Riverbed-Sediment Mapping in the Edwards Dam Impoundment on the Kennebec River, Maine By Use of Geophysical Techniques

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INTRODUCTION

In July 1997, the Federal Energy Regulatory Commission (FERC) issued a Final Environmental Impact Statement recommending that the 162-year-old Edwards Dam on the Kennebec River in Augusta, Maine, be removed. The impoundment formed by Edwards Dam extends about 15 mi to the city of Waterville, near the confluence of the Sebasticook River with the Kennebec River. The impoundment has a surface area of 1,143 acres, a gross storage of approximately 740 million ft^3, and a usable storage of about 184 million ft^3 (Stone and Webster, 1995a). According to FERC, removal of the 917-ft-long, 24-ft-high timber crib and concrete structure would restore 15 mi of riverine habitat, improve passage of ocean-migrating fish species native to the Kennebec River, and result in substantial recreational enhancements (Federal Energy Regulatory Commission, 1997).

Because the removal of Edwards Dam would change the hydraulic characteristics of the river in the present-day impoundment, the potential transport of erodible, fine-grained sediment currently in the impoundment is a concern. Of particular concern is the erosion and transport of this sediment to areas downstream from the dam, a process that could introduce possible bacterial and chemical contamination and could impede river navigation as a result of sediment deposition.

In an effort to build upon available information on the composition of the riverbed, the U.S. Geological Survey (USGS), in cooperation with the Maine State Planning Office, classified riverbed sediment types and mapped their areal extents in the lower (southern) half of the Edwards Dam impoundment. This report describes the methods used to collect and analyze the data used to create a map of sediment types in the Edwards Dam impoundment. The map is included with this report. Data used to map riverbed sediment types were also used to estimate the volume of observed mud and mud-containing sediment in the study area.

STUDY AREA

The Kennebec River, in west-central Maine, originates at the outlet of Moosehead Lake and flows south for about 145 mi to Merrymeeting Bay, where it is joined by the Androscoggin River before it flows for an additional 20 mi to the Atlantic Ocean. The Kennebec River drains about one-fifth of the State; its drainage area is 5,493 mi^2 at the Edwards Dam in Augusta and 5,893 mi^2 at the inlet of Merrymeeting Bay (Fontaine, 1980).

The study area (fig. 1) includes approximately 8 mi of the Kennebec River channel between the Sidney boat launch and the Edwards Dam. In this area, the Kennebec River has no extensive flood plains and is bordered by steep eskers, which comprise much of its gravel riverbanks. The geology in the study area consists of bedrock overlain by till and glaciomarine deposits containing gravel, sand, silt, clay, and rock (Thompson and Borns, 1985).

A USGS streamflow-gaging station was operated on the Kennebec River in North Sidney, 11.5 mi upstream from the Edwards Dam from 1978 to 1993. The drainage area of the Kennebec River at North Sidney is 5,402 mi^2. The mean annual flow for this period of record was 9,015 ft^3/s. The gaging station recorded a maximum daily mean flow of 186,000 ft^3/s on April 2, 1987, and a minimum daily mean flow of 1,160 ft^3/s on July 7, 1988. The highest instantaneous flow recorded at the station was 232,000 ft^3/s on April 2, 1987 (Nielsen and others, 1994).

The Edwards Dam, in the City of Augusta, is the first hydroelectric project on the Kennebec River upstream from the Atlantic Ocean. The original Edwards Dam, built in 1836-37, was founded on ledge and was constructed of timber cribs filled with rock ballast. Since then, the dam has been breached five times and has undergone extensive repairs and improvements during which boulders, crushed stone,

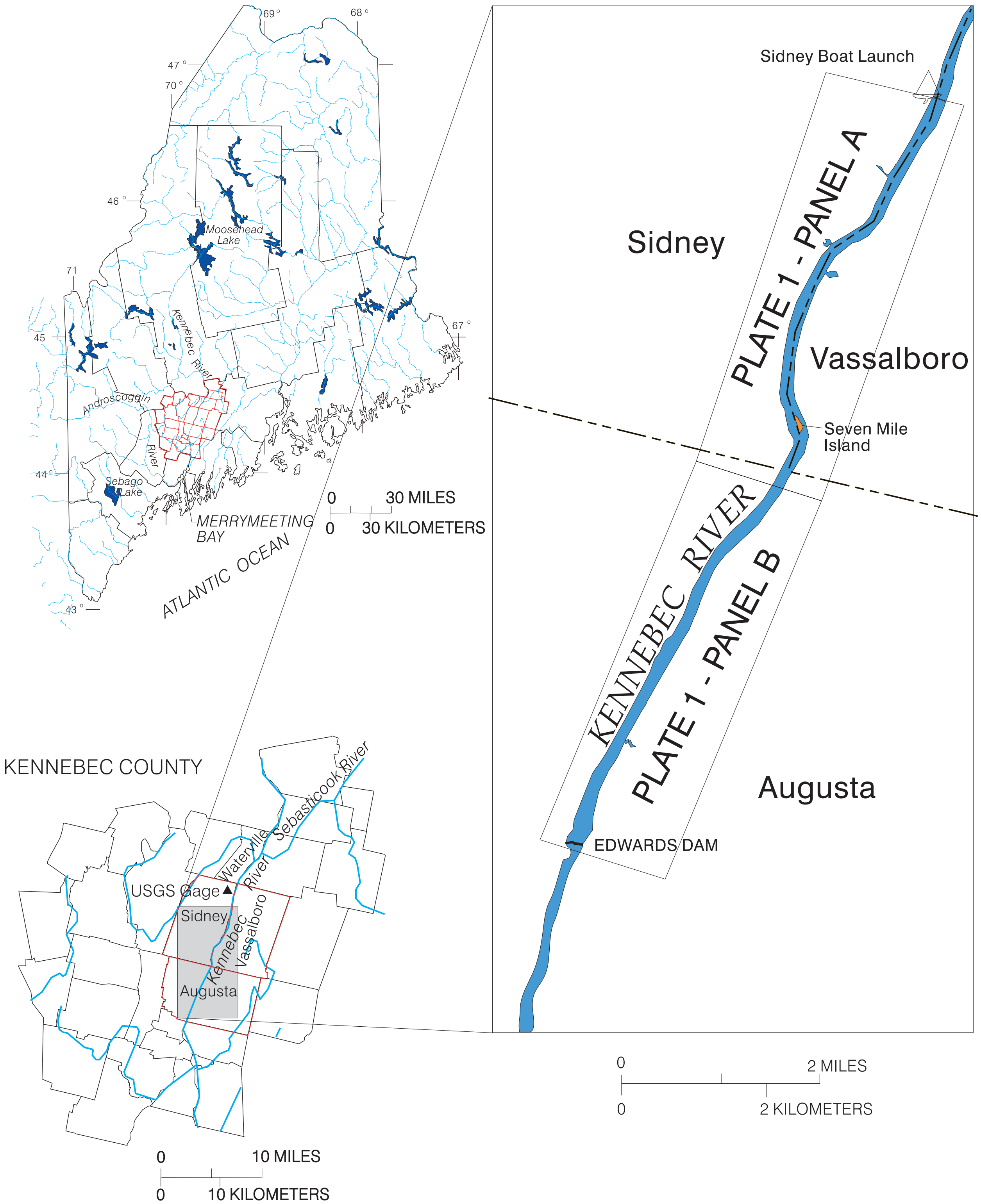

Figure 1. Location of study area.

rockfill, and concrete were added. The Edwards Project has a hydraulic capacity of 3,300 ft^3/s and a total power capacity of 3.5 MW with nine turbine units. Because of the structure of the dam and the limited storage capacity, the Edwards Project is generally operated at full capacity in run-of-the-river mode (Stone & Webster, 1995a).

A sediment-sampling program was done by the Maine Department of Environmental Protection (DEP) in 1990 to evaluate the presence of toxic contaminants in sediment behind the dam. Samples were collected approximately 650 ft upstream from the Edwards Dam. Sampling observations indicated a composition of coarse sand and gravel with cobbles and little organic-matter content. The DEP did not find any significant contamination associated with heavy metals, polyaromatic hydrocarbons, or dioxin in the sediment samples (Maine Department of Environmental Protection, 1990a, 1990b).

A sediment-characterization survey of the entire Edwards Dam impoundment was done for FERC by Stone & Webster Environmental Technology & Services in November 1994. Coarse sands, gravel, and mixtures of gravel with cobbles of various sizes were the most common sediment types found during the survey. Mud was found at the mouths of tributaries and along the riverbanks where flow velocities are low and overland runoff enters the river. Mud rarely extended more than 100 ft from the riverbanks and was never seen along the centerline of the river channel (Stone & Webster, 1995b).

STUDY METHODS

The USGS survey of the riverbed sediment lasted from June 25 to July 23, 1998, and covered 8 river miles of the impoundment from the boat launch in the town of Sidney to the Edwards Dam. Side-scan sonar (SSS) was used to identify surficial sediment types and their areal extent in the river channel and ground-penetrating radar (GPR) was used to determine the thickness of mud and mud-containing sediment types. In addition, sediment was sampled, probed, and cored to facilitate interpretation of the geophysical data.

Sediment-thickness data were collected with Geophysical Survey Systems, Inc. (GSSI) SIR-10 ground-penetrating radar. The GPR data-collection system includes a pair of modified 100-MHz antennas, which were floated on the water surface beside a fiberglass-hulled boat. A fiberglass hull was required to prevent any interference of the radar signal. The GPR data-collection system also includes a gray-scale graphic recorder that was used to plot the data in real time. GPR is capable of penetrating water and earth materials and has been proven to be a capable tool for the study of sediment layers (Izbicki and Parker, 1991; Haeni and others, 1992; Placzek and Haeni, 1995; Breault and others, 1998).

The GPR system emits short pulses of electromagnetic energy from a transmitting antenna. The energy passes through the materials of interest (which can include water, ice, buried structures, and sediment) until it reaches an interface between materials that have different dielectric properties. Because of the variation in dielectric properties at an interface, some of the energy is reflected back to the surface and detected by the GPR receiver. The GPR records the travel time and strength of the return signal. The remaining signal energy continues to travel through the material layers, and fractions of the energy are reflected at each interface until attenuation renders the signal undetectable (Beres and Haeni, 1991).

GPR data were collected along approximately 18.4 mi of zig-zagging transects from Seven-Mile Island to Edwards Dam during July 8-10 and from Seven-Mile Island to the Sidney boat launch on July 15, 1998. Sediment was sampled, cored, and probed on July 14 and 23, 1998, to aid interpretation of the GPR record. Sediment sampling was done with a grab sampler. Muddy sediments on the riverbanks were cored to determine sediment types and probed with a steel rod to measure sediment thickness.

SSS data were used as the primary record for classifying the riverbed sediment types. The riverbed was imaged with an EG&G model 260, slant-range corrected SSS device with a 272T towfish, which had a nominal frequency of 105 KHz. The SSS technology is useful for imaging underwater environments and has been used extensively by the University of Maine and the Department of Conservation, Maine Geological Survey, to produce accurate surficial geologic maps of the Gulf of Maine (Barnhardt and others, 1998; Fish and Carr, 1990).

The SSS produces a continuous image of the riverbed by transmitting sound energy and receiving the return signal reflected by the riverbed. The SSS imaging, analogous to aerial photography of the land surface, covers a 490-ft-wide swath of the river bottom, which is graphically recorded as a gray-scale image in real time.

A single SSS image was taken by pulling the towfish along the center of the river channel on July 21, 1998, from the Sidney boat launch to within 400 ft of the Edwards Dam. A 14.6-acre area behind the dam was not imaged because of navigation hazards close to the dam. The SSS transect deviated from the center of the channel in a few areas where rocks presented navigation hazards. The sediment sampling on July 14 and 23, 1998, was used to aid the interpretation of the SSS record.

A hand-held military Global Positioning System (GPS) unit was used to record all locations of geophysical data collection and sediment sampling for mapping into Geographic Information Systems (GIS) coverages. The accuracy of horizontal positioning reported by the GPS unit was variable, about 12 to 30 ft, depending upon GPS satellite availability and boat position relative to tree cover (a factor that could interfere with the positioning signals). By verifying the locations of the GPS points against landmarks on the digital maps, bad-positioning data points (greater than 30-ft accuracy) were easily identified and were not used during SSS and GPR interpretation.

In all, 580 acres of the river channel between the Edwards Dam and the boat launch in the town of Sidney were mapped into GIS. The mapped areal extent of the interpreted sediment types in the river channel is shown in plate 1 (at the back of this report). The sediment-type classification scheme used in this study is the same as was used for sediment mapping in the Gulf of Maine by Barnhardt and others (1998). The classification scheme defines 16 sediment types based on four basic units — rock (R), gravel (G), sand (S), and mud (M) — and 12 composite map units. The twelve composite map units represent combinations of the four basic units in which the dominant surficial texture comprises greater than 50 percent of the area of the map unit.

The sediment types imaged on the SSS record were characterized by correlating the strength of the reflecting acoustic signal with surficial-sediment grab samples. Rock was very acoustically reflective, appearing almost black on the SSS record, with clear structures including boulders, fractures, and geometric patterns. Gravel with cobbles and occasional boulders was recognized on the basis of its strong acoustic return, which appeared dark on the SSS record. Sand appeared in moderate gray tones on the SSS record and was generally structureless except where shadows of ripples could be identified. Mud appeared as a lighter gray than sand. Areas of the SSS record with no return signal (such as areas obstructed by islands, rock piles, or other structures) appeared white.

Some of the surficial-sediment grab samples were used to calibrate the interpretation of the SSS record. These sediment samples were located on the SSS record, and the strength of the return signal and any patterns or textures were noted. From this information, the SSS record was interpreted. The remaining sediment samples were used to validate interpreted sediment types throughout the river channel.

The SSS and GPR records were both used to classify the riverbed sediment types. The sediment types imaged on the GPR record were characterized on the basis of strength of the return radar signal, the ability of the radar signal to penetrate the riverbed, the appearance of the reflector, and correlation of the record with surficial-sediment grab samples and SSS images. Rocks and cobbles appeared graphically chaotic with multiple point reflectors represented by hyperbolas on the GPR record. Gravel appeared similar to rock, but with a smoother surface and with smaller hyperbolic point reflectors representing small cobbles. Sand appeared as wavy and hummocky patterns with a smooth surface at the sediment-water interface. In addition, sandy sediment types contained occasional small cobble point reflectors and chaotic patterns when gravel was present. Mud appeared as wavy to flat parallel lines with a smooth surface, and it allowed significantly less penetration of the radar signal than all other sediment types.

In about 79 percent of the surveyed riverbed area, SSS imagery and GPR transect data coincided. The SSS and GPR data were generally in good agreement throughout the study area. Riverbed sediment in areas surveyed with both geophysical techniques was able to be classified in a more robust fashion than areas with GPR coverage only. Because of insufficient resolution of the GPR records in areas not imaged by the SSS, only the four basic sediment types, without composite fractions, could be identified.

Mud thickness was estimated from interpreted GPR records. All mud or mud-containing sediment mapped in the study area was layered over sand and gravel or rock. For this study, “mud” is qualitatively defined as all observed fine-grained sediment (including silt and clay) that would be most easily eroded, resuspended, and transported as suspended river load (Stone & Webster, 1995b). The lower bounds of mud deposits were determined by identifying the location of sand, gravel, and rock beneath them. The distance from the first return signal of mud to the first return signal representing these other sediment types represented the two-way travel time of the radar signal through the mud. These time estimates, in nanoseconds, were converted to thicknesses by use of radar wave velocities reported by Markt (1988). Because of the resolution of the GPR equipment, mud layer thicknesses of less than 2.0 ft could not be determined. An estimate of 1.0 ft was used for deposits less than 2.0 ft in thickness. Overall, the mean computed thickness of all mapped mud and mud-containing sediment types is 2.3 ft, with a standard deviation of 1.6 ft.

Mud volume was computed for each mud-containing map unit from the area of that unit and the mean sediment-thickness estimate, which had previously been computed from thickness data confined to that unit. Composite sediment units presented a problem for estimating volumes because of the difficulty in precisely determining the relative composition of mud to the other observed sediment types. In these cases, a method was used that would yield both high and low estimates of mud volume. For composite map units in which mud is the subordinate sediment type, the volume was halved for the high estimate and set to zero for the low estimate. For composite map units in which mud is the dominant sediment type, the entire volume was used as the high estimate and half the volume was used as the low estimate. The high and low estimating methods are particularly important for mud map units inferred from the GPR record alone because these areas contained various basic sediment types (sand, gravel, rock) that could not be precisely quantified in relation to the muddy sediment.

SEDIMENT DISTRIBUTION, VOLUME, AND DISCHARGE

Approximately 90 percent of the total surveyed area consists of rock, sand, and gravel or combinations thereof (plate 1). The remaining area consists of mud or mud-containing sediment types in which mud is mixed with other sediment units. All of the interpreted riverbed sediment types with their associated acreages between the Edwards Dam to the Sidney boat launch are listed in table 1. Overall, the observed sediment types form long, thin units oriented longitudinally with the river channel. The main channel is composed primarily of varying mixtures of sand and gravel, whereas most of the eastern side of the channel consists of rocky sediment types. Boulders, bedrock, and large cobbles are common in map units classified as predominantly rock. Large man-made rock piles (cribs) are visible above the water surface north of Seven-Mile Island. Years ago, these rock cribs were constructed as part of cribworks used to sort and hold logs when felled trees were being transported by river. A few other smaller rock cribs below Seven-Mile Island are visible only during low flows. All significant mud-sediment units are confined to the banks of the river and mixed with other sediment types in the river channel near stream inlets.

As mentioned previously, a small area directly behind the Edwards Dam was not directly imaged because of hazards to boat navigation (plate 1); however, photographs of the impoundment during the 1974 breach show exposed gravel, sand, and cobbles. The nature of the exposed riverbed materials near the dam in 1974 is consistent with sediment samples and SSS images obtained immediately upstream from the dam during this study. SSS images at the edge of the unsurveyed area behind the dam show sand and gravel and evidence of scouring.

Volume computations yield approximately 1.5 to 3.7 million ft^3 of mud and mud-containing sediment distributed along the riverbanks in scattered, discontinuous deposits of highly variable extent and thickness. This estimated volume of mud and mud-containing sediment, if multiplied by a published value for the bulk density of mud sediment of 93 lb/ft^3 and adjusted for a porosity of 0.4 (Holtz and Kovacs, 1981), represents approximately 40,000 to 100,000 tons of material.

Suspended-sediment and streamflow data collected at the North Sidney gaging station from 1978 to 1993 were used to estimate an average annual suspended-sediment discharge at North Sidney using techniques outlined by Simmons (1993). Suspended-sediment-discharge computations result in an average annual load of about 152,000 tons (or 28 $tons/mi^2$ of drainage area) at the North Sidney station. Most of the suspended sediment is transported in the river during high flows, which typically occur in the spring. For example, on the basis of the above technique, the mean monthly flow in April of 22,320 ft^3/s transports about 1,300 ton/d of suspended sediment. The estimated peak flow with a 2-year recurrence interval at North Sidney of 62,200 ft^3/s transports suspended sediment at a rate of approximately 10,000 ton/d.

Table 1. Acreages and percentages of observed riverbed sediment units in the Edwards Dam impoundment, Kennebec River, Maine

[Dominant sediment types compose greater than 50 percent of the surficial texture of the map unit area; subordinate sediment types compose less than 50 percent of the surficial texture of the map unit area; --, unable to be interpreted]

Sediment units interpreted from side-scan sonar (SSS) and ground-penetrating radar (GPR)		Area (acres)	Percentage of total mapped area
Dominant	**Subordinate**		
Gravel	mud	3.7	1
Gravel	rock	35.8	6
Gravel	sand	98.7	17
Rock	gravel	42.4	7
Rock	mud	21.4	4
Rock	sand	60.0	10
Sand	sand	40.0	7
Sand	gravel	152.4	26
Mud	mud	.1	< 1
Mud	gravel	1.3	< 1
GPR-interpreted sediment units			
Dominant	**Subordinate**		
Gravelly	--	29.7	5
Muddy	--	31.3	5
Rocky	--	33.8	6
Sandy	--	29.8	5
	Totals	**581**	**100**

CONCLUSIONS

The integrated interpretation of SSS and GPR geophysical data was adequate for determining the sedimentary character of the riverbed. Results of this study indicate that the surveyed area of the Edwards Dam impoundment is a high-energy river environment where accumulation of fine-grained riverine sediment is minimal. It is probable that the narrow, confined nature of the river precludes significant fine-sediment accumulation. The map created from this survey of the river confirms observations by Maine Department of Environmental Protection sampling teams as well as observations from the 1994 survey conducted for FERC by Stone & Webster Environmental Technology & Services.

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REFERENCES CITED

Barnhardt, W.A., Kelley, J.T., Dickson, S.M., and Belknap, D.F., 1998, Mapping the Gulf of Maine with side-scan sonar: a new bottom-type classification for complex seafloors: Journal of Coastal Research, v. 14, no. 2, p. 646-659.

Beres, Milan, Jr., and Haeni, F.P., 1991, Application of ground-penetrating radar methods in hydrogeologic studies: Ground Water, v. 29, no. 3, p. 375-386.

Breault, R.F., Weiskel, P.K., and McCobb, T.D., 1998, Channel morphology and streambed-sediment quality in the Muddy River, Boston and Brookline, Massachusetts, October 1997: U.S. Geological Survey Water-Resources Investigations Report 98-4027, 6 p., 1 pl. (map; scale 1:5,000), 4 figs.

Federal Energy Regulatory Commission, 1997, Order denying new license and requiring dam removal: Project no. 2389-012, issued November 25, 1997, 27 p.

Fish, J.P., and Carr, H.A., 1990, Sound underwater images—A guide to the generation and interpretation of side scan sonar data: Orleans, Mass., Lower Cape Publishing, 188 p.

Fontaine, R.A., 1980. Drainage areas of surface water bodies of the Kennebec River basin in southwestern Maine: U.S. Geological Survey Open-File Report 78-556E, 83 p.

Haeni, F.P., Placzek, Gary, and Trent, R. E., 1992, Use of ground-penetrating radar to investigate refilled scour holes at bridge foundations: Fourth International Conference on Ground Penetrating Radar, Geological Survey of Finland, Special Paper 16, p. 285-292.

Izbicki, J.A., and Parker, G.W, 1991, Water depth and thickness of sediment in reservoirs 1 and 2, Framingham and Ashland, Massachusetts: U.S. Geological Survey Open-File Report 91-508, 18 p.

Holtz, R.D., and Kovacs, W. D., 1981, An introduction to geotechnical engineering: Englewood Cliffs, N.J., Prentice-Hall, 733 p.

Maine Department of Environmental Protection, 1990a, Expected water quality changes from the removal of the Edwards Dam, Augusta: 22 p.

Maine Department of Environmental Protection, 1990b, Expected water quality changes from the removal of the Edwards Dam, Augusta—Addendum: 6 p.

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

Nielsen, J.P., Higgins, W.B., and Lippert, R.G., 1994, Water resources data Maine, Water Year 1993: U.S. Geological Survey Water Data Report ME-93-1, 243 p.

Placzek, Gary, and Haeni, F.P., 1995, Surface-geophysical techniques used to detect existing and infilled scour holes near bridge piers: U.S. Geological Survey Water-Resources Investigations Report 95-4009, 44 p.

Simmons, C.E., 1993, Sediment characteristics of North Carolina streams, 1970-79: U.S. Geological Survey Water Supply Paper 93-2364, 84 p.

Stone & Webster Environmental Technology & Services, 1995a, Edwards Dam removal evaluation report: Prepared for Federal Energy Regulatory Commission by Stone and Webster Environmental Technology and Services, Boston, Mass., 139 p.

Stone & Webster Environmental Technology & Services, 1995b, Edwards Dam removal evaluation—physical and biological study results: Prepared for Federal Energy Regulatory Commission by Stone and Webster Environmental Technology and Services, Boston, Mass. 145 p.

Thompson, W.B., and Borns, H.W., 1985, Surficial geologic map of Maine: Maine Geological Survey, Department of Conservation, scale 1:500,000.