JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 44, No. 2 AMERICAN WATER RESOURCES ASSOCIATION April 2008

INTRODUCTION TO WATER USE FROM ARCTIC LAKES: IDENTIFICATION, IMPACTS, AND DECISION SUPPORT[1]

Paul K. Sibley, Daniel M. White, Peter A. Cott, and Michael R. Lilly[2]

The arctic region has experienced considerable population and industrial growth in recent years. Growth is likely to continue as industries intensify their search for natural resources previously economically inaccessible. In much of the Arctic, permanent road infrastructure is nonexistent, so access to new natural-resource reserves is often dependent on the construction of ice roads during winter. Water used to support ice-road construction and related industrial activity is predominantly drawn from lakes, placing increased pressure on these water reserves and their associated biota.

Arctic lakes spend a significant proportion of the year under ice-cover. This presents significant challenges to resource and industry managers interested in determining the suitability of arctic lakes for the purpose of water withdrawal. Although the Arctic has many lakes, many are not suitable for water withdrawal due to potential effects on aquatic biota, particularly fishes. Until recently, water-withdrawal thresholds in Alaska and northern Canada guiding the removal of water from ice-covered lakes have been largely based on experience with limited supporting measured data. As such, there is considerable uncertainty regarding how protective these thresholds are with respect to mitigating the potential risks of water use. There is a need for simple, practical methods to identify lakes that can be used for water-withdrawal purposes and safe limits on water-use volumes. These must be based on an understanding of the potential environmental risks involved with this activity and adaptive to increased understanding of arctic-lake processes and changing climate conditions.

This collection on arctic lakes contains seven papers, each focusing on different aspects of water-withdrawal activities in support of industrial activities. The impetus for the creation of this series of papers began three years ago when several collaborating Alaska and Canadian researchers presenting at the AWRA summer specialty conference on adaptive management realized that they were dealing with various and complimentary aspects of water use in arctic lakes. While lakes in the Arctic and Subarctic have been studied in many scientific investigations, there was need to improve the understanding of arctic lakes related to current resource management challenges. These papers present topics ranging from the development of new approaches for the identification of lakes that may be suitable for water withdrawal to the impacts that water withdrawal may have on arctic lakes. Several papers focus on the chemistry in arctic lakes to improve our general understanding of the lake environment.

In the first paper, White *et al.* (2008a) presented an approach using synthetic aperture radar (SAR) imagery to identify lakes that contain water throughout the year, and may therefore be candidates for industrial use in the late winter. Other lakes, shown to freeze completely in winter, conversely, could be candidates for early season industrial use. These authors also noted that flooded gravel mines (also required for road construction) may serve as a good source of water for ice road construction as they often

[1]Paper No. J07998 of the *Journal of the American Water Resources Association* (JAWRA). Received December 17, 2007; accepted December 18, 2007. **Discussions are open until October 1, 2008**.

[2]Respectively, Associate Professor, Department of Environmental Biology, University of Guelph, Guelph, Ontario, Canada N1G 2W1; Director, Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks, Alaska 99775; Fisheries Biologist, Department of Fisheries and Oceans, Yellowknife, Northwest Territories, Canada X1A 1E2; and Principal, Geowatersheds Scientific, Fairbanks, Alaska 99775-5860 (E-Mail/Sibley: psibley@uoguelph.ca).

contain large volumes of oxygenated water. If overwintering fishes are present in flooded gravel mines, they are unlikely to be affected by winter water withdrawals. The SAR approach presented by White *et al.* (2008a), combined with the chemistry and biological criteria and decision support framework suggested by Cott *et al.* (2008a) and Cott *et al.* (2008b), respectively, could provide the basis for a rigorous approach to the identification and selection of lakes for winter water withdrawal.

In the second paper, Hirose *et al.* (2008) evaluated the application of SAR remote sensing to detect candidate lakes for the purpose of water withdrawal and compare this approach to the more traditional approach of using bathymetric soundings. Although bathymetric soundings can provide much detailed information, they are expensive and difficult to undertake in remote arctic lakes. The SAR approach indicated good potential for detecting lakes with ground-fast ice and compared favorably with the bathymetric sounding approaches for the accurate detection of ground-fast ice. Potential benefits of this technique include cost savings and rapid identification of lakes that are unlikely to be fish bearing. Such lakes are good candidates for water withdrawal during late winter ice road construction activity with minimal risk to over-wintering fish.

Beginning with the third paper, the focus turns to in-lake chemical and biological processes that are predicted to be affected by water withdrawal. In this paper, White *et al.* (2008b). presented a potentially useful, and attractively simple model that can be applied by industry and resource managers to predict under-ice oxygen concentrations in lakes in northern Alaska. This model required only basic information on lake morphology. Based on measurements taken over a five-month winter period from three arctic lakes with no surface or subsurface recharge, the model provides the user with information on winter oxygen depletion rates, oxygen profiles, and importantly, the projected date after which oxygen will drop below a given threshold required to support over-wintering fishes. The model is less complex than previous models, an important aspect for practical use in arctic lakes where detailed information on lake morphological characteristics is often lacking and difficult to obtain. The authors indicate that further validation of the model is required, most notably in the context of water-withdrawal activities, but has the potential to be a very effective tool for modeling the under-ice oxygen concentration for the purpose of fisheries management.

In the fourth paper, Walter *et al.* (2008) discussed the application of a novel technique, applied previously by the authors, in which SAR is used to estimate fluxes of methane from arctic lakes. The study focuses on the amount of SAR backscatter detected from vertically oriented gas bubbles trapped in the ice of seven tundra lakes and one boreal forest lake. Most climate change models, including those used by the Inter-governmental Panel on Climate Change, predict that the arctic region will experience some of the most profound impacts of climate change. Arctic lakes, through the process of ebullition, have recently been shown to constitute a significant source of methane, one of the key greenhouse gases contributing to climate change, particularly in northern latitudes. The authors found that methane ebullition was common in all of the lakes studied although there was considerable variation between lakes. The authors showed that the abundance of methane bubbles trapped in early winter lake ice can be predicted using SAR imagery. The implications of this study could be significant; with refinements of this technique, it may be possible to estimate methane emissions from arctic lakes on a pan-arctic scale. This would greatly aid the predictive capacity of climate change models and help to refine predictions of potential impacts of global climate change on arctic lake ecology. In addition, consumption of methane by bacteria within the lake can impact the oxygen concentration, and hence, the fishery. Identifying lakes with high ebullition rates could be useful in identifying lakes that are not candidates for late winter pumping.

In the fifth paper, Chambers *et al.* (2008) evaluated changes in water chemistry characteristics of four lakes subject to water withdrawal for ice-road construction and one lake used as a reference. The lakes were monitored over a five-month winter period on the North Slope of Alaska. Similar to Cott *et al.* (2008a), this study found that lake morphological and physicochemical properties, and not water-withdrawal activities, were the most important predictors of under-ice chemistry changes, most importantly oxygen depletion and concentration increases of solutes due to exclusion from lake-ice formation. The authors conclude that the depth-based models were reasonably effective at predicting average oxygen depletion rates but did not fit any one lake well over the assessment period. This may mean that the broad application of general, empirically based models to predict oxygen depletion in arctic lakes may be difficult.

In the sixth paper, Cott *et al.* (2008a) used an experimental approach to evaluate the potential impacts of water withdrawal on fish and invertebrate populations of ice-covered lakes in the Northwest Territories. Depletion of oxygen due to under-ice water use could be detrimental to resident populations, especially fishes that must have an adequate supply of oxygen to survive extended periods of ice cover. In this study, 10 and 20% of under-ice water volume was withdrawn from two lakes, while two lakes served as references. The authors found that 10% withdrawal had little effect on oxygen concentration or total volume-weighted oxygen concentration, or amount of over-wintering fish habitat. In contrast, 20% withdrawal resulted in a vertical reduction in the oxygen profile, a reduction in the total volume-weighted oxygen, and a reduction in the amount of over-wintering fish habitat. However, northern pike abundance was not affected under either water-withdrawal scenario. The authors concluded that the physicochemical changes reflected the variability of the lakes and would be expected to vary between lakes. Importantly, these authors suggest that a winter general withdrawal threshold of 10% would be acceptable in arctic lakes, if accompanied by precautionary measures. This is higher than the previously used 5% withdrawal threshold in Canada, but lower than those currently in use in Alaska (15-35% depending on the fisheries habitat).

In the final paper, Cott *et al.* (2008b) provided a comprehensive review of the potential chemical and biological effects of water-level fluctuations in arctic lakes as a result of water-withdrawal activities. The authors focus on one of the most important biological assessment endpoints: fish populations and fisheries management; however, information on potential impacts on other biota, from benthic invertebrates to fur-bearers, is also discussed. The authors present a decision support system (DSS) for the protection of fishes and fur-bearers in relation to winter water-withdrawal activities. Based on empirically derived data from Cott *et al.* (2008a), this simple DSS, particularly when used in conjunction with lake-identification methods and tools described in the other papers of this collection, may provide a practical basis for informed decision making and mitigation of impacts from industrial and community water-withdrawal activities from arctic lakes.

LITERATURE CITED

Chambers, M.K., D.M. White, M.R. Lilly, L.D. Hinzman, K.M. Hilton, and R.C. Busey, 2008. Exploratory Analysis of the Winter Chemistry of Five Lakes on the North Slope of Alaska. Journal of the American Water Resources Association 44:316-327.

Cott, P.A., P.K. Sibley, A.M. Gordon, R.A. Bodaly, K.H. Mills, W.M. Somers, and G.A. Fillatre, 2008a. The Effects of Water Withdrawal From Ice-Covered Lakes on Oxygen, Temperature and Fish. Journal of the American Water Resources Association 44:328-342.

Cott, P.A., P.K. Sibley, M. Somers, M.R. Lilly, and A.M. Gordon, 2008b. A Review of Water Level Fluctuations on Aquatic Biota With an Emphasis on Fishes in Ice-Covered Lakes. Journal of the American Water Resources Association 44:343-359.

Hirose, T., M. Kapfer, J. Bennett, P. Cott, G. Manson, and S. Solomon, 2008. Bottomfast Ice Mapping and the Measurement of Ice Thickness on Tundra Lakes Using C-Band Synthetic Aperture Radar (SAR) Remote Sensing. Journal of the American Water Resources Association 44:285-292.

Walter, K.M., M. Engram, C.R. Duguay, M.O. Jeffries, and F.S. Chapin III, 2008. The Potential Use of Synthetic Aperture Radar (SAR) for Estimating Methane Ebullition From Arctic Lakes. Journal of the American Water Resources Association 44:305-315.

White, D.M., P. Prokein, M.K. Chambers, M.R. Lilly, and H. Toniolo, 2008a. Use of Synthetic Aperture Radar for Selecting Alaskan Lakes for Winter Water Use. Journal of the American Water Resources Association 44:276-284.

White, D.M., H.M. Clilverd, A.C. Tidwell, L. Little, M.R. Lilly, M. Chambers, and D. Reichardt, 2008b. A Tool for Modeling the Winter Oxygen Depletion Rate in Arctic Lakes. Journal of the American Water Resources Association 44:293-304.