Chapter 1
Introduction

1-1. Purpose

This manual provides a general coverage of the field of ice engineering as it pertains to the responsibilities of the Corps of Engineers. For convenience, it is divided into three parts: first, *Ice Properties, Processes, and Problem Solutions*; second, *Ice Jams and Mitigation Measures*; and third, *Winter Navigation on Inland Waterways.* This manual does not address the environmental impacts of ice.

a. Role.

(1) Part I gives fundamental information about ice and about the hydraulics of ice-affected river flow. It presents current guidance for the planning, design, construction, and operation and maintenance of ice-control and ice-suppression measures for Corps of Engineers projects. It also supplies basic information on selected problems for which ice is a significant engineering factor.

(2) Part II addresses ice jams and related flooding, including prevention and remediation methods. The information presented is intended to be useful to interested parties outside of the Corps of Engineers, as well as within.

(3) Part III gives the current guidance for engineering and operational solutions to ice problems on rivers used for navigation throughout the winter. These solutions can contribute to efficient, cost-effective, reliable, and safe navigation during ice periods. Part III also presents guidance for developing River Ice Management Plans for specific rivers or river systems.

b. Scope.

(1) In Part I, *Ice Properties, Processes, and Problem Solutions*, Chapter 2 discusses ice processes, namely formation, growth, and decay, and the physical and mechanical properties of ice. In Chapter 3 the focus is on techniques for mechanical and thermal ice control in lakes and rivers. Chapter 4 describes methods for modeling the hydraulics of ice-affected rivers and determining the associated water-surface profiles, while Chapter 5 presents approaches for assessing ice-affected stage-frequencies for rivers. Chapter 6 discusses ice-induced forces on riverine, coastal, and offshore structures for inclusion in design considerations. Chapter 7 presents guidance on estimating the effects of ice covers on sediment transport in alluvial channels. Chapter 8 deals with evaluating the bearing capacity of sheet ice for stationary and moving loads as a function of ice thickness and ice conditions. Chapter 9 discusses small-scale ice physical modeling that can be conducted to test concepts for resolving ice problems in all types of water bodies.

(2) In Part II, *Ice Jams and Mitigation Measures*, Chapter 10 presents a general overview of the problem of ice jams and ice jam flooding. Chapter 11 gives a brief review of ice types as a basis for discussing the types of ice jams, their causes, and their prediction. Chapter 12 covers the broad range of methods used to reduce or eliminate ice jam difficulties.

(3) In Part III, *Winter Navigation on Inland Waterways*, Chapter 13 discusses the conduct of a river ice management study, a system-wide approach to solving winter navigation problems. In Chapter 14 the broad range of river ice problems affecting winter navigation is summarized, and guidance for identifying and conducting surveys of these problems is given. Chapter 15 presents river ice forecasting concepts

and methodologies. Systems and techniques for the collection of hydrometeorological data are covered in Chapter 16, including numerical information as well as imagery. Chapter 17 presents basic information regarding navigation in ice, and includes discussion of alternatives for increasing the ease and efficiency of such operations. Chapter 18 addresses structural solutions to ice problems at navigation structures. Lastly, Chapter 19 covers operational solutions to winter navigation problems.

(4) Appendix A, *Glossary*, provides abbreviations and definitions of terms used throughout this manual. Appendix B, *Ice Jam Mitigation Case Studies*, is related to Part II and provides details for many solutions successfully applied to a wide variety of ice jam problems. Appendix C, *Typical River Ice Management Study*, associated with Part III, outlines and organizes the elements necessary to a river ice management study, which would lead to a formal River Ice Management Plan.

1-2. Applicability

This manual is applicable to all USACE commands having civil works design, construction, or operations responsibilities.

1-3. Explanations of Terms

Abbreviations and special terms used in this manual are listed in Appendix A, *Glossary*.

1-4. Ice Impacts on Corps Activities

Figure 1-1 shows the area of North America where temperatures in winter are below freezing over a sufficient length of time for ice to form in rivers, streams, and lakes. Ice in streams and waterways affects Corps projects for navigation, flood control, water supply, and power generation. It can also result in ice jams and lead to flooding at river discharges that would be trouble-free under open-water conditions. During spring breakup, especially, ice may severely damage riprap installations and other riverine structures. Offshore and coastal structures in the Arctic and in subarctic regions, and specifically along the Alaska coastline, need to be designed to withstand the significant forces exerted by sea ice driven by wind or current. Ice in navigable waterways adversely affects many Corps activities and creates the need for specific ice management measures.

a. Ice interference with lock and dam operations. Corps of Engineers navigation projects cannot operate properly when ice accumulates at locks, dams, and related facilities. A few examples illustrate how ice at navigation projects leads to accelerated damage and increased maintenance needs, greater demands on personnel, and more dangerous working conditions. Ice interferes with the movement of lock and dam gates (Figure 1-2) and places added loads on structural components. Lock widths are often not fully usable owing to the accumulation of broken ice in recesses behind miter gates (preventing full gate opening) and the buildup of ice collars on one or both walls of the chamber (Figure 1-3). Broken ice is pushed into lock chambers ahead of tows, sometimes limiting the length of tow that can fit. Floating mooring bitts freeze in place, becoming useless. The passing of ice at dams, while simultaneously trying to maintain navigation pool levels and avoid downstream scour, is often difficult or impossible.

b. Ice effects at flood control projects. Problems at flood control projects are often similar to those at navigation facilities. Dam gates are particularly susceptible to freezing in place because of leaking seals and resulting ice buildup, especially if gates are moved infrequently. Hoisting chains, trunnion arms, etc., may become so loaded with ice as to be too heavy for lifting mechanisms. Personnel

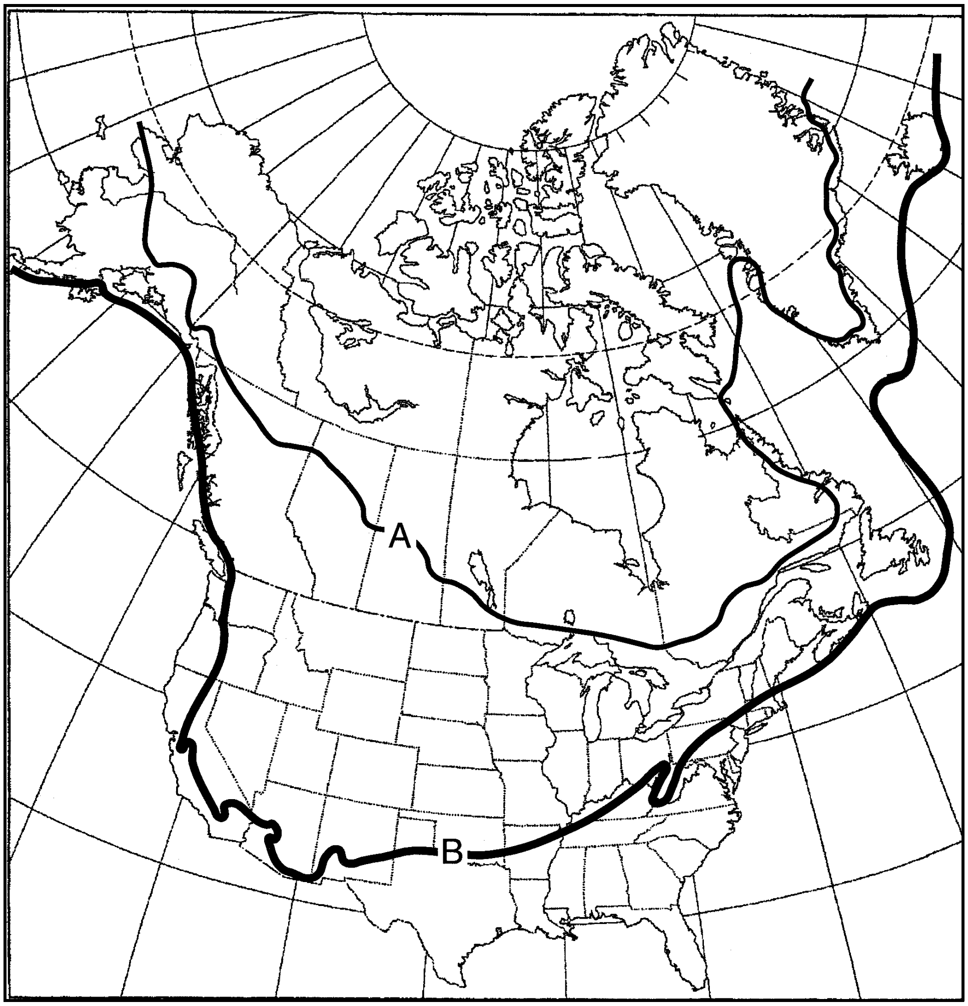

Figure 1-1. Cold regions in North America. *A-line is southernmost boundary of the area where the average temperature of the coldest winter month is -18ºC (0ºF) or less and ice covers navigable waters for at least 180 days of the year; B-line is the southern border of the area where the average temperature of the coldest winter month is between -18 and 0ºC (0 and 32ºF) and ice covers navigable waters for 100–180 days.*

walkways can become dangerously coated with ice from water spray. If not conducted cautiously, water releases from reservoirs may have the effect of dislodging downstream river ice, leading to ice runs, ice jams, and subsequent flooding.

c. Ice effects on water supply and power plants. Frazil ice and brash ice can accumulate on trash racks, thereby blocking water intakes of water supply systems, water intakes at hydropower plants, or cooling water intakes at thermal power plants. Excessively rough ice accumulations may lead to undue head losses in water supply and power canals.

d. Ice effects on river stage. A stationary river ice cover, whether an ice sheet or a jam, introduces an additional boundary and therefore increases energy losses. This translates to an increase in stage compared to open-water conditions for the same discharge. Numerical models for river hydraulics must be able to account for the effects of ice if they are to reliably describe river flows and stages. The

Figure 1-2. Ice accumulation on dam gates

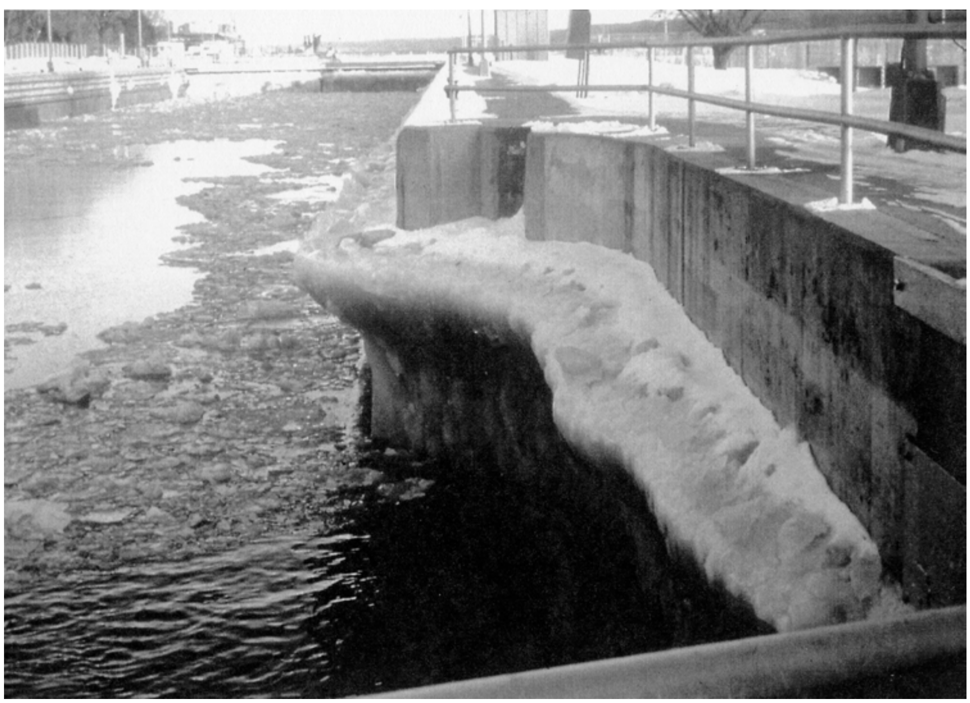

Figure 1-3. Ice collar on lock wall

resistance offered by an ice cover will lead to upstream water storage, resulting in rapid stage rise and possible flooding, and simultaneously will lead to a drop in stage and a discharge deficit downstream from the ice cover. If the stage drop is severe enough, downstream water intakes may become exposed, affecting municipal and industrial water supplies, especially during periods of drought or very low flow.

e. Ice effects on sediment transport and scour. The presence of a floating ice cover roughly doubles the wetted perimeter of a wide channel, which in turn modifies the magnitude and distribution of the velocities and, thus, the boundary and internal shear stresses. For a movable bed channel, an ice cover may, therefore, affect the bed sediment transport and the suspended sediment transport characteristics of the stream and modify the channel geometry and the bed regime. For an abrupt thickening of an ice accumulation, such as the toe of an ice jam, there may be significant bed scour because of the deflection of the flow against the bed. When this happens in the vicinity of a riverine structure, such as a bridge pier, the resulting scour may eventually cause structural failure.

f. Ice-related shore and structure damage. Damage caused by normal ice conditions in ice-prone rivers is often minor. But in more severe ice seasons, scour and ice-force damage to shorelines, pilings, piers, and levees may become significant. Unprotected earth surfaces at shorelines can be severely gouged and eroded. Particularly during ice breakup, ice floes shearing along the riverbank or striking river training structures may severely damage riprap or erode the banks. Public and private riverside structures can be weakened, distorted, or even destroyed.

g. Ice forces on structures. The design of riverine, lake, coastal, and offshore structures to be built in ice-prone areas, such as riprap installations, river training structures, docks, bridge piers, artificial islands, or oil drilling platforms, needs to take into account the potential forces exerted by ice runs at breakup or by large ice floes driven by currents or wind stresses (Figure 1-4). These forces will depend on ice thickness, ice mechanical properties, and the anticipated mode of failure of the ice (crushing, bending, or buckling).

h. Ice jam flooding. River ice jams may contribute to winter and early spring flood damage (Figure 1-5). Ice blockages in main stems and tributaries cause stages to rise and force water out of the channel over the floodplain, even when discharges are low compared to warm-water floods. Ice jam floods, while usually not as extensive as open-water floods, often take place with little or no warning. The factors and relationships that determine the probability of ice jams and ice jam flooding are more complex than those for open-water flooding. This means that the extensive statistical analysis methods applied to normal flooding phenomena are not readily applicable to ice-related occurrences. Many mitigation measures have been developed for preventing or reducing ice jam floods; these methods may be structural or nonstructural, and they may be deployed on a permanent, advance, or emergency basis. Effective Corps emergency management responses depend on fully understanding ice jam phenomena.

i. Ice effects on navigation. Ice-prone rivers in the U.S. directly serve 19 states containing 45% of the Nation's population. These rivers also serve as conduits to eight other river states and connect the U.S. heartland to world markets through the Gulf of Mexico, the St. Lawrence Seaway, and the ports of the Northwest. The principal rivers among these that generally support year-round navigation are the Ohio River (including the Monongahela and Allegheny rivers), the Illinois Waterway, and the Upper Mississippi River from Keokuk, Iowa, downstream to Cairo, Illinois (its junction with the Ohio). Elsewhere, ice formation on the Great Lakes and their connecting channels and in the Upper Mississippi River above Keokuk generally forces the suspension of commercial navigation during most of the winter season. The presence of sheet ice or brash ice in any of these waterways slows navigation considerably (Figure 1-6), may damage the hull or propulsion systems of vessels, and can cause the breakup of tows.

Figure 1-4. Ice action on bridge piers

Figure 1-5. Flooding caused by an ice jam

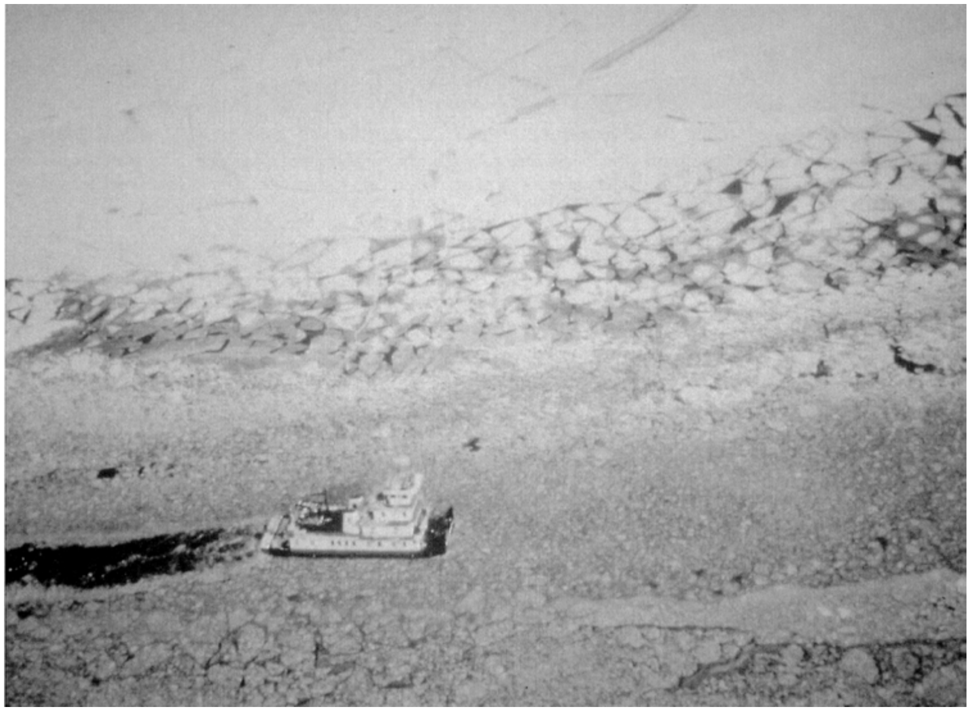

Figure 1-6. Towboat in ice

Broken ice caused by multiple vessel passages may accumulate in navigation channels or under adjacent sheet ice, further exacerbating navigation difficulties. When ice causes navigation to stop or to become significantly curtailed on these waterways, the portions of the local, regional, and national economies dependent on waterborne transportation may be adversely affected.

j. Ice problems for towboat operators. Aside from the obvious effects of ice on the navigation industry, such as increased demands on personnel, accelerated wear and tear on equipment, and increased maintenance requirements for towboats and barges, ice imposes several limitations on tow operations that directly affect the industry's efficiency. The first of these is reduced tow size. The added resistance caused by the heavy ice accumulations means that towboats are not able to push as many barges through the ice as through open water. Thus, for the same operating costs, less tonnage can be moved when ice is extensive. The next limitation is lower travel speeds. Again, this is a function of the extra energy needed to move a tow through ice accumulations, and it varies with the amount of ice in the waterway. And, finally, there are the delays at locks already enumerated, including ice restrictions on usable lock widths dictating narrower tow configurations.

k. Ice effects on industry, commerce, and the general public. When freight is delayed or stopped on ice-prone rivers by adverse ice conditions, the effects are felt by industries served by river transportation. And, as industry is affected, so also are commerce and the general public, since they rely directly or indirectly on industrial payrolls. Ice problems can curtail shipments of fuels, industrial feedstocks, finished goods, road salt, etc. These delays may lead to a range of results, from added transportation costs for alternative shipping modes to industrial plant cutbacks with associated layoffs. Delayed movement of goods leads to the depletion of reserve stockpiles, added inventory carrying costs, and extra labor costs for additional handling of bulk products. Road salt shortages may result in hazardous road conditions. Fuel shortages affect both industry and homes; often when fuel is scarce, industrial cutbacks (and layoffs) are implemented to ensure at least minimum service to hospitals and residences. Major interruptions in industrial raw materials lead to terminating process heating, and this can result in costly shutdown and restarting expenses.

1-5. References

a. Required publications.
None.

b. Related publications.

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