RIVER ICE PROCESSES IN TIDAL RIVERS: RESEARCH NEEDS

Brian Morse
Université Laval,
Québec, PQ, Canada, G1K 7P4,
Brian.Morse@gci.ulaval.ca

Brian Burrell
New Brunswick Department of the Environment
P.O. Box 6000, Fredericton, NB, E3B5H1
brianb@gov.gc.ca

St. Hilaire, André
Groupe-Conseil Génivar,
926 Melanson Rd., Dieppe, NB., E1A 7N9
hilpag@nbnet.nb.ca

Bergeron, Normand
Institut National de Recherche Scientifique –Géoressources, Université du Québec
2535, boul. Laurier, C.P. 7500, Sainte-Foy, PQ, G1V 4M3
nbergeron@inrs.uquebec.ca

Messier, Danielle and Quach Thanh, Tung
Groupe Production, Hydro Québec
855, rue Sainte-Catherine Est, 18e étage, Montréal (Québec) H2L 4P5
messier.danielle@hydro.qc.ca & Quach_Thanh.Tung@hydro.qc.ca

Abstract

In 1998, the Committee on River Ice Processes and the Environment (CRIPE) formed a Task Force on Ice in Tidal Rivers and Estuaries. This Task Force paper invites Workshop participants to join a CRIPE Working Group to identify, perform and publish multi-disciplinary field studies and research. Topics may include tidal processes, physical features of estuaries, ice formation, decay and physical properties, ice jamming and transport, the interplay among ice, hydraulics, fish habitat and hydraulic structures. This paper briefly reviews the state of the art and discusses the research needs.

1. Introduction

Since the beginning of time, people have settled along seashores, tidal inlets, estuaries and tidal rivers for transportation, sustenance, energy and quality of life. There have been many scientific and engineering studies of coastal and estuarine zones. They cover such topics as tidal hydrodynamics, fish habitat, ecology and the development of marine structures. In our northern climate, these studies must account for the presence of ice which:

- blocks navigation routes,
- forms in jams and subjects towns to flooding and ice damage,
- influences sediment erosion, transport and deposition processes,
- subjects marine structures to additional forces,
- modifies tidal amplitudes and propagation,
- influences the fresh-salt water mixing and
- may have very significant impacts on fish habitat and migration patterns.

Despite significant investment in open water estuarine research, scientific databases and researchers tell us that very little is known about ice behaviour in our tidal rivers and estuaries and its impact on hydraulic, sedimentological, chemical and biological processes. While most people in Eastern Canada live on or near a tidal river or estuary subjected to ice processes, where is the research on ice that so influences their lives?

To respond to this need, the Canadian Committee on River Ice Processes and the Environment (CRIPE) formed the Task Force on Ice in Tidal Rivers in 1998. This Task Force article introduces ice research issues. At the end of the 10th annual Workshop on Hydraulics of River Ice, a Working Group on Ice in Tidal Rivers and Estuaries will replace the Task Force. This article is an open invitation to the ice community researchers and students to participate in the Working Group (WG) along with some of the Task Force members.

The will choose an estuary (and/or the tidal portion of adjacent rivers) for multidisciplinary study. Basic data would be available for common purposes (e.g., water levels, bathymetry, currents, water temperature, etc.) providing a sound foundation for more specialised research into particular topics. We have identified some potential preliminary sources of funding. The goal of the WG is to publish a CRIPE book on Ice in Tidal Rivers and Estuaries. The project may last three to five years.

Participation in the Working Group could take many forms. The following pages present an invitation to the reader to consider how he or she may wish to participate in research in ice processes in tidal rivers and estuaries.

2. Ice jams and ice processes

In this section, we present some historical ice jam events that occurred in Eastern Canada. They formed in estuaries or tidal portions of rivers, but the relationship between tides and the jams' occurrence is completely unknown.

In his overview of floods in New Brunswick, Kindervater (1985) introduces us to ice jams in the Restigouche basin. The Restigouche River, located between Québec and New Brunswick, empties into the Gulf of Saint-Lawrence via the Bay des Chaleurs. The tidal portion of the river and the upper part of the estuary are characterised by a network of shallow meandering channels, separated by islands.

> *"The Restigouche is tidal for about 40 km of its length, and navigable for ocean-going vessels for about 30 km. It is in this lower portion of the basin that flooding results from high tides and winds combining with high runoff and/or ice jams. The effects of this flooding are predominantly felt in the communities of Flatland, Tide Head, Atholville, Campbellton and, to some extent, Dalhousie."* For example on April 29-May 18, 1974, *"a major ice jam occurred on the Restigouche River at the old Interprovincial Bridge near Campbellton. At Sillarsville, Quebec, ice damage to the C.N.R. tracks was reported to be quite severe. A trailer park at Cross Point, Quebec, was inundated. The icebreaker Tupper alleviated some of the problem when it cut a path in the river up to the Cross Point-Campbellton Bridge. "*

Kindervater also describes some historical floods in the Miramichi basin. The Miramichi, in New Brunswick, also empties into the Gulf of St. Lawrence, not too far south of the Restigouche.

> On April 16-24, 1934, *"an ice jam formed at Middle Island below Chatham. When this ice jam broke, large cakes of ice were piled some 20 feet high on the shores."* On March 16-25, 1936, *"a huge ice jam occurred at Elm Tree Brook about four miles upstream of Bryeton. The ice was reported to have piled up at Nelson and also at the bridge between Newcastle and Chatham Head."* On April 15-20, 1940, *"a heavy ice jam occurred two miles below Renous. Highway No. 8 was impassable, with four feet of water over the highway."* [Renous is sometimes defined as the head of tide on the SW Miramichi River.] On February 2 - 6, 1970, *"at Newcastle, an ice jam occurred at the Morrissey Bridge. This jam was reported to be at bridge level, which is about 50 feet. Two icebreakers, the Tupper and the Wolfe, were brought to the area in an attempt to break the ice jam. In the northeast section of town, homes were evacuated on Water and Lower Castle Streets. About 25% of the downtown business establishments were flooded, particularly in the castle and Mitchell Street area. Approximately 50*

cars, owned by tow automobile dealers near the river, were damaged. The town's water supply was polluted and oil tanks situated on the wharf were threatened."

For southern New Brunswick, Desplanque and Bray (1986) describe the inter-relationship among the estuaries' bathymetry, the tidal harmonics and ice processes in the high-energy well-mixed estuaries of the Bay of Fundy. This unique study of ice dynamics in estuaries proposes an ice classification system for estuaries. The authors go on to present 5 distinct ice regime zones:

(1) At the upstream end, sheet ice with hinges parallel to the banks to accommodate water level fluctuations make up the tidal zone. (The downstream boundary of zone (1) often corresponds to the location of a hydraulic structure such as a bridge and points to the interplay between natural phenomena and human activity);

(2) within the reach defined by the high water marks of the neap tides and those of the spring tides, shorefast ice strongly dominates. In this zone, shorefast ice severely restricts winter channel geometry thus changing local hydraulics considerably;

(3) further downstream, ice stranded on the channel bottom and mud flats at low tide makes a third zone with reports of significant ice formation. (This points to an interesting research topic on the formation of ice under continuous tidal wetting and drying). Refloated stranded ice and its frozen substrate can become a significant means of local sediment transport;

(4) a wider area near the mouth of the estuary is the fourth zone in which there is always some depth of water even at low tide but in which the depths are sufficiently small for the whole (salt) water column to cool thus generating important quantities of ice which is subsequently transported upstream; and

(5) finally, the last zone is so deep that there is virtually no ice production.

Desplanque and Bray describe how zone (2) is very susceptible to the formation of ice jams. They also discuss the implications for the design and construction of engineering structures (bridges, ports, aboiteaux, etc.). Issues vary significantly from one zone to another both in terms of impact of the structures on ice dynamics and in terms of the impact of ice on design criteria. Nelson and Whitney (1996) also discuss the particularities of ice formation in a tidal zone and the effects on hydraulic structures within Cook Inlet, Alaska. They suggest that ice build-up, on shore-based structures, results in significant downward and upward vertical forces as well as potential horizontal forces. Nottingham and Drage (1983) discuss the influence of ice on design considerations of port and coastal structures.

Ice jams are also notorious in the tidal portion of the Truro River in Nova Scotia. In Québec, dozens of tributaries to the tidal portion of the St. Lawrence River are subject to jamming. At the mouth, huge quantities of ice accumulate creating a wall that no spring ice run can break through. To reduce flood risks, municipalities often resort to preventive ice removal by backhoes in anticipation of the spring freshet.

Very severe ice jams have occurred on the Saint-Lawrence River itself at the old Québec City Bridge. Jams often form as the tidal range (approximately 5 m) diminishes and can only be released by icebreakers once spring tide pattern begins to emerge. Prior to the introduction of a modern fleet of Canadian Coast Guard icebreakers, these jams were serious obstacles to winter navigation. Further upstream, where the diurnal tide dampens out, ice jams occur annually where the river widens («Lake St. Peter»). Only an aggressive ice management strategy and the presence of icebreakers have secured winter navigation for the Port of Montreal.

There are many mysteries related to ice jams in tidal rivers and estuaries. For example how does ice-arching and ice-breaking occur in relation to tidal water levels and currents?

In dealing with these questions, one has to manage the interdependence between hydraulic and ice dynamics. The presence of ice modifies the physical attributes of the estuary (Knight and Dalrymple, 1976). Winter waves and currents do not resemble those in the open water period. On the other hand, there is very little documentation on ice properties in the tidal zone (Meese et al. 1987). In addition to the influence of the ever-changing salt content, the prolonged exposure of shorefast ice and stranded ice to wind, snow, rain and sun during low tide may change its bulk porosity and cohesion properties considerably. Increased thermal erosion may also modify the angle of internal friction. The presence of sediment mixed into the ice may change its relative density. We note that the residual buoyancy is often the significant parameter in many equations describing physical processes and therefore ice jam dynamics may be quite different for relatively heavier ice (due to sediment) or heavier water (due to salt in water) in these zones.

3. Tides

There has been intensive research on tidal propagation in estuaries and rivers but mostly in ice-free areas or focusing on the ice-free season in colder areas (e.g. Le Blond, 1978, Jay 1991, Lanzoni and Seminara 1998). It has been recognised for a long time that the bathymetry, as well as the general topography (i.e. changes in width), of estuaries and the lower reaches of their associated rivers will determine the degree of amplification and/or dissipation of tides. The presence of an ice cover can also interact with various tidal harmonics.

Murty et al. (1985) studied the influence of marginal ice cover on storm surges. In lakes, Maln et al. (1998) have shown that wind-ice interactions can cause oscillating water movements (seiches). It is conceivable that in large ice-covered tidal rivers and estuaries, seiching could occur under certain conditions and interact with tidal dynamics.

The bulk of the research dealing with the impact of ice on tidal dynamics has focused on coastal areas (e.g. Godin, 1986). Also in the coastal area, Marsden et al. (1994a) showed that the interaction between tidal flow and ice structure (e.g. a compression ridge) produced internal waves. The only similar study known to the authors for estuaries is that by Arkhipov et al. (1997) which describes a hydrothermodynamic to simulate the tidal level and velocity oscillations, storm surges thermohaline and ice processes. However, Hydro-Québec has a number of unpublished and raw data for different northern undisturbed estuaries that could be used for research needs. If internal waves were to develop in estuarine waters, the mechanism of dispersion and/or propagation of this energy would likely be different than in deeper coastal areas.

4. Stratification and mixing

In estuaries, a number of phenomena affect the relative mixing of salt and fresh water. Bottom friction, shear at the pycnocline and wind-induced turbulence may enhance mixing, while increased buoyancy associated with fresh water discharge may stratify the water column. When present, an ice sheet precludes a strong interaction between the wind and the water surface. Calculations of the Layer Richardson Number in the lower Restigouche Estuary, a relatively shallow and normally well-mixed area in summer, showed that it was stratified during 16% of the ice-covered season (Clément et al. 1998).

In coastal areas of the Canadian Arctic, Marsden et al. (1994b) have calculated Richardson numbers and showed that there was sufficient vertical velocity shear in highly stratified portions of the water column to promote dynamic instability. The same study measured density inversions in the water column under the ice.

Mixing and stratification of the water column may have repercussions in the lower reaches of the rivers, as the tides advect water masses back and forth. In the case of highly stratified water, the upstream migration of the salt wedge during periods of winter low flow may impact on the aquatic life, as well as on water intakes or effluent outfalls located in the area.

5. Hydro production and river regulation

There's nothing like a dam to change the ice regime of a river. A case in point is the construction of dams on La Grande River in Québec, which empties into James Bay. The fact that deep water drawn from the reservoir is warmer than surface water under natural conditions has led to a significantly weakened ice cover downstream. Superimposed is the effect of increased discharge in winter on water level fluctuations and currents. Subsequent to the construction of the dams, ice conditions are so unstable (SEBJ, 1990) that it is now forbidden for anyone to cross the river in the estuary and coastal area close to the river mouth.

This problem of the bearing capacity of ice in the tidal zone may at first not seem very significant in economic terms but it is nevertheless a very important subject due to the risk to human lives. For example, last winter in the tidal zone of southern New Brunswick rivers, three trucks went through the ice. Fortunately, no one was seriously injured. At La Grande, Hydro Québec facilitated the crossing of the river by modifying the different structures of La Grande 1 powerhouse, dam and spillway to ensure a secure crossing over the river and by building a 45 km access road from the bridge to James Bay coast. Although this means a detour for the local Native Crees, there are the offsetting benefits of reliability and speed (SEBJ, 1990).

One principle of scientific research is that a key ingredient enabling the understanding of a phenomenon is to develop appropriate terminology to describe it. The elders of the Inuit and other Native nations such as Crees and Innus have a very rich vocabulary for ice and snow. Some of these words probably correspond to phenomena totally unknown to the scientific community. One research activity that may be very promising is to develop a collaboration between the scientific community and the Native communities to facilitate a cultural exchange.

6. Transport processes in ice infested waters

There have been a number of studies on the impact of ice on sediment transport in tidal areas, particularly those done by Dionne (e.g. 1989) and Troude and Sérodes (1988). Most of the time, ice protects banks from waves and currents. On the other hand, during spring tides, shorefast ice (zone 2) can rip significant quantities away. In other areas, sediment on the estuary bottom (zone 3) adhering to stranded ice can move around considerably (Knight and Dalrymple, 1976). Although significant concentrations of sediment in ice have been measured, most of the transport is local. In addition to the impacts on the physical environment, these processes can be significant when one considers the transport of any present toxic materials.

Without more field studies, numerical modelling of these lagrangian processes is virtually impossible. On the matter of the value of dispersion coefficients to be used in these models, very few measurements have been taken in tidal zones and even fewer in rivers in the presence of ice covers. To our knowledge, no measurements have been taken in ice infested tidal zones.

Of course, the transport of drift ice is interesting *per se*. The Department of Fisheries and Oceans (Saucier, personal communication, 1999) is trying to develop predictive tools to forecast ice ridging to optimise navigation channel route selection. Transport of drift ice is also a consideration in the design of engineering structures such as bridges, intakes and other marine structures. Environmental aspects notwithstanding, the presence of ice in Canadian waters makes it very difficult to entertain a tidal power plant.

7. Fish habitat in ice-covered tidal flow environments

Although a growing number of studies have recently described the characteristics of fish habitat in ice-covered rivers (for review, see Power et al. 1993 and Cunjak, 1996), comparatively little information is available concerning such habitat in ice-covered tidal flow environments. However, because of the complexity of the interactions between ice and flow processes in tidal rivers, one should expect that they will have a profound effect on many important fish habitat parameters such as substrate, cover, temperature, water depth and water velocity.

For example, Bergeron et al. (1998) showed that the characteristics of winter geomorphological processes influence the migratory behaviour of the Atlantic tomcod population of the Sainte-Anne River (Sainte-Anne de la Pérade, Québec). Measurements of channel morphology and flow velocity at low water indicated that the development of the ice cover at the onset of winter gradually closes several of the shallowest sections of the multi-threaded channel estuary. This reduces the cross-sectional area of the channel which leads to an increase of flow velocity in order to maintain continuity. Underwater video counts of tomcod movements indicated that this velocity increase limited the access of upstream migrating fish to the river and then to the spawning grounds located approximately 6 km upstream from the estuary. The data demonstrated that upstream fish migrants avoided the downstream large flow velocities occurring during falling tide and favoured the short period of flow reversal associated with large rising tides in order to move upstream.

Another factor that may limit fish production in northern tidal river is the occurrence of frazil ice generated mainly in turbulent areas such as rapids and falls (Michel and Drouin, 1981 ; Roy, 1989). These ice crystals accumulate under the stable ice layer and pile up to form suspended dams, that can reach a thickness up to 50 m. In shallow stretches with a rough bottom, frazil attaches the stones on river bed and forms anchor ice. If both types occur simultaneously, ice dams are formed and the section of the river is restricted causing an increase in local velocities. Such phenomenon are known but their consequences on aquatic habitats is not totally understood nor are the processes quantified for tidal areas.

This example demonstrates one of the possible effects of tidal processes on fish habitat. Other effects relating to fish species await study, including effects of winter processes on the characteristics of summer habitat.

One interesting application is the impact of ice on survival rates for shellfish. This is a key consideration for the Eastern Canada aquaculture business. There are indications that winter habitat may be one of the most critical elements for species development (Boghen and St.-Hilaire, 1997).

8. Field study

There is little literature on ice processes in tidal rivers and estuaries. The processes are complex and hard to measure. As the Task force sees it, one of the goals of the project is to develop instrumentation appropriate for the measurement of pertinent variables. There have been recent promising technological advances (e.g. Prinsenberg). For example, airborne laser technology can now make digital elevation models quickly, cheaply and precisely. An ice profiling system to measure keel depths is now available commercially. The Canadian Coast Guard (Morse and Crookshank, 1998) have developed and tested digital imaging systems. There is new satellite data available from Radarsat and soon from Radarsat II. Acoustic doppler profilers have come down in price. And global positioning systems have been developed providing decimetre accuracy in real time.

Unfortunately, many highly sophisticated instruments don't work very well in the rigours of winter out on the ice. Also, there are very real constraints related to human safety in such a dynamic and cold environment including those concerns mentioned related to bearing capacity.

Over the next months, the Working Group will develop a field program in support of the research needs. We have to address the issues of collaborations, scientific considerations, logistics, financing and appropriate technologies. We welcome whole-heartedly researchers willing to participate. At the end of the efforts, in addition to the individual publications, the goal of the WG is to publish a book on the subject under a CRIPE banner.

9.0 Climate change

We can't end this article without addressing the issue of climate change. Although, for many of us, a warmer Canada might be a good thing, we know that the ice regime in tidal portions of rivers and in estuaries is probably more sensitive to climate change than in other areas (Barnes, 1990). In order to measure the potential effects of climate change, it's time now to quantify the fascinating ice processes in tidal rivers and estuaries.

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