DETERMINATION OF GEOHYDROLOGIC FRAMEWORK AND EXTENT OF GROUND-WATER CONTAMINATION USING SURFACE GEOPHYSICAL TECHNIQUES AT PICATINNY ARSENAL, NEW JERSEY

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CONVERSION OF INCH-POUND UNITS TO METRIC INTERNATIONAL SYSTEM UNITS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units in this report, values may be converted using the following factors:

Multiply Inch-Pound Unit	By	To Obtain Metric Unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per second (ft/s)	0.3048	meter per second (m/s)

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AND EXTENT OF GROUND-WATER CONTAMINATION

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ABSTRACT

Seismic-refraction, electric-resistivity sounding, and electromagnetic-conductivity techniques were used to determine the geohydrologic framework and extent of ground-water contamination at Picatinny Arsenal in northern New Jersey. The area studied encompasses about 4 square miles at the southern end of the Arsenal.

The bedrock surface beneath the glacial sediments was delineated by seismic-refraction techniques. Data for 12 seismic lines were collected using a 12-channel engineering seismograph. Competent bedrock crops out on both sides of the valley, but is about 290 feet below land surface in the deepest part of the topographic valley. Where the exposed bedrock surface forms steep slopes on the valley side, it remains steep below the valley fill. Likewise, gentle bedrock valley slopes have gentle subsurface slopes. The deepest part of the bedrock valley is along the southern extension of the Green Pond fault.

The electric-resistivity sounding technique was used to determine the sediment types. Data were collected from four sites using the offset Wenner electrode configuration. Below the surface layer, the sediments have apparent and computed resistivity values of 120 to 170 ohm-meters. These values correspond to a saturated fine-grained sediment such as silt or interbedded sand and clay.

Ground-water contamination was investigated by electromagnetic-conductivity techniques using transmitting and receiving coils separated by 32.8 and 12 feet. Thirteen sites have apparent conductivity values exceeding 15 millimhos per meter. Of these, seven sites indicate ground-water contamination from a variety of sources including a sanitary landfill, pyrotechnic testing ground, burning area, former domestic sewage field, salt-storage facility, hazardous-waste disposal lagoon, sewage treatment plant, and fertilizer storage shed. Three areas underlain by clay or muck are interpreted to be free of contamination. Three additional areas of high apparent conductivity may be underlain by contaminated ground water or highly conductive sediments.

INTRODUCTION

Picatinny Arsenal, in northern Morris County, New Jersey, is a military installation used for research and development of armaments (fig. 1). This area has been a site for the manufacture and storage of military hardware since the American Revolution. The use, storage, and disposal of the various chemicals involved in research and development has caused localized degradation in ground-water quality within the Arsenal.

In 1983, the U.S. Geological Survey, in cooperation with the U.S. Army Armament Research and Development Command (ARDC), began an investigation to determine the geohydrologic framework and the extent of ground-water contamination within the Arsenal. This report is one of four resulting from this investigation. The other reports concern the test drilling program (Harte, P.T., U.S. Geological Survey, written commun., 1985) water-quality data (Sargent B.P., U.S. Geological Survey, written commun., 1985) and contamination at two wastewater facilities (Vowinkel E.F., U.S. Geological Survey, written commun., 1985) in Picatinny Arsenal.

Purpose and Scope

The purpose of this report is to present surface geophysical data as a preliminary technique to aid in defining the geohydrologic framework, and to delineate areas of ground-water contamination at the Arsenal.

Seismic-refraction and electric-resistivity techniques were used to delineate the various subsurface units. Twelve seismic lines were run to determine the depth to and configuration of the bedrock surface. Four resistivity soundings helped to identify the sediments overlying the bedrock. Electromagnetic-conductivity data collected at 630 sites were used to locate and delineate contaminated areas.

The study area for the geohydrologic framework investigation is about 5 mi^2; for the ground-water contamination investigation the area is about 2.5 mi^2. Each area is in the southern part of the Arsenal (fig. 1). All data were collected from February through September 1983.

Methods of Investigation

Surface geophysical data collection and analysis are an initial part of broad-based ground-water investigations. Other methods used at the Arsenal include test drilling, borehole geophysics, aquifer tests, and water analyses. In this study, surface geophysics is a preliminary technique that is time- and cost-effective. It does not eliminate the need for a subsequent drilling program or water analysis, but rather, provides a more effective and scientific way for siting new well locations and selecting wells for water sampling.

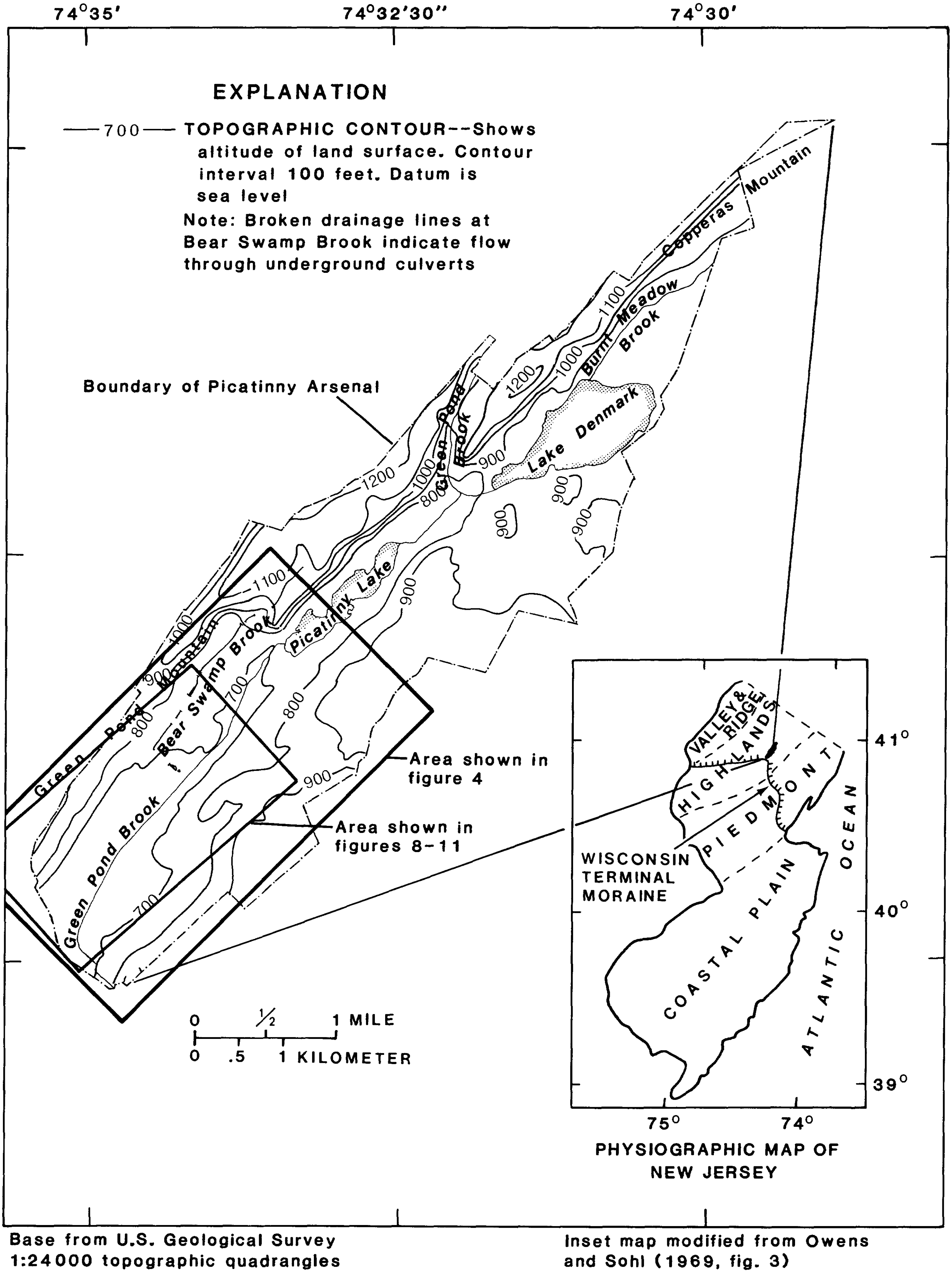


Figure 1.--Picatinny Arsenal, surface water bodies, topography, and physiographic setting.

Geohydrologic Setting

The study area is in the valley drained by Green Pond Brook. This valley lies within the New Jersey Highlands--a ridge and valley province that trends northeast to southwest (fig. 1) and is underlain by folded and faulted Precambrian through Silurian rocks (fig. 2). The area is flanked on the southeast by Precambrian gneiss (Sims, 1958) and on the northwest by the Silurian Green Pond Conglomerate (Bayley and others, 1914). The Hardyston Quartzite and Leithsville Formation of Cambrian age (Drake, 1969) unconformably overlie the gneiss, and form the bedrock below the valley fill and the bedrock to the northeast and southwest of the valley. The Leithsville Formation consists of a carbonate sequence, predominantly dolomite, and thin beds of quartzite, sandstone, and shale. The steeply dipping Green Pond fault (Sims, 1958), parallel with and along the west side of the valley, has displaced the rock on the northwest side upward in relation to the rock on the southeast side.

The study area is situated a short distance north of the Wisconsin terminal moraine (fig. 1 inset map). The area is covered by glacial deposits with a maximum thickness of 210 feet. Glacial till, interpreted to be less than 25 feet thick, directly overlies the bedrock in most places. Stratified drift overlies the till in the center of the valley. The stratified drift is 10 to 200 feet thick, and consists of interbedded sand, silt, and clay. Locally, it is overlain by muck and peat with a maximum known thickness of 40 feet. The stratigraphic section for the study area is given in table 1. Numerous bog iron deposits are present in the valley (Sims, 1958).

Three aquifers--the water table or unconfined stratified-drift, confined stratified-drift, and bedrock aquifers--have been defined in the central part of the valley. The water-table aquifer generally is within 15 feet of the ground surface and extends to a depth of about 35 feet. Flow in this aquifer is toward Green Pond Brook. This aquifer is separated from the confined aquifer by a confining unit of sand, silt, and clay about 20 to 30 feet thick. The confined aquifer is about 75 feet thick. The weathered bedrock forms a confining unit separating the confined from the bedrock aquifer. Water flow in the confined and the bedrock aquifer appears to be southward (Harte, P.T., US Geological Survey, oral commun., 1985).

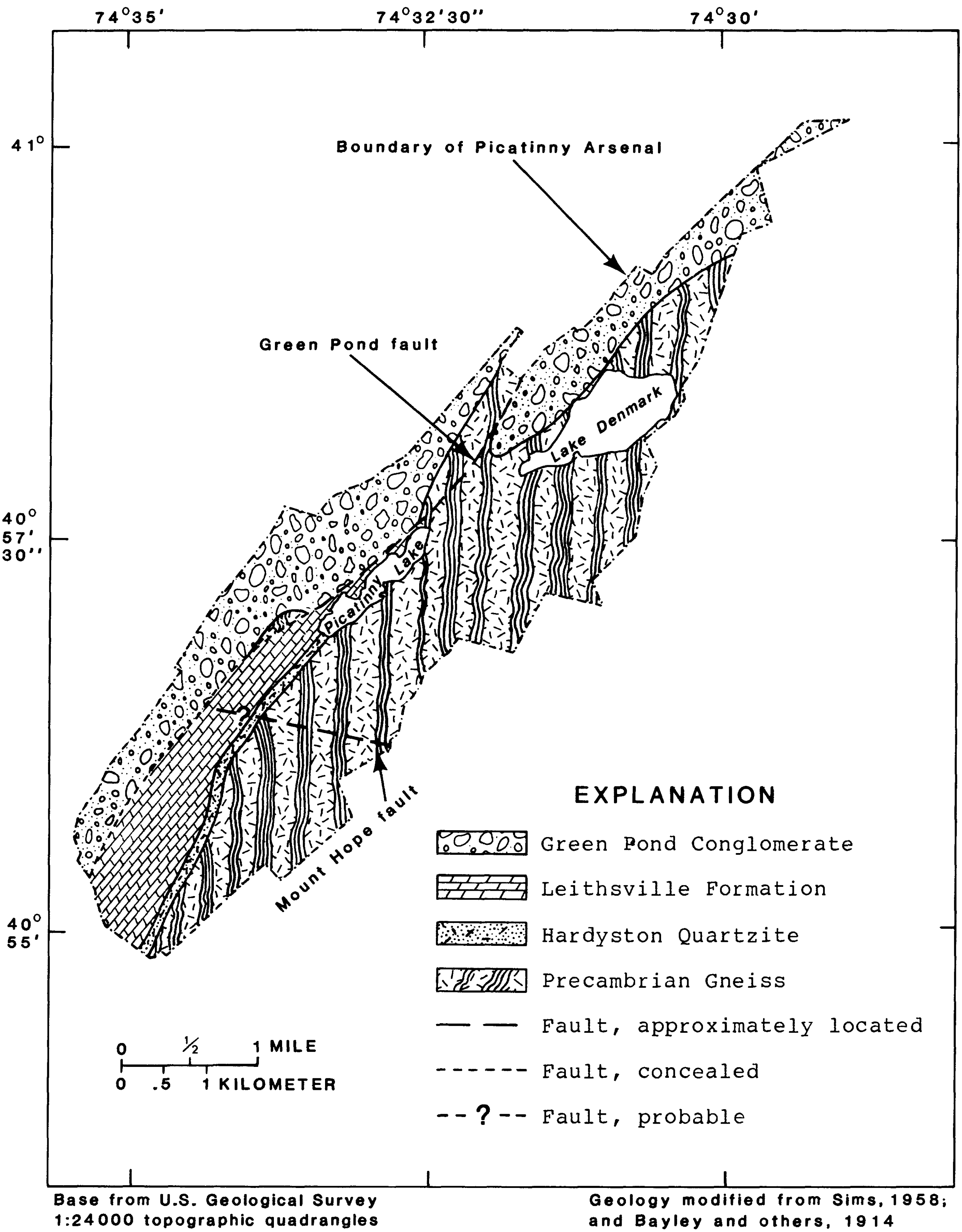


Figure 2.--Bedrock geology of Picatinny Arsenal, New Jersey.

Table 1.--Stratigraphic and geohydrologic characteristics of geologic units at Picatinny Arsenal

Geologic time: Era	Time-stratigraphic units: System	Time-stratigraphic units: Series	Geologic unit: Formation or lithologic unit	Maximum thickness (in feet)	Lithology	Geohydrologic characteristics
Cenozoic	Quaternary	Holocene	Alluvium	10	Ranges from a sandy loam in the valley to a stony gravel on hillsides.	Too thin to be tapped.
			Swamp Deposits	30	Black, brown and gray organic material.	Permeability rapid along organic layers.
		Pleistocene	Stratified drift	200+	Present in the form of glaciofluvial and glaciolacustrine deposits, mostly sand to clay size sediments, exhibits stratification and in some cases rhythmic laminations (varves).	Yields dependent on degree of sorting and grain size. The well-sorted and coarse-grained deposits are good aquifers with yields up to 2,200 gal/min. Clay and silt deposits are generally unsuitable as aquifers.
			Unstratified drift	100+	Unstratified drift deposits are present in the form of ground, terminal and recessional moraines. Deposits are generally tightly packed and poorly sorted with grain sizes, ranging from boulders to clay.	Yields dependent on degree of sorting and packing. Generally low yields.
					Unconformity	
Paleozoic	Silurian		Green Pond Conglomerate	1500+	Coarse quartz conglomerate interbedded with and grading upward into quartzite and sandstone. Generally massive and red but also may have white and green beds.	Generally yields small amount of water from fracture and joints.
					Unconformity	
	Cambrian	Middle	Leithsville Formation	1000+	Predominantly a light- to medium-gray, microcrystalline, locally stylolitic rock to a fissile, siliceous to dolomitic micrite rock. Often highly weathered into a medium-yellow silty clay.	Contains water bearing fractures and cavities that generally have moderate yields of up to 380 gal/min.
					Gradational	
		Lower	Hardyston Quartzite	200	Orthoquartzite to conglomerate, generally well indurated.	Generally few fractures, yields small amounts of water.
					Unconformity	
Precambrian			Alaskite	Basement	Medium- to coarse-grained predominantly granitoid gneiss composed principally of microperthite, quartz, and oligoclase. Includes local bodies of microantiperthite granite and granite pegmatite. Amphibolite inclusions are common.	All three lithologic units are similar in hydrologic characteristics. Ground water occurs in fractures and joints. Yields are generally low, from 26 to 75 gal/min.
			Hornblende granite		Medium- to coarse-grained predominantly granitoid gneiss, composed principally of microperthite, quartz, oligoclase, and hornblende. Includes local bodies of biotite granite, hornblende granite gneiss, granodiorite, and granite pegmatite. Amphibolite inclusions are common.	
			Biotite-quartz-feldspar gneiss		Medium- to coarse-grained gneiss of widely different composition. The predominant facies is composed of biotite, quartz, and oligoclase; minor facies are characterized by abundant garnet and microperthite, and locally by sillimanite and graphite.	

[1] Modified from Drake, 1969, table 20, Sims, 1958, plate 1, Gill and Vecchioli, 1965, table 3.

Previous Investigations

An aeromagnetic survey (Henderson and others, 1957) that was made as part of a regional reconnaissance geophysical investigation of northern New Jersey included data collected over the Arsenal. A report by Gill and Vecchioli (1965) presented hydrogeologic data in Morris County. Another county wide report (Canace and others, 1983) determined the feasibility of supplementing surface-water reservoirs with ground-water supplies. Layne-New York Co., Inc. (1980) reported on the quality of water from wells at Picatinny Arsenal.

Acknowledgments

The author gratefully acknowledges the assistance of United States Army and ARDC personnel especially from Dave Bayha of the U.S. Army Hygiene Agency and Kevin Dixon of ARDC. P.B. Duran of the U.S. Geological Survey collected the surface geophysical data.

DETERMINATION OF GEOHYDROLOGIC FRAMEWORK

Seismic Refraction Study

Theory

The surface-geophysical technique, seismic refraction, can be used to map the configuration of the bedrock surface. This method uses a seismograph to measure the travel time of seismic waves from a shot point to a detector. Travel time depends on the wave velocity of the sediments and rock and on the pathway of the seismic waves. A diagrammatic geologic section that depicts saturated sediment and bedrock as the two layers, illustrates the principles of seismic refraction (fig. 3). The source, usually an explosion, sends seismic waves in all directions. Only two pathways--the direct and the refracted wavepath--are used in the analysis.

Seismic detectors called geophones are spaced 0 to 800 feet away from the seismic source or shotpoint in a linear array. The direct wave travels near the surface toward the geophones at the seismic velocity of layer one. The refracted wave travels through layer one and layer two, then back through layer one to the geophones, following a pathway defined by Snell's Law (Telford and others, 1976). Snell's Law states that, when energy arrives at the boundary between different materials, the energy is refracted or bent. The amount of refraction depends upon the angle of incidence of the seismic wave and the ratio of the velocities for the two materials. The refracted wavepath intersects a refraction boundary at a critical angle θ and is refracted to travel parallel to the boundary. The seismic wave that travels in layer two, parallel to the boundary, sends discrete amounts of seismic energy back to the surface. At a point along the line of geophones, the refracted wave will reach

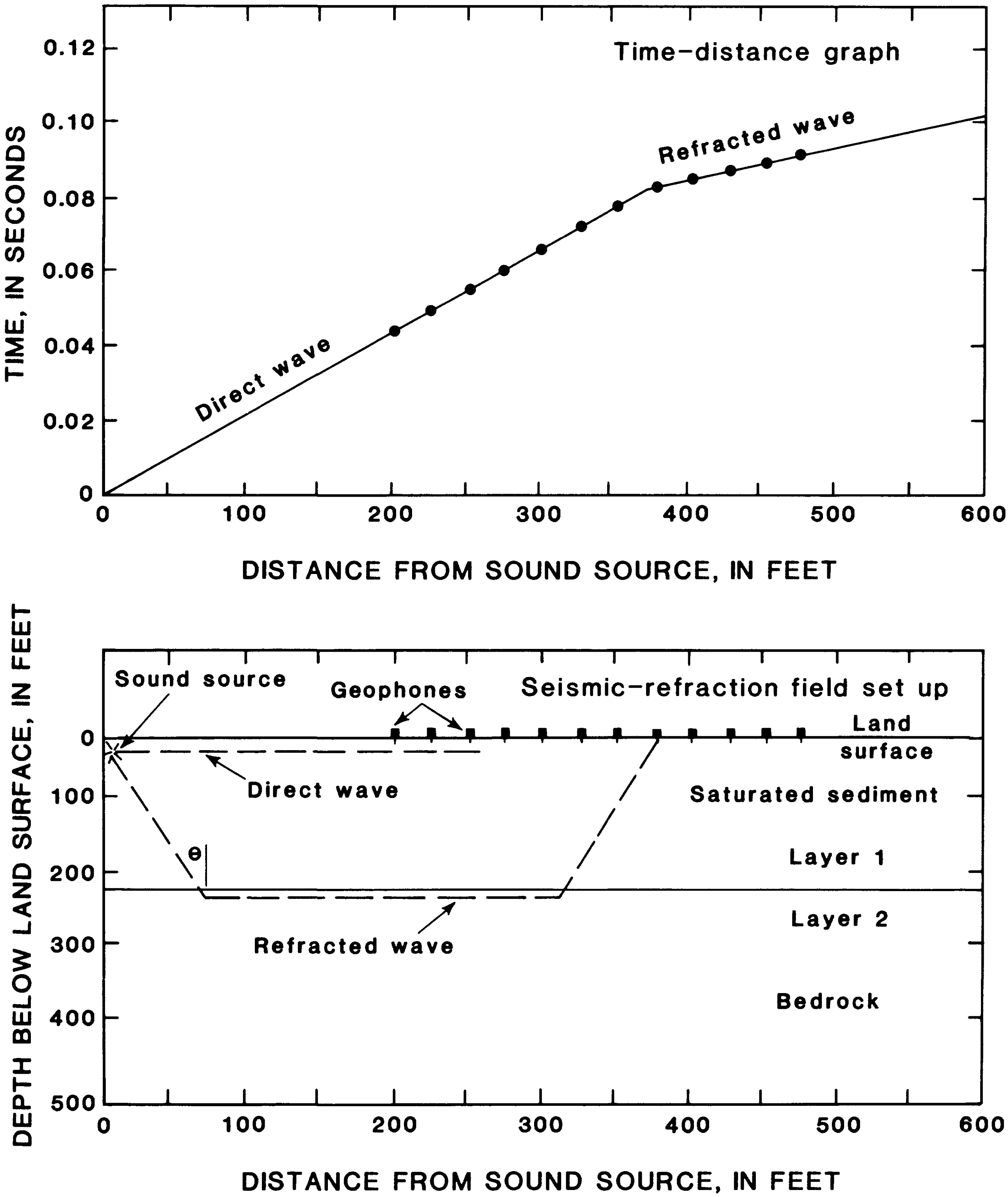


Figure 3.—Time-distance graph and corresponding diagrammatic geologic section of seismic-refraction field setup.

the geophones ahead of the direct wave because the seismic velocity of layer two is greater than that of layer one. A time-distance graph (fig. 3) is generated by plotting the time it takes for the sound waves to travel from the source to each of the geophones, against the distances from the shot point to geophones.

The geophones closest to the shot point detect the direct wave first, whereas the more distant geophones detect the refracted wave first. From the travel-time data, it is possible to calculate the depth to bedrock below each geophone. All seismic data were analyzed and the depth to bedrock was calculated using Seismic Interpretation Program Two (SIPT) by Scott and others (1972). This method uses the time-delay technique to calculate depths to the bedrock surface.

Field Procedure

Seismic-refraction data were collected with an EG&G 1210-F[1] twelve-channel, signal-enhancement seismograph. Twelve vertical 14-hertz geophones were implanted in the ground for each refraction setup or spread. Four of the seismic lines had more than one spread. The distance between each geophone was 50 or 100 feet, depending on the spread length. The seismic source was a two-component explosive detonated about 5 feet below land surface in a backfilled and tamped hole. An instantaneous blasting cap detonated 0.5 to 2 pounds of explosives for each shot point. Each spread had at least one shot point at either end and most spreads had more. In the southern part of the area, seismic data were collected across the valley. In the northern part of the area, data were collected wherever it was possible to lay out the full length of the geophone cable. Throughout the valley, data collection was hampered by paved areas and buildings. The locations of the 12 seismic lines are shown in figure 4.

Data analysis

Data for seismic lines 1 to 10 were used to determine the configuration of the bedrock surface at the Arsenal (fig. 4). Data for seismic lines 11 and 12 were used to determine the bedrock velocity of the conglomerate and gneiss. It was assumed that the seismic velocity of each of these units could be used as a signature to identify that unit below the valley fill.

[1] "Use of the trade names in this report is for identification only and does not constitute endorsement by the U.S. Geological Survey."

page 11 follows

Analysis of the seismic data indicates that the bedrock slope beneath the consolidated sediment closely parallels the slope of the valley walls. Where the exposed bedrock surface forms steep slopes on the valley side, it remains steep below the valley fill. Likewise, gentler bedrock valley slopes have gentler subsurface slopes. The greatest depths to the bedrock are on the northwestern side and along the trace of the Green Pond fault. This coincides with the more easily weathered and eroded calcite-rich beds of the Leithsville Formation.

Data from seismic lines 1, 2, 3, and 4 (fig. 4) define the bedrock surface at the southern end of the Arsenal. At the northern end, cross-valley traverses were impractical because of extensive paved areas and many buildings. Therefore, the bedrock configuration here is based on five short seismic lines, five well logs, and the topography of bedrock outcrops.

Seismically determined depth to bedrock correlates closely with depth determination from borehole data. The southern end of seismic line 4 is close to observation well 250 (see fig. 4). The depth to bedrock determined by seismic methods is 330 feet, by the drilling method, it is 322 feet. This is well within the 10-percent error that can be expected using seismic refraction.

At or near the intersection of seismic lines, the depths to bedrock surface determined by independent lines are similar. Where seismic lines 1 and 4 intersect, the depths to bedrock are 335 and 318 feet, respectively. Where seismic line 5 is close to line 3, depths to bedrock are 270 and 250 feet, respectively. At the intersection of lines 6 and 7, depths to bedrock are 135 and 145 feet, respectively. Bedrock depths at the eastern ends of lines 6 and 7 are close to those at line 8.

The bedrock surface at line 9 is 150 feet below land surface, even though it is close to the outcropping conglomerate, indicating that the steepness of the valley wall continues below the valley fill. Based on data from line 10, depth to bedrock in the area drained by Bear Swamp Brook is 70 feet. Five wells in the center of the study area are too far from any seismic lines to permit a direct correlation, but they exhibit the general trend of a deeper bedrock surface near the valley center.

Data for lines 11 and 12 were collected to determine the seismic velocity of the conglomerate and the gneiss, respectively. Their velocities are about 15,000 ft/s (feet per second). This value was to be used to identify these rocks below the valley fill, but the results were ambiguous. High seismic velocities for the bedrock were determined along lines 4, 8, 9, and 10, but only lines 9 and 10 correlate closely with the conglomerate or gneiss outcrops. The high velocity refracter of line 4 does not correspond with seismic line 1 or with limited testhole information. The reason for the high velocity refractor in lines 4 and 8 is unknown.

Electric Resistivity Study

Theory

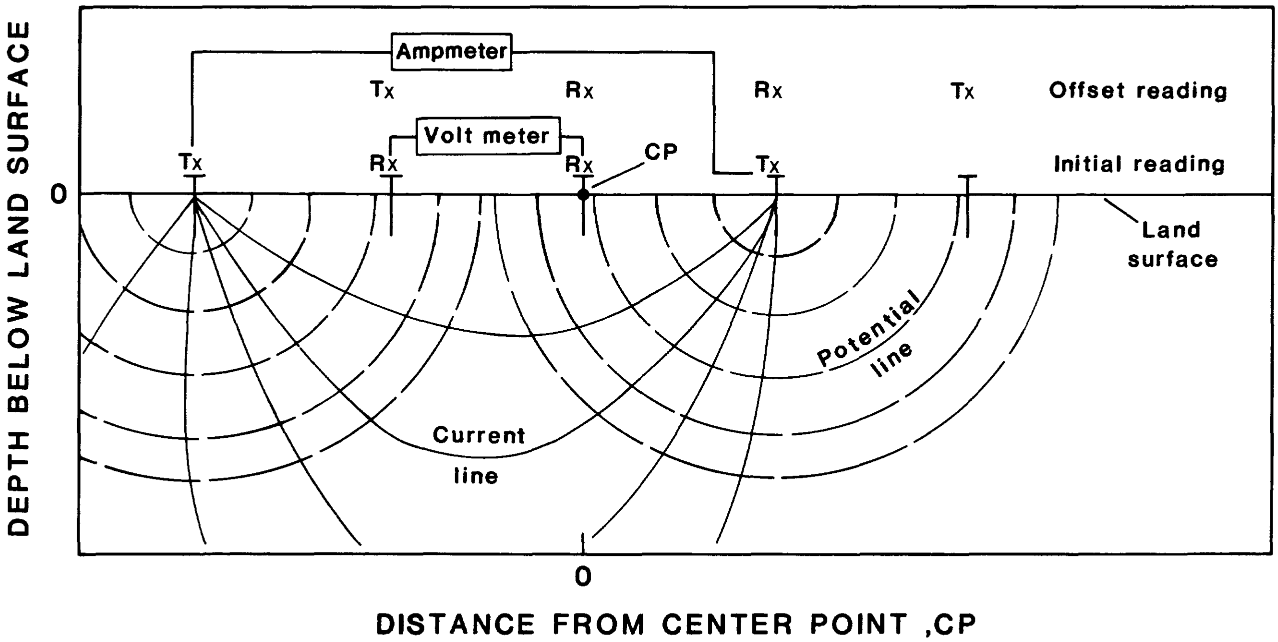
Electric resistivity is a surface-geophysical technique that measures variations in the electrical character of the subsurface. These variations are used to identify different geohydrologic layers. The method uses a transmitter which generates an electric current that penetrates the ground through two metal electrodes. The current flows through the subsurface and creates a potential field. By measuring this field between two additional electrodes, the apparent resistivity of the subsurface is calculated with the following formula (Zohdy and others, 1974):

$$\rho_a = \frac{K \Delta V}{I} ,$$

where ρ_a = is the apparent resistivity,
K = is a constant which is a function of the volume of earth material,
ΔV = is the voltage change between the two potential electrodes, and
I = is the amperage at the current electrodes.

The Offset Wenner electrode configuration (Barker, 1981) (fig. 5) used at the Arsenal is one of many configurations used to collect electric resistivity data (Telford and others, 1976). Current, in milliamperes, is impulsed into the electrodes (labeled Tx, in fig. 5) and potential, in millivolts, is measured between the electrodes labled Rx. A value for the apparent resistivity, in ohm-meters, is calculated for this particular electrode spread. In an iterative manner, additional data are collected at progressively larger electrode spacings to measure the deeper layers. This technique of collecting data with different electrode spacing over a centerpoint is called the vertical electric sounding (VES) method.

From the apparent resistivity values calculated for each VES, it is possible to generate a model of the subsurface. The model, a geoelectric section, is composed of three to seven layers, each of which has a specific resistivity value. The range of such values for various sediments is given in table 2. The geoelectric section can be correlated with nearby geohydrologic data in order to determine its geohydrologic framework.



EXPLANATION

Tx Transmission electrodes

Rx Receiving electrodes

┬ Electrode

Figure 5.--Two of five electrode configurations used in the offset Wenner sounding technique.

Table 2.--Range of resistivity values for various sediment and rock types (Modified after Benson and others, 1983)

```
                                       Resistivity
                                      in ohm-meters
                       10      100      1,000    10,000  100,000

Earth Material         +________+________+________+________+

Topsoil                +_____XXXX________+________+________+
Saturated clay         XXXXXXXXX+________+________+________+
Saturated silt         +_______XXXXXX____+________+________+
Saturated sand         +________+___XXXXXXXXXXX___+________+
Unsaturated sediments  +________+__XXXXXXXXXXXXXXXXXXX_____+
Crystalline rocks      +________+________+__XXXXXXXXXXXXXXX+
```

Field Procedure

A Bison 2390 transmitter and receiver were used to input the current and measure the potential. The data collected with the Offset Wenner array used electrode spacings of 0.5, 1, 2, 4, 8, 16, 32, and 64 meters in each VES. The location of the VES sites is shown in figure 4. Interference sources such as pipelines, metal fences, railroad tracks, overhead and underground wires, or guard rails severely limited data acquisition at the Arsenal.

Data analysis

Offset Wenner VES data are presented in figure 6. The data are transformed into geoelectric sections by means of the Wenner inversion computer program written by Zohdy and Bisdorf (1975). The interpreted geohydrologic sections are presented with the geoelectric sections (fig. 7).

VES sites 1, 2, and 3 are in the valley at the southern end of the Arsenal. The apparent-resistivity values and geoelectric-resistivity values at these sites are similar at electrode spacings exceeding 25 feet and deeper than 15 feet. The resistivity values between 120 and 200 ohm-meters are interpreted as interbedded fine sand and clay, or silt. The high resistivity for the top of geoelectric sections 1 and 3 corresponds to an unsaturated surface layer. The 150 ohm-meter value at the top of VES 2 is interpreted to be a saturated surface layer.

VES site 4 is located on the western slope of the valley, which is underlain by gneiss. A 20-foot-thick layer of glacial till overlies the gneiss. The VES data indicate that unsaturated, highly resistive sediment overlies highly resistive bedrock.

DETERMINATION OF EXTENT OF GROUND-WATER CONTAMINATION

Electromagnetic Conductivity Study

Theory

The electromagnetic (EM) conductivity technique measures variations in the apparent conductivity of the subsurface. With this method and additional geohydrologic data, it is possible to locate suspected ground-water contamination sites and determine their lateral extent.

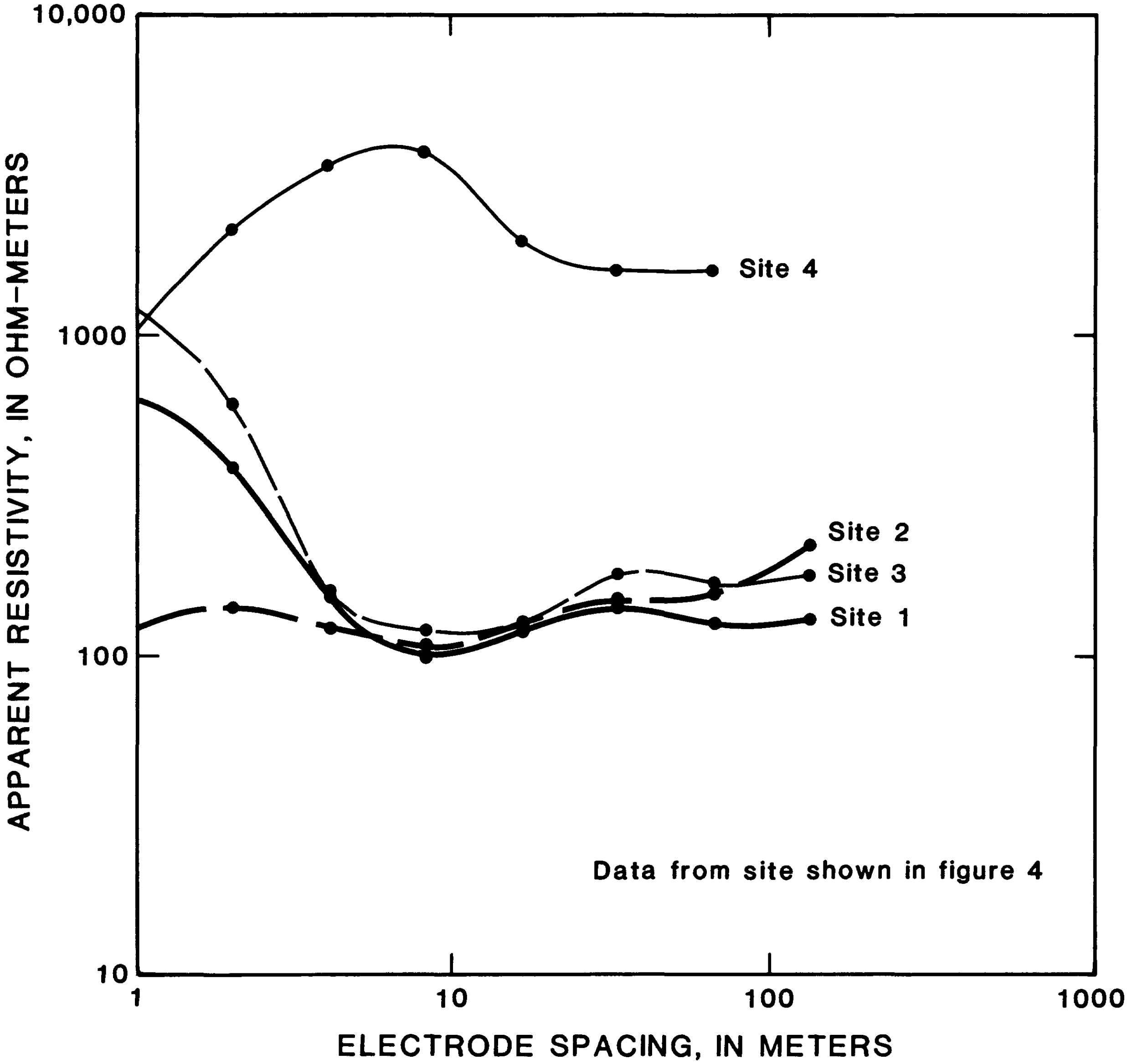


Figure 6.--Apparent resistivity graph for vertical electric sounding sites 1, 2, 3, and 4.

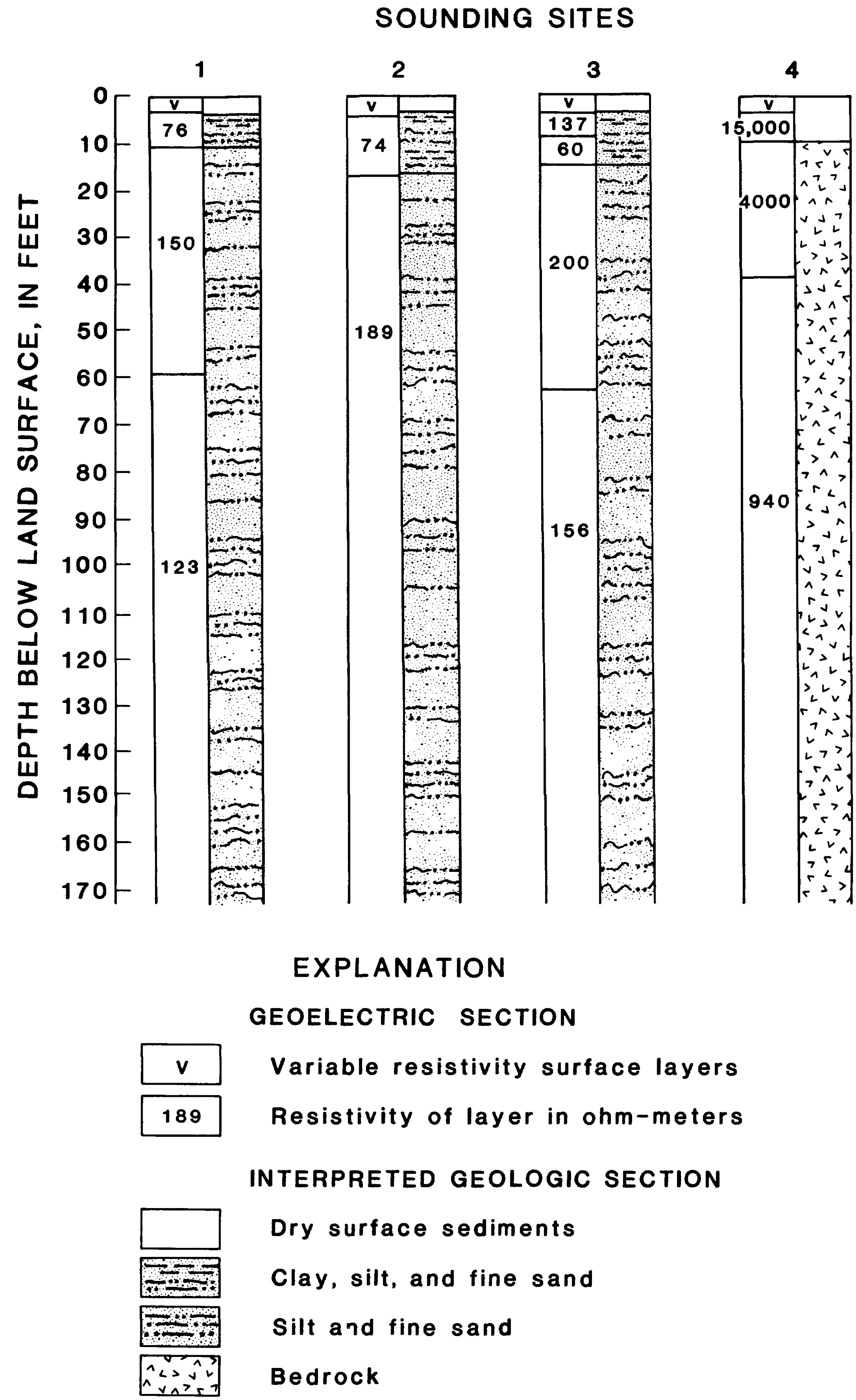


Figure 7.—Geoelectric sections and interperted geologic sections generated from the vertical electric sounding data.

The technique uses an electromagnetic transmitter and a receiver. The transmitter creates a primary electromagnetic field by passing alternating current through a loop of wire or coil. The electromagnetic field passes through the subsurface and induces a flow of electric current proportional to the conductivity of the ground water and earth materials. The current flow induces a secondary electromagnetic field with the same frequency as the primary field but with a different phase and direction. The primary and secondary electromagnetic fields are measured as a change in the potential induced in the receiver coil. The apparent conductivity of the subsurface is calculated by the receiver.

Changing the orientation of the coils alters the effective depth of measurement of apparent conductivity. Two coil orientations used are the horizontal dipole and vertical dipole configurations. The horizontal configuration method is used with the coils up on edge and coplanar. This configuration measures the electrical character of the shallow subsurface. The effective depth of measurement is typically 0.75 of the intercoil spacing. The vertical configuration method is used with the coils flat on the ground and coplanar. This method measures the deeper subsurface, about 1 to 1.5 times the intercoil spacing.

Apparent conductivity values of the subsurface can be used to differentiate presumably contaminated from noncontaminated ground water by comparison of its values with additional geohydrologic data. Such additional data includes depth to water table, soil type, water analysis, influences of metallic objects, and land use. The absolute value of the apparent conductivity is not diagnostic of any particular feature, but its relative variation is diagnostic.

Field Procedure

Field data were collected with a Geonics* EM 34-3 and a Geonics EM 31 transmitter and receiver system. The instrument, intercoil spacing, transmission frequency, and number of stations at which data were collected are given below.

Instrument	Intercoil spacing in feet	Frequency in hertz	Number of stations
EM 31	12.0	9.8	294
EM 34-3	32.8	6.4	336

The EM 34-3 data were collected on a grid pattern with 200-foot centers. Data were collected at each station in both the horizontal and vertical dipole configuration. EM 31 data were collected every 100 feet along lines 200 feet apart in the vertical dipole mode. Station locations were determined by pace-and-compass methods. Areas thought to be influenced by metallic interference sources were avoided. Measuring stations and apparent conductivity values are shown in figures 8, 9, and 10.

Data Analysis

Apparent conductivity values at the Arsenal range from 1 to 250 mmhos/m (millimhos per meter). This range of values is interpreted in the context of the geohydrologic setting as follows:

Apparent conductivity in mmhos/m	Types of Earth materials
less than 7	Water table greater than 4 feet below land surface
7 to 14	Water table less than 4 feet below land surface
15 to 30	Conductive sediments or contaminated ground water near land surface
30 to 100	Contaminated ground water
greater than 100	Contaminated ground water or metallic interference.

Areas in the Arsenal with apparent conductivity values below 15 mmhos/m indicate uncontaminated ground water, and areas with values of 15 or more mmhos/m indicate conductive sediment, contaminated water, and/or metallic interference. In general, the study area is divisible into subareas containing water that is uncontaminated, presumably contaminated, or possibly contaminated. Figure 11 shows where apparent conductivity data were collected and delineates the 13 areas where apparent conductivity exceeds 15 mmhos/m.

Areas 1, 12, and 13 are interpreted to have conductive sediments and not contaminated water. The high values indicate muck or clay near the land surface. Areas 1 and 13 are underlain by an organic-rich and highly conductive muck 5 to 40 feet thick. Area 12 is underlain by a highly conductive clay layer 4 to 10 feet thick.

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Areas 2, 4, 5, 6, 7, 9, and 11 are interpreted to be underlain by contaminated ground water. Each area is adjacent to a known or potential ground-water contamination source (table 3). The size and shape of the contamination plumes are outlined in figure 11. The direction of ground-water flow in the water-table aquifer at the Arsenal is toward Green Pond Brook. The shape of each plume suggests that the contamination follows the ground-water flow lines from the source area to the brook.

Table 3.--Contaminated areas and presumed sources

Area	Presumed contamination source
2	A former waste-disposal site
4	Pyrotechnic area, formerly used to test explosive devices, currently used to store equipment
5	Burning-ground used to incinerate discarded explosives
6	Road-salt storage facility
7	Former septic field for small nearby residential community
9	Down gradient from the Building 95 waste-water-treatment lagoon, includes the Sewage-Treatment Plant
11	Adjacent to the pesticides- and fertilizer-storage shed

In addition, areas 3, 8, and 10 also may be underlain by contaminated ground-water. More intensive study would be needed to determine the cause for their high apparent conductivity. Area 3 is underlain by 6 feet or more of highly conductive muck. It was formerly used as a waste-disposal site (Dixon, K.M., U.S. Army Armament Research and Development Center, oral commun., 1983), which may account for its high conductivity. Area 8 contains numerous storage facilities that may be sources of contamination. This area is underlain by a layer of muck 2 to 4 feet thick. Contamination from the storage facilities or from the underlying muck that is 2 to 4 feet thick may cause the high apparent conductivity. Area 11 is underlain by a network of service lines but they are not believed to affect the data. Its high conductivity is of uncertain origin.

The areas with an apparent conductivity value of less than 15 mmhos/m are not considered to be contaminated with a conductive material. These areas generally consist of a thin muck layer underlain by fine sand or silt.

SUMMARY AND CONCLUSION

This report presents and analyzes surface geophysical data that were collected as a preliminary technique to determine the geohydrologic framework of Picatinny Arsenal and the extent of areas of ground-water contamination.

The seismic-refraction method was used to map the configuration of the bedrock surface beneath the glacial deposits in the valley of Green Pond Brook. Data from 12 seismic-refraction lines were collected and analyzed. The greatest depth to consolidated bedrock is about 290 feet below land surface. The deepest part of the subsurface bedrock is aligned with the Green Pond fault or follow the strike of the easily weathered and eroded Leithsville Formation.

Electric-resistivity sounding data define the lithology of the unconsolidated sediments in the less developed parts of the Arsenal. A shallow, unsaturated surface layer of variable thickness is underlain by a thick layer of interbedded fine-grained sediments. Data for one electric resistivity line were collected on the gneiss ridge to the eastern side of the study area. Twenty feet of unsaturated sediment overlie the gneiss.

Electromagnetic conductivity techniques delineated 13 sites with apparent conductivity exceeding 15 mmhos/m. These are divided into uncontaminated, presumed contaminated, and possibly contaminated areas. Of the 13 sites, 3 are considered to be uncontaminated and 7 are contaminated. The contaminated areas coincide with, or are adjacent to the following sources:

Site	Source
2	Former waste-disposal site
4	Pyrotechnic area
5	Burning ground
6	Road-salt storage facility
7	Former septic field
9	Building 95 wastewater-treatment lagoon and sewage-treatment plant
11	Pesticide- and fertilizer-storage shed

Three subareas are interpreted to be underlain by possibly contaminated ground-water, but further study is needed. These are area 3, which has a thick muck layer, but is reported to be a former waste disposal site; area 8, which has a thick muck layer but also has many storage buildings; and area 10, which contains many service lines that may mask possible ground-water contamination.

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GLOSSARY

Apparent conductivity: A measure of the ease with which a material transmits electric current. The measurement is made without physically contacting the material that is measured. Its inverse is apparent resistivity.

Apparent resistivity: A measure of the difficulty with which a material transmits electricity. The measurement is made without physically contacting the material measured. Its inverse is apparent conductivity.

Current: A flow of electricity, measured in amperes.

Electrode: A metal stake driven into the ground to input electricity or to measure voltage.

Electromagnetic conductivity: A surface geophysical technique that uses electromagnetic energy to measure the apparent conductivity of sediments and ground water.

Horizontal dipole: A pair of magnetic poles that are parallel with the earth's surface.

Intercoil spacing: The distance between the transmitter and receiver coil for an electromagnetic measurement.

Interference source: A material or current that adversely affects electric or electromagnetic measurements. Examples of interference sources include large metal objects such as fences, pipelines, overhead and underground service lines, railroad tracks, metal buildings and debris. Stray electrical current emitted from electricity-generating facilities and lightning bolt strike are other forms of interference.

Offset Wenner array: An electric-resistivity setup with five electrodes that are linearly arranged and equally spaced. Current is induced in electrodes 1 and 4 and potential is measured between electrodes 2 and 3. Current is then induced in electrodes 2 and 5 and potential is measured between electrodes 3 and 4.

Potential: The work involved or the energy released in the transfer of electricity from one point to another point, measured in volts.

Vertical dipole: A pair of magnetic poles that are perpendicular to the earth's surface.