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Characteristics of suspended sediment and metal transport during ice breakup, Saint John River, Canada

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ABSTRACT

During the spring freshet and the resulting breakup of river ice covers, the erosive capacity of the flow is enhanced not only by the rising discharge, but also by the highly dynamic waves that form upon the release of ice jams. Concentrations of suspended sediment and particulate contaminants, such as trace metals, increase sharply. To enhance the very limited knowledge on this issue, comprehensive data have been collected on the Saint John River (SJR). Herein, first-time data sets are presented on sediment and metal transport characteristics during the highly dynamic flow conditions of the ice breakup period. The median sediment particle size is nearly 10 μm and decreases slightly with suspended sediment concentration (SSC). Though moving ice prevented direct examination of flocculation processes during the breakup period, indirect evidence suggests that it does occur and may be more pronounced than during open-water conditions. Owing to high breakup flow velocities, bed deposition and entrapment of suspended sediment are likely minimal in the study reach, though more pronounced in the reservoirs of downstream control structures. In general, the trace metals examined in this study exhibited strong attachment to suspended sediment. At any but the lowest of SSCs, sorbed amounts were much larger than dissolved, with the sole exception of strontium. Particulate metal concentrations and partition coefficients occurring during ice breakup in the SJR were within known ranges from previous, open-water studies and did not exceed "probable effect" levels of Canadian guidelines. Changing climatic conditions could lead to increased amounts of particulate metals.

1. Introduction

The ice cover of northern rivers alters the physical processes within the ecosystem and causes changes to the flow regime that can be both beneficial and harmful to the natural environment. Many of these changes occur during the ice breakup event. Factors contributing to changes in river water quality during the breakup period include greatly increased suspended sediment concentrations, seasonal changes in flow, chemistry of snow meltwater, composition of the winter ice cover, and rate of thermal melt. Recent comprehensive reviews (Turcotte et al. 2011; Ettema and Kempema 2013) discuss the various mechanisms that influence sediment transport in cold-region rivers and stress the importance of the breakup event.

During the spring freshet and the associated breakup of the ice cover, the erosive capacity of the flow is enhanced not only by the rising discharge, but also by the highly dynamic waves that arise upon the release of ice jams, termed "javes" for short, in river ice literature (e.g. Beltaos 2013). The few available data sets (Prowse 1993; Beltaos et al. 1994; Milburn and Prowse 1996; Beltaos and Burrell 2000) indicate that suspended sediment concentrations can exceed many-fold those occurring under an equivalent open-water discharge. Potential sediment sources include hillslopes as well as the river banks and bed, though river bed erosion is not considered a significant source (Miller and Orbock Miller 2007). Prowse (1993) suggested that higher suspended sediment concentrations can possibly be due to the greater exposure of river banks to erosion as a consequence of elevated water levels, of higher flow velocities occurring during breakup, and of accelerated erosion resulting from the interaction between ice and the bed and banks (Prowse 1993).

Large suspended sediment concentrations can have both positive and negative effects on aquatic ecology and the environment (Chapman 1992, section 3.8). Dissolved and particulate matter flushed into the river from shorelines and flood plains often contain important nutrients and organic material for lotic food webs. On the other hand, high concentrations can reduce the quantity and quality of available habitat for various species and pose difficulties in feeding. Since many substances, including trace metals, are absorbed by, or adsorbed on, sediment particles, water quality is also affected by sediment

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concentration (Cheng et al. 1993). Therefore sediment loads during the breakup period are important to understanding the spring water chemistry of a river system. Despite this, measurements of suspended sediment characteristics during the breakup period are rare.

The transport and fate of sediment in rivers is largely dependent on the settling rates of the various particles that are found in suspension. Such rates can be very different between solid (primary) particles and flocs consisting of agglomerations of fine-grained primary particles. The process of flocculation is therefore a key aspect of sediment transport in rivers (Droppo et al. 1998) and forms a major element of predictive mathematical models (Krishnappan 2007).

A five-year study of ice breakup and jamming along the Saint John River (SJR) from the Dickey area in Maine, United States, to St. Leonard, New Brunswick, Canada (Fig. 1), was initiated in December 1992 as a joint project of the National Water Research Institute (NWRI) of Environment Canada and the New Brunswick Department of the Environment (NBDOE). One of the study goals was to obtain information needed for understanding and quantifying ice and sediment processes, their interactions and dependency on river morphology and climatic inputs, as well as their potential impact on the aquatic ecosystem. The need for this kind of information for an economically and ecologically important international river such as the Saint John is accentuated by the issue of climatic variability and change, which has significant implications to the hydrology and thence to the ice regime and ecology of cold-regions rivers (Beltaos 1997, 2000, 2002; Beltaos and Prowse 2001; Prowse and Beltaos 2002; Beltaos and Burrell 2003; Beltaos and Prowse 2009; Prowse et al. 2011a, 2011b, 2011c).

Sediment-related measurements focused on suspended sediment concentration (SSC) and particle size distributions during the breakup events of the study years 1993 to 1997, inclusive. These data were supplemented by bed material information (1993) and by dissolved and total concentrations of seventeen trace metals (1997 breakup event). Changing priorities did not permit the writers to fully analyze and report this material, though partial aspects of the data have been presented at conference proceedings (Beltaos et al. 1994; Beltaos and Burrell 1999, 2000). It is only recently that time has been found to examine and analyze the complete data sets, which have proven to be too voluminous to present in a single paper. Herein, the focus is on two aspects: (a) particle size of suspended sediment, both in flocculated (in situ) and primary (sonicated) state; and (b) dissolved and particulate concentrations of the sampled metals.

Following background information on the water quality of the SJR and a description of field sampling procedures and methods of analysis, typical results are presented. These include comprehensive data on the bed material composition of the SJR, particulate organic content, size of primary particles that are found in suspension, size of flocs of particles as measured in situ, and concentrations of various metals, both dissolved and particulate. The results are then discussed in light of findings by others and implications to the fate of suspended sediment and sorbed contaminants are examined. Potential ecological impacts of the measured amounts of trace metals are also explored.

2. Background information

The water quality of the SJR was recently reviewed in a state-of-the environment report by Curry et al. (2011) in terms of such variables as pH, DO, metals (Al, Fe, Mn, Cu, Zn) and bacteria. Sampling locations extended from the northern part of the province at Clair to the far south at Westfield. Average pH values in the reach Clair to Grand Falls (Fig. 1) were near 7.3 during the 1990s, with one-standard deviation limits at 6.9 and 7.7, which almost entirely reflected temporal variability. Dissolved oxygen was generally close to 10 mg/L while metals were generally below Canadian water quality guidelines for various uses.

Waters (1995) stated that "…*sediment has been labeled the most important single pollutant in US streams and rivers*". In their state-of-the-environment report, Kidd and Luiker (2011) extended this assessment to all of North America, citing sediment impacts on fish populations through turbidity, suspended sediment, and deposition of sediments. Yet, their report contains no quantitative information pertaining to sediments in the SJR. A search of WSC (Water Survey of Canada) archives revealed that SJR sediment data are available only for the years 1966–68 and only at the gauging station below Mactaquac (No. 01AK004). These data indicate a maximum SSC of 140 mg/L occurring in November 1966, possibly resulting from a moderate rainstorm as attested by concomitant flow data; there is no information on particle size.

Beltaos et al. (1994), citing early results of the present study, reported a typical median (D_{50}) primary particle size of ~10 μm, based on analysis of numerous samples obtained during the 1993 breakup

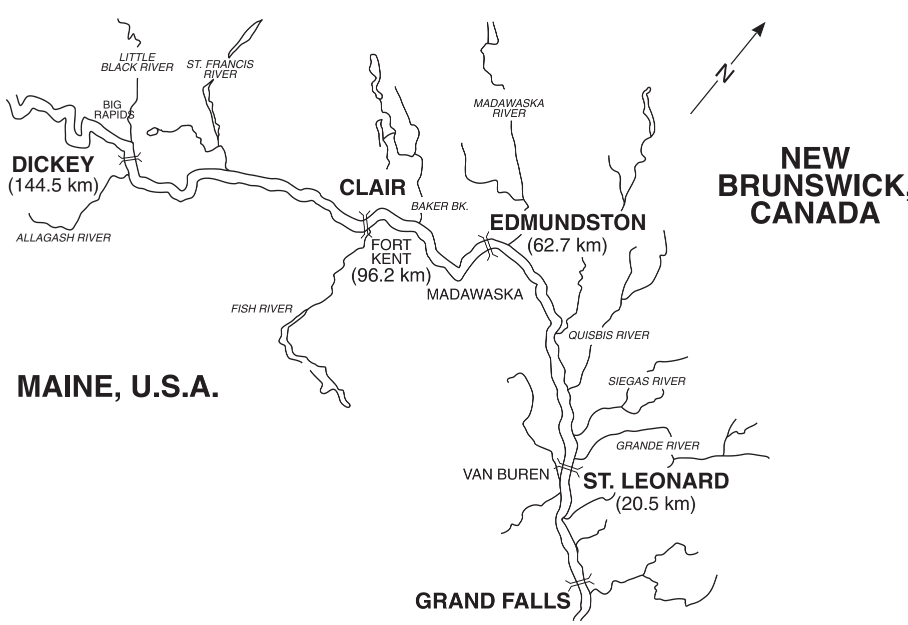

Fig. 1. Planview of upper Saint John River between Dickey, Maine and Grand Falls, New Brunswick. Flow is from NW to SE. Channel width has been exaggerated for clarity and is not to scale. Bridge locations are indicated in river kilometers above the Grand Falls Control Structure.