U.S. Department of the Interior
U.S. Geological Survey

ARSENIC AND METALS IN SOILS IN THE VICINITY OF THE IMPERIAL OIL COMPANY SUPERFUND SITE, MARLBORO TOWNSHIP, MONMOUTH COUNTY, NEW JERSEY

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 98-4016

Prepared in cooperation with the

U.S. ENVIRONMENTAL PROTECTION AGENCY and the

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USGS
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By Julia L. Barringer, Zoltan Szabo, and Thomas H. Barringer

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Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare
square foot (ft^2)	0.09294	square meter
	Volume	
ounce, fluid (fl. oz)	29.57	milliliter (mL)
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter
quart (qt)	0.9464	liter
gallon (gal)	3.785	liter
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
ounce, avoirdupois (oz)	28,350	milligram (mg)
ounce, avoirdupois (oz)	28,350,000	microgram (µg)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)

Vertical Datum

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

g/s	- grams per second
µg/s	- micrograms per second
m/s	- meters per second
mg/kg	- milligrams per kilogram
µg/kg	- micrograms per kilogram
mg/m^2	- milligrams per square meter
ppm	- parts per million (equivalent to mg/kg)

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS--Continued

Al - aluminum
As - arsenic
Ba - barium
Ca - calcium
Cr - chromium
Cu - copper
Fe - iron
H - hydrogen
K - potassium
Mg -magnesium
Mn -manganese
Ni - nickel
O - oxygen
Pb - lead
S - sulfur
TOC - total organic carbon
V - vanadium
Zn - zinc

ARSENIC AND METALS IN SOILS IN THE VICINITY OF THE IMPERIAL OIL COMPANY SUPERFUND SITE, MARLBORO TOWNSHIP, MONMOUTH COUNTY, NEW JERSEY

Julia L. Barringer, Zoltan Szabo, and Thomas H. Barringer

ABSTRACT

Concentrations of arsenic exceed the New Jersey State Cleanup Criterion of 20 parts per million in sandy and clay-rich soils of two residential areas in the vicinity of the Imperial Oil Company Superfund site in Marlboro Township, Monmouth County, New Jersey. Industrial activities at this Superfund site included possible roasting of arsenical ores and the production of arsenical pesticides from about 1917 to 1945; arsenic concentrations that greatly exceed 20 parts per million have been measured in soils at the Superfund site. Although the Imperial Oil Company Superfund site potentially is a source of the arsenic found in the soils of nearby residential areas, identification of the source is complicated by the presence of minerals in the geologic substrate that can contain arsenic, and possible past use of arsenical pesticides in the orchards upon which the residential areas were built. Residential area 1 is adjacent to the Superfund site; residential area 2 is 0.5 mile to the north-northeast and was developed on former orchard land.

In order to determine the source of the arsenic and metals in soils in the two residential areas, soil samples were collected from (1) long-term forested areas, to determine background geologic and regional atmospheric inputs of arsenic and metals; (2) former and current orchards, to assess the range of concentrations of arsenic and metals that could be contributed by past use of pesticides; (3) the Imperial Oil Company Superfund site, to characterize the chemical composition of contamination from activities at the site; (4) a wooded area adjacent to the Superfund site, to determine whether arsenic and metals from the Superfund site were evident; and (5) the two residential areas, to compare soil chemistry in these areas with the chemistry of soils from forests, orchards, and the Superfund site.

The soil samples were divided by soil horizon and were analyzed for 23 metals and metalloids, total organic carbon, and total sulfur. Results of chemical analyses were stratified by horizon and analyzed statistically to compare data sets among land uses. A chemical signature for A-horizon soils in each "endmember" land-use group (undeveloped, geologic and regional atmospheric input; orchard, pesticide input; and Imperial Oil Company Superfund site, industrial input) was developed by using graphical methods and multivariate statistical procedures. Additionally, air-flow models were used to determine whether roasting of arsenic at the Imperial Oil Company Superfund site was a possible source of arsenic in the soils.

The precision and accuracy of the soil analyses achieved by the laboratories did not meet the low analytical uncertainty required in the workplan developed at the beginning of the study, and analytical difficulties prevented use of data for a few analytes. Nor was it possible to collect undisturbed, contaminated soil samples from the Imperial Oil Company Superfund site, as specified in the workplan. Nevertheless, despite these modifications to the workplan, the chemistry of

soils from the various land-use groups was sufficiently different that groups of samples could be statistically distinguished from each other on the basis of chemistry, and representative samples of soil horizons from the disturbed soils at the Imperial Oil Company Superfund site could be identified. Therefore, it was possible to identify background concentrations of arsenic, lead, and other metals, orchard inputs of the same metallic substances, and effects of former industrial activities at the Imperial Oil Company Superfund site on residential soils, where these existed.

Results of the analyses of soils from undeveloped forested areas indicated that background (geologic and regional atmospheric) concentrations of arsenic generally are small (less than 10 parts per million (or mg/kg (milligrams per kilogram)) in sandy soils but concentrations up to about 40 mg/kg were measured in clays. Sandy orchard soils contained more arsenic (median 12 mg/kg) than did sandy undeveloped forest soils (median 5 mg/kg). Arsenic concentrations in soil samples collected in the wooded area adjacent to the Imperial Oil Company Superfund site were found to be within the range measured for undeveloped forested areas, although the median value for soils from the A horizon was slightly higher than the median for background concentrations in A-horizon soils. Soil samples collected at the Superfund site as part of the study reported here generally contained elevated concentrations of arsenic, barium, copper, and lead (up to 114, 106, 167, and 284 mg/kg, respectively); concentrations of these constituents in previously collected soil samples also were highly elevated.

The chemical signature of A-horizon soil samples from residential area 1, although similar, overall, to the signature of orchard soils, showed similarities to the chemical signature of soils at the Imperial Oil Company Superfund site in that concentrations of barium and copper were large. The chemical signature of A-horizon soil samples from residential area 2 also was statistically similar to the chemical signature of A-horizon soil samples from orchards. Results of the air-flow simulations indicated that emissions from smokestacks at the Imperial Oil Company Superfund site are unlikely to have deposited arsenic as fallout on soils at residential area 2. Soil samples from residential area 1, adjacent to the Imperial Oil Company Superfund site, contained cinders and brick debris similar to that found onsite. The results of the investigation indicate that arsenic concentrations above background in upper soil horizons in residential area 2 probably are the result of former pesticide use and that arsenic also is contributed by geologic materials, whereas elevated arsenic concentrations in residential area 1 soils adjacent to the Imperial Oil Company Superfund site appear to be related in part to earth-moving activities at the site.

INTRODUCTION

Concentrations of arsenic that exceed the New Jersey State Cleanup Criterion of 20 ppm (mg/kg) (New Jersey Department of Environmental Protection, 1996) have been measured in sandy Coastal Plain soils of residential areas in the vicinity of the Imperial Oil Company Superfund site (IOC)[1] in Marlboro Township, Monmouth County, New Jersey (fig. 1). The early history of industrial activities at IOC included the manufacture of arsenical pesticides, which may have involved roasting of arsenical ores, from about 1917 to 1945. Past activities at IOC thus represent

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[1] Any reference to the Imperial Oil Company Superfund site or the abbreviation (IOC) is solely for purposes of identification of the Superfund site and does not impute any responsibility for contamination to Imperial Oil Company, the current tenant of the site.

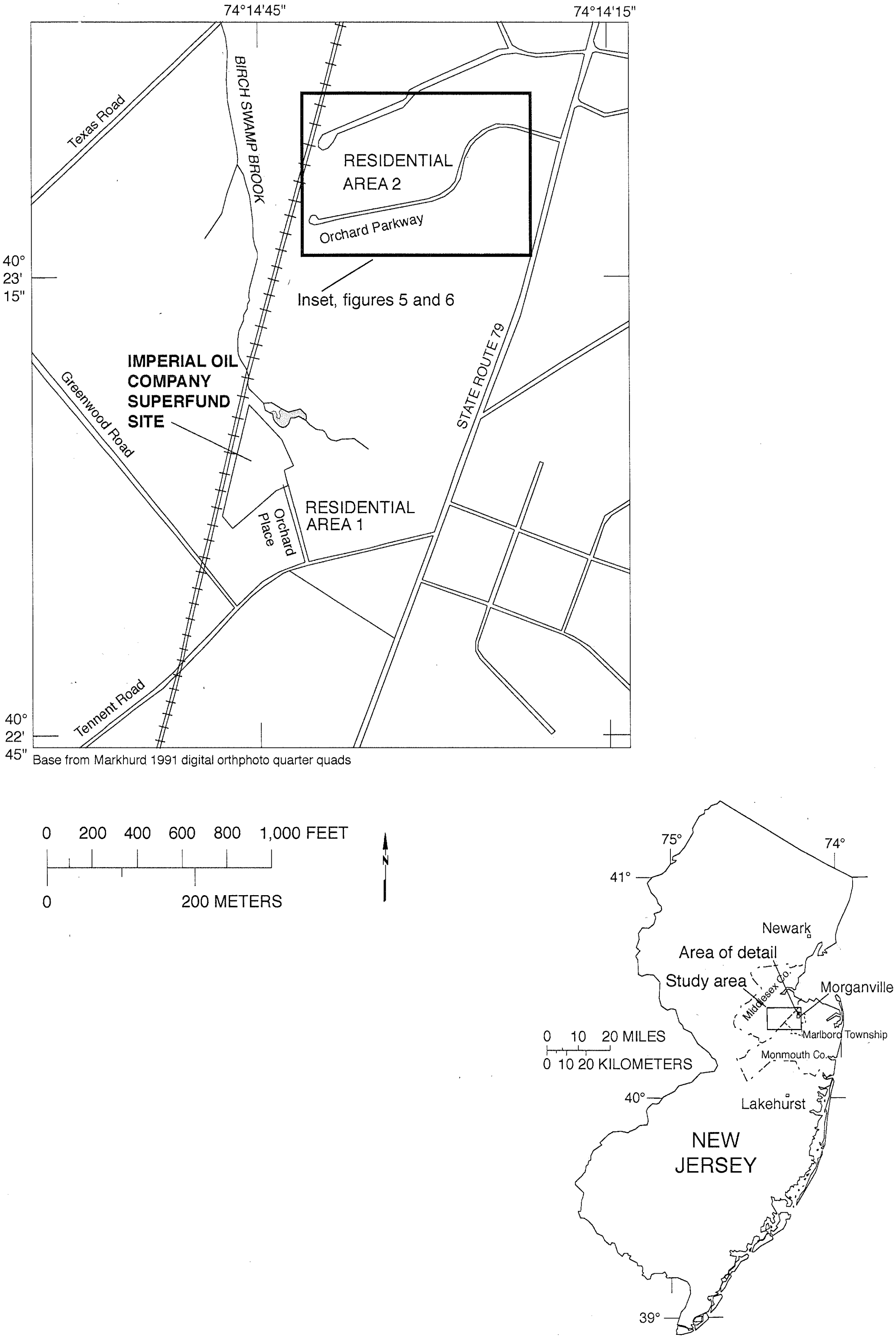

Figure 1. Location of Imperial Oil Company Superfund site and nearby residential areas, Marlboro Township, Monmouth County, New Jersey.

a possible source of the arsenic found in the residential soil. Additionally, parts of the residential areas were built on former orchard land where arsenical pesticides may have been used, and the underlying geologic substrate of the Englishtown Formation may include minerals that contain arsenic. The presence of multiple possible sources of arsenic complicates the identification of the actual source or sources of the elevated arsenic concentrations, and adds complexity to decisions regarding remediation efforts.

In August 1995, the U.S. Geological Survey (USGS) designed a study of the possible sources of arsenic and of metals such as lead, also found in elevated concentrations in the soils, for the U.S. Environmental Protection Agency (USEPA). The study was conducted for the USEPA by the USGS, with the assistance of the New Jersey Department of Environmental Protection (NJDEP), beginning in October 1995.

The overall purpose of the study was to determine the source or sources of arsenic and metals that occur in elevated concentrations in the soils of the residential areas adjacent to and north of IOC. The study had three specific objectives: (1) to determine "background" (geologic and regional atmospheric) concentrations of arsenic and metals in area soils; (2) to assess the range of concentrations of arsenic and metals that could be introduced to area soils by possible emanations from IOC, either as smokestack fallout or from dumping of wastes, and by pesticide applications in an agricultural setting; and (3) to determine "chemical signatures" of soils from different land uses for comparison with chemical signatures of soils from the residential areas.

The results of the investigation are presented in this report. These include results of identification, sampling, and chemical and mineralogical analysis of soils developed on the Englishtown and Woodbury Formations from (1) 17 sites in long-term forested areas where background concentrations of arsenic, lead, and other metals could be measured; (2) 15 sites in former or current orchards where agricultural contributions of arsenic, lead, and other metals to soils could be determined; and (3) 8 sites at IOC and 17 sites in the woods adjacent to IOC, where alterations to soil chemistry from industrial activities could be determined. Results of analyses of soils from 29 sites in residential areas adjacent to and near IOC also are presented, and chemical characteristics of residential, industrial, orchard, and background soils are compared. Additionally, results of airflow modeling, used to determine the possible extent of deposition from a smokestack plume, are presented and discussed.

Acknowledgments

The authors gratefully acknowledge Trevor Anderson of USEPA and Joseph Maher, project manager at NJDEP, for their assistance. NJDEP staff Steven Byrnes and John Evenson worked closely with the authors in collecting and shipping samples; Chad Van Sciver of NJDEP also assisted in sample collection. Mindy Mumford of NJDEP gave invaluable assistance in obtaining permission from landowners to sample soils. The authors thank Kathleen Grimes, Winnie Chu, Joseph Sanguiliano, and Gregory Toffoli of NJDEP for validating the analytical data. Kevin Schick, William Lowery, Paul Zarillo, and Thomas Cozzi of NJDEP also assisted the authors. Peter Sugarman of the New Jersey Geological Survey (NJGS) gave unstintingly of his time and knowledge of area geology.Thanks are due to John Dooley and Frederick L. Muller of NJGS, who performed the mineral analyses, and to Paul Lamothe of the USGS, who coordinated the total-sulfur analyses. The authors also acknowledge Joann Held and Robert Huizer of NJDEP for constructing the dry-deposition simulation model. Dennis Dunn of the Sachs Group provided advice on statistical analyses.

The authors thank their USGS colleagues Nicholas Smith, Robert Rosman, and Timothy Oden for collecting the soil samples. Thanks are also due to Donald Rice and William Ellis, USGS, for GIS and cartographic work, and to Vincent DePaul, who helped with field work and illustrations. The authors are grateful to Timothy Wilson and Eric Vowinkel, also of USGS, for help and advice throughout the course of the project, and to Dale Simmons, Ruth Larkins, Ingrid Heerwagen, and Melicia Morgan for their work on the final report.

The authors thank Elizabeth Poulsen of the Burnt Fly Bog/Imperial Oil Citizens' Action Committee for assistance in obtaining access for soil sampling, and Lester Jargowski, Monmouth County Health Department, for supplying valuable background information on the area. Finally, the authors extend their gratitude to the property owners who allowed us access to their property for soil sampling.

Historical Background

Past land use in Marlboro Township can be determined from aerial photographs taken over the past 60 years. Although the general character of the industrial activities at the site of IOC is known, many details are not readily available or have never been recorded; therefore, the depth of historical information about activities at IOC and in the surrounding area is limited.

Discovery of Arsenic Contamination of Soils

As part of the routine investigation of contamination at IOC, 16 samples of soils from several nearby residences were collected during 1994-95 by the contractor for NJDEP. Some of the soil samples were found to contain elevated concentrations of arsenic and (or) lead, and metals such as beryllium, cadmium, and mercury were present in measurable concentrations in several samples (L. Robert Kimball and Associates, 1995). Subsequent sampling of soils in 1995 by NJDEP at residences next to IOC (residential area 1) and about 0.5 mi north-northeast of IOC (residential area 2) confirmed earlier findings and revealed a more widespread pattern of elevated arsenic and lead concentrations. Arsenic concentrations in the residential areas in samples from the upper 6 in. of soil range from 1.2 to 220 mg/kg (Steven Byrnes, New Jersey Department of Environmental Protection, written commun., 1995); lead concentrations ranged from 7.0 to 417 mg/kg. Arsenic and lead concentrations as large as 92 and 836 mg/kg, respectively, were measured in samples from depths of 12 to 18 in.

Past Activities at the Imperial Oil Company Site

Industrial activities at the IOC location, the active part of which consists of about 4.2 acres, began in 1912 when the original buildings were constructed. Tomato ketchup and paste were produced at the site until 1917, when Stratford Chemical Company[2] began producing

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[2] Use of company names is for identification purposes only, and does not impute responsibility for contamination to the companies identified.

arsenic acid and calcium arsenate (E.C. Jordan Co., 1992). Calcium arsenate is a pesticide formerly used on some vegetable crops and on cotton crops until recently, and arsenic acid was used as a desiccant for cotton bolls before harvesting. Arsenical copper ores are believed to have been roasted at the site (Steven Byrnes, oral commun., 1995), and two ovens with smokestacks about 30 ft high still exist as part of the original brick buildings. As a result of later modifications by Imperial Oil Company, the ovens are not accessible at this time.

The company name was changed to Brocker Chemical Company in the 1930's. Production of arsenical compounds continued until about 1945, when the bankrupt Brocker Chemical Company sold the site to S.B. Penick and Company, which manufactured flavors and essences until 1949 (E.C. Jordan Co., 1992).

Subsequent industrial activities involved oil reclamation operations and oil blending. Champion Chemical Company bought the property in about 1950 and began to reclaim used motor oil. The process included washing used oil with caustics, distilling it, and clarifying the distilled oil in large holding tanks with a filter clay (diatomaceous earth). Information gathered during a remedial investigation by E.C. Jordan Co. indicates that waste washwater was discharged to a lagoon onsite and was also used to oil local dirt roads. The waste filter clay was both piled onsite and removed to a local dump; oil-contaminated soil also was disposed of onsite (E. C. Jordan Co., 1992).

In 1969, Imperial Oil Company leased the site from Champion Chemical Company and has conducted an oil-blending operation there since that time. The site was added to USEPA's National Priorities List of hazardous-waste sites in 1982, and currently includes an offsite area where industrial wastes apparently accumulated in a wooded wetlands area northwest of the active part of the site (E. C. Jordan Co., 1992).

Former Land Use in the Study Area

Undeveloped Forested and Agricultural Areas

The sandy soils and forests of the Pine Barrens in the New Jersey Coastal Plain were considered suitable for grazing cattle and for lumbering in the late 17th century (Wacker, 1979). The study area, which lies partly within the area defined as the Pine Barrens (McCormick and Forman, 1979), is likely to have been grazed and extensively lumbered during the 18th century, and some areas probably were farmed during the 18th and 19th centuries; thus, forested areas in the early 20th century are unlikely to represent virgin forest.

Agriculture in the study area was devoted largely to general farm crops throughout most of the 19th century. The sandiest soils are best suited to vegetables such as asparagus (Jennings and others, 1916), and potatoes were an important crop during the 19th and early 20th centuries (Lee and Tine, 1932). In the early 20th century, vegetable growing was the dominant form of agriculture, and fruit growing had "not been developed to that point where careful attention is given to the selection of orchard sites" (Jennings and others, 1916, p. 12). In the next decade, however, fruit growing apparently increased in the area, as Lee and Tine (1932, p. 13), writing in 1927, state that "The production of fruit, mainly apples with some peaches, is of considerable importance in the...area." Thus, the extensive orchards shown in the 1932 aerial photographs (shown in figure 2 as a geographic information system (GIS) coverage prepared from those photographs) probably had been developed largely during the previous 15 years. After World War II, residential development of former agricultural land began throughout much of New Jersey, and, by the mid-1950's, some of the orchards near IOC were being converted to housing developments. Residential and commercial development has continued in the area to the present (1997). A few active orchards can still be found several miles west of IOC in Monmouth and Middlesex Counties.

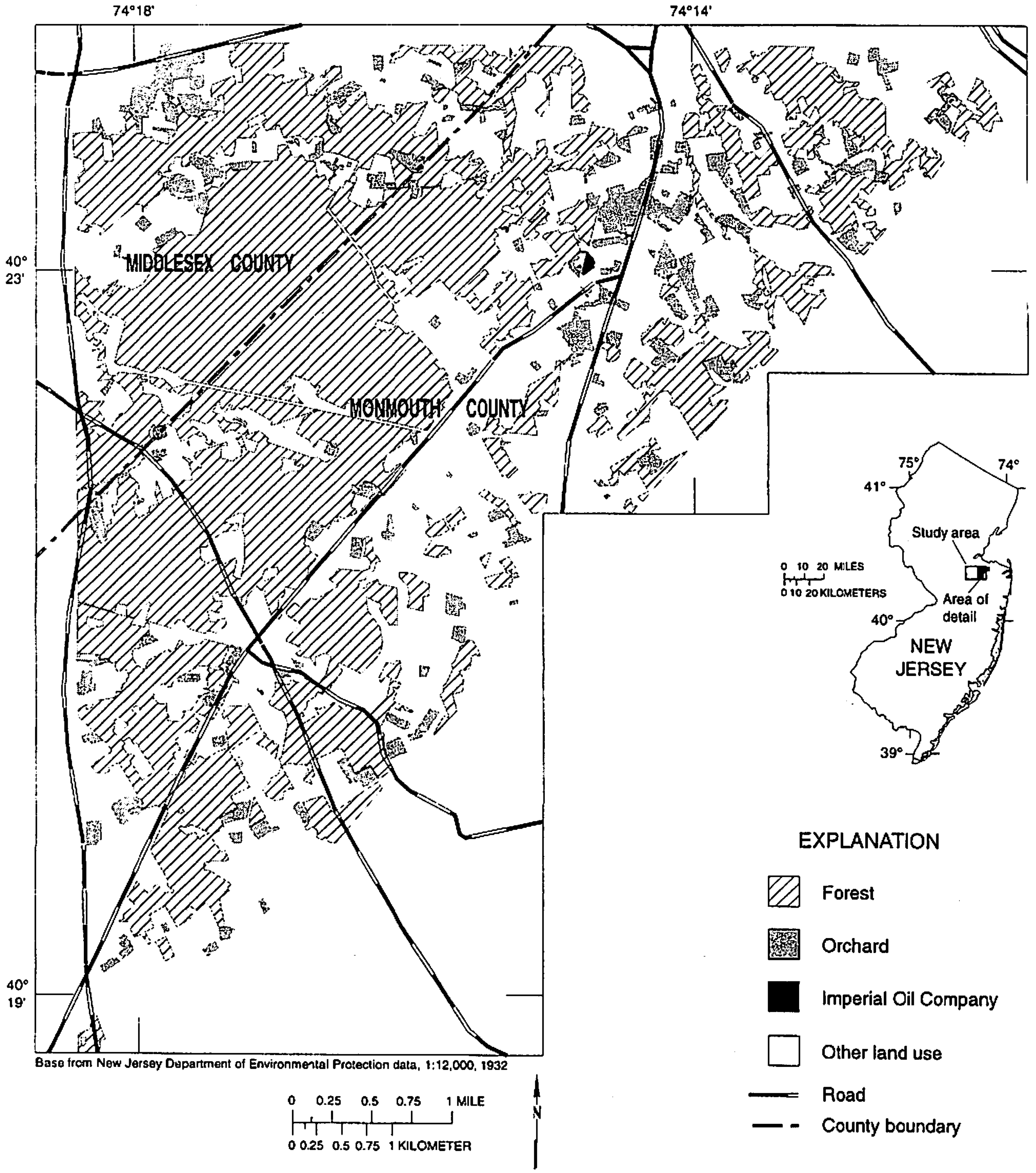
Mature forested land shown in aerial photographs from 1932 (see fig. 2) would be likely to contain trees that are at least 30 to 40 years old and, thus, if formerly cleared, represents reforestation from the late 19th century or earlier. In an 1899 assessment of forests Vermeule (1900, p. 18) reports that "Monmouth, Mercer, and all counties farther north excepting Sussex, show stationary forest area after 1860" which, according to Vermeule (1900, pl. III), would have been 10 to 20 percent forest in the immediate area of IOC and 40 to 60 percent forest to the west. Most of the land clearing for agriculture at the turn of the century was taking place in the counties south of Monmouth and Mercer (Vermeule, 1900). Thus, most of the forested land in the study area identified in aerial photographs taken in 1932 probably has been forested since 1900 or earlier.

Whether arsenical compounds were used on the vegetable crops that were dominant in the agricultural parts of the study area during the 19th century cannot be deciphered from former-land-use information. Use of inorganic arsenical compounds as insecticides dates to the late 17th century, and Paris Green ($C_4H_6As_6Cu_4O_{16}$) was used in the mid-19th century in the eastern United States to control the Colorado potato beetle (Walsh and Keeney, 1975). In addition to the use of arsenicals as pesticides, several studies in the 1920's and 1930's indicated that small amounts of arsenic acted as a growth stimulant for various vegetable and grain crops (Woolson and others, 1971). Lead arsenate, the current formulations of which were developed at the end of the 19th century, was used primarily as a pesticide spray on orchard fruits during the first half of the 20th century; larger amounts were used on apples than on peaches.

Residential Area 1

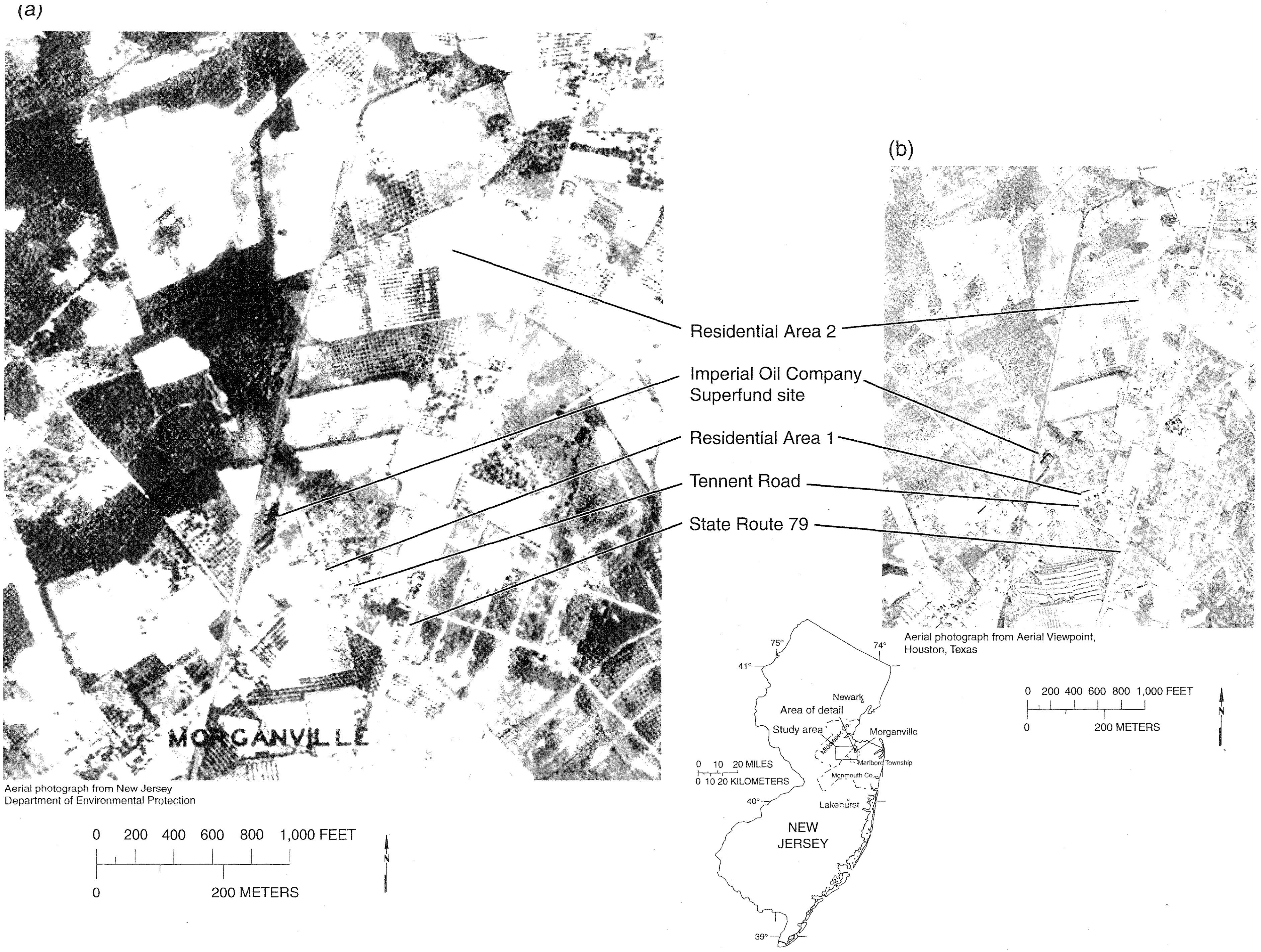
The houses of residential area 1 were built on farmland adjacent to the lot on which the original buildings at IOC are visible in an aerial photograph from 1932 (fig. 3a). A rectangular patch of orchard is present about 400 to 500 ft east of the properties that front Orchard Place, which runs from Tennent Road to the gates at IOC. Fragments of orchard may be present at the rear of some of the properties on Orchard Place in the 1932 photograph; they are not visible in the 1940 aerial photograph (fig. 3b), although the orchard to the east, in an area that is now a parking lot, is visible. Two large, apparently old, apple trees are present in the yards of the two properties closest to IOC, on either side of Orchard Place.

Large open fields were present between IOC and Tennent Road to the west of Orchard Place in 1932; fields were present east of Orchard Place in 1940, and several structures, including a long, barn-like structure, had been added. In a 1954 photograph, the barn is not present, and expansion at the IOC property is apparent, with the addition of tanks and other structures.



Base from New Jersey Department of Environmental Protection data, 1:12,000, 1932

Figure 2. Part of the study area, showing orchards and forests digitized from aerial photographs taken in 1932. (From New Jersey Department of Environmental Protection, Tidelands, Trenton, New Jersey)



Aerial photograph from New Jersey Department of Environmental Protection

Aerial photograph from Aerial Viewpoint, Houston, Texas

Figure 3. Aerial photographs showing part of the study area in (a) 1932 and (b) 1940. ((a), from New Jersey Department of Environmental Protection, Tidelands, New Jersey, and (b) from Aerial Viewpoint, Houston, Texas: by permission).

Residential Area 2

Residential area 2 is a housing development built mostly on former orchard land. The orchard was active in 1932 and 1940 (fig. 3) and, although several houses had been built by 1954, part of the orchard was still active in the 1950's. Orchard Parkway, which runs through the southern part of the residential area and along which most of the soil sampling has been conducted, was laid out in the 1950's. Old apple trees that are remnants of the former orchards were observed on more than a dozen residential properties in this area during the reconnaissance phase of this study.

Geology and Soils

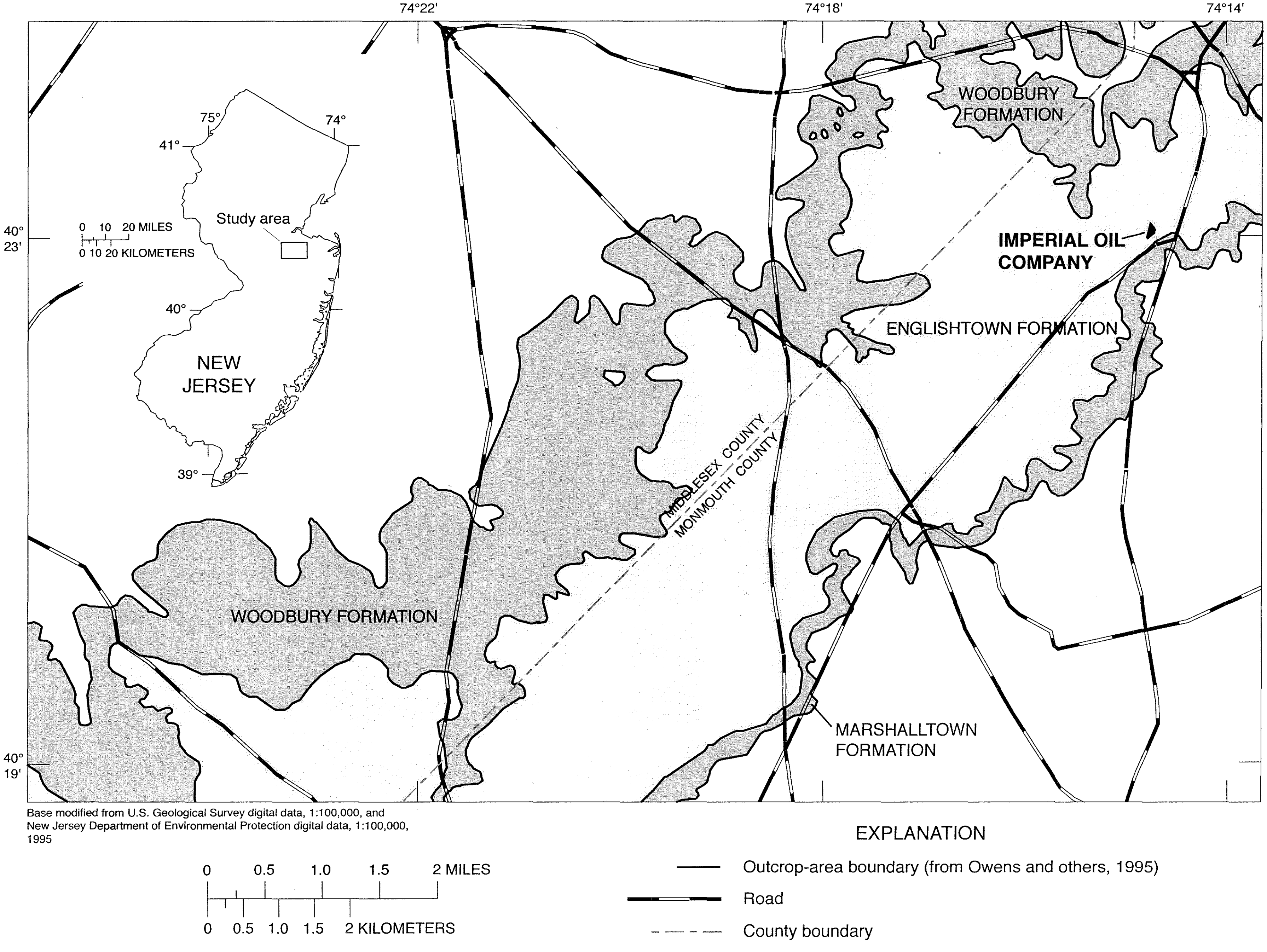
Geologic units and soils in the study area were mapped in detail within the past decade. Stratigraphy and mineralogy are described by Owens and others (1995). Soils in Monmouth County and Middlesex County are described by Jablonski and Baumley (1989) and Powley (1987), respectively.

Geology

The study area is underlain by unconsolidated sediments of the Atlantic Coastal Plain that form a seaward-thickening wedge of sands and gravels interspersed with silt and clay layers; these sediments, where of regional extent, form a series of aquifers and confining units. The geologic formations range in age from Cretaceous to Holocene (Zapecza, 1989).

Three Cretaceous formations crop out in the vicinity of IOC; the outcrops trend southwest-northeast. The oldest unit, the Woodbury Formation, crops out to the northwest of IOC, and underlies some of the soils sampled for this study. IOC and the nearby residential areas are directly underlain by the Englishtown Formation (fig. 4). The youngest unit, the glauconitic Marshalltown Formation, overlies the Englishtown Formation and crops out to the southeast of IOC. The Marshalltown Formation does not crop out in any of the areas sampled for this study.

The Englishtown Formation constitutes a major aquifer, as do other sandy units in the New Jersey Coastal Plain. Locally, the sands of the Englishtown Formation contain beds or lenses of clay (Owens and Sohl, 1969). Soil sampling conducted during the present study indicates that clay lenses are common at shallow depths on hilltops. The Englishtown Formation, which ranges in thickness from 90 to 140 ft, is composed primarily of quartz sand with some pebbles; feldspar constitutes up to 10 percent of the sand fraction, and muscovite is present in amounts that range from sparse to moderate (Owens and others, 1995). Lignite is found locally and is particularly abundant in the clay layers; pyrite and marcasite also are present, both as finely disseminated grains and as large masses, and are most abundant in carbonaceous layers. Opaque heavy minerals are primarily ilmenite and leucoxene and nonopaque minerals include zircon, tourmaline, rutile, and a variety of metamorphic minerals (Owens and others, 1995). Siderite concretions are found in sands near the base of the formation (Owens and others, 1995).



Base modified from U.S. Geological Survey digital data, 1:100,000, and New Jersey Department of Environmental Protection digital data, 1:100,000, 1995

Figure 4. Outcrop areas of the Woodbury, Englishtown, and Marshalltown Formations in the study area. (From Owens and others, 1995)

Welch and others (1988), who summarize geologic sources of arsenic, point out that pyrite and organic matter in marine clays contain arsenic, whereas arsenic tends to be sorbed to nonmarine clays. Sedimentary iron ores and coal also contain substantial amounts of arsenic (Onishi, 1969). Of the minerals reported to be present in the Englishtown Formation, the most likely to contain arsenic are pyrite and marcasite, iron oxyhydroxides, and clay minerals; lignite also may contain arsenic.

The contact of the Englishtown Formation with the underlying Woodbury Formation is gradational over several feet, with the frequency of clay lenses increasing near the base of the Englishtown Formation. Basal clay lenses within the Englishtown Formation are similar in composition to the clays of the Woodbury Formation. The distinction between the formations is drawn on the basis of the abundance of sandy strata (Owens and others, 1995), as the Woodbury Formation is composed almost entirely of dark-gray clay-silt with iron oxides present as fracture fillings and as layers in weathered beds near the land surface. Thin stringers of glauconite are found locally near the top of the Woodbury Formation. Both carbonaceous matter and pyrite are generally abundant in the micaceous clays that compose this unit. Thin quartz sand layers are present at the base of the unit (Owens and others, 1995). In addition to lignite, minerals in the Woodbury Formation that can contain arsenic are glauconite, pyrite, iron oxyhydroxides, and clays.

The Woodbury Formation lies about 50 ft below IOC and crops out about 1 mi northwest of the site. A clay lens within the basal Englishtown Formation underlies IOC and the adjacent woods to the east at depths ranging from about 2 to about 20 ft below land surface. Residential area 2 (0.5 mi to the north-northeast of IOC) is underlain by a similar clay lens. This clay is encountered below the top of a small rise at depths of about 2 to 4 ft from land surface (fig. 5). A second clay lens is encountered at lower altitudes in residential area 2 at depths of about 4 ft from land surface (fig. 6, sampling site R18).

Soils

The soils developed on the Englishtown Formation typically are sandy, but contain substantial amounts of clay where they are developed on clay lenses near the surface. Soil development is controlled by the texture and composition of underlying geologic material, slope, drainage, and length of time the surface is exposed to weathering processes. As weathering proceeds, the geologic material is altered as material is leached from it and plants supply organic debris to the land surface. As a result of weathering and accumulation of organic material, a soil profile develops that is characterized by a sequence of layers or horizons. These horizons are generally classified on the basis of various properties such as amounts of organic material (humus), silicate clays, and iron and aluminum oxides.

In New Jersey Coastal Plain soils, organic (O) horizons that contain organic material in various stages of decomposition may develop at the land surface. Beneath the O horizons or at the land surface are gray to dark brown A horizons that contain decomposed organic matter and mineral soil from which iron and aluminum oxides and clays have been leached. In some soils, an E (eluviated) horizon is found beneath the A horizon; this horizon also is leached and contains little organic material, resulting in a paler color soil than that of the A horizon. The materials leached from A and E horizons accumulate at greater depths, creating the B horizons, which

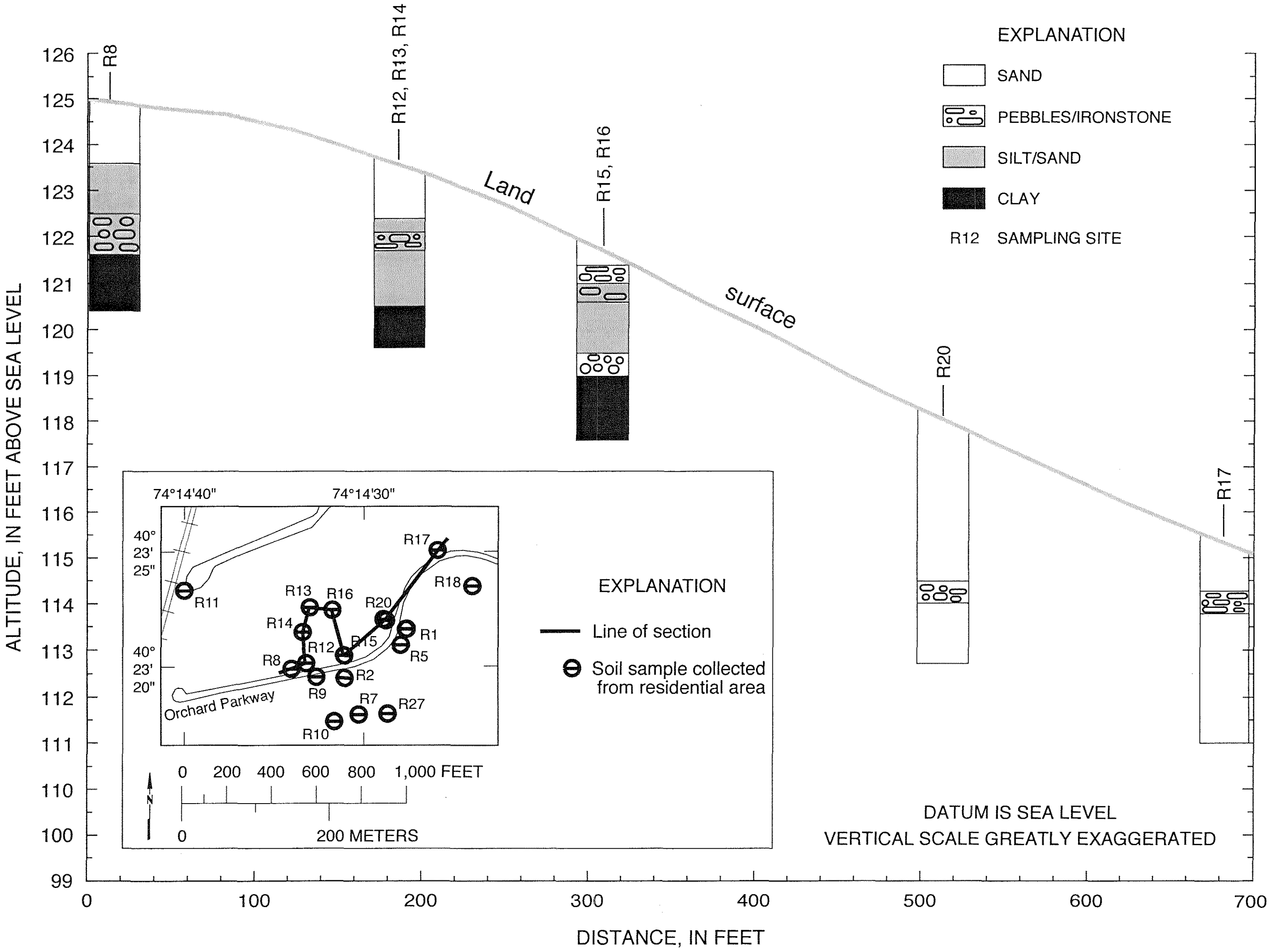


Figure 5. Stratigraphy of soils and sediments at eight locations north of Orchard Parkway in residential area 2, Marlboro Township, Monmouth County, New Jersey. (See fig. 1 for location of inset.)

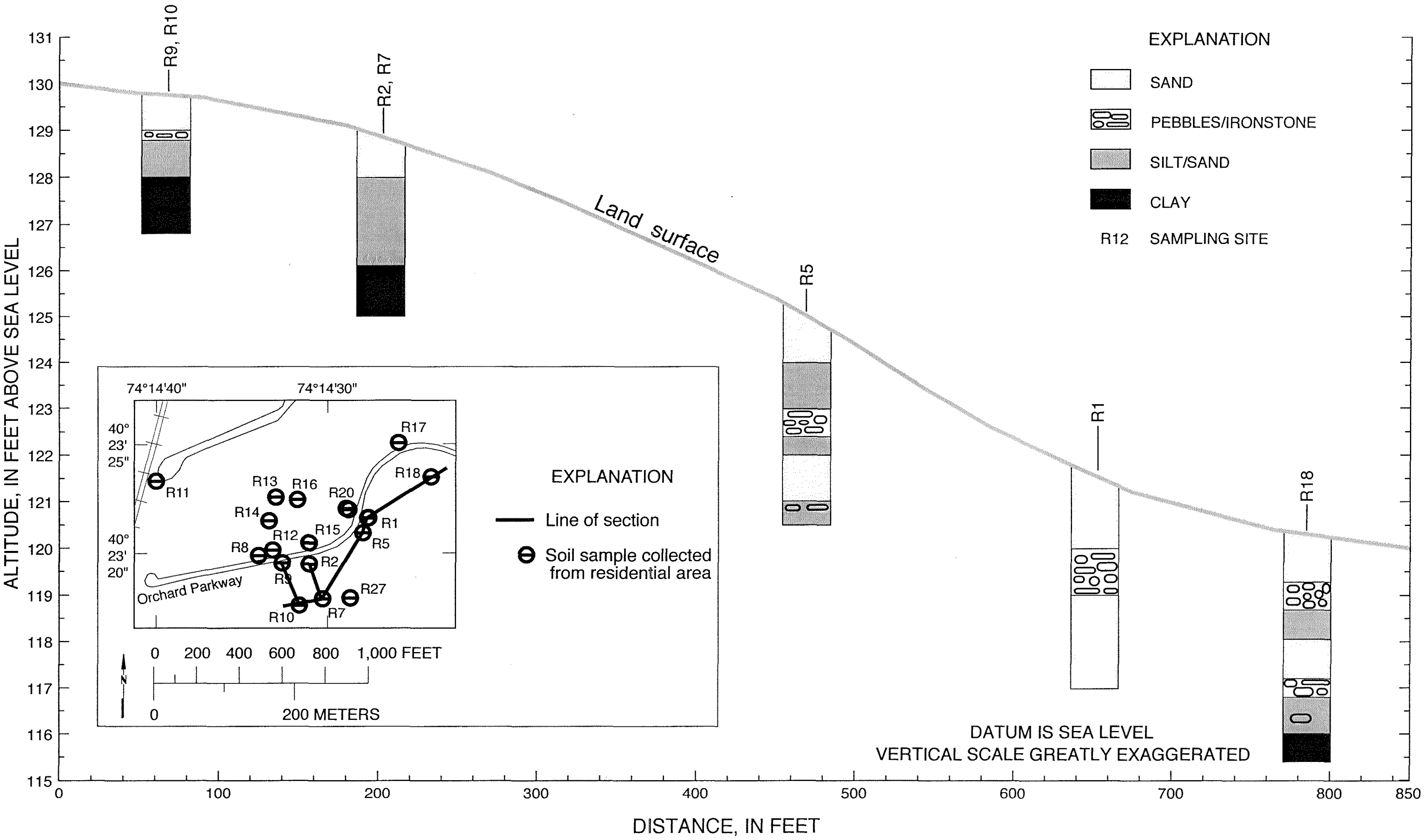


Figure 6. Stratigraphy of soils and sediments at seven locations south of Orchard Parkway in residential area 2, Marlboro Township, Monmouth County, New Jersey. (See fig. 1 for location of inset.)

contain iron and aluminum oxides and clays. B horizons typically are orange or yellow-brown because of the iron oxyhydroxides that have accumulated. Below the B horizons are C horizons, which are composed mostly of nearly unaltered geologic materials.

A vertical section through all the soil horizons, extending into the parent geologic materials, is referred to as a soil profile. Soils that are similar in the major characteristics of their soil profiles are classified by soil scientists as a discrete, basic unit known as a soil series (Brady, 1974). An idealized soil profile for the Coastal Plain soils of the study area that includes all of the horizons discussed above is shown in figure 7.

Three soil series are dominant at and in the immediate vicinity of IOC. The soils at IOC, in the woods east of IOC, and in much of residential area 2, north-northeast of IOC, are the Keyport soil series, which are either loams or sandy loams, depending on whether the substrate is clayey or sandy. These are moderately well-drained, medium-acid to very strongly acid (pH 4.5-6.0) soils. The Evesboro soil series, excessively drained and extremely acid (pH less than 4.5), also is present in the woods east of IOC and residential area 2. The Klej series of very strongly acid (pH 4.5-5.0) loamy sands is found in the eastern part of this residential area (Jablonski and Baumley, 1989).

The soil series described above are found throughout the study area. Additional soil series are present in the study area as well. Strongly acid to extremely acid (pH less than 4.5-5.5) sandy soils of the Sassafras and Lakehurst series are encountered southwest and west, respectively, of the site. North and east of IOC, the poorly drained, extremely acid soil series of the Elkton loam and Atsion sand are found near and adjacent to Birch Swamp Brook, the stream that traverses IOC property and flows north through the study area.

Mobility of Metallic Substances in Soils

The term "metal" refers to the majority of elements in the periodic table, and includes alkali and alkali-earth metals as well as transition metals. Elements that have some characteristics of metals, such as arsenic, are known as metalloids; however, metalloids commonly are lumped with true metals for discussion purposes (see, for example, McLean and Bledsoe (1992)). In this report, arsenic, a metalloid, is referred to as "metallic."

The differing affinities of metals and metalloids for various materials present in soils depend mostly on the characteristics of the element, but also, in some cases, on the oxidation state of the element, which can affect solubility. Some metallic species bind strongly to organic matter, others to iron oxides or clays. Thus, some metallic substances are more mobile in soils than others, and this mobility (or lack thereof) affects the distribution of substances that are input at the land surface through the soil profile. A brief summary of factors affecting the mobility of several metallic substances that are present in elevated concentrations in the soils at IOC and in some of the soils in the larger study area is given below.

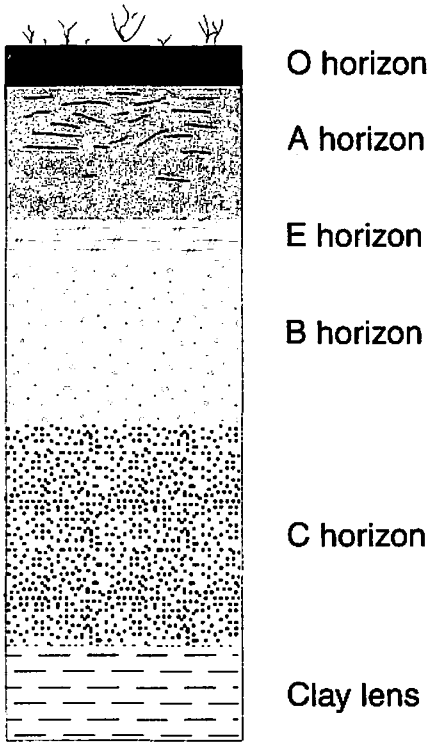


Figure 7. Idealized soil profile, New Jersey Coastal Plain soils.

Arsenic

Arsenic ions can occur in three stable oxidation states (3^-, 3^+, 5^+); two forms with positive oxidation numbers, As(V) and As(III), typically are found in the soil environment (McLean and Bledsoe, 1992). As(V) occurs as the arsenate ion (AsO_4^{3-}); As(III) occurs as the arsenite ion (AsO_2^-), which is the more toxic of the two inorganic species. In addition to these inorganic species, arsenic can be methylated by bacterial action to form as many as four methylated species.

Several studies have shown that arsenic species have an affinity for iron and aluminum oxides (Anderson and others, 1976; Griffin and Shimp, 1978; Leckie and others, 1980). In a study of arsenic sorption by iron oxides and oxyhydroxides, Bowell (1994) found that arsenic (V) sorbed most strongly, arsenic (III) least strongly, and the methylated species moderately strongly at pH's less than 7. Ferric hydroxide sorbs dissolved arsenic species more strongly than does ferrous hydroxide (Matisoff and others, 1982).

Arsenic sorption is controlled, in part, by pH (Anderson and others, 1976; Griffin and Shimp, 1978; Pierce and Moore, 1980; Elkhatib and others, 1984). In general, sorption of arsenic species to aluminum and iron oxides or oxyhydroxides is greatest at acid pH's (about 3-5), although Pierce and Moore (1980) found that sorption of arsenite to iron oxides was greatest at pH 7. Masscheleyn and others (1991) reported that increasing pH promoted desorption of arsenate from contaminated soils; they also found redox potential to be an important factor in arsenic mobility, as oxidizing conditions promote the predominance of less soluble arsenic (V). The chemical behavior of arsenate is similar to that of phosphate (McLean and Bledsoe, 1992), and it appears that inputs of phosphate fertilizer to soils could displace sorbed arsenate (Davenport and Peryea, 1991).

Barium

Barium is an alkali-earth metal with a II oxidation state. It is geochemically similar to calcium and strontium (Adriano, 1986). Barium substitutes for potassium, calcium, and sodium in feldspars (Deer and others, 1976) and also can be incorporated in micas (Fairbridge, 1972); consequently, barium appears as a trace element in clays that are formed from weathered feldspars and micas.Two common barium ore minerals are barite ($BaSO_4$) and witherite ($BaCO_3$) (Fairbridge, 1972).

Barium can be removed from solution by adsorption on clay minerals and on manganese oxides (Fairbridge, 1972; Adriano, 1986). Barium in soils tends to be immobilized by additions of lime or sulfur, which result in precipitation of the carbonate or sulfate, both of which are only sparingly soluble (Adriano, 1986).

Copper

Copper, a transition metal, occurs in both I and II oxidation states, and is found in nature as the native metal, and as sulfide, oxide, sulfate, and carbonate minerals (Adriano, 1986). Copper can form complexes with various inorganic ligands, including nitrate, chloride, and ammonium, and forms stable complexes with humic substances (Moore and Ramamoorthy, 1984). Copper applied to soils tends to be strongly fixed by organic matter, some clay minerals (Farrah and others, 1980), and iron, manganese, and aluminum oxides, and therefore tends to be immobile in the soil profile (Adriano, 1986), although Slavek and Pickering (1985) found that some copper sorbed to manganese oxides could be removed by strong acids. McLean and Bledsoe (1992) suggest that mobility of copper in soils can be enhanced because of the affinity of copper for soluble organic ligands.

Several studies have examined the role of pH in copper mobility. Tyler and McBride (1982) report low mobility of copper in an acid (pH 5) mineral soil, and virtual immobility in a highly organic soil with even lower pH. King (1988) found that copper (sorbed and nonexchangeable) in the A horizon of a southeastern Coastal Plain soil was unaffected by pH, but that most of the variation in sorbed copper in B and C horizons could be explained by change in pH. Huang and others (1977) found an increase in copper adsorption by hydrous oxides in Coastal Plain soils between pH 5 and 6, which agrees with results of studies of metal sorption by goethite (Forbes and others, 1976) and ferromanganese grain coatings (Robinson, 1983). Cavallaro and McBride (1978) indicate that copper is less likely to be removed from solution in low-pH soils than in neutral or high-pH soils.

Lead

Lead has two stable oxidation states, Pb(II) and Pb (IV), but, of these, the divalent state as the plumbous ion Pb^{2+} is the more abundant in the environment (Davies, 1990). Although biological methylation of lead has been observed in laboratory experiments, it is not clear whether this process occurs in natural systems (Moore and Ramamoorthy, 1984).

Both naturally occurring and anthropogenic lead tends to accumulate in soil surface horizons; the organic fraction generally sequesters most of the lead in the system (Davies, 1990). Lead also sorbs to hydrous oxides (Huang and others, 1977), although the amount of lead fixed to iron oxides is less than that found in organic phases (Davies, 1990). In addition, lead has been found to have an affinity for clays (Riffaldi and others, 1976). The amount of lead fixed by clays (montmorillonite, illite, and kaolinite) was found to decrease with decreasing pH (Hildebrand and Blum, 1974); lead fixation was greatest with montmorillonite and least with kaolinite. Nevertheless, Scrudato and Estes (1975) found that kaolinite strongly sorbed lead at pH's from 3.0 to 4.5. In an acidic environment, lead generally is preferentially sorbed by humic acids in organic matter rather than by clays (Moore and Ramamoorthy, 1984).

Zinc

Zinc ion occurs in only one oxidation state as Zn^{2+}. Zinc precipitates as a hydroxide at alkaline pH, and, in solution, forms complexes not only with hydroxyl ions, but also with chloride, phosphate, nitrate, sulfate, ammonium, and cyanate ions (Adriano, 1986). Studies of zinc sorption to constituents of soils such as organic matter, clays, and iron and aluminum hydroxides indicate that zinc is less strongly sorbed than either lead or copper (King, 1988; Tyler and McBride, 1982; Farrah and others, 1980; Forbes and others, 1976). Under some experimental conditions, however, zinc is sorbed more strongly by clays and goethite than other metals such as nickel and cadmium (Tiller and others, 1984). Studies of soils contaminated with heavy metals indicate that lead and copper tend to remain in surface soils, whereas zinc is more mobile (Elliot and others, 1986). Mobility of zinc is affected by pH and redox conditions; zinc is most soluble in acidic soils but forms an insoluble sulfide under strongly reducing conditions (Adriano, 1986).

STUDY APPROACH AND METHODS

The study approach was to determine sources of arsenic and other metals in soils by developing chemical signatures or "fingerprints" that would be indicative of different sources. A chemical signature is based on the presence/absence and (or) concentrations of various analytes in a group of samples. To develop signatures, soil samples were collected from soil horizons in areas with three different ("endmember") land uses--undeveloped, orchard, and industrial--which represent single land uses (and their effects on the soil), rather than a succession of land uses such as that found in residential areas 1 and 2. The endmember land uses were defined as representing soils that had received only geologic and atmospheric inputs (undeveloped areas), soils that likely would have received lead arsenate pesticide inputs (former or current orchards), and soils that contained inputs of industrial contaminants (IOC). Air-flow modeling was used to test the hypothesis that some of the arsenic was derived from a contaminant plume emitted by smokestacks at the IOC location.

Design of Study

Three major considerations guided the design of the study. First, the sampling network was designed so that samples from soils deemed unlikely to be affected by industrial activities at IOC could be compared with samples that potentially were affected by activities at IOC in order to identify inputs of arsenic, lead, and other metals from sources other than IOC. Second, the soil samples were analyzed for constituents that would yield information about both the magnitude of metals concentrations and the processes involving sequestration or mobilization that control the distribution of metals within the soil column. Finally, because the samples were collected from different soil series in different land-use areas, soil-sample chemistry was compared on a horizon-by-horizon basis so that differences in chemistry as a function of soil characteristics would be revealed. These differences may be obscured by sampling at fixed depth increments because different soil horizons may be combined in a sample.

Sampling-Network Development

Soils were sampled in several stages. The first stage was designed to determine soil chemistry in endmember land-use areas by collecting samples that would reflect background geologic and regional atmospheric contributions of metals to soils and orchard pesticide contributions. In addition, samples that were considered to represent possible contributions from industrial activities at IOC were collected from soils at and adjacent to the site.

Background chemistry of soils in the vicinity of IOC was determined by selecting sampling sites in areas representative of undisturbed soils. Areas more than 1 mi from IOC that had been forested in the 1930's and that had continued as forested areas to the present were chosen by using aerial photographs from 1932, 1940, and 1954, topographic maps, digital orthophoto quads, and results of field reconnaissance. Agricultural contributions of metals to soils were characterized by identifying former orchards that had experienced no further disturbance (such as residential development) as well as existing orchards on aerial photographs. The areas of former orchards were digitized and overlays at the same scale as that of topographic maps were prepared by using a GIS. Maps and overlays were used in the field to identify the present condition of former orchard areas so that the suitability of soil for collection from each potential site could be assessed. Once potential sampling sites had been identified, access agreements for sampling were obtained by contacting the property owner. Ultimately, the design of this part of the sampling network was controlled in part by whether access agreements with NJDEP were in place or could be obtained. Locations of all sampling sites are shown in figures 8 and 9. Descriptions of the sampling sites are found in table 1.

A sampling grid was laid out in the woods adjacent to IOC to assess what effects, if any, from smokestack-plume fallout could be discerned in soils that were located between IOC and residential area 2, 0.5 mi north-northeast of IOC. A sampling-grid strategy was used so that gradients in metal concentrations with distance from IOC could be delineated if they existed. Grid nodes were located 100 ft apart; samples were collected at 17 sites, generally at 200-ft intervals, except where local topographic features (natural or man-made) or the presence of disturbed soil or disposed waste prevented the collection of a representative soil sample. In these instances, the samples were collected near the node or at an adjacent node.

Soil samples also were collected at IOC. Soil logs from test borings at IOC (E.C. Jordan Co., 1992) were examined for examples of petroleum-free soils, but, given the widespread contamination from petroleum products associated with activities that occurred later than 1945, few areas where soils contained only metals associated with arsenical-pesticide manufacture could be located. Ultimately, sampling locations at IOC were chosen to represent a range of arsenic concentrations (based on previous work by E.C. Jordan Co. (1992)) and soil conditions, including minor petroleum contamination. Samples of the filter clay, with substantial petroleum contamination, also were collected. In addition, samples from beneath paved areas at IOC, collected by NJDEP during the latter stages of this study, were included to represent possible metals inputs related to pesticide-manufacturing activities.

The second stage of sampling was carried out in the two residential areas in which elevated arsenic and lead concentrations in soils had already been measured. Two types of soil samples were collected. Relatively undisturbed soils dating to former agricultural land use were sampled beneath old apple trees, where these could be found; samples also were collected from areas previously sampled by NJDEP where highly elevated arsenic concentrations were measured.

In the third stage, a few samples were collected from soils in a residential area (the "broader area") that had been built on land previously used for orchards that is farther from IOC than residential areas 1 and 2. These samples were collected for comparison with those obtained from residential areas 1 and 2.

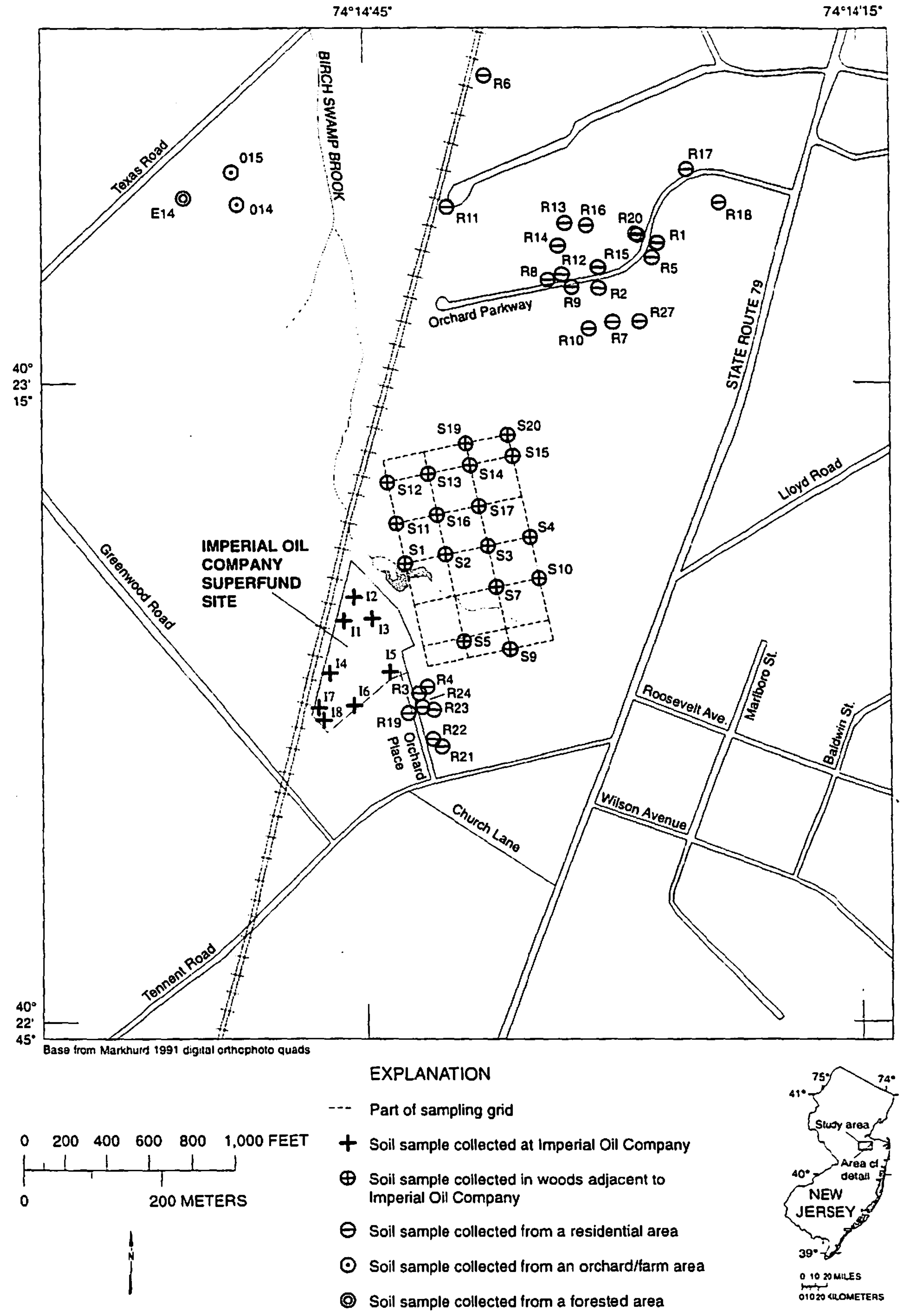
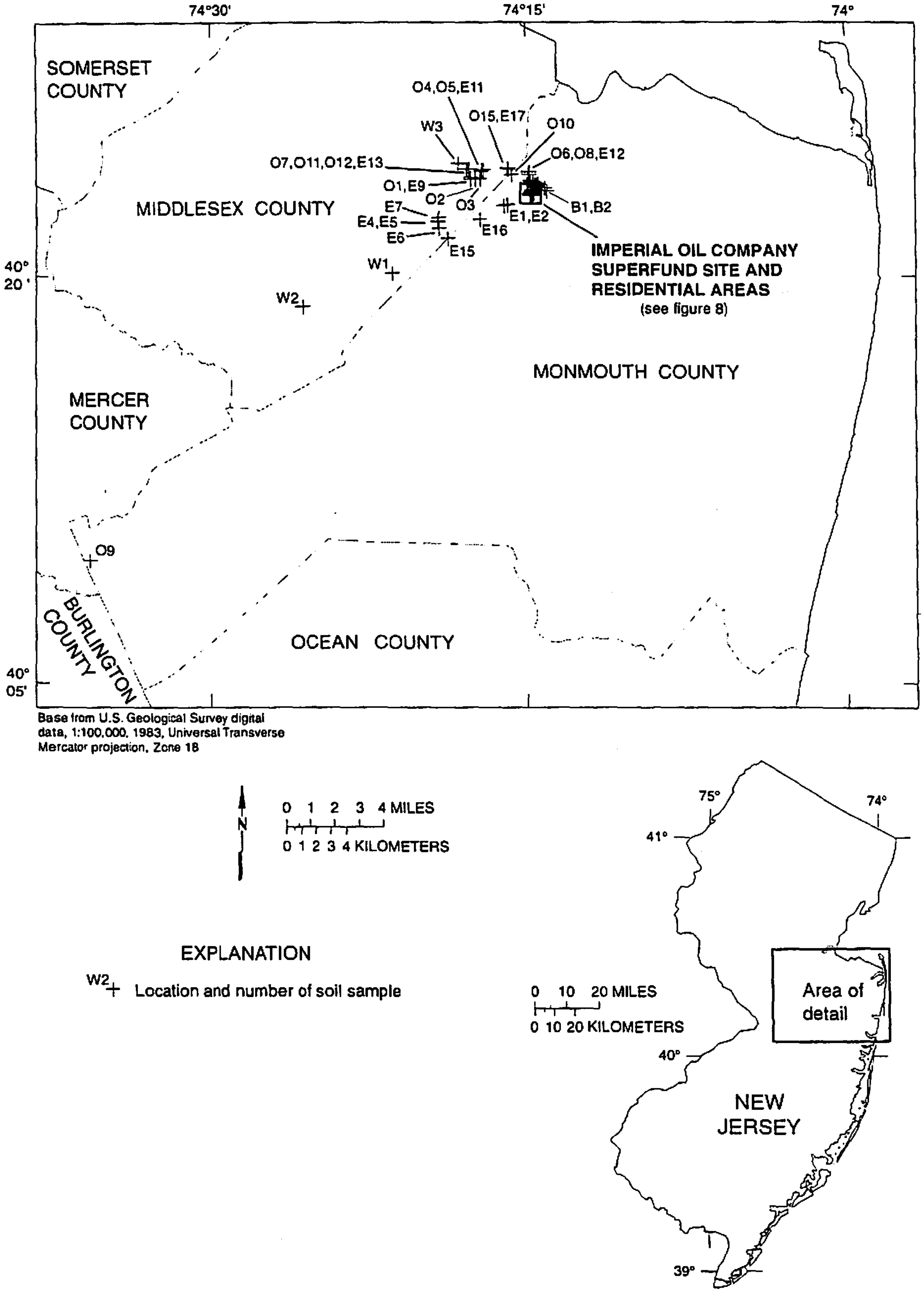


Figure 8. Location of soil-sampling sites within 0.5 mile of the Imperial Oil Company Superfund site, Marlboro Township, Monmouth County, New Jersey.



Base from U.S. Geological Survey digital data, 1:100,000, 1983, Universal Transverse Mercator projection, Zone 18

Figure 9. Location of soil-sampling sites in the study area, Monmouth and Middlesex Counties, New Jersey.

Table 1. Description of soil-sampling sites, Monmouth and Middlesex Counties, New Jersey

[Twp., Township; Co., County; IOC, Imperial Oil Company Superfund site]

Site number	Geographic location	Soil series	Site description/Land-use type
E1	Marlboro Twp., Monmouth Co.	Lakehurst	forested, geologic
E2	Marlboro Twp.,Monmouth Co.	Lakehurst	forested, geologic
E4	Madison Twp., Middlesex Co.	Lakewood	hill, forested, geologic
E5	Madison Twp. Middlesex Co.	Klej?	forested, geologic
E6	Madison Twp., Middlesex Co.	Keyport	forested, geologic
E7	Madison Twp., Middlesex Co.	Lakewood	hill, forested, geologic
E9	Old Bridge Twp., Middlesex Co.	Keyport	forested, geologic
E11	Old Bridge Twp., Middlesex Co.	Keyport?	forested, geologic
E12	Matawan, Monmouth Co.	Elkton	forested, geologic
E13	Old Bridge Twp., Middlesex Co.	Keyport	forested, geologic/orchard
E14	Marlboro Twp., Monmouth Co.	Keyport	forested, geologic
E15	Madison Twp., Middlesex Co.	Keyport	forested, geologic
E16	Marlboro Twp., Monmouth Co.	Humaquepts	forested, geologic
E17	Old Bridge Twp., Middlesex Co.	Elkton	forested, geologic/orchard
W1	Manalapan., Middlesex Co.	Keyport	park, geologic
W2	Monroe Twp., Middlesex Co.	Keyport	above claypit, geologic
W3	Old Bridge Twp. Middlesex Co.	Keyport	forested, geologic
O1	Old Bridge Twp., Middlesex Co.	Evesboro	orchard, active 1932-96
O2	Old Bridge Twp., Middlesex Co.	Keyport	orchard, active 1932-96
O3	Old Bridge Twp., Middlesex Co.	Keyport	orchard, active 1932-96
O4	Old Bridge Twp., Middlesex Co.	Keyport	orchard, active 1954-70
O5	Old Bridge Twp., Middlesex Co.	Klej	orchard, active 1954-70
O6	Freneau, Monmouth Co.	Evesboro	apple tree, former orchard, active 1932-70
O7	Old Bridge Twp., Middlesex Co.	Keyport	apple tree, former orchard, active 1932-70
O8	Freneau, Monmouth Co.	Evesboro	forested, former orchard, active 1932-70
O9	Upper Freehold Twp., Monmouth Co.	Sassafras	field, former orchard, active 1932-70
O10	Old Bridge Twp., Middlesex Co.	Keyport	apple tree, former orchard, active 1954-?
O11	Old Bridge Twp, Middlesex Co.	Keyport	field, former orchard, active 1932-70
O12	Old Bridge Twp., Middlesex Co.	Keyport	field, former orchard, active 1932-70
O14	Marlboro Twp., Monmouth Co.	Evesboro	forested, former orchard, active 1932?-40
O15	Marlboro Twp., Monmouth Co.	Evesboro	forested, field 1932?-70
O16	Old Bridge Twp., Middlesex Co.	Keyport	apple tree, former orchard, active 1932-70
I1	Marlboro Twp., Monmouth Co.	filter clay	contaminated waste pile, IOC
I2	Marlboro Twp., Monmouth Co.	Keyport	disturbed contaminated soil, IOC
I3	Marlboro Twp., Monmouth Co.	Keyport	disturbed contaminated soil, IOC
I4	Marlboro Twp., Monmouth Co.	Keyport	disturbed contaminated soil, IOC
I5	Marlboro Twp., Monmouth Co.	Keyport	disturbed contaminated soil under paving, IOC
I6	Marlboro Twp., Monmouth Co.	Keyport	undisturbed uncontaminated soil under paving, IOC
I7	Marlboro Twp., Monmouth Co.	Keyport	disturbed contaminated soil under paving, IOC
I8	Marlboro Twp., Monmouth Co.	Keyport	disturbed slightly contaminated soil under paving, IOC
S1	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former field
S2	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former field
S3	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former field

Table 1. Description of soil-sampling sites, Monmouth and Middlesex Counties, New Jersey--Continued

[Twp., Township; Co., County; IOC, Imperial Oil Company Superfund site]

Site number	Geographic location	Soil series	Site description/Land-use type
S4	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former field
S5	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC
S7	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC
S9	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC
S10	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC
S11	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former orchard (?), 1932
S12	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former field
S13	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former field
S14	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former field
S15	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former field
S16	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former orchard, 1932
S17	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former orchard, 1932
S19	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former orchard, 1932
S20	Marlboro Twp., Monmouth Co.	Keyport	woods adjacent to IOC, former orchard, 1932
R1	Marlboro Twp., Monmouth Co.	Klej	apple tree, residential area 2, former orchard
R2	Marlboro Twp., Monmouth Co.	Keyport	apple tree, residential area 2, former orchard
R3	Marlboro Twp., Monmouth Co.	Keyport	forested, residential area 1, former orchard/farm
R4	Marlboro Twp., Monmouth Co.	Keyport	forested, residential area 1, former orchard/farm
R5	Marlboro Twp., Monmouth Co.	Klej	front yard, residential area 2, former orchard
R6	Marlboro Twp., Monmouth Co.	Keyport	back yard, residential area 2, former farm
R7	Marlboro Twp., Monmouth Co.	Keyport	back yard, residential area 2, former orchard
R8	Marlboro Twp., Monmouth Co.	Keyport	front yard, residential area 2, former orchard
R9	Marlboro Twp., Monmouth Co.	Keyport	front yard, residential area 2, former orchard
R10	Marlboro Twp., Monmouth Co.	Keyport	back yard, residential area 2, former orchard
R11	Marlboro Twp., Monmouth Co.	Keyport	trees, residential area 2, former farm
R12	Marlboro Twp., Monmouth Co.	Keyport	front yard, residential area 2, former orchard
R13	Marlboro Twp., Monmouth Co.	Keyport	back yard, residential area 2, former orchard
R14	Marlboro Twp., Monmouth Co.	Keyport	apple tree, residential/orchard
R15	Marlboro Twp., Monmouth Co.	Keyport	front yard, residential area 2, former orchard
R16	Marlboro Twp., Monmouth Co.	Keyport	back yard, residential area 2, former orchard
R17	Marlboro Twp., Monmouth Co.	Keyport	apple tree, residential area 2, former orchard
R18	Marlboro Twp., Monmouth Co.	Klej	apple tree, residential area 2, former orchard
R19	Marlboro Twp., Monmouth Co.	Keyport	front yard, residential area 1, former orchard/farm
R20	Marlboro Twp., Monmouth Co.	Keyport	apple tree, residential area 2, former orchard
R21	Marlboro Twp., Monmouth Co.	Keyport	back yard, residential area 1, former orchard/farm
R22	Marlboro Twp., Monmouth Co.	Keyport	near garden, residential area 1, former orchard/farm
R23	Marlboro Twp., Monmouth Co.	Keyport	back yard, residential area 1, former orchard/farm
R24	Marlboro Twp., Monmouth Co.	Keyport	front yard, residential area 1, former orchard/farm
R27	Marlboro Twp., Monmouth Co.	Keyport	apple tree, residential area 2, former orchard
B1	Marlboro Twp., Monmouth Co.	Keyport?	disturbed soil near apple tree, residential area, former orchard
B2	Marlboro Twp., Monmouth Co.	Freehold	apple tree, residential area, former orchard

In all, soil samples were collected from four present and (or) past land-use areas: undeveloped land, agricultural land (specifically orchards), industrial land, and residential land. The first three land uses represent the endmember land uses used to construct the statistical models.

Analytical Strategy

Soil samples were analyzed for 23 target analyte list (TAL) metals (table 2). Total organic carbon (TOC) concentrations also were determined, as certain metals, such as lead, bind strongly to naturally occurring organic matter. On the basis of limited information about possible ore roasting activities at the IOC site, it appeared that if deposition from a smokestack plume had occurred, sulfur concentrations in soils near IOC might be elevated as a result of roasting sulfide ores. Therefore, concentrations of total sulfur also were determined. The pH of selected samples of surficial (A- horizon) soils, where the effects of metals inputs were most apparent, was measured in the field. Appendix 1 contains the chemical data.

Table 2. Constituents and characteristics measured in soil samples from Monmouth and Middlesex Counties, New Jersey, 1995-96

[CRDL; contract-required detection limit; values in milligrams per kilogram; NA, not applicable]

Constituent/ characteristic	CRDL	Constituent/ characteristic	CRDL	Constituent/characteristic	CRDL
aluminum	19.8	iron	3.7	thallium	0.6
antimony	0.44	lead	0.3	vanadium	0.22
arsenic	0.42	magnesium	18.5	zinc	5.0
barium	0.68	manganese	0.08	total organic carbon	NA
beryllium	0.04	mercury	0.002	total sulfur	NA
cadmium	0.06	nickel	0.1	pH (selected samples)	NA
calcium	17.4	potassium	21.04	mineralogy (selected samples)	NA
chromium	0.1	selenium	0.74	grain size (selected samples)	NA
cobalt	0.2	silver	0.16	lead isotopes (selected samples)	NA
copper	0.14	sodium	40.04		

Isotopes of various elements have been used in other studies to establish source "fingerprints," or chemical signatures (Faure, 1977; Mazor, 1991). In the absence of multiple isotopes of arsenic, isotopes of lead were determined to have potential as a component of the chemical signature, at least with regard to separating inputs of a commonly used arsenical pesticide, lead arsenate ($PbHAsO_4$), from inputs from other lead sources. Thus, lead-isotope ratios ($^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$) were determined in selected soil samples.

Grain size and soil mineralogy were recorded in the field for each core sample. A detailed analysis of grain size and mineralogy was performed for selected representative samples to help explain differences in metal concentrations between different land uses as a function of processes within the soil as well as inputs resulting from human activities.

Soil Sampling, Sample Preparation, and Soil Analysis

Soil Sampling

The various soils in the study area have developed under slightly different conditions, and the soil horizons do not have fixed thicknesses; therefore, sampling to predetermined depths can have the effect of blending parts of adjacent soil horizons that may have different properties and affinities for metals. Consequently, soil samples were collected so that subsamples of particular horizons could be extracted. Furthermore, because some of the metals input to the soils was believed to have resulted from atmospheric deposition or surficial applications, sampling methods that would prevent soils from upper soil horizons (with possibly higher metal contents) from mixing with soils from lower horizons were necessary. Therefore, continuous cores were collected wherever possible, and the cores were subsampled thereafter.

Cores of sandy soils were collected by using 3-ft-long stainless-steel corebarrels with carbon-steel cutter heads; the corebarrels were lined with 2-in.-diameter butyl acetate transparent liners in 1-ft sections that contained a plastic cone-shaped corecatcher just above the cutter head. The corers were driven into the soil with a slide hammer, typically to a depth of about 4 ft. Because the soil sample is compacted during coring, a 4-ft soil profile could be sampled and collected in less than 3 ft of corebarrel. Before each core was collected, the various horizons and other features of the soils at that location were determined by hand-augering a sample to a depth of about 4 ft, and recording soil properties such as color, texture, presence of pebbles and cobbles, channers (thin, flat fragments of iron hydroxide), lignite fragments, and gross mineralogy, such as quartz sand, clay minerals, and muscovite flakes. The depths from land surface at which soil properties changed were measured with an accuracy of about 1 in. The collection of the auger sample permitted identification of disturbed soils or buried wastes.

Samples of O horizons, where found, were collected with a clean stainless-steel trowel and placed in clean, labelled plastic bags. During the winter months the A-horizon soils also were collected in this manner if they were frozen; samples containing frozen ground could not be collected with the corer because the frozen soil acted as a plug and was driven deeper into the ground with each blow of the slide hammer. Under these circumstances, the corecatcher failed, the plug of frozen soil remained at the end of the corebarrel or fell into the borehole, and no sample was driven up into the corebarrel liner. Therefore, when the ground was frozen, coring was begun where unfrozen soil was encountered, typically at the bottom of the A or E horizon.

Samples with a high clay content were difficult to retrieve because the plastic corecatcher at the end of the corebarrel also failed when subjected to suction from wet clays. Hardened-steel 2-ft-long split spoons that contain 2-ft-long, 1-in.-diameter polyethylene liners were used to collect clay samples. The corecatcher for the split spoons is constructed of thicker plastic than the corecatcher used in the 3-ft-long corers, and thus retained the sample in the corebarrel despite suction. Details of the sampling procedure can be found in appendix 2.

The corebarrel liners were retrieved from the 3-ft-long corers and the split spoons once the sampling device had been brought to the surface by upward blows from the slide hammer, or, for clayey soils, with a jack. The corebarrel liners were capped and marked with sample number, date, time of sampling, "up" direction, and other information that was deemed important, such as position and approximate depth of interfaces between soil horizons. The capped liners were placed in a clean, dedicated cooler with icepacks and were transported to the USGS, New Jersey District, laboratory in West Trenton, New Jersey, where they were refrigerated until subsampling began. The personnel handling the corebarrel liners and caps wore clean, disposable vinyl gloves that were changed each time a different facet of the procedure began (for example, augering, driving the corer, retrieving the corebarrel liner).

Prior to use in the field, the corebarrel liners, corecatchers, and caps were cleaned by using the following procedure: equipment was first scrubbed with tapwater and detergent; second, rinsed with tap water; and finally, copiously rinsed with analyte-free deionized water. Cleaning generally was performed in the laboratory at the end of a sampling day, but the metal parts of the coring devices were cleaned in the same manner in the field when necessary. Equipment parts were air-dried and covered with clean laboratory tissues, except for the split spoons which, because they are hardened carbon steel, rusted easily and therefore were wiped dry with clean laboratory tissues. Personnel cleaning the equipment wore disposable vinyl gloves, and changed gloves between the tapwater rinse and the deionized-water rinse. All equipment parts were sealed in clean plastic bags after washing. Details of the cleaning procedure are given in appendix 2.

A soil pH probe that operates on the principle of measuring the electrical potential between two dissimilar metal plates was used to determine of pH in A-horizon soils. The probe was inserted in soil that had been moistened with deionized water, and pH was recorded after 3 minutes or when the meter reading stabilized.

Sample Preparation

Soil cores, which were refrigerated at 4 °C, were subsampled by soil horizon within 1 week of the date of collection on a lab bench covered with clean laboratory tissues that were changed between each horizon subsampling. Personnel performing the subsampling procedures wore disposable vinyl gloves that were changed between each horizon subsampling. The sample was removed from the corebarrel liner with a disposable plastic spatula; for the clay samples, which required a stronger spatula, clean stainless-steel or Teflon-coated spatulas were used. The inner part of the core was sampled, and soil adhering to the corebarrel liner was not included in the sample. Parts of the soil cores in contact with the caps and interfaces between horizons also were discarded. The soil removed from the liner was thoroughly homogenized in a clean glass bowl (cleaned with the same procedure as field equipment; that is, washed with tapwater and detergent, tapwater-rinsed, and rinsed copiously with analyte-free deionized water) and placed in the sample bottles with the appropriate spatula. The sample bottles for TAL-metals and TOC analysis were supplied by the laboratory conducting the analysis and were precleaned by using the prescribed USEPA procedures. Polyethylene sample bottles for total-sulfur analysis were precleaned at the District laboratory (same procedure as glass bowls). Samples for lead-isotope analysis were placed in clean plastic "whirl-pack" bags; samples for mineralogical and grain-size analysis were placed in clean plastic jars or bags.

Sample jars containing subsamples for TAL-metals and TOC analysis were refrigerated until they were packed for shipping; the jars were packed in clean coolers with ice packs and were shipped by overnight-delivery service (TAL-metals) or by a courier for the contract laboratory (TOC). Chain-of-custody forms accompanied the samples for TAL-metals and TOC analysis. Samples to be analyzed for total sulfur and lead isotopes were refrigerated and were shipped by overnight-delivery service. All leftover sample material was archived under refrigeration. Details of the sample-preparation procedures are found in appendix 2.

Soil Analysis

Analysis of soils for TAL metals was performed by inductively coupled plasma spectroscopy for all alkali metals, semi-metals, and metals, except mercury, which was analyzed by the cold-vapor atomic absorption method (USEPA Methods 200.7 CLP-M and 245.5 CLP-M, respectively). TOC analyses were performed by using the Lloyd Kahn method (USEPA Method for the Determination of Total Organic Carbon in Sediment, July 27, 1988). Total sulfur in soil was determined by infrared-adsorption spectroscopy. Lead-isotope analyses were performed by mass spectrometry. A summary of the analytical methods for TAL metals, TOC, total sulfur, and lead isotopes is included in appendix 1.

Grain-size analysis was performed by the hydrometer method (Day, 1965, p. 562) and by sieving, mineralogy of the sand fraction was determined optically, and clay mineralogy was determined by using X-ray diffraction.

Air-Flow Modeling

Emissions from the chimney stacks at IOC were hypothesized as a possible source of arsenic in residential areas 1 and 2. To supplement the geochemical data, two air-flow models were used. A preliminary air-flow screening model (Christian, 1995) was programmed in Fortran. This model is based on a double Gaussian distribution that is typically used in modeling of continuous processes (Christian, 1995). The equations used in the model are given in appendix 3. The model was run to determine possible contaminant-distribution patterns in air at ground level, given various relevant meteorological conditions. Meteorological data for Lakehurst Naval Air Station, 28 mi south of IOC, were used as input to the model (app. 3).

The preliminary model was not used to quantify contaminant levels in air at ground level because no data are available on possible emissions from the stacks. Several hypothetical emissions rates ranging from 1,200 to 12,600 µg/s were used in the model to determine the distance from the stacks to the location where the maximum contaminant deposition was likely to occur.

On the basis of results of the preliminary simulation, a second air-flow model was constructed at NJDEP, Bureau of Air Quality Evaluation, to simulate patterns of dry deposition in the vicinity of IOC. Deposition was analyzed by using the Industrial Source Complex Short Term (ISCST3) model (Version 96113) with dry-deposition plume depletion algorithms (Robert Huizer, New Jersey Department of Environmental Protection, written commun., 1996). Surface-meteorological data from Newark Airport for 1984-97 and 1989 were used with concurrent upper-air data from Atlantic City Airport; terrain heights were obtained from USGS 7.5-minute quadrangle topographic maps. Because no information is available for possible stack-emissions rates, a normalized emission rate of 1 g/s was used. As with the preliminary air-flow model, the goal of this simulation of dry deposition was to determine the likely distribution pattern of contaminants (primarily arsenic) on the ground rather than to quantify expected concentrations. Details of this modeling procedure are available from NJDEP, Trenton, New Jersey.

Data Analysis

Data Conditioning

Chemical data received from the analyzing laboratory were validated by NJDEP (app. 4), and the results were transmitted to USGS. For contractual reasons, three laboratories were used to perform the TAL-metals analyses. Although the laboratories provided analysis results with instrument detection limits (IDL's) less than the contract-required detection limit (CRDL), the IDL's differed among the three laboratories. Therefore, for the purposes of statistical analysis, the highest IDL (or reporting limit) was used in every case. For some elements, most of the analysis results were reported in a range less than the IDL (that is, the values are "no detects"). These elements (antimony, beryllium, cadmium, cobalt, mercury, selenium, silver, sodium, and thallium) were excluded from the statistical analysis. Additionally, some samples were found not to be representative of the soils they were collected to represent; these are not included in the statistical analyses.

The analyzing laboratories experienced difficulties in achieving viable results for antimony and silver; many analysis results were rejected, although most concentrations apparently were less than the IDL. The complete chemical data (less antimony and silver results) are shown in appendix 1; the numbers of the samples used in the statistical analyses, including discriminant analyses and boxplots, are shown in table 3. Where spatial-replicate data for a sampling site were available, the decision to use one of each pair of replicates was random, based on a coin toss.

Data used in the statistical analysis included a few values less than the IDL. Where multiple censoring limits were present as a result of analytic instrument limitations, the highest censoring limit was chosen as the censoring threshold for the data. Any value reported that was less than the censoring threshold for that constituent was considered a "no detect." Furthermore, distributions of constituent concentrations generally were not symmetrical about the mean, but tended to be right-skewed. Therefore, rank-transformed data were used to ameliorate censoring and skewing effects. To apply a rank transformation, the largest constituent concentration is assigned a value equal to the number of measurements (N) and the smallest value is assigned a value of 1. Equal ranks between 1 and N are assigned to samples with equal concentrations.

Table 3. Soil samples for which chemical-constituent data were used in statistical analyses, Monmouth and Middlesex Counties, New Jersey

[Samples are listed by type, as follows: E, W--geologic; O, orchard; I, Imperial Oil Company Superfund site; S, adjacent woods; R, B--residential. Within each type, samples are listed by sampling-site number and soil horizon]

E1DO
E1A
E1E
E1B1
E1B2
E2O
E2A
E2B1
E2B2
E4O
E4A
E4E
E4B1
E4B2
E5E
E5B1
E5B2
E5C
E6A
E6E
E6B1
E6C
E6CL1
E7E
E7B1
E7B2
E9O
E9A
E9B1
E9B2
E9C
E11A
E11B1
E11B2
E11CL1
E11CL2
E12DO
E12DA
E12E
E12B1
E12B2
E14A
E14B1
E14B2
E15A
E15B1
E15CL1
E15CL2
E15DCL3
E16A
E16B1
E16B2
W1CL1
W1CL2
W1CL3
W1CL4
W2CL1
W2CL2
W2CL3
W2CL4
W2CL5
O1A
O1E
O1B1
O1SB1
O1B2
O2O
O2A
O2E
O2B1
O2B2
O3A
O3B1
O3B2
O4DO
O4A
O4DB1
O4B2
O4DB3
O5A
O5B1
O5B2
O5C
O6DA
O6DE
O6B1
O6B2
O7A
O7CL1
O7CL2
O8O
O8A
O8B1
O9DA
O9DB1
O9B2
O11A
O11B1
O11B2
O11CL1
O12CL1
O12CL2
O12CL3
O14A
O14B1
O14B2
O14C
O16A
O16CL1
O16CL2
I2A
I2CL1
I2CL2
I3A
I3B1
I4A
I4B1
I4B2
I4CL1
I4B3
I4B4
I5A
I5CL1
I7A
I7C1
I7B1
I7C2
I7CL1
I8CL1
I8B1
I8C1
I8C2
S1O
S1A
S1B1
S1B2
S2O
S2A
S2B1
S2CL1
S2CL2
S3O
S3A
S3B1
S3B2
S4O
S4A
S4B1
S4B2
S5O
S5A
S5B1
S5B2
S5CL1
S5CL2
S7O
S7A
S7CL1
S7CL2
S9O
S9A
S10SO
S10A
S10B1
S10C
S11A
S11E
S11B1
S11C
S12A
S12E
S12B1
S12C
S13A
S13B1
S13C
S14O
S14B
S15A
S15B1
S15B2
S16A
S16B1
S16CL1
S17A
S17B1
S19A
S19B1
S19CL1
S19CL2
S20A
S20B1
S20B2
R1DA
R1B1
R1B2
R1B3
R2A
R2B1
R2B2
R2CL1
R2CL2
R5A
R5B1
R5C
R6A
R6B1
R6B2
R6B3
R6C
R7A
R7E
R7B2
R8A
R8B1
R8B2
R8CL1
R8CL2
R9A
R9B1
R9B2
R9CL1
R9CL2
R10A
R10B1
R10CL1
R10CL2
R10C
R11A
R11B1
R11CL1
R11CL2
R11C
R12A
R12B1
R12B2
R12CL1
R13A
R13B1
R13DB2
R13B3
R14A
R14B1
R14B2
R15A
R15B1
R15DCL1
R15CL2
R16A
R16B1
R16CL1
R16CL2
R17A
R17B1
R17B2
R18A
R18B1
R18B2
R18C
R18CL1
R18CL2
R20A
R20B1
R20B2
R20B3
R27A
R27B1
R27C
R27CL1
R27CL2
R3CL1
R3DB2
R4B1
R4B2
R4CL2
R19A
R19CL1
R19CL2
R19CL3
R19CL4
R21A
R21B1
R21B2
R22A
R22B1
R22B2
R23A
R23CL1
R23CL2
R23C
R24A
R24CL1
R24CL2
B1A
B1A2
B1CL1
B1B1
B1CL2
B2A
B2B1
B2CL1
B2CL2

Because a goal of the investigation was to classify samples on the basis of their chemical characteristics, discriminant analysis (DA) was used as a classification procedure. A nonparametric discriminant model (which uses rank-transformed data) was used because of its lack of distributional assumptions regarding the variables. Given the data distribution, use of nonparametric techniques is appropriate; the shortcomings of a nonparametric model include loss of information due to rank ordering of the data and, presumably, lower power relative to a normal discriminant when applied to normally distributed data.

Statistical Analysis

The goal of the statistical analysis was to determine whether samples designated as background, orchard, or IOC endmembers could be accurately classified into those categories on the basis of their chemical signatures. If the endmember sample groups could be adequately classified, the resulting best-fit statistical model would then be used to classify unknown samples (soils from the residential areas) into one of the three endmember groups in order to determine the dominant land-use effect on the residential-soil chemistry.

Following data conditioning, descriptive statistics and graphics were computed by using the univariate procedure of SAS (SAS Institute Inc., 1990a). Variable (analyte) distributions for endmember categories were generated and illustrated with boxplots; other graphical representations of analyte distributions among and between categories also were prepared.

Nonparametric DA, a statistical classification procedure, was used to classify the groups of soil samples by chemistry. Nonparametric DA is based on the assumption that variables do not follow the multivariate normal distribution.

Nonparametric DA, as used in this study, is based on a nearest-neighbor classification method. The nearest neighbors were selected on the basis of statistical similarity of geochemical attributes. In the simplest case, a set of observations is first assigned, on the basis of prior assumptions about classification, to one or the other of two groups. Common attributes are then observed that are useful in discriminating between groups. Samples (observations) with unknown group characteristics can then be assigned to a group on the basis of how closely the attributes resemble the attribute range of one of the two groups previously identified. In other words, which group of nearest neighbors does an unknown most closely resemble?

In this study, soil samples from undeveloped forested areas (geologic + regional atmospheric inputs), from orchards (geologic + pesticide inputs), and from IOC (geologic + industrial inputs) were identified as three separate endmember groups that formed a "training" data set. A-horizon, B-horizon, and clay samples from all three groups were examined; A-horizon samples exhibited the largest differences in distribution of chemical constituents, and thus most clearly formed three separate groups, each of which has a distinctive pattern of concentrations of chemical constituents, referred to as a "chemical fingerprint" or "chemical signature."

Chemical signatures are not sharply defined because many factors affect the inputs of chemicals to soils in different land-use areas and the subsequent movement of those chemicals through the soil. Group membership in the DA models, therefore, is assigned on the basis of cross-validated "posterior probability." Cross-validation is the procedure whereby an observation is dropped from its group so that it will have no effect on the group, and then classified as an unknown to determine whether it classifies correctly. Posterior probability is the probability that a specific sample belongs to a particular category, given the signature observed for other samples (observations) in that category. Thus, a sample (observation) can have, for example, a 20-percent probability that it belongs in (hypothetical) Group I, a zero probability that it belongs in Group 2, and an 80-percent probability that it belongs in Group 3. As a result, the observation is assigned to Group 3. Observations for which the posterior probability of membership in two or more groups is equal are assigned by the DA model to an "other" category.

The discriminant models developed by using various combinations of chemical constituents as signatures of the three endmember groups were then used to classify the soil samples from residential areas 1 and 2, the woods adjacent to IOC, and the broader area.

The classification models used the nonparametric kernel-density discriminant (SAS DISCRIM) procedure. The models were fitted by assuming both equal variances and unequal variances. In addition, both constant-number and constant-radius models were tested. (These terms refer to the method of choosing neighbors of an observation in model space.) Finally, the effect of proportional rather than equal prior probabilities was investigated. (Prior, or pre-experimental, probabilities reflect the analyst's estimate of the state of the categories before observing the experimental evidence provided by the chemical concentrations.) These models were applied to ranks of individual elements as well as to principal components derived from those variables. The selected model incorporated the assumptions of equal variances, proportional prior probabilities, and constant numbers of neighbors.

Quality-Assurance Program

Objectives

The study objectives included determining (1) the concentrations of arsenic and metals in soils in several different land-use areas in order to define ranges of concentrations, and (2) the combinations of metals that could be used as chemical signatures, or "fingerprints," to identify the possible sources of arsenic and some of the metals. Therefore, quality-assurance procedures initially were envisioned as being significantly more rigorous than they would have been were the sole objective the identification of contaminant levels in soil known to be (or suspected to be) contaminated.

The initial data-quality objectives of the study, as discussed in the sampling Quality-Assurance/Quality-Control (QA/QC) workplan (unpublished document on file at the USEPA-Region II office, New York, New York) developed at the beginning of the study, required that the analytical precision should be high and that the distribution of the analyzed metals be definitive in soils from different land uses even when the metal concentrations were small. To statistically define chemical signatures of soil from different land uses, the analyses needed to be sufficiently precise to clearly distinguish among metal-concentration population distributions that might be only slightly different. Random variation introduced by imprecise measurements could result in a sufficiently large variance in the measured metal-concentration distribution in soils from the different land uses so that the populations would appear to overlap when, in fact, they were slightly different.

The quality-assurance program included in this study was designed to evaluate and ensure the precision of analyses at small concentrations; to evaluate and ensure accurate determinations of both small and large concentrations of constituents; to provide documentation for assessing performance during sample collection, preparation, and analysis; and to provide an assessment of the total measurement error or variance resulting from sample acquisition and analysis.

The analytical rigor envisioned in the sampling QA/QC workplan could not, in practice, be attained and, thus, the QA/QC goals of the study were modified to accept less precise data for further analysis. Nevertheless, the differences in chemistry of soils from different land uses were sufficiently large that a higher level of imprecision in the data could be tolerated and meaningful results achieved.

Design

No previous studies of background metal concentrations in soils in the study area are available, nor is there any documentation of the concentration ranges of metals in orchards soils in the study area. Therefore, given the possibility of overlapping concentration ranges for soils from different land-use areas, minimum analytical error was sought. Analytical error was addressed by analyzing split subsamples taken from thoroughly mixed soil-horizon samples. Splits were submitted to the analyzing laboratory as blind samples. These analysis results are reported in appendix 1. Additionally, a randomly selected split subsample from each batch of 20 samples submitted was analyzed. Analytical results for these latter splits were evaluated by NJDEP during the data-validation procedure.

In general, the analytical techniques selected can deliver a precision of about 5 percent difference from the mean. In practice, precision generally ranged from about 3 to 16 percent difference from the mean, but some of this difference may have resulted from incomplete mixing of the samples. Unlike water samples, soil samples are composed of particles, each with a particular chemistry. Although samples are thoroughly mixed during preparation for bottling, it is impossible to determine whether splits of a sample contain exactly the same number and sizes of particles of different materials. In some cases, the presence of small particles of a particular material in only one of the split samples could result in a larger variance in concentration than is related to analytical precision.

The IDL's for metals differed depending on the metal, and reporting limits differed among laboratories. In most cases, the laboratories achieved detections well below the CRDL's (table 2).

To address the issue of laboratory analytical accuracy at different concentrations, three different soil standard reference materials (SRM's) containing arsenic and metals were submitted as blind samples to the analyzing laboratory. For one SRM (1646a), no data for acid-extracted material were available, and results of the analysis of this SRM were used to check for reproducibility of analysis, much as a split sample would be used. The other two SRM's were used to check laboratory accuracy. Although many of the analyte concentrations closely matched published values for the SRM's, some values were less accurate. In general, values reported for a given analyte in this study were within the range of published values (app. 4, table 3). Some of the variance noted may be the result of differences in the method of sample preparation between the laboratories initially analyzing the SRM's and the laboratories conducting analyses for this study.

In addition to the measures described above, the analyzing laboratories spiked split subsamples and spike recovery was documented. Initial and continuing analytical-instrument calibration and methods for analyte quantification were approved by NJDEP in order to meet CRDL's; laboratory performance in meeting these requirements was reviewed and evaluated by NJDEP throughout the course of the study. The data-validation procedures performed on the analytical data by NJDEP are discussed in appendix 4.

Factors other than the precision of the analyses that may contribute to the variance in the sample population include the spatial variability of constituents in adjacent soil samples, differences in the soil matrix that result in different extraction efficiencies for metals, and variance introduced by using different sample-collection and -preparation techniques. To determine the expected variance in spatially colocated samples, spatial replicates of soil samples were collected at about 15 percent of the sampling sites. These replicates were two adjacent soil samples that were collected, processed, and analyzed independently. The relative percent difference in concentrations of selected constituents between replicate pairs is reported in appendix 4. Although the variances in metal concentrations for spatial replicates spanned a wide range, the variance for many constituents generally was smaller than the differences in ranges of concentrations for samples from different land uses.

The USEPA method for TAL-metals analysis was designed to extract solved metals efficiently and thoroughly. The analyzing laboratories spike samples with various analytes in both pre- and post-digestion phases of sample preparation. Thus, matrix effects can be evaluated on the basis of spiked-sample recovery. Evaluation of these results is part of the NJDEP data-validation process, outlined in appendix 4.

Variance that could be introduced by changes in sampling procedures and sample preparation was addressed by establishing a protocol (outlined in the sampling QA/QC workplan) developed by using "practice" samples prior to actual sample collection. Frozen ground and substantial clay lenses encountered as sampling progressed necessitated changes in sampling protocol; these changes are discussed earlier in this report. Use of the split-spoon samplers is documented in an addendum to the sampling QA/QC workplan. These minor changes in sample-collection protocol are unlikely to affect the comparability of samples, particularly as virtually all clay samples were collected with the split-spoon samplers.

The project requirement for data precision at small concentrations also necessitated the collection and preparation of soil samples by methods that minimized contamination of samples. The introduction of random, low-level metal contamination to soil samples during the sampling, preparation, and analysis procedures could result in metals-concentration data with larger variances than actually exist. Thus, low-level contamination could increase the likelihood that ranges of metals concentrations in samples from different land-use areas would overlap. The potential amount of low-level random contamination attributable to the soil-sampling equipment and procedures was documented and evaluated, as was the degree of sample contamination during sample preparation and analysis at the analyzing laboratories. The issue of contamination during sampling was addressed by collecting rinsate blanks of soil-sampling equipment by using both analyte-free water supplied by the laboratories and analyte-free water generated at the USGS, New Jersey District, laboratory in West Trenton, New Jersey. Sample-collection quality-assurance procedures are summarized below; details are presented in appendix 4. The issue of contamination during sample preparation and analysis was addressed by the laboratories by analysis of method blanks. Evaluation of results of method-blank analysis was part of the NJDEP data-validation procedure, as discussed in appendix 4.

Sample Collection and Preparation

Because accurate analyses of small concentrations of metals were required, it was essential to minimize contamination of the soil samples. In previous studies of soil-sampling equipment, NJDEP had determined that, given appropriate care in cleaning the equipment, contamination of soil samples was not detected (John Evenson, New Jersey Department of Environmental Protection, oral commun., 1995). Unlike water samples, much of which can be in contact with the sampling equipment, allowing any contamination to travel easily through the sample, very little of the soil collected by corers or split spoons actually comes in contact with the sampling equipment. Furthermore, the concentrations of most metal constituents in water samples are exceedingly small (parts-per-trillion to parts-per-billion range) relative to those in soils (parts-per-million range); hence, aqueous-concentration data can be biased high by even the slightest amount of contamination (Windom and others, 1991; Ivahnenko and others, 1996).

Procedures designed to minimize sample contamination in the parts-per-billion range were appropriate for analytical work because leachate concentrations were measured in that range and then converted to equivalent concentrations in the solid. Sampling procedures aimed at minimizing contamination in the same range also were considered adequate for collection of soil samples, which are less vulnerable to sampling and processing contamination than are water samples.

Contamination of the soil samples with metals from the sampling equipment was minimized by use of the 3-ft corers (described in appendix 2). The soil sample came in contact only with the cutter head (about 1-3/4 in. long) and the 2-ft sections of butyl acetate corebarrel liner; furthermore, only the outer surfaces of the soil grains were in contact with the equipment. A conservative estimate of the amount of sample that might be subject to contamination from contact with sampling equipment can be made by assuming that a depth equal to one-half the diameter of the largest grains (about 0.02 in., or 0.5 mm) would be affected. Using this estimate, only about 3.9 percent of the sample collected with the 3-ft corers (diameter about 2 in., or 5.08 cm), potentially could be affected by contamination. Only about 7.8 percent of the sample collected by the split spoon (diameter 1 in., or 2.54 cm) could be affected. Moreover, the first soil entering the corehead in the study area, except where a thick O horizon is present, is abrasive quartz sand that would likely remove all or most of any residue left from previously sampled material that might not have been removed by the sampler-cleaning process or metals leached from the steel equipment during washing. Additionally, the first 0.5 to 1 in. of soil at the top of the core typically was discarded, and soil clinging to the walls of the corebarrel liner was not included in the samples bottled for chemical analysis.

Equipment rinsate blanks were used to determine equipment cleanliness in a "worst-case" scenario in which all parts of the equipment were assumed to come in contact with the sample. Therefore, 1 L of analyte-free water supplied by the analyzing laboratories was poured in about 200-mL increments down the entire length of the corer or split spoon in fully assembled condition. Some of the water ran down the inside of the plastic liner, across the cutter head, and into a glass mixing bowl. About 20 to 25 percent of the water ran over the upper corebarrel threads and down along the wall of the corebarrel underneath the liner, and dripped into the glass mixing bowl. A clean plastic spatula was placed in the glass mixing bowl in which the water was collected so that all equipment used in sample preparation was touched by the water. The water was then decanted into the sample bottle provided by the analyzing laboratory, and the process was repeated until the entire liter of analyte-free water was used. A similar procedure was completed using USGS, New Jersey District, laboratory analyte-free water. One equipment blank of the exterior of a split spoon also was prepared, by pouring the water over the outside of the steel split spoon into a glass mixing bowl and then decanting it into the sample bottle. The samples were acidified to a pH of less than 2 with nitric acid for TAL-metals analysis.

Sample Analysis

The contract laboratories were required to conduct an internal quality-assurance program, which included collection and analysis of method preparation blanks, analysis of SRM's during analysis of each batch of samples, addition of a known amount of analyte spike to 1 sample of each batch of 20 unknown samples, and analysis of a split of 1 sample from each batch (New Jersey Department of Environmental Protection, 1992). Three SRM's (SRM 2711, SRM 2709, and SRM 1646a) obtained from the National Institute of Standards and Technology (NIST) were sent as blind samples to each laboratory. Lab duplicates (splits) of several samples also were sent as blind samples to the contract laboratories analyzing for metals, TOC, and sulfur. Data for splits and field replicates are presented in appendix 1. Data for SRM's and equipment rinsate blanks are presented in appendix 4.

The USGS laboratory performing total-sulfur analyses analyzed a standard soil (NIST SRM 1633b) with each batch of samples analyzed; batches typically ranged from 15 to 25 samples. At least one blank also was analyzed per batch; two blanks were analyzed with large batches.

Lead-isotope analyses were carried out in a better-than-Class 100 ultraclean laboratory by using quartz/Teflon-distilled reagents and quartz or Teflon labware. Lead in process blanks did not exceed 100 picograms. National Bureau of Standards (NBS) SRM's for lead isotopes typically were analyzed during the procedure; these include SRM 981 and SRM 982. The lead-isotope ratios measured on the samples for this study were normalized to SRM 981. Total-process blanks were collected and analyzed as well (R.W. Hurst, Chempet Research, written commun., 1996).

Air-Flow Modeling

The parameters and calculations used in the preliminary air-flow model are given in Christian (1995). A Fortran program was written to perform the calculations. To check whether the program would produce accurate simulation results, the example of contaminant-plume distribution in Christian (1995) was run. Identical results were achieved with the model as programmed by USGS personnel.

SOIL-PROFILE CHARACTERISTICS AND MINERALOGY AT SAMPLE-COLLECTION SITES

Characteristics of Soil Profiles at Sample-Collection Sites

Although the characteristics of the soil series sampled differed in some respects, certain features remained relatively constant. A typical soil profile contained a leached A horizon that was gray to dark brown, depending on the amount of organic matter present. In some soils, an E (eluviated) horizon was found below the A horizon; this was typically light gray to pale brown. Below the A or E horizon was a B horizon, where eluviated materials accumulate. The B horizons contained clays and sand grains coated with iron oxides and typically were yellowish-brown to reddish-yellow. In some soils the B horizon could be subdivided, on the basis of color changes, structure or texture, or presence of mottles.

The C horizon below the B horizon consisted of geologic materials that had undergone little of the pedogenesis that created the overlying soil horizons. In some parts of the study area, the essentially unaltered, pale yellowish-brown to whitish sands of the Englishtown Formation were encountered; in other parts, gray to brownish-gray clay lenses were found. Some of the soils sampled lacked an organic (O) horizon at the land surface because it had been removed by various human activities; other, undisturbed soils lacked a well-developed O horizon, apparently because the vegetation was too sparse to provide sufficient organic matter.

Although sampling of undisturbed soils was a desired goal, as discussed in the sampling QA/QC workplan, in practice this goal could not always be achieved.The soils sampled in the study area included some that had undergone little or no modification due to human activity, and some that had been substantially modified. The soils that had undergone substantial modification primarily were present at IOC and in residential area 1. Because the soils at IOC are disturbed in the areas sampled, some horizons are altered, obliterated, or superimposed. A horizons, whatever the local stratigraphy, were identified on the basis of texture (sandy) and color (gray to brown). B horizons, regardless of stratigraphy, were identified as sandy and orangey-brown. C horizons were identified as sandy and pale brown to whitish; geologic materials also included gray to brown clay with stringers of reddish silt.

Mineralogy of Soil Samples

Mineralogical analyses of selected soil samples were performed by the New Jersey Geological Survey (table 4). The sand- and silt-size fractions were dominated by quartz. Iron oxyhydroxide coatings of sand grains were ubiquitous in the samples. Small flakes of muscovite and fragments of lignite were abundant in most sand fractions examined in the laboratory and in the field. Metamorphic and (or) heavy minerals such as ilmenite, tourmaline, staurolite, and zircon were identified in trace amounts. A few samples contained trace amounts of a sulfide phase. Foreign materials such as brick and cinder or slag fragments also were encountered in some samples. Trace amounts of limonitic materials in small (2-3 mm) fragments with a vesicular appearance that superficially resemble the large cindery slag pieces were found in a few samples from undeveloped forested areas (Frederick R. Muller, New Jersey Geological Survey, written commun., 1996).

The dominant clay mineral in the clay fraction was kaolinite; illite and fine-grained muscovite also were present. Small amounts of glauconite were found in several samples, and chamosite also was detected in a sample (John Dooley, New Jersey Geological Survey, written commun., 1996). Of the minerals that have been determined to be present in the samples, those most likely to contribute arsenic to the soils are clays, glauconite, and sulfide minerals such as pyrite.

Some clay samples for which mineralogy was not determined were analyzed for total sulfur; those samples in which sulfur was measured at detectable levels are presumed to contain sulfide minerals. Typically, these clays also contained elevated concentrations of arsenic, such as those in samples E15 CL3, W2 Cl2, W2 CL3, W2 CL4, and E17 CL2 (app. 1).

DISTRIBUTION OF ARSENIC AND METALS IN SOILS

Vertical Distribution of Arsenic and Metals in Undisturbed Soil Profiles

For the purposes of this study, an undisturbed soil profile is defined as a profile in which all horizons that define the soil series are present and identifiable, and are in the correct sequence with depth. Undisturbed soil profiles were found primarily in undeveloped areas. Any land use that involves human activities is likely to disturb the soil profile, but these disturbances can range from relatively minor, where most of the profile is intact, to extreme, where no vestige of the original soil stratigraphy can be discerned.

The disturbance associated with agricultural land use was considered to be relatively minor, as most cultivation does not extend deeper than about 6 in., except where holes were dug to plant apple tree seedlings. The soil logs from auger samples at the edge of the mature tree canopies indicate that, with the exception of the absence of O horizons in many orchard-soil sampling sites, the soil horizons were intact. Relatively undisturbed soil profiles also were found where samples were collected under apple trees in residential area 2. Soil profiles in lawn areas distant from the apple trees showed varying degrees of disturbance; most were relatively undisturbed. Soil profiles in residential area 1 ranged from relatively undisturbed to extremely disturbed, and only one undisturbed profile was observed among the eight sampling sites at IOC.

Table 4. Mineralogy and percentage of silt and clay in selected soil samples, Monmouth and Middlesex Counties, New Jersey

[>, greater than; <, less than; %, percent; "ironstone," a colloquial term for iron oxyhydroxides of indeterminate crystallinity; N/A, not analyzed; --, not present; 1T, one-layer trigonal unit cell; 3T, three-layer trigonal unit cell; 1M, one-layer monoclinic unit cell; 2M1, 2M2, two-layer monoclinic unit cells]

Sample number	Major phases (>10%), sand size	Minor phases (2-10%), sand size	Trace phases (<2%), sand size	Silt/ clay %	Clay mineralogy
E1B1	quartz	muscovite	organic matter, ilmenite, leucoxene, feldspar, aluminosilicates, rutile, zircon, monazite, magnetite, tourmaline, staurolite	10	N/A
E2A	quartz	glauconite, organic matter	muscovite, ilmenite, rutile, leucoxene, lignite, tourmaline, "ironstone," magnetite, staurolite, hematite, aluminosilicates, monazite	15	N/A
E6B2	quartz, "ironstone"	muscovite	tourmaline, glauconite, feldspar, ilmenite, chloritoid, magnetite, rutile, leucoxene, zircon, organic matter, vivianite?	22	N/A
E11CL1	quartz, "ironstone"	muscovite, feldspar	ilmenite, tourmaline, rutile, leucoxene, organic matter	27	kaolinite, illite 2M1, muscovite 3T, glauconite 1M
E13CL	"ironstone," quartz	organic matter, muscovite	hematite, glauconite, magnetite, rutile, ilmenite, aluminosilicates, feldspar, zircon, monazite, tourmaline	85	N/A
E15CL1	"ironstone," quartz	--	muscovite, lignite, leucoxene, tourmaline, aluminosilicates, chlorite, staurolite, monazite, zircon	85	kaolinite 1T, kaolinite/smectite interstratified, illite 2M1, glauconite 1M
E15 CL2	"ironstone," quartz	muscovite	chlorite, tourmaline, lignite, aluminosilicates, rutile, zircon, monazite, ilmenite, organic matter	76	generally similar to E15CL1
E15DCL3	"ironstone," quartz, muscovite	--	chloritoid, chlorite, zircon, monazite, glauconite, magnetite, feldspar	68	kaolinite 1T, kaolinite/smectite, illite 1M, muscovite 3T, glauconite 1M
W2CL1	quartz, muscovite, lignite	chlorite	"ironstone," organic matter, aluminosilicates, tourmaline, zircon, glauconite?	80	N/A
W2CL2	quartz, muscovite, lignite	chlorite	"ironstone," pyrite, amber glauconite? tourmaline, ilmenite, zircon, aluminosilicates, monazite	95	N/A
O1E	quartz	"ironstone"	organic matter, glauconite, muscovite, lignite, ilmenite, aluminosilicates, zircon, rutile, feldspar, monazite?	13	N/A
O2E	quartz	organic matter	feldspar, lignite, ilmenite, tourmaline, muscovite, aluminosilicates, staurolite, zircon, leucoxene, rutile	7	N/A
O5A	quartz	organic matter, lignite	feldspar, ilmenite,aluminosilicates,tourmaline, muscovite, limonite, rutile, monazite, leucoxene, staurolite	16	N/A

Table 4. Mineralogy and percentage of silt and clay in selected soil samples, Monmouth and Middlesex Counties, New Jersey--Continued

Sample number	Major phases (>10%), sand size	Minor phases (2-10%), sand size	Trace phases (<2%), sand size	Silt/ clay %	Clay mineralogy
O6B1	quartz	--	organic matter, glauconite, ilmenite, tourmaline, rutile, aluminosilicates, leucoxene, magnetite, feldspar, zircon, monazite	1	N/A
O6B2	quartz	"ironstone"	ilmenite, aluminosilicates, rutile, lignite, tourmaline, feldspar, muscovite, zircon, monazite, tourmaline, magnetite, staurolite	16	N/A
O9A	quartz	feldspar	"ironstone," glauconite, ilmenite, rutile, leucoxene, magnetite, lignite, tourmaline, monazite, epidote, staurolite	30	N/A
O11B1	quartz	muscovite, "ironstone"/siderite, feldspar	glauconite, aluminosilicates, tourmaline, zircon, monazite	17	N/A
O12CL	"ironstone"	quartz	glauconite, ilmenite, tourmaline, zircon	76	kaolinite 1T, kaolinite/smectite, illite, montmorillonite, muscovite 3T,2M, tosudite
S5CL	--	quartz, muscovite	glauconite, monazite, tourmaline, lignite	91	kaolinite 1M, illite, muscovite 2M2, chlinochlore, chamosite
S10C2	quartz	--	muscovite, chlorite, staurolite, sillimanite, ilmenite, monazite	27	kaolinite/smectite interstratified, illite, muscovite 3T glauconite
S19CL2	quartz, "ironstone"	muscovite	organic matter, chlorite, rutile, aluminosilicates, tourmaline, lignite, ilmenite, zircon	80	N/A
R1B1	quartz	glauconite	organic matter, "ironstone," leucoxene, aluminosilicates, ilmenite, tourmaline, rutile, muscovite, magnetite, zircon, monazite	10	N/A
R2A	quartz	organic matter	"ironstone," glauconite, tourmaline, magnetite, ilmenite, leucoxene, rutile, zircon, monazite	21	N/A
R2 B1	quartz	glauconite	"ironstone," organic matter, magnetite, ilmenite, rutile, leucoxene, lignite, aluminosilicates, staurolite, zircon, monazite, chlorite, muscovite, feldspar	35	N/A
R2CL1	quartz	muscovite, feldspar, "ironstone," zircon	rutile, magnetite, ilmenite, sillimanite	62	kaolinite, kaolinite/smectite, illite, muscovite 3T, glauconite, palygorskite?
R3DCL1	"ironstone," quartz	slag	muscovite, lignite, glauconite, zircon	95	N/A

Table 4. Mineralogy and percentage of silt and clay in selected soil samples, Monmouth and Middlesex Counties, New Jersey--Continued

Sample number	Major phases (>10%), sand size	Minor phases (2-10%), sand size	Trace phases (<2%), sand size	Silt/ clay %	Clay mineralogy
R5A	quartz	"ironstone," glauconite	organic matter, muscovite, lignite, feldspar, aluminosilicates, ilmenite, zircon, chlorite, hematite, monazite	23	N/A
R11CL	quartz	"ironstone," organic matter, muscovite	ilmenite, rutile, tourmaline, zircon, monazite, chlorite, staurolite	86	kaolinite, illite, muscovite 3T, chlinochlore
R14B1/2	quartz	"ironstone"/siderite	feldspar, muscovite, tourmaline, glauconite, ilmenite, rutile, zircon, monazite, leucoxene, staurolite, chlorite	27	N/A
R17B1	quartz, "ironstone"	muscovite, glauconite	organic matter, tourmaline, ilmenite, aluminosilicates, feldspar, lignite, staurolite, magnetite, hematite, rutile, zircon, leucoxene, monazite	45	N/A
R21A	quartz	glauconite, slag	muscovite, coal, lignite, staurolite, tourmaline, zircon, monazite, ilmenite, feldspar	52	N/A
R23CL	quartz	muscovite	feldspar, chlorite, siderite, hematite, lignite, tourmaline, ilmenite, rutile, zircon, monazite, aluminosilicates	54	N/A
B1B	quartz	glauconite, lignite, "ironstone"	feldspar, zircon, chlorite, monazite	55	N/A
B1CL	quartz, "ironstone"	glauconite, muscovite	zircon, monazite, tourmaline	38	N/A
B2CL1	quartz, "ironstone"	glauconite, feldspar	staurolite, ilmenite, sillimanite, rutile, zircon, monazite	21	N/A

Arsenic

Arsenic concentrations in soil profiles from representative soil-sampling locations in three land-use areas are shown in figure 10a. In samples from undeveloped forest soils, concentrations of arsenic tended to be larger in the B horizon than the A horizon. The vertical distribution of arsenic in orchard soils and residential soils, which include former orchard soils, tended to differ from the distribution in undeveloped forest soils. Although arsenic concentrations in the orchard and residential soils sampled varied over a wide range (from less than 3.5 mg/kg to 149 mg/kg), the largest concentrations in orchard and residential soil profiles generally were associated with the A or, where it was identified, the E horizon. At a few sites in the residential areas, the larger arsenic concentrations were measured in samples from the upper B horizon rather than the A horizon. The sample with 149 mg/kg of arsenic is from a B horizon; however, the soil profile at this site does not appear intact.

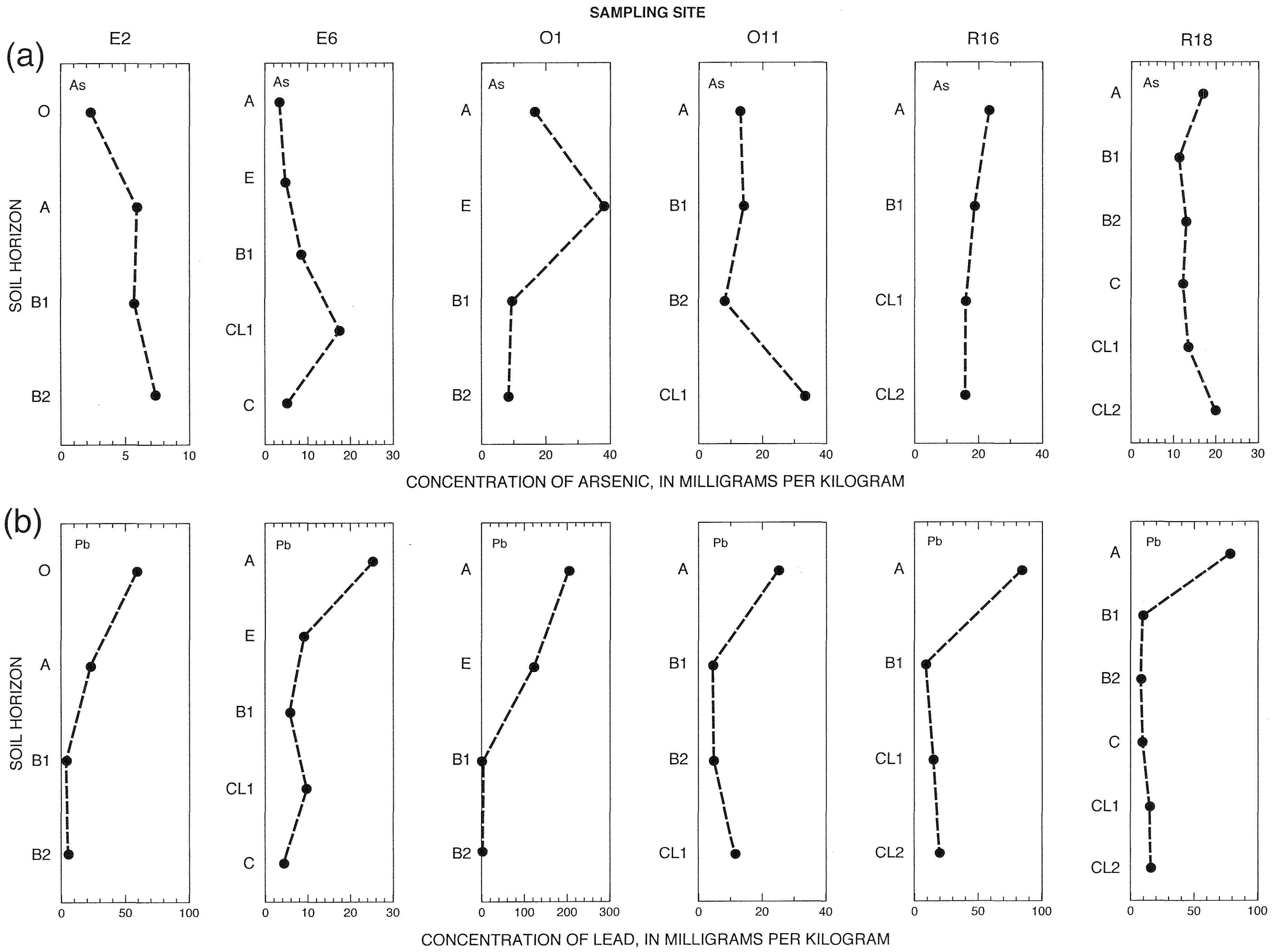


Figure 10. Concentrations of (a) arsenic and (b) lead in soil profiles from undeveloped areas, orchards, and residential areas, Monmouth and Middlesex Counties, New Jersey. (Sampling locations shown in figs. 8 and 9)

The difference in vertical distribution of arsenic in undeveloped and orchard soils indicates that, as weathering of geologic materials produces soil horizons, naturally occurring arsenic tends to remain with iron and (or) aluminum hydroxide phases and accumulates with them in the B horizon, whereas arsenic resulting from human activities, introduced at the surface most likely as arsenic (V), apparently is sparingly mobile and sorbs to organic matter or any residual clays or iron hydroxides present in A or E horizons. At some sites (R22, R9, R13, and R20), however, substantial amounts of arsenic appear to have moved to the upper B horizons. Unless the anthropogenic arsenic is mobilized by some agent such as phosphate fertilizer, as suggested by Davenport and Peryea (1991), it appears likely to remain in the upper parts of the soil profile. The amounts and types of fertilizers added are likely to have varied among the orchards sampled, and, where residential development has supplanted the orchards, among residential properties as well. Thus the amount of anthropogenic arsenic that could be mobilized by this mechanism and translocated to deeper soil horizons probably varies spatially.

In undeveloped areas, arsenic concentrations in the geologic materials below the soil column typically were small in sands (less than 10 mg/kg) but substantially larger in the clays (ranging up to 41 mg/kg). Where clays were encountered below orchard and residential soils, arsenic concentrations typically ranged from about 15 to about 40 mg/kg.

Clays in the study area can contain naturally large concentrations of arsenic and probably can trap any anthropogenic arsenic that leaches from the soil horizons above them. Wherever clay lenses were encountered during soil sampling, the clays were subsampled at the top of each clay lens and again at a location deeper within the lens (typically at the bottom of the interval sampled, or about 8 to 10 in. from the uppermost subsample) to determine whether arsenic concentration decreased with depth. If arsenic from upper soil horizons were leached and sorbed to the clay lenses at depth, clay at the top of each lens would contain larger arsenic concentrations than clay at greater depth in the lens. This vertical distribution was anticipated because water bearing arsenic in soluble form would move slowly through the clay, and movement of arsenic by diffusion would be even slower. No consistent pattern of decrease in arsenic concentration with depth in clay lenses was observed in areas where anthropogenic inputs of arsenic were likely, however.

Barium

Barium concentrations tended to be larger in samples from the O horizon than in those from other horizons in soils from undisturbed soil profiles in undeveloped areas. In orchard-soil samples, barium concentrations tended to be larger in A horizons than in underlying horizons; the same pattern was seen in samples from relatively undisturbed profiles in residential areas.

Copper

Concentrations of copper tended to be largest in O-horizon samples, and to decrease with depth in soil profiles in undeveloped areas and in the woods adjacent to IOC. Although few O horizons were found in orchard soils, copper concentrations typically were larger in samples from O horizons than in those from A horizons, and, overall, tended to be largest in samples from the shallowest horizon (usually an A horizon) and to decrease with depth. The same pattern was observed for samples from soil profiles in residential areas. In samples of the relatively unaltered geologic materials underlying the soils, clays tended to have slightly larger copper contents than sands of the C horizon.

Lead

Lead concentrations in soil profiles from representative soil-sampling locations in three land-use areas are shown in figure 10b. Lead concentrations were largest in samples from the O horizon (both O1 (organic debris) and O2 (decayed organic matter)) in forested soils, ranging up to 238 mg/kg in samples from the woods adjacent to IOC. Although few orchard soils contained enough organic matter to be considered O horizons, lead concentrations were larger in samples from vestigial O horizons than in those from underlying A horizons. Typically, the upper soil horizon in orchards was identified as an A horizon; lead concentrations were as large as 187 mg/kg in the A-horizon samples collected. Lead concentrations in samples of orchard B-horizon soils generally were less than 10 mg/kg. Although lead concentrations decreased with depth in the soil profile, they tended to range from 10 to 20 mg/kg in those locations where clays were encountered.

Zinc

Where O horizons exist (in undeveloped areas and some orchards), zinc concentrations were larger in samples from O horizons than in those from deeper horizons. Where O horizons were absent (in residential areas and some orchards), zinc concentrations were larger in samples from A horizons than in those from deeper horizons. Zinc concentrations also tended to be larger in clays than in the mineral soil horizons.

Other Metals

Iron concentrations varied widely in the soils sampled, but, at a given location, tended to be larger in the B horizon and in clay lenses than elsewhere in the soil and geologic profile. Manganese concentrations did not appear to follow a discernible pattern. Vanadium concentrations tended to follow the pattern of iron concentrations.

No patterns were discerned for chromium and nickel concentrations in the soil samples collected from the undisturbed soil profiles. Chromium concentrations tended to be larger in clays than in sands, however. Concentrations of aluminum and potassium typically were largest in samples from clay-rich horizons and clays.

Beryllium, cadmium, cobalt, and selenium were not detected in many of the samples; when detected, the concentrations generally were less than 2 mg/kg. Additionally, sodium was seldom detectable. Although most of the samples did not contain detectable mercury, the samples from both residential areas tended to contain larger mercury concentrations than any other groups of samples, including those collected at IOC during the present investigation. Results of previous sampling at IOC (E.C. Jordan Co., 1990) indicate that slightly elevated mercury concentrations were present in a few samples from the site, but that mercury is not a ubiquitous contaminant as are arsenic and several other metals.

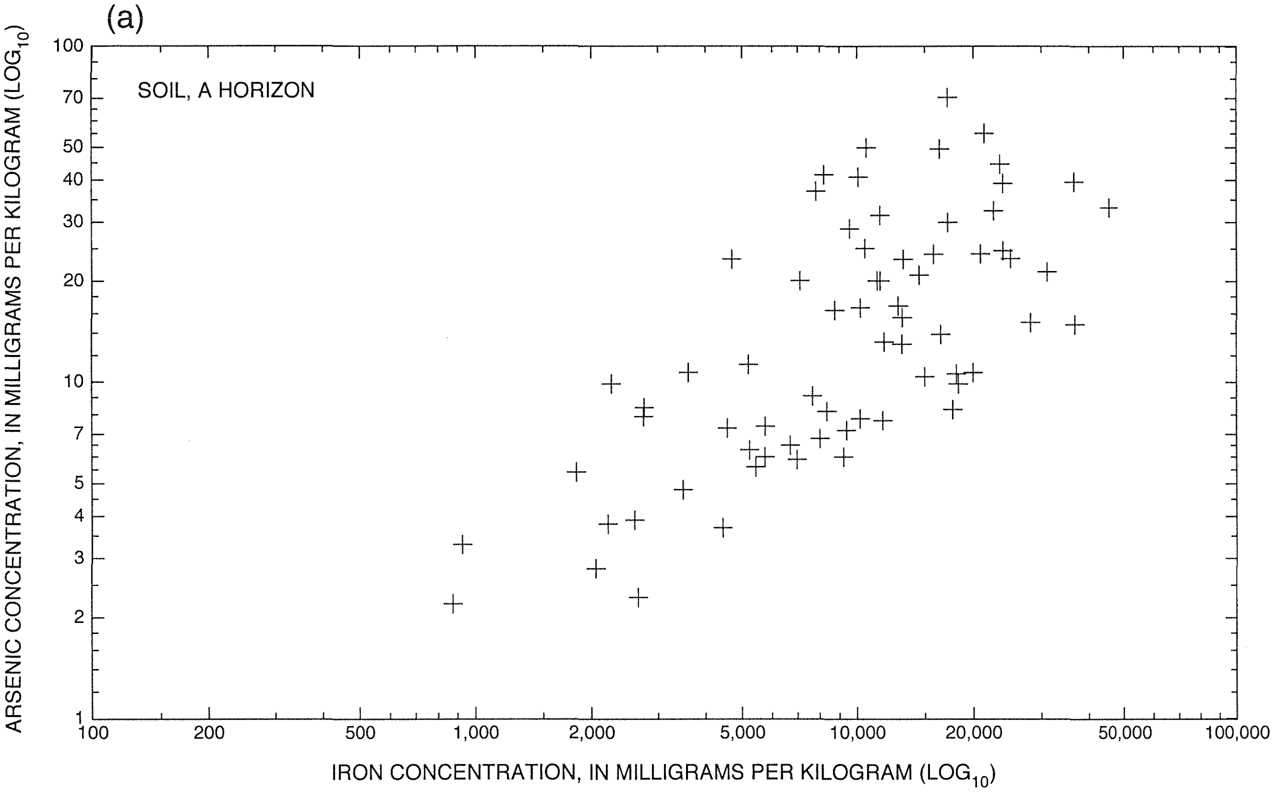
Geochemical Associations Among Selected Metallic Constituents

Concentrations of arsenic and iron were strongly associated in all soil horizons sampled, indicating that arsenic may be bound to iron oxyhydroxides that coat the sand grains and the pockets of silt in the clay lenses, and that are found as "ironstone" (iron oxyhydroxide of indeterminate crystallinity) channers (thin, flat rock fragments up to 6 in. in major diameter) throughout the soil and geologic profile. The association of arsenic with iron has been noted in several studies of arsenic in soils (Adriano, 1986).

Concentrations of arsenic also are positively correlated with those of aluminum and potassium. Adriano (1986) reports studies that indicate that arsenate ion may form compounds with aluminum; whatever the geochemical mechanism, the results of soil sampling and analysis for the present study indicate that arsenic concentrations are likely to be elevated in the clay component of soils (the primary natural reservoir of aluminum and potassium) in addition to the iron oxyhydroxide coatings on sand and silt grains. The relation between arsenic concentrations and those of iron and aluminum was particularly well demonstrated by A-horizon samples (fig. 11).

The association of arsenic with clays indicates that substantial concentrations of arsenic can occur naturally. Concentrations of arsenic in clays commonly ranged from 13 to 26 mg/kg (25th-75th percentile), and several clay samples contained about 40 mg/kg. The boxplots in figure 12 also show that B-horizon soil samples (with accumulated iron oxides and clays) typically contain larger arsenic concentrations than do A-horizon samples; the moderately large arsenic concentrations in O-horizon samples indicate that arsenic can sorb to organic matter as well. The boxplots of arsenic concentrations in the soil horizons and clays from soil cores collected in undeveloped areas shown in figure 12 illustrate that clays generally contain the largest arsenic concentrations in the samples collected.

Lead concentrations were not strongly correlated with TOC concentration in the samples collected, although the presence of larger concentrations of lead in O-horizon soils than in samples from the deeper horizons indicates that atmospherically deposited lead probably is not strongly leached from the surface by precipitation and that most lead remains bound to organic matter. Lead concentrations also tended to be large in some A-horizon soils, primarily those from orchard and residential areas. The organic-matter content of samples from A horizons generally was substantially larger than that of samples from B horizons, which would explain, in part, why concentrations of lead tended to be larger in A-horizon samples than in B-horizon samples. The lead in A-horizon soils, particularly those where O horizons are absent, probably represents mostly atmospherically deposited lead as well as any other lead compounds, such as pesticides, applied to the land surface.



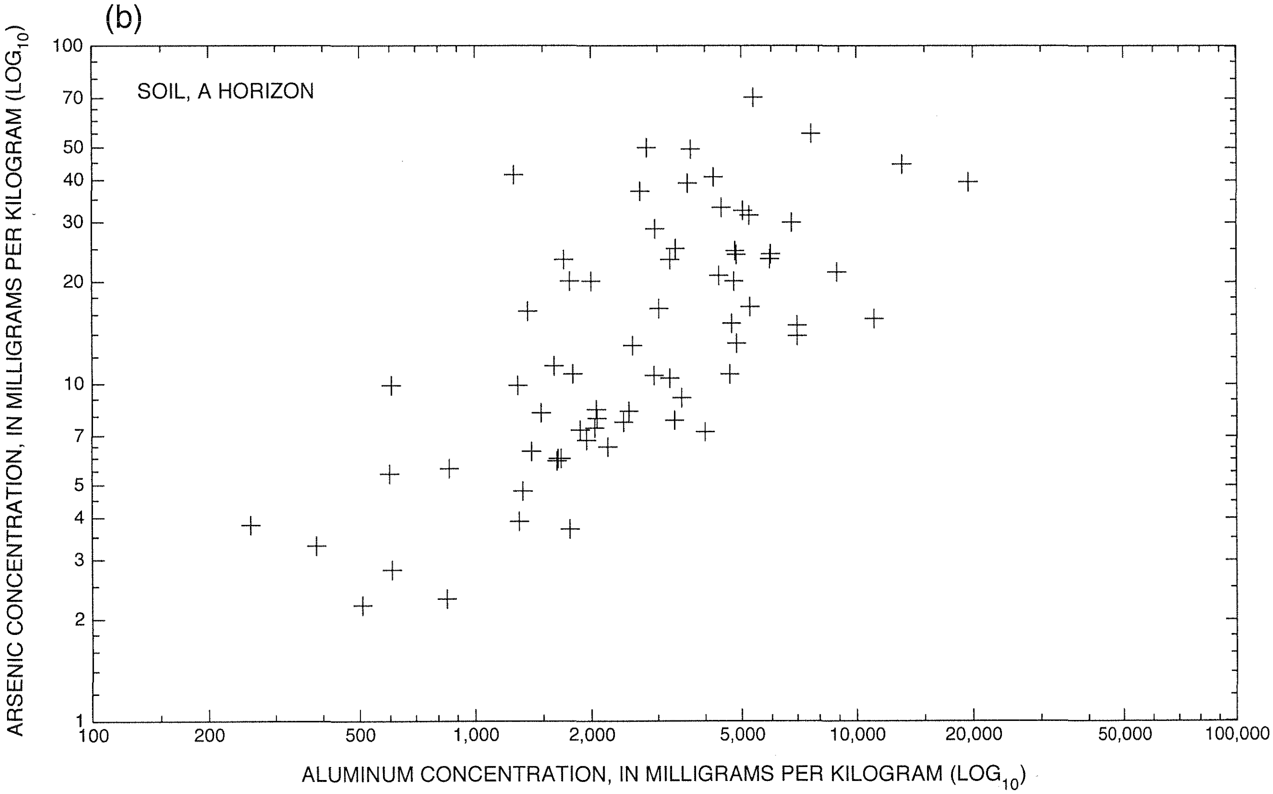


Figure 11. Relation of arsenic concentrations to (a) iron concentrations and (b) aluminum concentrations in A-horizon soil samples, Monmouth and Middlesex Counties, New Jersey.

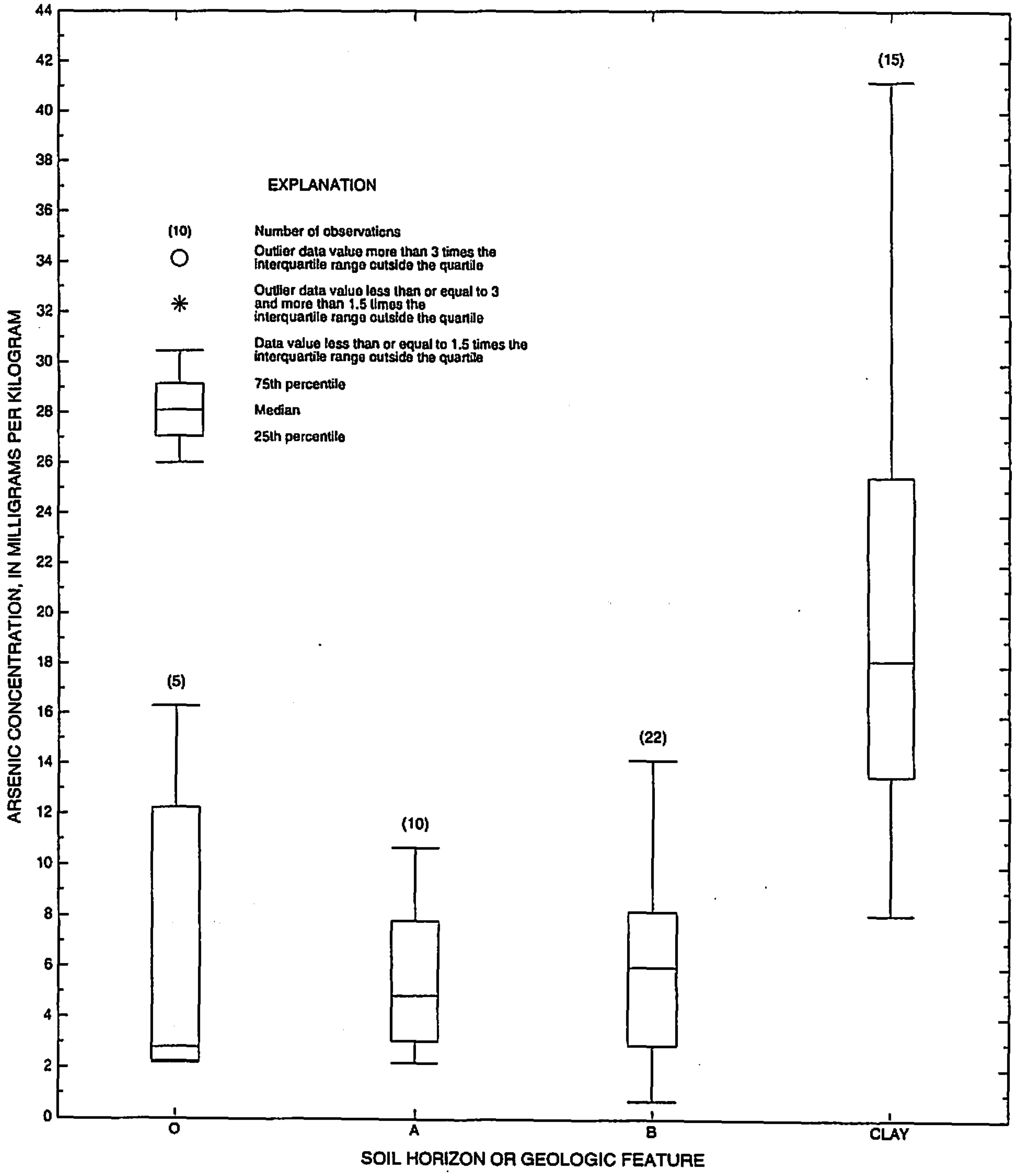


Figure 12. Distribution of arsenic concentrations in soil and clay samples from undeveloped forested areas, Monmouth and Middlesex Counties, New Jersey.

Copper and TOC concentrations were positively correlated; this relation demonstrates, as shown by studies reported in Adriano (1986), that copper tends to bind to organic matter. Concentrations of lead and copper as a function of TOC concentration in A-horizon soil samples collected from all land-use areas are shown in figure 13.

RELATIONS OF SOIL CHARACTERISTICS AND CONCENTRATIONS OF ARSENIC AND METALS TO LAND USE

The results of sampling and analysis of soils to determine concentrations of arsenic and metals in undeveloped forested areas and orchards, at IOC, and in residential areas indicate that concentrations of arsenic and of some metals can be related to land use. Moreover, some changes to natural soil characteristics are directly related to land use and can have a substantial effect on the observed distribution and magnitude of arsenic and metal concentrations in the soil samples collected during this study.

Relation of Soil Characteristics to Land Use

Absence of Soil Horizons

Although some soil series in undeveloped areas do not have discernible O horizons, O horizons are likely to form where sufficient organic matter is contributed by natural vegetation. O horizons typically were present on soils in the undeveloped forested areas from which soil samples were collected, and in the woods adjacent to IOC. In developed areas, existing O horizons typically are removed. As noted earlier, O horizons generally were absent in orchard soils and were not encountered either at IOC or in the residential areas. Lawns in residential areas may contribute sufficient organic matter so that new O horizons can form, but lawn turf was not sampled during this study. A section of lawn turf and the associated shallow soil in the root zone was removed, set aside, and then replaced during the sampling process.

The soil horizons that generally are common to all land uses investigated are the A (occasionally E) and B horizons. At some locations, however, one or more of these horizons is missing as a result of soil disturbance. In particular, the horizon sequence in soil profiles at IOC commonly was disturbed; various horizons were buried or removed. In part of residential area 1, clays from the lens beneath IOC and the surrounding area had been brought to the surface, burying either the natural A horizon or, where this had been removed, the B horizon.

Presence of Foreign Debris

Debris such as brick and coal fragments and pieces of slag or cindery material was found in both sands and clays at several of the sampling sites in residential area 1. Additionally, small, whitish fragments of what appear to be mortar and (or) roasted limestone were present in some samples. Moreover, the fragments of brick and mortar, coal, and cinders or slag material in samples of residential area 1 soils were similar to fragments and cindery slag found at depth and on the surface in samples of IOC soils (fig. 14).

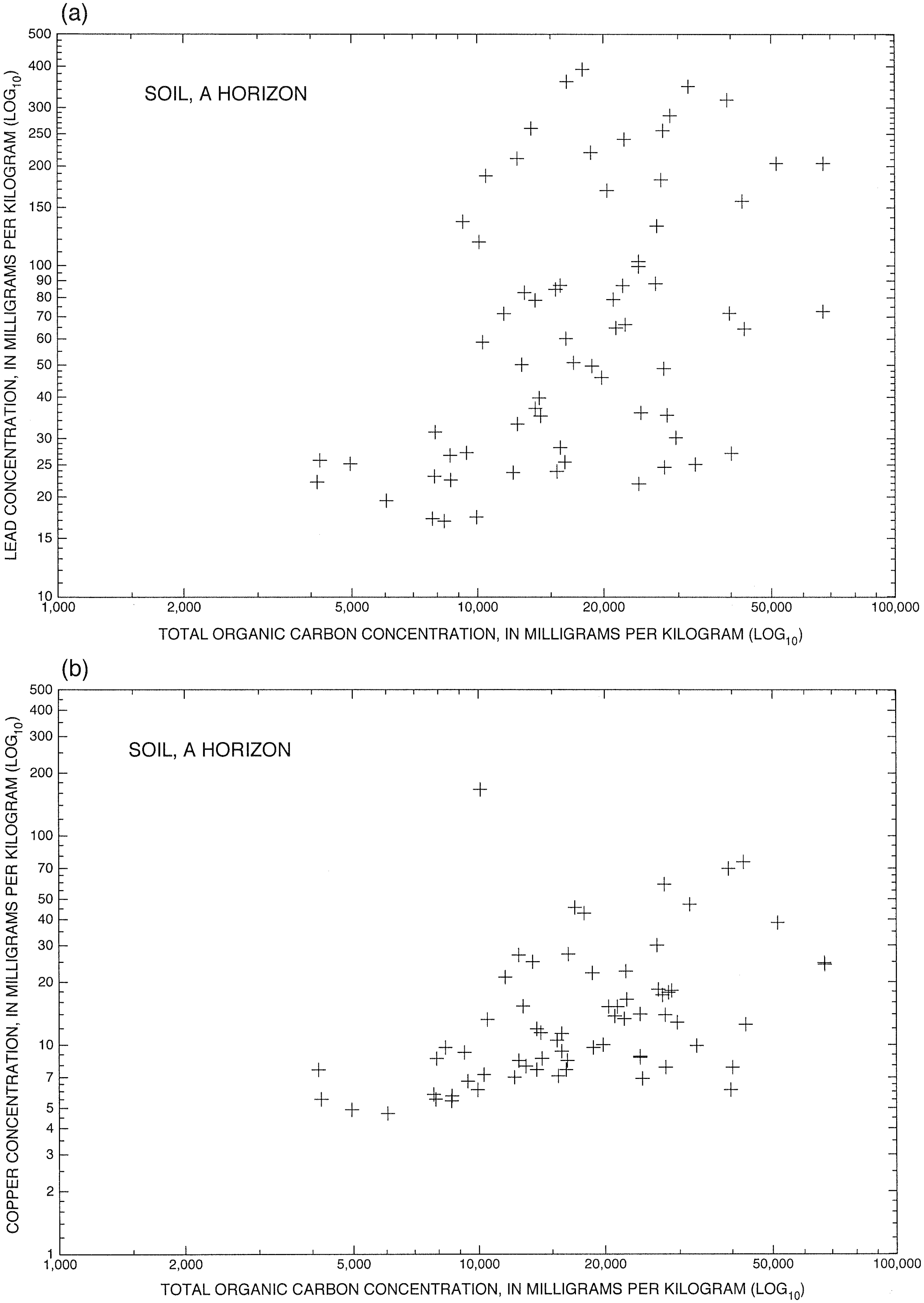
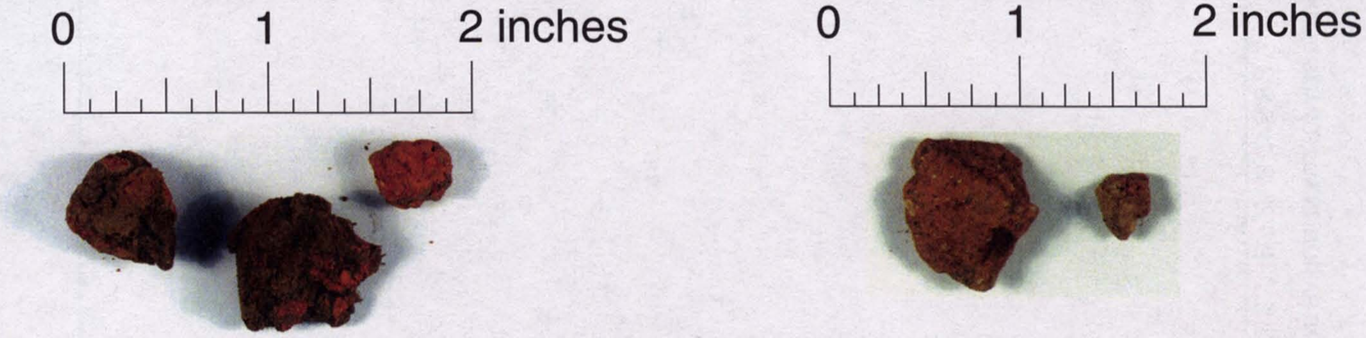


Figure 13. Relation of (a) lead concentrations and (b) copper concentrations to total organic carbon concentrations in A-horizon soil samples, Monmouth and Middlesex Counties, New Jersey.



RESIDENCE
Sampling site R-24; depth 15 in. - 20 in.
Brick fragments in gray clay

IMPERIAL OIL SITE
Sampling site I-4; depth 39 in. - 45 in.
Brick fragments from brown sand

RESIDENCE
Sampling site R-22; various depths
Slag

IMPERIAL OIL SITE
Sampling site I-4; depth 3 in. - 7 in.
Slag

Figure 14. Photographs of cindery slag and brick fragments from soils at and near the Imperial Oil Company Superfund site, Marlboro Township, Monmouth County, New Jersey.

At some point in the history of activities at IOC, clay-rich soils containing debris from IOC probably were moved offsite and onto the adjacent area that is now residential. Some sandy soils also may have been moved from the site to the adjacent residential area; debris similar to that found at IOC appears to be mixed into A-horizon sandy soils from land surface to a depth of 23 in. in residential area 1.

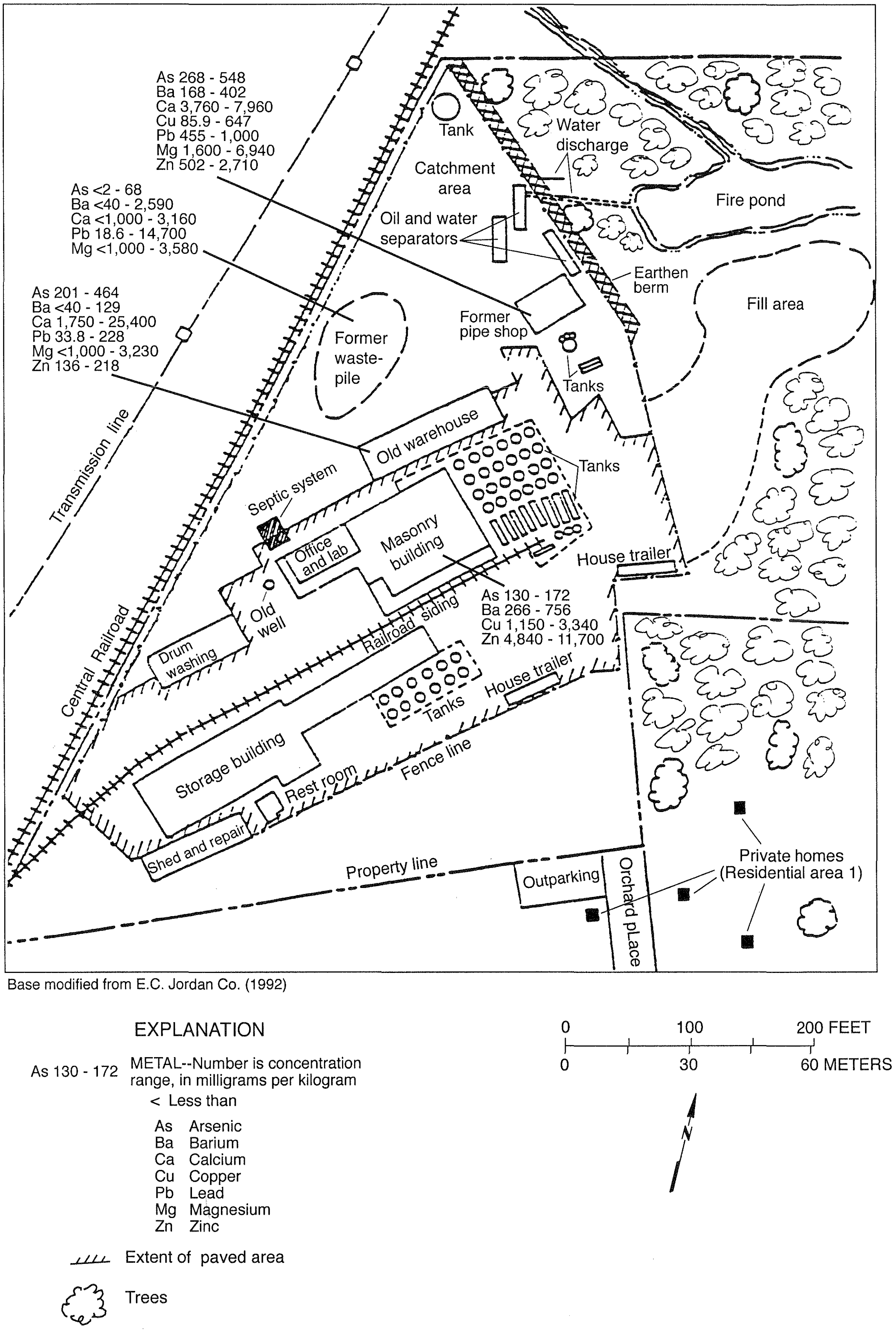
The brick fragments may be from the oldest buildings at IOC; the origin of the cindery slag fragments is unknown. The slag pieces resemble cinders from coal burning and may be related to coal-burning steam locomotives that supplied the pesticide company from the railroad siding onsite (fig. 15). Similar cindery slag is found along the tracks of the main line west of IOC, and in the large fill area east of the IOC fenceline and south of the fire pond, which contains black oil sludge as well as solid debris (E.C. Jordan Co., 1992). Several soil samples from the fill area contained arsenic concentrations that exceeded 100 mg/kg (E.C. Jordan Co., 1990). The railroad siding runs along the south side of the large brick building (referred to as the masonry building (E.C. Jordan Co., 1992)) where elevated arsenic concentrations (greater than 100 mg/kg) have been measured in sediment collected from the floor (E.C. Jordan Co., 1990). The masonry building and siding are about 300 to 400 ft from the residential properties from which soil samples containing elevated arsenic concentrations have been collected.

Whether some of the slag could have come from the ovens at the site cannot be determined at this time, as it is currently not possible to gain access to the old ovens. Two pieces of the slag, one from IOC and one from soils at a residence about 400 ft from IOC, were analyzed; they contained 55 and 72 mg/kg of arsenic, respectively (table 5).

The type of debris found in soils in residential area 1 was not found in soil samples from residential area 2. The soil profiles in the latter area retain natural horizons, particularly soils beneath old apple trees; however, the natural sequence of soil horizons could not be discerned in a few locations. The disturbed soils contain a mix of quartz pebbles and ironstone fragments similar to those found in undisturbed soils in the area. In undisturbed soils, however, the pebbles tend to be present in layers, as do ironstone channers.

Relation of Concentrations of Arsenic and Metals to Land Use

The concentrations of metallic constituents measured in soils are controlled, in part, by the materials to which they sorb. Therefore, the gross characteristics of the soil, such as the different horizons, degree of disturbance, and presence of foreign materials, can affect the observed distribution of metallic constituents. Because disturbance of natural soil horizons commonly (although not always) is the result of human activities, and metallic substances can be introduced to soils by various human activities, land use is an important explanatory variable with respect to interpretation of metallic-constituent concentrations in soil samples.



Base modified from E.C. Jordan Co. (1992)

Figure 15. Locations of buildings and other features at, and metal concentrations in soil samples from, the Imperial Oil Company Superfund site, Marlboro Township, Monmouth County, New Jersey.

Table 5. Constituent concentrations in slag from the Imperial Oil Company Superfund site and residential-area site R22, Monmouth and Middlesex Counties, New Jersey

[IOC, Imperial Oil Company Superfund site; <, less than; concentrations are in milligrams per kilogram; sampling-site locations shown in fig. 8]

Constituent	IOC slag	R22 slag	Constituent	IOC slag	R22 slag
Aluminum	582	856	Magnesium	98.8	108
Antimony	1.4	1.4	Manganese	2.8	5.4
Arsenic	75.1	55.1	Mercury	0.08	0.06
Barium	72.4	30.6	Nickel	3.1	8.3
Beryllium	0.09	0.14	Potassium	350	561
Cadmium	<0.14	0.57	Selenium	<0.98	<0.98
Calcium	386	270	Silver	<0.12	<0.12
Chromium	5.4	9.7	Sodium	221	<130
Cobalt	0.85	4.3	Thallium	<0.76	<0.76
Copper	15.1	10.2	Vanadium	3.9	21.8
Iron	2280	7010	Zinc	7.2	61.7

Imperial Oil Company Superfund Site

Because industrial activities at IOC have varied over time, it is difficult to ascribe the presence or amount of some metals in the soils there to any particular time period or activity. Nevertheless, results of previous analyses of borings into the filter-clay wastepile, of soil samples from IOC, and of sediments from within or beneath some of the buildings at the site can provide some information about the composition of materials processed at IOC during and after the production of arsenical pesticides. (The tanks, drum-washing building, shed and repair building, restroom, and house trailer shown in figure 15 all postdate pesticide production at IOC.)

Analyses of the filter-clay wastepile materials sampled in 1989 indicate that arsenic concentrations ranged from less than 2 to 68 mg/kg, barium concentrations ranged from less than 40 to 2,590 mg/kg, calcium concentrations ranged from less than 1,000 mg/kg to 3,160 mg/kg, lead concentrations ranged from 18.6 to 14,700 mg/kg, and magnesium concentrations ranged from less than 1,000 to 3,580 mg/kg (E.C. Jordan Co., 1990, app. G, table 3). Concentrations of all other constituents were within ranges of naturally occurring concentrations for soils in the area. Polychlorinated biphenyls (PCB's) and volatile organic compounds (VOC's) were detected in several of the wastepile samples.The filter-clay wastepile is associated with waste-oil-processing activities at IOC, and, according to aerial photographs, was not present in 1940, about 5 years before arsenical pesticide production ceased (E.C. Jordan Co., 1992).

In contrast to the filter clay, soils from areas of IOC near the tanks, the drum-washing building, and the septic system contained small concentrations of barium; all but one of 19 samples contained barium concentrations less than 40 mg/kg. Arsenic concentrations ranged from less than 2 to 874 mg/kg; the largest concentration was measured in a sample from orange-brown sands (B-horizon?) at a depth of 5 to 7 ft. Seven samples contained arsenic concentrations greater than 100 mg/kg; concentrations in the other 12 samples ranged up to 17.4 mg/kg. Zinc concentrations ranged from 9.8 to 156 mg/kg, with a median concentration of 71.4 mg/kg. Calcium concentrations generally were small; 11 of 19 samples contained less than 1,000 mg/kg, but a concentration of 11,900 mg/kg was reported for one sample from brown sand with brick fragments at a depth of 2 to 4 ft. Magnesium concentrations also were less than 1,000 mg/kg with one exception (1,580 mg/kg) (E.C. Jordan Co., 1990, app. E; app. G, table 3). VOC's were detected in a few samples; one sample contained low levels of PCB's (E.C. Jordan Co., 1990).

In three samples of soil collected beneath the floor of the old warehouse building, arsenic concentrations ranged from 201 to 464 mg/kg, barium concentrations ranged from less than 40 to 129 mg/kg, calcium concentrations ranged from 1,750 to 25,400 mg/kg, lead concentrations ranged from 33.8 to 228 mg/kg, magnesium concentrations ranged from less than 1,000 to 2,230 mg/kg, zinc concentrations ranged from 136 to 218 mg/kg (fig. 15), and an elevated copper concentration was measured in one sample (206 mg/kg). VOC's and PCB's also were detected in these samples. Two samples of sediment from the floor of the masonry building yielded slightly smaller concentrations of arsenic (130 and 172 mg/kg), but larger barium concentrations (266 and 756 mg/kg) and much larger zinc concentrations (4,840 and 11,700 mg/kg) and copper concentrations (1,150 and 3,340 mg/kg) than the soil samples from beneath the warehouse. Calcium concentrations were within the range of the concentrations measured in the samples from the warehouse, but magnesium concentrations were larger (7,420 and 14,600 mg/kg) (fig. 15). Lead was measured in one sample at 600 mg/kg, but was less than 40 mg/kg in the other. Additionally, chromium and nickel concentrations were about an order of magnitude larger than in the samples from other areas of IOC discussed above. In three samples of sediment from the old pipe shop, arsenic concentrations ranged from 268 to 548 mg/kg, barium concentrations ranged from 168 to 402 mg/kg, calcium concentrations ranged from 3,760 to 7,960 mg/kg, magnesium concentrations ranged from 1,600 to 6,940 mg/kg, zinc concentrations ranged from 502 to 2,710 mg/kg, copper concentrations ranged from 85.9 to 647 mg/kg, and lead concentrations ranged from 455 to 1,010 mg/kg (fig. 15). Chromium and nickel concentrations were less than those in soils from the masonry building (85.9-647 mg/kg and 24.3-260 mg/kg, respectively) (E.C. Jordan Co., 1990, app. G, table 3).

If the analytical results for the filter-clay wastepile are compared with those for soil samples and for sediments collected in or beneath the three buildings, it appears that the constituents that tended to be more abundant in the wastepile samples are barium, calcium, lead, magnesium, and zinc. The calcium and magnesium probably were contributed by the clay, the barium also may have been contributed by the clay, and the lead and zinc probably are related to the petroleum products that were passed through the filter clay. By process of elimination, arsenic, chromium, copper, and nickel are likely to be related to activities that occurred earlier than waste-oil processing, which may include roasting of arsenical copper ores. Roasting of copper ores also can release some lead and manganese (Adriano, 1986). Some calcium, magnesium, and barium also may be related to roasting activities, as limestone ($CaCO_3$, with magnesium and barium as impurities) may have been used as a flux, and, if calcium arsenate was being produced, some source of calcium would be necessary. The soils and sediments sampled in and beneath the buildings probably contain a mixture of constituents from roasting and from waste-oil processing, as do the soil samples from the tank areas, drum-washing area, and septic-system area, although the sediments in the buildings are more highly contaminated with metals than are the soils outside.

Mercury is not commonly measured in highly elevated concentrations in IOC soils. In 1989, mercury concentrations were reported as less than 0.1 mg/kg in most of the soil and sediment samples. Concentrations ranged from 0.39 to 0.76 mg/kg in sediments from the old pipe shop, from 0.18 to 0.21 mg/kg in sediment from the masonry building, and from 0.15 to 0.22 mg/kg in soils from the various tank farms (E.C. Jordan Co., 1990). A slightly larger concentration range is reported for soils from beneath the old warehouse (0.13-1.1 mg/kg) (E.C. Jordan Co., 1990).

Study Area

Insufficient samples were collected from O-horizon soils in the various land-use areas during this study to perform meaningful statistical analyses of the chemical constituents therein. The most apparent differences in metal concentrations in soils among land-use categories were in A-horizon soil samples. Concentrations of arsenic and metals in B-horizon soil samples differed among land uses, but the differences were less distinct than those seen in A-horizon soil samples, and preliminary statistical models do not adequately classify each of the endmember land uses using B-horizon metal-concentration data. Chemistry of clays from different land-use areas was similar, except for that of a few samples from IOC. Therefore, the geochemical relations illustrated in element-element plots and the statistical models developed to create the chemical signatures of soils from each land-use type are based on data from the A horizons.

Because the soils at IOC are disturbed, the grouping of the soils sampled there into soil horizons is arbitrary and is based primarily on characteristics such as color and texture, regardless of stratigraphy. A-horizon soils could be identified on the basis of their sandy texture and gray to brown color. A few B-horizon soils were identified by a higher proportion of clay to sand than that found in A-horizon soils, and also by an orangey-brown color. C-horizon soils are identified by their sandy texture and tan color. In the following discussions of the relation between concentrations of selected constituents and land use, results of analyses of A-horizon soil samples are emphasized.

Arsenic

The distribution of arsenic in soil samples from various horizons in undeveloped forested areas, orchards, and IOC is shown in figure 16. Concentrations in samples from the soil horizons in undeveloped areas were small (typically less than 10 mg/kg) compared with those in samples from orchards and IOC. The range of concentrations of arsenic in the A-horizon samples from orchard soils overlapped the arsenic concentrations found in A-horizon samples from undeveloped areas, but both maximum and median values of arsenic in orchard A-horizons soils were larger than those in undeveloped-area A-horizon soils.

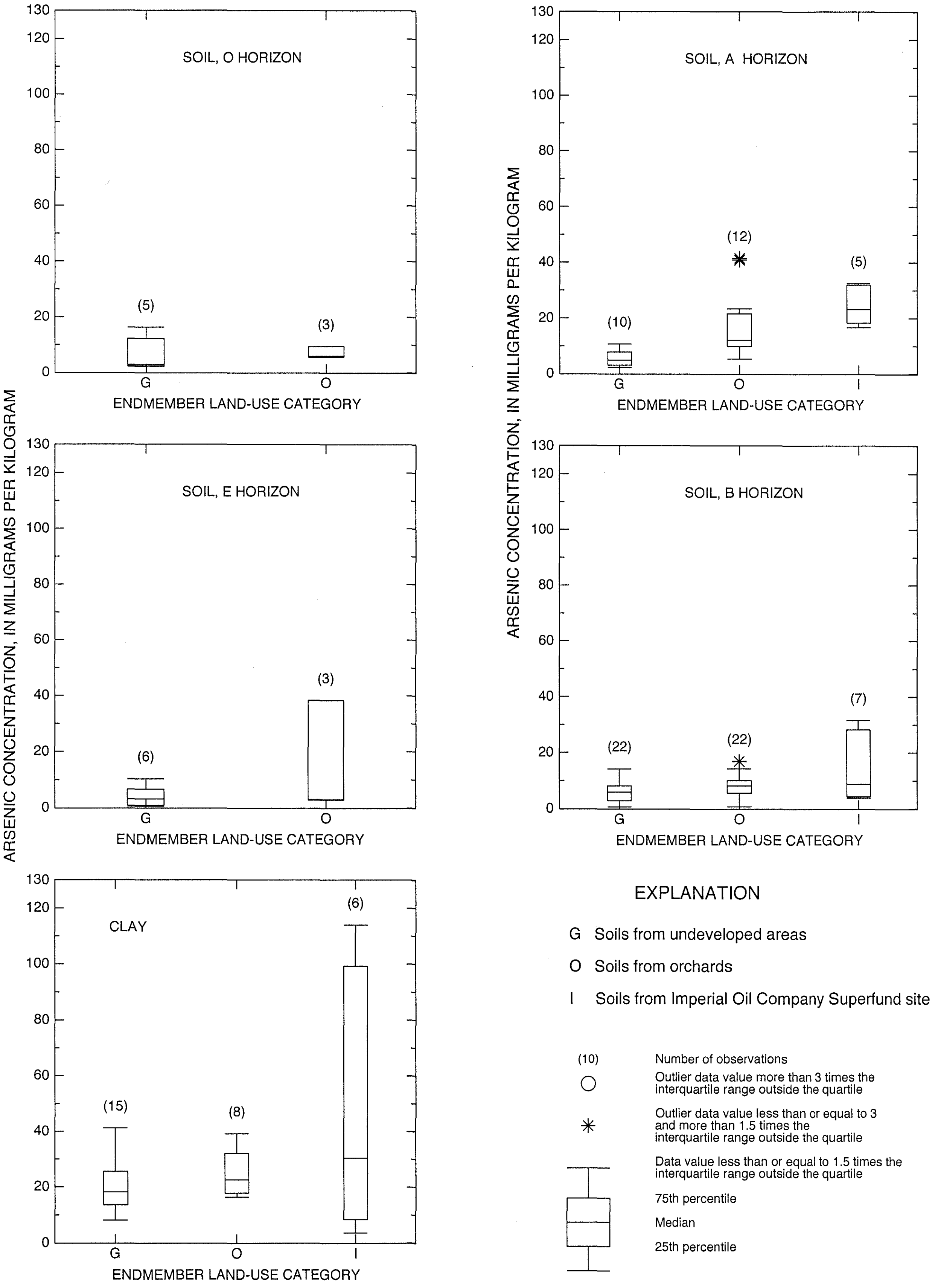


Figure 16. Distribution of arsenic concentrations in soil horizons and clays, by endmember use, Monmouth and Middlesex Counties, New Jersey.

Median values and ranges of arsenic concentrations measured in A-horizon soils from undeveloped and orchard areas, IOC, the woods adjacent to IOC, and the residential areas are shown in table 6. All land-use categories include minimum arsenic-concentration values that could be considered natural, with the possible exception of residential area 1, where the smallest arsenic concentration (20 mg/kg) in the A-horizon samples was smaller than the arsenic concentrations in several clay samples, but larger than those in sandy A-horizon samples from undeveloped areas. The silt in the A-horizon soils at residential area 1 may account for slightly larger arsenic concentrations, but, given the presence of debris in these soils, the contributions from natural and anthropogenic sources cannot be differentiated.

Table 6. Arsenic concentrations in A-horizon soil samples from four land-use categories and woods adjacent to the Imperial Oil Company Superfund site, Monmouth and Middlesex Counties, New Jersey

[IOC, Imperial Oil Company Superfund site; concentrations, in milligrams per kilogram, are rounded to the nearest whole number; number in parentheses is number of samples]

	Undeveloped (12)	Orchard (12)	IOC (5)	Woods adjacent to IOC (17)	Residential area 1 (5)	Residential area 2 (19)
Maximum	11	42	32	15	45	70
Median	5	12	24	7	30	25
Minimum	2	5	6	3	20	7

The median arsenic concentration in the A-horizon samples from the woods adjacent to IOC was slightly larger than the median concentration determined for samples from undeveloped areas. The median arsenic concentration in orchard samples was larger than the median values for soil samples from either undeveloped areas or the woods adjacent to IOC. The maximum values for these three groups exhibit the same relation. Nevertheless, the largest arsenic concentration measured in orchard soils in this study (about 42 mg/kg) was substantially smaller than the smallest concentration reported for orchard soils in New Jersey in an earlier study, in which total arsenic in field soils ranged from 92 to 270 ppm (mg/kg) (Walsh and Keeney, 1975). These investigators also report a larger range of concentrations (48-2,553 ppm) for orchard soils in the State of Washington.

The observed range of arsenic concentrations in orchard soils is the result of factors such as the period of time in which the orchard was active and the amount of arsenical pesticides applied by individual farmers. The location of the soil-sampling site relative to an individual tree also could be a factor, as agricultural chemicals such as pesticides and lime tend to be concentrated within the drip-line of the tree canopy, rather than widely broadcast (John Hauser, local farmer, oral commun., 1996).

Concentrations of arsenic in soils from the orchards that were determined on the basis of aerial photographs to have been active in the 1930's through the 1940's tended to be larger than those in soils from orchards that were not active until the 1950's. This difference in arsenic concentration presumably reflects the phasing out of arsenical and other metal-containing pesticides in favor of organic pesticides, which gained in popularity following World War II. Although use of lead arsenate in orchards has declined, use of organic arsenical herbicides for weed control on turf as well as on citrus and cotton crops increased during the 1970's (Adriano, 1986).

Arsenic concentrations in the A-horizon soil samples (sands with variable amounts of silt and clay) indicate that the median arsenic concentration in samples from IOC was larger than the median concentrations for samples from all other land-use groups, except samples from the residential-area groups, where the medians were slightly larger. Additionally, the maximum arsenic concentrations measured in A-horizon soils were in samples of residential soils. A comparison of arsenic concentrations in soils at IOC with those in residential soils must take into account soil characteristics, however.

Clays were encountered at various depths in the soil cores collected at IOC. At some sampling locations, they may represent deposits at the surface from excavation activities or wastes from industrial activities at the site. Concentrations of arsenic in the sandy layers vary, and some are within the range measured in samples from undeveloped areas, which represent natural conditions. Arsenic concentrations in the samples from IOC tended to be largest in the clays; elevated concentrations also were measured in some samples that contained cindery slag and brick fragments.

None of the samples collected at IOC during the present study contained arsenic concentrations as large as those measured previously in the northern and eastern parts of the site, which ranged up to 198 mg/kg in surficial samples (0-2 ft below land surface) and from 231 to 812 mg/kg in three samples collected from 2 to 5 ft below land surface (E.C. Jordan Co., 1990). Selection of appropriate sampling locations for IOC soils was difficult because the soils were disturbed, information about activities involving soil movement was lacking, and, consequently, the constituent concentrations varied greatly over short distances, both vertically and horizontally. Many of the samples collected are soils that contain a mixture of debris, some of which appears to be traceable to early activities at the site--that is, brick, slag or cinders, and what appear to be mortar or roasted-limestone fragments. These soils, then, are appropriate for comparison with soils from residential area 1, where similar debris is present and arsenic concentrations are generally in the same range.

One soil core was collected during this study in a wastepile deposit of the oil-soaked filter clay from the tanks used during the waste-oil reprocessing activities at IOC. Arsenic concentrations in subsamples of the filter clay are not shown in figure 16, as the filter clay is not part of the local soil. Nevertheless, arsenic is present in the filter clay; in the samples collected during this study, arsenic concentrations ranged from 4.4 mg/kg at the bottom of the 4-ft augered hole to 41.3 mg/kg at the top of the hole. Given that the arsenic concentrations decreased with depth in the core, the arsenic in the filter clay may be derived from arsenical debris previously deposited at the site. At the hand-specimen level, the filter clay is distinctive and is unlike any of the naturally occurring clays in the study area. The filter clay has not been identified in any other samples collected during the present study, but, if dusts from the wastepile had blown onto adjacent properties, small particles of filter clay would probably be indistinguishable in the matrix of local soils except, perhaps, at the microscopic level.

Concentrations of arsenic in soil samples from residential areas 1 and 2 were large relative to those in samples from the woods adjacent to IOC (fig. 17), which were similar to those in samples from undeveloped areas (fig. 16). Although the median arsenic concentration in A-horizon soils from the woods adjacent to IOC was slightly larger than the median arsenic concentration in A-horizon soils from undeveloped land, many of the soil samples from the woods adjacent to IOC contained arsenic in concentrations that were not significantly different, statistically, from those in soils from undeveloped areas. Exceptions are samples from an area about 500 ft north-northeast of the fenceline at IOC that formerly was orchard land. Arsenic concentrations were slightly larger in two A-horizon samples (S16A, 10.6 mg/kg; S19A, 15.1 mg/kg) than in the rest of the A-horizon samples from the woods adjacent to IOC, where arsenic concentrations all were less than 10 mg/kg. Surficial soils in the woods adjacent to IOC, which lie between IOC and residential area 2, generally do not contain elevated concentrations of arsenic and metals that can be attributed to fallout from a smokestack plume.

Arsenic concentrations in soils from the two residential areas generally overlap concentrations found in orchard soils and in soils onsite at IOC. In residential area 2, arsenic concentrations in A-horizon soil samples (sites R6 and R11) from two properties that border the former orchards were smaller than arsenic concentrations in A-horizon soil samples from elsewhere in this area; on the basis of aerial photographs, R6 and R11 are not located on former orchard land. The spatial distributions of arsenic in the A horizon in the vicinity of IOC and in the study area more than 0.5 mi from IOC are shown in figures 18 and 19, respectively.

Arsenic concentrations did not differ substantially among clay samples from undeveloped areas, orchards, and the woods adjacent to IOC (table 7). The arsenic concentrations in clay samples from the woods adjacent to IOC were in the range of naturally occurring concentrations in clays, as were those in samples from clays underlying orchards, although the median arsenic concentration in clay samples from orchards was slightly larger than that in clay samples from undeveloped land or the woods adjacent to IOC.

Table 7. Arsenic concentrations in clays from four land-use categories and woods adjacent to the Imperial Oil Company Superfund site, Monmouth and Middlesex Counties, New Jersey

[IOC, Imperial Oil Company Superfund site; concentrations, in milligrams per kilogram, are rounded to the nearest whole number; number in parentheses is number of samples]

	Undeveloped (20)	Orchard (9)	Imperial Oil Company (IOC) (6)	Woods adjacent to IOC (9)	Residential area 1 (14)	Residential area 2 (21)
Maximum	41	39	114	25	156	42
Median	19	22	30	15	47	18
Minimum	8	14	4	3	12	11

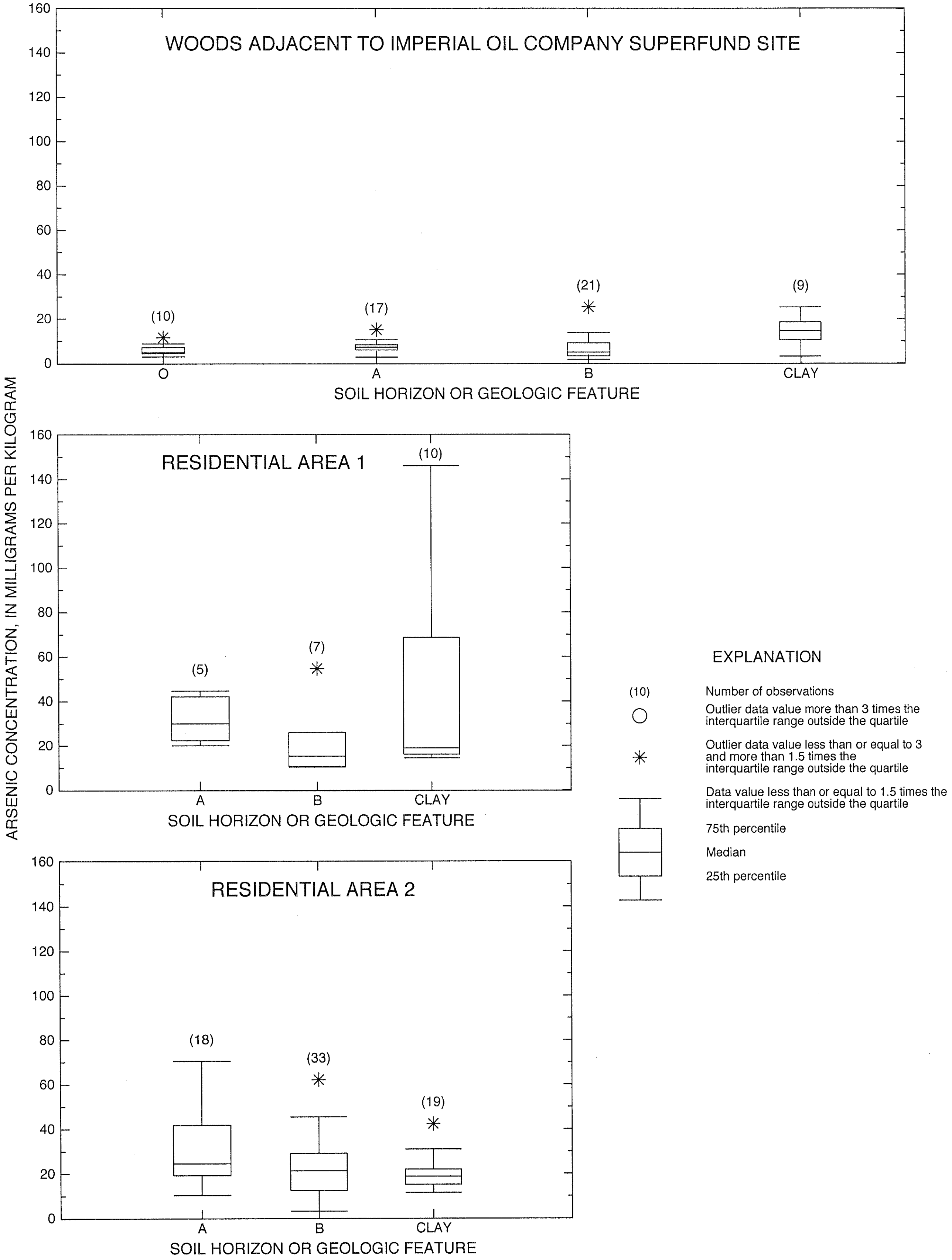


Figure 17. Distribution of arsenic concentrations in soil horizons and clays in woods and residential areas adjacent to and near the Imperial Oil Company Superfund site, Marlboro Township, Monmouth County, New Jersey.

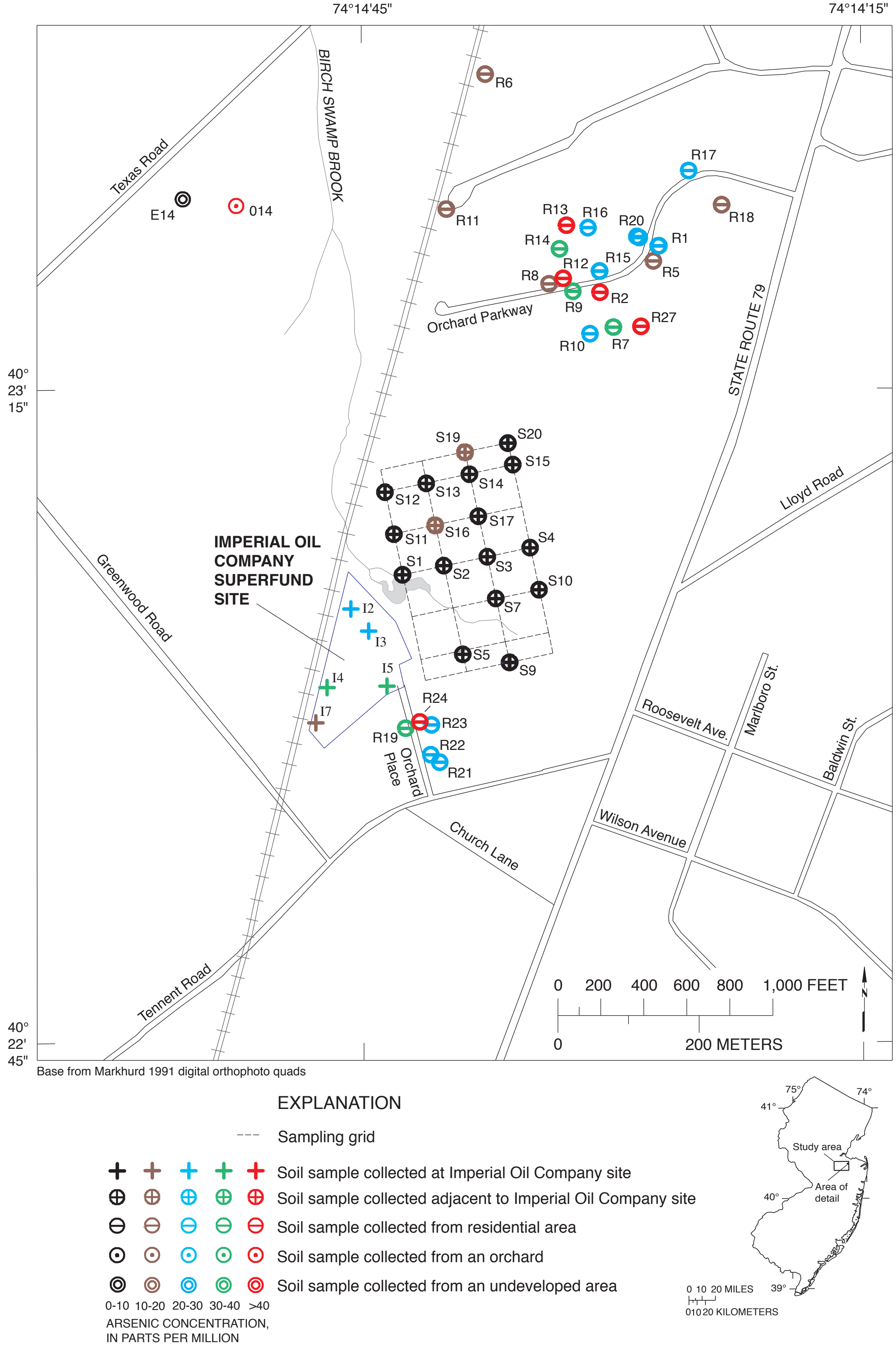


Figure 18. Arsenic concentrations in A-horizon soils in the vicinity of the Imperial Oil Company Superfund site, Marlboro Township, Monmouth County, New Jersey.

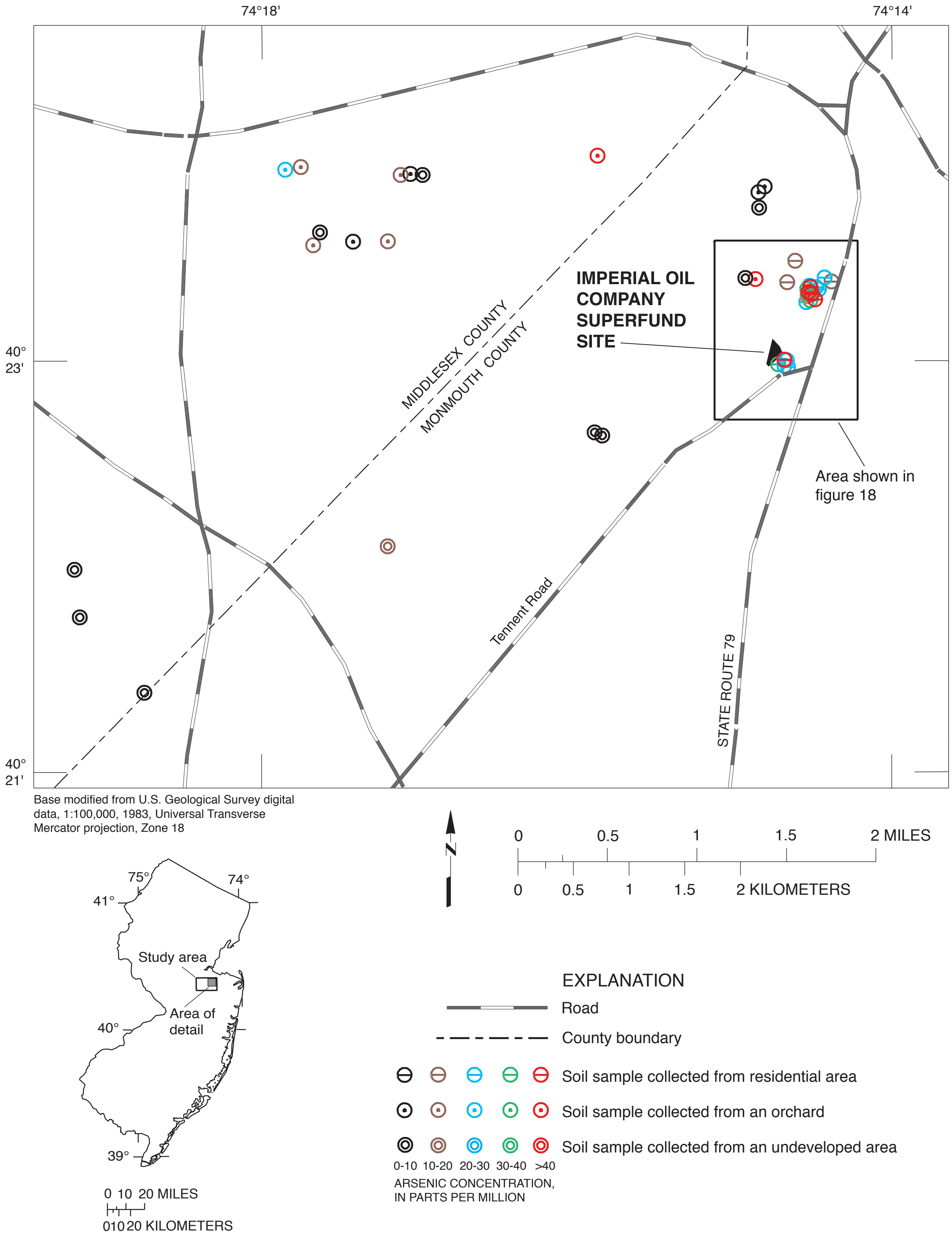


Figure 19. Arsenic concentrations in A-horizon soils more than 0.5 mile from the Imperial Oil Company Superfund site, Marlboro Township, Monmouth County, New Jersey.

Arsenic concentrations in clay samples collected beneath residential area 2 typically ranged from about 11 to about 25 mg/kg, although concentrations in two samples were about 31 and 42 mg/kg. The largest concentrations of arsenic measured during this study were those in clay samples from IOC and from a wooded area on a residential property immediately adjacent to IOC (sampling site R3). The clay at R3 contained many pieces of cindery slag to about 20 in. below land surface.

Overall, arsenic concentrations in soils from residential area 1 tended to be largest in those samples in which slag or cinder pieces are most abundant. Concentrations in soils from residential area 2 were largest in samples from soils beneath some of the apple trees and from some areas where the soils appear to have been disturbed by earth-moving activities. No foreign materials such as the slag/cinder fragments or coal found in soils at residential area 1 have been identified in the soils from residential area 2. The B-horizon soil sample from the broader area that contained 149 mg/kg arsenic is from a site where some of the natural soil horizons appear to be disturbed.

Barium

Barium concentrations in soil samples from undeveloped areas generally were less than 10 mg/kg, except in O-horizon and clay samples, where the concentrations ranged from about 10 to about 40 mg/kg (fig. 20). A similar range of concentrations was found in samples from orchard soils. Some soil samples collected from IOC, however, contained larger barium concentrations (up to 204 mg/kg) than soils from undeveloped or orchard areas; these IOC samples also contained elevated arsenic and (or) lead concentrations. The largest barium concentrations in samples from IOC (714-2,290 mg/kg) were measured in the filter clay.

Barium concentrations in soils from residential area 1 ranged from 18.2 to 166 mg/kg; the larger concentrations tended to be present in A-horizon soil samples. The large barium contents of the soils in residential area 1 probably are not due solely to a high clay content relative to that in other soils sampled, because the barium concentrations in some of the sandy A-horizon samples, in particular, were substantially larger than the barium concentrations not only in A-horizon samples collected elsewhere, but in clay samples as well. The A horizons in soils from residential area 1 typically contained some slag or cinder debris and, in some instances, brick fragments. The elevated barium concentrations in soils of residential area 1 may be related to the transport of contaminated soil to the residential properties as part of the debris that apparently originated at IOC.

The elevated barium concentrations (3.2-204 mg/kg) in soil samples from IOC may derive from the filter clay used in waste-oil processing or from limestone used in the ore-roasting process; calcium concentrations in IOC soils also were large. Furthermore, the barium contents of the two slag samples from IOC and residential area 1 (30.6 and 72.4 mg/kg) also were large, as were barium concentrations in samples of sediment collected in 1989 from buildings onsite, the masonry building, the pipe shop, and the old warehouse (168-756 mg/kg) (E.C. Jordan Co., 1990).

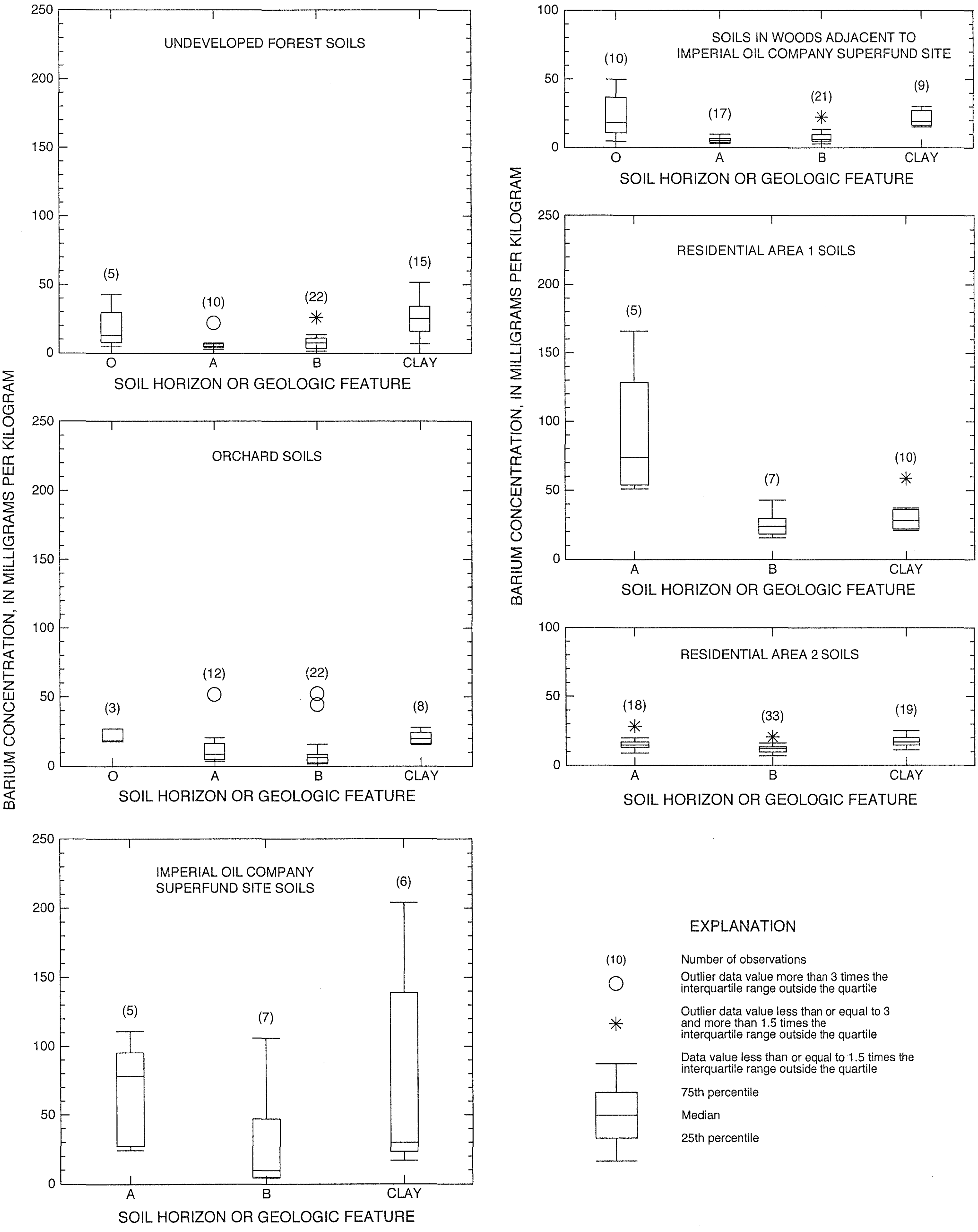


Figure 20. Distribution of barium concentrations in samples from soil horizons and clays by land use, Monmouth and Middlesex Counties, New Jersey.

Overall, the soil samples from residential area 1 contained barium in concentrations that typically were larger than those measured in the soils from residential area 2 (fig. 20). Barium concentrations in residential area 2 soil samples tended to be between 10 and 20 mg/kg; these are similar to the concentrations found in samples of some orchard soils and the more clay-rich horizons of soils from undeveloped areas.

Copper

Copper concentrations in samples from O horizons of soils in undeveloped areas tended to be larger than those in samples from the other horizons (maximum 38 mg/kg) (fig. 21). Copper concentrations in samples from undeveloped areas generally were slightly larger in clays than in the sandy soil horizons. Copper concentrations generally were larger in samples of A-horizon orchard soils (4.9-24.3 mg/kg) than in samples of A-horizon soils from undeveloped forested areas (5.5-15.2 mg/kg), possibly as a result of the use of copper-bearing pesticides, such as Paris Green ($C_4H_6As_6Cu_4O_{16}$), in orchards or of the addition of copper, typically as copper sulfate, to soils as a micronutrient (Adriano, 1986).

Copper concentrations in soil samples from IOC vary widely (0.48-167 mg/kg); the largest copper concentration measured during this study was in soils sampled at IOC (167 mg/kg). A concentration of 1,020 mg/kg in a surface soil sample from an area north of the old warehouse at IOC was reported previously, and copper concentrations in sediment samples, both sandy and clayey, from the floor of the masonry building, the pipe shop, and beneath the old warehouse were highly elevated (85.9-3,340 mg/kg (E.C. Jordan Co., 1990)). The ores processed at IOC are believed to have been arsenical copper sulfides (Steven Byrnes, oral commun., 1996); elevated copper concentrations in IOC soils and in the sediments in the old buildings there probably are related to ore-processing activities, as discussed earlier.

Copper concentrations in soil samples from the residential areas were larger than those in soil samples from undeveloped forested areas. In residential area 1, copper concentrations ranged from 3.8 to 69.9 mg/kg in all horizons and clays sampled; copper concentrations in most of the samples ranged from 10 to 20 mg/kg. Concentrations of copper in residential area 1 soils were largest in A-horizon samples (30.0-69.9 mg/kg). In residential area 2, copper concentrations commonly were larger in A-horizon soil samples (9.7-42.7 mg/kg) than in samples from B and C horizons (0.74-33.7 mg/kg); the largest concentration was measured in an A-horizon sample that also contained 70.5 mg/kg of arsenic.

Lead

Elevated (greater than natural geologic) lead concentrations in soils, even in undeveloped areas, result from regional atmospheric fallout, which derives from industrial emissions and, until recently, gasoline-powered vehicle exhaust. Several studies have shown that this atmospheric lead accumulates in the O horizons of soils (Siccama and others, 1980; Friedland and others, 1984; Friedland and Johnson, 1985). The lead measured in O-horizon soils in the study area probably removed, such as orchard and residential soils, would contain more lead derived from atmospheric fallout than soils in which the O horizon has been preserved because the lead that

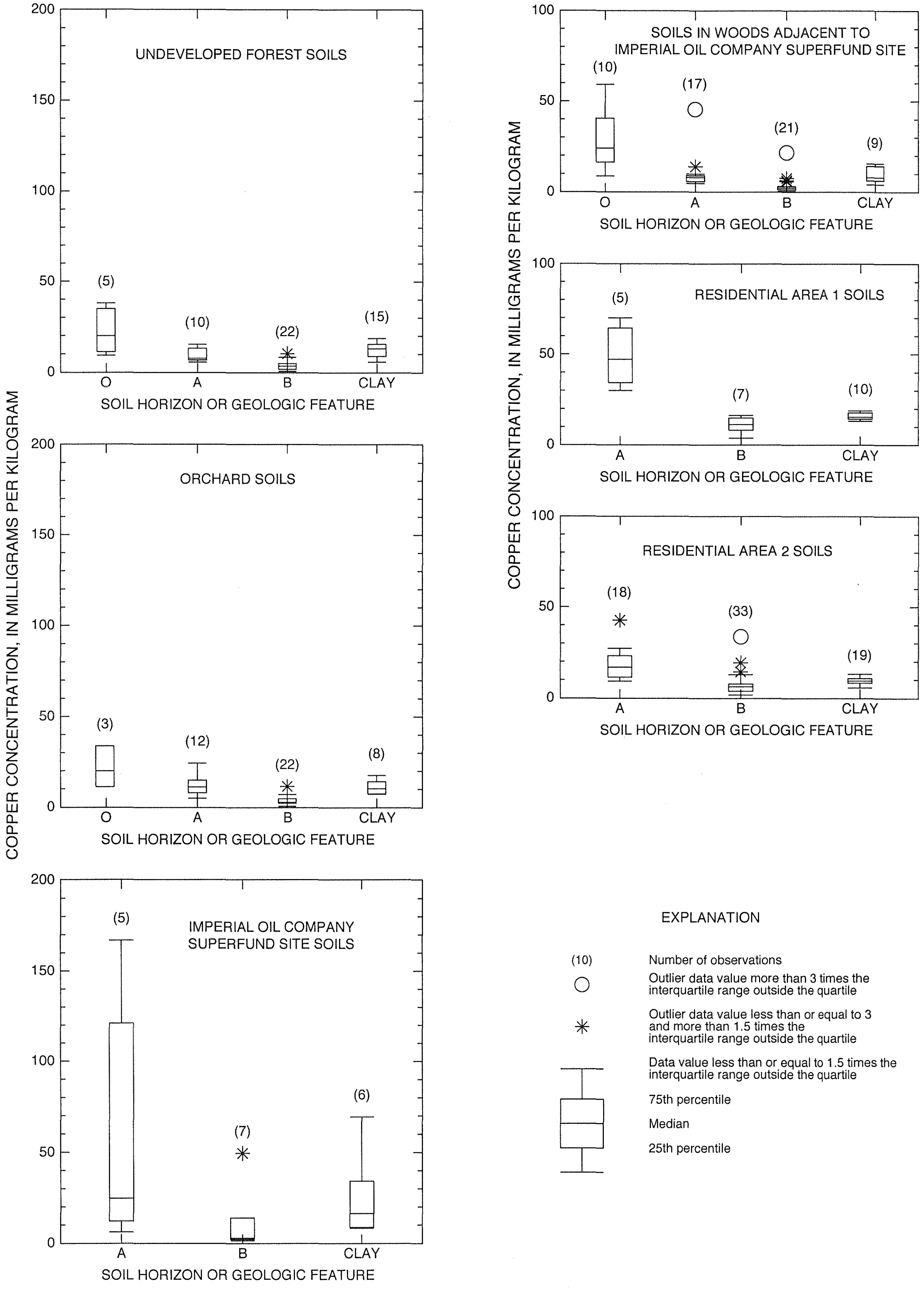


Figure 21. Distribution of copper concentrations in samples from soil horizons and clays by land use, Monmouth and Middlesex Counties, New Jersey.

accumulated before soil-churning activities would have been removed with the O horizon. Therefore, lead in A horizons of soils developed for orchard or residential use would include any atmospheric lead accumulated since the removal of the O horizon as well as any other surficial inputs associated with the presence of orchards or residences, such as the application of pesticides containing lead.

Lead concentrations in samples from the O horizons of soils on undeveloped land were smaller than those in samples from the O horizons of soils on orchard land, and the median concentration of lead for A-horizon samples from undeveloped soils was smaller than the median concentration for A-horizon samples from orchard soils (fig. 22). These concentrations indicate that pesticides containing lead may have been used on at least some of the orchard soils sampled. Coupled with anecdotal evidence from area farmers that lead arsenate pesticides were used on orchards, these soil lead-concentration data indicate that pesticide residues can be found in soils from former orchards, including residential areas built on former orchard land.

The range of lead concentrations in A-horizon soil samples from IOC (6.1-284 mg/kg) is similar to the range of lead concentrations in orchard A-horizon soil samples (20.4-204 mg/kg) (fig. 22). Several soil samples from IOC identified as B-horizon soils contained larger lead concentrations (38.9-224 mg/kg) than did B-horizon soil samples from orchards or undeveloped areas, where lead concentrations typically were less than 10 mg/kg. Nevertheless, some lead concentrations in IOC soils were found to be at background levels measured in soils from undeveloped areas. Lead concentrations in IOC samples were largest in samples from the filter clay (713-4,450 mg/kg) (not shown).

Lead concentrations typically were largest in those IOC soil samples that contained petroleum, indicating that some of the lead may derive from that source. Previous sampling at IOC yielded a few samples in which lead concentrations approached the largest value measured in the filter clay during this investigation. Three samples from the wastepile area (within 150 ft of the location of USGS samples of the filter clay) contained lead concentrations of 3,010, 2,730, and 1,350 mg/kg; these were found at depths of 7 to 9 ft, 13 to 15 ft, and 2 to 4 ft, respectively (E.C. Jordan Co., 1990).

On the basis of available data from this and previous studies, elevated lead concentrations are not always associated with elevated arsenic concentrations in soil samples from IOC, possibly because the mobilities are different (arsenic is the more mobile). Alternatively, the sources of these two contaminants may be different; the bulk of the arsenic contamination could be related to pesticide production and much of the lead contamination could be related to the oil-reprocessing activities at IOC. As discussed earlier, results of analyses of samples from the filter-clay wastepile indicate that elevated lead concentrations are associated with processing of waste oil.

Lead concentrations in residential area 1 were largest (88.3-348 mg/kg) in samples of the sandy A-horizon soils (fig. 23). TOC concentrations in these soil samples also were larger than those in samples from other horizons, which may explain the accumulation of lead in A-horizon soils in residential area 1. Nevertheless, no VOC's and only small concentrations of semivolatile compounds associated with coal tar were detected during previous sampling for organic compounds at two sites in residential area 1; these samples were collected from the top 6 in. of soil (L. Robert Kimball and Associates, 1995).

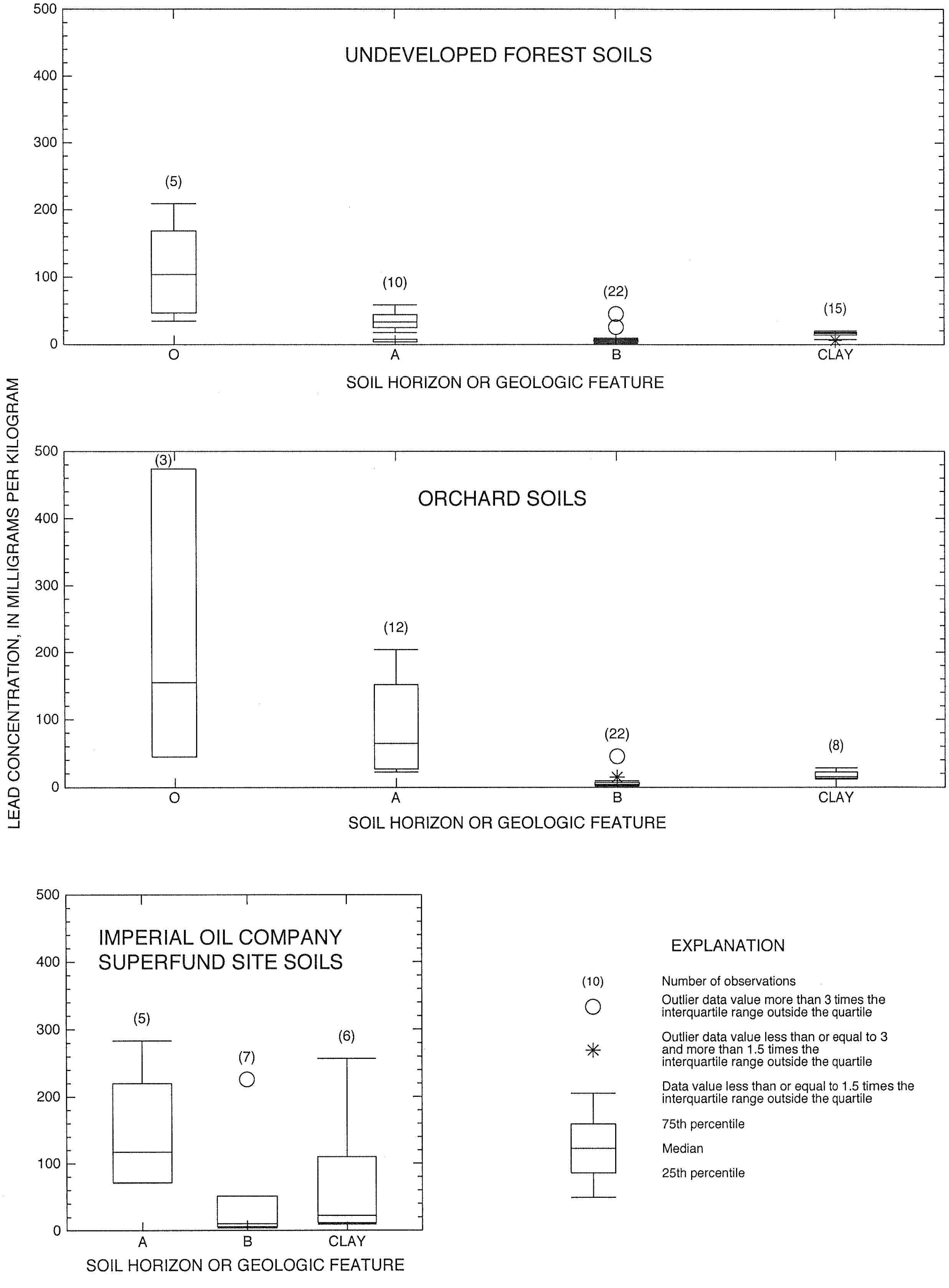


Figure 22. Distribution of lead concentrations in samples from soil horizons and clays by endmember land use, Monmouth and Middlesex Counties, New Jersey.

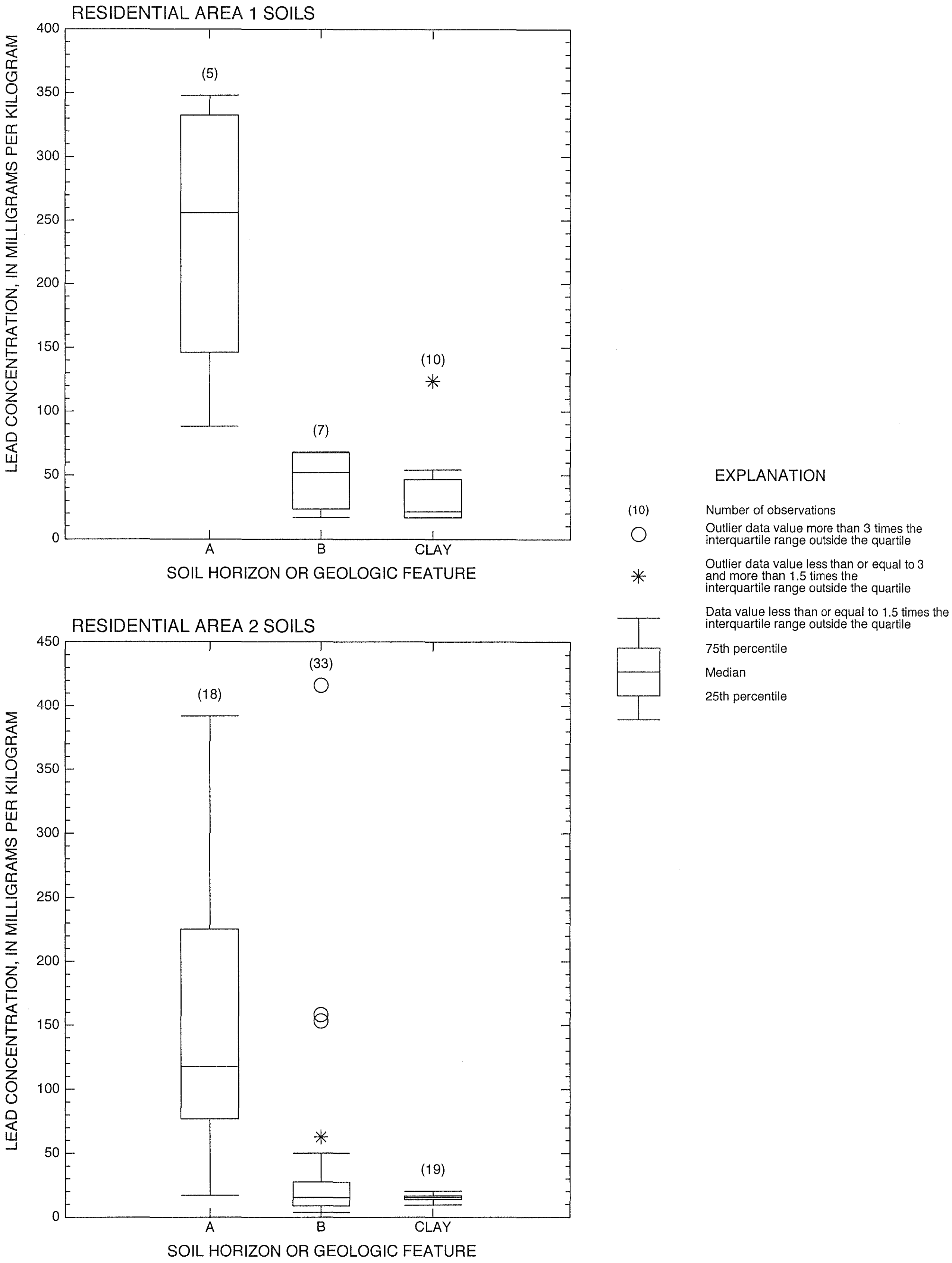


Figure 23. Distribution of lead concentrations in samples from soil horizons and clays in residential areas in the vicinity of the Imperial Oil Company Superfund site, Marlboro Township, Monmouth County, New Jersey.

Some samples of B-horizon soils and clays collected in this area also contained relatively large lead concentrations, ranging from 16.6 mg/kg in a B-horizon sample to 124 mg/kg in a clay containing cindery slag and other debris. Lead concentrations in the B-horizon and clay samples from residential area 1 were larger than would be expected in B-horizon soils and clays from long-term undeveloped forested areas (fig. 22), where lead derives from geologic inputs.

In residential area 2, lead concentrations generally were largest in samples from the A horizon (16.9-392 mg/kg), with more than half the samples containing greater than 100 mg/kg (fig. 23). These concentrations overlap the largest lead concentrations measured in orchard A-horizon soil samples (20.9-474 mg/kg). Two of the smaller lead concentrations (16.9 and 66.3 mg/kg) in the A-horizon samples from residential area 2 were in soils from the two properties that border the former orchards; lead concentrations in samples of soils from these two properties are within the range measured in samples of soils from undeveloped areas.

Lead concentrations in the soils from two sampling sites in the broader area (20.8-54.2 mg/kg) generally were in the upper end of the concentration range measured in soil samples from undeveloped, long-term forested areas or in the low end of the concentration range measured in samples from orchard areas (typically soils from orchards active only after 1950). The exceptions are the sample from a disturbed B horizon (sample B1B1, app. 1), which contained 149 mg/kg of arsenic and 400 mg/kg of lead, and a clay sample (sample B2Cl2), which contained 18.3 mg/kg of arsenic and 95.6 mg/kg of lead. On the basis of the limited number of samples collected from former orchard land southeast of residential area 2 (the broader area), highly elevated arsenic and lead concentrations do not appear to be confined to residential areas 1 and 2.

Lead Isotopes

Selected soil samples were analyzed for four lead isotopes (table 8). Three isotopes of lead, ^{206}Pb, ^{207}Pb, and ^{208}Pb, are derived from radioactive decay of uranium and thorium (^{238}U, ^{235}U, and ^{232}Th, respectively). The fourth isotope, ^{204}Pb, is not radiogenic. The ratios of the activities of radiogenic isotopes to activity of nonradiogenic ^{204}Pb measured in geologic materials are a function of (1) the amounts of uranium, thorium, and ^{204}Pb present in the original geologic materials and (2) the length of time during which the uranium and thorium have decayed. Thus, because the composition and geologic history of lead ores are unique to a given area and formation, the ratios can be used to identify particular geologic sources of lead (Faure, 1986). Additionally, because industrial sources of lead have been derived from known ore sources, lead-isotope ratios have proved useful in distinguishing an anthropogenic source of lead such as an ore smelter from other anthropogenic sources such as leaded gasoline or house paint (Hurst, 1994).

The lead isotopes measured in soils from the study area were expected to indicate input from more than one source. Regional fallout from leaded-gasoline emissions was considered likely to be ubiquitous. Lead from lead arsenate pesticides was expected to be confined to areas that are or formerly were orchards, where it is added to lead deposited as regional fallout.

Because ^{206}Pb, ^{207}Pb, and ^{208}Pb are all isotopes of lead derived from radioactive decay, ratios of the activities of these isotopes to that of ^{204}Pb, which is not radiogenic, can indicate the degree to which the lead that is present in the sample is radiogenic. The larger the ratio, the more

Table 8. Lead-isotope ratios and concentrations in selected soil samples, Monmouth and Middlesex Counties, New Jersey
[ppm, parts per million; sampling locations shown in figs. 8 and 9]

Sample number	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$	$^{206}\text{Pb}/^{207}\text{Pb}$	Pb extract[1] (ppm)	Total Pb[2] (ppm)
E2O	18.888	15.660	38.513	1.2061	782.0	38.45
E2A	18.292	15.615	38.237	1.1714	1836	27.14
E6A	18.547	15.631	38.343	1.1865	1006	17.61
E9A	18.605	15.636	38.428	1.1899	1340	11.85
E9O	18.615	15.616	38.301	1.1920	2056	149.5
E14DA	18.600	15.687	38.496	1.1857	1522	10.35
E7E	18.646	15.665	38.534	1.1903	345.8	4.999
O1A	18.523	15.635	38.335	1.1847	2977	189.8
O1E	18.308	15.627	38.252	1.1716	7931	180.3
O2E	18.234	15.597	38.118	1.1691	20236	298.0
O3A	18.468	15.717	38.586	1.1750	7935	104.6
O4A	18.646	15.673	38.425	1.1897	2547	63.12
O4O	18.876	15.690	38.598	1.2031	1426	96.62
O6A	18.682	15.678	38.560	1.1916	898.4	15.52
O7A	18.295	15.614	38.170	1.1717	1237	39.63
O8O	18.742	15.653	38.484	1.1973	1075	23.74
O9A	18.677	15.651	38.613	1.1933	1664	51.98
O16A	18.305	15.662	38.312	1.1687	4085	159.7
S1O	18.839	15.651	38.466	1.2037	2292	53.56
S1A	18.635	15.681	38.516	1.1884	1043	20.17
S4A	18.607	15.633	38.388	1.1902	1358	19.28
S5O	18.413	15.647	38.196	1.1768	1933	62.29
S5A	18.547	15.665	38.412	1.1840	946.2	34.66
S7O	18.741	15.695	38.538	1.1941	2822	137.0
S7A	18.679	15.664	38.589	1.1925	716.3	21.41
R2A	18.025	15.624	37.922	1.1537	14660	294.1
R3 17	18.168	15.623	38.097	1.1629	3083	50.40
R3B2	18.488	15.664	38.474	1.1803	1396	25.38
R6A	18.618	15.608	38.423	1.1928	2634	46.20
R7A	18.100	15.614	37.938	1.1592	10282	134.8
R7E	18.120	15.639	38.043	1.1586	12544	142.2
R9A	18.383	15.653	38.401	1.1744	5031	60.89
R10A	18.165	15.623	38.100	1.1627	3419	64.12
R13DB1	18.106	15.603	37.951	1.1604	14983	185.4
R19A	18.427	15.669	38.398	1.1760	2797	66.19
R20A	18.088	15.604	37.938	1.1592	7744	146.6
R21A	18.654	15.694	38.568	1.1880	10075	235.1
R23A	18.823	15.684	38.723	1.2001	11849	332.0

[1] "Extract" is based on the amount of sample digested in 8N HNO3 at room temperature (typically tens of milligrams).

[2] "Total" is based on the total amount of sample used (typically 0.5 grams).

radiogenic the source of the lead. Mixed sources of lead that differ from each other can be identified by plotting one ratio as a function of another. Such plots may delineate mixing lines, which are linear trends in the ratios, permitting a separation of samples into different source categories. The results of these analyses indicate that lead-isotope ratios in soil samples from residential area 1 and the woods adjacent to IOC generally are similar; ratios in soil samples from some of the orchards and from residential area 2 tend to be similar. The relation of the lead-isotope data to possible arsenic sources is discussed in the subsequent section on arsenic sources.

Zinc

Regional atmospheric input of zinc to the study-area soils is evidenced by the presence of larger concentrations of this metal in the O horizon than in the A and B horizons in soils from undeveloped areas and in some orchard soils (fig. 24). Several relatively large zinc concentrations (59.5-74.8 mg/kg) were measured in orchard soil samples. Zinc concentrations also were large in three soil samples from IOC (72.2-205 mg/kg), and in 7 of the 28 samples from residential area 1 (70.8-330 mg/kg). Only 3 of the 88 samples from residential area 2 contained similar concentrations of zinc (65.4-105 mg/kg); these are from areas on two properties where concentrations of arsenic also were highly elevated. The addition of zinc as a micronutrient to some of the orchard soils sampled (John Hauser, oral commun., 1996) may explain some of the zinc concentrations encountered in the former orchard soils of residential area 2. Any metal ores processed at IOC probably contained zinc as well as arsenic; sediment samples collected in 1989 from the floor of the masonry building, the old pipe shop, and beneath the floor of the old warehouse at IOC all contained highly elevated concentrations of zinc (502-11,700 mg/kg (E.C. Jordan Co., 1990)).

Other Metals

Throughout the study area, iron concentrations tended to be larger in clay-rich B horizons and clayey geologic substrate than in sandy soils and sandy geologic substrate. The clays typically contain stringers and blebs of orange silty sand; in some of the stringers, ironstone is forming.

Iron concentrations in A and B horizons tended to be larger in samples from residential soils than in soil samples from the undeveloped areas and orchards (fig. 25). This difference may be related, in part, to differences in vegetative cover, as trees in forests have deeper root systems and intercept precipitation at greater depths than do grasses. Thus meteoric water is most effective at leaching soils in forests. Acidic conditions in soils in the forested areas, particularly where conifers abound, also could promote an increase of iron in the soil solution and greater availability of iron to plants (Foth, 1978). Available geochemical data do not provide a clear explanation for the difference in iron concentrations, however.

For the most part, soils in residential areas 1 and 2 are developed on clay lenses containing iron hydroxide-coated silt, which may explain the large iron contents of residential soils. Iron oxyhydroxides in these soils provide sorption sites for arsenic that has entered the soil system, either through weathering of arsenic-bearing minerals or through inputs such as arsenical pesticides or industrial activities. Waychunas and others (1993) have demonstrated that adsorption, rather than coprecipitation or solid solution, appears to be the dominant process by which

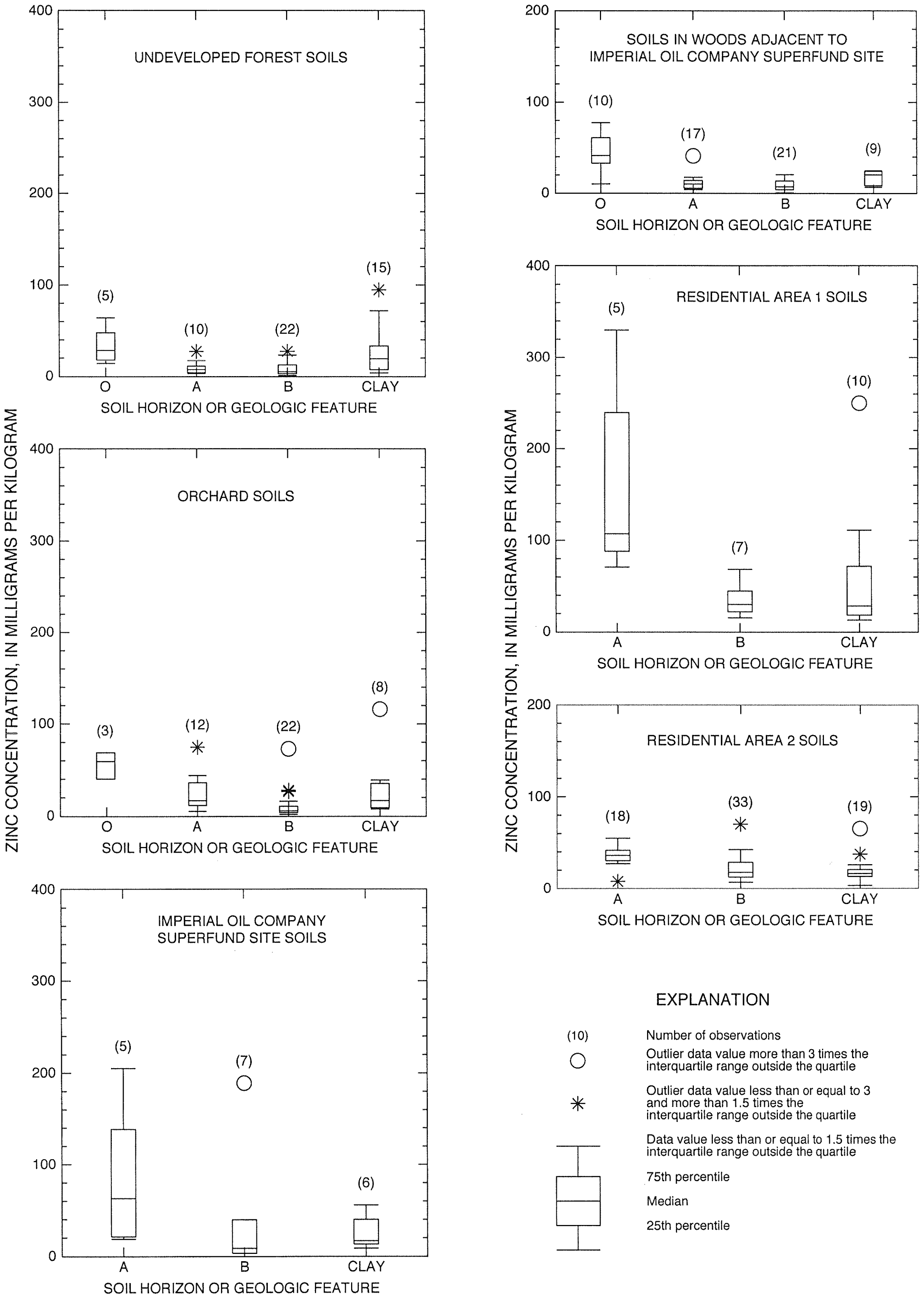


Figure 24. Distribution of zinc concentrations in samples from soil horizons and clays by land use, Monmouth and Middlesex Counties, New Jersey.

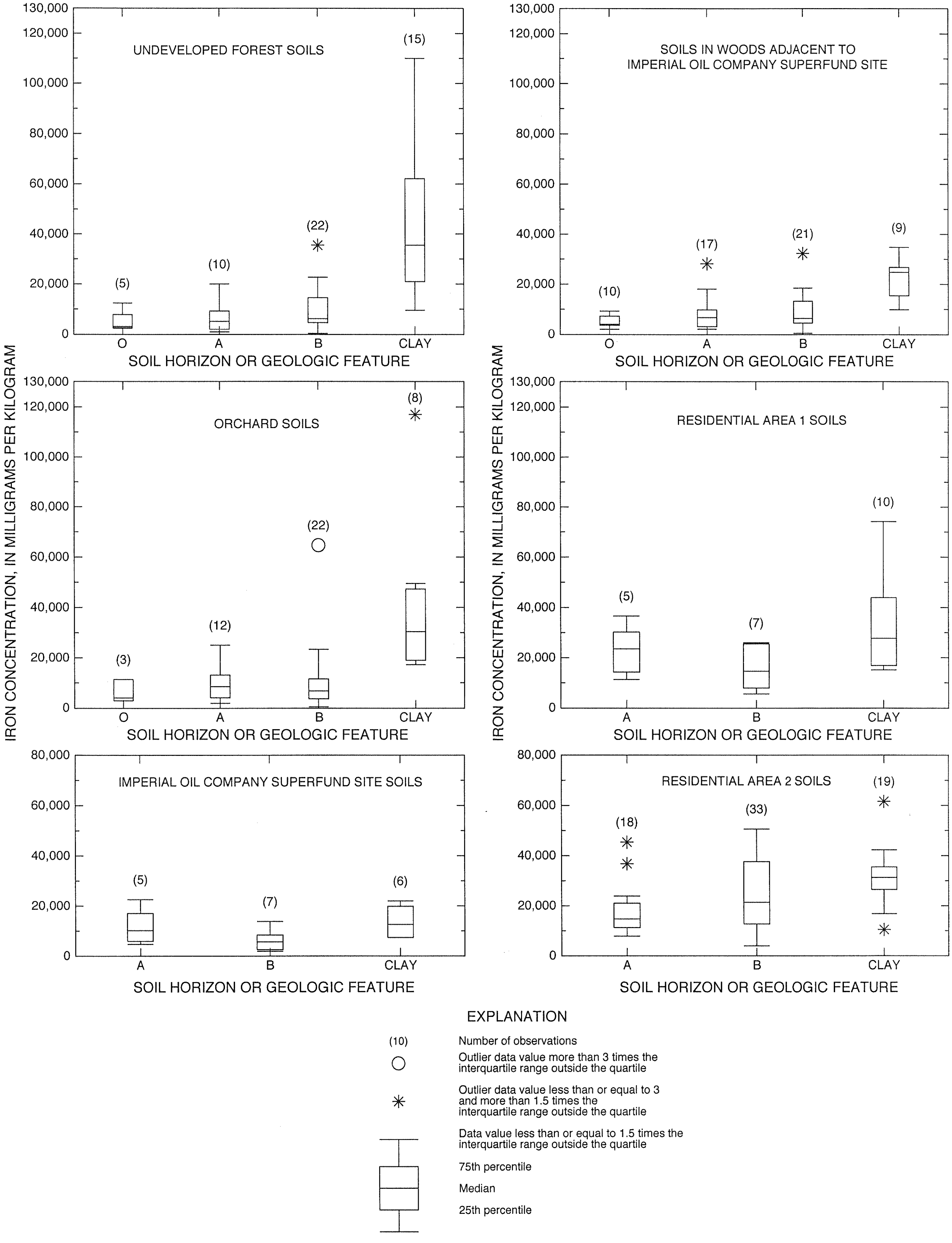


Figure 25. Distribution of iron concentrations in samples from soil horizons and clays by land use, Monmouth and Middlesex Counties, New Jersey.

arsenate associates with iron oxides, either ferrihydrite (poorly ordered hydrous ferric oxide) or goethite (crystalline FeOOH). Thus, soil iron concentrations can be indicators of the amount of arsenic that is present, as much of the arsenic is likely to be sorbed to the iron hydroxides.

Nickel concentrations in soil samples from orchards and from the woods adjacent to IOC generally were similar to those in samples from undeveloped areas; concentrations in most sandy samples were less than 2 mg/kg. Nickel concentrations in soil samples from the two residential areas generally were larger than those in samples from undeveloped areas and most orchards. The soil samples from residential area 1 generally contained nickel in concentrations larger than those in samples from residential area 2 (<0.98-9.4 mg/kg and <0.28-6.8 mg/kg, respectively). Nickel concentrations in soil samples from IOC ranged from <0.28 to 333 mg/kg. Chromium concentrations among soil samples from different land-use areas generally followed the same pattern as nickel concentrations. The larger concentrations of both metals typically were measured in clay-rich samples. Only one sample (R7E) from residential area 2 contained an anomalously large amount of chromium (166 mg/kg); this sample also contained an anomalously large amount of zinc (105 mg/kg) and a substantial amount of arsenic (38.5 mg/kg).

Relation of Geochemical Associations Among Constituents to Land Use

Differences in concentrations of arsenic and metals as a function of land use are demonstrated by the boxplots showing distributions of various metals in soils from the different land-use areas (figs. 16, 20-25). Nevertheless, the ranges of concentrations associated with the different land uses typically overlap. To establish chemical signatures for soils from different land uses, groups of constituents must be evaluated for proportions of the constituents as well as ranges of concentrations. Those metallic constituents of soils likely to be derived in part from anthropogenic sources are most useful in this regard; these include arsenic, barium, calcium, copper, lead, magnesium, mercury, nickel, potassium, and zinc. Constituents that appear to be contributed primarily by geologic materials in the study area include aluminum, chromium, iron, manganese, and vanadium.

Many of the inorganic contaminants (arsenic, barium, copper, lead, and zinc) identified in soils and sediments at IOC, presumably contributed by industrial activities, also can be contributed to soils by agricultural chemicals. Pesticide use can contribute arsenic, copper, lead, and mercury; barium also is present in some inorganic orchard sprays (Jones and Hatch, 1937). Barium, as well as calcium and magnesium, also is contributed to soils by lime; zinc is a micronutrient in some fertilizers. As a consequence, similarities in chemistry between IOC soils and orchard soils could be anticipated. Nevertheless, certain groups of constituents appear to be distinctive in their proportions or concentrations.

Proportions (calculated as a percentage of the sum of the concentrations of the three constituents illustrated) of arsenic, barium, and zinc in A-horizon soil samples from orchards, IOC, and residential areas 1 and 2 are shown in figure 26. Samples from IOC and residential area 1 tend to be grouped near the base of the trilinear diagram, whereas samples from orchards and residential area 2 tend to be grouped nearer the middle and right side of the diagram. Despite some overlap, proportions of these three constituents in the A-horizon soils sampled at IOC and in orchards

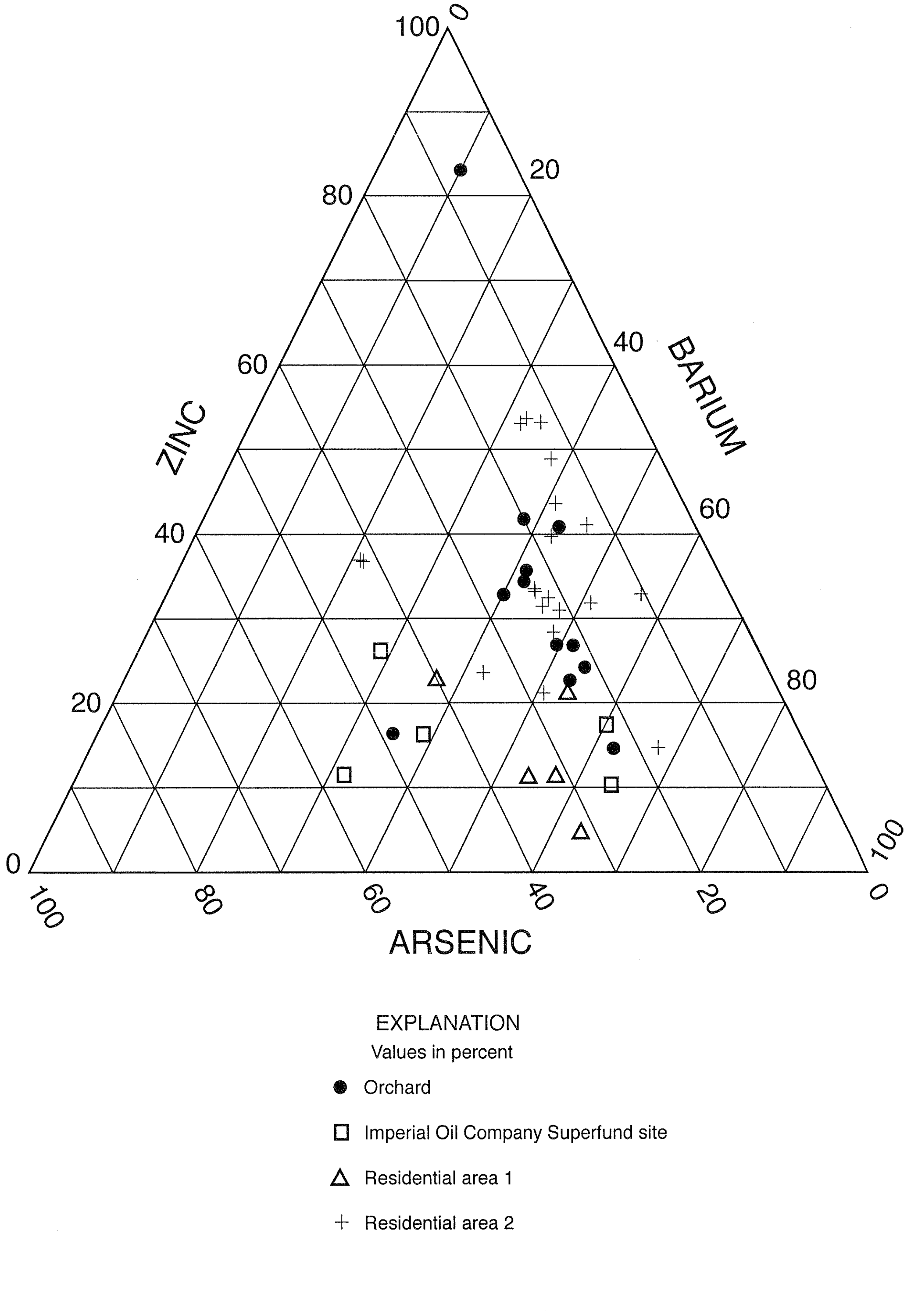


Figure 26. Proportions of arsenic, barium, and zinc in A-horizon soil samples from different land-use areas, Monmouth and Middlesex Counties, New Jersey.

generally are distinctive, and proportions of these constituents in the A-horizon soils from the two residential areas tend to (1) be different from each other and (2) resemble those in soils from one or the other of the two endmember land-use areas shown.

Nickel is present at elevated concentrations (10.3-1,320 mg/kg) in some of the soil and sediment samples collected previously from IOC (E.C. Jordan Co., 1990). Background concentrations in A-horizon soils determined during this study typically were less than 1 mg/kg, although larger concentrations were present in O-horizon samples and some clay samples. Some of the A-horizon samples collected from IOC during this study also contained large concentrations of TOC (10,100-67,200 mg/kg), most likely as a result of minor petroleum contamination. TOC was not measured during previous investigations at IOC, but anthropogenic components of TOC, such as total petroleum hydrocarbons, VOC's, and semivolatile compounds, were measured and found to be major contaminants in some samples. The range of background concentrations of TOC in A-horizon soil samples collected during this study was smaller (7,880-40,100 mg/kg) than the range in samples from IOC.

Despite some overlap, A-horizon soil samples from IOC can be distinguished from A-horizon samples from orchards on the basis of nickel and TOC concentrations. Additionally, A-horizon soils from residential areas 1 and 2 differ with respect to nickel and TOC concentrations (fig. 27). Furthermore, the soil samples from residential area 1 are similar with respect to nickel and TOC concentrations to some of the soil samples from IOC, but different from many of the orchard samples, whereas the samples from residential area 2 generally are similar to the orchard samples.

Of all the combinations of constituents investigated, the most distinctive with regard to a chemical signature for soils from IOC is the grouping of barium and copper. Concentrations of barium and copper in A-horizon soil samples tended to be smallest in soils from orchards and residential area 2, and largest in soils from IOC and residential area 1 (fig. 28). (Concentrations in four samples collected earlier from soils in the old pipe shop and beneath the old warehouse (E.C. Jordan Co., 1990) are included in the graph to emphasize that the trend of high barium and high copper concentrations is characteristic of soils at IOC.)

Mercury seldom was detectable in soil samples from any of the land-use areas except those from residential area 2 and the broader area. In A-horizon soils from these areas, arsenic and mercury concentrations are positively correlated; the correlation is significant at the 0.05 level. The correlation is less strong in B-horizon soils and clays from these areas. Although mercury was detected previously in some soil samples from IOC (E.C. Jordan Co., 1990), no statistically significant correlation with arsenic concentrations was found in samples in which both constituents were measured; furthermore, mercury was detected in IOC samples that did not contain arsenic, and vice versa. No statistically significant relation between arsenic and mercury is apparent in those few samples from undeveloped or orchard land or residential area 1 in which mercury was detected.

Chemistry of soil samples from the woods adjacent to IOC was evaluated to determine whether effects of a hypothetical smokestack plume during the early industrial phase of the site could be discerned. Relations among concentrations of several constituents, two of which probably are related to geologic inputs (chromium and vanadium) and six of which are contaminants at

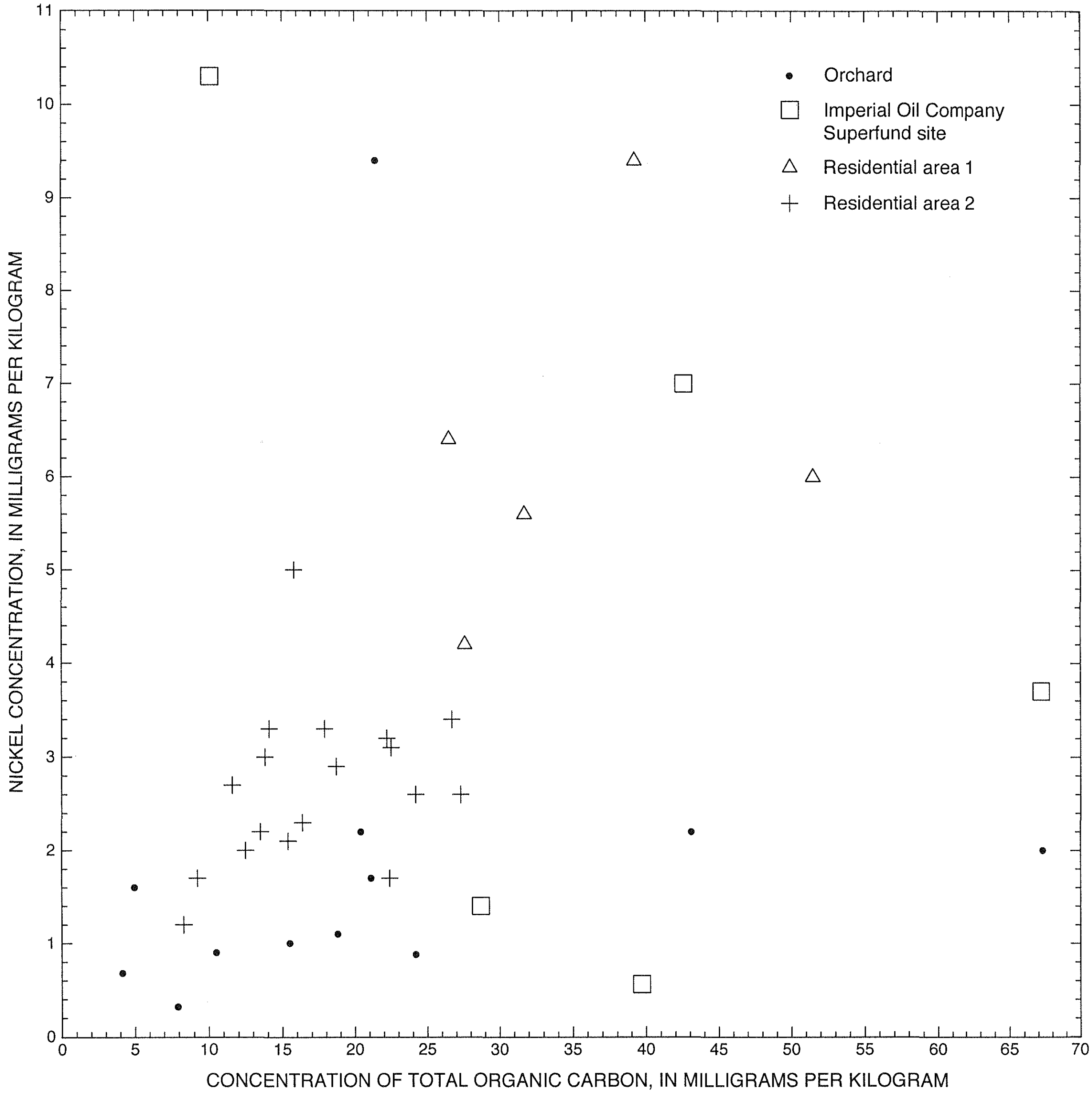


Figure 27. Relation of nickel concentration to total organic carbon concentration in A-horizon soil samples from different land-use areas, Monmouth and Middlesex Counties, New Jersey.

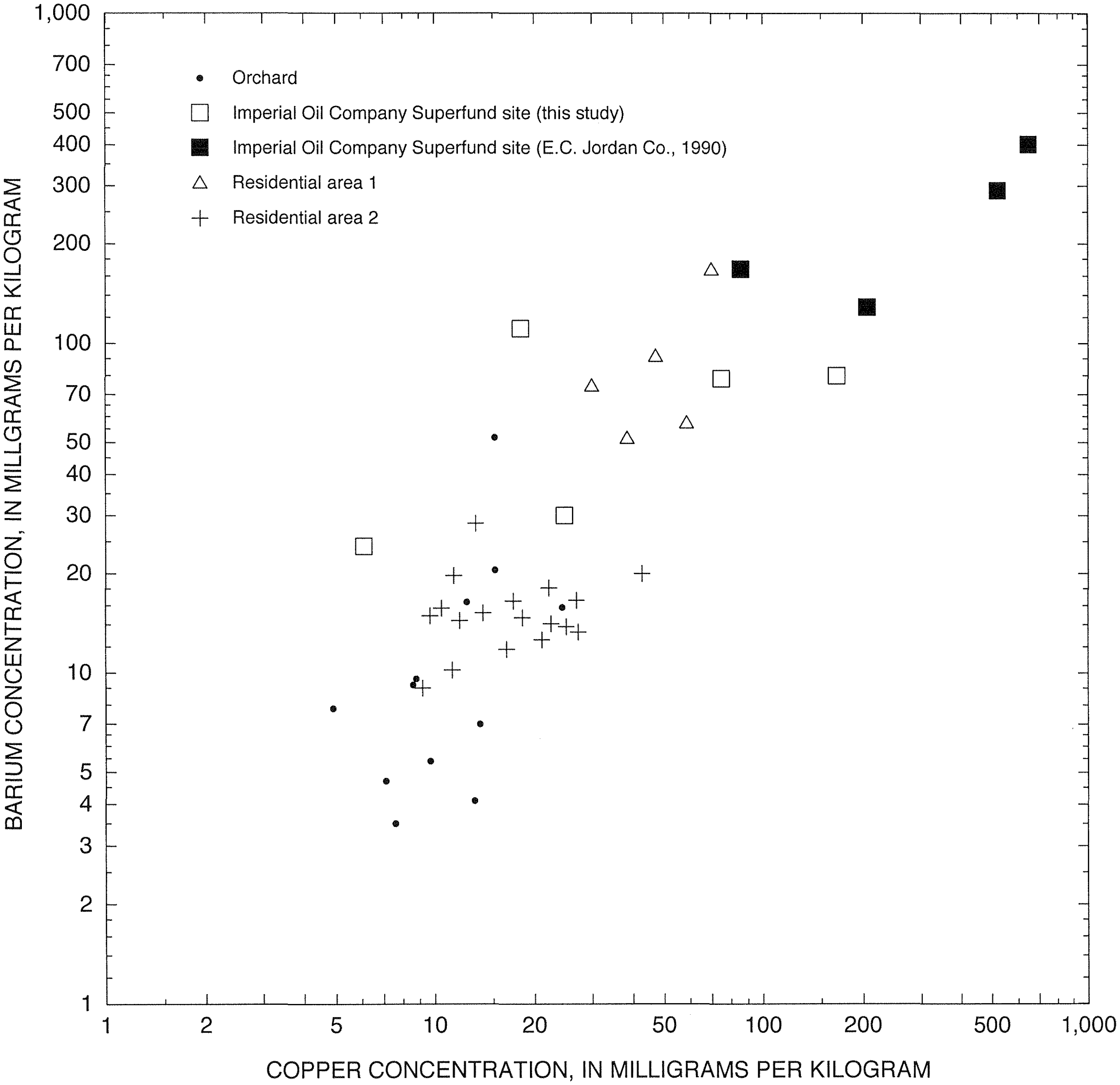


Figure 28. Logarithmic relation between barium and copper concentrations in A-horizon soils from different land-use areas, Monmouth and Middlesex Counties, New Jersey.

IOC (arsenic, barium, copper, lead, nickel, and zinc) in background samples from A-horizon soils in undeveloped forested land and A-horizon soils in the woods adjacent to IOC are shown in figure 29. Nearly all of the data points for soil samples from the adjacent woods lie within the clusters defined by concentrations in background soils.

Although the chemical data were not rigorously precise, soil chemistry of A-horizon soil samples differed among land-use groups, and the samples from the two residential areas differed from each other but were similar to soils from one of two other endmember groups. Therefore, statistical analysis of the constituent-concentration data could be used to classify samples on the basis of chemistry.

Classification of Soils by Land Use

Nonrepresentative Soil Samples

A few samples were excluded from the statistical characterization of the endmember group (although results for these samples are included in appendix 1) because information acquired subsequent to sampling indicated they were not suitable or representative samples for the groups. The sampling was conducted to obtain soils from particular land uses such that the chemistry of the soils would represent the chemical inputs associated with that land use. In a few cases, previous land uses initially were incorrectly identified or samples were inadvertently collected in the wrong location for the particular land-use area.

Samples from sampling site O15 were collected specifically to determine whether an orchard signature could be discerned in the soils, as it was not possible to determine conclusively from the aerial photographs if that part of the farm field had been planted as an orchard. The nearby sampling site, O14, is located where rows of trees are visible in a 1940's aerial photograph. The chemistry of O15 samples indicated that they probably are not from an orchard site, and the best interpretation of the aerial photographs indicates that the site is located in a former farm field. Thus the O15 sample did not fit any of the previously defined land-use categories investigated.

Sampling site O10 is located beneath an apple tree, but information received after sampling from a descendant of the original owner indicates that the tree is a recent replanting at the edge of a former orchard and thus it received no arsenical pesticide spray. Because soils from this sampling site do not represent what the orchard samples are intended to represent--that is, agricultural inputs from the period of time in which arsenical pesticides were used--this sample is not representative of orchard soils as defined at the beginning of the study.

Sampling site E13 is located at the edge of a wooded area that borders a farm field that previously was an orchard. Careful measurements on the ground and on aerial photographs indicate that the woods appear to have encroached slightly on the field, and that the site was originally at the edge of the orchard. Further, this site is downhill from the former orchard and the soils there may have received runoff from the former orchard. Sampling site E17 is in woods adjacent to a former orchard; evaluation of the altitude of this site indicates that it, too, could have received

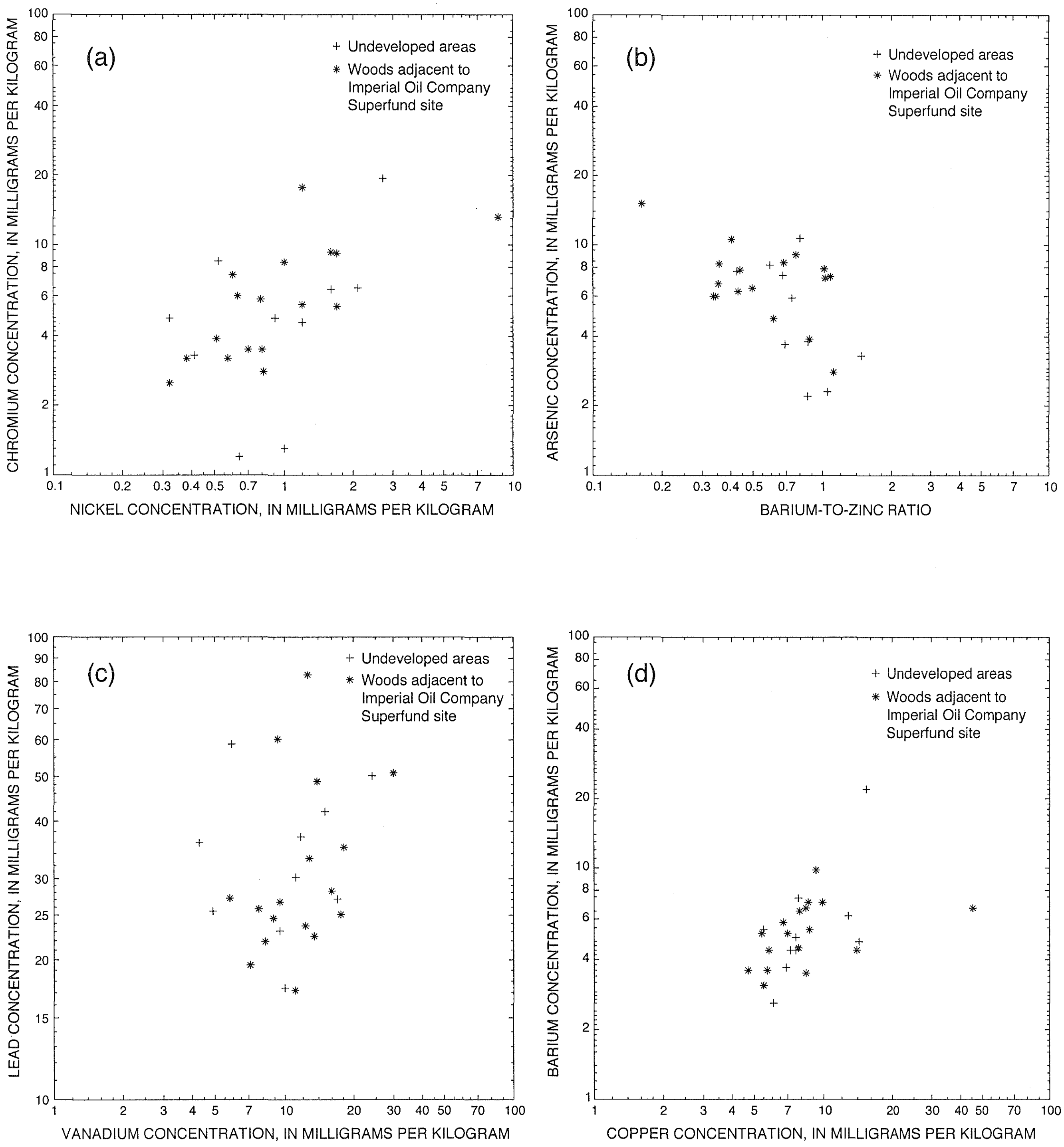


Figure 29. Logarithmic relations between concentrations of (a) chromium and nickel, (b) arsenic and barium-to-zinc ratio, (c) lead and vanadium, and (d) barium and copper in A-horizon soil samples from the woods adjacent to the Imperial Oil Company Superfund site and from undeveloped areas, Monmouth and Middlesex Counties, New Jersey.

runoff from the adjacent orchard. Moreover, the surficial soil sampled at E17 appears to be developed directly on the Woodbury Formation rather than on basal Englishtown Formation sediments. The so-called A horizon at E17 is silty clay that is unlike any other A horizons sampled, and is more correctly designated as a clay sample. Given the textural nature of soil samples from E17 and the uncertainty in assigning the chemistry of both E13 and E17 samples to either the geologic or orchard category, they were not included in the endmember groups.

Sampling site W3 also was excluded from the geologic endmember group because it is unclear whether the site is underlain by the basal Woodbury Formation or the underlying Merchantville Formation; the core was collected near the mapped contact between these two units. Only Englishtown Formation sands and clays from the Englishtown and Woodbury Formations were sampled for this study because of their association with the area in which IOC and the residential areas are located and because of mineralogical and, presumably, geochemical similarities.

Finally, samples from sites I1 and I6 at IOC were not included in an endmember group. The IOC endmember group of samples was defined as soils containing industrial contamination; sampling site I1 is in a filter-clay deposit that is not a soil and that postdates the arsenical pesticide production, and samples from I6 contained no discernible contaminants and, therefore, do not represent IOC endmember land use.

The exclusion of the nonrepresentative samples from sampling sites O10 and O15 resulted in no significant bias to the overall distribution of the chemical signature, as some other orchard soils contained arsenic and metal concentrations in the same range, and the median arsenic concentration for orchard A-horizon soils is greater than 10 mg/kg whether or not these samples are included. One of the largest orchard arsenic concentrations (38.8 mg/kg) was measured in an E-horizon soil, but the smaller concentration in the A-horizon sample (16.4 mg/kg) from this site was used in the model because the E-horizon sample did not meet the criteria used to identify A horizons.

The geologic endmember group of soils contains no A-horizon samples with arsenic concentrations nearly as high as those from the two excluded sampling sites (E13 and E17); this fact indicates that the A horizons at these two sampling sites probably either are not representative of A-horizon soils containing arsenic from only geologic sources, as in the case of E13, or are not representative of A horizons in the study area, as in the case of E17, where the upper layer of the silt/clay is more representative of a clay sample, in both texture and arsenic concentration (21.7 mg/kg). A-horizon arsenic concentrations in both samples are extreme outliers, and their exclusion from the geologic endmember group barely changed the median value or the population distribution because all but one of the remaining samples contained arsenic in concentrations less than 10 mg/kg.

Representative Soil Samples

DA (using the SAS DISCRIM procedure, option npar (SAS Institute Inc., 1990b)) was used to obtain a model that correctly classified samples into their endmember groups. Results of preliminary modeling indicated that, in general, a better fit was obtained by using ranked concentrations of chemical variables than by using reported concentrations. Use of ranked data yields more robust results when data distributions are skewed and some data are censored. Thus the skewness is reduced, and only the relations of one observation to another within the ordered set are important. This data transformation is particularly useful if a variable includes some censored ("no-detect") observations, because these, which have no actual value, simply occupy the lowest rank in the ordered set of observations.

The discriminant models were compared for accuracy in classifying the three endmember groups in the "training" data set by cross-validation. This procedure consists of extracting, one by one, each of the observations used to form the training set so that they could not affect the model, and then running the extracted observation as a "test" (unknown) observation to see whether it classified correctly.Those models with about 50 percent or less accuracy of classification were discarded. Some of the models with the greatest accuracy in categorizing the endmember groups were then used to categorize the groups in the "test" data set; these included the samples from the woods adjacent to IOC, residential area 1, residential area 2, and the broader area. In fitting a model, the chemical data for both the training and the test data sets were combined and ranked. Selected modeling results are summarized in table 9.

Principal components analysis (PCA) was used as a data-reduction technique in some of the initial models. Principal components are linear combinations of the ranked variables; each successive component represents a smaller fraction of the total variance in the data set than did the preceding component and each is independent of the other components. As modeling progressed, discrimination using principal components resulted in models with less than 88-percent classification accuracy. Ultimately, models that discriminated on principal components were discarded because simpler models were found to classify samples with greater accuracy.

Several simple models that use two to three constituents (variables), the concentration distributions of which generally overlapped least among land-use groups, were able to discriminate among endmember groups with a classification accuracy of about 80 percent to more than 90 percent. Both two-category (lumped orchard and background category and IOC category) and three-category (separate background, orchard, and IOC categories) training models were used. A three-category training model using ranks of arsenic concentration and barium to zinc ratio and four nearest neighbors separated the endmembers with an 81-percent classification accuracy. Because this model was more successful in correctly classifying background and orchard observations than IOC observations, it was run again as a two-category model using only background and orchard observations. Classification accuracy increased to 91 percent. To discriminate between IOC observations and background plus orchard observations, a second two-category model was run using ranks of barium and copper and four nearest neighbors. The observations were correctly classified with an overall accuracy of 93 percent. This model was then used to classify the test observations; it classified all but two residential area 2 observations as lumped orchard and background, and all residential area 1 observations as IOC category. This was the only model that classified residential area 1A-horizon soils as IOC; this is not a surprising result, insofar as barium and copper concentrations in samples from IOC and residential area 1 were clearly different from those in samples of orchard and residential area 2 soils (fig. 28), whereas a greater overlap in concentration ranges is apparent for other constituents.

Table 9. Summary of selected results of discriminant and principal-component modeling to classify soil samples, Monmouth and Middlesex Counties, New Jersey

Model	Number of neighbors in discriminant	Classification accuracy (percent)
As, Ba/Zn; 2 categories	4	91
Ba, Cu; 2 categories	4	93
As, Ba/Zn; 3 categories	4	81
Al, As, Ba, Ca, Cr, Cu, Fe, Mg, Mn, Pb, Ni, K, V, Zn; 3 categories	4	92
Al, As, Ba, Ca, Cr, Cu, Fe, Mg, Mn, Pb, Ni, K, V, Zn, TOC; 3 categories	4	88
4 to 13 principal components; 3 categories	4	All less than 88
Al, As/Fe, Ba, Ca, Cr, Cu/TOC, Pb/TOC, Mg, Mn, Ni, K, V, Zn; 3 categories	4	96
Al, As/Fe, Ba, Ca, Cr, Cu/TOC, Pb/TOC, Mg, Mn, Ni, K, V, Zn; 3 categories	5	100

The constituents that were useful discriminants among endmember land-use groups were not always apparent from simple graphical geochemical plots because the relations in multidimensional space are impossible to depict graphically or to imagine. For example, plots depicting combinations of arsenic, barium, copper, nickel, zinc, and TOC concentrations graphically demonstrated some degree of separation of the land-use groups in element/element space; however, a model using ranks of these constituents (TOC concentration was divided by 1,000 to improve compatibility with the other values) and five nearest neighbors achieved only a overall classification accuracy of 58 percent.

In some cases the variables that discriminated relatively well were not immediately apparent from inspection of the geochemical data. A parametric step-wise discriminant procedure on ranks, using stepwise and forward selection options, was used to identify constituents that discriminated strongly. Both options resulted in a four-variable model that included ranks of arsenic, barium, manganese, and aluminum. These latter two constituents were not anticipated because their source was thought to be geologic materials rather than anthropogenic inputs related to land use. Nevertheless, the nonparametric discriminant model using these four variables and five nearest neighbors achieved an overall classification accuracy of 68 percent.

Several more complete models were developed that used up to 15 variables and four nearest neighbors; accuracy in correctly classifying endmember A-horizon samples ranged from 88 to 96 percent. In general, classification accuracy tended to increase with the number of variables used, indicating that some of the geochemical differences and similarities among soils from the different land-use areas were subtle.

Classification accuracy also tended to increase when the number of nearest neighbors was increased. One model, which used ranks of 13 variables and five nearest neighbors, could discriminate among the three endmember categories with 100-percent accuracy. The variables used in the 13-variable, five-nearest-neighbor model were ranks of concentrations of aluminum, barium, calcium, chromium, magnesium, manganese, nickel, potassium, vanadium, and zinc, and three normalized variables--arsenic normalized to iron (ratio of arsenic to (iron/1,000)) and copper and lead normalized to TOC (ratios of copper and lead to (TOC/1,000)). (Because iron and TOC concentrations generally were at least three orders of magnitude greater than arsenic, copper, and lead concentrations, dividing iron and TOC concentrations by 1,000 is geochemically appropriate, as the smaller value is representative of the number of sites to which the measured amounts of arsenic, copper, or lead could sorb.) Deletion of selected variables from this model increased the number of misclassifications, indicating that the model was not overfitted. This model, therefore, was used to classify the "test" samples (residential areas 1 and 2, woods adjacent to IOC, and broader area).

Of the three signatures developed with the final model, statistical similarities were noted between the orchard signature and the IOC signature, but they were not sufficiently similar to cause misidentification of the groups using a cross-validated model, which is the most robust test of similarities. (See appendix 5 for the SAS printout of the results obtained with the final model.)

When this model (13 variables, five nearest neighbors) was applied to the test data set, all but 2 of the 18 samples from residential area 2 classified as orchard type; one classified as undeveloped (geologic), which was appropriate because this sample is from an area that apparently was not orchard land, and the other sample classified as "other." (The "other" category is specified when the model gives an equal probability of membership in two or more groups.) The samples from the woods adjacent to IOC classified as a mix of undeveloped (geologic) and orchard type. Broader area samples were classified as orchard. This model also classified the residential area 1 samples as orchard, but they contained a substantial IOC component.

The residential area 1 chemical signature is the most complex signature encountered during this study. The samples from all land-use categories contain the geologic chemical imprint; added to that are agricultural inputs in orchards, in former orchard land such as residential area 2, and in farm fields and orchards that preceded residential area 1. As discussed above, the orchard chemical signature is composed of metals added by pesticide use; fertilizer inputs, which can contribute copper and zinc; and lime additions, which contribute calcium, magnesium, and barium.

The residential area 1 soil samples were collected from land determined from aerial photographs to be mostly former farm fields, with possible remnants of an area of orchards in 1932. Therefore, it is likely that an agricultural signature, which may include lead and arsenic from pesticide sprays, existed in these soils before debris apparently derived from the IOC site was added. Consequently, the DA model is likely to classify residential area 1 A-horizon soils as orchard soils; the agricultural signature, which may include elevated concentrations of arsenic and lead, apparently is overprinted by additional arsenic, as well as barium, copper, and nickel, associated with an industrial source. The concentrations of these constituents in residential area 1 A-horizon soils are not sufficiently large to cause the 13-variable model to unequivocally assign residential area 1 A-horizon soils to the IOC category, given the distribution of the other constituents. Further, using five nearest neighbors, instead of four, means that, for observations (concentrations) from IOC and residential area 1 A-horizon samples, at least one of the nearest neighbors must be classified in another endmember group, because only five samples each of A-horizon soils from IOC and from residential area 1 were collected.

Another factor that affects the strength of the IOC chemical signature in residential area 1 soils is that the A-horizon soil samples contain smaller contaminant concentrations and less debris than do some of the samples from B horizons and clays. Therefore, the IOC signature is weaker in A-horizon soils in residential area 1 than in the B horizons and clays. Neither B-horizon soils nor clays from endmember groups were found to produce models that discriminated among endmember samples with an accuracy greater than about 60 percent, however; these models, therefore, could not be used to classify the residential soils. Although the residential area 1 A-horizon soils retain an agricultural chemical signature, the debris common to IOC and residential area 1 soils indicates that materials from the Superfund site are a likely source of at least some of the arsenic, barium, copper, and nickel in residential area 1 soils.

PCA did not provide the most useful group of discriminants in the modeling effort but did identify a major discriminating factor for soils in the study area--mass loading. There are clear differences in mass loading of the soils from different categories--that is, the mass of constituents present in endmember A-horizon soils increases from geologic background to orchard to IOC samples. The mass loading for soils from both residential areas is large. Some of this mass loading is from anthropogenic inputs, but some is probably natural, as soils of both residential areas are developed on clay lenses. Overall, the A-horizon soil samples from the two residential areas contained more aluminum and more potassium than A-horizon soil samples from undeveloped areas and most of the orchards. These larger concentrations indicate that the clay content of the residential A-horizon soils is greater than the clay content of the background A-horizon soils and at least some of the A-horizon orchard soils. Results of limited grain-size analyses and field observations appear to support this assessment. Therefore, the higher clay content of the residential soils means that larger concentrations of metals in general, and of arsenic in particular, that derive from geologic materials are present.

Although A-horizon soil samples from both residential areas 1 and 2 are classified by the final model as orchard-type soils, the samples from the two residential areas are chemically distinct (figs. 26-28). When observations from the two residential areas are entered in the final model as a two-category training set, the 13-variable, five-nearest-neighbor model separates residential area 1 samples from residential area 2 samples with 100-percent accuracy. This indicates that some of the anthropogenic effects on soil chemistry observed in samples from residential area 1 are different from those observed in samples from residential area 2.

Classification of Soil Samples by Lead-Isotope Ratios

Lead-isotope ratios for soil samples E2A, E2O, and E6A, all from undeveloped forested areas, are consistent with ratios established for atmospherically deposited gasoline lead (R.W. Hurst, Chempet Research, written commun., 1996) and ratio/ratio plots may delineate an atmospheric trend for the region (figs. 30 and 31). The atmospheric trend illustrated in figure 31 is similar to that shown in Faure (1986, p. 333, fig. 19.11), which is defined by the average lead-isotope ratios of galena from the Mississippi Valley, a source of lead in gasoline in pre-1940's, and later

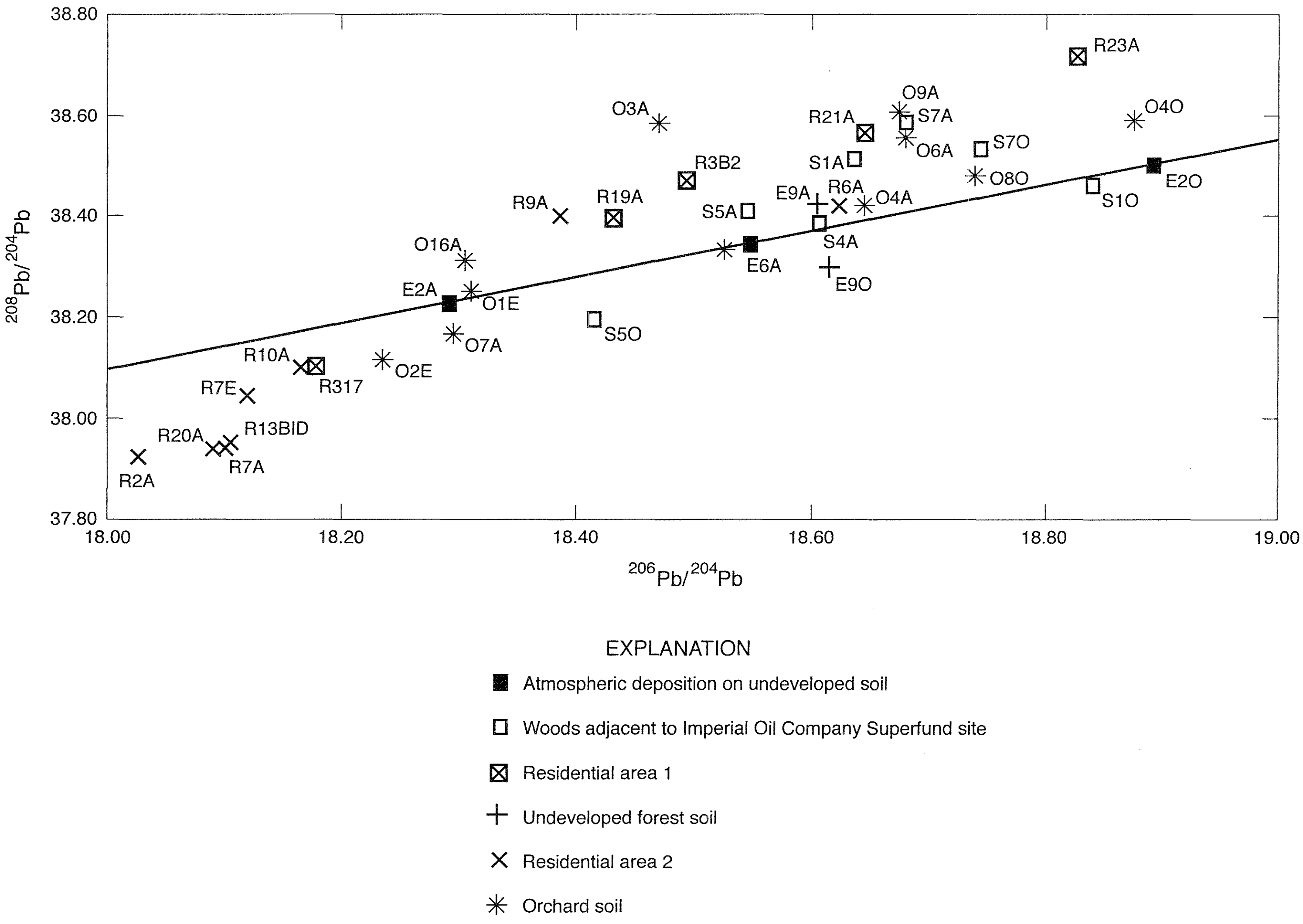


Figure 30. Ratio of ^{208}Pb to ^{204}Pb as a function of ratio of ^{206}Pb to ^{204}Pb in selected soil samples from undeveloped and orchard areas, woods adjacent to the Imperial Oil Company Superfund site, and residential areas 1 and 2, and in samples with ratios indicative of atmospheric deposition, Monmouth and Middlesex Counties, New Jersey.

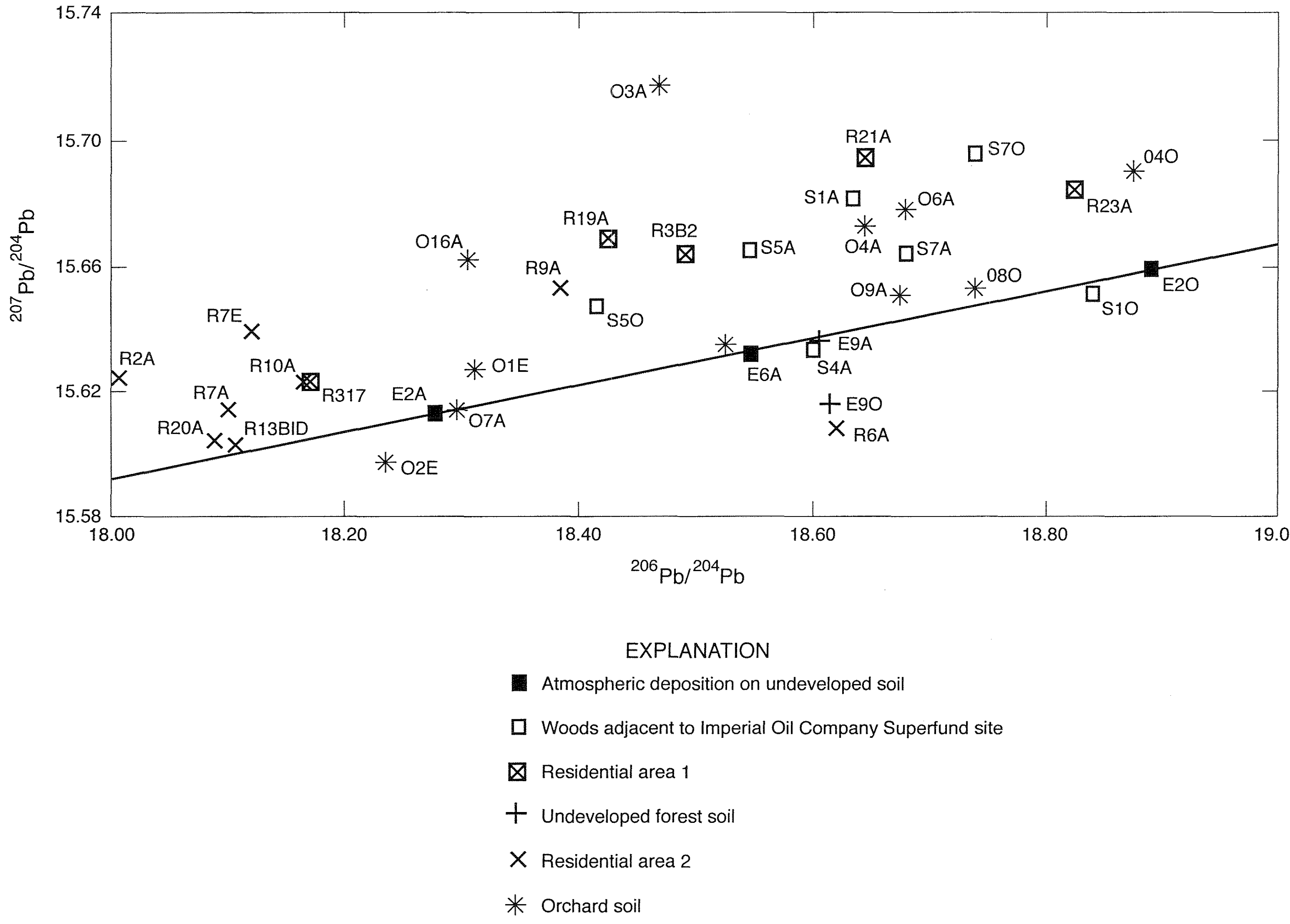


Figure 31. Ratio of ^{207}Pb to ^{204}Pb as a function of ratio of ^{206}Pb to ^{204}Pb in selected soil samples from undeveloped and orchard areas, woods adjacent to the Imperial Oil Company Superfund site, and residential areas 1 and 2, and in samples with ratios indicative of atmospheric deposition, Monmouth and Middlesex Counties, New Jersey.

(1960's), less radiogenic lead from gasoline. The lead-isotope ratios developed for soils from sampling sites in residential area 1 (R3, R19, R21, and R23) generally plot above the atmospheric trend, as do those for most soil samples from the woods adjacent to IOC (all "S" samples). Lead-isotope ratios for soils from sampling sites R3, R19, S5, and S7 (all within 100 ft of IOC) appear to define a mixing curve whereby a statistically significant trend indicates mixing of leads of different isotopic compositions (R.W. Hurst, written commun., 1996). The isotope ratios, in general, illustrate that lead in soil samples from areas near IOC, whether from woods or residential land, tends to be isotopically distinct from lead in soil samples from some orchards and from residential area 2; isotope ratios for these latter soil samples tend to plot below the regional atmospheric trend or at the less radiogenic region of the figures, near the origin. Those samples that plot near the regional atmospheric trend, such as many of the "R" samples, may contain some lead from atmospherically deposited gasoline lead (R.W. Hurst, written commun., 1996), as well as lead from some other source.

The isotopic similarity of lead in soils from residential area 1 and the woods adjacent to IOC may be related to industrial activities at IOC; although no chemical evidence exists for contaminants deposited from a smokestack plume, wind-blown dust from wastepiles could have been distributed in the areas adjacent to IOC. The isotopic similarity of lead in soils from residential area 2 and some orchards indicates that some of the lead in the soil samples from residential area 2 may be derived from lead-bearing pesticides. Overall, the lead-isotope ratios differ between soils of residential area 1 and residential area 2, and thus support other chemical evidence that some inputs of metals to soils from these two areas derive from different sources.

SOURCES OF ARSENIC AND METALS IN SOILS

The goal of the study described herein was primarily to determine the sources of arsenic in soils of the residential areas and, secondarily, to determine the sources of metals in the residential soils. Three possible sources were considered likely candidates: natural (geologic) sources, manufacturing activities at IOC, and pesticides formerly used in orchards.

Natural Sources

The soils in the study area have developed both from sandy and from clayey geologic materials. The limited number of samples of sandy geologic materials (C horizons) collected during this study, when contrasted with the clay samples collected, contained small concentrations of metals. Concentrations of arsenic, lead, copper, barium, and zinc were less than 10 mg/kg. The clays, however, contained much larger concentrations of arsenic--from 8.2 to 41.2 mg/kg in the samples from undeveloped forested areas (representing natural geologic inputs). Possible mineral sources of the arsenic in the clays sampled include iron oxyhydroxides, glauconite grains, and sulfides. As a result, arsenic concentrations were smaller in A and B horizons of soils developed on a sandy substrate than in those of soils developed on a clay-rich substrate.

Concentrations of metals in soil samples from undeveloped areas tended to be larger in clays than in sandy soils. The presence of relatively large concentrations of copper in O-horizon samples from undeveloped-area soils several miles from IOC indicates input from regional atmospheric fallout of copper over the study area. Lead in soil samples from undeveloped areas derives partly from geologic materials, but, in O- and A-horizon samples, reflects substantial atmospheric deposition as well. Iron, manganese, and vanadium in samples from undeveloped areas appear to derive mostly from geologic materials. Aluminum, barium, and potassium in soils from undeveloped areas are contributed mostly by clay minerals. Although some zinc is contributed by geologic materials, the presence of larger concentrations of zinc in A-horizon soil samples than in deeper horizons indicates that much of the zinc is contributed by regional atmospheric deposition; Moore and Ramamoorthy (1984, p. 190) report that "large quantities of zinc are transported and deposited by precipitation" on a worldwide basis.

Imperial Oil Company Superfund Site

Large concentrations of arsenic and metals have been measured in soils from the IOC site. One of the questions to be resolved by this study is whether inorganic contamination at IOC has migrated offsite to the woods adjacent to IOC, to residential area 1, or to residential area 2, through either atmospheric fallout, earth-moving activities, or some other means.

Smokestack Plume

If activities at IOC have contributed arsenic and metals to residential area 2, contaminants would have to have been transported about 0.5 mi north-northeast of the site. One hypothesis that has been advanced is that a contaminant plume emanated from the stacks of the roasting ovens at IOC (Steven Byrnes, oral commun., 1995). For material in the hypothesized plume to have been transported by the wind from IOC to residential area 2, the wind would have to have been blowing from the south-southwest.

Data from the National Weather Service for the Naval Air Station at Lakehurst, New Jersey, about 28 mi south of IOC, indicate that the prevailing wind direction south of the study area is from the west. During the 10-year period from 1973 to 1982, west winds blew 12.7 percent of the time; west-northwest and northwest winds blew 9.7 and 8.5 percent of the time, respectively. South-southwest winds blew only 4.6 percent of the time. Data for 1984-87 and 1989 at Newark Airport, about 24 mi north-northeast of IOC where north-northeast winds are more prevalent because of proximity to the ocean, indicate that west winds blew about 7 percent of the time, northwest winds about 8.8 percent of the time, southwest winds about 11.5 percent of the time, and south-southwest winds about 6.5 percent of the time. No data are available for the Morganville airport, about 1 mi south of IOC, but airport personnel state that the prevailing wind direction is west. Data for Lakehurst, New Jersey, and a windrose for Newark, New Jersey, are presented in appendix 3.

Contaminants issuing from the stacks at IOC would likely have been deposited in an arc from the northeast to the southeast of IOC more often than in other directions, on the basis of available wind-direction data. Therefore, if arsenic and lead in soils from residential area 2 were deposited by fallout from a smokestack plume, the contaminants would be borne on a south-

southwest wind, which probably blew 6.5 percent of the time at most (using the Newark wind-direction data). Any fallout measured in the soils, therefore, probably would represent only a small percentage of the total amount of contaminants deposited in the area.

The highest wind speed for a south-southwest wind recorded at Lakehurst is in the range of 11 to 16 knots. Stability classes range from very unstable (A) to stable (F). At the surface wind speed of 8.2 m/s, stability classes A through D are most likely to be applicable. Results of the preliminary air-flow simulation, conducted by using an arbitrary contaminant emission (mass flow) of 12,000 μg/s, a virtual stack height of 12.2 m (a 30-ft stack and 10-ft plume rise), a wind speed of 8.2 m/s (16 knots), and three meteorological air-stability classes (A, D, and F), are shown in figure 32. The peak contaminant concentration moves farther from the source as stability increases; nevertheless, even under unrealistic conditions (a relatively high wind speed and stable meteorological conditions (F)), the peak contaminant concentration at ground level cannot be moved in the simulation farther than about 0.5 km (about 0.3 mi) from the source. Residential area 2 is about 0.5 mi, or 0.8 km, from the chimney stacks at IOC.

The more sophisticated model used by NJDEP takes into account the terrain surface and upper-air wind speeds and directions and the height of the original buildings at IOC. It uses surface-air data from Newark and upper-air data from Atlantic City. Various particle-size distributions can be simulated; arsenic emitted during the hypothetical ore-roasting is assumed to be associated with particles less than 1.25 μm in diameter. An arbitrary stack emission of 1 g/s is used. (A complete discussion of the model is presented in an unpublished report available at the NJDEP office in Trenton, New Jersey.)

The results of the simulation done by NJDEP are shown in figure 33. Although use of surface-wind data from Newark tends to emphasize winds blowing from the southwest and south-southwest, the bulk of deposition from the hypothetical smokestack plume falls near IOC and east-northeast and southeast of IOC because of the terrain. Relatively little deposition occurs to the north-northeast, and nearly all of it is shown to occur within 150 m of IOC. This distribution is similar to that predicted with the preliminary model. An arbitrary emission rate was used in both models because no data on actual emissions were available; therefore, amounts of contaminant deposition shown are completely hypothetical.

Soil samples from the woods adjacent to IOC contained arsenic, barium, copper, lead, nickel, and zinc in concentrations that are within the range of concentrations measured in the background samples. The area of the woods from which the samples were collected lies on a north-northwest line between IOC and residential area 2. Therefore, if smokestack-plume fallout were contributing arsenic and other contaminants to the soil, some of that fallout would likely be deposited on the soils in the woods adjacent to IOC. Additionally, analyses of soil samples collected by NJDEP during 1995 from an area near the corner of Tennent Road and Route 79, due east of IOC, show that arsenic concentrations in the uppermost 6 in. of soil are small (Steven Byrnes, written commun., 1996) and are in the range of concentrations measured in samples of sandy A-horizon soils from undeveloped areas. Thus no evidence currently exists for elevated arsenic concentrations that could be attributed to smokestack-plume deposition north-northeast and due east of IOC.

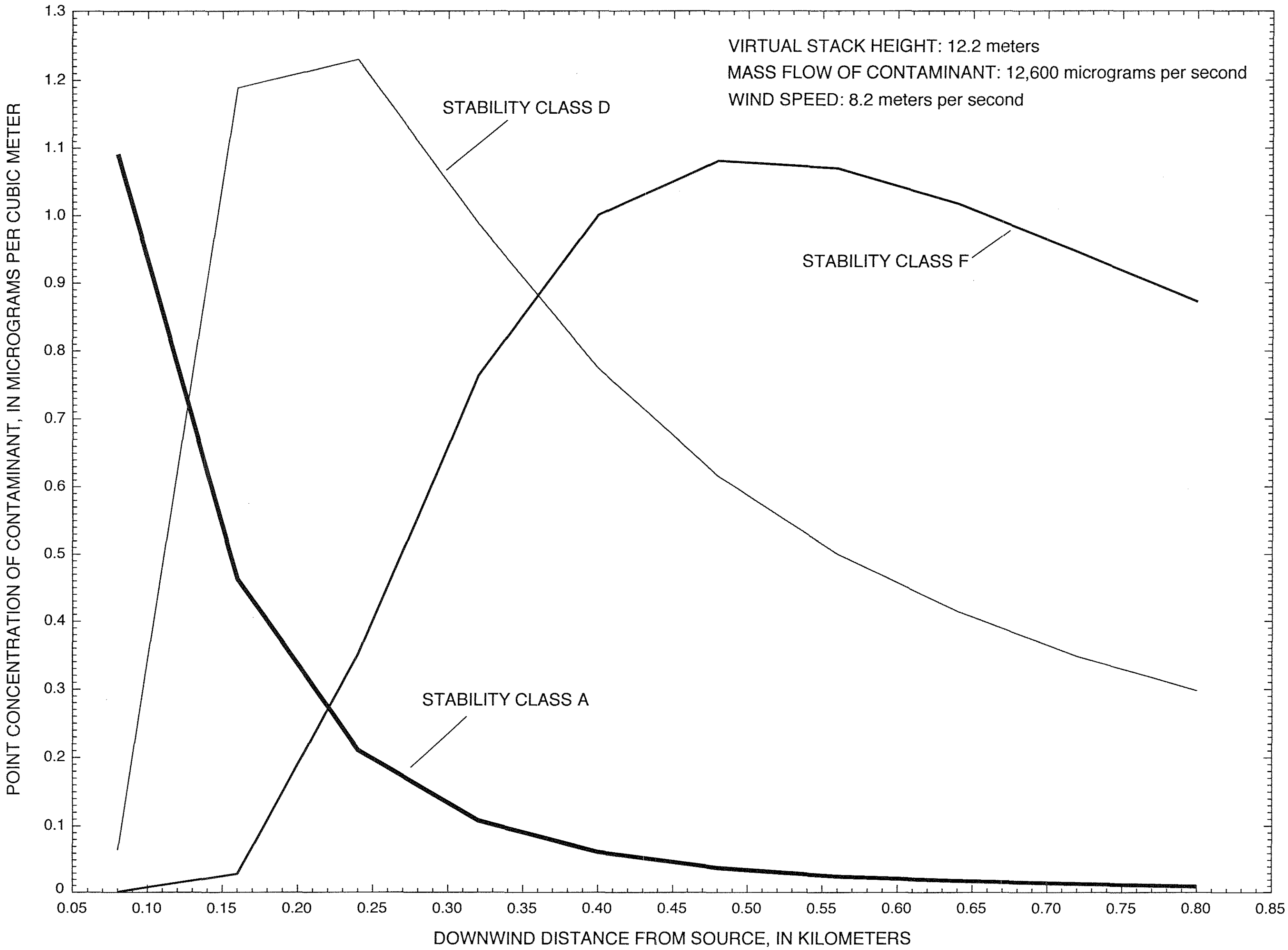
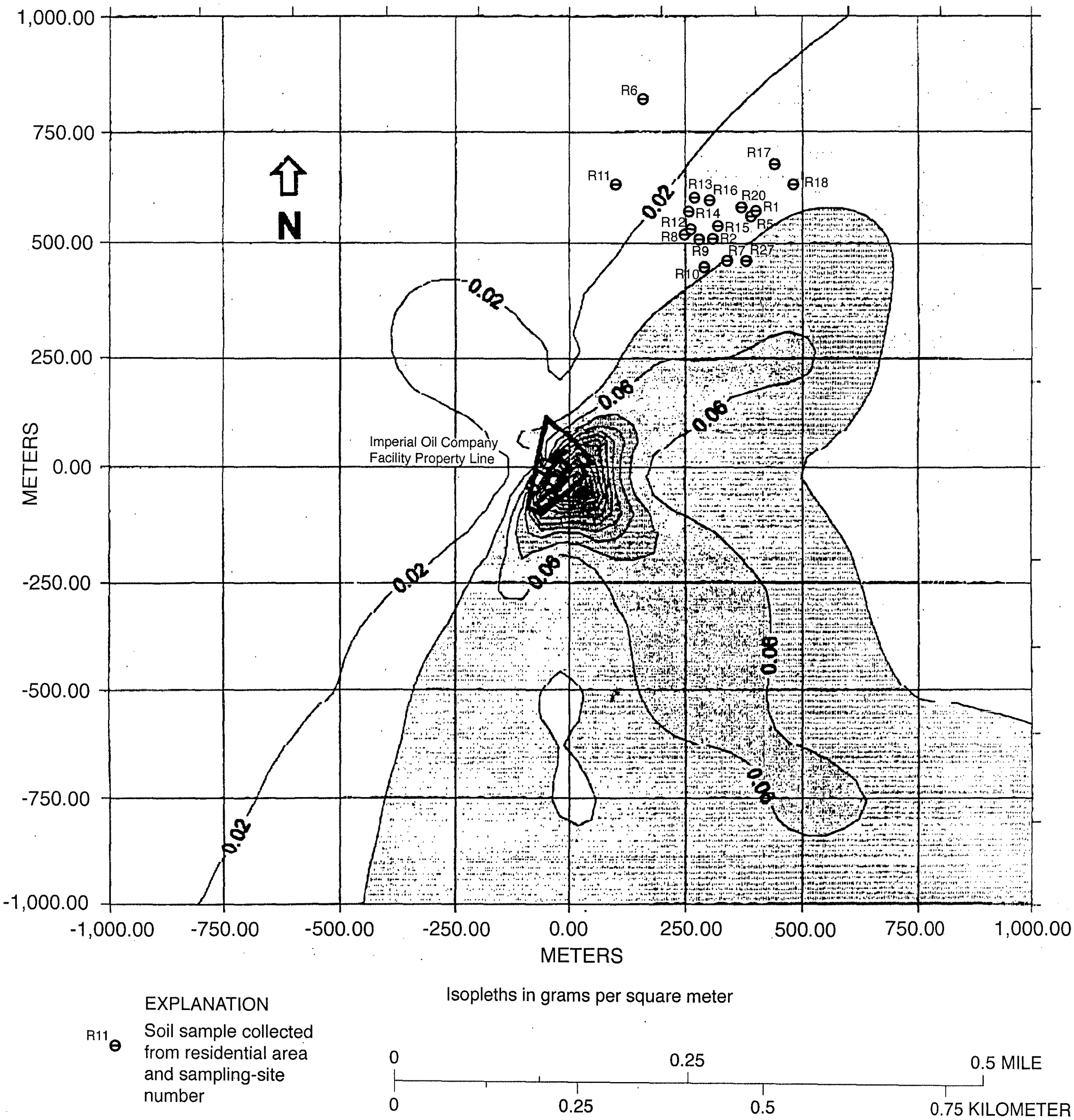


Figure 32. Simulated downwind concentrations of contaminant in air at ground level determined by using a two-dimensional air-flow screening model.



ISCST3 Version (96113)
1984-89, 1989 Newark/Atlantic City meterological data
Normalized emission rate of 1 gram per second
Represents particulates with an aerodynamic diameter less than 1.25 micrometer

Figure 33. Dry-deposition pattern of small particles in the vicinity of Imperial Oil Company Superfund site simulated by using an arbitrary normalized emission rate of 1 gram per second and meterological data from 1984-89 from Newark and Atlantic City airports, New Jersey. (From unpublished report available at New Jersey Department of Environmental Protection office in Trenton, New Jersey)

A smokestack plume hypothetically could also deposit sulfur, as sulfide ores typically are roasted to obtain various metals. Sulfur was detected in some IOC soil samples at concentrations generally greater than those found elsewhere in the study area, although sulfur also was detected in several clayey soils and clay samples from undeveloped and orchard areas. One clay sample from the Woodbury Formation contained 3.35 percent sulfur, the largest concentration measured during this study. Sulfide minerals were visible in this sample.

The absence of sulfur in nearly all the A- and B-horizon soil samples from the woods adjacent to IOC militates against significant fallout from the hypothetical smokestack plume. A study of sulfur and heavy metals in organic soil horizons near copper and nickel smelters in Russia indicates that, although sulfur is more easily leached than some metals, some atmospherically deposited sulfur is retained by humic materials (Niskavaara and others, 1996). Sulfur (as sulfate) also is adsorbed by acid soils (Chao and others, 1962), such as those in the vicinity of IOC. Sulfur was present in O-horizon samples from the woods adjacent to IOC in small concentrations similar to those measured in O horizons in undeveloped and orchard soils throughout the study area. Sulfur in O-horizon soils in the study area probably derives from acid precipitation, which has been enriched in anthropogenic sulfur for decades (see Hileman, 1981; Gould, 1983)

Although sulfur was seldom detected in sandy soils from the other land-use areas, two A-horizon samples from residential area 1 contained sulfur at the limit of detection (0.05 percent), indicating that some sulfur from the IOC site may have migrated to adjacent soils. Sulfur also was found in the A-horizon soil at sampling site S4, in the woods immediately east of IOC. In the broader area, about 1 mi east of IOC, samples from both sites contained detectable sulfur in some of the horizons; the largest concentration measured was 0.13 percent in a clay sample that contained 26.1 mg/kg of arsenic. Both arsenic and sulfur in this sample could be geologic in origin, on the basis of concentrations measured in other background samples in the study area.

No sulfur was detected in soil samples from residential area 2. Currently available data do not conclusively support the existence of fallout from a smokestack plume and therefore do not demonstrate that the arsenic and other contaminants in soils from residential area 2 can be attributed to dry deposition of airborne material emanating from IOC.

Earth-Moving and Other Activities

The soils at IOC show clear evidence of disturbance. Buildings and tank farms were added to the site after pesticide production ceased and the property was sold; much of the expansion appears to have taken place during the 1950's, as documented by aerial photographs from 1940, 1951 (E.C. Jordan Co., 1990), and 1954 (this study). A pile of material, located where the filter-clay wastepile was identified during initial investigations in the late 1980's, is visible in a 1962 aerial photograph (E.C. Jordan Co., 1990). The fire pond north of IOC apparently was constructed some time during 1962-74, as it appears in a 1974 aerial photograph, as does an area of excavated soils (now about 250 by 200 ft) immediately south of the fire pond (E.C. Jordan Co., 1990). More recently (1976), contaminated soil at the oil/water separators is reported to have been excavated and replaced with clean sand and an earthen berm constructed along the northeastern boundary of the active part of the site. Several tanks then were removed, apparently in the late 1980's (E.C. Jordan Co., 1990).

Although waste-disposal practices at IOC during the first half of this century are not documented, the soils that were disturbed in the 1950's are likely to be contaminated with wastes from earlier arsenical pesticide production. More recently disturbed soils also could contain oily wastes from later industrial activities. The large area of fill that extends northward from IOC's eastern fenceline to the fire pond contains pieces of brick, concrete, and other construction debris, as well as fragments of cindery slag similar to the pieces extracted from soil cores at IOC and found on the surface at IOC near the site of the filter-clay wastepile. Samples from the fill contain elevated arsenic, barium, copper, and lead concentrations (E.C. Jordan Co., 1990). Although the history of earth-moving activities at IOC is poorly known, it is apparent that contaminated soils have been moved, and that some of the soil and debris probably was moved to the adjacent properties that are part of residential area 1.

The soils in residential area 1 at the land surface that contain the largest concentrations of arsenic are clays similar to the clay underlying IOC and the adjacent woods. No sequence of naturally occurring soil horizons is present at these sampling sites (R3 and R4); these soils clearly are disturbed, and they contain debris that is similar to that found both dispersed at the land surface and at depth at IOC and in the adjacent area of fill. Smaller amounts of the same type of debris are present in the adjacent, less disturbed topsoil. Moreover, samples of the cindery slag debris, one piece from IOC and one from a private property in residential area 1, contain elevated concentrations of arsenic.

Other, less visible sources of arsenic also may be present in the residential area 1 soils; these may be sources of elevated barium, copper, and lead concentrations as well. In addition to the elevated barium and copper concentrations measured in some of these soils during this study, elevated arsenic, barium, and copper concentrations were measured earlier in three soil samples collected near sites R3 and R4, near sites R21 and R22, and on the property south of site R22 (L. Robert Kimball and Associates, 1995). A lead concentration of 611 mg/kg in one sample and zinc concentrations greater than 200 mg/kg in two samples also were measured. These inorganic contaminants commonly are associated with activities at IOC, and it is possible that, in addition to arsenic being distributed during moving of excavated soils from IOC to adjacent areas, arsenic and these other contaminants could have been distributed as dust by the wind.

The chemistry of soils from residential area 2, on the other hand, generally is not indicative of contamination from IOC. Although contaminants could have been transported by means other than smokestack-plume fallout from IOC to residential area 2, none of the debris common to IOC soils and soils from residential area 1 has yet been found in soils from residential area 2. The chemical signature of most of the soil samples collected from residential area 2 is consistent with geologic and orchard inputs.

Orchard Pesticides

Elevated arsenic concentrations are, in some cases, associated with orchard soils, particularly in the A and E horizons. Overall, arsenic concentrations tended to be higher in the A and (or) E horizons of orchard soils than in the same horizons in soils from undeveloped forested areas.

The median arsenic concentration in orchard A- and E- horizon samples combined was 11.3 mg/kg, whereas the median arsenic concentration in A- and E-horizon samples from undeveloped areas was 4.25 mg/kg.

Arsenic concentrations in B-horizon soils from most of the undeveloped areas tended to be larger than the concentrations in A- or E-horizon soils, particularly those developed on a clay-rich geologic substrate. Arsenic concentrations in B-horizon soils from orchards tended to be smaller than those in the A or E horizons, however. The decrease in arsenic concentration with depth in the soil profile is less pronounced in clay-rich soils from orchards than in sandy soils, indicating a fairly homogeneous distribution of elevated arsenic concentrations in the clayey geologic substrate. The vertical distribution of arsenic in soils of residential area 2 tends to follow the pattern seen in clay-rich orchard soils.

Lead concentrations, which were greater than 100 mg/kg in some of the A and E horizons of orchard soils, also tended to be large in the A horizons of soils in residential area 2. The distribution of lead in the soil profile in orchards and at some sampling sites in residential area 2 tended to be similar.

Copper inputs to orchard soils can be atmospheric and (or) the result of applications of copper-bearing pesticides or fertilizers such as copper sulfate. Potassium also may have been added to soils by fertilizers used in the orchards. Barium can be contributed by lime added to agricultural soils to raise the pH. Kozinski and others (1995) found barium to be a useful marker of ground water recharged through agricultural land in the Coastal Plain; the soil in agricultural areas likely contains elevated concentrations of barium. Some zinc may be contributed to study-area orchard soils by agricultural chemicals, as zinc is added to fruit trees as a micronutrient (John Hauser, oral commun., 1996). All these constituents tended to be present in larger concentrations in sandy soil samples from orchards than in sandy soil samples from undeveloped areas; concentrations of these constituents also were larger in samples containing clay, regardless of land use. Concentrations of these constituents in soil samples collected at sites O7, O12, and O16, all in orchards underlain by the Woodbury Formation (and therefore rich in clay), most closely resemble those in many of the soil samples collected from residential area 2, also underlain by clay.

In general, the chemistry of soils from sampling sites in residential area 2, many of which are located beneath old apple trees (see table 1), resembles the chemistry of soils from orchards (figs. 26-28). In a few of the soil samples from residential area 2, arsenic concentrations were highly elevated (49.5-73.9 mg/kg in samples from sites R2, R12, R13 and R27); these values are larger than any concentrations measured in other orchard soils collected during this study. Orchard pesticide inputs of arsenic could increase naturally occurring arsenic concentrations, which appear to be on the order of about 20 mg/kg in the clays underlying many of the residential area 2 sampling sites. Furthermore, because organic arsenical pesticides were used increasingly in the United States during the 1970's to control crabgrass (Adriano, 1986), additional inputs of arsenic from lawn-care products also are possible.

The significant positive correlation between arsenic and mercury concentrations in residential area 2 A-horizon soils and the broader area samples is not present in soils from other land-use groups, including IOC. The cause of this relation is unknown; perhaps mercurial pesticides also were used for control of crabgrass and other weeds in some of the residential areas.

It is unclear whether the confluence of naturally occurring arsenic and arsenical pesticides could result in the “hotspots” of 77.4 and 151 mg/kg of arsenic measured previously by NJDEP (Steven Byrnes, written commun., 1996) in soils adjacent to sampling sites R15 and R13, respectively. The large arsenic concentration (149 mg/kg) in a sample collected about 1 mi east of IOC, in the broader area, indicates that “hotspots” of arsenic-contaminated soil are not limited to the two residential areas investigated during this study. Storage of arsenical pesticides, or mixing of them, or spills related to the filling of spraying equipment, could be responsible for the isolated instances of highly elevated arsenic concentrations in residential area 2 and the broader area. Alternatively, the arsenic “hotspots” may result from activities unrelated to the former orchards in the area. The available data do not permit a definitive interpretation at this time.

SUMMARY AND CONCLUSIONS

In order to determine sources of arsenic and metals found in elevated concentrations in residential soils in the vicinity of the Imperial Oil Company Superfund site (IOC), the U.S. Geological Survey collected soil cores from long-term forested areas (undeveloped land), from former and existing orchards, and from IOC to determine the amounts of arsenic contributed by geologic material, by use of arsenical pesticides, and by industrial activities. Soil cores also were collected in the woods adjacent to IOC, and at two residential areas near IOC where elevated arsenic and lead concentrations had been measured previously in the soils. Residential area 1, formerly farm and orchard land, is adjacent to IOC; residential area 2, built on former orchard land, is located beyond the woods about 0.5 mi north-northeast of IOC. Two soil cores also were collected in a residential area built on former orchard land about 1 mi east of IOC.

The soil cores were divided by horizon into samples that were analyzed for 23 metallic constituents, total organic carbon, and total sulfur. Arsenic concentrations generally were smaller than 10 mg/kg in samples of sandy soils from undeveloped areas, but were as large as 40 mg/kg in clay samples. Arsenic concentrations in samples of orchard soils were found to be as large as 40 mg/kg in A and E horizons, and were greater than 20 mg/kg in samples from underlying clay lenses. Arsenic concentrations in soil samples from IOC typically were smaller than 50 mg/kg, but a few clay samples contained concentrations of about 100 mg/kg. Barium, copper, and zinc concentrations tended to be larger in soil samples from IOC than in those from undeveloped and orchard land.

Chemical signatures indicative of background (geologic and regional atmospheric input), orchard (pesticide input), and industrial (pesticide-manufacturing input) concentrations of arsenic and metals in soils of the area were determined graphically and statistically and were compared to the chemistry of soils from the residential areas. Discriminant analysis of the chemical data provided chemical signatures for soils from undeveloped land, from orchards, and from IOC on the basis of ranks of 13 chemical-constituent concentrations. The chemistry of most of the soils from residential area 2 is statistically similar to that of orchard soils. Much of residential area 2 is underlain by clay lenses; therefore, the natural geologic contribution of arsenic also tends to be large. Soils from residential area 1 are chemically similar to orchard soils, but show some chemical similarities (larger barium and copper concentrations) to soils at IOC; moreover, debris (slag and brick fragments) found at IOC also is found in the adjacent residential soils.

The hypothesis that arsenic in the soils was derived from a smokestack plume during the years when arsenical pesticides were produced at IOC was tested by air-flow modeling of possible contaminant distributions emitted from the stacks. The wind direction from which the hypothetical smokestack plume would travel to residential area 2 is south-southwest; winds, however, blow from that direction less than 7 percent of the year. Contaminant distributions at ground level simulated by the air-flow model do not match the distributions of contaminants measured in soils. The soil samples from the woods located between IOC and residential area 2 contained arsenic and metals in concentrations that were small and within the ranges found in forested, undeveloped-area soils, although concentrations were slightly larger in the area of woods that had been an orchard. The distribution of arsenic and metals in the soils, lack of detectable sulfur in the soils, and results of air-flow modeling do not support the hypothesis of arsenic deposition from a smokestack plume.

Overall, the chemical data and soil characteristics indicate the following:

1. Arsenic concentrations in sandy soils of the area are small (generally less than 10 mg/kg), but are substantially larger in clays (up to 40 mg/kg).

2. Arsenic concentrations in orchard soils can range from background levels (less than 10 mg/kg) to at least 40 mg/kg in A and E soil horizons.

3. Elevated concentrations of arsenic in soils from residential area 1 are likely to be derived, in part, from waste materials from IOC, on the basis of the presence of debris, bricks, and cindery slag common to soils at IOC and residential area 1.

4. Concentrations of copper and barium are elevated (above background levels) in soils from IOC and residential area 1, which is interpreted as being indicative of a connection between IOC and residential area 1.

5. Elevated concentrations of arsenic in soils from residential area 2 appear, for the most part, to be derived from geologic sources and from use of arsenical pesticides in the former orchards there. A few instances of highly elevated arsenic concentrations (greater than 50 mg/kg) cannot be interpreted on the basis of available data.

6. Soils in a third residential area on former orchard land (broader area) about 1 mi from IOC also contain elevated concentrations of arsenic.

7. Lead-isotope ratios indicate that some lead in soils in the study area is contributed by atmospheric deposition. Lead-isotope ratios in residential and woods soils nearest to IOC are similar to each other but different from lead-isotope ratios in some soil samples from orchards and residential area 2.

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APPENDIXES

APPENDIX 1

Summary of Analytical Methods and Chemical and Field Data for Soil Samples Collected During 1995-96, Imperial Oil Company Superfund Site Study Area, New Jersey

Analytical Methods

Samples for inductively coupled plasma spectroscopy (ICP) analysis are prepared by digesting 1 g of soil in nitric acid and hydrogen peroxide and refluxing the digestate with nitric acid or hydrochloric acid. In the ICP spectrometer, the sample is nebulized, and characteristic atomic-line emission spectra produced by plasma are dispersed by a grating spectrometer and intensities increased by photomultiplier tubes; the photocurrents are then processed by computer. Samples for mercury analysis by cold-vapor atomic absorption (CVAA) undergo oxidation with potassium permanganate and potassium persulfate; sodium chloride-hydroxylamine sulfate is added to reduce excess permanganate; the headspace in the sample bottle is purged and stannous sulfate is added to reduce the mercury. The sample bottle is attached to an aeration apparatus and the mercury vapor passes through a cell placed in the light path of an AA spectrophotometer.

Determination of total organic carbon by the Lloyd Kahn method first involves removal of inorganic carbon (from carbonates and bicarbonates) by acid treatment. Second, organic compounds are decomposed by pyrolysis, and the carbon dioxide thus formed is measured. The carbon dioxide determination can be made by direct nondispersive infrared detection, flame-ionization gas chromatography following catalytic conversion of carbon dioxide to methane, or thermal-conductivity detection on samples from which water is removed.

The concentration of total sulfur in soil is determined by infrared-adsorption spectroscopy (IR) on the evolved sulfur dioxide gas from combustion of a 0.25-g air-dried sample, ground to pass through an 80-mesh (<180 micron) sieve and mixed with 1 g of vanadium pentoxide flux, in a pressurized oxygen atmosphere at 1,370 ^{o}C (Curry, 1990). Twigs and pebbles were removed from the sample before grinding with a coarse 10-mesh sieve. The precision of the technique is about ± 0.01 percent.

Lead-isotope analyses are performed by mass spectrometry on samples from which the labile lead has been extracted by reaction with 8N nitric acid for 10 minutes. The extracted sample is weighed and split into two aliquots, one of which is used for isotopic analysis; the other is spiked with enriched ^{206}Pb for lead-concentration determinations. The lead is separated by anion-exchange chromatography, concentrated by using hydrobromic acid, and purified with hydrochloric acid, resulting in a lead chloride salt. The lead salt is dissolved in phosphoric acid and loaded on a rhenium filament, and lead isotopes (^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb) are determined by repeated scans in a thermal ionization mass spectrometer. Fractionation effects are corrected by running lead-isotope standards (R.W. Hurst, Chempet Research Corporation, written commun., 1996).

Appendix 1

Table 1. Concentrations of constituents measured in soil samples from undeveloped forested areas in Monmouth and Middlesex Counties, New Jersey

[All concentrations in milligrams per kilogram (parts per million) unless otherwise noted; B, detectable value but below the contract-required detection limit; U, below the instrument detection limit; J, qualified--data may exhibit bias; <, less than; NA, not analyzed; see figs. 8 and 9 for locations]

Sample number[1]		Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
E 1	O	951130	1020	2.1 B	7.4 B	0.03 U	0.14 B	283 B	2.9	0.39 U	10.8	2290	44.0	144 B	12.9
E 1 D	O	951130	793	2.2 B	4.7 B	0.02 U	0.07 U	125 B	2.9	0.32 U	9.3	3060	34.5	101 B	8.3
E 1	A	951130	843	2.3	4.4 B	0.02 U	0.07 U	31.1 U	3.2	0.31 U	7.2	2660	58.7	88.4 B	7.5
E 1	E	951130	527	1.0 B	3.5 B	0.02 U	0.05 U	24.2 U	1.1	0.24 U	1.3 B	1360	3.0	24.7 B	6.8
E 1	B1	951130	3250	2.9	7.4 B	0.06 B	0.05 U	25.3 U	9.2	0.31 B	1.5 B	8010	2.9	66.0 B	10.9
E 1	B2	951130	1010	0.97 B	2.8 B	0.02 U	0.05 U	24.2 U	2.5	0.24 U	0.55 B	1100	1.3	31.7 B	3.1
E 2	O	951201	1230	2.3 B	10.8 B	0.03 U	0.13 B	348 B	3.7	0.40 U	13.2	2660	59.2	140 B	12.1
E 2 S	O	951201	1470	2.3 B	14.4 B	0.03 U	0.18 B	650 B	7.5	0.36 U	15.2	5280	62.4	213 B	21.1
E 2	A	951201	1630	5.9	5.4 B	0.02 U	0.06 U	30.9 U	8.4	0.30 U	5.5	6980	23.1	127 B	12.6
E 2	B1	951201	4570	5.7	11.6 B	0.10 B	0.07 U	32.1 U	8.6	0.31 U	2.9 B	8540	3.5	150 B	13.2
E 2	B2	951201	3380	7.4	7.7 B	0.05 B	0.06 U	119 B	14.9	0.61 B	4.2 B	5640	5.1	318 B	10.6
E 4	O	960206	922 J	2.8 B J	42.9 B	0.21 B J	1.1 B	1690 J	5.0 J	0.92 U	20.0 J	2340	104	546 B J	99.7
E 4	A	960206	508 J	2.2 B J	3.7 B J	0.08 B J	0.16 U	26.0 U	1.3 J	0.3 J	6.9 J	876	35.9	24.5 U	2.0 J
E 4	E	960206	286 J	1.6 B J	1.7 B J	0.09 B J	0.15 U	19.1 U	0.79 U	0.28 U	1.6 U	357	6.7	16.0 U	1.8 J
E 4	B1	960206	1800 J	3.1 J	3.9 B J	0.07 B J	0.27 U	15.1 U	2.2 J	0.18 U	3.4 B J	2260	6.4	38.2 U	2.7 J
E 4	B2	960206	1330 J	2.2 B J	3.0 B J	0.11 J	0.19 U	16.5 U	2.2 J	0.18 U	1.8 U	1280	3.0 J	25.6 U	1.8 J
E 4	C	960206	435 J	1.2 B J	1.8 B J	0.06 B J	0.10 U	13.1 U	1.3 J	0.17 U	0.51 U	557	1.7 J	9.1 U	1.0 J
E 5	E	960206	709 J	5.4	1.8 B J	0.05 U	0.05 U	24.0 U	1.8	0.24 U	2.2 B J	4220 J	8.6 J	31.7 B J	4.9 J
E 5	B1	960206	913 J	6.3	1.4 B J	0.07 U	0.05 U	22.2 U	2.7	0.22 U	2.6 B J	6330 J	5.7 J	33.4 B J	3.9 J
E 5	B2	960206	2440 J	7.1	3.1 B J	0.11 U	0.08 B J	23.9 U	4.6	0.23 U	1.2 B J	5220 J	7.7 J	75.5 B J	3.6 J
E 5	C	960206	1920 J	6.0	2.3 B J	0.08 U	0.04 U	21.3 U	5.0	0.21 U	0.91 B J	3330 J	3.7 J	79.2 B J	2.5 J
E 6	A	960206	388 J	3.3	4.4 B J	0.02 U	0.09 U	28.9 U	1.2 J	0.18 U	7.6 J	925 J	25.5 J	12.4 U	1.5 J
E 6	E	960206	986 J	4.7 J	3.8 B J	0.04 U	0.22 U	23.3 U	2.0 J	0.18 U	5.0 J	2110	9.1	27.3 U	1.5 J
E 6	B1	960206	4410 J	8.5	7.5 B J	0.11 B J	0.52 U	8.3 U	7.5	0.24 U	3.3 B J	5680 J	5.7 J	68.3 U	2.2 J
E 6	C	960227	2510	4.7	8.0 B J	0.19 B J	0.05 U	24.7 U	20.8	0.36 B	6.7	7500	4.2 J	58.1 B J	8.2
E 6	CL1	960206	6290 J	17.6 J	12.0 B J	0.25 B J	0.97 B J	17.2 U	15.9 J	0.37 U	5.7 J	9520	9.7	163 B J	3.1 J

[1] The initial letter denotes sample sites in the undeveloped areas; the following number is the number of the individual site. In the next two columns, samples marked D are spatial duplicates; samples marked S are splits. The final letter refers to the soil horizon; CL denotes clays. The final number denotes increasing depth with increase in value.

Table 1. Concentrations of constituents measured in soil samples from undeveloped forested areas in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]		Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
E 7	E	960206	2900 J	10.3	3.5 B J	0.17 B J	0.05 U	22.0 U	12.4	0.28 B J	6.9	47300 J	20.2 J	48.2 B J	15.6 J
E 7	B1	960206	6120 J	11.5	10.1 B J	0.28 B J	0.06 U	26.4 U	23.3	0.57 B	4.5 B J	21100 J	6.2 J	204 B J	12.6 J
E 7	B2	960206	6230 J	14.2	10.4 B J	0.28 B J	0.05 U	23.4 U	34.1	0.85 B J	6.3	35500 J	8.5 J	233 B J	16.4 J
E 9	O	960206	874 J	8.2	16.7 B J	0.08 U	0.65 B J	615 B J	5.1	2.0 B	38.0 J	3240 J	209 J	154 B J	17.8
E 9	A	960206	258 J	3.8	2.6 B J	0.02 U	0.25 B J	26.0 U	4.8	0.18 U	6.1 J	2210 J	17.4 J	9.4 U	3.0
E 9	B1	960206	1650 J	4.4 J	3.5 B J	0.04 U	0.52 B J	37.9 U	4.2 J	0.18 U	4.7 J	5550	4.4 J	51.4 U	3.3
E 9	B2	960206	3080 J	9.2 J	5.1 B J	0.27 B J	1.1 J	25.4 U	24.0 J	0.20 U	3.4	10700	5.2	77.1 U	6.0
E 9	C	960206	3170 J	8.6 J	5.2 B J	0.10 B J	0.68 U	22.0 U	10.0 J	0.19 U	2.1 J	7280	4.1 J	61.6 U	37.7
E11	A	960227	2040	7.4	5.0 B J	0.05 B J	0.06 U	90.8 B J	4.8	0.28 U	7.6	5760	37.0 J	93.3 B J	8.1
E11	B1	960227	2270	3.6	4.1 B J	0.08 B J	0.06 U	29.1 U	6.8	0.29 U	5.8	19100	9.1 J	50.9 B J	6.3
E11	B2	960227	6650	7.0	10.7 B J	0.15 B J	0.06 U	27.1 U	13.0	0.55 B	4.4 B	13000	5.1 J	178 B J	8.5
E11	CL1	960227	6140	9.0	9.9 B J	0.17 B J	0.07 U	33.1 U	16.3	0.36 B J	6.2	15800	5.5 J	144 B J	7.2
E11	CL2	960227	3320	8.2	6.7 B J	0.16 B J	0.06 U	28.1 U	20.1	0.28 B	7.3	10500	6.8 J	74.5 B J	4.9
E12	O	960131	1150	6.2 J	42.7 B J	0.05 U	0.88 B J	2470	6.5	1.9 B J	28.6	4600	126 J	303 B J	63.9
E12D	O	960131	2110	16.3 J	13.1 B J	0.03 U	0.17 B J	390 B J	13.2	1.1 B J	31.8	12400	128 J	237 B J	21.1
E12	A	960131	427	4.3	2.5 B J	0.03 U	0.19 U	62.3 U	2.2 J	0.26 B J	5.1 J	2730	18.5 J	75.7 U	2.5
E12D	A	960131	1480	8.2 J	4.8 B J	0.02 U	0.05 U	40.4 B J	6.4	0.33 B J	14.2	8360	42.0 J	128 B J	9.4
E12	E	960131	485	1.3 U	4.0 B J	0.03 U	0.10 U	12.5 U	2.0 J	0.22 U	5.9 J	735	11.1 J	25.5 U	2.6
E12D	E	960131	352	1.9 J	1.7 B J	0.02 U	0.07 B J	26.1 U	1.9	0.26 U	2.2 B J	1670	7.9 J	25.9 B J	6.6
E12	B1	960131	667 J	0.95 U	2.6 B J	0.12 U	0.68 U	3.3 U	1.9 J	1.6 U	4.1 B J	722 J	1.9 J	13.4 U	0.79 B J
E12D	B1	960131	424	0.71 B J	2.0 B J	0.02 U	0.05 U	22.0 U	1.2 B J	0.22 U	1.3 B J	292	1.9 J	21.0 U	1.9 B J
E13	O	960201	4870	42.8 J	24.9 B J	0.21 B J	0.38 B J	968 B	13.9	1.2 B	17.7	21600	139 J	508 B J	52.8
E13	A	960201	4540	45.5 J	17.6 B J	0.19 B J	0.18 B J	316 B J	11.6	1.1 B J	15.2	19400	136 J	417 B J	55.1
E13	CL1	960201	22400	34.3 J	36.0 B J	0.77 B J	0.19 B J	108 B J	51.0	3.2 B J	18.4	52400	24.1 J	2020	57.3
E14	A	960212	1760 J	3.7	6.2 B J	0.11 B J	0.06 U	129 B J	4.6 J	0.30 U	12.8	4440 J	30.2 J	90.7 B J	9.3 J
E14	B1	960212	3000 J	2.9	8.1 B J	0.14 B J	0.05 U	22.9 U	7.2	0.27 B J	5.3	5910 J	7.1 J	95.3 B J	10.7 J
E14D	B1	960212	3810 J	2.6	9.4 B J	0.18 B J	0.06 U	30.9 U	5.8	0.30 U	5.5	5140 J	4.7 J	95.8 B J	9.9 J
E14	B2	960212	2450 J	4.1	6.2 B J	0.21 B J	0.06 U	29.5 U	8.9	0.29 U	2.6 B J	5140 J	2.3 J	70.4 B J	5.8 J
E15	A	960422	2430	7.7 J	7.4 B J	0.23 B J	1.1 B J	129 B J	6.5 J	0.37 B J	7.8	11700 J	27.1 J	191 B J	18.8 J
E15	B1	960422	4250	8.1 J	13.1 B J	0.23 B J	0.94 B J	24.3 B J	7.8 J	0.34 B J	10.2	11100 J	25.5 J	242 B J	9.5 J
E15	CL1	960422	10800	18.8 J	33.2 B J	0.58 B J	3.3 J	34.0 B J	29.9 J	0.52 B J	12.4	48400 J	19.8 J	813 B J	20.7 J

Table 1. Concentrations of constituents measured in soil samples from undeveloped forested areas in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]		Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
E15	CL2	960422	13900	41.2 J	25.0 B J	0.58 B J	4.0 J	35.0 B J	31.1 J	0.19 U	12.0	57100 J	19.7 J	1190 B J	21.9 J
E15 D	CL2	960422	8520	17.9	38.2 B	0.36 B J	0.19 U	23.7 B	26.1	2.2 B	14.8	36500	16.7	692 B	14.6
E15	CL3	960422	9530	18.3 J	36.3 B J	0.35 B J	2.2 J	35.4 B J	23.7 J	1.3 B J	9.1	31500 J	23.7 J	852 B J	17.9 J
E15 D	CL3	960422	11600	15.9	25.3 B	0.43 B	0.18 U	42.3 B	23.7	2.0 B	12.5	21000	16.4	1080 B	23.0
E16	A	960513	4640	10.7 J	22.0 B J	0.44 B J	0.16 U	973 B J	19.4	1.7 B J	15.3	20000	50.2 J	696 B J	36.9
E16	B1	960513	5110	11.0 J	26.0 B J	0.48 B J	0.16 U	317 B J	23.3	2.0 B J	8.3	22700	45.2 J	845 B J	43.6
E16	B2	960513	966	2.2 J	3.1 B J	0.09 B J	0.15 U	26.0 B J	2.9	0.31 B J	1.3 B J	2770	3.4 J	149 B J	5.3
E17	A	960513	9680	21.7 J	21.7 B J	0.30 B J	0.23 U	96.9 B J	18.3	1.5 B J	35.6	35100	69.7 J	572 B J	16.1
E17	CL1	960513	14200	25.5 J	20.6 B J	0.48 B J	0.22 U	74.6 B J	31.4	1.5 B J	15.8	61600	26.7 J	868 B	15.9
E17	CL2	960513	17300	40.0 J	20.4 B J	0.81 B J	0.20 U	142 B J	54.6	2.2 B J	12.0	118000	16.5 J	1530	18.1
W 1	CL1	960424	3970	13.6	15.9 B	0.44 B	0.16 U	508 B	12.4	0.91 B	8.8	27600	17.1	301 B	32.4
W 1	CL2	960424	12200	25.5	27.6 B	0.51 B	0.32 B	473 B	28.6	1.5 B	14.9	62100	13.9	787 B	16.2
W 1	CL3	960424	9960	23.4	24.4 B	0.50 B	0.47 B	368 B	27.3	1.5 B	18.3	75300	16.0	623 B	11.2
W 1	CL4	960424	11500	29.2	27.2 B	0.53 B	0.52 B	274 B	31.0	1.6 B	18.0	80500	17.9	801 B	14.5
W 2	B2	960509	7290	7.9 J	13.5 B J	0.21 B J	0.16 U	480 B J	18.9	1.1 B J	4.7 J	20100	6.7 J	674 B J	11.7
W 2	CL0	960509	8340	8.1 J	24.6 B J	0.36 B J	0.17 U	327 B J	27.7	1.4 B J	13.0	23200	13.4 J	710 B J	14.6
W 2	CL1	960509	10700	18.2 J	34.9 B J	0.43 B J	0.18 U	204 B J	25.1	2.0 B J	14.3	35900	17.5 J	1130 B J	21.6
W 2	CL2	960509	14500	21. J	34.1 B J	0.73 B J	0.18 U	216 B J	31.6	2.0 B J	15.5	110000	14.8	829 B J	22.3
W 2	CL3	960509	7500	18.1 J	36.1 B J	0.89 B J	0.17 U	1980	23.3	11.3 B J	13.6	26900	13.7	2890	149
W 2	CL4	960509	10200	34.3 J	51.6 B J	1.3 J	0.18 U	2670	37.4	14.8	18.7	35500	19.0	3690	155
W 3	A	960513	1230	5.2 J	3.9 B J	0.08 B J	0.16 U	36.6 B J	3.9	0.49 B J	7.2	11800	18.1 J	97.7 B J	8.8
W 3	B1	960513	1620	5.1 J	3.8 B J	0.07 B J	0.17 U	21.3 B J	4.4	0.43 B J	3.2 J	12700	2.4 J	105 B J	6.4
W 3	B2	960513	3280	11.4 J	5.2 B J	0.15 B J	0.17 U	20.5 B J	8.4	0.76 B J	1.5 B J	22000	2.5 J	219 B J	7.7
W 3	B3	960513	3190	10.5 J	4.6 B J	0.18 B J	0.17 U	23.3 B J	9.6	0.84 B J	1.4 B	25600	3.1 J	289 B J	12.1
W 3	CL1	960513	7370	12.8 J	15.3 B J	0.34 B J	0.17 U	41.0 B J	22.2	1.2 B J	10.0	93600	7.0 J	401 B J	18.6

Appendix 1

Table 1. Concentrations of constituents measured in soil samples from undeveloped forested areas in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
E 1 O	951130	0.07 B	2.4 B	320 B	1.3 B	52.1 U	0.64 U	9.0 B	22.5	115000	<0.05
E 1 D O	951130	0.08 B	1.6 B	257 B	0.83 B	42.2 U	0.52 U	8.8 B	14.7	69700	NA
E 1 A	951130	0.05 U	0.41 B	290 B	0.48 U	40.8 U	0.50 U	5.9 B	4.2 B	10300	<0.05
E 1 E	951130	0.04 U	0.24 U	107 B	0.37 U	31.6 U	0.39 U	2.4 B	1.7 B	NA	NA
E 1 B1	951130	0.05 U	1.4 B	102 B	0.66 B	33.1 U	0.41 U	8.4 B	13.1	4490	<0.05
E 1 B2	951130	0.04 U	0.27 B	56.3 B	0.37 U	31.6 U	0.39 U	1.5 B	3.0 B	1140	<0.05
E 2 O	951201	0.16	2.9 B	282 B	1.O B	53.9 U	0.66 U	9.4 B	22.1	154000	<0.05
E 2 S O	951201	0.15	4.4 B	381 B	1.5	48.0 U	0.59 U	12.8	34.2	279000	NA
E 2 A	951201	0.04 B	0.52 B	453 B	0.48 U	40.5 U	0.50 U	9.5 B	7.3	7880	<0.05
E 2 B1	951201	0.04 U	2.0 B	202 B	0.79 B	42.0 U	0.52 U	13.2	23.3	5250	<0.05
E 2 B2	951201	0.03 U	1.0 B	394 B	0.42 U	36.0 U	0.44 U	8.2 B	3.9	NA	<0.05
E 4 O	960206	0.44	9.5 J	912 J	2.7 U	253 B	2.4 U	8.7 J	64.7 J	545000 J	0.08
E 4 A	960206	0.12 U	1.0 J	84.8 U	1.1 U	80.1 U	0.97 U	4.3 J	4.1 J	24500 J	<0.05
E 4 E	960206	0.11 U	0.32 U	68.0 U	1.0 U	73.6 U	0.89 U	2.4 J	0.90 U	3110 J	<0.05
E 4 B1	960206	0.11 U	0.46 J	90.7 U	1.0 U	82.1 U	0.93 U	5.0 J	1.4 U	5200 J	<0.05
E 4 B2	960206	0.11 U	0.60 J	87.6 U	1.0 U	73.9 U	0.90 U	3.1 J	3.1 J	863 J	<0.05
E 4 C	960206	0.11 U	0.32 U	73.7 U	0.99 U	68.2 U	0.88 U	1.3 J	1.1 U	2450 J	<0.05
E 5 E	960206	0.05 U	0.31 B J	65.1 B J	0.37 U	31.5 U	0.39 U	28.3	2.2 B J	3760 J	<0.05
E 5 B1	960206	0.05 U	0.22 U	65.3 B J	0.34 U	29.0 U	0.43 U	33.3	2.3 B J	3280 J	<0.05
E 5 B2	960206	0.05 U	0.62 B J	153 B J	0.37 U	31.3 U	0.39 U	37.5	5.0	1930 J	<0.05
E 5 C	960206	0.05 U	0.53 B J	201 B J	0.33 U	27.9 U	0.34 U	29.5	2.5 B J	973 J	<0.05
E 6 A	960206	0.11 U	0.64 B J	85.6 U	1.0 U	76.7 U	0.92 U	4.9	3.0 J	16200 J	<0.05
E 6 E	960206	0.11 U	0.33 U	128 U	1.0 U	72.4 U	0.93 U	5.9 J	2.1 U	8070 J	<0.05
E 6 B1	960206	0.11 U	1.1 U	241 B J	1.1 U	84.9 U	0.96 U	16.3	9.8	4480 J	<0.05
E 6 C	960227	0.04 U	0.41 B J	298 B J	1.1 J	32.3 U	0.40 U	18.2	3.0 B J	5250 J	<0.05
E 6 CL1	960206	0.12 U	0.43 J	600 B J	1.1 U	90.3 U	1.00 U	16.1 J	4.1 J	3350 J	<0.05

Table 1. Concentrations of constituents measured in soil samples from undeveloped forested areas in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]		Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
E 7	E	960206	0.06 U	0.88 B J	176 B J	0.34 U	28.7 U	1.2 U	64.2	9.1	3330 J	<0.05
E 7	B1	960206	0.05 U	2.0 B J	424 B J	0.41 U	34.6 U	0.82 U	70.7	13.2	2510 J	<0.05
E 7	B2	960206	0.06 U	2.9 B J	692 B J	0.36 U	30.6 U	0.85 U	52.6	27.4	1600 J	<0.05
E 9	O	960206	0.27 B J	5.3 B J	232 B J	1.6 U	162 B	1.4 U	18.9	29.0	131000 J	0.07
E 9	A	960206	0.11 U	0.34 U	79.8 U	1.1 U	85.8 U	0.94 U	10.0 J	3.0 J	9940 J	<0.05
E 9	B1	960206	0.11 U	0.34 U	114 J	1.1 U	74.2 U	0.96 U	14.5	1.9 U	10500 J	<0.05
E 9	B2	960206	0.12 U	0.37 U	198 J	1.2 U	96.6 U	1.0 U	25.9 J	4.8 J	4260 J	<0.05
E 9	C	960206	0.12 U	0.35 U	201 J	1.1 U	80.3 U	0.99 U	17.8 J	3.1 J	1930 J	<0.05
E11	A	960130	0.05 U	0.91 B J	210 B J	0.49 B J	37.1 U	0.46 U	11.8	7.4	13800 J	<0.05
E11	B1	960130	0.04 U	0.29 U J	129 B J	0.91 B J	38.1 U	0.47 U	10.5	5.0	3960 J	<0.05
E11	B2	960130	0.04 U	1.2 B J	324 B J	0.42 U	35.4 U	0.44 U	18.5	8.6	1910 J	<0.05
E11	CL1	960130	0.04 U	0.63 B J	361 B J	0.68 B J	43.3 U	0.53 U	22.4	6.3	1750 J	<0.05
E11	CL2	960130	0.05 U	0.28 U	293 B J	0.43 B	36.8 U	0.45 U	16.7	3.6 B J	2600 J	<0.05
E12	O	960131	0.24 U	8.7 J	579 B J	3.6 J	185 B	2.0 U	18.3 J	69.9 J	585000 J	0.12
E12 D	O	960131	0.38 J	7.3 B J	660 B J	2.2 J	56.4 U	0.69 U	41.0	32.1 J	117000 J	NA
E12	A	960131	0.12 U	0.50 B J	126 U	1.1 U	72.7 U	0.99 U	8.9 J	4.3 J	11300 J	<0.05
E12 D	A	960131	0.06 U J	1.6 B J	310 B J	0.34 U	28.5 U	0.35 U	15.0	8.1 J	NA	<0.05
E12	E	960131	0.14 U	0.54 B J	125 U	1.3 U	87.4 U	1.2 U	3.3 J	4.3 J	6550 J	<0.05
E12 D	E	960131	0.06 U J	0.90 B J	81.9 B J	0.40 U	34.2 U	0.42 U	4.5 B J	4.1 J	2360 J	<0.05
E12	B1	960131	0.12 U	0.37 B J	95.2 U	0.47 U	73.7 U	0.47 U	2.2 J	1.6 U	3070 J	<0.05
E12 D	B1	960131	0.05 U J	0.22 U	41.5 B J	0.34 U	28.7 U	0.35 U	1.4 B J	0.81 U	1840 J	<0.05
E13	O	960201	0.10 B J	7.2 B J	1250	0.65 B J	41.3 U	0.51 U	43.9	53.3 J	49200 J	<0.05
E13	A	960201	0.06 B J	3.8 B J	1060	0.45 U	38.4 U	0.47 U	38.1	34.4 J	19600	<0.05
E13	CL1	960201	0.09 B J	8.2 B J	4320	0.68 B J	92.2 B J	0.58 U	104	47.0 J	7240 J	<0.05
E14	A	960212	0.05 B J	1.2 B J	147 B J	0.47 U	39.5 U	0.49 U	11.2	9.0	29600 J	NA
E14	B1	960212	0.13 J	1.3 B J	166 B J	0.35 U	30.0 U	0.37 U	10.3	5.3	5130 J	NA
E14 D	B1	960212	0.03 U J	1.3 B J	156 B J	0.48 U	40.4 U	0.50 U	7.2 J	5.0	4360 J	NA
E14	B2	960212	0.05 U J	1.2 B J	234 B J	0.46 U	38.7 U	0.48 U	6.4 B J	3.8 B J	2290 J	NA

Table 1. Concentrations of constituents measured in soil samples from undeveloped forested areas in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
E15 A	960422	0.13 J	2.1 B J	145 U	1.3 U	167 U	1.1 B J	17.0 J	17.4 J	40100 J	NA
E15 B1	960422	0.14 J	1.4 B J	199 U	1.2 U	157 U	0.91 U	21.7 J	12.2 J	25100 J	<0.05
E15 CL1	960422	0.11 B J	2.7 B J	1840 J	1.3 U	177 U	2.5 B J	77.9 J	33.2 J	13100 J	<0.05
E15 CL2	960422	0.11 B J	2.3 B J	2230	1.3 U	176 U	3.8	69.2 J	27.7 J	7220 J	NA
E15 D CL2	960422	0.07 U	3.0 B	2510	1.3 U	175 U	1.0 U	62.0	53.6	NA	NA
E15 CL3	960422	0.13 J	5.4 B J	1980 J	1.3 U	170 U	2.2 B J	33.2 J	21.9 J	10300 J	0.86
E15 D CL3	960422	0.11 B	3.2 B	2770	1.3 U	248 B	1.0 U	39.2	19.5	8530 J	NA
E16 A	960513	0.06 U	2.7 B J	983 B J	1.1 U J	150 U	0.88 U	24.1	27.4	12800 J	<0.05
E16 B1	960513	0.06 U	2.9 B J	1200 B	1.1 U J	151 U	0.88 U	27.5	20.3	12400 J	0.06
E16 B2	960513	0.05 U	0.56 B J	346 B J	1.0 U J	137 U	0.80 U	4.5 J	2.2 J	927 J	<0.05
E17 A	960513	0.13 B J	2.3 B J	1280 B J	1.6 U J	209 U	1.2 U	59.1	17.8	68900 J	NA
E17 CL1	960513	0.08 U	0.34 B	1720 J	2.8 J	200 U	1.2 U	78.7	16.1	36600 J	NA
E17 CL2	960513	0.07 U	0.32 U	4190	2.1 J	188 U	1.1 U	151	26.3	8200 J	0.07
W 1 CL1	960424	0.07 B	2.1 B	435 B	1.1 U	150 U	0.88 U	56.8	23.8	10900	NA
W 1 CL2	960424	0.12	3.1 B	1790	1.9	162 U	0.95 U	106	19.2	NA	<0.05
W 1 CL3	960424	0.10 B	2.4 B	1650	1.6	180 B	0.95 U	126	14.2	9000 J	0.05
W 1 CL4	960424	0.12	3.0 B	1940	1.4	211 B	0.95 U	107	19.1	7380 J	0.05
W 2 B2	960509	0.06 U	1.2 B	1030 B J	1.1 U J	349 B	0.85 U	36.7	6.8 J	1550 J	<0.05
W 2 CL0	960509	0.06 U	0.90 B	1540	1.2 U J	383 B J	0.92 U	69.3	7.3 J	7350 J	<0.05
W 2 CL1	960509	0.06 U	2.2 B J	1890 J	1.2 U J	350 B J	0.96 U	80.0	12.9	11600 J	<0.05
W 2 CL2	960509	0.07 U	0.29 U	2030	1.3 U J	325 B	1.00 U	83.8	45.5	12400 J	0.15
W 2 CL3	960509	0.06 U	19.9	2300 J	1.2 U J	450 B J	0.94 U	56.0	71.8	25900 J	0.99
W 2 CL4	960509	0.07 U	29.2	2640	1.3 U J	239 B J	0.99 U	104	94.7	54000 J	3.35
W 3 A	960513	0.06 U	0.25 U	320 B	1.1 U J	148 U	0.86 U	17.9	4.3 B J	7900	<0.05
W 3 B1	960513	0.06 U	0.26 U	257 B	1.2 U J	154 U	0.90 U	18.9	5.3 J	3330	<0.05
W 3 B2	960513	0.06 U	0.26 U	573 B J	1.2 U J	188 B	0.90 U	31.1	5.9 J	1700	<0.05
W 3 B3	960513	0.06 U	0.26 U	864 B J	1.2 U J	377 B	0.90 U	34.9	5.5 J	1430	<0.05
W 3 CL1	960513	0.07 B J	0.26 B	1140 B J	1.2 U	156 U	0.91 U	44.6	26.2	4310	0.18

Appendix 1

Table 2. Concentrations of constituents measured in soil samples from former and active orchards in Monmouth and Middlesex Counties, New Jersey

[All concentrations in milligrams per kilogram (parts per million) unless otherwise noted; B, detectable value but below the contract-required detection limit; U, below the instrument detection limit; J, qualified--data may exhibit bias; <, less than; NA, not analyzed; see figs. 8 and 9 for locations]

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
O 1 A	960205	1310 J	16.4 J	15.8 B J	0.29 B J	1.4 J	5360	11.9 J	0.67 J	24.3	8750	204	2490	75.5
O 1 E	960205	1870 J	38.3 J	7.6 B J	0.16 B J	1.5	572 J	12.5	0.18 U	13.1 J	15300	125	125 B J	11.8
O 1 B1	960205	486 J	9.4 J	2.2 B J	0.11 B J	0.42 U	52.1 U	2.0 J	0.17 U	2.5 U	4410	3.7 J	18.4 U	2.8 B
O 1 S B1	960205	506 J	8.9	1.6 B J	0.10 U	0.05 U	34.6 B J	1.5 B J	0.22 U	1.3 B J	4170 J	2.9 J	21.9 U	1.4 B J
O 1 B2	960205	381 J	8.4	1.7 B J	0.08 B J	0.39 J	60.4 U	1.9 J	0.17 U	1.5 J	3990 J	2.0 J	35.3 U	2.7 B
O 1 S B2	960200	516 J	8.3	5.5 B J	0.11 U	0.05 U	25.8 U	1.8 B J	0.25 U	1.1 B J	3830 J	2.4 J	24.7 U	3.4 J
O 2 O	960205	898	9.5 J	17.7 B J	0.07 U	0.70 J	4180	13.2	0.70 J	33.8	2830	474 J	463	54.1
O 2 A	960205	605	9.9 J	4.1 B J	0.02 U	0.19 U	383 B J	3.8	0.25 B J	13.2	2260	187	54.6 U	5.9
O 2 E	960205	276	2.8 J	1.8 B J	0.02 U	0.09 U	35.8 U	0.70 J	0.27 B J	1.1 U	636	1.9 J	11.3 U	4.5
O 2 B1	960205	693 J	12.1 J	3.3 B J	0.03 U	0.17 U	114 U	0.95 B J	0.17 U	1.9 B	1850	2.1 J	79.8 U	2.2 B J
	960205	2360	16.9 J	4.4 B J	0.02 U	0.14 U	43.9 U	2.1 J	0.19 B J	2.3 B J	2640	2.1 J	51.5 U	2.3 B J
O 3 A	960205	1790	10.7 J	9.6 B J	0.03 U	0.27 B J	739 J	3.9	0.24 B J	8.8	3610	99.5 J	167 J	20.5
O 3 B1	960205	6090	8.5 J	8.9 B J	0.06 B J	0.53 B J	341 J	10.0	0.44 B J	5.8 J	12000	5.7 J	201 B	6.8
O 3 B2	960205	2230	5.7 J	7.0 B J	0.02 U	0.32 B J	56.4 U	4.5	0.30 B J	2.5 B J	7550	2.8 J	68.8 U	4.8
O 4 O	960130	1530	9.7 J	13.5 B J	0.03 U	0.25 B J	1070 B J	7.4	0.37 B J	17.7	4580	165 J	306 B J	17.7
O 4D O	960130	1960	5.6 J	26.9 B J	0.03 U	0.69 B J	3230 J	11.1	0.50 B J	20.0	3960	155 J	686 B J	84.1
O 4 A	960130	1600	11.3 J	7.0 B J	0.02 U	0.10 B J	156 B J	4.3	0.31 U	13.7	5210	79.0 J	101 B J	6.8
O 4D A	960130	2240	10.6 J	8.7 B J	0.02 U	0.16 B J	215 B J	11.1	0.24 U	15.5	7450	60.7 J	133 B J	8.7
O 4 B1	960130	3160	7.9 J	11.9 B J	0.02 U	0.05 U	51.6 B J	5.7	0.26 B	6.0	4150	10.8 J	93.2 B J	9.6
O 4D B1	960130	3830	7.7 J	15.8 B J	0.03 B J	0.04 U	30.9 B J	5.7	0.24 B	4.4	4300	6.6 J	85.5 B J	19.5
O 4 B2	960130	4040	9.3 J	12.7 B J	0.03 B J	0.06 U	52.0 B J	7.4	0.31 B J	4.1 B J	5930	6.2 J	104 B J	10.0
O 4D B2	960130	3330	5.4 J	9.1 B J	0.04 B J	0.05 U	39.9 B J	7.6	0.32 B	2.9 B	4590	4.8 J	88.2 B J	13.6
O 4D B3	960130	2660	6.2	7.7 B J	0.09 B J	0.04 U	33.2 B J	8.7	0.23 B J	2.4 B J	8570	3.6 J	50.8 B J	7.1

[1] The initial letter denotes sample sites in former and active orchards; the following number is the number of the individual site. In the next two columns, samples marked D are spatial duplicates; samples marked S are splits. The final letter refers to the soil horizon; CL denotes clays. The final number denotes increasing depth with increase in value.

Table 2. Concentrations of constituents measured in soil samples from former and active orchards in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
O 5 A	960130	599	5.4 J	5.4 B J	0.06 U	0.21 U	292 B J	2.0 J	0.34 B J	9.7	1830	49.7 J	101 U	7.5
O 5 B1	960130	330	3.3 J	2.1 B J	0.02 U	0.17 U	97.7 U	0.69 J	0.18 B J	2.6 J	2300	9.1 J	67.5 U	2.4 J
O 5 B2	960130	2580	6.8 J	6.8 B J	0.10 B J	0.30 B J	22.6 U	4.2	0.36 B J	6.4	8540	3.0 J	29.6 U	7.3
O 5 C	960130	1700 J	3.9 J	3.0 B J	0.11 U	0.18 B J	11.9 U	3.5	0.18 B J	1.9 B J	5090	1.3	15.4 U	1.9 J
O 6 A	960131	755	5.5 J	4.5 B J	0.08 U	0.33 B J	36.9 U	3.7	0.43 B J	6.7	5150	20.9 J	86.1 U	5.1
O 6D A	960131	857	5.6 J	4.7 B J	0.02 U	0.09 B J	46.6 B J	3.9	0.29 U	7.1	5440	23.9 J	94.2 B J	6.0
O 6 E	960131	550	2.4 J	3.3 B J	0.02 U	0.17 U	7.3 U	2.2	0.25 J	3.4 J	3830	5.0 J	24.8 U	24.2
O 6D E	960131	745	3.0 J	3.7 B J	0.02 U	0.05 U	24.3 U	3.7	0.24 U	3.0 B J	4650	5.8 J	48.0 B J	22.7
O 6 B1	960131	702 J	3.9 J	2.4 B J	0.07 J	0.50	68.6 U	5.3	0.40 B J	2.7 B J	10500 J	1.7	79.5 B J	9.8
O 6D B1	960131	1200	8.5 J	2.7 B	0.02 U	0.07 B J	27.4 U	71.1	0.27 U	2.1 B J	27100	4.6 J	32.3 B J	14.4
O 6 B2	960131	2640	5.4 J	5.4 B J	0.11 B J	0.50 J	19.4 U	10.5	0.48 B J	3.8 B J	10300	2.5 J	116 U	8.6
O 6D B2	960131	3080	11.4 J	5.7 B J	0.02 U	0.09 B J	28.3 U	15.4	0.28 U	2.9 B J	22700	5.1 J	123 B J	10.5
O 7 A	960227	5930	23.4	16.4 B J	0.32 B J	0.06 U	892 B J	16.8	0.95 B J	12.5	25000	64.4 J	593 B J	25.5
O 7 CL1	960227	6020	17.8	15.6 J	0.21 B J	0.06 U	946	17.6	0.62 B J	8.4	17900	23.7 J	444 B J	12.0
O 7 CL2	960227	6830	22.4	15.4 B J	0.25 B J	0.04 U	383 B J	19.7	0.67 B J	7.6	23500	13.3 J	432 B J	7.8
O 8 O	960112	1180 J	6.0	18.3 B J	0.15 B J	0.12 B J	747 B J	7.9	0.35 B J	11.2	11300 J	44.9 J	225 B J	38.5 J
O 8 A	960112	1290 J	9.9 J	9.2 B J	0.13 B J	1.9 J	201 B J	14.2 J	0.18 U	8.6 J	18300	31.4	158 B J	19.8
O 8 B1	960112	3980 J	14.3 J	7.1 B J	0.51 B J	5.8 J	117 U	38.5	0.17 U	5.5 J	64700	6.6	194 B J	38.1
O 9 A	960209	6640 J	18.1	47.6 J	0.60 B J	1.1 J	368 B J	12.4	4.3 J	9.9 J	10800	48.8 J	628 B J	169
O 9D A	960209	11100 J	15.6	51.8	0.76 B J	0.15 B J	369 B J	13.4	5.2 B J	15.2	13100 J	64.8 J	789 B J	206 J
O 9 B1	960209	10000 J	5.3 J	112	0.68 B J	1.3	118 U	13.7	6.2 J	5.9 J	13300	9.0	868 B J	170
O 9D B1	960209	11200 J	12.7	44.5	0.67 B J	0.07 B J	98.5 B J	12.0	5.3 B J	11.5	11400 J	45.2 J	707 B J	171 J
O 9 B2	960209	11000 J	5.9 J	52.4	0.75 B J	1.7	78.4 U	20.3 J	7.3 J	7.0 J	17800	7.3	940 B J	187
O10 A	960227	1540	4.3	27.4 B J	0.09 B J	0.27 B J	1770	8.0	0.50 B	12.8	7650	86.3 J	867 B J	23.5
O10 B1	960227	1080	3.3	16.8 B J	0.06 B J	0.28 B J	394 B J	3.3	0.28 B J	5.1	5560	15.3 J	113 B J	25.5
O10 B2	960227	2290	4.7	8.2 B J	0.12 B J	0.06 U	321 B J	10.9	0.29 B J	3.0 J	13400	9.7 J	121 B J	10.7
O10 CL1	960227	4930	13.6	8.8 B J	0.16 B J	0.07 U	730 B J	23.3	0.41 B J	7.5	43300	7.2 J	219 B J	5.5

Table 2. Concentrations of constituents measured in soil samples from former and active orchards in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
O11 A	960326	2570	13.0 J	7.8 B J	0.06 B J	0.07 U	179 B J	7.3	0.53 B J	4.9 B J	13100	25.2	257 B J	30.6
O11 B1	960326	4200	14.0 J	8.1 B J	0.17 B J	0.16 B	192 B J	13.4	0.87 B J	3.3 B	23300	4.4	338 B J	23.3
O11 B2	960326	3980	8.1 J	7.4 B J	0.03 U	0.09 B J	357 B J	11.8	0.60 B J	2.7 B J	13300	4.7	401 B J	15.9
O11 CL1	960326	13300	33.4 J	20.6 B J	0.51 B J	1.2 B J	338 B J	47.9	6.2 B J	17.6 J	117000	11.4	977 B J	180
O12 CL1	960326	9500	28.1 J	18.9 B J	0.24 B J	0.52 B J	995 B J	30.7	2.9 B J	12.2	49500	28.1	1230	94.4
O12 CL2	960326	12200	39.2	24.6 B	0.23 B	0.31 B	251 B	32.9	1.6 B	14.0	40700	16.8	1470	28.2
O12 CL3	960326	13500	22.7 J	27.9 B J	0.31 B J	0.25 B J	117 B J	35.3	1.7 B J	14.2	37300	15.8	1610	25.4
O14 A	960209	1260 J	41.5	3.5 B J	0.13 B J	0.06 B	29.4 U	5.8	0.46 B J	7.6	8220 J	22.2 J	90.9 B J	9.3 J
O14 B1	960209	1200 J	3.5	4.7 B J	0.13 B J	0.15 B	27.3 U	2.3	0.46 B	3.9 B J	2820 J	14.5 J	64.7 B J	17.5 J
O14 B2	960209	286 J	0.79 B J	2.3 B J	0.05 U	0.05 U	23.6 B	0.61 B	0.23 B	0.51 B J	448 J	1.3 J	22.3 U	5.1 J
O14 C	960209	1190 J	1.7	4.2 B J	0.07 U	0.09 B J	28.7 B	1.5 B J	0.27 B J	0.73 B J	2160 J	3.3 J	38.0 B J	10.6 J
O15 A	960209	1170 J	4.2	3.6 B J	0.08 U	0.05 B J	20.6 U	3.8	0.22 B J	5.6	3590 J	20.4 J	67.6 B J	7.7 J
O15 B1	960209	1620 J	3.5	4.7 B J	0.09 B J	0.07 B J	26.6 U	3.5	0.34 B J	6.1	3030 J	15.0 J	77.4 B J	13.1 J
O15 B2	960209	2830 J	3.3	6.5 B J	0.12 U	0.06 B	26.5 U	4.6	0.33 B J	7.0	4120 J	6.3 J	81.9 B J	12.9 J
O16 A	960513	4200	40.9 J	20.5 B J	0.12 B J	0.18 U	1360 J	9.9	0.75 B J	15.2	10100	169 J	280 B J	21.9
O16 CL1	960513	12000	16.3 J	23.3 B J	0.33 B J	0.17 U	304 B J	23.1	1.7 B J	7.2	17200	12.3 J	970 B J	22.1
O16 CL2	960513	8510	17.9 J	17.7 B J	0.29 B J	0.18 U	218 B J	23.4	1.3 B J	7.3	22000	14.3 J	803 B J	18.4

Appendix 1

Table 2. Concentrations of constituents measured in soil samples from former and active orchards in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
O 1 A	960205	0.16 U	2.0 B J	351 B J	1.5 U	125 U	1.4 U	11.2 J	74.8 J	67300 J	0.06
O 1 E	960205	0.11 U	0.34 U	350 B J	1.1 U	80.6 U	0.96 U	15.3 J	17.9 J	18400 J	<0.05
O 1 B1	960205	0.11 U	0.32 U	108 U	0.99 U	80.2 U	0.89 U	1.9 J	4.6 J	713 J	<0.05
O 1 S B1	960205	0.05 U	0.22 U	74.4 B	0.35 B	29.9 U	0.41 U	2.5 B J	2.7 B J	NA	NA
O 1 B2	960205	0.11 U	0.32 U	77.6 U	1.00 U	67.4 U	0.89 U	2.1 B J	1.7 B J	572	<0.05
O 1 S B2	960205	0.05 U	0.32 J	65.6 B J	0.72 B J	33.8 U	0.61 U	3.0 B J	2.2 B J	NA	NA
O 2 O	960205	0.15 U	4.0 B J	327 B J	1.4 U	113 U	1.2 U	12.3 J	68.8 J	83700 J	0.07
O 2 A	960205	0.19	0.90 B J	180 B J	1.0 U	71.3 U	0.94 U	7.5 J	10.2 J	10500 J	<0.05
O 2 E	960205	0.11 U	0.32 U	110 U	1.0 U	67.9 U	0.90 U	2.2 J	2.6 J	1150 J	<0.05
O 2 B1	960205	0.11 U	0.32 U	137 B J	1.0 U	65.8 U	0.91 U	4.3 J	1.8 J	2100 J	<0.05
O 2 B2	960205	0.11 U	0.67 B J	121 U	1.0 U	74.8 U	0.92 U	5.6 J	4.9 J	2160 J	<0.05
O 3 A	960205	0.13 U	0.88 B J	355 B J	1.3 U	91.8 U	1.1 U	7.4 J	21.1 J	24200 J	<0.05
O 3 B1	960205	0.12 U	0.96 B J	326 B J	1.1 U	85.1 U	0.97 U	20.9	6.6 J	2190 J	<0.05
O 3 B2	960205	0.10 U	0.30 U	207 B J	0.95 U	68.7 U	0.85 U	10.6	4.5 J	756 J	<0.05
O 4 O	960130	0.10 B J	3.3 B J	570 B J	0.78 B J	48.9 U	0.60 U	16.6	32.8 J	69800 J	NA
O 4 D O	960130	0.12 B J	5.8 B J	703 B J	0.67 U	56.8 U	0.70 U	15.0 B	59.5 J	99900 J	<0.05
O 4 A	960130	0.06 U J	1.7 B J	387 B J	0.49 U	41.6 B	0.51 U	15.3	12.8 J	21100 J	<0.05
O 4 D A	960130	0.07 B J	1.5 B J	448 B J	0.38 U	32.0 U	0.39 U	17.4	12.7 J	19800 J	<0.05
O 4 B1	960130	0.05 U J	1.5 B J	307 B J	0.38 U	32.7 B	0.40 U	15.3	7.1 J	5840 J	<0.05
O 4 D B1	960130	0.05 U J	1.0 B J	274 B J	0.31 U	26.2 U	0.32 U	14.8	6.0 J	3870 J	<0.05
O 4 B2	960130	0.05 U J	1.5 B J	323 B J	0.42 U	35.4 U	0.44 U	17.9	9.2 J	2830 J	<0.05
O 4 D B2	960130	0.05 U J	1.5 B J	328 B J	0.37 U	31.3 U	0.39 U	15.9	9.8 J	1890 J	<0.05
O 4 D B3	960130	0.05 U	1.3 B J	344 B J	0.28 U	24.1 U	0.30 U	29.9	3.8 J	NA	NA

Table 2. Concentrations of constituents measured in soil samples from former and active orchards in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
O 5 A	960130	0.11 U	1.1 B J	155 U	1.1 U	77.8 U	0.97 U	6.5 J	11.6 J	18800 J	<0.05
O 5 B1	960130	0.11 U	0.32 U	101 U	1.0 U	71.5 U	0.91 U	5.1 J	3.7 J	2660 J	<0.05
O 5 B2	960130	0.11 U	7.7 B J	140 U	1.1 U	82.3 U	0.94 U	8.4 J	8.9 J	2100 J	<0.05
O 5 C	960130	0.11 U	0.45 B J	126 U	0.44 U	88.9 U	0.44 U	6.9 J	4.2 J	933 J	<0.05
O 6 A	960131	0.11 U	0.81 J	257 B J	1.0 U	72.9 U	0.91 U	11.1	11.3 J	11400 J	<0.05
O 6 D A	960131	0.10 J	1.00 B J	399 B J	0.68 B J	39.4 B J	0.48 U	11.3	11.6 J	15500 J	<0.05
O 6 E	960131	0.10 U	0.36 B J	144 U	0.96 U	65.3 U	0.86 U	6.5 J	4.3 J	2690 J	<0.05
O 6 D E	960131	0.05 U J	0.25 B J	223 B J	0.37 U	31.8 U	0.39 U	7.7 B J	4.3 J	3870 J	NA
O 6 B1	960131	0.11 U	0.54 B J	115 U	0.44 U	67.0 U	0.44 U	12.0	8.1 J	1120 J	<0.05
O 6 D B1	960131	0.04 U J	0.47 B J	155 B J	0.42 U	35.8 U	0.44 U	49.4	9.5 J	1020 J	<0.05
O 6 B2	960131	0.11 U	1.2 J	228 B J	1.0 U	87.2 U	0.94 U	18.9	14.5 J	1910 J	<0.05
O 6 D B2	960131	0.05 U J	1.4 B J	336 B J	0.44 U	37.1 U	0.46 U	35.1	17.1 J	1940 J	NA
O 7 A	960227	0.05 B J	2.2 B J	1360	1.7	36.9 U	0.45 U	44.4	29.4	43100 J	<0.05
O 7 CL1	960227	0.07 B J	0.94 B J	963	1.2	69.2 B	0.43 U	40.6	9.0	5050 J	<0.05
O 7 CL2	960227	0.04 U	1.0 B J	1150	0.88	31.5 U	0.33 U	69.3	7.5	4950 J	<0.05
O 8 O	960112	0.06 B J	2.5 B J	479 B J	0.51 B J	40.3 U	0.50 U	23.6	40.2	62900 J	<0.05
O 8 A	960112	0.11 U	0.34 U	273 B J	1.1 U	75.5 U	0.95 U	24.9 J	19.2 J	7920 J	<0.05
O 8 B1	960112	0.11 U	1.1 J	475 B J	1.0 U	74.0 U	0.92 U	58.3 J	72.9 J	2260 J	<0.05
O 9 A	960209	0.13 U	6.2 B	372 B J	1.1 U	95.5 U	1.0 U	14.7	32.2	18900 J	<0.05
O 9 D A	960209	0.10 J	9.4 B J	650 B J	0.60 U	44.3 U	0.54 U	20.1	44.0	21400 J	<0.05
O 9 B1	960209	0.11 U	7.6 J	409 B J	1.1 U	83.5 U	0.95 U	17.1 J	24.8 J	2670 J	<0.05
O 9 D B1	960209	0.11	7.6	429 B J	0.36 U	30.3 U	0.37 U	16.9	27.9	7170 J	NA
O 9 B2	960209	0.11 U	8.2	483 B J	1.1 U	87.8 U	0.94 U	22.9 J	26.7 J	1970 J	<0.05
O10 A	960227	0.13	2.6 B J	348 B J	0.47 U	39.6 U	0.49 U	13.8	42.5	18400 J	<0.05
O10 B1	960227	0.07	0.79 B, J	255 B J	0.38 U	48.0 U	0.40 U	9.0	47.6	3850 J	<0.05
O10 B2	960227	0.04 B J	1.0 B J	216 B J	1.5	37.7 U	0.46 U	17.2	20.2	2870 J	<0.05
O10 CL1	960227	0.04 U	0.54 B J	500 B J	0.80 B J	40.6 U	0.50 U	42.8	11.9	2530 J	NA

Table 2. Concentrations of constituents measured in soil samples from former and active orchards in Monmouth and Middlesex Counties, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
O11 A	960326	0.06 U	1.6 B J	610 B J	1.4 J	37.0 U	0.77 U	23.7	14.3	4960 J	<0.05
O11 B1	960326	0.06 U	1.8 B J	814 B J	2.2 J	36.5 U	0.76 U	40.5	16.0	2810 J	<0.05
O11 B2	960325	0.05 U	1.9 B J	1130 B J	1.7 J	39.1 U	0.82 U	29.1	9.3	2660 J	<0.05
O11 CL1	960326	0.06 U	10.4	2830	7.5 J	42.7 U	3.0	74.6	116	10400 J	0.06
O12 CL1	960326	0.05 U	5.3 B J	2430	3.7 J	41.2 U	0.86 U	70.6	39.0	7720 J	<0.05
O12 CL2	960326	0.06 U	3.6 B J	3310	3.6 J	45.4 U	0.95 U	57.5	23.8	7230 J	<0.05
O12 CL3	960326	0.05 U	3.8 B J	4090	2.7 J	45.0 U	0.94 U	59.8	22.6	9220 J	<0.05
O14 A	960209	0.05 U J	0.68 B J	225 B J	1.3 J	38.5 U	0.47 U	6.4 J	3.8 J	4140 J	<0.05
O14 B1	960209	0.06 B J	0.54 B J	151 B J	0.42 U	35.8 U	0.44 U	3.7 B J	5.3	3460 J	<0.05
O14 B2	960209	0.05 U J	0.23 U	25.1 B J	0.36 U J	30.5 U	0.38 U	1.3 B	3.6	873 J	<0.05
O14 C	960209	0.04 U J	0.23 U	66.6 B J	0.55 B	30.5 U	0.38 U	4.3 B J	4.6	1760 J	<0.05
O15 A	960209	0.08 J	0.64 B J	207 B J	0.46 U J	27.0 U	0.33 U	6.8 B J	4.0	5670 J	NA
O15 B1	960209	0.06 B J	0.55 B J	222 B J	0.41 U	34.8 U	0.43 U	6.2 B J	3.5 B J	4550 J	NA
O15 B2	960209	0.06 U	0.73 B	214 B J	0.46 U	34.7 U	0.43 U	8.3 B J	4.9	4840 J	NA
O16 A	960513	0.10 B J	2.2 B J	583 B J	1.2 U J	165 U	0.96 U	29.9	38.5	20400 J	<0.05
O16 CL1	960513	0.06 U	2.5 B J	1810 J	1.2 U J	280 B J	0.91 U	41.4	10.8	4640 J	<0.05
O16 CL2	960513	0.06 U	1.5 B J	1430	1.2 U J	273 B J	0.96 U	109	8.9	4480 J	<0.05

Appendix 1

Table 3. Concentrations of constituents measured in soil samples from the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey

[All concentrations in milligrams per kilogram (parts per million) unless otherwise noted; B, detectable value but below the contract-required detection limit; U, below the instrument detection limit; J, qualified--data may exhibit bias; <, less than; NA, not analyzed; see fig. 8 for locations]

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
I 1 CL1	960411	14700	41.3	1140	0.26 B	1.6	5520	30.4	1.4 B	63.3	10700	1520	9010	123
I 1 CL2	960411	12300	12.9	714	0.13 B	1.3 B	6100	18.3	3.1 B	50.5	11300	713	6550	112
I 1 CL3	960411	12600	12.2	823	0.08 U	1.2 B	4210	12.5	1.2 B	55.3	11300	822	4510	81.6
I 1 CL4	960411	7710	4.4	2290	0.07 U	1.5	2490	4.4	0.16 U	33.0	6470	4550	1520	39.6
I 2 A	960411	2000	20.1	24.2 B	0.07 U	0.51 B	265 B	6.5	0.17 U	6.1	7100	71.8	135 B	5.2
I 2 CL1	960411	10700	34.2	117	0.11 B	1.7	746 B	24.7	0.19 U	13.0	19100	61.3	750 B	16.7
I 2 CL2	960411	5970	114	204	0.08 U	0.97 B	653 B	15.8	0.32 B	22.5	10700	257	472 B	15.0
I 3 A	960411	1700	23.3	111	0.07 U	0.45 B	538 B	7.6	0.16 U	18.2	4700	284	263 B	8.8
I 3 B1	960411	251	7.2	15.5 B	0.08 U	0.18 U	57.9 B	1.4 B	0.18 U	1.3 B	1890	38.9	26.9 B	4.0
I 4 A	960411	5040	32.5	78.3	0.24 B	2.5	3100	34.9	2.2 B	75.1	22600	157	860 B	55.1
I 4 B1	960411	6160	31.6	106	0.07 U	1.9	9480	34.4	3.6 B	49.5	13800	224	1130 B	63.8
I 4 B2	960411	6490	28.2	47.0 B	0.08 U	0.61 B	4740	14.8	0.75 B	13.9	8360	49.5	496 B	26.1
I 4 CL1	960411	10000	10.0	33.1 B	0.08 U	0.48 B	1280 B	21.1	0.19 U	8.2	7370	28.1	422 B	9.7
I 4 B3	960411	4090	10.6	9.6 B	0.07 U	0.33 B	1010 B	7.8	0.16 U	3.1 B	6800	8.3	294 B	8.0
I 4 B4	960411	2060	3.9	9.4 B	0.07 U	0.22 B	622 B	6.4	0.28 B	2.0 B	5640	7.1	352 B	21.4
I 5 A	960611	5240 J	31.5	79.9	0.99 B J	0.34 B J	5430	58.7	3.4 B J	167	11500	118 J	1850	70.4
I 5 CL1	960611	3850 J	94.3	26.6 B J	0.18 U	0.37 B J	4790	8.2	0.94 B J	8.9	7380	16.9 J	662 B J	27.0
I 6 A	960611	4600 J	5.9	10.7 B J	0.14 U	0.27 B J	297 B J	7.0	0.41 B J	5.7	6950	6.1 J	282 B J	10.3
I 6 B1	960611	5040 J	5.2	11.0 B J	0.15 U	0.32 B J	535 B J	7.3	0.77 B J	5.3 J	6160	5.9 J	425 B J	17.3
I 6 C1	960611	656 J	3.3	2.3 B J	0.57 U	0.11 U	42.5 B J	1.8 B J	0.15 U	0.48 B J	1120	2.5 J	27.5 B J	5.6
I 6 C2	960611	3850 J	5.4	10.0 B J	0.11 U	0.18 B J	322 B J	11.0	0.62 B J	6.3	5090	5.9 J	324 B J	15.0

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[1] The initial letter denotes sample sites within the fenced area of the Imperial Oil Company Superfund site; the following number is the number of the individual site. The final letter refers to the soil horizon; CL denotes clays. The final number denotes increasing depth with increase in value.

Table 3. Concentrations of constituents measured in soil samples from the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
I 7 A	960611	3020 J	16.7	30.0 B J	0.89 B J	0.14 B J	1160	8.4	1.4 B J	24.7	10200	72.7 J	342 B J	25.2
I 7 C1	960611	2290	3.3	6.1 B J	0.54 U	0.11 U	102 B J	2.9	0.15 U	2.3 B J	2920	4.7 J	89.5 B J	6.9
I 7 B1	960611	1480 J	4.4	4.6 B J	0.13 U	0.11 U	84.6 B J	3.5	0.15 U	2.7 B J	2510	2.5 J	34.3 B J	5.1
I 7 C2	960611	876 J	6.8	3.3 B J	0.43 U	0.11 U	81.7 B J	1.3 B J	0.15 U	2.8 B J	2830	2.8 J	34.5 B J	4.0
I 7 CL1	960611	5060 J	26.6	16.9 B J	0.72 U	0.13 U	174 B J	20.2	0.18 U	19.7	14500	12.4 J	153 B J	5.0
I 8 CL1	960611	9180 J	3.6	25.4 B J	0.77 U	0.19 B J	8180	18.0	10.4 B J	69.4	22000	9.7 J	4740	219
I 8 B1	960611	1820 J	8.8	4.2 B J	0.68 U	0.11 U	160 B J	2.5	0.15 U	2.0 B J	4490	3.9 J	95.1 B J	6.4
I 8 C1	960611	610 J	7.0	3.2 B J	0.08 U	0.12 B J	131 B J	1.1 B J	0.15 U	1.4 B J	1020	2.2 J	67.7 B J	4.3
I 8 C2	960611	851 J	6.7	3.7 B J	0.45 U	0.10 U	141 B J	10.8	0.17 B J	4.1 B J	1860	2.9 J	72.4 B J	5.9

Appendix 1

Table 3. Concentrations of constituents measured in soil samples from the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
I 1 CL1	960411	0.06 U	13.8	1290 B	1.3 U	164 B	1.0 U	26.3	67.3	341000 J	0.71
I 1 CL2	960411	0.06 U	14.9	1050 B	1.4 U	341 B	1.1 U	19.8	76.8	278000 J	0.84
I 1 CL3	960411	0.06 U	7.1 B	879 B	1.4 U	347 B	1.1 U	15.3	40.3	358000 J	0.62
I 1 CL4	960411	0.05 U	6.1 B	349 B	1.1 U	417 B	0.86 U	6.5 B	33.9	259000 J	0.72
I 2 A	960411	0.04 U	0.56 B	266 B	1.2 U	66.3 B	0.91 U	27.1	24.0	39700 J	NA
I 2 CL1	960411	0.06 U	2.0 B	1870	1.4 U	169 B	1.1 U	43.6	16.7	NA	<0.05
I 2 CL2	960411	0.08 U	3.0 B	869 B	1.2 U	112 B	0.96 U	29.0	55.7	24900 J	0.16
I 3 A	960411	0.06 U	1.4 B	231 B	1.1 U	61.1 B	0.85 U	14.3	62.8	28700 J	0.05
I 3 B1	960411	0.05 U	0.28 U	84.8B	1.2 U	52.5 B	0.95 U	3.6 B	3.1 B	1140 J	<0.05
I 4 A	960411	0.07 U	7.0 B	632 B	1.3 U	99.2 B	1.0 U	24.8	205	42600 J	NA
I 4 B1	960411	0.15	7.0 B	689 B	1.2 U	211 B	0.92 U	19.9	189	26200 J	0.06
I 4 B2	960411	0.04 U	3.3 B	766 B	1.2 U	108 B	0.96 U	21.2	39.7	29700 J	NA
I 4 CL1	960411	0.07 U	2.3 B	763 B	1.3 U	224 B	1.0 U	45.5	16.7	50200 J	<0.05
I 4 B3	960411	0.06 U	0.43 B	532 B	1.1 U	63.7 B	0.89 U	14.7	5.6	3520 J	<0.05
I 4 B4	960411	0.04 U	0.94 B	809 B	1.1 U	54.8 B	0.85 U	7.2 B	9.3	4790 J	<0.05
I 5 A	960611	0.09 B J	10.3	664 B J	0.84 BJ	235 B J	0.79 U	27.6	72.2	10100 J	NA
I 5 CL1	960611	0.51	7.2 J	677 B J	0.91 BJ	201 B J	0.87 U	16.6	14.7	27300 J	NA
I 6 A	960611	0.06 U	1.6 BJ	361 B J	1.0 BJ	143 B J	0.77 U	13.7	8.4	3510 J	NA
I 6 B1	960611	0.05 U	2.4 BJ	447 B J	0.80 BJ	117 B J	0.76 U	13.7	23.3	NA	NA
I 6 C1	960611	0.05 U	0.53 U	100 B J	0.76 U	38.1 U J	0.74 U	1.2 B J	1.9 B J	612 J	NA
I 6 C2	960611	0.05 U	30.2	371 B J	0.77 U	153 B J	0.75 U	10.8	7.2	3980 J	NA
I 7 A	960611	0.05 U	3.7 BJ	497 B J	1.0 BJ	63.9 B J	0.77 U	16.3	18.5	67200 J	NA
I 7 C1	960611	0.05 U	1.1 BJ	244 B J	0.77 U	75.4 B J	0.75 U	5.1 B J	6.8	1880 J	NA
I 7 B1	960611	0.05 U	0.33 U	196 B J	0.79 U	52.2 B J	0.77 U	1.6 B J	8.4	5600 J	NA
I 7 C2	960611	0.05 U	0.73 BJ	192 B J	0.87 BJ	61.1 B J	0.75 U	1.7 B J	5.2	619 J	NA
I 7 CL1	960611	0.06 U	0.77 BJ	753 B J	0.90 U	45.3 U J	0.88 U	9.5 B J	8.6	3540 J	NA

Table 3. Concentrations of constituents measured in soil samples from the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
I 8 CL1	960611	0.05 U	31.8	560 B J	0.76 U	1560	0.74 U	81.2	34.6	36600 J	NA
I 8 B1	960611	0.05 U	0.69 BJ	252 B J	0.77 U	41.1 B J	0.75 U	7.2 B J	3.3 B J	1300 J	NA
I 8 C1	960611	0.05 U	0.46 BJ	129 B J	0.76 U	39.1 B J	0.74 U	2.5 B J	3.4 B J	1440 J	NA
I 8 C2	960611	0.05 U	333	152 B J	0.75 U	37.6 U J	0.73 U	3.2 B J	3.0 B J	NA	NA

Appendix 1

Table 4. Concentrations of constituents measured in soil samples from the woods adjacent to the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey

[All data in milligrams per kilogram (parts per million) unless otherwise noted; B, detectable value but below the contract-required detection limit; U, below the instrument detection limit; J, qualified--data may exhibit bias; <, less than; NA, not analyzed; see fig. 8 for locations]

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
S 1 O	051128	1290	4.7	15.9 B	0.07 U	0.15 B	448 B	4.5	0.49 B	18.3	4040	70.4	230 B	16.7
S 1 DS O	951130	1870	5.2	27.4 B	0.1 U	0.32 B	699 B	6.4	0.74 B	35.5	5230	137	346 B	22.3
S 1 D O	951130	1230	4.9	9.6 B	0.03 U	0.1 B	581 B	5.5	0.44 B	16.9	3940	39.6	254 B	15.9
S 1 DD O	951130	1400	3.3 B	28 B	0.03 U	0.37 B	760 B	6.9	0.82 B	18.3	3700	78.9	334 B	31.9
S 1 DD O2	951130	1350	2.6 B	26 B	0.13 U	0.36 B	1270 B	4.7	0.64 B	22	3730	78.9	329 B	41.9
S 1 A	951128	1870	7.3	5.2 B	0.05 U	0.05 U	20.3 B	3.2	0.23 B	5.4	4570	26.7	123 B	11.6
S 1 B1	951128	2160	3.3	5.5 B	0.13 B	0.05 U	15 U	4.2	0.29 B	1.3 B	10000	2.7	45.6 B	4.4
S 1 B2	951128	3590	5.2	11.1 B	0.08 B	0.06 U	37.3 B	6.3	0.2 U	1.4 B	17400	2.4	110 B	5.1
S 2 O	951128	3660	8.8	23.7 B	0.12 B	0.12 B	916 B	7.5	0.64 B	22.5	7170	86.7	413 B	24.3
S 2 A	951128	3460	9.1	9.8 B	0.11 B	0.07 U	35.9 B	5.8	0.23 U	9.3	7670	28.2	203 B	13.9
S 2 B1	951128	11600	7.9	22.4 B	0.24 B	0.06 U	54.9 B	14.3	0.73 B	5.7	15900	8	580 B	12.9
S 2 CL1	960226	16500	15.6	30.3 B J	0.55 B J	0.08 U	42.6 B J	29.7	1.7 B J	13.9	28000	16.5 J	1150 B J	26.1
S 2 CL2	960226	15200	12.6	27.7 B J	0.57 B J	0.07 U	170 B J	26.2	1.8 B J	14.4	17700	18.6	1350	28.6
S 3 O	951128	1420	4.8	13.7 B	0.08 B	0.13 B	686 B	4.8	0.61 B	21.7	3650	115	212 B	36.9
S 3 A	951128	1330	4.8	3.5 B	0.05 U	0.06 U	18.4 B	3.5	0.19 U	8.4	3490	60.2	124 B	4.4
S 3 B1	951128	3360	2.7	6.1 B	0.07 B	0.06 U	16 U	4.5	0.22 B	0.7 B	5630	3.6	125 B	4.3
S 3 B2	951128	6860	10.8	9.3 B	0.16 B	0.06 U	16.1 U	11	0.41 B	1.9 B	18500	4.9	220 B	3.6
S 4 O	951128	1490	4.5	20.6 B	0.1 B	0.15 B	1090 B	5.4	0.5 B	25.5	3980	146	209 B	24.6
S 4 A	951128	1300	3.9	3.6 B	0.06 U	0.06 U	18.7 U	3.2	0.22 U	4.7 B	2600	19.5	92.8 B	6.4
S 4 B1	951128	2380	3.7	4.9 B	0.09 B	0.06 U	16.4 U	5.7	0.19 U	0.98 B	7240	2.3	117 B	4.8
S 4 B2	951128	2870	7	6.2 B	0.08 B	0.05 U	21.4 B	5.3	0.19 B	1.4 B	4440	2.5	167 B	3.3

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[1] The initial letter denotes sample sites in the woods adjacent to the Imperial Oil Company Superfund site; the following number is the number of the individual site. In the next two columns, samples marked D are spatial duplicates; samples marked DD are additional spatial duplicates; samples marked S are splits. The final letter refers to the soil horizon; CL denotes clays. The final number denotes increasing depth with increase in value.

Table 4. Concentrations of constituents measured in soil samples from the woods adjacent to the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
S 5 O	951128	2090	6.6	11.1 B	0.09 B	0.07 U	320 B	8.2	1.4 B	26.6	3530	59.4	191 B	17.8
S 5 OA	951128	2220	8.8	11.5 B	0.03 B	0.08 B	248 B	5.2	0.57 B	24.4	3610	94.6	181 B	14.4
S 5 A	951128	2060	8.4	4.5 B	0.05 U	0.06 U	16.7 B	2.8	0.19 U	7.8	2760	24.6	95 B	5.9
S 5 B1	951128	340	1.7 B	2.9 B	0.02 U	0.06 U	27.7 U	0.74 B	0.27 U	0.37 B	429	2.5	26.6 U	1.5 B
S 5 B2	951128	5300	25.4	13.5 J	0.22 B	0.05 U	148 B	6.2	0.64 B	1.7 B	6790	3.7	274 B	12.1
S 5 CL1	960226	9830	25.3	21.9 B J	0.37 B J	0.06 U	74.1 B J	22.8	0.97 B J	13.1	13200	17.5 J	358 B J	6.1
S 5 CL2	960226	9760	14.6	26.6J B J	0.80 B J	0.07 U	422 B J	22.4	2.5 B J	15.6	25300	19.2 J	872 B J	17.9
S 7 O	951129	5740	11.6	36.9	0.15 B	0.34	1860	10.9	1.2	59.2	9280	238	466	59.2
S 7 A	951129	3990	7.2	7.1	0.13 B	0.07	47	7.2	0.31	9.9	9400	25.1	102	5.0
S 7 CL1	960226	9080	3.1 J	15.8 B J	0.15 B J	0.06 U	22.3 B J	14.8 J	0.64 B J	4.1 B J	9860 J	11.2 J	427 B J	5.7 J
S 7 CL2	960226	10800	8.2 J	19.2 B J	0.25 B J	0.07 U	20.7 B J	24.9 J	0.93 B J	6.6	25500 J	16.9 J	543 B J	7.4 J
S 9 O	951130	694	3.0	4.6 B	0.08 B	0.07 U	148 B	2.6	0.31 U	8.7	2020 J	46.9	75.8 B	6.7
S 9 S O	951130	883	3.2	9.9 B	0.02 U	0.07 B	427 B	3.2	0.31 U	10.3	2100	41.5	110 B	11.1
S 9 D O	951130	979	3.0 B	23.4 B	0.15 B	0.17 B	1280 B	3.8	0.54 B	19.1	2350	53.6	222 B	35.2
S 9 A	951130	607	2.8	5.8 B	0.08 B	0.06 U	27.4 U	2.3	0.27 U	6.7	2060	27.2	37.8 B	3.4
S10 O	951130	3050	5.3	36.5 B	0.04 U	0.44 B	1720 B	6.8	0.82 B	39.5	4870	141	455 B	25.4
S10 S O	951130	2860	4.2 B	49.9 B	0.24 B	0.39 B	2910	5.1	0.67 U	43.4	3920	174	546 B	50.7
S10 A	951130	2070	7.9	5.4 B	0.12 B	0.07 U	32.7 U	3.7	0.32 U	8.7	2750	21.9	114 B	2.4 B
S10 B1	951130	3450	10.6	5.7 B	0.11 B	0.06 U	29 U	7.9	0.28 U	2.4 B	6350	4.7	114 B	1.9 B
S10 C	951130	6120	9.9	14.4 B	0.21 B	0.07 U	34.9 U	18.3	0.34 U	6.5	6230	8.9	207 B	2.3 B
S11 A	960207	1400 J	6.3	3.1 B J	0.12 B J	0.06 U	69.3 B J	3.5	0.32 B	5.5	5240 J	25.8 J	148 B J	11.7 J
S11 E	960207	2010 J	4.5	5.1 B J	0.11 U	0.05 B	30.5 B J	3.1	0.24 U	4.7	3690 J	6.5 J	78.4 B J	11.4 J
S11 B1	960207	2510 J	3.1	5.9 B J	0.12 B J	0.06 U	28.9 U	2.9	0.28 U	1.2 B J	3210 J	2.6 J	58.0 B J	4.7 J
S11 C	960207	2000 J	5.6	9.6 B J	0.09 U	0.05 U	53.2 B J	3.8	0.27 B J	2.1 B J	4030 J	2.6 J	49.4 B J	4.6 J
S12 A	960207	1640 J	6.0	4.4 B J	0.22 B J	0.05 U	34.6 B J	9.2	0.35 B	5.8	9230 J	17.2 J	198 B J	13.7 J
S12 S A	960207	1690 J	5.4	6.1 B J	0.19 B J	0.08 B J	192 B J	8.5	0.51 B J	8.5	9060 J	29.1 J	271 B J	14.4 J
S12 E	960207	453 J	1.2 B J	2.0 B J	0.10 U	0.05 U	23.7 U	0.99 B J	0.23 U	0.84 B J	1450 J	1.6 J	22.7 U	6.3 J

Table 4. Concentrations of constituents measured in soil samples from the woods adjacent to the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey--Continued

Sample number[1]		Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
S12	B1	960207	1100 J	3.3	3.3 B J	0.10 U	0.06 U	26.8 U	2.3	0.26 U	0.68 B J	5420 J	2.6 J	37.3 B J	6.8 J
S12	C	960207	2010 J	5.5	7.5 B J	0.16 U	0.06 U	64.0 B J	6.1	0.27 U	2.1 B J	3640 J	3.3 J	70.3 B J	3.5 J
S13	A	960207	2510 J	8.3	5.2 B J	0.22 B J	0.06 U	42.8 B J	5.4	0.34 B	7.0	17700 J	23.7 J	203 B J	12.1 J
S13	B1	960207	2920 J	13.7	4.7 B J	0.25 B J	0.06 U	32.8 B	30.0	0.70 B J	7.6	32300 J	25.9 J	171 B J	51.7 J
S13	C	960207	2790 J	7.1	8.3 B J	0.13 B J	0.05 U	30.0 B J	6.7	0.49 B J	3.0 J	23600 J	3.0 J	101 B J	13.4 J
S14	O	960207	2290	5.0	9.9 B J	0.14 B J	0.11 B J	485 B J	7.5	0.50 B J	10.3	7530	33.4	437 B J	17.3
S14	A	960207	3310 J	7.8	6.5 B J	0.28 B J	0.07 U	98.2 B	9.3	0.66 B J	7.9	10200 J	82.9 J	643 B J	17.4 J
S14	B	960207	3580	3.4	9.5 B J	0.10 B J	0.09 B J	64.1 B J	3.9	0.40 B J	3.2 J	4540 J	3.5	139 B J	17.6
S15	A	960207	1940 J	6.8	3.6 B J	0.13 B J	0.06 U	39.1 B J	8.4	0.43 B J	5.7	8020 J	22.5 J	308 B J	11.1 J
S15	B1	960207	1860	3.3	3.9 B J	0.08 U	0.04 U	18.6 U	2.5	0.19 B J	2.1 B J	5900 J	2.8 J	70.5 B J	6.2 J
S15	B2	960207	5770 J	8.9	9.7 B J	0.22 B J	0.04 U	46.2 B J	7.9	0.69 B J	2.6 B J	13900 J	4.9 J	276 B J	14.1 J
S16	A	960212	2930	10.6 J	7.1 B J	0.18 B J	0.04 U	100 B J	17.7 J	0.56 B J	8.6	18100 J	35.1 J	314 B J	19.2 J
S16	B1	960212	2990	6.8 J	10.8 B J	0.16 B J	0.06 U	44.6 B J	6.7 J	0.44 B J	6.3	10800 J	13.2 J	226 B J	20.5 J
S16	CL1	960212	6970	15.0 J	15.1 B J	0.24 B J	0.05 U	228 B J	40.6 J	0.66 B J	5.9	34800 J	11.6 J	233 B J	14.6 J
S17	A	960212	2210	6.5	6.7 B J	0.11 B J	0.08 B J	41.3 B J	6.0	0.31 B J	8.4	6700	33.2	304 B J	13.7
S17	B1	960212	1910	3.6	6.3 B J	0.06 B J	0.08 B J	30.6 B J	2.6	0.26 U	2.3 B J	3960	5.0	85.8 B J	14.3
S19	A	960213	4700	15.1	6.7 B J	0.33 B J	0.12 B J	107 B J	13.2	3.4 B J	45.5	28200	50.9	437 B J	48.5
S19	B1	960213	3610	9.4	6.1 B J	0.16 B J	0.12 B J	75.0 B J	8.7	0.44 B J	21.7	12600	41.6	312 B J	13.6
S19	CL1	960213	9260	21.5 J	18.6 B J	0.29 B J	0.06 U	270 B J	20.6 J	0.91 B J	8.0	24800 J	17.3 J	369 B J	9.5 J
S19	CL2	960213	7720	13.0 J	16.9 B J	0.26 B J	0.07 U	182 B J	16.9 J	0.89 B J	6.8	18400 J	21.8 J	444 B J	10.9 J
S20	A	960213	1670	6.0	4.4 B J	0.10 B J	0.31 B J	99.2 B J	5.5	0.31 B J	13.9	5750	48.8	248 B J	9.0
S20	B1	960213	2520	3.3	5.1 B J	0.12 B J	0.06 U	31.0 B J	3.0	0.31 B J	2.1 B J	3900	4.2	101 B J	16.2
S20	B2	960213	2690	5.0	4.7 B J	0.10 B J	0.08 B J	28.2 B	3.6	0.28 U	2.2 B J	4800	3.9	97.7 B J	11.3

Appendix 1

Table 4. Concentrations of constituents measured in soil samples from the woods adjacent to the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
S 1 O	951128	0.22	5.3 B	247 B	1.7	52.3 U	0.78 U	14.8	38.8	283000	0.11
S 1 DS O	951130	0.33	8.2 B	400 B	2	83.6 B	1.1 U	19.9	58.6	660000	<0.05
S 1 D O	951128	0.09	2.5 B	286 B	1.1 B	47.8 U	0.59 U	8.7 B	17.4	248000	NA
S 1 DD O	951130	0.18	8.9 B	581 B	2.1	65.4 B	0.77 U	11.6 B	59.4	NA	NA
S 1 DD O2	951130	0.22	6.8 B	543 B	2.2	64.6 U	0.80 U	13.4 B	49.5	NA	NA
S 1 A	951128	0.06 B	0.57 B	221 B	0.85 B	36.1 U	0.54 U	9.5	4.8	8600	<0.05
S 1 B1	951128	0.02 B	0.97 B	83.1 B	0.9	34.6 U	0.52 U	15.2	8.5	1420	<0.05
S 1 B2	951128	0.01 B	0.48 B	193 B	0.91 B	39.1 U	0.59 U	21.4	6.6	2150	<0.05
S 2 O	951128	0.21	5.4 B	535 B	2	52.8 U	0.79 U	25.3	44.9	103000	0.07
S 2 A	951128	0.13	0.79 B	374 B	0.85 U	46.1 U	0.69 U	16	12.7	15800	NA
S 2 B1	951128	0.03 B	2.6 B	871 B	1.6	42.0 U	0.82 B	33.9	18.2	7390	NA
S 2 CL1	960226	0.04 U	3.3 BJ	2540	1.4	75.3 U	0.59 U	56.8	23.9	5230 J	<0.05
S 2 CL2	960226	0.05 U	3.6 BJ	2840	0.81 BJ	89.4 U	0.56 U	44.3	21.1	4270 J	<0.05
S 3 O	951128	0.25	4.4 B	219 B	1.5	49.4 U	0.74 U	14.6	38.4	16000	<0.05
S 3 A	951128	0.01 B	0.7 B	222 B	0.85 B	37.2 U	0.56 U	9.3	5.7	16300	<0.05
S 3 B1	951128	0.13	0.9 B	196 B	0.79 B	36.8 U	0.55 U	10.8	6.4	3130	<0.05
S 3 B2	951128	0.02 B	0.83 B	453 B	0.83 B	37.1 U	0.56 U	30.2	10.1	2120	<0.05
S 4 O	951128	0.14 B	5.7 B	264 B	1.4	55.9 U	0.84 U	15.1	43.6	178000	0.05
S 4 A	951128	0.10 B	0.38 B	153 B	0.95 B	43.1 U	0.65 U	7.1 B	4.1 B	6040	<0.05
S 4 B1	951128	0.01 B	0.68 B	136 B	0.70 U	37.7 U	0.57 U	9.3 B	7.6	1240	<0.05
S 4 B2	951128	0.01 U	0.40 B	276 B	0.93	33.6 U	0.50 U	8.1 B	3.3 B	930	<0.05

Table 4. Concentrations of constituents measured in soil samples from the woods adjacent to the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
S 5 O	951128	0.10	7.2 B	426 B	1 B	44.7 U	0.55 U	11.1 B	36.8	74200	0.07
S 5 OA	961128	0.18	3.4 B	446 B	1.2	44.0 U	0.54 U	17.8	27.2	NA	NA
S 5 A	951128	0.13	0.81 B	135 B	1.3	37.9 U	0.57 U	8.9 B	6.6	27800	<0.05
S 5 B1	951128	0.04 U	0.27 U	47.4 B	0.43 U	36.3 U	0.45 U	1.3 B	0.59B	627	<0.05
S 5 B2	951128	0.02 U	2.0 B	463 B	0.34 U	29.0 U	0.36 U	13.9	14.2	1970	<0.05
S 5 CL1	960226	0.06 BJ	1.9 BJ	1280	0.70 BJ	49.5 U	0.45 U	43.4	20.3	9260 J	<0.05
S 5 CL2	960226	0.04 U	3.8 BJ	2380	1.00 BJ	85.6 U	0.51 U	43.2	24.5	14400 J	<0.05
S 7 O	951129	0.48	10.5 B	754 B	3.2	72.3 U	0.89 U	34.3	65.8	260000	0.17
S 7 A	951129	0.10	0.60 B	267 B	1.3	40.8 U	0.50 U	17.6	6.9	32900	<0.05
S 7 CL1	960226	0.03 U	1.1 BJ	913 BJ	0.72 UJ	46.2 U	0.99 U	20.4	6.9 J	7520 J	<0.05
S 7 CL2	960226	0.04 U	1.6 BJ	1380 J	1.5 J	50.9 U	1.1 U	40.4	9.8 J	9690 J	<0.05
S 9 O	951130	0.09 B	1.0 B	216 B	0.55 B	41.3 U	0.51 U	6.2 B	9.9	36600	<0.05
S 9 S O	951130	0.09	2.3 B	198 B	0.89 B	41.3 U	0.51 U	7.9 B	19.4	131000	NA
S 9 D O	951130	0.20	4.7 B	335 B	1.6	57.3 U	0.70 U	8 B	41.1	52200	<0.05
S 9 A	951130	0.06 B	0.27 B	127 B	0.55 BJ	35.8 U	0.44 U	5.8 B	5.2	9410	<0.05
S10 O	951130	0.09 U	8.6 B	741 B	1.9	70.5 U	0.87 U	18.0 B	58.9	431000	0.12
S10 S O	951130	0.27	10 B	837 B	2.3 B	89.0 U	1.1 U	16.3 B	77.1	339000	NA
S10 A	951130	0.15	0.51 B	259 B	0.79 B	42.8 U	0.53 U	8.2 B	5.3	24200	<0.05
S10 B1	951130	0.04 UJ	0.28 U	322 B	0.91 B	38.0 U	0.47 U	18.7	3.9 B	2660	<0.05
S10 C	951130	0.06 UJ	0.57 B	862 B	1.1 B	45.6 U	0.56 U	26.1	6.9	4880	<0.05
S11 A	960207	0.05 UJ	0.80 BJ	419 BJ	0.42 U	36.0 U	0.44 U	7.7 BJ	7.2	4200 J	<0.05
S11 E	960207	0.05 UJ	1.6 BJ	191 BJ	0.38 U	32.0 U	0.40 U	4.0 BJ	11.2 J	2350 J	<0.05
S11 B1	960207	0.04 UJ	0.68 BJ	94.8 BJ	0.55 BJ	37.8 U	0.46 U	3.6 BJ	6.9	1330 J	<0.05
S11 C	960207	0.03 UJ	0.99 BJ	176 BJ	0.40 U	34.3 U	0.42 U	3.1 BJ	1.8 BJ	940 J	<0.05

Table 4. Concentrations of constituents measured in soil samples from the woods adjacent to the Imperial Oil Company Superfund site, Morganville, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
S12 A	960207	0.08 J	1.7 BJ	580 B J	0.39 U	30.4 U	0.56 BJ	11.1	12.8	7790 J	<0.05
S12 S A	960207	0.06 BJ	2.8 B	726 B J	0.47 U	90.8 B	0.49 U	13.4	16.9	19600 J	NA
S12 E	960207	0.04 UJ	0.23 U	88.3 B J	0.63 U	31.0 U	0.39 BJ	3.0 B J	1.9 B J	1420 J	<0.05
S12 B1	960207	0.05 UJ	0.29 BJ	59.0 B J	0.43 U	35.1 U	0.43 UJ	7.0 B J	3.6 B J	1120 J	<0.05
S12 C	960207	0.04 UJ	0.81 BJ	122 B J	0.43 U	36.4 U	0.45 U	5.9 B J	2.7 B J	3560 J	<0.05
S13 A	960207	0.05 BJ	1.7 BJ	600 B J	0.45 U	38.3 U	0.47 U	12.3	14.6	12200 J	<0.05
S13 B1	960207	0.05 U	1.0 BJ	453 B J	0.43 U	36.6 U	0.45 U	29.8	20.6	4340 J	<0.05
S13 C	960207	0.05 U	1.0 B	203 B J	0.51 BJ	31.3 U	0.38 U	9.8	10.8	1220 J	<0.05
S14 O	960207	0.09 BJ	1.9 BJ	1430	0.52 U	44.2 U	0.54 UJ	15.3	20.4 J	50100 J	NA
S14 A	960207	0.08 BJ	1.6 BJ	2150 J	1.2 U	42.0 U	0.52 U	12.6	14.8	13000 J	<0.05
S14 B	960207	0.05 U	1.9 BJ	258 B J	1.1 J	36.5 U	0.45 UJ	9.7 J	15.5 J	3190 J	<0.05
S15 A	960207	0.07 BJ	1.0 BJ	942 B J	0.81 BJ	38.3 U	0.47 U	13.4	10.2	8620 J	<0.05
S15 B1	960207	0.05 UJ	0.39 BJ	127 B J	0.44 B	24.3 U	0.30 U	15.6	3.4	3130 J	<0.05
S15 B2	960207	0.06 UJ	1.9 BJ	513 B J	0.58 BJ	26.1 U	0.32 U	23.2	16.5	NA	<0.05
S16 A	960212	0.14	1.2 BJ	991	0.44 UJ	28.6 U	0.61 U	18.2	17.6 J	14200 J	<0.05
S16 B1	960212	0.07 BJ	0.55 BJ	671 B J	0.73 UJ	47.2 U	1.0 U	14.8	10.4 J	4120 J	NA
S16 CL1	960212	0.09 BJ	2.2 BJ	512 B J	0.94 J	35.8 U	0.77 U	47.4	24.9 J	4750 J	<0.05
S17 A	960212	0.07 BJ	0.63 BJ	1000 B J	0.84 BJ	40.9 U	0.50 UJ	12.8	13.5 J	12500 J	NA
S17 B1	960212	0.05 U	0.26 UJ	194 B J	0.42 U	35.4 U	0.44 UJ	7.4 B J	4.2 J	2030 J	NA
S19 A	960213	0.05 U	8.6 BJ	1290	0.67 BJ	41.2 U	0.51 UJ	30.0	41.2 J	17000 J	NA
S19 B1	960213	0.06 U	1.1 BJ	987	0.39 U	33.4 U	0.41 UJ	21.4	13.2 J	10700	NA
S19 CL1	960213	0.06 BJ	1.3 BJ	1000 B J	0.70 UJ	45.2 U	0.97 U	37.5	13.1 J	4600	<0.05
S19 CL2	960213	0.06 BJ	1.1 BJ	1030 B J	0.74 UJ	47.4 U	1.0 U	40.1	6.6 J	2780	<0.05
S20 A	960213	0.18 J	1.2 BJ	939	0.37 BJ	29.1 U	0.36 UJ	13.8	13.1 J	27700	NA
S20 B1	960213	0.06 U	1.2 BJ	261 B J	0.43 U	36.6 U	0.45 UJ	8.4 B J	5.9 J	3270	NA
S20 B2	960213	0.06 U	0.82 BJ	204 B J	0.43 U	36.9 U	0.45 UJ	11.1	7.3 J	1980	NA

Appendix 1

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey

[All concentrations in milligrams per kilogram (parts per million) unless otherwise noted; B, detectable value but below the contract-required detection limit; U, below the instrument detection limit, J, qualified--data may exhibit bias; <, less than; NA, not analyzed; see figs. 8 and 9 for locations]

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
							Residential area 1							
R 3 CL1	960301	13500 J	146 J	35.8 B J	0.52B J	0.07 U	1010 B J	25.4 J	1.7 B J	18.9	22800 J	124 J	1060 B J	29.3
R 3D CL1	960301	11800 J	67.9 J	25.9 B J	0.42B J	0.06 U	899 B J	22.9 J	1.6 B J	14.5	20200 J	64.8 J	902 B J	22.5
R 3 B2	960301	13800 J	54.9 J	29.6 B J	0.51B J	0.06 U	834 B J	25.3 J	1.7 B J	14.9	25500 J	51.8 J	985 B J	22.9
R 3D B2	960301	15400	10.3	24.8 B J	0.56B J	0.11 B J	811 B J	30.4	1.6 B J	19.5 J	26700 J	17.3 J	1140	16.4 J
R 3 17	960301	13500 J	156 J	29.2 B J	0.52B J	0.06 U	815 B J	24.7 J	1.7 B J	14.4	23400 J	88.2 J	1030 B J	22.1
R 3 710	960301	14900 J	84.7 J	28.9 B J	0.61B J	0.06 U	786 B J	29.6 J	1.8 B J	15.8	33100 J	109 J	1160	21.7
R 3 1015	960301	13800 J	94.3 J	28.7 B J	0.59B J	0.07 U	859 B J	26.5 J	1.9 B J	15.7	25500 J	105 J	1110 J	20.5
R 4 B1	960301	11900	23.0	28.0 B J	0.52B J	0.14 B J	748 B J	25.3	1.6 B J	16.4 J	26000 J	46.9	960 B J	24.8 J
R 4 B2	960301	11000	15.4	21.9 B J	0.44B J	0.09 B J	431 B J	20.7	1.3 B J	11.3 J	22800 J	16.5 J	777 B J	15.1 J
R 4 CL2	960301	10300	11.7	22.0 B J	0.47B J	0.08 U	190 B J	23.0	1.4 B J	14.9 J	15100 J	17.2 J	695 B J	7.0 J
R19 A	960318	19400 J	39.6 J	73.8 J	0.66B J	0.07 U	1650	35.7 J	2.5 B J	30.0	36600 J	88.3 J	1630 J	48.0 J
R19 CL1	960318	16200 J	18.1 J	27.4 B J	0.57B J	0.09 U	558 B J	32.0 J	1.8 B J	17.9 J	52800 J	22.9 J	1430 J	28.6 J
R19 CL2	960318	9440	14.4 J	20.8 B J	0.15B J	0.14 B J	326 B J	21.1	1.3 B J	15.6	15500	16.9	597 B J	9.4
R19 CL3	960318	9800	17.6 J	28.6 B J	0.13B J	0.15 B J	238 B J	20.7	1.9 B J	14.4	17300	17.6	1040 B J	21.0
R19 CL4	960318	8710	15.6 J	22.0 B J	0.15B J	0.27 B J	161 B J	19.9	1.8 B J	14.2	23600	17.2	909 B J	17.7
R21 A	960322	6770	30.0 J	90.8 J	0.15B J	0.73 B J	1870	22.9	1.6 B	47.1	17200	348	752 B J	93.8
R21 B1	960322	2770	13.6 J	18.2 B J	0.03U	0.09 B J	405 B J	7.7	0.35 B J	8.2	8670	67.4	215 B J	27.1
R21 B2	960322	3860	10.8 J	15.4 B J	0.03U	0.07 B J	230 B J	4.7	0.24 B	3.8 B J	5550	23.2	171 B J	15.1

[1] The initial letter denotes sample sites in residential areas; the following number is the number of the individual site. In the next two columns, samples marked D are spatial duplicates; samples marked S are splits. The final letter refers to the soil horizon; CL denotes clays. The final number denotes increasing depth with increase in value. R3 samples followed by 17, 710, and 1015 are auger samples collected from depths of 1-7, 7-10, and 10-15 inches, respectively.

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
Residential area 1--Continued														
R22 A	960322	4770	20.1 J	56.9 J	0.06B J	0.56 B J	1530	24.8	1.2 B J	58.7	11300	256	626 B J	54.2
R22 B1	960322	5770	26.2	42.9	0.14B J	0.07 U	2130	17.3	0.86 B J	13.4	14600	67.9	552 B J	56.9 J
R22 B2	960322	4060	10.5	23.8 B J	0.05B	0.07 U	827 B J	9.8	0.56 B J	10.8	7930	54.7	390 B J	44.4 J
R23 A	960325	4800	24.7	166	0.31B J	0.59 B J	1120 B J	28.8	2.3 B J	69.9	23900	317	468 B J	73.3 J
R23 CL1	960325	16000	61.9	58.7	0.03U	0.07 U	1510	22.9	0.72 B J	16.1	40900	44.6	887 B J	22.7 J
R23 CL2	960325	14400	88.4	33.6 B J	0.03U	0.08 U	1030 B J	24.0	0.53 B J	13.2	74200	38.8	671 B J	16.3 J
R23 C	960325	6420	35.9	13.6 B J	0.03U	0.07 U	393 B J	11.1	0.24 U	8.3	53100	19.7	268 B J	10.0 J
R24 A	960325	13100	44.7	51.1	0.31B J	0.08 U	1500 J	30.5	1.0 B J	38.5	23500	204	1200 B J	62.5 J
R24 CL1	960325	18400	33.2	37.2 B J	0.37B J	0.08 U	909 B J	31.5	1.6 B J	17.7	34600	54.5	1390	33.7 J
R24 CL2	960325	12700	16.2	23.7 B J	0.29B J	0.08 U	228 B J	26.7	1.2 B J	15.3	31800	20.5	858 B J	12.6 J
Residential area 2														
R 1 A	960228	1600	27.1 J	8.5 B J	0.16B J	0.04 U	559 B J	10.7 J	0.80 B J	17.7	17600 J	159 J	244 B J	25.2 J
R 1D A	960228	1760	20.1 J	9.0 B J	0.16B J	0.04 U	543 B J	7.4 J	0.56 B J	9.2	11500 J	136 J	309 B J	15.0 J
R 1 B1	960228	1560	27.0 J	8.3 B J	0.15B J	0.24 B J	497 B J	6.6 J	0.61 B J	11.9	12900 J	158 J	193 B J	17.2 J
R 1D B1	960228	1590	16.8 J	6.3 B J	0.14B J	0.05 U	373 B J	5.1 J	0.52 B J	7.7	6770 J	83.7 J	312 B J	11.2 J
R 1 B2	960228	1890	25.2 J	9.4 B J	0.14B J	0.04 U	419 B J	8.8 J	0.39 B J	7.7	12700 J	15.0 J	212 B J	21.0 J
R 1 B3	960228	5620	29.4 J	12.1 B J	0.54B J	0.05 U	448 B J	29.0 J	1.1 B J	7.6	43600 J	13.1 J	206 B J	21.5 J
R 1D B3	960228	4430	16.7 J	9.3 B J	0.24B J	0.06 U	350 B J	19.6 J	0.76 B J	5.5	32300 J	7.9 J	166 B J	11.1 J
R 2 A	960228	5370	70.5 J	20.0 B J	0.33B J	0.06 U	798 B J	14.5 J	1.2 B J	42.7	17200 J	392 J	622 B J	46.7 J
R 2 B1	960228	5770	33.2 J	12.7 B J	0.21B J	0.05 U	773	11.7 J	0.87 B J	12.9	15600 J	37.8 J	479 B J	13.1 J
R 2 B2	960228	8920	25.2 J	13.5 B J	0.31B J	0.07 U	1000 B J	22.8 J	1.0 B J	7.4	30000 J	15.0 J	655 B J	11.6 J
R 2 CL1	960228	9830	25.9 J	13.6 B J	0.39B J	0.06 U	753 B J	21.6 J	1.2 B J	10.8	31400 J	15.6 J	790 B J	13.2 J
R 2 CL2	960228	12200 J	17.0 J	16.8 B J	0.44B J	0.05 U	316 B J	19.8 J	1.4 B J	8.7	24400 J	12.5 J	933 J	14.6
R 2 SCL2	960228	14000 J	20.0 J	19.5 B J	0.50B J	0.06 U	381 B J	24.5 J	1.6 B J	14.6	33800 J	17.1 J	1060	17.8

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
Residential area 2--Continued														
R 5 A	960304	4350 J	20.9 J	28.4 B J	0.31B J	0.07 U	754 B J	12.1 J	1.8 B J	13.3	14500 J	87.1 J	652 B J	190
R 5 B1	960304	13500 J	13.5 J	20.5 B J	0.55B J	0.07 U	515 B J	25.3 J	4.0 B J	7.8	23800 J	16.7 J	3110	60.3 J
R 5 SB1	960304	12300 J	13.9 J	18.8 B J	0.49B J	0.06 U	497 B J	23.3 J	3.7 B J	7.2	23200 J	15.4 J	2780	54.4
R 5 C	960304	9220 J	32.4 J	15.9 B J	0.34B J	0.07 U	444 B J	18.1 J	1.3 B J	13.8	22300 J	70.4 J	739 B J	16.0
R 6 A	960304	3220 J	10.4 J	11.8 B J	0.22B J	0.07 U	104 B J	12.1 J	0.75 B J	16.5	15000 J	66.3 J	346 B J	21.9
R 6 B1	960304	2110	5.39	11.7 B J	0.15B J	0.11 B J	82.9 B J	6.5	0.65 B J	11.0 J	9470 J	39.5 J	137 B J	32.7 J
R 6 B2	960304	1270	4.1	7.5 B J	0.06B J	0.10 B J	57.7 B J	3.3	0.51 B J	4.2 J	4600 J	20.3 J	144 B J	24.8 J
R 6 B3	960304	2890 J	3.3 J	7.5 B J	0.05U	0.05 U	146 B J	2.8 J	0.21 B J	1.7 B J	4220 J	3.3 J	48.9 B J	5.5
R 6 C	960304	71.4	0.84U	2.5 B J	0.02U	0.09 B J	25.7 B J	0.51B J	0.26 B J	0.74B J	156 J	1.68 J	7.6 U	2.1 B
R 7 A	960304	3590	39.2	18.1 B J	0.38B	0.21 B J	832 B J	20.7 J	1.0 B J	22.1 J	23900 J	220 J	420 B J	34.6 J
R 7 E	960304	6540	38.5	17.3 B J	1.2	0.37 B J	846	166	1.7 B J	24.4 J	77400 J	184 J	517 B J	39.8 J
R 7 B2	950304	4810	11.5	11.2 B J	0.47B J	0.07 B J	551 B J	27.7	1.0 B J	6.5 J	36000 J	19.7 J	489 B J	24.1 J
R 8 A	960305	6990	14.9	19.7 B J	0.41B J	0.10 B J	413 B J	29.3	1.1 B J	11.4 J	36800 J	39.8 J	571 B J	27.2 J
R 8 B1	960305	9530	21.5	12.2 B J	0.45B	0.06 U	781 B J	24.0	1.3 B J	6.2 J	37500 J	10.7 J	907 B J	21.3 J
R 8 B2	960305	10900	14.0	13.4 B J	0.61B J	0.05 U	340 B J	52.9	1.6 B J	7.7 J	50600 J	8.17 J	1100	24.5 J
R 8 CL1	960305	8570	13.7	14.7 B J	0.39B J	0.07 U	441 B J	20.5	1.2 B J	9.6 J	26500 J	11.5 J	806 B J	18.3 J
R 8 CL2	960305	11500	21.0	20.1 B J	0.46B J	0.08 U	509 B J	22.9	1.5 B J	13.1 J	27900 J	14.7 J	927 B J	15.1 J
R 9 A	960305	4420	33.2	10.2 B J	0.58B J	0.08 B	127 B J	54.1	1.9 B J	11.3 J	45400 J	87.2 J	341 B J	41.3 J
R 9 B1	960305	3650	43.6	13.2 B J	0.20B J	0.06 U	235 B J	14.9	0.60 B J	6.0 J	16100 J	49.8 J	270 B J	10.6 J
R 9 B2	960305	4940	21.2	13.0 B J	0.34B J	0.08 U	650 B J	14.9	0.67 B	3.5 B	24600 J	6.61 J	243 B J	7.0 J
R 9 CL1	960305	6900	13.0	11.1 B	0.43B	0.06 B	1090	21.4	0.93 B	5.7	34900	8.2 J	510 B	11.4
R 9 CL2	960305	11400	15.1	14.6 B J	0.44B J	0.07 U	823 B J	24.9	1.4 B J	9.5 J	33100 J	9.88 J	868 B J	13.1 J
R10 A	960305	5960 J	24.2 J	12.6 B J	0.30B J	0.06 U	853 B J	19.3 J	1.00 B J	21.1	20900 J	71.6 J	626 B J	22.8
R10 B1	960305	9590 J	24.2 J	12.8 B J	0.51B J	0.07 U	841 B J	32.9 J	1.3 B J	10.8	40300 J	20.7 J	795 B J	17.8
R10 CL1	960305	9470 J	25.1 J	14.8 B J	0.34B J	0.08 U	891 B J	22.1 J	1.2 B J	8.9	31300 J	13.9 J	747 B J	15.2
R10 CL2	960305	9050 J	21.9 J	15.0 B J	0.41B J	0.06 B	616 B J	18.5 J	1.3 B J	9.5	39300 J	16.8 J	654 B J	13.3
R10 C	960305	4040 J	19.3 J	14.5 B J	0.23B J	0.05 U	183 B J	11.1 J	0.62 B J	3.3 B J	15100 J	16.9 J	310 B J	6.5

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
Residential area 2--Continued														
R11 A	960311	4840	13.2	14.9 B J	0.18B J	0.07 U	214 B J	12.8 J	0.71 B J	9.7	11800 J	16.9 J	340 B J	13.1 J
R11 B1	960311	5450	12.1	10.9 B J	0.14B J	0.05 U	63.3 B J	9.4 J	0.66 B J	3.1 B J	13100 J	5.7 J	189 B J	7.0 J
R11 CL1	960311	7150	15.5	25.1 B J	0.20B J	0.06 U	181 B J	16.1 J	0.58 B J	6.6	16800 J	15.6 J	258 B J	4.9 J
R11 CL2	960311	6800	11.4	19.4 B J	0.22B J	0.05 U	109 B J	14.4 J	0.65 B J	6.8 J	10500 J	16.8 J	278 B J	4.8 J
R11 C	960311	397	4.3	1.7 B J	0.02B J	0.07 B J	8.2 U	2.3 J	0.18 U	0.44B J	3000 J	2.3 J	16.9 B J	0.04U J
R12 A	960311	3660	49.5	13.8 B J	0.33B J	0.13 B J	500 B J	15.7 J	0.76 B J	25.0	16400 J	260 J	513 B J	19.0 J
R12 B1	960311	3250	35.6	14.4 B J	0.32B J	0.12 B J	535 B	15.2 J	0.74 B J	14.4 J	19600 J	62.5 J	366 B J	18.6 J
R12 B2	960311	6590	15.5	9.7 B J	0.45B J	0.05 U	813 J	33.3 J	0.94 B J	5.2 B J	37800 J	9.2 J	697 B J	15.7 J
R12 CL1	960311	8650	21.4	14.8 B J	1.0	0.05 U	859 B J	89.0 J	1.3 B J	8.3	61600 J	20.2 J	763 B J	16.1 J
R13 A	960312	2800	50.0	13.3 B J	0.21B J	0.15 B J	552 B J	10.7 J	0.58 B J	27.2	10600 J	360 J	473 B J	19.8 J
R13 B1	960312	2300	62.3	12.3 B J	0.18B J	0.16 B J	465 B J	7.5 J	0.50 B J	33.7	9120 J	416 J	323 B J	17.3 J
R13D B1	960312	2230	73.9	10.5 B J	0.22B J	0.10 B J	357 B J	10.3 J	0.50 B J	27.1	12000 J	242 J	271 B J	14.3 J
R13 B2	960312	2620	30.6	6.0 B J	0.21B J	0.06 U	176 B	12.9 J	0.53 B J	5.2 B J	12700 J	12.0 J	154 B J	12.3 J
R13D B2	960312	4910	29.2	8.3 B J	0.38B J	0.05 U	286 B J	20.8 J	0.81 B J	4.6	29500 J	8.3 J	327 B J	31.8 J
R13 B3	960312	4980	12.0	10.9 B J	0.29B J	0.06 U	527 B J	15.1 J	0.86 B J	2.9 B J	23600 J	4.4 J	441 B J	12.0 J
R14 A	960312	2690	37.1	14.1 B J	0.14B J	0.22 B J	688 B J	8.7 J	0.59 B J	22.5 J	7840 J	241 J	340 B J	17.4 J
R14 B1	960312	3370	23.3	6.8 B J	0.17B J	0.07 B J	230 B J	11.9 J	0.45 B J	6.3	10200 J	26.3 J	213 B J	7.4 J
R14 B2	960312	6330	15.3	8.9 B J	0.33B J	0.06 U	400 B J	15.8 J	0.98 B J	4.4 B J	24600 J	7.0 J	610 B J	20.1 J
R15 A	960313	2950	28.7	16.6 B J	0.22B J	0.15 B J	535 B J	9.0 J	0.67 B J	26.9	9580 J	211 J	456 B J	27.1 J
R15D A	960313	3820 J	29.9 J	19.4 B J	0.11B J	0.07 U	797 B J	13.7 J	0.63 B J	20.4	11600 J	236 J	628 B J	37.3 J
R15 B1	960313	5290	31.0	11.3 B J	0.51B J	0.08 B J	434 B J	43.2 J	0.87 B J	5.0	50300 J	15.4 J	272 B J	13.6 J
R15D B1	960313	3070 J	19.0 J	9.3 B J	0.03U	0.07 U	437 B J	9.0 J	0.25 B J	3.4 B J	13200 J	10.8 J	286 B J	14.6 J
R15 CL1	960313	9720 J	17.6 J	12.7 B J	0.36B J	0.07 U	1000 B J	33.2 J	0.80 B J	6.6	63500 J	19.0 J	777 B J	14.9 J
R15D CL1	960313	10300 J	42.3 J	13.1 B J	0.19B J	0.07 U	1260	18.7 J	0.80 B J	10.0	28300	16.3 J	841 B J	13.7 J
R15 CL2	960313	13400 J	19.0 J	19.8 B J	0.32B J	0.08 U	525 B J	23.8 J	1.0 B J	10.7	28600 J	16.7 J	1040 B J	18.2 J
R15D CL2	960313	6730 J	13.0 J	8.9 B J	0.10B J	0.07 U	783 B J	18.0 J	0.48 B J	3.5 B J	23300 J	5.0 J	528 B J	10.0 J

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
							Residential area 2--Continued							
R16 A	960313	3230 J	23.3 J	15.7 B J	0.18B J	0.07 U	481 B J	11.1 J	0.58 B J	10.5 J	13200 J	84.8 J	659 B J	28.6 J
R16 B1	960313	4440 J	18.7 J	11.1 B J	0.22B J	0.07 U	220 B J	39.4 J	0.64 B J	3.4 B J	42100 J	8.7 J	488 B J	19.4 J
R16 CL1	960313	11900 J	16.0 J	18.7 B J	0.17B J	0.08 U	574 B J	27.3 J	0.85 B J	12.1	36800 J	14.8 J	888 B J	12.3 J
R16 CL2	960313	15700 J	15.8 J	24.6 B J	0.31B J	0.08 U	570 B J	30.5 J	1.2 B J	13.2 J	35500 J	19.7 J	1150 B J	15.9 J
R17 A	960318	4840 J	24.1 J	15.2 B J	0.16B J	0.08 U	1850	12.3 J	0.70 B J	14.0 J	15800 J	103 J	756 B J	40.6 J
R17 B1	960318	9620 J	25.3 J	14.6 B J	0.25B J	0.07 U	1150	39.6 J	0.73 B J	7.6	43700 J	22.9 J	719 B J	17.1 J
R17 B2	960318	5920 J	21.3 J	14.3 B J	0.09B J	0.07 U	584 B J	13.5 J	0.41 B J	3.9 B J	19900 J	14.3 J	479 B J	16.9 J
R18 A	960318	5260 J	16.9 J	14.4 B J	0.21B J	0.08 U	938 B J	14.6 J	0.87 B J	11.9	12800 J	78.6 J	979 B J	29.6 J
R18 B1	960318	5510 J	11.3 J	10.9 B J	0.06B J	0.07 U	473 B J	12.5 J	0.36 B J	2.8 B J	15100 J	8.9 J	382 B J	12.3 J
R18 B2	960318	6960 J	13.0 J	12.0 B J	0.03U	0.07 U	762 B J	14.0 J	0.41 B J	3.6 B J	21400 J	7.8 J	629 B J	12.3 J
R18 C	960318	6020 J	12.2 J	9.8 B J	0.10B J	0.07 U	419 B J	23.4 J	0.42 B J	4.2 B J	34300 J	9.3 J	477 B J	8.8 J
R18 CL1	960318	10500 J	13.6 J	17.9 B J	0.19B J	0.07 U	1950	23.2 J	0.62 B J	10.9	29500 J	14.6 J	959 B J	11.5 J
R18 CL2	960318	9290 J	19.9 J	15.3 B J	0.71B J	0.08 U	964 B J	49.5 J	0.68 B J	8.6	42300 J	15.7 J	734 B J	19.9 J
R20 A	960322	3340	25.1 J	16.5 B J	0.11B J	0.18 B J	1280	10.0	0.81 B J	17.3	10500	182	686 B J	57.3
R20 B1	960322	3380	45.6 J	16.1 B J	0.13B J	0.25 B J	759 B J	12.2	0.73 B J	19.4	12800	153	622 B J	37.5
R20 B2	960322	3800	23.9 J	12.7 B J	0.13B J	0.10 B J	430 B J	10.1	0.81 B J	6.6	11800	28.1	970 B J	45.6
R20 B3	960322	2480	9.6 J	7.7 B J	0.03U	0.07 U	156 B J	3.4	0.23 U	2.5 B J	3990	12.9	202 B J	14.3
R27 A	960424	7610	55.1 J	14.7 B J	0.34B J	1.7 J	857 B J	16.9 J	1.1 B J	18.4	21400 J	132 J	736 B J	16.1 J
R27 B1	960424	11800	37.2 J	15.2 B J	0.45B J	3.5 J	357 B J	22.1 J	0.17 U	5.0 B J	48800 J	17.9 J	840 B J	13.2 J
R27 C	960424	4380	16.9 J	7.4 B J	0.26B J	2.5 J	110 B J	14.9 J	0.18 U	3.7 B J	36000 J	9.5 J	354 B J	5.8 J
R27 CL1	960424	12700	18.7 J	22.3 B J	0.46B J	1.4 J	521 B J	23.7 J	0.77 B	9.7 J	21300 J	18.5 J	1100 B J	20.1 J
R27 CL2	960424	11100	30.9 J	20.6 B J	0.44B J	2.1 J	284 B J	23.3 J	0.27 B J	6.1 B J	32400 J	20.5 J	1030 B J	18.9 J

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese
							Broader area							
B 1 A	960417	8880	21.4	33.2	0.44B	3.5	407 B	29.3	1.2 B	10	31100	45.9	1160 B	110
B 1 A2	960417	8500	30.4	29.7 B	0.33B	4.7	162 B	39.4	0.39 B	11.8	44200	54.2	980 B	67.7
B 1 CL1	960417	5190	26.1	26.0 B	0.07U	2.3	198 B	15.8	0.36 B	11.6	24000	40.1	678 B	21.9
B 1 B1	960417	11500	149	40.4 B	0.78B	2.8	316 B	34.7	2.7 B	28.4	28900	400	1950	57.4
B 1 CL2	960417	13400	28.3	50.3	0.75B	3.8	1350	45.1	7.8 B	12.4	36100	30.8	2360	163
B 2 A	960424	6990	13.9 J	44.9 B J	0.40B J	1.3 J	5780	19.8 B J	1.9 B J	17.8	16500 J	35.3 J	1620 J	180 J
B 2 B1	960424	5330	13.9 J	18.9 B J	0.33B J	1.3 J	1110 B J	15.5 J	0.65 B J	6.2	18500 J	28.9 J	813 B J	57.5 J
B 2 CL1	960424	10900	21.0 J	21.5 B J	0.51B J	1.9 J	645 B J	25.4 J	0.75 B J	6.9	27400 J	20.8 J	1240 J	36.4 J
B 2 CL2	960424	7730	18.3	23.2 B J	0.53B J	1.9	559 B J	36.7 J	0.36 B J	5.6 B J	32600	95.6 J	967 B J	32.2

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
					Residential area 1						
R 3 CL1	960301	0.16 J	4.3 B J	2320 J	1.5 J	65.2 U	1.0 U	46.3	41.8 J	28000 J	<0.05
R 3D CL1	960301	0.09 J	3.2 B J	1910 J	1.9 J	45.1 U	0.88 U	45.6	31.3 J	27100 J	<0.05
R 3 B2	960301	0.05 U J	3.1 B J	2220 J	1.7 J	59.3 U	0.99 U	44.5	28.6 J	11400 J	<0.05
R 3D B 2	960301	0.07 U J	2.6 B J	2560	1.6 J	84.3 U	1.1 U	71.1 J	18.1 J	8660 J	<0.05
R 3 17	960301	0.26 J	3.6 B J	2310 J	1.8 J	67.5 U	0.99 U	48.3	30.8 J	14200 J	<0.05
R 3 710	960301	0.20 J	3.3 B J	2610 J	1.4 J	44.3 U	0.86 U	70.3	29.0 J	18900 J	<0.05
R 3 1015	960301	0.11 J	3.0 B J	2600 J	2.3 J	96.4 U	1.2 U	46.6	26.8 J	10700 J	<0.05
R 4 B 1	960301	0.07 B J	3.7 B J	2060	1.4 J	69.8 U	1.0 U	46.8 J	44.6 J	19000 J	<0.05
R 4 B 2	960301	0.04 U J	2.2 B J	1640	1.1 B J	51.4 B	1.1 U	41.7 J	22.0 J	11100 J	<0.05
R 4 CL2	960301	0.05 U J	1.5 B J	2100	0.91 U	58.3 U	1.3 U	29.1 J	12.9 J	9110 J	<0.05
R19 A	960318	0.05 U J	6.4 B J	3470 J	2.9 J	88.6 U	1.1 B J	65.7 J	70.8 J	26500 J	NA
R19 CL1	960318	0.03 U	3.3 B J	3400 J	3.1 J	51.0 U	1.4 B J	62.0 J	31.4 J	6610 J	<0.05
R19 CL2	960318	0.07 U J	1.8 B J	2130	1.2 B J	47.3 U	0.99 U	29.2	17.2	9390 J	<0.05
R19 CL3	960318	0.10 B J	2.9 B J	2200	1.9 J	46.4 U	0.97 U	50.0	23.8	8650 J	<0.05
R19 CL4	960318	0.06 U J	2.6 B J	2130	2.2 J	46.7 U	0.98 U	43.0	25.1	9650 J	<0.05
R21 A	960322	0.22	5.6 B J	1490	1.8 J	39.5 U	0.83 U	29.4	149	31700 J	<0.05
R21 B 1	960322	0.06 U	1.3 B J	459 B J	0.70 U	34.8 U	0.73 U	12.2	32.8	5470 J	<0.05
R21 B 2	960322	0.05 U	1.2 B J	324 B J	1.3 J	37.8 U	0.79 U	10.6 B J	15.3	4220 J	<0.05
R22 A	960322	0.15	4.2 B J	1070 B J	1.2 J	40.1 U	0.84 U	19.3	105	27600 J	<0.05
R22 B 1	960322	0.14	2.8 B J	1230	1.8 J	37.2 U	0.75 U	24.5	68.3	23600 J	<0.05
R22 B 2	960322	0.09 U	1.8 B J	991 B J	0.75 U	54.3 B J	0.79 U	14.4	29.9	12500 J	<0.05

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
					Residential area 1--Continued						
R23 A	960325	0.25	9.4 B J	985 B J	1.7 J	42.4 U	0.89 U	29.8	330	39200 J	0.05
R23 CL1	960325	0.10 U	3.8 B J	2090	3.6 J	39.3 U	0.90 B J	87.5	250	8300 J	<0.05
R23 CL2	960325	0.09 U	2.2 B J	1680	6.2 J	41.9 U	2.3 B J	210	111	6860 J	<0.05
R23 C	960325	0.07 U	0.98 B J	696 B J	4.1 J	39.1 U	1.2 B J	183	52.0	4240 J	<0.05
R24 A	960325	0.23	6.0 B J	2550	2.4 J	41.9 U	0.88 U	47.8	107	51500 J	0.05
R24 CL1	960325	0.12 J	4.1 B J	3210	2.8 J	42.5 U	0.89 U	60.5	58.6	15300 J	<0.05
R24 CL2	960325	0.14 U	1.9 B J	2820	2.4 J	45.2 U	1.1 B J	63.0	18.6	9140 J	<0.05
					Residential area 2						
R 1 A	960228	0.07 B J	3.2 B J	543 B J	0.51 B J	26.3 U	0.56 U	19.6	29.8 J	7430 J	<0.05
R 1D A	960228	0.07 B J	1.7 B J	837	0.51 B J	30.5 U	0.66 U	14.2	26.9 J	9230 J	<0.05
R 1 B 1	960228	0.08	1.6 B J	400 B J	0.61 U J	39.4 U	0.85 U	12.6	29.0 J	3390 J	<0.05
R 1D B 1	960228	0.05 B J	0.95 B J	1010	0.59 U J	48.2 B J	0.82 U	8.6 B J	14.4 J	1980 J	<0.05
R 1 B 2	960228	0.03 U	1.0 B J	500 B J	0.49 U J	54.5 B J	0.67 U	18.3	10.2 J	3120 J	<0.05
R 1 B 3	960228	0.04 B J	6.7 B J	451 B J	1.4 J	39.3 U	0.84 U	63.3	70.1 J	3480 J	<0.05
R 1D B 3	960228	0.03 B J	2.0 B J	410 B J	1.3 J	44.8 B J	0.92 U	51.5	15.0 J	3230 J	NA
R 2 A	960228	0.31 J	3.3 B J	1590	0.71 U J	46.0 U	0.99 U	26.1	44.9 J	17900 J	<0.05
R 2 B 1	960228	0.10	2.2 B J	796	0.82 J	37.5 B J	0.71 U	23.5	12.9 J	3920 J	<0.05
R 2 B 2	960228	0.03 B J	2.4 B J	1310	0.78 U J	50.4 U	1.1 U	45.6 J	17.2 J	5530 J	<0.05
R 2 CL1	960228	0.05 U	1.7 B J	1770	1.0 J	42.4 U	0.91 U	48.9	13.1 J	4440 J	<0.05
R 2 CL2	960228	0.05 U J	2.4 B J	2240 J	1.9 J	39.5 U	0.83 U	44.1	13.1 J	4820 J	<0.05
R 2 S CL2	960228	0.04 B J	2.9 B J	2590 J	2.2 J	58.3 U	0.98 U	53.2	15.6 J	NA	NA
R 5 A	960304	0.11 J	3.2 B J	1370 J	1.4 J	79.2 U	1.1 U	19.5	27.2 J	22200 J	<0.05
R 5 B 1	960304	0.05 U J	6.6 B J	3820 J	1.7 J	53.3 U	1.1 U	27.7	42.4 J	5340 J	<0.05
R 5 S B 1	960304	0.04 U J	5.7 B J	3400 J	0.70 U J	45.1 U	0.97 U	26.1	37.1 J	NA	NA
R 5 C	960304	0.14 J	2.3 B J	1710 B J	1.2 J	49.6 U	1.1 B J	36.9	15.4 J	NA	NA

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
Residential area 2--Continued											
R 6 A	960304	0.23 J	3.1 B J	916 B J	0.76 U J	49.2 U	1.1 U	18.0	45.7 J	22500 J	NA
R 6 B 1	960304	0.23 J	1.1 B J	329 B J	0.62 U	39.6 U	0.85 U	9.4 J	17.6 J	15400 J	<0.05
R 6 B 2	960304	0.10 J	0.53 B J	411 B J	0.54 U	51.3 U	0.75 U	5.1 B J	11.0 J	7780 J	<0.05
R 6 B 3	960304	0.04 B J	0.80 B J	53.1B J	0.73 B J	35.2 U	0.76 U	6.5 B J	8.0 J	3490 J	NA
R 6 C	960304	0.03 U J	0.31 U	16.5B J	0.65 U	41.7 U	0.90 U	0.70BJ	4.2 J	792 J	<0.05
R 7 A	960304	0.21 J	2.9 B J	1120	1.1 B J	47.6 U	1.0 U	28.2 J	41.3 J	18700 J	<0.05
R 7 E	960304	0.24 J	5.0 B J	1440	2.0 J	31.5 U	0.68 U	90.0 J	105 J	12700 J	NA
R 7 B 2	950304	0.06 B J	3.1 B J	1110	0.99 J	44.5 U	0.93 U	39.2 J	27.4 J	4230 J	<0.05
R 8 A	960305	0.08 J	3.3 B J	1150	1.1 B J	48.5 U	1.0 U	51.7 J	36.2 J	14100 J	<0.05
R 8 B 1	960305	0.03 B J	2.8 B J	1790	1.0 J	44.3 U	0.95 U	43.5 J	19.9 J	5480 J	<0.05
R 8 B 2	960305	0.04 U J	2.8 B J	2900	1.8 J	35.2 U	0.76 U	61.3 J	23.7 J	3900 J	<0.05
R 8 CL1	960305	0.06 U J	1.8 B J	1930	1.2 J	51.2 U	1.1 U	36.9 J	15.6 J	NA	NA
R 8 CL2	960305	0.12	2.1 B J	2380	0.88 U	56.3 U	1.2 U	42.0 J	15.4 J	6410 J	<0.05
R 9 A	960305	0.18	5.0 B J	851 B J	1.4 J	75.2 U	1.0 U	69.2 J	54.8 J	15800 J	<0.05
R 9 B 1	960305	0.13	1.6 B J	610 B J	0.53 U	40.5 U	0.73 U	20.8 J	21.6 J	6000 J	<0.05
R 9 B 2	960305	0.06 B J	1.6 B J	415 B J	0.93 B J	46.3 U	0.99 U	29.1 J	15.4 J	3680 J	<0.05
R 9 CL1	960305	0.04 U	2.3 B	1000	0.64 U	41.1 U	0.88 U	41.1	21.7	3760 J	NA
R 9 CL2	960305	0.04 B J	6.8 B J	2130	0.77 U	62.7 U	1.1 U	55.9 J	65.4 J	4200 J	<0.05
R10 A	960305	0.10 J	2.7 B J	1550 J	1.3 J	49.9 U	0.98 U	34.0	38.4 J	11600 J	<0.05
R10 B 1	960305	0.06 B J	3.0 B J	1980 J	2.0 J	51.0 U	1.1 U	67.9	36.5 J	4520 J	<0.05
R10 CL1	960305	0.05 U J	2.2 B J	1790 J	1.6 J	54.8 U	1.2 U	107	20.6 J	3580 J	<0.05
R10 CL2	960305	0.06 U J	1.8 B J	1560 J	1.4 J	41.7 U	0.90 U	64.5	18.7 J	4190 J	<0.05
R10 C	960305	0.04 U J	0.83 B J	858 J	1.3 J	36.1 B	0.73 U	20.5	6.9 J	NA	NA
R11 A	960311	0.05 U	1.2 B J	851 B J	1.2 J	48.4 U	1.0 U	24.6	7.8 J	8320 J	<0.05
R11 B 1	960311	0.04 U	1.7 B J	537 B J	0.61 U J	39.4 U	0.85 U	25.4	9.5 J	4940 J	<0.05

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
Residential area 2--Continued											
R11 CL1	960311	0.08 B J	0.59 B J	1020 B J	1.1 J	46.5 U	1.00 U	31.3	4.9 J	2910 J	<0.05
R11 CL2	960311	0.05 B J	0.71 B J	1030	0.57 U J	36.4 U	0.78 U	14.5	3.4 J	5230 J	<0.05
R11 C	960311	0.03 U	0.31 U	66.2B J	0.66 U J	42.6 U	0.92 U	9.1 B J	0.60BJ	NA	NA
R12 A	960311	0.23	2.2 B J	1360	0.69 U J	44.7 U	0.96 U	29.1	30.8 J	13500 J	NA
R12 B 1	960311	0.15	2.1 B J	924 J	0.57 U J	36.8 U	0.79 U	19.5	28.1 J	7350 J	NA
R12 B 2	960311	0.03 U	2.1 B J	1570	1.3 J	34.2 U	0.74 U	37.9	22.5 J	3030 J	<0.05
R12 CL1	960311	0.04 U	4.0 B J	2170	1.4 J	39.7 U	0.85 U	61.4	37.4 J	3470 J	NA
R13 A	960312	0.12	2.3 B J	1410	1.1 B J	50.6 U	1.1 U	14.3	39.6 J	16400 J	NA
R13 B 1	960312	0.14	1.7 B J	959	0.74 J	29.1 U	0.63 U	11.8	33.6 J	11500 J	<0.05
R13D B 1	960312	0.10	1.6 B J	790	0.50 B J	31.2 U	0.67 U	13.4	26.2 J	7630 J	<0.05
R13 B 2	960312	0.04 U	1.5 B J	353 B J	1.0 B J	47.0 U	1.0 U	13.5	16.1 J	11500	<0.05
R13D B 2	960312	0.04 U	2.9 B J	637 B J	0.65 B J	36.5 U	0.78 U	25.6	17.4 J	3510	<0.05
R13 B 3	960312	0.04 U	1.5 B J	1050	1.1 J	41.8 U	0.90 U	29.7	12.6 J	2360	<0.05
R14 A	960312	0.09 B J	1.7 B J	749 B J	0.85 B J	45.9 U	0.99 U	12.6	35.9 J	22400 J	<0.05
R14 B 1	960312	0.04 U	1.7 B J	439 B J	0.67 U J	43.2 U	0.93 U	14.6	12.1 J	5590 J	<0.05
R14 B 2	960312	0.04 U	2.1 B J	1260 J	0.95 B J	47.0 U	1.0 U	37.3	13.5 J	2430 J	<0.05
R15 A	960313	0.24	2.0 B J	1270	0.75 U J	48.4 U	1.0 U	13.3	42.6 J	12500 J	<0.05
R15D A	960313	0.23	2.8 B J	1880 J	1.0 B J	67.0 U	0.77 U	16.6 J	41.3 J	NA	<0.05
R15 B 1	960313	0.12	4.4 B J	627 J	1.0 J	26.5 U	0.57 U	50.8	34.9 J	3640 J	<0.05
R15D B 1	960313	0.07	1.4 B J	705 B J	0.97 B J	41.3 U	0.74 U	15.0 J	11.9 J	NA	<0.05
R15 CL1	960313	0.04 U	2.5 B J	2140 J	3.9 J	39.6 U	1.7 B J	50.2 J	29.4 J	5170 J	<0.05
R15D CL1	960313	0.06 B J	2.1 B J	2040 J	2.0 J	40.3 U	0.81 U	40.0 J	17.3 J	NA	<0.05
R15 CL2	960313	0.05 U	2.4 B J	2890 J	1.9 J	44.5 U	0.90 U	53.0 J	14.9 J	5870 J	<0.05
R15D CL2	960313	0.04 U	2.0 B J	1100 J	1.2 J	37.5 U	0.95 B J	32.2 J	12.9 J	NA	<0.05
R16 A	960313	0.10	2.1 B J	2150 J	1.1 B J	42.1 U	0.80 U	15.9 J	32.9 J	15400 J	<0.05
R16 B 1	960313	0.03 U	4.2 B J	1530 J	2.2 J	36.9 U	0.77 U	45.5 J	30.3 J	3140 J	<0.05

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
Residential area 2--Continued											
R16 CL1	960313	0.05 U	1.8 B J	2690 J	2.7 J	45.4 U	1.5 B J	55.2 J	16.6 J	5730 J	<0.05
R16 CL2	960313	0.05 U	2.6 B J	3590 J	2.1 J	50.0 U	1.3 B J	72.0 J	20.2 J	7020 J	<0.05
R17 A	960318	0.14	2.6 B J	1930 J	1.5 J	53.6 U	0.85 U	22.3 J	30.1 J	24200 J	NA
R17 B 1	960318	0.05 U	2.4 B J	1540 J	3.1 J	37.6 U	1.4 B J	73.9 J	23.3 J	4350 J	<0.05
R17 B 2	960318	0.04 B J	1.8 B J	1080 J	1.5 J	48.4 U	0.74 U	27.2 J	12.4 J	2330 J	<0.05
R18 A	960318	0.12	3.0 B J	2960 J	0.83 U J	88.2 U	0.87 U	17.9 J	30.3 J	13800 J	<0.05
R18 B 1	960318	0.04 U	2.3 B J	938 B J	1.3 J	53.9 U	0.77 U	22.2 J	12.4 J	3580 J	<0.05
R18 B 2	960318	0.03 U	1.2 B J	1600 J	1.2 J	61.2 U	0.82 U	35.9 J	8.8 J	2320 J	<0.05
R18 C	960318	0.03 U	1.3 B J	1450 J	1.2 J	35.8 U	1.00 B J	42.3 J	14.1 J	NA	NA
R18 CL1	960318	0.04 B	1.6 B J	2210 J	1.6 J	84.1 U	1.1 B J	60.7 J	10.9 J	6100 J	NA
R18 CL2	960318	0.05 U	3.8 B J	2050 J	2.7 J	78.5 U	1.3 B J	62.1 J	25.8 J	5410 J	<0.05
R20 A	960322	0.12	2.6 B J	2270	1.7 J	40.8 U	0.85 U	14.5	38.6	27300 J	<0.05
R20 B 1	960322	0.13	2.5 B J	2210	1.3 J	38.4 U	0.80 U	16.4	30.4	10900 J	<0.05
R20 B 2	960322	0.05 B J	2.5 B J	3180	0.76 B J	35.3 U	0.74 U	10.1 B J	15.3	5970 J	<0.05
R20 B 3	960322	0.05 U	1.2 B J	537 B J	0.73 U	36.3 U	0.76 U	6.5 B J	6.8	3110 J	<0.05
R27 A	960424	0.22 J	3.4 B J	1270 J	1.3 U	171 U	1.9 B J	42.5 J	35.6 J	26700 J	<0.05
R27 B 1	960424	0.10 B J	1.2 B J	1850 J	1.2 U	163 U	2.7	92.6 J	17.9 J	5210 J	<0.05
R27 C	960424	0.10 B J	0.28 U	927 B	1.3 U	166 U	2.0 B J	120 J	10.1 J	3360 J	NA
R27 CL1	960424	0.11 B J	2.2 B J	2380	1.4 U	182 U	1.6 B J	31.3 J	12.1 J	6770 J	<0.05
R27 CL2	960424	0.11 B J	2.2 B J	2060 J	1.3 U	172 U	2.1 B J	95.2 J	16.3 J	6140 J	<0.05

Table 5. Concentrations of constituents measured in soil samples from residential areas 1 and 2 and the broader area, Marlboro Township, Monmouth County, New Jersey--Continued

Sample number[1]	Sample date	Mercury	Nickel	Potassium	Selenium	Sodium	Thallium	Vanadium	Zinc	Total organic carbon	Total sulfur (percent)
					Broader area						
B 1 A	960417	0.14	5.7 B	1810	1.2 U	76.3 B	1.3 B	39.6	60.0	19800 J	<0.05
B 1 A2	960417	0.06 U	4.2 B	1730	1.2 U	77.1 B	0.90 U	54.5	48.2	16400 J	0.06
B 1 CL1	960417	0.06 U	2.7 B	1480	1.2 U	110 B	0.94 U	46.8	25.2	15800 J	0.13
B 1 B 1	960417	0.64	8.5 B	3150	1.2 U	77.3 B	0.92 U	45.0	57.1	16800 J	0.06
B 1 CL2	960417	0.25	14.7	3340	1.2 U	90.5 B	0.95 U	52.4	83.0	16700 J	0.05
B 2 A	960424	0.12 J	6.2 B J	1600 J	1.2 U	155 U	0.91 U	29.2 J	66.7 J	28200 J	0.05
B 2 B 1	960424	0.19 J	3.1 B J	1110 J	1.1 U	148 U	1.3 B J	26.0 J	29.2 J	5500 J	<0.05
B 2 CL1	960424	0.12 J	3.2 B J	2590	1.3 J	160 U	1.9 B J	38.9 J	23.9 J	5790 J	NA
B 2 CL2	960424	0.06 U	5.6 B J	1980	2.3 J	156 U	1.4 B J	44.6 J	37.7 J	4800 J	<0.05

Table 6. Field pH measurements, A- and (or) E-horizon soils, Monmouth and Middlesex Counties, New Jersey

Site number	pH (units)	Site number	pH (units)
E1	5.8	O1	5.6
E2	5.8	O2	6.3
E4	6.0	O3	6.2
E5	6.1	O4	6.0
E6	6.2	O5	6.4
E7	5.9	O6	5.8
E9	6.0	O8	5.4
E12	5.2	O15	5.4
E15	6.2		
E16	6.0		
E17	5.0		

Field Data--Soil Logs

During soil sampling, soil-horizon samples initially were identified by the nomenclature used in the U.S. Department of Agriculture soil surveys for Middlesex and Monmouth Counties. For example, a sample collected at site E2, in the B_w horizon would be identified as sample E2Bw. A few samples collected in disturbed soils at the Imperial Oil Company Superfund site were designated as fill (for example 17F1, 17F2), in that A-, B-, and C-horizon soils and clays were not found in order of natural occurrence. Samples that represented a resampling of some areas as a result of unforeseen difficulties in securing timely analytical services were marked R, as in E4RO.

When the chemical data set was prepared for statistical analysis, this system of sample identification was found to be overly complicated and cumbersome, and samples of similar characteristics could not be compared easily. Therefore, sample identifications were changed to be consistent from one set of samples to another. All samples of disturbed soils that could readily be identified as belonging to A, B, or C horizons were renamed, regardless of order of occurrence in the soil profile. All samples of bleached soils below the A horizon were designated as E horizon. All B-horizon samples that were collected consecutively at increasing depths in the soil profile were numbered B1, B2, B3, and so on. Additionally, one set of samples was inadvertently designated as E18, indicating an Englishtown Formation substrate, rather than a "W" designation, indicating a Woodbury Formation substrate. This set of samples also was renumbered. Split samples, originally numbered with a 9, were identified with an S following the site number and horizon designation; similarly, spatial replicates were identified with a D instead of "Dup." The R was deleted from samples representing a resampling event.

The soil logs include the estimated depths from which the individual samples were collected. These depths are estimated from the soil logs noted from the auger samples; depths cannot be measured accurately from the cores because of compaction during the coring process.

The sample numbers given in appendix 1, tables 1 to 5, represent the renumbered sample identifications used in the statistical analyses. Table 7 gives the original field-sample designations and the renumbered sample identifications so that samples indicated on the following soil logs can be compared with the samples listed in the tables of chemical data.

Table 7. Conversion of field-sample designations to renumbered statistical-analysis sample identifications, soil samples collected 1995-96, Imperial Oil Company Superfund site study area, New Jersey

[FSD, field-sample designation; SASI, statistical-analysis sample identification]

Geologic samples		Orchard samples		Imperial Oil Company Superfund site samples		Adjacent woods samples		Residential-area samples	
FSD	SASI	FSD	SASI	FSD	SASI	FSD	SASI	FSD	SASI
E1OD	E1DO	O1BWS	O15B1	I1W	I1C1	S1OD	S1DSO	R92CL2	R2SCL2
E1BC	E1B2	O1BWD	O1SB2	I1X	I1CL2	S91O	S1DO	R3DA	R3DCL1
E20D	E2O	O1RA	O1A	I1Y	I1CL3	S91OD	S1DDO	R3A	R3CL1
E2ODD	E2SO	O1BWS	O1B1	I1Z	I1CL4	S1D	S1DDO2	R4A	R4B1
E4RO	E4O	O1BWD	O1B2	I3B	I3B1	S9DUP	S9SO	R5B	R5B1
E4RA	E4A	O2RO	O2O	I4B	I4B1	S9OD	S9DO	R95B	R5SB1
E4RE	E4E	O2RE	ORE	I4B1/2	I4B2	S10	S10O	R6BC	R6B3
E4RBH	E4B1	O2RB1	O2B1	I4CLA	I4CL1	S10O	S10SO	R7A2	R7E
E4RBC	E4B2	O2RC	O2B2	I5SA	I5A	S1C2	S10C	R10B	R10B1
E4RC	E4C	O3RA	O3A	I5S	I5CL1	S11RA	S11A	R12E	R12A
E5RE	E5E	O3FBW1	O3B1	I6D	I6C2	S11RE	S11E	R13B1D	R13DB1
E5RB1	E5B1	O3RBW2	O3B2	I6SA	I6B1	S11RB1	S11B1	R13B2U	R13B2
E5RB2	E5B2	O4ODUP	O4DO	I6C	I6C1	S11RC	S11C	R13B2OD	R13DB2
E5RC	E5C	O4ADUP	O4DA	I7F	I7A	S12RA	S12A	R13B2L	R13B3
E6RA	E6A	ORBW	O4B2	I7F2	I7C1	S12RAD	S12SA	R23S	R2BC
E6RE	E6E	O4BWD	O4DB2	I7F3	I7B1	S12RE	S12E	R27B	R27B1
E6RB	E6B1	O4B2D	O4DB3	I7C	I7C2	S12RBW	S12B1	OB1LA	B1A
E6RC	E6CL1	O5BW1	O5B1	I8BC	I8B1	S12RC	S12C	OB1A	B1A2
E7RE	E7E	O5BW2	O5B2	I8C	I8C1	S13RA	S13A	OB1CL1	B1CL1
E7RB1	E7B1	O5BW2/C	O5C	I8G	I8C2	S13RB	S13B1	OB1B	B1B1
E7RB2	E7B2	06DUPA	O6DA			S13RC1	S1BC	OB1CL22	B1CL2
E9RO	E9O	O6E/B	O6E			S14RO	S14O	OB2B	B2B1
E9RA	E9A	O6DUPB	O6DE			S14RA	S14A	OB2A	B2A
E9RB1	E9B1	O6BW	O6B1			S14RB	S14B1	OB2CL1	B2CL1
E9RCB	E9B2	O6DBW	O6DB1			S15RA	S15A	OB2CL2	B2CL2
E9RC	E9C					S15RB1	S15B1		
E12OD	E12DO					S15RB2	S15B2		
E12AD	E12DA					S16B	S16B1		
E12ED	E12DE					S16CL	S16CL1		
E12B1D	E12DB1					S19B	S19B1		

Table 7. Conversion of field-sample designations to renumbered statistical-analysis sample identifications, soil samples collected 1995-96, Imperial Oil Company Superfund site study area, New Jersey--Continued

Geologic samples, continued	
FSD	SASI
E13RMA	E13O
E13B22	E13CL
E14B1D	E14DB1
E15B	E15B1
W1014	W1CL1
W12025	W1C2
W12529	W1CL3
W12934	W1CL4
E18A	W3A
E18B1	W3B1
E18B2	W3BC
E18B3	W3B
E18CL1	W3CL1

In the soil description on the soil-sampling field sheets that follow, descriptions of color use standard notations from the Munsell color chart (for example, 10 YR4/3). "Below land surface" commonly is abbreviated BLS. Personnel initials refer to the following: TDO or TO, Timothy Oden; NPS or NS, Nicholas Smith; RR, Robert Rosman; ZS, Zoltan Szabo; JLB, Julia Barringer; VdP, Vincent dePaul; GCS, Gregory Steckroat; EV, Eric Vowinkel (all of the U.S. Geological Survey). SB, JE, DS, and JS refer to Steven Byrnes, John Evenson, David Springer, and Jerry Schoenlever, respectively, of the New Jersey Department of Environmental Protection (NJDEP). Chad VanSciver also is NJDEP personnel; Peter Sugarman is New Jersey Geological Survey personnel. Corrections to spelling and grammar have not been made.

Site number: E1 Date: 11/30/95
Personnel: T. Oden R.Rosman
Location: Behind house in woods
Soil series: Lakehurst (LaA)

Time (auger):
Quadrangle: South Amboy
Weather: Sunny & cold (40's) snow on ground
Sampler: corer

Time (core): 1430
Formation: Englishtown
Hole Depth: 4 ft

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	black, roots, organic mat	organic mat	0-2"
A	brownish gray	sandy	2-9"
E	light gray, yellowish	sandy	9-14"
Bh	brownish to orange	sand, some clay	14-18"
Bw	brownish orange	sand, some clay	18-21"
BC	paler brownish orange	pebbles	21-27"
C	pale yellow	clay	27-35"

COMMENTS

Cored to 4 ft.
Soil augered and logged 11/8/95 - JLB's field notes
Samples B1 correspond to the Bw, pebbles appear at the bottom of Bw.

Samples:	E1O	E1OD	E1A	E1B1	E1BC	E1E	Date bottled: 12/6/95
Depths:	0-2"	0-2"	2-9"	14-18"	24-30"	9-14"	
Comments:	E1BC-TOC, metals, sulfur; E1E-metals only.						

Site number: E2 Date: 12/1/95
Personnel: Oden, Rosman
Location: In woods ~100 ft from E1
Soil series: LoA

Time (auger):
Quadrangle: South Amboy
Sampler: corer

Time (core): 1140
Formation: Englishtown
Weather: Partly cloudy, 40
Hole Depth: 36"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	grey	sandy, root hairs	0-8"
E	pale tan	sandy	same as E1
Bh	orangy yellowish brown	sandy; pebbles at about 22"	same as E1
BC	orangy yellowish brown	much more clay compared w/ layer above pebbles	28-?"

COMMENTS

pulled large pebbles out - layer several inches thick
Bh horizon is equivalent to sample B1.
Soil augered and logged 11/8/95 - JLB's field notes

Samples:	E2OD	2ODD	E2A	E2B1	E2BC	Date bottled: 12/6/95
Depths:	0-1"		1-8"	9-14"	28-35"	
Comments:	E2BC, metals and Sulfur (not TOC)					

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: E4
Date: 12/12/95
Time (auger): 1020
Time (core): 1050
Personnel: Z. Szabo, J. Barringer, V. dePaul, N. Smith, P. Sugarman
Formation: Englishtown
Location: Marlboro Rd., top of hill w/ side of road
Quadrangle: Freehold
Weather: Clear, cold, mid-20's
Soil series: Lakewood
Sampler:
Hole Depth: 4 ft

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	10 YR 3/1 v. dark gray	roots	0-1"
A	10 YR 4/1 dark gray	fine sand	1-5"
E	10 YR 5/2 grayish brown	medium sand	5-13"
Bh	7.5 YR 4/6 strong brown	medium sand	13-16"
BC	10 YR 5/6 yellowish brown	fine to medium sand	15-31"
	10 YR 6/6 brownish yellow		24-31"
C	10 YR 7/6 yellow	fine sands, well-sorted	31-37"
	10 YR 8/6 yellow	fine sands, well-sorted	37-42"
	10 YR 7/6 yellow	fine sands, well-sorted	42-45"

COMMENTS

Refusal of corer twice C2' starter 3rd hole OK
top liner will contain triple A horizon

Samples:	Date bottled:
Depths:	
Comments:	

Site number: E4-Repeat
Date: 2/6/96
Time (auger):
Time (core): 0940
Personnel: RR, NPS, TO, EV, ZS, JB
Quadrangle: Freehold
Formation: Englishtown
Location:
Weather: Cold (teens), sunny
Soil series:
Sampler: corer
Hole Depth: 48" BLS

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E4	

COMMENTS

"O" horizon sample bagged.

Samples:	E4RO	E4RA	E4RE	E4RBH	Date bottled: 2/9/96
Depths:	0-1"	1-5"	5-12"	13-16"	
Comments:					

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

Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: E5 Date: 12/12/95
Personnel: Z.Szabo, N.Smith, J.Barringer, V.dePaul
Location: near 1st stream below top of hill
Soil series: Lakehurst/Keyport/Klej

Time (auger): 1100
Quadrangle: Freehold
Weather: very cold, breezy clear, mid-20's
Sampler:

Time (core): 1125
Formation: Englishtown
Hole Depth: 4 ft

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	7.5 YR 3/3 dark brown		0-1.5"
A	5 YR 3/1 very dark gray	medium sand	1.5-4.5"
B(1)	7.5 YR 6/8 reddish yellow	medium sand; picking up silt @ 16", lighter @ 43"	4.5-48"
B	7.5 YR 7/4 pink	mottled yellow/pink	48-50"
C	10 YR 7/4 very pale brown	medium	50-61"

COMMENTS

Probably Klej; although it isn't mapped

Samples:	Date bottled:
Depths:	
Comments:	

Site number: E5-Repeat Date: 2/6/96
Personnel: RR, NPS, TO, ZS
Location:
Soil series: Lakehurst? or Klej?

Time (auger):
Quadrangle: Freehold
Sampler: corer

Time (core): 1027
Formation: Englishtown
Weather: cold (teens), sunny
Hole Depth: 49" BLS

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		same as E5	

COMMENTS

"O" horizon sample bagged; "C" horizon has virtually no mineral soil, all organic debris. A horizon is too small to subsample. There is what appears to me to be an E horizon in E5R. This looks more like Lakewood to me, or Lakehurst as it is a bit downslope.

Samples:	E5RE	E5RB1	E5RB2	E5RC	Date bottled: 12/13/96
Depths:	2-5"	5-12"	36-42"	48-49"	
Comments:E5RB2, from top of 3rd liner at 23"; E5RC, at very bottom of 3rd liner					

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: E6 Date: 12/12/95 Time (auger): 1430 Time (core): 1440
Personnel: N.Smith, V.dePaul, Z.Szabo Quadrangle: Formation: Englishtown
Location: Weather:
Soil series: Keyport Sampler: corer Hole Depth: 26"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	10 YR 3/2 very dark grayish brown	roots	0-1"
A	10 YR 3/2 very dark grayish brown	sand, med	1-4"
E or B1	10 YR 4/4 dark yellowish brown	sand, med; getting darker slowly below 5"	4-9"
B2	10 YR 5/6 yellowish brown	sand, med; becomes silty 15-22", mostly silt, then at 22" becomes wet fine sand	9-26.5"
Clay	10 YR 6/1 light gray	massive clay; mottled w 10 YR 5/6 clay	26.5-31"

COMMENTS

Clay - geologic material, basal Englishtown

Samples:	Date bottled:
Depths:	
Comments:	

Site number: E6-Repeat Date: 2/6/96 Time (auger): Time (core): 1155
Personnel: RR, NPS, TO, ZS Quadrangle: Formation:
Location: Weather: cold (~20), sunny
Soil series: Keyport Sampler: corer Hole Depth: 25"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E6	

COMMENTS

"O" horizon sample bagged. This is mostly root mat & leaf debris - not a real O2

Samples:	E6RA	E6RED	E6RB	E6RC	Date bottled: 2/12/96
Depths:	1-4"	4-9"	10-16"	25"+	

Comments: E6RC from 25" quite clayey - rename E6CL

Site number: E6-Clay
Date: 2/27/96
Time (auger):
Time (core): 1347
Personnel: T.Oden, R.Rosman
Quadrangle:
Formation: Englishtown
Location:
Weather: Sunny, warm-upper 50's-60
Soil series:
Sampler: split spoon
Hole Depth: 50"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E6	

COMMENTS

Augered to 26" then 2 ft split spoon 26-50"

Samples: E6C	Date bottled: 8/4/96
Depths: 40-50"	
Comments: silty, rather dark brown layer. This is adjacent to original E6 but did not hit the clay lens present at E6.	

Site number: E7
Date: 12/12/95
Time (auger): 1500
Time (core):
Personnel: Z.Szabo, N.Smith, V.dePaul
Quadrangle:
Formation:
Location: Highest hill on E side after coming off hill, adjacent to large water seep
Weather: clear, cold, mid-20's
Soil series: Lakewood
Sampler: corer
Hole Depth: 50"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O		roots, dense tangle	0-2"
A	10 YR 5/3 brown	sand, med very organic	2-4"
E1	5 YR 6/1 gray	sand, med and fine	4-5"
E2	5 YR 5/3 reddish brown	sand fine	5-6"
B1	10 YR 6/6 brownish yellow	silty sand, med to fine; grades to very wet silty sand at 8"	6-31"
B2	10 YR 5/8 yellowish brown	silty sand, wet blocky	31-35"
C1	10 YR 5/4 yellowish brown	sand, fine to med	35-41"
C2	10 YR 4/4 dark yellowish brown	sand, fine wet	41-45"
C3	10 YR 4/2 dark yellowish brown	silt, sand wet mottled with 10 YR 6/6	45-52"

COMMENTS

Samples:	Date bottled:
Depths:	
Comments:	

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: E7-Duplicate
Date: 12/15/95
Time (auger):
Time (core): 1510
Personnel: V.dePaul, N.Smith
Quadrangle:
Formation:
Location:
Weather: cloudy, cold, 30's
Soil series: Lakewood
Sampler: corer
Hole Depth: 38"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E7	

COMMENTS

Pounded sampler 12", augered to 15"--stuck!! Huge rocks; could not remove, even by hand, moved over 1', augered to 21" (more huge rocks), pounded to 36" (top of sampler flush with ground); actual hole depth measured at 38".

Samples:	Date bottled:
Depths:	
Comments:	

Site number: E7-Repeat
Date: 2/6/96
Time (auger):
Time (core): 1120
Personnel: ZS, NPS
Quadrangle:
Formation:
Location:
Weather:
Soil series: Lakewood
Sampler: corer
Hole Depth: 36"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E7	

COMMENTS

Drove sampler to 15", augered out ~4" soil, then drove from ~19" to 36"; "O" horizon sample bagged
No real humic layer; "O" is only organic ---little mineral horizon ....
Virtually no A was retrieved - not enough for a sample.

Samples:	E7RE	E7RB1	E7RB2	Date bottled: 2/13/96
Depths:	4-6"	7-14"	35-36"	
Comments: E7RB2, from bottom of 3rd liner @ ~36" silty sand				

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: E8
Date: 12/13/95
Time (auger): 1145
Time (core):
Personnel: JLB, VdP, NPS, ZS
Quadrangle: South Amboy
Formation: Englishtown
Location: Farm in woods next to ditch east of housing development
Weather: Overcast, cold
Soil series: Atsion
Sampler: corer
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O		organic	0-1”
A	5 YR 3/2 dark brown	sandy, organic; 8-10” wettish	1-8”

COMMENTS

Refusal of auger @ 8” - too many roots. Start second auger hole. Same refusal. Abandoned hole.

Samples: No sample collected.
Date bottled:
Depths:
Comments:

Site number: E9
Date: 12/13/95
Time (auger): 1200
Time (core): 1428
Personnel: JLB, ZS, NS, VdP
Quadrangle: South Amboy
Formation: Englishtown
Location: Farm, woods, south of fields
Weather: cloudy, cold, mid- to hi-20’s
Soil series: Keyport
Sampler: corer
Hole Depth: 36”

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	blackish	organic	0-1.5”
A	10 YR 4/2 gray/brown	sandy loam to loam	1.5-13”
B1	10 YR 5/4 yellowish brown	sandy loam; becomes slightly clayey with depth	13-24”
BC?	10 YR 6/4 pale yellowish brown	sandy, some clay	24-28”
BC?	10 YR 5/6	faint mottle at 36”	28-38”
C	10 YR 6/3 grayer	clayeyer, moister	38-41”

COMMENTS

Remove frozen O horizon with trowel and bagged.
Remove A to 6” with trowel and bagged.

Samples:
Date bottled:
Depths:
Comments:

Site number: E9-Repeat
Date: 2/6/96
Time (auger):
Time (core): 1338
Personnel: RR, NPS
Quadrangle: South Amboy
Formation: Englishtown
Location:
Weather: Cold (20's), sunny
Soil series: Keyport
Sampler: Corer
Hole Depth: 36"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E9	

COMMENTS

"O" horizon sample bagged. Some pebbles beneath or within BC - yellowish brown.
Horizon E9RB1 taken above pebbles.

Samples:	E9Ro	E9RA	E9RB1	E9RBC	E9RC	Date bottled: 2/12/96
Depths:	0-1"	2-12"	13-23"	30-35"	38-41"	
Comments:						

Site number: E10
Date: 12/15/95
Time (auger): 1152
Time (core):
Personnel: Z.Szabo, V.dePaul, N.Smith
Quadrangle:
Formation: Englishtown
Location: woods east of orchard, Ticetown Road
Weather: cloudy, cold (30's)
Soil series: Atsion
Sampler:
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
01	10 YR 2/2	roots	0-4"
02		peaty	4-8"
	10 YR 5/2 grayish brown		8-12"
	10 YR 5/1 gray		12-18"
	10 YR 4/3 brown		18-23"

COMMENTS

Not sampled

Samples:	Date bottled:
Depths:	
Comments:	

Site number: E11
Date: 1/30/96
Time (auger): 1316
Time (core): 1340
Personnel: JLB, RR, NPS
Quadrangle: South Amboy
Formation: Englishtown
Location: woods east of orchard on east side of Higgins Rd.
Weather: cloudy, cool - low 40's
Soil series: Keyport
Sampler: corer
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10 YR 4/4 dark yellowish grayish brown	sandy	0-1.5"
B1	10 YR 5/6 brownish yellowish orange	sandy, some clay; cobbles!	1.5-19"
B2	10 YR 5/6 yellowish orangey brown	clayeyer with depth; grades into clayeyer soil	19-28"
B3	10 YR 5/4 yellowish brown and orange	clayey sand; mottled gray brown & orangey yellow brown	28-35"
	10 YR 7/3 pale yellowish brown	clay; mottles - grades into sandier soil @ 38"	35-40"
	greyish yellow brown	sandy; grades into darker brown sand	40-47"

COMMENTS

Drove to ~4' with sampler, pulled up no sample!! Drove to 3', no sample!!

Samples:	Date bottled:
Depths:	
Comments:	

Site number:E11-Clay
Date: 2/27/96
Time (auger):
Time (core): 1045
Personnel: T.Oden, R.Rosman
Quadrangle: South Amboy
Formation: Englishtown
Location:
Weather: Partly sunny, 50's
Soil series:
Sampler: corer + split spoon
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E11	

COMMENTS

Top 2 ft 2 coreliners with 3' spoon
bottom 2 ft with 1 liner in 2 ft split spoon

Samples:	E11A	E11B1	E11B2	E11CL1	E11CL2	Date bottled: 3/11/96
Depths:	0-2"	2-10"	25-28"	35-40"	42-46"	
Comments: E11CL1-clayey, silty lens orangey brown; E11CL2-clayey silty-bottom of clay lens						

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

Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: E12 Date: 1/31/96
Personnel: JLB, RR, NS
Location: Wilson Road in woods across from 06, 08
Soil series: Elkton
Time (auger): 1144
Quadrangle: Keyport
Sampler: corer
Time (core): 1155
Formation: Englishtown
Weather: Cold, 30 or colder, snowing
Hole Depth: 36"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	black	organic, some sand	0-2"
A	dark brown 10 YR 3/2	sandy	2-6"
E	yellowish 10 YR 5/4	sandy	6-14"
E or B1	gray 10 YR 3/3	sandy; getting wetter with depth	14-30"
B	lighter yellow 10 YR 6/4	sandy; water at ~30"	30-36"

COMMENTS

Pen won't write. Hit water at ~30".

Samples:	E12O	E12A	E12E	E12B1	Date bottled: 2/5/96
Depths:	0-2"	2-6"	6-12"	14-20"	
Comments:					

Site number: E12-Dup Date: 1/31/96
Personnel: JLB, RR, NS
Location: Wilson Rd., woods, across from 06, 08
Soil series: Elkton
Time (auger):
Quadrangle: Keyport
Sampler: corer
Time (core): 1200
Formation: Englishtown
Weather: Cold, snowing
Hole Depth: 36"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E12	

COMMENTS

Snow blowing hard. Pen won't write, even under cover. This field sheet written in office 2/1/96.

Samples:	E12O-Dup	E12A-Dup	E12B1-Dup	Date bottled: 2/5/96
Depths:	0-2"	2-6"	14-20"	
Comments: E12E-Dup not sampled.				

Site number: E13
Date: 2/1/96
Time (auger): 1050
Time (core): 1110
Personnel: RR, NPS
Quadrangle: South Amboy
Formation: Englishtown
Location: Edge of woods, E of Cottrell Rd.
Weather: cold (20’s), mostly sunny
Soil series: Keyport
Sampler: corer
Hole Depth: 15”

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10 YR 4/3 dark brown	sandy loam	0.5-10”
A	10 YR 2/2 very dark brown	sandy loam	10-15”
B21	10 YR 5/4 yellowish brown	silty sand	15-20”
B22	10 YR 5/8 yellowish brown	clayey; mottled with 10 YR 5/1 gray clay from ~25-28”	20-28”

COMMENTS

Sampled after removing 0.5” frozen soil, drove to 15” to avoid clay and silt; recovered less than 1 ft in sampler.
Downgradient from and next to old orchard, probably received runoff--reclassify as orchard? Can’t tell which category is appropriate

Samples:	E13RM/A	E13A	E13B22	Date bottled: 2/5/96
Depths:	0-2”	2-10”	20-28”	

Comments: Sampled rootmat and upper A (E13RM/A); E13B22 very clayey.

Site number: E14
Date: 2/12/96
Time (auger): 1038
Time (core): 1100
Personnel: RR, NPS
Quadrangle: Keyport
Formation:
Location: 180 ft from edge of Texas Rd.
Weather: Cold (20’s), sunny breezy
Soil series: Keyport
Sampler: corer
Hole Depth: 48”

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	7.5 YR 3/3 dark brown	coarse organic; pine needles, organic matter, root mats	0-3”
A	10 YR 5/3 brown	medium sand - fine sand; some cobbles	3-8”
B1	10 YR 5/6 yellowish brown	medium sand - fine sand; some roots, cobbles, somewhat silty 27”	8-36”
B2	10 YR 4/3 brown	medium sand	36-48”
C	10 YR 6/3 pale brown	medium sand, silty; mottled with 10 YR 4/3 brown	48-54”

COMMENTS

“O” sample bagged @ 1038

Samples:	E14A*	E14B1	E14B2	Date bottled: 2/20/96
Depths:	3-8”	8-16”	36-42”	

Comments: * only TOC and metals

Site number: E14-Duplicate Date: 2/12/96
Personnel: RR, NPS
Location: 180 ft from edge of Texas Rd.
Soil series:

Time (auger):
Quadrangle: Keyport
Sampler: corer

Time (core): 1107
Formation:
Weather: Cold (20's), sunny breezy
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as E14	

COMMENTS

Did not take "O" in bags before coring; after coring, bagged "O" layer @ 1130 from ~1' away from sample hole.

Samples:	E14B1-Dup	Date bottled: 2/20/96
Depths:	8-15"	
Comments:		

Site number: E15 Date: 4/22/96
Personnel: NS, TDO, JLB
Location: Woods at swim club
Soil series: Keyport

Time (auger): 0925
Quadrangle: Freehold
Sampler: split spoon

Time (core): 1030
Formation: Englishtown
Weather: Clear, sunny, warm (65-70)
Hole Depth: 34"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O		organic mat	0-5"
A	10 YR 3/3 dark brown	loamy, medium sand, some roots	5-8"
B	2.5 YR 4/4 olive brown	siltier, some clay; some mottling-darker 5 YR 3/1; clay 10 YR 4/3 brown	8-12"
Clay	5 YR 2.5/1 black clay	silty clay, tiny silty blobs 10 YR 5/8; small ironstone fragments; brown clay becomes dominant at ~15"; also lighter clay below 10 YR 5/3 brown	12-22"
Clay	clay becomes olive colored	mica flakes, clay, silty blobs; 2.5 YR 6/4 light yellowish brown	22-23"
Clay	10 YR 5/3 brown	dark clay, silty blobs that are partly lithified to ironstone; light grey efflorence in some areas - 10 YR 7/1 - slightly reflective to reflectivey silty texture; small flecks of lighter more larger medium sand layers with depth 10 YR 6/6 brownish yellow	23-40"
E town sand	10 YR 5/6 yellowish brown	sand, damp, mottled; 10 YR 6/2 light brownish grey, very light to yellowish brown - lighter bits, grades to a greener shade at ~47"	40-48"

COMMENTS

Original land surface-area was cleared at some point. Trees are ~25 ft high; larger trees ~100 ft to west, but there's trash near them. Area is shown as wood in 1932, 1940, 1954 (aerial photos)

Samples:	E15A	E15B	E15CL1	E15CL2	E15CL3	Date bottled: 4/25/96
Depths:	5-8"	8-12"	14-20"	22-23"	25-30"	
Comments:	E15A - TOC, TAL only very small amount; E15B - sand, small amount of clay; E15CL1 - top of clay few ironstone channers, lenses of orangy silty sand; E15CL2 - middle of clay sampled; E15CL3 - blacker clay below sand stringer slight sulfuric smell, ironstone channers.					

Site number: E15-Dup
Date: 4/22/96
Time (auger):
Time (core): 1100
Personnel: NS, TDO
Quadrangle:
Formation:
Location:
Weather:
Soil series:
Sampler: Split spoon
Hole Depth: 34"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
		Same as E15	

COMMENTS

Samples:	E15D-S1 E15D-SS1	E15D-S2 E15D-SS2	E15D-S3 E15D-SS3	E15D-CL2 E15D-CL3	Date bottled: 5/2/96
Comments:	acid-washed mixing dish	soap& water rinse deI rinse	soap & water rinse		

Site number: E16
Date: 5/13/96
Time (auger): 0920
Time (core): 1020
Personnel: TDO, GCS
Quadrangle: Freehold
Formation: Englishtown
Location: SE side of Road near creek (Deep Run)
Weather: Sunny, cold (50)
Soil series: Humaquepts
Sampler:
Hole Depth:

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
A	10 YR 4/3 brown	medium sand, very little silt; few root hairs, few pebble minor clay balls 10 YR 5/1 gray	1-19"
B1	10 YR 5/3 brown	med-course sand; ironstone @ 27", 2-5y 3/1 very dark gray silt; minor pebbles, no silt, minor clay 10 YR 6/8 brownish yellow	19-30"
B2	10 YR 6/2 light brownish gray	medium-coarse sand; some root hairs, cobbles, small tree fragments; finer grained; some clay 7.5 YR 6/2 pinkish gray, little silt w/depth 2.5 y 4/2 dark grayish brown clay 7.5 YR 6/2 & 5/2 intermixed layered clay balls some silty clay 10 YR 6/4 light yellowish brown	30-41"
	10 YR 3/4 dark yellowish brown	fine silty sand; some roots	41-50"
	7.5 YR 4/6 strong brown	fine sand clean	50-?"

COMMENTS
No continuous clay, some minor "pieces" throughout the auger.

Samples:	E16A	E16B1	E16B2	Date bottled: 5/16/96
Depths:				
Comments: E16A - S, TOC, Metals, Isotopes; E16B1 - S, TOC, Metals; E16B2 - S, TOC, Metals				

Site number: E17 Date: 5/13/96 Time (auger): 1220 Time (core): 1335
Personnel: TDO, GCS Quadrangle: South Amboy Formation: Englishtown/Woodbury
Location: 110 yds from road in woods toward stream 25 yds from edge of woods Weather: Sunny, 55
Soil series: Elkton Sampler: split spoon Hole Depth:35+"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	Black root mat	Rooty	0-1"
A	10 YR 3/2 very dark grayish brown	Clayey silt; lots of roots, some mixing of the "O" 10 YR 2/1 black	1-4"
CL1	10 YR 5/6 yellowish brown	clay; lots of roots	4-10"
	7.5 YR 5/6 strong brown	clay; mottled with 7.5 YR 6/8 reddish yellow & 10 YR 6/2 light brownish gray; hit water, hole filling w/water @ 20"; @ 32" no more 7.5 YR 5/6 just 7.5 YR 6/8 & 10 YR 6/2	10-35"
	10 YR 6/1 gray	clay; mottled with 7.5 YR 6/8 reddish yellow; very wet, water in the hole	35-?"

COMMENTS

Sample ~110 yds from road going toward the creek.

Samples:	E17A	E17CL1	E17CL2	Date bottled: 5/16/96
Depths:	1-4"	4-10"	28-34"	

Comments: E17A, TOC, metals; E17CL1, TOC, metals; E17CL2, TOC, metals, S

Site number: W1 Date: 4/24/96 Time (auger): 1355 Time (core): 1455
Personnel: TDO, NPS Quadrangle: Freehold Formation: Woodbury
Location: Field east of Pension Rd., just north of Raceway Park Weather: Sunny, warm (60), breezy
Soil series: Sampler: split spoon Hole Depth: 34"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		sod	0-1"
	10 YR 4/4 dark yellowish brown	medium-fine sand; fine roots, little whitish medium sand grains	1-9"
	10 YR 6/6 brownish yellow	fine sandy silt to clay; 10 YR 6/1 gray mottle at ~14", becomes silty clay at ~12", more gray mottles, more prevalent 19-25"; 10myr 5/2 grayish brown clay mottles along with 10 YR 6/1 gray mottles ~25-29"; 10 YR 6/8 brownish yellow clay mottles, in addition from ~29-34"; from ~34-48", 10 YR 6/6 absent; 10 YR 5/2 and 10 YR 6/8 dominate with little 10 YR 6/1.	9-48"

COMMENTS

Samples:	W1CL1	W1CL2	W1CL3	W1CL4	Date bottled: 5/2/96
Depths:	0-14"	~20-25"	~25-29"	~29-34"	

Comments:

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

Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: W2
Date: 5/9/96
Time (auger):
Time (core): 1000
Personnel: ZSzabo/Chad VanSciver
Quadrangle: Jamestown
Formation: Woodbury
Location: At end of dirt road behind house at cliff face
Weather: slight drizzle or mist, 50
Soil series:
Sampler: DEP Geoprobe
Hole Depth: 24 ft

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
	2.5 YR 5/6 clay and fill	clay; admixed with white quartz gravel	1'3"-2'8"
	2.5 YR 5/2 clay and fill	clay; admixed with quartz gravels & brick fragments	4'
Clay	2.5 YR 5/2 grayish brown	clay; mottled with orange Fe oxide every 6" or so, large diagonal & horizontal fractures	4-11'
Clay	2.5 YR 2.5/1 black	clay; massive plastic with large grey concretions	11'-13'8"
	10 YR 5/6 yellowish brown	sand - cave in; admixed clay pieces	13'8"-14'3"
Clay	2.5 YR 2.5/1 black	interbedded clay & sand; clay:sand, 3:1; highly micaceous at 24' sand is likely wash down from cave in - only clay is native; hit water at about 12', lost water before 16', possibly at 14' in sand; sand is cave-in from surface. No sample 16-23'. 1' native clay 23-24'.	

COMMENTS

Samples:	W2B2	W2CL0	W2CL1	W2CL2	W2CL3	W2CL4	Date bottled: 5/16/96
Depths:	44-48"	5.5'-6.5'	6.5'-7'	~10'	14.7'-15.25'	23.5'-24'	
Comments:							

Site number: W3
Date: 5/13/96
Time (auger): 1450
Time (core): 1555
Personnel: TDO, GCS
Quadrangle:
Formation: Woodbury
Location: East side of on ramp to Rt. 9N in woods, 60 yds NW of police garage
Weather: Partly sunny, 58
Soil series:
Sampler: Corer / split spoon
Hole Depth: ~48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	Black	rooty, leaf litter	0-2"
A	10 YR 3/3 dark brown	fine sand; root hairs	2-10"
B1	7.5 YR 5/6 strong brown	medium-fine sand; root hairs and roots, wet	10-18"
B2 B3	75. YR 5/8 strong brown	medium-fine sand; very wet, water in hole, some sandstone	18-42
CL1	2.5 YR 4/8 red	clay, sandy; sand, red clay, hole collapsing @ 36"; mottled with 10 YR 6/1 gray.	42-?"

COMMENTS

Hole collapsing very fast; augered 2 more times, can't get past 48", collapsing so fast.
Pounded 3' sampler 30"-2 ft sampler 24" in same hole.
Originally E18, rename W3; this is not Englishtown.

Samples:	E18A	E18B1	E18B2	E18B3	E18CL1	Date bottled: 5/16/96
Depths:	2-10"	11-18"	20-30"	30-40"	42-48"	
Comments:	E18B3 - siltier & more clayey than B2; E18CL1 - layer pocket of red orange silt sand & gray clay Rename samples W3, etc. Not Englishtown; it's either Woodbury or Merchantville					

Site number: near E6 Date: 5/9/96
Personnel: ZSzabo/Chad VanSciver
Location: Roadcut immediately north of fork in road
Soil series:
Time (auger):
Quadrangle:
Sampler: DEP Geoprobe
Time (core):
Formation:
Weather: cloudy, 50
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10 YR 7/2 light gray	medium sand	
B	10 YR 7/3 very pale brown	medium sand	
C	2.5 YR 5/2 grayish brown	medium sand; organic	4'
E	2.5 YR 5/2 grayish brown	medium sand; very organic	8'
E	2.5 YR 7/2 light gray 2.5 YR 8/2 pale yellow layers	medium sand; numerous organic horizons, occasional yellow sand	12'
E	10 YR 6/8 brownish yellow	medium to fine sand; homogenous, no organic matter, saturated	16'

COMMENTS

Hit water about 13'; hole collapsed.

Samples:	Date bottled:
Depths:	
Comments: No samples analyzed	

Site number: near E5 Date: 5/9/96
Personnel: ZSzabo/Chad VanSciver
Location: Dirt road into woods ~30 ft off road
Soil series:
Time (auger):
Quadrangle:
Sampler: DEP Geoprobe
Time (core):
Formation:
Weather: Mist, 50
Hole Depth: 12 ft

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A1	7.5 YR 7/1 light gray	medium sand; organic matter	
A2	7.5 YR 7/1 light gray	medium sand; clean medium sand	
B1	7.5 YR 6/8 reddish yellow	medium sand; well-sorted clean sand	4'
Cor. Geol	10 YR 7/1 light gray	fine & medium sand; organic black laminae	
ET	10 YR 7/2 light gray	medium & fine sand; saturated at ~8', increasingly stained with organic matter	7'-8'
ET	10 YR 2/1 black	fine organic sand	11.5'-12'

COMMENTS

Hit water 7 or 8 ft. Hole had to be abandoned at 12'. Samples could not be collected in saturated sand.

Samples:	Date bottled:
Depths:	
Comments: No samples analyzed	

Site number: O1 REPEAT
Date: 2/5/95
Time (auger):
Time (core): 1125
Personnel: RR, NPS
Quadrangle: Keyport
Formation: Englishtown
Location:
Weather: cold (teens?), sunny
Soil series: Evesboro
Sampler: cover
Hole Depth: 48"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
		See O1 log	

COMMENTS
Removed 5" of frozen soil with trowel & bagged it @ 1115; drove sampler to 48" below land surface

Samples:	O1RA	O1E	O1BWS	O1BWO	Date bottled: 2/9/96
Depths:	1-6"	7-9"	11-16"	38-45"	
Comments:O1BWS,O1 BWD are shallow (S) and deep(D) - BW horizon is very thick - sampled from bottom of middle liner & bottom of bottom liner					

Site number: O-1
Date: 12/13/95
Time (auger): 1015
Time (core): 1015
Personnel: Z. Szabo, J. Barringer, V. dePaul, N. Smith
Quadrangle: South Amboy
Formation: Englishtown
Location: 2nd row of orchard trees, 5th tree from farm stand
Weather: very cold 18 cloudy
Soil series: Evesboro
Sampler: corer
Hole Depth: 58"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
A	10YR 5/6 yellowish brown	medium sand, some organic matter	0-7
E	10YR 6/8 yellowish brown	medium sand, some organic matter	7-9
BW	10YR 6/8 yellowish brown	medium sand	10-17
BW	10YR 6/8 yellowish brown	medium sand	18-56
C	10YR 7/6 yellow	medium sand; stopped augering at 58"; pounded sampler to 49"	56-58

COMMENTS
235 blows/ft for second section of barrel; 382 blows/ft for last section of barrel

Samples:	Date bottled:
Depths:	
Comments:	

Site number: O1 dup
Date: 12/13/95
Time (auger): 1412
Time (core):
Personnel: ZS, JLB, VdP, NS
Quadrangle: S. Amboy
Formation: Englishtown
Location: orchard, back of sign
Weather: cloudy, cold, breezy, 20
Soil series: Evesboro
Sampler:
Hole Depth:

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS
See O1 for auger data; collected part of A (frozen) in baggie w/trowel then cored

Samples:	Date bottled:
Depths:	
Comments:	

Site number: O2 REPEAT
Date: 2/5/96
Time (auger):
Time (core): 1210
Personnel: RR, NPS
Quadrangle: South Amboy
Formation:
Location:
Weather: cold (teens), sunny
Soil series: Klej
Sampler: corer
Hole Depth:

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS
See O2 log; Removed 4" of frozen soil with trowel, jarred it @ 1207; drove sampler to 48" bls

Samples:	O2RO	O2RA,	O2RE	O2RB1	O2RC	Date bottled: 2/5/96
Depths:	0-12"	2-11"	11-15"	20-30"	38-45"	
Comments: O2RA combines Ap + A2						

Site number: O2
Date: 12/15/95
Time (auger): 945
Time (core): 1010
Personnel: Z Szabo, N Smith, V DePaul
Quadrangle: S. Amboy
Formation:
Location:
Weather: ET
Soil series: Klej
Sampler: corer
Hole Depth: 48"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
O		mulch + organic matter + sand	1
Ap	10YR 3/2 very dark greyish brown	sand, med; mulch and roots	1-6
A2	10 YR 5/2 grayish brown	sand, med	6-11
E1	10 YR 6/3 pale brown	sand, med	11-13
F2	10 YR 5/3 brown	sand, med	13-18
B1	10YR 5/6 yellowish brown; color grades to 10YR 5/8 at about 26"	sand, med. slightly blocky	18-35
C	10YR 6/8 brownish yellow; grades to 10YR 7/6 yellow at about 39"; becomes mottled at 44" of the 2 colors	sand, med	35-57

COMMENTS

Frozen soil O horizon dug out to 2" w. stainless trowell

Samples:	Date bottled:
Depths:	
Comments:	

Site number: O3 REPEAT
Date: 2/5/96
Time (auger):
Time (core): 1240
Personnel: RR, NPS
Quadrangle: South Amboy
Formation:
Location:
Weather: cold (teens), sunny
Soil series: Klej
Sampler: corer
Hole Depth: 48"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS

see O3 log; Removed 4" frozen soil and jarred it @ 1236; drove to 48" BLS

Samples:	O3RA	O3RBW1	O3RBW2	Date bottled: 2/5/96
Depths:	1-7"	9-12"	15-25"	
Comments:				

Site number: O3
Date: 12/15/95
Time (auger): 1052
Time (core): 1130
Personnel: ZS, NPS, VdP
Quadrangle: South Amboy
Formation: EGLS
Location: 3rd row of trees from fire hydrant
Weather: cloudy, cold, 30's
Soil series: Klej
Sampler:
Hole Depth: 44"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 4/3 brown	medium sand, blocky, some organic	0-8 1/2
BW1	10YR 5/8 yellowish brown	medium sand, blocky	8 1/2 - 51
BW2	10YR 6/8 brownish yellow 12"-57"	slightly wet, some fine pebbles 4-5 mm, gray-black mottling below 12"	
C	at 51" slightly mottled with lighter-colored sand; 10YR 6/8 brownish yellow; 7.5YR 6/8 reddish yellow 57"-64"; 10YR 7/2 light gray clay balls at 59"-60"		51-64

COMMENTS

May have lost bottom foot retrieving sampler--core catcher destroyed

Samples:	Date bottled:
Depths:	
Comments:	

Site number: O4
Date: 1/30/96
Time (auger): 1020
Time (core): 1045 O horizon + core 1055
Personnel: JLB, RR, NS
Quadrangle: South Amboy
Formation: Englishtown
Location: Abandoned orchard E. side of Higgins Rd opposite soccer fields uphill N. end
Weather: cool, partly cloudy, low 40's
Soil series: Keyport
Sampler: corer
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	blackish	roothairs	0-1
A	gray brown 10YR 3/2	sandy loam, some roots;grades in to B orangish mottles	1-14
B1	yellowish brown 10YR 5/8	sandy, slightly more clay	14-15
B2	brownish yellow 10YR 5/6	sand, more clay than above	15-40
B3	slightly lighter - more orange 10YR 4/6	sandy, clay	40-45
C	brown greyish 10YR 5/3	sandy, less clayey; grades from orange to grey brown	45

COMMENTS

O Horizon collected w/trowel. Ground was not frozen. Hit root w corer almost immediately - pulled out, assessed situation-back in hole, went through root core will have doubled O + A - discard upper O + A and lower O

Samples:	O40	O4A	O4B1	O4BW	Date bottled: 2/5/96
Depths:	0-1"	2-13"	14-15"	20-30"	
Comments:	rename O4BW O4B2				

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: O4 dup
Date: 1/30/96
Time (auger): see previous sheet
Time (core): 1105
Personnel: JLB, NS, RR
Quadrangle: S. Amboy
Formation: Englishtown
Location: Higgins Rd - same as O4, dup 2' from O4
Weather: cool - low 40's
Soil series: Keyport
Sampler:
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

See O4; cap broke on cores; dug to cores, to remove remains of cap; screwed cap from other corer on + jacked corer out w/ second slam bar

Samples:	04O dup	O4A dup	O4B1 dup	O4B2 dup	O4B3	Date bottled: 2/5/96
Depths:						
Comments:						

Site number: O5
Date: 1/30/96
Time (auger): 1450
Time (core): 1535
Personnel: RR, NPS
Quadrangle: S. Amboy
Formation:
Location: low-lying section of orchard, 2nd row of trees from road
Weather: cloudy, cool - low 40's
Soil series: Klej
Sampler: corer
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O		roots	0-1
A	10YR 2/1 black	fine sand w/root mats	1-11
BW1	10YR 6/3 pale brown	medium-fine sand	11-15
BW2	10YR 5/3 brown	medium-fine sand; mix of colors going from brown thru red to yellow	15-18
BW2	5YR 3/4 dark reddish brown	medium fine sand; cobbles at 20"	18-26
C	10YR 6/8 brownish yellow	medium-fine sand	26-40
	10 YR 7/8 yellow	medium fine sand	40-46
	10YR 6/8 brownish yellow; & 5YR 5/8 strong brown	medium-fine sands of two colors intermixed	46-56

COMMENTS

Samples:	O5A	O5BW1	O5BW2	O5BW2C	Date bottled: 2/2/96
Depths:	2-10"	11-15"	21-26"	26-36"	
Comments: O5BW2--taken from below 26-36" the pebble/cobble layer; O5BW1 bottled 2/5/96					

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

Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: O6
Date: 1/31/96
Time (auger): 1015
Time (core): 1033 no O Horizon
Personnel: JLB, RR, NS
Quadrangle: Keyport
Formation: Englishtown
Location: Wilson Rd, W of house, old orchard area
Weather: cold, 30, light snow
Soil series: Evesboro
Sampler: corer
Hole Depth: 48”

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
O	black	root mat; not real soil,just rootlet mat	0-1
A	dark grayish brown 10YR 4/2	sandy; roots in A - grades to E	1-7
E	lighter yellowish brown 10YR 4/4	sandy	7-11
BW	yellowish brown 10YR 5/4	sandy	11-23
B2(this may be C JLB 2/1/96)	getting yellower 10YR 5/6	sandy; slightly clayey; pebbles @ 31” slightly more clay with depth	23-52
C	slightly lighter than B2		

COMMENTS
Augered to 52”

Samples:	O6A	O6E/B	O6BW	O6B2	Date bottled: 2/2/96
Depths:	1-7”	7-11”	12-20”	33-40”	
Comments:					

Site number: O6 dup
Date: 1/31/96
Time (auger): see O6
Time (core): 1036
Personnel: JLB, RR, NS
Quadrangle:
Formation:
Location: same as O6
Weather: cold snowing
Soil series: Evesboro
Sampler: Corer
Hole Depth: 48”

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS
soil log same as O6

Samples:	O6duPA O6DUPE/BO6DUPBW O6DUPB2	Date bottled: 2/5/96
Depths:		
Comments:	O6DUPB2 includes part of pebble layer	

Site number: O7 Clay
Date: 2/27/96
Time (auger):
Time (core): 1015
Personnel: T Oden, R Rosman
Quadrangle: S. Amboy
Formation: Englishtown/Woodbury
Location: front yard, Cottrell Rd
Weather: sunny mild mid 40's-50
Soil series: Keyport
Sampler: split spoon
Hole Depth: 32"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Soil log same as O7

Samples: O7A	O7CL1	O7CL2		Date bottled: 3/1/96
Depths: 1-6"	7-15"	20-28"		

Comments: O7A--slightly blotchy sandy loam, brown, brown + yellowish red mottles; O7CL,O7CL2--grades into clays, yellowish to yellowish brown

Site number: O7
Date: 2/1/96
Time (auger): 1005
Time (core): 1150
Personnel: RR, NPS
Quadrangle: S. Amboy
Formation: Englishtown cap on Woodbury clay
Location: front yard, next to Cottrell Rd (E. side) beneath old apple trees
Weather: cold (20), mostly sunny
Soil series: Keyport
Sampler:
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
	2.5Y 5/6 light olive brown	silty sand	0.5-6"
	2.5 Y 6/6 olive yellow	clayey	6-21"
		clay w/iron concretions; too much clay to sample? will auger under another tree	21-24"

COMMENTS

No O 0-0.5" root mat; removed 0.5" frozen soil before sampling, drove sampler to 18" empty when withdrawn!! too much clay

Samples:
Date bottled:
Depths:
Comments:

Site number: O8 Date: 2/12/96 Time (auger): 1215 Time (core): 1245
Personnel: RR, NPS Quadrangle: Keyport
Formation:
Location: Wilson Rd., back end of old orchard,30 before land slopes to creek
Weather: cold (20's), sunny, breezy
Soil series: Evesboro Sampler: corer
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O/A	10YR 3/2 very dark grayish brown	medium sand	O-1
A	10YR 4/4 dark yellowish brown	medium sand; cobbles at 12", ironstone @ 13"	1-19
B1	10YR 5/6 yellowish brown	medium sand-coarse sand; more cobbles throughout to 30"	19-47
B2	7.5 YR 5/8 strong brown	medium sand; 7.5 YR 6/8 reddish yellow mottles	47-51"

COMMENTS

"O" smaple bagged @ 1220; core-catcher driven 5" up barrel

Samples:	O8O	O8A	O8131	Date bottled: 2/13/96
Depths:	0-1"	2-15"	20-30"	
Comments:	no B2 collected - bottom of liner 3 is same material as higher up - sand + lots of cobbles, same color			

Site number: O9 duplicate Date: 2/9/96 Time (auger): 1400 Time (core): 1455
Personnel: T Oden, R Rosman Quadrangle: Allentown
Formation:
Location: off Ellisdale Road (130), b/w hooses by electric pole
Weather: cloudy, breezy 30's
Soil series: Sassafras Sampler: corer
Hole Depth: 4', lost 1f of core down hole

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/4 dark yellowish brown	clean fine grained; 0-13	0-13
B1	10YR 5/6 yellowish brown	fine, grain; getting clumpy (blocky) more silt	13-29
B2	7.5 YR 6/8 reddish yellow	medium-fine grained; little blocky minor coarse grains, less silt than B1	29-53

COMMENTS

Lack of O horizon, grass cover, tamp the augered hole and sample

Samples:	O9DA	O9DB1	Date bottled: 2/12, 2/15/96
Depths:	1-12"	14-20"	
Comments:			

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: O9
Date: 2/9/96
Time (auger): 1400
Time (core): 1415
Personnel: T Oden, R Rosman
Quadrangle: Allentown
Formation:
Location: off Ellisdale Road (130) b/w hooses by electric pole
Weather: cloudy, breezy, 30's
Soil series: Sassafras
Sampler: corer
Hole Depth: 4', lost -/+ 1f of core down hole

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/4 dark yellowish brown	clean fine grained	0-13
B1	10YR 5/6 yellowish brown	fine grain; getting clumpy (blocky) more silt?	13-29
B2	7.5 YR 6/8 reddish yellow	medium-fine grained	29-53

COMMENTS
Lack of O horizon, grass cover, tamp the augered hole,and sample; took duplicate sample @ 3 @ 1455 lost 1f core down hole

Samples:	O9A	O9B1	O9B2	Date bottled: 2/12/96
Depths:	1-12"	14-21"	30-34"	
Comments: O9B1--above core catcher, which got shoved up the barrel. O9B2 from soil below core catcher - stiffer, sample has more clay				

Site number: O10
Date: 2/27/96
Time (auger): 1155
Time (core): 1215
Personnel: T Oden, R Rosman
Quadrangle: S. Amboy
Formation: Englishtown into Woodbury
Location: apple tree behind gray house off of Morganville Rd
Weather: sunny 50's
Soil series: KfB/KEB Keyport
Sampler: corer
Hole Depth: 4'

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/2 very dark grayish brown	clean, medium-fine grained; minor pebbles	0-9
B1	10YR 4/4 dark yellowish brown	cobbles, some orangey sand; lots of cobbles	9-17
B2	10YR 5/8 yellowish brown	fine grained, minor cobbles	17-26
	10YR 6/8 brownish yellow	little silty fine grained; wetter w/depth	26-39
CL	10YR 6/8 mottled w/10YR618	mottled clay; clay is probably Woodbury fm	39-

COMMENTS
No O horizon; will sample 2 ft w/2 in x 3 ft core barrel - 24-48 inches w/1 in x 2 ft split spoon; large tree roots at 3'

Samples:	O10A	O10B1	O10B2	O10CL	Date bottled: 3/4/96
Depths:	1-8"	10-16"	24-30"	39-45"	
Comments:	O10B2--dk gray, mottles; O10B2--still some mottles but brighter yellowish above pebble layer				

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: O11 Date: 3/26/96 Time (auger): 1030 Time (core): 1115, 1135
Personnel: TDO, NPS Quadrangle: Formation: Woodbury
Location: in field off Maiden Lane, 148' A2 268 degrees from E-13 Weather: sunny, warm (50's)
Soil series: Keyport Sampler: corer, splitspoon Hole Depth: 30"corer, 49"splitspoon

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 5/5 yellowish + brown	medium sand, clean; at 10", mottled with, 10YR 2/1 black organic material	0-12"
B1	10YR 5/6 yellowish brown	medium sand, clean; wet at 16" very few cobbles; small amounts of 7.5YR 4/6 strong brown sand 20-26"; from 27"-32" 7.5YR 4/6 sand more prevalent; some ironstone at 35"	12
B2	7.5YR 4/6 strong brown	medium sand; bottled with 10YR 5/1 gray fine sand; wet	32-37
Clay	10YR 5/1 gray, 10YR 4/1 dark gray, 10YR 5/6 yellowish brown	clay, fine sand; 3 colors: 2 gray clays, 1 yel. br. fine sand; 11: water in 49" hole	37-49

COMMENTS

Drove 3-ft sampler to 30" BLS @ 1115; drove split-spoon from 25"-49" @ 1135; top liner of 3 ft sampler empty

Samples:	O11A	O11B1	O11B2	O11CL	Date bottled: 3/27/96
Depths:	1-12"	12-16"	32-36"	40-45"	
Comments:					

Site number: O12 Date: 3/26/96 Time (auger): 1215 Time (core): 1250
Personnel: TDO, NPS Quadrangle: Formation: Woodbury
Location: in field off Maiden Lane, 216', az 268 degrees from O11 Weather: sunny, warm (50's), breezey
Soil series: Keyport Sampler: split spoon Hole Depth: 36"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
	10YR 5/4 yellowish brown	mixture of clay; well-mixed clay, sand to 8", not as sandy below 10"	0-10
	10YR 4/1 dark gray, 10YR 5/1	gray mottles of clay more prevalent below 10"	10-15
	some small amounts of 10YR 2/1	black organic material at 15"	15-24
	10YR 5/3 brown clay more prevalent 24"	Getting massive clay, same color w/depth	24-30
	10YR 5/8 yellowish brown intermixed w/10YR 5/3 @ 30"		30-39

COMMENTS

stopped logging hole @ 39" will sample surface to 3 ft w split spoon. 1 liner

Samples:	O12CL1	O12CL2	O12CL3	Date bottled: 8/27/96
Depths:	1-8"	11-20"	22-30"	
Comments:				

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: O14
Date: 2/8/96
Time (auger): 1015
Time (core): 1045
Personnel: T Oden, R Rosman
Quadrangle:
Formation: Englishtown
Location: In the woods 1/10 mile from Greenwood Rd + Texas int
Weather: cloudy, cool, 40"s
Soil series: Keyport
Sampler: corer
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	black-dk brown	rooty mat	0-2"
A	2.5 Y 5/4 light olive brown	some roots, fine grained	2-8
E	10YR 5/4 yellowish brown	graditional into next layer	8-15
B1	10YR 5/1 gray	clean fine grained	15-21
B2	10YR 7/12 light gray	mottled w/light brown below	21-25
	7.5YR 5/6 strong brown	small pebbles	25-36
	7.5YR 6/8 reddish yellow	iron concretions + cobbles	36-50
	10YR 7/6 yellow	stopped @ 53 in.	50-

COMMENTS

lots of junk cars + parts rusting in the area

Samples:	O14A	O14B1	O14B2	O14c	Date bottled: 2/15/96
Depths:	2-8"	15-20"	21-25"	36-40"	
Comments:					

Site number: O15
Date: 2/9/96
Time (auger): 1115
Time (core): 1140
Personnel: R Rosman, T Oden
Quadrangle: Keyport
Formation: Englishtown
Location: 200' off road in woods sight flagged in yellow
Weather: cloudy low 40's
Soil series: Evesboro
Sampler:
Hole Depth: 24"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	dark brown	rooty mat	0-1.5
A	2.5 Y 3/2 very dark greyish brown	very fine sand	1.5-8"
B	2.5Y 5/4 light olive brown	v. fine-fine sand; some cobbles, some mottled orangy sand	8-13"
B	2.5 Y 6/6 olive yellow	very fine sand some silt; stones + cobbles	13-19
B	2.5Y light olive brown	silty sand, large cobbles + ironstone	19-23
B	2.5Y 5/6 light olive brown	silty sand; becomes clayey towards bottom flat ironstone at 27"	23-27
B	10YR 7/1	mottled gray clay very silty at top; clay 1" from top (28") TD=33"; ironstone then clay below 23" - took core to 24"	

COMMENTS

Large tree root in O + top of A horizons took several auger holes to ge thru A-horizon

Samples:	O15A	O15B1	O15B2	Date bottled: 2/15/96
Depths:	2-8"	6-16"	20'26"	
Comments:				

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: O16
Date: 5/13/96
Time (auger): 1111
Time (core): 1150
Personnel: TDO, GCS
Quadrangle: S. Amboy
Formation: Woodbury
Location: Kirshmans Lane, 1st apple tree west of house closest to Road
Weather: partly sunny 55 warm
Soil series: Keyport
Sampler: splitspoon
Hole Depth: 32"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
	10YR 5/2 grayish brown	silt, damp, little sand near bottom of unit; root hairs, minor pebbles	1-12
	10YR 6/4 light yellowish brown	clay, few roothairs; mottled w silt at the contact some roots @ 27" mottled w 10YR 6/8 + 7.5 YR 5/2 more massive w/depth; strongly mottled w/ 10YR 6/8, 7.5 YR 5/2, 10YR 6/1 + Dominant 10 YR 6/4	12-32"

COMMENTS

Samples:	O16A	O16CL1	O16CL2	Date bottled: 5/16/96
Depths:	2-10"	12-18"	20-30"	
Comments: O16CL1--upper part of clay; O16CL2--lower part of clay				

Site number:
Date:
Time (auger):
Time (core):
Personnel:
Quadrangle:
Formation:
Location:
Weather:
Soil series:
Sampler:
Hole Depth:

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Samples:	Date bottled:
Depths:	
Comments:	

Site number: I1
Date: 4/11/96
Time (auger): 1130
Time (core): 1150
Personnel: NPS, ZS, TDO
Quadrangle:
Formation:
Location: 6' S of Piezometer 7 under edge of black tarp
Weather: sunny, windy, 50"s
Soil series: oil-laden filter clay
Sampler: hand auger
Hole Depth: N/A

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
filter clay	black 2.5 Y N 2/0	silty-clay; oil laden, water logged, shiny; saturated completely at 7"	0-47"
CL W		from auger	0-6
CL2 X		from auger	7-13
CL3 Y		from auger	19-25
CL4 Z		from auger	42-47

COMMENTS

Collected baggied samples at 0-6, 7-18, 19-25; all samples from deconned hand auger 42-47"; no evidence of "natural" soil

Samples:	I1W	I1X	I1Y	I1Z	Date bottled: 4/11/96
Depths:	0-6"	7-13"	19-25"	42-47"	
Comments:					

Site number: I2
Date: 4/11/96
Time (auger): 1235
Time (core): 1430
Personnel: NPS, ZS, TDO
Quadrangle:
Formation:
Location: 30' S of old rusted tank in N corner
Weather: 55 sunny breezy
Soil series:
Sampler: split spoon
Hole Depth: 38"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	2.5 Y 5/6 light olive brown	silty sand	0-5
CL1	10YR 3/1 very dark gray & bright orange mottles of iron sand	clay, plastic; petroleum odor, mixed in orange sand	5-8
CL2	10YR 3/1 very dark gray	plastic clay; bright red mottles & orange mottles; 7.5 YR 6/8 (reddish yellow); extreme oil smell at 16" & below; no orange mottles below 16"	8-16
		becomes exceedingly "tight" below 27" slightly more sand below 37"	44 1/2"

COMMENTS

Samples:	I2A	I2CL1	I2CL2	Date bottled: 4/11/96
Depths:	0-5"	5-8"	8-16"	
Comments:				

Site number: I3
Date: 4/11/96
Time (auger): 1525
Time (core):
Personnel: ZS/TO/NS
Quadrangle:
Formation:
Location: 35’ SW of old pipe bldg, 5’ SE of 4 yellow steel poles, from under tarp
Weather:
Soil series:
Sampler: ss
Hole Depth: 25”?

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		gravel, trap rx, & brick mixed w. med. sand; road-surface material; mixed clay-sand-oil layer at 6”	0-6
A	2.5 Y 5/4 light olive brown	medium sand; stained black w. oil,mottled white & yellow & orange; 7.5 YR 5/6 strong brown	6-11
B	2.5 Y 5/4 light olive brown	medium sand; black spots w. oil & blobs of filter clay & brick pieces	11-20

COMMENTS

Samples:	I3A	I3B	Date bottled: 4/11/96
Depths:	~11-16”	2-25”	
Comments:			

Site number: I4
Date: 4/11/96
Time (auger): 1625
Time (core): 1800
Personnel: ZS, NPS, TDO
Quadrangle:
Formation:
Location: 10’ NE of drum washing bldg center door next to stake SS-110
Weather: sunny, breezy, 50’s
Soil series:
Sampler: corer
Hole Depth: 47”

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
I4 A	10YR 3/3 dark brown	fine sand, roots brick fragments, mica	0-3
I4 B2	2.5 Y 4/3 olive brown	medium sand; some glass; some pebbles, slag?, possible small amounts hydrocarbon	3-13
	2.5 Y 4/3 olive brown; 7.5 YR 5/6 strong brown	Med sand mixed w. gravel; black hydrocarbon layer, mottled strong brown	13-14
I4 B 1/2	5YR 2.5/1 black	gravel, rounded; mixed w. fine black sand, water & hydro C saturated	14-16
I4B2	5YR 2.5/1 black	silt grading to clay; micaeous; possible hydrocarbon	16-19
I4 CLA	5YR 2.5/1 black	massive clay; possible hydrocarbon - dry	19-21
I4B3	10YR 5/4 yellowish brown	medium sand;hydrocarbon ooze in 1st inch; black organic layers (natural organics layers; mottled 7.5 YR 5/8 strong brown mottling	21-34
I4 B4	10YR 5/3 brown	medium sand - dry	34-44
	10YR 7/6 yellow	medium sand - dry	44-58

COMMENTS

drove 3-ft sampler to 12”, augered hole to 15”, drove sampler from 15”, drove sampler from 15”-47” BLS

Samples:	I4 CLA	I4 A	I4 B	I4 B 1/2	I4B3	I4 B4	Date bottled: 4/15/96
Depths:	19-21”	0-3”	3-13”	14-16”/16-19”	21-34”	34-44”	

Comments:CLA--clay from auger; A--wet,roots, sand, high water content; B--sand & pebbles, roots; B 1/2--can’t differentiate layers; mixed together quartz pebbles 3/4-1”; B4--s.G. found brick and “cinders” in this zone - baggied them.

Site number: I5
Date: 6/11/96
Time (auger):
Time (core): N/A
Personnel: JLB, SB, JE, JS, DS
Quadrangle: Keyport
Formation: Englishtown
Location: Imperial OIl Company
Weather: warm, sunny
Soil series: disturbed
Sampler: Geoprobe
Hole Depth: ~8 ft

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
dry brown Fill	brown	dry clayey fill shards of asphalt	
Rubble		brick frags. etc	
SA	dk brown	sand w. faint petrol smell	~4'
grey SS Silt	grey	silt - wet, full of brick & concrete shards	~6'

COMMENTS

Samples:	I5SS	I5SA	Date bottled: 6/13/96
Depths:	~72-80"	~48-55"	

Comments: I5SS--silt from 6'. I5SS has enough clay to be considered a CL sample. Although I5SA has rubble on top, it is really an A horizon that appears to have been buried. Call this A to conform with other A samples.

Site number: I6
Date: 6/11/96
Time (auger): N/A
Time (core): 1050
Personnel: JLB, SB, JE
Quadrangle: Keyport
Formation: Englishtown
Location: Imperial Oil Comapny
Weather: warm, sunny
Soil series: disturbed
Sampler: Geoprobe
Hole Depth: ~54"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 5/3	sand, few sm. blackened pebbles; some admixture of other colors, disturbance, few roots v. faint organic smell (from the overlying asphalt?)	0-12 (less asphalt thickness)
B		brown sand	12-24
B	10 YR 6/6	sandy, black flecks, mica	~2.5 -3.0'
C ("O" horizon is OK)	10YR 6/4	sand, black flecks; looks like E'town sand	3.0'-3.5'
C	10YR 6/3	sand, dark pebbles, mica, ironstone channers	~4.0-4.5

COMMENTS

Samples:	IA6A	I6C1	I6C2	I6B	Date bottled: 6/12/96
Depths:	2-8"	3.0'-3.5'	4.0'-4.5'	brown sand from ~14"	

Comments:

Site number: I7 Date: 6/11/96
Personnel: JLB
Location: Imperial Oil Company
Soil series: Disturbed
Time (auger):
Quadrangle: Keyport
Sampler: Geoprobe
Time (core): 1140-1200
Formation: Englishtown
Weather: warm, sunny
Hole Depth: ~5'6"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
A? Fill?	Blackish	sand with debris; pebbles, flakes of concrete: dark slag or coal pieces, mica flakes	0-12"
C? F2	10YR 5/6	sand, black flecks; mica, some black debris, becomes more natural looking w/depth	12-26"
C or B? F3	predom. 10YR 5/5 10YR 5/2	sand, mica flakes; mixed colors - more orange 10YR 6/8, + 10YR 7/4	26-42
C	mostly 10 YR 7/2	tan sand, some iron; staining mica black flecks probably not disturbed	42-60
CL	yellowish brown/gray	clay & silt stringers	5'-5.5'

COMMENTS

Samples:	I7F	I7F2	I7F3	I7C	I7CL1	Date bottled: 6/12/96
Depths:	0-12"	12"-26"	26"-40"	~42"-50"		

Comments: I7F may not be in place but basically it's topsoil (A) with lots of debris mixed in. I7F3 appears to be B horizon material

Site number: I8 Date: 6/11/96
Personnel: JLB
Location: Imperial Oil Company
Soil series: Disturbed
Time (auger):
Quadrangle: Keyport
Sampler: Geoprobe
Time (core): 1210-1220
Formation: Englishtown
Weather: warm, sunny
Hole Depth: ~9 ft

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
CL disturbed material	10YR 4/2 bl. gray	silty clay - very dry; less thickness of asphalt	6-18"
C, Fill? Disturbed? C or E'town	10 YR 7/3 10YR 2/2	sand - lots of black stuff mixed in top of this section, looks more like E'town w/depth	~18-24"
C? may be disturbed	10 YR 7/3	sand, black flecks, mica, looks like E'town	24-30"
BC	10YR 4/4	sand, mica flakes - iron staining - looks like B horizon more clayey	30"-33"
Geologic		sand	3.6'-9'

COMMENTS

Samples:	I8CL1	I8C	I8BC	I8G	Date bottled: 6/12/96
Depths:	~8-14"	18-24"	30-32"	~40-46	

Comments: I8G geologic? at ~3.5', call this I8C2 for consistency

Site number: S1 Duplicate
Date: 11/30/95
Personnel: Rosman, Oden, Barringer, Szabo
Location: IOC woods
Soil series: KeB
Time (auger): 0840
Quadrangle: Keyport
Sampler:
Time (core):
Formation: Englishtown
Weather: Sunny & cold snow on ground
Hole Depth: 4 feet

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Just took cores, sulfur samples, Lead Isotope, TOC & metals

Samples:	S1D	Date bottled: 12/5/95
Depths:	0-1"	
Comments:		

Site number: S1
Date: 11/28/95
Personnel: RR, JLB, SB
Location: wooded, slopes
Soil series: Keyport
Time (auger): 9:57
Quadrangle: Keyport
Sampler:
Time (core): 10:20
Formation: Englishtown
Weather: warm, partly sunny 60 °
Hole Depth: ~40"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
O	black	root mat.	very thin 2.5
A	10 YR 4/3	sandy loam	5-11
B1	10 YR 5/6	sandy loam	11-37
B2	10 YR 4/6	clayey sandy loam,mottles; appears to contain flecks of pyrite or mica	37-58

COMMENTS

approaching C at 58" - still mottles, soil is becoming clayeyer and greyer

Samples:	S1O	S91O dup	S1A	S1B1	S1B2	Date bottled: 11/29, 11/30
Depths:	0-.5"	0-.5"	~1-7"	~12-20"	~38-40	
Comments:						

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: S2 clay
Date: 2/26/96
Time (auger):
Time (core): 1200
Personnel: TO, NPS
Quadrangle:
Formation:
Location:
Weather: sunny, warm (50's)
Soil series:
Sampler: split spoon
Hole Depth: 37"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

see S2 log

Samples:	S2CL1	S2CL2	Date bottled: 2/29/96
Depths:	~15"-26"	~29"-36"	

Comments: S2CL1--from top of liner - no mottling - yellowbrown; S2CL2--from bottom of liner - very mottled grey & brown

Site number: S2
Date: 11/28/95
Time (auger): 1045
Time (core):
Personnel: Z Szabo, T Oden, J Evenson
Quadrangle: Keyport
Formation: Englishtown
Location: N IOC woods
Weather: 60 °F
Soil series: Keyport
Sampler: corer
Hole Depth: 3 feet

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	dark brown		0-2
Ag	10YR 4/2 dk brown	sandy	2-8
B1	10YR 6/6	clay	8-18
B2	10YR 6/6 grading to 10YR 4/2	clay, mottled, orange & gray	18-27
B2	mottled 10YR 4/2 w. 10YR 6/6	clay, mottled gray & orange	27-42

COMMENTS

core recovery
0-8" = O & Ag
1-2' = compacted; 1-3' B1 & B2

Samples:	S2O	S2A	S2B1	Date bottled: 11/28, 11/30
Depths:	0-2"	~3-7"	~9-15"	

Comments:

Site number: S2
Date: 11/28/95
Time (auger): 1000
Time (core):
Personnel: Z Szabo, T Oden, J Evenson
Quadrangle:
Formation:
Location: wooded, N of IOC
Weather:
Soil series:
Sampler:
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
Ap	10YR 4/2	med sand; roots massive pebbles	0-.8 feet
Bt1	10YR 5/4grading to 10YR 6/6	silt v. clayey, pebbles	.8-1.6
Bt1	10YR 6/6	clay, mottled grey, orange, yellow-brown; so dry as to be virtually in compressible	1.6-2.4
Bt2	10 YR 4/2	clay mottled; dry	2.4-3.3

COMMENTS

Abandon hole too little sand to sample

Samples:	Date bottled:
Depths:	
Comments:	

Site number: S3
Date: 11/28/95
Time (auger): 1335, 1:35
Time (core):
Personnel: RR, JLB
Quadrangle: Keyport
Formation: Englishtown
Location: woods behind (E) of IOC
Weather: clear, windy, ~60 °
Soil series:
Sampler:
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	black	organic matt	0-2"
A	grey brown 10YR 4/2	sandy loam	2-11"
B1	yellow 10YR 6/4	sandy loam	11-24"
B2	yellowish orange 10 YR 6/6	sandy clay loam; reddish mottles, increasing clay w/ depth	24-28"
	orange, then greyish	clay lense; mottled clay	28"-

COMMENTS

stony layer @ 22" start second auger hold 1 ft away; hit WT in first hole at 22: perched w.T.

Samples:	S3O	S3A	S3B1	S3b2	Date bottled: 11/29, 11/30
Depths:	0-2"	~3-10"	~12-20"	~25-27"	
Comments:					

Site number: S4
Date: 11/28/95
Time (auger): 1355
Time (core):
Personnel: Z Szabo, J Evenson T Oden
Quadrangle Keyport
Formation: Englishtown
Location: woods near burial mound
Weather: warm, windy, ~60 °
Soil series: Keyport
Sampler: corer
Hole Depth: 4' auger, ~3' corer

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
O			2
A	10YR 4/2 grayish brown		
A	10YR 7/2 light gray	sand	12-17
B1	10YR 6/6 brownish yellow	sand	17-19
B1	10YR 5/8 yellowish brown	sand many ironstone, roots & silt balls at 30"	19-31
B2	mottled 10YR 5/8 & lesser	sand	
	10YR 6/6	mottled, large chunks of ironstone at ~43"; extremely bright color mottling	~ 48"
C	10YR 5/2 grayish brown	sand; loose	at 51"

COMMENTS

Samples:	S40	S4A	S4B1	S4B2	Date bottled: 11/29, 11/30
Depths:	0-2"	~3-9"	~18-22	~27-36	
Comments: S4B2 (may just be S4B1 deep)					

Site number: S5 clay
Date:2/26/96
Time (auger):
Time (core): 1325
Personnel: TO, NPS
Quadrangle:
Formation:
Location:
Weather: Partly cloudy, warm (50's)
Soil series:
Sampler: split spoon
Hole Depth: 32"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS
See S5 soil log

Samples:	S5CL1	s5CL2	Date bottled: 3/1/96
Depths:	~1-8	~20-30"	
Comments:			

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: S5 Date: 11/28/95
Personnel: R Rosman, Z Szabo
Location: IOC woods
Soil series: Keyport

Time (auger): 1545
Quadrangle: Keyport
Sampler:

Time (core):
Formation: Englishtown
Weather: warm, windy, 60 °
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O			0-0.1’
A	10YR 4/1 dark gray	sand	0.1’-0.6’
B1	10YR 4/4 dark yellowish brown	sand; massive	0.6’-1.1’
B2	10YR 6/4 light yellowish brown	sand; massive	1.1-1.6’
B3	10YR 7/3 very pale brown	sand; massive, saturated, probably perched on clay	1.6’-2.6’
B3	same colors as before	massive fine sand, same colors with very large bright orange mottles; perched water table!	2.6-3.0

COMMENTS

Samples:	S5O	S5O/A(metals)	S5A	S5B1	S5B2	Date bottled: 11/30
Depths:	0-11”	1.5-2”	~2-7”	~8-13”	13-28”	
Comments:						

Site number: S6 Date: 11/29/95
Personnel: T Oden, R Rosman
Location: IOC woods
Soil series:

Time (auger):
Quadrangle: Keyport
Sampler:

Time (core): Abandoned @ 1342
Formation: At
Weather: Cold, Snow cover
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	Black		3”
A	Black 10YR 2/2		26”

COMMENTS

Hole abandoned appears to be a wetland soil color change @ 26 in. to darker color black; probably Atsion - no sample collected

Samples:	Date bottled:
Depths:	
Comments:	

Site number: S7 clay	Date:2/26/96	Time (auger):	Time (core): 1230
Personnel: TO, NPS		Quadrangle:	Formation:
Location: IOC woods			Weather: sunny, warm (50's)
Soil series:		Sampler: split spoon	Hole Depth: 32"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

See S7 soil log

Samples:	S7CL1	S7CL2	Date bottled: 2/29/96 (CL2), 3/1/96(CL1)
Depths:	~13-18"	~25-32"	
Comments:			

Site number:S7	Date: 11/29/95	Time (auger): 1345	Time (core):
Personnel: R Rosman, T Oden		Quadrangle: Keyport	Formation: Englishtown
Location: IOC woods			Weather: cold cloudy snow covered
Soil series:KEB? May be Atsion JLB		Sampler:	Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	dark brown sand with roots darker than color chart 10YR 2/2	dark brown root mats; sand & loam	0-2"
A	dark brown sand with light gray sand	sand & loam sticky, some cobbles	2-12"
B	gray orange mottled clay	massive & blocky	starts at 1'

COMMENTS

Total depth of hole 20"; mottled grey & orange clay from 12"-20"

Samples:	S7O	S7A	Date bottled: 12/6/95
Depths:	0-2"	~2-12:	
Comments:			

Site number:S8
Date: 11/30/95
Time (auger): 9:50
Time (core):
Personnel: JLB, TO, RR, ZS
Quadrangle: Keyport
Formation:
Location:
Weather:
Soil series:
Sampler:
Hole Depth:

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
	blackish	clay	0-? in first 6"

COMMENTS
Abandon; no sample collected

Samples:	Date bottled:
Depths:	
Comments:	

Site number: S9 duplicate
Date: 11/30/95
Time (auger): 1135
Time (core):
Personnel: Szabo, Rosman
Quadrangle: Keyport
Formation: Englishtown
Location: woods behind IOC
Weather:
Soil series: KEB
Sampler:
Hole Depth: 4'

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS
Pounded core to 18" removed core barrel; dug out large cobble augering to 18". Resume coring to 4'.

Samples:	S9OD	Date bottled: 12/5
Depths	0-1":	
Comments:		

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: S-9 Dup
Date:
Time (auger): 11/30/95
Time (core):
Personnel: ZS, JLB, TO, RR
Quadrangle: Keyport
Formation: Englishtown
Location: IOC woods
Weather: cold, snow cover
Soil series:
Sampler:
Hole Depth:

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS

See S9 duplicate sheet

Samples:	Date bottled:
Depths:	
Comments:	

Site number: S9
Date: 11/30/95
Time (auger): 9:55
Time (core): 1040
Personnel: ZS, JLB, TO, RR
Quadrangle: Keyport
Formation: Englishtown
Location: IOC woods
Weather: cold, snow cover ~30 °
Soil series:
Sampler:
Hole Depth:

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
O	black	organic mat & sand	0-1"
A	dk grey 10YR 3/2	sandy, root hairs	1-12"
A2	yellowish tan 10YR 5/2	sandy loam; brown mottles begin @ 15"	12-18
B1	brown 7.5 YR 5/5	sandy loam; mottles - ironstone layer @ 19.5"	18-26
B2	yellow brown 10 YR 5/6	clayey sand; sandy, some clay	26-32
B3: or C	paler yellow tan	getting wet - W.T. @ 42"	32-57

COMMENTS

A horizon has faint sweetish smell - organic contaminant? Start second auger hole because of refusal @ 19.5"; second hole - refusal at same depth; start 3rd auger hole - Abandon, removed cemented layer in 2nd hole

Samples:	S9A	S9O	Date bottled: 12/5/95
Depths:	~2-10	0-11	
Comments:			

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: S10
Date: 11/30/95
Time (auger): 1318
Time (core): 1345
Personnel: Oden, Rosman, Szabo, JBarringer
Quadrangle: Keyport
Formation:Englishtown
Location: IOC woods
Weather:
Soil series:
Sampler: corer
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O			1 1/2
A	7.5 YR 3/2 dark brown	very root filled, fine sand	1 1/2 - 13"
B	10YR 6/3 pale brown	sandy, silty	13-18
C	10YR 5/1 gray	very silty, wet	18-27
C2	gray mottled clay		27-29
C3	10YR 6/8 brownish yellow;	coarse wet sand	29-38

COMMENTS

@ 27 mottled gray clay

Samples:	S10O	S10A	S10B1	S10C2	Date bottled: 12/5/95
Depths:	0-1	~2-10"	~14-17"	'27-29"	
Comments:					

Site number: S11 Repeat
Date: 2/7/96
Time (auger):
Time (core): 1143
Personnel: RR, TO
Quadrangle:
Formation: Englishtown
Location:
Weather: cold, clear, ~35°
Soil series:
Sampler: corer
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Sample taken
See S11 soil log

Samples:	S11RA	S11RE	S11Rb1	S11RC	Date bottled: 2/13/96
Depths:	~1-4"	~4-6	~8-15"	~31-36"	
Comments:	S11RC--small shiny flakes				

Site number: S11 Date: 12/11/95
Time (auger): 10:00
Time (core):
Personnel: ZS, TO, JLB, NS
Quadrangle: Keyport
Formation: Englishtown
Location: N of IOC woods
Weather: clear, very cold, 20 °s
Soil series: Evesboro
Sampler:
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	greyish brown 10YR 5/2	sandy	0-4"
E	yellowish brown 10YR 5/2-5/4	sandy	4-6
B_N	yellowish brown 10YR 5/6	sandy; cobbles & pebbles @ 14" & ironstone	6-30
C	greyish brown 10YR 5/3	sandy layer; wetter @ 40"	30-

COMMENTS

Will sample later - this area may have been orchard; No sample collected 12/11/95

Samples: Date bottled:
Depths:
Comments:

Site number: S12 Repeat Date: 12/7/96
Time (auger):
Time (core): 1125
Personnel: T Oden, R Rosman
Quadrangle: Keyport
Formation: Englishtown
Location: IOC woods
Weather: clear, cold 30's
Soil series: Evesboro
Sampler: corer
Hole Depth: 4 ft 3 inches

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A			
E			
B_W			
C?			
C			

COMMENTS

Moved hole 14 1/2 inches from previous ironstone @ 30" augered out next 4" reinserted @ 34" drove to 51"; no "O" horizon Frozen Top - A horizon top 5 inches put in Bag & labeled @ 1028

Samples:	S12RA	S12RAD	S12RE	RS12RB$_W$	S12RC	Date bottled: 2/14/96
Depths:	~1-8		~10-16	~20-30"	~47-50"	

Comments: S12RAD (duplicate/split)(from bag)

Site number: S12	Date: 12/11/95	Time (auger): 10:30	Time (core): 11:00
Personnel: JLB		Quadrangle: Keyport	Formation: Englishtown
Location: IOC woods			Weather: Clear, very cold, 20's
Soil series: Evesboro		Sampler: corer	Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	brownish grey 10YR 5/3	sand	0-9"
E	pale yellow 10YR 6/4	sand	9-18
B_W	orangey yellow 10YR 5/6	sand; cobbles & ironstone @ 27"; slightly wetter, faint mottles @40"	18-46
C?	greyer 10YR 5/3	sandy	46-57
C	grey 10YR 5/2	sand	57+

COMMENTS

Went to 2 ft, pulled out, augered past ironstone layer 26"-36" missing, reinserted corer @ 36"

Samples:	Date bottled:
Depths:	
Comments:	

Site number: S13 Repeat	Date: 2/7/96	Time (auger):	Time (core): 1408
Personnel: R Rosman, T Oden		Quadrangle: Keyport	Formation: Englishtown
Location:			Weather: clear cold 30's
Soil series: Evesboro		Sampler:	Hole Depth:4'

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Core catcher pushed into middle barrel. Only 1 ft of sample recovery. (middle barrel)
See S13 soil log

Samples:	S13RA	S13RB	S13RC1	Date bottled: 2/14/96
Depths:	~2-10	~15-22	~46-47"	
Comments: "O" (0-1")(horizon) frozen top bagged; S13RC1--taken from below ironstone fragments				

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: S13
Date: 12/11/95
Time (auger): 12/11/95
Time (core): 1145
Personnel: Tim Oden, Z Szabo
Quadrangle:
Formation:
Location: Imperial Oil Woods, briar patch near main trail
Weather: sunny, windy, cold ~20 °F
Soil series: Evesboro
Sampler: corer
Hole Depth: 4 ft

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	nearly black	sandy	0-1
A or E	10YR 4/3 dark brown, grading to 10YR 4/4 dark yellowish brown at 6"	sandy fine dry	1-12
B_1	7.5 YR 5/8 strong brown	sand, fine very; micaceous, no structure no pebbles, some roots, very dry	12-45
C_1	10YR 5/4 yellowish brown	sand, fine; mottled with strong brown & yellow dry	45-47
C_2	10YR 7/6 yellow	sand, fine to medium; mottled with yellowish brown; mottles large scale grainy black material or mica dry	47-55

COMMENTS

No O collected in jars w. trowell; Did not appear to reach C despite driving to 49" Compaction?

Samples:	Date bottled:
Depths:	
Comments:	

Site number: S14 Repeat
Date: 2/7/96
Time (auger):
Time (core): 1453
Personnel: R Rosman, T Oden
Quadrangle: Keyport
Formation:KEt Englishtown
Location: IOC woods
Weather: clear cold 30's
Soil series:Evesboro
Sampler: corer
Hole Depth: 24"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O			0-1

COMMENTS

"O" horizon "O"-1 - Frozen at surface. Sampled & bagged & Labeled ; wrong--will not drive any farther than 30; past 24 inches lost core catcher

Samples:	S14RO	S14RA	S14RB		Date bottled: 2/15/96
Depths:		0-1"	~2-9"	~20-24"	
Comments: S14RO--No S sample					

Site number: S14
Date: 12/11/95
Time (auger):
Time (core):
Personnel: N Smith, T Oden, Z Szabo
Quadrangle:
Formation: K Et
Location: clear patch woods, IOC
Weather: sunny, windy, cold ~25 °F
Soil series: Evesboro
Sampler: corer
Hole Depth: 3 '

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	nearly black	roots	0-1
A	10YR 4/2 dark grayish brown	sand, fine	1-10
E?	10YR 6/4 light yellowish brown	sand, fine	10-13"
	10YR 7/6 yellow	sand, fine	13-19"
B	10YR 6/6 brownish yellow	silt, w. fine sand; wet, sticks together-plastic	19-25"
	10YR 6/6	massive wet clay	25-31"

COMMENTS

No reason to go deeper; drive 3 ft, no reason to go too far in clay

Samples:
Date bottled:
Depths:
Comments:

Site number: S15 Repeat
Date: 2/7/96
Time (auger):
Time (core): 1220
Personnel: R Rosman, T Oden
Quadrangle: Keyport
Formation: Englishtown
Location: IOC woods
Weather: clear cold 30's
Soil series:
Sampler: corer
Hole Depth: 4'

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O			0-1

COMMENTS

O-Horizon o-1" sampled, bagged & labeled @ 1216
See S15 soil log

Samples:	S15RA	S15RB1	S15RB2	Date bottled:2/7/96
Depths:	~2-5"	'7-13"	~25-36"	
Comments:				

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: S15
Date: 12/11/95
Time (auger): 1446
Time (core):
Personnel: TO, ZS, JLB, NS
Quadrangle: Keyport
Formation:Englishtown
Location: IOC woods
Weather: clear, very cold, low 20's
Soil series:
Sampler:
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O		roots	0-1.5"
A	Brown 10YR 4/3	sandy	1.5-6
B1	yellowish brown 10YR 4/4	sandy	6-15
B2	orange brown 10YR 5/8	sand, some clay; pebbles: a few also roots wetter & siltier @ 32" more clay	15-37

COMMENTS

Samples:	Date bottled:
Depths:	
Comments:	

Site number: S16 clay
Date: 2/26/96
Time (auger):
Time (core): 1045
Personnel: TO, NPS
Quadrangle:
Formation: Englishtown
Location: N of IOC woods
Weather: sunny, warm (50's)
Soil series:
Sampler: split spoon
Hole Depth: 24"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Cleared leaves, drove split-spoon sampler to 24" BLS
See S16 soil log

Samples:	S16A	S16B	S16CL	Date bottled: 2/29/96
Depths:	~2-10"	~14-20	~30-34	

Comments: S16A--probably has a little O included, somwhat gradational A is V. organic W lots of roots, etc.; S-16CL--clay-silty clay, getting stiffer in depth composited ~ 4" at bottom of liner JLB

Site number: S16
Date: 2/12/96
Time (auger): 1427
Time (core): 1445 lost
Personnel: RR, NPS
Quadrangle: Keyport
Formation:
Location: woods near IOC
Weather: cold (20's), partly sunny, breeay
Soil series:
Sampler: corer
Hole Depth:24" lost sample

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	7.5 YR 3/2 dark brown	medium sandy loam	0-0.5
A	10 YR 4/3 brown	medium sand	0.5-12"
B	10YR 5/6 yellowish brown	fine sand, becoming a silty clay at 14" at 21:, some grayish clay mottles (10YR 5/1) virtually all silty clay from 14"-35"	

COMMENTS

Drove to 24", sampler came up empty - too clayey; "O" horizon bagged at 1433;
no sample

Samples:
Date bottled:
Depths:
Comments:

Site number: S17
Date: 2/12/96
Time (auger): 1500
Time (core): 1515
Personnel: RR, NPS
Quadrangle: Keyport
Formation:
Location: woods near IOC
Weather: cold (20's), partly sunny, breezy
Soil series:
Sampler: corer
Hole Depth: 19"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	7.5YR 3/2 dark brown	sandy loam	0-0.5"
	10 YR 4/3 brown	medium sand	0.5-12"
	10YR 5/6 yellowish brown	fine sand, bedding A silty clay at ~20", mottled with (10YR5/1 gray) clay 27"-37.5"	12-

COMMENTS

"O" Horizon bagged @ 1500; Drove sampler to 19" to avoid clay

Samples:	S17A	S17B1	Date bottled:2/20/96
Depths:	~2-9"	~13-18"	
Comments:			

Site number: S19 clay
Date: 2/26/96
Time (auger):
Time (core): 1025
Personnel: TO, NPS
Quadrangle:
Formation: Englishtown
Location: N of IOC woods
Weather: Sunny, warm (50's)
Soil series:
Sampler: split spoon
Hole Depth: 36"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Augered to 12", drove split spoon sampler to 36" BLS
See S19 soil log

Samples:	S19CL1	S19CL2	Date bottled: 2/29/96
Depths:	~20-25"	~29-35"	
Comments: S19CL1--yellow brown, stiff clay; S19CL2--mottled greyish clay & strongly orangey brown sand			

Site number: S19
Date: 2/13/96
Time (auger): 1230
Time (core): 1255 LOST, 1305 OK
Personnel: TO, NPS
Quadrangle:
Formation: E'town
Location: N of IOC woods
Weather: cold (20's), sunny, breezy
Soil series:
Sampler: corer
Hole Depth: 14 " LOST, 12" OK

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
O	7.5 YR 3/2 dark brown	organic, roots (frozen)	0-1
A	10 YR 4/3 brown	fine-medium sand	1-5
B	10YR 5/4 yellowish brown	slightly silty sand	5-10
	10YR 5/6 yellowish brown	silt	10-14
	10YR 5/6 yellowish brown	clay	14-28

COMMENTS

1" frozen soil removed before augering and bagged @ 1250; drove to 14" BLS, sampler empty; replaced liner and core-catcher in bottom section of sampler, drove to 12" - OK

Samples:	S19A	S19B	Date bottled: 2/16/96
Depths:	~2-5"	~6-10"	
Comments:			

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: S20 Duplicate
Date: 2/13/96
Time (auger):
Time (core): 1215
Personnel: TO, NPS
Quadrangle:
Formation:
Location: N of IOC woods
Weather: cold (20's), sunny, windy
Soil series:
Sampler:
Hole Depth: 44"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Removed 2" of frozen "O" at 1210 and bagged, sampler driven to 44"

Samples:	S20DA	S20DB1	Date bottled: 3/21/96
Depths:	~3-8	~12-15	

Comments: metals only sent to determine if there's systematic loss to liner walls over time. Hg will be over holding time; other metals OK

Site number: S20
Date: 2/13/96
Time (auger): 1130
Time (core): 1205
Personnel: TO, NDS
Quadrangle:
Formation: Englishtown
Location: woods near Imperial Oil
Weather: cold (20's), sunny, windy
Soil series:
Sampler: corer
Hole Depth: 44"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	7.5 3/2 dark brown	organic (frozen)	0-2"
A	10 YR 4/3 brown	fine-to-medium sand; some roots	2-10
B1	10YR 4/4 dark yellowish brown	fine-to-medium sand	10-16
B2	10YR 5/6 brownish yellow	fine-to-medium sand; roots at 27"; mottled with above horizon from 16-20	16-45
	10YR 5/6 yellowish brown	sandy silt; few roots, few small cobbles	45-53

COMMENTS

Drove sampler to 44" BLS; removed 2" of frozen "O" and bagged at 1200

Samples:	S20A	S20B1	Date bottled: 2/25/96
Depths:	~3-9"	~ 12-16"	

Comments:

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: S21
Date: 3/1/96
Time (auger): 1420
Time (core): none taken for sample
Personnel: Z Szabo/ T Oden
Quadrangle:
Formation:
Location: woods behind house - halfway to "S" "pit"
Weather: sunny 34 °F dry cold
Soil series: Keb on map - description appears to be Lakehurst LaA
Sampler:
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O	black	root mat	1
A	10YR 3/2 v. dark grayish brown	med sand w. roots; roots, friable	11
F	10YR 6/2 light brownish gray	med sand, quartzose	18
B_h	!0YR 5/3 brown	sand, med	20
B_w, B2	10YR 5/4 yellowish brown	sand, med, some sand fine	26
BC, B_3	10YR 6/3 pale brown	sand, fine some sand med; wet	
C	10YR 6/2 light brownish gray	sand, med - wet; at 41" mottled w. 10YR 7/4 & 7/6 sand very pale brown & yellow; at 48" mottles become 10YR 6/8; also standing water brownish yellow after about 45"; quit hole at 56"	

COMMENTS

Samples:
Date bottled:
Depths:
Comments:

Site number:
Date:
Time (auger):
Time (core):
Personnel:
Quadrangle:
Formation:
Location:
Weather:
Soil series:
Sampler:
Hole Depth:

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Samples:
Date bottled:
Depths:
Comments:

Site number: R1
Date: 2/28/96
Time (auger): 1115
Time (core): 1215
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: Under apple tree, front corner of lot
Weather: Cool, cloudy (40s)
Soil series: Keyport
Sampler: Corer
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10 YR 4/3 Brown	Medium sand	1-5"
B1	10 YR 5/4 Yellowish brown	Medium sand; few pebbles, roots near top of interval	5-21"
B1	10 YR 5/5 Yellowish brown	Medium sand	21-23"
B2	10 YR 5/6 Yellowish brown	Medium sand; many cobbles 23-38, ironstone, conglomerate (saved)	23-40"
B3	7.5 YR 5/6 Strong brown	Medium sand	40-46"
B3	10 YR 4/4 Dark yellowish brown		46-57"

COMMENTS

Removed 1" sod before augering, sampling; large ironstone conglomerate pulled from augered hole and saved.
Bottom 4" of sample lost with core-catcher.

Samples:	R1A	R91A	R1B1	R1B2	R1B3	Date bottled: 3/6/96
Depths:	1-5"		8-15"	23-28"	28-40"	

Comments: R1B2 mottled; R1B3 wet, more orangy, and more clayey sand. Many cobbles above and in samples. (Removed cobbles)

Site number: R1-Dup
Date: 2/28/96
Time (auger):
Time (core): 1330
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: Same as R1
Weather:
Soil series:
Sampler:
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		Same as R1	

COMMENTS

Removed 1" sod before sampling.
Core-catcher pushed up to top of bottom section of sampler; removed from sampler and bagged.

Samples:	R1DA	R1DB1	R1DB3	Date bottled: 3/6/96
Depths:	1-5"	8-15"	28-40"	

Comments:

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: R2
Date: 2/28/96
Time (auger): 1410
Time (core): 1450, 1510
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: Under apple tree
Weather: Cool, cloudy
Soil series:
Sampler: 2 split spoons
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10 YR 4/3 Brown	Medium sand	1-7"
B1	10 YR 5/6 Yellowish brown	Fine-medium sand	7-9"
B2	10 YR 4/6 Dark yellowish brown	Fine-medium sand; silty	9-42"
	7.5 YR 6/8 Reddish yellow	Fine-medium sand w/ clay	42-51"

COMMENTS

Removed 1" sod before augering, sampling; Pounded split-spoon sampler to 24" BLS, withdrew;
Pounded second split-spoon sampler from 23" to 48" BLS

Samples:	R2A	R2B1	R2B2	R2CL1	R2CL2	R92CL2	Date bottled: 3/4/96
Depths:	1-7"	8-12"	14-24"	26-30"	38-48"	48"	
Comments: R2CL2 just like clay beneath IOC woods, grey with mottles of red-orange silt							

Site number: R3
Date: 3/1/96
Time (auger): 1015
Time (core): 1200
Personnel: ZS, TO
Quadrangle: Keyport
Formation: ET
Location: contaminated corner 220
Weather: Sunny, cold (30), dry
Soil series: Keb from map; fill + keb from coring
Sampler: split spoon
Hole Depth: 32"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
Clay	10 YR 5/3 Brown	Clay, mottled w/ sand mixed in as orangish mottles	10"
	10 YR 6/6 Brownish yellow	for sandy mottles; clay blocks 7.5YR 5/2-brown; cinder material mixed thru clay, possible charcoal, blocky, mottled many roots	
fine black orgaic horizons		sand in places looks layered; sand very micaceous, large blocks of massive clay peds?	
	7.5 YR 5/2 brown	blocky clay dominant mixed w. copius black cinder? glass pieces; small amounts of bright intermixed sand 7.5YR 6/8 reddish yellow; clay & cinder; 15-20" sudden increase in slag/cinder amounts also presence of masses of granular white quartz abrupt change at 20" sudden disappearance of cinders;no sign of cinders below 20"	20"
Bt1	10YR 5/4 yellowish brown	clay, mixed thoroughly w. silt, some sand; roots, massive, occasionally blocky, occasional pebbles, no mottles	26"
Bt2	10YR 5/4 yellowish brown	clay, blocky, plastic, firm; mottled w. gray (10YR 6/1) & brownish yellow (10YR 6/8)	39"
Bt2-mottle	7.5 YR 6/8 reddish yellow	med. sand w. silt & plastic clay; wildly mottled w. gray 10YR 6/1, various shades of orange & 7.5 YR 5/4 brown; brown almost in layers or concentric bands around sand pockets; some 10YR 6/8 brownish yellow	41"

COMMENTS

1st 20" is possibly fill and 20" appears as natural B horizon

Samples:	R3	R3	R3	R3B2	R3A	Date bottled:3/6/96, 3/11/96,
Depths:	1-7"	7-10"	10-15"	20-32	1-20"	
Comments: R3B2, R3a core samples; rest auger samples. R3A not a true A horizon; clayey, some cinders, sand						

Site number:R3 spatial dup Date:3/1/96
Personnel:Z Szabo/T Oden/N Smith
Location: contaminated corner 220
Soil series: Keb + possible fill material

Time (auger):No
Quadrangle:Keyport

Sampler:split spoon

Time (core):1325
Formation: ET
Weather: sunny cold dry 30
Hole Depth: 37.5"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Same as R-3, spatial duplicate 18" away

Samples:	R3DA,	R3DB2	Date bottled:3/11/96
Depths:			
Comments: R3Da somewhat clayey, more cinders than R3A. R3DB2 sampled clay over larger interval than R3B2.			

Site number:R4 Date:3/1/96
Personnel: ZS, TDO, NPS
Location: near hole 2, 191 ppm site
Soil series: Keb

Time (auger):1445
Quadrangle: Keyport

Sampler: split spoon

Time (core): 1550
Formation: Englishtown
Weather: cold 35 sunny dry
Hole Depth: 36"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A? probably B1	10 YR 5/3 brown	silt; few roots, small amts clay	1-11"
B2	10 YR 5/3 brown	clay w. minor amts silt; 7.5 YR 5/6 strong brown, 10 YR 5/2 grayish brown at 14" becomes very blocky 7.5 YR 5/2 brown in color, at 21" bright 10 YR 6/8 brownish yellow mottles very common, at 28" becomes more 7.5 YR 5/3 brown, 10 YR 6/1 gray mottles more prevalent at 35-40"	11-44"

COMMENTS

Drove sampler to 36" BLS
Small cinders at 14"

Samples:	R4A	R4B2	R4CL2	Date bottled:3/11/96
Depths:	2-10"	12-20"	30-40"	
Comments:R4B2--Some cinders (?) + Brick specks but otherwise looks like clay at IOC woods w/ red silty stringers; R4CL2--Bottom of core, this is clay like that at IOC woods				

Site number: R5 Date: 3/4/96
Time (auger): 1050
Time (core): 1135
Personnel: T Oden, R Rosman
Quadrangle: Keyport
Formation: Englishtown
Location: Under tree swing in front yard, Orchard Pkwy
Weather: Sunny cold 20's
Soil series: Possibly Freehold
Sampler: 2 filled 3 ft corer
Hole Depth: 28"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10 YR 4/3 brown	roots, pebbles; Micaceous, roots, Silty	1-8"
B	7.5 YR 5/4 brown	Little mottled w/ 7.5 YR 5/8 strong brown; Micaceous, iron stones (Minor)	8-18"
Clay	10 YR 5/1 Gray	Mottle w/10 YR 5/8 yellowish brown	18-20"
C	10 YR 6/8 brownish-yellow	Sandy Strongly Silty; Iron Concretion, Pebbles, Cobbles, Minor Clay	20-28"
C	10 YR 4/3 brown	Sandy, little silt; iron ston conglomerate	28-34"
	10 YR 6/6 brownish yellow	Clean sand	34-40"
		Silty sand, ironstone, mica	40-

COMMENTS

Core catcher driven up into 3rd liner - silt/clay captured beneath it

Samples:	R5A	R5B	R5C	Date bottled: 3/7/96
Depths:	1-8	8-18	24-28"	

Comments: R5C--metals only - silt w/clay from bottom of hole - this is probably from 24 to 28"

Site number: R6 Date: 3/4/96
Time (auger): 1258
Time (core):
Personnel: T Oden, R Rosman
Quadrangle: Keyport
Formation: Englishtown
Location: Backyard near trees
Weather: Sunny cold low 30's
Soil series: Keyport
Sampler: cover
Hole Depth: Removed top 1" soil, 55"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/1 very dark gray	Fine sand, some roots	1-4
B1	2.5Y 4/4 olive brown	Roots fine sand	4-10
B2	2.5Y 5/4 light olive brown	Roots, medium sand	10-21
BC1 (B3)	10YR 6/2 light brownish-gray	Medium sand mottling; mottled w/ 10YR 7/1 light gray medium sand	21-26
	10YR 7/2 light gray	Fine medium sand, very clean	26-44
	10YR 7/2mottled with 10YR 5/6	Clean fine sand; mottles 10YR 5/6 yellowish brown ironstone pebbles @ 45	44
	10Y 5/8 yellowish-brown	fine, clean sand w/ ironstone	45-55

COMMENTS

Samples:	R6A	R6B1	R6B2	R6BC1	R6BC	Date bottled: 3/7 + 3/12/96
Depths:	1-4"	5-10"	12-18"	30-40"	45-55"	

Comments: R6B1--dk olive brown; R6B2--lighter olive brown; R6BC1--Bleached looking - light tannish gray; R6BC--orangey

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: R7
Date: 3/4/96
Time (auger): 1410
Time (core): 1500
Personnel: T Oden, R Rosman
Quadrangle: Keyport
Formation: Englishtown
Location: Backyard halfway up hill 10 feet from grove of trees
Weather: Sunny, cold, low 30's, windy
Soil series: Keyport
Sampler:
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/4 dark yellowish brown	Roots, cobbles, fine grained; Micaceous	1-7
A2	10YR 4/6 dark yellowish brown	Fine grained cobbles	7-12
B	10YR 5/8 yellowish brown	Silty cobbles wet, fine grained; cobble layer + ironstone @ 17" getting wetter w/depth, large boulder @ 28 augering next to hole	12

COMMENTS

Try 3 logs for hole couldn't get passed 25-28"; tried sampling it anyway pounded to 48 got 1 foot recovery too ~20-24"

Samples:	R7A	R7A2	R7B2	Date bottled: 2/11/96
Depths:	1-5"	5-7"	12 + 17	

Comments: upper layers may be disturbed; R7A2--bottom of soil horizon, at cobble layer which is at interface with clayey, silty, B horizon

Site number: R8
Date: 3/5/96
Time (auger): 0955
Time (core): 0-2' - 1020; 2-4' - 1045
Personnel: T Oden, R Rosman
Quadrangle: Keyport
Formation: Englishtown
Location: Looking at the house from Rd--Right side of Driveway 10' from Rd
Weather: Cloudy, cool, 45, breezey
Soil series: Keyport
Sampler: split spoon
Hole Depth: 48" Removed top 1" of soil

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/3 dark brown	very fine roots; Micaceous, little silty	1-5
B1	10 YR 5/8 yellowish brown	Silty, fine sand, blocky; iron pebbles, siltier with depth (13-18) less silty 18-	5-35
B2	10 Yr 5/8 yellowish brown	Mottled w/10YR 5/1 + 7.5 YR 6/8	35-39
Cl1+2	10YR 5/6 yellowish brown	Clay mottled w/sand; clay @ 45 10YR 5/1 gray	39-53

COMMENTS

Stopped augering @ 53"; split spoon samples

Samples:	R8A,	R8B1,	R8B2,	R8CL1,	R8CL2	Date bottled: 3/12/96
Depths:	1-5",	6-12",	35-39",	40-46"	46-50"	

Comments: R8B2--orangey silt, some clay; R8CL1--metals only - top of clay mixed w/some silt; R8CL2-clay w/silt blebs+stringers

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: R9
Date: 3/5/96
Time (auger): 1230
Time (core): 1250
Personnel: T Oden, R Rosman
Quadrangle: Keyport
Formation: Englishtown
Location: In front yard-5 feet from road in the middle of Circle Drive
Weather: Sunny, Cool, 45, breezey
Soil series: Keyport
Sampler: split spoon
Hole Depth: 32"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
O		Rooty, black; organic rich	1-2
A	10YR 4/4 dark yellowish brown	Minor roots few ironstone pebbles; ironstone pebbles, fine sand, siltier w/depth	4-10
B2	10YR 6/8 brownish yellow	Clayey, ironstone; extremely silty, massive iron stains	10-
C	10YR 6/8 mottled with 10YR 5/1 gray + 10YR 5/6 yellowish brown	Clayey, mottling; sand and clay mix; stopped @ 35"	26-

COMMENTS

Used magnatometer @ site; sprinkler system in front yard will stop between 18-24"; O sample @ 1233

Samples:	R9A,	R9B1,	R9B2,	R9CL1,	R9CL2	Date bottled: 3/13/96
Depths:	2-4"	4-10"	10-20"	28-30"	30-34"	

Site number: R10
Date: 3/5/96
Time (auger): 1330
Time (core):
Personnel: T Oden, R Rosman
Quadrangle: Keyport
Formation: Englishtown
Location: Backyard 15 feet east of shed in front of swing set
Weather: Sunny, warmer, 50-55
Soil series: Keyport
Sampler: split spoon
Hole Depth: 38"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 4/2 dark grayish brown	Wet rooty fine sand; few pebbles, little mica	1-3
B	10YR 6/6 brownish yellow	Silty sand; mottles 10YR 6/8 + 10 YR 5/1 appears to have some cinders, some iron stains, mottling @ 12"	3-15
CL1	Clay 10YR 5/1 gray mottled with 10YR 5/8 + 10YR 6/4	Clay becomes dominant; massive sand through the mix medium grains 7-5YR 6/8 reddish yellow	15-25
	10YR 8/6 yellow	little silt, fine grained sand; mixed with 10 YR 5/8 medium sand, 10YR 5/1 gray (very little)	25-27
CL2	10YR 5/2 TDO brown	massive; mottled clay	27-31
C	1-5YR 5/8 strong brown	medium sand intermixed; 59R 5/6 yellowish-red; the 5YR 4/6 seems to be a minor amount running through some clay mottles, sandy, silt clay 10YR 7/1 light gray	31-36

COMMENTS

Very intermixed hard to distinguish sandy silt 36-38; very intermixed hard to distinguish sandy silty clay 38-; extremely massive clay + silt stopped augering @ 46 inches

Samples:	R10A,	R10b,	R10CL1,	R10CL2,	RL10C	Date bottled: 3/7/96
Depths:	1-3"	4-12"	16-22"	25-27"	30-32"	

Comments: R10CL2--This is the same clay as that underlying 10Cw; R10C--metals only samples from 30-32" medium sand-orangey brown, some black bits in it, might be lignite

Site number: R11
Date: 3/11/96
Time (auger): 0950
Time (core): 1045, 1110
Personnel: RR, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: Between trees
Weather: Sunny, 20's
Soil series:
Sampler: Split spoons
Hole Depth: 2"-26, 26"-49"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
	7.5YR 3/3 dark brown	SOD	0-1"
A	10YR 5/6 yellowish brown, 7.5 YR 4/2 dark brown 3-color mottled, 10YR 5/1 gray	sandy clay, Micaceous; some roots, clay color moves to 10YR 5/2 grayish brown @ 10", ironstone at 16"	1"-16"
B1	one color sand, 10YR 5/6-25Y 5/6 light olive brown	fine-medium sand; some mica flecks as large as 1/16"; some black silty flecks @ 28"	16-30"
CL1+2	10YR 5/6 yellowish brown sand 10YR 5/2 grayish brown clay	sandy clay; some roots	30-48"
C	10YR 5/8 yellowish brown	medium sand	48-50

COMMENTS

Drove split-spoon sampler (cleaner one) from 2" BLS to 26" BLS, de-contaminated sampler, drove it (with new liner and catcher) from 26" BLS to 49" BLS

Samples:	R11A,	R11B1,	R11CL1,	R11CL2,	R11C	Date bottled: 3/15/96
Depths:	1-10"	16-25"	30-35"	36-42"	48-50"	

Comments: R11A--This is a mottled mixture of clay + sand - looks disturbed; R11B1--This looks like ordinary undisturbed B horizon; R11CL1--grey + brown clay - less silt than CL2 - mica flakes, mottled; R11CL2--the usual gray clay w/silty blebs; R11C--metals only, small sample of sand (E'town) from 50 +"

Site number: R12
Date: 3/11/96
Time (auger): 1240
Time (core): 1325, 1340, 1405
Personnel: RR, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: front yard in middle of group of trees (not apple trees)
Weather: Sunny, 20's
Soil series: Keyport
Sampler: split spoons
Hole Depth: 50"

DESCRIPTION

Horizon	Color	Texture	Thickness(in inches)
	10YR 3/2 very dark grayish brown	sod	0-2"
A	10YR 3/3 dark brown	fine sand	2-4
B1	10YR 4/4 dark yellowish brown	medium-fine sand	4-12
B2	10YR 6.5/6 brownish yellow	medium-fine sand	12-15
	10YR 5/6 yellowish brown	silty fine sand; some ironstone, mottled with 10YR 4/2 dark grayish brown 20-23", siltier at 36"-40", clayey at 40"-42"	15-42"
CL	grayish brown 10YR 5/2 clay yellowish brown 10YR 5/6 sand	mottled sandy clay roots	42-51"

COMMENTS

Pounded 3' sampler to 3', but lost part of sample down hole - recovered 1' sample; pounded split spoon from 2" to 32"; then de-contaminated sampler and drove from 32" to 50"

Samples:	R12E	R12B1	R12B2	R12C	Date bottled:3/15/96
Depths:	2-4"	6-12"	12-15"	42-48	

Comments: R12A--corer sample, metals toc, no S.; R12C--metals, TOC, no S. R12E should be R12A

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Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number:R13 Date:3/12/96
Personnel: TDO, NPS
Location: Backyard behind old shed
Soil series:

Time (auger): 0950
Quadrangle: Keyport
Sampler: corer

Time (core): 1040
Formation: Englishtown
Weather: sunny, cool(40's)
Hole Depth: 45"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 4/2 dark grayish brown	medium-fine sand	1-4"
B1	10YR 5/3 brown	medium-fine sand	4-10"
B2	10YR 5/3 brownish yellow	medium-fine sand; getting wet at 14", 10-14 grading from 10YR 5/3 to 10YR 6/6; some rocks 18-34:, getting silty at 24" (slightly); wet at 39"-52"	10-52"

COMMENTS

Bottle notes: B2U = upper part of B2
B2L = lower part of B2

Samples:	R13A,	R13B1,	R13B2U,	R13B2L	Date bottled: 3/15/96
Depths:	1-4"	4-10"	12-18"	28-38"	
Comments: R13A--TOC, metals no S.; R13B1, R13B2U, R13B2L--metals, TOC, S.					

Site number R13 Replicate: Date:3/12/96
Personnel: TDO, NPS
Location: back yard behind old shed
Soil series:

Time (auger):
Quadrangle: Keyport
Sampler:

Time (core): 1105
Formation: Englishtown
Weather: sunny, 40's
Hole Depth: 43"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Sample taken at 1055 lost down hole; took another at 1105, driving to only 43" BLS

Samples:	R13B1-dup,	R13B2U-dup	Date bottled: 3/15/96
Depths:	1-4"	12-20"	
Comments:			

Site number: R14 Date:3/12/96 Time (auger): 1135 Time (core): 1455
Personnel: TDO, NPS Quadrangle: Keyport Formation: Englishtown
Location: Back yard under old apple tree Weather: sunny, 40's
Soil series: Keyport Sampler: split spoon Hole Depth: 38"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/3 dark brown	medium-fine sand	1-8"
B1	10YR 5/4 yellowish brown	medium-fine sand; few cobbles, roots, getting wetter with depth	8-18"
B2	10YR 5/6 yellowish brown	slightly silty medium-fine sand; somewhat wet; some 10YR 4/2 dark grayish brown mottles; few quartz pebbles at 44" some grayish sandstreaks at 49-50"	18-52"
	10YR 4/2 dark grayish brown	clay with little sand	52-55"

COMMENTS

Pounded sampler to depth of 46", lost bottom foot of sample; pounded sampler to 40" - lost whole sample; pounded split spoon sampler to 38" BLS @ 1455 - good recovery

Samples:	R14A,	R14B1,	R14B2	Date bottled: 3/15/96
Depths:	2-8"	9-18"	30-37"	

Site number: R15 Date: 3/13/96 Time (auger): 1000 Time (core): 1100, 1120
Personnel: RR, NPS Quadrangle: Formation:
Location: Orchard Pkwy, front yard Weather: sunny, mid 50's
Soil series: Sampler: split spoons Hole Depth: 35" BLS, 51" BLS

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 4/2 dark, grayish brown	very fine sand; grass-root mat first 2-3"	0-5"
B	10YR 4/2 dark grayish brown till 10"	10YR 5/3 brown 10"; very fine sand-lightens at 10"; ironstone + some black cinders present	5-10"
B1	10YR 5/6 color change at 14" to yellow brown	very fine sand minor dark-silt; sample still moist, cobbles present	10-16"
B	10YR 5/8 yellowish brown matrix with colored silt as above sandy silt same as above	less moisture massive and few cobbles; increase in 10YR 5/1 gray silt lose olive brown silt	23-33"
CL1	silty sand	crumbling sand, very little moisture; increase in 10YR 4/1 dark gray silt decrease in 5/1 gray silt	33-38"
CL2		very tight gray clay with 10YR 5/8 yellowish brown sand; 5YR 5/8 yellowish red sand, dark gray silt still present (as above) new gray 10YR 7/1 lite gray silt very minor at about 42";	38-43"
		43-47" layer of very fine 7.5 YR 5/8 strong brown;	43-47"
		47-50" tight massive clay with rusty colored sand; 10YR 5/3 brown clay clinging to clay	47-50"
	10 YR 5/1 gray clay; 10YR 5/2 grayish brown to 54"	50-54" mottled gray with rust orange sand (10YR 5/8 yellowish brown sand)	50-54"

COMMENTS

Samples:	R15A	R15B1	R15CL1	R15CL2	Date bottled: 3/15/96
Depths:	1-5"	10-16"	38-40"	43-50"	
Comments: Note: "cinders" are v. small blackish pcs. of iron oxides, also lignite bits.					

Site number: R15 replicate   Date: 3/13/96   Time (auger):   Time (core): 1155, 1215
Personnel: RR, NPS   Quadrangle: Formation:
Location: Orchard Pkwy, front yard   Weather: sunny, warm (50's)
Soil series: Sampler: split spoons   Hole Depth: 2"-35", 35-50"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Removed 2"sod, drove to 35" BLS with split spoon; de-contaminated spoon, drove from 35" to 50"

Samples:	R15DA,	R15DB1,	R15DCL1	R15DCL2	Date bottled: 3/20/96(R15DA,
Depths:	1-5"	10-16"	38-40"	45-50"	R15DCL1)
Comments:	R15DB1--metals +S only; R15DCL2--metals + S only				bottled 3/21/96

Site number: R16   Date:3/13/96   Time (auger): 1325   Time (core): 1415, 1425
Personnel: RR, NPS   Quadrangle: Keyport   Formation: Englishtown
Location: Orchard Parkway, back yard   Weather: sunny, 50's
Soil series: Keyport   Sampler: split spoons   Hole Depth: 1-34", 34-53"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 4/3 brown	fine-medium sand; some roots throughout, cobbles	2.5-9"
B1	10YR 5/6 yellowish brown	medium-fine sand; pebbles, small ironstone bits, damp 10-12", 2-3" cobbles 16-20"	9-25"
B2	few 10R 3/2 dusky red mottles 24"; iron concretions 25-28"		
	7.5 YR 5/6 strong brown	sandy silt; mottled with 10YR 4/3 brown clay throughout	25-34"
CL1	10YR 4/3 brown	clay	34-47"
CL2	mottled with 7.5 YR 5/6 strong brown sandy silt	water at 45"	

COMMENTS

Bagged continuous augered sample from 36-41"; drove 1st spoon to 34", drove 2nd from 34-53"

Samples:	R16A	R16B1	R16CL1	R6CL1	R16CL2	Date bottled: R16A+B1 3/15/96, R16CL1 + R16CL2 3/20/96
Depths:	3-9"	10-16	25-28		40-50"	
Comments:						

Site number: R17
Date: 3/18/96
Time (auger): 0950
Time (core): 1050
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: Orchard Parkway under apple tree close to driveway
Weather: sunny, cool, 50
Soil series: Keyport
Sampler: corer
Hole Depth: 40" bottom 5.5" lost

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/3 dark brown	medium sand; some fine roots	1-5"
B1	10YR 5/8 yellowish brown	silty sand; few quartz pebbles some 7.5 YR 2/0 black; 10YR 3/3 dark brown mottles, few ironstone pebbles; large ironstone concretions at 15"	5-28
B2	10YR 4/3 brown	medium-fine sand	28-32"
	2.5Y light ollive brown	medium-fine sand	32-40"
	10 YR 6/6 brownish yellow	medium-fine sand	40-56"

COMMENTS
Sampler retrieved; found bottom of bottom liner bent up inside core; core-catcher driven into middle liner. Hole measured, depth of 40". Upper liner empty.

Samples:	R17A	R17B1	R17B2	Date bottled:3/20/96
Depths:	2-5"	10-20"	25-35"	
Comments:				

Site number: R18
Date: 3/18/96
Time (auger): 1134
Time (core): 1315
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: Orchard Parkway, apple tree east side of house
Weather: clear, sunny, 50's
Soil series: Keyport
Sampler: split spoon
Hole Depth: 46"

DESCRIPTION			
Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/3 dark brown	medium fine sand; few cobble, some roots, wet	1-12"
B1	2.5 Y 5/4 light olive brown	wet, few pebbles, some mottles 10YR 2/1 black; pebble, cobble layer @ 18	12-25"
B2	10YR 5/6 yellowish brown	drier, silty medium sand; some mottles 10YR 4/3 brown/ dk brown, small ironstone? flecks	25-35"
C	10YR 5/6 yellowish born	drier medium sand; graditional w/layer above, some cobbles, small ironstone flakes?	35-38"
CL1	10YR 5/6 yellowish brown	med.-fine sand; mottled clay 10YR 5/1 gray, ironstone + quartz pebbles; lots of small black flakes + chips, water in hole, very wet	38-45"
CL2	10YR 4/2 dark grayish brown	clay, dry, intermixed w/sand 10YR 5/6 yellowish brown; 1 1/2 water in hole	45-50"

COMMENTS
Sampled with auger bit twice without success. Drove split-spoon sampler to 46" BLS - Just filled liner to top

Samples:	R18A	R18B1	R18B2	R18CL1	R18CL2	R18C	Date bottled: 3/25/96
Depths:	2-12	13-24	26-34	34-45	45-49	35-38	
Comments:							

Site number: R19
Date: 3/18/96
Time (auger):
Time (core): 1430
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: NE corner of lot on lawn
Weather: sunny, warm (50's)
Soil series: Keyport
Sampler: split spoon
Hole Depth: 42"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 5/3 brown	fine silty sand; some black cinders	1-7"
CL	10YR 5/3 brown	clayey fine sand; blockier with depth , brownish yellow 10YR 5.5/1 gray clay mottles, black cinders 10YR 6/8 mottles 12"-23", more prevalent with depth	7-23"
CL	10YR 4/2 dark grayish brown	massive clay; brownish yellow 10YR 6/8 mottles, (up to 34" less with depth); more mottles 34"-52"	23-52"

COMMENTS

Pounded split-spoon sampler from 1" to 42" BLS; sampler full + 1/2"

Samples:	R19A	R19CL1	R19CL2	RL19CL3	R19CL4	Date bottled: 3/20/96, 3/21/96
Depths:	1-6"	8-12"	12-20"	24-30"	42-50"	
Comments:						

Site number: R20
Date: 3/22/96
Time (auger): 0920
Time (core): 1010
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: Orchard Parkway under apple tree
Weather: cloudy, cool, 40, breezy
Soil series: Keyport
Sampler: corer
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		sod	0-1"
A	10YR 3/3 dark brown	medium sand; some roots	1-17"
B1	10YR 5/3 brown	medium sand	17-22"
B2	10YR 5/3 brown and 10YR 4/2 dark grayish brown and 10YR 5.5 yellowish brown	medium sand; evenly mottled with three colors	22-26"
B3	10YR 5.5/5 yellowish brown	medium sand; few pebbles, weathered; ironstone layer at 45"	26-49"
	10YR 6/6 brownish yellow	medium sand	49-58"

COMMENTS

Samples:	R20A	R20B1	R20B2	R20B3	Date bottled:3/26/96
Depths-	2-17	18-22	23-26	35-45	

Site number: R20 Duplicate
Date: 3/22/96
Time (auger):
Time (core): 1020
Personnel: TDO, NPS
Quadrangle:
Formation:
Location: Orchard Parkway under apple tree
Weather: mostly cloudy, cool (40's)
Soil series:
Sampler:
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)

COMMENTS

Top liner empty

Samples:	Date bottled:
Depths:	
Comments:	

Site number: R21
Date: 3/22/96
Time (auger): 1100
Time (core): 1130
Personnel: TDO, NPS
Quadrangle:
Formation:
Location: hot spot back of garden
Weather: mostly cloudy, cool (40's)
Soil series:
Sampler: cover
Hole Depth: 48"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 3/3 dark brown	medium sand; some roots, cinders from 5"-16"; slightly silty 12"-16"	0-22"
B1	10YR 5/4 yellowish brown	medium sand; slightly mottled with 10YR 3/2 very dark grayish brown silty sand; wet from 35"-48"	22-48"
B2	10YR 6/6 brownish yellow	medium sand; wet throughout, hole collapsing	48-51"

COMMENTS

Top liner empty, core-catcher driven to top of middle liner

Samples:	R21A	R21A1	R21B1	R21B2	Date bottled: 3/27/96
Depths:	1-10"		22-30"	48-51"	
Comments:					

Site number: R22
Date: 3/22/96
Time (auger): 1300
Time (core): 1350
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: hot spot between house & garden
Weather: partly sunny, 40's
Soil series: Keyport
Sampler: split spoon
Hole Depth: 38"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 4/2 dark grayish brown	medium sand; cinders, big black ants, little glass; slightly silty 13"-18"	0-18"
B1	10YR 4/3 brown	silty medium sand; cinders; not silty 25"-30"	18-30"
B2	2.5Y 5/4 light olive brown	medium sand; some roots 36"-40"; wet throughout; hole collapsing to 40"	30-51"

COMMENTS

Bagged several samples at various depths; also bagged cinders from land surface near hole, and in garden

Samples:	R22A,	R22b1,	R22B2	Date bottled: 3/27/96
Depths:	1-12"	18-28"	32-42"	

Comments:R22A--has some mica flakes; R22B1--cinders, concrete(?) bits flecks of brick also mica; R22B2--sandy, little or no debris visible

Site number: R23
Date: 3/25/96
Time (auger): 1005
Time (core): 1115
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: backyard hot spot
Weather: sunny, warm (50's)
Soil series: Keyport
Sampler: split spoon
Hole Depth: 38"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
A	10YR 4/2 dark grayish brown	slightly silty medium-fine sand; numerous pebbles top of interval, some cinders	0-9"
CL1	10YR 5/3 brown	clay; mottled with 7.5 YR 5/6 strong brown clay; 10YR 4/2 sand; and 10YR 3/2 v. dark grayish brown medium-fine sand; few cinders	9-12"
CL2	10YR 4/6 dark yellowish brown	clay w/ ; mottled with 10YR 4/2 medium sand; some cobbles at 15"	12-18"
S	7.5YR 5/8 strong brown	sandy clay; few pebbles 18-22"	18-23"
S	10YR 5/8 yellowish brown	silty medium sand; wet at 30", not silty 30"-54"	23-54"

COMMENTS

Samples:	R23A	R23CL1	R23CL2	R23S	Date bottled: 3/27/96
Depths:	1-8"	9-12"	13-18"	25-30"	

Comments: R23CL1--brown, some cinders - some concrete (set aside in baggy); R23S--Silty layer beneath clay

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

Project: Imperial Oil
SOIL SAMPLING FIELD SHEET

Site number: R24
Date: 3/25/96
Time (auger): 1135
Time (core): 1340
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: front yard hot spot
Weather: sunny, warm (50's)
Soil series: Keyport
Sampler: split spoon
Hole Depth: 38"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		sod	0-1"
A	10YR 4/3 brown	slightly silty sand; some roots, few cinders, siltier with depth, slightly clayey	1-13"
B	10YR 5/3 brown	silt; slightly mottled with 10YR 4/1 dark gray clay	13-15"
CL	10YR 5/2 grayish brown	clay; some roots at 21-30" mottled with 7.5YR 5/8 strong brown clay at 35", clay becomes quite massive; 1 piece of 10YR 6/2 light brownish gray, 40", size 1 cubic inch	15-52"

COMMENTS

Samples:	R24A	R24CL1	R24CL2	Date bottled: 3/27/96
Depths:	2-10"	16-24"	40-50"	
Comments:				

Site number: R27
Date: 4/24/96
Time (auger): 0945
Time (core): 1035
Personnel: TDO, NPS
Quadrangle: Keyport
Formation: Englishtown
Location: backyard under fruit tree
Weather: sunny, cool (50), windy
Soil series: Keyport
Sampler: split spoon
Hole Depth: 36"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		sod	0-1"
A	10YR 2/2 very dark brown	slightly silty medium sand; roots	1-3"
B	10YR 5/8 yellowish brown	fine sandy silt; few cobbles, few roots; at 17", little mottles of 10YR 6/2 light brownish gray clay through to 30"	3-30"
CL1, CL2		water at 25"	
C	7.5YR 5/7 strong brown	medium-coarse sand; mixed with some 10YR 5/3 brown clay at 37-46", small amounts of 10YR 7/1 light gray medium-coarse sand; 20.5" water standing in 46" hole	30-46"

COMMENTS

1" sod removed before sampling

Samples:	R27A	R27B	R27CL1	R27CL2	R27C	Date bottled: 4/25/96
Depths:	1-3"	4-12"	17-23"	26-30		
Comments:						

Site number: OB1 Date: 4/17/96 Time (auger): 1045 Time (core): 1145
Personnel: TDO, NPS Quadrangle: Formation:
Location: Lloyd Rd., ~20' from trunk of apple tree Weather: partly sunny, breezy, 40's
Soil series: Sampler: split-spoon Hole Depth: 42"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
Loamy A	10YR 4/3 brown	medium sand; few cobbles, roots	0-6
Probably disturbed JLB A	clay: 5YR 3/1 very dark gray Sands: 10YR 3/4 dark	mix of clay and medium-fine sands (2 colors sand)	6-22
CL1	at 20", 7.5 YR 4/6 strong brown	clay mottles appear for only ~2"	
B	10YR 4/3 brown	medium sand; small amounts of silt - 10 YR 5/4 yellowish brown	22-25
B	10YR 5/4 yellowish brown	slightly silty medium sand	25-30
CL22	10YR 4/3 brown	sandy silt; mottled with 7.5 YR 5/8 strong brown medium sand grades into a silty clay at about 38"	30-49

COMMENTS

Augered to 56"; from 49"-54" a sandy, orangey layer was bagged

Samples:	OB1LA	OB1A	OB1CL1	OB1B	OB1CL22	Date bottled: 4/18/96
Depths:	~2-6:	6"-22"		22-30"	~45	
Comments:OB1LA--loam, some sand; OB1A--more sandy; OB1CL1--upper clay-like local clay-greyish w. stringers of silt, mica flakes, prob. distrbed, lg H2 pebble in clay "lignite" bits also; OB1B--sandy layer; OB1CL22--lower part of 2nd clay samples - typical grey clay w. silt stringers						

Site number: OB2 Date: 4/24/96 Time (auger): 1120 Time (core): 1205
Personnel: TDO, NPS Quadrangle: Keyport Formation:
Location: N.W. side of house under neighbor's appletree canopy Weather: sunny, 50's, breezy
Soil series: Sampler:split spoon Hole Depth: 38"

DESCRIPTION

Horizon	Color	Texture	Thickness (in inches)
		sod	0-1
A	10YR 3/3 dark brown	medium-fine sand; fine roots	1-4
B	10YR 6/6 brownish yellow	slightly silty fine sand; color grading slowly from 4-9" to 10YR 6/6, from 10YR 3/3 pebbles at 15" ironstone conglomerates; color goes to 10YR 5/8 yellowish brown from 20"-25"	4-25
CL1	10YR 5/4 brown	fine sandy clay; mottled with 10YR 5/1 gray clay; 1" diameter root at 30"; black clay laminae at 31" (2.5YN 2/0)	25-43
CL2		ironstone at 33-34:; few pebbles	
	10YR 5/8 yellowish brown	fine sandy silt	43-51

COMMENTS

Augered to 56"; from 49"-54" a sandy, orangey layer was bagged

Samples:	OB2A	OB2B	OB2CL1	OB2CL2	Date bottled: 4/24/96
Depths:	~1-4	~6-10"	~25-30	~30-38	
Comments:					

APPENDIX 2

Sample Collection, Preparation, and Documentation

Soil-Sampling Procedures

The sampling sites were selected by using aerial photographs, GIS coverages, and, in most cases, a site visit. At the time of sampling, the site was checked carefully for disturbance of soil, such as evidence of bulldozing or excavation activity, and trash that might indicate either disturbed soils or potential sources of sample contamination. The soils map for the sampling site was checked (either Powley, 1987, or Jablonski and Baumley, 1989), and the expected soil series description was reviewed.

The soil sample was collected by using the following procedure.

1. Preparation of a clean sampling area

   A clean plastic tarp was spread near the area where sampling would take place. The sampling equipment, stored in sealed plastic bags, was placed on it. A second plastic sheet was laid on the ground where the sampling would take place.

2. Removal of leaf litter or lawn

   The leaf litter was removed with a clean stainless-steel trowel or a plastic rake, and was set aside. If the sampling took place on a lawn, a cylinder of grass was removed and set aside; this was used to cover the hole when sampling was completed.

3. Description of soil horizons

   A clean bucket auger was used to collect soil samples. The samples were examined in order to describe the soil horizons, to determine the depths at which they are found, and to compare the results with descriptions of the soil series mapped at that location. The depths at which the different horizons were encountered were determined by augering until the bucket was full, removing the auger, and tipping it upside down at an angle of about 30° to the ground. The bucket was tapped to loosen the soil, which was scooped or dumped out onto the plastic sheet in about 2-in. intervals. The soil was examined closely for change in color, signifying a change in horizon. Because the height of the bucket is known, the depth of a soil change in the bucket could be measured, and the depth of the hole was measured with each bucket load. Therefore, the depth of a change in horizon could be determined with an accuracy of ±1 in., which is adequate for the purposes of description. The Munsell Color Chart was used to assign a color code to each soil horizon. The texture, induration, structure, and mottling (if present) of each horizon was described on the field form for each site. Pebble layers or other unusual features were noted as well. Augering continued to a depth of at least 4 ft, or to the C horizon, whichever was encountered first. If the augering revealed the presence of fill material, buried waste, or absence of soil horizons, the sampling location was abandoned except in the case of soils at the Imperial Oil Company Superfund site, where virtually all soils are disturbed. In all cases, the soil collected on the plastic sheet was returned to the hole and tamped down.

4. Information required for the field form

   The description of the soil horizons was matched to descriptions of expected soil series. Weather conditions, an estimate or measurement of air temperature, time of augering, and time at which the coring began also were recorded on the field sheet.

5. Documentation of the location of the sampling site

   A description of the sampling site was recorded, and the location was marked on a map of the area. The site was flagged, and the sampling-site designation was written on the flagging.

6. Use of latex gloves to ensure that samples are not contaminated during collection

   The field team typically consisted of two persons, one of whom wore clean gloves at all times for handling sampling equipment that had been previously decontaminated, and for handling the butyl acetate corer liners and the sample bottles. All field personnel wore disposable gloves to minimize contact with the soils, particularly when sampling near IOC and at orchard sites, where elevated concentrations of metals might be encountered; however, one of the pair was responsible for maintaining clean gloves during sampling, and handling only the decontaminated equipment, the core liners, and sample jars.

7. Collection of O-horizon sample

   A second area for coring was selected within about 2 ft of the auger hole. The leaf litter or grass was removed as before. If an O horizon was present, a sample of O-horizon soil was collected with a clean stainless-steel trowel by field personnel wearing disposable gloves. A small square of soil was outlined with the trowel, which was then used to cut through the root mat. The soil sample was placed in a sample jar, which was capped immediately and labeled with the sample number, date, and time. The jars were placed in a clean cooler with plastic freezer packs.

8. Collection of soil sample with the corer

   The corer was removed from the sealed plastic bag by a field person wearing fresh disposable gloves. The person with the clean gloves held the corer while other field person attached the slide hammer to the corer cap. The corer was placed vertically in the area to be sampled and driven into the soil by using downstrokes of the slide hammer.

   When the desired depth was reached with the corer, the corer was retrieved by upward strokes of the slide hammer. The corer was placed in a plastic bag, which was labeled with the sample-site designation, to await transport to the field vehicle, while other samples were collected with the second and (or) third corers at a nearby location. All sample holes were filled with available soil or clean coarse sand and tamped down. In the case of lawns, the grass plug was replaced.

9. Recovery of core from the corer and sample labeling

When sampling was complete, each corer was carried back to the field vehicle and placed on a plastic sheet in the vehicle. The field person with the clean gloves opened a plastic zip bag containing prewashed red and blue plastic caps, retrieved the butyl acetate liners, one by one, and capped them after the corer head was removed by the other member of the field team. Gloves were changed between samples. As each liner was capped (a red cap at the lower end and a blue cap at the top end), it was labeled with the sample-site designation and an "up" arrow, and individual horizons, if visible, were labeled.

10. Sample transport from the field

The capped liners were placed upright in a clean cooler with plastic freezer packs for transport. Upon arrival at the USGS, New Jersey District, laboratory, the liners were refrigerated until the soil samples were processed for shipment to the contract laboratory.

11. Coring through pebble layers

Because some of the soils encountered in the study area contain pebble layers or indurated horizons at depth, additional steps sometimes were needed to ensure sampling through the entire soil profile. If it proved impossible to drive the corer through one of these layers, the corer was retracted from the hole and laid on clean lab wipes on a clean plastic sheet. A clean, decontaminated bucket auger was removed from its plastic bag, and the hole was enlarged to the depth of the layer where refusal occurred. The auger was used to remove the pebbles or indurated material. If this could not be done, a field person, wearing clean gloves, reached into the hole and attempted to remove the pebbles or indurated material. If this was successful, the corer was disassembled as described above, and the filled liners capped and labeled as above. Then new, clean liners and a core catcher were placed in the corer. The hole, which was now larger in diameter than when coring began, was checked for loose material, and the corer was inserted and driven to the final depth. In this case, when the core liners were retrieved, the first 1 to 3 in. of soil collected in the upper liner were discarded, as they might contain fragments of soils from upper levels of the hole. This departure from the sampling procedure was noted on the field sheet, and the place in the soil profile where the core was not continuous was labeled on the butyl acetate liners. If the pebble or indurated layer could not be removed by using the above procedure, the sample site was moved several feet distant, and coring with a new, clean corer began.

Equipment-Decontamination Procedures

One of the objectives of the study was to determine metals contents of undisturbed soils in long-term forested areas. The metals contents of such soils may be substantially lower than those of soils in the immediate vicinity of IOC; therefore, sampling and handling procedures that minimized contact of these soil samples with metallic substances needed to be used, particularly as the soils in the study area are known to be strongly acidic. 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 posing an increased potential for low-level contamination of samples. The decontamination procedures described below are in accordance with the NJDEP Field Sampling Procedures Manual (New Jersey Department of Environmental Protection, 1992), but no acid-washing steps were used.

1. Cleaning procedure for butyl acetate liners and plastic caps

   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, described above.

2. Decontamination of the steel sampling equipment

   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. Decontamination of steel trowels and steel bucket augers

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

4. 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

The soil samples 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:

a. The field sheet for each sample site was examined to determine which horizons were encountered during collection of the auger sample prior to coring; the number of horizons to be extracted was determined.
b. The laboratory countertop was covered with clean laboratory paper wipes, which were changed between horizons. Disposable gloves were worn at all times and were changed between horizons.
c. 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 the small amount of O horizon that might be present as well as any soil that represented the interface between O and A horizons. A-horizon 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 the A and the next horizon (E or B, depending on soil series). Any large roots or pebbles were removed and discarded.
d. 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, a plastic jar for total-sulfur analysis, and a plastic bag for lead-isotope 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, at least 10 g in the TOC jar, at least 10 g in the total-sulfur jar, and at least 5 g in the lead-isotope bag.
e. For the next horizon within the liner (typically either E or B1), 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 for the A horizon, described above, was repeated.
f. Any soil material remaining on the walls of the liner from each horizon, as well as any soil remaining in the glass bowl after the previous sample jars were filled, was collected in a separate jar for identification of minerals and for grain-size analysis.

g. 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.

h. The sample jars were placed in a clean cooler with freezer packs; the coolers were transmitted to NJDEP personnel.

i. 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. COC forms are not required for total-sulfur, Pb-isotope, clay-mineralogy, or grain-size samples.

j. Any remaining sample material was stored in a refrigerator at the USGS, New Jersey District, laboratory or warehouse 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 are photocopied periodically and the copies are filed.

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 number
- sample location plotted on topographic map (attached)

- date and time the auger sample was collected
- date and time the core sample was collected
- brief description of the site
- weather conditions
- description of sampling procedures that deviate from SOP, problems encountered, or other observations relevant to conditions encountered at the sampling location
- log of the soil horizons encountered during augering with measurements of depths at which horizons were encountered and descriptions of soil textures and grain sizes
- identification of soil series
- name of USGS topographic quadrangle on which site is located
- map showing sample location (attached to the field sheet).

Field-data sheets were completed when the core samples were extracted and soil-horizon samples were bottled. Information added at this time included

- horizon sample number (core sample number + horizon designation)
- date sample was processed.

Copies of field sheets are filed separately from the original field sheets. Data from field sheets are included in appendix 1.

Sample Containers and Labels

Samples were not preserved, and sample containers were prescribed in advance by NJDEP.

a. All TAL-metals samples were placed in the glass jars provided by the laboratory contracted by NJDEP; the jars were labeled in advance by NJDEP.
b. All TOC samples were placed in the glass jars, which were labeled and provided in advance by NJDEP.
c. All total-sulfur samples were placed in plastic jars provided by USGS.
d. All Pb-isotope samples were placed in plastic bags provided by USGS.

Sample labels were securely affixed to the sample container. They clearly identify the sample, and include the following information:

- site name and project number
- sample number (core sample number + horizon designation)
- date and time the sample was collected
- analysis requested
- sampling location.

Sulfur and Pb-isotope containers were labeled with the same information as that placed on TAL and TOC sample containers.

Chain of Custody Record

COC forms are supplied by NJDEP to USGS. A COC Record was maintained from the time of sample collection until final disposition. Every transfer of custody was noted and signed for, and a copy of the record was kept by each individual who signed it.

Authorized signatures

> The soil cores were placed by the field personnel in the custody of the Task Manager/Project Chief, Julia L. Barringer, who was responsible for the core samples until they were processed and the sample bottles were transmitted to NJDEP for shipment to the analyzing laboratory.

Chain of custody requirements for various sample types

> A COC Record is maintained for each of the horizon samples (subsets of the core samples) that were bottled and sent for TAL and TOC analysis. COC Records were necessary only for those samples sent for TAL analysis, because the metals constitute the contaminants investigated during this study. TOC analyses were used only to define the naturally occurring organic-matter contents of the soils (twigs, rootlets, humic and fulvic substances), which were used as an explanatory variable when assessing the metals contents of the various soil horizons. Although COC Records are not deemed necessary to account for a naturally occurring material, they were maintained because the TOC analyses were performed by using a USEPA method that specifies a certain holding time and other strict adherences to analytical protocols. COC Records were deemed unnecessary for samples analyzed for total sulfur, Pb isotopes, clay mineralogy, or grain size because these constituents/characteristics are not contaminants.

The COC Records include at least the following information:
- sample identification
- sample location
- sample-collection date
- sample information, such as matrix and number of bottles collected
- signatures of all individuals who had custody of the samples.

Custody Seal

When samples were not under direct control of the individual currently responsible for them, they were stored in a locked container that was sealed with a Custody Seal. Custody Seals demonstrate that a sample container has not been opened or tampered with. The individual who had custody of the samples signed and dated the seal and affixed it to the container in such a manner that it could not be opened without breaking the seal.

Sample Shipment

NJDEP personnel arranged for contract couriers to deliver samples to the contract laboratories.

APPENDIX 3

Preliminary Air-Emission Model

The air-emission model is based on the following equation, which is a double Gaussian distribution used in most models of this type (Christian, 1995).

$$C = Q/2\ \pi\mu\sigma_y\sigma_z\ \mathrm{exp}\ (-1y^2/2\ \sigma^2{}_y)\{\mathrm{exp}(-1/2(z-H)^2/\sigma^2{}_z) + \mathrm{exp}(-1/2\ (z + H^2)/\sigma^2{}_z)\}\ ,$$

where C = point concentration, mg/m^3;
H = virtual stack height (stack height + plume rise), m;
Q = mass flow of contaminant, $\mu g/s$;
u = wind speed, m/s;
x,y,z = ground level coordinates of stack, m;
σ_y = standard deviation from mean path in y plane, m;
σ_z = standard deviation from mean path in z plane, m.

The local meteorological conditions are placed into six stability classes:

A = very unstable
B = moderately unstable
C = slightly unstable
D = neutral
E = slightly stable
F = stable.

The conditions that relate to these stability classes are shown in table 1, below (Turner, 1970).

Table 1. Stability classifications for local meteorological conditions

[A through E, stability classes; <, less than; >, greater than; m/s, meters per second]

Surface wind speed (m/s)	Day, solar insolation	Day, solar insolation	Day, solar insolation	Night, cloudiness	Night, cloudiness
	Strong	Moderate	Slight	Cloudy	Clear
<2	A	A-B	B	E	E
2-3	A-B	B	C	E	E
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

The standard deviations σ_y and σ_z are calculated by:

$$\sigma_y = ax^b$$

$$\sigma_z = cx^d + f \ .$$

The curve-fitting parameters a through f are given in table 2, below (from Martin, 1986).

Table 2. Parameters used to calculate standard deviations for each stability class

[x, distance from source; <, less than; >, greater than; km, kilometer; A through F, stability classes; a through f, curve-fitting parameters]

Stability class	x < 1 km	x < 1 km	x < 1 km	x < 1 km	x < 1 km	x > 1 km	x > 1 km	x > 1 km
	a	b	c	d	f	c	d	f
A	213	0.894	440.8	1.941	9.27	459.7	2.094	-9.6
B	156	0.894	106.6	1.149	3.3	108.2	1.098	2
C	104	0.894	61	0.911	0	61	0.911	0
D	68	0.894	33.2	0.725	-1.7	44.5	0.516	-13
E	50.5	0.894	22.8	0.678	-1.3	55.4	0.305	-34
F	34	0.894	14.35	0.74	-0.35	62.6	0.18	-48.6

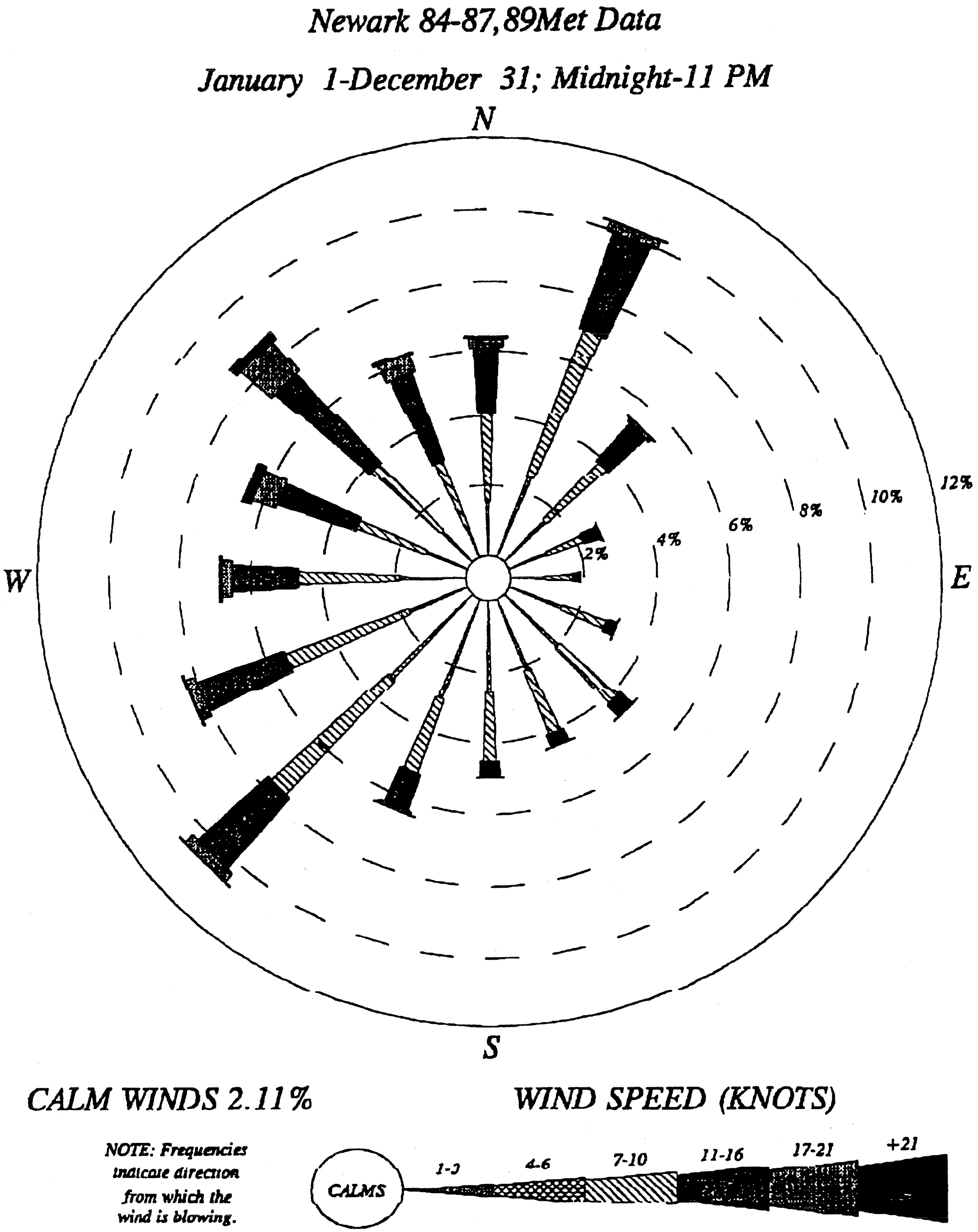
The summary table of wind data for Lakehurst, New Jersey (station 14780), for the years 1973-82, used in the USGS interpretation and simulation, is given below (table 3); a windrose summarizing wind data for Newark Airport, 1984-87 and 1989, used in the NJDEP simulation, is shown in figure 1.

Table 3. Percent frequency of wind direction and speed, from hourly observations, Lakehurst, New Jersey, 1973-82.

[Number of observations = 24,066; Dir., direction; N/A, not applicable; VAR, variable directions and speeds; a blank space indicates no entry; windspeeds greater than 40 knots were not recorded during the period of record--therefore, those columns are not reproduced from the data summary; data table is supplied by the Naval Weather Service, Asheville, North Carolina]

Dir.	Speed (knots)								All speeds (percent)	Mean wind speed
	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40		
N	1.6	1.6	0.7	0.1			0.0		3.9	4.5
NNE	1.1	1.1	0.4	0.1					2.7	4.5
NE	1.0	1.1	0.9	0.1					3.0	5.2
ENE	0.9	1.3	1.1	0.3	0.0	0.0			3.6	6.1
E	1.2	1.7	1.1	0.3	0.0	0.0			4.3	5.7
ESE	0.9	1.3	0.7	0.0					2.9	5.0
SE	0.9	1.5	1.0	0.1	0.0				3.5	5.4
SSE	1.3	1.3	1.0	0.3	0.0	0.0			3.9	5.6
S	1.8	2.2	1.9	0.7	0.1	0.0			6.6	6.3
SSW	1.1	1.5	1.4	0.6	0.0				4.6	6.3
SW	1.4	1.5	1.5	0.5	0.0				5.0	6.2
WSW	1.3	2.1	1.8	0.8	0.1	0.0			6.1	6.8
W	2.4	3.2	3.9	2.6	0.5	0.1	0.0	0.0	12.7	7.9
WNW	1.7	2.2	3.0	2.2	0.4	0.1	0.0		9.7	8.3
NW	1.4	2.2	2.8	1.8	0.3	0.1			8.5	8.0
NNW	1.3	1.7	1.4	0.5	0.0	0.0				
VAR									4.9	6.1
CALM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	14.1	
Total*	21.3	27.3	24.5	10.8	1.5	0.4	0.1		100.0	5.7

*Columns do not sum to totals due to rounding.



Newark 84-87,89Met Data

January 1-December 31; Midnight-11 PM

NOTE: Frequencies indicate direction from which the wind is blowing.

Figure 1. Windrose summarizing wind-speed and wind-direction data for Newark Airport, New Jersey, 1984-87 and 1989.

APPENDIX 4

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. A generalized summary of the data-validation process is given below.

Results of analyses of standard reference materials submitted as blind samples and of duplicate and split samples are given below. Results of analyses of equipment wash blanks are included. Conclusions regarding the quality of the analytical work also are presented.

Data-Validation Process

The data-validation process consists 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 summary form below, with a general level of detail given for the steps of particular importance to this project.

1. Sample holding times
    - A. Requirements
        - a. Metals: 180 days
        - b. Mercury: 26 days
    - B. Evaluation
        - a. Rejection: samples analyzed after the holding time for a particular analyte
        - b. Qualified: samples analyzed up to 10 days after the holding time
        - c. Acceptance: not rejected

2. Initial instrument calibration
    - A. Requirements
        - a. Daily calibration: for inductively coupled plasma-atomic emission spectroscopy (ICP-AES), calibration is done according to manufacturer's specifications
        - b. One blank and eight standards in graduated amounts are used for mercury analysis by cold-vapor atomic absorption spectroscopy (CVAA)
    - B. Evaluation

    a. Rejection: calibration not performed or the initial calibration-solution results are outside the range of 65 to 135 percent of the known values
    b. Qualified: initial calibration-solution results are outside the acceptance range of 90 to 110 percent but within the range of 65 to 135 percent of the known values
    c. Acceptance: not rejected

3. Continuing calibration verification
  A. Requirements
    a. Calibration is performed every 2 hours or for every 10 percent of sample load, whichever is more frequent
  B. Evaluation
    a. Rejection: initial calibration-solution results are outside the range of 65 to 135 percent of the known values
    b. Qualified: calibration not performed or initial calibration-solution results are outside the acceptance range of 90 to 110 percent but within the range of 65 to 135 percent of the known values
    c. Acceptance: not rejected

4. Analyses of required detection level standards
  A. Requirements
    a. Analysis is performed twice every 8 hours or for every run with a sample load, whichever is more frequent, after analysis of the initial calibration standard
  B. Evaluation
    a. Rejection: standard analysis is not performed or standard-solution result is outside the range of 30 to 175 percent of the known value
    b. Qualified: standard solution is analyzed before the calibration solution or standard-solution result is outside the acceptance range of 80 to 120 percent but within the range of 30 to 175 percent of the known value
    c. Acceptance: not rejected

5. Initial and continuing calibration blank
  A. Requirements
    a. Analysis of blank after analysis of the initial and each successive continuing calibration standard
  B. Evaluation
    a. Rejection: analysis of initial calibration blank is not performed or result is greater than the contract-required detection limit
    b. Qualified: analysis of continuing calibration blank is not performed after analysis of each successive continuing calibration standard solution analyzed
    c. Acceptance: not rejected

6. Laboratory process blanks and field blanks
  A. Requirements
    a. Process blank is analyzed after analysis of 20 samples of a given matrix

    b. One field blank is collected and analyzed per sampling date for aqueous samples. (NJDEP does not require field blanks for soil samples.)
  B. Evaluation
    a. Rejection: (1) analysis of process blank not performed or (2) result of blank analysis is greater than the contract-required detection limit (CRDL) and the result of sample analysis is less than 10 times greater than the result of blank analysis or (3) the result of blank analysis is greater than the instrument detection limit but less than the CRDL and the result of sample analysis is less than 3 times greater than the result of blank analysis
    b. Qualified: (1) analysis of process blank is not performed after 25 sample analyses or (2) the result of blank analysis is greater than the CRDL and the result of sample analysis is more than 10 times greater than the result of blank analysis or (3) the result of blank analysis is greater than the instrument detection limit but less than the CRDL and the result of sample analysis is more than 3 times greater than the result of blank analysis
    c. Acceptance: not rejected

7. ICP-AES interference-check-sample analysis
  A. Requirements
    a. Analysis of two check samples (major cations, metallic trace elements) twice every 8 hours or for every run with a sample load, whichever is more frequent, after analysis of the initial calibration standard
  B. Evaluation
    a. Rejection: check-sample analysis is not performed or standard-solution result is outside the range of 50 to 150 percent of the known value
    b. Qualified: check sample is analyzed 8 to 12 hours after the initial calibration solution or standard solution result is outside the acceptance range of 80 to 120 percent but within the range of 50 to 150 percent of the known value, and steps are being taken to adjust the instrument to generate results within the acceptance range of 80 to 120 percent
    c. Acceptance: not rejected

8. Spiked-sample analysis
  A. Requirements
    a. Spiked sample is analyzed after analysis of 20 samples of a given matrix
    b. One spiked sample is used for each analytical method employed
  B. Evaluation
    a. Rejection: analysis of spiked sample is not performed or spiked-sample recovery is outside the range of 30 to 200 percent of the expected amount
    b. Qualified: analysis of spiked sample is not performed until after 25 sample analyses, or an inappropriate spike concentration is used, or result is outside the acceptance range of 75 to 125 percent but within the range of 30 to 200 percent of the expected amount
    c. Acceptance: not rejected

9. Post-digestion spike recovery

A. Requirements
  a. Analysis of post-digestion spiked sample if pre-digestion spike recovery is outside the acceptance range of 75 to 125 percent and the sample result does not exceed four times the concentration of the added spike

B. Evaluation
  a. Rejection: analysis of post-digestion spiked sample is not performed when required by unacceptable results of pre-digestion spiked sample analysis or the post-digestion spiked-sample recovery is outside the range of 30 to 200 percent of the expected amount
  b. Qualified: inappropriate spike concentration is used or analysis result is outside the acceptance range of 75 to 125 percent but within the range of 30 to 200 percent of the expected amount
  c. Acceptance: not rejected

10. Duplicate samples

A. Requirements
  a. Analysis of a duplicate sample after analysis of 20 samples of a given matrix

B. Evaluation
  a. Rejection: analysis of duplicate sample is not performed
  b. Qualified: analysis of duplicate sample is not performed until after 25 sample analyses or duplicate result is outside the range of +/- 20 percent of the paired sample
  c. Acceptance: not rejected

11. Laboratory control samples

These quality-assurance sample types are required only for an aqueous matrix.

12. ICP-AES serial dilution analyses

A. Requirements
  a. Analysis of a five-fold dilution sample after analysis of 20 samples of a given matrix

B. Evaluation
  a. Rejection: analysis of dilution sample is not performed or, for an analyte with a concentration more than 50 times the instrument detection limit, the difference between the initial analysis result and the normalized dilution result is greater than 100 percent
  b. Qualified: analysis of duplicate sample is not performed until after 25 sample analyses or, for an analyte with a concentration more than 50 times the instrument detection limit, the difference between the initial analysis result and the normalized dilution result is greater than 10 percent
  c. Acceptance: not rejected

13. Graphite furnace atomic absorption quality assurance

This technique was not used for this study.

14. Quarterly verification of instrument parameters
    A. Requirements
        a. A suite of analyses verifying instrument detection limits, linear ranges, and interelement corrections for ICP-AES analyses must be completed quarterly
    B. Evaluation
        a. Rejection: analyses are not performed
        b. Qualified: analyses are performed as much as 15 days late
        c. Acceptance: not rejected

15. Verification of sample-analysis result

    The accuracy of data computation and transcription, validity of calibration curves, and correct usage of data codes are checked. The evaluation is described in detail in the unpublished NJDEP manual (on file at NJDEP office in Trenton, New Jersey) and is too complex to review here.

16. Preparation log
    A. Requirements
        a. Submit one form describing in detail quality-control preparations, weights, and volumes for every 32 preparations
    B. Evaluation
        a. Rejection: logs are not submitted
        b. Acceptance: not rejected

17. Analysis-run log
    A. Requirements
        a. Submit one form describing in detail a run containing field samples and quality-assurance samples for every 32nd batch
    B. Evaluation
        a. Rejection: logs are not submitted
        b. Acceptance: not rejected

Results of Quality Assurance

1. Field-equipment blanks

    A worst-case contamination scenario for the field-equipment blanking program was assumed where 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. Only samples FB10 and FB11 are washblanks from the split-spoon and corer cutting heads alone (see table 1), and these also constitute a worst-case scenario in that both the inside and outside of the cutting heads were rinsed, whereas the sample comes in contact only with the interior of the cutting head.

The field-equipment blanks were collected in the U.S. Geological Survey, New Jersey District, laboratory because that was the location of all sampling of soil cores, all bottling of samples, and most of the equipment decontamination.

Some of the field blanks were found to be slightly contaminated with iron and chromium after contact with the sampling equipment. Maximum iron concentrations were about 123 ppb (or 0.12 ppm), and maximum chromium concentrations were less than 10 percent of the iron concentrations. Field blanks containing the highest chromium concentrations were from a batch of samples in which the laboratory preparation blank contained chromium. Both iron and chromium are common contaminants in aqueous blank samples in contact with stainless-steel pumping equipment or stainless-steel screens used in water sampling (Tamara Ivahnenko, U.S. Geological Survey, written commun., 1996; Stoughton, 1966). Constituent concentrations in soils were reported in parts per million. Therefore, the amounts of iron and chromium noted in the worst-case contamination scenario are barely detectable by the analysis of the soil samples. Furthermore, the concentration of iron was generally greater than 1,000 ppm in the soil samples, or at least four orders of magnitude greater than the largest measured iron content of a soil sample. In general, the chromium concentration of the soil was also several orders of magnitude greater than the measured level of contamination. See table 1 (this appendix) for analytical results.

2. Sample-processing (sample-homogenization bowl) splits

   The significant amount of contact of the sample with the surface area of the glass bowl used for sample homogenization could result in sample cross-contamination by adsorption of metals or soil particles from samples to the side of the glass bowl. Cleaning techniques used for the sample-homogenization bowls were evaluated to determine the levels of contamination associated with sample processing.

   Six sets of split samples (three splits, each of which was split into two samples) were prepared in the sample-homogenization bowls after various cleaning techniques were used. Two split samples were prepared in a sample-homogenization bowl after one of the three following cleaning techniques was used: (1) acid wash and deionized-water rinse, (2) soap wash and deionized water rinse, and (3) soap wash and tapwater rinse. Chemical analysis of the split samples resulted in no significant differences regardless of the cleaning technique used, indicating the sample-homogenization bowl was unlikely to be a source of contamination (see table 2, this appendix). The soap wash and deionized-water rinse technique was used throughout the study to maintain consistency with the cleaning technique used for the field-sampling equipment, although the results of analysis of the split samples indicate a tapwater rinse would have been adequate.

3. Analysis of Standard Reference Materials submitted blind

Three Standard Reference Materials (SRM Montana Soil 2711, SRM San Joaquin Soil 2709, and SRM Estuarine Sediment 1646a) containing a wide range of arsenic and metallic-trace-element concentrations were submitted blind to the contract laboratories. Analytical results generally were within the range of accepted values for the mild acid leaching of SRM 2711 and SRM 2709. No mild-acid-leaching results are available for SRM 1646a; analytical results for this SRM were used to compare accuracy among laboratories. See tables 3 and 4, this appendix, for analytical results and evaluation.

4. Data-validation results

Antimony-concentration data for many of the samples were rejected because of low spike recovery; therefore, these data were not used in the study. Silver-concentration data commonly were rejected, or were negated (considered as undetected) because of low spike recovery or preparation-blank contamination. Silver-concentration data were not used in this study. Sodium-concentration data were negated for some samples because of contamination of preparation blanks. Sodium-concentration data are reported, but were not used in any statistical models. Some of the laboratory preparation blanks were contaminated with chromium; however, this contamination was not large or frequent enough to warrant rejection of the chromium-concentration data.

Arsenic- and lead-concentration data from one batch were rejected. These analyses were subsequently performed by another laboratory and results were acceptable. Analytical results for many constituents in one batch of 20 samples were found to be of questionable quality; the entire batch was rerun by the laboratory, using new equipment. The results of the reanalysis were acceptable. Only the acceptable data from these batches are presented in appendix 1.

Many of the data are 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 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 ICP serial dilution percent recovery was outside specified limits.

Therefore, high or low biases may exist in some of the data. For most of the qualified data, the bias is unknown. Because the samples were analyzed in batches of 20 that typically contained samples from two or three different land uses, there appears to be no systematic bias introduced into the data; rather, the biases are randomly distributed. See table 4 (this appendix) for evaluation of analytical precision and accuracy.

5. Field replicates

Data are presented in appendix 1. Variability in constituent concentrations in samples from adjacent soil cores is large, to the degree that adjacent soil cores (spatial duplicates) can be considered independent observations. Nevertheless, the variability between duplicates generally is not larger than the variability between samples from different land uses.

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

[All concentrations in micrograms per liter (parts per billion); letters I, O, GS, EE following FB in sample identifiers have the following meaning: I, interior of sampler; O, exterior of sampler; GS, washblank using U.S. Geological Survey analyte-free water; EE, washblank using contract laboratory analyte-free water. U, below instrument detection limit; B, detectable but below contract-equipment detection limit; *, interior assembled 3-foot corer; **, interior assembled split spoon; : , 3-foot corer head only; : *, split spoon head only; Al, aluminum; 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; V, vanadium; Zn, zinc]

Sample identifier	Sample date	Al	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Hg	Ni	K	Na	V	Zn
FB1*	951207	11.3 U	3.1 B	5.4 U	0.31 B	0.30U	143 U	0.60U	1.4 U	1.0 U	17.8 B	1.6U	137 U	0.50 U	0.10 U	1.4U	136 U	187 U	1.6 U	1.3 B
FB2*	951207	11.3 U	2.8 U	5.4 U	0.28 B	0.30U	143 U	0.60U	1.4 U	1.0 U	10.6 U	1.6U	137 U	0.68 B	0.10 U	1.4U	136 U	187 U	1.6 U	2.2 B
FB3*	960215	11.3 U	3.3 B	5.4 U	0.49 B	0.30U	143 U	2.2 B	1.4 U	1.0 U	24.2 B	1.6U	137 U	0.50 U	0.10 U	3.1 B	136 U	187 U	1.6 U	1.1 B
FBGS*	960215	122 B	4.7 U	0.80U	0.11 U	0.30U	122 B	5.7 B	0.80U	0.60U	89.7 B	2.3 U	92.4 B	0.20 U	0.20 U	2.9 B	35.5 B	223 B	0.80U	0.50U
FBEE*	960215	87.6 B	4.7 U	1.4 B	0.11 U	0.30U	94.8 B	0.40U	0.80U	0.60U	52.1 B	2.3 U	71.1 B	0.20 U	0.20 U	1.5U	25.1 U	174 B	0.80U	0.50U
FB4I**	960304	13.5 B	2.8 U	5.4 U	0.10U	0.36 B	143 U	0.60U	1.4 U	3.4 B	28.7 B	1.6U	137 U	0.61 B	0.10 U	1.4U	136 U	187 U	1.6 U	1.7 B
FB5O**	960304	44.1 B	2.8 U	5.4 U	0.10U	0.32 B	1660 B	0.60U	1.4 U	7.0 B	105	7.6	137 U	4.2 B	0.10 U	1.4U	192 B	187 U	1.6 U	5.1 B
FB6*	960304	11.3 U	2.8 U	5.4 U	0.10U	0.30U	143 U	8.0 B	1.4 U	1.0 U	39.9 B	1.6U	137 U	0.82 B	0.10 U	3.1 B	136 U	336 B	1.6 U	1.4 B
FB8**	960425	30.5 B	3.7 U	0.75B	0.31 B	0.70U	63.1 U	2.0 B	0.70U	1.3 B	123	2.1 U	114 B	2.1 B	0.10 U	1.2 B	499 U	651 U	0.50U	0.40U
FB10: *	960516	21.0 U	3.7 U	1.7 B	0.30U	0.70U	63.1 U	0.50U	0.72B	0.50U	11.8 U	2.1 U	88.3 U	0.11 U	0.10 U	1.1U	725 B	708 B	0.50U	1.7 B
FB11:	960516	21.0 U	3.7 U	0.70U	0.30U	0.70U	65.4 B	3.0 B	0.70U	0.64B	18.2 B	2.1 U	88.3 U	0.36 B	0.10 U	1.1U	562 B	817 B	0.89B	1.4 B

Table 2. Concentrations of constituents measured in splits of B-horizon soils (E15D) mixed in bowls cleaned using three preparations

[Concentrations in milligrams per kilogram (parts per million). U, below instrument detection limit; B, detectable, but less than contract-required detection limit; *, soap-and-tapwater, acid-washed, deionized water wash; **, soap-and-tapwater, deionized water wash; : soap-and-tapwater wash; Al, aluminum; 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; V, vanadium; Zn, zinc]

Sample number	Sample date	Al	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Hg	Ni	K	Na	V	Zn
S1*	960422	3650	6.0	8.2 B	0.14 B	0.17 U	22.3 B	5.7	0.71 B	7.5	10700	16.3	223 B	11.2	0.09 B	1.4 B	674 B	210 B	15.0	8.0
SS1*	960422	3050	5.5	7.5 B	0.12 B	0.17 U	40.1 B	4.9	0.42 B	7.9	7630	17.0	161 B	7.1	0.12 B	1.2 B	550 B	164 B	13.5	7.9
S2**	960422	3890	6.4	8.9 B	0.12 B	0.17 U	34.6 B	5.9	0.61 B	7.9	9600	16.7	242 B	9.5	0.12	1.4 B	773 B	251 B	15.9	7.8
SS2**	960422	4250	6.0	9.7 B	0.13 B	0.17 U	36.0 B	6.4	0.54 B	8.6	11400	17.0	241 B	9.5	0.09 B	1.5 B	742 B	224 B	15.7	11.1
S3:	960422	3330	6.6	8.0 B	0.12 B	0.16 U	39.1 B	5.4	0.55 B	7.7	9920	17.2	184 B	7.4	0.12	1.3 B	614 B	170 B	15.7	8.9
SS3:	960422	3350	5.2	7.7 B	0.15 B	0.16 U	24.6 B	5.8	0.66 B	7.7	15000	16.5	201 B	7.8	0.07 B	1.4 B	662 B	199 B	15.3	11.0

Table 3. Concentrations of constituents measured in splits of B-horizon soils (E15D) mixed in bowls cleaned using three preparations

[Concentrations in milligrams per kilogram (parts per million).U, below instrument detection limit; B, detectable, but less than contract-required detection limit; *, soap-and-tapwater, acid-washed, deionized water wash; **, soap-and-tapwater, deionized water wash; : soap-and-tapwater wash; Al, aluminum; 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; V, vanadium; Zn, zinc]

Sample number	Sample date	Al	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Hg	Ni	K	Na	V	Zn
S1*	960422	3650	6.0	8.2 B	0.14 B	0.17 U	22.3 B	5.7	0.71 B	7.5	10700	16.3	223 B	11.2	0.09 B	1.4 B	674 B	210 B	15.0	8.0
SS1*	960422	3050	5.5	7.5 B	0.12 B	0.17 U	40.1 B	4.9	0.42 B	7.9	7630	17.0	161 B	7.1	0.12 B	1.2 B	550 B	164 B	13.5	7.9
S2**	960422	3890	6.4	8.9 B	0.12 B	0.17 U	34.6 B	5.9	0.61 B	7.9	9600	16.7	242 B	9.5	0.12	1.4 B	773 B	251 B	15.9	7.8
SS2**	960422	4250	6.0	9.7 B	0.13 B	0.17 U	36.0 B	6.4	0.54 B	8.6	11400	17.0	241 B	9.5	0.09 B	1.5 B	742 B	224 B	15.7	11.1
S3:	960422	3330	6.6	8.0 B	0.12 B	0.16 U	39.1 B	5.4	0.55 B	7.7	9920	17.2	184 B	7.4	0.12	1.3 B	614 B	170 B	15.7	8.9
SS3:	960422	3350	5.2	7.7 B	0.15 B	0.16 U	24.6 B	5.8	0.66 B	7.7	15000	16.5	201 B	7.8	0.07 B	1.4 B	662 B	199 B	15.3	11.0

Table 4. Concentrations of constituents measured in splits of B-horizon soils (E15D) mixed in bowls cleaned using three preparations

[Concentrations in milligrams per kilogram (parts per million).U, below instrument detection limit; B, detectable, but less than contract-required detection limit; *, soap-and-tapwater, acid-washed, deionized water wash; **, soap-and-tapwater, deionized water wash; : soap-and-tapwater wash; Al, aluminum; 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; V, vanadium; Zn, zinc]

Sample number	Sample date	Al	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Hg	Ni	K	Na	V	Zn
S1*	960422	3650	6.0	8.2 B	0.14 B	0.17 U	22.3 B	5.7	0.71 B	7.5	10700	16.3	223 B	11.2	0.09 B	1.4 B	674 B	210 B	15.0	8.0
SS1*	960422	3050	5.5	7.5 B	0.12 B	0.17 U	40.1 B	4.9	0.42 B	7.9	7630	17.0	161 B	7.1	0.12 B	1.2 B	550 B	164 B	13.5	7.9
S2**	960422	3890	6.4	8.9 B	0.12 B	0.17 U	34.6 B	5.9	0.61 B	7.9	9600	16.7	242 B	9.5	0.12	1.4 B	773 B	251 B	15.9	7.8
SS2**	960422	4250	6.0	9.7 B	0.13 B	0.17 U	36.0 B	6.4	0.54 B	8.6	11400	17.0	241 B	9.5	0.09 B	1.5 B	742 B	224 B	15.7	11.1
S3:	960422	3330	6.6	8.0 B	0.12 B	0.16 U	39.1 B	5.4	0.55 B	7.7	9920	17.2	184 B	7.4	0.12	1.3 B	614 B	170 B	15.7	8.9
SS3:	960422	3350	5.2	7.7 B	0.15 B	0.16 U	24.6 B	5.8	0.66 B	7.7	15000	16.5	201 B	7.8	0.07 B	1.4 B	662 B	199 B	15.3	11.0

Table 5. Range and median of reported values* and analytical results for National Institute of Standards and Technology Standard Reference Materials (SRM) submitted as blind samples

[Al, aluminum; As, arsenic; Ba, barium; Cd, cadmium; Ca, calcium; Cr, chromium; Co, cobalt; Cu, copper; Fe, iron; Pb, lead; Mg, magnesium; Mn, manganese; Ni, nickel; K, potassium; Na, sodium; V, vanadium; Zn, zinc; wt.%, weight percent; ppm, parts per million; <, less than; N/A, data not available]

SRM*/ blind sample	Al, wt.%	As, ppm	Ba, ppm	Cd, ppm	Ca, wt.%	Cr, ppm	Co, ppm	Cu, ppm	Fe, wt.%	Pb, ppm	Mg, wt.%	Mn, ppm	Ni, ppm	K, wt.%	Na, wt.%	V, ppm	Zn, ppm
Montana Soil 2711*	1.2-2.3; 1.8	88-110; 90	170- 260; 200	32-46; 40	2.0-2.5; 2.1	15-25; 20	7-12; 8.2	91-110; 100	1.7-2.6; 2.2	930-1500; 1100	0.72-0.89; 0.81	400-620; 490	14-20; 16	0.26-0.53; 0.38	0.02-.029; 0.026	34-50; 42	290-340; 310
MONS	2.03	94.9	191	36.1	2.1	21.3	8.6	107	2.23	1070	0.77	476	15.1	0.51	0.028	48.5	300
M2711	1.25	103	203	44.8	2.18	12.9	8.6	119	1.41	1130	0.717	525	15.5	0.406	0.03	27.5	329
MS2711	1.33	89.5	171	35.4	1.94	13.9	7.7	101	1.60	1020	0.65	450	13.8	0.38	0.051	28.8	283
San Joaquin Soil 2709*	2.0-3.3; 2.6	<20	392-400; 398	<1	1.4-1.7; 1.5	60-115; 79	10-15; 12	26-40; 32	2.5-3.3; 3.0	12-18; 13	1.2-1.5; 1.4	360-600; 470	65-90; 78	0.26-0.37; 0.32	0.063-0.11; 0.068	51-70; 62	87-120; 100
SJS	2.91	16.4	391	<0.06	1.47	75.4	12.2	32.0	3.14	13.3	1.36	462	70.9	0.45	0.046	77.0	94.1
SJ2709	1.90	16.1	411	1.1	1.46	59.5	13.0	33.3	2.51	11.3	1.27	494	75.2	0.407	0.091	60.6	96.0
SJ2709	2.60	16.8	384	0.08	1.42	72.0	12.6	31.8	2.98	12.9	1.29	465	71.6	0.43	0.049	70.5	93.9
Estuarine Sediment 1646a*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ES&S	0.723	5.5	20.2	<0.05	0.369	21.7	4.2	9.6	1.69	8.0	0.318	109	18.5	0.217	0.396	21.7	36.8
ES1646a	0.436	5.7	16.5	0.68	0.343	17.4	4.0	9.7	1.35	7.2	0.28	97.9	18.0	0.181	0.416	16.6	40.3
E1646A	0.502	5.0	16.3	<0.05	0.345	19.3	3.9	10.8	1.50	7.9	0.278	97.7	18.0	0.191	0.389	17.6	36.3

Table 6. Results of statistical analyses of quality-assurance samples

[Al, aluminum; Ag, silver; As, arsenic; Ba, barium; Be, beryllium; Cd, cadmium; Ca, calcium; Cr, chromium; Cu, copper; Fe, iron; K, potassium; Mg, magnesium; Mn, manganese; Na, sodium; Ni, nickel; Pb, lead; Sb, antimony; Se, selenium; V, vanadium; Zn, zinc; TM, trace metals; PQL, practical quantitation limit; IDL, instrument detection limit; SRM, standard reference material; %, percent; ppb, parts per billion]

Type of sample and number of samples (x)	Purpose, results, and conclusions
Spatial duplicates (33)	**Purpose**: To determine variability in results between soil samples from cores collected from adjacent sites. **Results, As**: Range of difference from the mean is 0 to 87%, median 24%. Highly variable: about one-half the samples have a difference of more than 25%. As extremely variable in samples from residential area 1, less variable in samples from residential area 2. Least variability in A-horizon samples.. **Results, TM**: Median difference from the mean 12 to 14.5% for Al, Fe, Mg, and Zn, 15 to 17.5% for Ba, Cr, Cu, K, and V, and 18 to 20% for Ca, Pb, Mn, and Ni. Pb extremely variable in samples from residential area 1, generally less variable in samples from residential area 2. **Conclusions**: Variability of constituent concentrations in adjacent soil samples is greater than precision of analyses; the spatial variability in analyte distribution represents the greatest source of variability in the analytical results. This conclusion is especially true for As (except for A-horizon samples) and is true to a lesser degree for Ca, Mn, and Ni.
Splits (10)	**Purpose**: To determine analytical precision and variability in results because of sample heterogeneity. **Results, As**: Range difference from the mean is 0 to 12%, median 3%, or comparable to two of three SRM's. **Results, TM**: Median difference from the mean is 2.4% for Fe, 6 to 10% for Al, Cr, Pb, and Ni, 11 to 16% for Ba, Cu, Mg, Mn, Ni, V, and Zn, and 25% for Ca. **Conclusions**: Analytical results are generally reproducible, though minor sample heterogeneity is evident, especially for Ba, Ca, Cu, Pb, Mg, Mn, Ni, V, and Zn.
Blanks, field (11)	**Purpose**: To determine whether analytical results could be biased by random contamination by field equipment during sampling procedures. **Results, As**: Detected in only two blanks at estimated concentrations as great as 3.3 ppb; this concentration is less than the PQL for other analyses of field blanks. **Results, TM**: V detected in only one blank at an estimated concentration of 0.89 ppb. Cu, Pb, Mn, and Zn detected in 1 to 10 blanks at estimated concentrations of 7.6 ppb or less. Ba, Cr, and Ni detected in three to five blanks at estimated concentrations of 8 ppb or less. Al detected in five blanks; maximum estimated concentration 122 ppb. Mg and K detected in three to four blanks at an estimated concentration of 725 ppb or less; PQL for K is highly variable depending on laboratory and on batch. Ca generally reported at concentrations less than 143 ppb; one detection at 1,660 ppb. Fe detected in eight blanks; maximum concentration 123 ppb. **Conclusions**: Field sampling methods may produce extremely minor contamination that is too small to bias analytical results.
Reference samples (SRM's), blind (9; 3 standards analyzed 3 times each)	**Purpose**: To determine the accuracy and precision of analytical results reported by the laboratory. **Results, As**: Analyses within the range of values expected; small variance from the median reported values. **Results, TM**: Most analyses are within the range of reported values for SRM's 2711 and 2709. Exceptions are one each analysis for Ba, Cd, Pb, Na, and V biased high; three analyses for K biased high.One each analysis for Ca, Mg, Ni, and Zn biased low; two each analyses for Cr, Fe, and Na biased low. Three analyses for K biased high, relative to median values, by as much as 26%. As many as two analyses for Fe and Mg biased low by as much as 17%. As many as two analyses for Cr and Pb biased low by as much as 45%. Range of average difference from the median is less than 8% for Ba, Ca, Cu, Mg, Mn, Ni, and Zn; is as great as 20% for Al, Fe, and K; and is as great as 30% for Pb and V. No mild-acid leaching results for SRM 1646a are available, but analyses of this SRM by two laboratories used in this study produced generally comparable results. **Conclusions**: Analytical results generally are accurate and reproducible, though occasional random high bias for K can be expected.
Laboratory calibration standards, preparation blanks, spiked samples, post-digestion spiked samples, duplicate samples (at least 1 each required with each batch of 20 analyses)	**Purpose**: To determine whether analytical results may be biased by random contamination in the laboratory or by analytical interferences or instrument drift. **Results, As**: Occasionally qualified. Both high and low possible biases are identified; these are distributed randomly among samples from all land uses. **Results, TM**: Many constituents, particularly Ba, Be, Cd, Ca, Mg, Ni, and K, qualified in one or more batches as a result of small concentrations near the IDL. Many constituents qualified with unknown bias as a result of recovery of spikes and (or) standards outside required limits or duplicate results outside limits. Some constituents, most notably Be, but also Cr, Na, and occasionally Pb, detected in preparation blanks. Be, Cd, Na, and Se results were commonly below detection, and, if qualified, mostly negated (detected concentration reported as undetected). Ca, Cu, K, and Mg results occasionally were negated. Ag and Sb results were commonly below detection and commonly qualified or rejected (quality of data not acceptable). Some Pb analyses were biased high; these are distributed across samples from different land uses. **Conclusions**: Laboratory analytical techniques probably did not introduce significant bias into results for As and most other analytes; however, results for Ag and Sb could not be used. Results for Be, Cd, and Na are reported but not used in statistical analyses. Any negated values are reported as undetected and are treated as such in statistical analyses.

APPENDIX 5

Statistical Analysis of Chemical Data

The following pages are printout from the SAS nonparametric discriminant models (SAS Institute Inc., 1990b) used to analyze the chemical data for soils from differing land uses. Summary pages from three preliminary models are shown. These include:

(1) a model that classifies geologic (G), orchard (O), and Imperial Oil Company (I) soils as the training set, by using ranked barium-to-zinc ratio and ranked arsenic concentrations, and that classifies soils from residential area 1 (A), residential area 2 (R), broader area (B), and woods adjacent to IOC (S) as the test data set;

(2) a model that classifies lumped orchard and geologic (N) soils and Imperial Oil Company soils (I) as the training set, using ranked barium and ranked copper concentrations, and that classifies soils from residential area 1 (A), residential area 2 (R), broader area (B), and woods adjacent to IOC (S) as the test data set; and

(3) a model that classifies geologic (G) and orchard (O) soils as the training set, using ranked arsenic and ranked barium-to-zinc ratio, and that classifies soils from residential area 1 (A), residential area 2 (R), broader area (B), and woods adjacent to IOC (S) as the test data set.

In addition, printout of the final model is included. This model uses 13 ranked concentration variables, three of which are normalized (arsenic to iron/1,000, lead and copper to TOC/1,000). The other variables are aluminum, barium, calcium, chromium, magnesium, manganese, nickel, potassium, vanadium, and zinc.

This model first classifies geologic (G), orchard (O), and Imperial Oil Company (I) soils as the training set, and then classifies soils from residential area 1 (A), residential area 2 (R), broader area (B), and woods adjacent to IOC (S) as the test data set.

Table 1a. SAS classification-summary printout of discriminant-analysis results for test A-horizon samples classified as three endmember land-use types, using ranked barium-to-zinc ratios and ranked arsenic concentrations

[A, residential area 1; R, residential area 2; B, broader area; S, woods adjacent to the Imperial Oil Company Superfund site; G, geologic; O, orchard; I, Imperial Oil Company Superfund site; obs, observation; PRIOR, prior probabilities estimated by model before analyzing data distribution; posterior probabilities are computed after determining the data distribution; D, distance; X, Y, vectors; j, k, groups (land-use types); Pr, probability; COV^{-1}, inverse covariance matrix; •, not computed when priors are zero]

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          Discriminant Analysis      Classification Summary for Test Data:  WORK.TESTDAT

                              Classification Summary using 4 Nearest Neighbors

             Squared Distance Function:              Posterior Probability of Membership in each TYPE:

           D² (X, Y) = (X-Y)' COV⁻¹ (X-Y)            mₖ (X) = Proportion of obs in group k in 4 nearest neighbors of X

                                                     Pr (j/X)  =  m   (X)    PRIOR  / SUM   ( m (X)  PRIOR   )
                                                                  j               j    k       k             k

                                                   Number of Observations and Percent Classified into TYPE:

             From TYPE              G               I               O               Total
               B                    0               0               2                   2
                                 0.00            0.00          100.00              100.00
               R                    0               2              16                  18
                                 0.00           11.11           88.89              100.00
               S                    9               0               8                  17
                                52.94            0.00           47.06              100.00
               A                    0               1               4                   5
                                 0.00           20.00           80.00              100.00
               Total                9               3              30                  42
               Percent          21.43            7.14           71.43              100.00

               Priors          0.3704          0.1852          0.4444

               Error Count Estimates for TYPE:

               B               R               S               A               Total
 Rate          •               •               •               •               •
 Priority      0.0000          0.0000          0.0000          0.0000          0.0000
```

Table 1b. SAS classification of A-horizon soil samples from residential areas 1 and 2, the broader area, and woods adjacent to the Imperial Oil Company Superfund site as one of three possible endmember land-use types using ranked barium-to-zinc ratios and ranked arsenic concentrations

[A, residential area 1; R, residential area 2; B, broader area; S, woods adjacent to the Imperial Oil Company Superfund site; G, geologic; O, orchard; I, Imperial Oil Company Superfund site; obs, observation; PRIOR, prior probabilities estimated by model before analyzing data distribution; posterior probabilities are computed after determining the data distribution; D, distance; X, Y, vectors; j, k, groups (land-use types); Pr, probability; COV-1, inverse covariance matrix]

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Discriminant Analysis Classification Summary for Test Data: WORK.TESTDAT

Classification Summary using 4 Nearest Neighbors

Squared Distance Function:

$D^2 (X, Y) = (X-Y)' \, COV^{-1} (X-Y)$

Posterior Probability of Membership in each TYPE:

$m_k (X)$ = Proportion of obs in group k in 4 nearest neighbors of X

$Pr\ (j/X) = m_j\ (X)\ PRIOR_j\ /\ SUM_k\ (\ m_k\ (X)\ PRIOR_k\ )$

Posterior Probability of Membership in TYPE:

```
                  From    Classified into
Site     Obs      TYPE         TYPE           G         I         O
R 1        1       R            O          0.0000    0.2500    0.7500
R 2        2       R            O          0.0000    0.2500    0.7500
R 5        3       R            I          0.0000    0.7500    0.2500
R 6        4       R            O          0.2500    0.0000    0.7500
R 7        5       R            O          0.0000    0.2500    0.7500
R 8        6       R            O          0.0000    0.0000    1.0000
R 9        7       R            O          0.0000    0.2500    0.7500
R10        8       R            O          0.0000    0.2500    0.7500
R11        9       R            I          0.2500    0.5000    0.2500
R12       10       R            O          0.0000    0.2500    0.7500
R13       11       R            O          0.0000    0.2500    0.7500
R14       12       R            O          0.0000    0.2500    0.7500
R15       13       R            O          0.0000    0.2500    0.7500
R16       14       R            O          0.0000    0.0000    1.0000
R17       15       R            O          0.0000    0.0000    1.0000
R18       16       R            O          0.0000    0.0000    1.0000
R20       17       R            O          0.0000    0.2500    0.7500
R27       18       R            O          0.0000    0.2500    0.7500
R19       19       A            I          0.0000    0.7500    0.2500
R21       20       A            O          0.0000    0.2500    0.7500
R22       21       A            O          0.0000    0.0000    1.0000
R23       22       A            O          0.0000    0.2500    0.7500
R24       23       A            O          0.0000    0.2500    0.7500
S 1       24       S            G          1.0000    0.0000    0.0000
S 2       25       S            G          0.7500    0.0000    0.2500
S 3       26       S            G          1.0000    0.0000    0.0000
S 4       27       S            G          1.0000    0.0000    0.0000
S 5       28       S            G          0.7500    0.0000    0.2500
S 7       29       S            G          1.0000    0.0000    0.0000
S 9       30       S            G          1.0000    0.0000    0.0000
S10       31       S            G          1.0000    0.0000    0.0000
S11       32       S            O          0.2500    0.0000    0.7500
S12       33       S            O          0.2500    0.0000    0.7500
S13       34       S            O          0.2500    0.0000    0.7500
S14       35       S            O          0.2500    0.0000    0.7500
S15       36       S            O          0.2500    0.0000    0.7500
S16       37       S            O          0.2500    0.0000    0.7500
S17       38       S            G          0.7500    0.0000    0.2500
S19       39       S            O          0.0000    0.2500    0.7500
S20       40       S            O          0.2500    0.0000    0.7500
B 1       41       B            O          0.0000    0.2500    0.7500
B 2       42       B            O          0.2500    0.2500    0.5000
```

Table 2a. SAS classification-summary printout of discriminant-analysis results for test A-horizon samples classified as Imperial Oil Company Superfund site land-use type or lumped geologic and orchard land-use types, using ranked barium and copper concentrations

[A, residential area 1; R, residential area 2; B, broader area; S, woods adjacent to the Imperial Oil Company Superfund site; G, geologic; O, orchard; I, Imperial Oil Company Superfund site; obs, observation; PRIOR, prior probabilities estimated by model before analyzing data distribution; posterior probabilities are computed after determining the data distribution; D, distance; X, Y, vectors; j, k, groups (land-use types); Pr, probability; COV-1, inverse covariance matrix; •, not computed when priors are zero]

```
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           Discriminant Analysis        Classification Summary for Test Data:  WORK.TESTDAT

                              Classification Summary using 4 Nearest Neighbors

             Squared Distance Function:          Posterior Probability of Membership in each TYPE:

        D² (X, Y) = (X-Y)' COV⁻¹ (X-Y)           m  (X) = Proportion of obs in group k in 4 nearest neighbors of X
                                                  k
                                                 Pr  (j/X)  =  m   (X)    PRIOR   / SUM   ( m (X) PRIOR    )
                                                               j             j      k       k            k

                                              Number of Observations and Percent Classified into TYPE:

             From TYPE            I             N            Total
               B                  0             2                2
                               0.00        100.00           100.00
               R                  2            16               18
                              11.11         88.89           100.00
               S                  0            17               17
                               0.00        100.00           100.00
               A                  5             0                5
                             100.00          0.00           100.00
               Total              7            35               42
               Percent        16.67         83.33           100.00

               Priors        0.1852        0.8148

               Error Count Estimates for TYPE:

               B              R              S              A              Total
   Rate        •              •              •              •              •
   Priority    0.0000         0.0000         0.0000         0.0000         0.0000
```

Table 2b. SAS classification of A-horizon soil samples from residential areas 1 and 2, the broader area, and woods adjacent to the Imperial Oil Company Superfund site as either Imperial Oil Company Superfund site land-use type or lumped geologic and orchard land-use types, using ranked barium and copper concentrations

[A, residential area 1; R, residential area 2; B, broader area; S, woods adjacent to the Imperial Oil Company Superfund site; G, geologic; O, orchard; N, G+O; I, Imperial Oil Company Superfund site; obs, observation; PRIOR, prior probabilities estimated by model before analyzing data distribution; posterior probabilities are computed after determining the data distribution; D, distance; X, Y, vectors; j, k, groups (land-use types); Pr, probability; COV-1, inverse covariance matrix]

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Discriminant Analysis Classification Summary for Test Data: WORK.TESTDAT

Classification Summary using 4 Nearest Neighbors

Squared Distance Function:

$D^2(X, Y) = (X-Y)' \, COV^{-1} \, (X-Y)$

Posterior Probability of Membership in each TYPE:

$m_k(X)$ = Proportion of obs in group k in 4 nearest neighbors of X

$Pr(j/X) = m_j(X) \, PRIOR_j \, / \, SUM_k \, (m_k(X) \, PRIOR_k)$

Posterior Probability of Membership in TYPE:

Site	Obs	From TYPE	Classified into TYPE	I	N (G+O)
R 1	1	R	N	0.0000	1.0000
R 2	2	R	I	0.7500	0.2500
R 5	3	R	N	0.0000	1.0000
R 6	4	R	N	0.0000	1.0000
R 7	5	R	N	0.2500	0.7500
R 8	6	R	N	0.0000	1.0000
R 9	7	R	N	0.0000	1.0000
R10	8	R	N	0.2500	0.7500
R11	9	R	N	0.0000	1.0000
R12	10	R	N	0.2500	0.7500
R13	11	R	N	0.0000	1.0000
R14	12	R	N	0.2500	0.7500
R15	13	R	I	0.7500	0.2500
R16	14	R	N	0.0000	1.0000
R17	15	R	N	0.0000	1.0000
R18	16	R	N	0.0000	1.0000
R20	17	R	N	0.2500	0.7500
R27	18	R	N	0.2500	0.7500
R19	19	A	I	0.7500	0.2500
R21	20	A	I	1.0000	0.0000
R22	21	A	I	0.7500	0.2500
R23	22	A	I	1.0000	0.0000
R24	23	A	I	0.7500	0.2500
S 1	24	S	N	0.0000	1.0000
S 2	25	S	N	0.0000	1.0000
S 3	26	S	N	0.0000	1.0000
S 4	27	S	N	0.0000	1.0000
S 5	28	S	N	0.0000	1.0000
S 7	29	S	N	0.0000	1.0000
S 9	30	S	N	0.0000	1.0000
S10	31	S	N	0.0000	1.0000
S11	32	S	N	0.0000	1.0000
S12	33	S	N	0.0000	1.0000
S13	34	S	N	0.0000	1.0000
S14	35	S	N	0.0000	1.0000
S15	36	S	N	0.0000	1.0000
S16	37	S	N	0.0000	1.0000
S17	38	S	N	0.0000	1.0000
S19	39	S	N	0.0000	1.0000
S20	40	S	N	0.0000	1.0000
B 1	41	B	N	0.2500	0.7500
B 2	42	B	N	0.2500	0.7500

Table 3a. SAS classification-summary printout of discriminant-analysis results for test A-horizon samples classified as geologic or orchard endmember land-use types, using ranked barium-to-zinc ratios and ranked arsenic concentrations

[A, residential area 1; R, residential area 2; B, broader area; S, woods adjacent to the Imperial Oil Company Superfund site; G, geologic; O, orchard; I, Imperial Oil Company Superfund site; obs, observation; PRIOR, prior probabilities estimated by model before analyzing data distribution; posterior probabilities are computed after determining the data distribution; D, distance; X, Y, vectors; j, k, groups (land-use types); Pr, probability; COV-1, inverse covariance matrix; •, not computed when priors are zero]

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              Discriminant Analysis        Classification Summary for Test Data:  WORK.TESTDAT

                               Classification Summary using 4 Nearest Neighbors

                Squared Distance Function:            Posterior Probability of Membership in each TYPE:

              D2 (X, Y) = (X-Y)' COV-1 (X-Y)          mk (X) = Proportion of obs in group k in 4 nearest neighbors of X

                                                      Pr  (j/X)  =  m   (X)    PRIOR  / SUM   ( m (X)  PRIOR    )
                                                                    j              j     k       k            k

                                                     Number of Observations and Percent Classified into TYPE:

                From TYPE           G             O             Other           Total
                  B                 0             1               1               2
                                 0.00         50.00           50.00          100.00
                  R                 1            17               0              18
                                 5.56         94.44            0.00          100.00
                  S                 8             8               1              17
                                47.06         47.06            5.88          100.00
                  A                 0             5               0               5
                                 0.00        100.00            0.00          100.00
                  Total             9            31               2              42
                  Percent       21.43         73.81            4.76          100.00

                  Priors       0.4545        0.5455

                  Error Count Estimates for TYPE:

                  B             R             S             A             Total
      Rate        •             •             •             •             •
      Priority    0.0000        0.0000        0.0000        0.0000        0.0000
```

Table 3b. SAS classification of A-horizon soil samples from residential areas 1 and 2, the broader area, and woods adjacent to the Imperial Oil Company Superfund site as either geologic or orchard land-use types, using ranked barium-to-zinc ratios and ranked arsenic concentrations

[A, residential area 1; R, residential area 2; B, broader area; S, woods adjacent to the Imperial Oil Company Superfund site; G, geologic; O, orchard; I, Imperial Oil Company Superfund site; obs, observation; PRIOR, prior probabilities estimated by model before analyzing data distribution; posterior probabilities are computed after determining the data distribution; D, distance; X, Y, vectors; j, k, groups (land-use types); Pr, probability; COV-1, inverse covariance matrix; T, tie (occurs when posterior probabilities are equal)]

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Discriminant Analysis           Classification Summary for Test Data:  WORK.TESTDAT

                          Classification Summary using 4 Nearest Neighbors

     Squared Distance Function:              Posterior Probability of Membership in each TYPE:

   D^2 (X, Y) = (X-Y)' COV^-1 (X-Y)          m_k (X) = Proportion of obs in group k in 4 nearest neighbors of X

                                             Pr  (j/X)  =  m    (X)    PRIOR   / SUM   ( m (X)  PRIOR    )
                                                           j                j     k        k              k

                                                  Posterior Probability of Membership in TYPE:

                          From       Classified into
   Site        Obs        TYPE           TYPE             G          O
   R 1          4          R              O             0.2500     0.7500
   R 2          5          R              O             0.0000     1.0000
   R 5          6          R              O             0.2500     0.7500
   R 6          7          R              O             0.2500     0.7500
   R 7          8          R              O             0.0000     1.0000
   R 8          9          R              O             0.0000     1.0000
   R 9         10          R              O             0.0000     1.0000
   R10         11          R              O             0.0000     1.0000
   R11         12          R              G             0.7500     0.2500
   R12         13          R              O             0.0000     1.0000
   R13         14          R              O             0.0000     1.0000
   R14         15          R              O             0.0000     1.0000
   R15         16          R              O             0.0000     1.0000
   R16         17          R              O             0.0000     1.0000
   R17         18          R              O             0.0000     1.0000
   R18         19          R              O             0.0000     1.0000
   R20         20          R              O             0.0000     1.0000
   R27         21          R              O             0.0000     1.0000
   R19         22          A              O             0.0000     1.0000
   R21         23          A              O             0.0000     1.0000
   R22         24          A              O             0.0000     1.0000
   R23         25          A              O             0.0000     1.0000
   R24         26          A              O             0.0000     1.0000
   S 1         27          S              G             1.0000     0.0000
   S 2         28          S              G             0.7500     0.2500
   S 3         29          S              G             1.0000     0.0000
   S 4         30          S              G             1.0000     0.0000
   S 5         31          S              G             0.7500     0.2500
   S 7         32          S              G             1.0000     0.0000
   S 9         33          S              G             1.0000     0.0000
   S10         34          S              G             1.0000     0.0000
   S11         35          S              O             0.2500     0.7500
   S12         36          S              O             0.2500     0.7500
   S13         37          S              O             0.2500     0.7500
   S14         38          S              O             0.2500     0.7500
   S15         39          S              O             0.2500     0.7500
   S16         40          S              O             0.2500     0.7500
   S17         41          S           Other T          0.5000     0.5000
   S19         42          S              O             0.2500     0.7500
   S20         43          S              O             0.2500     0.7500
   B 1         44          B              O             0.0000     1.0000
   B 2         45          B           Other T          0.5000     0.5000
```

Tables 4a-j. SAS printout of discriminant-analysis results, using a 13-variable, five-nearest-neighbor model classifying A-horizon soils from endmember land-use types (geologic), orchard, and Imperial Oil Company Superfund site as the training set, and classifying A-horizon soils from residential areas 1 and 2, the broader area, and woods adjacent to Imperial Oil Company Superfund site as the test data set. This model uses 13 ranked concentration variables, 3 of which are normalized (arsenic to iron/1,000, lead to TOC/1,000, and copper to TOC/1,000); the other variables are aluminum, barium, calcium, chromium, magnesium, manganese, nickel, potassium, vanadium, and zinc.

Table 4a. SAS frequency, assigned weight, proportion, and prior probability for A-horizon soils from three endmember land-use types used in the training set of a 13-variable discriminant-analysis classification model

[DF, degrees of freedom; G, geologic; I, Imperial Oil Company Superfund site; O, orchard]

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                           Discriminant Analysis

                  26 Observations           25 DF Total
                  13 Variables              23 DF Within Classes
                   3 Classes                 2 DF Between Classes

                          Class Level Information

                                                                    Prior
   TYPE          Frequency          Weight        Proportion     Probability
    G                    9          9.0000          0.346154        0.346154
    I                    5          5.0000          0.192308        0.192308
    O                   12         12.0000          0.461538        0.461538
```

Table 4b. Descriptive statistics for variables in training set of A-horizon soil samples from endmember land-use types used in 13-variable discriminant-analysis classification model

[N, number of samples; Std Dev, standard deviation; R preceding variable denotes a rank transformation of the concentration; AL, aluminum; ASN, arsenic normalized to (iron concentration/1,000); BA, barium; CA, calcium; CR, chromium; CUN, copper normalized to (total organic carbon concentration/1,000); PBN, lead normalized to (total organic carbon concentration/1,000); MG, magnesium; MN, manganese; NI, nickel; K, potassium; V, vanadium; ZN, zinc; G, geologic; I, Imperial Oil Company Superfund site; O, orchard]

```
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                    Discriminant Analysis        Simple Statistics
                               Total-Sample

Variable    N          Sum        Mean      Variance    Std Dev    Label

RAL        26    651.50000    25.05769    408.44654    20.21006    Rank for Variable AL
RASN       26         1011    38.88462    446.82615    21.13826    Rank for Variable ASN
RBA        26    867.50000    33.36538    480.85115    21.92832    Rank for Variable BA
RCA        26    934.00000    35.92308    355.57385    18.85667    Rank for Variable CA
RCR        26    768.00000    29.53846    423.63846    20.58248    Rank for Variable CR
RCUN       26    739.00000    28.42308    438.09385    20.93069    Rank for Variable CUN
RPBN       26    785.00000    30.19231    372.64154    19.30393    Rank for Variable PBN
RMG        26    704.50000    27.09615    452.90038    21.28146    Rank for Variable MG
RMN        26    775.50000    29.82692    444.51885    21.08362    Rank for Variable MN
RNI        26    767.50000    29.51923    405.00962    20.12485    Rank for Variable NI
RK         26    556.50000    21.40385    180.12038    13.42089    Rank for Variable K
RV         26    763.00000    29.34615    403.11538    20.07773    Rank for Variable V
RZN        26    788.00000    30.30769    408.36154    20.20796    Rank for Variable ZN
------------------------------------------------------------------------------------------
                                 TYPE = G

Variable    N          Sum        Mean      Variance    Std Dev    Label

RAL         9    159.50000    17.72222    272.19444    16.49832    Rank for Variable AL
RASN        9    248.00000    27.55556    429.52778    20.72505    Rank for Variable ASN
RBA         9    173.00000    19.22222    256.88194    16.02754    Rank for Variable BA
RCA         9    199.00000    22.11111    206.54861    14.37180    Rank for Variable CA
RCR         9    171.50000    19.05556    291.34028    17.06869    Rank for Variable CR
RCUN        9    198.00000    22.00000    292.50000    17.10263    Rank for Variable CUN
RPBN        9    176.00000    19.55556    270.27778    16.44013    Rank for Variable PBN
RMG         9    152.00000    16.88889    262.67361    16.20721    Rank for Variable MG
RMN         9    170.00000    18.88889    282.67361    16.81290    Rank for Variable MN
RNI         9    183.50000    20.38889    257.42361    16.04443    Rank for Variable NI
RK          9    128.00000    14.22222    193.19444    13.89944    Rank for Variable K
RV          9    160.00000    17.77778    259.88194    16.12085    Rank for Variable V
RZN         9    129.00000    14.33333    177.93750    13.33932    Rank for Variable ZN
```

Table 4b. Descriptive statistics for variables in training set of A-horizon soil samples from endmember land-use types used in 13-variable discriminant-analysis classification model--Continued

```
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                         Discriminant Analysis          Simple Statistics
                                      TYPE = I

Variable      N        Sum          Mean       Variance      Std Dev          Label
RAL           5     197.00000     39.40000    285.80000     16.90562    Rank for Variable AL
RASN          5     254.00000     50.80000    159.70000     12.63725    Rank for Variable ASN
RBA           5     313.00000     62.60000     27.80000      5.27257    Rank for Variable BA
RCA           5     271.00000     54.20000    204.20000     14.28986    Rank for Variable CA
RCR           5     218.00000     43.60000    463.17500     21.52150    Rank for Variable CR
RCUN          5     167.00000     33.40000    867.30000     29.44996    Rank for Variable CUN
RPBN          5     175.00000     35.00000    611.50000     24.72853    Rank for Variable PBN
RMG           5     222.00000     44.40000    403.30000     20.08233    Rank for Variable MG
RMN           5     190.00000     38.00000    598.50000     24.46426    Rank for Variable MN
RNI           5     228.00000     45.60000    685.80000     26.18778    Rank for Variable NI
RK            5     131.00000     26.20000     93.70000      9.67988    Rank for Variable K
RV            5     224.00000     44.90000    111.05000     10.53803    Rank for Variable V
RZN           5     260.00000     52.00000    264.50000     16.26346    Rank for Variable ZN
------------------------------------------------------------------------------------------------

                                      TYPE = O

Variable      N        Sum          Mean       Variance      Std Dev          Label
RAL          12     295.00000     24.58333    488.62879     22.10495    Rank for Variable AL
RASN         12     509.00000     42.41667    461.90152     21.49189    Rank for Variable ASN
RBA          12     381.50000     31.79167    341.06629     18.46798    Rank for Variable BA
RCA          12     464.00000     38.66667    267.51515     16.35589    Rank for Variable CA
RCR          12     378.50000     31.54167    398.33902     19.95843    Rank for Variable CR
RCUN         12     374.00000     31.16667    414.33333     20.35518    Rank for Variable CUN
RPBN         12     434.00000     36.16667    285.96970     16.91064    Rank for Variable PBN
RMG          12     330.50000     27.54167    470.06629     21.68101    Rank for Variable MG
RMN          12     415.50000     34.62500    433.68750     20.82517    Rank for Variable MN
RNI          12     356.00000     29.66667    298.10606     17.26575    Rank for Variable NI
RK           12     297.50000     24.79167    169.61174     13.02351    Rank for Variable K
RV           12     378.50000     31.54167    462.06629     21.49573    Rank for Variable V
RZN          12     399.00000     33.25000    270.38636     16.44343    Rank for Variable ZN
```

Table 4c. SAS computation of squared distances between endmember groups of A-horizon samples used in 13-variable discriminant-analysis classification model

[G, geologic; I, Imperial Oil Company Superfund site; O, orchard; D, distance in 13-variable space; i/j, group i given group j; X, centroid (multivariate mean) of group; COV^{-1}, inverse of covariance matrix]

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           Discriminant Analysis    Pairwise Squared Distances Between Groups
```

$$D^2\,(i/j) = (\bar{X}_i - \bar{X}_j), COV^{-1}\,(\bar{X}_i - \bar{X}_j)$$

```
                              Squared Distance to TYPE

   From TYPE            G                  I                  O
       G                0           32.64027           26.08696
       I         32.64027                  0           17.12096
       O         26.08696           17.12096                  0
```

Table 4d. SAS computation of squared distances between endmember groups of A-horizon samples used in 13-variable discriminant-analysis classification model

[S, M, N, parameters underlying the joint distribution of the eigenvalues; F, F statistic for the test; Num DF, numerator degrees of freedom; Den DF, denominator degrees of freedom; Pr > F, probability greater than F statistic]

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                           Discriminant Analysis

                 Multivariate Statistics and F Approximations

                          S = 2     M = 5     N = 4.5

 Statistic                   Value          F      Num DF     Den DF     Pr > F
Wilks' Lambda             0.03798389     3.4954       26         22       0.0020
Pillai's Trace            1.58650774     3.5417       26         24       0.0013
Hotelling-Lawley Trace    8.88598900     3.4177       26         20       0.0032
Roy's Greatest Root       6.25937591     5.7779       13         12       0.0023

             NOTE:  F Statistic for Roy's Greatest Root is an upper bound.
                  NOTE:  F Statistic for Wilks' Lambda is exact.
```

Table 4e. SAS discriminant-analysis classification results for A-horizon soil samples from endmember land-use areas used to calibrate 13-variable classification model

[D, distance between groups; X, Y, vectors in multivariate space; COV^{-1}, inverse of covariance matrix; j, k, groups (land-use types); Obs, observation; Pr, probability; G, geologic; I, Imperial Oil Company Superfund site; O, orchard; T, tie for largest probability]

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Discriminant Analysis Classification Results for Calibration Data: WORK.ENDAT

Resubstitution Results using 5 Nearest Neighbors

Squared Distance Function:

$D^2 (X, Y) = (X-Y)' COV^{-1} (X-Y$

Posterior Probability of Membership in each TYPE:

$m_k (X)$ = Proportion of obs in group k in 5 nearest neighbors of X

$Pr\ (j/X) = m_j\ (X)\ PRIOR_j\ /\ SUM_k\ (\ m_k (X)\ PRIOR_k\ )$

				Posterior Probability of Membership in TYPE:		
Site	Obs	From TYPE	Classified into TYPE	G	I	O
E 1	1	G	G	1.0000	0.0000	0.0000
E 2	2	G	G	1.0000	0.0000	0.0000
E 4	3	G	G	1.0000	0.0000	0.0000
E 6	4	G	G	1.0000	0.0000	0.0000
E 9	5	G	G	1.0000	0.0000	0.0000
E11	6	G	G	1.0000	0.0000	0.0000
E12 D	8	G	G	1.0000	0.0000	0.0000
E14	9	G	G	1.0000	0.0000	0.0000
E15	10	G	G	1.0000	0.0000	0.0000
O 1	11	O	O	0.0000	0.0000	1.0000
O 2	12	O	O	0.2000	0.2000	0.6000
O 3	13	O	O	0.0000	0.0000	1.0000
O 4	14	O	O	0.0000	0.2000	0.8000
O 5	15	O	O	0.0000	0.2000	0.8000
O 6 D	16	O	O	0.0000	0.0000	1.0000
O 7	17	O	O	0.0000	0.0000	1.0000
O 8	18	O	O	0.2000	0.0000	0.8000
O 9 D	19	O	OTHER T	0.4000	0.2000	0.4000
O11	20	O	O	0.0000	0.0000	1.0000
O14	21	O	O	0.0000	0.0000	1.0000
O16	22	O	O	0.0000	0.2000	0.8000
I 2	23	I	I	0.2000	0.8000	0.0000
I 3	24	I	I	0.0000	0.8000	0.2000
I 4	25	I	I	0.0000	0.6000	0.4000
I 5	26	I	I	0.0000	0.6000	0.4000
I 7	27	I	I	0.2000	0.6000	0.2000

T Tie for largest probability

Table 4f. SAS discriminant-analysis classification summary for A-horizon soil samples from endmember land-use areas used as training set to calibrate 13-variable classification model

[D, distance between groups; X, Y, vectors in multivariate space; COV^{-1}, inverse of covariance matrix; j, k, groups (land-use types); Obs, observation; Pr, probability; G, geologic; I, Imperial Oil Company Superfund site; O, orchard; T, tie for largest probability]

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           Discriminant Analysis    Classification Results for Calibration Data:  WORK.ENDAT

                           Resubstitution Summary using 5 Nearest Neighbors

            Squared Distance Function:               Posterior Probability of Membership in each TYPE:

            D2 (X, Y) = (X-Y)' COV-1 (X-Y)           mk (X) = Proportion of obs in group k in 5 nearest neighbors of X

                                                     Pr (j/X) =  m   (X)   PRIOR  / SUM  ( m (X)  PRIOR   )
                                                                 j               j    k      k              k

                                                 Number of Observations and Percent Classified into TYPE:

   From TYPE          G            I             O            Other          Total
       G              9            0             0              0              9
                 100.00         0.00          0.00           0.00         100.00
       I              0            5             0              0              5
                   0.00       100.00          0.00           0.00         100.00
       O              0            0            11              1             12
                   0.00         0.00         91.67           8.33         100.00
     Total            9            5            11              1             26
     Percent      34.62        19.23         42.31           3.85         100.00

     Priors      0.3462       0.1923        0.4615

     Error Count Estimates for TYPE:

                                G             I              O             Total
                 Rate        0.0000        0.0000         0.0833          0.0385
                 Priors      0.3462        0.1923         0.4615
```

Table 4g. SAS discriminant-analysis classification summary for A-horizon soil samples from endmember land-use areas used as training set to calibrate 13-variable classification model

[D, distance between groups; X, Y, vectors in multivariate space; COV^{-1}, inverse of covariance matrix; j, k, groups (land-use types); Obs, observation; Pr, probability; G, geologic; I, Imperial Oil Company Superfund site; O, orchard; T, tie for largest probability]

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Discriminant Analysis      Classification Results for Calibration Data:  WORK.ENDAT

                   Cross-validation Summary using 5 Nearest Neighbors

   Squared Distance Function:              Posterior Probability of Membership in each TYPE:

D2 (X, Y) = (X-Y)' COV-1 (X-Y)             mk (X) = Proportion of obs in group k in 5 nearest neighbors of X

                                           Pr  (j/X)  =  m   (X)    PRIOR   / SUM   ( m (X) PRIOR    )
                                                         j                j     k       k             k

                                             Posterior Probability of Membership in TYPE:

           From      Classified
 Obs       TYPE      into TYPE        G            I            O
  1         G           G          1.0000       0.0000       0.0000
  2         G           G          1.0000       0.0000       0.0000
  3         G           G          1.0000       0.0000       0.0000
  4         G           G          1.0000       0.0000       0.0000
  5         G           G          1.0000       0.0000       0.0000
  6         G           G          1.0000       0.0000       0.0000
  8         G           G          1.0000       0.0000       0.0000
  9         G           G          1.0000       0.0000       0.0000
 10         G           G          1.0000       0.0000       0.0000
 11         O           O          0.0000       0.1864       0.8136
 12         O           O          0.3860       0.1930       0.4211
 13         O           O          0.0000       0.0000       1.0000
 14         O           O          0.0000       0.1864       0.8136
 15         O           O          0.0000       0.3793       0.6207
 16         O           O          0.0000       0.0000       1.0000
 17         O           O          0.0000       0.0000       1.0000
 18         O           O          0.1864       0.0000       0.8136
 19         O           O          0.3860       0.1930       0.4211
 20         O           O          0.0000       0.0000       1.0000
 21         O           O          0.0000       0.0000       1.0000
 22         O           O          0.0000       0.1864       0.8136
 23         I           I          0.1739       0.6522       0.1739
 24         I           I          0.0000       0.8333       0.1667
 25         I           I          0.0000       0.6522       0.3478
 26         I           I          0.0000       0.6522       0.3478
 27         I           I          0.1739       0.6522       0.1739
```

Table 4h. SAS discriminant-analysis classification summary of cross-validated results for A-horizon soil samples from endmember land-use areas used to calibrate 13-variable classification model

[D, distance between groups; X, Y, vectors in multivariate space; COV^{-1}, inverse of covariance matrix; j, k, groups (land-use types); Obs, observation; Pr, probability; G, geologic; I, Imperial Oil Company Superfund site; O, orchard; T, tie for largest probability]

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Discriminant Analysis     Classification Results for Calibration Data:  WORK.ENDAT

                     Cross-validation Summary using 5 Nearest Neighbors

    Squared Distance Function:            Posterior Probability of Membership in each TYPE:

    D2 (X, Y) = (X-Y)' COV-1 (X-Y)        mk (X) = Proportion of obs in group k in 5 nearest neighbors of X

                                          Pr  (j/X)  =  m   (X)    PRIOR  / SUM   ( m (X)  PRIOR    )
                                                        j              j    k        k            k

                                          Number of Observation and Percent Classified into TYPE:

From TYPE               G               I               O               Total
    G                   9               0               0                   9
                   100.00            0.00            0.00              100.00
    I                   0               5               0                   5
                     0.00          100.00            0.00              100.00
    O                   0               0              12                  12
                     0.00            0.00          100.00              100.00
Total                   9               5              12                  26
Percent             34.62           19.23           46.15              100.00

Priors             0.3462          0.1923          0.4615

                     Error Count Estimates for TYPE:

                        G               I               O               Total
Rate               0.0000          0.0000          0.0000              0.0000
Priors             0.3462          0.1923          0.4615
```

Table 4i. SAS discriminant-analysis classification of A-horizon soil samples from residential areas 1 and 2, the broader area, and woods adjacent to Imperial Oil Company Superfund site as one of three possible endmember land-use types, using the 13-variable classification model

[D, distance between groups; X, Y, vectors in multivariate space; COV^{-1}, inverse of covariance matrix; j, k, groups (land-use types); Obs, observation; Pr, probability; G, geologic; I, Imperial Oil Company Superfund site; O, orchard; T, tie for largest probability]

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         Discriminant Analysis      Classification Results for Calibration Data:  WORK.TESTDAT

                           Classification Results using 5 Nearest Neighbors

             Squared Distance Function:          Posterior Probability of Membership in each TYPE:

         D2 (X, Y) = (X-Y)' COV-1 (X-Y)          mk (X) = Proportion of obs in group k in 5 nearest neighbors of X

                                                 Pr (j/X) = m  (X)   PRIOR  / SUM  ( m (X) PRIOR  )
                                                             j             j     k      k          k

                                                 Posterior Probability of Membership in TYPE:
```

Site	Obs	From TYPE	Classified into TYPE	G	I	O
R 1	1	R	O	0.0000	0.0000	1.0000
R 2	2	R	O	0.0000	0.0000	1.0000
R 5	3	R	O	0.0000	0.0000	1.0000
R 6	4	R	O	0.0000	0.2000	0.8000
R 7	5	R	O	0.0000	0.0000	1.0000
R 8	6	R	O	0.0000	0.4000	0.6000
R 9	7	R	O	0.0000	0.0000	1.0000
R10	8	R	O	0.0000	0.0000	1.0000
R11	9	R	G	1.0000	0.0000	0.0000
R12	10	R	O	0.0000	0.0000	1.0000
R13	11	R	O	0.0000	0.0000	1.0000
R14	12	R	O	0.0000	0.2000	0.8000
R15	13	R	O	0.0000	0.2000	0.8000
R16	14	R	O	0.0000	0.0000	1.0000
R17	15	R	O	0.0000	0.0000	1.0000
R18	16	R	O	0.0000	0.2000	0.8000
R20	17	R	O	0.0000	0.0000	1.0000
R27	18	R	Other T	0.4000	0.2000	0.4000
R19	19	A	O	0.0000	0.4000	0.6000
R21	20	A	O	0.0000	0.2000	0.8000
R22	21	A	O	0.0000	0.4000	0.6000
R23	22	A	O	0.0000	0.2000	0.8000
R24	23	A	O	0.0000	0.2000	0.8000
S 1	24	S	G	1.0000	0.0000	0.0000
S 2	25	S	G	0.8000	0.0000	0.2000
S 3	26	S	G	1.0000	0.0000	0.0000
S 4	27	S	G	1.0000	0.0000	0.0000
S 5	28	S	G	1.0000	0.0000	0.0000
S 7	29	S	G	1.0000	0.0000	0.0000
S 9	30	S	G	1.0000	0.0000	0.0000
S10	31	S	G	1.0000	0.0000	0.0000
S11	32	S	G	0.8000	0.0000	0.2000
S12	33	S	O	0.4000	0.0000	0.6000
S13	34	S	G	0.8000	0.0000	0.2000
S14	35	S	G	0.8000	0.0000	0.2000
S15	36	S	O	0.4000	0.0000	0.6000
S16	37	S	O	0.2000	0.0000	0.8000
S17	38	S	O	0.2000	0.0000	0.8000
S19	39	S	O	0.0000	0.0000	1.0000
S20	40	S	O	0.0000	0.0000	1.0000
B 1	41	B	O	0.0000	0.0000	1.0000
B 2	42	B	O	0.0000	0.2000	0.8000

Table 4j. SAS discriminant-analysis classification summary for A-horizon soil samples from residential areas 1 and 2, the broader area, and woods adjacent to Imperial Oil Company Superfund site used as test data in the 13-variable classification model

[A, residential area 1; R, residential area 2; B, broader area; S, woods adjacent to the Imperial Oil Company Superfund site; G, geologic; O, orchard; I, Imperial Oil Company Superfund site; obs, observation; PRIOR, prior probabilities estimated by model before analyzing data distribution; posterior probabilities are computed after determining the data distribution; D, distance; X, Y, vectors; j, k, groups (land-use types); COV^{-1}, inverse covariance matrix; •, not computed when priors are zero]

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              Discriminant Analysis         Classification Summary for Test Data:  WORK.TESTDAT

                                 Classification Summary using 5 Nearest Neighbors

                  Squared Distance Function:              Posterior Probability of Membership in each TYPE:

             D^2 (X, Y) = (X-Y)' COV^-1 (X-Y)              m_k (X) = Proportion of obs in group k in 5 nearest neighbors of X

                                                          Pr (j/X)  =  m   (X)    PRIOR   / SUM   ( m (X)  PRIOR    )
                                                                       j                 j     k       k               k

                                                        Number of Observations and Percent Classified into TYPE:

          From TYPE            G            I            O           Other          Total
            B                  0            0            2             0              2
                             0.00         0.00       100.00          0.00         100.00
            R                  1            0           16             1             18
                             5.56         0.00        88.89          5.56         100.00
            S                 11            0            6             0             17
                            64.71         0.00        35.29          0.00         100.00
            A                  0            0            5             0              5
                             0.00         0.00       100.00          0.00         100.00
            Total             12            0           29             1             42
            Percent        28.57         0.00        69.05          2.38         100.00

            Priors        0.3462       0.1923       0.4615

                           Error Count Estimates for TYPE:

                                B        R               S              A               Total
        Rate                    •        •               •              •               •
        Priority           0.0000   0.0000          0.0000         0.0000          0.0000
```