Suspended Sediment Concentration During River Ice Break-Up

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ABSTRACT

River ice break-up is known to be an important geomorphologic agent, creating numerous erosional and depositional features within river channels and on adjacent floodplains. Despite such evidence, information about the suspended sediment concentration and bed load during break-up is virtually non-existent. Measurements of suspended sediment concentration were made during the 1987 break-up of the Liard River, N.W.T., Canada. Results showed a gradual rise during the pre-break-up period followed by an order of magnitude increase at the time of the major river-ice run. The ice-affected peak concentration of 1,067 mg/L falls within the recorded range of annual open-water peaks that were produced by flow events of 2 to 5-times greater discharge.

INTRODUCTION

The abrasive action of river ice can be an important modifier of channel bed and banks, particularly during the break-up period (e.g, Scrimgeour et al. 1992). Evidence for such ice-induced abrasion is provided by typical erosional features such as high-level benches (Smith 1980), undercut banks (e.g., Marusenko 1956) and, in permafrost regions, thermoerosional niches (e.g., Lawson 1983). The diversion of flow by ice jams at meander bends can also produce erosion at the inside of the bend (e.g., Martinson 1980), a sediment deposition-zone under normal open-water flow conditions. In extreme cases, such flow diversions could result in the cutting-off of meanders and reductions in river sinuosity (Williams 1973). Although most scour effects are evident on fluvial rivers, ice is also known to accelerate erosion of banks comprised of soft rocks such as shale and limestone (Dionne 1974; Danilov 1972). While most erosion features have been observed along the banks and flood-plains, break-up activity is also believed to promote scour of river beds by direct ice action (e.g., Danilov 1972) and through accelerated water velocities, such as found beneath ice jams (e.g., Wuebben 1988) or produced by ice-jam surges. Beltaos (1982), for example, estimates that sufficient shear stress could be produced by break-up surges (i.e., 5 m/s) to move bed material particles as large as 20 cm in diameter.

Despite the extensive geomorphologic evidence of ice-induced erosion, field data about suspended sediment concentrations and bed load during the break-up period are virtually non-existent. The major reasons for this obvious deficiency are twofold: safety and access. During both the open-water and stable ice-cover periods, sediment sampling is relatively easy and risk-free. However, once the ice cover begins to structurally deteriorate, access becomes difficult and potentially hazardous. Moreover, once the cover begins to break-up, conventional access is limited to the banks of the river which are often isolated from the main channel flow by shear walls produced by ice runs and/or jamming.

EXPERIMENT LOCATION

A unique opportunity arose during a field study of ice-cover strength to obtain measurements of suspended sediment concentration during a) the pre-break-up deterioration period and b) the actual break-up. Studies focussed on the Liard River near its confluence with the Mackenzie River. Draining an area of 277,000 km^2, the Liard is the largest tributary of the Mackenzie River downstream of Great Slave Lake. From its headwaters in the Cordillera, the Liard flows in a generally south-east direction until it meets the Fort Nelson River at Nelson Forks. From here, the river heads north-eastward across the plains of the Interior Plateau to its confluence with the Mackenzie River at Fort Simpson, N.W.T., a distance of approximately 430 km. The large scale pattern of ice clearance on the Liard River is typical of most "northward" flowing rivers in which break-up originates in the headwaters and then progressively moves downstream. Break-up is usually first initiated in the Fort Nelson River, the basin being substantially lower in elevation and more southerly than the Liard River upstream of Nelson Forks. Ice from the upper Liard is usually not part of the initial break-up front which passes down the Liard River, but rather comes down as a second wave of floating ice, sometimes after the Liard has initiated break-up of the Mackenzie River at Fort Simpson (Prowse 1989).

SAMPLING METHODOLOGY

All sampling was conducted in the reach used by the Water Survey of Canada to monitor discharge and sediment of the lower Liard River (Hydrometric Station No. 10ED002). It should be noted that the sediment-survey aspect of the field program was not pre-planned but was developed on-site. Although the sampling equipment was improvised from available equipment, it is believed that the system did not introduce significant sampling error. The basic unit employed a one-litre plastic sampling bottle with a convex lid perforated with approximately 15 3-mm holes. The sampler was suspended on a weighted cable in a vertical position within the flow. During the period of intact ice, the sampler was lowered through a standard 20-cm (8-inch) ice-drill hole, and then repeatedly lowered and raised (approximately 3 to 5 times) from the bed to the bottom of the ice until the sampler was full. Once the cover became too weak and during the period of ice fracturing, sampling was conducted by helicopter using the same vertical-integrating technique. All samples were obtained in a zone 300 to 500 m from the left bank. Approximate river width is 700 m.

All samples were analyzed following the procedure outlined by Stainton et al. (1977). A Millipore^R filtration assembly was used consisting of a funnel cup and filter holder placed on top of a 1000 mL filtering flask and attached to a vacuum pump. Whatman GF/C 4.25 cm glass microfiber filter papers with an effective retention of 1.2 μm (medium to fine clay size) were used. Dry filter papers with and without the particulate samples were dried at 100-104°C for at least 1 hour and then weighed to the nearest 0.1 milligram.

Although the filtration procedure excluded the fine to very-fine clay particles, these are believed to be a small percentage of the total suspended sediment concentration. For example, a sample obtained soon after the 1987 break-up revealed that only 14% of the suspended sediment was less than 2 μm in size (Water Survey of Canada 1989). Hence, the suspended sediment concentrations obtained in this study are considered to be conservative estimates.

SAMPLING/BREAK-UP OBSERVATIONS

Figure 1 shows the temporal trend of the suspended sediment concentration and discharge over the period April 18 to May 06. Aerial reconnaissance surveys revealed that by April 24 the Fort Nelson River was in break-up but the Liard remained intact. Up until April 26 the concentration remained below 10 mg/L but then began to steadily rise. Most lowland muskeg tributaries of the lower Liard were observed to be running by April 27 and had broken up by April 29, although they had little effect on initiating break-up of the Liard ice sheet. Discharge almost tripled from April 18 to April 30 (1420 m^3/s).

A localised break-up of the Liard River began 4 km upstream of the study site on April 30 and by May 1 had progressed downstream to the study site, first producing pressure ridges and then a rupturing of the ice cover. Measurements made by helicopter during the ice fracturing/fragmenting period revealed a sediment concentration of 70 mg/L by May 1. On May 2 this local break-up had formed a small ice jam, approximately 2 km in length just downstream of the study site which was now in open water. The associated rise in water levels to slightly above 120 m amsl (above mean sea level) are apparent on Figure 2. Upstream the Liard remained largely intact although periodically over the next few days, localised break-up occurred

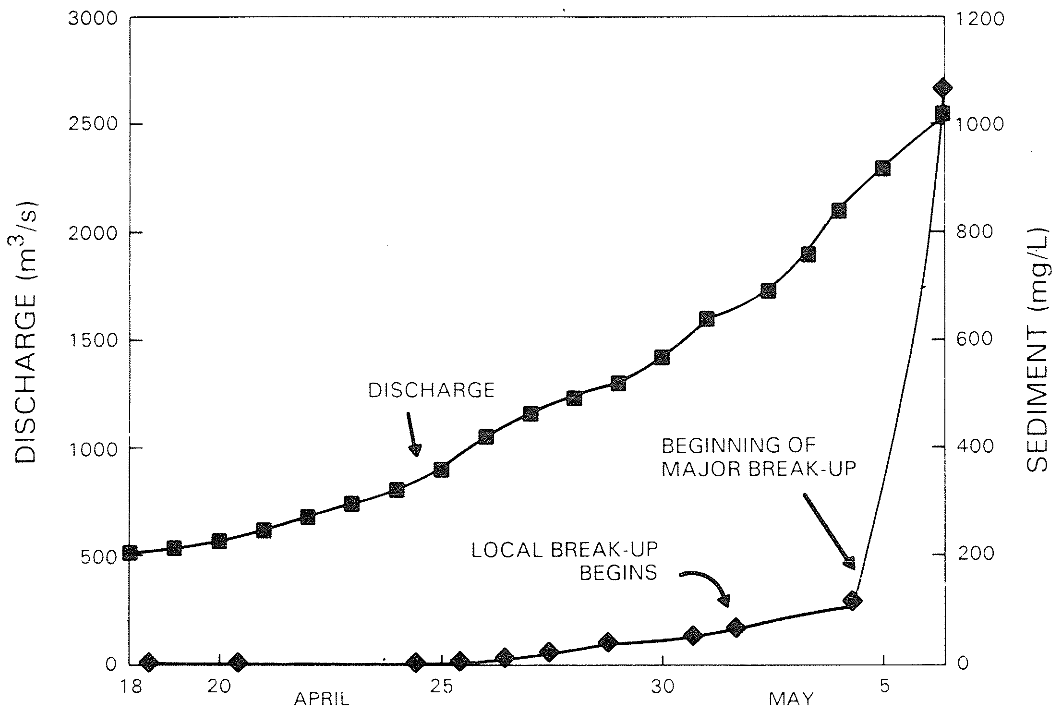

Figure 1. Suspended sediment concentration and discharge of the Liard River near the mouth, N.W.T., 1987.

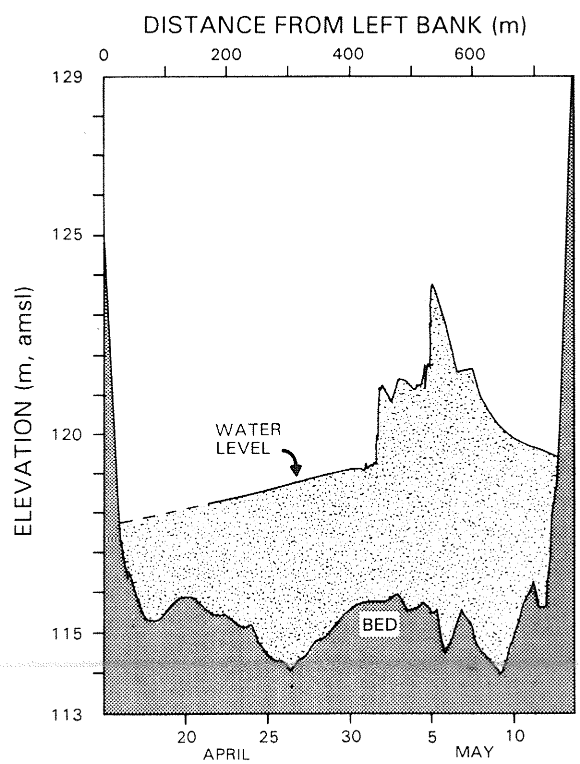

Figure 2. Channel cross-section and break-up water levels of the Liard River near the mouth, 1987.

in a number of reaches. A sample on May 4 revealed that the sediment concentration had risen to approximately 120 mg/L. On the same day, water levels began to rapidly increase again as the site was affected by large amounts of ice from upstream break-up activity. This resulted in a gradual downstream movement of the jam towards the Liard mouth and a final release into the Mackenzie River on May 5. This resulted in a drop in water levels although discharge continued to increase. On May 6, significant amounts of ice again began to flow by the study site, indicating the release of the remaining ice jammed on the lower Liard. A final helicopter survey of suspended sediment revealed a concentration of 1,067 mg/L.

DISCUSSION

The general rise in the suspended sediment concentration prior to break-up is attributable to three factors: a) the rise in velocities and discharge, b) additional contributions from upstream tributaries, and c) upstream ice-induced erosion. It is this latter factor that is believed to be most responsible for the rapid increase during the May 4-6 break-up period.

Overall the 1987 break-up of the Liard River was a medium-scale event with maximum water levels falling more than 4 m below those reported for more dramatic events documented in previous years (Prowse 1986). The peak sediment concentration, however, far exceeds that which is normal for open-water conditions with equivalent discharge. Moreover, as shown in Figure 3, it falls within the range of annual peak-sediment concentrations recorded at 2 to 5-times greater discharge.

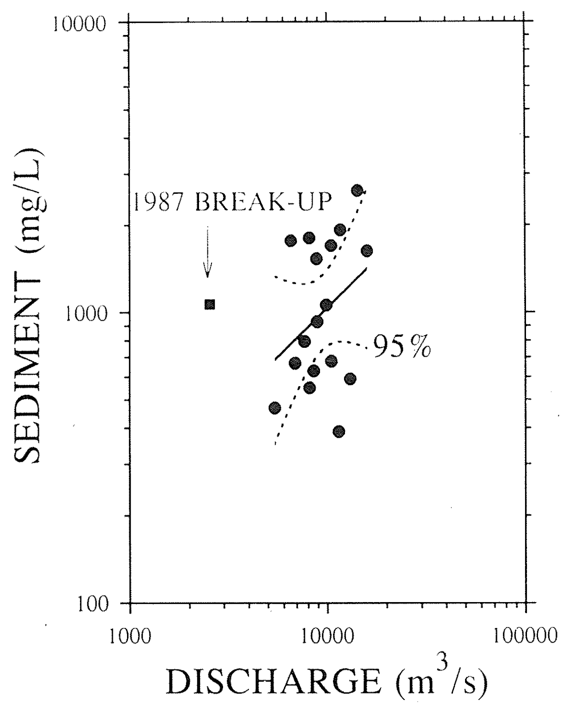

Figure 3. Annual recorded peak-sediment concentrations (dots, 1972-1990: Water Survey of Canada, 1992) and peak concentration for the 1987-break-up, Liard River near the mouth, N.W.T. Line is regressed only with dot-data. Dashed lines indicated 95% confidence limits. Note: some discrepancies exist in the historical summaries of maximum sampled suspended sediment concentrations.

There are two major reasons to explain the enhanced suspended sediment concentration associated with ice break-up activity. Firstly, the elevated water levels due to ice resistance exposed considerable additional bank area to potential erosion. For comparison, the stage achieved by this event are approximately equal to those which would be produced by an open water flow of approximately 14,000 m^3/s (Water Survey of Canada 1988). The extent of bank area exposed to potential erosion at such levels are noted in Figure 2. The annual mean discharge for the river occurs at only 118.8 m amsl (2,460 m^3/s) and the mean open-water discharge (May-October) at 119.6 m amsl (4378 m^3/s) (Water Survey of Canada 1987, 1991), approximately 4 to 5 m lower.

Second, such break-ups have the added potential of accelerating erosion because of the intensive ice-bank/bed interaction and high velocities. Break-up velocities resulting from ice jam surges are well known to exceed 5 m/s (and documented at this site in other years; Prowse 1984); a value well beyond that which could develop under normal open-water conditions. Examples of typical ice-related scour were cited in the introduction and most of the alluvial-type have been observed on the Liard River.

Since 1987 was only a moderate break-up event characterized by a non-uniform downstream progression of break-up, typical of the *thermal* type of break-up, it is possible that even higher sediment concentrations could be produced by more dramatic *mechanical/dynamic* events (e.g., Ferrick and Mulherin 1989; Prowse 1986). In such events, ice strength, velocity and stage are usually maximized and break-up progresses more-or-less sequentially downstream. More data is required to confirm this and, more generally, to establish the relative significance of break-up concentrations to those produced under open-water conditions. The results of this preliminary field experiment, however, suggest that a major component of the annual sediment cycle could be overlooked by conventional monitoring programs.

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