GROUND-WATER AND SOIL CONTAMINATION NEAR TWO PESTICIDE-BURIAL SITES IN MINNESOTA

By J. R. Stark[1], J. D. Strudell[2], P. A. Bloomgren[2], and P. Eger[2]

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CONVERSION FACTORS AND ABBREVIATIONS

Readers who prefer to use metric (International System) units rather than inch-pound units can make conversions using the following factors:

Multiply Inch-Pound Unit	By	To obtain Metric Unit
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	.3048	meter per day (m/d)
	.0003528	centimeter per second (cm/s)
square foot per day (ft^2/d)	.09290	square meter per day (m^2/d)
gallon (gal)	.003785	cubic meter (m^3)
gallon per minute (gal/min)	.06308	liter per second (L/s)
million gallons per day (Mgal/d)	.04381	cubic meter per second (m^3/s)
pound, avoirdupois (lb)	453.6	gram (g)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Chemical concentrations are given in metric units. Chemical concentrations of substances in water are given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Chemical concentrations of substances in soil are given in parts per million, which is equivalent to milligrams per kilogram.

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

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ABSTRACT

Preliminary investigations of the geology, ground-water hydrology, and soil and ground-water chemistry at sites in Pine and St. Louis Counties, Minnesota, have shown that contamination associated with pesticides buried at the sites is not widespread or highly concentrated. None of the pesticides sampled for in soil and in ground water at the sites exceeded Minnesota soil and drinking-water standards. About 1,500 pounds of lead arsenate were buried at the site in St. Louis County. Nearly 10,000 pounds of lead arsenate, as well as smaller quantities of organic pesticides (such as chlorpropham, DDT, endrin. and aldrin), lime sulfur, and magnesium carbonate were buried at the Pine County site. These chemicals were buried in shallow trenches at the sites during the early 1970's.

The first wells drilled at each site were located to establish the direction of horizontal ground-water flow in each area. Ground water flows to the northeast at the St. Louis County site and to the southeast at the Pine County site. Depths to the water table are about 30 feet at the Pine County site and about 25 feet at the St. Louis County site. In addition, ground water is perched seasonally at about 5 feet below land surface in the immediate vicinity of the burial site in Pine County. After the direction of flow was determined, additional wells were drilled downgradient from the disposal areas at both sites to determine whether contaminants were migrating with ground water away from the sites.

In general, concentrations of lead and arsenic in soil and ground water were below background concentrations for the areas. Concentrations of organic pesticides generally were below analytical-detection limits. The limited solubility of the chemicals and the tendency of the contaminants to be sorbed on soil particles probably combined to restrict mobilization of the chemicals.

[1]U.S. Geological Survey
[2]Minnesota Department of Natural Resources

INTRODUCTION

The MDNR (Minnesota Department of Natural Resources) buried pesticides in the early 1970's at two sites on State-owned land in east-central and northern Minnesota. The sites are located in Pine and St. Louis Counties (fig. 1). The Pine County site is in the St. Croix State Forest and lies within the St. Croix River drainage basin. The St. Louis County site is in the Kabetogama State Forest and lies within the Rainy River/Hudson Bay drainage basin.

In 1984, attempts by the MDNR to inventory and to dispose of surplus pesticides properly, as well as the efforts of the MPCA (Minnesota Pollution Control Agency) to locate and clean up arsenic-disposal sites, led to a study of possible soil and ground-water contamination at the two sites. An initial review of the available information on the sites led to their selection by the MPCA for inclusion under the Minnesota Environmental Responsibility and Liability Act. The MPCA issued a Request For Response Action Agreement with the MDNR. This request called for completion of Remedial Investigations at the two sites to determine the nature and extent of the hazardous substances disposed at the sites. In June 1984, the U.S. Geological Survey began a preliminary investigation of the geology and ground-water hydrology of the two sites as part of a cooperative agreement with the MDNR. This report presents results of that preliminary investigation.

Purpose and Scope

This report describes the results of a study to (1) verify the supposed location of two pesticide-disposal sites, (2) determine the magnitude and extent of possible soil and ground-water contamination at the sites, and (3) provide sufficient information to allow selection and implementation of response actions by the MDNR to reduce the possibility of future releases of pesticides to the environment.

Because the sites are located in remote parts of the State, little information pertaining to the geology or ground-water hydrology of the disposal sites existed prior to the beginning of field work. Therefore, the investigation was designed to provide detailed information about the geology, ground-water hydrology, and the degree of soil and ground-water contamination within several hundred feet of the disposal sites. This report describes the field methods used and the results of the investigation.

History of Pesticide Disposal at Study Sites

Throughout the 1940's, 1950's and 1960's, lead arsenate and various organic pesticides were used by the MDNR to control grasshoppers, weeds, and other insects and fungi that affect forests and tree nurseries. After use of these pesticides was restricted or became obsolete, surplus quantities were stored in MDNR warehouses throughout the State. In 1970, the MDNR canvassed its district offices in an attempt to inventory and arrange for the disposal of the surplus pesticides. A number of pesticides were buried at a site in Pine County and a large quantity of lead arsenate was buried at a site in St. Louis

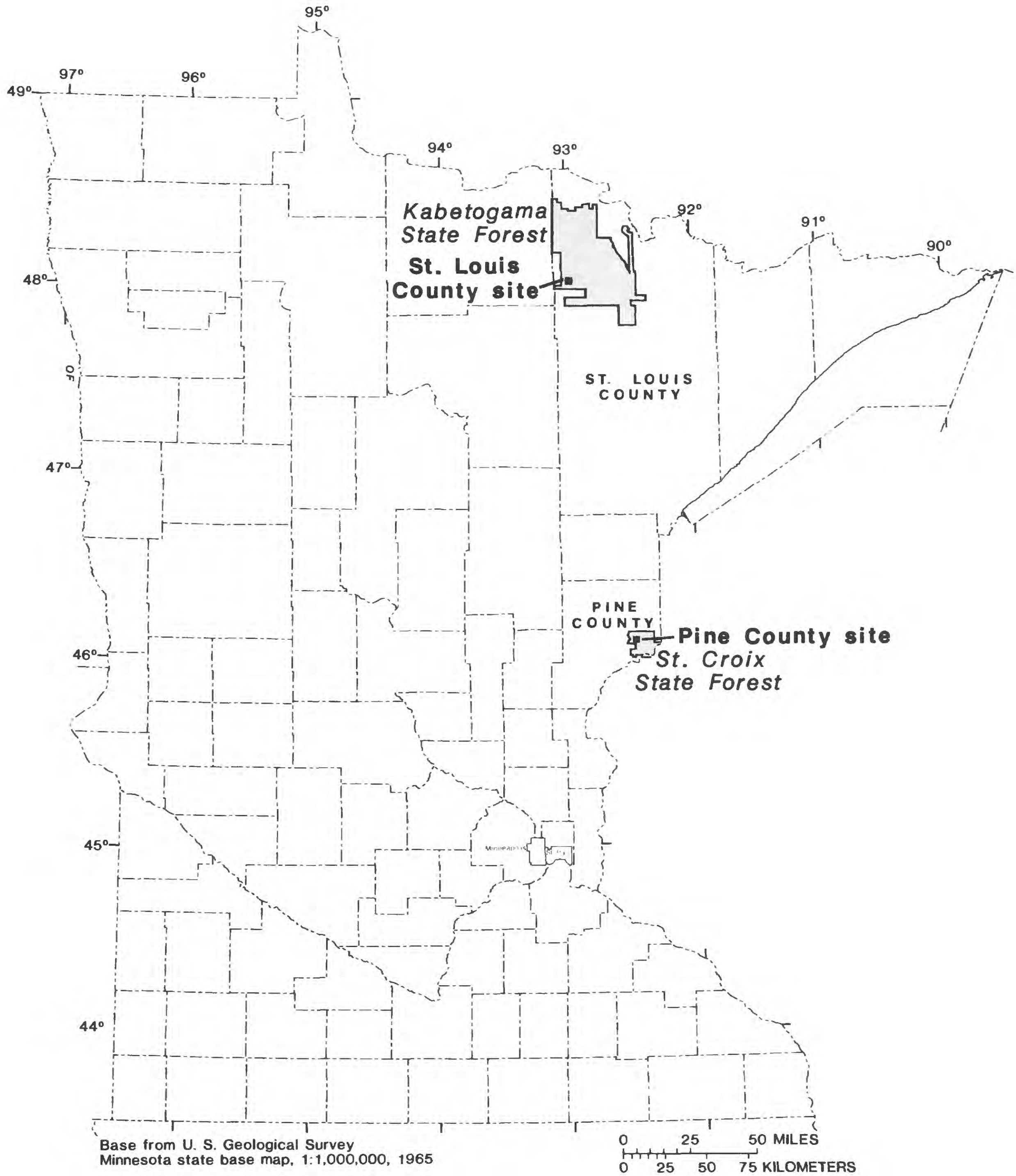


Figure 1.--Location of pesticide-disposal sites in Pine and St. Louis Counties, Minnesota

County (table 1). The sites were selected because they were thought to be remote enough so as not to pose a health hazard to humans. Both sites are located on State-owned land and the nearest known domestic wells are at least a mile from the sites.

At each site, trenches were dug 5 to 7 feet deep and pesticides (primarily lead arsenate) were placed in the trenches in cardboard containers. Metal drums containing liquid pesticides also were placed in the trenches at the Pine County site. After being placed in the trenches, the materials were covered with soil.

Study Approach

Investigations of each disposal site were conducted in several phases that included (1) surveying and drafting of topographic maps, (2) surface-geophysical surveying, (3) monitoring-well installation and development, (4) water-level measurements, and (5) water, soil and waste-material sampling and laboratory analyses.

Topographic surveying and survey-related drafting were completed in May 1984 by MDNR staff. Maps produced covered an area of approximately 40 acres at a contour interval of 1 foot. Geophysical surveys also were done during the spring and summer of 1984 by MDNR staff. Several geophysical-survey techniques were used at each site during summer 1984 to (1) aid in the selection of sites for drilling, (2) identify the location of the buried pesticides, (3) extend the interpretation of subsurface information that was to be collected during drilling, and (4) identify the extent and direction of movement of contaminated ground water. Magnetic, electrical earth-resistivity, seismic-refraction, and terrain electromagnetic-conductivity methods were used. These surveys were confined to within several hundred feet of the disposal sites. The surveys were conducted by MDNR staff and are discussed, in detail, in a report by the MDNR (1985).

Drilling for monitoring-well installation began at the St. Louis County site in August 1984 and at the Pine County site in September 1984. Initial test wells were drilled by a private contractor. The initial drilling method (hollow-stem auger) was used at the St. Louis County site but was abandoned at the Pine County site because of the stoney glacial materials at the site. Drilling at the Pine County site was resumed in October 1984 using an air-rotary rig with a casing hammer. All subsequent deep wells were installed by this method.

Because the local directions of ground-water flow were not known, three wells were drilled initially in a triangular pattern at distances of several hundred feet from the burial trenches. Water-level data from these wells were used to establish the general direction of ground-water flow. Several additional wells were drilled downgradient from the burial sites. At the St. Louis County site, 14 observation wells and 2 test holes were completed by the contractor during the summer of 1984. At the Pine County site, 7 test holes and 11 wells were completed by the contractor during the fall of 1984. Twenty-one additional shallow wells were constructed at the Pine County site during the fall of 1984 by MDNR and U.S. Geological Survey personnel using hand or

Table 1.--Amounts and characteristics of pesticides buried at the sites

[I, insecticide; H, herbicide; F, fungicide; S, solid; L, liquid; gals, gallons; lbs, pounds (avoirdupois); --, not buried; ?, unknown]

Name	Type	State	Amount: Pine County	Amount: St. Louis County
Lead-arsenate	I	S	9,775 lbs	1,500 lbs
Chlorpropham	H	S	1,030 lbs	--
DDT	I	S/L	308 lbs & 170 gals	-- --
Lime sulfur	F	S	85 lbs	--
Endrin	I	S	48 lbs	--
Aldrin	I	S/L	25 lbs & 5 gals	-- --
Magnesium carbonate	I	S	50 lbs	--
Ammonium carbonate	?	S	8 lbs	--
APC-Benzac[1]	?	L	2 gals	--
Borasu[2]	?	S	20 lbs	--
unknown[3]	?	S	50 lbs	--

[1] trichlorobenzoic acid and (or) polychlorobenzoic acid
[2] probably Borascu *, a herbicide
[3] probably chlorpropham

* Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

power augers. Eight additional test holes also were bored in conjunction with this phase of work. All deep wells were constructed of either 2- or 4-inch PVC pipe with 10-slot PVC screens. These wells have approximately 20 feet of screen that extends from slightly above the water table to the bottom of the well. The annular space around all screens in the deep wells was packed with sand, and the open interval above the screen was grouted and protected with a steel casing. Due to the difficulty and cost of drilling, nested wells were completed at only a few sites. All wells were constructed according to specifications set by the MDH (Minnesota Department of Health) (1983) for monitoring wells. Each well was developed until all drilling water had been removed and until discharge water was visibly clear of sediment. Water-levels were measured periodically from August 1984 through February 1985.

Drill cuttings were sampled in conjunction with monitoring-well installation. Additional soil samples were taken from the burial trenches and from the immediate vicininty of the trenches. Ground-water samples were collected by pumping all wells at least once in the period between August 1984 and April 1985. Selected water samples were obtained also from nearby surface-water bodies. Drilling and sampling were done according to a safety plan prepared for the sites (Minnesota Department of Natural Resources, 1984a; 1985). The plan outlined procedures for work at the sites and procedures that would be followed in the event that personnel came in contact with hazardous materials. The plan required that safety training and health monitoring be provided for all personnel at the sites. Protective clothing, including air-purifying respirators, were worn as required during certain activities. Decontamination facilities were provided at the sites for personnel and equipment. Drill cuttings and water pumped from wells were stored in containers at the sites until levels of contamination were determined.

All samples were analyzed under a quality-assurance program designed by the MDNR (1985) in accordance with USEPA (U.S. Environmental Protection Agency) and MDH standard methods (Sherma and Beroza, 1980; U.S. Environmental Protection Agency, 1980, 1982, 1983, 1984a and 1984b; Minnesota Department of Health, 1985). Analyses of organic compounds were by gas chromatography/mass spectrometry (GC/MS). Blanks were run with each set of samples. MDNR's Carlos Avery and Hibbing laboratories analyzed most organic and inorganic constituents, respectively, except for sample duplicates. Some duplicate samples and field splits were analyzed for organic and inorganic constituents by the U.S. Geological Survey Central Laboratory, Minnesota Department of Health. Braun Laboratories, and the Iowa Hygienic Laboratory. Intra-laboratory accuracy was determined by spiking samples with reference standards at various concentrations. Most reference standards were USEPA standards. To assess the reproducibility of laboratory analyses, at least 10 percent of all samples analyzed were field duplicates. At least 5 percent of all samples analyzed were split with other laboratories. The quality-assurance program and the results of the program are discussed in detail in a report by the MDNR (1985).

Selected soil samples were analyzed for particle-size distribution, moisture content, and concentrations of contaminants. Soil samples from the St. Louis County site were analyzed for lead and arsenic. Samples from the Pine County site were analyzed for lead, arsenic, and total concentrations of 4,4'-DDE; 2,4'-DDE; 4,4'-DDD; 2,4'-DDD; 4,4'-DDT; 2,4'-DDT; aldrin, dieldrin, endrin, and other hazardous organic compounds that may have been present as degredation products of pesticides (MDNR, 1985).

Selected water samples from the St. Louis County site were analyzed for temperature, pH, specific conductance, alkalinity, lead, and arsenic. Water samples from the Pine County site were analyzed for a number of properties and constituents including temperature, pH, specific conductance, total organic carbon, lead, arsenic, 4,4'-DDE, 2,4'-DDE, 4,4'-DDD, 4,4'-DDT, 2,4'-DDT, aldrin, dieldrin, endrin, chlorpropham, 3-chloroaniline, and other hazardous organic compounds that may have been present as pesticide formulation ingredients or degradation products.

PINE COUNTY SITE

Site Description

Physical Setting

The Pine County site is located about 2 miles south of Duxbury (NE1/4,SW1/4,SE1/4 sec. 20, T. 42 N., R. 17 W.) near the surface-drainage divide between the Lower Tamarack River, half a mile to the east, and the East Fork Crooked Creek, 1.25 miles to the west (fig. 2). Both streams flow southward into the St. Croix River. The area consists mainly of a series of south- southwest-trending low ridges and valleys developed on ground moraines. The ridges generally consist of coarse sand, gravel, and boulders, and the valleys commonly are wetlands. Local topographic relief generally is less than 100 feet.

The site is located on and surrounded by State-owned land in the St. Croix State Forest (fig. 2). The nearest residence is approximately one mile from the burial site, and there are no known wells within one mile of the site. Timber, forest-products production, and small farming are the major land uses.

Two trenches were dug for burial of pesticides at the Pine County site. Solid pesticides were placed in one trench and liquid pesticides in another. Liquid containers, usually metal drums, were punctured prior to being covered with soil (fig. 3).

The general topography of the Pine County site consists of a series of south-southwest-trending low hills and valleys (fig. 2). The hills generally are underlain by sand, gravel, and boulders and probably are depositional features associated with tunnel valleys that formed at the base of the Superior Lobe. The site is level and in a saddle-like depression between two small rises immediately to the east and west (fig. 2). The tops of these rises are approximately 10 to 20 feet above the site.

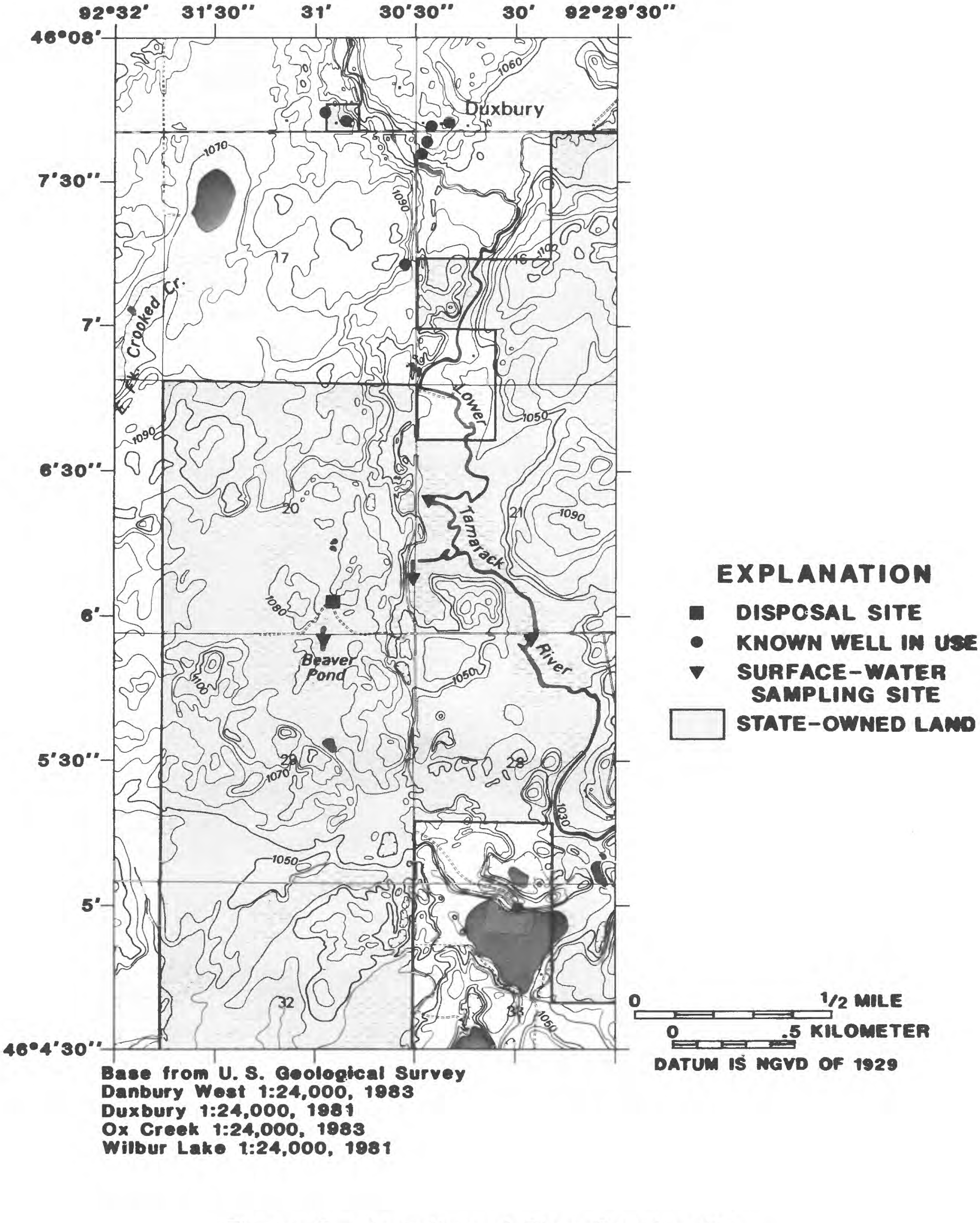
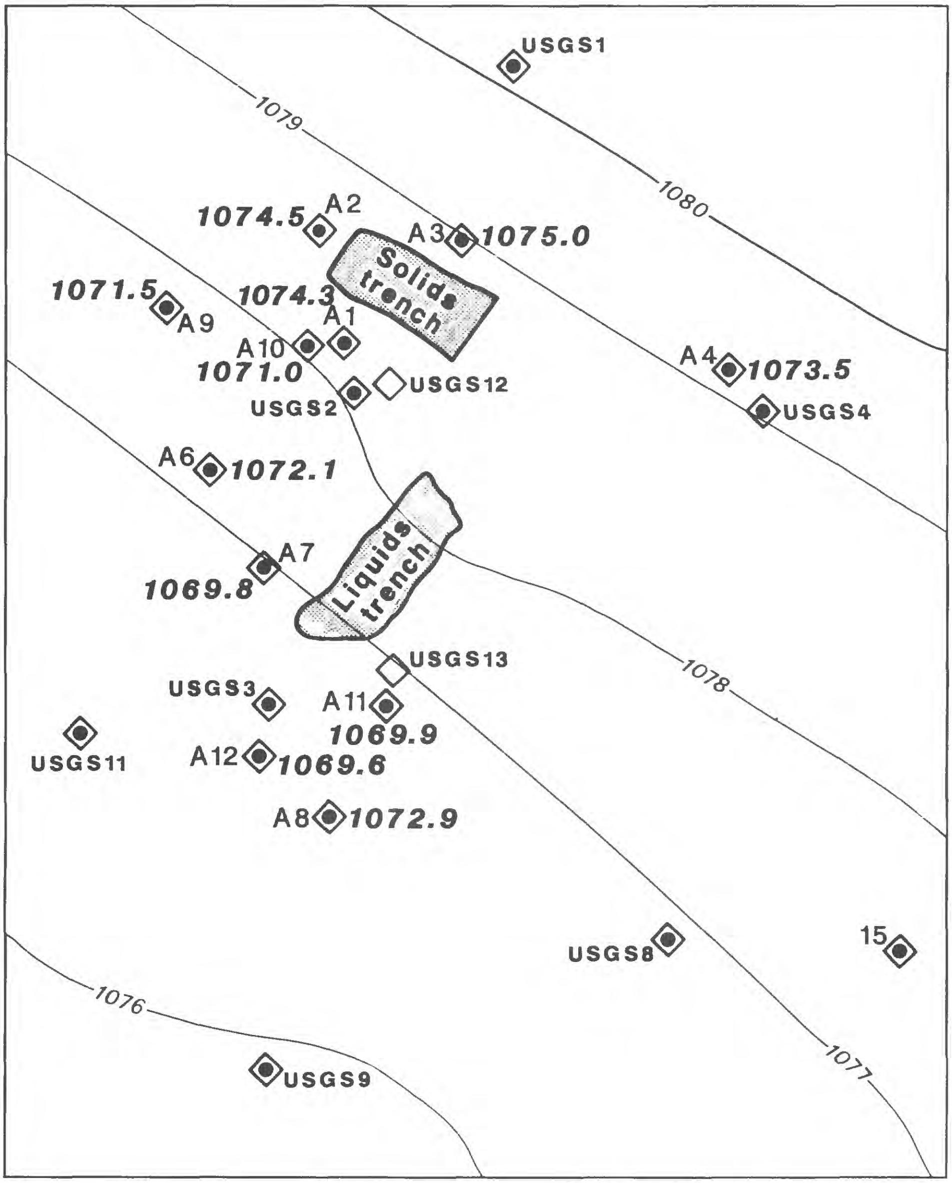


Figure 2.--Location of Pine County site



See figure 4 for location insert

N

0 10 20 30 FEET

0 2 4 6 8 METERS

DATUM IS NGVD OF 1929

EXPLANATION

—1080— **LAND-SURFACE CONTOUR--** Shows altitude of land surface. Contour interval 1 foot

A3◈ **MONITORING WELL AND NUMBER AND SOIL-SAMPLING SITE**

◇USGS13 **SOIL-SAMPLING SITE AND NUMBER**

1072.9 **WATER-SURFACE ALTITUDE--** Measured in wells completed in clay-rich lens Oct. 3, 1984

Figure 3.--Location of shallow wells, data-collection points, and water-surface altitudes, Pine County site

Drainage

Surface drainage is poorly developed (fig. 4) and small ponds form in local depressions after snowmelt and heavy rains. In the immediate vicinity of the burial site, surface drainage is toward the southwest to a small pond approximately 250 feet from the disposal site. Drainage from the pond appears to be to the south through an extensive wetland system. Additional small ponds and wetlands are located to the north, northwest, and east of the burial site. The surface elevation of the site is less than 10 feet above the surface of nearby wetlands.

Local runoff from the Pine County site moves southwestward toward a small uncontrolled pond, to a wetland south of the site, and to other ponds and wetlands located to the north, northwest, and east of the site (fig. 4).

Hydrogeology

Volcanic rocks of Precambrain age underlie the Pine County site; these rocks consist mainly of lava flows. Associated volcanic rocks, including tuff, and tuff breccia, are present in many locations (Morey and Mudrey, 1972). This volcanic sequence dips gently eastward and southeastward toward the axis of the Lake Superior syncline (Noland, 1967). Depth to bedrock in the vicinity of the Pine County site ranges from about 50 to 100 feet (Olsen and Mossler, 1982). Buried bedrock valleys are present in some areas.

Glacial deposits that overlie the consolidated rocks were deposited by the Superior lobe, which advanced from the north during the Wisconsin glaciation about 12,000 years before the present (Wright, 1972). The Pine County site is underlain by ground moraine associated with the Mille Lacs Highland moraine (Wright, 1972). The surficial materials are primarily red-brown, silty to sandy glacial till containing numerous pebbles, cobbles, and boulders. Sandy to gravelly glaciofluvial deposits also are in the stratigraphic sequence.

Seismic-refraction data collected along a northeast-southwest line extending about 300 feet southwest of the disposal site suggested that the water table was from about 3 to about 20 feet below land surface and that depth to bedrock averaged about 90 feet below land surface. Subsequent test drilling indicated that the upper 50 feet of unconsolidated material, in the immediate vicinity of the site, consists of glacial deposits that differ in texture in both the vertical and horizontal directions. Although correlation of stratigraphic units between closely spaced wells (tens to hundreds of feet separation) is difficult, three general zones can be identified (fig. 5).

The upper zone (upper 20 feet) consists predominantly of sand with silt, clay, and gravel. This zone generally is unsaturated but contains a shallow lens of silt and clay-rich sand as much as 8 feet thick in the immediate vicinity of the disposal site. This lens extends from just north of the burial sites to the vicinity of the pond to the southwest (fig. 6). At its widest point, the lens is approximately 200 feet wide in an east-west direction. The approximate areal extent of the lens, as shown on figure 6, was determined primarily by test drilling and electromagnetic-conductivity surveys (fig. 6).

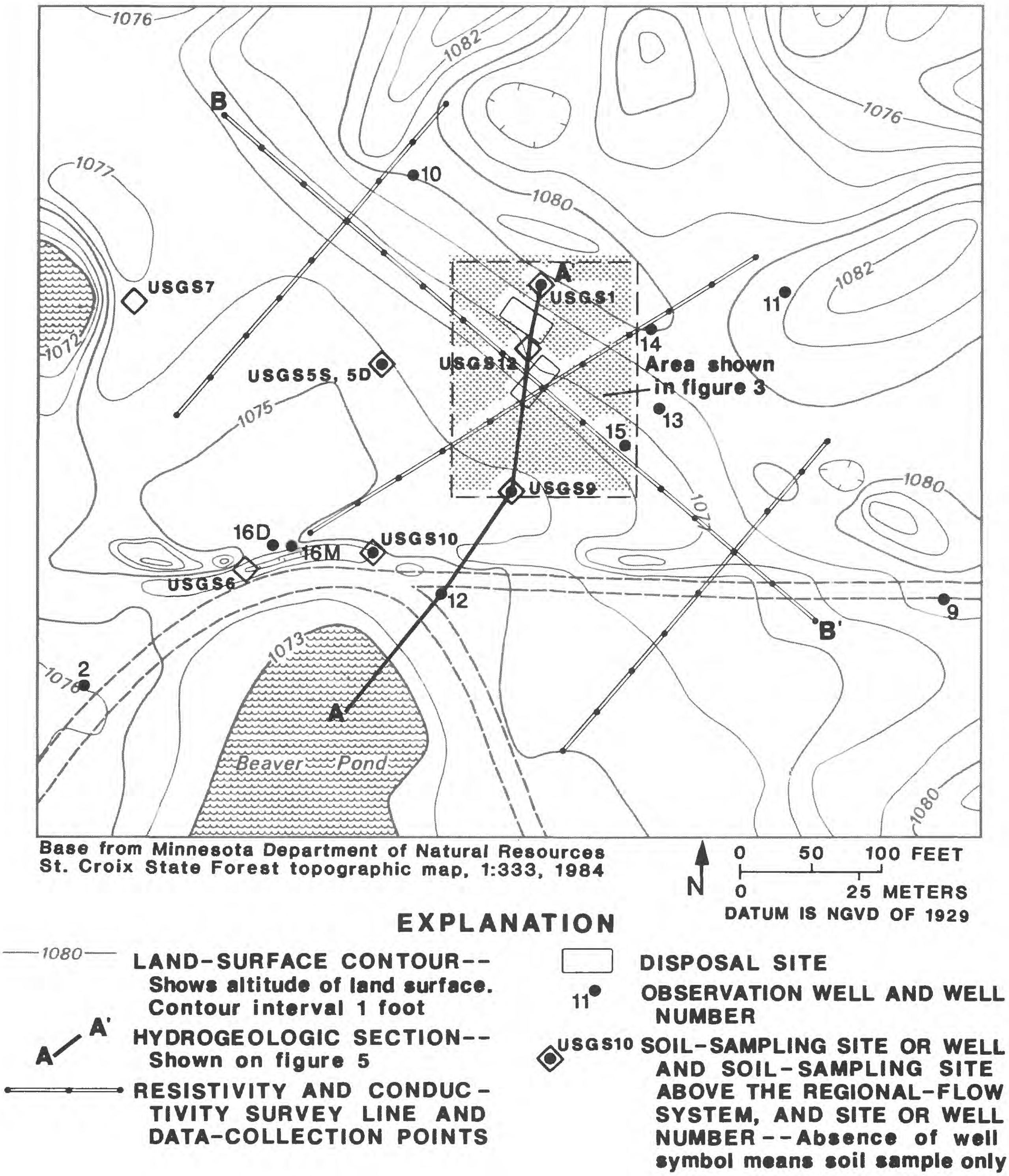


Figure 4.--Topographic setting and location of data-collection points, Pine County site

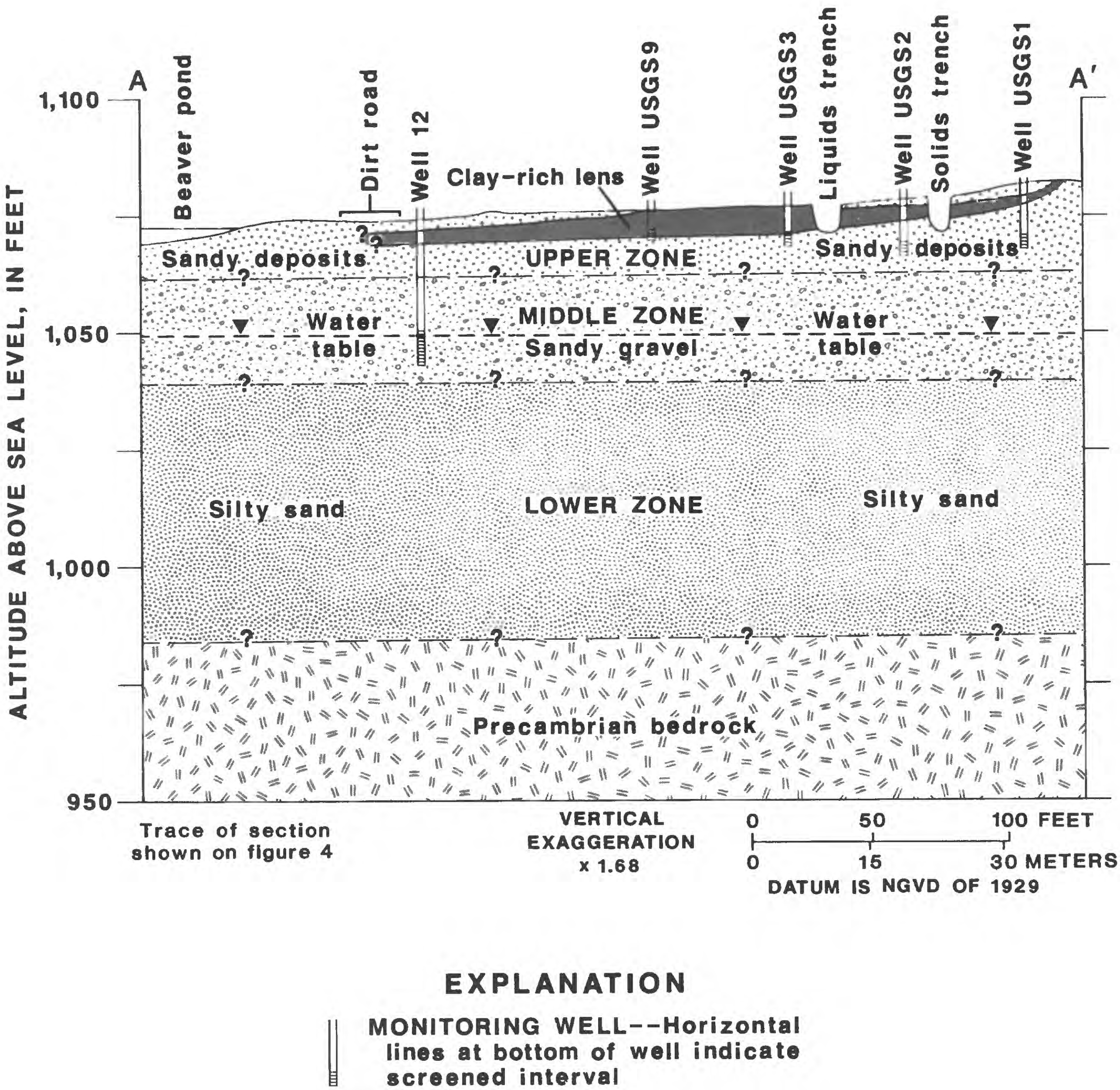


Figure 5.--Section A-A' through disposal trenches showing geologic relations and selected monitoring wells, south-southwest to north-northeast, Pine County site

Base from Minnesota Department of Natural Resources
St. Croix State Forest topographic map, 1:333, 1984

N

0 50 100 FEET

0 25 METERS

DATUM IS NGVD OF 1929

EXPLANATION

—50— LINE OF EQUAL ELECTROMAGNETIC CONDUCTIVITY--Interval 100 microsiemens per meter

• CONDUCTIVITY DATA-COLLECTION POINT

SOLIDS DISPOSAL TRENCH

LIQUIDS DISPOSAL TRENCH

APPROXIMATE LOCATION OF CLAY-RICH LENS IN IMMEDIATE VICINITY OF DISPOSAL TRENCHES

Figure 6.--Electromagnetic conductivity in approximate area of clay-rich lens, Pine County site

The altitude of the base of the clay-rich lens appears to be approximately 1,073 to 1,075 feet above sea level in the vicinity of the solids trench, and 1,072 to 1,073 feet in the vicinity of the liquids trench. The base of the lens slopes from the burial site toward the pond. The lens contains several discontinuous layers of clay-rich material between more sandy layers. Some clayey layers (from 0.25 to 1.0 foot thick) are sharply bounded by sandy layers above and below. This lens may not be the only fine-grained, near-surface zone in the area. Electrical-resistivity data from an area approximately 250 feet north of the trenches suggests another electrically conductive, possibly fine-grained, zone.

The middle zone in the glacial deposits is 10 feet thick and lies about 20 feet below land surface (fig. 5); it generally contains more gravel than the upper zone. Boulders, cobbles, pebbles, and silt-sized particles are common.

The lower zone (generally more than 30 feet below land surface) is predominantly silty sand or sandy silt with smaller amounts of clay, gravel, and larger particles. Particle-size analyses of samples from these zones illustrate the textural differences between the three zones (see table 2). The upper two zones probably are glaciofluvial whereas the lower zone probably is till.

The water table generally is about 30 feet below land surface in the Pine County area. The regional direction of ground-water movement is to the southeast toward the St. Croix River (Helgesen and others, 1973). However, the local direction of ground-water flow probably is toward a point of local discharge, such as a nearby stream or lake. Till deposits generally have low hydraulic conductivity and are not productive aquifers. Locally, however, deposits of sand and gravel provide sufficient quantities of water for domestic wells. In some areas, wells are completed in the Precambrian volcanic rocks, although water from these rocks commonly has elevated concentrations of dissolved minerals (Helgesen and others, 1973).

The water table at the site is approximately 20 feet below the level of ponds and wetlands near the site, indicating the presence of perched water locally. The direction of ground-water flow at the regional water table is to the east-southeast, based on depth to water data from April 1985 (fig. 7). Ground water in the regional flow system discharges to the Lower Tamarack River. Horizontal gradients in the vicinity of the site average about 0.013. This relatively steep gradient probably is indicative of the low hydraulic conductivity of glacial materials in the area. The water-level data also indicate that ground water at the regional water table under the site is not flowing to the pond and wetland south of the site. Therefore, water in the pond must be derived from surface drainage or from a local (perched) ground-water-flow system.

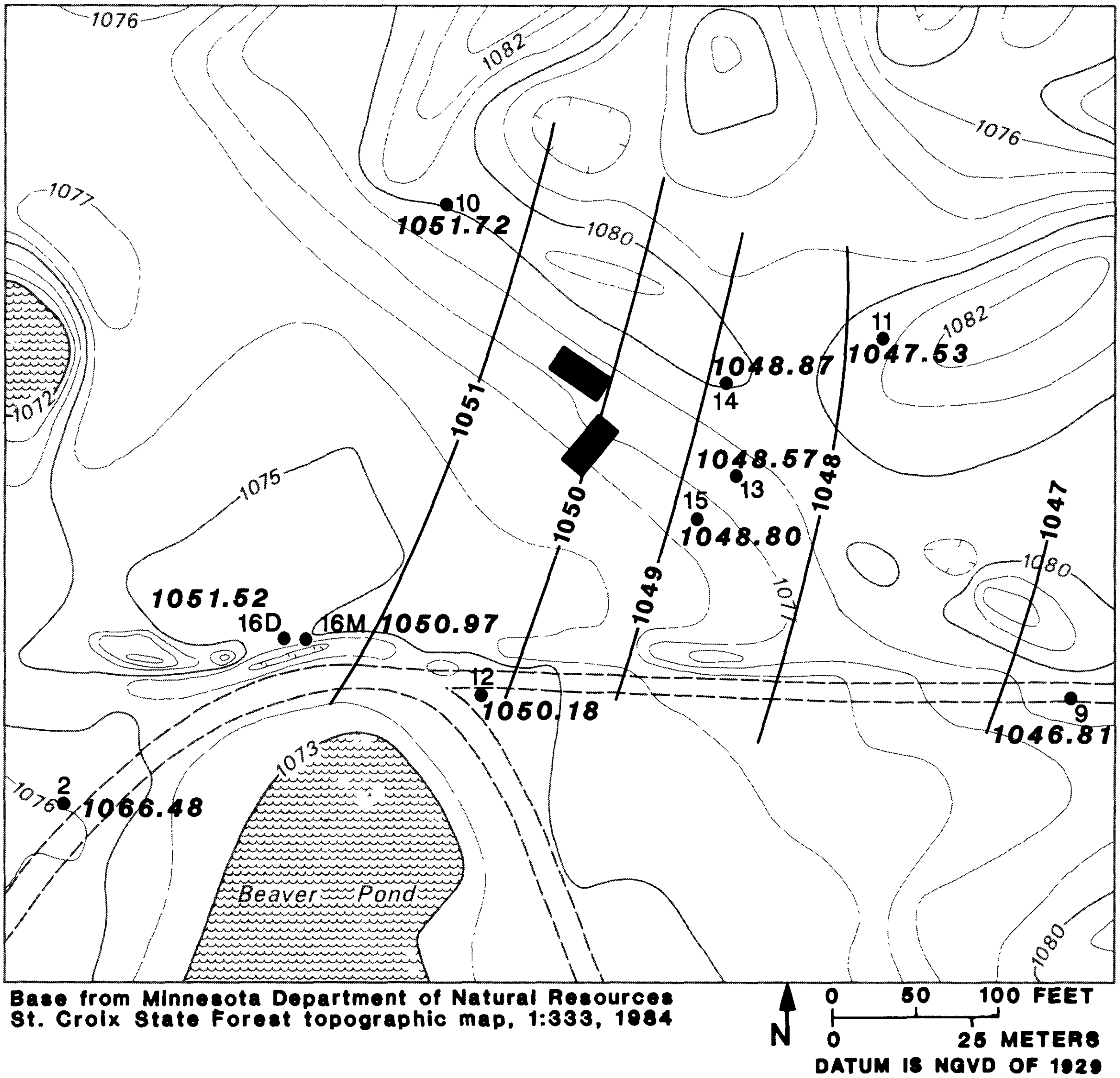
Table 2.--Hydraulic conductivity of glacial deposits at Pine County site estimated using Hazen's formula (from Minnesota Department of Natural Resources, 1985)

[cm, centimeters; cm/s, centimeters/second; ft/d, feet/day]

Hole number	Sampling depth interval (feet)	Soil type	Diameter at which 10 percent of soil mass is finer (D_{10}) (cm)	Saturated hydraulic conductivity (K)[1] (cm/s)	(ft/d)
2	10-15	Silty sand	2.0×10^{-3}	4.0×10^{-4}	1.1
2	15-20	Silty sand	5.2×10^{-3}	2.7×10^{-3}	7.7
2	20-25	Silty sand	3.5×10^{-3}	1.2×10^{-3}	3.5
	30-35	Sand with gravel	0.41×10^{-2}	1.7×10^{-3}	4.8
USGS[2]	5	Silty sand with a little gravel	4.3×10^{-4}	1.8×10^{-5}	0.05
USGS[2]	7-8	Silty sand with gravel	2.5×10^{-3}	6.3×10^{-4}	1.8
USGS[2]	8-11	Silty sand with a little gravel	1.1×10^{-3}	1.2×10^{-4}	.34
USGS[2]	12-13	Silty sand with gravel	2.9×10^{-3}	8.4×10^{-4}	2.4

[1] $K = 100(D_{10})^2$ (Lambe and Whitman, 1969)

[2] Sampled at air-rotary rig discharge hose; the sample is thus less representative than others that were collected by split spoon.



EXPLANATION

—1050— **POTENTIOMETRIC CONTOUR--** Showing altitude at which wells would stand in water open to the water table. Interval 1 foot. Datum is NGVD of 1929

■ **DISPOSAL SITES**

11 ● 1047.53 **OBSERVATION WELL, WELL NUMBER, AND WATER-SURFACE ALTITUDE MEASURED IN WELL**

Figure 7.--Configuration of regional water table at Pine County site on April 24, 1985

Hydraulic-head data from paired piezometers north of the pond indicate a slight upward component of vertical flow at the location.

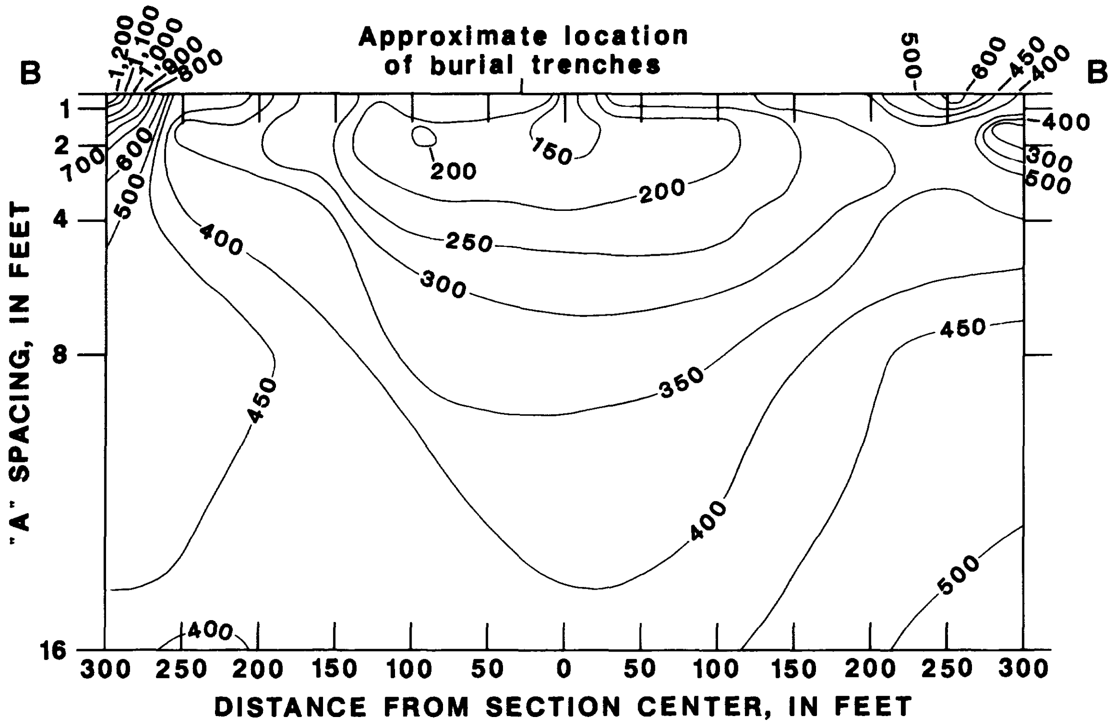
Saturated hydraulic conductivity of glacial deposits at the site ranges from 0.05 to 4.8 ft/d, estimated using Hazen's formula (table 2). The hydraulic conductivity in the upper part of the regional aquifer was estimated, also using Hazen's formula, to range from about 3 to about 8 ft/d. By applying Darcy's law to the gradients shown on figure 8, lateral specific discharge would be approximately 1 to 30 ft/yr. Assuming a porosity of 0.3, the average lateral seepage velocity could range from 3 to 90 ft/yr.

Relation of Burial Site to Geologic Environment

During the course of surveys to locate buried pesticides, additional information about the shallow clay-rich lens was obtained. Geophysical data and shallow augering in the immediate vicinity of the burial sites indicated that the pesticides were buried in trenches excavated in a shallow lens of saturated silt and clay-rich sand that lies about 25 feet above the regional water table. The magnetic survey identified two potential areas of buried metal objects. These areas, approximately 6 to 10 feet northeast and southwest of the assumed location of the trenches may be the actual locations of pesticide burial. Electrical-resistivity profiling (fig. 8) and gridded electromagnetic-conductivity surveys (fig. 8) identified materials with low electrical resistivity (high conductivity) in the depth interval from about 0 to 20 feet below land surface in the area under the disposal trenches and extending north-northwest and south-southeast from the disposal sites. These findings corresponded with earlier results from test drilling and electromagnetic-conductivity surveying that indicated the presence of a shallow, clay-rich lens (fig. 6). Interpretation of the geophysical data suggested that the lens contained a perched water table near land surface.

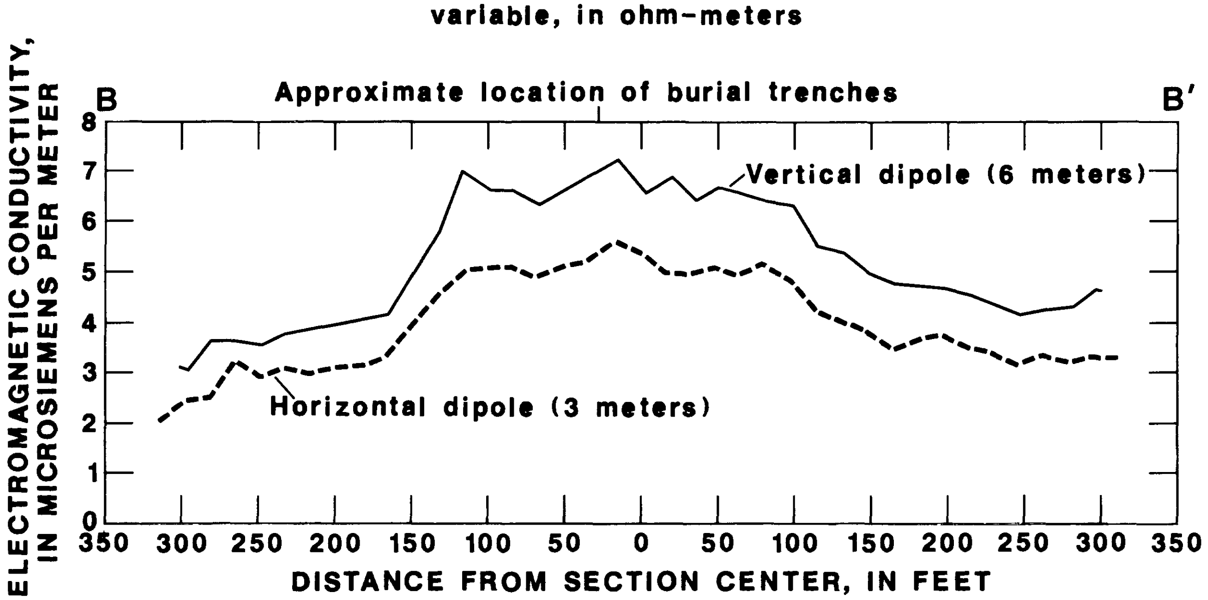
Twelve additional test holes, 10 to 15 feet deep, were drilled to better define the lithology, extent, thickness, and geometry of the clay-rich lens. Visual inspection of split-spoon samples of the material showed that the lens lacks fine laminae and grades into cleaner sand. The lens, which averages about 5 feet thick, extends from just north of the site to the vicinity of the beaver pond (fig. 6). The top of the lens slopes from the burial site toward the beaver pond.

Shallow wells (2-in. PVC) were installed in the lens (fig. 3). Water-level data (fall 1984, spring 1985) from these wells indicated that the direction of horizontal ground-water flow in the lens is to the south, toward the beaver pond, and approximately at right angles to the direction of regional ground-water flow (fig. 7). However, comparison of water levels measured concurrently in the pond and nearby shallow well USGS10 suggests that, at least part of the time, water from the pond discharges to the lens rather than the reverse. Depths to water in the shallow wells also were measured on February 14, 1985. All wells were dry or frozen, indicating that the lens may be saturated only temporarily during spring and during other wet periods.



EXPLANATION

—500— LINE CONNECTING POINTS OF EQUAL APPARENT RESISTIVITY--Interval variable, in ohm-meters



Trace of profile shown on figure 4

Figure 8.--Apparent resistivity and electromagnetic-conductivity profile along northwest to southeast survey line (B-B'), Pine County site

Estimates of the rate of ground-water movement (horizontal and vertical) in the lens cannot be made without more detailed information on the hydraulic characteristics of the lens. It is likely, however, that the lens is the major pathway for water and, possibly, for pesticide movement away from the disposal trenches. The relative magnitude of the horizontal and vertical components of this flow can not be evaluated with the available data.

Soil Contamination

Soil samples were collected from both disposal trenches at the Pine County site with a hand auger. Samples were obtained from eight auger holes in the liquids-disposal trench (fig. 9). In the southwestern part of the trench, three soil samples had combined DDT-series compound concentrations ranging from 0.2 to 2.5 ppm. The northeastern part of the trench had combined DDT-series compound concentrations of 150 to 2,300 ppm (tables 3, 4 and 5).

A soil sample from the center of the solids-disposal trench indicated a white lead-arsenate paste at about 6 feet below land surface. The bottom of the zone was not sampled to avoid perforation of any possible confining layer.

Soil within about 10 feet of the disposal trenches and above the bottom of the clay-rich lens showed little contamination by pesticide or pesticide-degredation products (table 6). This may be because contaminants have migrated laterally with ground water in the clay-rich lens. Soil samples from holes A1, A9, and A10 (fig. 9) had combined DDT-series-compound concentrations as high as 0.0010 ppm of dry soil. Lead concentratons as high as 48 ppm also were measured in soil from A9. The lack of similarly high concentrations of arsenic suggests that the lead value at A9 may be an anomaly.

Some vertical migration of contaminants through the clay-rich lens may have occurred. A concentration of DDT-series compounds, 0.10 ppm, was detected in soil at 10 to 12 feet in hole USGS 12, which is 15 feet from the solids-disposal trench and approximately 4 to 5 feet below the base of the lens. Contamination could not be detected in soil above the 10- to 12-foot depth, however, suggesting that contamination may have spread laterally from the disposal trenches in water flowing through the lens.

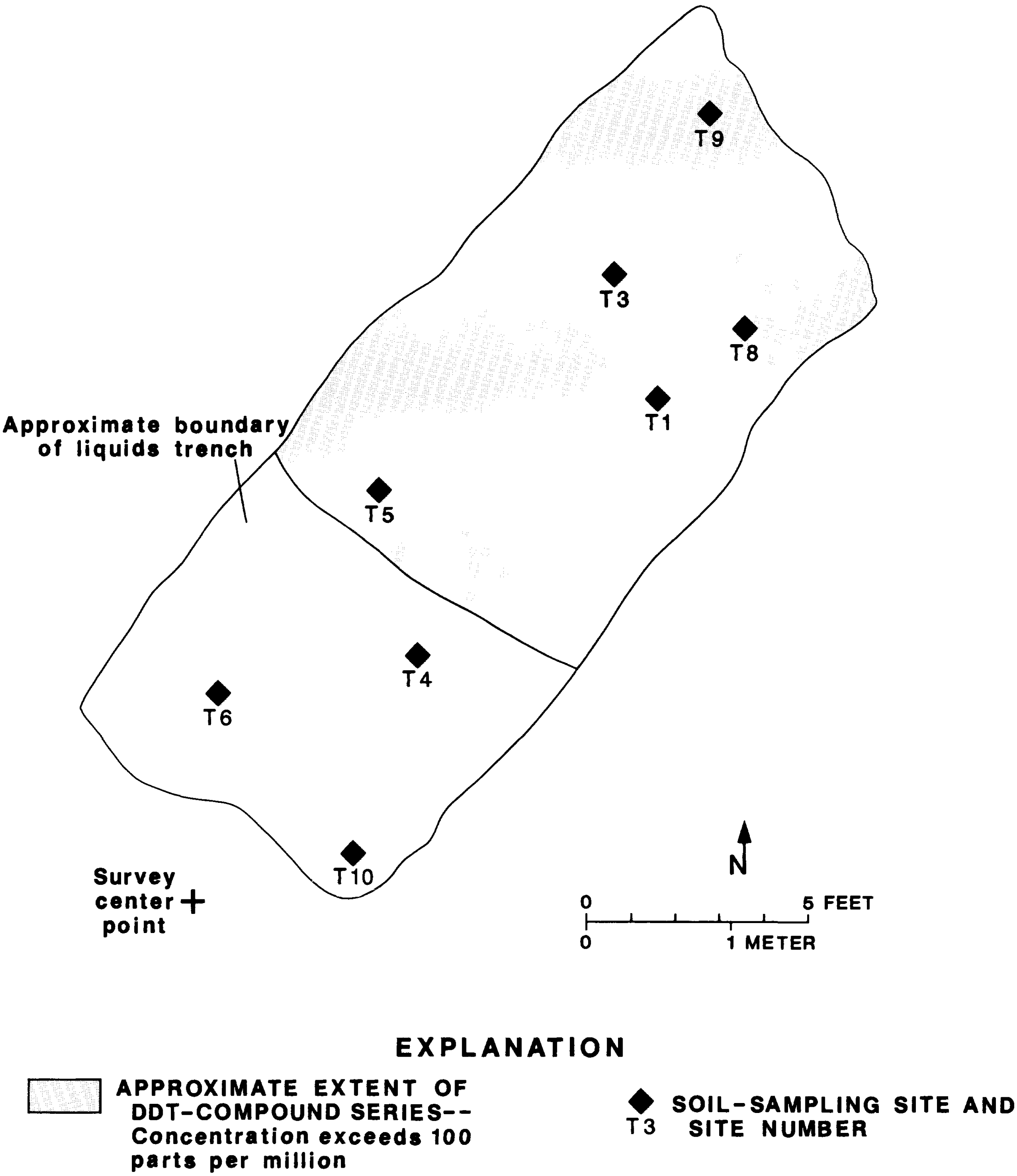


Figure 9.--Soil-sampling sites in liquids trench, Pine County site

Table 3.--Contaminants detected in soil samples from liquids trench, Pine County site

[Analyses by Department of Natural Resources laboratory, data from Minnesota Department of Natural Resources, 1985; NA, not available; <, less than]

Hole number	Sampling depth interval, feet	Concentration, parts per million dry									Purgeable and base/natural fraction organic priority pollutants
		Aldrin	Dieldrin	Endrin	4,4'-DDE	2,4'-DDE	4,4'-DDD	2,4-DDD	4,4'-DDT	2,4'-DDT	
T1	3-3.5	[1]<0.001	[1]<0.001	[1]<0.001	[1]4.32	[1]1.20	[1]15.6	[1]2.30	[1]107.4	[1]17.2	NA
T3	1.5-2.5	< .001	< .001	< .001	6.653	.455	84.07	34.52	428.1	67.64	NA
T3	3.25-4.0	< .001	< .001	< .001	12.96	.364	146.5	27.96	814.2	190.5	NA
T4	2.5-3.5	< .001	< .001	< .001	.019	.005	.691	.464	1.188	1.160	Some compounds detected see tables 5, 6
T5	2.5-6	[1]< .001	[1]< .001	[1]< .001	[1]7.998	[1] .180	[1]38.40	[1]9.152	[1]726.9	[1]97.63	NA
T6	2.5-5	[1]< .001	[1]< .001	[1]< .001	[1] .004	[1] .010	[1] .192	[1] .230	[1] .056	[1] .026	NA
T8	3.5-5.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	Some compounds detected, see table 6
T9	3-6	< .001	< .001	< .001	11.94	1.431	377.9	58.91	1,470.0	331.1	NA
T10	2.75-3.5	< .001	< .001	< .001	.005	.007	.271	.145	.104	.016	NA
T10	3.5-4.0	< .001	< .001	< .001	.002	.004	.089	.066	.036	.017	NA
T10	4.0-4.5	< .001	< .001	< .001	.003	.004	.085	.063	.063	.020	Some compounds detected, see table 5
T7 (control)	2-4.5	< .001	< .001	< .001	[1] .002	[1] .003	[1] .016	[1] .068	[1] .019	[1] .011	NA

[1] Mean of lab duplicate analyses.

Table 4.--Purgeable organic compounds in soil samples from liquids trench, Pine County site

[Analyses by Department Natural Resources Laboratory, data from Minnesota Department of Natural Resources, 1985; NA, not available; <, less than]

Parameter	Concentration, parts per million wet soil		
	Hole T4, 2.5-3.5 feet	Hole T5, 2.5-6 feet	Hole T10, 4.0-4.5 feet
Chloromethane	<0.005	<0.005	<0.005
Bromomethane	< .005	< .005	< .005
Vinyl chloride	< .005	< .005	< .005
Chloroethane	< .005	< .005	< .005
Methylene chloride[1]	.010	.019	.010
1,1-dichlorethene	< .005	< .005	< .005
1,1-dichlorethane	< .005	< .005	< .005
Trans-1,2-dichlorethene	< .005	< .005	< .005
Chloroform	< .005	< .005	< .005
1,2-dichloroethane	< .005	< .005	< .005
1,1,1,-trichloroethane	< .005	< .005	< .005
Carbon tetrachloride	< .005	< .005	< .005
Bromodichloromethane	< .005	< .005	< .005
1,2-dichloropropane	< .005	< .005	< .005
Trans-1,3-dichloropropene	< .005	< .005	< .005
Trichloroethene	< .005	< .005	< .005
Dibromochloromethane	< .005	< .005	< .005
Cis-1,3-dichloropropene	< .005	< .005	< .005
1,1,2-trichloroethane	< .005	< .005	< .005

Table 4.--Purgeable organic compounds in soil samples from liquids trench, Pine County site--Continued

Parameter	Concentration, parts per million wet soil		
	Hole T4, 2.5-3.5 feet	Hole T5, 2.5-6 feet	Hole T10, 4.0-4.5 feet
Benzene	<0.005	<0.005	<0.005
2-chloroethylvinyl ether	< .025	< .025	< .025
Bromoform	< .005	< .005	< .005
Tetrachloroethene	< .005	< .005	< .005
1,1,2,2-tetrachloroethane	< .005	< .005	< .005
Toluene	< .005	[2]< .005	[2]< .005
Chlorobenzene	< .005	< .005	< .005
Ethylbenzene	< .005	[2]< .005	[2]< .005
Acrolein	< .125	< .125	< .125
Acrylonitrile	< .125	< .125	< .125
Total xylenes	.005	.091	.007

1 Contaminant from laboratory extraction procedure.
2 Parameter detected but amount present was less than quantitation limit.

Table 5.--Base/neutral organic compounds in soil samples from liquids trench, Pine County site

[Analyses by Iowa Hygienic Laboratory, data from Minnesota Department of Natural Resources, 1985; <, less than]

Parameter	Concentration, parts per million wet soil		
	Hole T4, 2.5-3.5 feet	Hole T5, 2.5-6 feet	Hole T8, 3.5-5.5 feet
Bis-(2-chloroethyl) ether	<0.13	<0.13	<0.13
1,4-dichlorobenzene	< .07	< .07	< .07
1,3-dichlorobenzene	< .07	< .07	< .07
1,2-dichlorobenzene	< .07	< .07	< .07
Bis-(2-chloroisopropyl) ether	< .03	< .03	< .03
Hexachloroethane	< .07	< .07	< .07
Nitrobenzene	< .13	< .13	< .13
Isophorone	< .03	< .03	< .03
Bis-(2-chloroethoxy) methane	< .13	< .13	< .13
1,2,4-trichlorobenzene	< .07	< .07	< .07
Naphthalene	< .03	.061	1.36
1,3-hexachlorobutadiene	< .13	< .13	< .13
Hexachlorocyclopentadiene	< .13	< .13	< .13
2-chloronaphthalene	< .03	< .03	< .03
Acenaphthylene	< .07	< .07	< .07
Dimethyl phthalate	< .03	< .03	< .03
N-nitrosodi-n-propylamine	< .13	< .13	< .13
N-nitrosodimethylamine	< .3	< .3	< .3

Table 5.--Base/neutral organic compounds in soil samples from liquids trench, Pine County site

--Continued

Parameter	Concentration, parts per million wet soil		
	Hole T4, 2.5-3.5 feet	Hole T5, 2.5-6 feet	Hole T8, 3.5-5.5 feet
Acenaphthene	<0.07	<0.07	<0.07
Diethyl phthalate	< .07	< .07	< .07
Fluorene	< .07	< .07	[1]< .07
4-chloropheny phenyl ether	< .13	< .13	< .13
N-nitroso diphenyl amine	< .07	< .07	< .07
1,2-diphenyl hydrazine	< .13	< .13	< .13
4-bromophenyl phenyl ether	< .13	< .13	< .13
Hexachlorobenzene	< .13	< .13	< .13
Benzidine	<1.2	<1.2	<1.2
Phenanthrene	< .03	< .03	[1]< .03
Anthracene	< .03	< .03	< .03
Di-n-butyl-phthalate	[1]< .07	[1]< .07	[1]< .07
Fluoranthene	< .03	< .03	< .03
Pyrene	< .03	< .03	< .03
2,6-dinitrotoluene	< .3	< .3	< .3
2,4-dinitrotoluene	< .3	< .3	< .3
Butyl benzyl phthalate	< .13	< .13	[1]< .13
Bis-(2-ethylhexyl) phthalate	< .13	.44	[1]< .13
Di-n-octyl phthalate	.19	.66	[1]< .13

Table 5.--Base/neutral organic compounds in soil samples from liquids trench, Pine County site

--Continued

Parameter	Concentration, parts per million wet soil		
	Hole T4, 2.5-3.5 feet	Hole T5, 2.5-6 feet	Hole T8, 3.5-5.5 feet
Benzo(b) fluoranthene	<0.13	<0.13	<0.13
Benzo(k) fluoranthene	< .13	< .13	< .13
Chrysene	< .03	< .03	< .03
Benze(a)anthracene	< .13	< .13	< .13
1,2,3-indeno(c,d)pyrene	< .3	< .3	< .3
Dibenzo(a,h)anthracene	< .3	< .3	< .3
Benzo(g,h,i)perylene	< .3	< .3	< .3
Benzo(a)pyrene	< .13	< .13	< .13
3,3-dichlorobenzidine	< .3	< .3	< .3

[1] Parameter detected but amount present was less than quantitation limit.

Table 6.--Soil analyses from sampling sites nearest solids trench, Pine County site

[Analyses by Department of Natural Resources Laboratories, data from Minnesota Department of Natural Resources, 1985; NA, not available; <, less than]

Hole number	Sampling depth interval, feet	Concentration, parts per million dry soil										
		As	Pb	Aldrin	Dieldrin	Endrin	4,4'-DDE	2,4'-DDE	4,4'-DDD	2,4'-DDD	4,4'-DDT	2,4'-DDT
A1	1-2	1.3	8	NA	NA	NA	NA	NA	NA	NA	NA	NA
A1	3-4	1	5	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	0.006
A2	1-2	2	9	NA	NA	NA	NA	NA	NA	NA	NA	NA
A2	2-3	2	5	NA	NA	NA	NA	NA	NA	NA	NA	NA
A3	0.5-1.5	2	6	NA	NA	NA	NA	NA	NA	NA	NA	NA
A3	1.5-2.5	2	2	NA	NA	NA	NA	NA	NA	NA	NA	NA
A9	3-6	4	48	< .001	< .001	< .001	< .001	< .001	< .001	< .001	.003	.004
A10	4-6	2	4	< .001	< .001	< .001	.002	< .001	< .001	< .001	< .001	< .001
USGS2	2-5	NA	NA	< .001	< .001	< .001	< .001	< .001	< .001	< .001	.019	< .001
USGS2	7-8	3	3	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
USGS2	[3]12-13	NA	NA	< .001	< .001	< .001	< .001	< .001	< .001	< .001	.011	< .001
USGS12	3-4	1	3	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
USGS12	[1]5-7	2	2	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
USGS12	[2]10-12	1	2	< .001	< .001	< .001	< .001	< .001	.004	.001	.076	.025

[1]Mean of field duplicate analyses.
[2]Mean of laboratory duplicate analyses.
[3]Analyzed after six months holding time.

Water Quality

Ground Water

Ground water from site wells completed in the regional water-table aquifer have specific conductance, pH, and organic-carbon content concentrations typical of values reported by Trippler and Clark (1983) and Myette (1985) for sand and gravel aquifers in the Carlton-Pine-Kanabec County area. Specific conductance ranged from 120 to 350 µS/cm, (microsiemens per centimeter at 25 degrees celsius), pH ranges from 5.7 to 8.0.

Pesticides were not detected in any of the wells tapping the regional aquifer. The lack of pesticides in the regional aquifer may be explained in one or more of the following ways: (1) pesticides are strongly sorbed by fine-grained sediments, and chemical transport of the contaminants is greatly retarded, (2) the seasonally saturated lens above the regional aquifer results in lateral movement of the contaminants toward the beaver pond southwest of the site, (3) contamination has not yet migrated vertically to the regional water table, and (4) dispersion and dilution in the regional aquifer have resulted in undetectable concentrations at the wells sampled.

Specific conductance and pH of water sampled from wells completed in the clay-rich lens near the disposal trenches ranged from 40 to 90 µS/cm and 4.6 to 6.1, respectively. These values, generally lower than for water from wells completed in the regional aquifer, suggest a relatively short subsurface-residence time.

Pesticides were detected in water from shallow wells in the clay-rich lens in the immediate vicinity of the solids-disposal trench (table 7). Low levels of arsenic were detected in water from wells A1, A2, and A10. Water samples from wells A10 and A12 also contained low levels of some phthalate esters. These compounds may be residues of DDT formulation ingredients, pesticides packaging material, other waste organic material in the trenches and (or) well-construction material. The water-sampling results indicate lateral transport of pesticide compounds within 10 feet of the trench, but pesticides have not migrated great distances.

The failure to detect elevated concentrations of aldrin, dieldrin, endrin, chlorpropham and 3-chloroaniline and elevated lead in any of the wells could be due to several factors, individually or in some combination: (1) certain pesticides remained isolated in their containers after disposal, (2) various contaminants migrated in different directions, primarily owing to differences in placement of pesticides in the trenches, (3) some contaminants, due to retardation, have not migrated as far as others, (4) some contaminants have been degraded, and (5) the amount of certain pesticides put into the trenches was small. Lead, for example, might be expected to move in the same direction as arsenic, because they have the same source material, lead arsenate. The absence of high lead concentrations at locations where arsenic concentrations are high might be explained by greater sorption of lead relative to arsenic or the higher solubility of arsenic relative to lead. Fuller (1978) and Griffin and Shrimp (1978) indicate that lead is one of the least mobile trace elements in soil leachates, particularily in relation to arsenic.

Table 7.--Pesticide analyses of water from wells nearest solids trench, Pine County site

[Analyses by Department of Natural Resources Laboratories. from Minnesota Department of Natural Resources, 1985; samples taken April 25-26, 1985; <, less than]

Well number	Depth from land surface to base of screen interval, ft	Concentration, parts per million dry soil												
		As	Pb	Aldrin	Dieldrin	Endrin	4,4'-DDE	2,4'-DDE	4,4'-DDD	2,4'-DDD	4,4'-DDT	2,4'-DDT	Chlorpropham	3-chloraniline
A1	3.5	12	2	<0.010	<0.010	<0.010	0.053	<0.010	0.078	0.029	(2)	0.352	<0.10	<0.10
A2	3.2	2	2	[4]< .010	[4]< .010	[4]< .010	[4] .031	[4]< .010	[4] .026	[3,4] .010	[4] .176	[4] .026	[4]< .10	[4]< .10
A3	2.1	<1	1	< .010	< .010	< .010	< .010	< .010	< .010	< .010	< .010	< .010	< .10	< .10
A9	5.9	[1]1	[1]1	< .010	< .010	< .010	< .010	< .010	< .010	< .010	< .010	< .010	< .010	< .010
A10	6.4	[4]57	[4]1	[4]< .010	[4]< .010	[4]< .010	[4] .070	[4]< .010	[4] .044	[4] .014	(2)	[4] .122	[4]< .10	[4]< .10

[1]One sample indicated 12 µg/L. A laboratory reanalysis of this sample, however, indicated 1 micrograms per liter (µg/L), and a field duplicate that was also run twice in the laboratory gave values of <1 µg/L and <1 µg/L.
[2]Unidentified gas chromatograph peak obsured possible 4,4'-DDT peak.
[3]Parameter detected, but amount was less than quantitation limit.
[4]Mean of field duplicate analyses.

Surface Water

Pesticides were not detected in water samples from the beaver pond southwest of the disposal sites or from the Lower Tamarack River. Based on the proximity and projected directions of ground-water movement, these two surface-water bodies would be the most susceptible to contamination.

Summary of Investigation at Pine County Site

No significant soil or ground-water contamination by pesticides was found at the Pine County site. The relatively low solubility of the pesticides, the vertical separation between the buried materials and the regional water table, and the low hydraulic conductivity of the soils in which the pesticides were buried probably combined to limit mobility of the chemicals.

ST. LOUIS COUNTY SITE

Site Description

Physical Setting

The St. Louis County site is located about 3 miles north and 1 1/2 miles east of Greaney (SE1/4,SW1/4,SE1/4, sec. 22, T. 64 N., R. 21 W.) in a gravel pit near the top of an east-west trending ridge that rises 30 to 50 feet above the surrounding topography (fig. 10). The area in the immediate vicinity of the site ranges in elevation from 1,380 to 1,390 feet above sea level. Relief in the region is subdued with the exception of hills associated with the Vermillion End Moraine about 3 miles to the north (beyond the limits of figure 10). The site is located on and is surrounded by State-owned land in the Kabetogema State Forest. The nearest structures are hunting cabins approximately 1 mile to the north. Timber and forest-products production are the major land uses.

Drainage

Surface drainage in the area is poorly developed. Swamps, bogs and wetlands are numerous. The site lies atop a topographic divide that separates drainage to Prairie Creek (to the north) from the drainage to Willow River (to the south). Both Prairie Creek and Willow River flow to the west and are tributaries of the Little Fork River.

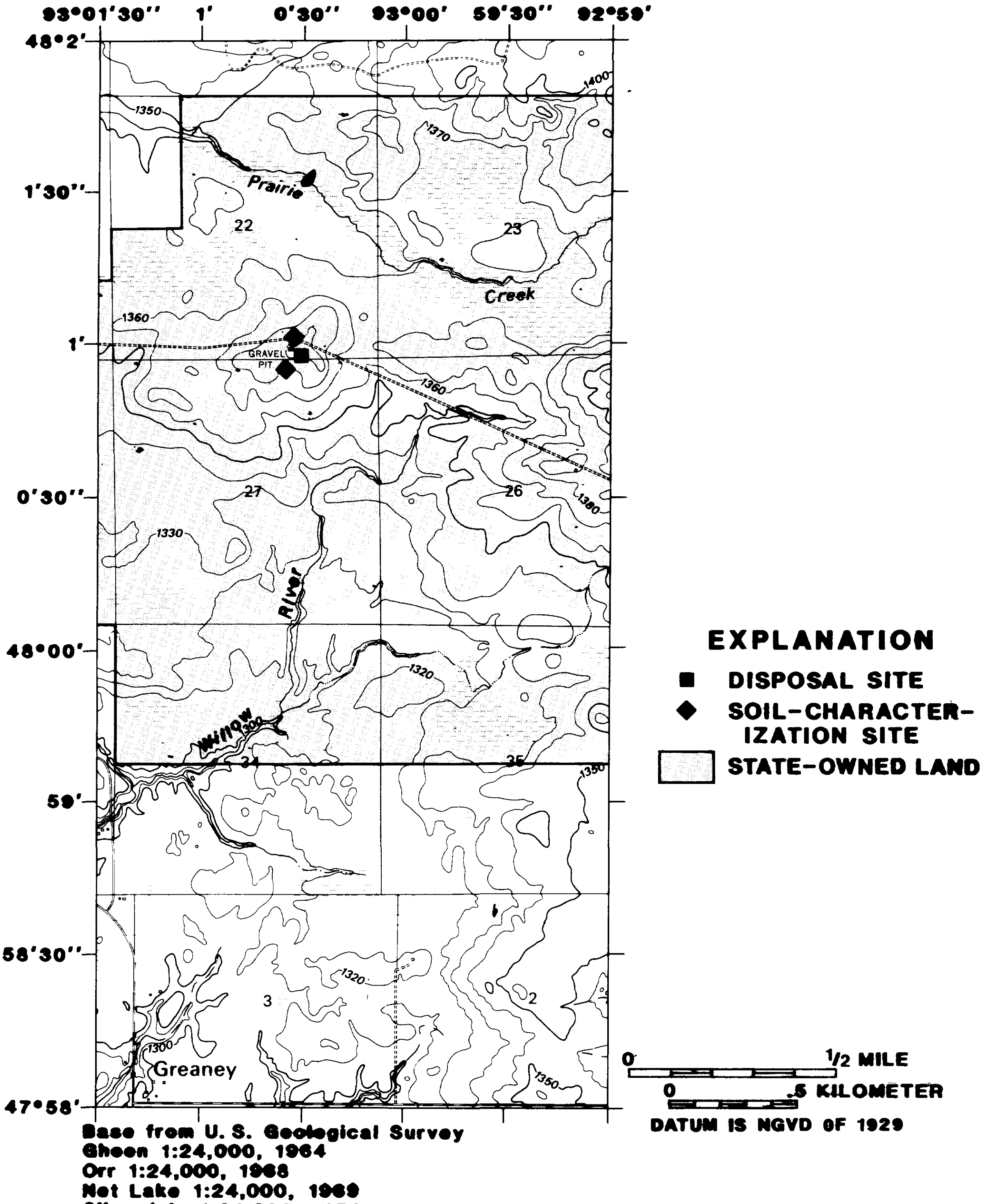


Figure 10.--Location of St. Louis County site

Hydrogeology

Consolidated rock in the vicinity of the St. Louis County site consists of Precambrian metamorphosed volcanic rocks (Helgesen and others, 1976). The bedrock surface, at a depth of about 200 feet below the site, dips northeastward toward Pelican Lake (Sims, 1972; Helgesen and others, 1976).

Glacial deposits overlie the consolidated volcanic rocks. The surficial glacial deposits consist of clay-rich calcareous till deposited by the Des Moines Lobe that was later reworked by wave action in Glacial Lake Agassiz and covered with a thin mantle of lake sediments (Hobbs and Goebel, 1982). Erickson and others (1977) note that discontinuous beach ridges, consisting of thin lake clays over sand and gravel, are numerous in the area. Till, lake clay, and discontinuous zones of sand and gravel are numerous at depth.

Aquifers in the general area can be placed in three groups: surficial sand and gravel deposits, buried sand and gravel deposits, and bedrock (Helgesen and others, 1976). Yields of wells range widely. In general, the depth to water in the area is less than 20 feet.

The St. Louis County site lies near the crest of a nearly east-west trending ridge that rises about 30 to 50 feet above surrounding lowlands (fig. 11). The ridge has a slope of approximately 1 to 5 percent in all directions. To the north, west, and southwest of the site the lowland areas are underlain by deposits of peat. These lowlands typically are underlain by lake deposits that can be as much as 10 feet thick (R. F. Norvitch. U.S. Geological Survey, written commun., 1962).

Geophysical surveys and test drilling were used to define local geology at the disposal site. Electrical-resistivity and electromagnetic-conductivity data suggested that the central part of the area (the ridge) consisted of sand and gravel and that the ridge was flanked by clay. The sand ridges probably are beach ridges or offshore bars deposited in glacial lakes.

North-south and east-west resistivity-sounding profiles were made along survey lines oriented relative to a "center station" located near the pesticide burial site (fig. 11). Offset Werner 'A' spacing readings were recorded at 3, 6, 12, 25, 50, and 100 feet at each station. The part of the north-south profile from 60 feet south of the center to about 140 feet north of the center had apparent-resistivity values greater than 300 ohm-meters (fig. 12), suggesting the presence of sand and gravel. The parts of the profile south of 60 feet south and north of 140 feet north of the center consistently had apparent-resistivity values less than 300 ohm-meters, suggesting the presence of clay. The east-west resistivity-sounding profile showed low-resistivity areas (less than 300 ohm-meters, probably clay) from 140 to 200 feet east and from 265 to 310 feet west of the center station (fig. 12). The remainder of the profile had apparent-resistivity values greater than 300 ohm-meters (probably sand and gravel).

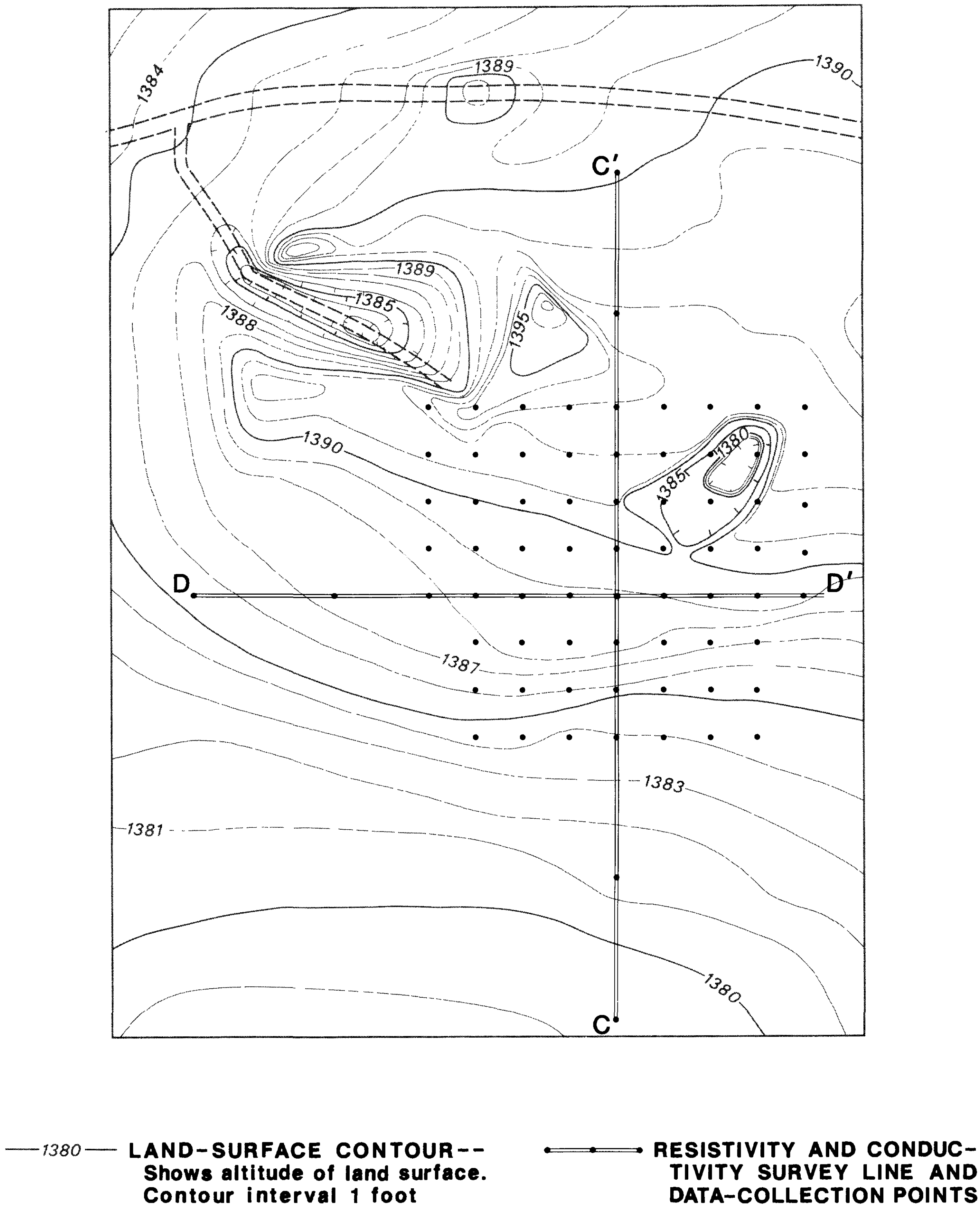


Figure 11.--Topographic setting and location of data-collection points, St. Louis County site

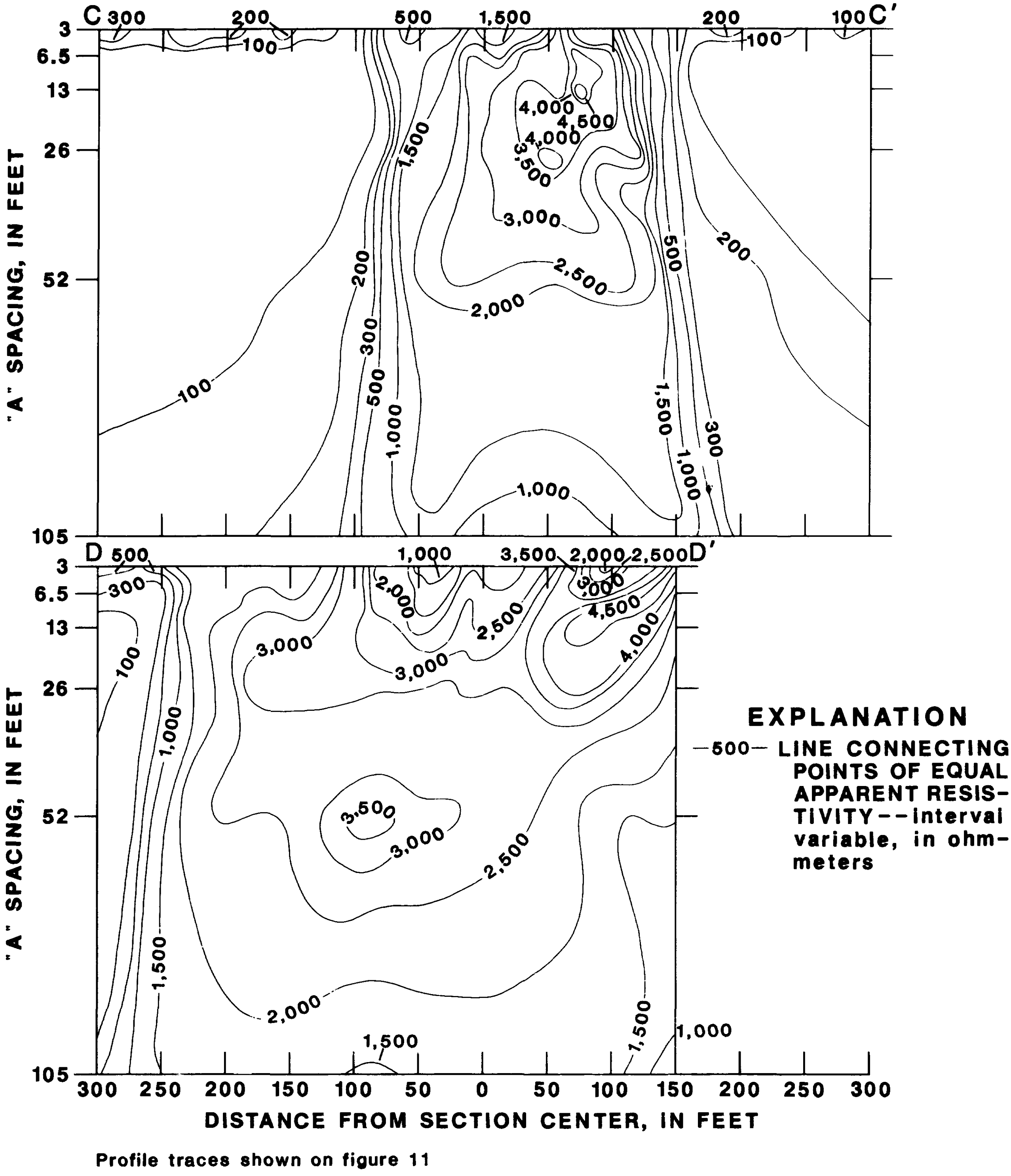


Figure 12.--Apparent-resistivity profiles along south to north (C-C') and west to east (D-D') survey lines, St. Louis County site

Electromagnetic-conductivity data showed results similar to the resistivity data. These data were collected along the resistivity-survey lines and in a gridded area in the center of figure 11. Horizontal and vertical dipole data (20-foot maximum penetration) were collected. Data collected along the north-south transect had high conductivity values, greater than 3 μS/m (microsiemens per meter), from 140 to 310 feet north and from 60 to 310 feet south of the center station (fig.13), indicating the presence of clay. The "highs" had very low conductivity, averaging about 1 μS/m, indicative of sand and gravel; conductivity from 155 to 185 feet east and from 280 to 310 feet west of the center station was higher (fig. 13).

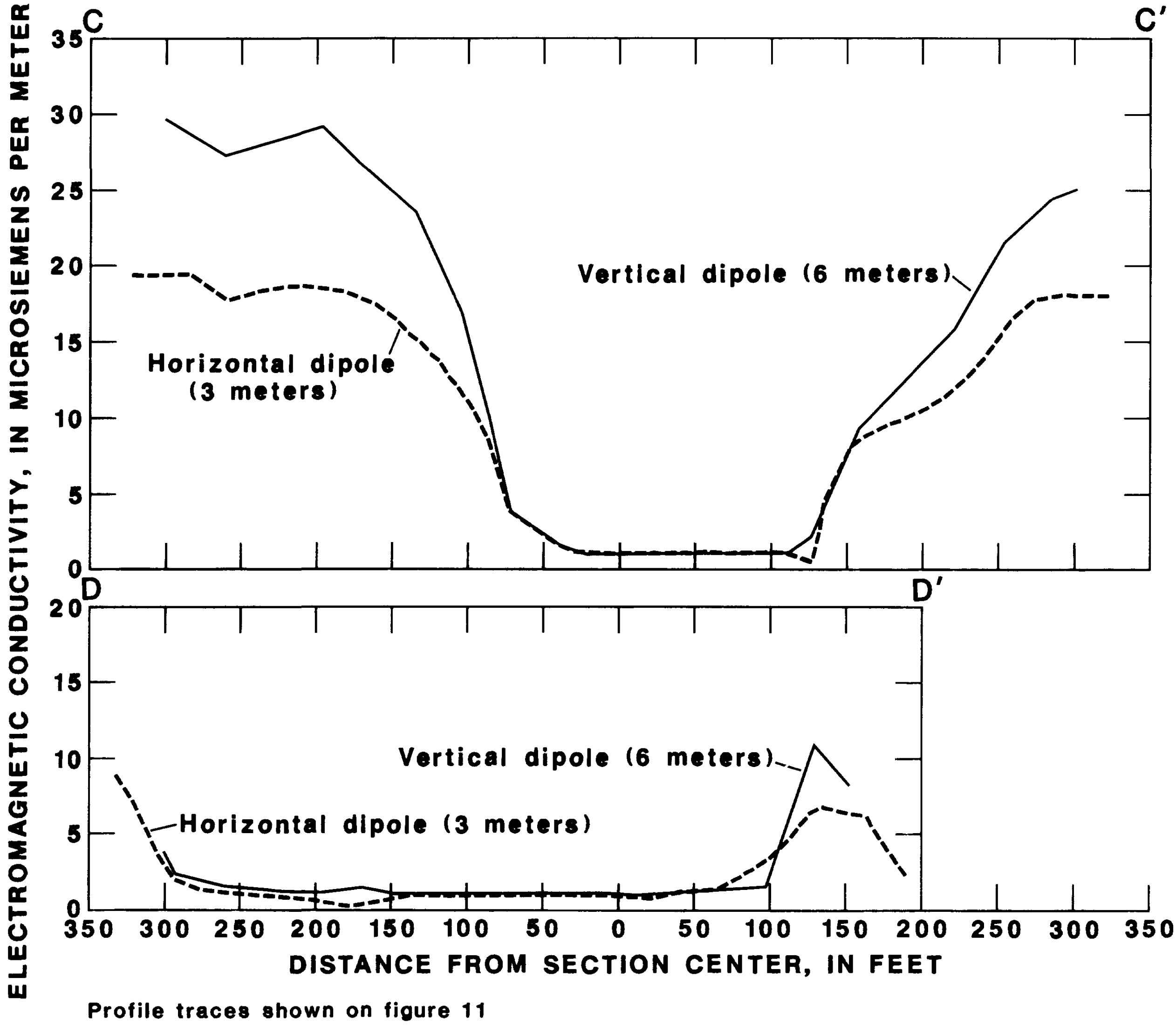
Test drilling done by power auger supported findings from the geophysical surveys. The ridge crest consists primarily of sand and gravel (fig 14). The sand and gravel deposits are generally more fine grained to the west. Power-auger drilling was limited to depths ranging from 11 to 33 feet below land surface because of cobbles and boulders in the glacial deposits. In the region, surficial sand and gravel is underlain by older glacial tills, lake clays, and other sand and gravel units (Helgesen and others, 1976). The surficial sand and gravel probably represents glaciofluvial deposits modified by Lake Agassiz into beach ridges.

The sand and gravel is overlain by as much as 20 feet of silty to sandy gray clay along the flanks of the ridge (within about 200 feet of the ridge). This boundary coincides with contrasts between areas of high and low electrical resistivity and electromagnetic conductivity. The clay may represent lake sediments or lake-modified glacial till.

Generally, water in the sand and gravel aquifer is unconfined. In some areas at the site, where clay overlies the sand and gravel aquifer, the water is under confined conditions (fig. 14). The direction of ground-water flow in the sand and gravel aquifer is to the northeast. Data from two pairs of nested piezometers are contradictory and the vertical component of flow in the area can not be determined without additional data. Depth to the water table from land surface varies from about 10 feet in the western part of the area to about 30 feet in the east. The gradient of the water table changes abruptly through the area from about 0.09 in the west to about 0.00043 in the east (fig. 15). This abrupt change in gradient probably is related to increasing aquifer thickness from west to east. Estimated hydraulic conductivity of the sand and gravel aquifer ranges from about 1 ft/d to about 200 ft/d based on published values for similar materials (Todd, 1959).

Soil Contamination

The approximate outline of the disposal trench was delineated by characteristics of the soil profile in the area of the trench. The dimensions of the trench were estimated to be 24 feet by 7.5 feet based on historical information. Lead arsenate (a white, pasty solid) was located at a depth of about 4.5 feet in this area.



Profile traces shown on figure 11

Figure 13.--Electromagnetic-conductivity profiles along south to north (C-C') and west to east (D-D') survey lines, St. Louis County site

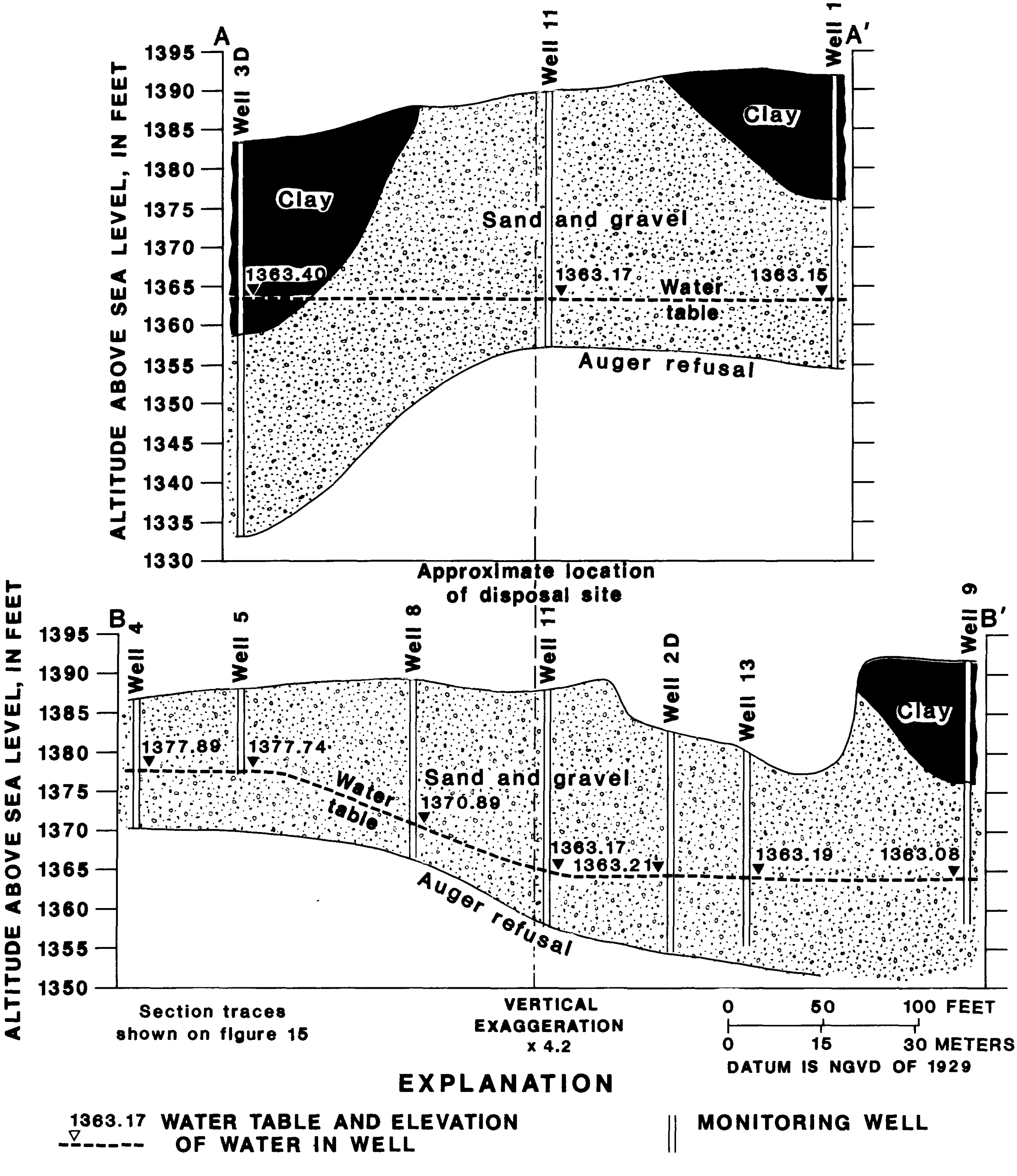
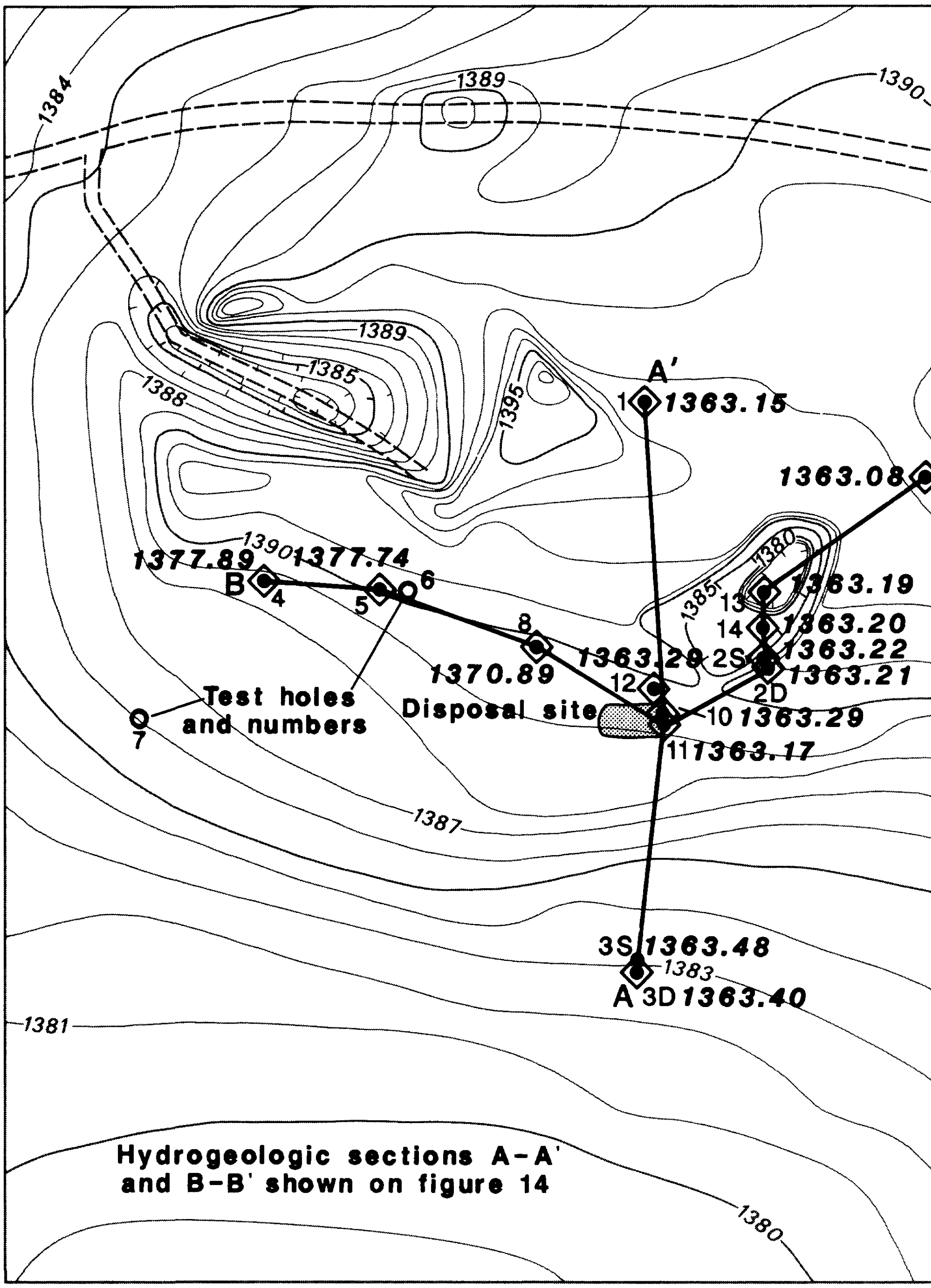


Figure 14.--Well and test-hole locations, south to north (A-A') and west to east (B-B') sections, and water levels measured in wells at St. Louis County site, September 25, 1984



Base from Minnesota Department of Natural Resources Kabetogama State Forest topographic map, 1:333, 1984

N

0 50 100 FEET
0 25 METERS

DATUM IS NGVD OF 1929

EXPLANATION

14◈ **MONITORING WELL AND NUMBER AND SOIL-SAMPLING SITE**

1363.20 **WATER-SURFACE ALTITUDE-- Measured in well Sept. 25, 1984**

Figure 15.--Well and test-hole locations, soil-and water-sampling sites, traces of section A-A' and B-B', and water levels measured in wells at St. Louis County site, September 25, 1984

Soil samples were collected from several locations and depths by bucket augering (table 8) in the immediate vicinity of the disposal trench and by use of a split-spoon sampler (table 9) outside of the disposal trench. Typically, arsenic and lead concentrations in soils were less than 10 ppm (tables 8 and 9). The maximum arsenic value of 31 ppm was measured in a sample that contained a small amount of the lead-arsenate solid. Mean values for arsenic and lead in soils of the United States are 7.5 ppm and 17 ppm, respectively (Rose and others, 1979). Mean values for arsenic in Pine County, Minnesota, ranged from 1.4 to 2.8 ppm (Morey and others, 1980). These data suggest, therefore, that the lead arsenate has not been sorbed by soils at the site.

In November 1984, approximately 3 feet of overburden was removed from the St. Louis County burial site with a bulldozer. The lead arsenate, a white pasty solid, was confined to a single layer about 8 inches thick covering an area of about 6 feet by 10 feet. The lead arsenate (about 2,000 pounds) was placed in barrels and prepared for transport to an approved landfill. After removal of the lead arsenate, composite soil samples were taken from 0 to 1.5 feet below the base of the area. None of the samples contained lead or arsenic above a State-mandated criterion of 500 ppm (Bruce Brott, Minnesota Pollution Control Agency, oral commun., 1985).

Water Quality

Ground Water

Results of analyses of ground-water samples collected from observation wells at the St. Louis County site on August 22 and September 25, 1984, are listed in tables 10 and 11. All values were below the Minnesota Class 1a water-quality standard of 10 µg/L for arsenic and 50 µg/L for lead (tables 10 and 11) (State of Minnesota, 1985). These results indicate that local ground water has not been contaminated by lead arsenate disposed of at the site.

Surface Water

Water samples were collected from Prairie Creek and from Willow River at several points near the disposal site in March 1984 as part of the initial investigation (Minnesota Department of Natural Resources, 1984a). Dissolved arsenic and lead concentrations in these samples were less than or equal to 3 µg/L (micrograms per liter) and less than 1 µg/L, repectively. The nearest sites for which background water-quality data are available are for the Rainy River, where arsenic and lead range from 0.5 to 1 µg/L and 1 to 8 µg/L, respectively (Minnesota Pollution Control Agency, 1981).

Summary of Investigation at St. Louis County Site

No significant soil or ground-water contamination by lead arsenate was found at the St. Louis County site. The relatively low solubility of the lead-arsenate pesticide combined with the vertical separation (20 feet) between the buried materials and the water table probably account for the absence of contaminants in the ground-water system.

Table 8.--Arsenic and lead concentrations in soil samples collected with bucket auger immediately adjacent to the St. Louis County disposal site

[Analyses by Department of Natural Resources Laboratory, Hibbing, Minn.; data from Minnesota Department of Natural Resources, 1984b; all samples were digested with HNO_3/AS_2O_2; ppm, parts per million]

Soil pit	Depth of sample, (feet)	Arsenic[4], (ppm)	Lead[4], (ppm)
1	7.5 - 8	2.4	2.2
2	7.7 - 8.2	2.4	2.4
3	2 - 2.5	4.7	3.3
	4 - 4.5	7.7	4.0
	6.5 - 7	3.2	2.4
4	2 - 2.5	5.4	5.1
	4 - 4.5	3.0	3.9
	7.5 - 8	2.9	4.2
5	2 - 2.5	6.5	3.8
6	[1]2 - 2.5	7.3	3.5
	[1]2 - 2.5	4.9	3.5
	4 - 4.5	2.2	4.1
	7.5 - 8	1.5	2.6
7	2 - 2.5	4.3	3.8
	4 - 4.5	5.1	5.5
8	2 - 2.5	6.5	3.7
	4	8.7	3.8
	[2]4.5	31.0	11.0

Table 8.--Arsenic and lead concentrations in soil samples collected with bucket auger immediately adjacent to the St. Louis County disposal site --Continued

Soil pit	Depth of sample, (feet)	Arsenic[4], (ppm)	Lead[4], (ppm)
10	2 - 2.5	8.7	4.3
	4 - 4.5	5.9	3.5
11	2 - 2.5	4.2	2.7
	4 - 4.5	4.4	2.5
	7.5 - 8	[3]4.1	[3]4.4
12	2 - 2.5	6.1	2.0
	4 - 4.5	5.6	15.0
	7.5 - 8	5.3	13.0
13	2 - 2.5	6.1	6.1
	4 - 4.5	4.2	2.4
	7.5 - 8	4.9	3.5
14	2 - 2.5	5.1	7.7
	4 - 4.5	2.6	2.9
	7.5 - 8	[3]3.5	[3]3.2

[1] Field duplicates.
[2] Lead arsenate was visibly noted at this depth.
[3] Average of duplicate laboratory digestions.
[4] Dry-mass basis

Table 9.--Arsenic and lead concentrations in soil samples collected with split spoon in well borings at the St. Louis County site

[Analyses by Department of Natural Resources Laboratory, Hibbing, Minn.; data from Minnesota Department of Natural Resources, 1984b; ppm, parts per million]

Well	Depth of sample, (feet)	Arsenic[2], (ppm)	Lead[2], (ppm)
3D	24 - 26	2.2	3.9
3D	34 - 36	3.0	3.9
3D	49 - 51	6.0	5.0
9	34 - 36	1.2	4.0
10	4 - 6	5.1	2.2
10	9 - 11	2.3	1.8
10	14 - 16	3.0	2.0
10	19 - 21	1.9	1.1
10	24 - 26	4.5	1.7
10	29 - 31	9.3	2.6
11	4 - 6	2.4	0.7
11	9 - 11	3.6	2.1
11	14 - 16	2.1	2.9
11	19 - 21	[1]1.4	[1]1.5
11	24 - 26	1.1	1.3
11	29 - 31	7.2	1.6
12	4 - 6	2.6	2.2
12	9 - 11	2.6	1.7
12	14 - 16	3.8	2.2

Table 10.--Results of ground-water analyses, August 22, 1984, St. Louis County site

(Analyses by Department of Natural Resources Hibbing Laboratory; data from Minnesota Department of Natural Resources, 1984b; mg/L, milligrams per liter; uS/cm, microsiemens per centimeter; µg/L, micrograms per liter; NA, not available; <, less than)

Sample	Well	pH	Alkalinity (mg/L as CaCO3)	Specific conduct- ance, (uS/cm)	Arsenic, (ug/L, dry mass basis)	Lead (ug/L, dry mass basis)
107	13	6.7	14.4	50	2	2
[1]108	14	6.9	12.2	45	2	<1
[1]109	14	6.9	NA	45	2	<1
[2]110	14	NA	NA	NA	2	1
111	2S	6.9	32.0	130	2	<1
112	9	7.2	124	280	3	<1
[3]113	3S	6.7	234	330	3	1
[3]114	3S	6.7	248	335	3	<1
115	11	6.7	41.7	95	2	<1
116	12	6.7	26.1	62	1	<1
117	10	6.5	28.6	82	1	1
118	10	6.5	NA	82	1	<1

[1] Field duplicates.
[2] Unfiltered metals.
[3] Field duplicates.

Table 9.--Arsenic and lead concentrations in soil samples collected with split spoon in well borings at the St. Louis County site

--Continued

Well	Depth of sample, (feet)	Arsenic[2], (ppm)	Lead[2], (ppm)
12	19 - 21	1.6	2.3
12	24 - 26	1.9	1.3
12	29 - 30	4.2	1.6
13	24 - 26	[1]4.0	[1]1.6
14	24 - 26	4.5	2.6

[1] Average of duplicate laboratory digestions
[2] Dry-mass basis

Table 11.--Results of ground-water analyses, September 25, 1984, St. Louis County site

(Analyses by DNR-Hibbing Laboratory; data from Minnesota Department of Natural Resources, 1984b; analysis on dry mass basis; µg/L, microgram per liter; <, less than)

Well	Arsenic, ug/L	Lead, ug/L
10	4	<1
11	4	<1
12	5	<1
13	5	<1

CONCLUSIONS

Investigations of the geology and ground-water hydrology and analysis of soil and ground-water samples collected at the sites of waste-disposal sites in Pine and St. Louis Counties, Minnesota, indicate that contamination from pesticides buried at the sites is not widespread or highly concentrated at short distances from the burial site. No significant soil or ground-water contamination was found at either site. The possible combined effects of relatively low solubility of the chemicals, sorption on soil particles, low vertical hydraulic conductivity of the soil (in the vicinity of the Pine County site) and significant vertical separation between the site of burial and the water table appear to have limited migration of the chemicals. At both sites, pesticides and pesticide-containing soils have been excavated and transported to approved disposal sites.

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