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# Geophysical Surveys of Country Pond and Adjacent Wetland, and Implications for Contaminant-Plume Monitoring, Kingston, New Hampshire, 1998

By Joseph D. Ayotte, Thomas J. Mack, and Craig M. Johnston

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U.S. GEOLOGICAL SURVEY
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## CONVERSION FACTORS, VERTICAL DATUM AND ABBREVIATIONS

| Multiply | By | To obtain |
|---|---|---|
| acre | 0.4047 | hectometer |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| meter (m) | 3.281 | foot |

Temperature in degrees Fahrenheit ($^{o}F$) can be converted to degrees Celsius ($^{o}C$) as follows:
$^{o}C = 5/9\ (^{o}F - 32)$.

**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 Sea Level Datum of 1929.

## ABBREVIATIONS OF WATER QUALITY AND GEOPHYSICAL UNITS USED IN THIS REPORT:

| | |
|---|---|
| dB/m | decibels per meter |
| ft/ns | foot per nanosecond |
| MHz | megahertz |
| m/ns | meter per nanosecond |
| mS/m | millisiemens per meter |
| m/µs | meters per microsecond |
| ns | nanoseconds |
| µs/cm | microsiemens per centimeter at 25° Celsius |

# Geophysical Surveys of Country Pond and Adjacent Wetland, and Implications for Contaminant-Plume Monitoring, Kingston, New Hampshire, 1998

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## Abstract

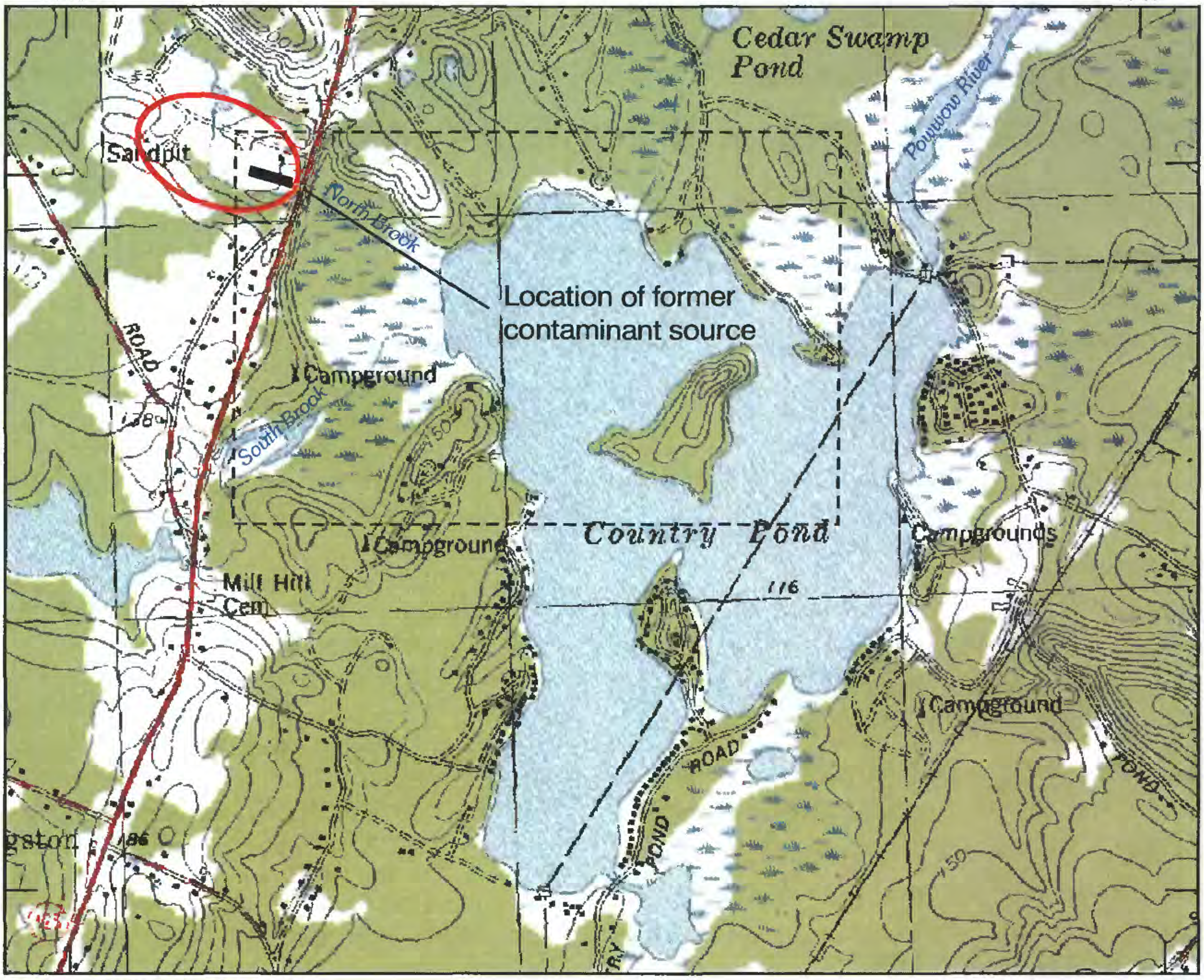
Contaminants from a hazardous-waste site have moved downgradient though a wetland and beneath Country Pond in Kingston, New Hampshire. This pond is a recreational resource for the area and is bordered by homes and seasonal camps that use onsite wells for water supply. Geophysical profiles, ground-penetrating radar, and electromagnetic-terrain-conductivity surveys provide information about the various lithologies and the position of the contaminant plume. Contour maps of the elevations of surfaces of various lithologies indicate that the sand surface beneath the relatively flat organic sediment surface is irregular. Terrain-conductivity data identify several anomalies, most of which are related to the thickness of the water column and organic sediments overlying the sand. One notable exception, however, is a large anomaly (high terrain conductivity) along the northwestern part of the wetland and pond area, which probably represents a contaminant plume, moving through the sand unit beneath the wetland and pond. Existing test-boring data were used to confirm the results of the geophysical surveys. The existing monitoring-well network does not adequately intersect the contaminant plume or provide a means to monitor plume concentration.

## INTRODUCTION

Country Pond, a 280-acre pond, is a recreational resource for the Kingston area and is bordered by homes and seasonal camps that use onsite wells for water supply. The extent and migration of ground-water contamination towards the pond, which is immediately downgradient (east) of a hazardous-waste U.S. Environmental Protection Agency (USEPA) Superfund site (fig. 1), is a concern for local residents and those using the pond for recreational activities. The U.S. Geological Survey (USGS), in cooperation with the USEPA, Waste Management Division, Region I, mapped subsurface sediments in the wetlands that drain to Country Pond by use of geophysical methods to determine the location of a contaminant plume and evaluate a monitoring-well network.

### Purpose and Scope

This report describes the results of geophysical investigations of glacial and post-glacial deposits near a former container manufacturing site. The area investigated includes parts of a wetland area to the east of the former site and parts of Country Pond adjacent to the marsh. Included in the report are geophysical profiles that provide information about the various lithologies, and contour maps of the elevation of surfaces of various lithologic units and the thickness of an organic material layer and terrain conductivity. Test-boring data were used to confirm the results of the geophysical surveys. The existing monitoring-well network was evaluated in relation to the results of this study. The investigation was limited to the wetland and pond east of the former container manufacturer's waste-disposal site (fig. 1).




Base from US. Geological Survey
Digital raster graph image, Kingston, N.H.,
1:24,000, 1989

1000-meter Universal Transverse Mercator grid, zone 19

0 1,000 2,000 3,000 4,000 FEET

0 200 400 600 800 1,000 METERS

CONTOUR INTERVAL 10 FEET

EXPLANATION

(Red ellipse) Approximate location of former contaminant source

- - - - - - - - Areal extent of subsequent illustrations


**Figure 1.** Location of the study area, Country Pond, Kingston, New Hampshire.

## Description of Study Area and Geohydrologic Setting

The study area includes the northwestern part of Country Pond, including the surrounding shoreline and wetland to the east (fig. 1). Country Pond is a glacial kettle lake in an extensive outwash plain (Stekl and Flanagan, 1992). Outwash deposits and ice-contact deposits are exposed on the northwest shore of the pond. The wetland is composed of fibrous organic matter, whereas much of the pond bottom is covered by very-fine grained, loose, organic sediment.

North Brook (fig. 1) flows along the north side of the waste site and drains the wetland adjacent to the pond. Another unnamed brook, flows along the south side of the wetland to the pond. Country Pond is drained by Powwow River northeast of the pond. The water level of Country Pond is controlled by a dam on Powwow River and ranges from 114 to 117 ft above sea level (Goldberg-Zoino and Associates, 1986). The water level of the pond is maintained at about 116 ft throughout spring and summer and is lowered about 2 ft during late fall and winter. In the study area, pond depths are generally less than 5 ft within 100 ft of the shoreline, and up to 14 ft deep farther from the shoreline.

## Previous Investigations

A regional investigation of ground-water resources was done by Stekl and Flanagan (1992). Koteff and Moore (1994) mapped the surficial geology of the Kingston 7.5-minute quadrangle, which includes the entire study area.

Locally, investigations by Goldberg-Zoino and Associates (1986), Ecology and Environment, Inc. (1982), and Arthur D. Little, Inc. (1991) were concerned with the nature and extent of contamination associated with the waste site and in the wetland southeast of the waste site. A previous study by the USGS (Stekl, 1994), in cooperation with the USEPA and the New Hampshire Department of Environmental Services (NHDES), focused on concentrations of volatile organic compounds (VOCs) in the ground water in the stratified-drift aquifer (glacial deltaic sand) beneath the pond. During a study by (Mack, 1995), 10 monitoring wells were installed beneath Country Pond and were used to measure pond-bottom sediment thicknesses, stratified-drift thicknesses, and ground-water quality at selected locations.

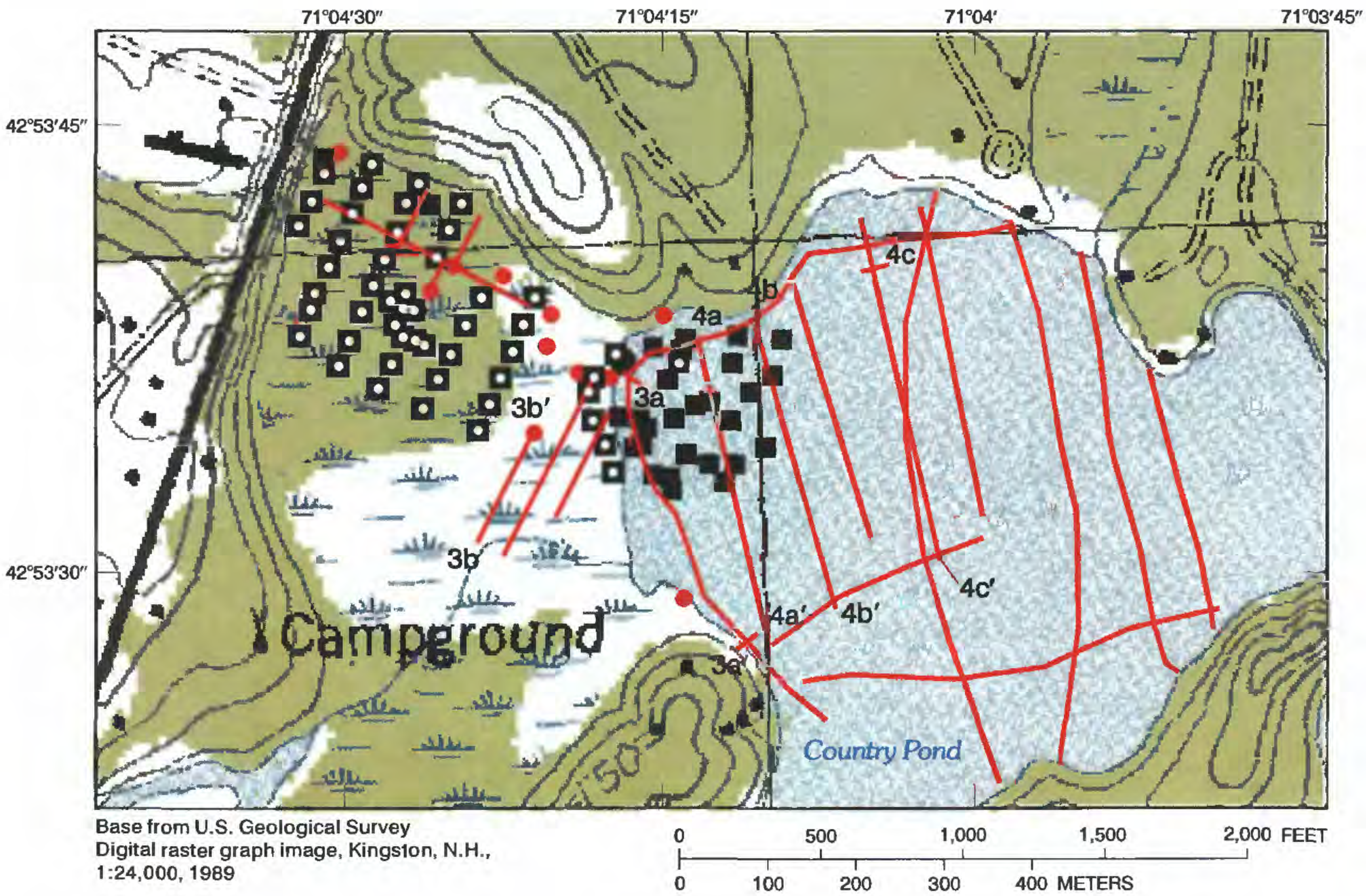
## Acknowledgments

Information for this study was provided by the New Hampshire Department of Environmental Services and the U.S. Environmental Protection Agency. The authors wish to thank the many property owners for their cooperation in granting U.S. Geological Survey personnel access to their property to perform geophysical surveys.

# GEOPHYSICAL SURVEY METHODS

Ground-penetrating radar (GPR) and electromagnetic terrain conductivity were used in conjunction to investigate the geohydrology of the glacial deposits and the probable location and extent of ground-water contamination in the study area. GPR data were collected to provide continuous profiles of the organic material surface and the underlying sand surface at the survey locations shown on figure 2. GPR provides detailed profiles of the stratigraphy of the subsurface deposits. Depths to reflectors and types of lithologies were verified by comparing depths to reflectors with depths to lithologic units inferred from well and test-boring logs. Terrain-conductivity measurements were collected at grid-point intersections in the wetland and at selected locations on the pond. Terrain-conductivity data were compared to GPR data to differentiate between the conductivity effects of geologic materials and high-conductivity ground water associated with a contaminant plume.

Most of the grid used in this study was surveyed for another investigation (Lynne Klosterman, Arthur D. Little, Inc., written commun., 1997), the southern part of the grid was created for this study. Data-collection sites on the pond and areas off the grid were located using a Global Positioning System (GPS) with an accuracy of about 30 ft. Depths to organic deposits and underlying glacial sands were delineated at 100-ft intervals on the GPR profiles and point values were entered into Geographic Information Systems (GIS) coverages. (Original data and GIS coverages are maintained at the USGS District office in Pembroke, N.H.)




EXPLANATION

| | |
|---|---|
| 3a 3a′ | GPR survey line--Cross bar and label indicates profile location |
| ◘ | Probe data |
| ● | Consultant monitoring wells |
| ■ | U.S. Geological Survey monitoring wells |

**Figure 2.** Location of ground-penetrating radar (GPR) profile lines, probes, and wells.

## Ground-Penetrating Radar

GPR surveys were conducted according to methods described by Beres and Haeni (1991), Haeni (1992), and Haeni and others (1987). The GPR-survey system transmits radio-frequency electromagnetic pulses into the ground and receives energy reflected back from subsurface reflectors. Reflectors can be any subsurface contact between geologic materials with different physical and electrical properties, such as the interface between lithologic units or layers within a unit. The surveys were conducted with bi-static 100 MHz center-frequency transmitting and receiving antennas that were towed over frozen wetland and pond surfaces. The profiles can be examined visually to provide indications of lithologic properties. Interpretation of GPR profiles are improved by comparisons with lithologic logs.

Beres and Haeni (1991) provide an interpretation guide for various types of typical reflector patterns for unconsolidated deposits. Parallel reflectors indicate the presence of laminated fine-grained sediments, such as pond-bottom sediments observed in this study. Complex, subparallel, and chaotic reflectors generally indicate coarse-grained sediments. Inverted V-shaped reflectors are indicative of point reflectors that can be from cobbles or boulders in till.

Transmission velocities of the radar signal were used to interpret depth to a reflector. Approximate values of radar-transmission velocities (Beres and Haeni, 1991; Geophysical Survey Systems, Inc., 1994) used for interpretation are summarized in table 1.

GPR data were processed to enhance reflector patterns and (or) to filter out noise in the data. Digital filtering, distance normalization, deconvolution, and amplification were used to process the data. These processes, as performed using commercial computer software, are described in manual MN43-116 for RADAN for Windows (Geophysical Survey Systems, Inc. 1994). The radar data were not migrated to correct the position of steeply dipping layers; this could lead to slight differences in the true position of a reflector for steeply dipping sections. Differences of this nature are likely to be rare because of the horizontal nature of the layers profiled.

Generally, ice thickness at the site was less than 1 ft and thus was ignored in determining depths to subsurface reflectors. Interpretation of GPR profiles, which includes water, organic materials, and saturated sediment, requires the use of multiple-depth scales. For any radar frequency, the primary factor limiting depth of penetration is the electrical conductivity of the subsurface materials (Beres and Haeni, 1991); however, high frequencies are attenuated faster than low frequencies. Electrically conductive materials, such as clay minerals or possibly a conductive contaminant plume, limit radar-signal penetration.

## Terrain Conductivity

A Geonics EM31 and a EM34 were used to measure terrain conductivity at grid points in the wetland and in selected sites on the pond. These instruments measure the apparent electrical conductivity of the earth materials and pore water in millisiemens per meter. The apparent terrain conductivity includes the electromagnetic effects of both the sediments and associated pore water. Data were collected with the EM31 at the ground surface in the wetland, at 100-ft intervals, for an effective exploration depth of about 20 ft. On the pond, terrain-conductivity data were collected using an EM34, with a 10-m intercoil spacing and vertical dipole mode, to provide a total effective penetration depth of about 50 ft. In the pond, the water depth and the thickness of sediments required greater survey penetration than could be provided by the EM31. The EM34 could not be used in most of the wetland area because of the dense vegetation.

**Table 1.** Approximate ground-penetrating radar velocity for selected materials

| Material | Approximate velocity, in feet per nanosecond |
|---|---|
| Ice | 0.25 |
| Water | .11 |
| Organic soils | .13 |
| Peats | .13 |
| Saturated sands | .20 |

Terrain-conductivity data must be interpreted in conjunction with other data so that the variability of the geology can be differentiated from variations in the conductance of the ground water. Maps of the depth to sand, thickness of organic materials, and the contaminant-plume area previously identified beneath the pond (Mack, 1995), provide the information necessary to interpret the terrain-conductivity data and further delineate and refine the location of the contaminant plume. The nature of the glacial sediments, primarily sand and gravel, show negligible variation at the site, and therefore, do not affect the terrain conductivity. The extent of glacial till in the study area is not known but is not believed to be extensive and is presumed to have almost no effect on terrain conductivity.

The terrain conductivity at this site, or the combined effect of all materials identified in the survey depth of the meter, is determined by variations in the depth of the water column in the pond, the thickness of stratigraphic units, and the quality of ground water. Ground water associated with the contaminant plume beneath the pond was found to have a high specific conductance, up to 950 µS/cm, whereas uncontaminated ground water outside the plume area had a much lower specific conductance of 71 µS/cm (Mack, 1995). Uncontaminated sand and gravel aquifer materials, typical of the study area, have low terrain conductivities. The terrain-conductivity values of the wetland sediments were relatively low (less than 4 mS/m) in areas known to be uncontaminated and at a nearby wetland. Observations of the GPR profiles indicate that the electromagnetic-radar wave penetrate these sediments with little attenuation.

## RESULTS OF GEOPHYSICAL SURVEYS

The results of the geophysical surveys presented in this section include selected GPR profiles, maps of the thickness of the organic layer, elevation of the sand surface, and a contoured terrain-conductivity data.

### Ground-Penetrating Radar

GPR data were collected over a total distance of more than 2 mi within the study area. The data-collection areas and the locations of selected profiles are shown in figure 2. Radar-signal-penetration depths were limited to about 500 to 600 ns throughout the study area. The water table was equivalent to land surface in wetland and pond areas surveyed. The surveys done on the pond were done on ice that was generally less than 0.5 ft thick with little to no snow cover.

Lithologic information obtained from drilling logs (Mack, 1995; Stekl, 1994) and from probes pushed into the wetland (Goldberg-Zoino and Associates, 1986) was used to help interpret GPR profiles. Electromagnetic reflectors could be present, for example, at a water-column—organic-material interface, at an organic material—sand interface, at a coarse to fine-grained interface, or at a bedrock surface. All of these reflectors might be represented as a dark, continuous band on the GPR profile; however, a thin electrically conductive layer, such as a clay lens, also might be represented by a dark band.

Differences between known thicknesses of organic materials at a point (Mack, 1995; Stekl, 1994) and time of travel of radar energy in the same materials near the same point are summarized in table 2. The average velocity of radar energy computed from this data compares well with approximate velocities for organic materials and peats (wetland materials) in table 1. Ulriksen (1980) reports an average velocity for radar energy in peat as 0.131 ft/ns (0.04 m/ns). Individual values are variable and are probably the result of variability in the accuracy of the locations of the well and GPR data.

**Table 2.** Computed ground-penetrating-radar propagation velocities for organic soils near selected wells or borings in Country Pond, Kingston, New Hampshire

[GPR, ground-penetrating radar]

| Well or boring | Thickness of organic material, in feet | Two-way travel time, in nano-seconds | GPR propagation velocity, in feet per nanosecond |
|---|---|---|---|
| [1]AB1-93 | 2 | 45 | 0.089 |
| [2]GZ-6 | 5 | 140 | .071 |
| [2]A3-91 | 5 | 110 | .091 |
| [2]A3-88 | 32 | 275 | .233 |
| [1]B2-93 | 15 | 169 | .178 |
| [1]B3-93 | 29 | 486 | .119 |
| [1]C2-93 | 10 | 187 | .107 |
| | | | **Average: .127** |

[1]Well location in Mack (1995, table 1, fig. 3).
[2]Well location in Stekl (1994, fig. 2).

Two distinct reflector signatures are evident on the profiles. The first signature type is a thin, continuous, and primarily horizontal line pattern that represents soft organic deposits beneath the pond and in the wetland area (figs. 3 and 4). The second signature type is a strong, two- to three-band reflector that is generally found beneath the first reflector, except where the organic layer is absent. This reflector represents the hard sand surface. The profiles illustrate the two types of reflectors commonly found in the study area. These profiles and associated reflectors are described in the following paragraphs. Test-boring data were used where available to aid in interpreting the data; some uncertainty, however, is always inherent in visual interpretations of GPR data.

Profile 3a-3a' was surveyed at the pond ice surface (fig. 3). The upper surface of the record shows multiple reflections from the ice surface and a lack of reflections within the water column. A strong, flat-lying, continuous reflector is present in the upper third of the record with mostly parallel, relatively unattentuated reflectors below. This represents loose organic deposits at the pond bottom above the irregular sand surface. The irregular, sloping strong reflector below the organic deposits indicates the top of the sand surface. Most GPR signals were attenuated by this reflector surface. In only a few profiles, reflectors deeper than the top of the sand surface are found indicating the sand stratigraphy. Till or bedrock surfaces were not apparent in any of the GPR profiles collected.

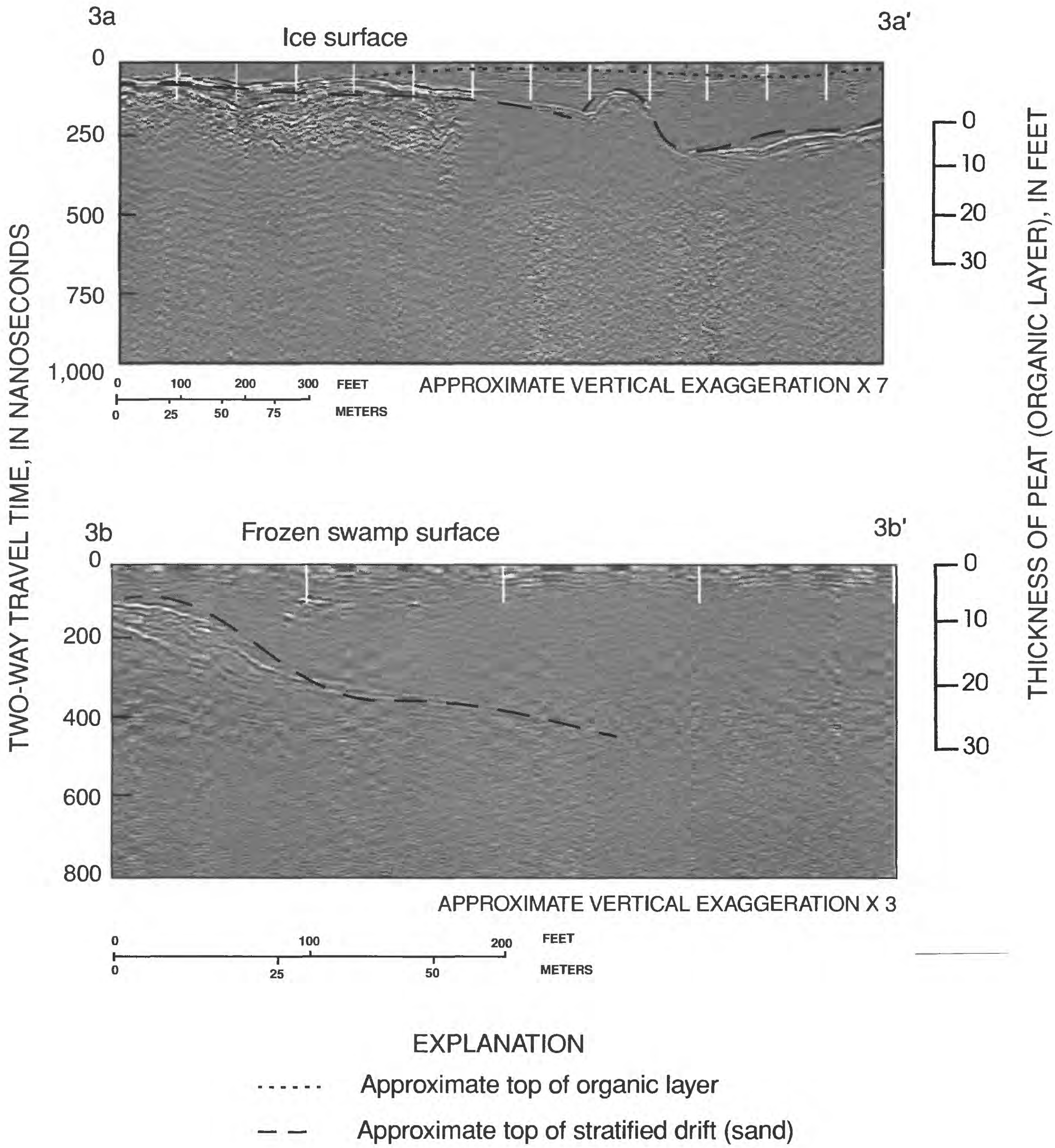



**Figure 3.** Processed ground-penetrating-radar profiles 3a-3a' and 3b-3b', Kingston, New Hampshire.

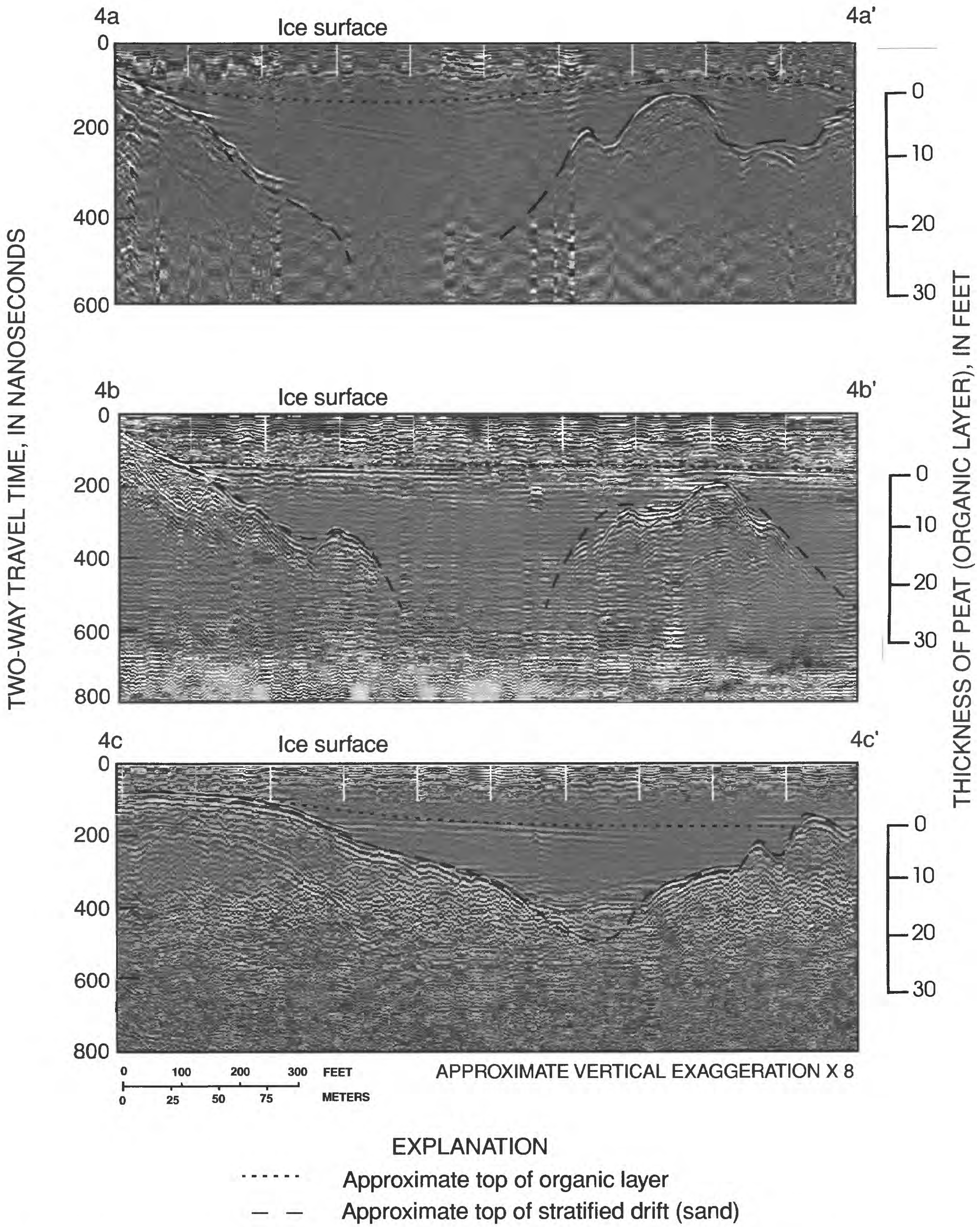



**Figure 4.** Processed ground-penetrating-radar profiles 4a-4a', 4b-4b', and 4c-4c', Kingston, New Hampshire.

Profile 3b-3b' was collected on the wetland adjacent to the pond (fig. 3). In the wetland, the organic surface and the water table are at the land surface. The strong reflector located one third of the distance below the top of the record represents the sand surface. Similar to sand-surface reflections beneath the pond, this layer attenuated most of the GPR signal and prevented detection of deeper reflectors. The sand-surface reflector is prominent and continuous on the left side of the record but is absent on the right side of the record. A sequence of parallel pond profiles (4a-4a', 4b-4b', and 4c-4c', fig. 2 and fig. 4) in succession, from the edge of the wetland out into the pond, shows a continuous buried sand ridge that extends from the southern part of the wetland out into the pond. It also shows the thick organic sediments that have accumulated between the northern shore of the pond and the buried sand ridge (fig. 4).

Figure 5 shows a map of the organic layer surface (pond bottom) generated from GPR data in the pond, and from GPR and previously collected probe data in the wetland. In general, the organic-layer surface slopes uniformly from the shore to the center of the northwestern arm of the pond and is deepest near the center of the northwestern arm. The organic surface is absent in a few small locations in the area surveyed. The greatest depth to the organic surface is approximately 12 ft below the pond surface.

A contour map of the sand surface also was generated from GPR and probe data. This surface is characterized by irregular topography consisting of depressions and ridges (fig. 6). Organic sediments fill the depressions. Two continuous sand ridges are present in the study area beneath the pond (fig. 6). One is along the boundary between the wetland and the pond, and the second protrudes out into the pond from the south end of the wetland. Two smaller ridges between depressions are present at the west end of the swamp, near the road.

The thickness of the organic layer (fig. 7) was determined by taking the difference of the top of the organic layer (fig. 5) (including the wetland surface) and the surface of the underlying sand surface (fig. 6). Organic-layer thicknesses of 30 to 35 ft are evident in the study area. An isolated, 35 ft thick organic-filled, depression (fig. 7, location a) is located at the mouth of North Brook (fig. 1) beneath Country Pond. A more extensive, 20 to 30 ft thick organic filled area (fig. 7, location b), extends from the edge of the center of the wetland out beneath Country Pond. Another broad area of thick organic sediments beneath the pond is in the south part of the study area (fig. 7, location c). A broad area of thick organic sediments beneath the wetland is at the center of the wetland 250 to 750 ft from the shoreline (fig. 7, location d). The organic layer is relatively thin (10 ft) at the wetland shore line (fig. 7, location e), and not present at some areas along the northern shore of Country Pond and to the south of the study area associated with a large, unnamed island (figs. 1 and 7).

## Terrain Conductivity

Terrain conductivity values ranged from 1 to 3 mS/m, over sand and gravel sediments at the shore of Country Pond in areas not influenced by the contaminant plume, to 12 to 20 mS/m in areas thought to be influenced by a contaminant plume. Terrain-conductivity data points and values (fig. 8) are shown as interpolated contour images of conductivity in figure 9. Anomalies are generally the result of changes in overburden type and thickness, or changes in water quality (electrically conductive contaminant plumes). In order to distinguish between contaminant anomalies and the anomalies that are the result of changes in the geology—most notably depth of water and organic material over the irregular sand surface—the sand-surface contours (from fig. 6) are plotted on the terrain-conductivity image (fig. 9).

Because the penetration depth of the terrain-conductivity survey (EM34) in the pond, to the east, is greater than that in the wetland (EM31), to the west, the terrain-conductivity data and resulting conductivity maps are presented in separate parts on figures 8 and 9. The EM31-survey data extend into the pond several hundred feet. This overlap of the EM34-survey data allows for a comparison of the data sets. The values of conductivity from each survey were comparable at the transition from the EM31 to the EM34 survey although the overall depth intervals sensed by the instruments are different. At the survey transition, the range of the data from the EM-31 survey was 1.8 to 19.5 mS/m, and the range of the data from the EM-34 survey was 0.2 to 13 mS/m.

In some areas, high terrain conductivities coincide with thick organic deposits and (or) large depressions in the sand surface (fig. 7, location a; fig. 9a). These conductivities could be elevated because of the greater water content, or porosity, of

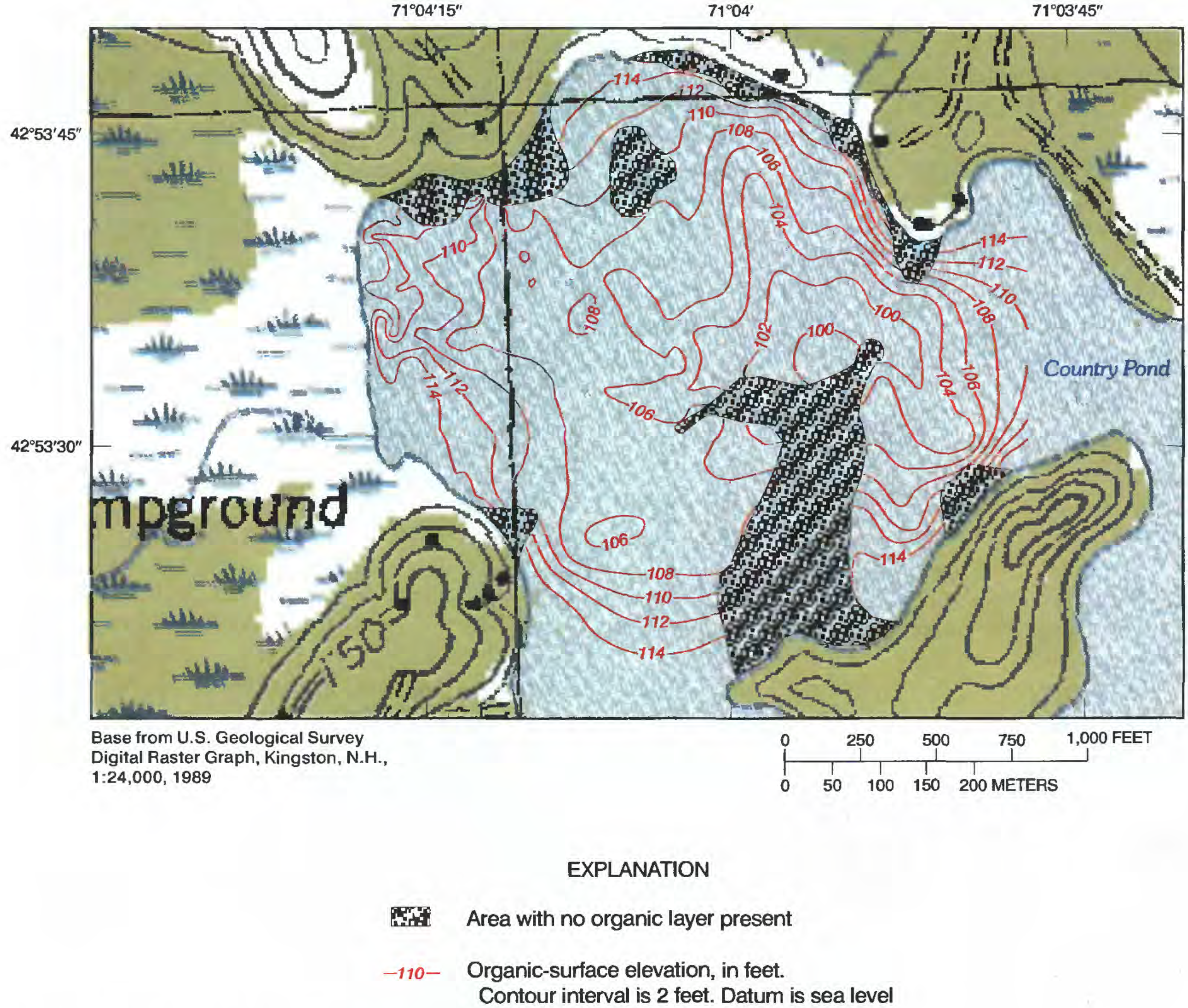
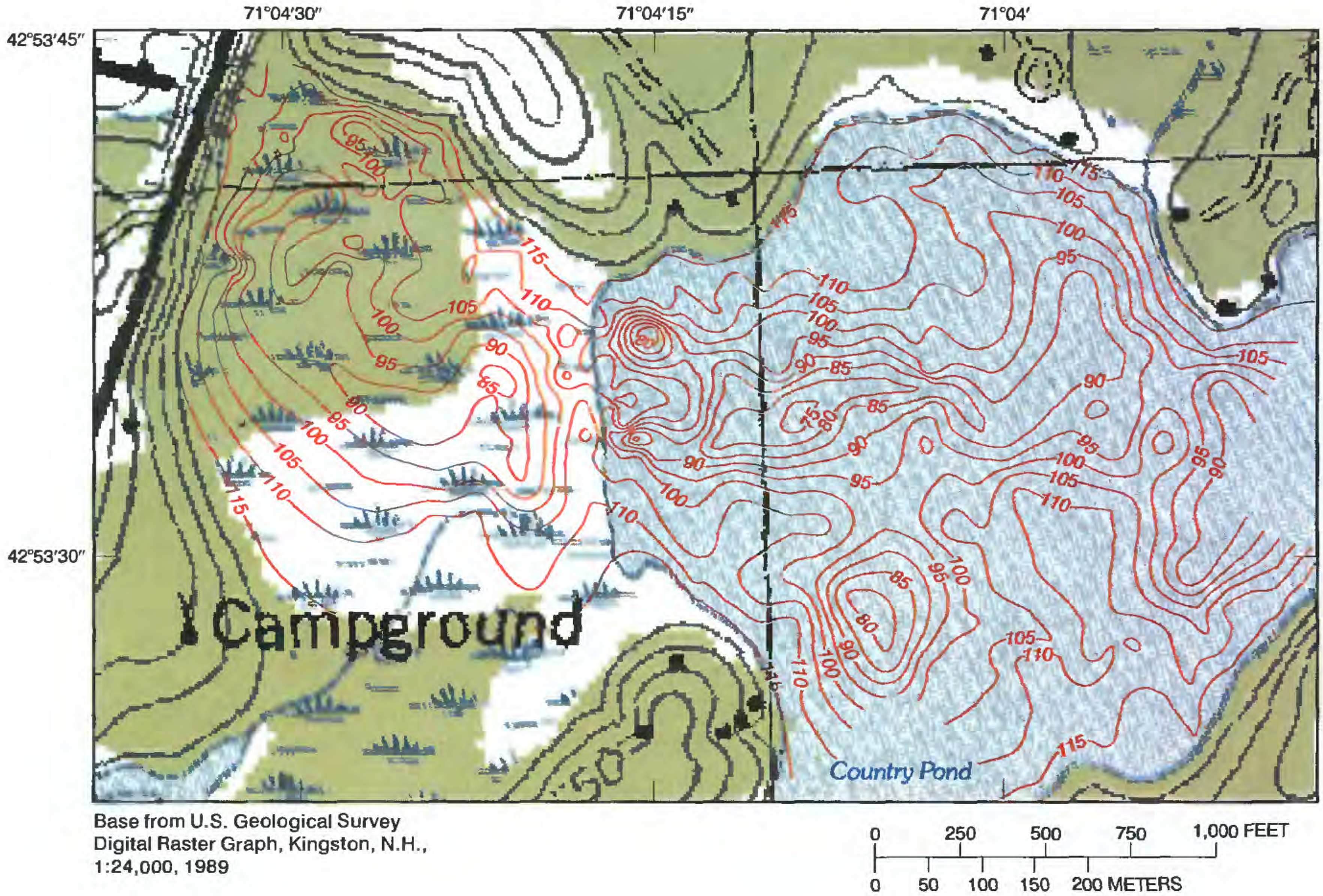



**Figure 5.** Elevation of organic sediments in Country Pond, Kingston, New Hampshire.

the organic sediments than that of sand sediments. Organic thickness, however, apparently does not dominate the conductivity measurement. Some areas of thick organic deposits (fig. 7, location c; fig. 9b) did not coincide with elevated conductivities.

The elevated terrain conductivity at the area of thick organic sediments in the wetland is an anomaly that coincides, in part, with an area of thick organic sediments (fig. 7, location d; fig. 9a). The effective penetration of the EM31 survey in this area is most likely limited to the organic sediments and not the underlying glacial-outwash sediments. Monitoring-well data, from the underlying highly transmissive stratified downgradient of this location, did not show elevated concentrations of contaminants near location d (Mack, 1995, table 4). This well data further indicates that the elevated conductivity is not likely to be from the underlying glacial aquifer. It is possible that the former contaminant plume, which was more than an order of magnitude more concentrated 10 years ago, diffused into and (or) through the organic sediments. Some electrically conductive ions remain in the organic sediments, causing the apparent electrical-conductivity anomaly.




EXPLANATION

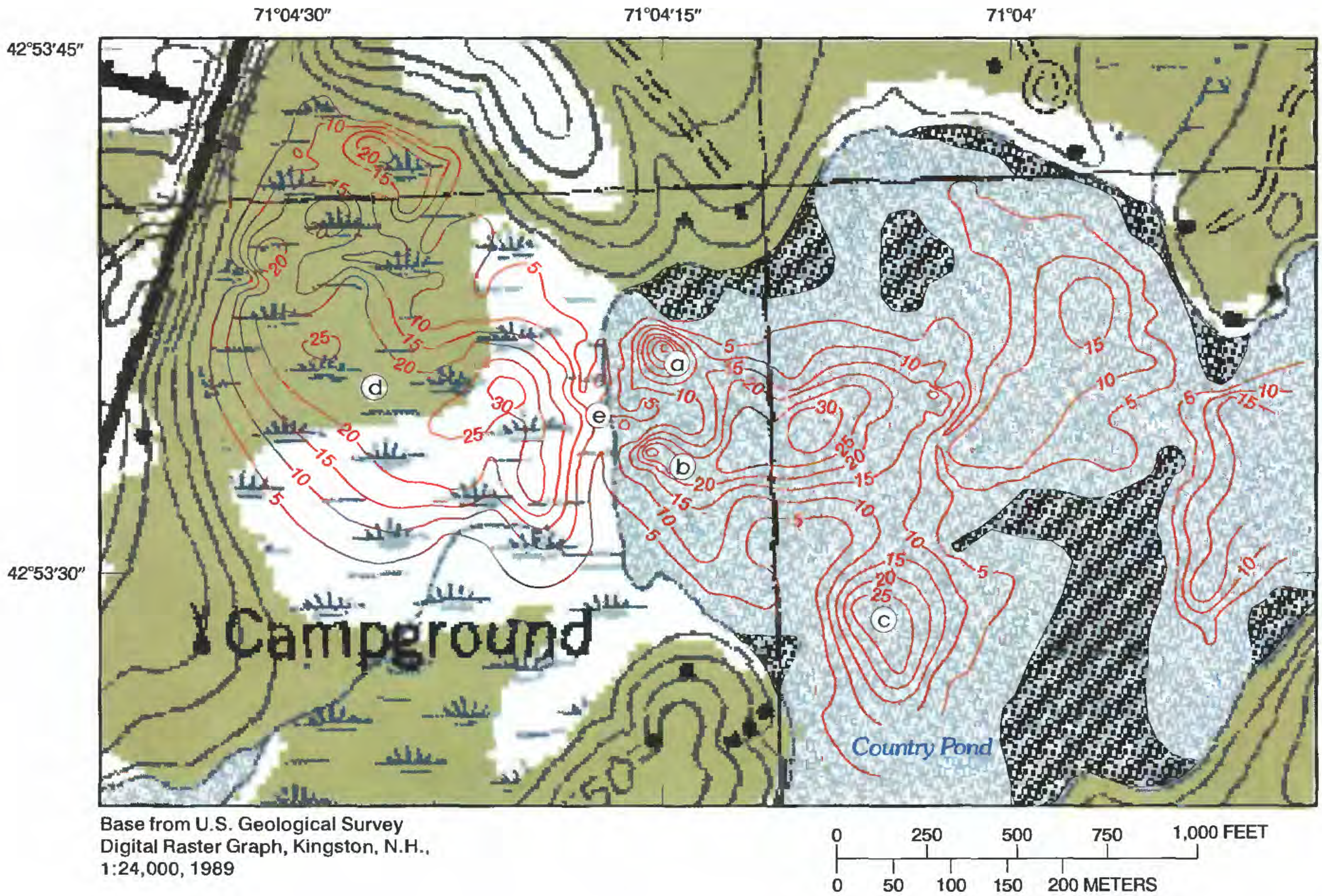
—100— Elevation of stratified drift (sand), in feet. Contour interval is 5 feet. Datum is sea level

**Figure 6.** Elevation of stratified (sand) drift in Country Pond and adjacent wetland, Kingston, New Hampshire.

Another possible explanation is that elevated concentrations of chloride, from road de-icing, could be moving with ground water through the wetland to the pond and diffusing into the organic sediments. The organic sediments in this area have a high porosity yet low transmissivity (Stekl, 1994). If road salt, however, was the cause of this anomaly (fig. 7, location d), this source of conductivity is present each winter and a large area of the wetland would more likely show high conductivities.

Two other areas show elevated conductivities where the glacial outwash aquifer is close to the surface and, therefore, distinctly not correlated with water-column or organic-layer thickness. One area was near North Brook, along the northern edge of the wetland, where terrain conductivities greater than 12 mS/m were measured with the EM31. The other area was at the wetland and pond boundary. These anomalies are somewhat continuous, yet fade in a northwesterly direction along the likely flowpath from the former contaminant source (fig. 1). The downgradient area coincides with the locations of the plume determined from monitoring wells in the aquifer beneath the pond (Mack, 1995, fig. 7) and could represent an electrically conductive component or remnant of a contaminant plume.

Areas where the low-transmissivity organic sediments are not present in the pond (fig. 7) are of




EXPLANATION

Area with no organic layer present

—10— Thickness of organic layer, in feet. Contour interval is 5 feet. Datum is sea level

Ⓒ Location referred to in text

**Figure 7.** Thickness of organic sediments in Country Pond and adjacent wetland, Kingston, New Hampshire.

concern because of the potential for increased ground-water discharge to the pond in these areas. Terrain conductivities in these areas, however, were generally at background levels, indicating that conductive contaminants were not discharging in these areas or were below detectable concentrations at the time of this survey.

## Monitoring-Well Network

Several monitoring wells present in the wetland are near the apparent contaminant-plume centerline. The length and depth of the screened zones of these monitoring wells, installed in the early 1980's, are not accurately known. Monitoring wells (piezometers) described by Mack (1995) are present beneath the pond near the wetland. These monitoring wells are accessed by sample tubing extended from 100 to 200 ft into the pond to the shoreline. The sub-pond wells are suitable ground-water-sample points but highly vulnerable to damage. Some of these wells have been lost or destroyed, and at the conclusion of this study only 5 of the 10 sub-pond network wells were still usable.

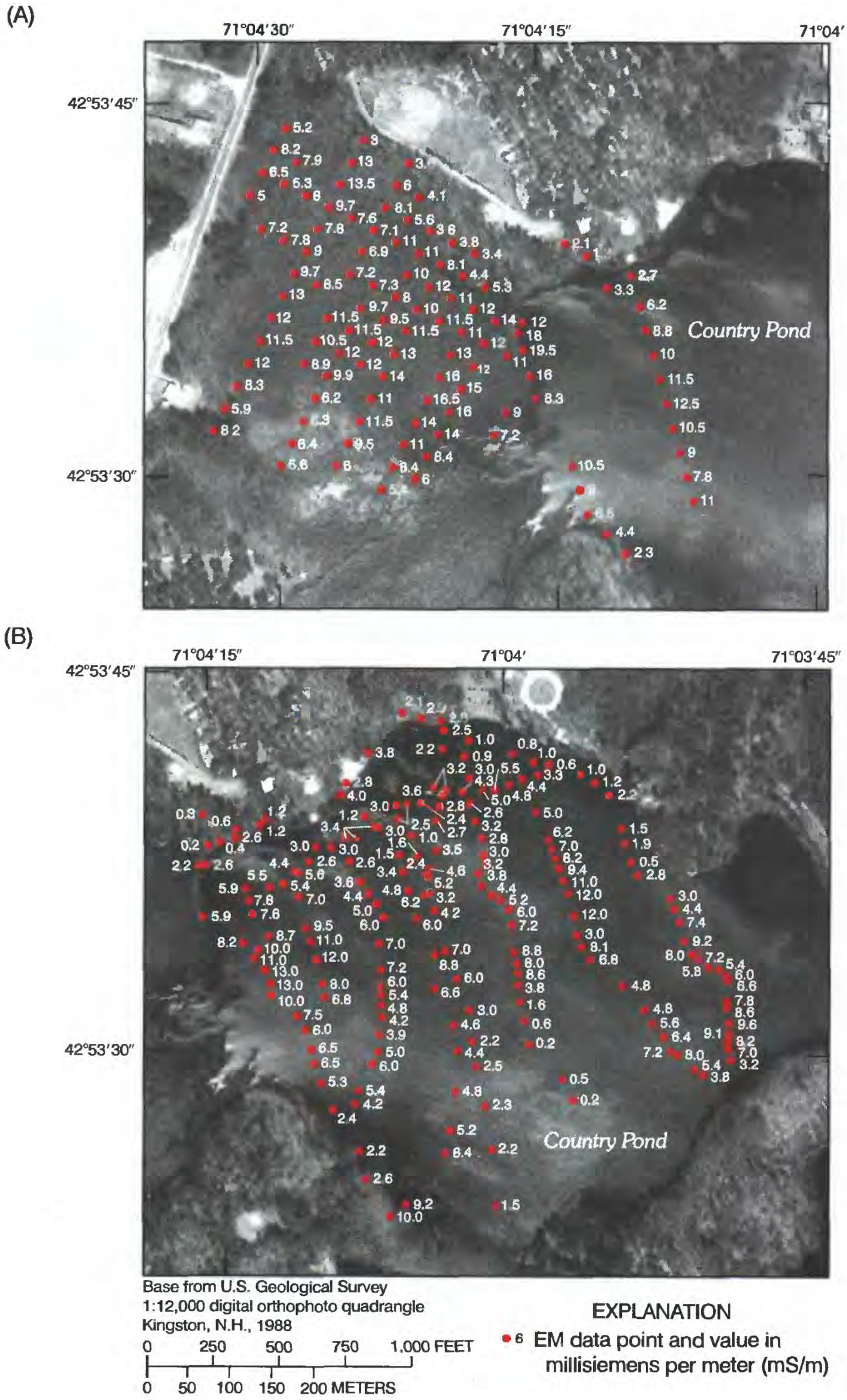



**Figure 8.** EM31 (A) and EM34 (B) terrain-conductivity data-collection locations and associated values, in millisiemens per meter (µS/m), in Country Pond and adjacent wetland, Kingston, New Hampshire.

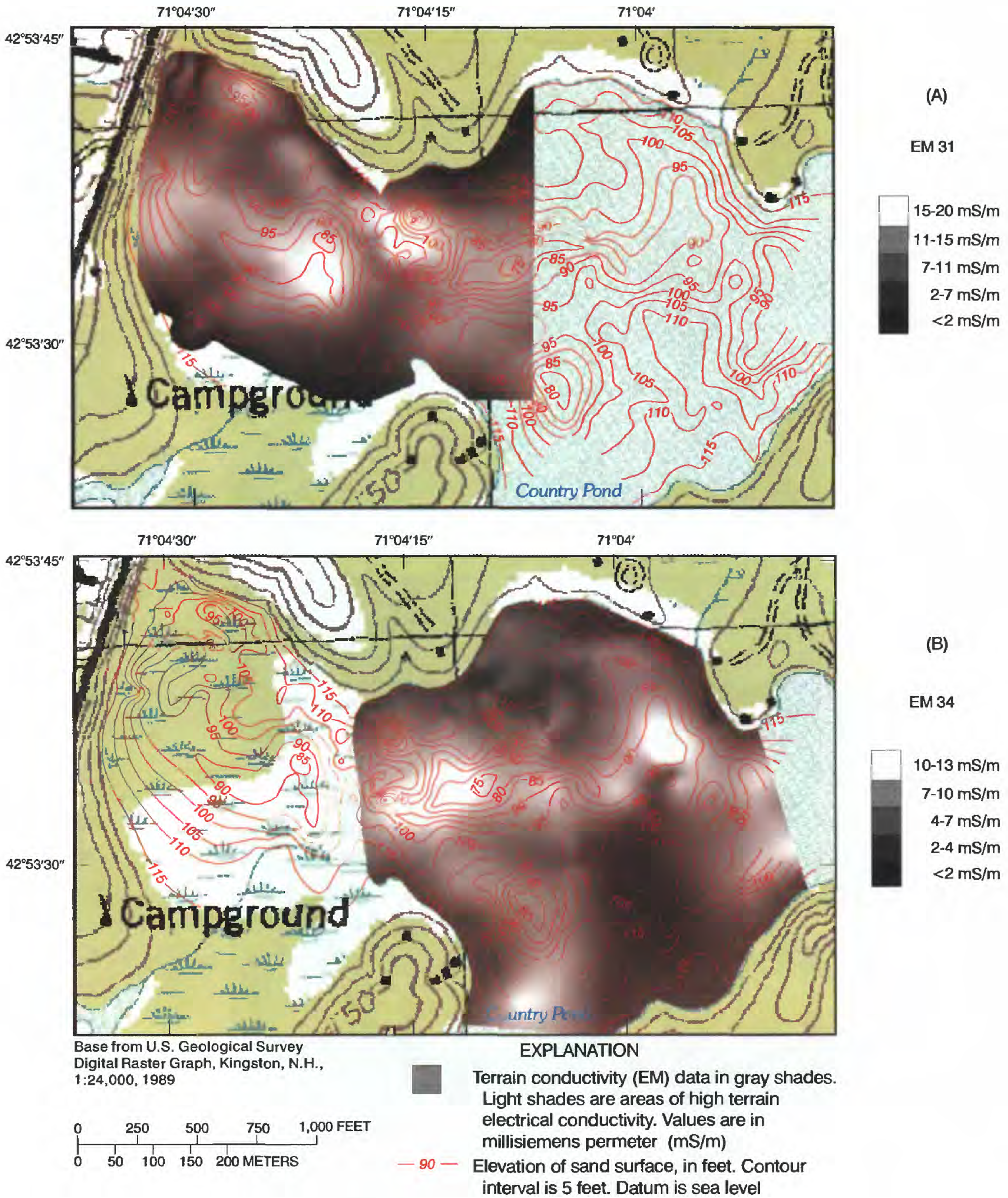



**Figure 9.** Terrain conductivity in an adjacent wetland (A) and Country Pond (B), Kingston, New Hampshire.

The wetland is a topographic low, which generally receives ground water from surrounding upland areas. Discharge from the wetland is naturally channeled towards the pond in the direction of North and South Brook (fig. 1). The conductivity surveys from this study and previous water-quality sampling indicate that a contaminant plume is concentrated along the northern part of the wetland adjacent to, and along, North Brook. Existing monitoring wells are located approximately in the center of this plume and probably in or at the base of the glacial aquifer. Screen lengths of existing monitoring wells in the wetland are not known and could be too long or in the wrong vertical locations to effectively monitor the concentrations of the contaminant plume. The current monitoring wells provide limited longitudinal, and no transverse, coverage of the plume and do not provide information on vertical stratification of the plume. The construction of monitoring wells towards the leading edge of the plume, and beneath the pond, are short screened and well documented (Mack, 1995), but do not assess the leading edge of the plume beneath the pond. Maintaining monitoring wells in the pond to address the leading edge of the plume, however, would not be feasible as the wells are in an area of considerable boat traffic.

A well network to effectively monitor the concentration of contaminants in this plume could be constructed by establishing sampling points that bisect the axis of the plume at multiple depths. This network would create a vertical "plane" of sampling points at a point where most of the ground-water fluxes would occur from the wetland to the pond through the underlying outwash aquifer. Such a network would provide measurements of the direction and vertical gradient of ground-water flow at the wetland and pond interface and would permit sampling of the contaminant plume and uncontaminated background water. If located immediately shoreward of the wetland-pond boundary, the wells could be protected and maintained for a long period of time. Such a network, sampled at regular intervals with consistent methods, would allow for monitoring of the concentration of the plume or evaluating the natural attenuation of contaminants (U.S. Environmental Protection Agency, 1998).

## SUMMARY AND CONCLUSIONS

Contaminants from a former hazardous-waste site are moving downgradient though a wetland and beneath Country Pond at Kingston, New Hampshire. Geophysical profiles and data provide information about the various lithologies and the position of the electrically conductive part of this contaminant plume. Contour maps of the elevations of surfaces of various lithologies indicate that the sand surface beneath the relatively flat organic sediment surface is highly irregular. Terrain-conductivity data identify several anomalies, most of which are related to the thickness of the water column and organic sediments overlying the sand. One notable exception, however, is an elongated anomaly along the northwestern part of the wetland and into the pond, where the anomaly is not related to deep depths of sand. This anomaly is probably indicative of a contaminant plume, moving through the sand unit beneath the wetland and pond. Existing test-boring data confirm the interpretation of the geophysical surveys.

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