RESERVOIR SEDIMENTATION DYNAMICS: INTERPLAY AND IMPLICATIONS OF HUMAN AND GEOLOGIC PROCESSES

[1]Rebecca K.R. Ambers and [2]Beverley C. Wemple

[1]*Department of Environmental Studies, Sweet Briar College, Sweet Briar, VA 24595; rambers@sbc.edu, 434-381-6483*
[2]*Department of Geography, 94 University Place, 200 Old Mill, University of Vermont, Burlington, VT 05401; bwemple@uvm.edu*

ABSTRACT: Extreme lake-level drawdown for dam repair at Waterbury Reservoir on the Little River near Stowe, Vermont, in 2002 provided an opportunity to explore reservoir sedimentation dynamics subaerially. Sedimentation surveys were performed on the main (Little River) and east branches of the reservoir and at the Stevenson Brook tributary delta. Sediment yields (in tons/km^2/year) were calculated to be 244 for the reservoir watershed as a whole (281 km^2 area), 255 for the main branch watershed (261 km^2), 98 for the east branch (20 km^2), and 48 for Stevenson Brook (15 km^2). Differences in yields relate to differences in watershed land use, erodibility of soil parent materials, and rapid bank erosion on the Little River upstream of the reservoir. Observations were also made of the behavior and stratigraphy of reservoir sediment, especially in the Stevenson Brook delta. Stratigraphic evidence revealed transgression and regression related to a previous drawdown in the early 1980s. Rapid erosion of reservoir sediment by free-flowing streams above the low pool was also observed, and even minor storms produced major changes. Colonization of much of the reservoir bottom by vegetation did not appreciably slow erosion occurring from scour and bank failure along these streams. These observations have important implications for the rapid and enormous sediment release that may occur following removal of large dams having reservoirs with similar size and sediment accumulation as Waterbury.

INTRODUCTION

Sediment collected in natural lakes has long been used to learn about past watershed and lake conditions. Sediment in human-made reservoirs is increasingly used for the same purpose, although reservoir management and issues such as trap efficiency may complicate interpretation of the sedimentary record (Foster 1995; Rowan et al. 1995; Bradbury and Van Metre 1997; Ambers 2001). The effect of reservoirs and dams on rivers has also been the subject of considerable study (Williams and Wolman 1984; Ligon, Dietrich, and Trush 1995; Collier et al. 1996; Graf 1999). As a result, in recent years many (mostly small) dams in the United States have been removed (e.g., Doyle, Stanley, and Harbor 2003). Discussion now focuses on removal of some large dams in order to mitigate their impact on stream ecology and endangered species (Kareiva, Marvier, and McClure 2000; Bednarek 2001; Grant 2001; Pizzuto 2002; Hart et al. 2002).

In light of the environmental significance of dam removal and the usefulness of reservoir sediment for measuring such geologic processes as watershed sediment yield, opportunities to learn more about reservoir sedimentation dynamics are valuable. Studying such processes in the aqueous environment can be difficult, but when water levels are drawn down to expose reservoir sediment, standard techniques of sedimentology and stratigraphy can be employed to interpret depositional environments and processes (Duck and McManus 1994; Ambers 2005). Observations can also be made about sediment behavior under conditions that simulate dam removal. Draining the reservoir drops base level significantly, allowing tributary streams to flow freely again and mobilizing sediment.

One such opportunity presented itself at Waterbury Reservoir on the Little River in the northern Green Mountains of Vermont (Fig. 1). There are no plans to remove this dam, but during extreme drawdown for dam repair in 2002, areas normally under many meters of water were exposed, and streams above the low pool returned to a free-flowing state. Direct observations of reservoir sediment could be made on foot along stream banks and using a soil corer.

The purpose of this paper is to present the results of a sedimentation survey of Waterbury Reservoir and to summarize observations of sediment dynamics made during drawdown. The survey included both the main branch of the reservoir along the Little River and the east branch along Alder Brook. Special attention was paid to the delta of Stevenson Brook, a minor lake tributary, where a microcosm of sediment dynamics on the larger lake bottom was observed and stratigraphic interpretation of the reservoir's sedimentary record could be made. Our findings have important implications for the magnitude and rapidity of sediment remobilization that can occur within a large reservoir when local base level drops suddenly, as may happen during dam removal.

STUDY AREA

Waterbury Reservoir is located in north-central Vermont near the towns of Waterbury and Stowe (Fig. 1). Its earthfill dam (643 m long and 57 m high) was completed in 1938 on the Little River, a tributary of the Winooski River that flows west into Lake Champlain. The reservoir has a surface area of 3.4 km^2 at normal summer pool elevation (180.4 m) and is used for flood control, hydroelectric power generation, and recreation. During most of the period between September 2000 and September 2006, water level was kept at 167.6 m while dam repair was planned and carried out; but for the initial summer 2002 repair season, levels were dropped as
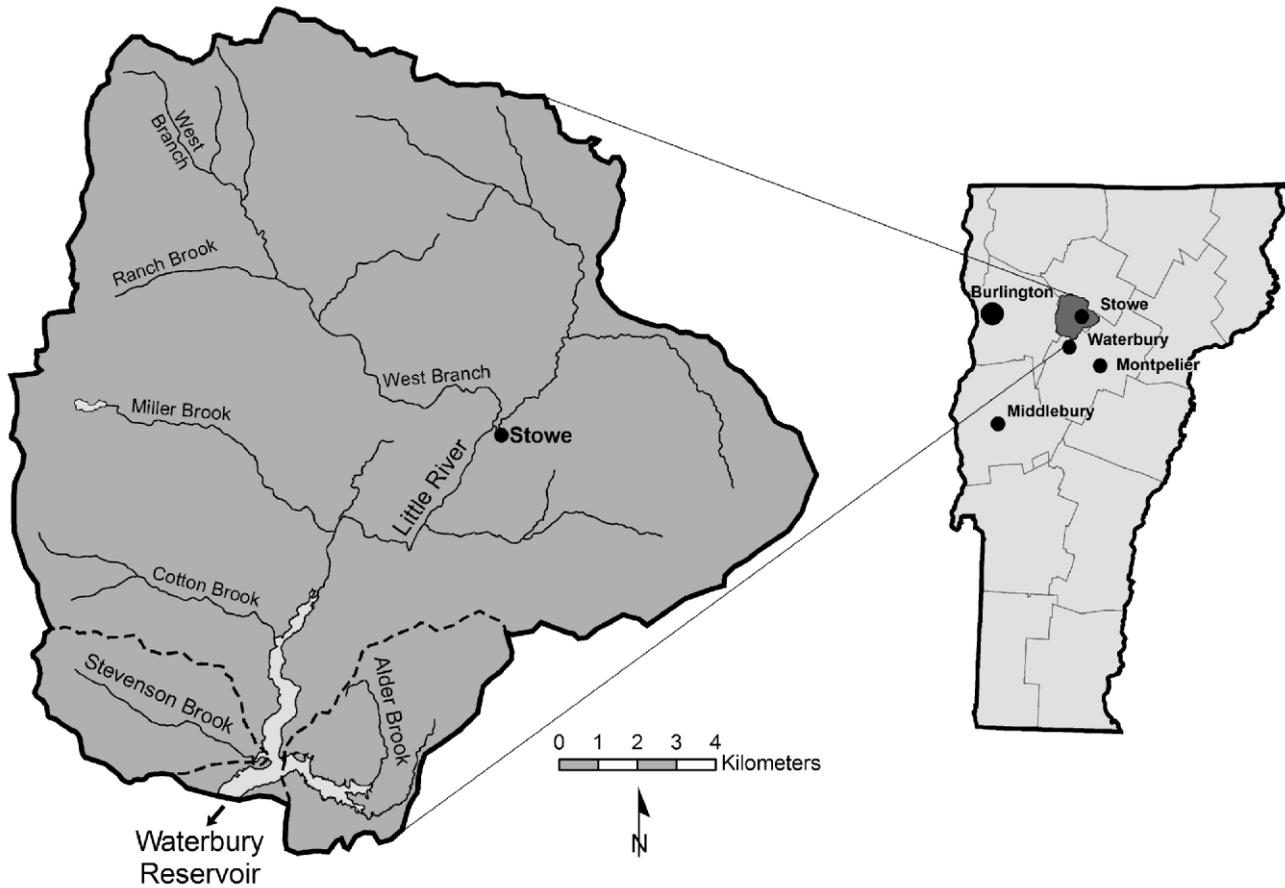
Figure 1. Location and major features of the Waterbury Reservoir watershed and the studied subwatersheds within it.

Figure 2. Waterbury Reservoir looking upstream from the dam during extreme drawdown for dam repair in early August 2002. Water level elevation shown is approximately 157.6 m, compared to a typical summer elevation of 179.8 m, shrinking the lake to <20% of its normal area.

low as 157.7 m, resulting in a low pool area of only 0.6 km² (Fig. 2).

The reservoir's watershed (281 km² in area) encompasses part of southern Lamoille, eastern Chittenden, and northern Washington counties. Much of the watershed is mountainous with elevations as high as 1339 m, but the valleys of the Little River and other large tributaries are wide (mostly 0.5 km but up to 1.6 km across) with fairly flat topography. Geologically, the soils of the watershed

are primarily developed on glacial materials ranging from dense till on the mountainsides to better-sorted outwash and glacio-lacustrine deposits in the valley bottoms. Recent alluvium is also abundant in major valleys. Larger valley bottoms are commonly used for agriculture, and sand and gravel mining has also taken place. Housing, transportation, and recreational development in the area is increasing, especially around Stowe and in the ski areas along the northwestern rim of the watershed.

Within the larger reservoir watershed, the Stevenson Brook basin (15 km^2) reaches a maximum elevation of 1036 m. It is located entirely within the Mount Mansfield State Forest and contains most of the Little River State Park that provides visitors with reservoir access and camping opportunities. The east branch of the reservoir is fed primarily by Alder Brook and Bryant Brook and is within a lower-relief, 20-km^2 basin containing the village of Waterbury Center.

METHODS

Field trips were first taken to the reservoir during maximum drawdown in early August and again in late September 2002. At that time, much of the exposed lake bottom was walked and interesting features photographed, and a detailed survey was made of the Stevenson Brook delta. Soil coring and stream bank cuts through deltaic sediments were used to measure reservoir sediment thickness, and a global positioning system (GPS) receiver and measuring tape were used to determine location and distance for mapping. In September and October of 2002 as water level elevation was returning to 167.6 m, another survey was done on foot in the east branch of the reservoir with a GPS and gouge auger type of soil corer to directly measure lake sediment thickness at 76 coring locations.

Lake sediment can be distinguished from pre-lake soil and glacial deposits by its color, grain size, consistency, organic matter, and layering. The observation of modern artifacts such as a tent and a plastic bottle buried meters deep confirmed the distinction.

The sedimentation survey on the main branch of Waterbury Reservoir was performed during summer 2004 from a boat using a Vixilar LC-10® depth sounder and Trimble GeoExplorer 3® GPS to record depth and location on 28 transects across the lake on an approximately 50 x 100 m grid for a total of 280 measurements. Exact lake level elevation during the survey was provided by dam managers so that water depths could be converted into elevation values. GPS positions were collected using manufacturer recommended settings of SNR5 and PDOP6 and yielded corrections with positional accuracies of <4 meters in all cases. Depth soundings have a nominal precision of ±3 cm, based on manufacturer specifications. We estimated accuracy of depth soundings to be ±10 cm based on a set of 50 manual depth measurements made with a weighted,

calibrated rope and compared to digital recordings in sections of the reservoir ranging from 4 to 8 meters water depth. Accuracy of any depth measured by the sounder is affected by water depth and sediment density which varied across our survey domain.

Depth and x-y location data were used to create a bathymetric map of the modern lake bottom using ArcGIS 9.1® geographic information system (GIS) software. Sediment volume was determined by comparison of modern bathymetry to a digitized, pre-lake topographic map surveyed by the U.S. Army Corps of Engineers in preparation for dam construction circa 1935. Because the pre-lake topographic map sheet for the east branch of the reservoir was missing from Army Corps archives, we were not able to use the bathymetric approach for that area.

ArcGIS software with 3D Analyst and Spatial Analyst extensions was used to create triangulated irregular network (TIN) surfaces out of the two bathymetric maps of the main reservoir branch using the Delaunay triangulation method, calculate the volume difference between them, and generate an isopach map showing sediment thickness. This software was also used to convert core thickness and location data from the east branch and Stevenson Brook delta into TIN surfaces and isopach maps from which sediment volume could be measured and displayed. Sediment thicknesses generated from the bathymetric survey appear to match well with direct observations made of the lake bottom above the low pool during drawdown.

To convert sediment volume to mass, six cubes of lake sediment of measured dimensions were cut from reservoir bottom exposures. Two samples each were taken of (a) sandy/gravelly, (b) organic-rich, and (c) fine-grained laminated reservoir sediment. The samples were oven-dried at 105°C then weighed. The volume of each sample was calculated from its original dimensions and divided by its dry mass to obtain bulk density. Sediment volumes from the different surveys were then multiplied by average bulk density to obtain sediment mass. Sediment yield was calculated by dividing sediment mass by watershed area and the time between reservoir construction and survey date (64-66 years).

Further GIS analysis of the watershed was performed using the U.S. Geological Survey (USGS) National Land Cover Dataset, digital USGS topographic maps, USGS digital elevation models (DEMs), digital aerial orthophotos, and Natural Resources Conservation Service soil survey datasets for Washington, Lamoille, and Chittenden counties in Vermont. Within watershed boundaries, the area under different land covers and underlain by different soil parent materials was measured and average slope calculated. The Little River and two major tributaries upstream of the reservoir were digitized on both the 1968 Stowe topographic quadrangle map and on 1996 orthophotos to measure how stream sinuosity and length have changed over time.

RESULTS AND DISCUSSION

Sedimentation Surveys and Sediment Yield

The bulk density measured for lake sediment samples of different types is reported in Table 1. The average value of 1.0 ton/m³ is in the middle of the range of 0.8-1.2 tons/m³ commonly measured or estimated for reservoir sedimentation surveys (Dendy and Champion 1973) and so was deemed appropriate, as well as convenient, for

estimating sediment mass. It also fits with qualitative field observations that reservoir's sediment is predominately clayey silt interbedded with layers that are coarser or more organic-rich.

The results of the sedimentation surveys are presented in Table 2 and Figure 3. Altogether, Waterbury Reservoir contains approximately 4.5 million m³ of sediment, 97% of which resides in the main branch. Sediment thickness is greatest near the dam and along the old channels of the

Table 1. Bulk density of reservoir sediment samples.

Sediment type	Bulk density (tons/m³)
sandy organic matter	0.6
laminated clayey silt	0.9
sand and gravel	1.4-1.8
average:	1.0

Table 2. Sedimentation survey results, assuming a bulk density of 1.0 ton/m³.

Watershed	Sediment volume (m³) and mass (tons)	Sediment yield (tons/km²/year)
Waterbury Reservoir (all)	4,530,000	244
Main branch of reservoir	4,410,000	255
East branch of reservoir	125,000	98
Stevenson Brook	47,200	48
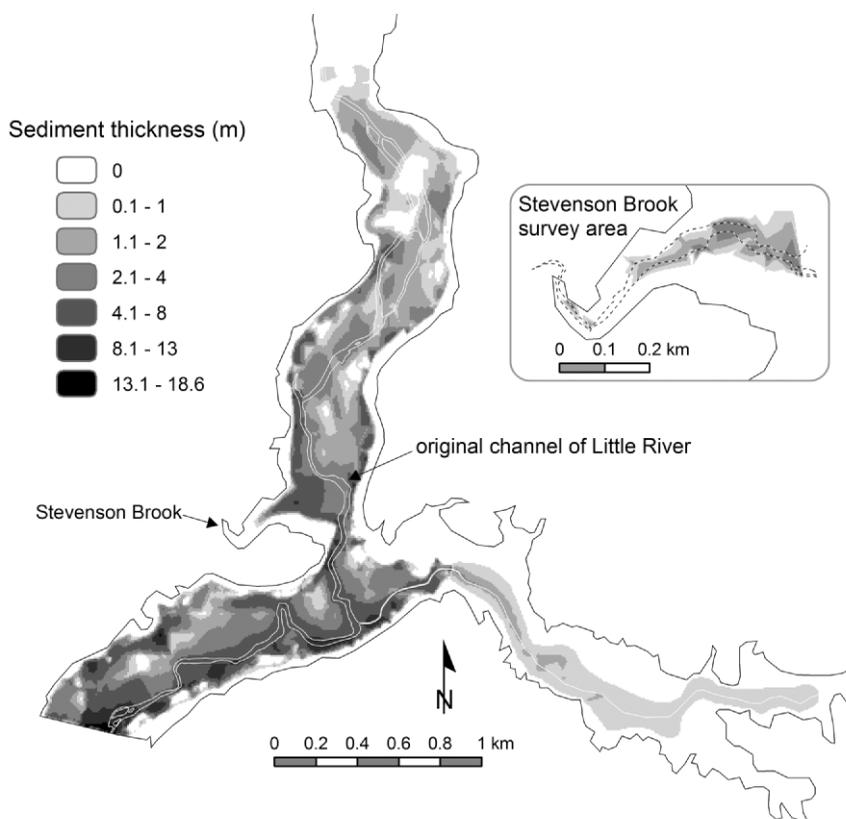
Figure 3. Isopach map showing sedimentation survey results for the main and east branches of Waterbury Reservoir performed using bathymetric and sediment coring methods. Pre-lake locations of the Little River and Alder Brook are shown with white lines. The inset map shows details of the Stevenson Brook delta survey as performed during reservoir drawdown in 2002.

Little River (Fig. 4). Very little lake sediment was observed in the upstream end of the reservoir, perhaps due to annual winter drawdown of water levels combined with an earlier extreme drawdown event discussed below. Average sediment thickness over the 3.4 km² area of the lake bottom is 1.34 m. At the typical summer pool elevation of 179.8 m, the reservoir lost 11% of its capacity in 66 years.

Sediment yield ranges from 48-255 tons/km²/year for the different watersheds (Table 2). Note that these values assume a reservoir trap efficiency (the percentage of sediment input into the lake that remains there) of 100%. In reality, some suspended sediment is lost in the outflow (enough to make the outflow quite turbid during the dam repair phase), but sediment trap efficiency is notoriously difficult to measure

or even estimate. The sediment yields we report are thus minimum values, with actual values greater by 10-20% or more (Brune 1953; Verstraeten and Poesen 2000). If the amount of organic matter (leaves, wood, etc.) in reservoir sediment is taken into account, however, the mass of inorganic sediment may be 5-20% less than reported values (Ambers 2001; Rowan et al. 1995). These issues consequently tend to cancel one another out, but a yield error of ±10-20% seems likely given these uncertainties.

In the northeastern United States, sediment yield values have been obtained for a number of different sized watersheds using a variety of methods (Fig. 5). Sediment yield is usually predicted to decrease with increasing drainage area because of increased sediment storage opportunities

Figure 4. Thick exposure of thin-bedded reservoir sediment in the left bank of the Little River approximately two-thirds of the way up the reservoir from the dam. Person used for scale is 1.78 m tall.
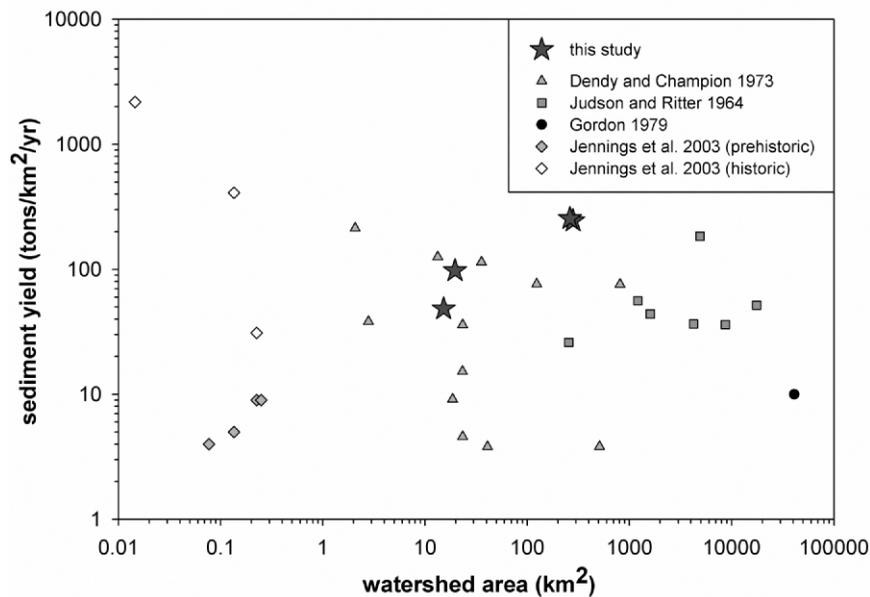
Figure 5. Relationship between sediment yield and watershed area for locations in the northeastern U.S. The height of the star symbols used to plot data from this study equals or exceeds 20% error on each value. Data collection methods include reservoir and estuarine sedimentation (Dendy and Champion 1973; Gordon 1979), subaerial fan sedimentation (Jennings et al. 2003), and stream sediment load monitoring (Judson and Ritter 1964).

(Walling and Webb 1983). In this region, such a pattern is not observed (Fig. 5). Sedimentation studies indicate that yields for 12 reservoir watersheds from New Jersey to Maine ranged from 4 to 214 tons/km^2/year, averaging 60 tons/km^2/year (Dendy and Champion 1973). Other reservoir studies in the Susquehanna River basin found an average of 36 tons/km^2/year (Williams and Reed 1972). Estuarine sedimentation in Long Island Sound indicates that sediment yield has averaged 10 tons/km^2/year for the past 8000 years (Gordon 1979). Similarly, sediment accumulation on several alluvial and debris fans throughout Vermont was used to calculate an average sediment yield of 4-11 tons/km^2/year for the Holocene, while historical rates were up to 100 times higher (Jennings et al. 2003). Three ponds in New Hampshire and Massachusetts also showed sharply increased sedimentation rates after European settlement began around 250 years ago (Francis and Foster 2001).

Stream sediment monitoring on very small watersheds at the Hubbard Brook Experimental Forest in the White Mountains of central New Hampshire between 1966 and 2000 show average yields of 1-6 tons/km^2/year (Martin 2007). A similar bedload yield of 2 tons/km^2/year was measured for the small, undisturbed Birch Brook catchment of northwestern Massachusetts (Ouimet and Dethier 2002). Suspended sediment monitoring during 2001-03 in the watersheds of Ranch Brook (9.6 km^2, forested) and upper West Branch (11.7 km^2, mostly forested with a ski resort) on the northwestern rim of the Waterbury Reservoir drainage basin found yields of 6 and 16 tons/km^2/year, respectively (Wemple et al. 2007).

In this study, the Stevenson Brook watershed has the lowest sediment yield, while the east branch has an intermediate value (Table 2). These represent 19% and 38%, respectively, of the yield of the Little River in the main reservoir branch. Variation in yield between subwatersheds is likely due to a combination of land use, soil/sediment erodibility, and geomorphic instability of the Little River upstream of the reservoir.

The Stevenson Brook basin has the highest percentage of land area underlain by glacial till and dense glacial till, which in this area is cohesive and not easily eroded (Stewart and MacClintock 1970; Larsen et al. 2003) (Table 3). It is also the most heavily forested subwatershed. Despite its high average slope, forest cover and erosion-resistant soils contribute to a low sediment yield.

In contrast, the east branch and main stem watersheds contain abundant deposits of more easily eroded glacial outwash, glacio-lacustrine sediments, and recent alluvium in major valley bottoms. Those same areas tend to have agricultural land use and a notable amount of development, making them more susceptible to erosion despite their lower average slopes. The sediment yield of these subwatersheds is thus two to five times higher than that of Stevenson Brook.

Land cover and soil type alone do not explain why the main branch of the reservoir has a sediment yield so much higher than in other parts of the watershed, however. Extensive bank erosion and sediment transport are being generated by active channel migration on the Little River upstream of the reservoir and, to some extent, its West Branch tributary. Channel location and length have changed significantly over time, as seen by digitizing the centerline of the streams on the 1968 Stowe 1:24,000-scale topographic quadrangle map and aerial orthophotos taken in 1996 (Fig. 6). The only measured reach to decrease in length over that 28-year period is one on the Little River that runs through a wetland area. Reaches on the Little River above its confluence with West Branch increased in length and sinuosity by as much as 23%, while reaches downstream and on West Branch

Table 3. Land characteristics for the studied watershed areas.

	Waterbury Reservoir (all)	Main branch of reservoir	East branch of reservoir	Stevenson Brook
Watershed area (km^2)	281	261	20	15
Average slope	32°	33°	23°	38°
*Land Cover:**				
forest	86.7%	87.5%	75.2%	99.2%
agricultural & shrub land	7.7%	7.3%	13.2%	0.2%
developed	2.8%	2.4%	8.0%	0.1%
wetlands	1.9%	1.9%	2.6%	0.5%
bare rock, quarries	0.9%	0.9%	0.9%	0.0%
*Soil Parent Material:**				
glacial & dense glacial till	80.1%	80.6%	73.5%	96.9%
glacio-lacustrine deposits	4.6%	3.6%	17.9%	0.0%
outwash	8.5%	8.7%	4.9%	1.8%
alluvium	1.9%	1.9%	1.7%	0.4%
organic deposits	0.4%	0.4%	0.4%	0.0%
miscellaneous	4.5%	4.7%	1.6%	1.0%

*Expressed as a percentage of land area
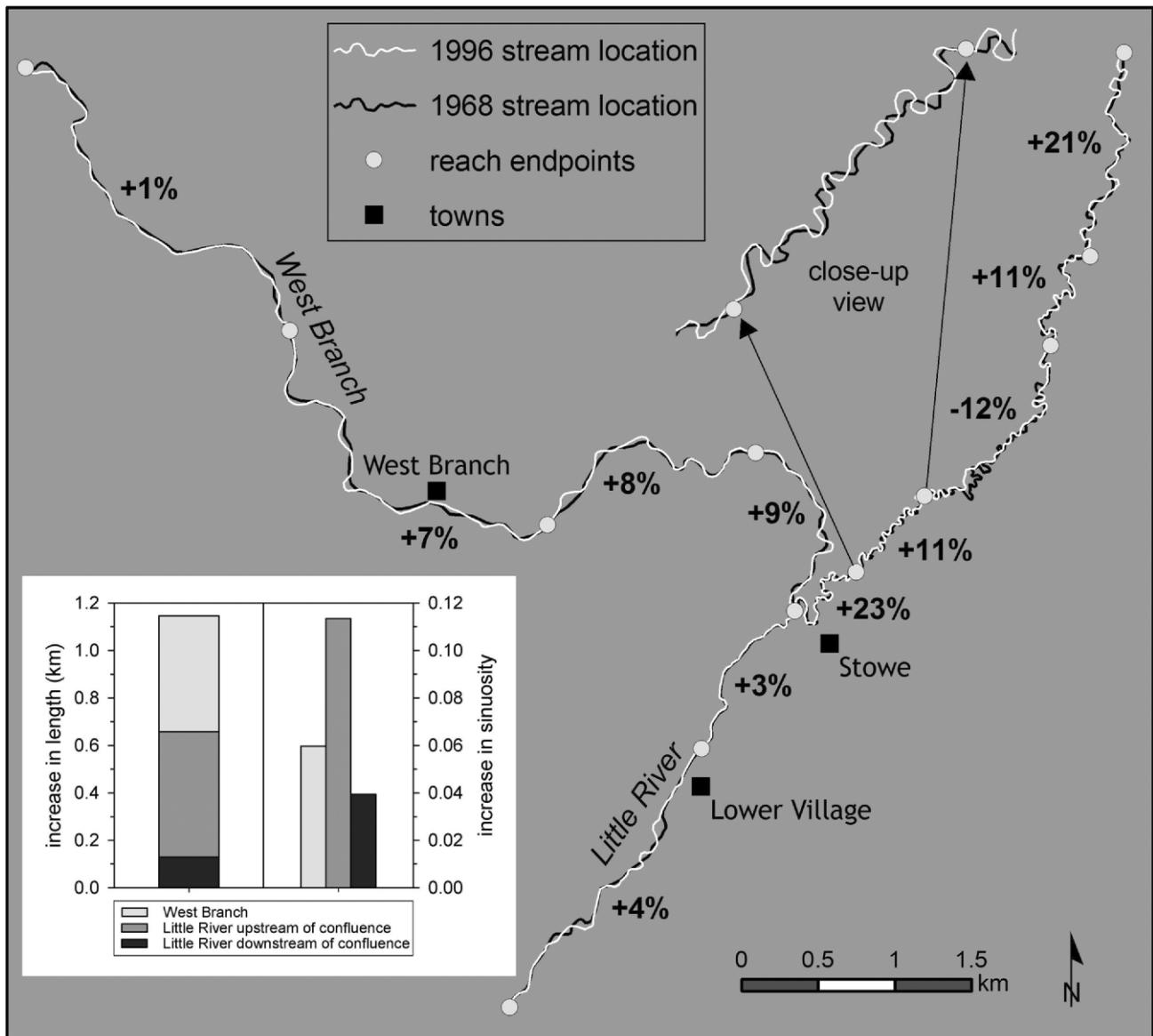
Figure 6. Map showing channel migration of West Branch and the Little River upstream of Waterbury Reservoir between 1968 and 1996 based on digitizing of a topographic map and aerial orthophotos. The percentages shown beside each reach indicate the change in length (and thus sinuosity). The inset graph summarizes results for the three major stream sections.

increased as much as 9%.

For a stream at equilibrium, erosion and deposition are balanced during channel migration. In this system, though, channel length increases are large enough to indicate that erosion dominates. Material winnowed and moved to create longer channels likely contributed an abundance of sediment to Waterbury Reservoir over past decades, elevating the sediment yield from this part of the watershed far above that of other adjacent subwatersheds.

Reservoir Sedimentation and Erosion Patterns

Within the reservoir itself, sedimentation and erosion

processes observed during extreme drawdown in 2002 serve both to explain patterns of sediment distribution on the lake bottom and to illustrate the rapidity of sediment transport when formerly stagnant areas become free flowing streams again.

During the normal annual management cycle of the reservoir, water levels are dropped approximately 10 m during the winter to provide sufficient capacity for flood control of spring snowmelt. This drawdown occurs when snow and ice protect much of the exposed reservoir bottom from erosion, but any sediment that has accumulated in the Little River channel at the upstream end of the reservoir is shifted further downstream. During the first phase of

dam repair in late summer 2002, however, water levels were dropped 28 m below the normal summer elevation, exposing areas of the lake bottom that had not seen the light of day for many years.

The result was rapid erosion of reservoir sediment deposits by the now free-flowing streams. Above the low pool, the Little River became choked with sediment and took on a braided morphology (Fig. 7) unlike its pre-lake meandering (or possibly anastomosing) form shown on Figure 3. Even small storm events resulted in significant reworking of lake-bottom deposits. Rapid downcutting of the Little River resulted in the formation of nickpoints along the course of many tributary streams, such as Stevenson Brook (Fig. 8a), and tributary deltas became heavily dissected. Sediment eroded from the reservoir bottom was shifted downstream to collect in the low pool area.

Steep stream banks experienced mass wasting, especially where fine-grained sediment drained and dried out (Figs. 8b and c). There, deep mudcracks formed, creating irregular blocks that were undercut and eroded en masse by the Little River. Where springs and seeps formed as reservoir sediments drained, water saturation led to liquefaction and mass movement (Fig. 8d). The rapid colonization of the exposed reservoir bottom by grasses and herbaceous plants likely reduced sheet wash but did little to slow streambank erosion. Roots were too shallow to have much effect along channel margins, and flooding scoured riparian zones of newly sprouted vegetation.

Rapid transport of fine-grained reservoir sediment is not unexpected, but even coarse-grained deposits of gravel and cobbles along high-gradient reservoir tributaries showed evidence of remobilization. In the upper Stevenson Brook delta over a period of less than six weeks, buried logs became significantly more exposed as bar material was moved downstream (Figs. 8e and f). As a result, a veneer of stream gravel was laid down on top of old reservoir deposits closer to the Little River (Fig. 8a). Hydrologic records for Waterbury Reservoir and its outflow on the Little River indicate that no sizable flood events occurred during this time, with peak discharge only reaching 23% of the mean annual flood and lake levels held nearly steady.

Stratigraphy of Stevenson Brook deltaic deposits indicates that the processes we observed on the reservoir bottom had happened there before. During water years 1981-86, reservoir managers tried to hold water levels approximately 18 m below normal summer pool for dam safety evaluations (Fig. 9a). Fluctuations occurred due to flood control, but the lake was almost completely drained on three occasions in 1981, 1984, and 1985 before normal management resumed in 1987.

Erosion of the Stevenson Brook delta during the 2002 drawdown exposed evidence of the events of the 1980s and earlier (Fig. 9b). At the base of the stream bank, cut tree stumps (cut date likely corresponding to reservoir construction in the mid-1930s) protruded from pre-lake soil. Overlying these stumps were typical, laminated, fine-grained reservoir sediments containing layers of leafy organic matter. The top of this unit was irregular and scoured, indicating an erosional unconformity, and

Figure 7. Braided form of the Little River on the reservoir bottom due to erosion of lake sediment during extreme reservoir drawdown in early August 2002. View is looking upstream from Little River State Park near Stevenson Brook, and channel width is approximately 30 m.
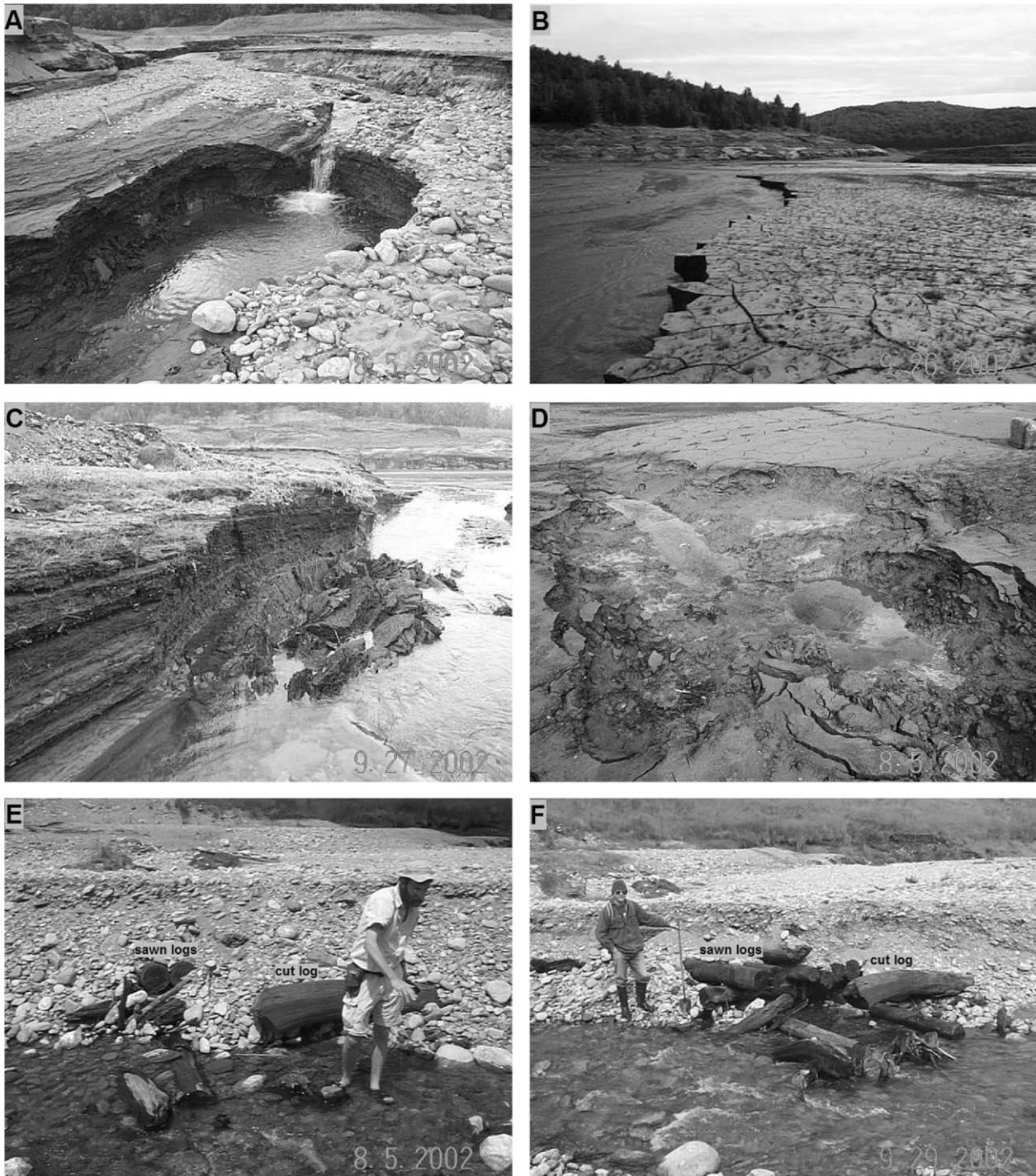
Figure 8. Erosional features observed on the lake bottom during extreme drawdown. (A) Meter-high nickpoint in reservoir sediment with later gravel/cobble veneer laid down by Stevenson Brook. (B) Deep mudcracks in exposed reservoir sediment and resulting bank erosion of irregular blocks along the Little River. Bank height is approximately 1 m. (C) Bank collapse along Stevenson Brook near its confluence with the Little River. Bank height is approximately 1.5 m. (D) Liquefaction and caving where a small spring has saturated lake sediment. Maximum width of collapse area is approximately 4 m. (E) Logs buried in a cobble bar in the Stevenson Brook delta on August 5, 2002, and (F) again on September 29, 2002, showing increased exposure due to bar erosion.

overlain by coarse stream gravel. The unconformity represents the lowering of lake level during the 1980s and subsequent erosion of lake sediment. As was seen in 2002, remobilization of upstream bars by Stevenson Brook coated downstream areas with gravel and cobbles. After lake levels were brought back up again in 1986, the brook delta
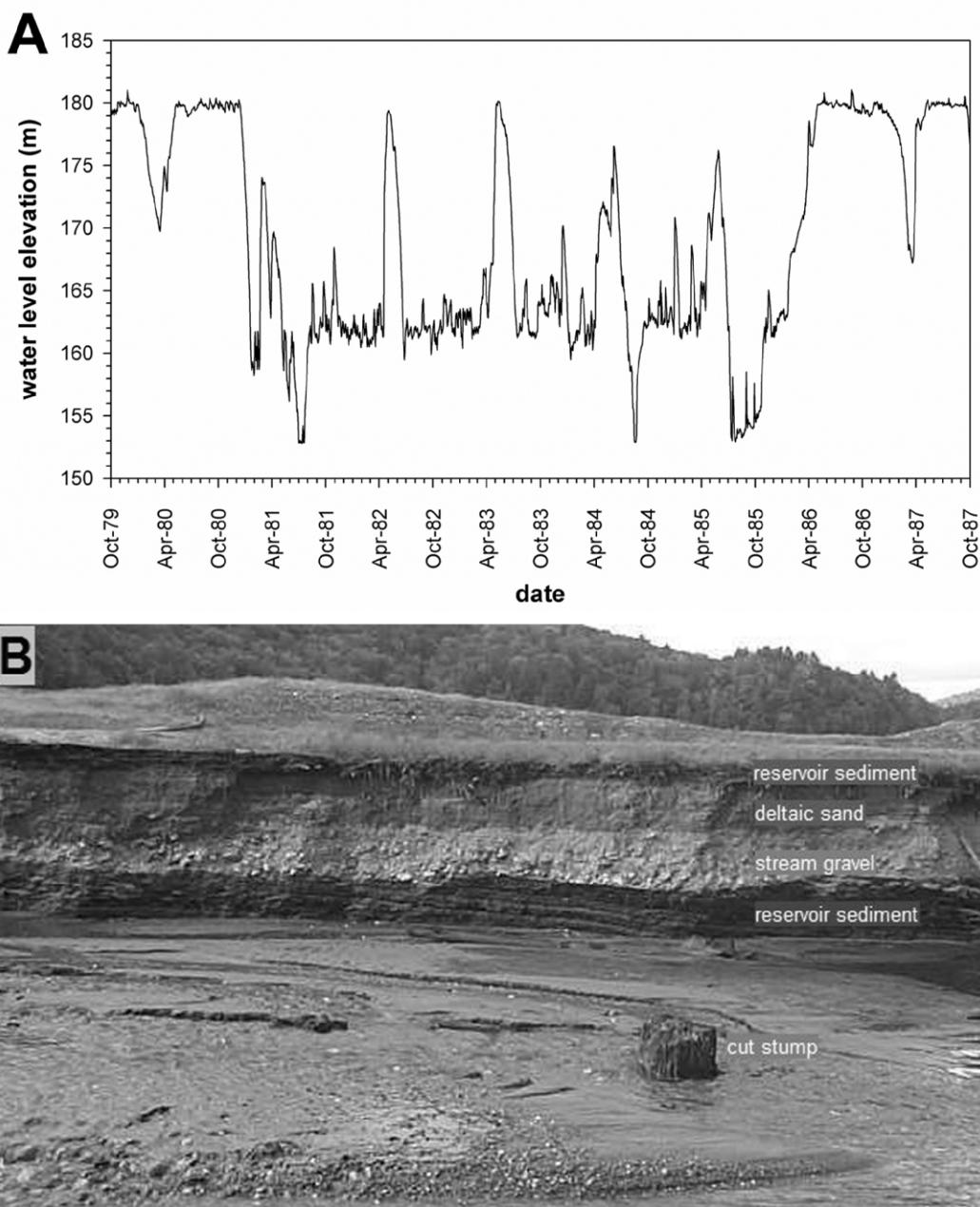
Figure 9. (A) Variation in Waterbury Reservoir water level elevation during normal operation (water years 1980 and 1987), which allows for flood control of spring snowmelt, and the drawdown phase that occurred in water years 1981-86 due to concerns over dam safety. (B) Stream bank cut (3 m tall) in the Stevenson Brook delta illustrating the stratigraphy of high water, regression, and transgression that occurred before, during, and after reservoir drawdown in the 1980s.

prograded over the gravel layer, resulting in a fining upward sequence containing abundant sand. The section was then capped by more organic-rich, laminated to thin-bedded reservoir sediment representing full pool deposition.

The general pattern of deposition and erosion observed in the Stevenson Brook delta is repeated on streams around the reservoir bottom. Material eroded from small tributary deltas during extreme drawdown contributes relatively little sediment volume to the low pool area, however, as these streams are dwarfed by the size and sediment input of the Little River. Sedimentation associated with the Little River is the most complex because it is by far the largest stream and the one most directly affected by reservoir management. Fluctuations in water level shift the location of deltaic deposition and move large quantities of sediment to the low pool during extreme drawdown events. Backwater areas along the margins of the main valley appear relatively protected from erosion during drawdown and thus retain great thicknesses of reservoir sediment (Fig. 3).

Drawdown as an Analog for Dam Removal

While the total amount of reservoir sediment erosion that occurred during the 2000-2006 drawdown was not quantifiable using the methods employed in this study, qualitative observations impressed viewers with the magnitude and rapidity of material transport. Although there are no such plans for this reservoir, should a dam like Waterbury be removed so that there was no low pool area to collect sediment and the entire main river became free-flowing, the massive quantity of sediment potentially mobilized could have a major impact on downstream reaches. Even with the dam in place, high outflow turbidity during the Waterbury drawdown raised concerns about the impact on water quality. Add a bedload component to the suspended load, and major changes in stream morphology and aquatic habitat could result. These types of changes have been observed following the removal of much smaller dams and are predicted by models (Simon 1989; Simon 1992; Doyle, Stanley, and Harbor 2003). If the lake sediment happened to be contaminated with heavy metals or toxic chemicals, pollution would be a significant problem as well.

Should a reservoir the size of Waterbury (which is only moderately sized as reservoirs go) be slated for removal, the best way to mitigate the impact of sediment remobilization may be to draw down the water level slowly over a period of years before taking down or notching the dam. This would allow sediment redistribution to occur more gradually. To prevent mass wasting along the river channel on the former reservoir bottom, banks may need to be reshaped with heavy equipment so they are not so steep, and planted with appropriate riparian vegetation. Design and construction of a quasi-equilibrium channel may even be warranted to avoid problems with stream instability.

CONCLUSIONS

As events at Waterbury Reservoir in 2002 illustrate, extreme drawdown of reservoirs permits direct observation of the lake bottom, providing data for sedimentation surveys and insight into sediment dynamics under both subaqueous and subaerial conditions. The total volume of sediment found in Waterbury Reservoir reflects erosion and delivery from the surrounding watershed, as influenced by land use, soil type, and stream behavior. Stratigraphy of reservoir-bottom sediment and tributary deltas record lake management practices over time. Swift erosion and redistribution of sediment on the lake bottom during drawdown also exemplify what might occur should a dam like Waterbury be removed without care being taken to stabilize the newly exposed lake bottom and stream channel. Whether drawdown occurs as an isolated event or on a regular basis, as in some flood-control reservoirs, drained lakes warrant investigation for the useful information they contain.

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