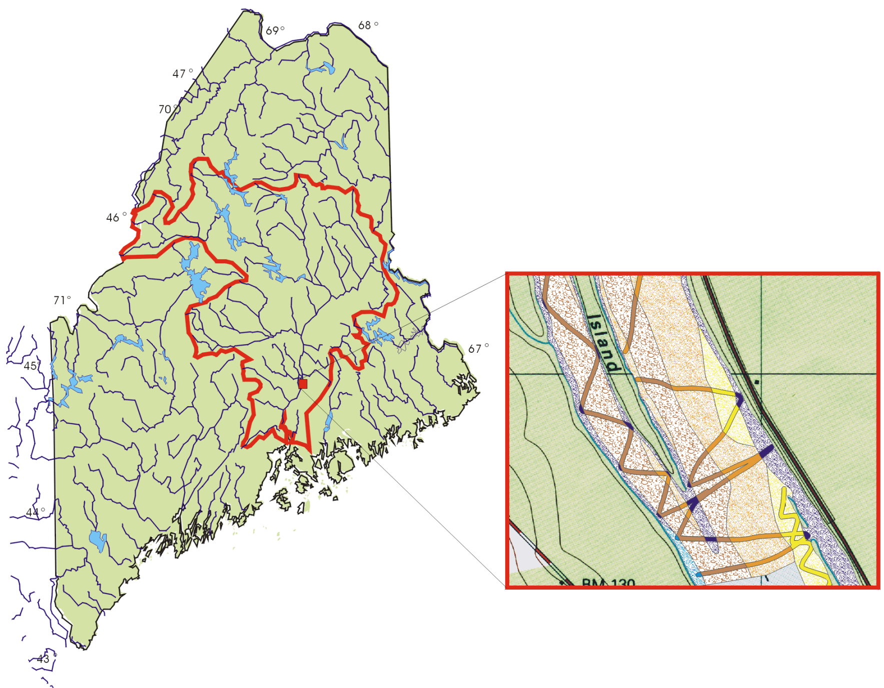
U.S DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Composition and Distribution of Streambed Sediments in the Penobscot River, Maine, May 1999

Water-Resources Investigations Report 01-4223



Prepared in cooperation with the
BUREAU OF INDIAN AFFAIRS
PENOBSCOT INDIAN NATION DEPT. OF NATURAL RESOURCES

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By Robert W. Dudley and Sarah E. Giffen

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U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
26 Ganneston Drive
Augusta, ME 04330

http://me.water.usgs.gov

Copies of this report can be purchased from:

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
acre	0.405	hectare
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot (ft^3)	0.02832	cubic meter
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.589	square kilometer

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C), by using the following equation:

$$^{o}C = 5/9\ (^{o}F - 32)$$

Vertical datum: 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.

Other abbreviations: MW, megawatts

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ABSTRACT

Sediment samples were collected and geophysical surveys were run along 50 miles of the Penobscot River, Maine, in the spring of 1999 to produce maps that describe the composition and distribution of streambed sediments for selected areas in the river channel. The objective of the sediment survey was to locate areas along the river where fine-grained, easily transportable sediment types were deposited between Old Town and Medway, Maine. These data can be used to design future sediment-sampling programs to assess the quality of streambed sediments and evaluate the health of the Penobscot River. This report describes the results of the sediment survey and the methods used to collect, analyze, and interpret the data used to create maps of streambed-sediment types in the study area.

Deposits of fine-grained sediments (mud and sand) are scattered along the shorelines of the mainland and the islands and at the downstream ends of islands and at the mouths of brooks and streams. The most extensive depositional areas were found in the Mattaseunk Dam impoundment near Medway. The main areas of the river channel consist primarily of gravel, sand, and rock.

INTRODUCTION

In May 1999, the U.S. Geological Survey (USGS), in cooperation with the Bureau of Indian Affairs (BIA) and the Penobscot Indian Nation Department of Natural Resources (PIN DNR), did a geophysical and sampling survey of the Penobscot River, Maine, to assemble maps that describe the composition and distribution of streambed sediments in selected areas in the Penobscot River channel. Specifically, the sediment survey focused on locating areas where fine-grained, easily transportable sediment types were deposited between Old Town and Medway, Maine. Identifying sediment types and the extent of the depositional areas is an important study objective for designing future sediment-sampling programs. This report describes the results of the geophysical surveys and sediment sampling done in 1999.

The authors gratefully acknowledge the following individuals who significantly contributed to this study: T. Jason Mitchell and Daniel H. Kusnierz, PIN DNR, for their assistance with river navigation and logistics associated with field work; Perry N. Silverman, USGS, for assistance with interpretation of the ground-penetrating radar (GPR) record and mapping; Gloria L. Morrill, USGS, for the production of the illustrations in this report; and Christopher J. Powers, USGS Branch of Geophysical Applications and Support, for providing expert assistance with the GPR equipment.

PHYSICAL SETTING

The study area (fig. 1) includes selected reaches along 50 mi of the Penobscot River between Old Town and Medway, Maine. The selected survey and sampling areas for the 1999 study were chosen to include the same three sites surveyed in 1995-96, as well as new sites where there were known or potential areas of fine-grained sediment deposition. The selected survey reaches were further limited by the proximity of motor-boat launches to river reaches deep enough for navigation.

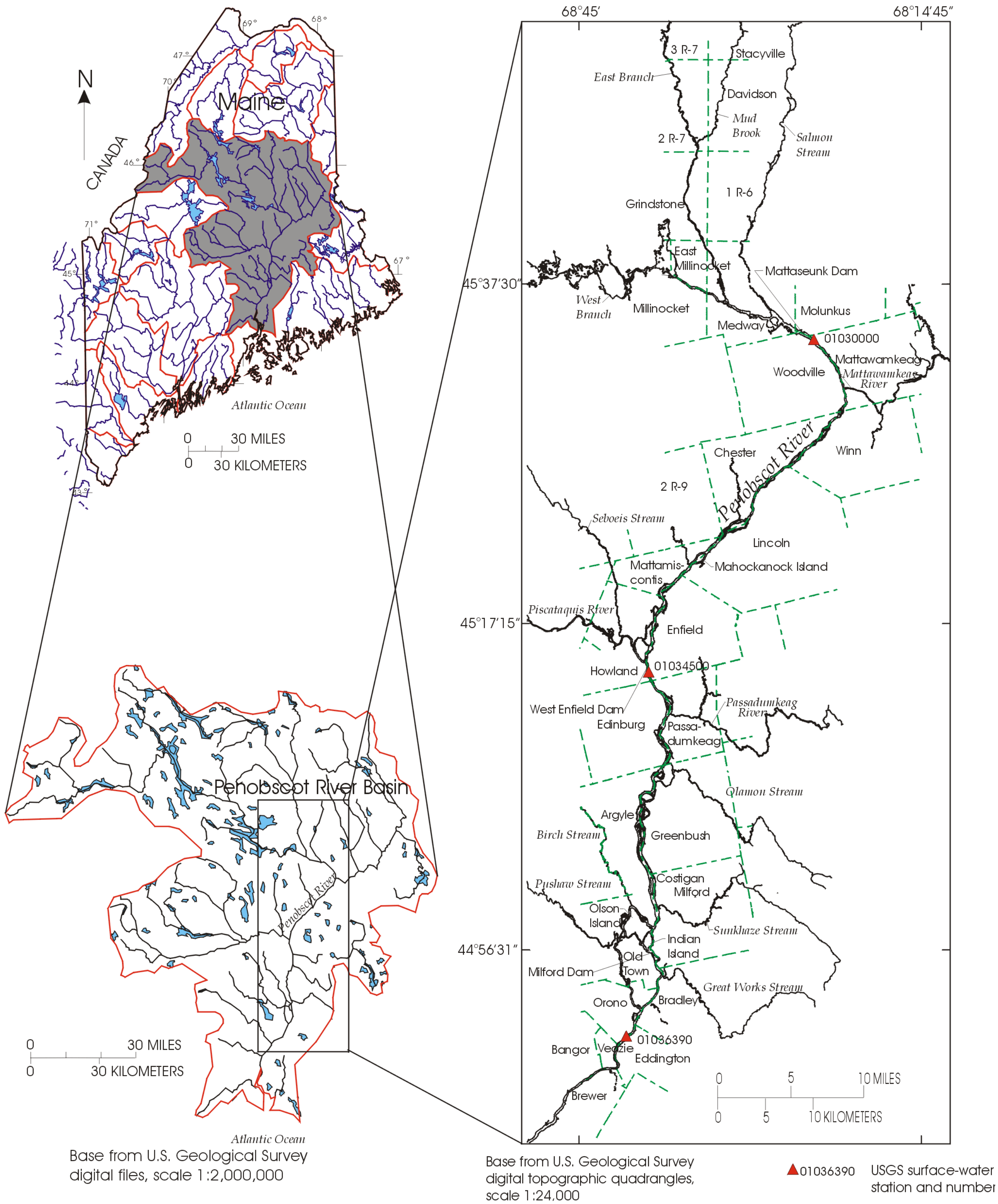


Figure 1. Location of the study area on the Penobscot River, Maine.

The combined population of the towns along the Penobscot River in the study area is approximately 26,000 people. About 40 percent of this population (11,200) is distributed at the downstream limit in the towns of Old Town and Milford and in part of the Penobscot Indian Reservation. The Penobscot Reservation includes all the islands in the Penobscot River extending from Old Town to Medway—a total of nearly 150 islands. At present, the only permanent settlement, as well as the seat of government of the Penobscot Nation, is on Indian Island, at Old Town (fig. 1). The towns of Lincoln and Chester have the next largest population group with a combined population of 6,300. The remaining population is distributed among small towns, farms, and sprawling suburban developments.

The principal industries in the Penobscot River Basin are paper manufacturing, sawmills, lumber preservation, and other wood products manufacturing. Other industries in the basin include leather and allied product manufacturing and textile production (U.S. Bureau of the Census, 2000).

Climate and Hydrology

The climate in the Penobscot River Basin is typically characterized by mild summers and cold winters. The average annual temperature is 41°F at a National Weather Service (NWS) station in Millinocket (about 10 mi west of Medway) and 43°F at a NWS station near Old Town. Mean monthly temperatures range from 13°F in January to 68°F in July at Millinocket and 17°F in January to 67°F in July near Old Town. The average annual precipitation in the basin is about 40 in. and is evenly distributed throughout the year (U.S. National Oceanic and Atmospheric Administration, 1995 and 1998).

The main channel of the Penobscot River begins at the confluence of two large branches—the East Branch and West Branch. The drainage divide at the headwaters of the West Branch is part of the Maine-Canadian border (fig. 1). At the confluence of the two branches at Medway, the East Branch has a drainage area of 1,120 mi^2 and the West Branch has a drainage area of 2,131 mi^2. From Medway, the Penobscot River flows south for approximately 110 mi to the Gulf of Maine, where it discharges into the Atlantic Ocean. The Penobscot River drains about one-quarter of the State of Maine with a drainage area of 8,592 mi^2 at its mouth (Fontaine, 1981). Streamflows in the Penobscot River Basin vary seasonally with high flows typically in early spring and late fall and low flows generally in the summer and early fall.

The Mattaseunk Dam (fig. 1), originally built in 1937–40 in the town of Mattawamkeag, is a run-of-the-river hydroelectric facility producing 19.2 MW of electrical power (Dana Murch, Maine Department of Environmental Protection, Bureau of Land and Water Quality, oral commun., 2000). The drainage area of the Penobscot River above the dam is 3,355 mi^2 (Fontaine, 1981). The Mattaseunk Dam impoundment has a surface area of 1,685 acres and a gross storage of approximately 915 million ft^3 (Dana Murch, oral commun., 2000). A USGS streamflow-gaging station (station number 01030000) was operated on the Penobscot River near the town of Mattawamkeag, 1,800 ft downstream from the Mattaseunk Dam, from 1940–91. The drainage area of the Penobscot River at the gaging station is 3,356 mi^2. The mean annual flow for the period of record was 5,796 ft^3/s. A maximum daily mean flow of 62,600 ft^3/s was recorded on April 30, 1973, and a minimum daily mean flow of 1,430 ft^3/s was recorded on August 17, 1941. The highest instantaneous flow recorded at the station was 66,000 ft^3/s on April 29, 1973 (Bartlett and others, 1992).

The West Enfield Dam (fig. 1) was originally built in 1894. In 1986, this dam was replaced by another dam constructed immediately downstream from the 1894 structure. The West Enfield Dam is a run-of-the-river hydroelectric facility producing 13 MW of electrical power (Dana Murch, oral commun., 2000). The drainage area of the Penobscot River above the dam is 5,217 mi^2 (Fontaine, 1981). The West Enfield Dam impoundment has a surface area of 1,125 acres and a gross storage of approximately 490 million ft^3 (Dana Murch, oral commun., 2000). The Piscataquis River joins the Penobscot River about 1 mi downstream from the dam and drains 1,453 mi^2 (Fontaine, 1981). A USGS streamflow-gaging station (station number 01034500) has been in operation on the Penobscot River at West Enfield, about 1,000 ft below the mouth of the Piscataquis River, since 1901. The drainage area of the Penobscot River at the gaging station is 6,671 mi^2. The mean annual flow for the period of record is 11,950 ft^3/s. The gaging station recorded a maximum daily mean flow of 152,000 ft^3/s on May 1, 1923, and a minimum daily mean flow of 1,630 ft^3/s on October 29, 1905. The highest instantaneous flow recorded at the station was 153,000 ft^3/s on May 1, 1923 (Nielsen and others, 1999).

The study reach in the towns of Old Town and Milford includes areas near Olson Island in the Milford Dam impoundment. The Milford Dam, originally built in 1905–06 in the town of Milford, is a run-of-the-river hydroelectric facility licensed to produce 8 MW of electrical power (Dana Murch, oral commun., 2000). The drainage area of the Penobscot River upstream from the dam is 7,325 mi^2 (Fontaine, 1981). The Milford Dam impoundment has a surface area of 235 acres and a gross storage of approximately 98 million ft^3 (Dana Murch, oral commun., 2000). USGS streamflow-gaging station 01036390 was operated on the Penobscot River in the town of Eddington, 9 mi below the Milford Dam, from 1979–96. The drainage area of the Penobscot River at the Eddington gaging station is 7,764 mi^2. The mean annual flow for the period of record at the Eddington gage was 14,110 ft^3/s. A maximum daily mean flow of 155,000 ft^3/s was recorded on April 3, 1987, and a minimum daily mean flow of 2,690 ft^3/s was recorded on September 7, 1995. The highest instantaneous flow recorded was 159,000 ft^3/s on April 3, 1987 (Nielsen and others, 1997).

Geomorphology

The Penobscot River valley can be separated into four distinct geomorphic units. From the headwaters of the East and West Branches of the Penobscot River downstream to the town of Medway is a mountainous upland area. This area is characterized by high-relief topography, which results in high-energy stretches of the river that are popular with white-water rafters and kayakers. This mountainous terrain, which is characteristic of the New England central highlands (Denny, 1982), has many ponds and tributary streams. Many of these ponds and streams are or have been affected by dams for the generation of hydroelectric power and flow control for log driving (Kelley and others, 1988). The high-energy white-water characterization is not true of the dam impoundments in this region. Water movement in the impoundments is significantly slower than in the high-energy reaches of the river, enabling fine-grained sediments to settle out and accumulate on the bottom.

The second section of river, running through the New England coastal lowlands (Denny, 1982) from Medway to Old Town, has a broad floodplain and a wider channel than the upstream section. This section of the river is characterized by numerous low-profile depositional islands and sand bars. Bedrock outcrops and rapids are rare. Aerial photographs of this part of the river show historical meandering and braiding of the river channel and indicate formation of islands by erosion and deposition (Kelley and others, 1988). The West Enfield Dam is located about midway on this second river reach.

The third section of the Penobscot River, from Old Town to Bangor, is characterized by numerous rapids and common bedrock outcrops. The Milford Dam is located at the beginning of this river reach. Bluffs of unconsolidated material dominate the riverbanks, and raised terraces are well developed in several locations (Kelley and others, 1988).

The fourth section of the river, below Bangor, is tidally influenced and passes through a geomorphic area classified as the New Brunswick highlands (Denny, 1982). This part of the river is characterized by bluffs of unconsolidated material and bedrock cliffs, with fringing salt marshes in protected areas (Kelley and others, 1988).

PREVIOUS INVESTIGATIONS

The results of the 1999 geophysical survey build upon sediment-type information collected by the PIN DNR during 1995–96 (Penobscot Indian Nation Department of Natural Resources, 1997). The PIN DNR study was a preliminary assessment of the character of streambed sediments and prompted the need for additional information. The PIN DNR study involved field observations, side-scan sonar (SSS) imaging, and collection of grab samples in three reaches on the Penobscot River: the Milford Dam impoundment, West Enfield Dam impoundment, and at Mahockanock Island. Overall, the three sites in the 1995–96 study were observed to be largely erosional and were composed of sand, gravel, and rock. Fine-grained sediments were observed near submerged logs and in patches near riverbanks and islands.

During low flow in the summer of 1995, PIN DNR personnel examined exposed areas of the river channel and took core samples from boat and shore at the Milford Dam impoundment, the West Enfield Dam impoundment, and at Mahockanock Island. SSS imaging was done in November 1995. Because of the threat of entangling or damaging the submerged sonar unit when navigating in shallow water, sonar imaging was limited to deep areas of the survey sites.

The sonar imaging showed that the bottom of the Milford Dam impoundment had rocks, cobbles, and gravel with logs scattered throughout. The submerged logs typically had mud deposits surrounding them. Other fine-grained sediment types were observed near shorelines, near the Old Town boat launch, and at the southern end of Orson Island and Indian Islands in the Old Town area. Elsewhere, the river channel was composed of coarse sand and gravel. SSS images showed the river channel to be rocky on the eastern side of Indian Island except at the southeastern tip.

Sediment grab samples were collected by the PIN DNR in the Milford Dam impoundment in the summer of 1996 to confirm the side-scan sonar record. Eleven samples were collected to represent each sediment type that was mapped by side-scan sonar in the fall of 1995. Two samples were collected in the mapped units of sand-mud, three samples in sand-gravel, two in gravel-sand, three in gravel, and one sample in the rock unit.

SSS images were obtained in the deep channel of the West Enfield Dam impoundment, from 1,000 ft to almost 1 mi upstream from the dam. The sonar images indicated a uniformly hard and rocky bottom. The river channel was noted to be heavily armored with gravel and boulders and only minor amounts of sand. The streambed sediment was classified as a hard-packed till, excavated by water erosion so that only the coarsest sediment particles remain.

SSS images along the southeastern side of Mahockanock Island at South Lincoln revealed mostly sand and gravel with ripples in the center streambed sediment. The ripples indicated a fine sediment overlying a hard material. Logs also were present with fine sediment trapped between them.

METHODS OF STUDY

The USGS geophysical survey of the river channel from May 4–19, 1999 covered selected reaches between Old Town and Medway. Ground-penetrating radar (GPR) was used to identify streambed sediments because it is an especially effective method to use in electrically resistive geologic settings, such as shallow (less than 6 m deep) freshwater streams with coarse-grained sediments (Haeni and others, 1992). Streambed sediments, sampled to a maximum depth of 6 in. with a Ponar grab sampler from May 24–26, 1999, confirm the geophysical data.

Streambed-sediment data were collected with Geophysical Survey Systems, Inc. (GSSI) SIR-10 GPR. 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 data-collection system included a 300-MHz transmitter and receiver contained in a sealed fiberglass unit, which floated on the water surface inside a small rubber raft. The raft, in turn, was secured to the side of a rubber inflatable boat.

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 with different dielectric properties. At each interface, some energy is reflected back to the surface and is detected by the GPR receiver. The GPR records the two-way 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 the signal is no longer detectable (Beres and Haeni, 1991).

The GPR surveys focused on known or potential reaches where fine-grained, easily transportable sediment would be deposited. Identifying the location and extent of depositional areas will guide the design of future sediment-sampling programs. Known depositional areas were identified by field reconnaissance, field observations, and the experience of biologists and natural-resources technicians who work extensively on the Penobscot River. Potential areas were identified by field reconnaissance and from topographic maps, which showed the locations of dam impoundments and other morphological features indicative of deposition, such as braided-island systems.

GPR data were collected along approximately 39 mi of zigzagging transects distributed along selected reaches between Old Town and Medway from May 4–19, 1999. The transects are shown in figures A1–12 in the appendix of this report. The Greenbush area (fig. A4) was the most densely surveyed location (11.8 mi of GPR coverage) because of the complex depositional-island system there. The remaining locations were covered by 2 to 5 mi of GPR transects each.

Seventy streambed-sediment samples were collected and characterized to aid interpretation of the GPR record. The locations of all sampling sites are shown in figures A-1 through A-12 as circumscribed point symbols. Table A1 in the appendix lists all grab samples collected, the latitude and longitude of the sampling sites, and visual field characterizations. Rocks and cobbles are characterized as stones with diameters greater than 3 in. Gravel and sand is characterized as coarse-grained, cohesionless, and visibly granular sediments. Gravel contains coarse sediment grains and small stones with diameters that range from 1/8 to 3 in. For this study, mud is qualitatively defined as fine-grained sediment, including silt and clay. Silt is characterized as cohesionless, fine-grained sediments in which the individual grains cannot be seen. Clay is characterized similarly to silt except that it is cohesive and plastic (Holtz and Kovacs, 1981).

All sampling locations and GPR survey transects were georeferenced using a hand-held global positioning system (GPS) unit. The horizontal accuracy of positions reported by the GPS unit range from about 12 to 30 ft, depending upon GPS satellite availability and boat position relative to tree cover. Trees and other structures can cause signal interference. By verifying the locations of the GPS points against landmarks on the digital maps, erroneous data points (greater than 30-ft accuracy) were easily identified and were not used to locate GPR data.

The GPR records and sediment grab samples were used to classify the streambed sediments. 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 river channel, the appearance of the reflector, and the correlation of the record with grab samples of streambed sediments. Rocks and cobbles appear graphically chaotic, with multiple point-reflectors represented by hyperbolas on the GPR record (fig. 2). Gravel appears similar to rock, but with a generally smoother water/riverbed interface and smaller hyperbolic point-reflectors than a GPR record representing rocks and small cobbles (fig. 3). Sand appears as wavy and hummocky patterns with a smooth surface at the sediment-water interface. In addition, sandy sediment can contain occasional point-reflectors that represent rocks or debris, such as logs (fig. 3). Mud appears as wavy-to-flat parallel lines with a smooth water/riverbed interface. The mud sediment type also attenuates the radar signal more than other sediment types because of the electrically charged properties of the sediment grains (fig. 4).

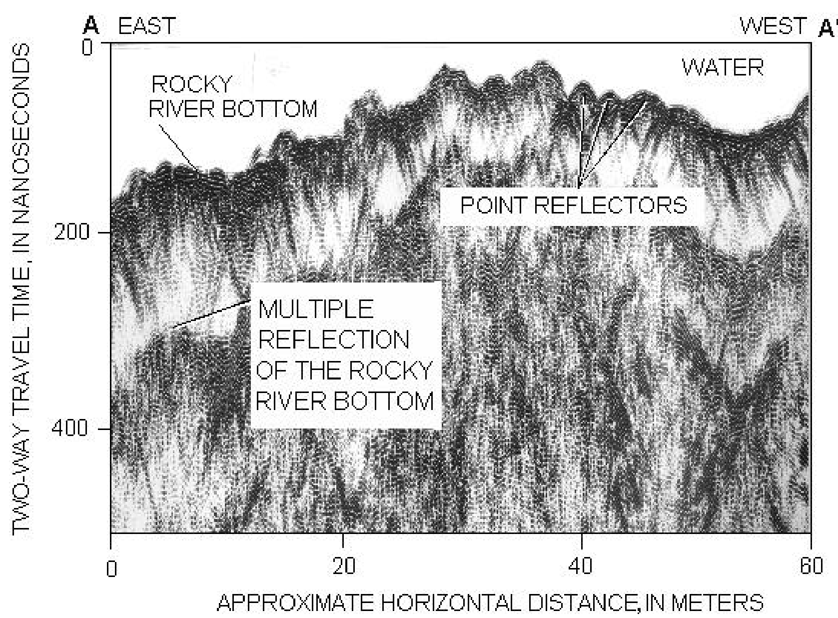


Figure 2. Ground-penetrating radar profile A-A' showing a rocky bottom in the Milford Dam impoundment, Milford, Maine, May 1999. (Location of profile shown in fig. A-1 in appendix.)

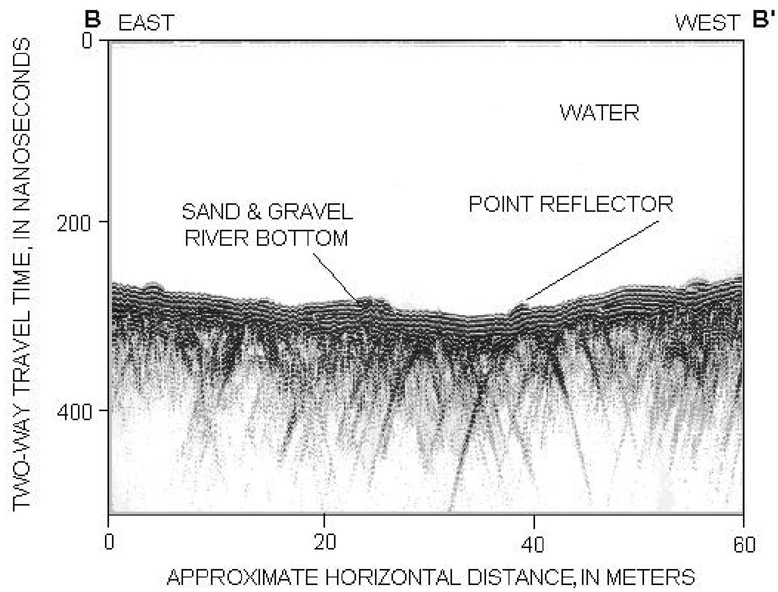


Figure 3. Ground-penetrating radar profile B-B' showing sand and gravel in the Milford Dam impoundment, Milford, Maine, May 1999. (Some point reflectors that represent rocks or debris, such as logs, are evident; location of profile shown in fig. A-1 in appendix.)

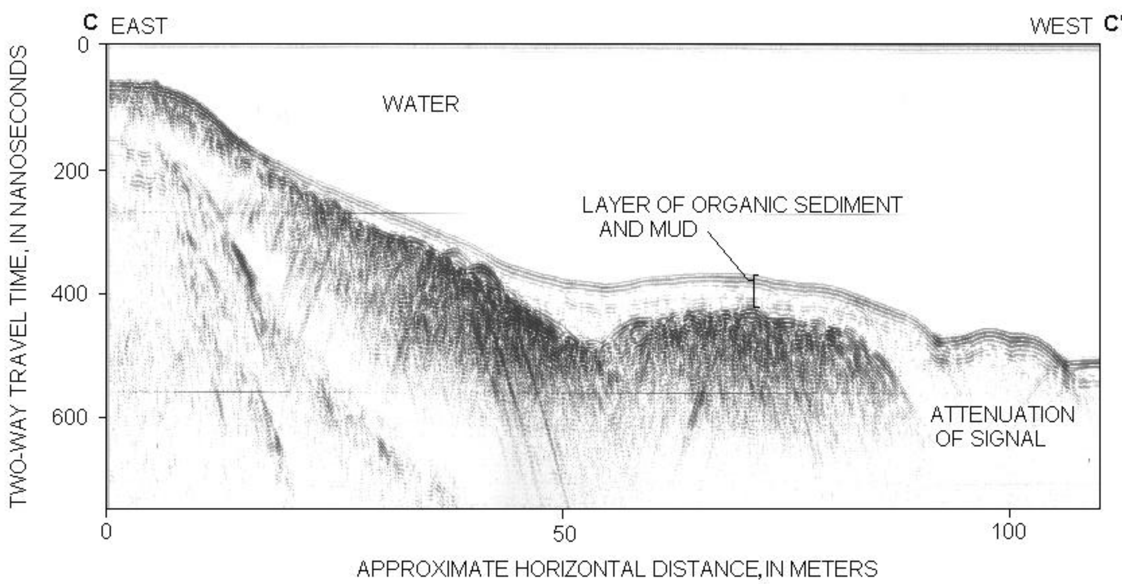


Figure 4. Ground-penetrating radar profile C-C' showing mud and organic sediment in the Mattaseunk Dam impoundment, Mattawamkeag, Maine, May 1999. (The hard substrate beneath the mud seems to disappear at the far right of the figure due to GPR signal attenuation by the mud; location of profile shown in fig. A-12 in appendix.)

Maps of the interpreted sediment types in the Penobscot River channel are shown in appendix figures A-1 through A-12. An index to the locations of these maps is shown in figure 5. The sediment-type classification scheme used in this study is the same as that used for sediment mapping in the Gulf of Maine (Barnhardt and others, 1998) and the Kennebec River (Dudley, 1999). The classification scheme defines 16 sediment types based on 4 basic units—rock (R), gravel (G), sand (S), and mud (M)—and 12 composite map units. The 12 composite map units represent combinations of the 4 basic units in which the dominant texture is greater than 50 percent of the area of the map unit (for example, Rs, Rg, Rm, Gs, Gr, Gm, Sg, Sr, Sm, Ms, Mg, Mr).

In appendix figures A-1 through A-12, the areas actually surveyed by GPR are represented by lines filled with solid colors. The unsurveyed areas, or inferred areas, are represented by lighter colored patterns. The inferred areas were not directly scanned with the GPR but rather represent a best guess on the basis of grab-sample information, visual observations, and field notes. The 40-ft width of the GPR lines on the figures represents the average uncertainty associated with the GPS location data for the transects (± 20 ft).

COMPOSITION AND DISTRIBUTION OF STREAMBED SEDIMENTS

Depositional and erosional areas are subject to change based on hydrologic and hydraulic properties and events. Depositional areas are those where sediment particles settle out of the water column because of low water velocities, gyres, and turbulence. The transported sediment, called suspended load, is dropped from suspension when a stream loses energy and can no longer transport sediment. Sediment is commonly deposited where a fast-moving stream enters a pond or lake (dam impoundment); where a tributary stream enters a large, slow-moving river; when discharge decreases; where the river channel widens; and where velocity is markedly reduced, such as downstream from islands, logs, boulders, and other obstructions.

Sediment is eroded in areas where the water velocity and turbulence is great enough to suspend and transport finer sediment types—leaving behind coarse sediment and an armored river bottom. Sediment is eroded when a stream increases in discharge, such as during a flood; where the river channel becomes constricted; where river-channel slope increases; and where moving water directly impacts the upstream face of islands, logs, boulders, and other obstructions.

Depositional and erosional areas are related to the physical and hydraulic features observed throughout the surveyed area. The main river channel typically consists of various mixtures of rock, gravel, and sand. Deposits of fine-grained sediment were found in thin bands along the shorelines of the mainland and the islands, where nonchannelized overland contributions of runoff enter the river, and in large areas at the downstream ends of islands and at the mouths of brooks and streams. The most extensive areas of deposition were in the Mattaseunk Dam impoundment, where the low velocities of the impoundment pond allow settling of suspended load. The sediment distribution in specific reaches along the Penobscot River is described in the following paragraphs, beginning at the downstream limit of the study area near Old Town and moving upstream to Medway.

The Old Town area includes Orono Island and the area around the southern end of Indian Island. These two areas are shown in detail in appendix figures A-1 and A-2. The sediments found along the eastern and southern end of Orono Island are shown in figure A-1. The sediments in the main channel are predominantly sand and gravel and become coarser at the northern (upstream) end of the island where the channel becomes predominantly gravel. A depositional zone of sand and mud is close to the shoreline of Orono Island and becomes more extensive along the southern (downstream) shoreline. The area near Indian Island (fig. A-2) is characterized by more gravel and rock, consistent with observations made in the 1995 SSS survey by PIN DNR (1997). The main channel around Indian Island is composed of various combinations of rock, sand, and gravel. A shallow area with deposits of sand and mud surrounds Grass Island; another relatively large deposit of sand and mud was observed nearby along the western shoreline of the Penobscot River.

Channel sediment in the Costigan area (fig. A-3) is predominantly gravel and rock but becomes less coarse near the shoreline and at the downstream end of Freese Island. Sand and mud is deposited along the western shoreline of the river and at the downstream end of Freese Island. The Costigan stretch of the river flows to the Old Town area through a number of rocky riffles.

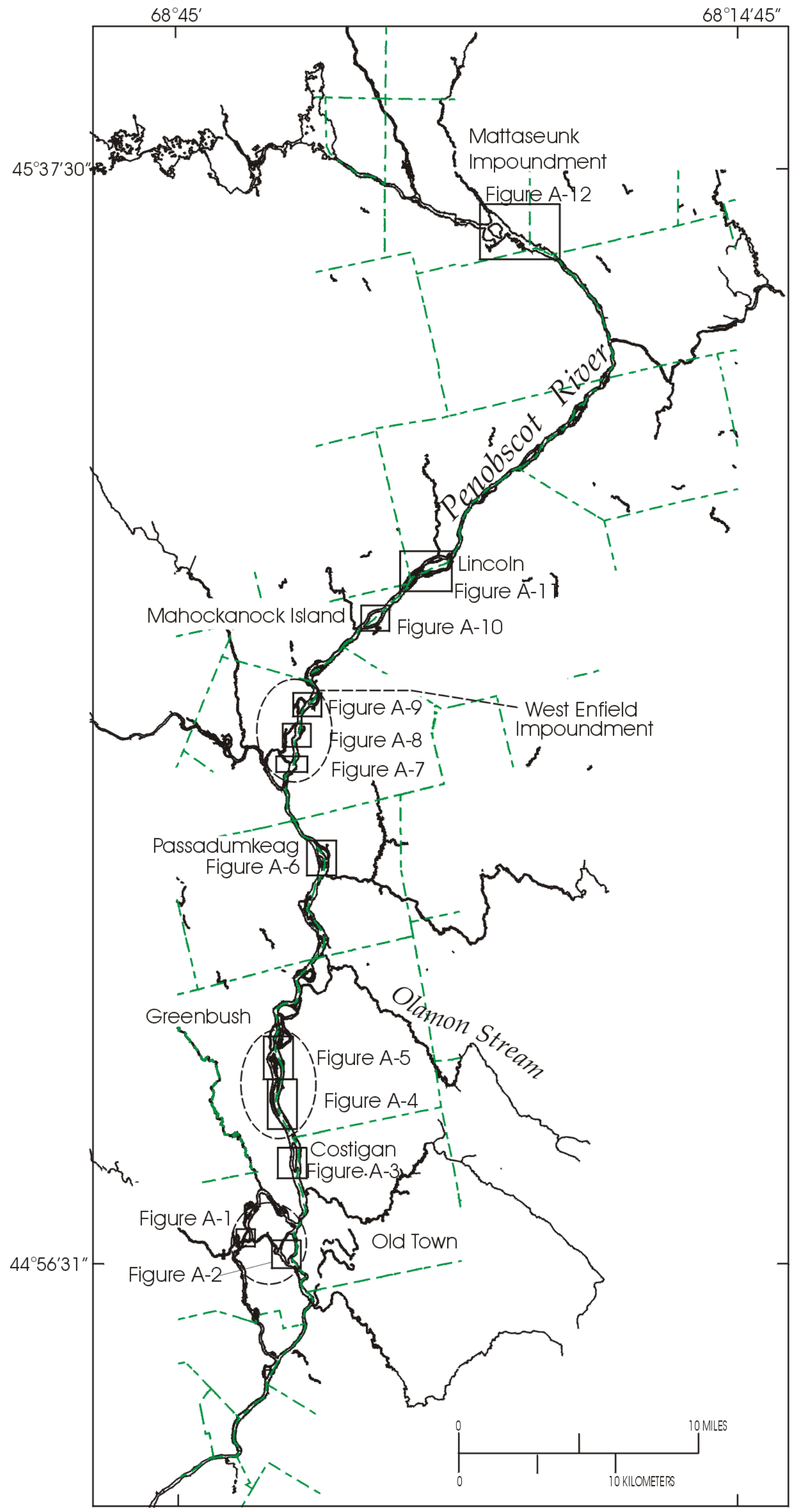


Figure 5. Index of locations of appendix figures A-1 to A-12.

The Penobscot River in the Greenbush area is physically complex, featuring numerous low-profile depositional islands, and is characterized by a variety of sediment types (appendix figs. A-4 and A-5). Gravel and sand are found in the broad main channels on each side of White Squaw Island (fig. A-4). Closer to shore, and at the more northern part of the area (fig. A-4), there are bands of sand and gravel and more sand. Sand and mud are deposited along the shorelines as point bars of both the mainland and the islands and at the downstream ends of the islands. A similar sediment-distribution pattern at the upstream end of the Greenbush area is shown in figure A-5. Again, sand and gravel are found in the middle of the channel between islands, and thin bands of sand and mud are found along the shorelines of the islands, particularly at their downstream ends.

The upstream stretch of river near the confluence with Olamon Stream (fig. 5), between the Greenbush and Passadumkeag survey reaches, was reconnoitered for potential geophysical surveying. Although no boat launches are available along this stretch of river, one location was accessible through a field between the highway and river. The river at this potential survey site was visually inspected and noted to have a predominantly gravel channel and multiple cobble riffles, making navigation by motorboat unfeasible.

When a river is fed a large load of sand and gravel, braided patterns are formed in the channel that create a maze of bars and depositional islands (Bates and Sweet, 1966). The depositional-island system of the Greenbush area resembles this pattern, as do, to a lesser extent, the Passadumkeag and Lincoln reaches farther upstream.

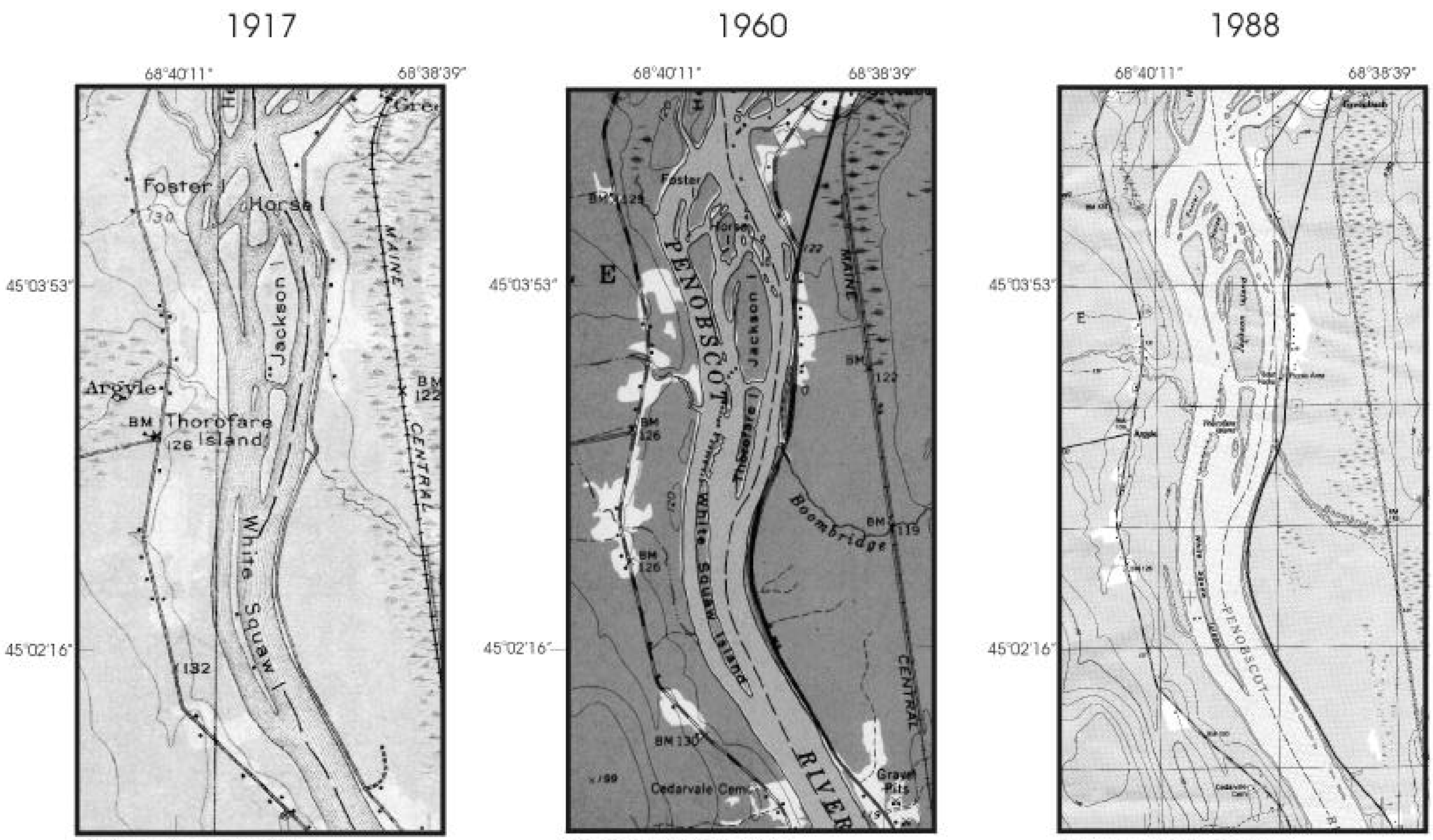
A series of topographical maps from 1917, 1960, and 1988 record some morphological changes in the Greenbush river reach (fig. 6). For example, at the northern end of White Squaw Island, islands in contact with a line of rock cribs formed and grew between 1917 and 1960. The most significant change in this area is the appearance of a series of depositional sand islands southeast of White Squaw Island between 1960–88. During the 1999 survey, these islands were in an area of the river channel composed of fine to medium sand. During low water, streamflow is cut off between these depositional islands and the main shoreline.

Farther north, the streambed-sediment types become coarser in the Passadumkeag area (figs. 5 and A-6). The areas surrounding the various islands shown in figure A-6 are composed of mixtures of rock, gravel, and sand. Sand and gravel is present in the main channel. The only sand and mud deposits observed are those along the western shores of Long Island and Hog Island.

Similarly to the Passadumkeag area, most of the sediments in the West Enfield area (figs. A-7, A-8, and A-9) are characterized by more rock and gravel than the sediment in reaches farther downstream. The impoundment immediately above the West Enfield Dam is shown in figure A-7. The western side of the main channel is rocky, bordered by a gravel-rock mix on each side. From west to east, the river channel becomes less coarse, changing to sand and gravel, and eventually forming a large deposit of mud and sand on the eastern side. Farther upstream, the main channel is again characterized by zones of predominantly rock and gravel with some sand (fig. A-8). The rocky substrate imaged by GPR correlates with the 1995 side-scan sonar observations made in this area by PIN DNR (1997). Deposits of sand and mud are found along each shoreline and at the mouth of Tate Brook. The northern limit of the West Enfield survey area is shown in figure A-9. The area around Gordon Island is almost entirely gravel and rock. Small areas of sand and mud are found along the shoreline where Gordon Brook flows into the Penobscot River. The area around Beatham Island consists of zones of sand and gravel. Small deposits of sand and mud were observed at the downstream end of the island.

The river channel around Mahockanock Island (fig. A-10) is composed of a mixture of gravel and sand of varying coarseness in the middle of the channel along the southeastern side of Mahockanock Island. Sand and mud are deposited along the shoreline of the island and the mainland and in the mouth of Pollard Brook. There is a small area of sand and mud in the middle of the channel.

In the town of Lincoln (fig. A-11), depositional areas are more extensive and less rocky, similar to the Greenbush area (fig. A-4). The main channel contains sand and gravel with deposits of sand and mud along the shorelines and at the downstream ends of islands. There is one area along the southern shoreline of the upstream end of Mattanawcook Island where the bottom becomes very hard with rock and gravel.



Base from U.S. Geological Survey topographical quadrangle, Greenbush Maine, 1917

Base from U.S. Geological Survey topographical quadrangle, Greenbush Maine, 1960

Base from U.S. Geological Survey topographical quadrangle, Greenbush Maine, 1988

SCALE
0 1 MILE
0 1 KILOMETER

Upstream from Lincoln, the Mattawamkeag River near its confluence with the Penobscot River was reconnoitered as a potential survey site. The river was shallow at the boat access, and the river channel was composed predominantly of gravel and cobbles with many boulders emerging above the water surface. The river banks were rocky throughout this stretch of river. Because of the rocky nature of the river and the shallow water, this site was not surveyed with GPR.

The Mattaseunk Dam impoundment (fig. A-12) is the upstream limit of the study area and contains the most extensive deposits of mud in the 50-mi river reach. The size of the impoundment was so large that the Mattaseunk area was only coarsely surveyed. The area is composed almost entirely of mud and sand, with gravel, rock, and sand in the narrow sections of the main channel. The deposits in the Mattaseunk Dam impoundment were different from the other deposits found at all other surveyed sites. Samples of the bottom material from the thick deposits in the impoundment yielded fine-grained sediment mixed homogeneously with fine wood fibers. The sediment sample taken near the Dam (appendix table A1, sample P70) was gray and brown, gelatinous, and had an objectionable odor.

The depth of deposition in the impoundment was much thicker at this site than any other surveyed site along the Penobscot River. Although no cores were collected to verify the thickness of sediment in the impoundment, the two-way travel times from the GPR record, converted to thicknesses using estimated radar-wave velocities (Markt,1988), indicate thicknesses that exceed 15 ft in some areas.

SUMMARY AND CONCLUSIONS

Depositional sediment types (sand and mud) in the Penobscot River are scattered along the shorelines of the mainland and the islands and in large areas at the downstream ends of islands and at the mouths of brooks and streams. The main areas of the channel tend to be composed of gravel and sand and rock. The largest areas of deposition of fine-grained material were found in the West Enfield and Mattaseunk Dam impoundments, although other large areas of deposition were found in the Greenbush, Mahockanock and Lincoln reaches. Conversely, the reaches of Passadumkeag and West Enfield (except the area immediately upstream from the West Enfield Dam on the eastern side of the channel) are predominantly rock, gravel, and sand.

Thick deposits at the Mattaseunk Dam impoundment site are likely the result of the size and location of the dam, which has produced a relatively large and deep reservoir. The large, deep impoundment has predominantly low velocities that allow fine-grained sediment to settle out of the water column and accumulate on the bottom. The Mattaseunk Dam impoundment also may receive, or has received in the past, high loads of suspended fine-grained sediment and (or) wood fibers. The sources of the wood fibers are likely to include the historical uses of the river for wood-product activities upstream from the impoundment.

The Milford and West Enfield impoundments do not have as heavy an accumulation of fine-grained sediment as the Mattaseunk Dam impoundment. This is most likely the effect of the narrow and shallow river channel, less ponding, and high-water velocities capable of transporting fine-grained sediment out of the impoundments. In particular, in the rocky West Enfield impoundment, deposits are present only on the edges of the main channel. These deposits may be thin because the input loads of fine-grained sediments and wood fibers to these impoundments are or were not as high as those of the Mattaseunk Dam impoundment, yielding less accumulated material.

The 1995–96 PIN DNR sediment survey used side-scan sonar to image large swaths of the river bottom; however, the imaging was limited to deep areas in the Penobscot River. The 1999 USGS sediment survey correlates with the findings of the PIN-DNR study. Both the GPR and SSS records show that the Milford Dam impoundment has a hard (rocks, cobbles, gravel) bottom in most places. The SSS could identify logs scattered along the bottom, whereas the same objects appear as point-reflectors on the GPR record—these can be interpreted as either rocks or logs. Both methods identify fine-grained sediment types near shorelines and at the southern end of Orson Island and Indian Islands. GPR surveys indicate a rocky river channel on the east side of Indian Island that matches SSS images of the same area.

Likewise, GPR records from this study correlate with SSS images obtained in the deep channel of the West Enfield Dam impoundment. Both methods indicate a heavily armored river channel with little sand. The GPR method, which can be used effectively in shallow areas, show that the streambed material in the deep part of the channel becomes increasingly fine-grained toward the shallow eastern side of the impoundment. SSS and GPR records also indicate that the southeastern side of Mahockanock Island at South Lincoln is composed largely of sand and gravel.

For the shallow-water conditions on the Penobscot River, the use of GPR provides a convenient way to map large areas of the streambed in a shorter time and at a greater resolution than could have been accomplished with a sampling program. Because the GPR record provides narrow lines of data, however, a relatively dense coverage of lines is required to adequately delineate the areal distribution of the streambed sediments. Furthermore, it is commonly difficult to distinguish between submerged debris (such as logs) and cobbles and rocks.

In contrast, SSS can image large swaths of the streambed, provided the water is deep enough to give the sonar a high vantage point over the bottom. SSS also can be used to determine the texture of the bottom by the strength of the reflected sound wave and the appearance of the image itself. A survey area also must be deep enough to prevent collision of the submerged SSS unit with underwater objects and debris. In a situation where penetration of sediment layers is of secondary concern and the study area is of sufficient depth, the use of SSS would greatly reduce the survey time and image the bottom more completely than GPR for an equivalent area. The areas surveyed for this study were not uniformly deep enough, except for parts of the dam impoundments, to safely use SSS.

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.

Bartlett, W.P., Higgins, W.B., and Lippert, R.G., 1992, Water resources data Maine, water year 1991: U.S. Geological Survey Water Data Report ME-91-1, 187 p.

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.

Bates, R. L., and Sweet, W. C., 1966, Geology—An introduction: Boston, D.C. Heath and Co., 367 p.

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).

Denny, C.S., 1982, Geomorphology of New England: U. S. Geological Survey Professional Paper 1208, 18 p., 1 pl.

Dudley, R.W., 1999, Riverbed-sediment mapping in the Edwards Dam impoundment on the Kennebec River, Maine, by use of geophysical techniques: U.S. Geological Survey Open-File Report 99-200, 7 p.

Fontaine, R.A., 1981. Drainage areas of surface water bodies of the Penobscot River Basin in central Maine: U.S. Geological Survey Open-File Report 78-556F, 92 p.

Haeni, F.P., Placzek, Gary, and Trent, R.E., 1992, Use of ground-penetrating radar to investigate refilled scour holes at bridge foundations, *in* Hanninen, Pauli and Autio, Sini, eds., Fourth International Conference on Ground Penetrating Radar, Rovaniemi, Finland, June 8-13, 1992, Proceedings: Geological Survey of Finland Special Paper 16, p. 285-292.

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

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.

Kelley, A.R., Kelley, J.T., Belknap, D.F., Sanger, D., 1988, Quaternary stratigraphy and geomorphology of the lower Penobscot River valley, *in* Field trip guide—Geological Society of Maine, summer meeting 1988: Geological Society of Maine, 7 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., Lippert, R.G., and Caldwell, J.M., 1997, Water resources data Maine, water year 1996: U.S. Geological Survey Water Data Report ME-96-1, 174 p.

———1999, Water resources data Maine, water year 1998: U.S. Geological Survey Water Data Report ME-98-1, 178 p.

Penobscot Indian Nation Department of Natural Resources, 1997, Penobscot Nation sediment evaluation project, Part 1—Riverbed characterization, 6/18/97, Draft Report: Penobscot Indian Nation Department of Natural Resources, 26 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.

U.S. National Oceanic and Atmospheric Administration, 1995, Climatological data, annual summary, New England: Washington D.C., U.S. Government Printing Office, v. 107, no. 13, 35 p.

———1998, Climatological data, annual summary, New England: Washington D.C., U.S. Government Printing Office, v. 110, no. 13, 35 p.

U.S. Bureau of the Census, 2000, 1997 Economic census of manufacturing, Maine: Washington D.C., U.S. Bureau of the Census, EC97M31A-ME, 140 p.

Appendix

Table A1. Location and description of grab samples of streambed sediments from the Penobscot River, Maine, May 24–26, 1999

Sample identification number	Latitude	Longitude	Description of samples
P1	44.9576	68.6858	silty sand and gravel; bark chips
P2	44.9604	68.6858	silt, sticks, organics
P3	44.9625	68.6866	silt, organics
P4	44.9594	68.6854	sand and gravel
P5	44.9510	68.6620	coarse sand to fine gravel
P6	44.9501	68.6616	silt, mud, organics (sticks, bark chips)
P7	44.9486	68.6612	silt, mud, organics (leaves, plant fibers, bark chips)
P8	44.9422	68.6514	silt, organics
P9	44.9448	68.6489	rocky, hard channel bottom
P10	44.9447	68.6490	silty sand, organics
P11	44.9985	68.6457	fine silty sand, organics
P12	44.9995	68.6472	small cobbles, rocks, sand, bark chips
P13	45.0102	68.6489	silt, mud, organics
P14	45.0103	68.6481	small cobbles, hard channel bottom
P15	45.0276	68.6507	sand
P16	45.0300	68.6525	sand with small amounts of silt
P17	45.0342	68.6555	coarse sand, bark chips, mussels
P18	45.0338	68.6595	mud, silt, organics
P19	45.0535	68.6584	sand and gravel, mussel shells
P20	45.0791	68.6549	sand, small bark chips
P21	45.0703	68.6692	sand and gravel, organic debris (sticks, bark chips, mussel shells)
P22	45.0635	68.6633	sand and gravel
P23	45.0581	68.6650	cobbles, hard channel bottom
P24	45.0510	68.6663	mud, silt, organics (leaves, bark chips, plant fibers)
P25	45.0378	68.6640	fine sand filled with bark chips, wood fibers
P26	45.0417	68.6620	coarse gravel and small cobbles
P27	45.0502	68.6624	coarse sand
P28	45.1902	68.6199	rocky, hard channel bottom, no sample retrieved
P29	45.1934	68.6194	sand and gravel, mussels
P30	45.1988	68.6202	silty sand, organics (grass and leaves)
P31	45.2014	68.6220	coarse gravel, small cobbles
P32	45.2050	68.6250	rocky, coarse gravel
P33	45.2521	68.6442	mud, silt
P34	45.2539	68.6441	mud, silt, some sand, some organics
P35	45.2537	68.6456	sand, cobbles, hard and sandy in spots, no complete sample retrieved
P36	45.2712	68.6458	mud, silt, some organics
P37	45.2713	68.6452	very rocky, no sample retrieved
P38	45.2717	68.6408	coarse sand, lots of organics (bark chips, roots, leaves)
P39	45.2739	68.6405	coarse sand, mussel shells, bark chips
P40	45.2769	68.6393	rocky, cobbles, coarse sand, incomplete samples retrieved
P41	45.2932	68.6345	gravel and sand

Table A1. Location and description of grab samples of streambed sediments from the Penobscot River, Maine, May 24–26, 1999--Continued

Sample identification number	Latitude	Longitude	Description of samples
P42	45.2918	68.6331	sandy silt, organics (plants, roots, bark chips)
P43	45.2910	68.6283	sand and gravel, some cobbles, aquatic plants
P44	45.2922	68.6251	hard-packed gravel, cobbles
P45	45.2931	68.6241	sandy silt, organics (plants, roots, bark chips)
P46	45.2929	68.6242	gravel, cobbles, sand observed closer to shore
P47	45.2960	68.6273	coarse to medium sand with some silt
P48	45.3476	68.5660	gravel and sand, some rocks
P49	45.3479	68.5666	gravel
P50	45.3476	68.5651	coarse gravel, small cobbles
P51	45.3407	68.5801	fine sand and silt, organics (bark chips)
P52	45.3401	68.5799	medium to coarse sand, pieces of wood
P53	45.3396	68.5797	gravel, cobbles and rocks, hard channel bottom, incomplete sample retrieved
P54	45.3640	68.5458	fine sand and silt, organics (grass, leaves)
P55	45.3653	68.5434	sand and gravel
P56	45.3658	68.5401	gravel and sand, cobbles
P57	45.3718	68.5361	medium to coarse sand
P58	45.3726	68.5303	mud, silt
P59	45.3723	68.5238	hard channel bottom, cobbles, coarse gravel, bark chips
P60	45.3742	68.5174	fine to medium sand, organics (fibrous material, sticks, bark)
P61	45.3753	68.5182	cobbles, hard channel bottom
P62	45.3840	68.5127	gravel, rocky
P63	45.3738	68.5354	fine to medium sand, well sorted, small mussel shells
P64	45.5932	68.4621	mud, silt, and wood fibers
P65	45.5917	68.4551	mud, silt, and wood fibers
P66	45.5863	68.4591	mud, silt, and wood fibers
P67	45.5802	68.4349	hard channel bottom, sand and cobbles with some silt
P68	45.5778	68.4375	mud, silt, with wood fibers throughout
P69	45.5748	68.4214	hard channel bottom, incomplete samples, sticks, silt, wood fibers, bark chips
P70	45.5716	68.4122	gelatinous mud, silt, and wood fiber matrix, heavy amounts of wood fibers

This figure can be downloaded from the USGS Maine District web site

Figure A-1. Streambed sediments near Orono Island, May 1999. (Map location shown in fig. 5.)

This figure can be downloaded from the USGS Maine District web site

Figure A-2. Streambed sediments near Indian Island in the Milford Dam impoundment, May 1999. (Map location shown in fig. 5.)

This figure can be downloaded from the USGS Maine District web site

Figure A-3. Streambed sediments near Freese Island, May 1999. (Map location shown in fig. 5.)

This figure can be downloaded from the USGS Maine District web site

Figure A-4. Streambed sediments in the southern part of the town of Greenbush, May 1999. (Map location shown in fig. 5.)

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Figure A-5. Streambed sediments in the northern part of the town of Greenbush, May 1999. (Map location shown in fig. 5.)

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Figure A-6. Streambed sediments in the town of Passadumkeag, May 1999. (Map location shown in fig. 5.)

This figure can be downloaded from the USGS Maine District web site

Figure A-7. Streambed sediments near the West Enfield Dam, May 1999. (Map location shown in fig. 5.)

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Figure A-8. Streambed sediments 1.5 miles upstream from the West Enfield Dam, May 1999. (Map location shown in fig. 5.)

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Figure A-9. Streambed sediments near Beatham and Gordon Islands, 3 mi upstream from the West Enfield Dam, May 1999. (Map location shown in fig. 5.)

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Figure A-10. Streambed sediments near Mahockanock Island, May 1999. (Map location shown in fig. 5.)

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Figure A-11. Streambed sediments in the town of Lincoln, May 1999. (Map location shown in fig. 5.)

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Figure A-12. Streambed sediments in the Mattaseunk Dam impoundment, May 1999. (Map location shown in fig. 5.)

District Chief
Maine District
U.S. Geological Survey
Water Resources Division
26 Ganneston Drive
Augusta, ME 04330

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