

River Ice Control and Fish Habitat Restoration Mutual Interests and Benefits

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ABSTRACT

To develop environmentally acceptable ice control measures for small rivers, researchers must screen alternatives for their impact on river ecosystems, including fish populations. Similarly, to develop structures to improve fish habitat in cold regions, we must understand how these structures alter ice regime and thence how the fish respond. Unfortunately, we have little information to determine how altering ice regime, for either ice control or habitat restoration, affects fish. We explore in this paper several areas of mutual interest to river engineers and ecologists. These interests begin with a need to quantify linkages between ice regime and ecological consequences. We also discuss the convergence of needs to control ice for the benefit of both aquatic and human communities and suggest specific topics for future research.

Key words: Fish habitat, Habitat restoration, Ice control, River ice

BACKGROUND

The needs of riverine ecosystems and human communities have often conflicted. Dams have permanently altered river flow regimes and impeded fish migration. Towns and farms have encroached on floodplains, often clearing riverbanks of vegetation necessary for maintaining the abundance and diversity of aquatic organisms. Protection of communities from open-water and ice-affected flooding by levee construction, river channelization, and removal of gravel and natural debris has also degraded aquatic habitat. Overfishing has depleted fish stocks, and effluent discharge and agricultural runoff has degraded water quality. These effects have severely stressed numerous plant and animal species dependent on high-quality riparian habitat.

Minimizing adverse environmental impact has consequently become an increasingly higher priority in flood control efforts. Indeed, it can provide a rationale to develop new flood control strategies, including

those pertaining to ice-jam flooding. However, we currently lack data and models needed to predict how changes in ice regime will impact stream ecology, including fish populations. This lack of prediction capability impedes development of new ice-jam flood-control techniques.

Fish habitat managers have attempted their own riverine manipulations in an effort to ameliorate past human impacts on rivers. These manipulations have included habitat restoration using in-stream structures, restoration of riparian vegetation, dam removal, and provision of fish-passage structures at dams. These efforts attempt to restore the physical attributes necessary for high-quality fish habitat within the constraints of continued human use of the rivers. Increasingly, fish-habitat managers have recognized that many management problems require innovative engineering solutions to meet performance and cost criteria. For example, habitat structures placed in cold regions streams must be inexpensive yet survive exposure to dynamic ice breakup events.

Engineers and fish-habitat managers clearly can offer useful input to each other's area of interest. However, in this paper, we explore a more thorough level of cooperation: mutual interests and benefits to human and fish communities associated with ice control in small rivers.

ICE DYNAMICS AND CONTROL STRATEGIES FOR SMALL RIVERS

Many small communities across the northern United States are located on small, unregulated rivers that can generate impressive ice jams and consequent flooding. Two types of ice jams occur: freezeup and breakup. Michel (1971), Beltaos (1983, 1984, 1995) and Ashton (1986) provide thorough descriptions of ice jam formation processes and their hydraulic consequences. Here we will briefly discuss ice jam formation processes in relation to ice control on small, unregulated rivers.

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Frazil ice is the dominant ice formed in all but very slow moving river sections. It forms within supercooled (i.e., below freezing) turbulent water along open water river sections, particularly along rapids. Frazil ice can collect in floes on the surface of slower moving sections, and these floes can arch between islands or constrictions, or stop against the ice covers formed thermally on slow reaches found at confluences with lakes or major tributaries. Frazil ice can also collect beneath ice covers to form very thick deposits that can close off major portions of a river channel. Additionally, frazil ice can deposit directly onto rocks, gravel or vegetation in supercooled sections to form anchor ice.

During prolonged cold periods, the surfaces of rapids often remain largely open to the air, and thus these sections can continue to generate frazil ice for deposition along ice-covered sections downstream. The resulting deposits, or freezeup ice jams, can be very thick relative to channel depth and the consequent increase in hydraulic resistance can be sufficient to cause flooding despite the accompanying low flows. A freezeup ice jam can progress slowly upstream, as stage rise reduces velocities and permits frazil floes to deposit at the head of the jam. Continued low temperatures can cause initially porous frazil deposits to freeze solidly, yielding ice covers much thicker than normally result from surface ice growth. Also, this freezing of frazil deposits can combine with low flow to leave portions of a freezeup ice jam grounded or frozen into the river bed, significantly reducing the river cross-section containing flowing water.

A breakup ice jam occurs after a river has grown an ice cover through the formation of frazil deposits and thermal ice growth. Rapid increase in discharge from snowmelt or rainfall, typically occurring in early spring, can lift the ice cover free of its attachments to the bed and banks and cause it to move abruptly downstream. This motion causes mechanical breakup of the cover and release of its stored water. The resulting ice run may stop abruptly against solid ice sheets on flatter reaches, may lodge in sharp river bends, or arch between islands or across obstructions (such as bridge piers), to cause a breakup ice jam. These ice jams can restrict flow so thoroughly that serious flooding may result within an hour of their formation. Beltaos (1984), Ferrick et al. (1986), and Ferrick and Mulherin (1989) provide good descriptions of this type of dynamic ice breakup and jamming process.

A few kilometers of ice cover can provide sufficient ice volume to cause breakup ice-jam flooding on small rivers. Along such a reach, breakup often occurs sequentially, with the breaking front moving from upstream to downstream. As the front encounters a sta-

tionary cover, it will lift the cover and significantly increase the downstream load on it. The cover may then move, releasing energy from in-channel water storage to sustain the breakup process. This type of sequential or progressive breakup can occur quickly on steep rivers (Ferrick and Mulherin 1989) and leads to a downstream increase in the quantity of moving ice and the amplitude of the accompanying water surge. Ice jams which result from progressive breakup can be very severe in comparison with ones where sections of ice release more independently due to increased deterioration (Ferrick and Mulherin 1989).

Flood damages from single ice jam events on small rivers can amount to hundreds of thousands of dollars in towns consisting of a few thousand residents. In addition, a breakup jam's sudden appearance and uncertain consequences can severely strain local flood fighting resources. Commonly, however, losses are insufficient to justify conventional flood control structures such as dams and levees. Ecological concerns also tend to render such structures unattractive.

Many types of specialized ice-control methods have been developed to mitigate ice-jam flooding (see Perham 1983, Belore et al. 1990, USACE 1994, Tuthill 1995). The methods differ according to whether they seek to mitigate effects from freezeup or breakup ice jams.

The main strategy to mitigate freezeup ice jams involves collecting frazil ice and promoting early ice cover formation upstream of the site to be protected. This strategy reduces frazil ice available to jam by collecting ice transported from upstream and reducing local ice production by insulating an open water section with an ice cover. Ice booms are proven freezeup ice-control technology. They usually consist of floating timbers or metal pontoons held together with wire rope and anchored into the bed or banks. They are generally of modest cost when scaled to the river width, and can be seasonally deployed to confine environmental effects to the winter and early spring. However, booms will collect frazil ice only if local velocities are below a threshold value. Thus, to protect a given ice jam site, it may be necessary to construct a low-head dam or weir to provide a suitable low-velocity pool in which to place a boom.

Breakup ice jams are more dynamic than freezeup jams and can generate much higher loads on the structures intended to control them. Ice booms offer limited mitigation of breakup jams. They reduce downstream ice thickness during freezeup, perhaps allowing a breakup ice run to pass through a problem area. Also, the ice covers formed by ice booms can interrupt progressive breakup by temporarily arresting an ice run and providing time for the ice cover below to break up

before arrival of the upstream ice. However, to provide breakup ice control for more extreme events, dams with ice-retaining piers have been constructed. These structures are much more expensive than booms for a given river size and have more potential for environmental disruption. Both factors tend to reduce their appeal for protection of small communities on small rivers.

The U.S. Army Corps of Engineers has recognized the limitations of existing ice control technology, and has asked CRREL to develop low-cost, environmentally acceptable ice control measures for small, unregulated rivers. As noted, such an objective implies a need to screen possible solutions for their impact on stream ecology, including fish populations. Recent papers by Prowse (1994) and Scrimgeour et al. (1994) summarize river ice processes and their ecological implications. Unfortunately, few data exist to quantify these linkages. Thus, we cannot predict effects on fish populations caused by altering a river's ice regime. Nevertheless, there appear to be opportunities to control river ice for ice jam flood mitigation that also lead to improved fish habitat.

GENERAL GUIDELINES FOR HABITAT RESTORATION

Riverine biota have evolved in the context of unregulated and structurally heterogeneous natural environments. Allowing a human-altered river system to revert to its natural state thus represents the best option from an ecosystem perspective. Where this approach is not feasible or desirable, habitat restoration is an option to re-establish what are thought to be critical physical characteristics along a river degraded by past human activity.

In general, habitat-restoration efforts in small streams attempt to restore the large variation in in-stream and bank conditions characteristic of small, natural rivers; that is, these efforts generally attempt to increase stream habitat heterogeneity relative to human-altered conditions. This approach sets a scale of activity for in-stream habitat restoration: many small changes along a river reach are preferable to large changes at a few sites. For example, adding low-head boulder dams to create pools that each extend for a few stream-widths would be a restoration option for a stream lacking pool habitat; adding a larger dam that would alter flow regime over a major fraction of the basin would generally not be considered a restoration option.

Hunt (1976) and Maughan and Nelson (1980) provide general guidelines and case studies of restoration efforts for small streams that seek to improve fish hab-

itat. So-called "in-stream large structures" such as large, woody debris (fallen trees or large logs) and boulder clusters increase local velocity and depth heterogeneity, providing resting areas for fish adjacent to high flows carrying prey. They also provide cover from predators. Boulder dams create small, low velocity pools upstream and plunge pools downstream that mimic those caused by natural obstructions. Restoration of a buffer strip of riparian vegetation seeks to re-establish many natural characteristics: it provides cover for fish from predators, reduces extreme water-temperature fluctuations, provides a source of nutrients and large, woody debris, reduces erosion of bank materials and helps to trap soil carried into the stream by flood waters.

The success of habitat-restoration work has been documented in many cases (Hunt 1988, Riley and Fausch 1995). However, predictive tools are still lacking, particularly for streams in cold regions subjected to annual ice cover formation and breakup. Nevertheless, we may infer, based on past studies of winter habitat preferences and known physical requirements for fish, the types of characteristics that habitat restoration should seek to enhance in small, cold regions streams.

RIVER ICE CONTROL: IMPLICATIONS FOR AQUATIC HABITAT

Liebig's law of the minimum states that population levels of organisms tend to be set by those factors, or "bottlenecks," which have the strongest affect on growth, survivorship, and reproduction. In cold regions streams, the extreme changes in physical conditions caused by winter processes may represent population bottlenecks to many stream organisms (Mason 1976, Koski et al. 1984, Resh et al. 1988). For salmonid fishes, anchor-ice formation, stranding of fish by ice formation, reduced oxygenated water flow and breakup-induced scouring of bed materials may significantly reduce both overwinter survivorship and early spring reproduction (Dolloff 1986, Murphy and Meehan 1991). Consequently, engineering activities that moderate these processes, or provide areas in which organisms can escape their negative effects, may significantly improve habitat quality.

Pools are an important physical habitat for many stream organisms. They are extensively used by salmonid fishes, often by larger catchable-sized and reproductively mature individuals, as these deepwater, low-velocity areas provide both cover from predators and preferred resting areas (Bjornn and Reiser 1991). Pools may also buffer the effects of extreme physical conditions such as floods, droughts, and extreme tem-

perature variation. Channelized (or cleared-channel) river systems with altered riparian forests may conspicuously lack sufficient pool extent to support fish populations approaching natural levels (Bjornn and Reiser 1991).

As noted, habitat-restoration efforts often seek to create small pools in rivers that lack them using boulder dams and collections of large, anchored logs. Increases in the percentage and stability of pool habitats may be particularly important during the winter. Several studies have documented a habitat shift by salmonids from shallow-water to deepwater areas in the fall and winter (Dolloff 1986, Walsh and Calkins 1986, Calkins 1990, Brown et al. 1993). Factors favoring this habitat shift may include reduced frazil and anchor ice formation in pools, increased water retention during winter flow minima, lower energy requirements, and protection from breakup ice runs.

Freezeup ice control structures (ICSs) have the potential to enhance aquatic habitat by seeking to control frazil ice production and transport. Booms located on existing pools will help promote ice-cover formation early in winter. Small, permanent or seasonally installed low-head weirs can create pools to assist ice booms or to reduce velocities sufficiently to cause frazil ice to arch between banks. Large, robust elements placed bank-to-bank to arrest breakup ice runs also tend to create pools on their upstream side, and may help frazil floes arch to form an ice cover.

Scrimgeour et al. (1994) describe several potential damaging effects of uncontrolled, dynamic ice breakup on invertebrate and fish communities. Water and ice velocities in excess of 5 m/s can accompany breakup ice runs, scouring bed and bank materials and thereby increasing sediment concentrations detrimental to fish and their eggs. Breakup surges can reduce the abundance of invertebrate prey and strand or displace fish downstream. Breakup surges can also remove significant portions of natural woody debris that provides refuge and cover for fish. Thus, habitat benefits may derive from a breakup ICS's main function: the arrest of a breakup ice run and the formation of a stable ice jam. A breakup ICS will reduce adverse effects of breakup surges for many river-widths downstream.

Other, indirect habitat benefits may derive from ICS's. Some communities now clear riverbanks and adjoining floodplain areas to provide access for excavators to remove ice jams. Low-velocity reaches where ice jams occur often collect gravel deposits, and communities frequently seek permission to remove these deposit in the hope that it will improve ice conveyance. Blasting to dislodge ice jams also continues to be used. By providing effective ice con-

trol, ICSs can reduce or eliminate these practices and hence improve overall habitat quality in an ice-jam prone area.

ICSs may have additional impacts on river ecosystems apart from their impact on physical habitat. The main function of an ICS is to reduce ice jam flooding in a human community. Such floods often cause leakage of gasoline, fuel oil and other contaminants into a river. A freezeup ICS can reduce or prevent this contaminated flow. A breakup ICS can be located adjacent to a more natural, vegetated floodplain and thereby replace contaminated floodplain flow with flow that potentially contains biologically important nutrients. Scrimgeour et al. (1994) note that such floodplain flow can be a significant source of nutrients for cold-regions rivers. Indeed, Prowse (1994) notes that the beneficial ecological effects of ice-jam flooding of the Peace-Athabaska Delta are sufficiently important that efforts are underway to induce it artificially (Demuth and Prowse 1995). Control of open-water flooding by large dams and levees, channelization and channel clearing have reduced the connections between rivers and their floodplains (Sedell and Luchessa 1982, Power et al. 1995) These connections may be crucial in the maintenance of both in-stream and floodplain biological productivity (Sparks et al. 1990, Murphy and Meehan 1991, Power et al. 1995). Because ice jam floods are more localized, it may be possible to transfer flooding to one or more upstream vegetated floodplains and still provide adequate flood protection for a human community.

AQUATIC HABITAT RESTORATION: IMPLICATIONS FOR ICE CONTROL

In many streams throughout North America, management agencies have attempted to undo the damage of the past by restoring in-stream large structures and riparian vegetation, with the aim of improving habitat for fish and other aquatic organisms (Murphy and Meehan 1991), and restoring predisturbance conditions (Sedell and Luchessa 1982). Continuing studies of the effects of these habitat-restoration efforts have demonstrated their value in enhancing stream ecosystems (Karr and Schlosser 1978, Murphy and Meehan 1991). As noted, in-stream large structures and riparian vegetation can affect ice regimes in ways beneficial to biological productivity. We consider here ways that they may also provide ice-control benefits to human communities.

Calkins et al. (1989) studied ice conditions established around large elements (boulders and large woody debris) used in fish habitat restoration in a small river in central Vermont. They found that when

these elements protruded above the water surface, they supported contiguous surface ice sheets that formed during freezeup. As water levels later dropped, air gaps formed between the ice sheets and the free stream. Calkins et al. suggested that these pockets of relatively warm air, insulated from rapid temperature change by an intact ice layer, should reduce local anchor ice and frazil ice production. Boulder dams used to increase pool habitat would also tend to reduce frazil production once the pools freeze over. That is, these habitat structures could act to mitigate freezeup ice jams. In addition, large structural elements placed to improve habitat may function as breakup ICSs by delaying, slowing or arresting ice movement, thereby interrupting progressive breakup.

Riparian cover has been demonstrated to dampen variation in stream temperature (Brown and Krygier 1970, Burton and Likens 1973). Conversely, Needham and Jones (1959) found that forest removal adjacent to a high-altitude California stream caused lower extreme winter water temperatures and increased anchor ice formation. Any reduction in ice production caused by riparian cover reduces the volume of ice available to jam and hence benefits ice control. Intact riparian vegetation may also play a key role in the function of low-cost breakup ICSs by helping to retain ice in the channel while allowing flow to bypass over an adjoining floodplain (see next section).

The presence of intact riparian vegetation has also been shown to decrease discharge rise in response to precipitation events (Karr and Gorman 1975, Karr and Schlosser 1978). This effect may also occur to some extent in cold regions. The snowpack melts more slowly in forested areas, decreasing runoff rates from snowmelt. Also, by ripening more slowly, the snowpack in a forested area can absorb more rain during rain-on-snow events, again decreasing runoff rates. A slower discharge rise may delay initiation of breakup to the extent that the rising ice cover is able to deform via creep rather than fracture or the flow is able to melt channels through the ice cover rather than lift it. Also, lengthening the hydrograph decreases the peak discharge for a given runoff volume, thereby reducing the forces tending to breakup the ice cover; this may allow a runoff event to pass through the system without initiating breakup. These effects improve the chances for thermal deterioration of the ice cover rather than mechanical breakup and associated breakup ice jams.

EXISTING STRUCTURES: ICE CONTROL AND AQUATIC HABITAT ISSUES

Few studies have explicitly considered the link between aquatic habitat restoration and ice engineering.

Calkins et al. (1989) found that fish habitat structures were effective accumulators of frazil ice, and that interactions between habitat structures and surface ice sheets may reduce the rate of frazil and anchor ice production, although this was not directly measured. In addition, Calkins et al. pointed out the potential vulnerability of fish habitat structures to damage or displacement by ice movement and associated high flows during breakup. Such damage has indeed occurred at a number of habitat restoration sites in central Vermont (Steve Roy, U.S. Forest Service, personal communication, 1995).

In the summer of 1994, the authors initiated a study of the ecological effects of construction and emplacement of a new, low-cost breakup ICS in the Lamoille River, a fifth order stream in northern Vermont. The structure consists of four large, sloped-faced granite blocks placed across the river adjacent to a treed floodplain. The blocks are partially buried in a riprap blanket to prevent bed scour and block sliding, and the large gaps between them allow easy fish and canoe passage. The structure works by arresting a breakup ice run and forming a stable, partially grounded ice jam. The treed floodplain provides for flow bypass while retaining ice pieces in the river channel (Lever et al., in press).

We designed the ecological study to compare conditions in four river study reaches, before and after ICS emplacement: 1) a downstream reach containing the historic ice-jam location that should see a reduction in ice-jam severity, 2) a reach immediately downstream of the ICS that will be sheltered directly by the structure from breakup ice runs, 3) a reach immediately upstream of the ICS that will experience the partially grounded ice jams developed by the structure, and 4) a reach well upstream of all effects of the ICS to act as a control. Each survey in the study consisted of physical habitat assessments, macroinvertebrate sampling, and fish sampling at each of the four study reaches. Because the presence of the ICS has implications for both cold-season and warm-season habitats and organisms, we conducted the surveys at three times during the year: during summer, just prior to ice formation, and just after ice breakup and spring runoff. In addition, we were just able to conduct a survey prior to ICS construction to establish a summer baseline. We have not complete the analysis of these data. However, preliminary results suggest that placement of the ICS resulted in a major increase in the extent of pool habitat, which may be a critical resource that is in short supply in this part of the river. Assessment of effects due to changes in the breakup process through the area will require longer term study.

Table 1. Summary of potential fish-habitat and ice-control mutual interests and benefits.

<i>Interest (structure)</i>	<i>Fish habitat benefit</i>	<i>Ice control benefit</i>
<ul style="list-style-type: none"> • increased pool/riffle ratio (<i>boulder dams, low-head weirs</i>) 	<ul style="list-style-type: none"> • less ice blockage of channel • less ice penetration of beds • plunge pools for feeding 	<ul style="list-style-type: none"> • promotes stable ice cover (less transport) • less ice production • slower breakup ice run
<ul style="list-style-type: none"> • increased in-channel structures (<i>boulder clusters, woody structures</i>) 	<ul style="list-style-type: none"> • more refuge • more lateral velocity and depth variation • more air gaps beneath ice cover 	<ul style="list-style-type: none"> • delay or partial arrest of ice run
<ul style="list-style-type: none"> • increased floodplain flooding (<i>large boulders, no levees, no channelization or channel clearing</i>) 	<ul style="list-style-type: none"> • reconnection of channel and floodplain processes • decreased breakup surge 	<ul style="list-style-type: none"> • decreased breakup surge
<ul style="list-style-type: none"> • revegetated riparian zone 	<ul style="list-style-type: none"> • dampen temperature fluctuations • source of large woody debris • cover from predators 	<ul style="list-style-type: none"> • lower cooling rate (less ice production) • prevent ice passage around ice-control structure
<ul style="list-style-type: none"> • revegetated drainage basin 	<ul style="list-style-type: none"> • slower runoff rate (lower peak velocities) • less organic & inorganic pollution 	<ul style="list-style-type: none"> • decreased runoff rate & peak discharge
<ul style="list-style-type: none"> • arrest of breakup ice run (<i>breakup control structure</i>) 	<ul style="list-style-type: none"> • less scour of bed and banks • less damage to restoration structures 	<ul style="list-style-type: none"> • lower ice jam flood damages

DISCUSSION

It appears that engineering activities that control ice regimes on small rivers for human benefit have potential to benefit biological communities. Conversely, activities designed to enhance aquatic habitats may benefit human communities through their influence on ice regime. Table 1 summarizes several potential mutual interests and benefits for aquatic habitat and ice-jam flood control for small, unregulated rivers.

Clearly, the potential mutual benefits listed in Table 1 may not be realizable in practice. Also, Table 1 probably is not a comprehensive list, and it does not list potential adverse effects of ice control on human and biological communities. Nevertheless, we feel that the potential benefits listed warrant thorough exploration. This exploration should take the form of concurrent empirical study of the effect of habitat restoration and habitat change on river ice regimes, and the effect of ice control strategies on stream habitats and organisms. Due to complex interactions between physical habitats and stream biota, and the variability between streams of different thermal and hydraulic characteristics, these potential benefits must be established empirically. In addition, manipulating ice regimes can provide an opportunity directly to test theories concerning the effect of winter conditions on the structure and function of high-latitude stream ecosystems, providing an "acid test" of ecological theory (Bradshaw 1987).

The following is a partial list of specific research issues that warrant investigation:

1. Design and placement of inexpensive fish-habitat structures that can withstand dynamic ice breakup. This is an important issue for habitat managers that ice engineers can readily assist with.
2. Ecological and ice-regime effects of existing fish-habitat and ice-control structures on upstream and downstream reaches. Quantifying the performance of these structures with respect to each discipline would establish important physical connections upon which we may base further developments.
3. Freezeup and breakup processes on natural small rivers (i.e., those unaltered by humans). This research would attempt to determine the effects of natural, heterogeneous river structure on the magnitude of ice-jam flooding and damage to aquatic communities. If these effects are found to be less severe than those occurring on hydraulically similar, human-altered rivers, allowing a small river to revert to its natural state could represent a viable option for the benefit of both human and aquatic communities.
4. Development of true, dual-purpose ice-control/fish-habitat structures. Where allowing a river to revert to its natural state is not a practical option, this research offers the prospect of developing methods to improve simultaneously conditions for human and fish communities. At present, the scale of structural alterations generally is differ-

ent for habitat restoration and ice jam flood control. To improve fish habitat along a damaged reach, restoration usually involves use of small, spatially distributed structures along the entire reach. Conversely, structures to control ice jam flooding are often located at a single cross section, although use of multiple ice booms or small dams at a few sites has been tried or proposed. Finding a compromise scale of structural alterations would require better knowledge of the ice/hydraulic factors affecting ice jam formation and the role of ice regime on fish populations. Eventual structural development would likely entail physical model testing and field validation, similar to the Lamoille River ICS (Lever et al., in press).

5. Potential effects of global climate change on ice dynamics, flood control and winter ecology of biological communities in high-latitude streams and rivers. Current global climate models predict that arctic and subarctic regions of North America will experience the relatively greatest increase in temperature due to increased CO₂ levels, with most of the warming occurring during winter and early spring (Rouse et al. 1994). As river-ice interactions may have strong effects on the maintenance of aquatic ecosystems, changes in ice regime associated with global warming scenarios may merit special attention (Scrimgeour et al. 1994).

Clearly the resolution of these issues requires the combined long-term efforts of researchers from a variety of disciplines. Yet the rewards could be significant in terms of reduction in ice jam flood damages and improved fish habitat quality along small rivers. By addressing these research issues, groups concerned with the well-being of human and aquatic communities have an opportunity to develop an integrated approach to river management based on common interests.

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