Geophysical Investigations in the Vicinity of a Former Electroplating Facility in Merrimack, New Hampshire

ADMINISTRATIVE REPORT
Dear Mr. Willey,

Enclosed are 10 copies of the Administrative Report by Thomas Mack, titled "Geophysical Investigations in the Vicinity of a Former Electroplating Facility in Merrimack, New Hampshire." This report has been approved by the Director of the U.S. Geological Survey as an Administrative Report.

cc: F. Lyford
    T. Mack
GEOPHYSICAL INVESTIGATIONS IN THE VICINITY OF A FORMER ELECTROPLATING FACILITY IN MERRIMACK, NEW HAMPshire

Administrative Report

Prepared for the
U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION I
GEOPHYSICAL INVESTIGATIONS IN THE VICINITY OF A FORMER ELECTROPLATING FACILITY IN MERRIMACK, NEW HAMPSHIRE

By Thomas J. Mack

Administrative Report

Prepared for the

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION I

Bow, New Hampshire
1994
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**Sea level:** In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

In this report, electrical conductivities of water are expressed as microsiemens per centimeter (μS/cm) at 25 degrees Celsius. Electromagnetic conductivities of earth sediments are expressed as millisiemens per meter (mS/m). Electromagnetic velocity of radar signals are measured in feet per nanosecond (ft/ns). Seismic velocity of sound waves are measured in feet per second (ft/s) and gamma radiation is measured in counts per second (cps).
Geophysical Investigations in the Vicinity of a Former Electroplating Facility in Merrimack, New Hampshire

By Thomas J. Mack

Abstract

A geophysical study was done by the U.S. Geological Survey to assist the U.S. Environmental Protection Agency in describing the hydrogeology and extent of contamination at a former plating facility in Merrimack, New Hampshire. The plating facility is on an alluvial terrace approximately 600 feet west of the Merrimack River. During operation, the facility discharged an estimated 35,000 to 60,000 gallons per day of plating wastes, including numerous metals and volatile organic compounds, into a series of four unlined lagoons.

Geophysical investigations were performed at or near the plating facility to describe the hydrogeology and to estimate the extent of contamination present. Marine seismic-reflection surveys were done on water bodies to estimate the depth to bedrock and determine the general lithology. Where possible, the depth to bedrock below the water surface was estimated to range from 0 to 20 feet in Horseshoe Pond, and generally from 20 to 50 feet in the Merrimack River.

Ground-penetrating radar was used to give an indication of the lithologic textures in the upper sediments. The ground-penetrating-radar surveys identified fine-grained sediments that range from fine sand to clay underlying the study area at about 30 to 35 feet below the land surface. These fine-grained sediments prevented further penetration of the radar signal.

Natural-gamma radiation and electromagnetic-induction borehole geophysical logs were utilized in seven observation wells to vertically delineate zones of electrically conductive ground water indicative of a contaminant plume. Three contaminated zones were delineated at a well adjacent to the plating facility at altitudes of approximately 15, 58, and 92 feet above sea level. The upper contaminant zone was delineated at observation wells farther downgradient from the site at 78 to 85 feet above sea level. Geophysical logs indicate that the screened intervals at a number of the well-cluster sites may not be optimally located with respect to zones of contamination.

INTRODUCTION

A study was done by the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency, to provide hydrogeologic information for ongoing remediation activities at a former electroplating facility, identified as the plating facility throughout this report. This facility is off Route 3 in the town of Merrimack in southern New Hampshire (fig. 1). From 1962 to 1985 the facility discharged on-site 35,000 to 60,000 gal/d of electroplating wastes into a series of four unlined lagoons. The wastes included cyanide plating baths and sludges, acids, and chlorinated solvents. Discharge of degreasing solvents into lagoons was discontinued in the late 1970's (New Hampshire Department of Environmental Services, 1985).
Figure 1. Location of the former electroplating facility and monitoring wells in Merrimack, New Hampshire.
A number of investigations have been performed at this site by State and Federal agencies and private consulting firms for the plating facility and its abutters. Weston (1990a,b) summarized previous investigations including a surface electromagnetic-induction (EM) terrain-conductivity survey that delineates a north-south trending, anomalously high terrain conductivity through the area of the lagoons to Wright Avenue.

**Purpose and Scope**

The purpose of this report is to describe the techniques and interpretation of results of geophysical investigations done at or near the plating facility. Included in the report are geophysical profiles that indicate the various lithologies present and depth to bedrock in some locations. Borehole-geophysical logs that vertically delineate areas of contaminated ground water are included. The extent of the investigation is limited to the area encompassed by Horseshoe Pond, the plating facility, and the Merrimack River (fig. 1).

**Hydrogeologic Setting**

The plating facility is on an alluvial terrace approximately 600 ft west of the Merrimack River (fig. 1). Surficial sediments include recent alluvium underlain by glaciolacustrine sediments and till (Koteff, 1976). The alluvium ranges in thickness from less than 5 to 25 ft and consists of sand, silt, and some gravel. The glaciolacustrine sediments consist primarily of sand, silt, and clay with some gravel, and total thicknesses may be as much as 100 ft. Coarse-grained stratified drift is interspersed with fine-grained lake-bottom sediments in areas along the Merrimack River (Toppin, 1987). Till discontinuously underlies these sediments near the plating facility. The till was described as a poorly sorted mixture of silt, sand, and gravel with some boulders and clay (Koteff, 1976) and was 1 to 3 ft thick in two borings (MW-102d and MW-105).

Bedrock outcrops, drill cuttings, and cores in the study area show that bedrock consists of schists and phyllites with minor amounts of granite and gneiss (Weston, 1990a). The bedrock surface forms a north-south trending trough and outcrops at the northwestern bank of Horseshoe Pond (Weston, 1990a). The total thickness of surficial sediments overlying bedrock in the study area ranges from zero at the northwestern bank of Horseshoe Pond to greater than 120 ft between the center of Horseshoe Pond and the plating facility, and approximately 20 ft along the northeastern bank of Horseshoe Pond (Weston, 1990a). The depth to the water-table surface is approximately 5 to 20 ft in the study area.

**Ground-Water Contamination**

During operation of the plating facility, wastewater discharged to the unlined lagoons contained cyanide, many metals, and volatile organic compounds (VOC's). Metals in the wastewater included cadmium, chromium, copper, iron, nickel, zinc, tin, silver, arsenic, lead, manganese, and sodium. VOC contamination in the wastewater was primarily from trichloroethylene (Weston, 1990a).
GEOPHYSICAL INVESTIGATIONS

Geophysical investigations were performed at or near the plating facility during 1992. Marine seismic-reflection surveys were performed on water bodies in September, ground-penetrating radar surveys were performed on land and water bodies in October, and natural-gamma and EM borehole logs of seven observation wells were performed in October.

Marine-Seismic Reflection

Marine seismic-reflection surveys were done on the Merrimack River and on Horseshoe Pond in the study area. Survey lines are shown on figure 2. Seismic-reflection profiles were interpreted visually and equipment setup and data interpretation are described by Haeni (1986, 1988) and Hansen (1986). For the seismic-reflection method, an acoustic signal transmitted from a sound source is reflected from sediments with contrasting acoustical impedances. Contrasts in acoustical impedances generally are found at changes in lithology. Contrasts are also present in lithologic units, at bedding planes, or at other interunit features. Descriptions of lithology can be determined from a visual assessment of the profile. For example, chaotic signatures indicate coarse-grained sediments and laminar signatures indicate fine-grained sediments. Factors that limit the penetration of the seismic-reflection survey include a hard or cobble lake-bottom surface or bottom sediments containing gases.

Methods of Study

The vertical scale on the seismic-reflection profile indicates the two-way travel time (down to the reflector and back to the receiver) of the seismic signal. The velocity of sound through saturated glacial sediments generally ranges from 4,000 to 6,000 ft/s in New England (Haeni, 1988). A seismic-sound velocity of 5,000 ft/s was used to calculate penetration depth of the seismic signal in saturated unconsolidated sediments or a water column. Accuracy of the interpretation may be within 10 percent of the investigation depth; however, interpretation accuracy will vary with changes in the seismic-sound velocity of the sediments surveyed and with the subjectivity of visual interpretations of reflector signatures.

Seismic-reflection-survey locations were adjusted in the field for optimum profile results. Bottom sediments in Horseshoe Pond prevented seismic-signal penetration at numerous sites along the survey line. Surveys that crossed the center of the pond were obscured by organic bottom sediments; therefore, these areas were avoided and the survey line (fig. 2) follows the banks of Horseshoe Pond. For example, the seismic-reflection profile from the survey line between stations A7 and A8 shows repeated multiple-bottom images caused by the signal reflecting off the pond bottom. Seismic-reflection-survey lines were positioned along the length of the Merrimack River (fig. 2). Survey lines that crossed the river were less successful and are not shown.
Figure 2. Location and results of seismic-reflection and ground-penetrating radar surveys, Merrimack, New Hampshire.
Results of Study

The seismic-reflection profiles (Appendixes 1, 2, and 3) indicate the presence of fine-grained sediments in many areas. Fine-grained sediments overlying coarse-grained sediments were observed in some locations. Seismic-reflection profiles on Horseshoe Pond (Appendix 1) indicate that bedrock is at the water surface at station A6 and up to 20 ft below the water surface near station A17 (fig. 2). The bedrock surface was interpreted to range from 10 to 20 ft below the water surface where the seismic-reflection surveys were successful on Horseshoe Pond (fig. 2). The seismic-reflection survey was not successful at station A3 where the drilling log of well MW-106 shows a 100-ft depth to bedrock. Organic pond-bottom sediments prevented penetration of the seismic-reflection signal at station A3.

The seismic-reflection profiles of the Merrimack River (Appendixes 2 and 3) were more successful than the profiles of Horseshoe Pond. The depth to bedrock below the river surface were interpreted to range from 10 to 50 ft (lines B and C, fig. 2). The depth to bedrock along the river shoreline was interpreted to be less than 20 ft (line B, fig. 2). A depth to bedrock of approximately 50 ft was indicated between C3 and C4 in the center of the river (fig. 2, Appendix 3). The higher quality of the seismic-reflection profiles of the river are a result of the accumulation of less organic bottom sediments in the river than in the pond (Appendix 2 and 3).

In general, the seismic-reflection profiles were successful where the water bottom sediments and conditions were suitable. Optimum sediments and conditions were fine to medium-grained sediments and shallow water depths. The major limiting condition in the study area was the organic bottom sediments that were present throughout most of Horseshoe Pond.

Ground-Penetrating Radar

Ground-penetrating radar (GPR) surveys were done according to the methods used by Beres and Haeni (1991). GPR surveys were done at the same locations as the marine seismic-reflection surveys and at locations adjacent to the plating facility as shown on figure 2. The GPR survey system transmits radio-frequency electromagnetic pulses into the ground and receives energy reflected back from subsurface reflectors. Reflectors are present at interfaces between sediments with different electrical properties, such as the interface between different lithologic units or at layers within a unit. Analysis of GPR profiles is similar to seismic-reflection profiles. The profiles can be examined visually to provide indications of lithologic properties. Beres and Haeni (1991) provide an interpretation guide for various types of reflection configurations. Parallel reflectors indicate laminated fine-grained sediments. Complex, chaotic reflectors indicate coarse-grained sediments or bedrock. Inverted v-shaped reflectors indicate boulders, buried pipelines, conduits, or metallic structures at the land surface, such as fences or buildings.
Method of Study

Electromagnetic velocities of radar signal transmissions were used to interpret depth to target signatures. Electromagnetic velocity in a water column is 0.1 ft/ns, in saturated unconsolidated sediments is 0.2 ft/ns, and in unsaturated unconsolidated sediments is 0.4 ft/ns (Beres and Haeni, 1991). Interpretation of a GPR profile depends on the penetration depth scale, which depends on the sediments penetrated and the scale adjustments as those sediments change. For any radar frequency, the primary factor limiting depth of penetration is the electrical conductivity of the sediments encountered (Beres and Haeni, 1991). Conductive sediments, such as clay, limit the radar-signal penetration. Dry unconsolidated coarse-grained sediments permit maximum-signal penetration.

The quality of GPR-profile interpretations is dependent on visually discriminating sediments with contrasting electromagnetic velocities. For example, where the radar signal penetrates an unsaturated sand unit overlying a saturated sand unit, the interpreted depths to reflectors in the saturated unit is dependent on correctly identifying the location of the water-table surface.

Independently derived lithologic information is used at a site to correctly interpret or confirm interpretations of GPR profiles. Electromagnetic velocity contrasts are present, for example, at a water-table surface, a coarse to fine-grained interface, or at a bedrock surface, and can be represented as a dark continuous band on the GPR profile. However, a thin conductive layer, such as a clay lens, can also be represented as a thick dark continuous band on the GPR profile. A water-table surface is represented as a continuous dark reflector on the GPR profile in areas of coarse-grained sediments. However, an extensive capillary fringe in fine-grained sediments could prevent the water-table surface from showing as a distinct reflector. If fine-grained sediments are present near the water-table surface, the depth to the water table is needed to correctly interpret the profile.

Results of Study

Ground-penetrating surveys done on land successfully determined sediment types to a depth of 30 to 35 ft. Annotated GPR profiles for the land surveys are presented in Appendix 4. Lithologic interpretations are noted on the record (Appendix 4) and are correlated with driller’s logs where possible. Fine-grained sediments are at land surface at the plating facility (profile D25, D30, D31), and to the west (profile D8) and north of the site, fine-grained sediments were found near the land surface (profile D21). The surficial fine-grained sediment consists of silt, clay, and very-fine sand. Fine-grained sediments prevented the water-table surface from showing as a distinct reflector throughout the study area.

Fine-grained sediments underlie the entire study area. Driller’s logs (Weston, 1990b) were used to confirm the lithology of the fine-grained sediments at depth, which ranged from a silt, sand, and clay near the lagoons to a fine-grained sand to the south near Horseshoe Pond. Depth to the lower fine-grained sediments, on the basis of interpreted GPR profiles and driller’s logs, was generally 30 to 35 ft throughout the study area (fig. 2). The fine-grained sediments consists of a fine-grained sand to the south (at MW-106) that grades into fine sand, silt, and clay to the north (at MW-8). At some sites, a thin silt or clay layer, as indicated by the borehole logs, showed as a thick, dark band on the GPR profile.
The GPR signal generally penetrated only a few feet into the lower fine-grained sediments. Because the near-surface sediments were also fine-grained, the GPR penetration depths were reduced throughout the study area. At some sites, the signal was completely obscured and a blank record can be seen below these sediments. For example, segments of the profiles D22 and D31 (Appendix 4) that cover an area between the plating facility building and the first lagoon show large blank areas on the profile. The blank areas coincide with areas reported to have high terrain conductivity as indicated by a surface electromagnetic-induction survey (Weston, 1990a). It is possible that the blank areas of the profiles indicate an area of sediments (including ground water) with a high electrical conductivity.

Ground-penetrating radar surveys done on the water bodies at the same sites as the marine seismic-reflection surveys yielded inconclusive data. Generally, the radar signal reflected off the bottom and did not penetrate beneath the bottom sediments. The lack of penetration was caused by the radar signal being attenuated by the water column and the fine-grained bottom sediments. Attempts to increase radar penetration by performing GPR surveys in as shallow water as possible were not successful and the data are not included in this report.

Borehole-Geophysical Logs

Two borehole-geophysical-logging techniques, natural-gamma radiation (gamma) and EM were used to characterize lithologic logs and vertically delineate areas of conductive ground water. Seven wells (MW-102d, MW-104d, MW-105, MW-106, MW-108d, MW-109d, and MW-8r, fig. 1) were logged by use of the methods described by Mack (1993). It was not possible to log well MW-7r because a bent well casing prevented the probes from entering the well. Water levels and specific conductance of ground-water samples were measured in August 1992 (Robert Polermo, Badger Engineering, written commun. 1993).

The logging probes were designed to fit in a 2 in.- or greater inside-diameter well. The gamma log can be used in uncased boreholes and in polyvinyl chloride (PVC) or steel-cased wells. Electromagnetic logs can only be used in open boreholes or in PCV or other non-metallic cased wells.

Natural-Gamma Radiation Log

Natural-gamma radiation logs, or gamma logs, are used to delineate silt and clay zones in unconsolidated sediments penetrated by the borehole. The gamma log measures the total gamma radiation, in counts per second, detected in a selected energy range. Gamma-emitting radioisotopes are natural products of uranium and thorium decay series and potassium-40. Uranium and thorium are concentrated in most clays by the process of adsorption and ion exchange (Keys, 1988). Potassium is abundant in some feldspars and micas that decompose to clay (Keys, 1988). In the glaciated sediments of the northeast, fine-grained sediments rich in clay are generally more radioactive than quartz sand or carbonate rocks.
Electromagnetic-Induction Log

Electromagnetic-induction logs, or EM logs, measure the electrical conductivity of the formation penetrated by the borehole and will be referred to as EM conductivity in this report. The EM conductivity of unconsolidated glacial sediments is primarily affected by the presence of clay minerals and the conductivity of ground water. Unsaturated sand or gravel is electrically resistive, saturated sand is more conductive, and saturated silt or clay are relatively conductive. The addition of ions in water, such as dissolved metals found in some contaminants, increases the electrical conductivity of that water.

The EM log probe is focused to obtain the maximum response from sediment about 1 ft from the probe or center of the borehole. This ensures that the EM log is measuring the electrical conductance of sediment outside a 4- to 6 in.-diameter borehole. Metal casing blocks the EM conductivity signal. For this reason, steel-well protectors often prevent the use of an EM log at the land surface. A bed thickness of about 13 ft is required to accurately determine the conductivity of a unit (Taylor and others, 1989). Units thinner than 1.6 ft can be detected given a large contrast in conductivity; however, an accurate determination of layer thickness and conductivity is not possible (Taylor and others, 1989).

Methods of Study

The gamma and EM logs are compared with each other in relation to lithologic descriptions from driller’s logs and specific conductance of well-water samples. Driller’s logs (Weston, 1990b) provide lithologic descriptions of specific intervals in a borehole. The gamma log may indicate lithologic differences, or variations, that are not evident from sediment descriptions at selected intervals. An interpreted lithologic log can be created by correlating the gamma log with the driller’s lithologic descriptions.

The EM log closely follows the pattern of the gamma log, if the specific conductance of the ground water is constant with depth. Differing trends between the EM and gamma logs are a result of a change in the specific conductance of ground water or the presence of other conductive sediments. In this case, the EM log trace will indicate a higher electrical conductivity than if that trace had followed the pattern of the gamma-log trace. Conductive sediments in the borehole that produce anomalous EM conductivity measurements, or interferences, include steel-well protectors, buried scrap metal, and metal worn from the drill bit during drilling (Mack, 1993). Generally such interferences are readily detected because the measured EM conductivity appears as a large (positive or negative) sharp spike.

Changes in the specific conductance of ground water, as indicated by a comparison of the geophysical logs and lithologic descriptions, should be confirmed, where possible, by measuring the specific conductance of ground-water samples from nearby wells. If the specific conductances of ground-water samples are available, the EM log can be qualitatively related to the specific conductance of ground water. The average specific conductance for 29 ground-water samples from the Nashua Regional Planning Commission area was 217 μS/cm (Toppin, 1987).
Results of Study

The geophysical logs and interpreted lithologic logs of observation wells MW-102d, MW-8r, MW-104d, MW-105, MW-106, MW-108d, and MW-109d are shown in figures 3 through 9. The figures also show the screened zones of adjacent wells and specific conductance of ground-water samples from those wells. Water levels shown are from the upper most well in a cluster. In the following paragraphs, the conductivity discussed refers to either the EM conductivity of the combined sediments composing the aquifer and ground water present or the specific conductance of ground-water samples, not aquifer hydraulic conductivity. Results are expressed in terms of altitude instead of depth below land surface, so that specific zones of interest on the logs are comparable.

Observation well MW-102d is upgradient of the plating facility and ground-water-flow gradients are to the southeast. The logs of this well (fig. 3) show that the sediments present are mostly fine-grained sand with some silt and clay. A large amount of silt or clay is present from an altitude of 82 to 93 ft, and coarse sand and gravel are below 82 ft. The EM conductivity log trace follows the gamma log trace (fig. 3) closely because the specific conductance of ground water is relatively constant (115 to 200 μS/cm). The EM log trace is near zero because the specific conductance of ground water is relatively low (less than 200 μS/cm) and the upper part of the log, above an altitude of 103 ft (25 ft below land surface), is unsaturated and electrically resistive.

The gamma and lithologic logs of observation well MW-8r (fig. 4) show generally fine sand, silt, and clay down to an altitude of 50 ft. The sediments composing the aquifer at an altitude of -8 to 50 ft are sand and fine gravel. The EM log shows three zones of elevated electrical conductivity (fig. 4). The upper zone of high conductivity (180 mS/m) is from 88 to 98 ft and is centered at an altitude of about 92 ft. The middle zone of high conductivity (170 mS/m) is from 54 to 64 ft and is centered at an altitude of about 58 ft. The lower zone of high conductivity (110 to 130 mS/m) covers a wide area from 2 to 34 ft and is centered at an altitude of about 14 ft. The screened intervals of the four wells at this site (B-8s and MW-8r, fig. 4; 2 wells not shown) do not encompass the three conductive zones described above.

The gamma and lithologic logs of well MW-104d (fig. 5) indicate a distinct fine-grained unit at the land surface to 15 ft below the land surface. Fine-grained units are indicated by the gamma log at altitudes of 47 to 52 ft, 67 to 78 ft, and from 20 ft to the bottom of the boring. The EM log, in parts of the log, follows a trace similar to the gamma log trace (fig. 5). The EM log trace appears anomalously high from 70 to 90 ft as can be seen by a comparison with the lower part of the log (2 to 22 ft) that also has a relatively high gamma trace (100 cps). This zone of high conductivity is concentrated at 71 to 78 ft and peaks (200 mS/m) at an altitude centered at about 75 ft indicating the presence of conductive ground water. The screened interval of well MW-104s samples ground water with a high specific conductance (660 μS/cm) but did not include the zone at 71 to 78 ft that probably contains highly conductive ground water. The zone of high conductivity indicated by the geophysical logs (at 71 to 78 ft) is in a zone of fine-grained sediments (66 to 78 ft) where an observation well would generally not be screened because of a relatively small well yield.
MW-102d
GAMMA, IN COUNTS PER SECOND
CONDUCTIVITY, IN MILLISIEMENS PER METER

Screened interval
Well number
Specific conductance of water sample

MW-102s
115 microsiemens per centimeter at 25 degrees Celsius

MW-102d
200 microsiemens per centimeter at 25 degrees Celsius

MW-107
300 microsiemens per centimeter at 25 degrees Celsius

EXPLANATION

C MEDIUM TO COARSE SAND
M FINE TO MEDIUM SAND

V VERY FINE TO FINE SAND
V VERY FINE SAND, SILT, OR CLAY

V WATER TABLE
EM ELECTROMAGNETIC CONDUCTIVITY

Figure 3. Borehole geophysical logs, lithologic sections, screened intervals, and associated specific conductance of ground water in Merrimack, New Hampshire at wells MW-102d and MW-107.
Figure 4. Borehole geophysical logs, lithologic section, screened interval, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-8r.
The screened interval of well MW-104d appears to include a zone of slightly higher conductive ground water (at an altitude of 26 to 38 ft) than would be expected from examination of the logs (fig. 5). The screened interval of MW-104d also includes the area from 5 to 26 ft that probably contains water with low specific conductance as indicated by the geophysical logs. The screened interval of well MW-104d may yield a mixture of high and low conductivity ground water. Long screened intervals can yield water samples that do not characterize the contaminant plume present (Mack, 1993). The specific conductance of ground water at 26 to 38 ft may be much higher than the 800 \( \mu \text{S/cm} \) measured from observation well MW-104d.

The logs of well MW-105 (fig. 6) show an increasing electrical conductivity anomaly from an altitude of 60 to 82 ft. The EM trace (fig. 6) follows the gamma trace at 70 to 75 ft; however, the EM trace indicates a higher-than-expected conductance from an examination of the EM and gamma traces at an altitude of 55 ft. A conductivity peak (110 \( \mu \text{S/m} \)) at 71 ft may be affected by a peak in the gamma log. A zone of high conductivity ground water is probably present in the zone from 60 to 66 ft where the gamma log indicates coarse sediments and the EM conductivity trace is about 100 \( \mu \text{S/m} \). The screened interval of well MW-105 most likely does not yield a representative sample of the variations in water quality at this site if a stratified contaminant plume is present as indicated by the geophysical logs (fig. 6).

The logs of well MW-106 (fig. 7) indicate an extensive zone of highly conductive ground water from an altitude of 57 to 87 ft. The gamma log indicates that fine sand, silt, and clay are present from 95 to 115 ft (0 to 20 ft below the land surface). The peak of the high conductivity zone (200 \( \text{mS/m} \)) is at an altitude of 78 ft. Well screen B-10d is near this zone but does not include the highest conductivity, ground water at 78 ft probably has a specific conductance greater than 810 \( \mu \text{S/cm} \). The thin spike in the gamma log at 81 ft is probably the fine-grained sediments indicated on the GPR profile. The remainder of the log is characterized as generally fine to coarse-grained sand. The water sample from MW-106d (560 \( \mu \text{S/cm} \)) and the EM trace (130 to 140 \( \text{mS/m} \)) indicate that the conductivity of ground water is elevated throughout the lower part of the boring log. The geophysical and lithologic logs of MW-106 do not indicate appreciable amounts of very fine sediments, such as silt and clay, to limit vertical ground-water flow that may have allowed more vertical contaminant movement than was possible at other sites.

The gamma and lithologic logs of well MW-108d (fig. 8) delineate fine sand, silt, and clay from an altitude of 60 to 88 ft. At depths below an altitude of 60 ft, the aquifer is predominantly fine sand with less silt and clay.

The EM log of well MW-108d (fig. 8), when compared to the gamma and lithologic logs, indicates an upper and lower zone of conductive ground water. An upper zone of slightly high EM conductivity (at most 70 \( \text{mS/m} \)) is indicated at an altitude of 84 to 92 ft. Well MW-108s is screened through most of this zone. A lower zone of high conductivity covers an altitude of 50 to 64 ft. A more highly conductive (175 \( \text{mS/m} \)) zone, in this lower zone, can be further delineated from about 52 to 58 ft (fig. 8). The screen of well MW-108d (fig. 8) includes the entire more conductive zone (50 to 64 ft altitude) and the less conductive ground water above and below this zone. The specific conductance of ground water from well MW-108d was 810 \( \mu \text{S/cm} \) and is probably not representative of the water quality of the less extensive zone of highly conductive ground water as indicated by the EM log (fig. 8). The bottom of the log of well MW-108d at an altitude of 38 ft (fig. 8) shows an increasing EM conductivity trace; however, interpretation of this trend with respect to water quality is not possible because the logs end at this point.
Figure 5. Borehole geophysical logs, lithologic section, screened intervals, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-104d.
Figure 6. Borehole geophysical logs, lithologic section, screened intervals, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-105.
Figure 7. Borehole geophysical logs, lithologic section, screened intervals, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-106.
Figure 8. Borehole geophysical logs, lithologic section, screened intervals, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-108d.
Figure 9. Borehole geophysical logs, lithologic section, screened intervals, and associated specific conductance of ground water in Merrimack, New Hampshire at well MW-109d.
The gamma and lithologic logs of well MW-109d (fig. 9) indicate generally fine sand, silt, and clay. Medium to coarse sand is indicated in the logs at an altitude of 85 to 90 ft. A slightly conductive zone (80 to 120 mS/m) is indicated by the EM log at an altitude of 75 to 88 ft. The peak conductivity is centered at an altitude of 79 ft and coincides with a gamma peak of 130 cps. The conductivity peak at 79 ft is interpreted to be a result of conductive water because gamma peaks of 140 cps, from 50 to 75 ft, do not result in EM conductivity peaks. The screen of well MW-109s (fig. 9) includes the top of the conductive zone but not the peak conductive zone (at 79 ft). Water from this well had a specific conductance of 310 µS/cm. Water samples from MW-109d probably represent ambient conditions, as indicated by the geophysical logs (fig. 9) and had a specific conductance of 160 µS/cm.

**SUMMARY AND CONCLUSIONS**

Geophysical surveys consisting of marine-seismic reflection, ground-penetrating radar, and natural-gamma radiation and electromagnetic-induction borehole logging were performed at the former plating facility.

Marine seismic-reflection profiles were performed on Horseshoe Pond and on the Merrimack River. The seismic-reflection profiles on Horseshoe Pond indicate that bedrock was generally less than 20 ft below the water surface. Reflection profiles were not successful in determining the depth to bedrock in the northern part of the pond where a 100-ft depression in the bedrock surface is known to exist. The seismic-reflection signal could not penetrate the bottom sediments in the center of the pond. Seismic-reflection profiles in the Merrimack River indicated that bedrock was up to 50 ft below the water surface.

The GPR profiles successfully identified fine-grained sediment that ranged from fine sand to clay and underlies most of the study area at about 30 to 35 ft below land surface. The fine-grained sediments prevented further penetration of the radar signal. The GPR profiles generally could not be used to detect the water-table surface because of the fine-grained sediments present.

Gamma and EM borehole logs were useful in refining lithologic logs at seven boreholes, when used in conjunction with lithologic descriptions, and were useful in delineating electrically conductive zones indicative of ground-water contamination. At the six wells downgradient of the former plating facility, the EM log was used to vertically delineate zones of increased electrical conductivity to identify contaminant plumes. Interpretations of EM logs were confirmed by specific-conductance measurements of ground-water samples from wells screened adjacent to the logged well. Immediately downgradient from the former plating facility, at well MW-8r, three distinct zones of conductive ground water were delineated. The zones were centered at altitudes of approximately 15, 58, and 92 ft above sea level. The upper contaminant zone is delineated by the EM log further downgradient from the site at an altitude of 78 to 85 ft above sea level in the wells downgradient from the former plating facility. The mid-level contaminant zone extends south toward Horseshoe Pond and east toward Merrimack River at an altitude of 51 to 58 ft above sea level. The deepest contaminant zone may extend from the plating facility to the south towards Horseshoe Pond.
Surface EM-terrain conductivity surveys, performed during an earlier investigation, delineated a north-south trending anomalously high terrain conductivity through the study area. Borehole EM logs identify the specific vertical zones that contribute to the high terrain conductivities. Additionally, the EM log indicates zones of high conductivity (greater than 100 mS/m) that the surface EM survey is not sensitive enough to distinguish from background sediments. The geophysical logs of wells MW-8r and MW-108d indicate that a significant west-east-trending contaminant plume may be present near the base of the unconsolidated aquifer. Wells MW-106, MW-108d, and MW-109d are examples of areas where a surface EM survey was not able to identify areas of elevated EM conductivity identified by borehole logging.

Wells screened without the benefit of geophysical-log data may produce misleading results. The well screen may miss the contaminant plume entirely or the well may be screened to include the contaminant zone and the uncontaminated zone resulting in an underestimation of the contaminant concentrations.

REFERENCES CITED


New Hampshire Department of Environmental Services, 1985, Preliminary assessment of the New Hampshire Plating Company, Inc. site, Wright Avenue, Merrimack, New Hampshire: Water Supply and Pollution Control Division.


APPENDIX 1. SEISMIC-REFLECTION PROFILES FOR LINE A, ON HORSESHOE POND, MERRIMACK, NEW HAMPSHIRE
APPENDIX 1. SEISMIC-REFLECTION PROFILES FOR LINE A, ON HORSESHOE POND, MERRIMACK, NEW HAMPSHIRE--Continued
Appendix 2
APPENDIX 2. SEISMIC-REFLECTION PROFILES FOR LINE B, ON THE WEST SIDE OF THE MERRIMACK RIVER, MERRIMACK, NEW HAMPSHIRE
APPENDIX 3. SEISMIC-REFLECTION PROFILES FOR LINE C, IN THE CENTER OF THE MERRIMACK RIVER, MERRIMACK, NEW HAMPSHIRE
Appendix 4
APPENDIX 4. GROUND-PENETRATING RADAR PROFILES FOR LINES D5 THROUGH D31, MERRIMACK, NEW HAMPSHIRE --Continued

EXPLANATION

vf  VERY FINE-GRAINED SEDIMENTS
f  FINE-GRAINED SEDIMENTS
m-f  FINE TO MEDIUM-GRAINED SEDIMENTS
m  MEDIUM-GRAINED SEDIMENTS
m-co  MEDIUM TO COARSE-GRAINED SEDIMENTS
c  COARSE-GRAINED SEDIMENTS
df  RADAR DEFRACTIONS
w  WATER-TABLE SURFACE
x  APPROXIMATE WATER-TABLE SURFACE
APPENDIX 4. GROUND-PENETRATING RADAR PROFILES FOR LINES D5 THROUGH D31, MERRIMACK, NEW HAMPSHIRE —Continued

EXPLANATION

- VERY FINE-GRAINED SEDIMENTS
- FINE-GRAINED SEDIMENTS
- FINE TO MEDIUM-GRAINED SEDIMENTS
- MEDIUM-GRAINED SEDIMENTS
- MEDIUM TO COARSE-GRAINED SEDIMENTS
- COARSE-GRAINED SEDIMENTS
- RADAR DIFFRACTIONS
- WATER-TABLE SURFACE
- APPROXIMATE WATER-TABLE SURFACE
APPENDIX 4. GROUND-PENETRATING RADAR PROFILES FOR LINES D5 THROUGH D31, MERRIMACK, NEW HAMPSHIRE—Continued

EXPLANATION

- Very Fine-Grained Sediments
- Fine-Grained Sediments
- Fine to Medium-Grained Sediments
- Medium-Grained Sediments
- Medium to Coarse-Grained Sediments
- Coarse-Grained Sediments
- Radar Diffractions
- Water-Table Surface
- Approximate Water-Table Surface
APPENDIX 4. GROUND-PENETRATING RADAR PROFILES FOR LINES D5 THROUGH D31, MERRIMACK, NEW HAMPSHIRE --Continued

EXPLANATION

- **vf**: VERY FINE-GRAINED SEDIMENTS
- **f**: FINE-GRAINED SEDIMENTS
- **fs**: FINE TO MEDIUM-GRAINED SEDIMENTS
- **ms**: MEDIUM-GRAINED SEDIMENTS
- **mcs**: MEDIUM TO COARSE-GRAINED SEDIMENTS
- **cs**: COARSE-GRAINED SEDIMENTS
- **r**: RADAR DIFFRACTIONS
- **w**: WATER-TABLE SURFACE
- **wa**: APPROXIMATE WATER-TABLE SURFACE
APPENDIX 4. GROUND-PENETRATING RADAR PROFILES FOR LINES D5 THROUGH D31, MERRIMACK, NEW HAMPSHIRE —Continued

EXPLANATION

d  VERY FINE-GRAINED SEDIMENTS
f  FINE-GRAINED SEDIMENTS
m-f  FINE TO MEDIUM-GRAINED SEDIMENTS
m  MEDIUM-GRAINED SEDIMENTS
m-co  MEDIUM TO COARSE-GRAINED SEDIMENTS
c  COARSE-GRAINED SEDIMENTS
df  RADAR REFRACTIONS
x  WATER-TABLE SURFACE
x  APPROXIMATE WATER-TABLE SURFACE
APPENDIX 4. GROUND-PENETRATING RADAR PROFILES FOR LINES D5 THROUGH D31, MERRIMACK, NEW HAMPSHIRE —Contd.

EXPLANATION

- vf VERY FINE-GRAINED SEDIMENTS
- sf FINE-GRAINED SEDIMENTS
- s Fine TO MEDIUM-GRAINED SEDIMENTS
- sm MEDIUM-GRAINED SEDIMENTS
- sc Medium TO COARSE-GRAINED SEDIMENTS
- cs COARSE-GRAINED SEDIMENTS
- dd RADAR DIFFRACTIONS
- W WATER-TABLE SURFACE
- X APPROXIMATE WATER-TABLE SURFACE