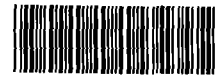# Water Depth and Thickness of Sediment in Reservoirs 1 and 2, Framingham and Ashland, Massachusetts

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U.S. GEOLOGICAL SURVEY

Open-File Report 91-508

Prepared in cooperation with the

U.S. ENVIRONMENTAL PROTECTION AGENCY

WASTE MANAGEMENT DIVISION, REGION I

WATER DEPTH AND THICKNESS OF SEDIMENT IN RESERVOIRS 1 AND 2, FRAMINGHAM AND ASHLAND, MASSACHUSETTS
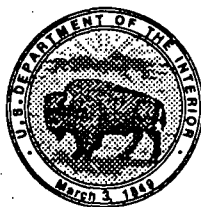
By John A. Izbicki and Gene W. Parker

U.S. GEOLOGICAL SURVEY

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ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
Length		
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi^2)	2.59	square kilometer
Velocity		
foot per nanosecond (ft/ns)	0.3048	meter per nanosecond
Flow		
cubic feet per second (ft^3/s)	0.2832	cubic meter per second

WATER DEPTH AND THICKNESS OF SEDIMENT IN RESERVOIRS 1 AND 2, FRAMINGHAM AND ASHLAND, MASSACHUSETTS

By John A. Izbicki and Gene W. Parker

ABSTRACT

Ground-penetrating radar was used to determine water depth and thickness of sediments in Reservoirs 1 and 2 on the Sudbury River in Framingham and Ashland, Massachusetts. More than 7 miles of ground-penetrating radar profiles were obtained during August 28 to September 1, 1989. Maximun water depth was 13 feet in Reservoir 1 and 18.5 feet in Reservoir 2. The greatest accumulations of sediment were in the northwestern arm of Reservoir 1 and in the southern part of Reservoir 2 near the Sudbury River inlet where sediment thickness was greater than 2 feet. Sediment accumulations were less than 1 foot near the upstream part of the southwestern arm of Reservoir 1 and the downstream part of Reservoir 2. In the remainder of Reservoirs 1 and 2, the sediment thickness was generally 1 to 2 feet. Depth of water and sediment thickness were checked by sounding and penetration measurements along selected profile lines.

INTRODUCTION

The Nyanza Superfund Site is an approximately 62-acre area formerly used for manufacturing and waste disposal in Ashland, Massachusetts. Heavy metals have migrated in ground water from the site to the Sudbury River located approximately 600 ft north of the site (fig. 1) (Pam Shields, U.S. Environmental Protection Agency, written communication, May 16, 1991). The U.S. Environmental Protection Agency (USEPA) is currently conducting a remedial investigation to determine the extent of contamination in the Sudbury River. Mercury from the Nyanza Superfund Site has been found in sediment samples as far as 16 mi downstream in Concord. The USEPA investigation area extends from the Nyanza Site to the confluence with the Assabet River in Concord, Massachusetts. Investigations by the USEPA include sampling of sediment, surface water, and biota within the upstream part of the Sudbury River. Information on depth of water and distribution of sediment in Reservoir 1 and 2 was needed to guide selection of sample locations.

Figure 1.--Location of study area

EXPLANATION

Open water

Town boundaries

Direction of streamflow
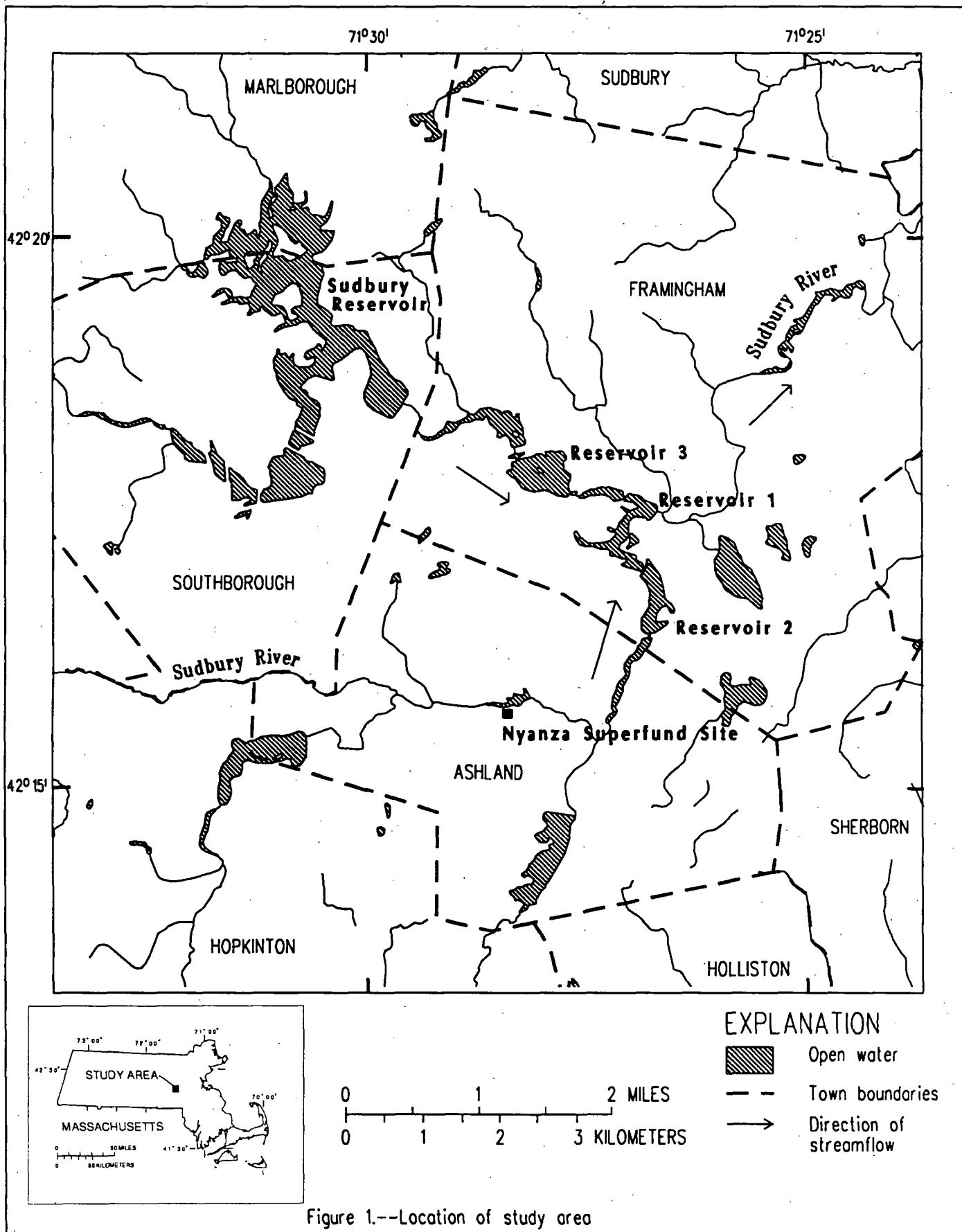
Purpose and Scope

The purpose of this report is to present the results of a reconnaissance study to map water depth and sediment thicknesses in Reservoirs 1 and 2, Framingham and Ashland, Massachusetts. The data obtained from this study will be used to guide selection of bottom-material sampling locations in Reservoirs 1 and 2 as part of USEPA's remediation activities at the Nyanza Superfund Site.

This study included collection and interpretation of ground-penetrating radar (GPR) data for Reservoirs 1 and 2 and verification of selected radar profiles by field measurements of water depth and sediment thickness. The field measurements were made by U. S. Geological Survey personnel from the Massachusetts-Rhode Island District during August 28 to September 1, 1989. Additional water-depth and sediment-thickness data would be necessary if quantitative estimates of reservoir capacity or total sediment volume are desired.

Hydrologic Setting

Reservoirs 1 and 2 were built as water supplies in 1878, and have a surface area of 0.19 and 0.18 mi^2, respectively. The total drainage area for these two reservoirs is 75.2 mi^2. The Sudbury River flows eastward from Ashland into Reservoir 2 and northeastward from Reservoir 2 into the southwestern arm of Reservoir 1 (fig. 1). A tributary, which includes Sudbury Reservoir and Reservoir 3, flows into the northwestern arm of Reservoir 1. The Sudbury River flows out of the northeastern end of Reservoir 1.

The average annual discharge below Reservoir 1 is 118 ft^3/s (U.S. Geological Survey, 1989). Additional flow data are available from the U.S. Geological Survey gaging station at Saxonville, Massachusetts (station number 01098530) located about 4 mi downstream of Reservoir 1. The reservoirs are bounded by unconsolidated glacial till and stratified-drift deposits (Brackley and Hansen, 1985). The Nyanza Superfund Site in Ashland, Massachusetts, is located about 1 mi upstream from Reservoir 2 (fig. 1).

METHODS

Ground penetrating radar was selected for use in this study because it is a versatile system capable of either deep penetration of water and sediments when using a low-frequency antenna or shallow penetration and detailed resolution when using a higher frequency antenna. Radar signals are not affected by aquatic vegetation, and GPR can be used in water depths as shallow as 0.5 feet (Izbicki and others, 1988). Previous studies have shown that radar can be used to determine the thickness of lake sediments (Haeni, and others, 1987) and stream sediments (Izbicki and others, 1988).

Ground penetrating radar systems radiate short pulses of electromagnetic energy from a transmitting antenna. This energy enters the material (in this study, the water column and bottom sediments) and passes through the material until it encounters an interface between materials having different dielectric constants. At this interface, some of the energy is reflected. The greater the difference in dielectric constant between the two materials at the interface, the stronger the reflected energy. The reflected energy is detected by a surface receiver, and the travel time and strength of signal is recorded. Additional electronic equipment records and displays the reflected signal (fig. 2). Graphic records of the reflected energy portray a strong energy signal as a dark-gray or black return and a weaker energy signal as a light-gray return. A water-saturated organic interface would reflect a weaker energy signal than a water-clay interface. As travel time increases, a signal's strength decreases and a lighter gray return is recorded. Some signals may be lost completely during long transits.

The graphic radar record shows the travel time for a signal to pass through the water column and sediment, reflect off an interface, and return to the surface. This two-way travel time is measured in nanoseconds (1×10^{-9} seconds). Travel time can be converted to thickness of material, if the dielectric constant of the material is known, using the following formula:

$$d = V_m(t/2) \tag{1}$$

where: $V_m = c/(E_r)^{1/2}$ (2)

       d is the thickness of material, in feet;
       t is the two-way travel time, in nanoseconds;
       V_m is the radar wave velocity, in feet per nanosecond;
       c is the speed of light in free space, in feet per nanosecond (0.9835712 ft/ns); and
       E_r is the dielectric constant of the material (a dimensionless ratio).

The dielectric constants and velocities of radar waves, and approximate conductivities of selected materials are given in table 1.

Radar-signal penetration depends on the electrical conductivity of the materials encountered (Olhoeft, 1984) and the frequency of the radar signal (Izbicki and others, 1988). In general, radar signals will penetrate low-conductivity (resistive) earth materials to greater depths than conductive (low-resistivity) materials, depth of penetration increases with decreasing signal frequency, and resolution increases with increasing signal frequency. On the basis of curves developed by Olhoeft (1984), the penetration of a 300-megahertz (Mhz) radar wave in a column of freshwater is about 32 ft.

Another factor that affects the depth of penetration is the instrument range or maximum length of "listening" time between signal transmission and reception. A commercial GPR system with a 300-Mhz frequency antenna was used to profile the water depth and thickness of sediments in Reservoirs 1 and 2. This system had a maximum range of about 380 nanoseconds. For a radar wave velocity of of 0.11 ft/ns for freshwater (table 1), from equation 1, the maximum depth of water through which the GPR system could detect a reflecting surface is 20.9 ft. Therefore, the system range, rather than the penetration of the radar wave, was the factor limiting water-depth measurements.

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POWER SUPPLY

TAPE RECORDER

GRAPHIC RECORDER

PULSE TRANSMITTER

RECEIVER

TRANSMIT-RECEIVE SELECTOR

WATER SURFACE

RAFT

ANTENNA

TRANSMITTED PULSE

REFLECTED PULSE

REFLECTING SURFACE

WATER BOTTOM

FIRST STRATA   SOFT SEDIMENTS

SECOND STRATA SOFT SEDIMENTS

HARD SEDIMENTS

NOT TO SCALE
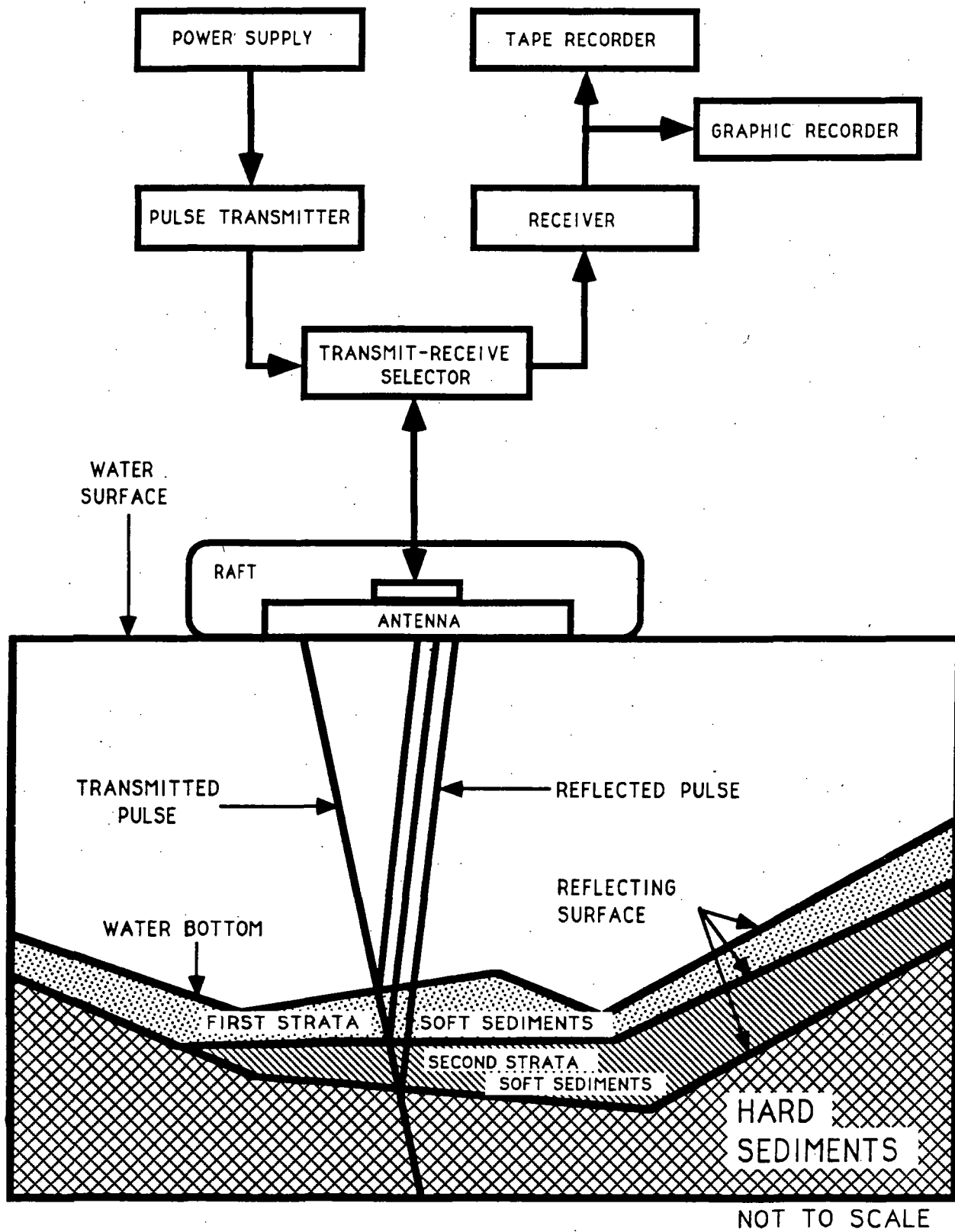
Figure 2.--Ground-penetrating radar system.

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Table 1.--*Electromagnetic properties and velocity of radarwaves in selected earth materials, from Markt (1988)*

[ft/ns, feet per nanosecond; mho/m, mho per meter]

Materials	approximate dielectric constant	Radarwave velocity (ft/ns)	Approximate conductivity (mho/m)
Air	1	0.98	0
Limestone	7	.37	10E-9
Granite (dry)	5	.44	10E-8
Sand (dry)	4 to 6	~ .44	10E-7 to 10E-3
Bedded salt	3 to 6	~ .46	10E-5 to 10E-4
Freshwater ice	4	.49	10E-5 to 10E-3
Permafrost	4 to 8	~ .40	10E-4 to 10E-2
Sand, saturated	30 to 50	~ .16	10E-4 to 10E-2
Freshwater	81	.11	10E-4 to 3 X 10E-2
Silt, saturated	10	.31	10E-3 to 10E-2
Rich agricultural	15	.25	10E-2
Clay, saturated	8 to 12	~ .31	10E-2 to 1
Sea water	81	.11	4

The GPR equipment was mounted in an inflatable raft, and the antenna (also in an inflatable raft) was towed alongside. Approximately 7 mi of radar profile lines were run. Location of profiles were determined using identifiable features on the lake shore and triangulation procedures (figs. 3 and 4). Although every effort was made to tow the antenna at a uniform speed, some variation in speed was unavoidable because of changing wind conditions and water currents. As a result, the interval and scale on the horizontal axis (distance) of the radar profiles are variable, but the control points allow for location of features on the profile.

The graphical field radar records were interpreted first by identifying soft sediments as a light-gray return and the underlining hard sediments as a dark-gray return (figs. 5 and 6). Then, from velocities and travel times calculated from dielectric constants reported in a previous study by Markt (1988) (table 1), the water depth and soft-sediment thickness were determined.

During data analysis, it was assumed that the radar wave velocity for soft sediments is similar to that of peat, and that the radar velocity is constant for soft sediments throughout the lake (Haeni and others, 1987). The exact nature of the sediments in Reservoirs 1 and 2 were not verified because of safety concerns associated with sampling and handling of sediments (Alan Klinger, U.S. Environmental Protection Agency, oral commun., September 1989). The radar velocities determined from eqs. 1 and 2 were 0.13 ft/ns for soft sediments.

- Water-depth and sediment-penetration measurements were made on October 4, 1989, along four selected radar profile lines for comparison to interpreted data. Two of these profile lines are shown in figures 5 and 6. Water depths were determined by sounding with a calibrated 2-in. inside-diameter plastic pipe at selected intervals along a tag line stretched across a section of the resevoir close to a radar profile line. Sediment thickness was determined by driving the pipe into the bottom sediments at each location sounded. Measurements were obtained from two sounding lines on each reservoir as shown in figures 7 and 8. Water depths and sediment thicknesses from the soundings and penetration measurements were compared to GPR surveys for 43 locations. Most interpreted radar-measured values were within 1 ft of the measured water depth and sediment thickness. The outliers beyond the ±1-ft agreement lines in figures 7 and 8 may result from not being able to relocate radar profile lines exactly. For reconnaissance purposes, a ±1-ft error in sediment thickness is considered acceptable for determining the location of sediment deposits having thicknesses greater than 2 ft.

WATER DEPTH AND THICKNESS OF SEDIMENTS

The results of the water-depth surveys are summarized by hand-drawn contour lines in figures 9 and 10. Maximum water depth in Reservoir 1 was approximately 13 ft. Maximum water depth in Reservoir 2 was 18.5 ft near the dam at the northern end of the reservoir. The streambed of the Sudbury River prior to impoundment is clearly visible by following the line of maximum depth from the inlet to Reservoir 2 along the Sudbury River and from the tributary inlet to the northwestern arm of Reservoir 1 to the outlet dam for Reservoir 1.

EXPLANATION

Open Water

Radar profile line

A ——————— A′ Radar profile line A–A′

Direction of streamflow

Reservoir 3

Sudbury River

FRAMINGHAM

71°27′

42°17′30″

71°27′30″

42°16′

Reservoir 2

A

A′

Direction of streamflow

0		1000		2000 FEET
0	250		500 METERS	
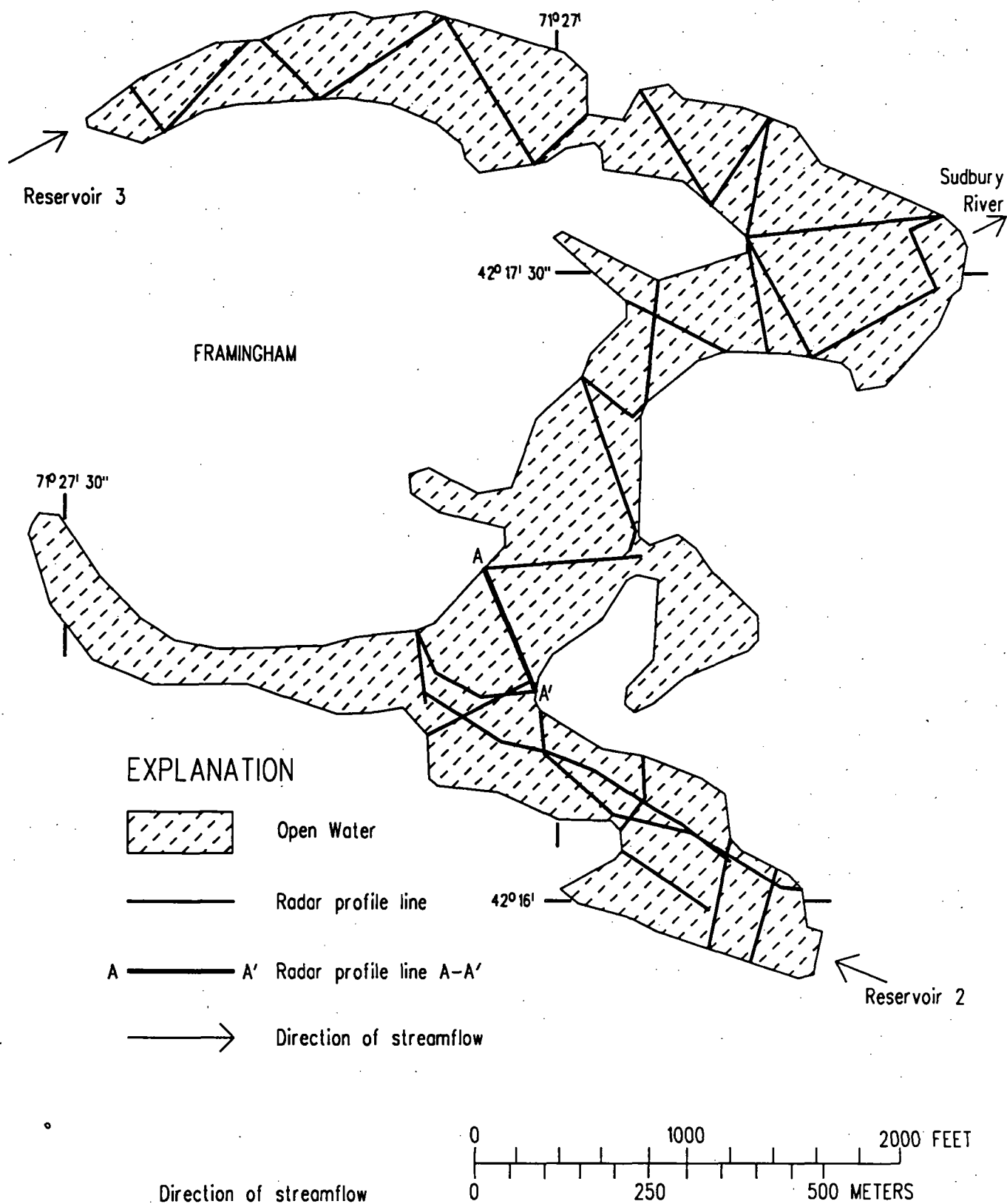
Figure 3.--Location of radar profile lines in Reservoir 1, Framingham, Massachusetts, 1989
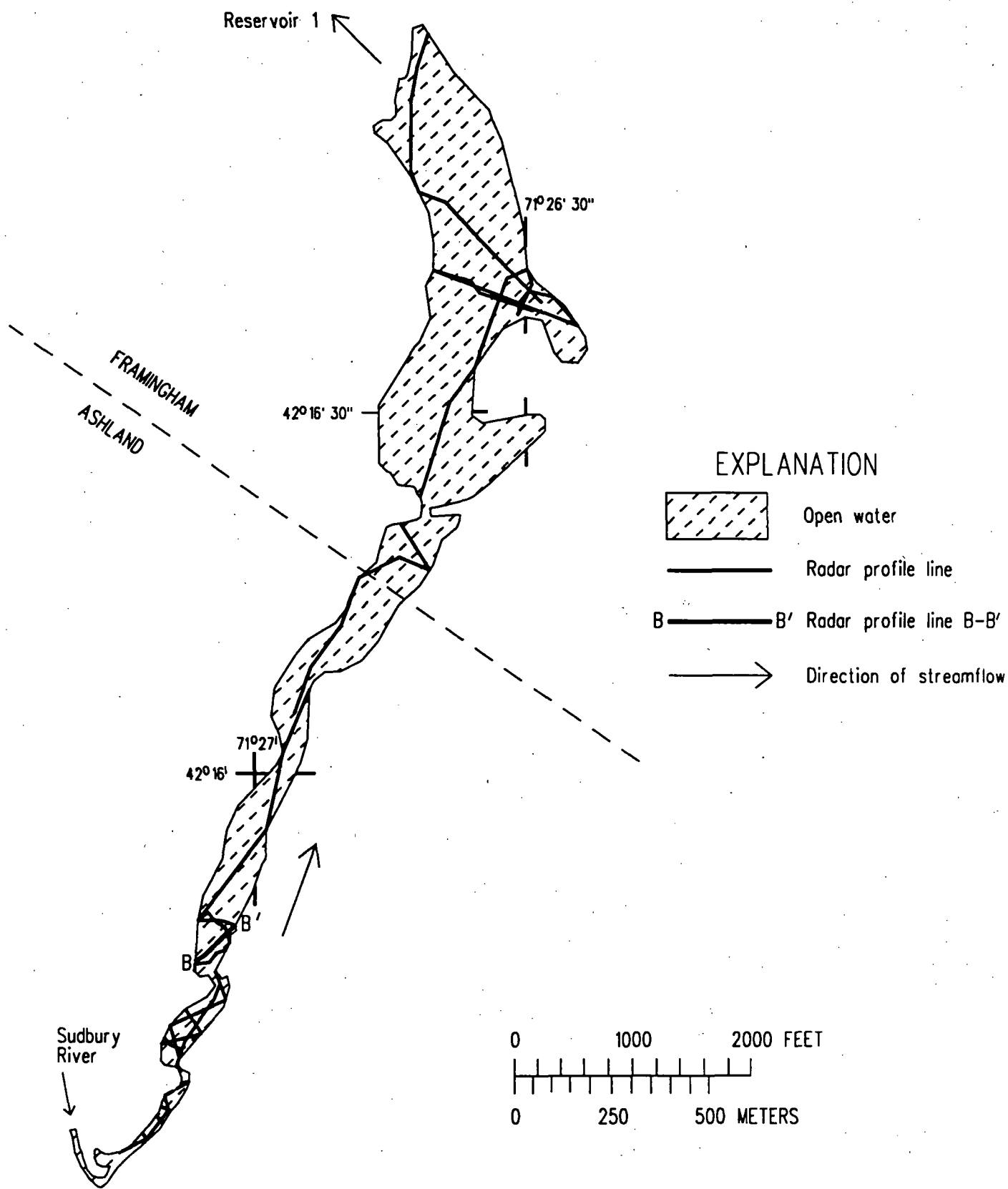
Figure 4.—Location of radar profile lines in Reservoir 2, Framingham and Ashland, Massachusetts, 1989

EXPLANATION

Open water

Radar profile line

B——————B' Radar profile line B-B'

Direction of streamflow

Reservoir 1

FRAMINGHAM

ASHLAND

71°26' 30"

42°16' 30"

71°27'

42°16'

B'

B

Sudbury
River

0   1000   2000 FEET

0   250   500 METERS

9

RADAR RECORD

A   A'

INTERPRETED PROFILE

WATER SURFACE

FIRST STRATA
SOFT SEDIMENTS

WATER BOTTOM

SECOND STRATA
SOFT SEDIMENT

HARD SEDIMENTS

ONE-WAY TRAVEL TIME, IN NANOSECONDS

DEPTH BELOW WATER SURFACE, IN FEET

THICKNESS OF SATURATED SEDIMENTS, IN FEET

PENETRATION MEASUREMENT

DEPTH BELOW WATER SURFACE, IN FEET

DISTANCE FROM NORTHERN SHORE, IN FEET (NONUNIFORM SCALE)

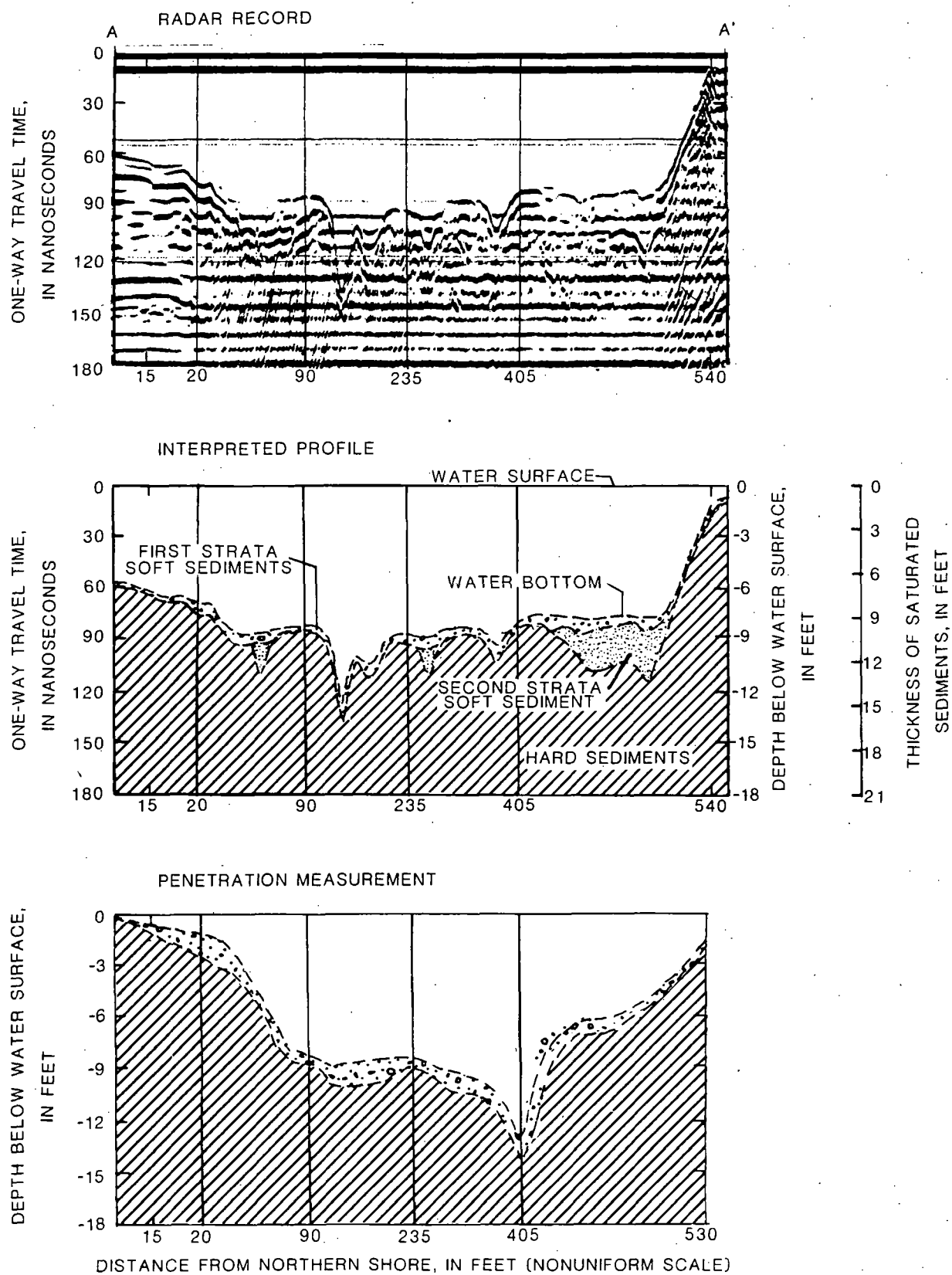Figure 5.–Field radar record, interpreted profile line, and penetration measurements for profile line A-A' in Reservoir 1, Framingham, Massachusetts, 1989.
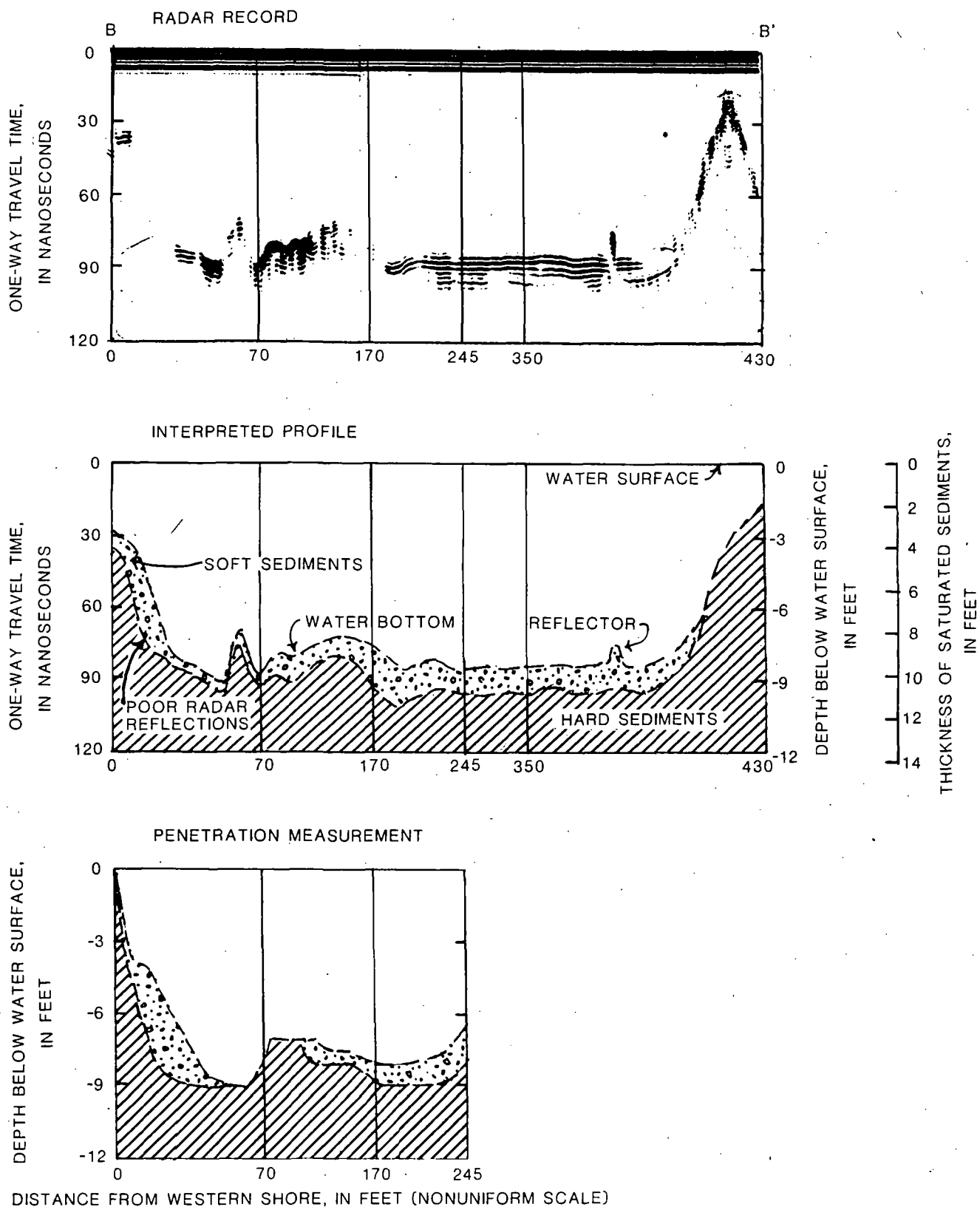
10

Figure 6.–Field radar record, interpreted profile line, and penetration measurements for profile line B-B' in Reservoir 2, Framingham and Ashland, Massachusetts, 1989.
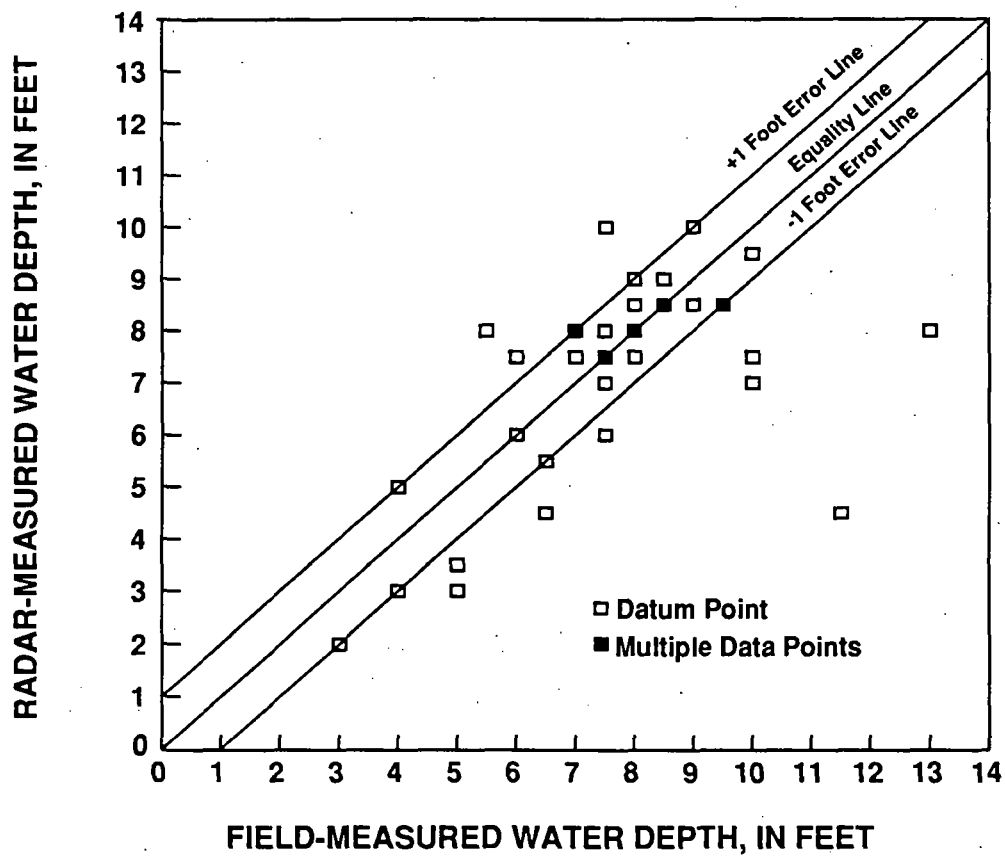
11

Figure 7.--Comparisons of water depths using ground-penetrating radar and field measurements in Reservoirs 1 and 2, Framingham and Ashland, Massachusetts, 1989.

Figure 8.--Comparisons of soft-sediment thickness using ground-penetrating radar and field measurements in Reservoirs 1 and 2, Framingham and Ashland, Massachusetts, 1989.

EXPLANATION

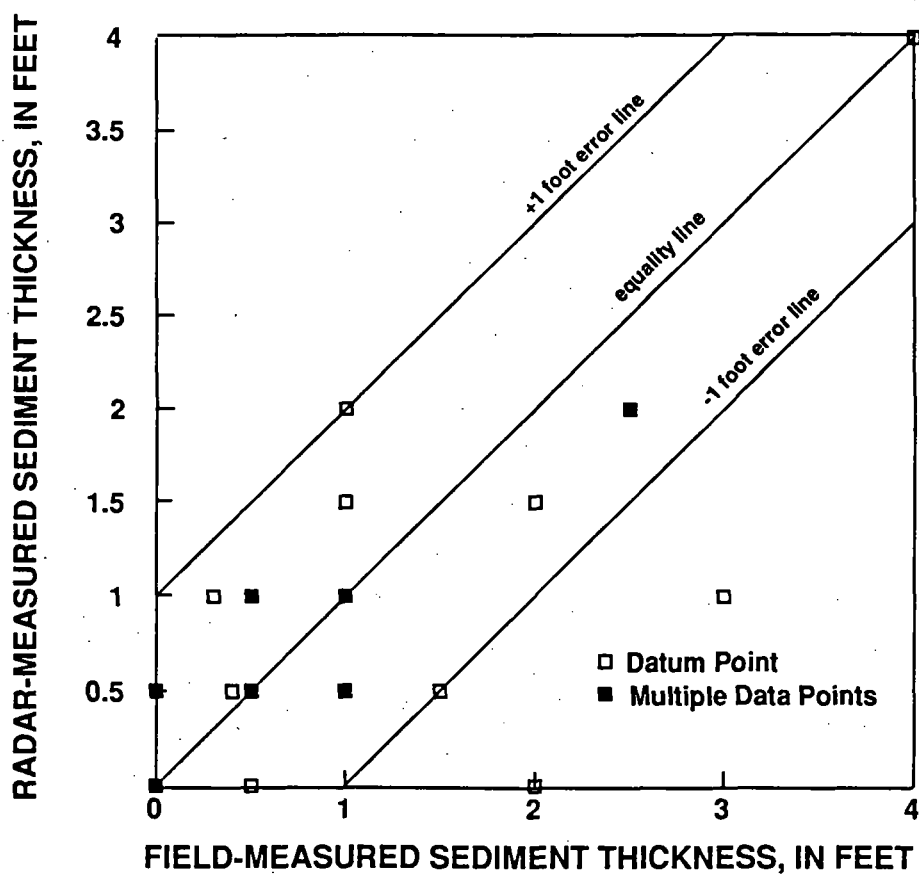|	
Unstudied	
0–4 feet deep	
4–8 feet deep	
8–12 feet deep	
12–16 feet deep	

→ Direction of streamflow

A ——— A′ Radar and penetration measurement line
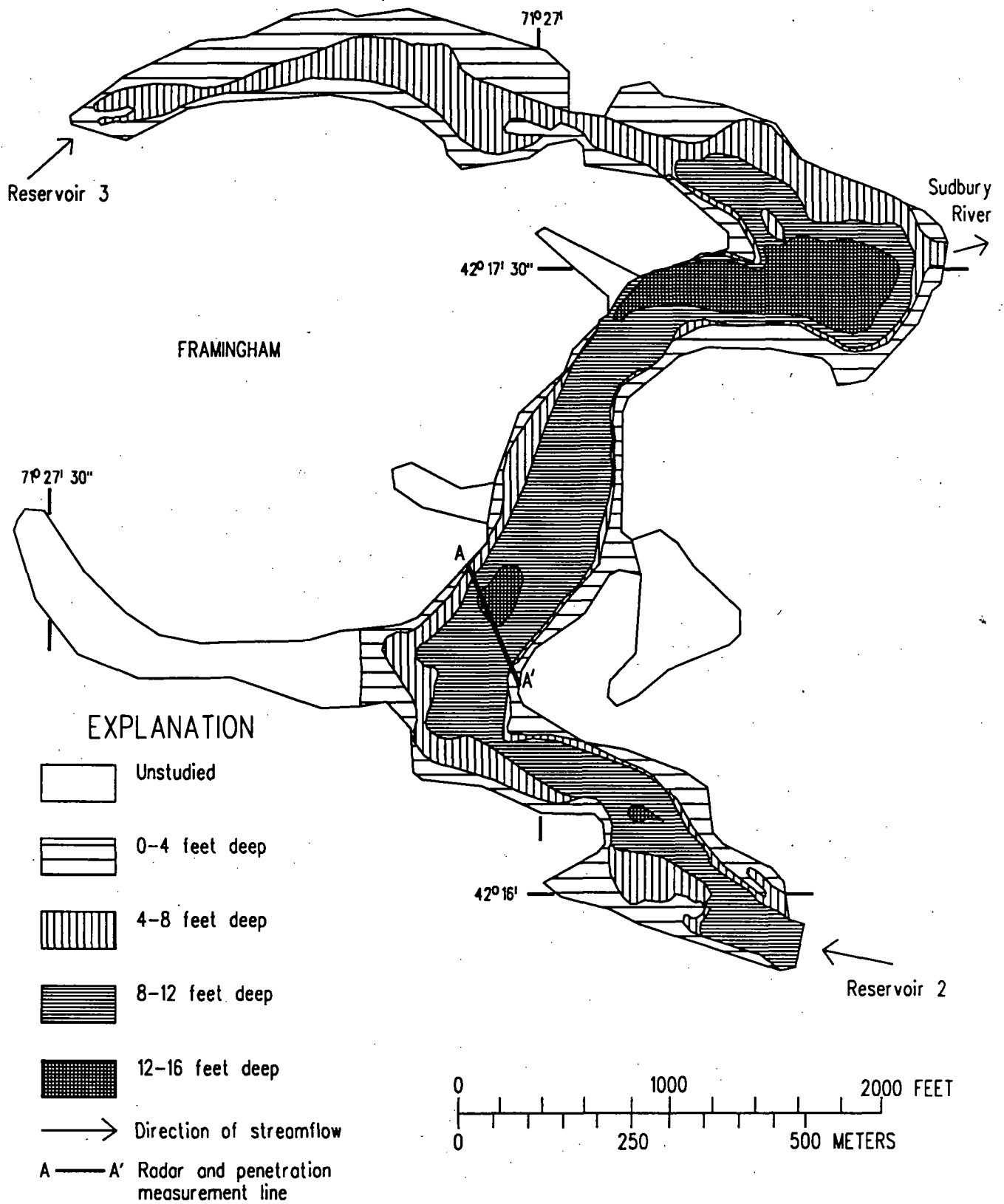
Figure 9.––Water depth in Reservoir 1, Framingham, Massachusetts, 1989

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EXPLANATION

	Unstudied
	0-4 feet deep
	4-8 feet
	8-12 feet
	12-16 feet
	Greater than 16 feet

B ————— B′ Radar and penetration measurement line

⟶ Direction of streamflow

0   1000   2000 FEET
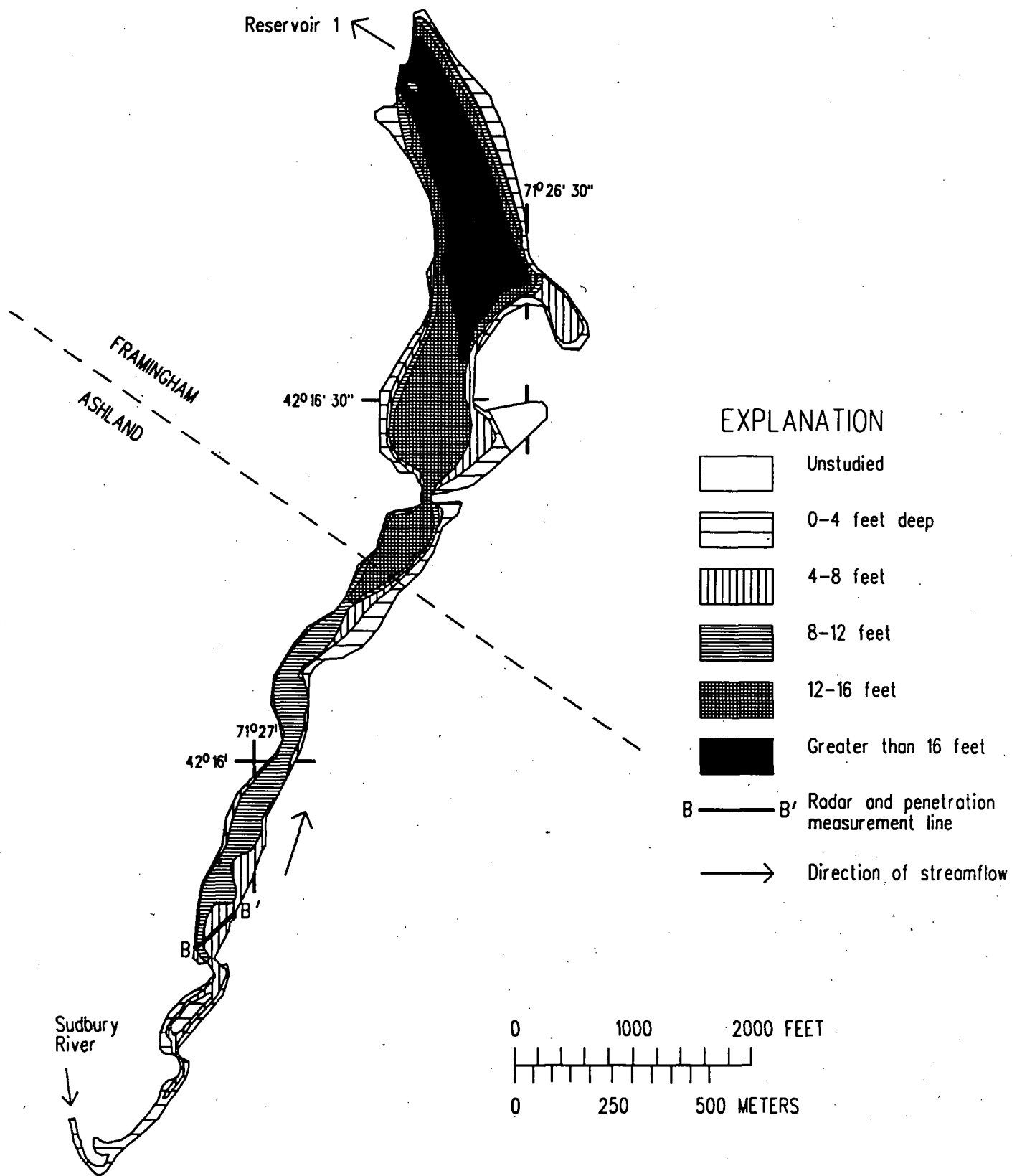
0   250   500 METERS

Figure 10.--Water depth in Reservoir 2, Framingham and Ashland, Massachusetts, 1989

The results of the sediment-thickness survey are shown by hand-drawn contour lines in figures 11 and 12. The areas of maximum sediment thickness in Reservoir 1 (fig. 11) are in the northeastern end and in the northwestern arm. Water depth measurements suggest (fig. 9) a pond was in the northeastern arm prior to the construction of the reservoir. In Reservoir 2, thickest sediments were found near the inlet at the southern end of the reservoir near the Sudbury River inlet (fig. 12) where fine materials settled because of slower water velocities. Sediment deposits in this southern part of Reservoir 2 ranged from 2 to 3 ft thick. A small area of thick sediments was observed at the mouth of a cove on the east shore. This deposit is probably the result of local tributary runoff. Relatively thick sediments in the northwest arm of Reservoir 1 (fig. 11) may have been deposited during the construction of Reservoir 3 and the Sudbury Reservoir (fig 1). The thicker sediment in the upstream part of Reservoir 2 probably was deposited after the reservoirs were completed. Radar profiles and measurements of depth and sediment thickness are available for inspection at the USEPA Office in Boston, Massachusetts.

SUMMARY

Ground-penetrating radar was used for reconnaissance mapping of water depth and sediment thichness in Reservoirs 1 and 2 in Framingham and Ashland, Massachusetts. More than 7 mi of profile lines were obtained during August 28 to September 1, 1989. Maximum water depth was 13 ft in Reservoir 1 and 18.5 ft in Reservoir 2. Sediment accumulations are generally less than 2 ft in both reservoirs. The areas of maximum sediment thickness in Reservoir 1 are in the northeastern end and in the northwestern arm. In Reservoir 2, thickest sediments were found near the inlet at the southern end of the reservoir near the Sudbury River inlet (fig. 12) where fine materials settled because of slower water velocities. Water depths and sediment thicknesses from the soundings and penetration measurements were compared to GPR surveys for 43 locations. Most interpreted radar-measured values were within 1 ft of the measured water depth and sediment thickness.

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Markt, George, 1988, Subsurface characterization of hazardous waste sites using ground-penetrating radar: Second International Symposium on Geotechnical Applications of Ground-Penetrating Radar, March 6-10, 1988, 41 p.

Olhoeft, G. R., 1984, Applications and limitations of ground-penetrating radar: Society of Exploration Geophysicists, Fifty-fourth Annual International Meeting, Atlanta, Georgia, p 147-148.

U.S. Geological Survey, 1989, Water resources data, Massachusetts and Rhode Island, water year 1987: U.S. Geological Survey Water-Data Report MA-RI-87-1, 243 p.

EXPLANATION

Unstudied
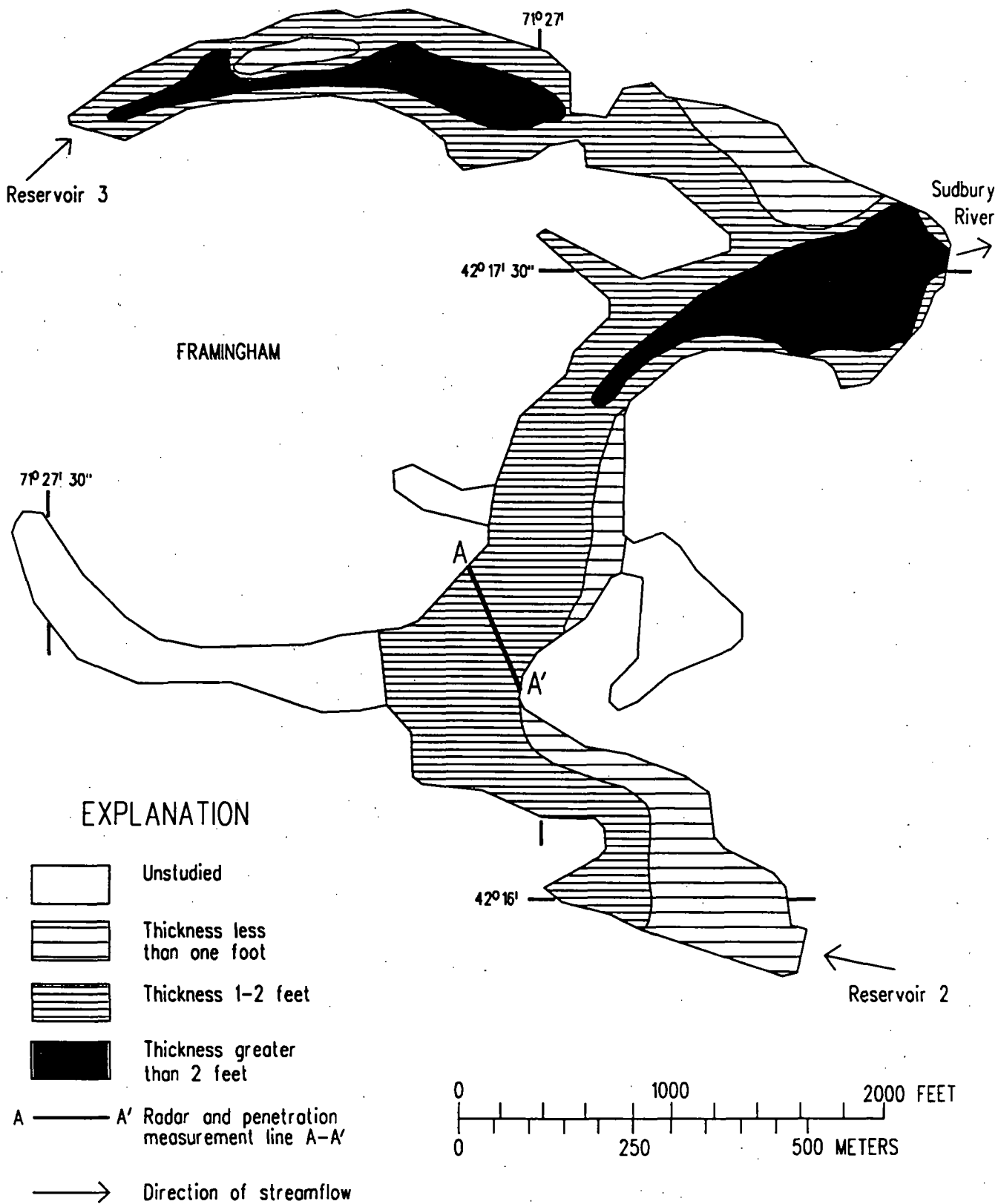
Thickness less than one foot

Thickness 1-2 feet

Thickness greater than 2 feet

A ————— A' Radar and penetration measurement line A–A'

⟶ Direction of streamflow

Figure 11.--Sediment distribution in Reservoir 1, Framingham, Massachusetts, 1989

Reservoir 1

71° 26' 30"

FRAMINGHAM

ASHLAND

42° 16' 30"

EXPLANATION

	Unstudied
	Thickness less than one foot
	Thickness 1-2 feet
	Thickness greater than 2 feet

B ————— B' Radar and penetration measurement line B-B'

⟶ Direction of streamflow

71° 27'

42° 16'

B'

B

Sudbury River

0   1000   2000 FEET
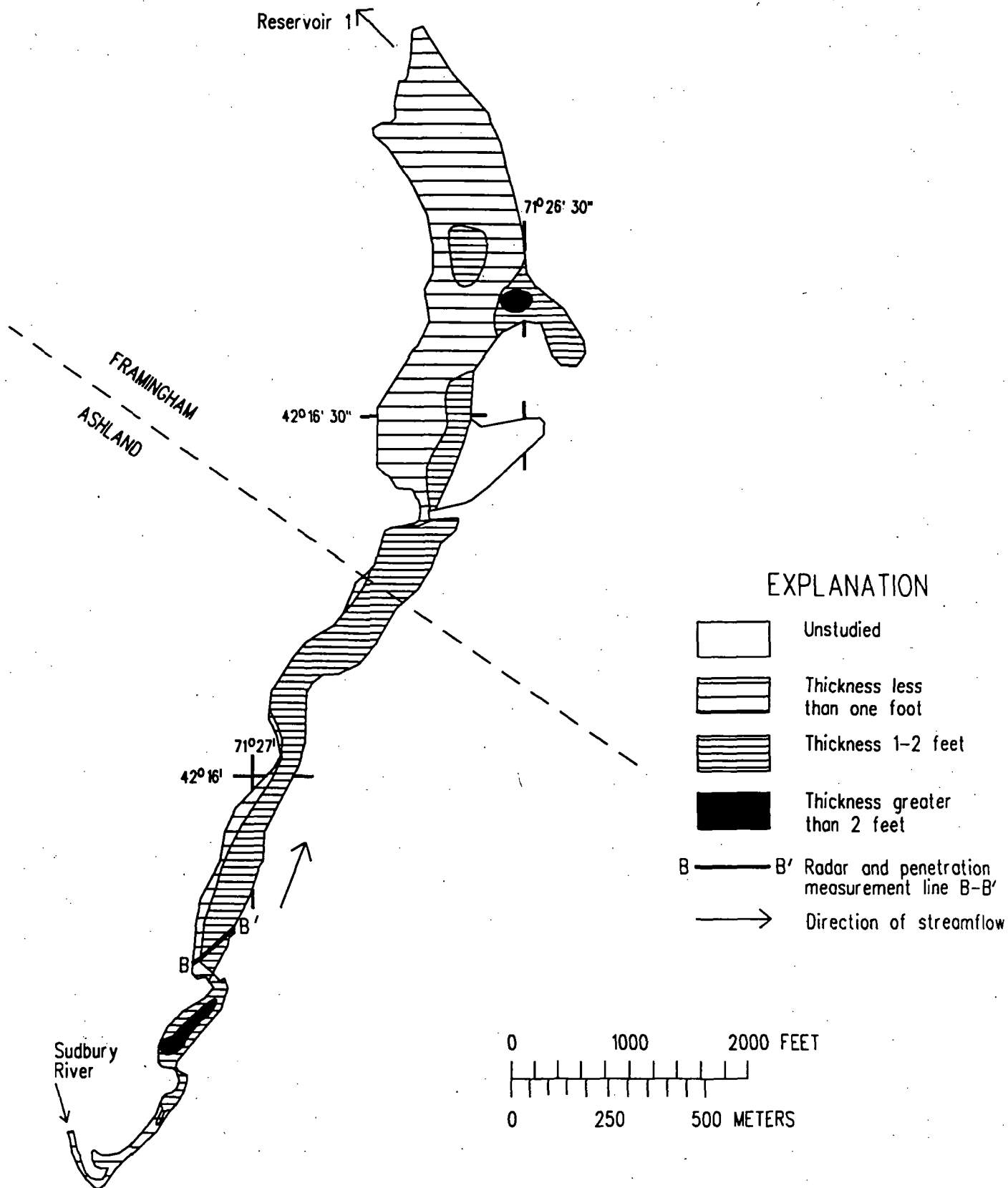|—|—|—|—|—|—|—|—|—|
0   250   500 METERS

Figure 12.--Sediment distribution in Reservoir 2, Framingham and Ashland, Massachusetts, 1989

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