U.S. Department of the Interior
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ARSENIC IN SOILS AND SEDIMENTS ADJACENT TO BIRCH SWAMP BROOK IN THE VICINITY OF TEXAS ROAD (DOWNSTREAM FROM THE IMPERIAL OIL COMPANY SUPERFUND SITE), MONMOUTH COUNTY, NEW JERSEY

Water-Resources Investigations Report 00-4185

Prepared in cooperation with the

U.S. ENVIRONMENTAL PROTECTION AGENCY and the

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

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By Julia L. Barringer, Thomas H. Barringer, Pierre J. Lacombe, and Charles W. Holmes

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West Trenton, New Jersey

2001

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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
inch	2.54	centimeter (cm)
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Mass	
ounce, avoirdupois (oz)	28,349	milligram (mg)
ounce, avoirdupois	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations:

ns - nanosecond (10^{-9} second)
MHz - megahertz (unit of frequency equal to 10^6 hertz)
mg/kg - milligrams per kilogram (equivalent to parts per million)
Al - aluminum
As - arsenic
Ba - barium
Ca - calcium
Cr - chromium
Cu - copper
Fe - iron
K - potassium
Mg - magnesium
Mn - manganese
Ni - nickel
Pb - lead
V - vanadium
Zn - zinc
TOC - total organic carbon

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By Julia L. Barringer, Thomas H. Barringer, Pierre J. Lacombe, and Charles W. Holmes

ABSTRACT

Concentrations of arsenic that exceed the proposed New Jersey State Cleanup Criterion for residential soils of 20 parts per million (20 mg/kg (milligrams per kilogram)) have been measured in soil samples from two residential and farm properties (referred to as the "Texas Road site") that abut Birch Swamp Brook immediately south of Texas Road and downstream from the Imperial Oil Company Superfund site in Monmouth County, New Jersey. Concentrations of arsenic that exceed the proposed cleanup criterion also have been measured in sediments along the banks and point bars of Birch Swamp Brook and in the organic soils through which the brook runs. The brook drains areas of contamination about 0.5 miles upstream that are associated with the Superfund site, where arsenical pesticide production (1917-45) and waste-oil processing (1950-69) took place. Prior to the current study, the Imperial Oil Company Superfund site was the only known major upstream source of contaminants, which include arsenic, petroleum, and polychlorinated biphenyls, but past use of arsenical pesticides had been shown to contribute substantial amounts of arsenic to the soils in the area. The source of the arsenic in the residential and farm soils was unknown, however.

The soils adjacent to the stream are organic-rich wetland soils, known as humaquepts, with areas of recent sand and clay fill, which overlie sands of the Englishtown Formation. Samples of soils and sediments were collected and analyzed for major cations, trace elements, and total organic carbon. Results of the chemical analyses indicate that arsenic concentrations are substantially larger (4.7-139 mg/kg) in the humaquepts than in the underlying sand of the Englishtown Formation (less than 0.64-7.6 mg/kg). Areas of sand and silt along the stream bank and on point bars contain elevated (greater than 20 mg/kg) arsenic concentrations that range up to 2,570 mg/kg. Similar arsenic levels, typically accompanied by petroleum and polychlorinated biphenyl contamination, have been measured in previous investigations.

Samples of humaquepts were collected from other, nearby watersheds in the New Jersey Coastal Plain and analyzed for arsenic, metals, and total organic carbon. Arsenic concentrations in these samples, which represent local ambient conditions, ranged from 4.9 to 43.1 mg/kg and include background arsenic levels and various anthropogenic inputs. These concentrations are similar to those measured in many of the humaquept samples from the Texas Road site, but statistically significant differences in calcium, barium, magnesium, and chromium concentrations are indicative of different chemical inputs to the other watersheds.

A ground-penetrating-radar survey of the Texas Road site revealed the presence of a buried stream channel between the present-day channel and the house nearest Texas Road.

Because the buried channel probably existed before the beginning of the 20th century, widespread arsenic contamination of the humaquept soils did not result from floodwaters emanating from a channel located elsewhere on the property. The rate of deposition of the humaquepts, determined by analysis of the samples for the isotope lead-210, indicates that the humaquepts were deposited over a period of at least 1,000 years; therefore, arsenic measured at or near the bottom of the humaquepts is unlikely to be derived from the Superfund site wastes or from pesticide applications unless it has leached from the land surface. An increase in arsenic and iron concentrations and a decrease in lead and copper concentrations with depth in the humaquepts at the Texas Road site indicate probable redistribution of surficially deposited arsenic by geochemical processes.

Anecdotal evidence for arsenical pesticide use on the farm fields indicates that some of the arsenic measured in soils at the Texas Road site probably is attributable to these pesticides. Given the small size of the basin and little recent history of major flooding along Birch Swamp Brook, arsenic from an upstream source would have been deposited on the fields only during major floods, such as those during the hurricane of 1938. The presence of elevated arsenic concentrations in association with petroleum and polychlorinated biphenyl contamination along the stream provides considerable evidence for stream-sediment contamination that is derived from the Superfund site, whereas the arsenic in the humaquept soils is probably derived, in part, from pesticide use, as well as from contaminated sediment originating at the Superfund site that was deposited during an extreme flood.

INTRODUCTION

Concentrations of arsenic that exceed the proposed New Jersey State Cleanup Criterion of 20 parts per million (ppm), or 20 mg/kg, have been measured in soils and sediments on residential and farm properties that abut Birch Swamp Brook immediately south of Texas Road (fig. 1) in Monmouth County, New Jersey. The properties are downstream from the Imperial Oil Company Superfund site (fig. 1) and during the past 60 years have included areas of orchard and farm fields (fig. 2). In samples of organic soils (humaquepts) collected during 1994, arsenic concentrations ranged from 2.1 to 60.8 mg/kg in the uppermost 6 in. of soil on two properties east of the brook (hereafter referred to as the "Texas Road site"). Arsenic concentrations in sediments along the channel from 0 to 6 in. deep generally were less than 60 mg/kg, although 125 mg/kg was measured in point-bar sediments near where the brook turns sharply northwest to flow beneath Texas Road. At this location, sediments from 12 to 18 in. deep contained 9,460 mg/kg of arsenic (L. Robert Kimball and Associates, Inc., 1995a); at other locations along the stream, sediments from the 12-to-18-in. interval tended to contain higher concentrations of arsenic than did the shallower sediments at the same locations.

Recent sampling by the New Jersey Department of Environmental Protection (NJDEP) failed to confirm the arsenic concentration of more than 9,000 mg/kg, but concentrations ranging from 11 to 488 mg/kg were measured in sediment from the same general location, and 39 to 2,550 mg/kg and 25 to 1,040 mg/kg were measured in sediment at two other locations along the stream channel about 120 and 160 ft, respectively, to the west (fig. 3) (Steven Byrnes, N.J. Department of Environmental Protection, written commun., 1997).

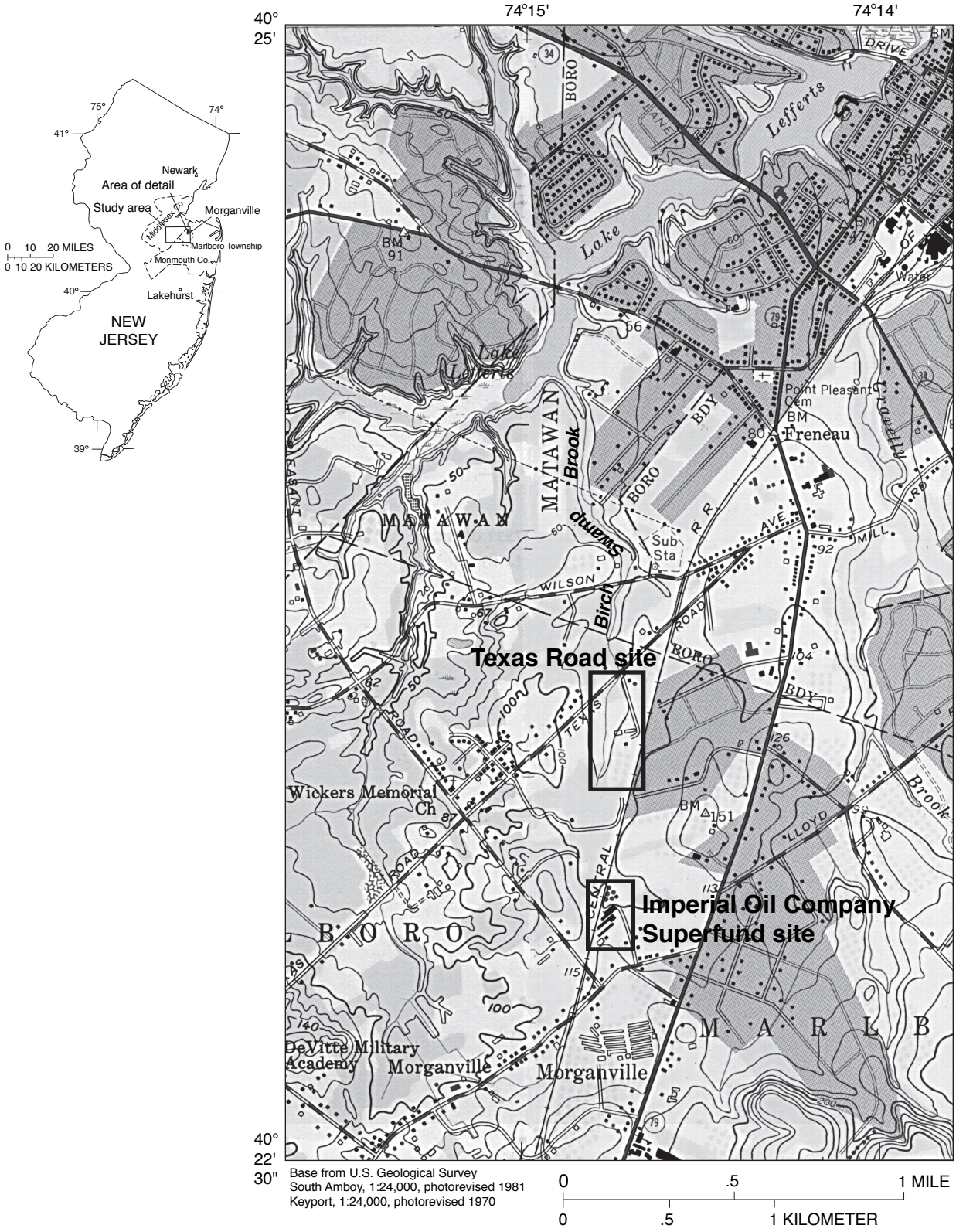
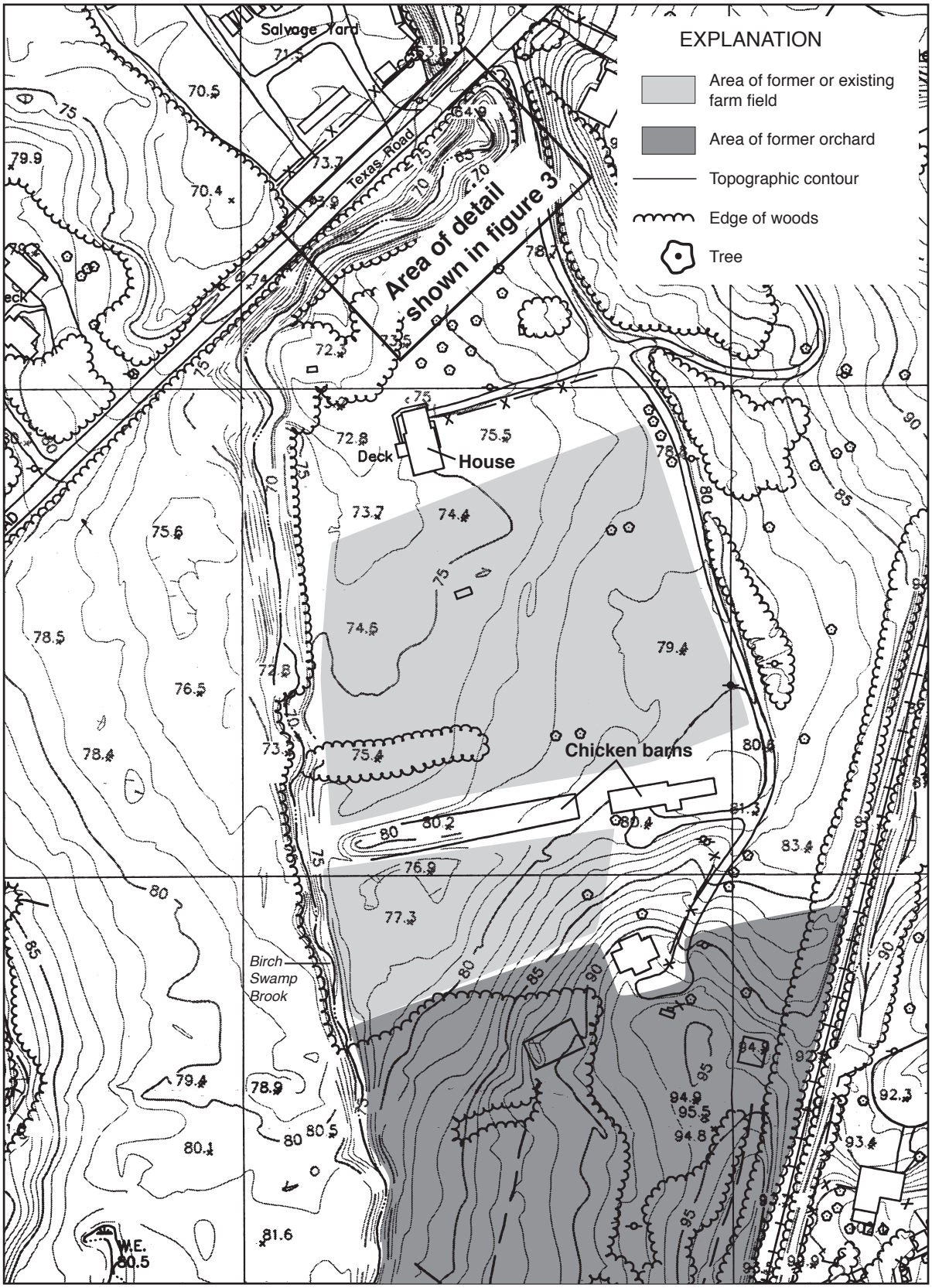
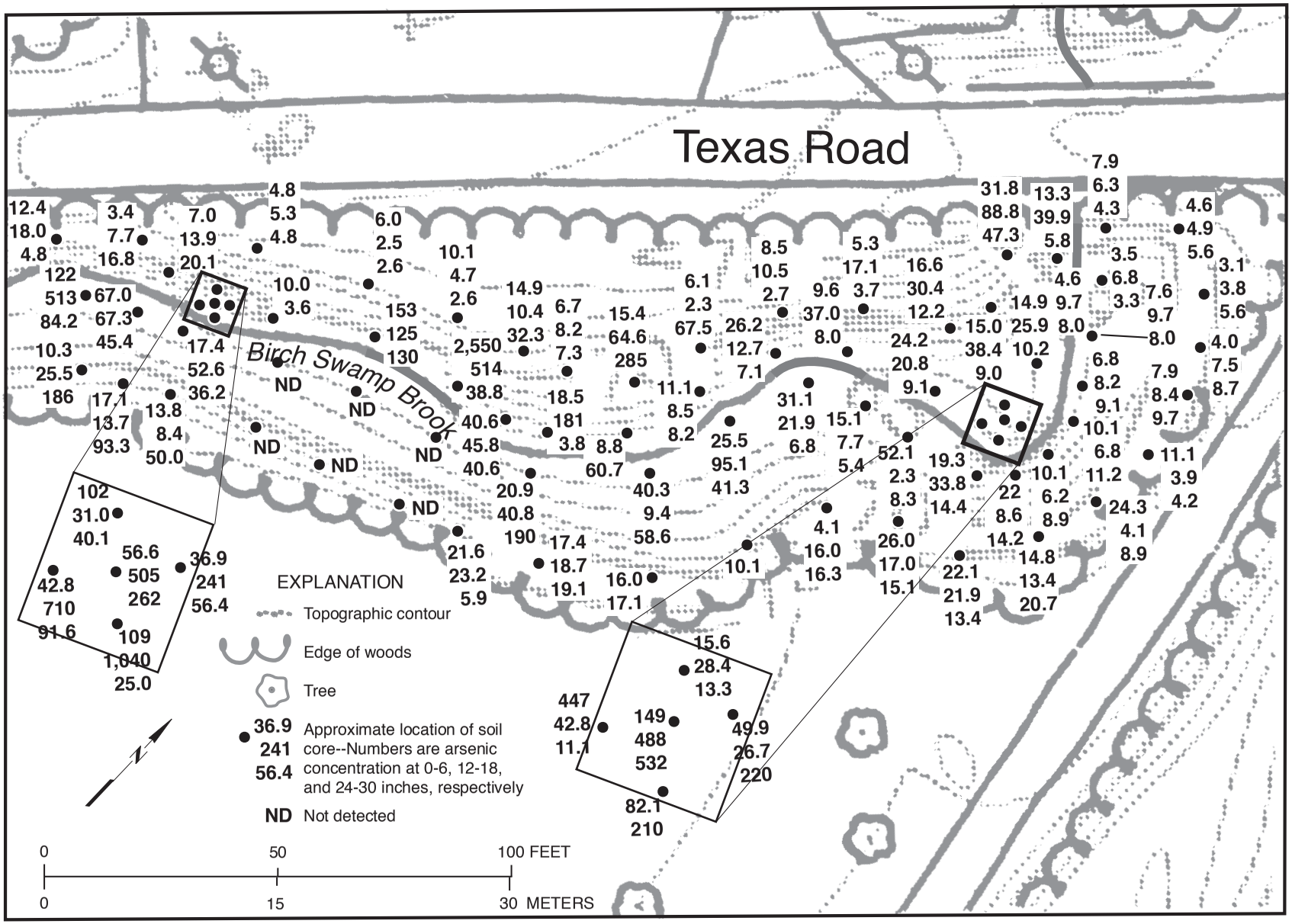


Figure 1. Location of the Texas Road site and the Imperial Oil Company Superfund site, Monmouth County, New Jersey.



Base from L. Robert Kimball and Associates, Inc., 1995b

Figure 2. Texas Road site, Monmouth County, New Jersey, and immediate vicinity, and approximate areas of former orchard and former and existing farm fields. (Modified from L. Robert Kimball and Associates, Inc., 1995b)



Base from L. Robert Kimball and Associates, Inc., 1995b

Figure 3. Detail of Birch Swamp Brook at Texas Road, Monmouth County, New Jersey, and arsenic concentrations measured in stream sediments during 1996 by New Jersey Department of Environmental Protection. (Location shown in fig. 2)

On the basis of previous soil and sediment sampling, one possible source of the elevated arsenic concentrations in the flood-plain and streambed sediments south of Texas Road was hypothesized by investigating agencies to be waste materials from the Imperial Oil Company Superfund site (IOC). Arsenic-bearing wastes were believed to have been generated during 1917-45, when arsenical pesticides were produced by Brocker Chemical Company (later Champion Chemical Company) at the IOC location off Tennent Road in Marlboro Township (E.C. Jordan Co., 1992). Waste materials from these activities and from later waste-oil-processing activities appeared to have accumulated in a wetland area of Birch Swamp Brook at the northern part of the Superfund site and upstream from the Texas Road site (fig. 1). The stream sediments south of Texas Road also contain areas of petroleum contamination, which may be related to one or more oil spills at IOC, that began to appear in Birch Swamp Brook in about 1952, according to the present owner of the Texas Road site properties. Some of the oil was transported down the length of Birch Swamp Brook and reached Lake Lefferts, about 1.5 mi north of IOC (Steven Byrnes, oral commun., 1997). Petroleum and polychlorinated biphenyls (PCBs) have recently been measured in stream-channel and bank sediments along the length of the stream (L. Robert Kimball and Associates, Inc., 1998a); the PCBs, present in soils at IOC, are presumed to be related to the waste-oil-processing activities there. The source of the elevated arsenic concentrations south of Texas Road in the soils east of the brook and at higher elevations than the stream banks was unknown, however, prompting the U.S. Environmental Protection Agency (USEPA) and NJDEP to extend a previous U.S. Geological Survey (USGS) cooperative study of arsenic in soils in the vicinity of IOC (Barringer and others, 1998). The objective of the present study was to identify the sources of arsenic in soils and sediments at the Texas Road site through an evaluation of relevant hydrologic processes and pathways and to determine background arsenic levels for wetlands soils in the area as well as rates of sedimentation in wetlands. Background arsenic concentrations determined during this study are applicable on a regional scale to similar wetlands in other parts of the Atlantic Coastal Plain.

Purpose and Scope

This report presents the results of a study to (1) develop and test hypotheses regarding the arsenic source(s); (2) determine the distribution of arsenic and other constituents in soils and sediments; (3) determine the mechanisms of arsenic distribution; and (4) identify the sources of arsenic in soils and sediments adjacent to Birch Swamp Brook in the vicinity of Texas Road in Monmouth County, New Jersey.

Description of the Study Area

Geology and Soils

The Texas Road site, organic wetlands soils (humaquepts) in nearby watersheds, and IOC, located about 0.6 mi south of the Texas Road site, are underlain directly by the Englishtown Formation, a sandy Coastal Plain deltaic deposit of Cretaceous age (Owens and Sohl, 1969). Clay lenses are interspersed throughout the formation, and are more common with depth. The contact between the basal Englishtown Formation and the underlying Woodbury Formation, primarily a clay deposit of Cretaceous age, is gradational (Owens and others, 1995).

The sands of the Englishtown Formation at the Texas Road site range from pale brown to dark grey in color; the darker colors appear to depend on the degree to which

a reducing environment is present. The sands are composed mostly of quartz grains, some with brown ferric (iron) hydroxide coatings. Muscovite occurs as a minor mineral phase; small fragments of “ironstone” (iron hydroxide) channers and (or) small fragments of lignite are observed in some samples.

The clay lenses in the Englishtown Formation are composed of greyish to brownish clay, which is mostly kaolinite, with some illite and smectites present (see analyses in Barringer and others, 1998). The clay contains blebs of bright orange to dark reddish brown silt that appears to derive its color from iron hydroxides. The low hill in the southern part of the Texas Road site, on which an orchard once stood, is underlain by a clay lens. Results of sampling during the present study indicate that some of the sediment at the Texas Road site is fill, both sand and clay, of local origin; these clearly represent anthropogenic deposits. Because the clay fill at the site is from local materials, it is similar to clays in naturally occurring lenses; however, the silt blebs in the fill clays are disturbed and deformed, and foreign materials such as asphalt and concrete fragments commonly are present.

The soils developed on the Englishtown Formation sediments tend to be sandy and acidic; where clay lenses are present, the soils are loamy, containing a higher percentage of clay and silt-size particles than soils developed on sand. The soils present at IOC belong to the Keyport soil series, which are sandy loams. Soils mapped at the Texas Road site include Keyport soils and the Elkton loam, although the dominant soils are humaquepts--highly organic, frequently inundated soils with little development of horizons (Jablonski and Baumley, 1989).

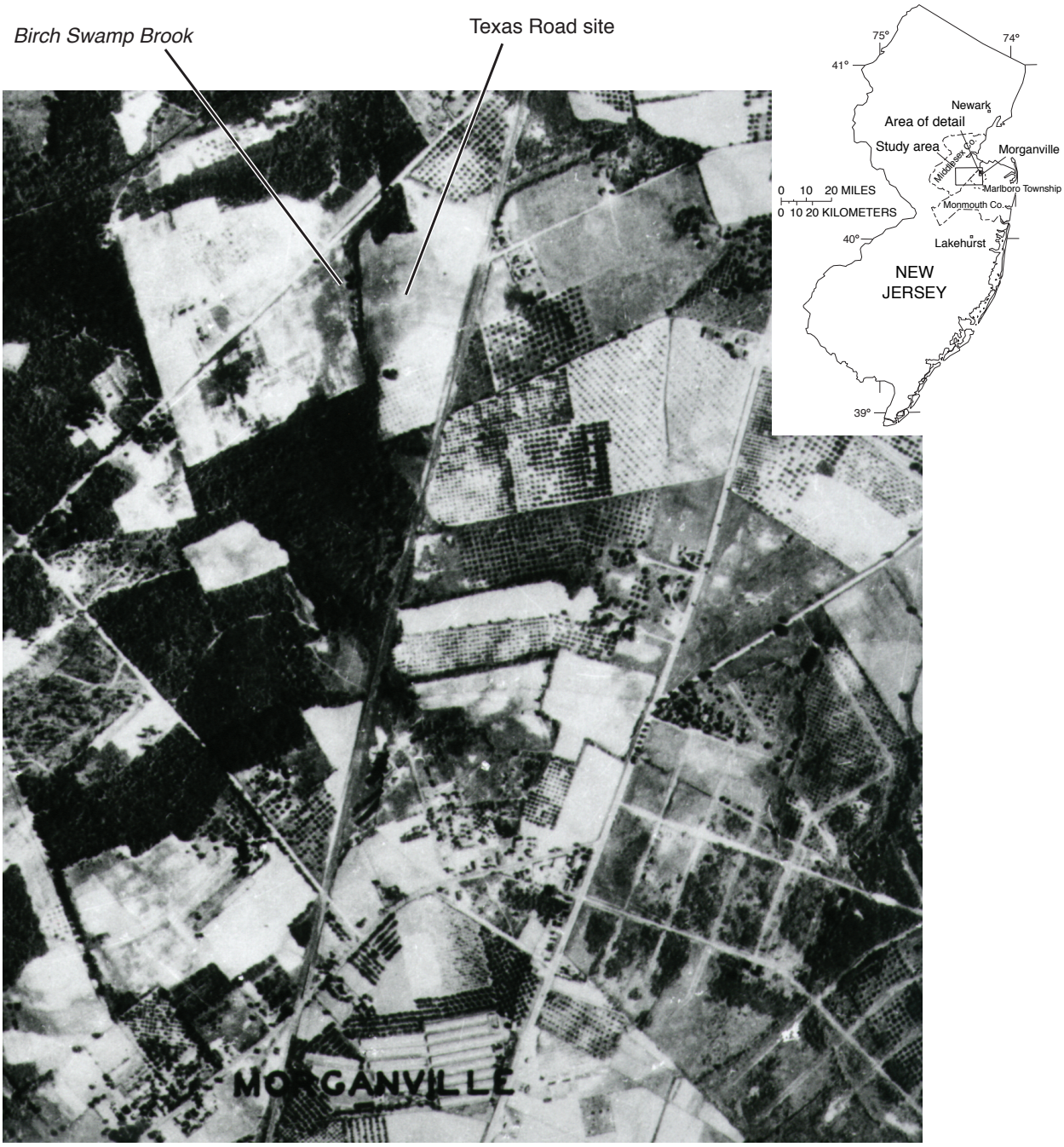
The humaquepts contain quartz sand and silt grains that range from whitish through brown to black in color. Partially decomposed leaves, twigs, and other organic matter compose the predominant material of the humaquepts. The humaquepts are dark blackish brown in color, acidic (pH 4.1-5.5), spongy in texture, and fairly easily compressed.

The sediments in the stream channel, point bars, and stream banks have variable characteristics. Thin layers of humaquept soils crop out sporadically along the stream banks; stream-deposited materials tend to be quartz-rich gravels, sands, and silts, which typically range from light brown to dark reddish brown in color.

Land-Use History

Settlement of the part of Monmouth County in which the Texas Road site is located began in the 17th century. Farming was a dominant activity in the 18th and 19th centuries. In the early 20th century, vegetables comprised the dominant crops (Jennings and others, 1916); fruit-growing increased in the area in the 1920’s (Lee and Tine, 1932). On the Atlas Sheet 29 of the Geological Survey of New Jersey (Kümmel and Vermeule, 1914), first surveyed in 1884 and revised in 1914, the Texas Road site and the area on the opposite side of Birch Swamp Brook are shown as a cranberry bog. An aerial photograph taken in 1932, however, indicates that both plowed fields and orchards were present at the Texas Road site and in the immediate vicinity (fig. 4).

Land use near the Texas Road site and IOC has changed substantially during the past 4 decades. The aerial photograph taken in 1932 (fig. 4) and also one from 1940 (not shown) indicate that much of this part of Monmouth County had remained as farmland (both row crops and orchards) and forest. Extensive residential development began after World War II, accelerated during the 1950’s,



Aerial photograph from New Jersey
Department of Environmental Protection

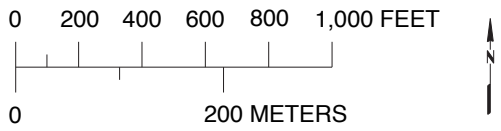


Figure 4. Aerial photograph of the study area, Marlboro Township, Monmouth County, New Jersey in 1932. (From New Jersey Department of Environmental Protection, Tidelands, Trenton, New Jersey).

and continues to the present (1998). Very little of the former farmland still exists in that form; where not developed for residential use, former fields and orchards have reverted to wooded areas.

Interpretation of aerial photographs indicates that much of the Texas Road site was open land, mostly under cultivation, during the 1930's and 1940's, and the area adjacent to the sharp bend in the brook was wooded, probably a wetland. Land immediately northeast of the Texas Road site was orchard until at least the mid-1950's, and the southern part of the Texas Road site also was orchard. The present owner indicates that the property was farmed even earlier than the 1930's. Other than the indication of a cranberry bog on the 1914 map, however, no information about crops grown before 1932 is available.

Some details of land-use history since 1940, based on recollections by local residents, are known. Crops on the farm fields during the late 1940's and 1950's included horse corn and peas in the area dominated by organic soils; tomatoes also were grown. Chicken barns were built in the southern part of the study area in the 1950's; a house in the former orchard area was built in 1948, and a second house nearer Texas Road was built in 1984. Although some of the land reverted to woods during the 1980's and early 1990's, the trees are being cleared, and row-crop cultivation is again underway.

Birch Swamp Brook was dammed at Texas Road in about 1950 to create a swimming hole, but this project was abandoned in about 1952 when oil spills or dumping, believed to originate at IOC, caused petroleum to travel down the brook (Steven Byrnes, oral commun., 1997). The present owner has no recollection of the stream having flooded the farm fields or orchard, even during severe storms such as Hurricane Diane in 1955.

According to the present owner, the area of sand fill next to the brook near the sharp bend (west of the property owner's house) was in place when his family moved to the site in the mid-1940's (fig. 5, p. 10). The area of clay fill north of the house, which extends to the stream bank, was placed there since about 1992; the clay is from a parking area within 5 mi of the Texas Road site.

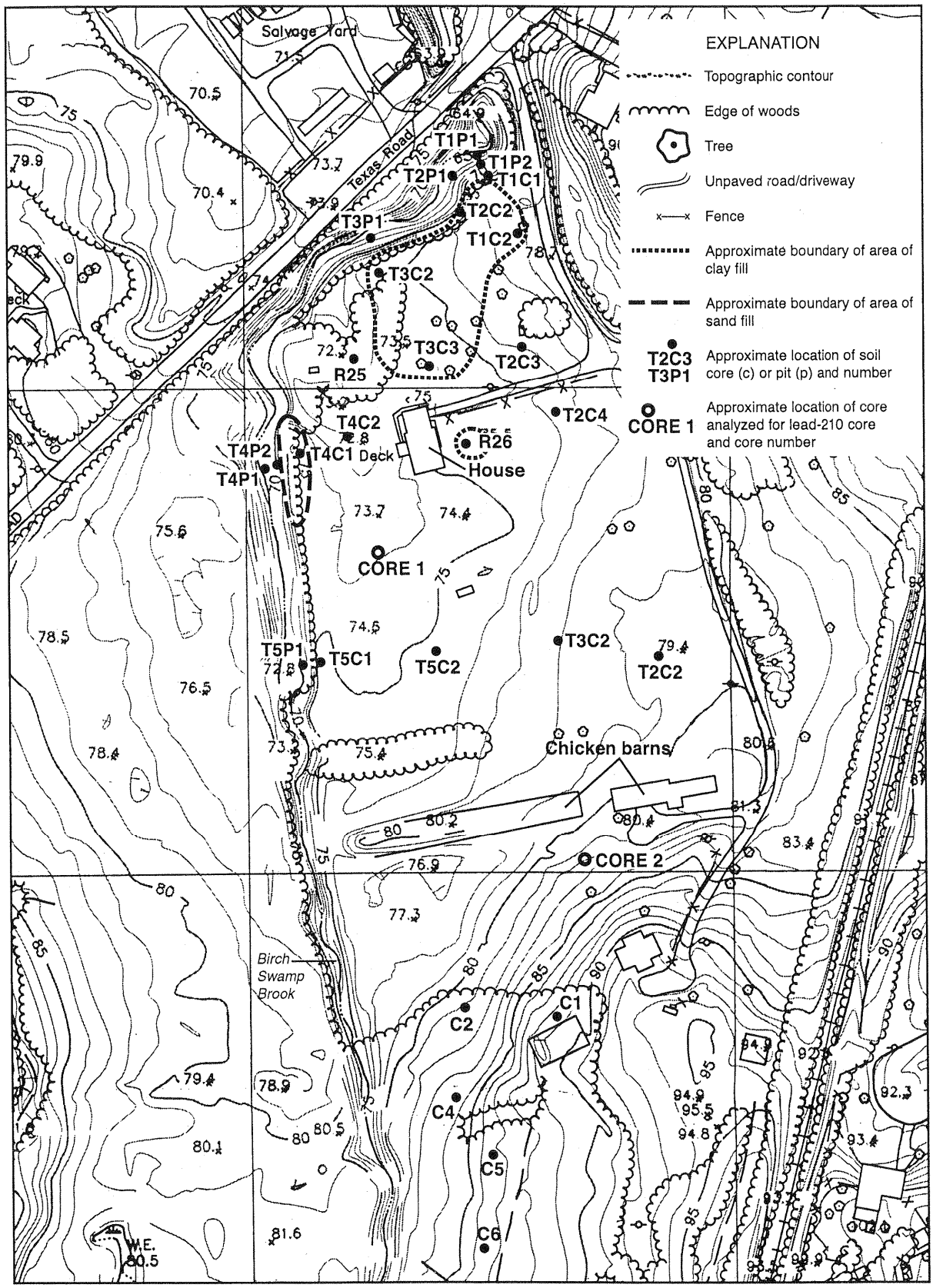
Acknowledgments

The authors thank Kim O'Connell and Trevor Anderson of USEPA, and Anthony Farro, Edward Putnam, Thomas Cozzi, Kenneth Petrone, and Joseph Maher of NJDEP for their technical support during this study. Field assistance and help in shipping samples from Steven Byrnes and John Evenson of NJDEP is gratefully acknowledged. Soil sampling was carried out by Nicholas Smith, Timothy Oden, and Robert Rosman of the USGS; the authors are most grateful for their careful work in this regard. The authors also thank Marci Marot of the USGS for collecting and analyzing samples for lead-210 ages. Richard Sanders, also of the USGS, assisted in sample collection.

STUDY APPROACH AND METHODS

Several hypotheses as to the possible source of arsenic at the Texas Road site were postulated and the study was designed to investigate each hypothetical source. The hypothetical sources are

1. Arsenic-bearing materials have been transported down the stream and have been deposited by fluvial processes both near and far from the stream.



Base from L. Robert Kimball and Associates, Inc., 1995b

Figure 5. Location of soil-sampling sites at the Texas Road site, Monmouth County, New Jersey. (Modified from L. Robert Kimball and Associates, Inc., 1995b)

2. Stream-deposited sediments contaminated by wastes from IOC have been moved from the streambed to higher elevations during farming, landscaping, or stream-channelizing activities.

3. Arsenic waste has been moved from IOC to the Texas Road site by means other than fluvial processes (waste dumping, for example).

4. The arsenic is naturally occurring, contributed by underlying geologic materials.

5. The arsenic results from past use of agricultural chemicals.

Given the observed distribution of arsenic in the soils, an additional hypothesis regarding arsenic distribution was postulated--that arsenic, whatever its source, has been mobile in the soils of the study area; thus the present distribution of arsenic is not the original distribution of arsenic.

Once the recently collected chemical data for soils in undeveloped forested land, in orchards, and at IOC (Barringer and others, 1998) and at the Texas Road site (L. Robert Kimball and Associates, Inc., 1995a) had been examined and the aerial photographs of the study area from 1932 to the present had been evaluated, the following tasks were conducted:

1. Sampling and analyzing soils and floodplain sediments adjacent to Birch Swamp Brook at the Texas Road site to determine the concentrations and distribution of arsenic and selected other chemical constituents in the various stratigraphic units;

2. Performing a ground-penetrating-radar survey of the Texas Road site to determine whether the humaquepts had been disturbed;

3. Determining the time of deposition and (or) exposure to the atmosphere of the humaquepts at the Texas Road site in order to evaluate evidence of human disturbance and fluvial deposition of arsenic in the humaquepts far from the stream.

4. Sampling and analyzing humaquepts in other watersheds in Monmouth and Middlesex Counties to determine background concentrations (from geologic and atmospheric inputs) of arsenic and other chemical constituents, and comparing the chemical composition of the humaquepts from the Texas Road site with that of the humaquepts from other watersheds by means of statistical tests;

5. Sampling and analyzing soils in the adjacent orchard to determine whether chemical constituents present (such as arsenic, lead, or calcium) are indicative of arsenical pesticide use.

Quality-Assurance Program

Because the present study was an extension of a previous study (Barringer and others, 1998), procedures were outlined in an addendum to the existing Quality Assurance Project Plan (QAPP) on file at, and approved by, the USEPA, Region II, in New York, N.Y. This work plan includes a description of standard operating procedures and the Sample and Analysis Plan.

The quality-assurance program used in the previous study is described in detail in Barringer and others (1998); procedures used in this study generally are the same and are summarized in appendix 1. Soil-sampling procedures followed the protocols for sampling developed by NJDEP and approved by USEPA. Although the NJDEP procedures do not mandate rinsate equipment blanks for soil samples, these blanks were collected during both the previous study and the current study. Barringer and others (1998) found that contamination of soil samples introduced during collection and handling was negligible. Therefore, only one rinsate equipment blank was collected for 16 soil cores collected during the present study. Two soil cores were collected during the previous study. No equipment blanks were collected during soil/sediment sampling in the seven soil pits, as the samples were collected directly into the sample bottle with clean, disposable equipment.

Standard reference materials (SRMs) were submitted for analysis as blind samples during the previous study, but this was deemed unnecessary during the present study, as laboratory results for the SRMs previously submitted were considered satisfactory. All analytical data were validated by NJDEP. A synopsis of the NJDEP validation procedures is found in Barringer and others (1998).

The ground-penetrating-radar survey was intended as a reconnaissance effort; therefore, quantification was not necessary. The reproducibility of results was assured by traversing the same path in a forward and backward direction, and comparing the two charts generated during the forward and backward traverses.

Quality-assurance procedures for the determination of lead-210 by polonium-210 analysis included adding to the samples a polonium-209 spike, calibrated to a National Bureau of Standards isotope standard.

Soil Sampling

Results of reconnaissance sampling of soils at the Texas Road site, conducted by using a bucket auger, indicated that the sediment on the point bars and along the stream bank consisted of about four to six separate soil horizons and (or) sediment layers representing distinct depositional events in the upper 18 to 24 in. of the soil/sediment profile. At higher elevations, the humaquepts overlie sands of the Englishtown Formation in most of the study area, except where recent fill is found, and Elkton soils are present in the former orchard area.

Sample Collection

Samples were collected along five transects (T1 through T5) that were roughly orthogonal to the stream channel. The soils and sediments along the stream bank and on point bars were sampled by digging pits (designated “P”) (fig. 5), exposing a clean face of soil/sediment by scraping with a clean stainless-steel trowel, and sampling from each stratigraphic layer directly into the sample bottle by using a clean, disposable plastic spatula for each layer. Locations of the sampling sites were determined by measuring distances from landmarks with a tape.

At higher elevations (fig. 5), where humaquepts overlie sand, where fill was identified, or where soils other than humaquepts are present, such as the former orchard, samples were collected by using a 3-ft stainless-steel corer with butyl acetate liners, as described in Barringer and others (1998). Core samples from the former orchard, which were not collected on a transect, were designated “C,” and numbered. Core samples along the transects also were designated with a C,

and numbered beginning with the core collected nearest the stream, but the core number was preceded by the transect number. Therefore, a core collected on transect 1, for example, would be designated T1C1, if the core were nearest the stream. Subsamples of each core were designated “S” for sand and silt, “H” for humaquept, or “CL” for clay. For those orchard cores collected from the Elkton soil series, the individual horizons were given the appropriate letter (A, E, or B). The same naming system used for the cores on transects was used for samples from the pits. Pit samples were collected starting with the transect farthest downstream and working upstream in order to avoid disturbing channel and bank sediments upstream that might contaminate downstream sediments.

The same coring technique used to sample humaquepts and other soils in the former orchard in the southern part of the Texas Road site was used to sample humaquepts in other nearby watersheds, including Matchaponix Brook, Weamaconk Creek, Pine Creek, and an unnamed tributary of Deep Run (fig. 6). Details of sampling protocols and equipment-cleaning procedures are found in Barringer and others (1998).

Core samples were chilled and returned to the USGS District laboratory, West Trenton, New Jersey, where they were subsampled by soil horizon or by sediment type and placed in precleaned sample bottles by using clean stainless-steel spatulas or disposable spatulas, depending on the stiffness of the sediment sample. Details of the subsampling method are given in Barringer and others (1998). The filled sample bottles were kept chilled and shipped in clean coolers to the analyzing laboratories, accompanied by chain-of-custody forms.

Sample Analysis

Inductively coupled plasma spectroscopy was used to analyze for all target analyte list (TAL) metals and metalloids except mercury, which was determined by the cold-vapor atomic absorption method. Total-organic-carbon analyses were performed using the Lloyd-Kahn method. These methods are described in Barringer and others (1998). Analytical results are reported in appendix 2, which also contains soil logs and sediment descriptions from field sampling sheets. Quality-assurance and quality-control information relating to soil sampling and analysis is contained in appendix 1.

Ground-Penetrating-Radar Survey

The GPR survey was conducted as an area reconnaissance to produce a generalized map of the geohydrologic framework at the site. The generalized map was used to determine the presence of any subsurface structural features that might be associated with movement and deposition of arsenic-bearing materials at the site. Although the aerial photograph from 1932 (fig. 4) shows the stream channel occupying its present position, a topographic map from 1914 (fig. 7) indicates an extensive wetland area, used as a cranberry bog, with a stream-channel location that appears to be farther east than the present location. If the stream channel were modified during 1914-32 to create a larger area for farming, it was anticipated that results of the GPR survey would delineate general areas of disturbance. The presence of such areas could indicate that arsenic wastes from early activities at IOC had been deposited in a former stream channel and, perhaps, redistributed.

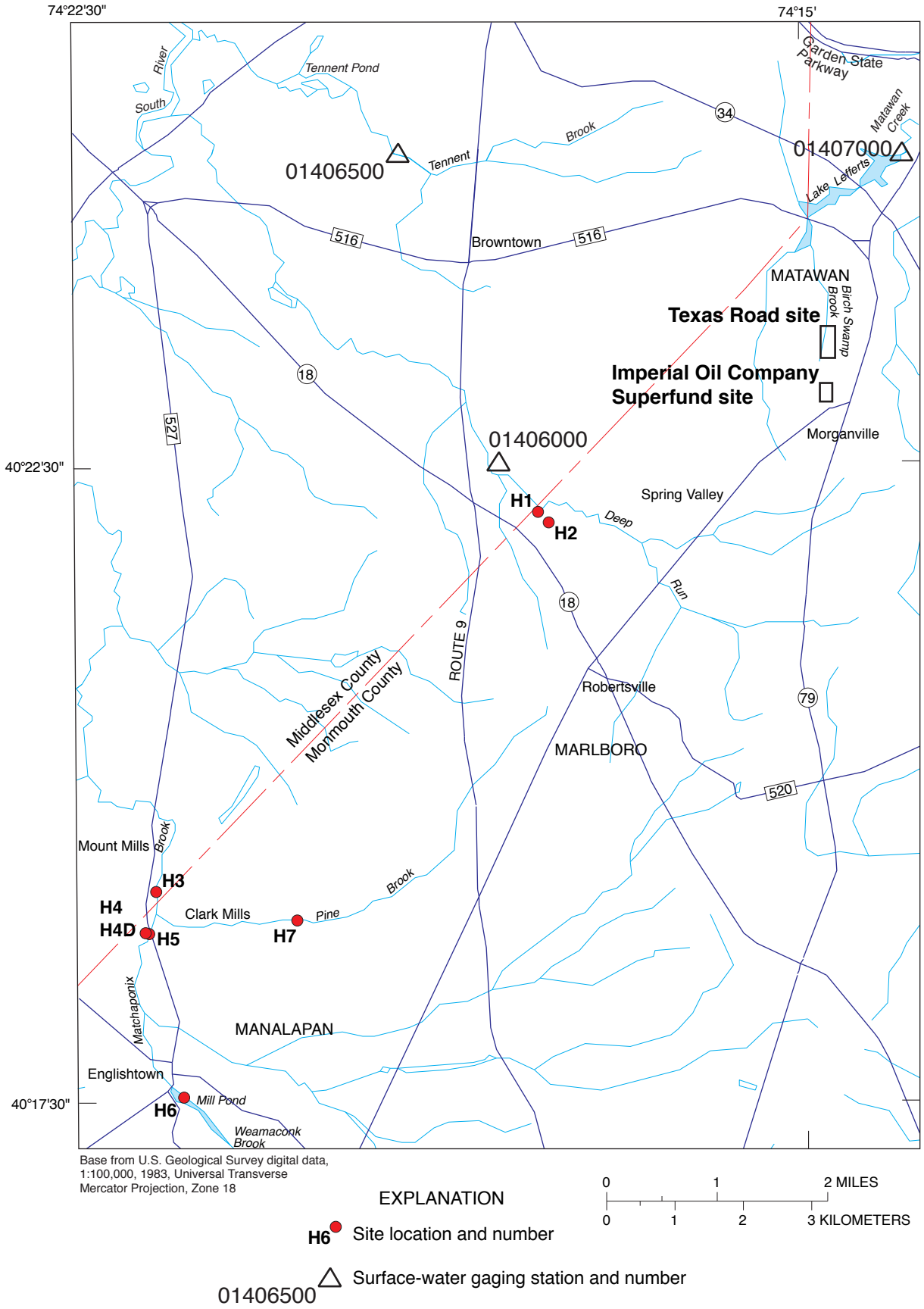


Figure 6. Location of humaquept sampling sites and surface-water gaging stations in watersheds in Middlesex and Monmouth Counties, New Jersey.

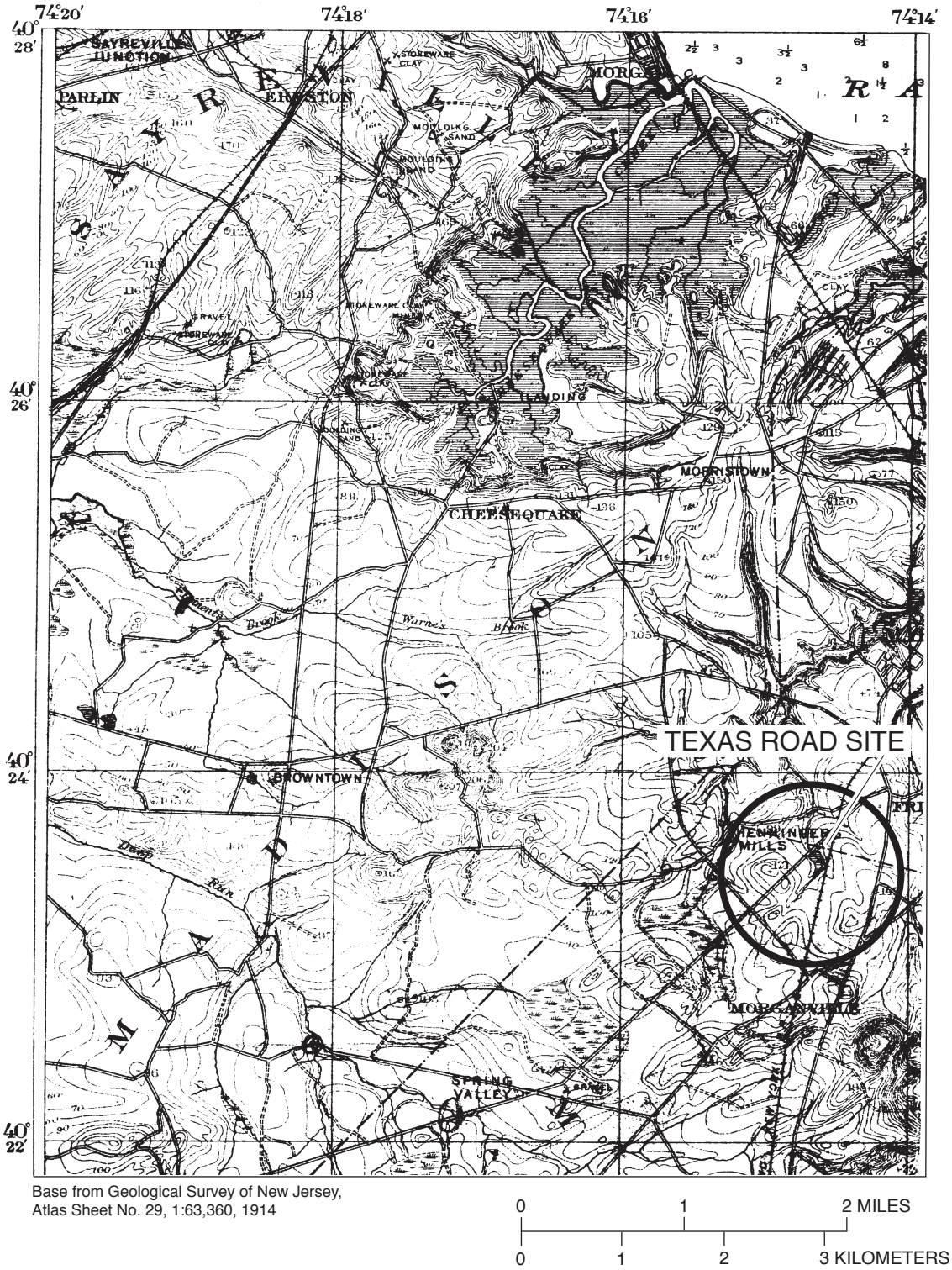


Figure 7. Topographic map from 1914 showing wetland cranberry-bog area, Texas Road site, Monmouth County, New Jersey.

Data Collection

The RAMA/GPR system, manufactured by Mala GeoScience[1], uses a 200-MHz antenna, which was towed by the operator who carried the electronics and recording equipment in chest- and backpacks. GPR profiles were collected continuously along six transects from the dirt access road across fallow farm fields to the bank of Birch Swamp Brook or to the treeline just east of the brook (fig. 8). (A seventh transect across a fill area is not reported as no radar penetration was measured.) The transects ranged from 295 to 440 ft in length; lengths were measured with a 300-ft tape measure. Data along the transects were collected in both an east-west direction and a west-east direction to determine reproducibility of data.

Data Analysis

The GPR data were downloaded and printed on paper charts, shown in appendix 3. The paper charts were analyzed by (1) delineating radar reflectors, such as the water table and bedding features; (2) calculating the depth to the water table and bedding features on the basis of two-way travel time (in nanoseconds), and (3) associating a bedding feature on the charts with sediment either exposed at land surface or known to be present in the soil/sediment profile from previously collected cores. The observed features were drawn on a Mylar overlay sheet, copies of which are shown in appendix 3.

The depth to observed features such as the water table or bedding was calculated by using the formula

$$D = T \times Vc/2$$

where T is the two-way travel time of the radar waves (in ns) and

Vc is the velocity of radar waves through the sediment.

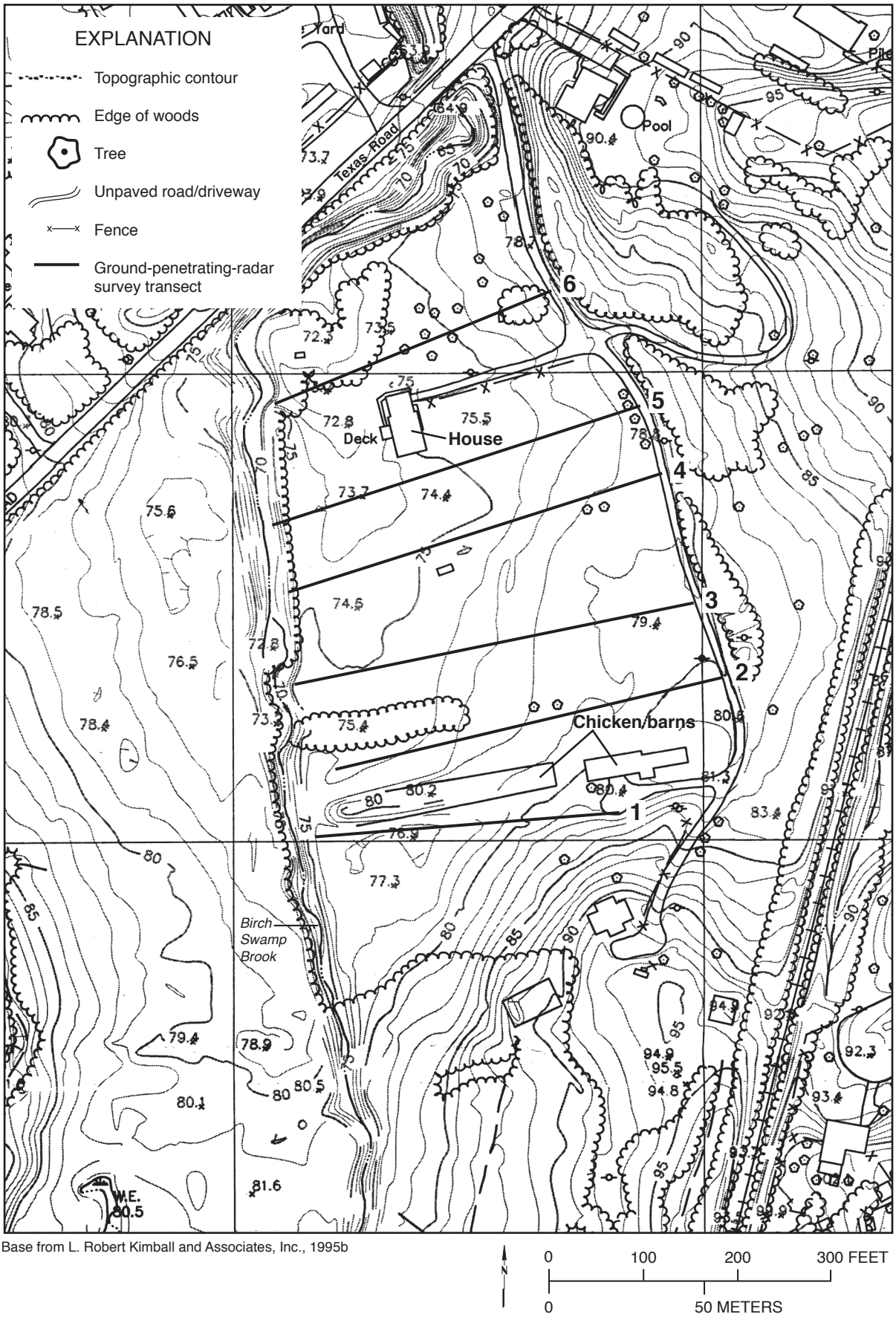
Details of the theory behind the GPR technique are presented in appendix 3.

Land surface in the part of the Texas Road site where the GPR survey was conducted is relatively flat; altitudes range from about 70 to 80 ft above sea level. The contact between the humaquepts and sands of the underlying Englishtown Formation was the strongest first radar reflector encountered (shown near the top of each GPR chart, app. 3). This contact typically is found at a depth of 1 to 4 ft below land surface. The reflection indicating the water table generally was deeper than the humaquept/sand interface; the depth to the water table varies seasonally and was greater during the summer, when the GPR survey was conducted. Above the water table, the velocity of radar waves was interpreted to be 0.45 ft/ns. Below the water table, the velocity of radar waves was calculated to be 0.2 ft/ns. As a result of this velocity change, a 10-ns interval above the water table was about 4.5 ft, whereas a 10-ns interval below the water table was about 2 ft.

Age Dating of Humaquepts

Because arsenic concentrations in the humaquepts typically were larger at depth than at the surface, the hypothesis that large amounts of arsenic were directly deposited when the humaquept layer was thinner than it is now was tested. Accordingly, the rate of deposition and age of the deepest humaquepts needed to be determined. Ages of recent

[1]The use of trade names is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.



Base from L. Robert Kimball and Associates, Inc., 1995b

Figure 8. Approximate location of transects used in ground-penetrating-radar survey, Texas Road site, Monmouth County, New Jersey. (Map modified from L. Robert Kimball and Associates, Inc., 1995b)

sediments (more precisely, the dates associated with recent exposure to the atmosphere) can be determined by measurements of atmospherically deposited radioisotopes of several elements (Faure, 1986); of these, lead-210 (^{210}Pb) is commonly used. To be a candidate for age-dating sediments, the chemistry and half-life (amount of time required for half a given number of atoms to decay to another element) of the radioisotope need to be known. Additionally, the initial amount of the isotope per unit of substrate needs to be known or accurately estimated, and, once the isotope is encapsulated in the substrate, any changes in concentration must be the result of radioactive decay. Further, the isotope's decay rate must be in a range appropriate to the scale of time investigated, and easy to measure. A member of the uranium-238 (^{238}U) series, ^{210}Pb, with a half-life of 22.8 yr, is produced by decay of radon-222 (^{222}Rn), an intermediate gaseous progenitor. ^{222}Rn, formed by decay of radium, escapes either by recoil during the ejection of the alpha particle or by diffusion into the atmosphere. ^{222}Rn rapidly decays to form ^{210}Pb, which has a residence time in the atmosphere of about 10 days, and is removed by rain or snow. ^{210}Pb is sorbed to or incorporated into depositing sediments (fig. 9); this ^{210}Pb is in excess of any ^{210}Pb present as "background" in the materials being deposited.

Sample Collection and Analysis

A 2-ft core was collected at the Texas Road site, in an area underlain by a buried stream channel, by using a 4-in.-diameter polyvinyl chloride (PVC) corer that contained a polycarbonate liner. Additionally, two 3-ft core samples of humaquepts were collected in a fallow farm field at the site (see fig. 5 for locations) by using a 2-in.-diameter stainless-steel corer with a butyl acetate liner. The cores were X-rayed at the Monmouth County Health Department facilities in Freehold, N.J., to determine the nature and depths of small-scale disturbances of the soils.

The soil cores were prepared for isotope analysis by sectioning at 2-cm (0.8-in.) intervals. The activity of ^{210}Pb was determined by measuring the activity of its "granddaughter" element, polonium-210 (^{210}Po). ^{210}Po decays solely by alpha-radiation and is easy to measure. The ^{210}Po is isolated from the samples by dissolving the material in nitric acid and plating the isotope on a silver planchet (Flynn, 1968). During dissolution of the sample, a known amount of the isotope ^{209}Po is added. The activity of ^{210}Po is determined by comparing the activity of the tracer to that of the Po in the sample. Because ^{210}Po and ^{210}Pb have been shown to be in equilibrium (their activities are about the same), the activity of ^{210}Pb can be calculated once ^{210}Po activity is determined. The results of isotope analysis are presented in appendix 4.

Data Analysis

The process by which ^{210}Pb is formed in, and deposited from, the atmosphere leads to the presence of excess or "unsupported" ^{210}Pb in sediments. "Unsupported" ^{210}Pb is that ^{210}Pb whose activity is greater than that of its radium progenitor in the sediments, whereas "supported" (or background) ^{210}Pb has the same activity as its radium progenitor (fig. 10). Dates of the sediment deposition are calculated by determining the decrease in ^{210}Pb activity at successive depths in the sediment core. If the initial ^{210}Pb activity is known, or is estimated, the age of sediment deposited at a particular depth is calculated by:

$$T_{age} = \ln(A^{210}Pb_0 / A^{210}Pb_h) \times 1/\lambda \ ,$$

where $A\ ^{210}Pb_0$ is the unsupported ^{210}Pb activity in disintegrations per minute at time zero (the present);

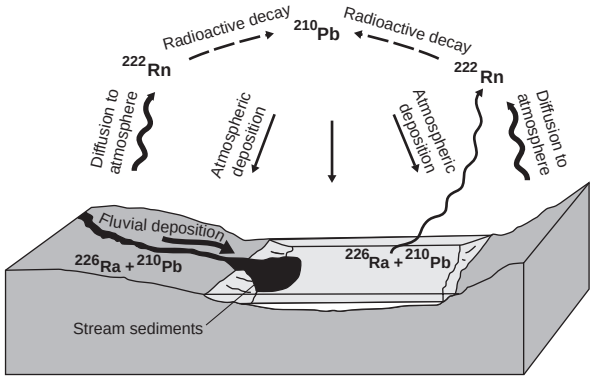


Figure 9. Conceptual model of the geochemical process that produces "excess" ^{210}Pb in sediments.

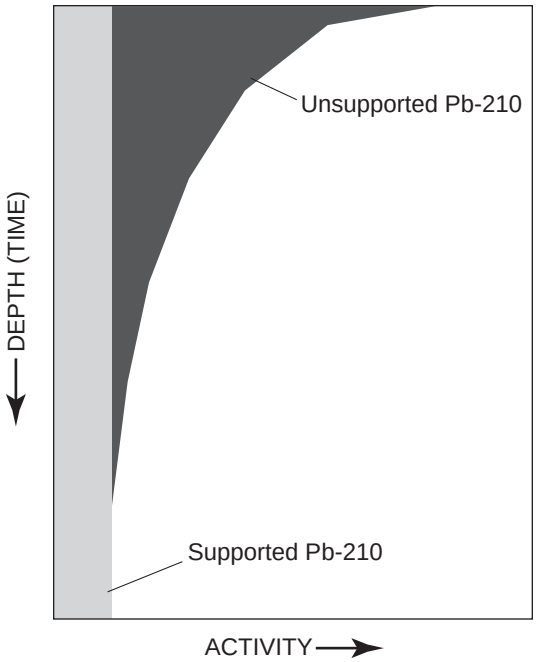


Figure 10. Ideal distribution of ^{210}Pb in a sedimentary section showing the difference between "supported" and "unsupported" ^{210}Pb.

A $^{210}Pb_h$ is the ^{210}Pb activity in disintegrations per minute at depth h; and

λ is the decay constant for ^{210}Pb, which equals 0.03114.

A plot of ^{210}Pb activity (on a logarithmic scale) as a function of depth ideally is a straight line, the slope of which indicates the relative sedimentation rate. A rapid decrease in ^{210}Pb activity with depth indicates a slow rate of sediment deposition; conversely, little or no decrease in ^{210}Pb activity with depth indicates a rapid rate of deposition.

Because no data on radium-226 (^{226}Ra) activity in the humaquepts were available, ^{226}Ra activity was estimated; the activity of ^{226}Ra is assumed to be at equilibrium with the activity of supported ^{210}Pb. The method of Binford (1990) was used to determine the activities of supported and unsupported ^{210}Pb. The limit of unsupported ^{210}Pb with depth is determined by using a Students t-test, which identifies the data point that is significantly different (at the 95-percent confidence level) from the mean of the activity data points near the asymptote on the plot of ^{210}Pb activity as a function of depth. The number of data points near the asymptote that are included depends on visual inspection of the curve. Activities at depths below the significantly different data point represent supported ^{210}Pb activities.

The calculation of dates of deposition depends on a model that best describes the geochemistry of ^{210}Pb. Two models that are widely applied to dating sedimentary deposits are the Constant Initial Concentration (CIC) model and the Constant Rate of Supply (CRS) model. In the CIC model, ^{210}Pb activity in the depositional system is assumed to have been constant through time, whereas in the CRS model, the flux of ^{210}Pb to the sediment is assumed to have been constant and a change in rate of sediment accumulation is assumed to result in dilution or concentration of ^{210}Pb. Lead is assumed to be immobile in both models; Binford (1990) indicates that lead can migrate only in extremely acidic environments.

These models do not account for mixing or post-depositional disturbances. In order to circumvent this problem, a variation of the CRS model, the Best-Fit model, was used in this study. The cores are examined prior to performing calculations; data from sections where mixing is indicated are excluded from the calculations. If several background (supported) ^{210}Pb activities are measured, the activity values are averaged, and excess (unsupported) ^{210}Pb for each data point (greater than background) is determined by subtracting the averaged background value from the measured activities greater than background. The natural logarithms (ln) of excess ^{210}Pb values from the unmixed portions of the cores are plotted (ln ^{210}Pb activity as a function of depth), and a best-fit line is calculated. If the correlation coefficient (r^2) for the best-fit line is greater than 0.9, the fit is considered to be acceptable. The apparent ^{210}Pb age for each depth sampled can be calculated by using the equation of the best-fit line. The rate of sedimentation can be determined from the slope of the line.

Statistical Analysis of Humaquept Chemical Constituents

Data Conditioning

The raw data consisted of concentrations of 15 chemical constituents in 52 humaquept samples. The variables used in statistical analyses were concentrations of the constituents Al, As, Ba, Ca, Cr, Cu, Fe, Mg, Mn, Ni, K, Pb, V, Zn, and TOC. Twenty-nine samples (observations) were humaquept samples from the Texas Road site. The remainder were humaquept samples collected

from four other watersheds. There were no missing values. Censored concentration values (below detection limits) were converted to the censoring threshold value. Ca and Mg each had three censored values. Al, Cu, and Fe concentrations were scaled by dividing by 1,000, and K concentrations were scaled by dividing by 100. Pb and Cu concentrations were normalized to TOC by dividing each value by the related TOC value divided by 1,000, and As concentrations were normalized similarly to Fe. Data were converted to logarithms (base 10) to reduce distributional skewing effects.

Model Testing and Validation

The conditioned data were subjected to canonical discriminant analysis, which is a statistical classification procedure conducted by using the "normal" option of the SAS statistical software procedure DISCRIM (SAS Institute Inc., 1990). This procedure was done to determine whether the observations could be classified into two groups (Texas Road and "other") on the basis of their geochemical composition as represented by the variables listed above. Because TOC was used in normalizing two of the other variables, it was not used as a separate variable in the analysis.

Canonical variates (variables) are linear combinations of the original variates used in the analysis, and contain all of the variance present in the original variate set. Canonical variates are used to simplify the geometry of the classification by reducing the dimensionality of the data set. In this case, only the first canonical variate was significant ($F = 21.06$, $\alpha = 0.0001$). That is, the two groups (Texas Road humaquepts and other humaquepts) were separable on the basis of their scores on a single linear combination of the original variables. On the basis of cross-validated posterior probabilities, which are asymptotically unbiased and robust measurements of model performance, the overall classification accuracy of the model was 96.15 percent. Accuracy for observations from the Texas Road category and the "other" category was 100 percent and 93.1 percent, respectively. The posterior-probability error-rate estimate for the model was 0.0012.

To confirm the classification performed by using the normal option of DISCRIM, the "npar" option was used. This is a nonparametric, nearest-neighbor classification method that is robust to violations of assumptions required under the normal option. Classification accuracy of the second procedure, on the basis of cross-validated posterior probabilities, was more than 98 percent, thus tending to confirm the classification determined under the normal option.

Because some of the 15 original variables correlated weakly with the canonical variate, data reduction was done by subjecting the original variables to a stepwise discriminant analysis. This produced a model with just five variables--the logarithms (base 10) of concentrations of normalized As, Ba, Ca, Cr, and Mg. That model was then re-estimated by using the DISCRIM procedure with the normal option. Classification accuracy with cross-validated posterior probabilities for the model was greater than 98 percent--compared to about 96 percent in the first model. Finally, the model was re-estimated by using nonparametric discriminant analysis. The nonparametric discriminant does not require assumptions made for the preceding model. Classification accuracy for this model was 100 percent.

ARSENIC IN SOILS AND SEDIMENTS ADJACENT TO BIRCH SWAMP BROOK

The current distribution of arsenic in soils at the Texas Road site varies areally as well as vertically through the soil profile. This nonuniform distribution probably results from a variety of transport and deposition mechanisms that have operated at different times during the past 7 decades. Natural mechanisms include fluvial transport and deposition of arsenic-bearing materials, weathering and illuviation of arsenic-bearing materials, and a series of geochemical processes. Mechanisms related to human activities include movement of soils and sediments during landscaping and agricultural activities.

Spatial Distribution of Arsenic and Other Constituents in Soils and Sediments

Stream Sediments

Arsenic concentrations in sediments collected from pits along the stream bank and on point bars were highly variable, both among locations and among stratigraphic layers at each location. With the exception of the sand layers from T5P1, the pit farthest upstream, arsenic concentrations in samples from sand layers typically were less than 20 mg/kg, whereas those in samples from silty and clayey layers were greater than 20 mg/kg. Organic-rich layers were present in some of the pits; arsenic concentrations varied from 4.7 to 59.5 mg/kg in samples from these sediments. In general, arsenic concentrations in sediments from pits other than T5P1 tended to be within the range of concentrations measured in sediment from other watersheds (table 1).

The layers exposed in pit T5P1 (fig. 11) were reddish sands, samples of which contained arsenic concentrations ranging from 179 to 2,570 mg/kg. The composite sample S3 contained an arsenic concentration of 179 mg/kg, whereas individual subsamples within the stratum contained arsenic concentrations ranging from 702 to 735 mg/kg. The concentration of arsenic in the composite sample S3 probably resulted from dilution of the highly contaminated sediment by less contaminated sediment.

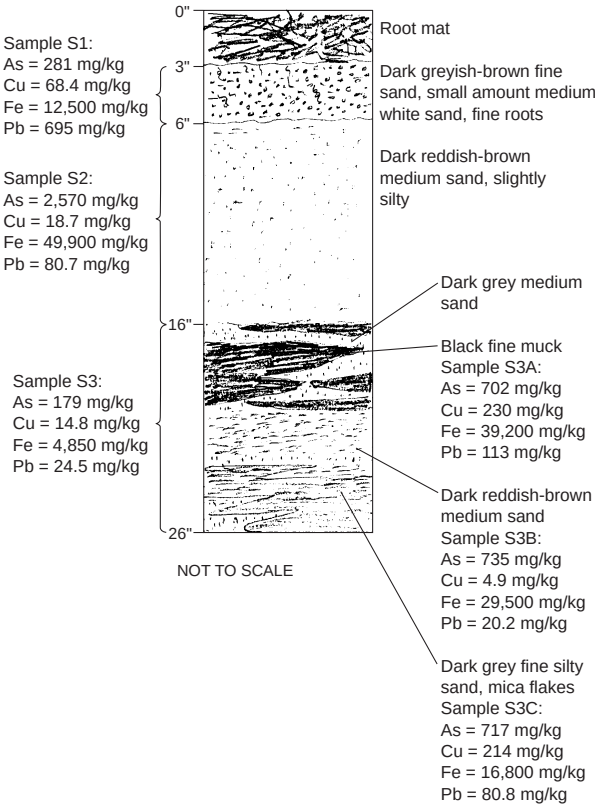


Figure 11. Stratigraphy of stream sediments in pit T5P1, Texas Road site, Monmouth County, New Jersey. (Pit location shown in fig. 5; ", inches; mg/kg, milligrams per kilogram)

The largest iron concentration measured during the study (49,900 mg/kg) was associated with the largest arsenic concentration (2,570 mg/kg) in this sand sample (T5P1S2), indicating that arsenic is strongly associated with iron hydroxide in this sample.

Table 1. Summary statistics for arsenic concentrations in soils and sediments, Middlesex and Monmouth Counties, New Jersey

[mg/kg, milligrams per kilogram; Fm., Formation; >, greater than; ≥, greater than or equal to; <, less than; ”, inches; ND, not detected; --, not calculated]

Material/land use		Number of samples	Concentration (mg/kg)			Number of samples >20 mg/kg, <40 mg/kg	Number of samples ≥40 mg/kg
			Minimum	Median	Maximum		
Geologic substrate	Englishtown Fm. sand[1,2]	11	1.1	5.4	11.1	0	0
	Englishtown Fm. sand[3]	4	1.2	5.4	8.6	0	0
	Englishtown Fm. sand[2,4,5]	23	ND[6]	1.8	18.8	0	0
	Englishtown/Woodbury Fm. clays[3]	21	8.1	18.3	41.2	7	2
Orchard soils	Texas Road site[1]						
	A horizon	3	5.2	5.7	6.1	0	0
	B horizon	8	2.3	7.7	15.6	0	0
	Clay	2	3.4	--	44.1	0	1
	Monmouth, Middlesex Counties[3]						
	A horizon	14	4.2	11.0	41.5	1	1
	E horizon	4	2.4	2.9	38.3	1	0
	B horizon	23	3.3	8.1	16.9	0	0
	Clay	6	17.8	25.4	39.1	5	0
	Texas Road site[4]						
	0 - 6”	12	3.4	5.3	11.5	0	0
	12 - 18”	12	ND[6]	2.9	18.5	0	0
	24 - 30”	9	ND[6]	2.9	40.1	0	1
Residential soils (former orchard)[3]							
	A horizon	23	10.4	25.1	70.5	14	4
	B horizon	40	3.3	21.4	149	17	5
	Clay	25	11.4	18.7	42.3	9	1
Humaquept soils	Texas Road site[1]	27	6.3	21.1	139	7	8
	Other watersheds (Monmouth, Middlesex Counties)[1]	24	4.9	22.0	43.1	14	1
	Texas Road site[4,5]	90	1.6	18.0	208	18	24
Fill materials[1]	Sand	5	0.68	3.4	15.9	0	0
	Clay	12	2.3	19.3	28.4	5	0
Birch Swamp Brook streambed and bank sediments[1]							
	Sand	17	<0.86	15.9	2,570	3	3
	Clay (fill)	2	36.7	-	40.7	1	1
	Humaquept	5	4.7	11.5	59.5	1	1
Streambed and bank deposits, other watersheds (Monmouth, Middlesex Counties)[1]							
	Sand	4	6.4	13.0	81.8	0	1
	Clay	1	6.8	--	6.8	0	0

[1]This study.
[2]Only sands underlying humaquepts and not part of a soil series or sand fill are included.
[3]Barringer and others, 1998.
[4]L. Robert Kimball and Associates, Inc., 1995a.
[5]Includes 8 sample sites on west side of stream and 32 sample sites on east side of stream.
[6]Reporting limit is about 0.3 mg/kg.

Another sample (T5P1S1) from the uppermost sand layer in this pit contained 281 mg/kg of arsenic, 695 mg/kg of lead, and 68.4 mg/kg of copper; these were the largest values for these latter two metals measured in soils from the Texas Road site during this study. The copper concentration in this sample was larger than concentrations previously measured in soils from nearby forested areas and orchards, and was similar to copper concentrations measured in some soil samples from IOC and the adjacent residential area (Barringer and others, 1998). The lead concentration also was larger than the largest measured in orchard soils, and similar to concentrations measured previously in soils at IOC, although still larger concentrations also are reported for IOC soils (Barringer and others, 1998). In addition to the highly elevated concentrations of arsenic, lead, and copper measured in samples from pit T5P1, water that collected at the bottom of the pit was observed to have an oily sheen and petroleum odor.

The stratigraphy revealed in the soil pits dug at the edge of the stream (T1P1, T2P1, T3P1) indicates that humaquepts underlie the sands along the banks; therefore, the original surface of the stream banks and channel probably was composed of highly organic materials derived from the surrounding vegetation. The sands and silts that overlie the humaquepts along the stream channel may have arisen from disturbances upstream, as they clearly postdate the original wetlands humaquept soils. At one location (T2P1), the upper humaquept layer contained small pieces of brick, which presumably had been transported by stream waters. The arsenic concentrations in the humaquepts along the stream channel (parallel to Texas Road in the northern part of the study area), measured at three locations (T1P1, T2P1, T3P1), ranged from 24.5 to 59.5 mg/kg, which are similar to, or slightly larger than, concentrations measured in humaquept samples from other watersheds.

The locations of stream sediment samples collected during this study are widely distributed along the stream channel; the sampling conducted by NJDEP along the stream reach parallel to Texas Road included a large number of cores (77) in stream-bank and point-bar sediments along a short (less than 300 ft) stream segment. Thus, the density of samples in this part of the stream is high, and the distribution of arsenic in the sediments (see fig. 3) can be examined in more detail than elsewhere along the stream. In general, arsenic concentrations on the banks are larger near the stream than farther from it, and large concentrations tend to be associated with point bars or incipient point bars, which are areas of sediment deposition. Near the stream, where arsenic concentrations are highly elevated, the concentrations generally increase with depth. Whether this vertical distribution indicates that more arsenic was deposited decades ago than was deposited recently, or whether it indicates arsenic mobility, cannot be assessed at this time. No other constituent concentrations were measured in the samples, so spatial trends for other constituent concentrations that might support a hypothesis of arsenic mobility cannot be determined from these data. It appears likely that sediments deposited at the Texas Road site during and shortly after arsenical pesticides were produced at IOC would contain larger concentrations of arsenic than sediments transported from the site several decades after pesticide production had ceased. Thus, deeper sediments could be expected to contain more arsenic than surficial sediments, if arsenic mobility is not a factor in the observed distribution.

Although some copper and lead concentrations measured previously in soil samples from IOC were in the range of background concentrations in area soils, concentrations of both metals in other soil and sediment samples from IOC were highly elevated (table 2). Therefore, copper and lead

Table 2. Summary statistics for copper and lead concentrations in soils and sediments, Middlesex and Monmouth Counties, New Jersey

[mg/kg, milligrams per kilogram; Fm., Formation; >, greater than; <, less than; “, inches; ND, not detected; -, not calculated]

Copper					
			Concentration (mg/kg)		
Material/location		Number of samples	Minimum	Median	Maximum
Imperial Oil Company Superfund site soils/sediments[1]		23	7.0	26.5	3,340
Imperial Oil Company Superfund site soils/sediments[2]		30	.48	8.5	167
Soils, undeveloped areas[2]	A horizon	12	5.5	7.7	35.6
	B horizon	23	.55	3.4	10.2
Geologic substrate[2]	Englishtown Fm. sand	4	<.51	1.5	6.7
	Englishtown/Woodbury Fm. clay	20	5.7	13.3	18.7
Birch Swamp Brook streambed and bank sediments[3]					
	Sand	20	<.23	7.9	68.4
	Clay (fill)	2	17.3	--	17.5
	Humaquept	5	2.2	11.3	16.2
Humaquept soils[3]	Texas Road site	26	6.9	14.9	33.1
	Other watersheds (Middlesex and Monmouth Counties)	24	4.2	13.2	148

Lead					
			Concentration (mg/kg)		
Material/location		Number of samples	Minimum	Median	Maximum
Imperial Oil Company Superfund site soils/sediments[1]		33	1.4	14.9	3,010
Imperial Oil Company Superfund site soils/sediments[2]		30	2.2	22.5	4,550
Soils, undeveloped areas[2]	A horizon	12	18.5	36.4	136
	B horizon	23	1.3	5.1	45.2
Geologic substrate[2]	Englishtown Fm. sand	4	1.7	3.9	4.2
	Englishtown/Woodbury Fm. clay	20	5.5	16.6	26.7
Birch Swamp Brook streambed and bank sediments[3]					
	Sand	20	1.2	21.9	695
	Clay (fill)	2	19.3	-	21.5
	Humaquept	5	4.9	21.0	25.8
Humaquept soils[3]	Texas Road site	26	4.1	27.4	89.9
	Other watersheds (Middlesex and Monmouth Counties)	24	8.2	21.1	998

[1]E.C. Jordan Co., 1990
[2]Barringer and others, 1998
[3]This study

might be expected to be present in elevated concentrations at the Texas Road site if sediments bearing wastes from IOC had been transported downstream. With the exception of a core of humaquepts (T4C2) west of the present owner's house, copper and lead concentrations tended to be largest in sediments, mostly sands, collected from the pits along the stream bank and channel. Although lead also has been deposited from the atmosphere as a result of lead-bearing emissions from automobiles and trucks, the stream sediments are less likely than soils to accumulate metals from the atmosphere, as stream sediments are moved about by water and can be shielded from additional atmospheric input by subsequent sediment deposition. Some of the lead measured in the stream sediments near the road could be derived from runoff rather than directly from atmospheric deposition. Additionally, runoff from the farm fields, where lead arsenate may have been used in the past, could have added lead to the stream sediments.

Nevertheless, the concentrations of lead and copper in samples of stream sediments from the Texas Road site were within the range of concentrations measured in samples of sands and clays from other watersheds. Sample S2 from pit T5P1, with evidence of petroleum contamination, highly elevated arsenic concentrations, and copper and lead concentrations in the range of those measured in IOC soils, does appear to indicate contaminant transport from IOC to the stream. Similar instances of highly elevated arsenic concentrations along the stream (see fig. 3) were observed in areas where lead and copper were not measured. Consequently, the distribution and concentrations of lead and copper in the sediments are less well known than the distribution and concentrations of arsenic. On the basis of available data, concentrations of lead and copper in stream sediments at the Texas Road site do not appear to be reliable markers of contaminant transport from IOC, although it is possible that some of the lead and copper measured in the sediments could have originated at IOC.

During sampling for the present study, petroleum was noted in streambed sediments upstream from the eastward bend, between T5P1 and T3P1. Disturbance of the sediments released petroleum to the stream. These sediments appear to be a reservoir of adsorbed petroleum that has travelled downstream. Because there is no known major land-surface source of petroleum at the Texas Road site, it is unlikely that petroleum is floating on the water table there, to be released into the sediments as ground water discharges to the stream. Sediments upstream and downstream from the Texas Road site also contain adsorbed petroleum (Steven Byrnes, oral commun., 1997). In a recent investigation, L. Robert Kimball and Associates, Inc. (1998a), also found petroleum along the stream channel, and PCBs in the sediments; concentrations of the latter contaminants generally were largest south of (upstream from) the Texas Road site.

These results indicate that arsenic concentrations in stream sediments are highly elevated, particularly on point bars, and are within the range of concentrations measured in soils at IOC. Relatively few copper and lead concentrations are available; concentrations of both metals were highly elevated in one sample but generally were within the ranges of concentrations measured in other watersheds. Petroleum was found in association with arsenic contamination.

Geologic Substrate and Humaquept Soils

Arsenic concentrations in soils and underlying Englishtown Formation sediments 10 ft or more from the stream, which were collected by coring, typically were larger in the humaquepts than in the sands that underlie

them (table 1). Arsenic concentrations in the sand samples were, for the most part, within the range of concentrations found to occur naturally in sands of the Englishtown Formation and the soils developed on that sandy substrate (Barringer and others, 1998); arsenic in the Texas Road samples ranged from less than 0.64 to 7.6 mg/kg.

Arsenic concentrations in humaquept samples collected from the Texas Road site during this study varied from what are estimated to be background levels (4.7-14.67 mg/kg in 7 samples) to levels estimated to represent anthropogenic inputs (20.2-139 mg/kg in 17 samples). On the basis of samples collected during this study, arsenic concentrations in the humaquepts at the Texas Road site tended to decrease with increasing distance from the stream, and also to increase with depth from land surface at sites within 200 ft of the stream channel. Similar trends were observed in data from a previous study (L. Robert Kimball and Associates, Inc., 1995a), although those samples were collected over fixed intervals (0-6 in., 12-18 in., and 24-30 in.) rather than by stratigraphic unit or soil horizon, as in the present study. In the previous study (L. Robert Kimball and Associates, Inc., 1995a), humaquept samples also were collected from the west bank of the stream; there, measured arsenic concentrations ranged from background concentrations several hundred feet from the stream to elevated concentrations near the stream.

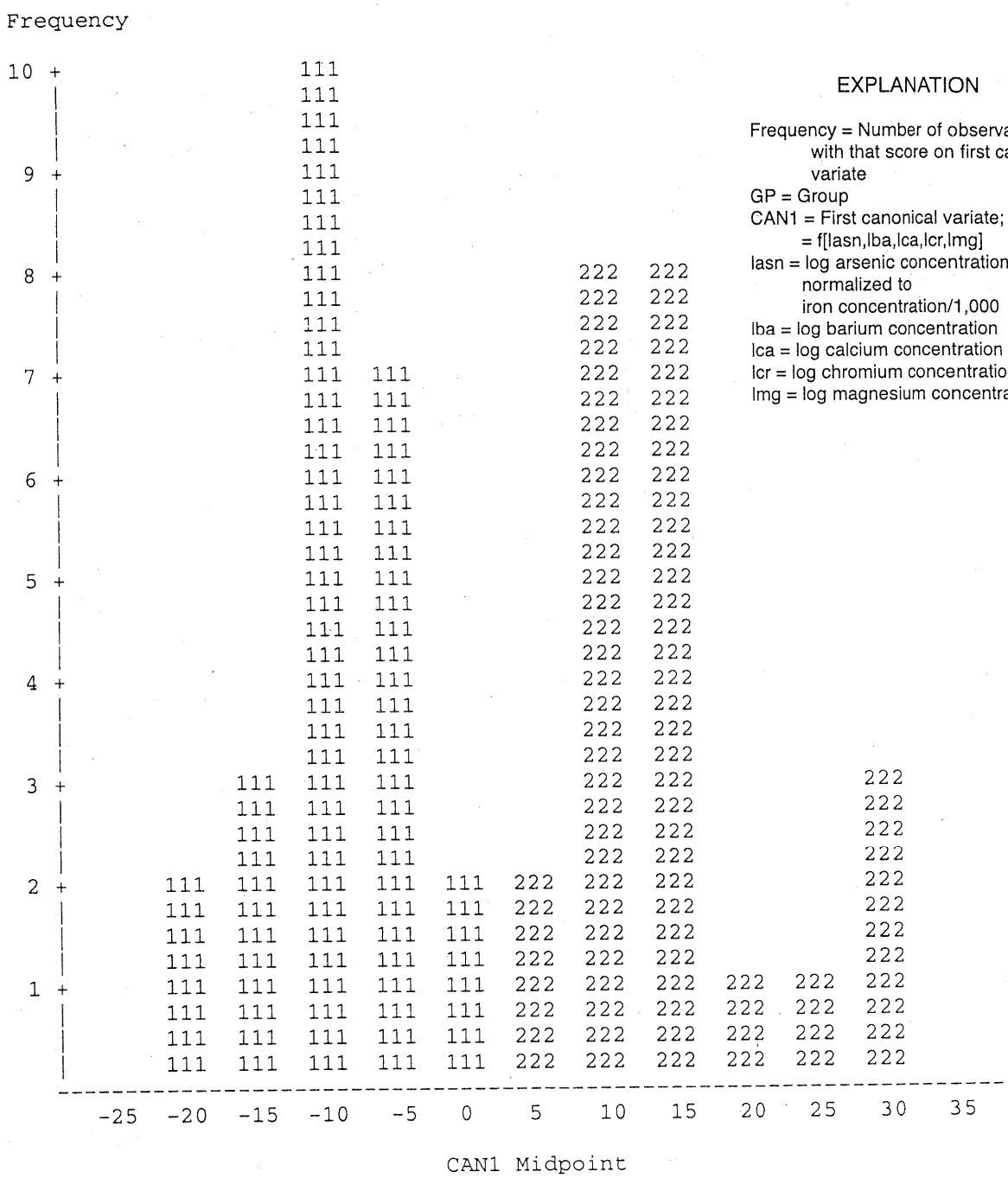
Arsenic concentrations in humaquepts from other, nearby watersheds ranged from 4.9 to 43.1 mg/kg, with a median concentration of 22.0 mg/kg (table 1). At two sampling sites (H4 and H7), arsenic concentrations decreased with depth to what appear to be background levels, indicating that arsenic deposited at the humaquept surface has migrated through only part of the soil column. Whether the arsenic results from runoff containing pesticides applied upstream, spraying of arsenical herbicides in the vicinity of the sampling site, or some other activity, is unknown. At a sampling site (H1) in a currently wooded wetland area, arsenic concentrations tended to increase with depth, perhaps indicating redistribution of arsenic by geochemical processes. On the basis of 10 humaquept samples in which arsenic concentrations were less than 20 mg/kg, and samples from the Texas Road site in which arsenic concentrations were low (L. Robert Kimball and Associates, Inc., 1995a), naturally occurring (background) concentrations of arsenic in humaquepts probably are in the range of 5 to 15 mg/kg. Arsenic concentrations larger than 20 mg/kg in 15 of the 24 humaquept samples from watersheds spatially and hydrologically unrelated to the watershed of Birch Swamp Brook (table 1) indicate that anthropogenic inputs of arsenic probably are widespread in the region.

The summary of arsenic data in table 1 indicates that concentrations of arsenic were higher in some samples of the humaquepts from the Texas Road site than in those of the humaquepts from other watersheds. Nevertheless, humaquepts from other watersheds, for the most part, did not appear to contain background concentrations of arsenic. Multivariate statistical analysis of the results of the chemical analyses was performed to determine whether there were differences in concentrations of other chemical constituents among the two groups of humaquept samples. The statistical analysis indicated that humaquepts from the Texas Road site and humaquepts from other watersheds formed two separate groups, on the basis of their chemistry. Both canonical and nonparametric discriminant analyses were successful in separating the two groups of humaquept samples with an overall accuracy of 96 and 100 percent, respectively.

As in the previous USGS study at IOC (Barringer and others, 1998), arsenic concentrations were normalized to iron concentrations by dividing each arsenic value by the related iron value divided by 1,000 for scaling purposes. This procedure corrects for inflated arsenic concentrations resulting from large concentrations of iron oxides with sorbed arsenic. In the nonparametric discriminant model, the important variables in discriminating humaquept samples from the Texas Road property from those from other watersheds were the logarithms of the concentrations of normalized arsenic, barium, calcium, chromium, and magnesium. On the basis of partial r^2 and F-statistics, their order of performance in the model, from most to least important, is magnesium > barium > calcium > normalized arsenic > chromium. All were significant above the 0.05 level. The canonical scores resulting from the statistical calculations for the two groups (illustrated as bars of ones or twos) of observations plotted on the canonical-variate axis are shown in figure 12; the separation of the two groups is apparent. The differences between groups in concentrations of predictor variables are shown in figure 13. (The differences in the two groups' median values for chromium and magnesium appear larger than the differences in median values for calcium, but this is because the scale of the concentration units differs among the boxplots.)

Because calcium and barium were good discriminators between the two groups of humaquept samples, interpreting the results of the statistical analyses was difficult. Background calcium concentrations in area soils typically are less than 150 mg/kg; background barium concentrations generally are less than 25 mg/kg (Barringer and others, 1998). Calcium and barium concentrations were highly elevated in soils at IOC, however, with calcium concentrations in 30 samples ranging from about 43 to 9,480 mg/kg (median 637 mg/kg) (Barringer and others, 1998), and barium concentrations ranging from 65 to 2,590 mg/kg (median 492 mg/kg) in 13 samples from a previous investigation (E.C. Jordan Co., 1990). These constituents are also major (calcium) and minor (barium) constituents of agricultural lime, which the present owner indicates was used on crops at the Texas Road site, both in conjunction with applications of a poisonous powder (tentatively identified as lead arsenate), and later, on a schedule of an application every 4 years. Given that two major discriminating constituents (calcium and barium) are present both at IOC and in the agricultural chemicals used at the Texas Road site, they are not clear indicators of the Superfund site as a source of contaminants. The chemical constituents in humaquepts from other watersheds are likely to be, in part, the result of runoff, but not of direct agricultural application; these humaquepts were not farmed, as were the humaquepts at Texas Road. Results of the statistical analysis clearly indicate that humaquepts at the Texas Road site have received chemical inputs that are different from chemical inputs to humaquepts in other watersheds.

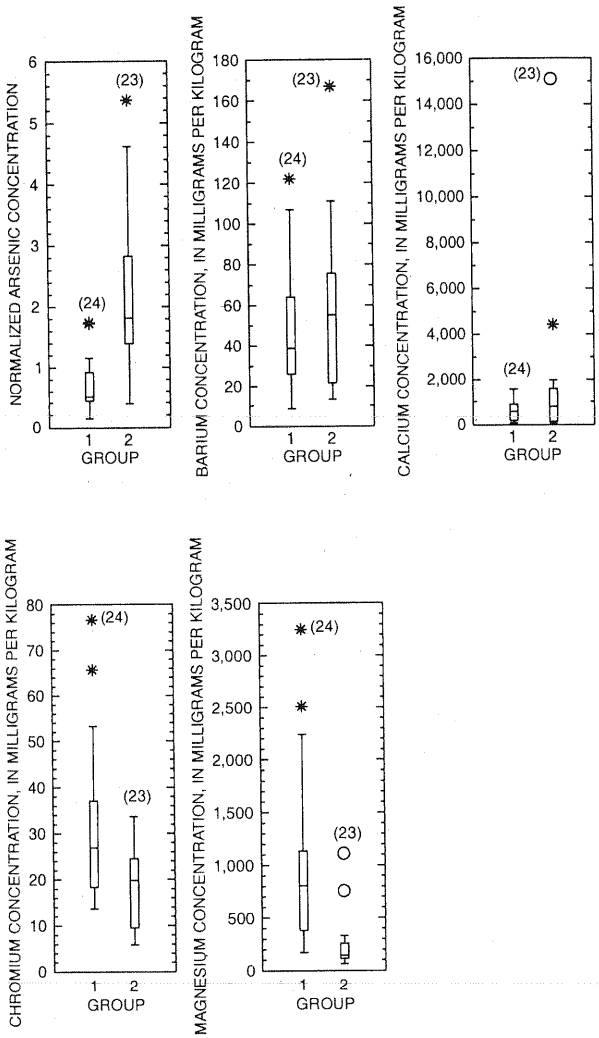
Results of this and previous investigations indicate that background concentrations of arsenic probably are 15 mg/kg or less in area humaquepts. Elevated arsenic concentrations are present in humaquepts from other watersheds and from the Texas Road site, but arsenic concentrations are larger in some samples from the Texas Road site than in samples from other watersheds. Arsenic concentrations tend to increase with depth in humaquepts at the Texas Road site, whereas underlying sands contain arsenic at background concentrations.



EXPLANATION

Frequency = Number of observations with that score on first canonical variate
GP = Group
CAN1 = First canonical variate; = f[lasn,lba,lca,lcr,lmg]
lasn = log arsenic concentration, normalized to iron concentration/1,000
lba = log barium concentration
lca = log calcium concentration
lcr = log chromium concentration
lmg = log magnesium concentration

Figure 12. Statisitical Analysis System (SAS) printout showing canonical scores for chemical variables from humaquept samples, Texas Road site, Monmouth County (group 2), and other watersheds in Middlesex and Monmouth Counties, New Jersey (group 1).



EXPLANATION

(10) Number of observations

○ Outlier data value more than 3 times the interquartile range outside the quartile

✱ Outlier data value less than or equal to 3 and more than 1.5 times the interquartile range outside the quartile

Data value less than or equal to 1.5 times the interquartile range outside the quartile

75th percentile

Median

25th percentile

Figure 13. Boxplots showing concentration distributions of selected chemical constituents in humaquept samples from other watersheds (group 1) and from the Texas Road site (group 2).

Former Orchard Soils

The previous USGS study of former and existing orchard soils near the Texas Road site showed that arsenic concentrations tended to be larger in the orchard A-horizon soil samples than in A-horizon soil samples from undeveloped forested areas (Barringer and others, 1998). Elevated arsenic concentrations have been found in soils from former orchards elsewhere in the New Jersey Coastal Plain (Kevin Schick, New Jersey Department of Environmental Protection, written commun., 1997).

The former orchard in the southern part of the Texas Road site is located on a low hill that is underlain by a clay lens. The soils are mapped as Elkton loam, which is moderately poorly drained, is acidic, and contains A, E, and B horizons. At the three locations sampled (C1, C5, and C6, fig. 5), arsenic concentrations in the A horizon ranged from 5.2 to 6.1 mg/kg (median 5.7 mg/kg), were smaller in the two E-horizon samples (2.4 and 4.4 mg/kg), and were generally greater in the B horizons, ranging from 2.3 to 15.6 mg/kg (median 7.7 mg/kg). These values are similar to arsenic concentrations measured during a previous study (L. Robert Kimball and Associates, Inc., 1995a) (table 1). One silty sample from the underlying clay contained 3.4 mg/kg; the other clay sample contained 44.1 mg/kg. This latter value could be within the range of geologically derived arsenic concentrations, as up to 40 mg/kg of arsenic was measured in undisturbed clays from undeveloped forested areas in Middlesex and Monmouth Counties in the previous study (Barringer and others, 1998).

Several soil samples collected during a previous study on property adjacent to the Texas Road site at the orchard's southern boundary contained elevated arsenic concentrations. One surface sample (0-6 in.) was found to contain 1,170 mg/kg of arsenic;

concentrations in other surficial samples ranged from 0.82 (a background value) to 89.0 mg/kg. Arsenic concentrations in deeper samples ranged from undetectable to 43.1 mg/kg (L. Robert Kimball and Associates, Inc., 1995a). The elevated arsenic concentrations in soils on the adjacent property do not appear to be natural.

It is unclear from the observed vertical distribution whether some of the arsenic in the former orchard soils derives from pesticides; pesticide arsenic may have leached over time and would now be sorbed to materials in the B horizon and the top of the clay lens. Nevertheless, lead concentrations in soil samples from the former orchard were not large, ranging from 29.4 to 41.4 mg/kg (median 30.3 mg/kg) in the three A-horizon samples. Thirteen samples from deeper horizons, excluding clays, contained substantially less lead (3.1-17.8 mg/kg; median 5.4 mg/kg) than did A-horizon samples. The observed chemistry of these samples and previously collected samples (L. Robert Kimball and Associates, Inc., 1995a) does not strongly support the hypothesis that lead arsenate pesticide was used in this part of the former orchard, although it does appear that arsenic was deposited on soils on the adjacent property. The presence of arsenical pesticide residues would be best detected if sampling were conducted at the base of old apple trees where the pesticide spray would have been concentrated. These trees, however, no longer exist.

Humaquepts are present in the former orchard on the slope that extends down to Birch Swamp Brook. Arsenic concentrations in the humaquepts in the orchard area tended to be in the range estimated to represent background concentrations. Arsenic concentrations increased with depth at the two locations sampled by the USGS (C2, C4), just as in humaquepts in the northern part of the site that contained elevated concentrations of arsenic. Several humaquept samples collected nearby at a depth of 12 to 30 in. during a previous study (L. Robert Kimball and Associates, Inc., 1995a) contained elevated arsenic concentrations, although the concentrations in the former orchard area generally do not increase with depth. Nevertheless, any concentration of arsenic at depth that exceeds what appear to be background levels in the humaquepts (less than 15 mg/kg) probably represents some migration of arsenic from surficial soils.

These results indicate that although elevated arsenic concentrations are present in some samples of the former orchard soils, evidence of arsenical pesticide use in the former orchard is unclear.

Fill Materials

Arsenic concentrations in the area of sand fill near the sharp bend in the stream (fig. 5) tended to be relatively small (from undetectable to 4.2 mg/kg), but one sample contained arsenic in a concentration of 15.9 mg/kg. Nevertheless, the arsenic concentrations were generally within the range of values (1.2-8.6 mg/kg; see table 1) reported for sands of the Englishtown Formation from other locations (Barringer and others, 1998).

The clay fill at the Texas Road site (fig. 5) is composed of locally derived grey clay with blebs and stringers of orangey-red silt, similar to the large clay lens beneath IOC and the clay lens beneath a nearby residential development described in Barringer and others (1998). The clay fill contains construction debris such as brick fragments, concrete and asphalt chunks, and wire. Petroleum was present in one sample collected from the clay fill. The range of arsenic concentrations (5.3-28.4 mg/kg; see table 1) measured in samples of the clay fill was similar to the range of

concentrations measured in samples of undisturbed local clays (Barringer and others, 1998).

An area of fill also is present on the east side of the house nearest Texas Road, according to the present owner. The extent and nature of the fill is not well defined, but some clayey materials were encountered during sampling for a previous study (L. Robert Kimball and Associates, Inc., 1995a). Arsenic concentrations in sediments from the interval in which orange and grey silty and clayey materials were encountered were reported as 33.9 and 30.2 mg/kg (L. Robert Kimball and Associates, Inc., 1995a); both concentrations are within the range of arsenic concentrations found to occur naturally in clays from this area (Barringer and others, 1998; table 1).

These results indicate that arsenic concentrations in fill materials are within the range of background concentrations in these materials.

Mechanisms Affecting the Spatial Distribution of Arsenic

The mechanisms that could cause the current spatial distribution of arsenic in soils and sediments can be divided into two groups. They include mechanisms by which arsenic-bearing materials were initially deposited at the Texas Road site, and mechanisms by which already deposited arsenic-bearing materials were redistributed, both areally and vertically.

Initial deposition mechanisms of arsenic-bearing materials could include land application of arsenical wastes at IOC and subsequent runoff followed by fluvial transport and deposition, and farmland application of compounds such as arsenical pesticides and subsequent runoff. Redistribution mechanisms of arsenic-bearing materials include movement of soils and sediments during various landscaping, building, or agricultural activities; redistribution through soil and sediment movement by burrowing animals and illuviation; redistribution of arsenic-bearing sediments by streamwater; and redistribution of arsenic through soils and sediments by geochemical or biogeochemical processes.

Fluvial Transport and Deposition of Sediments

Fluvial transport and deposition of wetland soils and sediments undoubtedly has occurred since Birch Swamp Brook developed as a headwaters stream. It is hypothesized that at some time in this process (after 1917, when pesticide production began at IOC), soils and sediments containing contaminants generated at IOC could have been transported and deposited downstream from the Superfund site. Because arsenic concentrations are elevated throughout the wetlands soils (humaquepts), and increase with depth, determination of the rate of deposition of the humaquepts is necessary in order to understand the presently observed distribution of arsenic. Similarly, where possible, the hydrologic history of the basin from the early 20th century to the present, as well as the pattern of arsenic distribution in stream sediments, must be examined to determine when and where deposition of arsenic-contaminated sediments was most prevalent.

Deposition of the Humaquepts.--Although humaquepts also are present on the west side of Birch Swamp Brook, and extend upstream from the Texas Road site as well, the largest expanse of these soils is at the Texas Road site, where they have been deposited over an area of about 9 acres.

The humaquepts are composed primarily of organic matter, and leaves and twigs are still visible in some samples. They

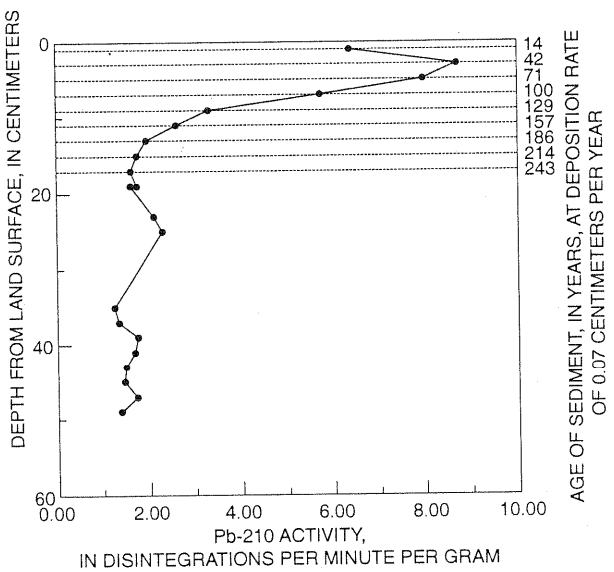


Figure 14. Lead-210 activity as a function of depth in a soil core from the area of the buried stream channel, Texas Road site, Monmouth County, New Jersey.

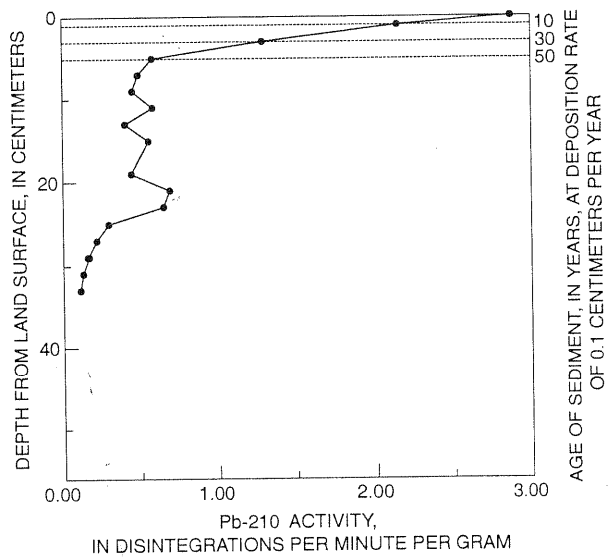


Figure 15. Lead-210 activity as a function of depth in a soil core from the farm-field area of the Texas Road site, Monmouth County, New Jersey.

also include inorganic materials such as sands and silts in relatively small amounts. They formed as leaves and other organic debris fell from wetlands vegetation and have accumulated to a thickness of 3 ft or more over much of the Texas Road site. Sands and silts from farther upstream and from less vegetated areas have washed into the accumulated organic debris over the years.

^{210}Pb ages were determined for two cores of humaquept soils (fig. 5). Core 1 was collected from the farm field about 100 ft from the stream; the humaquepts are at least 2 ft thick at that location. Although there was some disturbance in the upper 4 cm (1.6 in.) of core[2], probably from plowing, the sedimentation rate was determined to be about 0.07 cm(0.03 in.) per year (fig. 14). If the rate of deposition was constant over time, a 60-cm thickness (about 2 ft) of humaquept would have been deposited over 857 years; this calculation neglects compaction at the base of the humaquepts. A deposition rate of 0.10 cm (0.04 in.) per year was calculated for the upper 5 cm (2 in.) of core 2 (fig. 15), which was collected in the farm field near the chicken barns. Thus, the top 5 cm of humaquept accumulated over the past 50 years. Prior to that time, oscillations in ^{210}Pb activity indicate that a period of rapid deposition had taken place, making deposition rates for the period earlier than 50 years ago difficult to decipher.

[2]Because the humaquept cores were sectioned in 2-cm-thick segments for ^{210}Pb analysis, all calculations of deposition rate were made using metric units of measurement rather than English units.

The actual rate of deposition may be greater than the calculated rate of 0.10 cm (0.04 in.) per year. Core 2 was collected using the 2-in.-diameter soil corer because the 4-in.-diameter piston corer had broken. The smaller diameter corer tends to cause compaction which, in soils with distinct layering, can be as much as 25 percent of the actual thickness of soil sampled. Because the humaquepts contain no obvious layering, the amount of compaction could not be determined. If a 25-percent shortening of the core is assumed, then 5 cm of core is actually 6.67 cm, and the rate of deposition is about 0.13 cm (0.05 in.) per year. The piston corer used to collect core 1, however, causes negligible compaction; therefore, a greater degree of confidence is associated with the deposition rate determined for the humaquepts at the core 1 location.

If a deposition rate of 0.10 cm (0.04 in.) per year is assumed for the humaquepts, then material at the base of a 3-ft (90-cm) thickness of these soils would have been deposited about 900 years ago. If a deposition rate of 0.13 cm per year is used, the material at the base of a 3-ft thickness of humaquept would have been deposited 690years ago. If data from core 1 are used and a slower rate of deposition (0.07 cm, or 0.03 in., per year) is assumed, then the material at the base of a 3-ft thickness of humaquept would have been deposited about 1,300 years ago. Material at the base of the humaquepts at the T4C2 sampling site, where 114 cm (45 in.) of humaquept soil was measured, would have been deposited more than 1,600 years ago. These rates of deposition are in accord with rates measured elsewhere for organic soils (Craft and Richardson, 1993). Moreover, because excess (unsupported) ^{210}Pb decays to near equilibrium with background levels of ^{210}Pb at depths of 20 to 30 cm (approximately 8-12 in.), humaquepts deeper than 1 ft from the surface are at least 100 years old, and therefore, predate any activities at IOC.

Given that the humaquepts appear to have accreted over a period of time that is substantially longer than the period during which arsenical pesticides were produced at IOC, fluvial deposition of arsenic that could have originated at IOC would have affected only the upper 5 cm (2 in.) of humaquept, if humaquept accretion continued to the present. Because little accretion is likely to have occurred during the time the humaquepts were cultivated (at least 60 yr), then only the surface of the humaquepts is likely to have been affected. The highly elevated concentrations of arsenic measured near the base of the humaquepts indicate that processes other than direct fluvial deposition of arsenic during humaquept accumulation must account for the vertical distribution of arsenic within the humaquept profile.

Deposition of Stream Sediment.--Under natural conditions, sediment can be deposited in parts of a stream system during low flow, and then eroded and transported farther downstream during high flow. When human activities impinge on the natural system, flow regimes may change, and areas of deposition and erosion may change. Therefore, in order to understand the present distribution of arsenic and other contaminants, the transport and deposition of sediments bearing contaminants in Birch Swamp Brook were examined in light of the hydrologic history of the stream system during the 20th century.

Even where the channel is straight, streams do not flow in a precisely straight path. Because currents tend to be sinuous, areas along the channel will be scoured, or sediment will be deposited, depending on where the current is strongest (the water velocity is greatest). A stream channel tends to become more sinuous over time, with sediment building up in a curved bar shape on the insides of bends in the channel, where the

current is weakest, while sediment on the outsides of bends is eroded. The curved bars of sediment on the insides of bends are called point bars.

If it is assumed that much of the arsenic-contaminated sediment in Birch Swamp Brook came from an upstream source or sources, fluvial deposition of arsenic-bearing materials in the former wetlands area at the north end of the Texas Road site may have been enhanced for a short time. Damming of Birch Swamp Brook at Texas Road created a swimming area on the stream at the north end of the Texas Road site from about 1950 to 1952. The area that was flooded apparently was relatively low-lying; the elevation of the humaquept surface next to the stream now is less than 1 ft above the bottom of the current stream channel. As much of the area of humaquept soil within 10 ft of the stream currently is covered by about 1 to 2.5 ft of clay fill, the humaquept surface is probably slightly compressed by the clay. A sketch of three cross sections of stream levels at base flow, the stream channel, and the stream banks--one as the stream channel and banks are envisioned to have been in the 1930's, one as they appear to have been about 1950, and one as they appear now--is shown in figure 16. All views are in the downstream direction. It is apparent that any humaquepts that were flooded in the early 1950's could have received sediment that might have originated farther upstream, including arsenic-bearing sediment from IOC. Furthermore, because stream velocity would decrease in the broad swimming area created by the dam, sedimentation would increase in that area. Therefore, during the period in which the swimming area existed, deposition of any arsenic-bearing sediments carried from upstream likely would be enhanced in this stream reach.

The swimming area was abandoned and the dam dismantled in about 1952 because oil, believed to emanate from IOC, was fouling the streamwaters. Thus it appears likely that some of the arsenic measured in the humaquepts now buried by clay fill could have originated at IOC and was deposited during the period when the stream was dammed. Because the northern part of the property currently covered by fill originally was at a low elevation relative to the rest of the property, floodwaters also could have deposited arsenic-bearing sediment from IOC on the low-lying humaquepts before the stream was dammed.

The largest concentrations of arsenic in soils and sediments of the study area have been measured along the banks and channel of Birch Swamp Brook, typically in areas of deposition such as point bars, particularly in the northernmost segment of the stream where the swimming area was located. Over time, however, some of the deposits containing highly elevated concentrations of arsenic are likely to be eroded, transported as suspended load in flood-stage waters, and redistributed farther downstream. This process has undoubtedly occurred in the past and can be expected to continue as long as contaminated sediments are present.

Effects of Floods on Sediment Deposition.--Although concentration of a dissolved contaminant transported by floodwaters would be reduced because of dilution by the increased amount of water, the amount of an adsorbed contaminant transported by streamwaters would increase during a flood. Were arsenic wastes to be transported by streamwaters to the Texas Road site, it is likely that the arsenic would be sorbed to suspended sediment, rather than in dissolved form. Therefore, a flood would increase the amount of arsenic that could be brought by streamwaters from an upstream source to the Texas Road site. For the stream to carry sediment to the farm fields, however, likely would require a major hydrologic event, such as a hurricane,

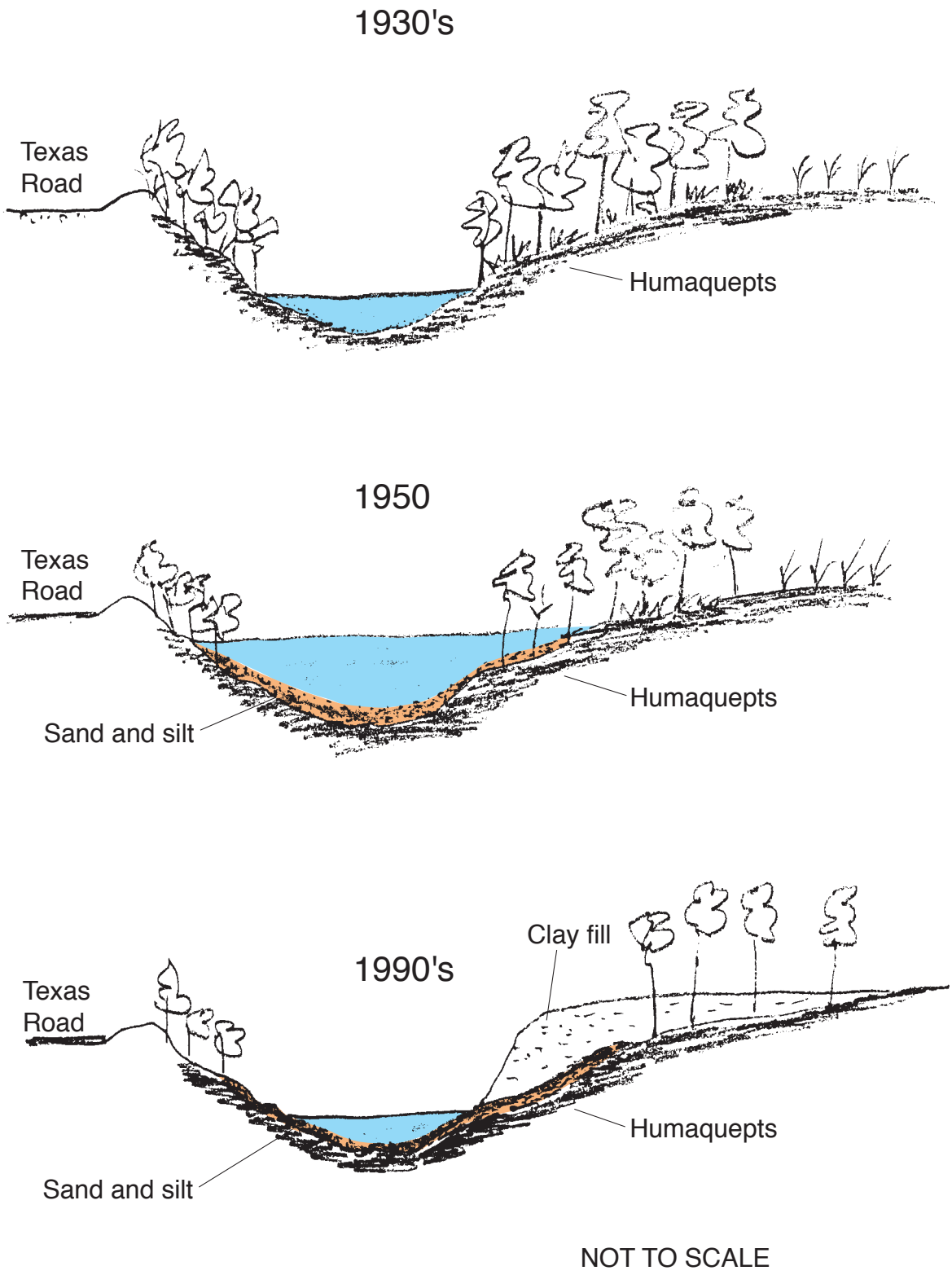


Figure 16. Three cross sections depicting water levels and sediments at Birch Swamp Brook near Texas Road, Monmouth County, New Jersey, prior to damming, during the period of damming, and in 1998.

or conditions in which the stream level was artificially raised by damming.

Fluvial transport of arsenic-bearing sediment to the humaquepts in the farm fields at the Texas Road site is likely to have occurred less frequently than fluvial transport and deposition of arsenic-bearing sediment along the stream channel and banks because stream levels would need to be substantially above normal for water to leave the stream banks. Extreme floods, during which streamwaters are much higher than bankfull stage, are relatively rare events for most headwaters streams in the New Jersey Coastal Plain because soils are highly permeable, the drainage area is small, and wetlands, which tend to mitigate flooding, commonly are present.

A technique for estimating depths of floods with 100-year recurrence intervals (Velnich and Laskowski, 1979) indicates that the height to which streamwaters rise during flood stage depends in part on the size of the upstream drainage area and the size of any area of wetlands upstream. On the basis of the relatively small drainage area upstream, the fairly extensive area of wetlands immediately upstream, and the present height of the stream banks in the farm-field area, a flood stage that would cause Birch Swamp Brook to flood the fields at the Texas Road site is rare. Moreover, the present owner has no recollection of the fields flooding during his family's occupancy of the properties--even in 1955, when Hurricanes Connie and Diane passed along the Atlantic Coast. To top the bank on the east side of the stream, floodwaters would need to be at least 3 ft above normal stream stage, given the current configuration of the landscape. Estimates by local residents indicate that the most extreme recent flood stages were about 2 to 2.5 ft above normal levels. Therefore, the waters of Birch Swamp Brook probably would not have deposited arsenic-bearing sediment on the humaquept soils of the farm fields unless the terrain was different in the past, floods were greater in the past, or arsenic was introduced into the humaquepts by a mechanism other than floodwater deposition. Several scenarios that could either be independent of each other or occur in concert were hypothesized: (1) the stream channel was located in a different position than it now is; (2) modifications to the stream banks to prevent flooding were made before the present owners acquired the property; (3) flood stage was much higher in the past than has recently been observed; and (4) bank storage distributed arsenic below the soil surface of the humaquepts in the farm fields near the stream.

Physical changes to the stream channel.--An earlier (before 1932) configuration of the stream, with lower banks that promoted flooding of what is now the farm-field area, could have led to the present arsenic distribution on the farm fields. Such flooding, if it were to deposit arsenic-bearing materials from IOC, would have occurred at a time (after 1917) when arsenical pesticide was being produced at the IOC location. Aerial photographs from 1932 show the stream channel in a position similar to its present location, but it is not known whether the location of the stream channel changed from 1917 to 1932. If the stream channel was located farther east during 1917-32 than it is now, then flooding could have distributed arsenic-bearing sediments in areas that most floodwaters might not now reach.

The 1914 topographic map (fig. 7) appears to indicate a more easterly position for the stream channel at that time, but the accuracy with which the stream channel was located on this map is unknown. The GPR survey conducted during this study indicated the presence of a buried stream channel east of the present stream channel.

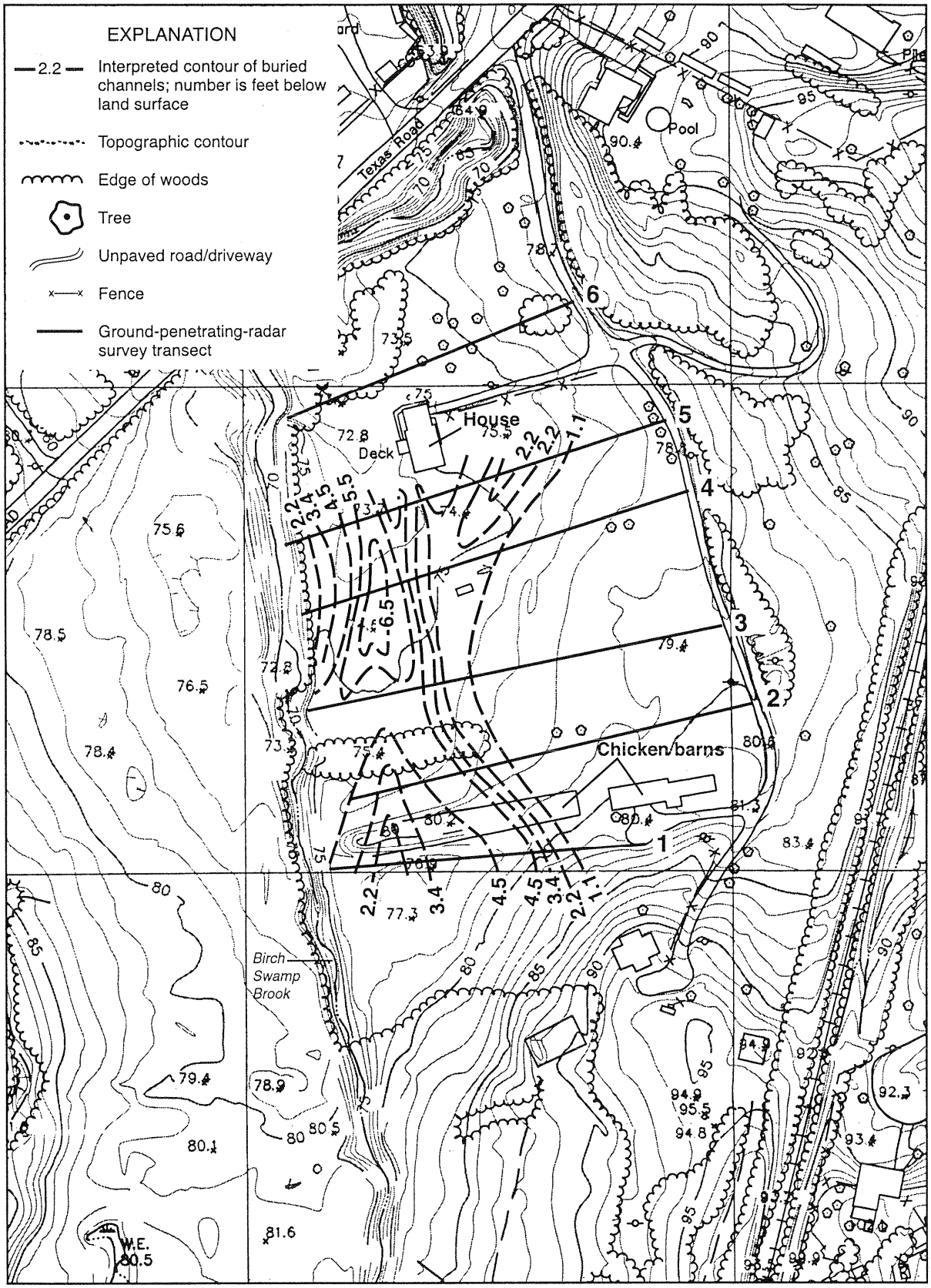
The buried stream channel indicated by the GPR survey is roughly parallel to the present channel of Birch Swamp Brook but is about 60 ft farther east (fig. 17). This buried channel was detected in the area between the old orchard and the present owner's house. The calculated depth of this feature is not much lower than the elevation of the bottom of the present stream channel, indicating that the buried stream channel is a relatively recent feature, geologically. Nevertheless, the ^{210}Pb activities indicate that sedimentation in the buried stream channel was slow; accumulation of organic sediments appears to have taken place over about 900 to 1,600 years. Furthermore, there is no evidence for disturbance at depth in core 1 (the core collected in the buried stream channel area) except in the upper 4 cm (1.6 in.) of sediment (fig. 14). The buried stream channel appears to represent part of the network pattern of an anastomosing stream through the wetland area that was gradually filled in, leaving the current channel as the main channel. Therefore, the hypothesis that fluvial deposition patterns at the Texas Road site were different in the early part of this century probably is not viable, at least for this segment of the stream.

The configuration of the stream banks may have been different in previous decades than it is now. If banks were lower, the humaquepts could have been flooded more frequently during moderate flood events. The area of sand fill referred to in previous sections (see fig. 5) was in place in 1946, when the land was acquired by the present owner's family. Therefore, some modification of the stream banks occurred before 1946.

The east bank of the stream upstream from the sand berm was modified by the present owner during 1996-98, as soil and vegetation from a recently wooded area was pushed to the stream bank when trees were cleared from the present farm fields. Because the east bank of the stream upstream from the sharp bend and the south bank of the stream at Texas Road have been modified during the past 5 or 6 decades, it is impossible to reconstruct, quantitatively, what the elevations of the bank would have been earlier in this century. Moreover, because no information is available about the size of the culvert or bridge height and span at Texas Road, it is not possible to reconstruct the size of the outlet for the upper part of Birch Swamp Brook basin. Therefore, although discharge during a flood of 500-year recurrence interval can be calculated by using data from nearby gaged basins, flood stage during such an event prior to the 1940's cannot be accurately calculated because the rate at which floodwaters could exit the basin at Texas Road cannot be reconstructed with certainty.

Height of flood stage.--The possibility of floodwater deposition of arsenic-bearing materials on the humaquepts was examined with respect to arsenic-concentration data from both banks of Birch Swamp Brook. Data collected during an earlier study (L. Robert Kimball and Associates, Inc., 1995a) indicate that elevated concentrations of arsenic are present in organic soils within about 150 ft of Birch Swamp Brook on both banks of the stream (fig. 18), and that even those concentrations smaller than 20 mg/kg tend to be larger than, or at the upper end of, the range of estimated background concentrations in humaquepts. Therefore, these data can be used to examine the possibility that arsenic-bearing sediment from an upstream source was deposited during an extreme flood event.

Although the present study was not designed to address arsenic contamination on the west bank of the stream, data from the earlier study (L. Robert Kimball and Associates, Inc., 1995a) were used to construct a series of sections that intersect the stream banks and channel (fig. 19). The sections

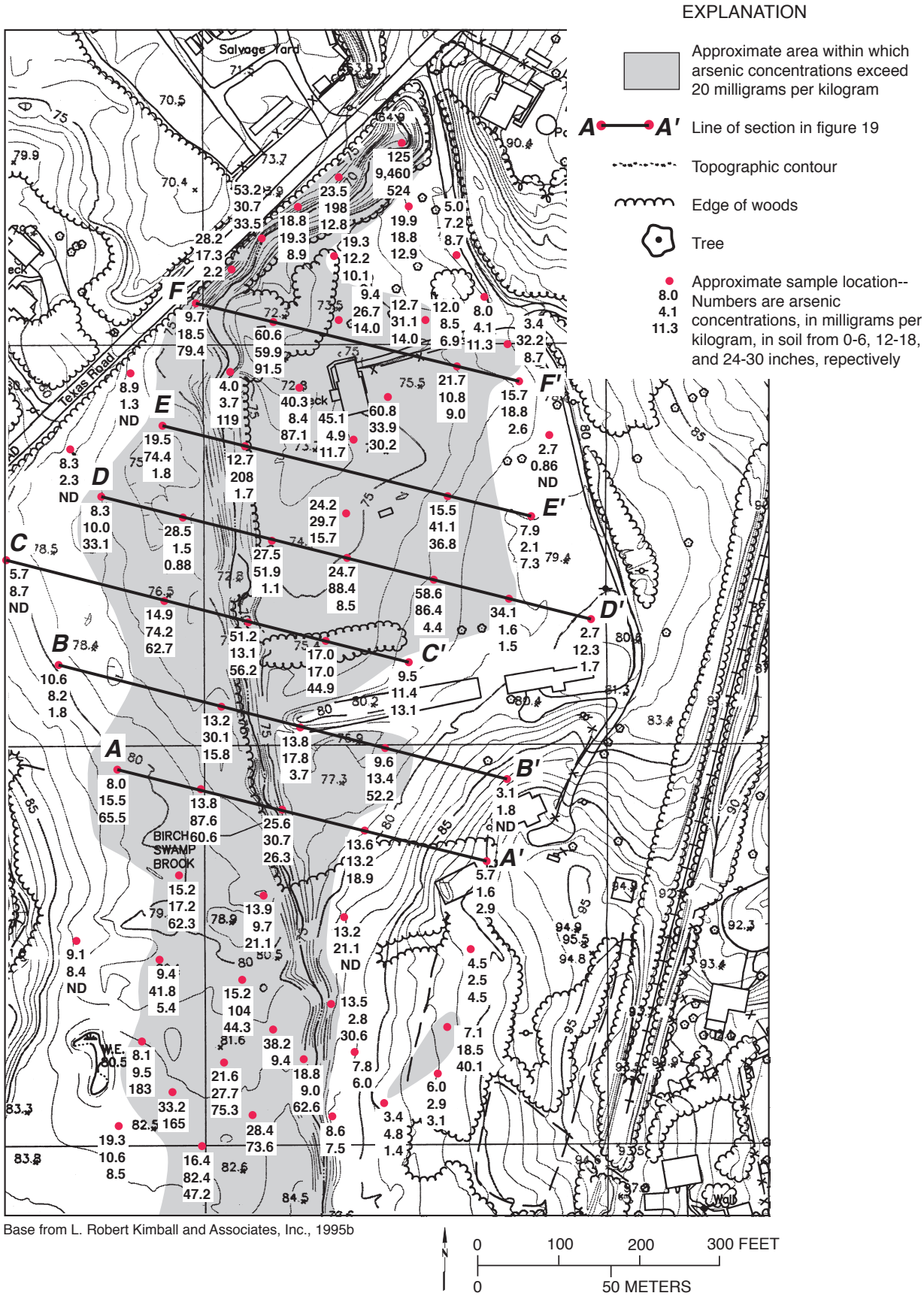


Base from L. Robert Kimball and Associates, Inc., 1995b

0 100 200 300 FEET

0 50 METERS

Figure 17. Location of buried channel identified during ground-penetrating-radar survey at the Texas Road site, Monmouth County, New Jersey. (Modified from L. Robert Kimball and Associates, Inc., 1995b)



Base from L. Robert Kimball and Associates, Inc., 1995b

Figure 18. Arsenic concentrations at three depths within soil profiles on east and west banks of Birch Swamp Brook near Texas Road, Monmouth County, New Jersey. (Modified from L. Robert Kimball and Associates, Inc., 1995b; arsenic concentrations from L. Robert Kimball and Associates, Inc., 1995a)

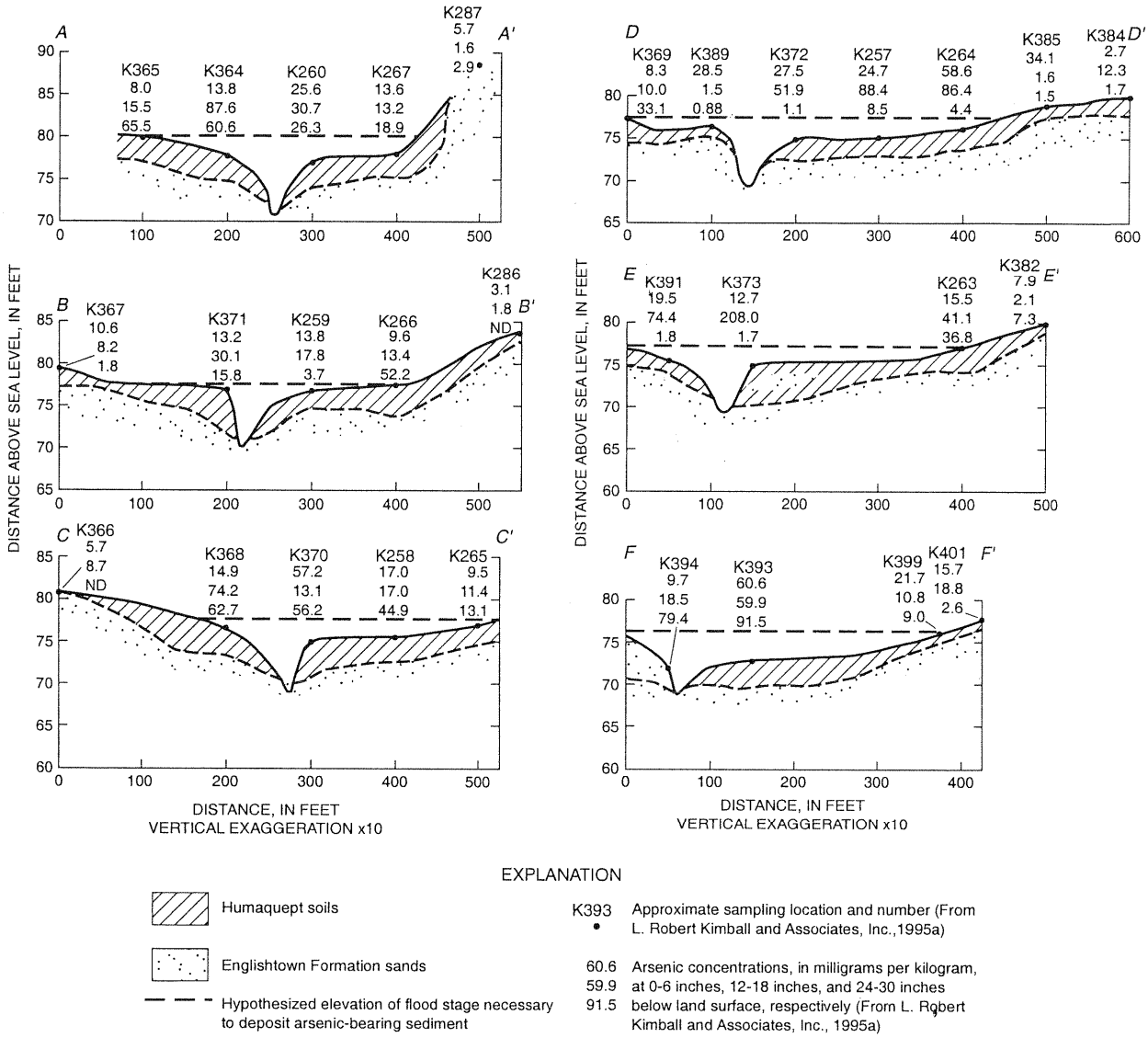


Figure 19. Six oblique sections intersecting west and east banks and channel of Birch Swamp Brook at the Texas Road site, Monmouth County, New Jersey. (Location of sections shown in fig. 18; ND, not detected)

(which are slightly oblique to the trend of the stream channel) show arsenic concentrations over 6-in. intervals (0-6-in., 12-18 in., and 24-30 in.) at the sites sampled during the earlier study. The elevation of the base of the humaquepts is not known in all core locations, as the holes typically did not extend beyond 3 ft below land surface. As in samples collected during the present study, arsenic concentrations generally increase with depth in the humaquepts near the stream channel. Measured arsenic concentrations in humaquepts generally are elevated closer to the stream channel, on the west bank than on the east bank, as shown in sections C-C′ through F-F′. The difference in relief between the east and west banks helps to explain any difference in distribution of elevated arsenic concentrations resulting from flooding; in the northern part of the site, floodwaters would spread farther out on the nearly flat area above the east bank than they would on the steeper west bank.

The current vertical distribution of arsenic in the soils is likely to be a secondary feature resulting, for the most part, from various geochemical processes that are discussed in a subsequent section of this report. If this supposition is correct, concentrations of arsenic at the surface in the areas in which large arsenic concentrations were measured at depth initially would have been larger than those that are now present. A dashed horizontal line in each cross section in figure 19 connecting the points farthest from the stream where arsenic concentrations at the surface would have been large indicates the elevation to which floodwaters would have to rise in order to deposit arsenic on the stream banks and on the farm fields on the floodplain. (One anomalously large concentration (34.1 mg/kg) was measured in soil from K385, a location that appears to be higher than floodwaters would be expected to reach. This occurrence may be related to pesticide use.) The elevations to which these hypothetical floodwaters would rise decrease downstream, supporting the hypothesis that extreme floods could have deposited arsenic-bearing materials from an upstream source. On the basis of the land-surface elevations at which soil samples containing elevated arsenic concentrations have been collected, the height of floodwaters that could have deposited arsenic-laden sediment ranges from about 80 ft above sea level in the southern part of the site to about 76 ft above sea level in the northern, downstream part of the site. Because the sections in figure 19 are oblique to the stream, the higher, upstream elevations are on the east (right) side of the brook.

On the basis of known maximum discharges of streams within a few miles of Birch Swamp Brook (Thomas, 1964), hurricanes that passed through the area are likely events to have caused major flooding at the Texas Road site. Although a storm in September 1944 caused major flooding in the area, some of the largest discharges and gage heights recorded are associated with the hurricane that passed through on September 21, 1938. The stream gage at Deep Run, near Browntown (fig. 6), which is only about 3 mi from the Texas Road site, recorded a gage height of 9.61 ft during this hurricane; bankfull stage at Deep Run was 4 ft. At nearby Tennent Brook (fig. 6), the gage height during this hurricane was about 1.7 ft above a bankfull stage of 9 ft. Because no discharge or gage-height measurements have been made for Birch Swamp Brook, the extent of flooding must be estimated indirectly.

In the Transfer Method (N.J. Department of Environmental Protection, 1988), measured discharge data from nearby stream basins are used to estimate flood-stage flows in an ungaged basin for 2-, 5-, 10-, 25-, 50- and 100-year recurrence intervals. Birch Swamp Brook has a drainage area of only

0.33 mi^2 from its headwaters to Texas Road. Discharge where the stream flows beneath Texas Road, estimated by using data from three nearby gaged streams, ranges from 72 to 300 ft^3/s for 2- through 100-year recurrence intervals (table 3). An additional calculation for a 500-year recurrence interval yields an estimate of 440 ft^3/s, which may be appropriate for the hurricane of 1938 and the combined effects of hurricanes Connie and Diane in 1955. Discharge data for Matawan Creek (fig. 6), the watershed adjacent to the west side of the Birch Swamp Brook basin, indicate that both discharge and gage-height measurements for these major hydrologic events in 1938 and 1955 are similar, although gage height was slightly higher in 1938, and also was higher as a result of a storm in 1934 than it was in 1955. If gage heights in the Matawan Creek basin were higher in 1938 than in 1955, the flood stage in the Birch Swamp Brook basin also may have been higher in 1938 than in 1955. Matawan Creek has a larger drainage area than does Birch Swamp Brook, however.

Calculations of depth of 100-year floods are not intended to be applicable to basins smaller than 4 mi^2 (Velnich and Laskowski, 1979); however, if Velnich and Laskowski's curves are extrapolated to accommodate a very small basin (0.33 mi^2) like Birch Swamp Brook, with 10 percent wetlands, the flood stage for a 100-year flood would be about 2.5 ft. This depth estimate is consistent with local anecdotal estimates of recent high water. During a 500-year event, such as occurred in September 1938, flood stage could be expected to be substantially higher because a larger volume of water is moving through the basin. The height of the flood stage could be enhanced if (1) the culvert or bridge span at Texas Road were smaller than it currently is, or (2) storm debris became wedged at the culvert under the railroad embankment adjacent to IOC and (or) the bridge over Texas Road. No information on the Texas Road bridge configuration or construction during the 1930's is available; the bridge present in the 1940's is described by the present owner of the property at the Texas Road site as a "high wooden bridge."

Table 3. Estimated flows for flood recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years for Birch Swamp Brook, calculated by using the Transfer Method[1]

Recurrence interval (years)	Discharge (cubic feet per second)
2	72
5	120
10	150
25	210
50	250
100	300
500	440

[1]New Jersey Department of Environmental Protection, 1988

If the discharge at Texas Road was about the same during the hurricane of 1938 and the combined hurricanes Connie and Diane in 1955, then, because the fields apparently did not flood in 1955, it is possible that they would not have flooded in 1938 or during the storms of 1934 and 1944, when discharges measured at Matawan Brook were nearly comparable to those of the hurricanes in 1938

and 1955 (Thomas, 1964). The arsenic concentrations in soils adjacent to the brook seem to indicate otherwise, however. The fields could have flooded in 1938 if the duration and intensity of precipitation during the 1938 hurricane was different from those of hurricanes Connie and Diane, or if the outlet at Texas Road was smaller in 1938 than in 1955 as a result of either differences in culvert construction or damming by storm debris. The sand berm near the sharp bend in the stream provides indirect evidence of past flooding; it was constructed before the mid-1940's, presumably to prevent flooding in the northern part of the farm fields.

In 1994, L. Robert Kimball and Associates, Inc., delineated floodplain boundaries for the upper part of the Birch Swamp Brook basin (L. Robert Kimball and Associates, Inc., 1994). Their calculations of discharge in the upper part of the basin (84.3 acres) for 100- and 500-year recurrence intervals were 293.51 and 440.50 ft^3/s, respectively. These values are similar to those calculated for the basin to Texas Road (table 3). If the discharge values calculated (this study) for the larger part of the basin (using a basin area of 0.33 mi^2, or 211 acres) are conservative, then discharge at Texas Road for a 500-year flood would be substantially larger than that calculated by using the Transfer Method. L. Robert Kimball and Associates, Inc. (1998b), extend boundaries of the 500-year flood to the area shown at the bottom (southern end) of the map in figure 18. The flood boundaries coincide with those of areas delineated as containing arsenic-contaminated soils and sediment (L. Robert Kimball and Associates, Inc., 1998b, fig. 4).

Because the 500-year floodplain calculated by L. Robert Kimball and Associates, Inc. (1994), for the upper part of the basin under current conditions matches the farthest extent of arsenic-contaminated soils so well, it appears that current conditions in the part of the basin upstream from Texas Road may not be substantially different, with respect to flooding, than they were 60 or more years ago. Nevertheless, clear evidence of floodwaters sufficiently high to flood the farm fields is not available; aerial photographs of the area following the 1938 hurricane apparently do not exist. The only quantitative estimate of conditions that can be made is that a flood with a 500-year recurrence interval (such as the hurricane of 1938) could be expected to produce more than six times the volume of water that is present in the basin under normal conditions.

Although circumstantial, the evidence that floodwaters during a 500-year flood deposited arsenic-contaminated sediment on the banks of the stream and as overbank deposits at higher elevations, including the farm fields, is substantial: (1) surface elevations of locations where concentrations of arsenic in the humaquepts are very large are the same on both sides of the stream; (2) these elevations decrease downstream; and (3) the 500-year-floodplain boundary calculated for the upper part of the basin coincides with the area where arsenic concentrations are elevated.

Effect of bank storage.--The distribution of arsenic in the humaquepts, as indicated by samples collected both during the present study, and previously (L. Robert Kimball and Associates, Inc., 1995a), indicates that arsenic concentrations increase with depth, particularly near the stream channel. Only one mechanism that could cause direct deposition of arsenic below land surface in the humaquepts appears to be viable. If flood stage exceeded ground-water levels in the seepage areas for the stream, then bank storage could have occurred along Birch Swamp Brook. During such a hydrologic event, floodwaters bearing arsenic-laden fine-grained sediment

could have moved into the bank sediments and left arsenic behind when water levels fell.

Conditions under which bank storage occurs are not common in small headwaters streams in the Coastal Plain (Edward Modica, U.S. Geological Survey, oral commun., 1998). Therefore, it is unlikely that bank storage occurred on a regular basis and can account for the present arsenic distribution in the humaquepts, particularly as streamwater would be entering the soil above the ground-water-saturated portion of the humaquepts. Thus, any arsenic-bearing sediment left behind by receding floodwaters would have been deposited in the upper parts of the humaquepts rather than in deeper, saturated parts of the soil profile. Furthermore, any arsenic deposited during bank storage would probably be associated with other contaminants, such as copper and lead. No evidence of elevated copper and lead concentrations at depth in the humaquepts was found, however. Nevertheless, geochemical evidence for arsenic mobility and movement deeper into the humaquept profile (discussed in a subsequent section of this report) does exist. Because arsenic appears to have been mobile in the humaquepts, it is difficult to reconstruct hydrologic conditions other than flooding that would account for its deposition in areas tens to hundreds of feet from the stream channel. Water levels in the humaquepts generally appear to be high following precipitation events, and to remain so as a result of the spongy nature of these organic soils; therefore, conditions during which bank storage could occur appear to be limited.

Land Application of Arsenic

Pesticide Use.--As described by the present owner, former agricultural practices at the Texas Road site included dusting of tomato crops with a "poisonous pink powder" mixed with lime; these applications occurred from about 1947 into the 1950's. The pink powder fits the description of lead arsenate (George Hamilton, Rutgers University, oral commun., 1997). Although evidence is weak, lead arsenate could have been used by the previous owners during the 1930's as a spray in the orchards, and could have been used during this time in the farm-field area as well; lead arsenate was a recommended pesticide for tree fruit, a wide variety of vegetables, and turf from the early 1900's to the early 1960's (E.A. Murphy and Michael Aucott, N.J. Department of Environmental Protection, written commun., 1997). On a mass basis, however, the amount of arsenic present in the humaquepts appears to be large relative to the amount of lead. Estimates of the exact proportions of these two elements in the soils is difficult, as arsenic appears to have been mobile, whereas lead has not. Nevertheless, summation of arsenic and lead concentrations in samples collected throughout the humaquept profile (core T4C2) indicates the presence of more arsenic than lead, on a mass basis. If all arsenic were the result of applications of lead arsenate, the mass of lead would be nearly three (2.77) times that of arsenic. A lead/arsenic ratio that approaches or exceeds 2.77 was observed only in surficial samples, where lead has been retained and probably enhanced by atmospheric deposition. It is likely, therefore, that the arsenic present in the humaquepts is not solely the result of applications of lead arsenate. Calcium arsenate has been used in the past on potato crops; it is not known whether previous owners grew potatoes at the Texas Road site or used calcium arsenate.

In addition to the insecticides lead arsenate and calcium arsenate, weed killers such as methanearsonic acid (CH_5AsO_3) were widely used in the 1940's and 1950's. Because there is no information regarding use of organic arsenical pesticides at the site, however, use of these compounds can only be

regarded as a possible but unconfirmed additional source of arsenic. There is little conclusive evidence of lead arsenate use in the former orchard at the southern end of the Texas Road site, although there is evidence for its use in other former orchards in the vicinity (Barringer and others, 1998); elevated arsenic concentrations in a few soil samples collected by L. Robert Kimball and Associates, Inc. (1995a), could be indicative of arsenical pesticide use in the former orchard. The land on the opposite (west) bank of Birch Swamp Brook was farmed at least as early as 1932. There is limited evidence of arsenical pesticide use in a former orchard area there (Barringer and others, 1998).

Fertilizer Use.--Fertilization with poultry litter can increase the arsenic burden in soils, because some chicken feeds contain arsenic (Adriano, 1986). Although the present owner no longer keeps chickens, a large flock previously was maintained by his family. The chicken manure was not used as fertilizer on the fields, however, but was removed periodically by a neighbor. Piles of chicken manure near the now partially demolished chicken barns could have created small areas of higher arsenic content in the soils there. Additionally, glauconite used as fertilizer in the 1800's could have contributed some arsenic to the humaquepts, if agricultural land use at the Texas Road site extends that far back in time. Glauconite from deposits in New Jersey has been shown to contain 7.1 to 31 mg/kg of arsenic (Dooley, 1998).

Mechanisms for the Redistribution of Arsenic

Natural and Human-Induced Movement of Soils and Sediments

The presence of the buried stream channel, as indicated by the results of the GPR survey, indicates that a reconfiguration, presumably by natural processes, of the stream channel has taken place. Nevertheless, the age-dating of humaquepts by analysis of ^{210}Pb activity (core 1) indicates that nearly 20 cm (7.9 in.) of sediment was deposited over about 280 yr in one area of the buried stream channel. There is no evidence that sediment deposition was interrupted during this period. Therefore, arsenic from IOC probably was not transported down an old stream channel and redistributed during channelization. ^{210}Pb activity in a second humaquept core (core 2) indicates recent slow accretion of sediments for about 40 to 50 yr, rapid accretion prior to that for an undefined period, and slow accretion before that (see fig. 15). Thus, the area of the farm fields where this core was collected has experienced some interruption in the process of slow, and presumably natural, deposition of sediment. Therefore, any arsenic present at the humaquept surface in this area of the farm fields before the disturbance could have been redistributed. Some redistribution of soils also would be likely in the 1980's during the excavation for the foundation of the house in the northern part of the properties; evidence of such redistribution is present in the immediate vicinity of the house at sites T2C3 and T2C4, where a few inches of humaquept overlies pebbly sands and clays.

Tilling of soils and disturbance by burrowing animals can redistribute soil materials near the surface (Peryea and Creger, 1994). Therefore, some of the vertical distribution of arsenic in the soil profile may be attributable to the actions of burrowing

animals. Repeated plowing in the area of the farm fields has caused surficial disturbance that also could carry arsenic-bearing materials deeper into the soil profile. Additionally, over time, arsenic sorbed to silts deposited in the humaquepts could be carried deeper in the soil profile as the silts are illuviated by precipitation or irrigation.

Physical mechanisms such as plowing or illuviation also would likely move other sorbed constituents such as lead and copper from the soil surface deeper into the soil profile. An increase in lead and copper concentrations with depth generally was not observed, however, in the samples collected during this study; rather, lead and copper concentrations tended to decrease with depth (fig. 20). This observation indicates that the vertical distribution of arsenic in the humaquepts is likely to be controlled mostly by geochemical rather than physical mechanisms, inasmuch as the arsenic-concentration gradient appears to be the reverse of the lead- and copper-concentration gradients.

Overland Runoff

Arsenic-bearing materials in overland runoff would move from higher to lower elevations. The area of former orchard in the southern part of the properties at the Texas Road site is on a low hill that slopes down to the stream banks to the west and the farm-field area to the north (fig. 2). Arsenic concentrations in A-horizon soil samples collected by the USGS from the former orchard area generally were small (5.2-6.1 mg/kg), whereas those in samples from the humaquepts at lower elevations along the stream and in the northern part of the farm-field area were larger. At the site and on the adjacent property to the south, surficial samples, which include the A horizon, collected during the previous investigation (L. Robert Kimball and Associates, Inc., 1995a), contained arsenic concentrations ranging from 0.82 to 1,170 mg/kg, with a median of 29.1 mg/kg. Some of the samples containing elevated concentrations of arsenic are located 50 to 75 ft from the stream channel along the slope of the small hill. Arsenic may have been deposited in or adjacent to the former orchard area, but whether the 1,170 mg/kg measured by L. Robert Kimball and Associates, Inc. (1995a), near the southern boundary of the former orchard is related to pesticide use or deposition of other arsenic-bearing materials cannot be conclusively determined.

Runoff from the orchard area could be expected to move toward the stream and toward the farm-field area. The farm-field area is virtually flat; therefore, overland runoff transporting arsenic-bearing soil materials from the orchard to this lower lying area probably would deposit most of the soil particles near the break in slope. The distribution of arsenic in samples collected during this and the previous studies (L. Robert Kimball and Associates, Inc., 1995a) does not support this scenario, however. The humaquepts are sufficiently porous that incident waters are likely to percolate vertically downward to the water table rather than moving laterally over the soil surface, unless the humaquepts are already saturated or frozen. Therefore, overland runoff containing residues from arsenical pesticides that might have been used in the former orchard is not likely to have contributed to the arsenic currently measured in farm-field-area soils.

Arsenic-bearing sediment on the west bank of Birch Swamp Brook, across from the Texas Road site, could have been transported by overland runoff from the orchards or farm fields at higher elevations than the humaquepts. This probably does not explain the present distribution of elevated arsenic concentrations in humaquept soils on the west bank, however, because most of the soils sloping down to the stream contain arsenic at background concentrations. The contaminated humaquepts on the west bank are at the same

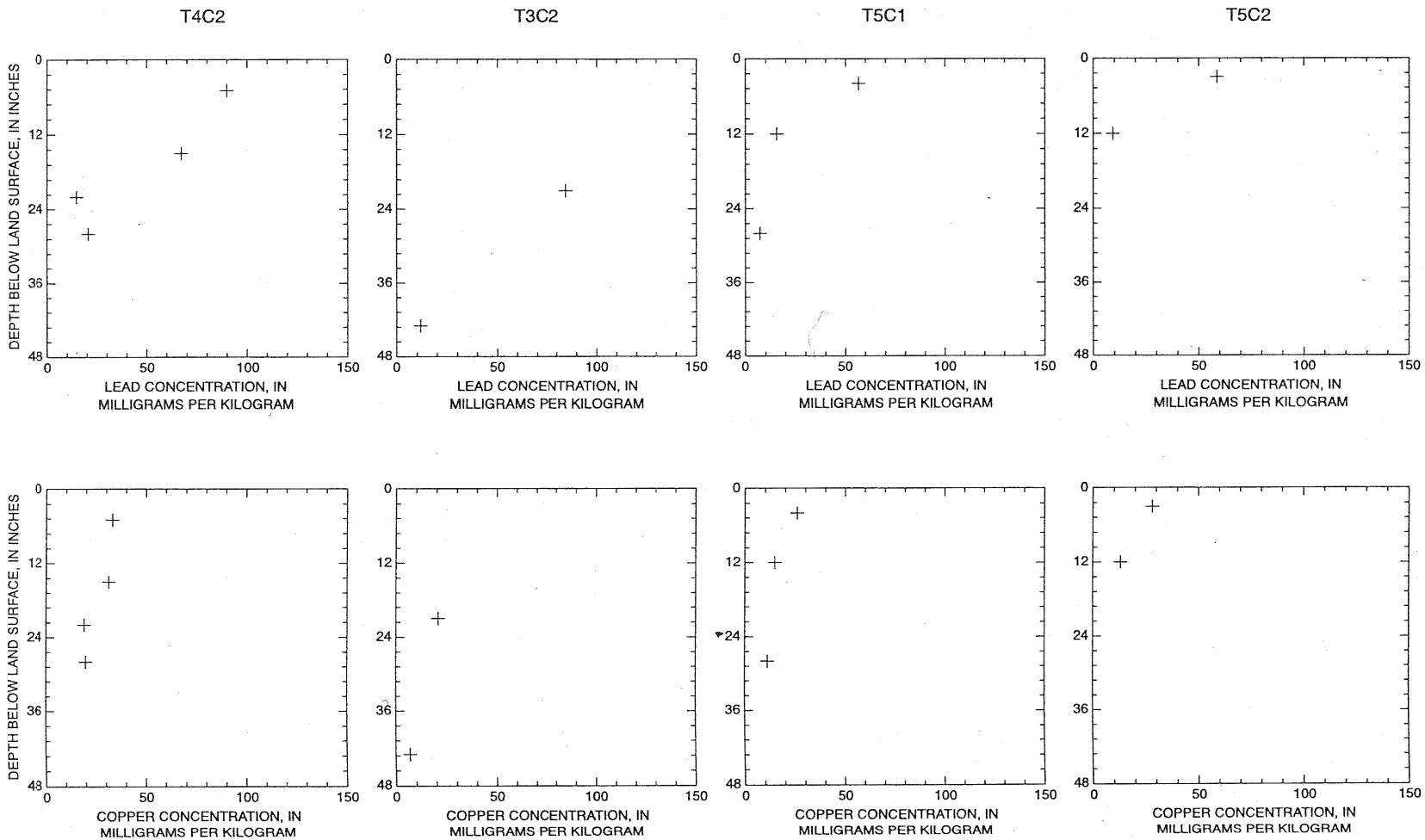


Figure 20. Relation of lead and copper concentrations to depth in humaquept soil cores from the Texas Road site, Monmouth County, New Jersey. (Core locations shown in fig. 5)

elevations as the contaminated humaquepts on the east bank, which is more suggestive of floodwater deposition than deposition by overland runoff.

Geochemical Processes

Arsenic concentrations in soils at the Texas Road site determined during this study and the previous study (L. Robert Kimball and Associates, Inc., 1995a) generally increase with depth in the humaquepts, and concentrations in the humaquepts generally are substantially larger than those in the underlying sands. This distribution indicates that (1) arsenic tends not to migrate out of the humaquepts into the underlying sands, and (2) arsenic is mobile within the humaquepts, moving downward over time. The rate of deposition of the humaquepts determined by ^{210}Pb analysis indicates that humaquepts at the bottom of the soil profile were deposited at least 1,000 years ago. Therefore, whether elevated arsenic concentrations are attributable to pesticide use, to floodwaters carrying sediment from IOC, or both, the elevated arsenic concentrations at depth in the humaquept profile are highly likely to have originated at or near the land surface, and to have migrated downward into the older sediments.

The sponge-like structure of the humaquepts promotes retention of water after a rainfall. Thus, during late fall through early spring, when precipitation tends to be higher than in late spring through early fall and evapotranspiration is negligible, the humaquepts are likely to be saturated at depths of about 3 ft or less below land surface. The presence of hydrogen sulfide gas in some saturated humaquept samples indicates that anoxic, reducing conditions are present at depth under these conditions. The humaquepts become drier during the summer months, when the water-table altitude decreases. Evidence of seasonally fluctuating oxidation/reduction (redox) conditions brought about by changes in the position of the water table is difficult to detect in the humaquepts; however, mottling is found in the silty and sandy soils and sediments at depth in the soil profile. Mottling indicates "alternate good and poor aeration" (Brady, 1974, p. 265).

Reduction of Iron, Arsenic, and Vanadium.--Iron concentrations increased with depth in most of the samples collected during this study from sites where an arsenic gradient was observed (fig. 21), indicating that both arsenic and iron probably are accumulating at depth. This distribution indicates an association of arsenic with iron in the sediments that has been noted elsewhere (Aggett and O'Brien, 1985; Aggett and Roberts, 1986; Brannon and Patrick, 1987).

As described in a previous section (Geology and Soils), iron hydroxide coatings were observed on sand and silt grains. In aerated soils at the land surface, iron may be present as iron hydroxide coatings on sand and silt grains in the humaquepts; iron also may be present as an iron arsenate precipitate, or may be associated with the organic matter. Given the presence of the abundant organic matter in the humaquepts, a reducing environment is likely to be present where contact with atmospheric oxygen is excluded and microbial degradation (oxidation) of organic matter occurs. The presence of reducing environments was confirmed by soil mottling and hydrogen sulfide odors noted during sampling, as described earlier. Reduction of iron (III) to iron (II) as the humaquepts become saturated is a viable mechanism for mobilizing iron; iron hydroxide coatings dissolve as iron is reduced, and iron becomes mobile and moves through the soil profile in dissolved form. Mobile iron probably reprecipitates as iron sulfide where conditions are sufficiently anoxic, such as those locations where the poisonous hydrogen sulfide gas was detected in the humaquepts.

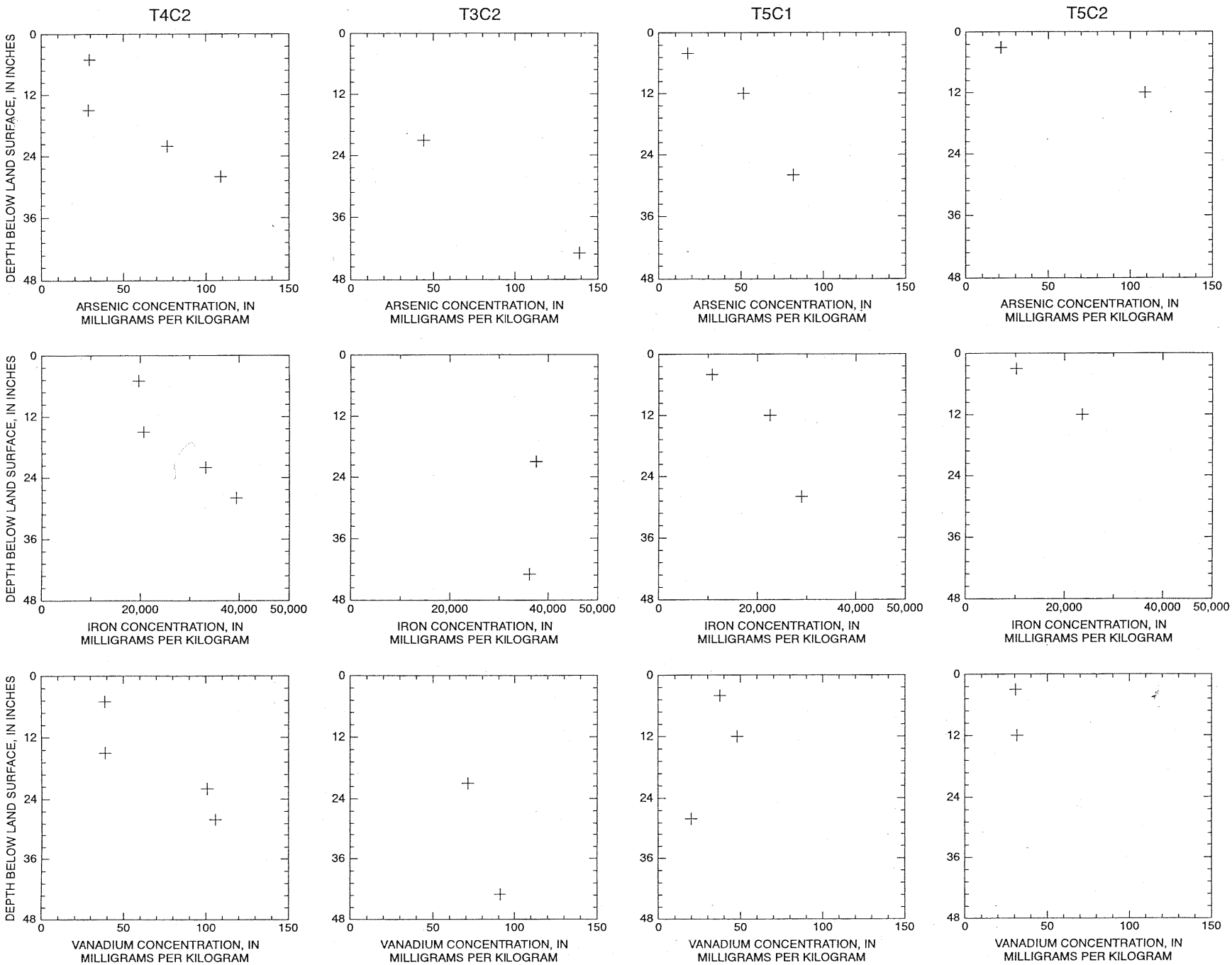


Figure 21. Relation of arsenic, iron, and vanadium concentrations to depth in humaquept soil cores from the Texas Road site, Monmouth County, New Jersey. (Core locations shown in fig. 5)

Because no data on arsenic-bearing mineral phases or arsenic species were collected during this study, the reactions responsible for the redistribution of arsenic under fluctuating redox conditions in the humaquepts are unknown. Although arsenite compounds or species are more soluble in soils than arsenate species (Deuel and Swoboda, 1972), arsenite has been found to sorb to amorphous iron oxides and hydroxides (Pierce and Moore, 1980; Sakata, 1987). One possible mechanism for mobilizing arsenic as soils become waterlogged and reducing is that arsenic (as either arsenate or arsenite) is adsorbed to iron hydroxides, which dissolve under reducing conditions. This mechanism for arsenic solubility is suggested by various researchers (for example, Masscheleyn and others, 1991; McGeehan and Naylor, 1994). Alternatively, Brannon and Patrick (1987) suggest that arsenic in sediments can be present as ferrous arsenate, which is dissolved under reducing conditions. It is also possible that organic matter initially forms colloids with iron-arsenate complexes, as indicated by the iron/phosphorus/organic-matter experiments of Jones and others (1993), but that these colloids are destabilized in a changing geochemical environment.

In the aerated humaquepts, arsenic presumably is present as arsenate (containing As (V)); it may be sorbed to iron hydroxide grain coatings, sorbed to colloids (which could be iron hydroxides or clays), or complexed with organic matter. Under saturated, reducing conditions, arsenate is reduced to As (III) or arsenite (AsO_2^-), which typically is present as arsenous acid (H_3AsO_3) in the aqueous environment (Amrhein and others, 1993). If much of the soluble arsenic in the humaquepts is present as arsenite, it is more toxic than if it were present as arsenate (Moore and Ramamoorthy, 1984).

Experiments indicate that some arsenic can become soluble before ferric hydroxides in soils under reducing conditions (Masscheleyn and others, 1991). In experiments on waterlogged soils, arsenic became soluble more slowly than other redox-sensitive elements such as manganese and vanadium, as formation of As (III) depended on more reducing conditions; however, arsenite was rapidly oxidized to arsenate and resorbed upon re-aeration of the soils (Amrhein and others, 1993). Additionally, vanadium species became soluble under reducing conditions, indicating that arsenic and vanadium exhibit similar chemical behavior with respect to changing redox conditions (Amrhein and others, 1993).

The vertical distribution of vanadium in the humaquepts in some cores at the Texas Road site is similar to that of arsenic (fig. 21). This observation may support the hypothesis that redox conditions influence constituent concentrations and, therefore, that the observed vertical distribution of arsenic in these organic sediments is a secondary feature related to geochemical rather than initial depositional processes. Iron, arsenic, and vanadium were not identically distributed in every profile examined, as their responses to redox conditions and the solubilities of resulting species or compounds, as discussed above, are slightly different. Consequently, it is difficult to determine whether iron, arsenic, and vanadium have been transported principally as dissolved species, or whether colloid transport has played an important role. Because no soil-water samples were collected or analyzed, it is not known whether these metals currently are in dissolved form.

Arsenic could move through the humaquepts by colloidal transport, particularly because it has been shown to have an affinity for iron hydroxides and clays in the Coastal Plain sediments (Barringer and others, 1998). A study of colloid mobilization in Atlantic

Coastal Plain sediments indicates that reduction of iron hydroxide cements released colloids from sediments; these colloids were composed mostly of clays with associated organic carbon (Ryan and Gschwend, 1990). Given the evidence for fluctuating redox conditions, reduced (arsenite) species may be dissolved and move in soil water, then resorb (as either arsenite or arsenate) to colloids, and migrate even deeper. Because arsenic concentrations in the sands beneath the humaquepts are small, arsenic probably does not migrate out of the humaquepts to the sands beneath. This observation may indicate that reduced arsenic is resorbed or precipitated, perhaps with an iron sulfide phase, or as an arsenic sulfide (Amrhein and others, 1993), at the base of the humaquept profile.

Effects of Changes in pH.--The role of pH in arsenic mobility in the humaquepts is unclear because pH was not measured except in selected surficial soil samples. Consequently, changes in pH with depth, with changes in redox conditions, or with time cannot be assessed. Experiments indicate that As (V), as arsenate species, was desorbed from iron hydroxides as pH increased; this process was attributed to the increasingly negative charge on the hydroxide surfaces (Masscheleyn and others, 1991). Reactions that are likely to occur naturally in the humaquepts, such as sulfur cycling by the biota, solubilizing of organic matter, complexation of iron and aluminum, and microbial degradation of organic matter, all generate hydrogen ion, thus reducing pH (Van Breeman and others, 1983; Stumm and Morgan, 1981); however, iron reduction and the concomitant dissolution of iron hydroxide consumes hydrogen ion, thus increasing pH. Additionally, as lime is known to have been applied during the time that the humaquepts were farmed, surface soil pH probably would have increased periodically above the levels currently measured in the surficial humaquepts (4.1-5.5). Thus, fluctuations in pH, in concert with fluctuations in redox conditions, could have enhanced arsenic mobility.

Methylation and Production of Arsenical Gases.-- Although details of the geochemical processes that redistributed arsenic in the humaquepts are yet to be determined, the available data indicate that adsorbed arsenate species can be reduced to more soluble arsenite species as the soils become waterlogged. Some of the arsenic could be present as a methylated species (methylarsinic acid, cacodylic acid); given the abundance of organic matter in the humaquepts, the presence of methylating fungi and bacteria is likely.

Generation of arsenical gases that are lost to the atmosphere is another mechanism for redistributing arsenic. Production of arsenical gas by fungi was recognized in the early 20th century; more recent studies have shown that arsenic can be methylated by bacterial and fungal metabolism in soils under both anaerobic and aerobic conditions (Cox, 1975; Faust and Aly, 1981; Gao and Burau, 1997). Various arsine gases are byproducts of such biological activity. These poisonous gases have been measured in laboratory experiments, using arsenic-treated soils (see, for example, Cheng and Focht, 1979), and in the field, where they were emitted by pond waters receiving runoff and soils treated with arsenical pesticides (Braman, 1975; Cox, 1975). Researchers have identified dimethylarsine and trimethylarsine among the gases emitted (Woolson, 1977; Cox, 1975), but it appears that arsine gas is produced from substrates containing inorganic arsenic, and the methylated arsine gases arise from substrates containing methylated arsenic compounds (Cheng and Focht, 1979). Study results indicate that larger amounts of arsenic are lost as arsine gases from organic-rich, reduced, wet soils than from clayey soils

(Akins and Lewis, 1976; Gao and Burau, 1997).

At the Texas Road site, methylation of arsenic by fungi in aerated soils near the surface could result in loss of volatile arsenic to the atmosphere, which would deplete the amount of arsenic present in surficial soils relative to soils at depth. Whether fungal activity in surface humaquepts or bacterial activity in the deeper, saturated humaquepts has resulted in production of volatile arsines is not known, as no samples of soil gases have been collected to date (1997). If arsine gases are abundant at depth in the humaquepts, their characteristic garlic odor has not been detected during recent sampling; if these gases are present in small amounts, the garlic odor may be masked by the odor of hydrogen sulfide emitted from these soils. Additionally, production of the gases may be moderated by season; most humaquept samples at the Texas Road site were collected during December, when biological activity is likely to be minimal.

Sources of Arsenic in Soils and Sediments Adjacent to Birch Swamp Brook

The present study was undertaken to determine whether the elevated arsenic concentrations in soils and sediments adjacent to Birch Swamp Brook were attributable to arsenical wastes from IOC, to naturally occurring arsenic sources, or to use of arsenical pesticides. Evidence relating to each of these possible sources is discussed below.

Imperial Oil Company Superfund Site

Results of analysis of soils at IOC (E.C. Jordan Co., 1992) indicate that this Superfund site is associated with both arsenic contamination and petroleum contamination. Elevated lead concentrations also are found in soils at IOC, and highly elevated concentrations of copper (>1,000 μg/kg) have been reported in sediments associated with some of the buildings there. Arsenic, lead, and copper concentrations measured in sediments from site T5P1 on the east bank of Birch Swamp Brook are the largest encountered during this study, and most likely have an upstream source. Lead and copper concentrations for other sampling sites along the stream where elevated arsenic concentrations were measured in previous investigations are sparse or lacking; lead and copper concentrations measured in most stream sediments during the current investigation were not larger than concentrations found in sediments from other watersheds.

In addition to the arsenic contamination at the Texas Road site, given the presence of petroleum and PCBs in stream sediments of Birch Swamp Brook, it is likely that some, if not all, of the arsenic measured in the stream sediments derives from the same source as the other contaminants. Arsenic probably is sorbed to iron hydroxide coatings on particles of stream sediment and has been carried down the stream with them, either directly from IOC, from materials that have already moved offsite to downstream areas, or both. Deposition of such particles is likely to have been enhanced during the time the stream was dammed; with the exception of one known upstream location sampled during this study (T5P1), the largest arsenic concentrations in sediments at the Texas Road site were measured in the swimming-hole area during an earlier study (L. Robert Kimball and Associates, Inc., 1995a) and recently by NJDEP. The most highly elevated arsenic concentrations were measured in sediments from the channel to about 2 ft above the channel; concentrations in soils at the top of the banks or beyond the banks at the Texas Road site generally did not exceed 200 mg/kg.

Given that fluvial transport of arsenic sorbed to sediment from an upstream source could have resulted in highly elevated arsenic concentrations in sediments along the stream channel, floodwaters carrying sediment from the same upstream source could be expected to deposit arsenic on soils at higher elevations. The frequency of extreme floods that could deposit arsenic-bearing sediment 3 ft above normal stream stage probably is low relative to minor events that would deposit arsenic-bearing sediments along the stream channel. Because the velocity of the streamwater largely determines the amount of sediment in suspension, a few major floods could have transported and deposited as much arsenic-bearing sediment as many much smaller events. The distribution of arsenic at the Texas Road site indicates that considerable deposition of arsenic-bearing sediment has been concentrated along the stream channel, particularly in the reach parallel to Texas Road. As a result of plowing in the farm fields and landscaping activities around the houses, any overbank deposits of silt and sand appear to have been incorporated into the humaquepts, as they are not readily identifiable as separate deposits. Nevertheless, the pattern of elevated arsenic concentrations in the humaquepts on both sides of Birch Swamp Brook supports the hypothesis that substantial amounts of arsenic have been contributed to the humaquepts of the farm fields by floodwaters, presumably from an upstream source.

Pesticide Use

There is anecdotal evidence of use of arsenical pesticides on the farm fields at the Texas Road site. Evidence of use of lead arsenate sprays in the former orchard is equivocal, however; the largest arsenic concentrations measured in the orchard during this study (15.6 and 44.1 mg/kg) were in B-horizon and clay samples, respectively. Concentrations of lead in samples of the former orchard soils were largest in the A-horizon samples, but were less than 50 mg/kg, a concentration that could result from atmospheric deposition. The elevation of the orchard area precludes deposition of arsenic-bearing sediments by floodwaters. The present owner's recollections include use of a pesticide on vegetables in the farm-field area; the pesticide is tentatively identified as lead arsenate. No information is available regarding pesticide use by previous owners from the 1920's through the early 1940's. If the area was farmed prior to 1914, use of glauconite as a fertilizer, a common practice in the late 18th and early 19th centuries (Cook, 1868), also could have contributed some arsenic to the humaquepts. Runoff containing pesticide residues from other orchards can contribute to the arsenic burden of soils; however, only one orchard upstream from the Texas Road site, present in the 1932 aerial photograph, appears to be a possible contributor, by means of runoff, of arsenic to Texas Road site soils. Other orchards in the vicinity were on the east side of the railroad tracks and berm; the tracks have been present since before 1914, and create an effective barrier to overland runoff toward the west. Because the mass of arsenic present at the Texas Road site exceeds the mass of lead, it is unlikely that all the arsenic at the site derives from lead arsenate pesticide use at the site or nearby.

Geologic and Organic Materials

In the previous investigation (Barringer and others, 1998), the arsenic content of the sandy parts of the Englishtown Formation was found to be small; soils developed on these sands also contained small concentrations (less than 10 mg/kg) of arsenic. Clays, however, contained larger concentrations, ranging up to about 40 mg/kg.

The concentrations of arsenic in the samples of humaquept soils from other watersheds ranged from about 5 to 43 mg/kg. Elevated concentrations of metals such as lead, copper, and chromium indicate that the humaquepts in other watersheds probably have received runoff that contains anthropogenic chemicals from roads, agricultural areas, and other land uses. A few of the samples from other watersheds contained arsenic in concentrations ranging from about 5 to 15 mg/kg; concentrations of lead, copper, and chromium tended to be small in these samples as well, indicating minimal anthropogenic effects. Similarly, although many of the humaquept samples collected at the Texas Road site during the present study and in the previous investigation (L. Robert Kimball and Associates, Inc., 1995a) contained elevated arsenic concentrations, a few contained arsenic in the range of less than 5 to 15 mg/kg. The natural arsenic content of the humaquepts probably is in this range and, therefore, the natural contribution of arsenic to that measured in most of the humaquept samples is relatively small.

The amount of arsenic contributed by the sandy geologic substrate is likely to be small relative to the amount of arsenic present in soils at the site. The former orchard area is underlain by a clay lens, however, which could result in a larger amount of arsenic in the overlying soils than in soils developed on sands of the Englishtown Formation.

Evaluation of Evidence Related to Possible Arsenic Sources

The evidence obtained during testing of the various hypotheses regarding possible sources of arsenic in soils and sediments at the Texas Road site is described in table 4. Each of the hypotheses is accepted, conditionally accepted, conditionally rejected, or rejected.

SUMMARY AND CONCLUSIONS

Concentrations of arsenic exceeding the proposed New Jersey State Cleanup Criterion for residential soils of 20 mg/kg have been measured in sediments from Birch Swamp Brook and adjacent soils on two properties (referred to as the "Texas Road site") about 0.5 mi downstream from the Imperial Oil Company Superfund site in Monmouth County, New Jersey. The stream sediments also contain petroleum and PCBs presumed to have originated at the Superfund site. The source(s) of the arsenic in the soils, which are highly organic humaquepts that were, and are, farmed, was unknown, however.

Samples of humaquepts from other watersheds were collected and analyzed for comparison with the humaquepts from the farm fields along Birch Swamp Brook. Arsenic concentrations were greater than the Cleanup Criterion in 15 of the 24 samples of humaquepts from other watersheds (maximum 43.1, median 22.0 mg/kg), but, overall, were not as large as some of the concentrations (maximum 139 mg/kg, median 20.7 mg/kg) measured in humaquepts at the Texas Road site. Arsenic concentrations in humaquepts at the Texas Road site generally increased with depth in the soil and with proximity to the stream channel.

To test the hypothesis that arsenic in the humaquepts at the Texas Road site had been sorbed to sediment and deposited during flood events, the hydrologic record for nearby, gaged streams was examined. A ground-penetrating-radar survey was performed to determine whether the stream-channel location had changed since the period when arsenical pesticides were produced at the Superfund site, or afterward. Results of lead-210 analysis were used to determine the rate of deposition of the humaquepts.

Table 4. Evaluation of evidence for each of six hypotheses regarding possible sources of arsenic at the Texas Road site, Monmouth County, New Jersey

[A, acceptance; R, rejection; E, equivocal; ?, questions remain; IOC, Imperial Oil Company Superfund site; GPR, ground-penetrating radar; yr, years; mg/kg, milligrams per kilogram]

Hypothesis number and description	Anticipated findings	Actual findings	A/R/E
1. Arsenic in stream sediments was transported from IOC.	Elevated arsenic concentrations, other contaminants from IOC in stream sediments.	Elevated arsenic concentrations, other contaminants from IOC in stream sediments.	A
1. Arsenic in farm-field soils is from flood deposition of contaminated sediments from IOC.	Evidence of flooding: overbank deposits, hydrologic data, aerial photos, anecdotal evidence. Presence of other IOC contaminants in farm-field soils.	Indirect evidence of past flooding: arsenic distribution in bands on both sides of stream, presence of sand berm along east bank. Hydrologic data indicate rainfall associated with hurricane of 1938 could have caused extensive flooding; calculated boundary of 500-year floodplain for upper part of basin (L. Robert Kimball and Associates, Inc., 1994) coincides with extent of elevated arsenic concentrations. Anecdotal information indicates no recent flooding. Absence of post-1945 contaminants (petroleum, PCBs) from IOC in soils may indicate pre-1945 flooding is plausible.	A?
1. Arsenic in soils at Texas Road is the result of deposition of sediments from IOC by stream when humaquept surface was at lower elevation.	Arsenic concentrations are greater at depth in humaquepts than at surface. Accumulation rate for humaquepts was rapid during last 80 years, resulting in relatively young age of humaquepts at depth.	Arsenic concentrations greater at depth in humaquepts than at surface. Accumulation rate for humaquepts based on lead-210 data has been slow. Humaquepts at bottom of soil column were deposited 1,000 yr ago or more.	R
1. Arsenic in soils at Texas Road is the result of contaminants deposited from stream waters during bank storage.	Arsenic concentrations are greater at depth in humaquepts than at surface.	Arsenic concentrations greater at depth in humaquepts than at surface. Evidence for arsenic mobility. Bank storage seldom occurs in headwaters streams.	E
2. Arsenic in farm-field soils was moved on sediments from streambed during farming/landscaping/channelizing stream.	Disturbed soils, lack of coherent sedimentation record, buried channels are filled with disturbed soils.	GPR survey indicates old, buried channel, no major soil disturbance. Lead-210 data indicate undisturbed sediments in buried channel, minor, surficial disturbance elsewhere.	R?
3. Arsenic in soils at Texas Road site is result of dumping of materials from IOC.	Fill materials present contain contaminants and debris consistent with those found at IOC.	Fill materials are present. Arsenic concentrations in clay fill are in range of naturally occurring concentrations determined for local clays. Debris in fill is not similar to debris found in IOC soils.	R

Table 4. Evaluation of evidence for each of six hypotheses regarding possible sources of arsenic at the Texas Road site, Monmouth County, New Jersey--Continued

Hypothesis number and description	Anticipated findings	Actual findings	A/R/E
4. Arsenic in soils at Texas Road site results from geologic and atmospheric inputs (background).	Arsenic concentrations are similar to those determined for similar soils and sediments in undeveloped settings.	Arsenic concentrations in Englishtown Formation sands at Texas Road site are similar to background concentrations. Arsenic concentrations in humaquepts are similar to or larger than arsenic concentrations in humaquepts from other watersheds; however, arsenic concentrations >15 mg/kg in humaquepts from other watersheds probably are anthropogenic.	Englishtown Formation sand: A Humaquepts, small arsenic concentration: A Humaquepts, large arsenic concentration: R
5. Arsenic in soils at Texas Road site results from past use of arsenical pesticides.	Soil chemistry is similar to that determined for area orchards. Anecdotal evidence will identify specific pesticides used.	Soil chemistry is not similar to that of other orchard soils because little lead is present. Anecdotal evidence exists for pesticide use on farm fields; lead arsenate is tentatively identified from description. Lead concentrations in farm-field soils are generally less than arsenic concentrations, indicating all arsenic inputs probably not from lead arsenate. Data are insufficient to determine whether runoff bearing arsenic-laden sediment from farm fields and orchards on west bank of stream is a source of arsenic to west-bank soils.	A?
6. Arsenic in humaquept soils has been mobile following deposition.	Arsenic concentrations are greater at depth than at surface. Evidence of reducing conditions, mobility of other redox-sensitive elements. Lack of mobility of non-redox-sensitive constituents.	Arsenic concentrations are greater at depth than at surface. Mottling of soils, presence of hydrogen sulfide indicate reducing conditions. Redox-sensitive elements such as iron and vanadium tend to accumulate at depth; copper and lead, which are less redox-sensitive, remain in surficial soils.	A

Hydrologic evidence of the stream flooding the humaquept farm fields is scant. The most likely event to have caused serious flooding is the hurricane of 1938. On the basis of the lead-210 analyses, the humaquepts were deposited over a period of about 1,000 years or more; therefore, the large concentrations of arsenic at depth in these soils appear to be the result of reduction of arsenic and its subsequent mobility in the saturated part of the soils rather than stream deposition on an exposed surface at a lower elevation. Accumulation of iron and, in some cases, vanadium at depth supports the evidence for arsenic mobility, whereas lead and copper, which are not affected by reducing conditions in the humaquepts, tend to remain in the upper part of these soils. Sands of the Englishtown Formation that underlie the humaquepts generally do not contain elevated concentrations of arsenic. Results of the ground-penetrating-radar survey indicated the presence of a buried stream channel, but lead-210 analyses of a soil core collected from the buried channel indicate slow accumulation of organic sediments. Therefore, the stream channel apparently has been in its present location longer than the Imperial Oil Company Superfund site location was used for manufacture of pesticides.

Some of the arsenic in the humaquepts probably is attributable to pesticide use on the farm fields, as anecdotal evidence indicates use of a pink powder mixed with lime, tentatively identified as lead arsenate.

Contaminants at the Imperial Oil Company Superfund site and those in stream sediments at the Texas Road site are clearly related; elevated concentrations of arsenic and total petroleum hydrocarbons are present in soils at the Superfund site and in stream sediments at the Texas Road site. Additionally, PCBs are present in soils at the Superfund site and in sediments of Birch Swamp Brook.

The connection between contamination at the Superfund site and contamination in the humaquepts of the farm fields is less clear because there is only indirect evidence of the farm fields having been flooded. The presence of a sand berm that dates to a time before 1946 indicates that the northern parts of the fields may have been flooded; the fields above the stream in the northern part of the Texas Road site are lower than the southern part of the site. Elevated concentrations of arsenic near the surface and at depth in humaquepts on both sides of the stream, in bands extending to about 150 ft from the stream channel, indicate that a flood depositing arsenic-bearing sediment in areas higher than the stream bank is plausible. Comparison of calculated maximum flow during a flood of 500-year recurrence interval with data from nearby gaged watersheds indicates that floods associated with the hurricane of 1938 are most likely to have deposited arsenic-bearing sediment on some parts of the farm fields. The coincidence of the extent of arsenic-contaminated soils with the boundary of the 500-year floodplain calculated previously for the upper part of the basin supports this hypothesis. Arsenic associated with flood-deposited sediments would have been added to any arsenic in the humaquepts resulting from pesticide use and to the relatively small amount that occurs naturally.

The arsenic in humaquepts at the Texas Road site appears to have been redistributed after deposition. Some redistribution is probably attributable to mechanical, human-related activities. Geochemical processes related to fluctuating redox conditions within the humaquepts probably are responsible for most of the vertical redistribution, which results in loss of arsenic from the land surface and accumulation of arsenic at depth. The

movement of arsenic from surface soils downward can be expected to continue as long as the humaquepts experience periods of saturation and concomitant reducing conditions. The rate of arsenic movement is unknown.

The humaquepts constitute the largest volume of arsenic-contaminated soil/sediment found to date at the Texas Road site. Many of the samples of humaquepts collected previously and during the present study contain arsenic within the range of concentrations measured in humaquepts from other watersheds. No evidence that elevated arsenic concentrations (20 mg/kg or greater) occur naturally in humaquepts was found; concentrations that exceed the current State Cleanup Criterion of 20 mg/kg probably are the result of anthropogenic inputs.

The properties of the humaquepts differ from those of non-wetlands soils elsewhere in the vicinity of the Imperial Oil Company Superfund site and the Texas Road site. Because the humaquepts are saturated periodically, the reducing conditions present at depth in the soil column not only promote arsenic mobility, but permit hydrogen sulfide gas, which is poisonous, to form. Given the concentrations of arsenic present in the humaquepts, the reducing conditions also may promote the generation of arsine gases. No samples of gases have been collected to date, however.

Although extensive data on soil chemistry, past land use, and local hydrology have been collected, key pieces of information are not available that would permit the unequivocal determination of arsenic sources to soils at the Texas Road site. The available information indicates that some, but not all, of the arsenic in soils in the farm fields may be attributable to pesticide use. In addition, contaminants carried by floodwaters from the Imperial Oil Company Superfund site probably have contributed to the elevated arsenic concentrations found in the soils and sediments of the properties adjacent to Texas Road and Birch Swamp Brook.

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GLOSSARY OF TERMS

Adsorb. To attract and hold ions or molecules on the surface of a solid or liquid.

A horizon. The surface layer of a mineral soil, containing maximum organic matter, from which iron and aluminum oxides and clays typically have been leached during weathering.

Alpha particle. Essentially a helium nucleus, composed of two protons and two neutrons, which is emitted by certain radioactive elements. The emission of an alpha particle reduces the mass number of the radioactive element by four, and the atomic and neutron numbers by two.

Analyte. The substance being analyzed.

Anastomosing. Term describing streams that branch and rejoin in an irregular net-like pattern.

Anion. An ion with a negative charge.

Anoxic. Without oxygen.

Anthropogenic. Produced or induced by humans.

Arsenate. A complex anion containing oxidized arsenic (V) and oxygen.

Arsenic. Chemical symbol As; a solid, brittle, poisonous chemical element, compounds of which have been used as insecticides and in drug preparations.

Arsenite. A complex anion containing arsenic (III) and oxygen.

Asymptote. A straight line associated with a curve that approximates the curve along an infinite branch or axis.

Auger. A device for boring solids by means of screw-shaped blades.

Bank storage. The introduction into, and retention of, streamwater in permeable material of streambanks above ground-water-seepage levels to the stream, during periods of high water.

Bankfull stage. The height of water in a stream that corresponds to the top of the stream bank, and, therefore, to the level of the floodplain.

GLOSSARY OF TERMS--Continued

Basal. Situated at or forming the base.

Biogeochemical. Term describing chemical processes or substances that involve chemical elements or geologic materials and that are caused or affected by living organisms, typically micro-organisms.

Butyl acetate. A clear plastic prepared from acetic acid and butyl alcohol.

Cation. An ion with a positive charge.

Censored. Term describing data that are truncated, typically by the analytical instrument detection limit; essentially, refers to concentrations that are not detected due to instrument limitations.

Channers. Thin, flat fragments of rock.

Clay. Hydrous aluminosilicate minerals formed by weathering; also refers to any mineral fragment smaller than 1/256 millimeter in its largest dimension.

Coastal Plain. A low, hilly to nearly flat plain developed on unconsolidated sediments along the coast of a continent.

Colloid. Very small inorganic or organic material particle (1- to 450-nanometer diameter).

Cretaceous. A period of the Earth's history that spans the time from 136 million years before present to 65 million years before present.

Deltaic. Like or from a delta, a typically fan-shaped wedge of sediment deposited in an ocean or lake at the mouth of a river.

Discriminant analysis. A statistical classification technique.

Evapotranspiration. The combined loss of water from soils through evaporation from the soil surface or shallow subsurface, and transpiration from plants.

Ferric hydroxide. A compound formed from oxidized iron (III), hydrogen, and oxygen (as hydroxyl).

Fluvial. Term describing the flow of surface water, specifically streams.

Geochemical. Term describing chemical processes or substances involving geologic materials.

Glauconite. A green sheet-silicate mineral with mica-like structure and chemistry, commonly a constituent of marine sediments.

Ground-penetrating radar. Long-wavelength electromagnetic energy that penetrates soils and sediments.

Humaquept. A highly organic wetland soil with no discernable horizons (layers).

Hypothesis. An assumption made for the purpose of testing its logical or observed consequences.

Illite. A clay mineral formed by weathering of micas and feldspars.

Illuviation. The process by which material is leached from a soil and deposited in a deeper zone.

Inductively coupled plasma spectroscopy. An analytical method that converts elements to a plasma and measures their characteristic emissions.

Ion. An atom that has gained or lost one or more electrons and has thereby acquired an electrical charge.

Iron hydroxide. See ferric hydroxide.

Isotope. One of several forms of a given element that has the same number of protons as the other forms, but a different number of neutrons, resulting in a difference in atomic weight.

Kaolinite. A clay mineral with no exchangeable cations that is formed by weathering of feldspars under acidic conditions.

Lignite. Brown coal, formed by compaction and heating during burial of peat (partially decayed organic matter); lignite represents a stage in the formation of black coal.

Logarithm. The exponent indicating the power to which a base number (typically either 10 or e, which equals 2.1828) is raised to yield a given number.

GLOSSARY OF TERMS--Continued

Megahertz. A unit of frequency equalling one million hertz; a hertz equals one cycle per second.

Methylate. The process by which a substance (in geochemistry, typically several metals) forms a compound with one or more methyl groups (organic radicals with the formula CH_3).

Muscovite. A sheet-silicate mineral, the most common mica. In hand specimen, it is composed of golden-brown, transparent sheets.

Nonparametric. Term describing statistical techniques that do not rely on the assumption that the data are normally distributed.

Normalize. In geochemistry, to adjust a concentration value of a substance so that it is not affected by the concentration value of another substance. Typically, this is done by dividing the concentration value for a substance by the concentration value for another substance with which the first substance is preferentially associated.

Organic. In chemistry, relating to carbon compounds.

Overbank. Term describing materials that are deposited on a floodplain by waters that rise higher than the stream banks.

Oxidation. A chemical reaction that involves loss of one or more electrons by an atom, whereby the atom acquires a positive charge.

pH. The negative logarithm of the hydrogen-ion activity (concentration); a measure of acidity.

Planchet. A wafer. As used in this report, a planchet is a 1.2-centimeter-diameter circular piece of pure silver.

Point bar. A deposit of sediment on the inner bank of a bend in a stream where the water velocity decreases.

Polycarbonate. A clear plastic.

Polychlorinated biphenyls (PCBs). A group of liquid or resinous industrial chemicals, no longer in use, but highly persistent in the environment. PCBs have been listed by the U.S. Environmental Protection Agency as carcinogens.

Polyvinyl chloride (PVC). A polymer plastic solid.

Precipitate. In geochemistry, solid compounds that form in solution and separate from the solution.

Precipitation. In meteorology, water falling as rain or snow, and including hail.

Progenitor. In isotope geochemistry, a radioactive element that decays to form a daughter element.

Recurrence interval. The length of time, on average, between hydrologic events (floods) of a particular magnitude.

Redox. "Shorthand" notation for reduction-oxidation; term describing the process by which atoms mutually gain and lose elections in a chemical reaction.

Reduction. A chemical reaction whereby an atom gains one or more electrons.

Runoff. Rainwater or snowmelt that leaves an area as surface or shallow-subsurface drainage.

Silt. Small sedimentary particles, ranging in size from 1/16 to 1/256 millimeter in diameter.

Smectites. A group of clay minerals that, owing to their molecular structure, can readily exchange ions and gain or lose water.

Soil series. Soils that are similar in major profile characteristics--that is, similar in the characteristics of the different horizons (layers) that make up the soil profile. The series is a basic classification unit for soils.

Species. In chemistry, a particular form or kind of chemical compound, or a particular ion.

Stratigraphic. Term describing the sequence of layering of geologic materials.

Stream reach. A straight part of a stream, typically between two bends.

GLOSSARY OF TERMS--Continued

Stream stage. The elevation of the water level in a stream measured with respect to a known reference point.

Substrate. A foundation.

Transect. A path across an area.

Variable. A quantity that can assume a succession or continuum of values.

Variate. See variable.

Volatile. Having the property of readily becoming a vapor at Earth-surface temperatures.

Watershed. The topographic high ground (divide) between two drainage systems; or, the area that drains to a particular surface-water body.

Water table. The plane forming the upper surface of the ground-water saturated zone.

Weathering. The processes, both physical and chemical, by which rocks are broken up and decomposed.

Wetland. Areas that are intermittently to permanently flooded, with unique soils and vegetation adapted to, or tolerant of, saturated soils.

APPENDIXES

APPENDIX 1. EQUIPMENT CLEANING, SAMPLE PREPARATION, SAMPLE DOCUMENTATION, AND QUALITY ASSURANCE

Equipment-Decontamination Procedures

Sampling and handling procedures that minimized contact of the soil samples with metallic substances were used because small concentrations of certain metals were anticipated in some samples. Strongly acidic soils can leach metals rapidly from metallic substances with which they come in contact. The sampling equipment, which is composed of stainless and carbon steel, is prone to etching and pitting by acids; the greater the amount of pitting, the more difficult it is to clean adhering particles of soils encountered during sampling from the sampling equipment.

Acid solutions used to clean the corers can mobilize and leach metals from the steel, thus increasing the potential for low-level contamination of samples. The decontamination procedures described below comply with the NJDEP Field Sampling Procedures Manual (New Jersey Department of Environmental Protection, 1992), but no acid-washing steps were used.

1. Butyl acetate liners, plastic caps, and core catchers

   Butyl acetate liners were used only once. Before use, they were washed with low-phosphate laboratory detergent and tap water, rinsed with tap water, and then copiously rinsed with analyte-free water. They were air dried under a covering of clean laboratory wipes, and then stored in clean plastic bags, three liners to a bag. The butyl acetate liners were not rinsed in 10-percent nitric or hydrochloric acid because this treatment causes etching of the plastic surface, thereby providing sorption sites for metals in the soil samples. The plastic core catchers and caps for the butyl acetate liners were washed and dried in the same manner as the liners.

2. Steel sampling equipment--corers and split spoons

   The steel sampling equipment was decontaminated each time the equipment was used. When the samples were removed and stored as detailed above, the corer was disassembled. The steel tubes, cutter head, and cap were wiped with laboratory wipes to remove any mud that might be clinging to the surface and then were soaked in a bucket with clean tap water and phosphate-free detergent. The pieces of the corer were then vigorously scrubbed with a stiff-bristled plastic brush. One field person, who performed this part of the operation, wore disposable gloves. The second field person, who was responsible for maintaining clean gloves at all times, took the scrubbed pieces of the corer and rinsed them with tap water from a pressure sprayer, and placed them on a clean plastic sheet. The second field person then changed gloves, rinsed the corer pieces copiously with analyte-free water, and placed them on a second clean plastic sheet to dry. The second field person then changed gloves again and assembled the corer, placing three butyl acetate liners with a core catcher inside the steel coring device. The corer was then placed in a clean plastic bag, which was sealed with tape. All ancillary equipment, such as the bucket and brushes, was cleaned after use.

3. Steel trowels and steel bucket augers

   The stainless-steel trowels and steel bucket auger were decontaminated in the same manner as described above.

4. Sampling equipment used in soil pits

   Individually wrapped, clean, disposable plastic spatulas were used to collect samples from individual strata in the soil pits along the stream banks. No cleaning of the spatulas was needed.

5. Transport of dirty equipment

   If brought back to the laboratory for decontamination, the dirty equipment was placed in plastic bags in order to keep the interior of the field vehicle clean.

Sample Preparation

Soil or sediment samples from pits along the stream banks were collected from each stratum with a disposable spatula; the sample was placed directly in the sample jar. The spatula was used to stir the sample in order to mix it, and the bottle was sealed.

The soil samples from the cores were extracted by soil horizon--that is, soils from each horizon within a given core liner were removed from the liner separately and were bottled separately. The procedure was as follows:

1. The field sheet for each sample site was examined to determine which horizons or strata were encountered during collection of the auger sample prior to coring; the number of horizons to be extracted was determined.
2. The laboratory countertop was covered with clean paper laboratory wipes, which were changed between horizons. Disposable gloves were worn at all times and were changed between horizons.
3. The cap at the upper end of the uppermost core liner was removed. A clean laboratory wipe was used to hold the core liner at all times. A Teflon-coated spatula was used to remove a small amount of soil that was in contact with the cap. Soil was collected in a decontaminated glass bowl by digging into the soil with a disposable plastic spatula. The sample was taken from the center of the core and was examined carefully for any change in color that might signify an interface between horizons. Any large roots or pebbles were removed and discarded.
4. When the bowl was full, the sample was mixed thoroughly with the spatula and was ladled into the sample jars (a glass jar for TAL-metals analysis, a brown glass jar for TOC analysis). The jars had been previously cleaned by using the appropriate certified method. At least 50 g of sample was placed in the TAL-metals jar and at least 10 g was placed in the TOC jar.
5. For the next horizon within the liner, the sample was accessed from the nearest liner end by removing the cap, discarding material that was in contact with the cap, and discarding any material that represented a soil-horizon interface; the procedure described above was repeated.

6. The sample jars for TAL-metals and TOC analyses had been labeled previously by NJDEP; the sample numbers, date and time of sampling, and location were added to the labels on each set of jars as soon as they were filled.
7. The sample jars were placed in a clean cooler with freezer packs; the coolers were transmitted to NJDEP personnel.
8. A chain-of-custody (COC) form filled out and signed for each TAL-metals and each TOC sample jar was shipped by NJDEP with the jars.
9. Any remaining sample material was stored in a refrigerator at the USGS, New Jersey District, laboratory or warehouse in West Trenton, N.J., for future reference.

Sample Documentation

All sample documents were completed legibly and in ink. Any corrections or revisions were made by lining through the original entry and initialling the change. The following sample documentation was maintained.

Field Logbook

The field logbook is a descriptive notebook detailing field-reconnaissance activities, which include investigation and selection of potential sampling sites. All entries were signed by the individuals making them. The field logbook is kept by the Task Manager/Project Chief, and is dedicated specifically to this investigation. The field logbook also contains a log of activities in the New Jersey District laboratory involving sample preparation and bottling.

Entries include, at a minimum, the following:
- site name and project number on first page of notebook
- names of personnel present at field activities
- dates of all entries
- descriptions of activities, including observations and (or) data collected
- records of noteworthy events and discussions
- records of any photographs taken
- site sketches, if relevant.

Contents of the field notebook were photocopied periodically and the copies were filed at the U.S. Geological Survey office in West Trenton, N.J.

Field-Data Sheets

Field data sheets were used to identify core-sample locations and to document field sampling conditions and activities. Field data and activities at the time of sample collection were entered on the field-data sheets; these include
- site name
- samplers
- sample location and core-sample or soil-pit number
- sample location plotted on a topographic map, or base map of the property.

Quality Assurance

NJDEP personnel reviewed all data from contract laboratories that used USEPA-approved procedures for quantification of contaminants. The validation of quality-assurance data followed procedures adopted by NJDEP, as modified from the USEPA Contract Lab Program (CLP) Statement of Work (SOW) Document ILM02.0. The data-validation guidelines in this document apply predominantly to data generated by using techniques documented and approved by the USEPA; these are the USEPA SW-846 (3rd edition) 6010 and 7000 series and the USEPA Methods for Chemical Analysis of Water and Wastes 200 series.

Results of analysis of an equipment wash blank are given in table 1. Conclusions regarding the quality of the analytical work also are presented.

Data-Validation Process

The data-validation process consisted of a preliminary review followed by a detailed step-by-step review procedure resulting in acceptance, qualification, or rejection of the data in question. The preliminary review ensures that chain-of-custody documentation exists, that appropriate quality-assurance procedures were followed, and that any problems affecting the analyses--complex matrix effects, inadequate sample size, unusual events--are documented. The steps of the data-validation process are outlined in Barringer and others (1998). The steps include verifying that sample holding times are met, that instrument-calibration procedures are met, that analysis of standards falls within the required range of results, that spiked-sample analytical results are within the required range, and that duplicate sample results are within the required range. Accuracy of data computation and transcription, validity of calibration curves, and correct usage of data codes also are checked.

Results of Quality Assurances

1. Field-equipment blanks

   A worst-case contamination scenario for the field-equipment blank program was assumed; the analyte-free blanking solution was poured in such a way as to contact the entire surface area of the stainless-steel sampling equipment, even though the soil sample itself contacted only the cutting head of the soil corer. The worst-case scenario, therefore, overestimates the degree of contamination that is possible from contact of the soil sample with the sampling equipment. Because results from analysis of equipment wash blanks had earlier indicated that contamination from equipment was negligible (Barringer and others, 1998), only one wash blank was collected during the present study. The results are given in table 1, below; they also indicate that contamination from equipment was negligible.

Table 1. Concentrations of constituents measured in wash blank collected from sampling equipment

[All concentrations in micrograms per liter (parts per billion); U, below instrument detection limit; Al, aluminum; Ag, silver; As, arsenic; Ba, barium; Be, beryllium; Cd, cadmium; Ca, calcium; Cr, chromium; Co, cobalt; Cu, copper; Fe, iron; Pb, lead; Mg, magnesium; Mn, manganese; Hg, mercury; Ni, nickel; K, potassium; Na, sodium; Sb, antimony; Se, selenium; Th, thallium; V, vanadium; Zn, zinc]

Sample identifier	Sample date	Concentration											
		Al	Ag	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb
FB1	961208	15.4U	1.4U	3.1U	8.0U	0.20U	0.50U	217U	1.4U	2.4U	1.8U[1]	30.4U	3.0U

Sample identifier	Sample date	Concentration										
		Mg	Mn	Hg	Ni	K	Na	Sb	Se	Th	V	Zn
FB1	961208	216U	0.90U	0.10U	2.9U	182U	449U	3.7U	4.4U	6.0U	2.1U	1.3U[1]

[1]Cu and Zn concentrations were negated (determined to be undetected) because the method blank contained detectable concentrations of both constituents.

2. Data-validation results

Chromium- and lead-concentration data from one batch of soil samples (former-orchard samples) were rejected. These analyses were subsequently rerun by the laboratory and results were acceptable. Only the acceptable data from this batch are presented in appendix 2.

Some of the TOC- and mercury-concentration data were qualified because the holding time was exceeded, and analytical results may be biased low.

Some of the inorganic-chemical concentration data were qualified because:

a. The concentration was at the low end of instrument performance,
b. the possibility of instrument drift existed,
c. the percent recovery and the contract-required detection limit (CRDL) standard were outside the control limits of 80 to 120 percent,
d. the spike recovery was outside the control limits of 75 to 125 percent,
e. the analyte was detected in the preparation blank, or
f. the inductively-coupled plasma spectroscopy (ICP) serial dilution percent recovery was outside specified limits.

Therefore, high or low biases may exist in some of the data. For some of the qualified data, the bias was unknown, but the most common bias was low. The most common qualification arose because the concentration measured was at the low end of instrument performance, and was considered estimated; lead-concentration data were qualified for many of the samples because the duplicate sample results, percent recovery, or CRDL standards were outside control limits. Analytes most commonly detected in the preparation blanks were aluminum, beryllium, copper, and manganese, and occasionally silver, cadmium, potassium, and vanadium. Arsenic-, mercury-, and vanadium-concentration data were rarely qualified; most aluminum- and iron-concentration data were not qualified. Antimony, sodium, and thallium were rarely detected.

APPENDIX 2. GEOCHEMICAL DATA AND SOIL-SAMPLING FIELD SHEETS, TEXAS ROAD SITE AND ADJACENT WATERSHEDS, MONMOUTH AND MIDDLESEX COUNTIES, NEW JERSEY

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey

[in., inches (below land surface); mg/kg, milligrams per kilogram; U, below instrument detection limit; B, detectable but below contract-required detection limit; J, qualified--data may exhibit bias; NA, not analyzed]

Sample number[1]	Depth (in.)	Concentration (mg/kg)											
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
T1P1S1	1-9	5580 J	2.6 BJ	23.5	27.2 BJ	0.41 BJ	0.46 BJ	27.9 U	15.8 J	0.70 BJ	35.6	11400	90.2 J
T1P1S2	9-14	1640 J	1.4 UJ	15.3	18.5 BJ	.05 U	.25 BJ	44.5 J	8.8 J	.27 U	4.0 BJ	8610	11.5 J
T1P1H1	14-24	2280 J	1.5 UJ	24.5	75.4	.11 BJ	.62 BJ	223 J	24.4	.49 BJ	11.3	24500	21.0 J
T1P2S1	2-7	4740 J	1.3 UJ	15.9	11.2 BJ	.21 BJ	.40 BJ	77.4 BJ	17.0 J	.65 BJ	8.6	13000	23.6 J
T1P2S2	7-12	6890 J	1.2 UJ	13.3	32.7 BJ	.29 BJ	.54 BJ	21.1 U	24.5 J	.84 BJ	3.8 BJ	18800	15.4 J
T1P2S3	12-19	2440 J	1.3 UJ	16.5	8.9 BJ	.18 BJ	.18 BJ	160 BJ	10.3 J	.35 BJ	7.3	2720	5.0 J
T1P2S4	19-28	699 J	.97 UJ	4.7	7.0 BJ	.04 U	.06 BJ	17.6 U	2.3 J	.19 U	.56 BJ	1310	1.8 J
T1P2H1	16-23	5730 J	1.6 UJ	11.5	109	.94 BJ	.78 BJ	35.4 BJ	24.5 J	1.1 BJ	2.2 BJ	29700	17.1 J
T1C1CL1	2-10	12000	.73 UJ	18.8	32.2 BJ	.25 BJ	.38 BJ	448 BJ	35.2	1.6 BJ	16.1	21800	17.2 J
T1C1CL2	25-30	12300	1.0 UJ	19.7	34.0 BJ	.82 BJ	.51 BJ	1170 BJ	53.3	2.2 BJ	17.2	29100	21.2 J
T2P1CL1	0-3	11300 J	.87 UJ	40.7	32.7 BJ	.31 BJ	.90	310 BJ	36.1 J	2.1 BJ	17.3	35600	21.5 J
T2P1S1	2-11	6010 J	1.3 UJ	17.2	18.4 BJ	.22 BJ	.55 BJ	709 BJ	16.7 J	1.0 BJ	7.0	23800	9.6 J
T2P1O1	11-14	4980	1.5 B	29.2	23.4 B	.17 B	.62 B	4150	19.9	1.5 B	43.5	17800	75.5
T2P1H1	14-22	10600 J	2.6 UJ	11.4	42.1 BJ	.81 BJ	.89 BJ	15100	19.8 J	1.7 BJ	12.6 J	13600	21.9 J
T2C2F1	3-6	11600	.91 U	5.3	55.4	.42 B	.80 BJ	17200	26.4	9.1	29.4	21700	36.5 J

[1]T followed by numbers 1-5 denotes the transect; P followed by 1 or 2 denotes soil-pit number along stream bank, whereas C followed by 1-5 denotes a core sample. The final letters denote the type of sediment; H, humaquepts; S, sand or silt; CL, clay. F, fill containing debris; O, humaquept containing petroleum. The final numbers increase with increasing depth within a given sediment type. Samples designated with initial "R" were collected during a previous investigation. Samples designated with initial "C" were collected in the former orchard area; the A, E, or B following denotes the soil horizon, H denotes humaquept, CL denotes clay. Final numbers increase with increasing depth in a given horizon or sediment type. Sample C1SB1 is a split of sample C1B1.

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Depth (in.)	Concentration (mg/kg)											
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
T2C3H1	3-6	2820	1.1 U	18.7	21.6 BJ	0.30 BJ	0.44 BJ	491 BJ	9.5	0.58 BJ	11.2	10600	28.5 J
T2C3S1	12-16	1630	.93 U	17.5	6.8 BJ	.12 BJ	.50 BJ	76.9 BJ	21.4	.53 BJ	3.3 B	23600	5.6 J
T2C3S2	25-32	1700	1.1 U	3.0	18.9 BJ	.07 BJ	.10 BJ	53.0 BJ	5.0	.40 BJ	2.1 BJ	3210	4.7 J
T2C3CL1	35-40	3350	.73 B	2.3	28.4 BJ	.18 BJ	.04 U	66.8 BJ	9.6	.64 BJ	4.5	1270	6.1 J
T2C3CL2	48-51	6540	1.3 U	2.8	48.0 BJ	.21 BJ	.16 BJ	56.2 BJ	30.3	4.1 BJ	8.8	5640	10.9 J
T2C4H1	2-4	2060 J	1.3 UJ	14.6	18.2 BJ	.19 BJ	.39 BJ	1300	9.2 J	.43 BJ	12.3	8050	27.0 J
T2C4S1	9-16	215 J	1.0 UJ	1.1 BJ	2.4 B	.04 U	.06 U	74.8 BJ	2.0 BJ	.20 U	.28 BJ	464	2.5 J
T2C4CL1	23-26	3910 J	1.3 UJ	3.2	35.7 BJ	.40 BJ	.15 BJ	683 BJ	13.3 J	.75 BJ	10.4	2670	11.5 J
T2C5H1	4-8	2430	.85 UJ	11.1	13.8 BJ	.19 BJ	.25 BJ	579 BJ	6.1	.55 U	12.7	6250	32.2 J
T2C5H2	12-16	8370	1.2 UJ	10.9	13.0 BJ	1.4 BJ	.22 BJ	632 BJ	8.1	.76 U	8.1	3640	14.5
T2C5S1	22-24	1730	.78 U	5.4	5.5 B	.09 B	.11 U	62.0 B	20.6	.51 U	1.0 B	1020	4.3
T2C5S2	36-40	837	.77 U	.64 U	5.2 B	.12 B	.10 U	45.0 U	12.9	.50 U	.91 B	111	1.5
T3P1CL1	0-6	14900	1.1 U	36.7	43.1 B	.40 BJ	1.1	1380	38.2	2.7 BJ	17.5	45100	19.3 J
T3P1S1	7-14	7890	1.5 U	35.0	43.8 BJ	.41 BJ	.79 BJ	126 BJ	32.7	1.4 BJ	34.1	31800	72.2 J
T3P1H1	14-21	2650	2.8 U	59.5	72.8 BJ	.11 U	.91 BJ	156 BJ	25.8	.58 BJ	16.2	37000	25.8 J
T3C2CL1	2-8	8970	.77 UJ	20.0	25.0 BJ	.23 BJ	.55 BJ	2470	26.8	1.6 BJ	15.2	29600	20.1 J
T3C2CL2	10-13	8520	.85 UJ	19.0	27.5 BJ	.21 BJ	.53 BJ	3350	26.9	1.5 BJ	16.1	30000	21.3 J
T3C2CL3	13-17	5960	.84 UJ	15.3	19.4 BJ	.15 BJ	.48 BJ	2640 J	18.7	1.4 BJ	12.8	24700	21.4 J
T3C2H1	18-22	11400	1.2 UJ	44.3	107 J	.99 BJ	.87 BJ	924 B	33.7	1.5 BJ	20.8	37600	84.5 J
T3C2H2	40-48	1030	1.1 UJ	139	26.0 BJ	.06 U	.78 BJ	81.4 BJ	24.3	62.2	6.9 BJ	36300	11.7 J

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Depth (in.)	Concentration (mg/kg)											
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
T3C3CL1	3-7	9670	0.85 U	21.6	24.6 B	0.35 B	0.65 B	1190	25.0	1.9 B	13.0	26100	15.7
T3C3H1	29-35	3880	1.3 U	35.0	50.0 B	.39 B	.70 B	1700	13.3	.81 B	22.2	16500	51.9
T3C3S1	40-45	667	1.1 U	11.1	5.4 B	.04 U	.07 B	33.1 B	2.0 B	.21 U	.73 B	819	3.8
T3C5H1	2-6	8000	.94 UJ	21.2	15.9 BJ	.72 BJ	.42 BJ	801 BJ	7.6	.61 U	15.1	3950	25.9 J
T3C5H2	10-13	4000	.89 UJ	13.7	17.8 BJ	.32 BJ	.44 BJ	1610	5.8	.58 U	18.8	4650	40.4 J
T3C5S1	15-18	424	.73 U	1.2 B	2.9 B	.04 U	.10 U	42.5 U	2.1	.47 U	.53 B	74	1.1
T3C5S2	32-37	448	.73 U	1.9 B	2.0 B	.04 U	.10 U	43.0 U	2.6	.48 U	1.0 B	287	1.7
T4P1S1	3-9	3510	2.8 BJ	22.1	20.7 BJ	.13 BJ	.68 BJ	57.4 BJ	15.4	1.1 BJ	58.5	16300	286 J
T4P1S2	9-21	916	1.0 U	3.8	5.1 BJ	.04 U	.11 BJ	18.2 U	3.7	.20 BJ	2.2 BJ	3180	8.7 J
T4P1S3	21-26	623	1.0 U	.86 U	3.8 BJ	.04 U	.06 U	19.0 U	1.8 BJ	.21 U	.82 BJ	977	1.8 J
T4P1S4	26-34	502	1.2 U	4.2	7.6 B	.05 U	.11 B	21.5 U	2.9	.23 U	.23 U	3520	1.5
T4P2S1	3-13	6290	1.6 U	12.1	18.1 BJ	.47 BJ	.69 BJ	101 BJ	22.1	.82 BJ	9.5 J	23500	44.3 J
T4P2H1	13-26	9130	2.2 U	4.7	75.6 BJ	1.9 BJ	.30 BJ	70.2 BJ	9.8	.82 BJ	5.7 BJ	6930	4.9 J
T4P2S2	26-43	326	.84 U	1.7	1.3 BJ	.03 U	.08 BJ	123 BJ	1.3 BJ	.16 U	4.6 J	507	1.2 J
T4C1S1	2-6	1290 J	.95 UJ	3.4	5.8 BJ	.09 BJ	.17 BJ	45.1 BJ	4.0 J	.19 U	6.9	2960	22.4 J
T4C1S2	20-24	365 J	.82 UJ	.68 U	1.7 BJ	.03 U	.05 U	14.9 U	1.0 BJ	.16 U	.65 BJ	202	1.6 J
T4C1S3	27-30	975 J	.79 UJ	15.9	5.3 BJ	.03 U	.07 BJ	15.3 BJ	3.2 J	.16 U	1.3 BJ	2220	3.0 J
T4C1S4	30-36	502 J	1.2 UJ	4.2	7.6 BJ	.05 U	.11 BJ	21.5 U	2.9 J	.23 U	.23 U	3520	1.5 J
T4C1S5	38-42	232 J	.77 UJ	1.0 BJ	1.3 BJ	.03 U	.05 U	14.1 U	1.3 BJ	.15 U	.19 BJ	854	1.3 J
T4C2H1	2-6	7520	1.1 UJ	29.3	63.4	.82 BJ	.78 BJ	4430	20.6	1.3 BJ	33.1	19700	89.9 J
T4C2H2	12-16	8140	1.1 UJ	28.8	55.3 BJ	.97 BJ	.65 BJ	1990	22.4	1.3 BJ	31.3	20700	67.2 J
T4C2H3	20-24	3840	1.8 UJ	76.7	104	.14 BJ	.60 BJ	1830 BJ	24.8	1.2 U	19.0	32200	14.7 J
T4C2H4	30-35	3310	1.6 UJ	109	111	.09 UJ	.74 BJ	783 BJ	25.0	1.0 U	19.8	39400	20.6 J

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Depth (in.)	Concentration (mg/kg)											
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
T5P1S1	3-6	3500	3.8 BJ	281	79.9	0.11 BJ	0.47 BJ	49.0 BJ	20.0	0.92 BJ	68.4 J	12500	695 J
T5P1S2	6-16	1720	9.8 B	2570	29.9 B	.04 U	.97 B	25.8 B	10.7	.90 B	18.7	49900	80.7
T5P1S3	16-26	3590	1.1 U	179	19.6 BJ	.32 BJ	.67 BJ	67.3 BJ	12.8	2.9 BJ	14.8 J	4850	24.5 J
T5P1S3A		24900	2.6 BJ	702	48.1 BJ	5.4	1.0 BJ	752 BJ	56.7	55.9	23.0 J	39200	113 J
T5P1S3B		951	7.9 B	735	18.1 BJ	.05 U	.54 BJ	24.7 BJ	6.2	.92 BJ	4.9 BJ	29500	20.2 J
T5P1S3C		15400	2.0 BJ	717	31.9 BJ	2.0	.67 BJ	244 BJ	35.9	22.8	21.4 J	16800	80.8 J
T5C1H1	2-6	6770	1.4 U	17.5	23.3 BJ	.89 BJ	.65 BJ	115 BJ	13.2	.73 BJ	25.9	10800	56.6 J
T5C1H2	10-14	7630	2.4 U	51.6	167	1.4 BJ	.69 BJ	134 BJ	21.3	1.5 B	14.8	22500	15.5
T5C1H3	25-30	3240	2.9 U	81.7	71.8 BJ	.22 BJ	.74 BJ	83.7 BJ	28.0	2.0 BJ	11.2 J	28900	7.1 J
T5C1S1	35-40	362	1.1 U	5.5	8.6 B	.04 U	.07 U	20.7 U	1.3 BJ	.22 U	.38 BJ	946	1.6 J
T5C2H1	1-6	6580	.89 U	21.1	41.7 BJ	.64 BJ	.56 BJ	1390	14.6 J	.96 BJ	28.1	10200	58.7 J
T5C2H2	10-15	4330	1.6 U	109	71.9 BJ	.08 UJ	.49 BJ	946 BJ	19.6 J	1.0 U	13.0	23600	9.2 J
T5C2S1	17-19	329	.80 U	7.6	3.2 BJ	.04 UJ	.11 U	47.1 U	1.3 BJ	.52 U	.91 UJ	379 J	1.1 J
T5C2S2	33-36	441	.67 U	7.3	11.2 BJ	.04 UJ	.09 U	39.2 U	5.9 J	.43 U	1.7 BJ	751 J	1.7 J
R25A/CL	1-3	12200	1.1 U	28.4	33.4 B	.48 B	2.3	746 B	33.6	.89 B	15.2	32300	33.2
R25CL1	3-5	8610	1.0 U	27.3	21.5 B	.36 B	2.2	341 B	26.3	.25 B	7.9	32300	13.2
R25CL2	8-9	12700	1.1 U	22.7	29.2 B	.44 B	2.3	260 B	32.4	.67 B	7.9	34400	14.0
R25H2	36-40	6090	2.0 U	41.4	184	.63 B	1.8 B	598 B	25.7	.54 B	23.2	24600	26.4
R25S1	53-55	862	1.3 B	7.7	8.1 B	.10 B	.25 B	31.3 B	15.0	5.4 B	2.2 B	1250	4.6
R26H1	6-8	2930	1.0 U	20.2	31.8 B	.35 B	.75 B	1020 B	9.8	.26 B	12.7	2940	45.4
R26H2	38-40	3270	1.1 U	36.8	35.6 B	.47 B	1.5	1310	15.3	.18 U	15.1	18000	50.5

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Depth (in.)	Concentration (mg/kg)											
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
C1A	3-8	1320 J	0.54 UJ	5.2	4.0 BJ	0.07 BJ	0.08 U	28.2 U	6.6 J	0 .47 BJ	6.8	6860 J	41.4
C1E	10-13	1770 J	.49 UJ	4.4	4.5 BJ	.09 BJ	.07 U	25.4 U	6.1 J	.28 BJ	6.2	13300 J	10.4
C1E/B	15-21	2150 J	.58 UJ	5.9	5.2 BJ	.07 BJ	.08 U	30.1 U	7.0 J	.29 U	3.5 BJ	11300 J	7.7
C1B1	22-28	2560 J	.51 UJ	4.0	7.6 BJ	.08 BJ	.07 U	26.5 U	6.2 J	.47 BJ	2.5 BJ	6560 J	3.5
C1SB1	22-28	2340 J	.52 UJ	4.0	6.1 BJ	.06 BJ	.07 U	26.7 U	5.4 J	.26 U	2.1 BJ	7820 J	3.1
C1B2	30-34	2090 J	.50 UJ	2.3	8.0 BJ	.06 BJ	.07 U	25.8 U	7.3 J	.45 BJ	3.1 BJ	4720 J	3.8
C1B3	34-39	2260 J	.59 UJ	3.5	10.3 BJ	.05 BJ	.08 U	222 BJ	6.3 J	.41 BJ	10.0	5220 J	5.2
C2H1	0-5	3530 J	1.0 UJ	7.3	34.8 BJ	.20 BJ	.29 BJ	2570	9.6 J	.51 U	20.0	9940 J	48.8
C2H2	6-9	4970 J	.74 UJ	8.4	13.5 BJ	.30 BJ	.11 U	145 BJ	11.2 J	.37 U	12.6	10600 J	27.8
C2H3	12-18	5560 J	.76 UJ	6.3	18.2 BJ	.38 BJ	.12 BJ	70.6 BJ	11.3 J	.40 BJ	10.2	8580 J	20.8
C2H4	24-28	1510 J	.73 UJ	10.8	11.6 BJ	.09 BJ	.10 U	50.6 BJ	6.7 J	.36 U	3.2 BJ	4610 J	4.1
C2S1	33-40	818 J	.57 UJ	2.9	4.1 BJ	.18 BJ	.08 U	29.6 U	25.8 J	.29 U	.70 BJ	15100 J	4.0
C4H1	0-10	2450 J	.69 UJ	7.8	12.5 BJ	.11 BJ	.10 U	375 BJ	6.2 J	.34 U	11.2	8220 J	37.4
C4H2	20-24	7450 J	.84 UJ	11.5	32.6 BJ	.43 BJ	.12 U	1580	17.5 J	1.0 BJ	9.1	21400 J	24.7
C5A	1-9	1640 J	.67 UJ	5.7	9.3 BJ	.09 BJ	.10 U	95.5 BJ	4.3 J	.34 BJ	8.2	6270 J	29.4
C5E	10-15	1990 J	.56 UJ	2.4	6.2 BJ	.12 BJ	.08 U	131 BJ	5.3 J	.28 U	1.9 BJ	6560 J	6.4
C5B1	20-30	3120 J	.61 UJ	15.6	6.3 BJ	.14 BJ	.09 U	69.7 BJ	11.7 J	.51 BJ	3.5 BJ	28400 J	4.1
C5B2	35-40	2330 J	.64 UJ	6.5	5.9 BJ	.12 BJ	.09 U	87.0 BJ	14.2 J	.39 BJ	3.6 BJ	19400 J	3.9
C5CL1	44-48	6980 J	.67 UJ	44.1	8.5 BJ	.78 BJ	.10 U	69.8 BJ	64.8 J	1.1 BJ	14.5	92200 J	14.7
C6A	0-10	2160 J	.65 UJ	6.1	13.5 BJ	.09 BJ	.09 U	477 BJ	5.2 J	.39 BJ	8. +	8240 J	30.3
C6B1	12-17	3460	.54 UJ	9.0	3.5 BJ	.21 BJ	.08	65.2 BJ	20.0 J	.42 BJ	2.5 BJ	34400	5.4
C6B2	20-25	3480	.36 UJ	12.8	3.4 BJ	.50 BJ	.05	68.3 BJ	44.4 J	.58 BJ	2.4 BJ	70400	6.6
C6B3	30-34	3690	.59 UJ	15.0	6.5 BJ	.47 BJ	.08	127 BJ	58.2 J	1.5 BJ	7.5	67300	17.8
C6CL1	35-39	3770	.64 UJ	3.4	11.9 BJ	.10 BJ	.09	179 BJ	13.1 J	.32 U	3.4 BJ	5730	5.4

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Concentration (mg/kg)											
	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc	Total organic carbon
T1P1S1	152 BJ	6.5 J	0.24	4.0 BJ	418 BJ	2.4	0.30 UJ	85.0 U	1.1 U	39.9	19.8	187000
T1P1S2	147 BJ	5.3 J	.07 U	.58 BJ	326 BJ	.73 U	.27 UJ	76.7 U	1.0 U	33.5	5.7	44800
T1P1H1	145 BJ	4.4 BJ	.10 BJ	1.1 BJ	296 BJ	3.4	.30 UJ	106 BJ	1.1 U	73.6	7.7	270000
T1P2S1	275 BJ	8.2 J	.09 B	1.9 BJ	712 BJ	1.2 BJ	.25 UJ	70.5 U	.92 U	38.1	12.1	60900
T1P2S2	419 BJ	10.1 J	.09 BJ	1.8 BJ	946 BJ	1.3	.23 UJ	64.3 U	.84 U	44.2	16.0	21900
T1P2S3	134 BJ	1.4 BJ	.06 BJ	.74 BJ	123 BJ	.99 BJ	.25 UJ	69.5 U	.91 U	89.5	3.7 BJ	36700
T1P2S4	27.2 BJ	2.1 BJ	.04 U	.40 U	188 BJ	.51 U	.19 UJ	53.6 U	.70 U	11.8	1.5 BJ	3320
T1P2H1	113 BJ	3.7 BJ	.21	4.6 BJ	276 BJ	2.9	.31 UJ	87.3 U	1.1 U	49.3	10.6	293000
T1C1CL1	1340	24.8	.05 UJ	4.0 BJ	2060	.87 U	.28 U	88.9 U	1.2 U	45.6	16.1 J	10900
T1C1CL2	1500	40.4	.05 BJ	5.4 BJ	2220	1.2 U	.38 U	123 U	1.6 U	57.6	29.8 J	12600
T2P1CL1	1390	27.3 J	.06 U	4.5 BJ	1770	.75 BJ	.17 UJ	48.5 U	.63 U	50.3	20.2	9880
T2P1S1	651 BJ	14.7 J	.05 U	2.1 BJ	1340	.79 BJ	.25 UJ	69.4 U	.91 U	42.8	13.3	11700
T2P1O1	780 B	28.0	.24	4.6 B	847 B	1.9	.26 U	74.1 U	.97 U	40.6	28.0	46900
T2P1H1	1110 J	12.6 J	.25 BJ	7.7 BJ	459 BJ	4.1	.52 UJ	147 U	1.9 U	33.3	23.0	510000
T2C2F1	9160	484	.05 U	20.0	2400	.48 U	.18 UJ	468 BJ	.66 U	41.5	110	21700 J
T2C3H1	118 BJ	9.6	.15	2.5 BJ	208 BJ	1.0 B	.22 UJ	61.0 B	.80 U	20.6	18.9	111000 J
T2C3S1	81.2 BJ	4.1	.05 U	.62 BJ	352 BJ	.57 B	.18 UJ	51.6 U	.68 U	48.4	12.6	8370
T2C3S2	56.0 BJ	6.5	.06 U	.46 U	392 BJ	.59 U	.22 UJ	61.5 U	.80 U	7.0 BJ	3.8 BJ	10400 J
T2C3CL1	81.0 B	7.6	.06 U	2.2 BJ	566 BJ	.39 U	.14 UJ	40.5 U	.53 U	7.6	7.9	26400 J
T2C3CL2	140 BJ	9.7	.06 U	4.2 BJ	1410	1.1 BJ	.26 UJ	73.1 U	.96 U	24.0	6.9	66200
T2C4H1	196 BJ	16.1 J	.07 BJ	1.9 BJ	205 BJ	.82 BJ	.25 UJ	69.4 U	.91 U	19.2	23.9	49800 J

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Concentration (mg/kg)											
	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc	Total organic carbon
T2C4S1	24.9 BJ	2.6 BJ	0.05 U	0.43 U	86.4 BJ	0.55 U	0.20 UJ	57.8 U	0.76 U	1.7 BJ	1.0 BJ	723
T2C4CL1	299 BJ	17.5 J	.05 U	1.6 BJ	847 BJ	.91 BJ	.25 UJ	71.6 U	.94 U	11.9 BJ	21.5	22400 J
T2C5H1	147 BJ	11.8	.12 J	2.0 BJ	200 BJ	1.0 U	.32 U	104 U	1.4 U	14.8	21.7 J	856000
T2C5H2	91.1 BJ	5.7	.11 BJ	4.4 BJ	124 BJ	1.9	.44 U	142 U	1.9 U	37.1	19.9 J	99000
T2C5S1	45.8 U	1.9 B	.05 U	2.9 B	152 B	.93 U	.30 U	95.2 U	1.3 U	25.0	31.4	18900
T2C5S2	44.8 U	2.4 B	.03 U	.60 U	134 B	.91 U	.29 U	93.2 U	1.2 U	5.2 B	1.9 B	3060
T3P1CL1	1570	39.1	.08 U	6.1 BJ	2560	.77 BJ	.21 UJ	58.5 U	.77 U	54.3	30.4	17000
T3P1S1	384 BJ	10.9	.15 BJ	6.8 BJ	1110 BJ	3.0	.29 UJ	80.9 U	1.1 U	66.6	20.6	137000
T3P1H1	154 BJ	7.3 BJ	.18 BJ	1.4 BJ	964 B	3.8	.54 UJ	154 U	2.0 U	52.6	11.0	504000
T3C2CL1	1150	29.7	.05 UJ	4.1 BJ	1700	.91 U	.29 U	93.4 U	1.2 U	42.3	21.6 J	129000 J
T3C2CL2	1230	35.4	.05 UJ	3.9 BJ	1560	1.0 U	.32 U	103 U	1.4 U	45.0	20.8 J	114000 J
T3C2CL3	997 BJ	44.6	.06 UJ	7.7 BJ	1150	1.0 U	.32 U	108 BJ	1.4 U	35.5	80.7 J	9490 J
T3C2H1	293 BJ	17.5	.17 J	7.6 BJ	1300 BJ	1.4 U	.46 U	147 U	2.0 U	71.2	36.8 J	103000 J
T3C2H2	65.3 U	3.2 BJ	.07 UJ	85.5	122 BJ	1.3 U	.42 U	136 U	1.8 U	91.0	12.3 J	79100 J
T3C3CL1	1080	31.1	.07 B	4.2 B	1680	.51 B	.17 U	47.2 U	.62 U	46.7	19.1	11500
T3C3H1	278 B	22.8	.32	4.0 B	391 B	2.3	.26 U	73.4 U	.96 U	27.7	32.1	197000 J
T3C3S1	47.0 B	2.3 B	.05 U	.45 U	167 B	.58 U	.21 U	60.4 U	.79 U	1.8 B	1.4 B	4850
T3C5H1	127 B	7.2	.16	13.3	123 B	1.1 U	.35 U	114 U	1.5 U	71.7	130	153000
T3C5H2	202 B	23.8	.15	24.4	341 B	1.1 U	.34 U	108 U	1.4 U	22.8	171	106000
T3C5S1	42.4 U	.67 B	.04 U	.57 U	68.1 B	.86 U	.27 U	88.0 U	1.2 U	6.0 B	1.1 B	3390
T3C5S2	42.8 U	1.5 B	.03 U	.57 U	113 B	.87 U	.28 U	88.9 U	1.2 U	10.3	.93 B	4190

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Concentration (mg/kg)											
	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc	Total organic carbon
T4P1S1	207 B	16.3	0.44	4.5 B	482 B	2.2	0.29 U	81.8 U	1.1 U	39.2	23.9	170000
T4P1S2	69.8 B	4.1	.05 U	.41 U	202 B	.53 U	.20 U	55.6 U	.73 U	10.7	3.0 B	12700
T4P1S3	60.6 B	2.4 B	.04 U	.43 U	187 B	.55 U	.21 U	58.0 U	.76 U	4.7 B	2.8 B	3520
T4P1S4	41.3 B	1.8 B	.05 U	.49 U	300 B	.66 B	.23 U	65.6 U	.86 U	18.2	1.3 B	4550
T4P2S1	287 B	16.5	.37	2.6 B	530 B	1.4 B	.31 U	87.0 U	1.1 U	34.7	18.6	125000
T4P2H1	32.8 B	1.4 B	.15 B	6.8 B	51.4 B	2.8	.43 U	120 U	1.6 U	34.2	20.0	351000
T4P2S2	88.9 B	1.0 B	.04 U	.35 U	52.1 B	.44 U	.16 U	46.6 U	.61 U	7.6 B	.83 B	3480
T4C1S1	48.3 B	2.8 B	.07 B	.84 B	108 B	.54 B	.19 U	52.9 U	.69 U	11.5	5.5	33800 J
T4C1S2	23.1 B	.78 B	.05 U	.34 U	68.7 B	.43 U	.16 U	45.5 U	.60 U	1.7 B	1.0 B	1100 J
T4C1S3	57.3 B	1.2 B	.05 U	.33 U	175 B	.99	.16 U	44.0 U	.57 U	52.0	1.7 B	12500 J
T4C1S4	41.3 B	1.8 B	.05 U	.49 U	300 B	.66 B	.23 U	65.6 U	.86 U	18.2	1.3 B	NA
T4C1S5	13.0 B	1.1 B	.05 U	.32 U	50.8 B	.41 U	.15 U	42.9 U	.56 U	12.9	.90 B	685 J
T4C2H1	755 B	59.1	.50	6.1 B	628 B	1.6	.42 U	136 U	1.8 U	38.7	64.8	205000
T4C2H2	333 B	23.3	.54	6.5 B	472 B	1.7	.43 U	139 U	1.9 U	39.0	43.1	292000
T4C2H3	135 B	4.8 B	.41	4.7 B	193 B	3.0	.69 U	222 U	3.0 U	101	17.9	202000
T4C2H4	122 B	6.0 B	.38	3.1 B	265 B	2.1 B	.60 U	192 U	2.6 U	106	22.0	482000
T5P1S1	157 B	8.3	.75	2.2 B	329 B	1.3	.25 U	70.9 U	.93 U	67.9	15.6	76800
T5P1S2	90.8 B	4.2	.20	1.0 B	226 B	1.0 B	.30 B	63.2 U	.83 U	58.4	10.9	26600
T5P1S3	105 B	3.8	.15	7.5 B	250 B	.58 U	.21 U	60.7 U	.79 U	59.0	42.1	30700
T5P1S3A	766 B	14.5	.78	147	1950 B	1.7 B	.43 U	123 U	1.6 U	362	616	113000
T5P1S3B	59.9 B	2.9 B	.17	1.6 B	124 B	.65 U	.24 U	68.0 U	.79 U	71.3	10.1	20400 J
T5P1S3C	481 B	9.0	.74	63.1	1230 B	1.5 B	.34 U	95.9 U	1.3 U	189	288	66100

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Concentration (mg/kg)											
	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc	Total organic carbon
T5C1H1	101 B	9.3	0.35	4.0 B	174 B	2.1	0.28 U	80.4 U	1.1 U	37.5	18.1	197000 J
T5C1H2	79.9 B	5.7 B	.37	6.3 B	187 B	5.2	.46 U	131 U	1.7 U	48.1	31.5	367000
T5C1H3	127 B	4.0 B	.18 B	1.3 B	373 B	3.5	.56 U	159 U	2.1 U	20.0 B	16.2	301000 J
T5C1S1	23.0 B	2.1 B	.04 U	.47 U	83.1 B	.60 U	.22 U	63.2 U	.83 U	2.1 B	1.0 B	4760 J
T5C2H1	260 B	16.3	.30	5.8 B	428 B	1.5	.34 U	108 U	1.4 U	30.6	40.3	279000
T5C2H2	180 B	4.1 B	.19 B	2.4 B	353 B	2.5	.59 U	190 U	2.5 U	31.5	12.2	361000
T5C2S1	46.9 U	1.2 U	.04 U	.93 B	106 B	.96 U	.30 U	97.5 U	1.3 U	1.9 B	7.2	4190
T5C2S2	39.0 U	1.1 U	.04 U	.52 U	147 B	.79 U	.25 U	81.1 U	1.1 U	1.7 B	1.7 B	10600
R25A/CL	1240 B	26.8	.13	5.7 B	1420	1.3 U	.95 B	173 U	1.9 B	56.5	29.1	31900
R25CL1	883 B	17.8	.18	2.6 B	1120 B	1.2 U	2.7	161 U	1.9 B	51.3	18.3	9210
R25CL2	1190 B	20.6	.08 B	3.7 B	1450	1.2 U	1.3 B	164 U	1.9 B	53.3	22.8	4740
R25H2	237 B	11.2	.29	5.8 B	238 B	2.9	.29 U	310 U	2.7 B	49.3	28.4	428000
R25S1	40.1 B	7.7	.08 B	16.7	127 U	1.3 U	.15 U	166 U	.97 U	18.0	14.9	5930
R26H1	439 B	16.7	.17	2.8 B	120 U	1.3	.58 B	157 U	.91 U	19.2	32.4	66000
R26H2	201 B	20.6	.18	4.1 B	126 U	1.2 U	1.8 B	165 U	1.1 B	37.0	50.0	61900
C1A	67.1 BJ	6.1	.05 U	.49 BJ	208 BJ	.60 U	.51 U	65.3 U	.78 U	11.0	7.1	7360
C1E	72.7 BJ	8.9	.05 U	.86 BJ	236 BJ	.54 U	.45 U	58.7 U	.70 U	9.9	8.0	4520
C1E/B	88.5 BJ	6.8	.06 U	.33 U	246 BJ	.64 U	.54 U	69.86 U	.83 U	14.3	7.8	12000
C1B1	90.3 BJ	4.4	.05 U	.50 BJ	272 BJ	.57 U	.48 U	61.4 U	.73 U	11.3	4.0	2520
C1SB1	68.6 BJ	4.0	.05 U	.36 BJ	227 BJ	.57 U	.48 U	61.8 U	.74 U	10.5	5.0	NA
C1B2	48.4 BJ	2.2 BJ	.05 U	.29	312 BJ	.55 U	.46 U	59.9 U	.71 U	9.2	3.4 BJ	1450
C1B3	183 BJ	4.9	.04 U	.61 BJ	400 BJ	.66 U	.55 U	71.0 U	.85 U	7.7 BJ	6.0	1170

Table 1. Concentrations of constituents in soil samples from the Texas Road site, Monmouth County, New Jersey --Continued

Sample number[1]	Concentration (mg/kg)											
	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc	Total organic carbon
C2H1	278 BJ	31.1	0.24	3.7 BJ	577 BJ	3.2	0.96 U	124 U	1.5 U	19.4	48.3	221000
C2H2	107 BJ	12.9	.11 BJ	1.7 BJ	222 BJ	2.1	.68 U	88.5 U	1.1 U	21.8	11.9	132000
C2H3	78.3 BJ	4.9	.11 BJ	2.7 BJ	214 BJ	1.5	.71 U	91.4 U	1.1 U	19.6	12.1	150000
C2H4	29.5 U	1.3BJ	.07 BJ	.50 BJ	82.0 BJ	1.1 BJ	.67 U	87.1 U	1.0 U	16.1	5.8	93100
C2S1	23.3 U	2.1BJ	.05 U	.33 U	149 BJ	.63 U	.53 U	68.7 U	.82 U	32.4	11.3	920
C4H1	179 BJ	18.3	.12	.89 BJ	406 BJ	.76 U	.64 U	82.8 U	.99 U	14.4	16.9	36900
C4H2	309 BJ	35.9	.16	3.0 BJ	644 BJ	1.2 BJ	.78 U	101 U	1.2 U	30.2	25.4	110000
C5A	156 BJ	19.9	.06 U	.82 BJ	463 BJ	.74 U	.62 U	80.2 U	.95 U	11.7 BJ	16.2	17700
C5E	49.9 BJ	4.3	.05 U	.32 U	142 BJ	.62 U	.52 U	67.2 U	.80 U	9.8 BJ	6.7	4270
C5B1	169 BJ	14.2	.05 U	.78 BJ	342 BJ	.67 U	.57 U	73.1 U	.87 U	23.0	13.9	2310
C5B2	109 BJ	5.1	.06 U	.54 BJ	367 BJ	.71 U	.59 U	76.8 U	.91 U	20.7	11.2	2640
C5CL1	178 BJ	5.5	.05 U	1.9 BJ	945 BJ	.99 BJ	.62 U	80.4 U	.96 U	75.9	50.5	4360
C6A	246 BJ	64.6	.07 BJ	1.3 BJ	556 BJ	.72 U	.60 U	78.1 U	.93 U	13.3	25.7	28000
C6B1	54.8 BJ	7.0	.11 U	1.7 BJ	218 BJ	.89 BJ	.50 U	64.6 U	.77 U	33.1 J	19.0 J	3210
C6B2	57.6 BJ	13.2	.09 U	1.8 BJ	281 BJ	.69	.33 U	43.0 U	.51 U	50.5 J	37.9 J	2890
C6B3	79.1 BJ	8.3	.10 U	2.7 BJ	401 BJ	.65 U	.54 U	70.3 U	.84 U	63.9 J	64.7 J	3540
C6CL1	125 BJ	6.1	.12 U	.36 U	593 BJ	.70 U	.59 U	76.3 U	.91 U	13.9 J	2.7 BJ	4680

APPENDIX 2. GEOCHEMICAL DATA, TEXAS ROAD SITE AND ADJACENT WATERSHEDS, MONMOUTH AND MIDDLESEX COUNTIES, NEW JERSEY

Table 2. Concentrations of constituents in wetland soil samples from four watersheds in Monmouth and Middlesex Counties, New Jersey

[in., inches (below land surface); mg/kg, milligrams per kilogram; U, below instrument detection limit; B, detectable but below contract-required detection limit; J, qualified--data may exhibit bias]

Sample number[1]	Depth (in.)	Concentration (mg/kg)											
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead
H1H1	2-6	13400	2.8 UJ	18.2	25.6 B J	0.36 BJ	0.40 UJ	327 B J	24.1	1.4 B J	65.7	37800	189 J
H1H2	8-12	10300	1.6 BJ	43.1	20.3 B J	.99 BJ	.13 UJ	92.1 B J	18.8	1.6 B J	18.3	59600	46.2 J
H1H3	12-16	7730	.82 BJ	21.4	20.7 B J	.69 BJ	.11 U	91.0 B J	16.2	1.2 B J	13.0	54700	24.3 J
H1H4	16-24	8440	.82 UJ	37.0	35.2 B J	1.5	.12 UJ	146 B J	16.8	2.6 B J	9.3	259000	16.6 J
H2H1	2-5	6000	1.9 BJ	27.6	16.9 B J	.32 BJ	.17 UJ	128 B J	13.6	.69 B J	17.2	24000	59.0 J
H2H2	5-12	7110	1.0 UJ	26.4	8.4 B J	.89 BJ	.15 UJ	256 B J	15.0	.52 U	8.7 B J	15300	10.0 J
H2S1	14-18	5200	.97 BJ	6.4	5.7 B J	.36 BJ	.08 UJ	28.4 U	16.5	.40 B J	.93 B J	19900	3.8 J
H2CL1	18-24	5370	.66 UJ	6.8	5.2 B J	.43 BJ	.09 UJ	34.2 U	14.9	.33 U	1.3 B J	37600	3.2 J
H3H1	1-10	14300	1.3 BJ	22.6	70.3 B J	1.1 BJ	.18 UJ	1590 B J	40.4	5.0 B J	148	50500	998 J
H3S1	18-24	12600	1.2 BJ	13.4	38.0 B J	1.1 BJ	.12 U	656 B J	34.2	2.9 B J	10.1	47400	32.9 J
H4DH1	6-15	31800	1.1 UJ	25.9	107	2.7	.16 UJ	560 B J	76.7	7.0 B	22.6	76800	61.0 J
H4DH2	15-25	21100	1.4 UJ	13.5	57.3 B J	2.5 BJ	.21 UJ	889 B J	31.5	2.3 B J	10.7 B J	38000	16.9 J
H4DH3	30-36	17900	2.1 UJ	4.9 BJ	27.3 B J	2.1 BJ	.31 U	560 B J	23.9	1.1 U	11.3 B J	11400	10.9
H4DH4	38-48	22000	2.5 UJ	12.3	33.5 B J	1.9 BJ	.35 UJ	628 B J	27.7	1.7 B J	13.0 B J	15300	10.7 J
H4DH5	48-58	29700	2.1 UJ	10.9	42.3 B J	2.6 BJ	.30 UJ	612 B J	36.6	2.0 B J	14.5 B J	11600	17.9 J
H4H1	7-15	23100	.97 UJ	28.4	90.7	2.0	.14 UJ	819 B J	53.3	6.5 B J	29.5	59200	120 J
H4H2	15-28	23900	1.7 UJ	20.2	64.8 B J	2.8 BJ	.24 UJ	1260 B J	37.2	3.1 J	12.5 J	39700	98.2 J
H4H3	30-36	28200	1.8 UJ	7.9	41.3 B J	2.6 BJ	.26 UJ	354 B J	33.0	1.4 J	13.3 J	7690	17.3 J
H4H4	36-48	25200	1.8 UJ	8.4	45.5 B J	2.3 BJ	.25 UJ	268 B J	29.9	1.8 B J	14.1 B J	7280	17.4 J
H5S1	0-22	9350	.66 UJ	12.6	33.1 B J	.85 BJ	.09 UJ	436 B J	38.2	3.5 B J	10.4	28300	48.2 J
H5H1	25-35	28200	1.4 BJ	23.8	122	3.1	.15 UJ	1150 B J	65.7	9.4 B J	11.7	50100	29.3 J
H6S1	0-6	22300	2.1 U	81.8	198	2.3 B	.29 U	3380	90.1	14.9 B	44.3	137000	94.3
H6H1	6-13	7490	1.7 B	26.0	62.1 B	1.2 B	.16 U	1300 B	38.2	7.7 B	22.5	66000	48.0
H6H2	13-21	2730	.62 U	30.1	24.8 B	.96 B	.09 U	611 B	20.3	3.6 B	4.2 B	59800	8.9
H6H3	21-30	2890	.92 B	25.5	36.2 B	.86 B	.07 U	825 B	18.4	5.7 B	4.2 B	52800	10.6
H7H1	0-9	14600	1.1 U	21.3	60.3 B	1.2 B	.16 U	520 B	35.5	4.1 B	27.2	42400	105
H7H2	9-19	10600	1.5 U	23.7	78.0 B	1.3 B	.21 U	1200 B	26.1	8.3 B	30.7	39400	103
H7H3	22-30	3040	.66 B	13.4	35.9	.23 B	.07 U	77.8 B	15.6	4.6 B	7.3	15700	9.3
H7H4	30-35	5230	.58 U	19.3	36.2 B	.43 B	.08 U	55.6 B	18.3	3.8 B	7.5	11100	8.2

[1]The initial H denotes a sample of wetland soils; the following number is the site number. The site number is followed by letters denoting the type of sediment--H denotes humaquepts, S denotes sand or silt, CL denotes clay. The final number indicates relative depth within the core sample; numbers increase with increasing depth within a particular sediment unit. H4D samples are spatial duplicates of H4 samples; core H4D was collected about 4 feet from core H4.

Table 2. Concentrations of constituents in wetland soil samples from four watersheds in Middlesex and Monmouth Counties, New Jersey--Continued

Sample number[1]	Concentration (mg/kg)											
	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc	Total organic carbon
H1H1	811 BJ	23.1	0.45	7.9 BJ	1600 BJ	3.0 UJ	2.6 U	334 U	4.0 U	48.6	43.7	351000
H1H2	564 BJ	23.9	.11 BJ	5.4 BJ	936 BJ	1.1 UJ	.82 U	106 U	1.3 U	37.9	65.9	79500
H1H3	487 BJ	16.7	.10 U	4.7 BJ	718 BJ	1.2 UJ	.70 U	90.0 U	1.1 U	29.9	46.7	69400
H1H4	349 BJ	29.6	.09 U	7.5 BJ	521 BJ	1.0 UJ	.76 U	111 BJ	1.4 BJ	35.2	73.2	70100
H2CL1	64.9 BJ	2.4 BJ	.07 U	1.0 BJ	314 BJ	.55 UJ	.61 U	79.1 U	.94 U	34.6	12.1	8310
H2H1	360 BJ	11.4	.11 BJ	3.5 BJ	555 BJ	.99 UJ	1.1 U	140 U	1.7 U	30.1	21.4	91700
H2H2	171 BJ	3.2 BJ	.09 U	2.5 BJ	113 U	1.2 BJ	.96 U	124 U	1.5 U	28.7	11.1	90500
H2S1	103 BJ	2.2 BJ	.06 U	.94 BJ	325 BJ	.68 UJ	.51 U	65.8 U	.78 U	37.7	9.1	16000
H3H1	2240	93.2	.33	19.4	2080 BJ	1.2 UJ	1.1 U	224 BJ	1.8 U	59.6	214	116000
H3S1	1110 BJ	44.6	.09 U	5.9 BJ	1500	.84 UJ	.75 U	96.9 U	1.2 U	53.6	50.3	29600
H4DH1	3250	76.8	.16 BJ	18.8	4130	1.8 BJ	1.0 U	189 BJ	1.6 U	107	97.0	992000
H4DH2	820 B	34.1	.17 U	13.7 BJ	937 BJ	2.2 BJ	1.3 U	218 BJ	2.1 U	56.9	30.6	305000
H4DH3	429 BJ	14.1	.20 U	4.2 BJ	680 BJ	2.4 U	2.0 U	257 U	3.1 U	54.7	18.2	314000 J
H4DH4	652 BJ	17.5	.20 U	5.9 BJ	1000 BJ	3.4 BJ	2.3 U	297 U	3.5 U	64.9	16.8 BJ	407000 J
H4DH5	983 BJ	19.2	.19 U	11.1 BJ	1380 BJ	2.3 UJ	2.0 U	268 BJ	3.1 BJ	68.4	28.5	425000
H4H1	2060	55.7	.17 BJ	16.7	2450	1.7 UJ	.90 U	117 U	1.4 U	82.6	87.5	141000
H4H2	1120 BJ	44.8	.17 U	14.3 BJ	1370 BJ	2.9 J	1.6 U	205 U	2.4 U	71.6	38.0	290000 J
H4H3	881 BJ	13.9	.20 U	10.7 BJ	1450 BJ	2.5 UJ	1.7 U	216 U	2.6 U	67.3	27.4	400000
H4H4	508 BJ	10.6	.20 U	11.7 BJ	693 BJ	2.5 UJ	1.6 U	210 U	2.5 U	55.8	22.9	385000
H5S1	1150 BJ	53.8	.11 BJ	6.4 BJ	1760	.51 UJ	.61 U	189 BJ	1.2 BJ	43.9	43.7	13500
H5H1	2510	116	.11 BJ	20.2	3860	1.3 UJ	.99 U	239 BJ	1.5 U	86.9	81.4	82300 J
H6S1	3590 B	506	.67	34.1	3630 B	9.2	1.9 U	247 U	2.9 U	87.8	263	116000
H6H1	1140 B	144	1.1	16.1 B	1410 B	4.5	1.1 U	136 U	1.6 U	36.5	150	41600
H6H2	326 B	63.8	.06 U	8.9	1030 B	3.4	.58 U	74.7 U	.89 U	19.5	109	4850
H6H3	367 B	89.6	.06 U	11.7	991	2.7	.48 U	61.9 U	.74 U	18.6	99.7	9760
H7H1	1620 B	55.6	.12 U	12.1 B	2330	4.8	1.0 U	133 U	1.6 U	61.4	40.0	116000
H7H2	920 B	81.6	.13 U	20.1 B	1190 B	5.6	1.4 U	178 U	2.1 U	56.3	94.3	247000
H7H3	334 B	12.5	.07 U	5.5 B	890	1.5	.94 U	56.7 U	.67 U	26.0	11.2	42300
H7H4	798 B	23.2	.07 U	5.7 B	1780	.64 U	.54 U	69.2 U	.82 U	27.3	13.7	28600

U.S. Geological Survey
810 Bear Tavern Road, West Trenton, New Jersey 08628

Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T1 P1 Date: 12/10/96 Time (pit): 1400 Time (core): —
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Texas Rd site, point bar along stream , E. bank, ~35 ft from drive Weather: Partly sunny high 30's - low 40's
Soil series: — Sampler: — Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		Organic root mat	0" - 1"
	10 YR 2/1 Black	Black organic rich fine sand; some white medium sand grains	1" - 9"
	10 YR 2/2 very dark brown	Slightly silty medium sand	9" - 14"
	Black	Damp mucky fine humic material	14" - 24"

COMMENTS
Total depth of pit 24" to water; 3 layers

Samples:	T1P1S1	T1P1S2	T1P1H1	Date bottled: 12/10/96
Depths:	1" - 9"	9" - 14"	14" - 24"	
Comments:				

Site number: T1 P2 Date:12/10/96 Time (pit): 1100 Time (core):
Personnel: TDO, NPS, JLB Quadrangle: Keyport Formation: Englishtown
Location: Texas road site, E. stream bank ~35 ft from drive Weather: Sunny mild ~40
Soil series: Sampler: Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		"O"?	0" - 2"
	10 YR 4/4 dark yellowish brown	Medium silty sand	2" - 7"
	10 YR 4/4 dark yellowish brown	Medium silty sand	7" - 17"
	10 YR 2/1 black	Organic rich fine sand with medium sand	12" - 19"
	10 YR 6/2 light brownish gray	Clean medium sand	19" - 28"
	Black organic		16" - 23"

COMMENTS
Total depth of Pit 28" 5 layers; 4 continuous layers with an organic rich side that appears to pinch out. Pinches out going into the hill

Samples:	T1P2S1	T1P2S2	T1P2S3	T1P2S4	T1P2H1	Date bottled: 12/10/96
Depths:	2" - 7"	7" - 12"	12" - 19"	19" - 28"	16" - 23"	
Comments:						

U.S. Geological Survey
810 Bear Tavern Road, West Trenton, New Jersey 08628

Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T2 P1 Date: 12/11/96 Time (pit): 0955 Time (core): —
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Texas Rd site, along S side of stream bank, next to stream, ~120 ft from dirt rd. Weather: cloudy, mild, mid 40's
Soil series: — Sampler: — Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 5/4 yellowish brown with some gray mottles	Clay intermixed with some sand	0 - 3"
	10 YR 4/6 dark yellowish brown	Medium sand intermixed with small amounts of clay 10 YR 5/1 gray	3" - 11"
	7.5 YR 3/2 dark brown	Organic layer, lots of root hairs some small brick fragments, and small rocks	11" - 14"
		Black humic layer, organic rich	14" - Bottom

COMMENTS
Sand must be below stream level - 4 layers - Depth of pit to water 22 inches - occasional sulfur smell inthe lower part of pit in humic stuff. dug pit to where water came into the pit, but did not find any of the clean white sand (Englishtown) @ 13" appears to be a root mat, like you would expect at the surface

Samples:	T2P1CL1,	T2P1S1,	T2P1Og1,	T2P1H1	Date bottled: 12/11/96
Depths:	0 -3"	3" - 11"	11" - 14"	14" - Bottom	
Comments:					

Site number: T3 P1 Date: 12/12/96 Time (pit): 1030 Time (core): 1030
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Refer to map, 15 feet from Creek, in bend of creek NNW side of house Weather: Cloudy light breeze mid 40's
Soil series: Sampler: Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 5/3 brown with some gray and orange mottles	Clay fill	0 - 6"
		Root Mat, very dense. Maybe the "O" layer?	6" - 7"
	10 YR 2/2 very dark brown	Fine grain sandy silt	7" - 14"
		Black damp fine humic layer	14" - bottom

COMMENTS
Depth of pit to water, 21 inches. dug into bank found clay fill, blackish brown sand root mat and humic layer down to water lots of roots, wire was found in clay, rusty, stiff.

Samples:	T3P1CL1	—	T3P1S1	T3P1H1	Date bottled: 12/12/96
Depths:	0 - 6"	6" - 7"	7" - 14"	14" - bottom	
Comments:					

U.S. Geological Survey
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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T4 P1 Date: 12/12/96 Time (pit): 1315 Time (core):
Personnel: TDO, NPS Quadrangle: Keyport Formation:Englishtown
Location: Directly behind house chimney, ~6 ft from stream bank Weather:Cloudy, breezy, 40s
Soil series: Sampler: Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		Root mat, organic, "O" layer	0 - 3"
	10 YR 2/1 black	fine sand with medium sand grains throughout	3 - 9"
	7.5 YR 3/2 dark brown	medium sand, clean	9 - 21"
	7.5 YR 5/2 brown	medium sand, clean	21" - 26"
	10 YR 4/1 dark gray	medium sand, clean, damp	26" - 34"

COMMENTS
Depth of pit to water: "34"; at bottom of pit, ironstone, iron-stained sand (reddish)

Samples:	T4P1S1	T4P1S2	T4P1S3	T4P1S4	Date bottled: 12/12/96
Depths:	3 - 9"	9 - 21"	21 - 26"	26 - 34"	
Comments: Depth of pit to water: "34"; at bottom of pit, ironstone, iron-stained sand (reddish)					

Site number: T4 P2 Date:12/16/96 Time (pit): 1005 Time (core):
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Up streambank from T4P1 Weather:Cloudy, 40s, misty off-and-on
Soil series: Sampler: Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		Root mat, organic, "O"	0 - 3"
	10 YR 2/2 very dark brown	slightly silty fine sand with small amounts of white medium sand grains	3 - 13"
	Black	fine humic with small amounts of white medium sand grains	13 - 26"
	10 YR 5/6 yellowish brown	clean medium sand	26 - 43"

COMMENTS
Depth of pit 43"

Samples:	T4P2S1	T492H1	T4P2S2	Date bottled: 12/16/96
Depths:	3 - 13"	13 - 26"	26 - 43"	
Comments:				

U.S. Geological Survey
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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T5 P1 Date: 12/16/96
Personnel: TDO, NPS
Location: ~8 ft from stream edge at sand bar
Soil series:

Time (pit): 1115
Quadrangle: Keyport
Sampler:

Time (core):
Formation: Englishtown
Weather: cloudy, 40's
Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		Root mat, organic, "O" layer	0 - 3"
	10 YR 3/2 very dark grayish brown	fine sand with small amounts of medium white sand, some fine roots	3 - 6"
	2.5 YR 3/3 dark reddish brown	medium slightly silty sand	6 - 16"
	10 YR 4/1 dark gray	medium sand; this layer has horizontal stripes of different colors, described below; these stripes are discontinuous, occurring at various levels within the layer	16 - 26"
	Very black	fine, much with slight sulfur smell	
	5 YR 3/3 dark reddish brown	medium sand	
	10 YR 3/1 very dark gray	fine silty sand with some mica flakes	

COMMENTS
Rainbow sheen on top of water in hole smells like hydrocarbon, probably heavier-molecular compounds (oily). Water at 26".

Samples:	T5P1S1	T5P1S2	T5P1S3	T5P1S3A	T5P1S3B	T5P1S3C	Date bottled: 12/16/96
Depths:	3 - 6"	6 - 16"	16 - 26"				
Comments:							

Site number:
Personnel:
Location:
Soil series:

Date:

Time (pit):
Quadrangle:
Sampler:

Time (core):
Formation:
Weather:
Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)

COMMENTS

Samples:	Date bottled:
Depths:	
Comments:	

U.S. Geological Survey
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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T1C1 Date:11/20/96
Personnel: NPS, JLB
Location: Texas road site, 15 ft from stream
Soil series: Fill

Time (auger):
Quadrangle: Keyport
Sampler:

Time (core):
Formation: Englishtown
Weather: cloudy, snow shower
Hole Depth: 26"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 5/4 yellowish tan, then gray, 10 YR 5/2	mix of clay and silty sand	0 8"
	mixed yellowish tan and gray	clayey and silty - some fine sand	8 - 15"
	mixed yellowish tan and gray	clay and silty sand	15 - 22"
	mixed yellowish tan - some brick red spots	sandy, some clay, piece of aluminum soft drink can, small stones; @ 23", 2" black rock saved for examination; layer of rocks, cobbles, pebbles, etc.	22 -26"

COMMENTS
Hit stone at 22", bent auger blade - straightened it, need new hole 1 ft away same clay/silty sand mix, more clay

Samples:	Date bottled:
Depths:	
Comments:	

Site number: T1 C1 Date: 12/4/96
Personnel: TDO, NPS, JLB
Location:
Soil series:

Time (auger): see attached
Quadrangle: Keyport
Sampler: 1 split-spoon

Time (core): 1000
Formation: Englishtown
Weather:
Hole Depth: 30.5"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		see attached	

COMMENTS

Samples:	T1C1CL1	T1C1CL2	Date bottled: 12/9/96
Depths:	2 - 10"	25 - 30"	
Comments:			

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T1 C2 Date: 12/4/96 Time (auger): 1025 Time (core):
Personnel: TDO, NPS, JLB Quadrangle: Formation:
Location: Texas Road site Weather: mostly cloudy, 40s
Soil series: Sampler: Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 5/6 yellowish brown	medium silty sand, smooth pebbles and cobbles, 2" brick @ 5 1/2", slightly damp	0 6"
	10 YR 4/3 brown	medium slightly silty sand, pebbles, black cinders (saved), little brick pieces, large rock at 8"; more rocks - lighter sand appearing at ~13"	6 - 13"

COMMENTS
Hole filled because of rocky fill; may be sampled later No samples

Samples:	Date bottled:
Depths:	
Comments:	

Site number: T2 C2 Date: 12/9/96 Time (auger): 1405 Time (core): 1515
Personnel: TDO, NPS Quadrangle: Keyport Formation:
Location: Texas Road site Weather: cloudy, cold
Soil series: Sampler: 1 split spoon Hole Depth: 10"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		sod	0 - 1"
	5 YR 3/3 dark reddish brown	sandy clay, many brick pieces, large rocks	1 - 5"
	10 YR 4/3 brown	clayey sand, medium, many rocks, fragments as above, hydrocarbon smell ~17"	5 - 17"
	5 YR 2/1 black	humic organic, fine roots, pieces of tree branch	30 - 39"
	10 YR 4/3 brown	medium sand, clean sand	39 - 56"

COMMENTS
Drove split spoon from 0 - 10", could not get farther. Out of caps; perhaps sample on later date

Samples: T2C2F1	Date bottled:12/19/96
Depths: ~3 - 6"	
Comments:	

U.S. Geological Survey
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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number:T2 C3 Date: 12/9/96 Time (auger): 1145 Time (core): 1225, 1240
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: 30 ft from Drive NW Corner of House ~110 ft up drive Weather: cloudy cold 30s (low)
Soil series: Sampler: Hole Depth: 52"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		1" sod removed	0 - 1"
	10 YR 2/1 black	organich rich some medium white sand	1 - 11"
	10 YR 4/6 dark yellowish brown	slightly silty med. sand; some cobbles very minor 2.5 YR 3/4 dark reddish brown	11" - 18"
	7.5 YR 4/6 strong brown	medium silty sand; (1 piece) some small amount black stuff, some silty sand 10 YR 3/2 very dark grayish brown	18 - 34"
	10 YR 3/2 very dark grayish brown	some pebbles fine grained sandy clay; less sandy with depth	34" - 42"
	7.5 YR 5/2 brown	medium grained sandy; some rust colored streaks	42 - 47"
	10 YR 3/2 very dark grayish brown	clay very little sand	47 - 52"

COMMENTS
Hole stopped @ 52" water @ 50" Pounded 2" sampler from 1" to 40", pounded second 2" sampler from 40" to 52"

Samples:	T2C3H1	T2C3S1,	T2C3S2,	T2C3CL1	T2C3CL2	Date bottled: 12/18/96
Depths:	~3 - 6",	~12 - 16",	~25 - 32"	~35 - 40"	~48 - 51"	
Comments:						

Site number: T2 C4 Date: 12/5/96 Time (auger): 1245 Time (core): 1330
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Texas Road site - lawn, S of driveway, 29.5 ft from fence Weather: cloudy, 40s
Soil series: Sampler: 1 split-spoon Hole Depth: 33"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		sod , 0 - 1" removed	
	10 YR 2/1 black	humic, organic; small amounts light-colored sand through-out; fine roots	1 - 7"
	10 YR 5/2 grayish brown	medium sand; damp, clean	7 - 22"
	10 YR 4/1 dark gray	clay; massive; water at 26"; at 42", medium sand of same color mixed with predominant clay; water at 43", not 26" anymore - perched water draining to lower region??	22 - 47"
	7.5 YR 4/1 dark gray	medium sand; clean, wet; water now down to 46", then to 50"	47 - 62"

COMMENTS
Bagged core-catcher contents; total depth of sample hole 33"

Samples:	T2C4H1,	T2C4S1,	T2C4CL1	Date bottled: 12/17/96
Depths:	2 - 4"	~9 - 16"	~23 - 26"	
Comments:				

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T2 C5 Date: 12/3/96 Time (auger): 1015 Time (core): 1055
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Texas Road site - farm field, 291 ft south of fence Weather: partly sunny, cold
Soil series: Sampler: corer Hole Depth: 42"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 2/2 very dark brown	medium-fine (slightly silty) sand; light-colored medium sand grains throughout	0 -18"
	7.5 YR 6/3 light brown	medium sand; medium sand mottled; with some silt and clay; clay color: 10 YR 4/1 dark gray	18" - 24"
	7.5 YR 5/2 brown	medium sand; 7.5 YR 6/8 reddish yellow mottles, more with depth some smooth pebbles at ~30"	24 - 35"
	10 YR 4/1 dark gray	medium sand; few pebbles	35 - 50"
	10 YR 3/1 very dark gray	clayey sand; wet; water in hole ~1" deep	50 - 52"

COMMENTS

Samples:	T2C5H1,	T2C5H2,	T2C5S1,	T2C5S2	Date Bottled: 12/9/96
Depth:	~4 - 8"	~12 - 16"	~22 - 24"	~36 - 40"	
Comments:					

Site number: T3 C2 Date: 11/20/96 Time (auger): 11/18/96 Time (core): 1055
Personnel: NS, JLB Quadrangle: Keyport Formation: Englishtown
Location: Texas Road site - about 30 ft from stream, about 100 ft W of T2C2 Weather: clear, low 40s
Soil series: fill Sampler: Hole Depth: 43" with corer; went to 51" with split spoon

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	Blebs 10 YR 4/6; clay grey and brown 10YR 4/3, blackish areas	clayey w/sandy silt blebs; 2 pc brick?? gets sandier near 10"	1 - 10"
	same as above	silty clay; same as above; much humic mat'l (twigs & leaves) @ 15 - 17"	10 - 17"
	blackish	humic layer	17 - 24"
	black humic mat'l; silt/clay balls bright red 2.5 YR 4/16	humic mat'l some clays; silt balls	24 - 33"
	blackish	humic material;@ 38 - 48" H2S smell, @48" - 50" sandier, lighter color	33 - 50"
	blackish humics, grey sand 10 YR 3/2	humic, grey sand @ 54" wet water table @ 58"	54 - 58"

COMMENTS
only 2 ft retrieved w/corer - attempted to retrieve the rest w/splitspoon down same hole; retrieved ~ 1/2 2 ft liner (compacted soil)

Samples:	T3C2CL1,	T3C2CL2,	T3C2CL3,	T3C2H1, T3C2H2	Date bottled: 12/6/96
Depths:	~2 - 8"	~10 - 13"	~13 - 17"	~18 - 22" ~40 - 48"	
Comments: T3C2CL3 siltier than CL1 + CL2					

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T3C3 Date: 12/9/96 Time (auger): 1010 Time (core): 1100/1125
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: 30 ft from drive NE corner of house Weather: cloudy cold low 30s some rain snow
Soil series: Sampler: split-spoon Hole Depth: 46"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		1" sod removed	0 - 1"
	7.5 YR 5/6 sand strong brown	mixture of sand/clay; medium sandy silty clay - clay - 10 YR 3/3 dark brown	1 - 11"
	10 YR 2/1 black	organic-rich w/medium sand crystals; root fragments, pieces of wood, sulfur smell in 19" bucket	11" - 38"
	10 YR 3/3 very dark grayish	wet medium to fine sand; wetter at depth a little silt, some cobbles @ 55" a little browner sand 7.5 YR 4/2 drk brown	38"

COMMENTS
hole stopped @ 58", water @ 47"; drove 1" to 27" w/split spoon obstruction @ 27" hand augered to obstruction @ 27" drove 2" sampler 28" to 46" 1 liner full

Samples:	T3C3CL1,	T3C3H1,	T3C3S1	Date bottled: 12/19/96
Depths:	~3 - 7"	~29 - 35"	40 - 45"	
Comments:				

Site number: T3C5 Date: 12/3/96 Time (auger): 1245 Time (core): 1315
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Refer to map - farm field between houses, 245 ft S of fence Weather: sunny, light wind low 40s
Soil series: Sampler: 3 one-footers; 1 split spoon Hole Depth: 42"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 2/1 black	medium grained slightly silty sand; organic material Light colored medium sand grains throughout @ very bottom - minor amounts of 2.5 YR 4/8 red	0 - 14"
	7.5 YR 6/3 light brown	medium grained sand; 48 inches depth of hole intersected water table @ 35 inches	14"

COMMENTS
Core catcher is in middle liner top liner empty bottom about 3-4 inches sample, hole open til 30"; split spoon down same hole to 42" @ 1335

Samples:	T3C5H1,	T3C5H2	T3C5C1	T3C5C2	Date bottled: 12/9/96
Depths:	~2 - 6"	~10 - 13"	~15 - 18"	~32 - 37"	
Comments:					

U.S. Geological Survey
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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T4 C1 Date: 12/4/96 Time (auger): 1149 Time (core): 1225
Personnel: T Oden, N Smith, J Barringer Quadrangle: Keyport Formation: Englishtown
Location: Located behind house 109 feet from house on berm before creek Weather: Partly sunny - mid 40's light breeze
Soil series: Sampler: Hole Depth: 42"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 3/2 very dark grayish brown	medium-fine sand; root hairs	0 - 12"
	10 YR 5/2 grayish brown	medium grained sand; some root hairs - getting moist w/ depth	12 - 25"
	5 YR 4/2 dark reddish gray	medium to fine grained sand	25 - 30"
	7.5 YR 6/2 pinkish gray	clean medium sand; slightly mottled	30 - 39"
	10 YR 8/3 pale brown	medium sand, little silt 24 1/2 feet; getting wet w/depth 10 YR 4/6 dark yellowish brown mottles slightly grayer where sitting in water table	39 - 72"

COMMENTS
water in table intersected @ 62 inches; hole stopped @ 72"; no humaquepts detected, no humic layers discovered

Samples:	T4C1S1,	T4C1S2,	T4C1S3,	T4C1S4	T4C1S5	Date bottled: 12/12/96
Depths:	~2 - 6"	~20 - 24"	~27 - 30"	~30 - 36"	~38 - 42"	
Comments:						

Site number: T4 C2 Date: 12/4/96 Time (auger): 1050 Time (core): 1125
Personnel: TDO, NPS, JLB Quadrangle: Formation:
Location: w of house, 67 ft W of back wall of house Weather: mostly cloudy, 40s
Soil series: Sampler: Hole Depth: 32"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	7.5 YR N 2/0	humic, organic; few fine roots; little medium sand, wetter with depth, more compacted	0 - 26"
	10 YR 3/3	humic, organic;with bits of leaf, sticks; water at 36", H_2S smell	26 - 45"
	10 YR 4/1 dark gray	medium sand, wet	45 - 53"
	10 YR 5/0 yellowish brown	pebbles; mix of two sand colors	

COMMENTS

Samples:	T4C2H1	T4C2H2,	T4C2H3,	T4C2H4	Date bottled: 12/6/96
Depths:	~2 - 6"	~12 - 16"	~20 - 24"	~30 -35	
Comments:					

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: T5C1 Date: 12/5/96 Time (auger): 1025 Time (core): 1055/1115
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: top of stream bank/beginning of field, N of storm drain outlet Weather: Sunny cold high 30s
Soil series: Sampler: Hole Depth: 49"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 2/1 black	Organic rich humic layer; minor medium light colored sand grains, root hairs	0 - 23"
	10 YR 2/1 black	fine grained-silt	23 - 31"
	7.5 YR 5/3 brown	medium grained sand; mottled, getting damp with depth; color grays @ depth; some cobbles @ 50" 10 YR 5/2 grayish-brown	31 -

COMMENTS
Intersected water @ 51" Lost some sample pounded to 42 and got 38" core. Drove second sampler from 38" to 49". Only 1 core liner filled for second sampler

Samples:	T5C1H1,	T5C1H2,	T5C1H3,	T5C1S1	Date bottled: 12/17
Depths:	2 - ~6"	~10 - 14"	~25 - 30"	~35 - 40"	
Comments:					

Site number: T5C2 Date: 12/4/96 Time (auger): 1345 Time (core): 1405
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Texas Road site - farm field, 257 ft W of T3C5 Weather: cloudy, 40s
Soil series: Sampler: Hole Depth: 37"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 2/1 black	humic, organic; small amounts of light medium sand	0 - 16"
	7.5 YR 4/2 brown	medium sand; clean	16 - 20"
	7.5 YR 5/2 brown	medium sand; clean; mottled with 7.5 YR 4/2 sand; water at 37" small amounts 7.5 YR 4/6 strong brown medium sand @ ~37"; pebbles at 37 - 42" also; small amounts of 10 YR 3/2 silty sand at 45"	20 - 48"

COMMENTS

Samples:	T5C2H1,	T5C2H2,	T5C2C1,	T5C2C2	Date bottled: 12/9/96
Depths:	~1 - 6"	~10 - 15"	~17 - 19"	~33 - 36"	
Comments:					

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: R25 Date: 4/22/96 Time (auger): 1245 Time (core): 1325
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: off northwest corner of house, ~ halfway to Texas Rd., (map) Weather: sunny, hot
Soil series: Sampler: corer Hole Depth: 48"

DESCRIPTION			
Horizon/ Stratum/ Stratum	Color	Texture	Thickness (in inches)
		sod, removed	0 - 1"
	10 YR 2/1 black	sandy loam; fine roots	1 - 2"
	10 YR 5/8 yellowish brown sand 10 YR 5/1 gray clay	medium sand, clay; clay and sand intermixed, clayier w/depth	2 - 9"
	7.5 YR N2/0 black	medium sand, humic; some black, hard material at 27 - 31" bagged	9 - 32"
	10 YR 2/1 black	silt? organic?; muddy, damp, swampy	32 - 40"
	5 YR 3/3 dark reddish brown	medium sand; some 5 yr 4/1 dark gray medium sand, bagged	40 - 56"

COMMENTS
C horizon 53 - 56" medium sand, light gray and darker gray bagged; sampler pounded from 1 - 48"; sampled hole measured to 48", so soil in sampler, though only ~13", is a compaction of 48" of sample.

Samples:	R-25-A/CL	R-25-CL1	R-25-CL2	R-25-H2	R-25-C	Date bottled: 4/25/96
Depths:	~1 - 3"	~3 - 5"	~8 - 9"	~36 - 40"	53 - 55"	

Comments: R-25-A/CL some "A" topsoil stuck to massive clay. The clay is disturbed; grey with swirls of brown
R-25-CL1 top of clay, grey clay intermixing w/red silty sand & black streaks. This is similar to clay under IOC, but looks disturbed.
R-25-CL2 bottom of clay less disturbed-looking may be in place ~9"
R-25-H2 bottom of black humic layer from ~36 - 40"
R-25-C wet sand from 53 - 55" TAL + TOC only

Site number: R-26 Date: 4/22/96 Time (auger): 1405 Time (core): 1435
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: front yard (map) Weather: sunny, hot, (80 degrees)
Soil series: Sampler: corer Hole Depth: 48"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		sod; some fine roots	0 - 1"
	5 YR 2.5/1 black	loamy medium sand; some light-colored sand well-mixed 0 - 8" @36", some black, hard material (lignitic?) bagged; 40 - 44" grading (mottled) to 10 YR 4/2 dark grayish brown medium sand	1 - 44"
	10 YR 4/2 dark grayish brown	medium sand; damp; cobbles 47 - 52"; ~50" some iron-stone (strong brown 7.5 YR 5/8)	44 - 52"

COMMENTS
Sampler withdrawn, hole sampled measure 43" BLS

Samples:	R-26-A	R-26-H	Date bottled: 4/25/96
Depths:	~6 - 8"	~40"	

Comments: This is not Keyport - probably some disturbance. R-26-A: this turns out to be more of a humaquept than "A" horizon . **Renumber R26H1.** R-26-H: Keyport, **make this R-26-H2**. The sand beneath is Englishtown.

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: C-1 Date: 6/2/97 Time (auger): 1030 Time (core): 1100
Personnel: TDO, RR Quadrangle: Formation: Englishtown
Location: Refer to Orchard Map of property. In woods behind house Weather: rainy cool 50s windy
Soil series: Sampler: corer Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 2/2 very dark brown	medium ground sand; rooty, clean, very little silt if any	0 - 2"
	10 YR 4/3 dark brown	medium grained; some cobbles + pebbles, mottled @~20"	2 - 21"
	10 YR 3/3 dark brown	med grained, slightly silty	21 - 25"
	10 YR 5/6 yellowish brown	silty medium grained; gray fined grained snd mixed in	25 - 30"
	10 YR 6/2 light brownish gray	fine grained sand; grades to medium grained; getting silty 10 YR 5/8 mottles	30 - 42"
	10 YR 5/8 yellowish brown	medium sand silty; clumpy clay at the bottom about 1" - 2" thick back into sand.	42"

COMMENTS
Hole stopped @ 53"

Samples:	C1-A,	C1-E,	C1-E/B,	C1-B1,	C1-D1,	C1-B2,	C1-B3	Date bottled: 6/5/97
Depths:	~3 - 8"	10 - 13"	~15 - 21"		~22 - 28"	30 - 34"	34 - 39"	
Comments: C1-E/B: mottled grey brown + yellowish brown; C1-B1, C1-D1 split of C1B1; C1-B2 very mottled grey + orange								

Site number: C-2 Date: 6/2/97 Time (auger): 1130 Time (core): 1200 + 1225
Personnel: T Oden, R Rosman Quadrangle: Formation: Englishtown
Location: Refer to Property Map. In woods East of house Weather: Rainy breezy cool
Soil series: Sampler: corer, split spoon Hole Depth: 40"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 2/1 black	medium-fine sand; very black no sulfur smell, rooty	0 - 1"
	Very black no color this dark in chart	fine-grained; some medium grain, light colored crystals, rooty, more gray crystals w/depth	9 - 19"
	10 YR 4/1 dark gray	med grained; roots orange mottles @ bottom	19 - 28"
	10 YR 6/2 light brownish gray	medium to fine sand; clean no silt, some cobbles, @ 34" large stone	28 - 35"
	7.5 YR N 7/0 light gray	fine-medium sand; very clean sand	35

COMMENTS
Hole stopped @ 51", 3 ft sample pounded to 39" recovery about 12 - 16". Used 2 ft split spoon pounded in same hole 24 - 40" to light brownish gray sand.

Samples:	C2-H1	C2H2	C2H3	C2H4	C2-S1	Date bottled: 6/4/97
Depths:	0 - 5"	~6 - 9"	12 - 18"	24 - 28"	~33 - 40"	
Comments:						

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: C-3 Date: 6/2/97
Personnel: T Oden, R Rosman
Location: Refer to Map. Woods, old orchard
Soil series:

Time (auger): 1333
Quadrangle:
Sampler:

Time (core):
Formation: Englishtown
Weather: rainy, breezey, cool
Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 5/4 yellowish brown	medium grained; roots	0 - 10"
	10 YR 6/6 brownish yellow	silty fine grained; roots, some ironstone @ 17"	10" -

COMMENTS
Augured to 46" from 17" - 46" lots of ironstone, from ~26" to 46" almost like an ironstone gravel bucketfulls full of 1 -2 mm size stone. No core taken today.

Samples: no samples	Date bottled:
Depths:	
Comments:	

Site number: C-4 Date: 6/2/97
Personnel: T Oden, R Rosman
Location: woods behind house, old orchard
Soil series:

Time (auger):
Quadrangle:
Sampler:

Time (core): 1445
Formation:
Weather:
Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 2/1	silty fine sand; organic rich black roots	0 - 10"
	very black	fine grained; roots	10 - 19"
	10 YR 4/2 dark greyish brown	med sand, mottled with orangish sand, silty	19 - 31"
	10 YR 5/1 gray	silty fine sand; silty mottled with 7.5 YR 5/8 med sand	31 - 38"
	10 YR 6/1 gray	silty fine sand	38 - 48"
		massive gray clay	48 -

COMMENTS
Hole stopped @ 50"

Samples:	C4H1	C4H2	Date bottled: 6/5/97
Depths:	~0 - 10"	~20 - 24"	
Comments:			

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: C-5 Date: 6/3/97
Personnel: T. Oden, R . Rosman
Location: Refer to map, woods behind house, old orchard
Soil series:

Time (auger): 1224
Quadrangle: Keyport
Sampler: corer, split spoon

Time (core): 1250
Formation: Englishtown
Weather: cloud, cool, light breeze, 50's
Hole Depth: 48"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 3/2 very dark grayish brown	medium sand; roots, clean, some white sand grains	0 - 12"
	10 YR 5/6 yellowish brown	fine medium sand; clean roots, some silt w/depth; mottled around 25" with 10 YR 6/1 + 10 YR 5/6	12 - 32"
	10 YR 6/1 light gray to gray	very silty fine sand; very silty layer grades into clay @ 49"	32 -

COMMENTS
Hole auger stop @ 50" used 3 ft corer to 2 ft; got 1 ft of recovery; used 2 ft split spoon in same hole 12" to 48"

Samples:	C5-A,	C5-E,	C5-B1,	C5-B2,	C5-CL1	Date bottled: 6/5/97
Depths:	~1 - 9	~10 - 15"	~20 - 30"	~35 - 40"	~44 - 48"	
Comments: C5-E incipent E - somewhat leached, little organic matter, grades into orangey B						

Site number: C-6 Date: 6/3/97
Personnel: T. Oden, R. Rosman
Location: Refer to map, woods behind house, old orchard
Soil series:

Time (auger): 1308
Quadrangle: Keyport
Sampler: split spoon

Time (core): 1350
Formation: Englishtown
Weather: cloudy, cool, light rain during auger
Hole Depth: 39"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 3/3 dark brown	medium grained sand; little silt, some ironstone pebbles	11 - 35"
	10 YR 5/1 gray	fine grand silty sand; grades into a clay	35 -

COMMENTS
Stopped augering @ 48"; pounded to 39"

Samples:	C6-A,	C6-B1,	C6-B2,	C6-B3	C6-CL1	Date bottled: 6/4/97
Depths:	0 - 10"	~12 - 17"	~20 - 25"	~30 - 34"	35 - 39"	
Comments: C6-B2 lots of ironstone channers						

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: H-1 Date: 6/19/97 Time (auger): 1340 Time (core): 1415
Personnel: TDO, NPS Quadrangle: Freehold Formation: Englishtown
Location: marshy woodland, Cemetery property, tributary to Deep Run Weather: mostly sunny, hot, humid
Soil series: Sampler: Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 2/1 black	root mat	0 - 2"
	10 YR 2/2 very dark brown	very fine, wet, organic, silty	2 - 16"
	10 YR 4/6 dark yellowish brown	very fine, wet, silty w/pebbles	16 - 24"
	10 YR 3/1 very dark gray	very fine sand, silty, mottling 10 YR 5/1 gray very fine sand, predominant micaceous	24" - 50"

COMMENTS
Hole collapsing, water @ ~27"; drove from 2" - 36" BLS; hole measured after sampling 15" BLS

Samples:	H1H1,	H1H2,	H1H3,	H1H4	Date bottled: 6/25/97
Depths:	~2 6"	~8 - 12"	~12 - 16"	~16 - 24"	
Comments:					

Site number: H-2 Date: 6/20/97 Time (auger): 1100 Time (core): 1220
Personnel: TDO, NPS Quadrangle: Freehold Formation: Englishtown
Location: Go into Cemetery; Make A left to dead end path enter woods in opening on right 100 ft in front of vehicle in woods follow yellow ribbon on the left. Weather: sunny, warm 80s, humid
Soil series: Sampler: Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		root mat	0 - 2"
	10 YR 3/2 very dark grayish brown	very fine silty sand; roots, very damp	2" - 5"
	10 YR 2/2 very dark brown	organic rich, fine silt minor sand; very wet, moist, no sulfur	5" - 14"
	10 YR 3/2 very dark grayish brown	medium to fine sandy silt	14" - 18"
	10 YR 6/8 brownish yellow	clay, very wet mottled with 10 YR 5/1 gray clay; some pebbles, roots	18" - 24"
	5 Y 4/1 dark gray	sandy clay, roots, wet	24 - 33"
	5 Y 4/1 dark gray	medium sand wet mottled with 10 YR 4/1	33 - 36"
	10 YR 5/1 gray	medium sand silty micaceous wet, roots	36" -

COMMENTS
Hole stopped @ 46", water @ 36"; drove 24" split-spoon from 1" to 37" BLS; hole measured 37" BLS

Samples:	H2H1,	H2H2,	H2S1	H2CL1	Date bottled: 6/25/97
Depths:	~2 - 5"	~5 - 12"	~14 - 18"	~18 - 24"	
Comments: H2S1 silty sand; H2CL1 silty clay					

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: H-3 Date: 6/20/97 Time (auger): 1340 Time (core): 1430
Personnel: NPS, TDO Quadrangle: Freehold Formation: Englishtown
Location: along embankment, farm Weather: sunny, hot, humid
Soil series: Sampler: split spoon Hole Depth: 38"

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		root mat	0 - 1"
	10 YR 3/2 very dark grayish brown	wet, silt; very minor amounts of reddish fine sand, few pebbles	1 - 18"
	5Y 2.5/2 black	wet silt	18 - 28"
	5 Y 4/1 dark gray	silt w/many pebbles, some cobbles	28 - 30"
	7.5 YR 6/8 reddish yellow	clay mottled with larger amounts of very fine sandy silt, color 5Y 5/1 gray	30" - 42"

COMMENTS
hole collapsing; water at 6" BLS; drove 2 ft split-spoon sampler from 1" - 38" BLS; hole depth 38" BLS

Samples:	H3H1	H3S1	Date bottled: 6/25/97
Depths:	~1 - 10"	~18 - 24", silty	
Comments:			

Site number: H-4 Date: 6/23/97 Time (auger): 1100 Time (core): 1150
Personnel: TDO, NPS Quadrangle: Freehold Formation: Englishtown
Location: about 160 ft from Rte 527, West side, N side of creek (Matchaponix) Weather: sunny, warm 80s, breezy
Soil series: Sampler: corer, split spoon Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 3/2 very dark grayish brown	root mat; may have been pushed down not really 7" thick very wet water table @ surface	0 - 7"
	5 Y 2.5/1 black	root hairs, wet silt; no sulfur smell, faint sulfur smell w/ depth, finer grained w/depth ~27"	7 - 48"
	buried tree branch?	woody	48 - 51"

COMMENTS
Dug out ~3" root mat; pushed 3 ft sampler to 69" BLS; retrieved 1, 1 ft liner of sediment w/core-catcher intact (tried pushing 2 ft split-spoon sampler to 50", but it came up empty)

Samples:	H4H1,	H4H2,	H4H3,	H4H4	Date bottled: 6/25/97
Depths:	~7 - 15"	~15 - 28"	~30 - 36"?	36 ~48"	
Comments:					

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: H-4 duplicate Date: 6/23/97 Time (auger): 1100 (same as H-4) Time (core): 1205
Personnel: TDO, NPS Quadrangle: Freehold Formation: Englishtown
Location: about 160ft from rte. 527, west side, N. side of Matchaponix Weather: sunny, 80s, breezy
Soil series: Sampler: corer Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)

COMMENTS
Dug out ~6" root mat, pushed 3 ft sampler to 78" BLS; retrieved 2, 1 ft liners of sediment with core-catcher intact in bottom liner

Samples:	H4DH1,	H4DH2	H4DH3,	H4DH4,	H4DH5	Date bottled: 6/25/97
Depths:	6 - 15"	15 - 25"	30 - 36"	38 - 46:	48 - 58"	
Comments:						

Site number: H-5 Date: 6/23/97 Time (auger): 1240 Time (core): 1315
Personnel: TDO, NPS Quadrangle: Freehold Formation: Englishtown
Location: about 30 ft from rte 527, west side, north side of Matchaponix Brook Weather: sunny, 80s, breezy
Soil series: Sampler: corer Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
		root mat; water table close to land surface	0 - 2"
	5 Y 2.5/1 black	wet silt; some root hairs to ~12"	2 - 28"
	5 YR 2.5/1 black	silt; hole collapsing	28 - 32"
	5 Y 2.5/1 black	silt; hole still collapsing	32- 60"

COMMENTS
Pushed 3 ft sampler from 3" BLS to 51" BLS, retrieved; 1, 1 ft core liner with about 7" sediment

Samples:	H5S1,	H5H1	Date bottled: 6/25/97
Depths:	~0 - 22"	~25 - 35"	
Comments:			

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Project: Imperial Oil/Texas Road site
SOIL SAMPLING FIELD SHEET

Site number: H-6 Date: 8/7/97 Time (auger): 0930 Time (core): 1005
Personnel: NPS Quadrangle: Freehold Formation: Englishtown
Location: end of Victory Dr., East side stream (Weamaconk) Weather: sunny, 60s
Soil series: Sampler: corer Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 4/3 brown	silt; many fine roots; water @ 5" BLS	0 -6"
	5Y 2.5/1 black	silt; fewer, finer roots; sulfur smell	6 - 13"
	5Y 2.5/1 black	fine-medium sand; sulfur smell	13 - 40"

COMMENTS
drove 3 ft sampler 36" BLS; bottom section of sampler; full, middle section contains about 3".

Samples:	H6S1,	H6H1,	H6H2,	H6H3	Date bottled: 8/11/97
Depths:	0 - 6",	6 - 13",	~13 - 21",	~21 - 30"	
Comments:					

Site number: H-7 Date: 8/7/97 Time (auger): 1105 Time (core): 1200
Personnel: NPS Quadrangle: Freehold Formation: Englishtown
Location: behind 2nd + 3rd houses from Birmingham Dr. cul-de-sac about 100 ft from stream, small clearing in woods Weather: sunny, 70s
Soil series: Sampler: split spoon Hole Depth:

DESCRIPTION			
Horizon/ Stratum	Color	Texture	Thickness (in inches)
	10 YR 3/3 dark brown	fine sandy silt; some organic matter	0 - 9"
	5 YR 2.5/1 black	fine sandy silt; sulfur smell	9 - 19"
	10 YR 3/1 very dark gray	fine sandy silt	19 - 31"
	5 Y 2.5/2 black	fine-medium sand; many pebbles, mostly rounded; hole collapsing, water @ 27"	31 - 38"

COMMENTS
drove 2 ft split-spoon sampler to 35" BLS; hole measured after withdrawal 32" BLS

Samples:	H7H1,	H7H2	H7H3	H7H4	Date bottled: 8/11/97
Depths:	~0 - 9"	~9 - 19"	~22 - 30"	~30 - 35"	
Comments: H7H3 H7 H4 grains of pyrite visible! lots in H4					

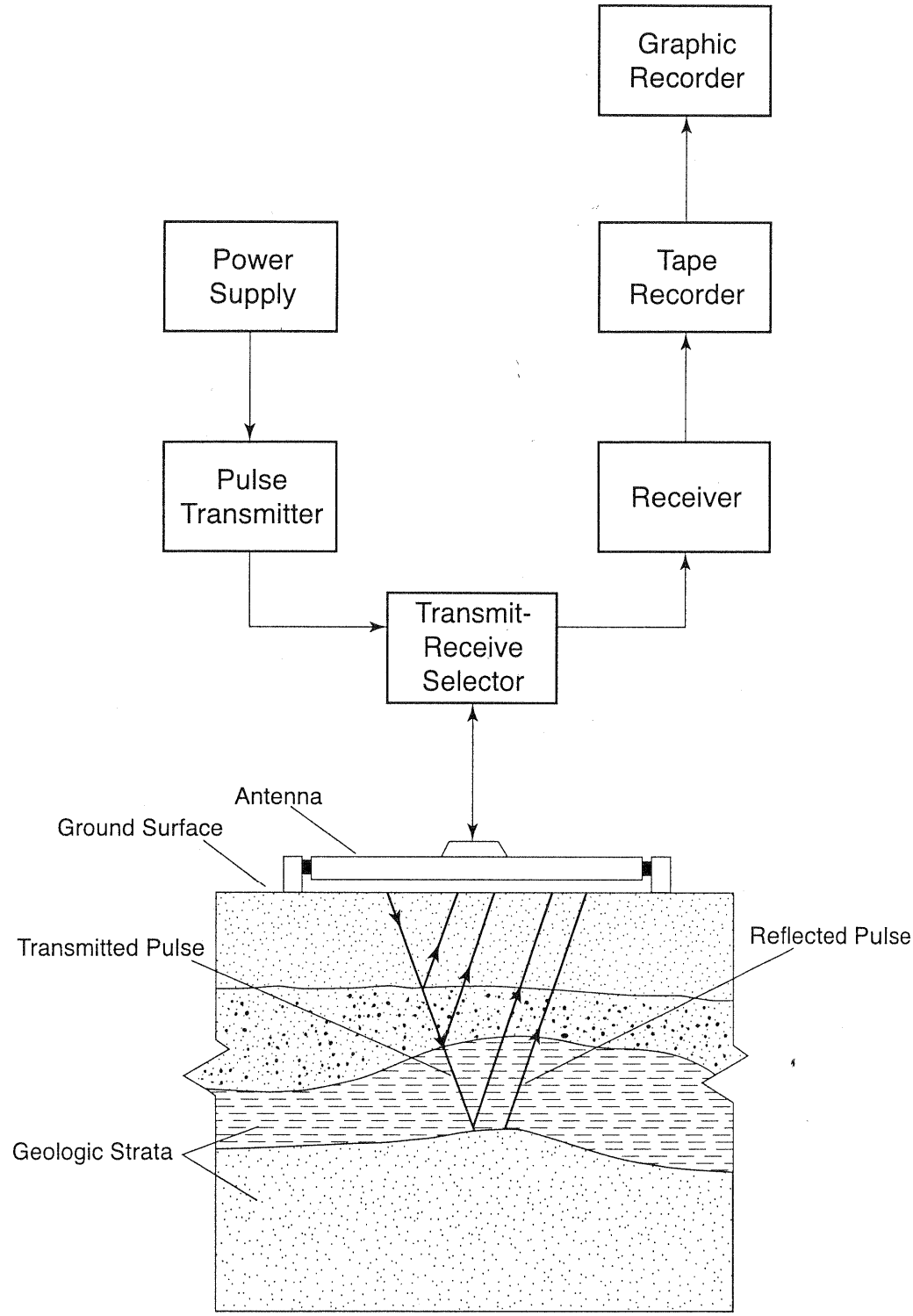
APPENDIX 3. GROUND-PENETRATING-RADAR SURVEY EXPLANATION AND RESULTS

Theory and Practice

Short pulses of long-wavelength electromagnetic energy are emitted by the transmitting antenna of a ground-penetrating-radar (GPR) system. The energy, which enters the subsurface, is partially reflected back to the antenna when inhomogeneities, such as the water table, changes in geologic strata, cross-bedding, or other depositional features in the subsurface are encountered. Some of the energy is transmitted to deeper layers. The inhomogeneities that act as partial reflectors are caused by degree of saturation, clay content, or other compositional changes in subsurface materials. Anthropogenic materials such as buried drums also act as reflectors. Typically, clay layers reflect virtually all of the energy back to the antenna, permitting little or no penetration of the radar waves beyond the clay surface.

A diagram of a typical GPR system is shown in figure 1. The total travel time for a signal to pass through the subsurface, reflect from inhomogeneities, and return to the antenna at land surface is recorded in nanoseconds (10^{-9} seconds). The two-way travel time is converted to depth below land surface when the relative dielectric permittivity of the subsurface material is known; this can be calculated from a control point.

The results of the GPR survey--printouts of the radar signals and the interpretations originally traced on mylar overlays--are shown in figures 2-6. Results from transect 6 are not shown because no significant subsurface features were evident, and results from transect 7 also are not shown because no signal was detected, owing to the clay fill underlying the transect.



NOT TO SCALE

Figure 1. Diagram of a ground-penetrating-radar system. (Modified from Haeni and others, 1987, fig. 3)

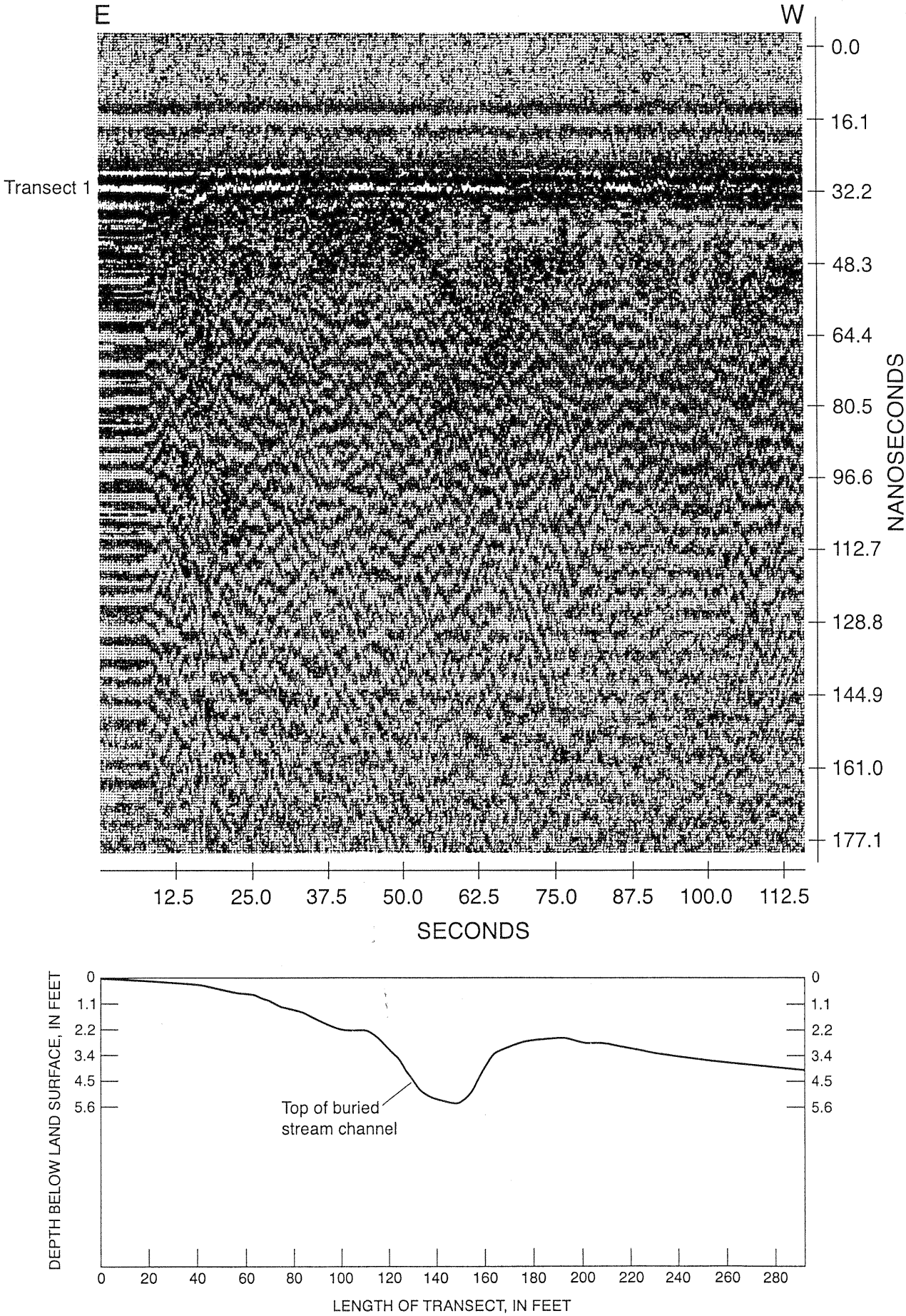
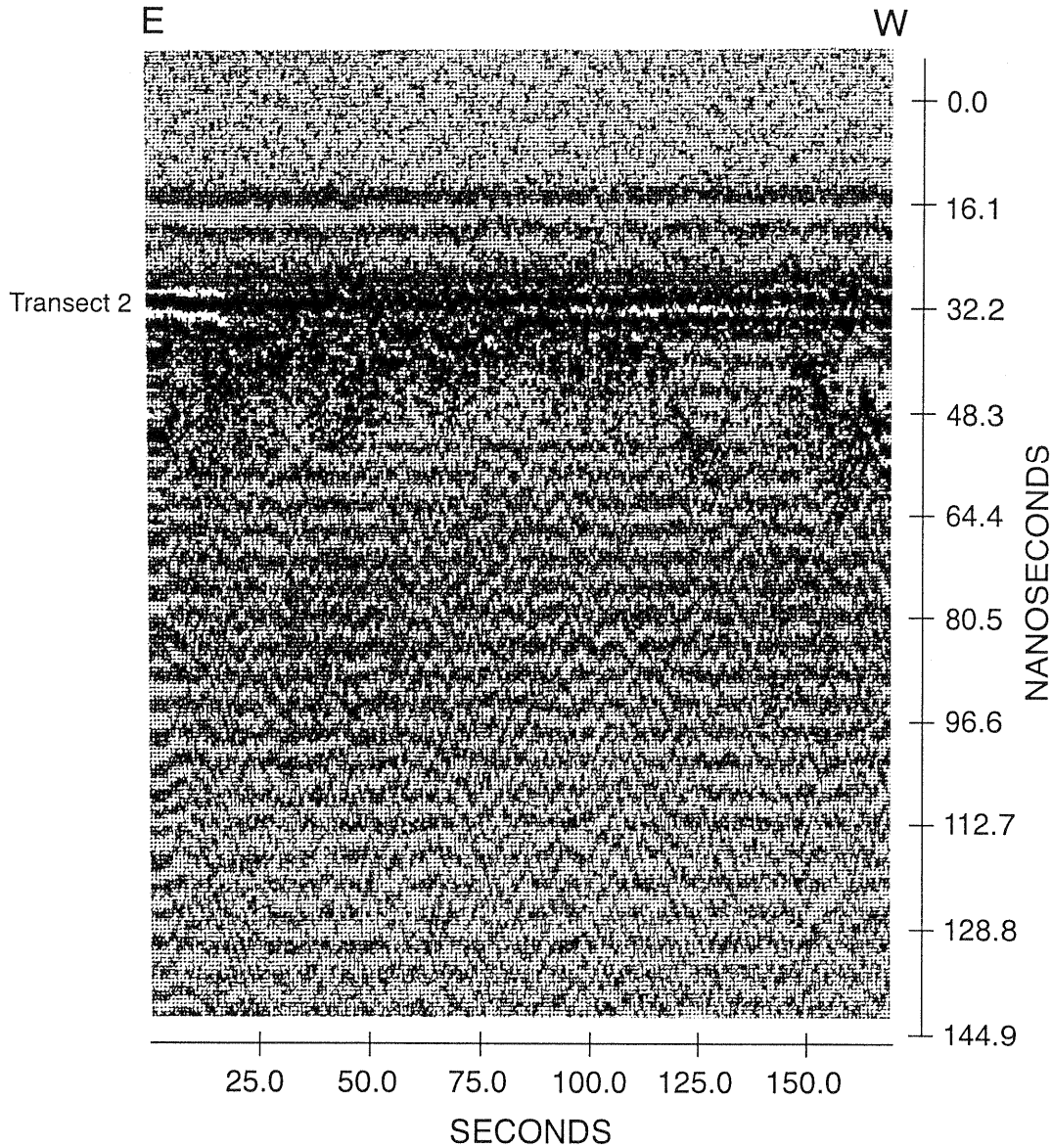


Figure 2. Ground-penetrating-radar printout of signal, and interpretation of results, Transect 1.



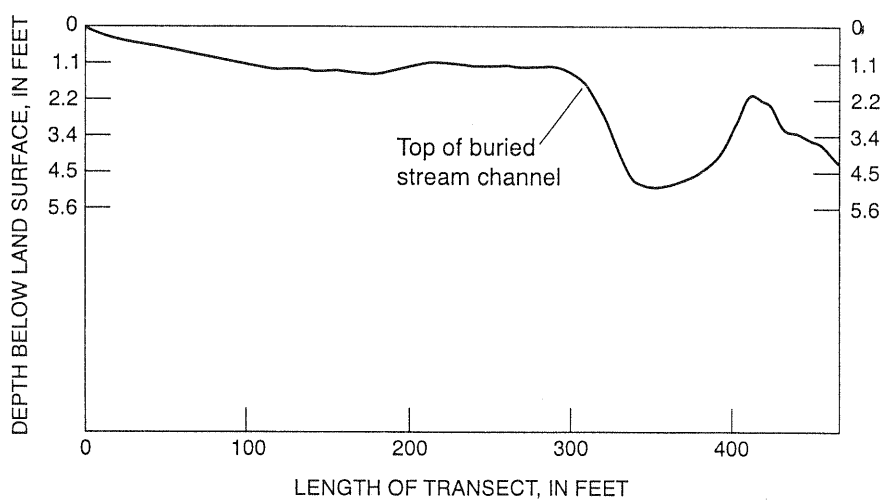


Figure 3. Ground-penetrating-radar printout of signal, and interpretation of results, Transect 2.

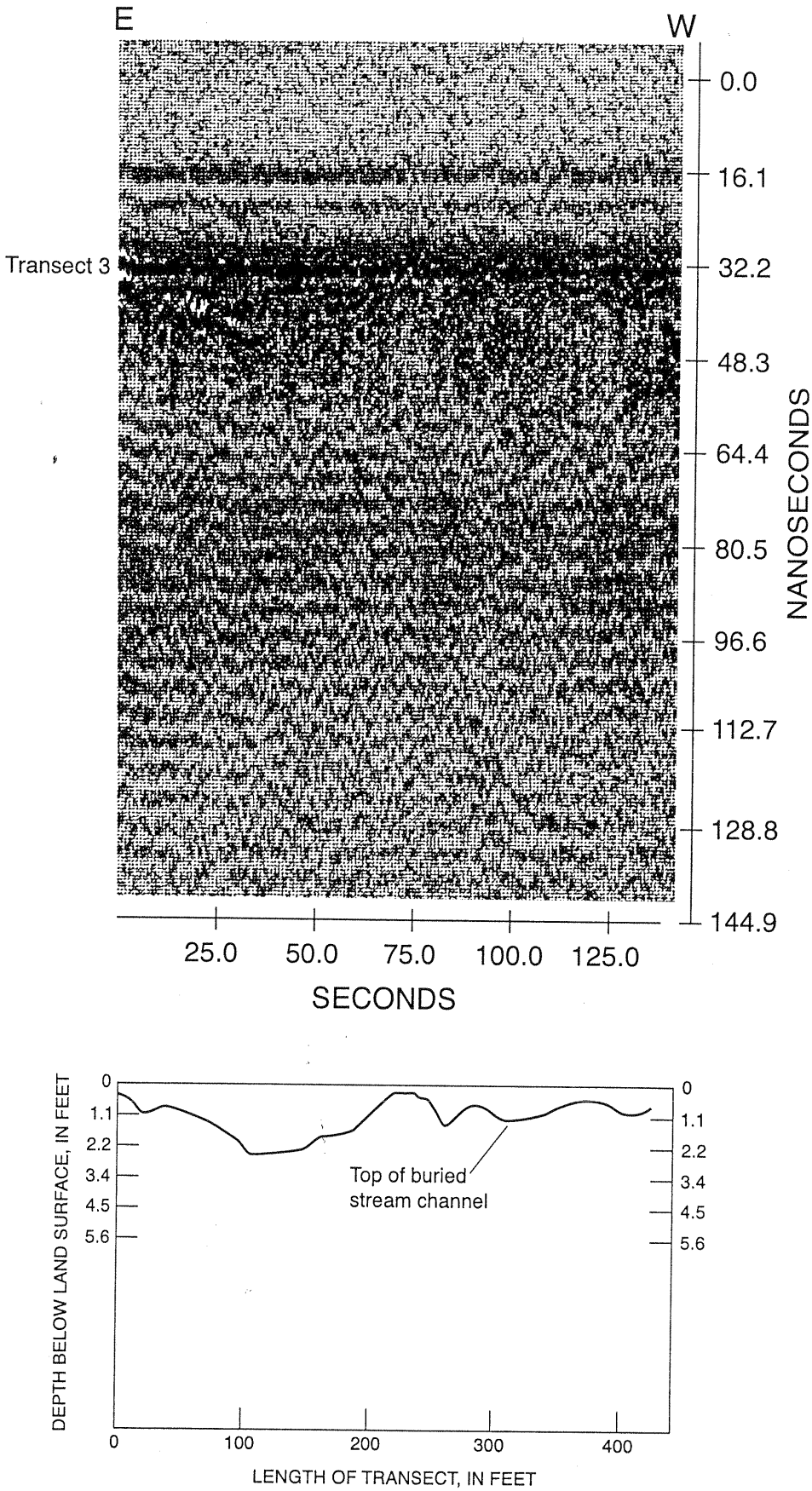
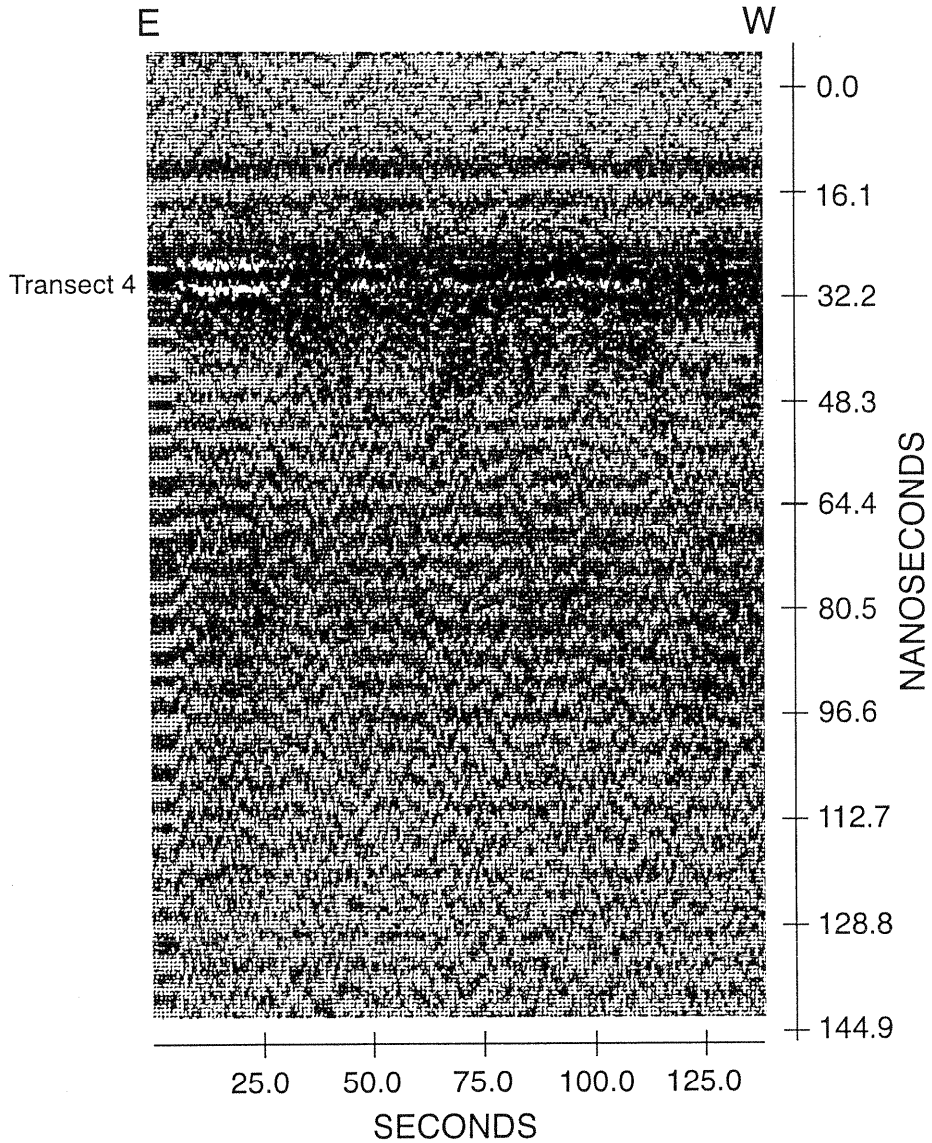


Figure 4. Ground-penetrating-radar printout of signal, and interpretation of results, Transect 3.



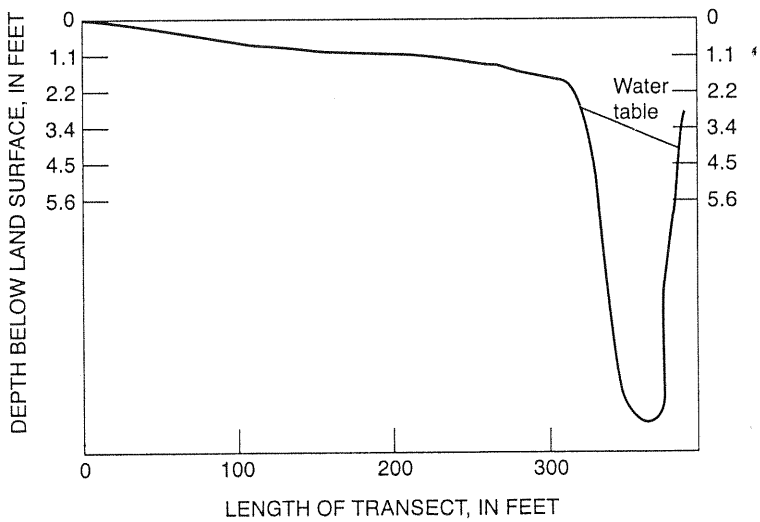


Figure 5. Ground-penetrating-radar printout of signal, and interpretation of results, Transect 4.

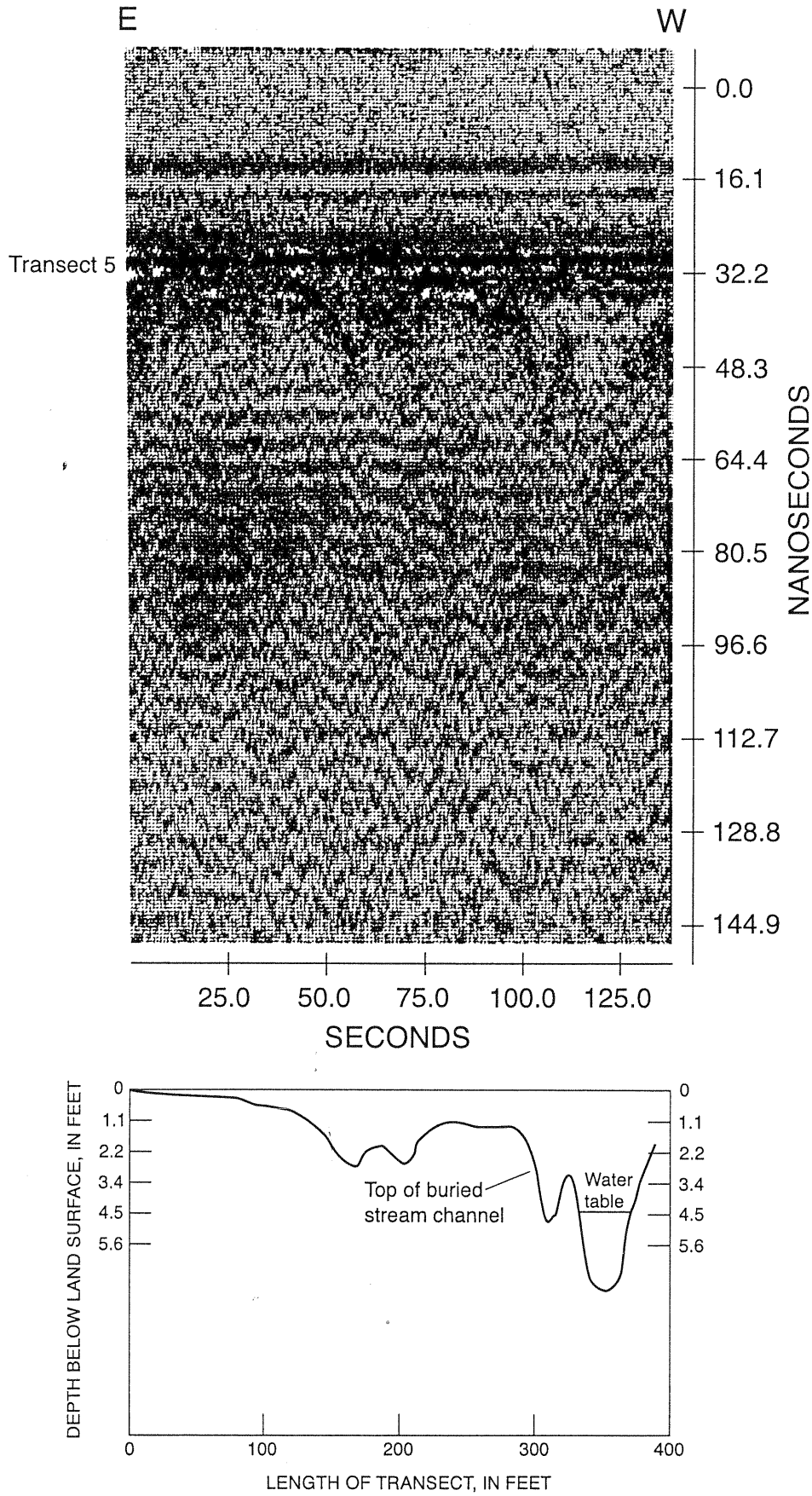


Figure 6. Ground-penetrating-radar printout of signal, and interpretation of results, Transect 5.

APPENDIX 4. LEAD-210 ACTIVITY DATA

Table 1. Lead-210 activity in humaquept soils at different depth increments, cores 1 and 2, Texas Road site, Monmouth County, New Jersey

[cm, centimeters; Pb, lead; dpm/g, disintegrations per minute per gram; nc, sample lost in preparation; bg, not analyzed as considered background; pt., point]

Core number	Depth (cm)	Center pt. depth (cm)	Total Pb-210 activity (dpm/g)	Total Pb-210 activity error (+/-)
1	0-2	1	6.37	0.126
1	2-4	3	8.69	0.281
1	4-6	5	7.97	0.274
1	6-8	7	5.73	0.154
1	8-10	9	3.31	0.082
1	10-12	11	2.62	0.077
1	12-14	13	1.96	0.059
1	14-16	15	1.75	0.050
1	16-18	17	1.62	0.029
1	18-20	19	1.75	0.033
1	18-20	19	1.61	0.022
1	20-22	21	nc	nc
1	22-24	23	2.11	0.039
1	24-26	25	2.30	0.060
1	26-28	27	nc	nc
1	28-30	29	nc	nc
1	30-32	31	nc	nc
1	32-34	33	nc	nc
1	34-36	35	1.26	0.053
1	36-38	37	1.36	0.042
1	38-40	39	1.75	0.080
1	40-42	41	1.68	0.041
1	42-44	43	1.49	0.040
1	44-46	45	1.46	0.053
1	46-48	47	1.72	0.037
1	48-50	49	1.39	0.016
1	50-52	51	bg	bg
1	52-54	53	bg	bg
1	54-56	55	bg	bg
1	56-58	57	bg	bg
1	58-60	59	bg	bg

Core number	Depth (cm)	Center pt. depth (cm)	Total Pb-210 activity (dpm/g)	Total Pb-210 activity error (+/-)
2	Top	0	2.87	0.039
2	0-2	1	2.14	0.044
2	2-4	3	1.29	0.024
2	4-6	5	0.58	0.015
2	6-8	7	0.49	0.011
2	8-10	9	0.45	0.011
2	10-12	11	0.58	0.013
2	12-14	13	0.40	0.011
2	14-16	15	0.55	0.019
2	16-18	17	nc	nc
2	18-20	19	0.44	0.015
2	20-22	21	0.69	0.021
2	22-24	23	0.65	0.016
2	24-26	25	0.29	0.008
2	26-28	27	0.22	0.004
2	28-30	29	0.16	0.002
2	28-30	29	0.16	0.005
2	30-32	31	0.13	0.003
2	32-34	33	0.11	0.003
2	34-36	35	bg	bg
2	36-38	37	bg	bg
2	38-40	39	bg	bg
2	40-42	41	bg	bg
2	42-44	43	bg	bg
2	44-46	45	bg	bg
2	46-48	47	bg	bg
2	48-50	49	bg	bg
2	50-52	51	bg	bg
2	52-54	53	bg	bg
2	54-56	55	bg	bg