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ICE THICKNESS AND ICE BRIDGES
An Annotated Bibliography

Compiled for the
Region III Forest Practices Riparian Management Committee

by
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SUMMARY

The purpose of this literature review was to document our knowledge and lack of knowledge on 2 related topics: ice thickness regimes of Region III lakes, streams, and rivers; and ice-bridge construction. The focal point for this review was to better understand the potential impacts of river ice and ice-bridges on fish and fish habitat. Therefore, some redundancy may exist in citations found below and in the bibliographies on "Fish Use of Upwellings" and "Winter Fish Use of Glacial Streams".

A considerable amount of data and data analysis has been published by the U.S. Army, Cold Regions Research and Engineering Laboratory (CRREL), regarding ice-thickness regimes. These and other data indicate the range of cumulative seasonal ice thickness for interior Alaska to be from 75 to 160 cm (30 to 63 inches). There exists considerable variation in the date of ice initiation and date of ice breakup as well as ice thickness growth as a function of air temperatures and water body characteristics. Aldrich (1981) gives the 1, 2, 5, 10, 20, 50, and 100 year return period ice thickness values for many Alaskan and Canadian locations. Many theoretical studies exist that analyze and attempt to model the ice growth and decay processes. Simpler methods correlating ice thickness with freezing degree-days provide a more accessible guideline for estimating ice thickness under given conditions. Some methods include the effects of snow depth on the ice cover. Frazil ice and submerged frazil slush can accelerate the initiation and early season growth rates of ice thickness. Of great concern to the Region III Forest Practices Stream Classification Committee (SCC) was the location and frequency of open water (leads or polynas) in rivers with a general ice cover. Although widely recognized, little scientific attention has been given to this phenomenon in the literature reviewed. One author speculated that polynas are related to island frequency (Gerard, 1989).

Several references from CRREL and others offer guidelines for ice-bridge construction. The ideal site has the following characteristics: deep, narrow, slow flow in a single straight channel with gradual approaches to the ice; no tributary streams, creeks or lakes immediately upstream; and it is located near an existing road network. The site should also be free of warm springs and sand bars and not subject to major snow drifting. Being downstream of riffles/rapids may be conducive to supercooling and frazil ice formation that might accelerate ice formation and

growth at the bridge site. One reference suggested sites with low flow rates, thick ice over flowing water or dry channels during winter. Booms have been used to trap or collect frazil ice at the bridge site. Once natural ice cover has progressed across the channel thick enough to bear the weight of personnel and light equipment, existing snow cover is removed to accelerate ice growth at the bottom of the ice sheet. Variation exists in whether snow is removed or just compacted. Snow removal is recommended on upstream and downstream sides of the road for a distance of 23-30 meters (75-100 feet) as well as on the road itself. Subsequent to ice growth in response to snow removal, surface flooding is recommended to build up ice thickness on the road surface. Some references indicate initiating this flooding stage immediately after deep snow removal. Removal of shallow snow cover is often ignored prior to the flooding process. Lateral barriers of snow, logs or boards are used to contain floodwater on the road surface. Water should be applied by layering, allowing full freezing of previous water applications before the next. Conflicting recommendations exist as to whether brush or logs should be incorporated into the ice. One study did document the increase in ice strength after incorporating geo-grid material during the ice buildup process. A regular regime of ice drilling and monitoring of ice thickness is recommended. Snow packing is commonly used to grade approaches to the ice bridge. Steep exit grades may result in trucks losing power and rolling backward onto the ice. The number of freezing degree-days possible in a region places a physical limit to ice thickness under conditions of no snow cover. Therefore, if one does not wish to freeze the whole water column or the streambed, one should have enough water depth and winter flow to allow the desired unfrozen water depth to be maintained. One may also need to allow for deflection (elastic sagging of large ice sheets under vertical load) of the ice bridge, and for the increased draft of floating ice bridges under loads due to surface ice buildup and traffic. While much anecdotal experience and some documentation exists for the complete freezing of natural cross-sections of small streams (Haugen et.al., 1982), little documentation of complete water-column freezing under ice bridges was found. An interagency correspondence was found (Ott, 1990) discussing the "grounding" of an ice-bridge and subsequent overflow on an interior Alaska river.

The final, but motivating focus of this review, is also the realm of sparsest data and greatest uncertainty. While there is evidence of heightened awareness of possible interactions between ice and fish, there are few data sets and little documentation of the occurrence, direction, or magnitude of such impacts either under natural ice-cover regimes or those affected by humans. Logic and theory may allow the forecasting of physical and hydraulic effects of ice cover occurrence, thickness and duration on cross-sectional or longitudinal channel form and water flow characteristics. However, the direct or secondary effects on individual fish survival (various life stages), fish behavior, or population dynamics rests on more speculative grounds. Two main dimensions of this problem are (1) the logistic and technical difficulties of conducting such studies and (2) the lack of communication between hydrologists (broadly defined) and biologists (broadly defined). However, there are encouraging signs of advances on both fronts including the new generation of digital sensors and recorders, and the increase in multi-disciplinary research and management teams and "cross-trained" graduate students. Citations by Chacho(1992), Scrimgeour et.al.(1992), Calkins (1989, 1990), Prowse (1992) and Rundquist and Baldrige (1990), as well as discussion by members of the SCC, point out some areas of concern and convey some anecdotal and general observations. Fish habitat requirements differ from species to species and change from one life stage to another. For example, the range of water velocities that a fish can use increases with the fish size and swimming capabilities. In addition to water flowing over the surface of a streambed, groundwater also can be important. In winter, living space can be restricted due to ice cover and low stream flow. Cold water temperatures and limited oxygen supply in conjunction with limited space can stress fish. Upwelling groundwater is usually warmer than surface water during winter months and may contain oxygen (the source of which seems enigmatic). These areas are also less likely to freeze and therefore may be important for incubating embryos as well as overwintering resident species or juvenile anadromous species requiring more than one year in freshwater. Warmer water temperatures may also be significant for Fall spawners in terms of physiological thresholds or behavioral triggers based on thermal time (cumulative degree-days or degree-hours).

Research needs specific to ice thickness and ice bridges include: (1) measurement of ice thickness growth and hydraulic conditions upstream, downstream and immediately under ice bridges; (2) the use of models to explore the reduction in habitat space associated with ice bridge construction under various conditions of original water depth, freezing degree-days, and patterns of snow removal and surface flooding; (3) monitoring the annual variation in the occurrence of leads in important fish streams in winter. Research needs related to ice and ice-bridge effects on fish and fish habitat are found under the literature reviews on fish use of upwellings and winter use of glacial streams.

REFERENCES

Note: All library call numbers are from the University of Alaska Fairbanks libraries: "Geophy. Inst." refers to the Geophysical Institute Library on UAF campus, "Alaska" refers to the Alaska Collection in the UAF Rasmuson Library, "Doc" refers to the government document collection in the Rasmuson Library, and all others refer to the general collection in the Rasmuson Library.

Abele, G. 1990. Snow roads and runways. US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory, Monograph 90-3.

Snow characteristics are discussed. These characteristics include snow strength, grain size, effects of time and temperature on snow strength, interrelationship between snow properties, and behavior under load. Methods of measuring snow strength, and snow pavement construction techniques are described.

Adam, Kenneth M. 1978. Building and operating winter roads in Canada and Alaska. Published under contract for Environment Division, Northern Environmental Protection and Renewable Resources Branch, Department of Indian and Northern Affairs, Ottawa, Canada.

This is a useful reference that includes sections on building and operating winter roads, planning winter roads, and experience with winter roads. Within the section on building and operating winter roads there is a chapter on ice bridges that reviews the general considerations of site selection, construction, operation, maintenance, and closure. Appendixes include maps of permafrost, date of cumulative freezing degree-days > 550 F, date of snow depth > 4 inches, and general vegetation cover for Canada. Appendixes also include guidelines on the bearing capacity of ice, descriptions of testing equipment, and recommendations for safety. (Alaska TE 175 A33 1983, Microform, in French; English version was borrowed from ABR, Inc. for review.)

Alaska Dept. of Fish & Game. (undated). Tips on the weight-bearing capacity of ice. One page hand-out obtained from CRREL files, Fort. Wainwright , AK

Contains 10 guidelines for travel on ice covered waters, including maximum loads for given ice thickness:

Minimum Ice Thickness (inches)	Max. Load
02	1 man on foot
03	Group, single file
08	Automobile (2 tons GVW)
12	Heavy truck
25	45 tons
36	110 tons

Aldrich, J. W. 1981. A stochastic analysis of some existing ice thickness data. The Northern Engineer 13(1):4-10.

The author utilizes data reported by CRREL on average date ice was first observed, the ice sheet was continuous across the water body, the earliest maximum ice thickness occurred, water was first observed within the ice sheet, and the water body was ice free, to test three distributions , the Gumbel I, the Log Normal, and the Log Pearson Type III. He found the Pearson Type III distribution to fit the data best. He then presents tables of recurrence intervals for ice thickness for selected Alaskan and Canadian rivers and lakes.

Allen, W.T.R. 1977. Freeze-up, break-up and ice thickness in Canada. Fisheries and Environment Canada. Report CLI-1-77.

This is a valuable compilation of river ice data across Canada from 1974 and earlier; in some cases dating back to the turn of the century. May be of limited utility for specifics of interior Alaska rivers except as comparative opportunities and as a base for general data analysis. (Geophy.Inst. GB 2429 A44 1977)

Anonymous.1986. Squad leaders guide for constructing ice bridges. Dept. of the Army, 6th Infantry Division (Light) Pamphlet No. 350-11.

This pamphlet briefly describes how to (1) conduct a site reconnaissance for locating an ice bridge; (2) construct an ice bridge profile; (3) classify a bridge based on ice thickness, color, and strength; (4) strengthen a bridge; (5) maintain a bridge; and (6) cross an ice bridge.

Anonymous. (undated). Construction of an ice bridge across the Imjin river in Korea. (obtained from CRREL files, Fort. Wainwright , AK)

Five pages of typed notes describing the ice bridge construction.

Anonymous. (undated). Ice bridge construction : 1978-1979. (obtained from CRREL files, Fort. Wainwright , AK)

One and one-half pages of typed notes describing ice bridge construction on the Tanana River, Alaska.

Anonymous. (date unknown). Ice bridge construction briefing outline. (obtained from CRREL files, Fort. Wainwright , AK)

Five typed pages of ice bridge construction guidelines.

Anonymous. (undated). Workshop on ice-bridging. Notes. (obtained from CRREL files, Fort. Wainwright , AK)

Four typed pages of notes.

Arctic Environmental Information and Data Center. 1984a. Assessment of the effects of the proposed Susitna Hydroelectric Project on instream temperature and fishery resources in the Watana to Talkeetna reach. Final Report for Harza-Ebasco for the Alaska Power Authority. Volume 1.

This report presents the results of weekly instream temperature simulations for the Susitna River comparing Watana-only and Watana/Devil Canyon project configurations with natural condition temperature simulations. These simulations were run using historic hydrometeorological data covering four summers and five winters. The effect of these temperatures on anadromous fish species is assessed by comparison with life stage-specific temperature tolerance criteria established from the literature, field studies, and lab studies. The model SNTEMP was used to simulate instream temperatures at various locations. Simulated stream temperatures were then used as input to the ICECAL model used to calculate ice conditions in the river. While this report notes the need for information on ice effects on fish resources it foresee that work as subject of some future report. (Alaska SH 177 T45 A87 1984 v.1)

Arctic Environmental Information and Data Center. 1984b. Assessment of the effects of the proposed Susitna Hydroelectric Project on instream temperature and fishery resources in the Watana to Talkeetna reach. Final Report for Harza-Ebasco for the Alaska Power Authority. Volume 2. APPENDICES A-H.

Contains details of simulated weekly water temperatures at selected middle Susitna River locations, isotherm plots of temperature simulation results, stream width functions, observed vs.

predicted air temperatures for water years 1981-1983, observed vertical air temperature profiles, basin weekly wind speeds, residual errors, and temperature histories at selected locations in relation to the five Pacific salmon life phase activities for all simulation scenarios. (Alaska SH 177 T45 A87 1984 v.2)

Ashton, G.D. 1980. Freshwater ice growth, motion, and decay. Pages 261-304 in S.C. Colbeck , editor. Dynamics of Snow and Ice masses. Academic Press, NY

This chapter in Colbeck's edited volume is an overview of the general processes involved in river ice phenomenon. Review the energy balance of ice growth, deals with frazil ice formation, floes, breakup and ice jams. (Geophy. Inst. GB 2403.2 D95).

Ashton, G.D. 1990. Ice Effects on Hydraulics and Fish Habitat. Cold Regions Research & Engineering Laboratory Special Report 90-8, U.S. Army, CRREL, Hanover, New Hampshire.

One of the only reports on ice that mentions possible effects on fish habitat. However, there is actually little discussion of fish habitat per se, beyond the opening statement that since ice cover affects water velocities and depths, and water velocities and depths are attributes of fish habitat, then ice cover must affect fish habitat. The rest of the report presents a mathematical analysis of the effect of ice cover on depth of flow, stage, and velocity. Other effects are briefly discussed qualitatively. Application is made to the Platte River in Nebraska. (Alaska GB 2401 U533 no. 90-8).

Ashton, G.D. and J.F. Kennedy. 1970. Temperature and flow conditions during the formation of river ice. IAHR Ice Symposium, Reykjavik, Iceland, 2.4.

This is a detailed investigation of the velocities and temperatures characteristic of flow in rivers during the onset and occurrence of ice covers. Vertical and lateral temperature and velocity distributions, and ice thickness and configuration were measured in an Iowa river at frequent intervals during the period of ice cover. (Alaska TC 163 I5 1970).

Barthelemy, J.L. 1975. Snow-road construction - a summary of technology from past to present. Tech. Report R 831, Civil Engineering Lab., Naval Construction Battalion Center, Port Hueneme, California.

Mainly reviews snow-road construction techniques and is not particularly useful with respect to ice-bridge construction. Discusses two methods: layered-compaction and depth-processing. This report documents the evolution of vehicle road systems on snow and presents a synoptic overview, summarizing all aspects of snow-road technology.

Bates, R.E. and D Saboe. 1968. Ice conditions and prediction of freeze-over on streams in the vicinity of Ft. Greely, Alaska. Cold Regions Research & Engineering Laboratory Special Report 121 Part *I*, U.S. Army, CRREL, Hanover, New Hampshire.

Descriptions of the events leading to freeze-over of the Delta River, near Ft. Greely, including ground and aerial photos and diagrams showing the changes in river ice conditions, are given. Curves that can be used to forecast ice formation at three river locations near Ft. Greely, Alaska, were developed. (Alaska GB 2401 U533 no. 121).

Bergman, G.R. and B.V. Proskuriakov. 1954. Ice Crossings. Original publication in Russian, Moscow 1943. translated by SIPRE Bibliography Project, Library of Congress for U.S. Army, Corps of Engineers.

Translated from the Russian book (chapter 1,2 &5 with Appendices 1-6,&8). Includes introduction to problem of determining safe loads on an ice cover and construction of ice crossings. Briefly describes conditions of water bodies and properties of ice and snow, and discusses "Natural Ice Bridges" and reinforcement of the ice cover. Appendices are tabulated values of math functions used in formulas in text and table for calculating the supporting power of an ice cover. (note: first authors name may be spelled Bregman). (Alaska TE 247 B74 1954).

Bilello, M.A. 1964. Method for predicting river and lake ice formation. Journal of Applied Meteorology 3(1):38-44.

Two sets of curves are developed which can be used to forecast the dates of first appearance of ice in the Fall, and ice formation from shore to shore on the Mackenzie River at Fort Good Hope, Canada. Similar curves could be developed for other locations based on relationships between mean daily air temperature and previously observed dates of ice formation. To apply the curves, an adjusted temperature record is maintained starting in early summer. Subsequently, this daily-adjusted temperature is applied to the family of curves to provide a day-to-day forecast of the date of ice formation.

Bilello, M.A. 1968. Ice conditions and prediction of freeze-over on streams in the vicinity of Ft. Greely, Alaska. Cold Regions Research & Engineering Laboratory Special Report 121 Part II, U.S. Army, CRREL, Hanover, New Hampshire.

Develops a site specific temperature accounting method and curves to reproduce observed freeze-over dates on the Delta River near Ft. Greely, Alaska. (Alaska GB 2401 U533 no. 121).

Bilello, M.A. 1980. Maximum thickness and subsequent decay of lake, river and fast sea ice in Canada and Alaska. Cold Regions Research & Engineering Laboratory Report 80-6, U.S. Army, CRREL, Hanover, New Hampshire.

This report analyzes weekly ice thickness data collected over a period of 10-15 years with particular attention to ice decay and its relation to accumulated thawing degree-days . Ice decay curves are presented for various locations. (Alaska GB 2401 U53 no. 80-6).

Bilello, M.A. and V.J. Lunardini. 1961,1964,1966,1969,1971,1972,1975,1991,1996. Icethickness observations, North American Arctic and Subarctic, 1974-75, 1975-76 and 1976-77. Cold Regions Research & Engineering Laboratory Special Report 43 part *s I-IX*, U.S. Army, CRREL, Hanover, New Hampshire.

Most detailed record of ice thickness data for Canada and Alaska. First 2 or 3 reports have only sparse data for Alaska, but subsequent reports have many more Alaskan river measurement sites. Measurements reported are maximum ice thickness for the season, weekly ice thickness and snow depth measurements at select cross-sections throughout the winter ice cover period. Generally, the least end-of-season ice thickness values range from near 60 cm. in the southern part of the state (excluding the Aleutian Chain and the southeast panhandle regions) to 170 cm on the west coast. The range of maximum ice thickness in Alaska ranges from 100 cm. in the southern part to 180 cm. on the North Slope. (Alaska GB 2401 U533 no. 43 pt. 1-9).

Blinn, C. 1998. Ice bridges. Forest management practices fact sheet: crossing options. Series #*4*, Univ. of Minnesota Extension Service, FS-7004-GO.

Describes ice bridges as used for temporary use in streams with low flow rates, thick ice, or dry channels during winter. Bridges made by pushing and packing snow into streams and applying water to freeze the structures solid. He suggests state permits may be required; choose a period when night temperatures below 0 F.; choose a site that has low flow, is completely frozen or dry, or has a layer of ice on top of flowing water; approaches should be level or nearly level. Recommends against adding brush or other vegetation to the snow-ice-water mix, claiming it will weaken structure and can dam the stream when the bridge melts. Build up ice for level approach and load-bearing capacity.

Blinn, C. R., R. Dahlman, L. Hislop, and M. A. Thompson. 1998. Temporary stream and wetland crossing options for forest management. USDA, Forest Service, North Central Res. Sta., General Technical Rpt. NC-202, 127 pp.

A comprehensive general review of the topic of temporary stream crossings. Only one page and one reference cited with regards to ice bridges. A good literature review for non-winter and non-ice bridge concerns. (Docs. [microform] A13. 88: NC-202).

Bouzoun, John. 1985. Review of Ice Bridging – Appendix C. Disposition Form, Cold Regions Research & Engineering Laboratory, AK.

Contains notes and suggestions for changes in Appendix C of Ice Engineering manual based on personal observations and experience of the reviewer.

Calkins, D. J. 1979. Accelerated ice growth in rivers. Cold Regions Research & Engineering Laboratory Report 79-14, U.S. Army, CRREL, Hanover, New Hampshire.

Reports on and calculates the effect of frazil slush beneath the ice cover on increasing the solid ice growth rates by as much as 50–90 %. (Alaska GB 2401 U53 no. 79-14).

Calkins, D. J. 1989. Winter habitats of Atlantic salmon, brook trout, brown trout and rainbow trout: A literature review. Cold Regions Research & Engineering Laboratory Special Report 89-34, U.S. Army, CRREL, Hanover, New Hampshire.

This review, citing 44 references, concluded that a lack of continuous physical, chemical and biological measurements throughout the ice-covered season was a common deficiency of the studies. He found that the interaction of the ice cover with other physical processes in the stream was rarely addressed. All species of fry were found at depths less than 40 cm and at velocities of 10 cm/s or less. Juveniles of all species were found at velocities of less than 15 cm/s. Information in this citation overlaps with information in the next citation. (Alaska GB 2401 U533 no. 89-34).

Calkins, D. J. 1990. Winter habitats of Atlantic salmon and brook trout in small ice-covered streams. Pages 113-126 in Proceedings IAHR Symposium on Ice 1990, vol. 3. Espoo, Finland.

This is a review of winter habitat studies conducted in ice-covered streams for two species of salmonids gives some general information on substrate conditions, flow velocities and depths. Brook trout were usually found at depths of <40 cm and at focal velocities of 5 cm/s or less. Juveniles were found at velocities < 17 cm/s but at slightly greater depths. Atlantic salmon young-of-the-year and parr (age 1) were found in the substrate. The velocities at 0.6 depth in 40-45 cm of water were 40-45 cm/s. The size of substrate used by all salmonids is a function of fish size, with both preferring a combination of sand, gravel and rubble. A lack of continuous physical, chemical and biological measurements throughout the ice-covered season was a common deficiency of the studies reviewed. Some duplication of information exists between this citation and the previous one. This review cited 34 references. (Geophy. Inst. GB 2401.2 I57 1990 vol. 3)

Carlson, R. F. 1981. Ice formation on rivers and lakes. The Northern Engineer 13(4): 4-9

This is a good overview of the energy balance components of a river reach or lake and the linkage to the ice formation and ice growth processes.

Chacho, E.W. ,Jr., 1993. Rapporteur report: Northern research basins workshop #4 on Environmental effects of river ice. Pages 701-704 in T. D. Prowse, C.S.L. Ommanney, and K. Ulmer, editors, Proceedings of the Ninth International Northern Research Basins Symposium/Workshop , Yukon Territory to Inuvik, NWT. National Hydrology Research Institute, NHRI Symposium Series no. 10.

This report summarizes a workshop on the environmental effects of river ice. It recognizes that while the effects of the growth and breakup of river ice should be a major event in the physical and biological environment of river systems, only recently has its ecological significance been recognized. Accordingly, there are few studies and little relevant data. This workshop provided a framework for considering these effects. Some examples of significant effects include river channels rerouted around ice jams, scour holes developed beneath ice jams, buried contaminants released from a scoured streambed and subsequently transported with sediment and meander bend cutoffs. The difficulty of collecting relevant data during winter and the historical lack of interaction and communication between biologists and hydrologists were cited as problems that should be addressed. (Geophy. Inst. GB 2401 N572 vol. 2).

Chacho, E., W. Traub, and J. Gosink. 1987. Frazil ice characteristics on the Tanana River as related to siting ice bridges. Technical Note, U.S. Army Cold Regions Research and Engineering Laboratory, Ft. Wainwright, Alaska. (An informal, unofficial memorandum for limited distribution only).

Case study of recon information on frazil ice formation relative to the Goose Island ice bridge on the Tanana river. Discusses the role of frazil ice flows and jams in initiating early ice cover as a base for ice bridge construction. Discusses use of ice booms to create frazil dams for ice bridge formation.

Dean, Jr., Arnold M. (undated). Evaluation of ice-covered water crossings. U.S. Army, Cold Regions Research & Engineering Laboratory, Hanover, New Hampshire. Pages 443-453 of unknown document. No detailed citation information available. (Obtained from CRREL files, Fort. Wainwright , AK)

Makes reference to using radar unit to obtain ice thickness data for an ice bridge on the Tanana river near Fairbanks, AK. Makes note of difficulties encountered and mentions several pieces of equipment lost through the ice.

Delaney, A. J., S. A. Arcone, and E. F. Chacho, Jr. 1990. Winter Short-pulse radar studies on the Tanana River, Alaska. Arctic 43(3):244-250.

Subsurface profiles were obtained during airborne and surface short-pulse radar surveys along a winter roadway over the Tanana River near Fairbanks, AK. The roadway crossed ice-covered channels and intervening frozen channel bars. This paper, while indicating the utility in ice-thickness profiling, concentrated on locating unfrozen channels and measuring the depth of frost penetration beneath bars in a braided river.

DenHartog, S.L., T. McFadden, and L. Crook. 1976. Failure of an ice bridge. Cold Regions Research & Engineering Laboratory Report 76-29, U.S. Army, CRREL, Hanover, New Hampshire.

Reports on experiment where a heavily loaded truck was used to make successive passes over two ice bridges in order to verify current theoretical equations on ice bearing capacity. Breakthrough occurred on one bridge with a vehicle weight of 53,630 lb (24,327 kg). The ice thickness as 17.5 in. (44.5 cm). This one test was in good agreement with the theoretical equations. (Alaska GB 2401 U53 no. 76-29).

Ettema, R. M.F. Karim, and J.F. Kennedy. 1984. Frazil ice formation. Cold Regions Research & Engineering Laboratory Report 84-18, U.S. Army, CRREL, Hanover, New Hampshire.

Reports the results of laboratory studies on the influence of turbulence and water temperature on frazil ice formation. The rate and the quantity of frazil ice formed in a specified volume of supercooled water increase with both increasing turbulence intensity and decreasing water temperature. Larger particle sizes were found with lower supercooled water temperatures while particle size decreased with increasing turbulence. (Alaska GB 2401 U53 no.84-18).

Ettema, R. and Hung-Pin Huang. 1990. Ice formation in frequently transited navigation channels. Cold Regions Research & Engineering Laboratory Special Report 90-40, U.S. Army, CRREL, Hanover, New Hampshire.

Deals with the problem of greater ice growth in channels where ice is frequently broken by ships. Reviews general math and physics of river ice growth. Reports on experiments in flumes and on rivers to minimize the re-growth of ice on frequently traveled river routes by careful scheduling of ships. Only a convoy strategy seemed to mitigate the re-freezing problem. (Alaska GB 2401 U533 no. 90-40).

Fox, J.D. 1992. Incorporation freeze-thaw calculations into a water balance model. Water Resources Research 28(9):2229-2224.

Combines a soil water balance accounting model with the St. Paul (MN) equations (layered Stephan equations) to predict soil freezing and thawing based on cumulative freezing degree-days and accounting for variable snow depth throughout the winter. Presents a sensitivity analysis of the model and tests against field measurements.

Frey, Paul J. 1969. Ecological changes in the Chena river. Federal Water Quality Administration, U.S. Dept. of Interior, Northwest Region, Alaska Water Lab., College, Alaska

Describes and documents changes in the Chena river physical, chemical and biological conditions in response to 10-15 years of change in human population and activity in the watershed. (Geophy.Inst., GB 1227 C48 F7).

Frey, Paul J., Ernst W. Mueller, Edward C. Berry. 1970. The Chena River, A study of a subarctic stream. Federal Water Quality Administration, U.S. Dept. of Interior Northwest Region, Alaska Water Lab, Project No. 1610—10/70, College, Alaska

Classic study of the Chena river limnology including documentation of low D.O. in winter and high Coliform bacteria counts in the lower reaches of the river. Includes weekly temperature data at 4 stations on the river. Also includes water chemistry data and stream benthic survey data. (Geophy.Inst., GB 1227 C48 F7).

Gerard. R. 1989. Ice formation on northern rivers: summary of presentation. Page 23 in Mackay, W.C., editor, Northern lakes and rivers. Occasional Publ. no. 22, The Boreal Institute for Northern Studies.

Brief one page summary of presentation. Makes interesting discussion of frazil ice, ice dam effects, and open water polynas. Relates speculation that fish could suffocate on frazil ice crystals. Also mentions that the number of natural polynas (areas that stay open during winter) is a function of island frequency (0.2 x island frequency). (Alaska GB 1629 N67 1989).

Gerding, Richard L. 1990. U.S. Dept. of the Army Memorandum for Director of Engineering and Housing, ATTN: Bill Peake. SUBJECT: Arctic Warrior 91 Ice Bridges – Tanana river and tributaries. (Obtained from CRREL files, Fort. Wainwright , AK).

Memo describes results of meeting with ADF&G regarding ice bridges, permits, problems of overflow and upwellings at bridge sites, as well as concerns about retrieving a bulldozer.

Ginzburg, B.M. 1969. Probability characteristics of the freeze-up and break-up dates of rivers. Soviet Hydrology: Selected Papers, no.1:64-78.

This paper reports a study of the probability distribution of ice phenomenon for the former USSR. Twenty to seventy years of observational data were available from a large number of gaging stations across European and Asiatic USSR. Small-scale maps of the former USSR with lines of equal probability of ice appearance, beginning of freeze-up, and beginning of ice run are presented. The statistical distributions found most useful were of the Pearson type III, binomial. A discussion of the geographic variation of parameters is included.

Gold, L.W. 1971. Use of ice covers for transportation. Canadian Geotech. J. 8:170-181.

Reports observations on the failure and use of freshwater ice covers for vehicular trafiic. Experience in the contruction and use of ice roads and parking areas in included. The study suggests that good quality ice covers can support loads 250 h^2 pounds where h is the ice thickness in inches. (volume missing from UAF Rasmuson Library).

Green, G.M. and S.I. Outcalt. 1985. A simulation model of river ice cover thermodynamics. Cold Regions Science and Technology 10:251-262.

A numerical model of ice growth and decay along the international section of the St. Lawrence River for winter 1980-81. The model calculates a surface equilibrium surface temperature at the air-ice interface using surface characteristics and meteorological data. At the lower boundary, an empirical algorithm simulates turbulent transfer of heat from the water. Within the ice an implicit numerical solution to the general heat diffusion equation is used. Five river sites were simulated. The model represented ice growth rates well but produced decay rates slower than those observed. During the growth period, the model was more sensitive to the values assigned to ice properties than it was to the error range in the meteorological variables. During breakup, the most sensitive boundary variable was water temperature.

Gow, A. J. and J. W. Govoni. 1983. Ice growth on Post Pond, 1973-1982. Cold Regions Research & Engineering Laboratory Report 83-4, U.S. Army, CRREL, Hanover, New Hampshire.

Describes the analysis of ice thickness measurements on Post Pond, New Hampshire and results of using Stefan formula to calculate ice growth and decay. Includes a good description of the progression of events at this one site and the utility of freezing and thawing degree-day methods. (Alaska GB 2401 U53 no. 83-4).

Gulliver, J.S., and H.G. Stefan. 1986. Wind function for a sheltered stream. J. Environ. Engineering 112(2):1-14.

Tests various empirical wind functions to be used in air-water transfers of heat and mass. These wind functions while derived for use primarily over large lakes were fitted to data for a sheltered stream. All functions performed well but one suggested as best in terms of simplicity.

Haggag, M. R. I. 1976. Hydraulics of ice covered channels. Master of Applied Science thesis, University of Windsor, Ontario, Canada.

Primarily a theoretical and laboratory study aimed at the problem of estimating the composite roughness of a channel with an ice cover and subsequently the discharge. (Alaska GB 1398.2 H34 1976a, [microform]).

Harza-Ebasco Susitna Joint Venture. 1984. Instream ice, calibration of computer model. Susitna hydroelectric project, document no. 1122, Alaska Power Authority.

Reports on the calibration of the ICECAL model for the Susitna River reach from the confluence at Talkeetna to Gold Creek. The model was only used for freeze-up calculations and not for break-up. A brief description of the model is given followed by a description of the data available for the calibration task. The model would require "post-project" simulated stream temperature data from the SNTEMP model operated by AEIDC, for post-project ice effects. This calibration is for pre-project conditions. Computed ice-free water surface profiles within 0.5 ft of observed values for flow rates of 3000 and 9700 cfs were realized. Maximum water/ice elevations were generally within ± 2 ft. of observed values although there were some locations where differences of 3-8 ft. resulted. Computed ice thickness agreed very well with observed following the 1982 freeze-up. Observed thickness were considerably higher than calculated thickness following the 1983 freeze-up. Mixed results were also found for simulations of the leading edge progression of ice, with better results in 1982 than in 1983. (Alaska TK 1424 A4 S834 1984).

Harza-Ebasco Susitna Joint Venture. 1984. Instream ice simulation study. Susitna hydroelectric project, final report, document no. 1986, Alaska Power Authority.

This report presents the results of the instream ice simulation studies for the Susitna Hydroelectric Project. The objective of these studies was to determine the effect of the proposed

Watana and Devil Canyon Dams on river ice processes and the corresponding water surface elevations during the winter season in the Susitna River downstream of the dams. The studies are limited to the middle reach of the Susitna River (upstream from the confluence with the Chulitna River). The study results are based on the use of 3 models : a Dynamic Reservoir Simulation Model (DYRESM), a stream temperature simulation model, (SNTEMP), which computes longitudinal stream temperature profiles on a weekly basis, and a model for the simulation of instream hydraulic and ice conditions (ICECAL). Exhibits A through T are provide the graphical portrayal of results for both natural conditions, and post-project conditions. (Alaska GB 1398.4 A4 I57 1984).

Harza-Ebasco Susitna Joint Venture. 1985. Instream ice simulations [microform]: supplementary studies for middle Susitna River. Susitna hydroelectric project, document no. 2845, Alaska Power Authority.

This is a follow-up study of the "Instream Ice Simulation Study", to report the results of supplementary simulations to evaluate the sensitivity of the ice processes to alternative instream flow requirements, alternative operating policies for multi-level power intakes, alternative low levels for Watana power intake, and alternative levels for Devil Canyon cone valves. (Alaska TC 425 S9 I584 1985a Microform).

Harza-Ebasco Susitna Joint Venture. 1985. Instream ice simulations [microform]:supplementary studies for middle Susitna River. Susitna hydroelectric project, document no. 3524, Alaska Power Authority.

This is a follow-up study of the "Instream Ice Simulation Study", to report the results of supplementary simulations to evaluate the sensitivity of the ice processes to a revised three-stage construction of the project, alternative instream flow requirements, alternative operating policies for multi-level power intakes, alternative low levels for Watana power intake, and alternative levels for Devil Canyon outlet works. (Alaska TC 425 S9 I585 1985a Microform).

Haugen, R.K., C.W. Slaughter, K.E.Howe, and S.L. Dingman. 1982. Hydrology and climatology of the Caribou-Poker Creeks research watershed, Alaska. Cold Regions Research & Engineering Laboratory Report 82-26, U.S. Army, CRREL, Hanover, New Hampshire.

This general report on the hydrology and climatology of the Caribo-Poker Creeks watershed area does include interesting observations of the lack of flow in Caribou Creek during the period from 11 Dec. 1975 to 4 April 1976. The conditions thought to cause the stream to completely freeze that winter were a combination of low precipitation the preceding fall and extremely low temperatures. Heavy aufeis formed downstream from the gaging station that winter. (Alaska GB 2401 U53 no. 82-26).

Haynes, F. Donald, Charles M. Collins, and Walter W. Olson. 1992. Bearing capacity tests on ice reinforced with geogrid. Cold Regions Research & Engineering Laboratory Special Report 92-28, U.S. Army, CRREL, Hanover, New Hampshire.

Laboratory tests were conducted on floating freshwater ice sheets, reinforced with a high-strength polymeric mesh (Geogrid). Geogrid reinforced ice sheets increased the bearing capacity of thin ice(49 mm) up to 38% and of thicker ice(96 mm) about 10-15 %. In a field test, the Geogrid reinforced ice also reduced deflection of the ice sheet under load. (Alaska GB 24012 U533 no. 92-28).

Hoffman, C.R. 1967. Ice construction – methods of surface flooding. Technical Report R-511, Naval Facilities Engineering Command, U.S. Naval Civil Eng.Lab., Port Hueneme, CA.

Two surface-flooding techniques for improving natural ice areas have been developed by the U.S. Naval Civil Engineering Laboratory. Confined flooding, in which the flood is contained by natural barriers or man-made dikes, is used principally for filling and leveling ice areas where deflection of the natural ice is not a problem. Free flooding, in which the outward flow of water is governed by natural forces such as gravity and freezing of the flood perimeter, is generally used for the accelerated buildup of thinner natural ice areas where deflection is encountered. Adequate method have been developed for surface flooding a relatively small area with a maximum dimension of 1,200 feet and for increasing ice thickness by as much as 5 feet. Continued investigation is required for the multi-pump flooding of areas 5,000 feet long, the flooding of deep snow, and the construction of ice roadways through tidal and pressure-ice areas.

Hough, A., J. King, and A. Bailey. Report on the use of snowmaking machine for ice bridge construction. U.S. Army, 47th Engineer Company, Fort Wainwright, AK. (Obtained from CRREL files, Fort. Wainwright , AK)

This reports on tests of a snowmaking machine as an alternative to flooding in ice bridge construction. Results indicated both snowmaking and spraying results in faster freezing than flooding and that although the ice created was air-entrained, it had higher compression strength.

Irons, J.G. and M.W. Oswood. 1992 Seasonal temperature patterns in an arctic and two subarctic headwater streams. Hydrobiologia 237:147-157.

The thermal regime of three Alaska streams were studied: Monument Creek and Little Poker Creek, in interior Alaska, and Imnavait Creek in the arctic tundra. Although it is about 450 km north of the other streams, the tundra steam accumulated more degree-days, had higher maximum and mean temperatures, greater daily temperature amplitudes, and steeper slopes of vernal and autumnal temperature rises and declines. The absence of a canopy of riparian plants, channel morphology, and continuous sunlight during summer accounted for these results. Useful background data from two subarctic Alaskan streams.

Johnson, Phil. 1980. A guide for operating cars and light trucks on a floating ice sheet.: using thin plate analytical solutions. Report prepared by Phil Johnson Engineering, Fairbanks, AK. (Obtained from CRREL files, Fort. Wainwright , AK)

The author used the “Thin Plate” method to investigate the reaction of floating ice sheets to cars and light trucks. He developed a general solution and technique that makes it possible to predict the reation of an ice sheet to any car or light truck without resorting to a computer solution. He discusses factors other than tensile stress that affect the behavior of ice under load.

Johnson, Phil. 1980. An ice thickness-tensile stress relationship for load-bearing ice. Cold Regions Research & Engineering Laboratory Special Report 80-*9*, U.S. Army, CRREL, Hanover, New Hampshire.

The “bearing capacity” of a floating ice sheet is of considerable interest. The pattern of ice thickness versus tensile stress for a fixed load and fixed ice properties was examined and showed some constant relationships. It proved possible to completely describe the ice thickness-tensile stress pattern in terms of a single number. When the load was changed by increasing the payload but not altering the geometry of the load pattern, other relationships were found that described the tensile stress in the ice sheet for any combination of payload and ice thickness. This provides a simple method of finding tensile stress in the ice that can be used in the field.

Joslin, S. J. 1999. Tanana River ice formation study: Surprise Side timber sale. Delta Junction, Alaska, October 1998 to March 1999. (unpublished report, State of Alaska, Division of Forestry).

A brief report with photographs documenting the rise in river water and ice between October 1998 and March 1999 on the Tanana River between the Delta and Little Delta Rivers.

Kerr, A.D. 1975. The bearing capacity of floating ice plates subjected to static or quasi static loads: a critical survey. US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory, Research Report 333. 43 pp.

This report contains a critical survey of the literature on the bearing capacity of floating ice plates. It consists of a discussion of general questions, a critical survey of analytical attempts to determine the bearing capacity of floating ice plates, and a survey of field and laboratory tests on floating ice plates and their relation to the analytical results. The paper concluded with a systematic summary of the results, a discussion of observed shortcomings, and suggestions for needed investigations.

Kivisild, H.R., G.D. Rose, and D. M. Masterson. 1975. Salvage of heavy construction equipment by a floating ice bridge. Can. Geotech. J., 12:58-69.

Describes the construction and operational results of an ice-bridge built to access a grounded barge carrying a load of heavy equipment for the James Bay Project. Following completion of the 100 ft wide and 74 inch thick bridge, the ice bridge was instrumented and tested prior to and during the unloading process. Parameters measured were thickness, width, temperature, ice soundness, and deflections. Loads of 70 tons and heavy trucks were removed with no problem. Deflections were very small. Ice was built up by flooding and freezing in layers not greater than 1.5 in. Fifty-eight inches of ice was built up in 2 week.

Lal, A., M. Wasantha, and H. T. Shen. 1993. A mathematical model for river ice processes. Cold Regions Research & Engineering Laboratory Report 93-4, U.S. Army, CRREL, Hanover, New Hampshire.

This publication describes a detailed mathematical model of river ice growth and decay applicable to composite ice covers consisting of snow, ice and frazil layers. The model has been applied to the St. Lawrence River and the Ohio River system, with simulated results comparing favorably with field observations. It is a one-dimensional model called RICE. While somewhat obtuse for the lay person, this publication does include a nice flow-chart of river ice processes in its brief introduction. (Alaska GB 2401 U53 no. 93-4).

Lindgren, S. and J. Neumann. 1982. Crossings of ice-bound sea surfaces in history. Climatic Change 4:71-97.

Seven documented cases of the use made of ice-bound sea areas in winter for the purposes of warfare are reviewed. These crossings took place in 1495, 1577, 1581, 1658, 1809, 1940, and 1943. The early crossings took place in the Gulf of Finland and the Gulf of Bothnia and were thought to have been fairly common during what is called “the little ice age”.

Marsh, P., and T. D. Prowse. 1987. Water temperature and heat flux at the base of river ice covers. Cold Regions Science and Technology 14:33-50

Detailed measurements of water temperature and velocity were made in the Liard River prior to and during breakup. Comparison of four different techniques for calculating heat transfer coefficients showed that it is essential to consider ice roughness and to measure water temperature to a high degree of accuracy. The water temperatures had large spatial and temporal variations. The highest temperatures and heat fluxes tended to occur in the high velocity sections of the channel which had a thin ice cover. Heat transfer coefficients calculated from the Colburn analogy method were in closest agreement to those using a temperature decay approach. A standard empirical technique derived from laboratory data seriously under-predicted the heat flux.

McFadden, T., and M. Stallion. 1975. 1974 ice break-up on the Chena river. Cold Regions Research & Engineering Laboratory Special Report 241. (ADA018352). U.S. Army, CRREL, Hanover, New Hampshire.

This report documents breakup of the Chena River in the spring of 1974. Ice thickness was measured at specific locations on the Chena River, from its confluence with the Tanana River upstream to the first bridge on the Chena Hot Springs Road. Average ice thicknesses were computed as well as average ice volumes per mile of river length. Water temperatures and velocities were measured at different locations on the river. Comparisons to other years’

breakups were made and it was concluded that the 1974 breakup was extremely mild. (Alaska GB 2401 U533 no. 241).

Melloh, R. A. 1990. Analysis of winter low-flow rates in New Hampshire streams. Cold Regions Research & Engineering Laboratory Special Report 90-26, U.S. Army, CRREL, Hanover, New Hampshire.

This report on winter low-flows is of marginal direct interest but does remind us that flow rates are generally declining over winter and under the ice due to reduction in liquid input to the stream-groundwater system. This recession is generally associated with the geology and climatology of the particular stream basin with some uniformity due to regional geology, elevation, and climate. (Alaska GB 2401 U533 no.90-26).

Mellor, M., and D. J. Calkins. 1988. Deployment of floating bridges in ice covered rivers. Cold Regions Research & Engineering Laboratory Report 88-20, U.S. Army, CRREL, Hanover, New Hampshire.

This report focuses mainly on clearing ice from an ice-covered river in Korea in order to deploy the U.S. Army Ribbon floating bridge. Chain saw cutting and explosives were used.

Michel, B. 1971. Winter regime of rivers and lakes. Cold Regions Science and Engineering Monograph III-B1a, CRREL, U.S. Army, Hanover, New Hampshire.

Excellent monograph summarizing the major processes and phenomenon encountered on lakes and rivers in cold regions. (Geophy Inst., GB 2401 C742 III-B1a).

Michel, B., M. Drouin, L.M. Lefebvre, P. Rosenberg, and R. Murray. 1974. Ice bridges of the James Bay project. Canadian Geotech. J. 11:599-619.

Discusses a winter road built in 1972-73 which crossed 8 rivers in the James Bay territory. Reports bearing capacity theory, design, site selection, construction and testing of the ice bridges spanning the main rivers.

Osterkamp, T. 1975. Supercooling and frazil ice formation in a small sub-arctic stream. In Williams, G.P., editor, Proceedings: Research Seminar Thermal Regime of River Ice., Technical Memorandum no.114, National Research Council Canada.

Field at Goldstream creek supplemented with lab studies suggest the possible role of ice fog crystals falling into supercooled water to initiate frazil ice formation. (Geophy.Inst., GB 1229 R48 1974).

Ott, A. 1990. Letter addressed to Dennis E. Klein, Dept. of the Army, U.S. Army engineer Dist., Alaska. RE: Arctic Warrior 91 Ice Bridges – Tanana River and Tributaries. (Obtained from CRREL files, Fort. Wainwright , AK)

Memo from ADF&G expressing concern over selected ice bridge sites requested for permitting. Concerns over ice jamming downstream, white ice formation(Tanana R., Goose Island), open water holes (Tanana R., nine mile), past bulldozer breakthrough (Tanana R., Harding Lake/Flag Hill), overflow, ice grounding, flow constriction (McDonald Creek), open water leads, bank cuts and channel fills (Salchaket Slough), equipment broken through, ice bridge grounded causing overflow (Clear Creek (Nelson Clearwater) on Tanana Flats).

Perham, R. E. 1988. Imjin river ice boom. Cold Regions Research & Engineering Laboratory Report 88-22, U.S. Army, CRREL, Hanover, New Hampshire.

This report discusses difficult yet successful efforts in obtaining materials for building an ice boom in the field from office design specifications. Provides data for reusing the boom as well as design data and background information.

Peters, D. B., J. R. Ruser, and B. J. Watt. 1982. Rational basis for design of floating ice roads and platforms. Paper OTC 4314, presented at 14th Annual Offshore Technology Conf., Houston, Texas, p.153-158 + tables.

This report proposes a modified limit state approach be used to design load capacities to avoid first crack development. The stress distribution is predicted using elastic theory but based on the use of finite element models which provide a more realistic simulation of the stress distribution through the sheet. The technique has been used for construction operations in the Beaufort Sea.

Power, G., R. Cunjak, J. Flannagan, and C. Katopodis. 1993. Biological effects of river ice. pp. 97-127 In Prowse, T. D., and N. C. Gridley, editors. Environmental aspects of river ice. Environment Canada, National Hydrology Research Institute Science Report No. 5.

Summarizes effects of river ice on invertebrates and fish. Includes diagrams of available habitat under icing conditions throughout the winter in arctic and temperate streams.

Purple, R. A. 1965. Crossing frozen rivers in Korea. The Military Engineer. No. 379 (Sept-Oct): 331-333.

Deals with pallet bridges, inverted balk bridges and float bridges.

Raphael, J.M. 1962. Prediction of temperatures in rivers and reservoirs. J. of the Power Division, Proceedings of the ASCE, July.

Reports an energy balance model for use in predicting water temperatures. Does not deal with ice covers. May be a useful scheme for simulating summer stream temperatures and effects of altering solar energy inputs.

Rhoads, Edwin M. 1974. Ice crossings. The Northern Engineer *5*(1):19-24.

This is an excellent, readable and informative article. Reviews some of the history of ice bridges in the north and cites examples from the late sixties of crossings on the Yukon River to facilitate getting heavy equipment north to Prudhoe Bay, as well as the Pike's Landing crossing on the Chena River near Fairbanks.

Rhoads notes the effect of removing early snow on accelerating ice thickness growth but points out that maximum thickness without snow (assuming a 3600 ^{o}F freezing degree-days) would be limited to 57 inches. After accelerating ice growth by snow removal, surface flooding is recommended for increased ice thickness (build up on the surface) and consequent load bearing capacity. For maximum strength and duration of use, he cites the practice of reinforcing the ice with brush and wood and even dusting the surface with sawdust in spring to retard surface melting.

Rundquist, L.A. and J.E. Baldrige. 1990. Fish habitat considerations. Pages 579-613 in: W.L. Ryan and R.D. Crissman, editors. Cold Regions Hydrology and Hydraulics. Am. Soc. of Civil Engineers, NY, NY.

This is a good review of general fish habitat requirements with a slant toward cold regions and Alaska. Authors note the potential significance of groundwater upwellings for winter habitat and the role of ice in winter fish habitat. This review contains little primary data.

Ryder, T. 1954. Compilation and study of ice thickness in the Northern Hemisphere. New York: Arctic Construction and Frost Effects Laboratory, Technical Rpt. 47.

Ryder has reviewed 186 references for ice thickness data and presents early information on river ice thickness and snowpack thickness for Tanana, Alaska on the Yukon River (winters 1927-41), Fairbanks, Alaska on the Chena Slough (winters 1932-35 and 1950), Noorvik, Alaska on the Kobuk River (winters 1917-24), Anchorage, Alaska on Lake Spenard (winters 1936-37), Nome, Alaska on the Snake River (winters 1932-33 and 1933-34), and Bethel, Alaska on the Kuskokwim River (winters 1918-28). (Alaska GB 2413 R95).

Scrimgeour, G. J., T.D. Prowse, J.M. Culp, and P.A. Chambers. 1992. Ecological effects of river ice break-up: a perspective. Pages 469-488 in T. D. Prowse, C.S.L. Ommanney, and K. Ulmer, editors, Proceedings of the Ninth International Northern Research Basins Symposium/Workshop , Yukon Territory to Inuvik, NWT. National Hydrology Research Institute, NHRI Symposium Series no. 10.

River ice break-up is a seasonal disturbance in northern rivers worldwide and is characterized, in part by large increases in current velocity, stage, water temperature, concentrations of suspended materials, and substrate scouring. This paper provides a hydrologic and ecological perspective on the potential effects of ice break-up on aquatic systems. Specifically, the potential importance of break-up on water temperature, river sediments and geomorphology, riverine energy sources, and their effects on river biota and food-web dynamics is evaluated. (Geophy. Inst. GB 2401 N572 vol. 2).

Shen, H.T., E.P. Foltyn and S.F. Daly. 1984. Forecasting water temperatures decline and freeze-up in rivers. CRREL Report 84-19, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, N.H.

Describes a prediction scheme for river ice formation. St. Lawrence river. Method requires initial water temperature at an upstream station, long-range air temperature forecast, predicted mean flow velocity in reach, and water temperature response parameters. The latter can be estimated from air and water temperature data. (Alaska GB 2401 U53 no. 84-19).

Shen, H.T., and P.D. Yapa. 1985. A unified degree-day method for river ice cover thickness simulation. Canadian Journal of Civil Engineering 12(1):54-62.

Provides a degree-day method for simulating the growth, decay and breakup of river ice covers and applies the technique to the St. Lawrence River . The model variables include initial ice thickness, freezing degree-days since formation of ice cover, number of days since initial ice formation, and 3 empirical coefficients. Simulated ice thickness compared well with measured values over a range of ice thickness from 25 to 60 cm.

Sinokrot, B.A., and H.G. Stefan. 1993. Stream temperature dynamics: measurements and modeling. Water Resources Research 29(7):2299-2312.

A numerical model (MNSTREM) based on a finite difference solution of the unsteady heat advection-dispersion equation is formulated to predict water temperatures in streams at time increments of 1 hour. An energy balance accounts for the effects of air temperature, solar radiation, relative humidity, cloud cover, and wind speed on the net rate of heat exchange through the water surface, and heat conduction between water and streambed. After calibration, accuracies of hourly and daily water temperature predictions over periods of several weeks are of the order of 0.2 ^{o} to 1 ^{o}C. Ice conditions are not included.

U.S. Dept. of the Army. 1980. Training: Ice Bridging. 172d Brigade Pamphlet no. 350 Headquarters, 172d Infantry Brigade (Alaska), Fort Richardson, Alaska, 15 pp. (Obtained from CRREL files, Fort. Wainwright , AK)

Contains similar to that in U.S. Army (1985) and (1986b) below. Contains a table of how fast flooded layers of water will freeze under different air temperature conditions. Also contains some different illustrations. This pamphlet in conjunctions with the other references mentioned, might serve as an initial basis for publishing a guide for use of ice bridges in logging.

U.S. Dept. of the Army. 1982. Ice Engineering. Engineer Manual 1110-2-1612. U.S. Army Corps of Engineers, Washington, D.C. (Obtained from CRREL files, Fort. Wainwright, AK)

This is a section of the U.S. Army Engineer Manual dealing with ice formation and characteristics, ice jams, ice breaking, ice adhesion, ice control, floating ice dispersion, river and ice hydraulic computations, ice forces on structures, sediment transport, and bearing capacity of floating ice.

U.S. Dept. of the Army. 1985. CRREL Notes for the winter battlefield. Excerpts from FM 31-71, Northern Operations. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, N.H. (Obtained from CRREL files, Fort. Wainwright , AK)

Contains an appendix on ice bridges. This appendix lists the following requirements for an ideal ice bridge site:

a. river channel fairly straight
b. only one main channel wide enough for slow river current
c. gradual approaches to the ice
d. no streams or creeks tributaries immediately upstream
e. site near an existing road network
f. the ice should be level
g. site should be free of warm springs and sand bars
h. site should be free of major snow drifting

Field procedures are given for testing the depth of ice downstream of proposed ice bridge centerline. Methods outlined for determining the “class” of ice that involves thickness, color factor, and strength factor. Guidelines for marking and using the roadway are given.

U.S. Dept. of the Army. 1986a. Field Guide: Fresh Water Ice Crossings. CRREL, U.S.Army, a pocket laminated card. (Obtained from CRREL files, Fort. Wainwright , AK)

This two-sided card has Vehicle Class ratings, the required ice thickness, and the distance between vehicles as about 100 times the required ice thickness in feet or meters. Additional annotations adjust if parking on ice, ice strength ratings, water support of ice, and cracks.

U.S. Dept. of the Army. 1986b. Training: squad leader's guide for constructing ice bridges. 6th Infantry Division (Light) Pamphlet no. 350-11, Headquarters, 6th Infantry Division (Light) and U.S. Army Garrison, Alaska, Fort Richardson, AK. (Obtained from CRREL files, Fort. Wainwright , AK)

Contains similar information as is contained in U.S. Army (1985), cited above. Discusses snow removal to accelerate freezing and surface flooding to build ice thickness. Minimum width recommended is 150 feet. Bridge maintenance considerations are discussed including ice thickness checking, new snowfall compaction or removal, crack checking. Approaches should be less than 3% grade. Refrozen wet snow can be used to re-grade approaches that are greater than 3%.

Wankiewicz, A. 1984. Analysis of winter heat flow in an ice-covered Arctic stream. Can. Jour. Civil Eng. 11:430-443.

Ice growth is modeled for an Arctic stream near Inuvik, Northwest Territories. Shows how water flows in narrow conduits under the ice in winter, generating friction and convected streambed heat. Includes some useful diagrams relating ice thickness variations along the channel to pool-riffle structure. Also reports daily streambed temperature measurements during winter.

Wilcox, Dorothy E. 1980. Geohydrology of the Delta-Clearwater area, Alaska. U.S. Geol. Survey, Water Resources Investigations 80-92. Prepared in cooperation with the AK Dept. of Nat. Resources, Division of Forest, Land and Water Management, Anchorage, AK, 26 pp.

Describes the groundwater hydrology associated with the Delta-Clearwater Creek network and Clearwater Lake, the mouth of the Delta River, and the Tanana River along the study area's north boundary. Average annual ground water discharge is estimated to be > 1,200 cubic feet per second. The aquifer is recharged by seepage through streambeds and by infiltration of precipitation. Some uncertainty still surrounds the contributions from the Delta River, Jarvis Creek, and the Tanana River east of the Clearwater Creek aquifer area.

Williams, G. P. 1963. Probability charts for predicting ice thickness. Engineering Journal 46(6):31-35. (reference unavailable for review).

Williams, J. R. 1951. Observations on river-ice conditions near highway bridges in Alaska, winter, 1949-1950. U.S. Geological Survey, 40 pp.

General descriptive report. Does include section on "River crossings on ice" which includes discussion of bearing capacities of ice, approaches to ice-crossing sites, and damage to highways and bridges by river ice. Observations include Copper River Valley (Tazlina River, Chistochina River) and the Tanana River valley (Tanana River – east of Tok Junction and at Big Delta; Chena Slough near bridge north of Badger Road; Chena River at Fairbanks; Salcha River near Richardson Highway bridge; Chisana river near Northway; Robertson River; Gerstle and Little

Gerstle Rivers; Johnson River; Tok River), the Matanuska River at Palmer and the Yukon River at Beaver. (Alaska GB 1398.4 A4 W57 1951).

Wilson, W. J., E. H. Buck, G. F. Player, and L. D. Dreyer. 1977. Winter water availability and use conflicts as related to fish and wildlife in arctic Alaska – a synthesis of information. FWS/OBS-77/06, Biological Services Program, Fish and Wildlife Service, U.S. Dept. of Interior.

Includes a chapter on "Importance of unfrozen water during winter to arctic fish and wildlife". Discusses use patterns by fish during winter; importance of unfrozen water to fish and non-fish organisms during winter; Arctic lake ice thickness; Arctic grayling. (Alaska TC 424 A4 W4).

Woo, Ming-ko, and Richard Heron. 1989. Freeze-up and break-up of ice cover on small arctic lakes. Pages 56-62 in Mackay, W.C.,editor, Northern Lakes and Rivers. Occasional Publ. No. 22, The Boreal Institute for Northern Studies.

Lake ice growth in Canadian Arctic is strongly affected by snow depths and ice thickness is predictable using heat conduction equations. Breakup involves both thermal and mechanical processes; at Resolute, NWT, 40% of ice ablation occurred at the upper ice surface, 10% at the bottom, and the rest involved internal melt. While a process-oriented approach produces superior results in ice prediction, the cost of acquiring the requisite data may necessitate use of empirically based, but simpler, degree-day techniques. (Alaska GB 1629 N67 1989).

Wortley, C. Allen. 1990. Ice engineering for rivers and lakes bibliography. College of Engineering, Dept. of Engineering Professional Development, University of Wisconsin-Madison.

An excellent literature review sorted by the following topics:

Ice formation, growth, deterioration, classification, characterization
Simulation, processes, thermal regimes.
Ice strength, deformation, mechanics, properties.
Bearing capacity and deflection, ice roads and bridges, construction methods.
Ice forces and pressures on structures, buckling, vibrations.
Hydraulics of river and reservoir ice, ice jams and hanging dams, frazil ice problems.
Design of structures, harbors, ports, quays, wharves, marinas.
Instrumentation, testing, measurements, mapping.
Data bases- climatological, hydrological.
General references, historical, anecdotal.
Primary Author Index.

(Alaska GB 1398.2 W67 1990)