

QTf Fluvial Deposits

Tw Wilcox Formation

—— +420 —— Generalized contour at top of Wilcox Formation

Figure 3.-- Geologic map of burial ground and vicinity (after Parks, 1974 and 1977).

Fluvial deposits of the Quaternary and Tertiary (?) Periods cover much of the uplands of the site. Composed of sand and silt, the fluvial deposits range in thickness from 0 to 35 feet, and are found mostly above 460 feet altitude. The fluvial deposits are remnants of ancient alluvium laid down by present streams or an earlier drainage system. The silt that caps the fluvial deposits may be wind-blown loess.

Below the fluvial deposits lie sediments of the Claiborne Formation of Tertiary age. The Claiborne Formation consists primarily of quartz sand containing a few thin clay-rich lenses. The Claiborne Formation crops out between approximately 410 and 460 feet altitude at the side. The maximum thickness at the site is about 80 feet. A thin, iron oxide-cemented sandstone locally marks the erosional contact between the Claiborne Formation and the younger fluvial deposits.

Beneath the Claiborne Formation lies the older Wilcox Formation, also of Tertiary age. The Wilcox is composed of a heterogeneous mixture of sand, silt, and clay, which are variously interbedded and interlensed. The Wilcox crops out about 0.6 mile northeast of the site and may be as much as 200 feet thick at the site. The contact between the Wilcox and Claiborne Formations is an erosional surface having considerable local relief. At the disposal site the contact is usually marked by a thin gravel or very coarse sand unit at the base of the Claiborne Formation.

A cross-section of part of the disposal site appears in Figure 6b.

Hydrology

There are three ground-water zones beneath the site which are pertinent to this study. A perched water zone is present seasonally when water accumulates above one of the silt-clay lenses in the sand of the Claiborne Formation. The perched water zone develops because the downward percolation of water is slowed by the low permeability of the silt-clay lens. Fluids in the perched water zone tend to migrate laterally to the margins of the retarding lens, although some downward migration (leakage) of fluids through the lens does occur.

About 90-100 feet beneath the land surface, a water-table aquifer is in sand near the base of the Claiborne Formation or in the top of the Wilcox Formation. This aquifer is recharged by leakage through the perched water zone and by direct infiltration of rainfall in areas where the perched water zone is absent. Discharge from the water-table aquifer occurs at seeps and springs where the land surface intersects the water table. Most domestic wells in the vicinity of the disposal site obtain water from this aquifer.

An artesian aquifer occurs deeper in the Wilcox Formation at a depth of about 230 feet at the site. Between the water-table aquifer and the artesian aquifer are approximately 100 feet of silt and clay that act as an upper confining layer of the artesian aquifer. Although water levels in the artesian aquifer are lower than those in the water-table aquifer, the intervening clay-rich layer retards recharge of the artesian aquifer from the water-table aquifer.

Most of the recharge to the artesian aquifer is believed to come from the outcrop area of the Wilcox Formation east of the site (Rima and others, 1967, p. 9). Discharge and pumpage from this aquifer occur primarily in the outcrop area, although some domestic wells in the vicinity of the disposal site obtain water from the lower part of the Wilcox.

Burial of the Wastes

According to Rima and others (1967, p. 9-10), the buried wastes consisted of both liquids and solids which were transported to the site in 55-gallon steel drums and smaller fiber cartons. The drums and cartons were dumped into disposal trenches and compacted, a process which ruptured many of the containers and released their contents. After a trench was filled, a minimum of three feet of earth cover was compacted over the wastes.

In the years since 1967, eroded cover material was replaced intermittently. Attempts to reduce erosion of the earth cover included sowing the disposal area with grasses, and re-grading some of the steeper slopes.

STUDY METHODOLOGY AND RESULTS

Plan of Study

The study was divided into five work elements:

1. Determine the geologic setting of the site and locate points of ground-water use in the vicinity of the site.
2. Qualitatively assess the overland migration of the wastes, especially into Pugh Creek South.
3. Determine the extent of contamination in the perched water zone and the water-table aquifer.
4. Examine the possibility of migration of the leachates in a direction contrary to prevailing ground-water gradients.
5. Establish a few monitoring wells which could be used to detect future movement of leachates from the site.

These five phases of the study were accomplished in the period April 1976 to February 1978 by the Geological Survey and personnel from the Jackson, Tennessee, office of TDWQC.

Geologic Mapping and Domestic Well Locations

The manuscript for a geologic map of the Teague, Tennessee 7-1/2-minute quadrangle was completed in the summer of 1976 (Parks, 1977). This map will be published by the Tennessee Division of Geology. Parts of the Teague (Parks, 1977) and Bolivar East (Parks, 1974) geologic maps were combined in Figure 3 to show the surficial geology in the vicinity of the disposal site. The contours depicting the top of the Wilcox in Figure 3 show the regional dip of the formation toward the northwest (W.S. Parks, written communication, 1975).

Local water well information was obtained from the files of the Tennessee Department of Conservation, Division of Water Resources (TDWR). Collection of drillers records and preparation of location maps of domestic wells in Hardeman County were made by TDWR personnel over a period of years, and were not part of this investigation. Well locations and identifying numbers assigned by TDWR are shown in Figure 4. Additional data for the wells shown in Figure 4 are given in Table 1.

As part of this study, three water-level observation wells were drilled at the locations shown on Figure 4. Available water-level measurements from these wells are given in Table 2. Records on wells drilled or measured for this study are given in Table 3.

The water level observation wells were installed by dry drilling to depth with 4-inch inside diameter (I.D.) hollow-stem auger. Once the desired depth was reached, the stem was filled with clean water obtained from a well about two miles north of the site. Then 2-inch I.D. polyvinyl chloride (PVC) well casing with 10 feet of slotted section at the bottom was lowered into the auger stem. The PVC casing was pushed through the knock-out plug (at the bottom of the auger stem) into the underlying sands until the casing was firmly held in place. The auger stems were then retrieved, the annular space was backfilled with previous auger returns, and the casing was cemented in the upper five feet. A PVC cap was slotted and screwed onto the top of the casing. No slug testing or further development of the well was performed.

Sampling Surface Runoff

The techniques for sampling surface runoff described by Rima and others (1967, p. 11) were used to sample a tributary to Pugh Creek South. At sites SR-1 and SR-2 (Figure 5), a clean, galvanized steel pan was used to funnel overland runoff (water and sediments) into a receiving glass bottle. The filled sample bottles were retrieved within hours after storm events by personnel from the Jackson, Tennessee, office of the TDWQC. Samples were sealed with Teflon-lined lids and were kept chilled until they were analyzed.

Bottom sediments (locations P-1 through P-4, Figure 5) from four impoundments on the eastern margin of the site were obtained by TDWQC personnel. The bottom sediments were collected and transferred to clean wide-mouth jars in the field. The samples were sealed with Teflon-lined lids and were kept frozen until they were analyzed.

Table 1--Records of domestic wells near the pesticide waste disposal site, Hardeman County, Tennessee

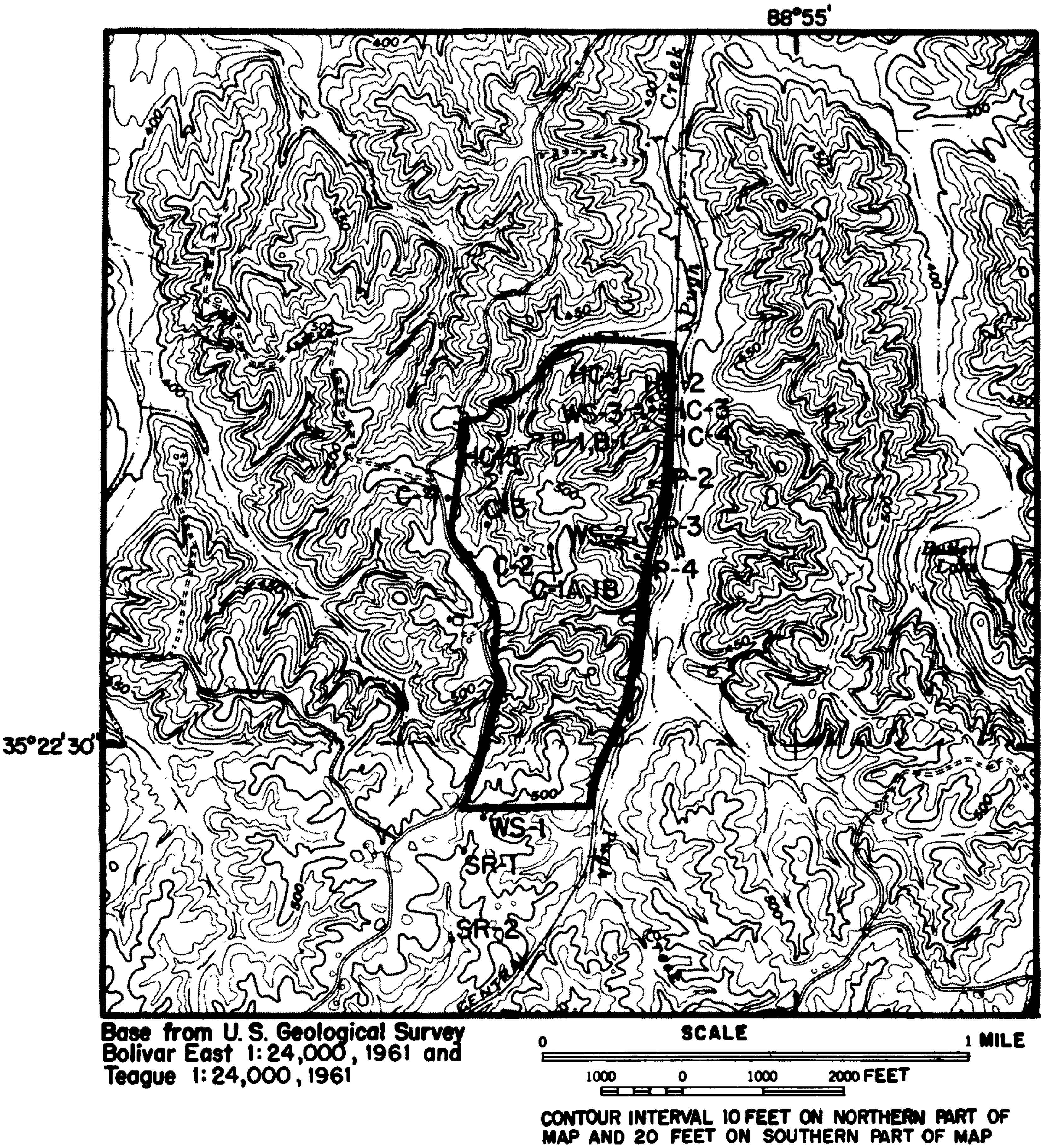
Well Number	Land Surface Elevation, ft. abv. msL	Well Depth, ft.	Depth to top Well Screen, ft.	Formation Source[1]
10	400	48	41	Tw
13	515	110	103	Tw
16	385	46	40	Tw
61	525	126	120	Tw
103	480	156	151	Tw
108	550	140	136	Tw
132	545	140	136	Tw
161	510	225	221	Tw
185	565	150	146	Tw
198	515	128	124	Tw
215	475	413	405	Tcl (?)
224	495	116	112	Tw
226	470	98	94	Tw
258	490	116	112	Tw
262	485	96	92	Tw
266	470	45	41	Tc
268	460	131	111	Tw
286	395	219	211	Tp (?)
292	485	164	157	Tw
303	570	160	---(2)	Tw
311	510	145	138	Tw
316	380	63	59	Tw
326	520	155	150	Tw
329	540	145	140	Tw
336	500	106	102	Tw
394	520	125	---(2)	Tw
409	500	155	150	Tw
433	480	105	100	Tw
451	540	135	127	Tw
456	540	150	146	Tw
462	540	148	140	Tw
501	460	126	96	Tw
504	510	125	121	Tw
525	460	124	74	Tw
532	380	34	30	Tw
538	485	97	93	Tw
542	480	88	84	Tw
543	500	122	118	Tw
548	525	137	127	Tw
552	405	220	200	Tp (?)
556	465	135	125	Tw
558	540	140	120	Tw
568	500	130	126	Tw

Table 1--(cont'd)--Records of domestic wells near the pesticide waste disposal site, Hardeman County, Tennessee

Well Number	Land Surface Elevation, ft. abv. msL	Well Depth ft.	Depth to top Well Screen, ft.	Formation Source[1]
574	475	84	80	Tw
587	505	145	141	Tw
624	520	130	126	Tw
659	490	115	111	Tw
678	495	100	96	Tw
679	500	145	141	Tw
705	485	108	104	Tw
734	495	145	---(2)	Tw
771	560	149	145	Tw
796	380	35	27	Tw
806	505	120	112	Tw
1000	505	129	125	Tw
1015	485	120	110	Tw
1026	430	84	80	Tw
1027	490	150	146	Tw
1029	390	130	122	Tw

(1) - Depth of well screen was used to identify source: Tc - Claiborne Fm., Tw - Wilcox Fm., Tp - Porters Creek Clay, Tcl - Clayton Fm.

(2) - Depth not available.



EXPLANATION

B-1	Bio-assay sample	**P-1**	Pond sediment sample
C-1	Dennison core sample	**SR-1**	Surface runoff sample
HC-1	Hand auger sample	**WS-1**	Well water sample

Figure 5.--Chemical sampling points around the disposal site.

Table 2.--Water levels in observation wells tapping the water-table aquifer near the pesticide waste disposal site, Hardeman County, Tennessee

Altitude of water surface in feet

Date	WL-1	WL-2	WL-3	W-1[1]	WS-2[2]
6 Apr 76	421.1	408.3	401.3	---	---
28 May 76	422.6	409.8	403.1	---	---
22 July 76	422.2	409.4	403.3	---	---
31 Aug 76	422.3	408.7	402.7	---	---
19 Nov 76	421.9	408.9	402.3	416.9	---
1 June 77	420.4	408.0	401.6	415.8	---
14 Feb 78	418.7	406.8	400.7	414.3	411.8

1/Well reported by Rima and others (1967).

2/Well also used to obtain chemical samples (see Figure 5).

Table 3.--Records on monitoring wells, Hardeman County, Tennessee

Well No.	Depth below land surface (feet)	Elevation above mean sea level		Casing			Screen		
		Land surface (feet)	Measuring point[1] (feet)	Type	Length (feet)	I.D.[2] (inches)	Type	Length (feet)	I.D.[2] (inches)
W-1	118	513.4	514.4	Steel	116	2.5	Brass	3	1.5
WL-1	112	517	518.0	PVC[3]	107	2.5	Steel	6	1.5
WL-2	109	496	497.4	PVC	100	2.5	PVC[3]	10	2.5
WL-3	105	476	477.9	PVC	97	2.5	PVC	10	2.5
WS-1	117	517	519.1	Aluminum	109	2.5	Aluminum	10	2.5
WS-2	52	451	451.9	Aluminum	43	2.5	Aluminum	10	2.5
WS-3	18	457	458.6	Aluminum	14	2.5	Aluminum	5	2.5

[1] Top of casing

[2] Inside diameter

[3] Poly-vinyl chloride (plastic)

In order to qualitatively assess the long-term presence of pesticide residues in the impoundments, small vertebrate organisms (tadpoles and salamanders) were collected by the TDWQC from one of the ponds (site B-1, Figure 5). The intent of the TDWQC was to obtain bio-assay data on pesticide residues in the flesh of the organisms (D.M. (Mike) Robinson, oral communication, 1977). The results of the bio-assays were not available to include in this report.

Sampling the Ground Water

The report by Rima and others (1967) indicated an easterly to northeasterly direction of ground water flow beneath the disposal site. In order to examine the extent of leachate migration in this direction, two water sampling wells were placed on the eastern side of the disposal site. Well WS-2 (Figure 5) was cased with 2-inch I.D. aluminum conduit which was slotted in the bottom 10 feet. The slotted section was set in the interval 42 to 52 feet to allow withdrawal of water from the water-table aquifer.

Well WS-3 (Figure 5) was also cased with 2-inch I.D. aluminum conduit and slotted in the bottom five feet. This well was intended to obtain water from the perched water zone. The well was drilled and completed in what was presumed to be the perched water zone, but it has been dry since emplacement in 1976.

To compensate for the inability to obtain water samples from well WS-3, four small-diameter soil samples (HC-1 through HC-4, Figure 5) were obtained from perched-water seeps along the northeastern margin of the disposal site. A fifth small diameter core (HC-5, Figure 5) was obtained from slopes of the western margin of the site.

The five soil cores were obtained by hand augering horizontally into a bankside to a depth of two feet. The hole was then reamed out and cleaned of loose soil. The auger was then withdrawn and a soil sampling tube 1-foot long was mounted on the end. The entire auger was then washed and rinsed with acetone. The auger was reinserted into the hole and the sample tube was drilled in until full.

The soil samples were transferred by clean spatula to wide-mouth, clean glass jars. The sample jars were sealed with Teflon-lined lids and the samples were kept frozen until they were analyzed.

The possibility of underground contaminant migration toward the Pugh Creek South drainage basin was not investigated during the 1967 study because wastes had not been buried near the drainage divide of the Pugh Creek South drainage basin. During the current study, water sampling well WS-1 (Figure 5) was drilled to test for the presence of waste leachates in the water-table aquifer south of the site.

Well WS-1 was cased with 2-inch I.D. aluminum conduit which was slotted in the bottom 10 feet. The slotted casing was set at a depth of 107-117 feet, allowing withdrawal from the middle and upper part of the water-table aquifer.

The water sampling wells were drilled dry with washed and acetone-rinsed hollow-stem auger. Once the desired depth was reached, washed and acetone-rinsed aluminum well casing was lowered in the dry stem. The aluminum casing was pushed through the knock-out plug into the underlying sand until the casing was firmly seated in the aquifer. After the auger stem was withdrawn, the annular space was backfilled with sand brought to the well from a quarry about 3 1/2 miles east of the site. The casing was cemented in the top 5-10 feet to hold it firmly at the surface. A slotted galvanized cap was screwed onto the top of the casing. No development of the well was performed, other than the pumping prior to obtaining water samples for chemical analysis.

Water samples for chemical analysis were obtained from wells WS-1 and WS-2 using a small, gas-operated (compressed nitrogen or compressed air) pump. The pump and all hoses were washed inside and out with detergent and rinsed with distilled water and acetone before obtaining samples. The pump was operated at approximately two gallons per minute for 30 minutes before water samples were collected in clean narrow-mouth glass bottles. The sample containers were sealed with Teflon-lined lids and kept chilled until they were analyzed.

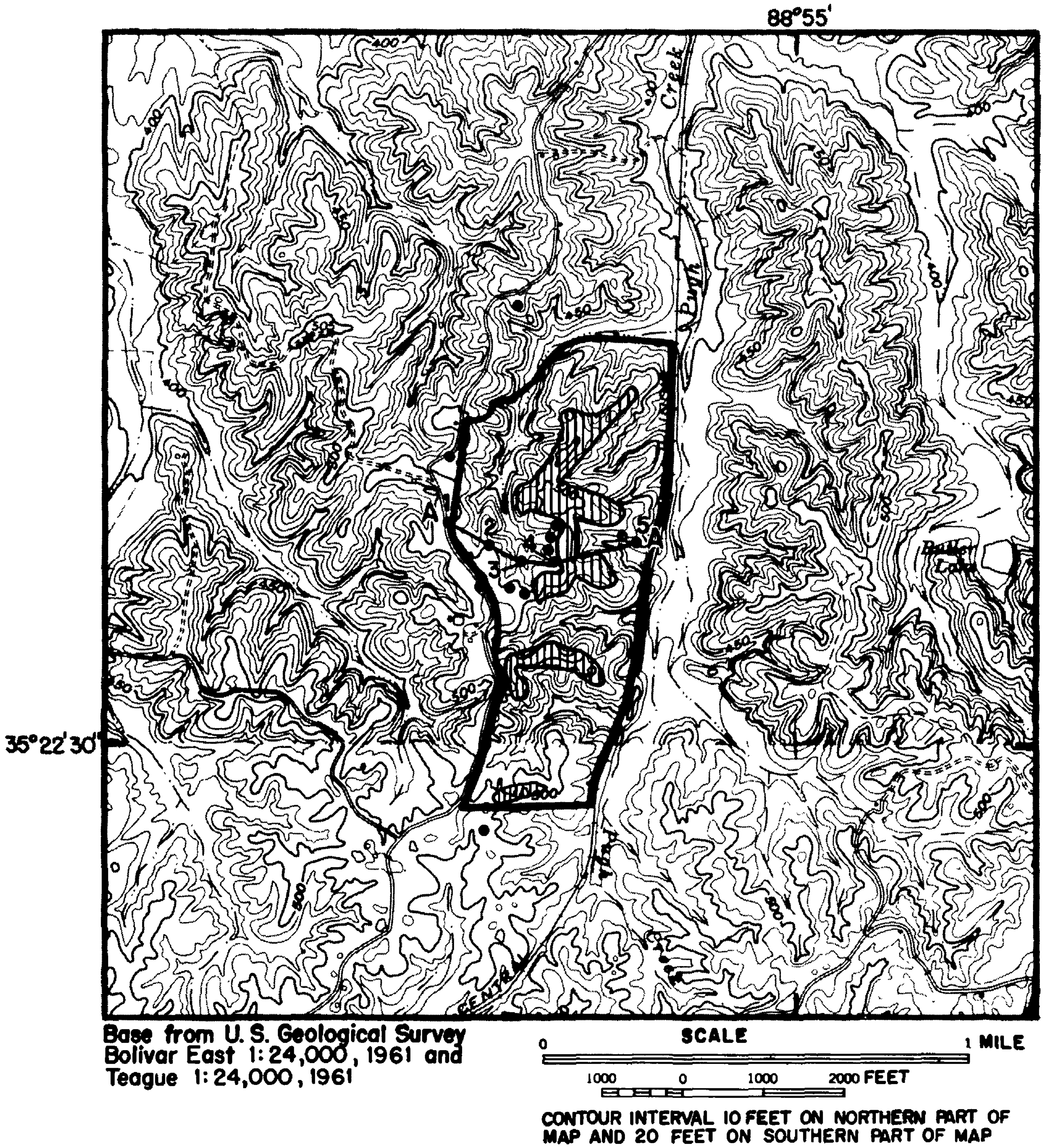
Testing for Heavy Liquid Migration

During the 1967 study, examination of the waste mixtures revealed that a significant amount of the liquid portion had a density greater than water (D.R. Rima, oral communication, 1975). This greater density combined with the poor miscibility of the liquid wastes in water created concern that the wastes might sink to the top of the upper confining bed of the Wilcox Formation (base of the water-table aquifer) and flow under gravity gradient in directions contrary to prevailing ground-water gradients.

In theory, heavier-than-water, immiscible liquids will seek the low areas at the base of the water-table aquifer. Gravity flow of the liquids would, in theory, encourage lateral migration across the top of the upper confining bed (base of the water-table aquifer) in the direction of the regional dip of the bed. The top of the Wilcox Formation dips approximately 20 feet/mile toward the northwest (Figure 3). Thus, the area tested for potential migration of the heavy liquids was northwest of the oldest burial pits.

Preparatory to obtaining samples of sediments at the top of the upper confining bed, a series of auger holes were drilled on the northwest side of the disposal site (Figure 6). These auger holes were drilled to determine both the depth to the upper confining bed and the nature of the sediments in the water-table aquifer. Typical lithologies and location of the top of the upper confining bed (base at the water-table aquifer) shown in Figure 6b are based on auger drilling.

Using the information obtained from auger drilling, four holes (C-1 through C-4, Figure 5) were made with a mud-rotary drill in order to sample the top of the upper confining bed. Four core samples were obtained from the top of the upper confining bed using a Denison core barrel. A fifth core sample was obtained from hole number C-1 (Figure 5) at depths 85 feet to 90



EXPLANATION

● Auger drilling location

A—A' Location of section shown in Figure 6

▥ Disposal trenches

Figure 6.--Auger drilling locations of this study.

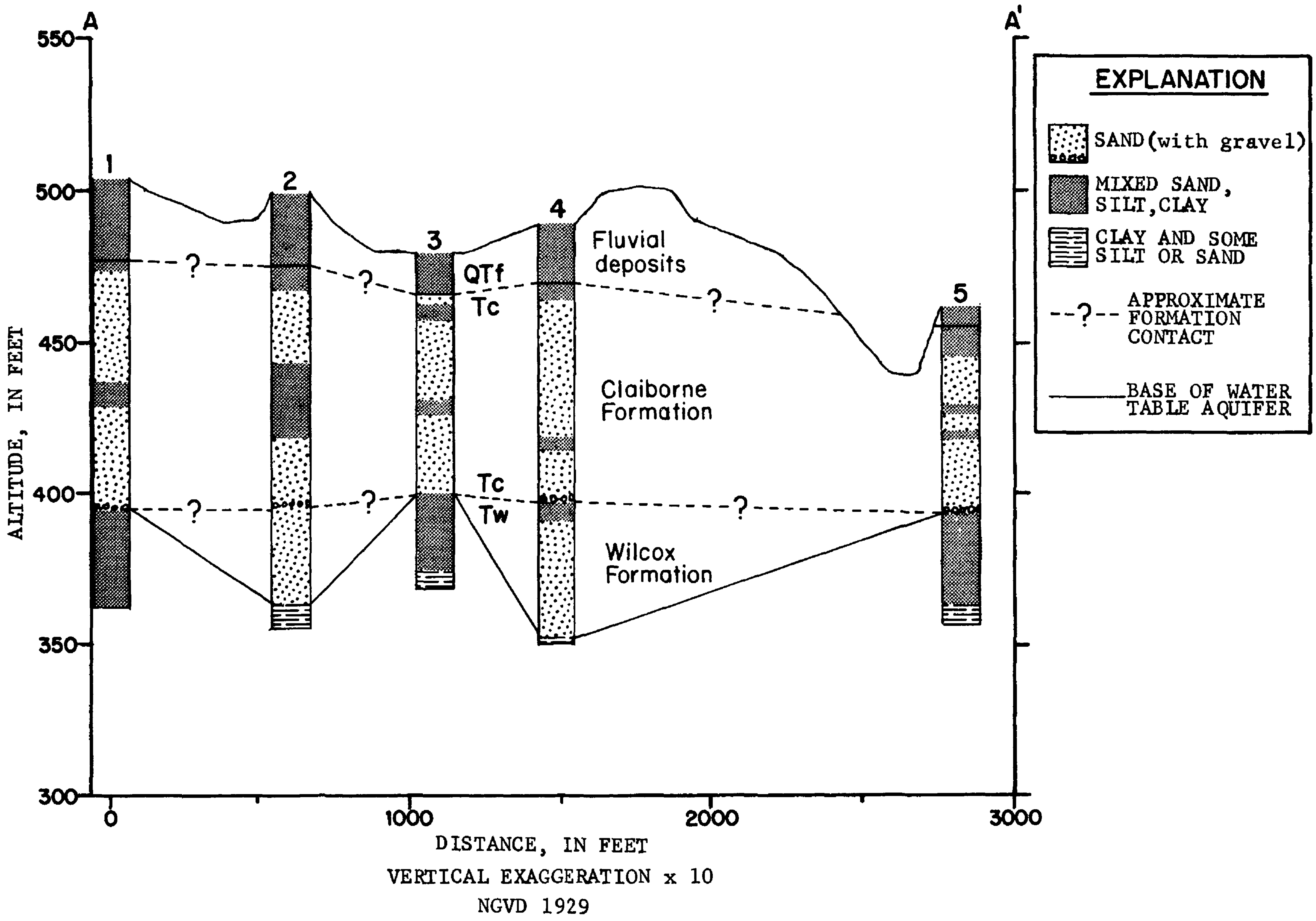


Figure 6b.--Cross section through the disposal site, based on records of auger drilling and gamma logs, 1977.

feet because a strong organic chemical odor was detected in this interval during previous auger drilling.

A Denison core barrel is normally used to obtain physically undisturbed core samples. An inner barrel assembly, which retains the earth core, has a metal cutting edge extending below the bottom of the outer barrel. This cutting edge protects the unconsolidated earth materials from washing or compaction by the drilling mud, which is circulated through the annular space between the inner core-retaining barrel and the outer cutting-shoe assembly. During sampling of the upper confining bed, a five-feet long, 2.75-inch I.D. brass barrel-insert was placed inside the core-retaining barrel.

The Denison barrel has the advantage of obtaining large diameter cores of unconsolidated sediments. It has the disadvantage of being exposed to the circulating mud until coring begins, so that contaminants in the drilling mud could be transferred to the samples retained in the brass insert.

After the Denison barrel had penetrated the proper zone, the entire drill string and core barrel were retrieved from the hole. The brass insert with core inside was removed from the barrel and sealed at each end with tight plastic caps. The ends were then wrapped with paper tape and dipped in melted beeswax in an effort to keep the core samples air tight. Samples of the drilling mud were obtained during core sampling to determine if contaminants were carried down the hole by the circulation of the mud.

An unscheduled delay occurred before the core samples and drilling muds could be analyzed for leachates. The core samples were stored in their brass barrels for seven months; during the same period, the mud samples were stored in 1-quart glass bottles with Teflon-lined lids. In March 1977, the brass barrels were cut open and core material sub-samples were spooned into clean glass jars. The core sub-samples and the mud samples were shipped to the Geological Survey Laboratory and held frozen until August 1977 when chemical analyses were performed.

Chemical Analysis of Samples

For the study a total of 25 sediment and seven water samples were sent to the Geological Survey - Water Resources Division's Central Laboratory in Arvada, Colorado. The samples were prepared and extracted using the methods described by Goerlitz and Brown (1972). Sediment-water mixtures from the overland runoff samples were filtered to separately analyze the water and sediment phases.

A halogen sensitive Hall detector was used in conjunction with gas chromatography to screen the sample extracts for significant halogen content. Those samples which exhibited the presence of halogens greater that five micrograms per kilogram (ug/kg) were split, with one half being used for total organic chlorine analysis by the methods described by Rima and others (1967, p. 16-18). The remaining half was analyzed for specific pesticide compounds using the methods of Goerlitz and Brown (1972). Several samples containing sufficiently high concentrations of unknown halogen-containing compounds were scanned by gas chromatography-mas spectrometry (GC-MS) to attempt further specific compound identification.

The results of halogen screening and total organic chlorine determinations are given in Table 4. The sample locations listed in Table 4 refer to Figure 5. Specific compounds that were identified by gas chromatography and/or gas chromatography-mass spectometry are given in Table 5.

DISCUSSION OF RESULTS

The concentration of pesticide waste leachates measured in the sediment from the ponds and in the soil samples does not clearly indicate the expected concentration of the chemicals in the water phase. There can be as little as 0.01 μg/L of a pesticide residue in the water phase when the associated sediment has as much as 100,000 times that value (1,000 μg/kg)(Federal Working Group on Pest Management, 1974, p. IV-1). Studies by Goerlitz and Law (1974) point out that the relative distribution factor of pesticides between water and associated sediment is at least as dependent on the types of organic matter and bioactivity in the sediments as it is dependent on the size fraction or mineralogy of sediments. Prediction of pesticide concentrations in surface or ground water near the site would be questionable at this time, even though the leachate concentrations in the sediments are known.

Geologic Data

The geologic information obtained from on-site drilling and preparation of the geologic map of the Teague quadrangle showed that the types and areal distribution of the unconsolidated deposits below the site are not as uniform as originally interpreted. The thin silty and clayey sand lenses of the Claiborne Formation are variable in both thickness and areal extent (Figure 6b). This non-homogeneity means more than one perched water table similar to that described by Rima and others (1967, p. 8) may occur at different depths in different areas of the disposal site. Where present, deeper perched water zones could discharge contaminants in seeps further downslope from the contact between the fluvial deposits and the Claiborne Formation shown on Figure 3.

Several auger holes revealed only a thin-silty sand layer separating the lowest quartz sand of the Claiborne and similar quartz sand in the upper Wilcox. From study of the records of well drilling near the site (Table 1), the water-table aquifer is made up of sand in both the lower part of the Claiborne and the upper part of the Wilcox. It appears that a direct hydraulic connection exists between the lowest sand of the Claiborne and the uppermost sand of the Wilcox. In areas where this connection is present, it is possible for contaminants transported by ground-water flow to enter the uppermost Wilcox.

About 100 feet of clay-rich sediments in the Wilcox separate the water-table aquifer from the artesian aquifer beneath the site. This clay layer could act as a barrier to downward migration of leachates because the layer not only has a very low hydraulic conductivity, but there is also a strong sorption of the leachate compounds on clay particles (Rima and others, 1967, p. 4). Thus, the possibility of contaminants migrating through the clay-rich sediments into the artesian aquifer below the site appears extremely remote.

The bottom of the water-table aquifer is a highly irregular surface. Beneath the site this surface varies from about 395 feet altitude to less than 360 feet altitude (Figure 6b). The irregularity of the surface makes it difficult to identify and sample the potential flow paths of heavier-than-water liquids. The data from the few auger holes and core holes drilled during this study are insufficient to determine whether this hypothetical flow mechanism is operating or to predict migration patterns of "heavy" leachates. Much more extensive testing would be required to determine whether or not heavier-than-water liquids are migrating from the site by gravity flow contrary to water-table gradients.

Contaminant Migration on the Surface

The study by Rima and others (1967) found overland migration of contaminants into the tributaries of Pugh Creek North. Samples of bedload from Pugh Creek North collected in 1967 evidenced contamination as far as 1.5 miles downstream from the site (Rima and others, 1967, p. 1). Sometime after the 1967 report was released, several impoundments were built on site, presumably to trap sediment washed from the disposal areas. Sediment samples collected from four of the impoundments (P1, P2, P3, and P4 on Figure 5) in 1977 were found to be contaminated (Tables 4 and 5). Other evidence of continuing surface migration of contaminants is the eight milligrams per kilogram of waste residues found in sediment samples collected from gullies on-site in May 1975 (D.R. Rima, written communication, 1975).

A small tributary to Pugh Creek South was sampled twice to test for overland migration of contaminants during 1977. The results of the March sampling indicated some halogenated organic materials attached to the sediments at SR-1 and SR-2 (Figure 5 and Table 4). Attempts to identify the specific halogenated compounds by GC-MS were not successful owing to other interfering organic compounds (R. McAvoy, written communication, 1978). The sample from SR-1 collected in September of 1977 indicated no halogenated organic compounds.

Although one pair of samples from Pugh Creek South gave positive results for organic halogens, the source of the contaminants is uncertain. Whether the disposal site is the sole source of the unidentified contaminants cannot be determined with the available data, since similar compounds may be derived from croplands upstream from SR-1 and SR-2. More intensive sampling and identification of specific contaminant compounds are needed before the magnitude and extent of surface migration of leachates from the disposal site into Pugh Creek South can be determined.

The available data indicate that surface contamination still exists in some areas of the site. Since sediments from the impoundments on the margins of the site occasionally spill into Pugh Creek North, it appears likely that there will be some contaminants in the creek. More soil samples and stream

Table 4.--Results of chemical analysis of samples from pesticide waste disposal site, Hardeman County, Tennessee

Sample location	Date collected	Sample type	Hall halogen detector response	Total organic chlorine
B-1	Aug 77	Small vertebrates	(1)	---
C-1A	13 July 76	Earth core from 84 to 90 ft. zone	(2) N.R.	---
C-1A	13 July 76	Drilling mud from C-1A core sampling	(3) Trace	---
C-1B	13 July 76	Earth core from transition zone (131-137 ft.)	N.R.	---
C-1B	13 July 76	Drilling mud from C-1B core sampling	Trace	---
C-2	8 July 76	Earth core from transition zone (103-108 ft.)	N.R.	---
C-2	8 July 76	Drilling mud from C-2 core sampling	N.R.	---
C-3	25 July 76	Earth core from transition zone (126-131 ft.)	N.R.	---
C-3	25 July 76	Drilling mud from C-3 core sampling	Trace	---
C-4	27 July 76	Earth core from transition zone (146-155 ft.)	Trace	---
C-4	27 July 76	Drilling mud from C-4 core sampling	(sample broken in transit)	---

(1) Results of bio-assay not received from TDWQC.
(2) N.R. - no response.
(3) Trace - response between 0 and 5 microgram per kilogram (μg/kg) estimated relative to peak heights of a one nanogram per microliter (ng/μL) Aldrin standard.

Table 4.--(Cont'd).--Results of chemical analysis of samples from pesticide waste disposal site, Hardeman County, Tennessee

Sample location	Date collected	Sample type	Hall halogen detector response	Total organic chlorine
HC-1	18 Nov 76	Soil sampled by hand auger (3 feet depth)	(4) Positive	540 µg/kg
HC-2	18 Nov 76	Soil sampled by hand auger (3 feet depth)	N.R.	---
HC-3	18 Nov 76	Soil sampled by hand auger (3 feet depth)	Positive	500 µg/kg
HC-4	18 Nov 76	Soil sampled by hand auger (3 feet depth)	N.R.	---
HC-5	18 Nov 76	Soil sampled by hand auger (3 feet depth)	N.R.	---
P-1	30 Aug 77	Pond sediment	Positive	---
P-2	30 Aug 77	Pond sediment	Positive	---
P-3	30 Aug 77	Pond sediment	Positive	---
P-4	30 Aug 77	Pond sediment	Trace	---
SR-1	4 Mar 77	Surface runoff (water phase) (sediment phase)	 (sample broken in lab) Positive	--- 7.6 µg/kg
SR-1	9 Sep 77	Surface runoff (water and sediment extraction)	N.R.	---
SR-2	4 Mar 77	Surface runoff (water phase) (sediment phase)	 N.R. Positive	10 µg/kg
WS-1	1 Jun 77	Water sample from water table well	N.R.	---
WS-1	1 Jun 77	Duplicate sample	N.R.	---
WS-2	1 Jun 77	Water sample from water table well	Positive	6.8,7.0(5) µg/L
WS-2	1 Jun 77	Duplicate sample	Positive	11,13(5) µg/L

(4) Positive - response greater than 5 µg/kg estimated relative to peak heights of a ng/µL Aldrin standard.

(5) Duplicate analyses made on water sample.

Table 5.--Specific compounds identified in samples from pesticide waste disposal site, Hardeman County, Tennessee

Sample location	Date collected	Compound(s) identified	Quantity
C-1A (mud)	13 July 76	heptachlor	0.1 µg/kg
C-1B (mud)	13 July 76	heptachlor	0.2 µg/kg
C-3 (mud)	25 July 76	dieldrin	0.4 µg/kg
		endrin	0.4 µg/kg
		heptachlor	0.4 µg/kg
C-4 (core)	27 July 76	heptachlor	0.1 µg/kg
HC-1	18 Nov 76	dieldrin	46 µg/kg
		endrin	29 µg/kg
		heptachlor	35 µg/kg
		heptachlor epoxide	1.0 µg/kg
		pentachlorocyclo-pentadiene	-
		Hexachlorbicyclo-heptadiene	-
HC-3	18 Nov 76	dieldrin	5.4 µg/kg
		endrin	14 µg/kg
		heptachlor	33 µg/kg
		heptachlor epoxide	9.6 µg/kg
P-1	30 Aug 77	chlordene	460 µg/kg
		dieldrin	10 µg/kg
		endrin	1.0 µg/kg
		heptachlor epoxide	4.2 µg/kg
P-2	30 Aug 77	chlordene	23 µg/kg
		dieldrin	1.3 µg/kg
		endrin	0.3 µg/kg
		heptachlor	0.9 µg/kg
P-4	30 Aug 77	chlordene	2 µg/kg

sediment samples need to be analyzed before the full extent of surface contamination on and around the site can be determined.

Contaminant Migration in the Subsurface

The migration of contaminants in the subsurface is believed to follow the pattern shown in Figure 7. Conceptually, leachates percolate downward under the influence of gravity until they reach the uppermost perched water zone. Within this zone the leachates can migrate laterally to the margins of the perching layer. Some contaminants will continue to migrate downward through the perched zone, enter underlying beds, and finally reach the water-table aquifer. Thereafter, the leachates would migrate with ground-water flow in directions determined by local hydraulic gradients.

The presence of contaminants in the shallow perched water table was reconfirmed during this study. Soil cores from discharge points of the shallow perched water zone on the northeastern portion of the site were found to be contaminated (Table 4). In addition, during auger and core drilling operations, a strong organic chemical odor was observed on sediments from the shallow perched water zone at holes C-1 and C-2 (Figure 5). Based on these results and observations, an inferred contamination extent map of the shallow perched water zone is shown in Figure 8.

Deeper perched zones were also found during auger drilling. During auger and core drilling operations at C-1 (Figure 5), a strong odor was detected from a deep perched water zone, but chemical analysis of core C-1A failed to show the presence of contaminants (Table 4). Although contamination of deeper perched water zones is depicted in Figure 7, the data available are insufficient to draw a map of the extent of contamination in deeper perched-water zones.

The presence of waste leachates in the water-table aquifer was confirmed by the chemical analysis of water samples from WS-2 (Figure 5 and Table 4). However, the levels reported for total organic chlorine were low and individual organic compounds were not identified.

The contaminants found in WS-2 are believed to have been transported to the well in the water-table aquifer because no perched-water zone was found while drilling the well. A perched-water zone was found during exploratory drilling upslope from WS-2, and it is possible that contaminants were transported by flow in perched water zones before reaching the water table and WS-2 (see Figure 7).

The presence of contaminants in well WS-2 sets a lower limit on the rate of migration of some of the leachates through the water-table aquifer. Assuming the leachates migrated from the oldest pits along the flow lines reported by Rima and others (1967, p. 24), a distance of about 800 feet was traveled by the contaminants to well WS-2. If the leachates reached the water-table aquifer shortly after the 1966-67 study, the minimum rate of migration would be about 80 feet per year in order for the contaminants to reach well WS-2 in 1977. Thus, the minimum rate of migration of some leachate constituents

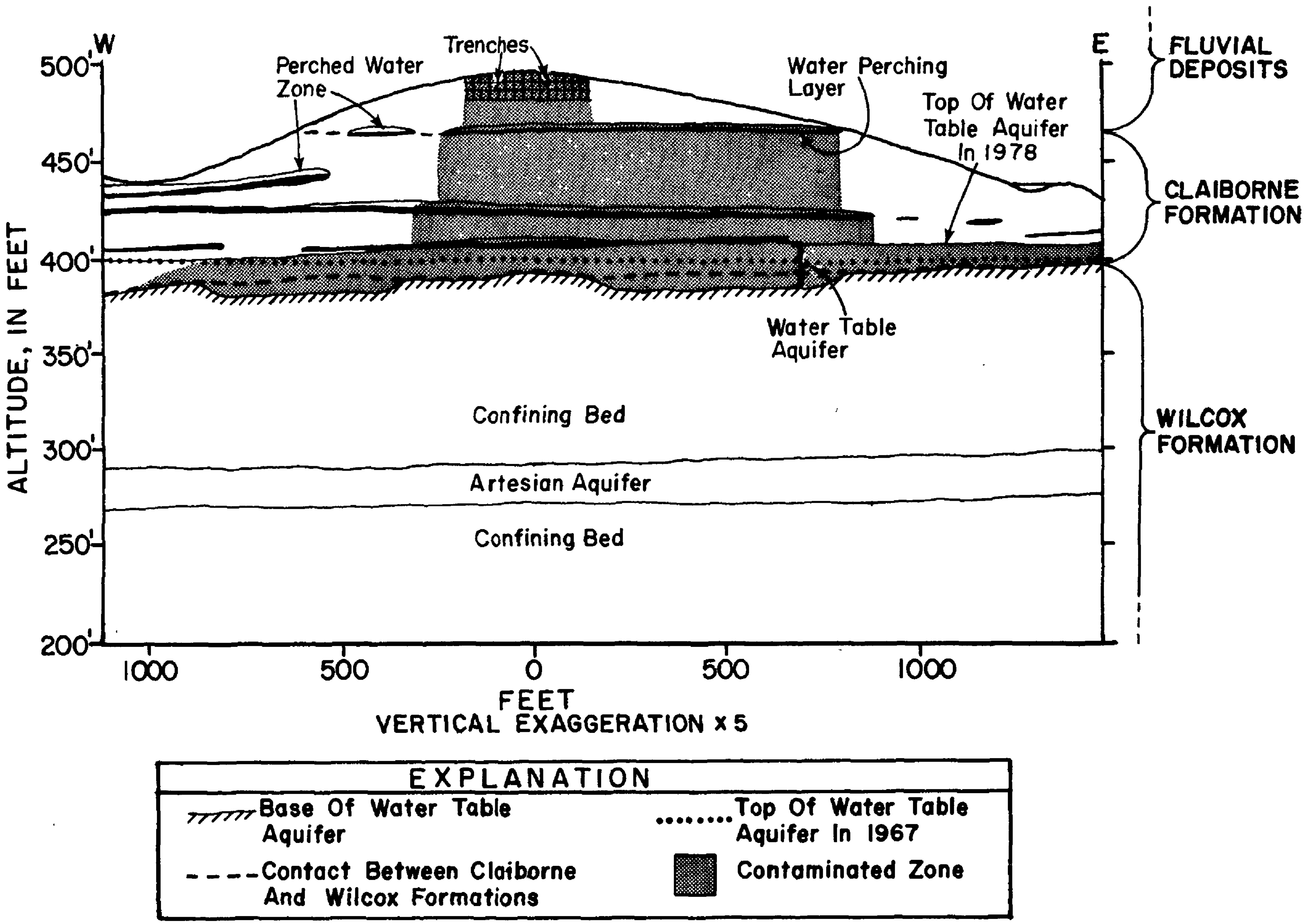


Figure 7.-- Conceptual diagram of contaminant percolation below the disposal trenches.

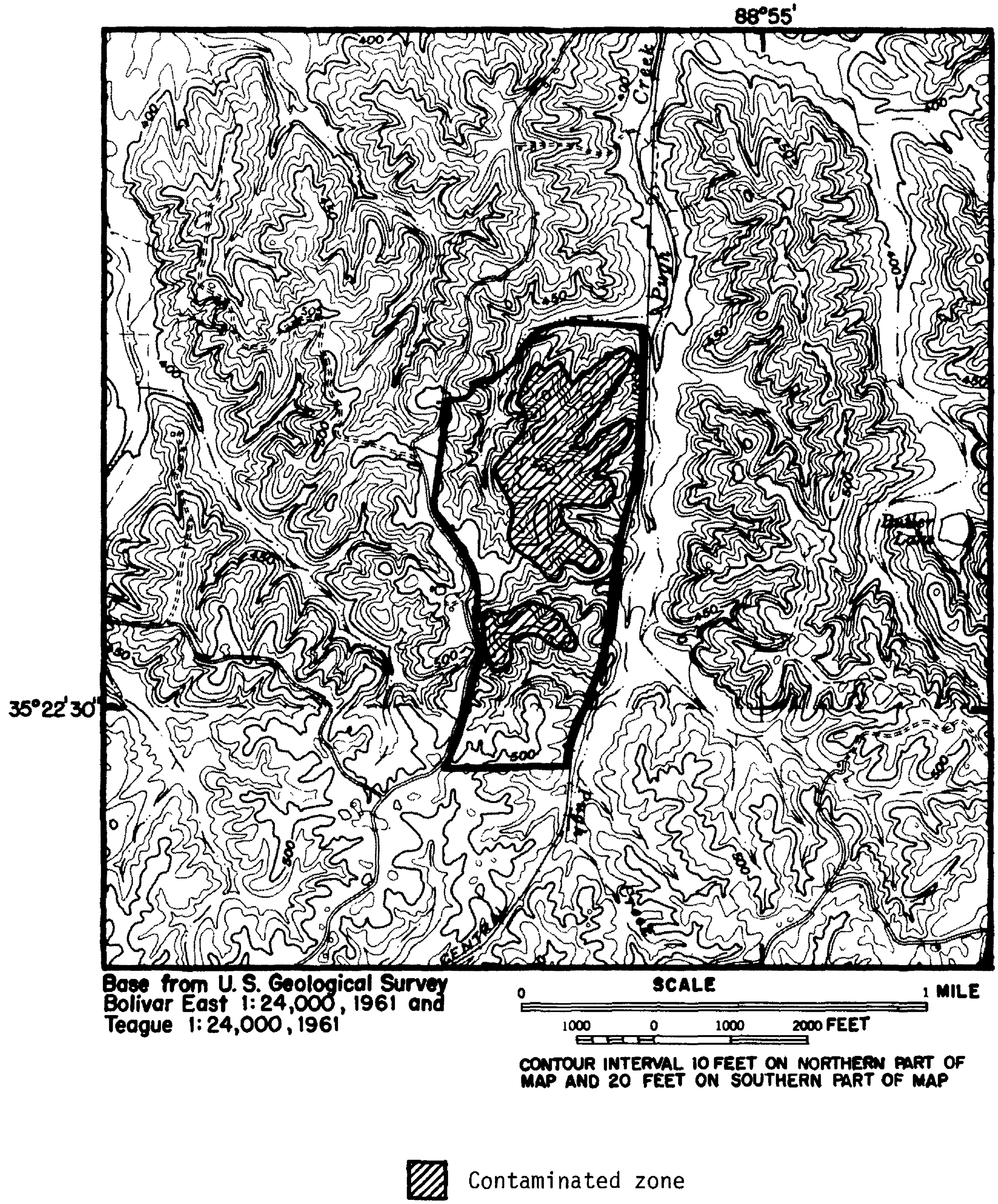


Figure 8.--Inferred extent of contamination in the perched water zone.

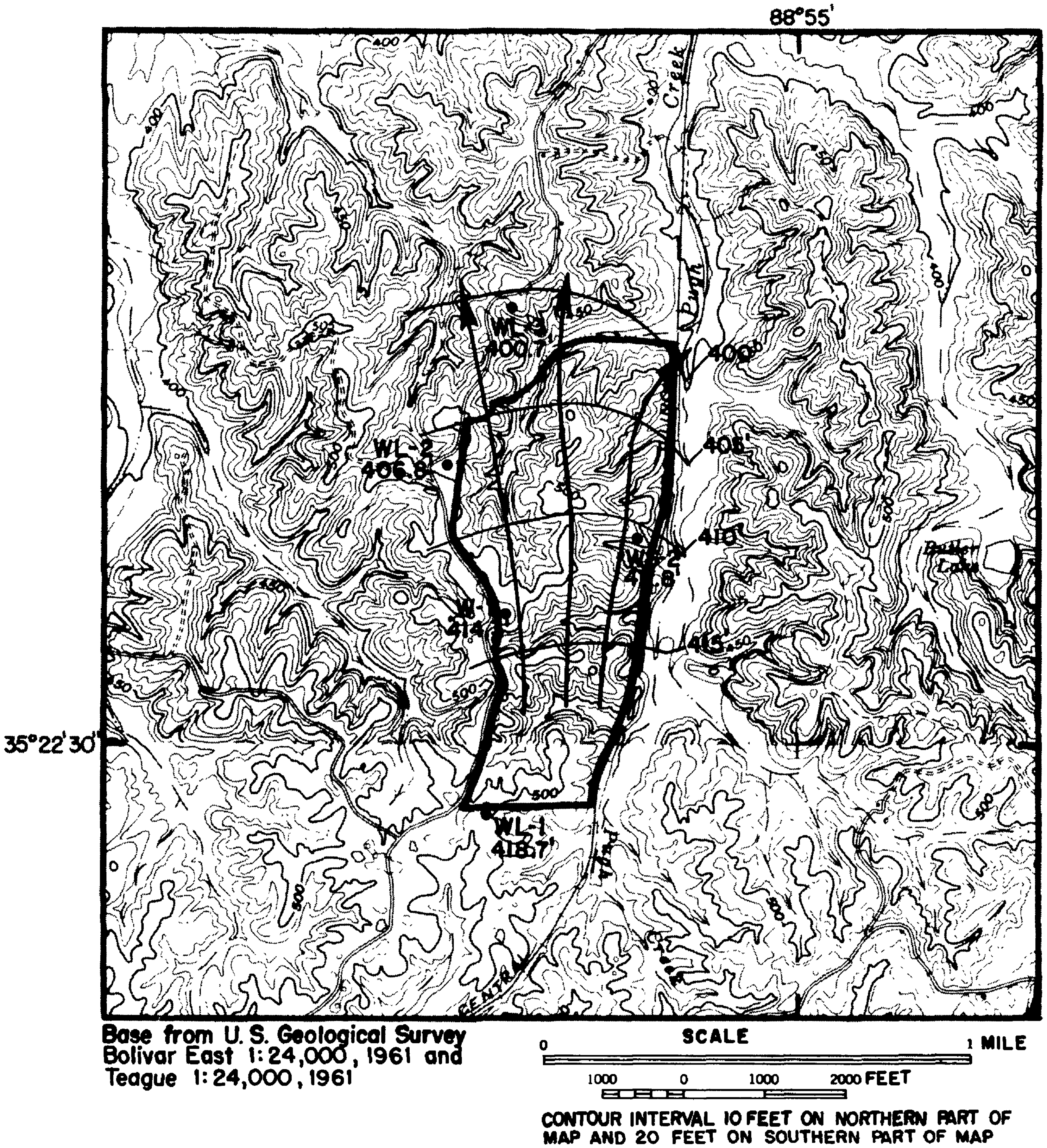
in the water-table aquifer must range between about 80 feet per year and about 300 feet per year (the rate of water movement reported by Rima and others, 1967, p. 23). However, no data are available to indicate the maximum rate of leachate migration, which could be greater than the rate of water movement due to chemical concentration gradients.

Rima and others (1967, p. 23-24) indicated that the direction of ground-water movement in the water-table aquifer beneath the disposal site was toward the east and northeast. However, measurements of water levels in observation wells in February 1978 (Figure 9) indicate that ground-water moves toward the north and northwest. Both interpretations of the ground-water flow system are based on a limited number of water-level observations, and both are imprecise. The 1978 data are more numerous and encompass a larger area than the 1967 data, and are considered to be the more accurate representation of the local pattern of present day ground-water movement.

Several factors have tended to increase recharge on the site since 1967, and some local modification of ground-water movement may have occurred as a result. The acreage of the disposal site more than doubled after 1967; during the process of waste burial, the land was cleared of trees and the surface soil texture was disturbed by excavation and back filling of numerous trenches. Site clearing and trenching have brought about both a decrease in the rate of transpiration from the site and an increase in the rate of infiltration of precipitation through the disturbed soil. Additionally, depressions have formed over the disposal trenches owing to compaction and soil subsidence around the waste drums. These depressions tend to increase infiltration either by allowing ponding of rain water on the surface or by providing ready access to the subsurface by water flow through tension cracks associated with the depressions.

The net effect of these local changes would be an overall increase in the amount of ground-water recharge entering the water-table aquifer beneath the disposal site. This, in turn, would tend to raise the position of the water table beneath the site (develop a ground-water mound) and perhaps locally change the direction of ground-water flow. Effects similar to those hypothesized at this site have been observed in other areas. Studies in Illinois by Hughes and others (1971) indicated that ground-water mounds often develop beneath solid-waste (refuse) landfills. Moreover, studies of the radioactive waste burial grounds at the Oak Ridge National Laboratory by Webster (U.S. Geological Survey, oral communication, 1978) indicate that the position of the water table beneath one burial ground had been raised several feet due to the increased rate of infiltration through disturbed surface soils.

Whether or not a change in the direction of ground-water movement has actually occurred, the present-day flow system (Figure 9) and the locations of the disposal trenches (Figure 2) can be used to show the inferred areal extent of contamination of the water-table aquifer (Figure 10). The smaller contaminated area in Figure 10 is based on the minimum contaminant migration rate of 80 feet per year; the larger area is based on a migration rate of 300 feet per year, as discussed previously. The maximum possible extent of con-



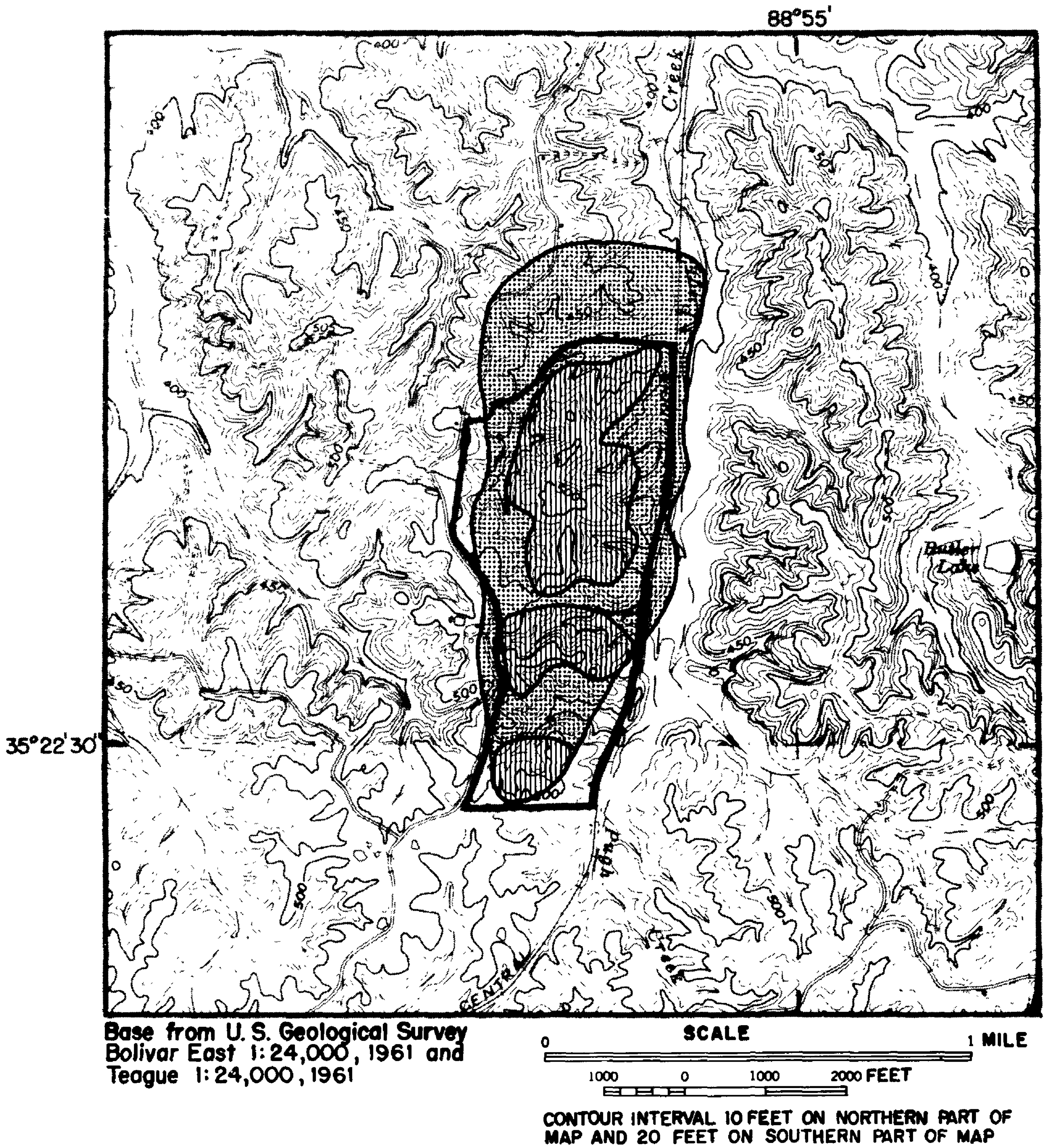
EXPLANATION

•WL-1, 418.7' Water level observed on February 14, 1978, feet.

415' Piezometric contour, feet

Ground-water flow path

Figure 9.--Piezometric surface map of the water table aquifer below the disposal site.



EXPLANATION

Contaminated zone, based on migration rate of 25 meters per year for 6 years (1972-78)

Contaminated zone, based on migration rate of 100 meters per year for 6 years (1972-78)

Figure 10.--Inferred extent of contamination of the water-table aquifer in 1978

tamination cannot be determined at this time, because the maximum rate of migration is unknown.

The only chemical evidence supplied by this study that contaminant migration has occurred toward the northwest is the trace amounts of waste related chemicals found in the drilling muds of C-1 and C-3, and the core samples from C-4 (Tables 4 and 5). Considering the delay between sample collection and chemical analysis, these results are probably not indicative of the original levels of contaminants in the cores. In fact, during both the augering phase and the drilling phase of obtaining core samples at C-1, an extremely strong organic chemical odor was detected, yet the chemical analysis showed no halogenated compounds.

Several wells used for domestic water supplies are north and northwest of the disposal tract and are in the inferred path of the leachate as it moves under natural gradients. Withdrawals from these wells could introduce slight distortions to the contamination patterns shown in Figure 10. The magnitude of these distortions cannot be estimated with the data available. Pumping test data are needed to determine more accurately the hydraulic characteristics of the water-table aquifer. Additional observation well data are also needed to define the water-table gradients between the disposal site and the domestic water wells.

No contaminant migration toward the south of the site is shown in Figure 10 for two reasons: 1) the water-table gradients indicate ground-water flow is in the opposite direction, and 2) two water samples from WS-1 (Table 4) showed no contaminants present. Periodic water-level observations from WL-1 and water sample analyses from WS-1 would provide additional information on changes in the water-table aquifer in this area.

This study was planned on the basis of predictions of contaminant migration from the disposal site towards the east and northeast (Rima and others, 1967, p. 22-24). For this reason, except for the Dennison core samples, no samples were collected from the water-table aquifer on the north or northwestern margins of the site. Based on the observed water-table gradients, however, it appears that wells for measuring water levels and for obtaining chemical samples of the water-table aquifer are needed in these areas.

Whether or not heavier-than-water liquids are migrating away from the site could not be determined with any degree of certainty by this study. The potential of this mechanism to transport contaminants toward the northwest from the disposal site is moot since observed water-table gradients seem to favor migration of contaminants toward the north or northwest in normal groundwater flow.

SUMMARY AND FUTURE STUDIES

Between 1964 and 1972 approximately 300,000 drums of liquid and solid wastes associated with the manufacture of pesticides were buried in northern Hardeman County, Tennessee. The disposal site was initially studied in 1967 with the following results:

1. Contaminated surface minerals had washed from the site into a nearby stream (Pugh Creek North).

2. Vertical percolation of leachates had contaminated the shallow perched water zone.

3. The water-table aquifer beneath the site would soon become contaminated.

4. Attenuation of the leachates was prominent in both surface and subsurface movement.

5. At the time of the study, no local domestic well was close enough to the disposal pits to be affected by contaminants.

A re-investigation of the site began in 1976 to examine the possibility of surface or subsurface migration of contaminants into the Pugh Creek South drainage basin. Chemical analysis of stream sediments and ground-water samples indicated that leachates from the site were not migrating into Pugh Creek South basin in 1977.

The current study produced the following additional results:

1. Chemical analysis of sediments from impoundments on the margins of the site indicated continued overland migration of contaminants.

2. Chemical analysis of soils receiving seepage from the perched water zone indicate contamination was still present in that zone in 1976.

3. Chemical analysis of water from a well (WS-2) penetrating the water-table aquifer indicated that the aquifer is contaminated, as was predicted by the 1967 study. In addition, the distance of the well from the disposal pits establishes a minimum migration rate of 80 feet per year for some leachate compounds transported in the water-table zone.

4. Additional water-level data indicate water moves toward the north and northwest of the site, and increased recharge may have modified local gradients slightly. Leachate migration in the water-table aquifer should also be toward the north or northwest.

5. Additional drilling around the site and preparation of a geologic map of the area revealed the presence of thick sand lenses in the upper Wilcox Formation. These sand lenses are in hydraulic connection with the water-table aquifer and probably have become contaminated by leachates from the disposal site.

In consideration of the results of this study, future monitoring of the site should attempt to provide data on the following aspects of contaminant migration:

1. Contaminated sediments are temporarily trapped on-site by impoundments in the drainways. Periodic chemical analysis of sediment samples from Pugh Creek North and Pugh Creek South would provide data on transport of contaminants into these streams.

2. The water-table aquifer to the south of the site did not show evidence of contamination in 1977. Periodic water-level observations and water samples from wells south of the site would provide data on changes in the water-table aquifer in that area.

3. The presence of contaminants in and the flow pattern of the water-table aquifer indicates a need for monitoring wells on the northwestern and northern margins of the site.

4. Natural gradient will cause leachates to move toward domestic wells along the Toone-Teague road north and northwest of the site; more aquifer test data and water-level data are needed to define the effects of local water use on the flow system.

5. Hydrologic data obtained from site monitoring could be utilized to develop a model of ground-water flow in the vicinity of the site. This model would be helpful in predicting future contaminant migration patterns; furthermore, a model would predict the impact of alternate ground-water management plans on contaminant migration.

Future Studies

There are other questions raised by the studies of this site whose answers might have transfer value to other waste disposal sites:

1. Which chemicals are degraded or transformed in the ground-water system?

   What are the degradation or transformation products? What processes are active in degrading or transforming these compounds?

2. What are the rates of chemical breakdown on the surface? How far would sediments travel before becoming decontaminated?

3. What are the sorptive characteristics of the contaminants on sediments and how does sorption effect the flow rates of different compounds in the ground-water system? What concentrations of chemicals can be expected in the ground water when in contact with contaminated sediments?

4. If a ground-water mound exists below the site, how long will it remain, and how will it change?

5. What are the long-term biological effects of the leachates in the ponds and surface streams? Are biological processes effective in decontaminating the sediments?

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