

THE EFFECT OF ICE COVER ON SEDIMENT TRANSPORT CAPACITY AND STREAM CHANNEL MORPHOLOGY IN A REACH OF CAZENOVIA CREEK, NY

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ABSTRACT: *Many Great Lakes tributaries experience ice cover during winter months. The type of ice cover and situations surrounding melt can have very different effects on stream channel morphology. The effect of ice cover on channel morphology can be catastrophic when ice jams form and fail, which often causes excessive streambank scour; however, if ice covers melt gradually, the ice left on streambanks can provide protection from erosion by high velocity flows. The objective of this study was to determine the overall impact of ice cover on channel morphology at the USGS gage station on Cazenovia Creek, Buffalo, NY. Site set-up occurred in August 2004 and included establishing benchmarks and surveying channel morphology at permanent cross sections using a total station. Subsequent surveys occurred before and after the 2004-2005 and 2005-2006 winter seasons to assess the impact of ice cover on channel morphology. Overall channel change in Cazenovia Creek during the study period was minimal; however, erosion was the dominant process during both summer-fall seasons, whereas deposition was greater during the winter-spring seasons. Winter-spring deposition occurred at the base of the streambanks and along the channel bed throughout most of the reach. The volume of material deposited during the 2004-2005 winter-spring season also was approximately equal to the volume of material eroded during the 2005 summer-fall season. These results were similar to previous studies that have found: 1) deposition of material on the channel bed in relatively straight uniformly deep channels with a centrally located thalweg and a free-floating ice cover, and 2) that the deposition that occurs during periods of ice cover typically is eroded during high flow events in the spring and summer.*

Keywords: *Ice cover, Sediment transport, Stream morphology*

INTRODUCTION

Many Great Lakes tributaries experience ice cover during winter months. The type of ice cover and situations surrounding melt can have very different effects on stream channel morphology. The objective of this study was to determine the overall impact of ice cover on sediment transport capacity and channel morphology at the USGS gage station on Cazenovia Creek, Buffalo, NY.

Ice covers are classified as fixed or free-floating. Fixed ice covers are physically attached to the streambanks at the level of water freezeup (Zabilansky and White, 2005). If flow discharge increases above the level of freezeup, pressurized flow and increased velocity can occur under the ice cover, which typically leads to scour of the channel bed (Zabilansky and White, 2005; Ettema and Daly, 2004). Free-floating ice covers are not attached to the streambanks; therefore, the ice cover can move freely with changes in discharge (Zabilansky and White, 2005). Aggradation of the channel bed typically occurs in the presence of a free-floating ice cover

because the ice cover increases roughness and provides resistance to flow, which reduces the sediment transport capacity of the stream (Ettema and Daly, 2004).

The effect of ice cover on channel morphology can be catastrophic when ice jams form and fail, which often causes excessive streambank scour (Morgan et al., 2004). However, if ice covers melt gradually, the ice left on streambanks can provide protection from erosion by high velocity flows.

Background on ice cover in Cazenovia Creek

Ice covers, and resulting ice jams, have been a problem on Cazenovia Creek for at least the last one hundred years and served as the impetus for this study. The first recorded ice jam occurred in 1904 and subsequent jams have occurred regularly since that time (Morgan et al., 2004). Past ice jams have caused substantial flooding throughout the lower portion of the watershed, particularly in the Town of West Seneca, and resulted in significant property damage (Morgan et al., 2004).

These frequent ice jams warranted construction of an ice-control structure (ICS) that was built upstream of this study's site during the 2005-2006 winter season (Lever et al., 2000) (Figure 1).

The ICS consists of six 1.5 meter diameter cylindrical piers that are 3 meters above the average streambed elevation. The piers are spaced approximately 4 meters apart. The ICS is designed to block an ice jam and allow the ice to accumulate on the floodplain for storage to alleviate downstream flooding.

Figure 2 shows the USGS gage site after an ice jam breakup in December 2002. That event caused excessive bank erosion where 45-degree streambanks were sheared off by ice slabs to near-vertical banks.

Figure 3 shows the gage site with a free-floating ice cover in December 2005. The field team was preparing to collect data on ice thickness and water depth and velocity for a graduate student project associated with the current project.

STUDY AREA

The Buffalo River, NY watershed (Figure 4) has been severely impacted by human activity and sediment pollution has been a particular problem. This sediment pollution problem, as well as other

impairments, led the International Joint Commission (IJC) to designate the Buffalo River one of 43 Areas of Concern (AOC). Sediment from upstream bank erosion has been cited as a primary problem in the watershed (Versar, 1975). Early work in the Buffalo River watershed found that soil and bed and bank erosion from the upper watershed has been the primary contributor of sediment to the (AOC) (Versar, 1975). Versar (1975) estimated that sediment load to the Buffalo River AOC from upstream erosion was 460,000 tons/year; 66% and 40% greater than sediment loads from combined sewer overflows and direct industrial discharges, respectively.

Cazenovia Creek (Figure 4) is 48 km long and has a drainage basin area of 350 km². The creek is one of three main tributaries to the Buffalo River. Cazenovia Creek has received a high prioritization for the identification of non-point pollution sources to improve water quality (Erie County Water Quality Coordinating Committee (ECWQCC), 2000) and silt-sized sediment from streambank erosion from upstream sources has been cited as the primary impairment in Cazenovia Creek (NYS DEC, 1996). Bank stabilization has been implemented in the creek in an effort to reduce sediment input from streambank erosion. Fourteen kilometers of Cazenovia Creek were part of a Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation District) bank stabilization program in



Figure 1. Cazenovia Creek ice-control structure.



Figure 2. Streambank scour.



Figure 3. Winter 2005 field work.



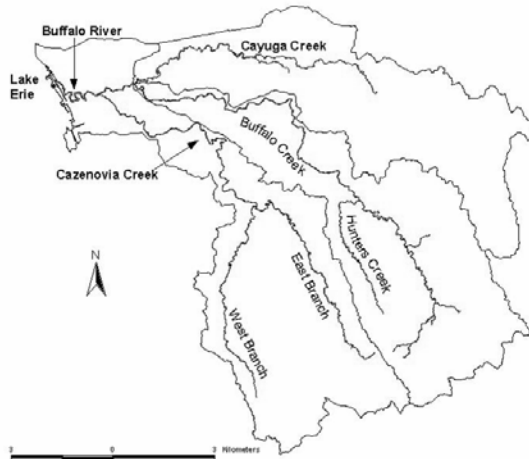


Figure 4. Cazenovia Creek and Buffalo River watershed.

the Buffalo River watershed that began in 1953 (Parsons et al., 1963). Despite the fact that the impact of ice scour on channel erosion has not been quantified, the type of bank stabilization engineering implemented is currently based on the effect of ice scour on riprap, rather than on the effect of a particular design storm discharge on an untreated bank.

METHODS

Channel morphology was mapped using a Sokkia® total station. The site was initially set up and surveyed in July 2004. Two local benchmarks were established at the USGS gage station site on Cazenovia Creek for horizontal and vertical control and survey data was reduced to Cartesian (X, Y, Z) coordinates. Eight permanent cross sections were established that encompassed the full range of morphologic variability in the reach. After the initial set up, channel morphology was surveyed prior to ice cover in the late fall and after ice cover in the early spring of the 2004-2005 and 2005-2006 winter seasons. Contour maps were generated from the coordinate information using the computer software

package Surfer®, which defines contours for a uniform grid of elevation data interpolated via kriging. Spatial variability of channel morphology within the reach was evaluated qualitatively by visually inspecting variations in bed elevation on contour maps. Temporal variability in channel morphology was defined by changes in the profiles of surveyed cross sections. Sediment dynamics were quantified in terms of net sediment accumulation or removal by volume within the reach between channel surveys. Calculations of net volumetric sediment flux were performed in Surfer® by interpolating a uniform grid of elevation data from the survey information using kriging, and then differencing the interpolated elevation values for each grid node for successive surveys. Negative flux volumes indicate net deposition and positive flux volumes indicate net erosion.

RESULTS AND DISCUSSION

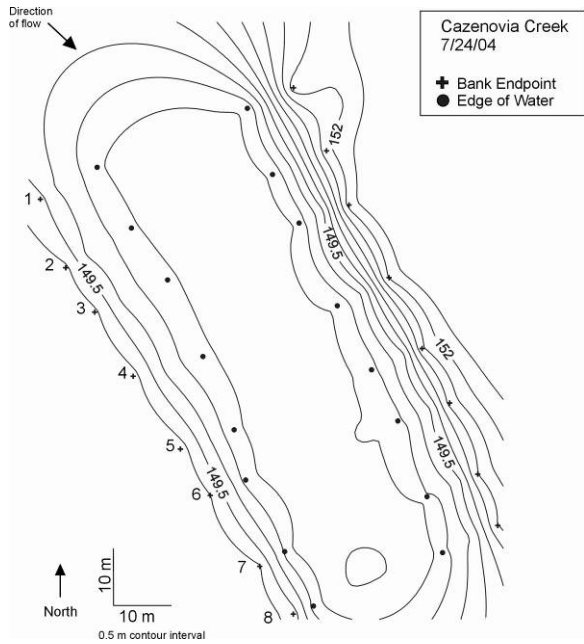
During the course of this two-year project the Cazenovia Creek site experienced periods of ice cover (Table 1 and Figure 3); however, ice jams did not occur. The thickness of each ice cover was relatively constant (e.g., 3-4 cm thick) across channel cross sections and the ice covers were free-floating. In addition, it was noted that the ice melted gradually (e.g., over a period of days) starting in the center of the channel. Ice on the streambanks melted last, which appeared to protect the banks from erosion, and in some cases, blocks of ice accumulated on the streambanks, which further protected the banks from erosion.

The Cazenovia Creek reach was approximately 80 m long and averaged 50 m wide (Figure 5). The reach was relatively straight and uniformly deep with a centrally located thalweg. Reaches in other ice cover studies, both in the field and in lab studies, had similar morphology (e.g., Ettema and Daly, 2004).

Profiles of surveyed cross sections (Figure 6) indicate that overall change throughout the reach

Table 1. Ice Covers on Cazenovia Creek

Winter season	Ice cover period	Winter season days with ice cover
Winter 2004-2005	Dec. 19-28, 2004	10
	Jan. 17-Feb. 5, 2005	20
	Feb. 16-Mar. 6, 2005	19
	Total days with ice	49
Winter 2005-2006	Dec. 8-22, 2005	15
	Feb. 19-22, 2006	4
	Feb. 27-Mar. 8, 2006	10
	Total days with ice	29



was minimal during the study period. The upstream portion of the reach (cross-sections 1-4) showed greater relative change with as much as 25 cm point elevation change in a cross section. The downstream end of the reach was more stable; for example, less than 5 cm elevation differences along the west bank of cross-section 8.

Sediment dynamics were quantified in terms of net sediment accumulation or removal by volume between surveys of channel morphology (Table 2). While overall channel change in Cazenovia Creek was minimal, erosion was the dominant process during both summer-fall seasons, whereas deposition was greater during the winter-spring seasons. Winter-spring deposition occurred at the base of the streambanks and along the channel bed throughout most of the reach (Figure 6). These results were similar to other studies that have found deposition of material on the channel bed in relatively straight uniformly deep channels with a centrally located thalweg and a free-floating ice cover (Ettema and

Figure 5. Cazenovia Creek morphology.

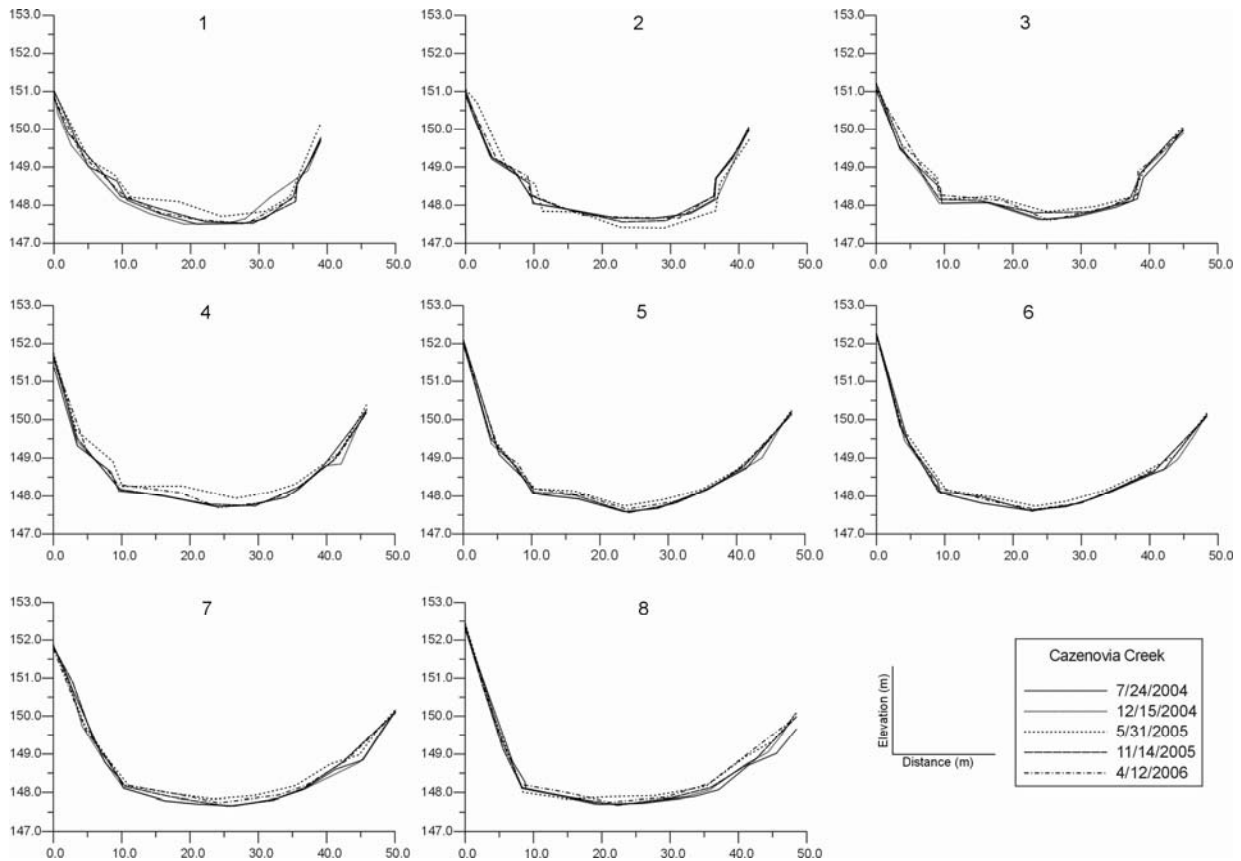


Figure 6. Surveyed cross sections.

Table 2. Volume of Material Eroded and Deposited Over Time

	Summer-Fall	Winter-Spring	Summer-Fall	Winter-Spring
Cazenovia Creek	7/24/04-12/15/04	12/15/04-5/31/05	5/31/05-11/14/05	11/14/05-4/12/06
erosion (m ³)	176	9	765	26
deposition (m ³)	46	863	8	290

Daly, 2004). In addition, other researchers have found that the deposition that occurs during periods of ice cover typically is eroded during high flow events in the spring and summer, thus, the net change in erosion and deposition over time is zero (Ettema and Daly, 2004). This relationship was illustrated by looking at the 863 m³ of deposition during the 2004-2005 winter spring season and the 765 m³ of erosion that occurred during the following summer-fall period (Table 2) and provided further evidence to explain the minimal channel change observed over time in Cazenovia Creek.

CONCLUSIONS

Surveys of cross section profiles and analysis of the volumes of sediment erosion and deposition indicate that channel bed aggradation occurred during periods of ice cover at the Cazenovia Creek site. These results are similar to previous results that have shown that free-floating ice cover reduces a stream's ability to move sediment supplied to the channel (Zabilansky and White, 2005; Ettema and Daly, 2004). When the sediment load is greater than the sediment transport capacity of the stream, bed aggradation occurs. Therefore, ice cover clearly had an impact on channel morphology at the Cazenovia Creek site by reducing sediment transport capacity, which led to bed aggradation. However, the net impact of the ice cover was zero because the material deposited during ice cover was eroded during the remainder of the year.

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