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CRREL Ice Jam Database

Kathleen D. White and Heidi J. Eames

February 1999

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This report provides information on the CRREL Ice Jam Database and its potential use for analyzing ice-related flooding problems. Rivers in the northern United States are subject to ice jams that cause flooding; block hydropower and water supply intakes; delay or stop navigation; damage riverine structures such as locks, dams, bridges, dikes, levees, and wingwalls; and decrease downstream discharge. The lack of readily available information on historical ice events hinders rapid, effective response to ice jam flooding and other ice-related damage. The CRREL Ice Jam Database was developed to provide a centralized record of ice events.

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Cover: Ice in Montpelier, Vermont, one day after the ice jam flood of 1992.

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CRREL Report 99-2

US Army Corps of Engineers®
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CRREL Ice Jam Database

Kathleen D. White and Heidi J. Eames

February 1999

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Kathleen D. White, Research Hydraulic Engineer, and Heidi J. Eames, Engineering Aid, Ice Engineering Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL).

Technical review of this report was provided by Dr. Jon E. Zufelt and Dr. J.-C. Tatinclaux, both of CRREL. Funding was provided by the Office of the Chief of Engineers.

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CRREL Ice Jam Database

KATHLEEN D. WHITE AND HEIDI J. EAMES

INTRODUCTION

This report provides an overview of the CRREL Ice Jam Database and provides examples of the application of information contained in the database. It should be of interest to all Corps of Engineers elements, major subordinate commands, districts, laboratories, and field operating activities located in the freezing zone or having civil works responsibilities concerning ice. In addition, this information is intended to be helpful to hydrologic and hydraulic engineering specialists and emergency operations personnel, as well as state and local officials who are responsible for responding to ice jam emergencies.

PROBLEM

Ice jam flooding in the United States

Rivers in the northern United States may be affected by the formation of ice jams. Costly damage to riverine communities is a direct result of these ice jams, which often leave little time for engineers and state officials to prepare for flooding and evacuate the communities or structures to be affected by rapidly rising waters. Although no specific damage figures are available, it is estimated that ice jams cause over $100 million in damages annually in the United States (Fig. 1). Roads may be flooded and closed to traffic, or bridges weakened or destroyed, limiting emer-

a. Along the Saranac River, New York, January 1996.

b. Along the St. John River, Maine, April 1991. The bridge piers visible in the river mark the location of the bridge destroyed during ice jam.

Figure 1. Examples of ice jam damage.

gency and medical relief to the affected areas. The potential exists for death or serious injury from jam and flood conditions, or during evacuations. Ice covers and ice jams also block hydropower and water supply intakes; delay or stop navigation; damage riverine structures, such as locks, dams, bridges, dikes, levees, and wingwalls; and decrease downstream discharge. In addition, ice movement and ice jams can severely erode streambeds and banks, with adverse effects on fish and wildlife habitat.

Engineers and state officials work together to prevent damage caused by ice jams, and many are working to anticipate future measures required to prevent serious ice jams from forming. These efforts depend upon accurate and reliable ice jam data that can be used to research previous ice jams, to predict and assess conditions that may increase the probability of an ice jam formation, and to document steps taken by engineers and relief officials in previous years when confronted with ice jam conditions during emergencies.

Ice jam data collection

While much information has been collected and compiled for open-water floods, documentation on ice jams and other ice events, such as freezeup and ice cover breakup, is not often readily available in the United States. Additionally, while open-water stage can be determined at a site by flood routing from other sites upstream or downstream, the complex nature of ice jams requires highly site-specific methods of estimating flood stage. The relatively small quantity and limited availability of ice event data reflect the facts that ice events usually occur less frequently, are of shorter duration, and adversely affect only short reaches of river, compared to open-water floods, which can affect long reaches for up to several weeks.

In the past, the lack of readily available information on historical ice events has hindered the rapid, effective response to ice jam flooding and other ice-related damage. Collecting information specifically related to ice events, such as stage, flooded area, and previous mitigation methods, has generally required a time-consuming search of a variety of potential data sources. During emergency situations, this is rarely possible. Information that might have assisted the emergency response effort may not be found until after the event, if at all.

The need for an accessible collection of ice data was particularly evident to researchers in CRREL's Ice Engineering Research Division (IERD), who are involved in research on the hydraulics of ice, including ice cover formation and breakup, bed and bank erosion caused by ice, ice effects on riverine structures, and ice jam initiation, prediction, mitigation, and control, and who are called on to advise on ice jam flooding emergencies.

Creation of an ice jam database

An initial compilation of ice event information from IERD and CRREL formed the nucleus of the CRREL Ice Jam Database (White 1992, 1996). The database has expanded to encompass historical ice information from many sources. As of September 1998, the CRREL Ice Jam Database included data on over 11,000 ice events in the United States between 1780 and 1997. It includes the name of the water body; the city and state where the ice event took place; the month, year, and date of the ice event; the ice event type, if known; a brief description of damage; the names of IERD and Corps personnel familiar with the event or site (points of contact); whether IERD files contain visual records of the event; latitude and longitude; USGS gage number, if available; and hydrologic unit code. Records also contain narrative descriptions of ice events (which can be several pages long) and a list of information sources. There is a separate database entry for each discrete ice event at a given location.

This new database is useful, not only as a centralized record of ice events, but also for the many potential applications of the information. These include rapid identification of potential ice jam stages, flooded areas, and mitigation methods at some known ice jam locations. The listing of sources and contacts may aid in the search for additional information about particular ice events. The ice event data provided can be evaluated with other meteorological and hydrological data to characterize the conditions most likely to cause ice events at a particular location. The database is useful for reconnaissance level evaluation, for detailed studies of a problem area, and for designing ice control techniques, as well as for emergency responses to ice jam events.

The CRREL Ice Jam Database is constantly enlarging as historical ice event data are collected and entered. It is maintained by IERD personnel using the ORACLE database manager. The inclusion of geographical information will allow future development of GIS applications. USGS hydrologic unit codes allow searches by Corps Districts and Divisions, many of which are delineated by watershed boundaries. The database may be accessed via the CRREL web site at http://www.crrel.usace.army.mil. The user interface allows for database queries that are displayed in a manner that allows additional data screening and processing.

OVERVIEW OF THE CRREL ICE JAM DATABASE

Definition of ice events

Ice events included in the CRREL Ice Jam Database can be described by the broad definition used by the International Association for Hydraulic Research (IAHR) Working Group on River Ice Hydraulics (1986): "a stationary accumulation of fragmented ice or frazil that restricts flow." The database includes ice jams that form in the early winter during ice cover formation (freezeup jams), those that form during ice cover breakup (breakup jams), and those that contain elements of both. Ice cover formation that results in increased upstream water levels or decreased downstream water levels is also considered an ice event. Thermally induced expansion of an ice cover that damages the shoreline or a structure, and aufeis—or thickened surface ice accumulated through the successive freezing of sheets of water, also called naled (Carey 1973, Schohl and Ettema 1986)—are also included.

Sources of ice event information

The database draws largely from two sources: the United States Geological Survey (USGS) report series that provides gaging station data collected for a study of the magnitude and frequency of floods (e.g., Green 1964) and the annual USGS Water-Data Reports (e.g., Toppin et al. 1993). Both of these contain information on peak stage and discharge events at USGS gages. About 85% of the ice events in the database are documented at USGS gages from these sources.

Other data sources are newspapers, historical records, such as town histories and government agency reports, anecdotal reports by local residents obtained from personal interviews, and CRREL files. These sources may provide good narrative information about an ice event and the damage it caused, but quantitative information of the type found in USGS sources is often lacking. Although sources vary in reliability, everything identified as an ice event is included in the database. Where conflicting information about the same event is found, all of it is presented for the user to evaluate.

Some ice events are well documented, perhaps by more than one source, while only sketchy information exists for others. The most complete documentation consists of gage records (usually containing quantitative stage and flow information) supplemented by other sources (which can supply either qualitative or quantitative information, or both). We can safely assume that ice events did occur at the locations and dates noted in the database, but the converse is not true. That is to say, we cannot assume that no ice events took place at times or locations not listed, since often an additional search of records or interviews with local residents will reveal ice events that are not in the database.

Therefore, the database is best viewed as a collection of *identified* ice events, subject to selection bias introduced by the literature search process and the types of records examined thus far. For statistical analysis, we must consider the database to be a biased, limited sample of the entire ice event population. The presence of bias does not prevent us from undertaking statistical analyses, but the biases must be recognized and taken into account.

Temporal bias

Because about 70% of the database entries originated from the mid-1960s USGS series on the magnitude and frequency of floods in the United States (USGS Water-Supply Papers 1671 through 1689), a significant temporal bias was introduced into the database, as is shown in Figure 2. Without considering the bias introduced by heavy reliance on a single source, it might be erroneously concluded from a search of the database that most ice events in the United States occurred between about 1935 and 1965. This bias is accentuated when a smaller subset of the database is examined. For example, in Montana, where data collection efforts are adequate for the historical (i.e., before 1965) and recent (since 1995) periods, but poor for the intervening period (Fig. 3).

Further investigation may reveal that what appears to be an obvious temporal bias in the database entries for a particular location may actually reflect changes in river hydraulic conditions that significantly altered the ice regime. An example of this is the Israel River in Lancaster, New Hampshire, an ungaged location for which the database includes one ice jam in 1895 and 13 ice jams between 1950 and 1992. One might

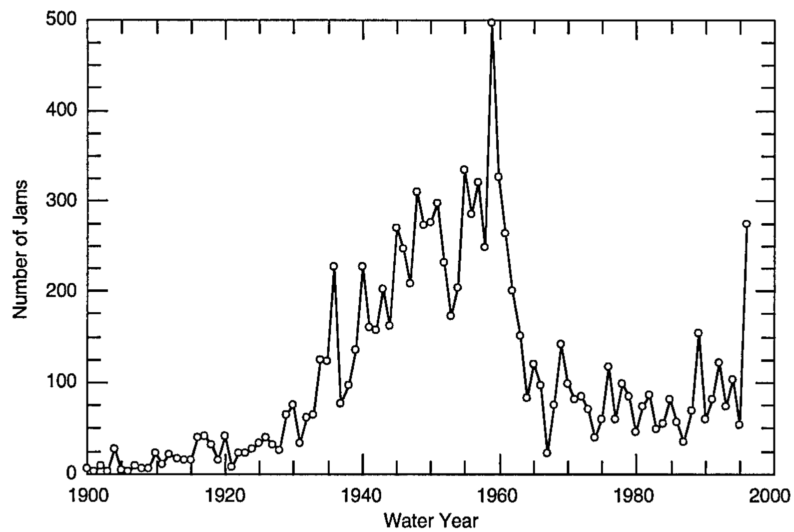

Figure 2. Annual number of ice events recorded in the CRREL Ice Jam Database since 1900.

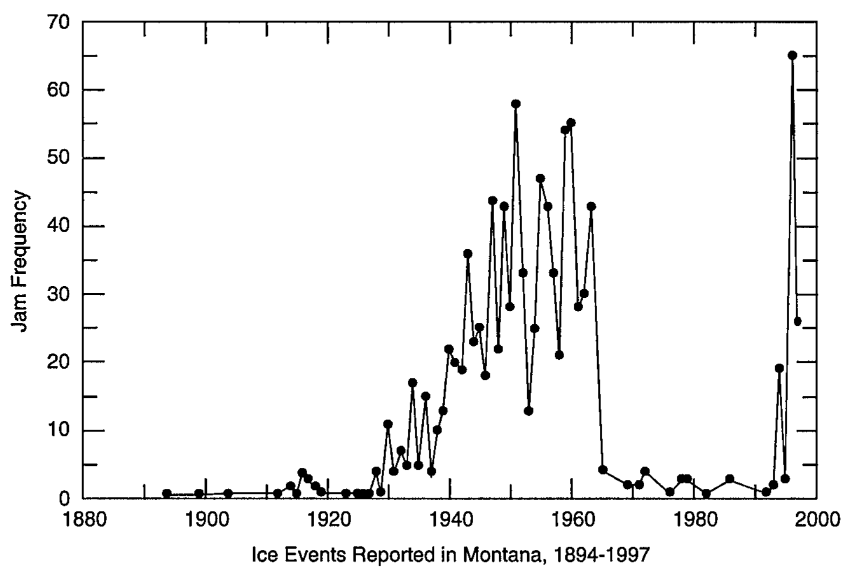

Figure 3. Annual number of ice events recorded between 1894 and 1997 in Montana (after Eames et al. 1998). Data are lacking for the period 1965 to 1995.

assume that the unusual temporal variation in ice events is a result of bias, but in this case, evidence suggests that the database record is a good representation of what actually took place. A careful review of flood records since 1870 (USACE 1973) indicated that there was only one documented ice jam flood in Lancaster prior to 1950 (in 1895). The marked change in ice event frequency at this site after 1950 may be attributed to the failure by then of four mill dams in Lancaster that were damaged in the extreme open-water floods of March 1936. The dams had provided ice storage and impeded the breakup and movement of the ice cover, limiting the formation of damaging ice jams. After all the dams were gone, significant ice jams occurred with much greater frequency. Following the ice-related flood of record in March 1968, the Corps of Engineers and CRREL became involved in a series of studies that resulted in the construction of an experimental ice control structure in 1981. Since that time, there have been no major ice jam floods.

Spatial bias

A spatial bias toward ice events at USGS gaged sites also results from reliance on USGS records, so that ice events at sites without gages are likely to be underrepresented or missed entirely. For example, we know from anecdotal evidence that the Waits River near Bradford, Vermont, experiences both freezeup and breakup ice jams almost annually, yet the database contains only four entries for this ungaged site. The information sources are one newspaper story each in 1964, 1976, and 1992, and brief reports by two CRREL personnel that mention ice events in 1973, 1976, and 1992. It is probable that many more ice events could be identified through a search of local newspapers and historical records.

CRREL's proximity to many ice jam sites in New England has introduced another spatial bias into the database. The database is more likely to contain information for ungaged sites, and from sources other than the USGS, for locations in the New England states than for other states. Likewise, ice jam problem areas that have been the focus of detailed study by CRREL or another government agency, such as the lower Platte River Basin in Nebraska or the Salmon River near Salmon, Idaho, will have more complete information than a gaged site that has not been the focus of such a study.

Single source bias

The database's heavy reliance on the USGS sources at this time also introduces a source bias. For example, ice events that took place at gaged sites, but outside the period of record, will be underreported. For instance, the USGS gage on Collyer Brook at Gray, Maine, operated during water years 1965 through 1982. In 11 of these 18 years, the maximum annual gage height resulted from an ice jam at or downstream from the gage. The annual USGS Water-Data Reports (e.g., USGS 1981) is the only information source listed. No other sources were identified, with the result that there are no ice event entries for years outside the gage's period of record, although it is very likely that there were many such events.

In a case such as this, additional sources (e.g., local newspapers) must be reviewed to obtain any ice information for years outside the period of record, as well as for more complete information on the events listed in the database.

Perception stage bias

One bias that must be considered for ice events reported by all sources is the perception stage. Perception stage, as defined by Gerard and Karpuk (1979), is the minimum stage that must be attained before a particular source will perceive and report an event. Different sources will have different perception stages for the same event, and the reliability of each source must be assessed when comparing stages reported by different sources. The effect of this bias is that ice events that are not damaging or that have stages less than the perception stage are often unreported.

For example, ice events that flood a residential area may be reported, but similar ice events that do not cause flooding may not be reported. Or, events that took place before development may simply not have been observed by anyone and therefore have gone unreported. It is also possible that ice events that did not cause an annual peak stage will not be reported in the USGS series on magnitude and frequency, which was primarily concerned with peak events. In other words, if an ice event that caused a high winter stage is followed later in the year by a higher open-water flood stage, usually only the open-water stage is reported.

Perception stage can vary; for the USGS, gages might have a precise perception stage at which water goes overbank. Sometimes perception stage can be quite high. For example, when contacted by telephone about ice jam flooding at Akiak in 1983, Hugh Olsen reported "It's not really a problem (but) I'm standing in about four inches talking to you" (Campbell 1983).

Because of the perception stage bias, the database should be used with care when developing ice jam stage-frequency curves. Even unspectacular ice events can be quite important.

Potential bias must be considered

All of these examples underscore the need to consider potential biases when evaluating information in the database. If data for a particular site appear to be biased, additional sources should be examined to determine whether the apparent bias is real or a reflection of actual conditions. As a general rule, bias effects can be minimized if the database is augmented by other sources, such as old newspapers and other historical documents, photographs, field notes made by USGS personnel during normal winter discharge measurements, and field observations by others, such as Corps or emergency response personnel.

Despite its biases and uncertainties (e.g., measurement errors, source reliability), the CRREL Ice Jam Database can be a useful source of ice event information. Presented in the following sections are several potential applications of the database:

- Using ice event information in ice jam emergency response efforts.
- Preparing a thumbnail sketch of ice jams in a particular state.
- Characterizing ice jams on a regional basis.
- Characterizing ice jams by year.

USING THE ICE JAM DATABASE TO IMPROVE EMERGENCY RESPONSE TO ICE JAMS

Emergency response

Emergency response to ice jams is often less effective than it could be because of a lack of information on past ice jam locations, stages, and mitigation measures. If ice jamming is infrequent in a river, contemporary emergency response agencies or coordinators may have no useful knowledge about previous ice events. CRREL personnel are often asked to provide technical information in ice jam emergencies. In the past, this effort involved scouring IERD files for information on past jams at a site or locating a person who had responded to past events there, all within a very short time. In some cases, more complete, site-specific technical advice could have been provided if the information had been readily accessible.

Since the advent of the database, information on past ice events at the site can be rapidly located and passed on. This is particularly important when information on the success or failure of past mitigation measures is available. In addition, the sources used in developing database entries, such as relevant publications and newspaper articles, are now available in the IERD Ice Jam Archive (Herrin and Balch 1995).

Using information about historical ice data and mitigation at a site

The database contains information that is immediately useful in emergency response, such as for the Winooski River in Montpelier, Vermont, where ice covers form and break up annually. Although Montpelier has suffered several damaging ice jams in the past, the jam of 11 March 1992, which caused about $5 million in damage, came as a shock to many residents. Knowledge of the potential depth and extent of flooding might have prevented some of the damage. At the time of the 1992 ice jam, the database was in its nascent stages, and there were few entries for Montpelier. However, current entries show that the area flooded and the stage reached in the 1992 event virtually duplicated the ice jam flood of 13 February 1900. The flood of 9 January 1978 was also similar, although less damaging. Past ice jam mitigation measures are also described; as recently as 1973, blasting was used successfully to clear ice jams at Montpelier. If an ice event occurs at this location in the future, the database can provide rapid access to information needed by emergency response agencies, including the ice jam removal methods used in the 1992 event.

Using database information to guide search for additional information

The database is useful for an emergency response to an ice jam in other ways. For example, knowing the dates when large numbers of ice events occurred allows an efficient search of historical records for ice events not already in the database. This method proved useful in Connecticut, where ice cover breakup is generally uneventful. In 1994, unusually cold weather resulted in thicker than normal ice and local officials were concerned that the unusual conditions might cause jams and flooding at breakup. They were aware of a few previous ice events but suspected that there were several unreported ice events at other times and locations. The officials were concerned that emergency response would be hindered with no knowledge about where and when ice events had occurred in the past, what damage resulted, and what, if any, mitigation measures had been used. A search of the database produced entries for Connecticut and a list of ice event dates in the upper Connecticut River basin back to 1900. The latter was provided with the expectation that lower Connecticut River basin events might have happened at about the same time. Knowing these dates allowed a rapid search of historical records for useful ice event information.

The database can also be searched for particular words or phrases such as "blasting," "dusting," or "ice jam removal, "to obtain information regarding the success or failure of applying different techniques (Fig. 4) and points of contact knowledgeable about carrying out such mitigation measures. For example, the entry for Saranac River, Morrisonville, New York, in 1996 includes the following: "two bulldozers and a backhoe

Figure 4. Blasting on the Platte River near Ashland in February 1997. Following a devastating jam in 1993, state and Federal officials developed a rapid response plan that allows blasting to begin within hours. (Photo courtesy of J. Mastandrea, Sarpy County, Nebraska, Emergency Management Agency.)

were rented to release the jam. A channel was made about 1/2 mile long in 9 hours. They planned to continue breaking the jam to a couple hundred feet below the upstream end of the jam. The rest of the jam was to be blasted. A temporary dike was being put in place to prevent further flooding. The dike was an extension to the berm that was put in place during an event in 1980." (Figure 1 depicts typical damage during this event.) This type of information will be useful for future events at this and other sites, and will also allow searchers to contact the local officials to obtain first-hand information on the success or failure of mitigation measures.

USING THE ICE JAM DATABASE TO DEVELOP A THUMBNAIL SKETCH OF ICE JAMS BY STATE

Review of ice jam summaries by state

The Ice Jam Database provides quick access to general information about specific ice jam events in a particular state. These historical data are crucial during emergency situations where information about jam locations or stages would be helpful. Historical information is also important for studies at specific sites. For example, Alaskan database entries were used by CRREL during the Kuskokwim River Navigation Reconnaissance Study, which evaluated the feasibility of navigation on the river. Hydrological data are also used to make predications about ice jam occurrences. In an article in *The Northern Engineer*, Fountain (1984) notes that much remains to be done in the effort of predicting ice jam floods and that an examination of river ice breakup statistics would aid in the process. White (in prep.) has developed an ice jam progression model for the Yukon River, based on ice event information contained in the database (Fig. 5).

CRREL plans to prepare summaries for all states and has completed brief summaries for New Hampshire and Vermont (White 1995), Alaska (Eames and White 1997), and Montana (Eames et al. 1998) to date. Following is the summary of ice jam data in Alaska, based on information contained in the CRREL Ice Jam Database.

Example: Ice jams in Alaska

Ice jams occur frequently in Alaska, a state containing 3000 rivers and located in the subarctic and arctic regions of the North America (Herb 1993). In this sparsely populated state of 587,766 people (as of the 1992 census), ice jams can form and flood large areas without endangering any people or towns. However, many Alaskans depend on rivers as a source of food and transportation (Fountain 1984), and as a result many towns are situated on river banks, thus being at risk for ice jam flooding. As of December 1996, 747 Alaskan ice jam events were documented in the CRREL Ice Jam Database (Fig. 6).

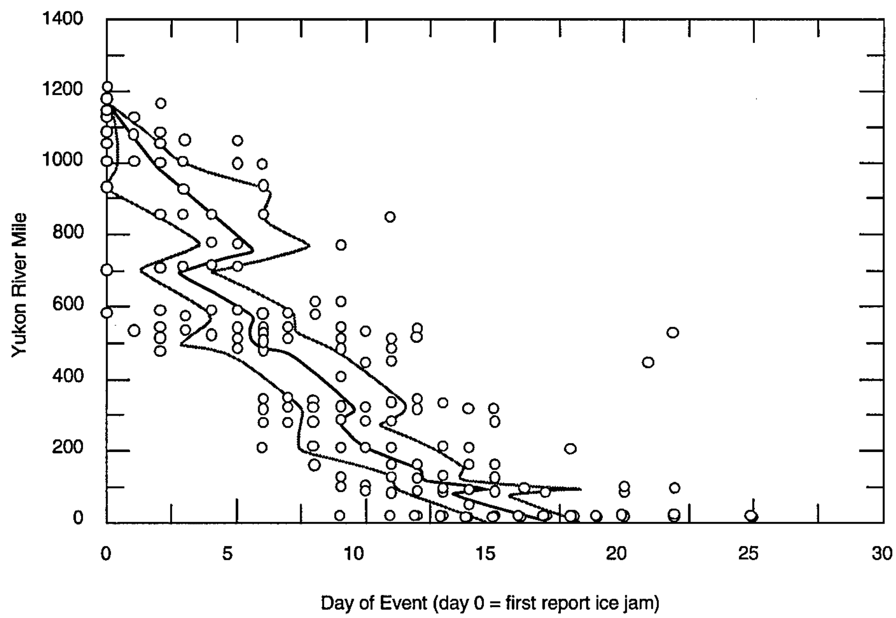

Figure 5. Proposed near-term ice jam occurrence model on the Yukon River is based on information taken from the CRREL Ice Jam Database. Presented here is the expected ice jam occurrence, shown along with the 95% confidence interval on which forecasts are based (after White, in prep.).

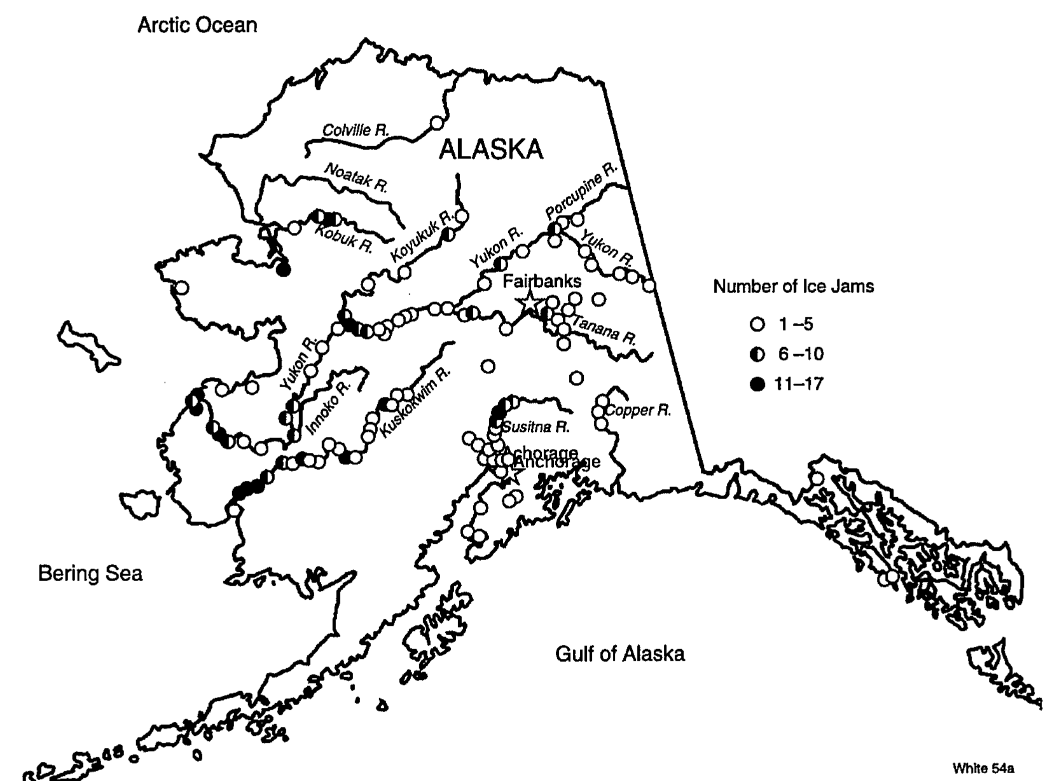

Figure 6. Locations of reported ice events in Alaska.

A substantial amount of information on ice jams in Alaska was collected during an examination of files of the National Weather Service in Anchorage, Alaska, and as a result 74% of the source publications are from the NWS. Other sources of information are the USGS, the U.S. Army Engineer District, Alaska, CRREL, and newspapers (17%). A series of CRREL Special Reports on ice observations in the North American arctic and subarctic (Bilello 1961, 1964; Bilello and Bates 1966, 1969, 1971, 1972, 1975, 1991; Bilello and Lunardini 1996) provided about 4% of the ice jam information. The Alaska Division of Emergency Services (ADES) was the source of about 5% of the information.

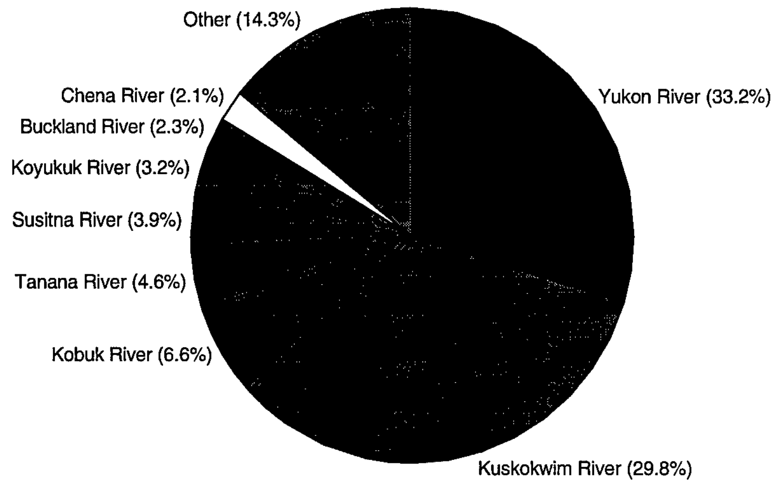

Figure 7. Distribution of jams in Alaska by river.

The database has information on ice jam events on 60 different rivers in Alaska at 149 different locations. However, only nine have a population greater than 1000 (1995 census data), 82 of the towns in the database had less than 1000 people in 1995, and 54 of the locations in the database are described as not populated. Of the Alaskan entries in the database, 85.7% describe jams on the Yukon, Kuskokwim, Kobuk, Tanana, Susitna, Koyukuk, Buckland, and Chena rivers (Fig. 7). The Yukon River has the most reported ice jams (248), followed by the Kuskokwim River with 222 events. The town of Bethel on the Kuskokwim River has the greatest number of ice jam records for one location—26. It is important to note that the perception bias is particularly important in a sparsely settled state like Alaska. The high frequency of ice jam events on the Kuskokwim and Yukon rivers is in part attributable to these being the two longest rivers in Alaska. More information is available for these rivers than for shorter, less-populated rivers. Jams that happen away from populated areas are not likely to be recorded.

The earliest entry in the Ice Jam Database for Alaska is a 1937 event in Fairbanks. Between 1937 and 1970, only 56 ice jams in Alaska are recorded in the database (Fig. 8). From 1970 to the present, there are significantly more ice events reported because this is the period for which records were readily available at the NWS. The limited ice jam data before 1970 is partly attributable to the lack of USGS gaging stations before the late 1940s and early 1950s (Lamke 1989). In addition, while Alaska was purchased in 1867, it was not admitted to the union until 3 January 1959, which may have hampered record keeping (Herb 1993). Ice jam frequency varies, with the highest number of ice jams (61) recorded in 1989. In 1991 there were 55 ice jams recorded. The number of ice jams reported in the database in certain years largely depends on the jam location and availability of jam records. For example, in 1991, one of the more populated areas, Fairbanks,

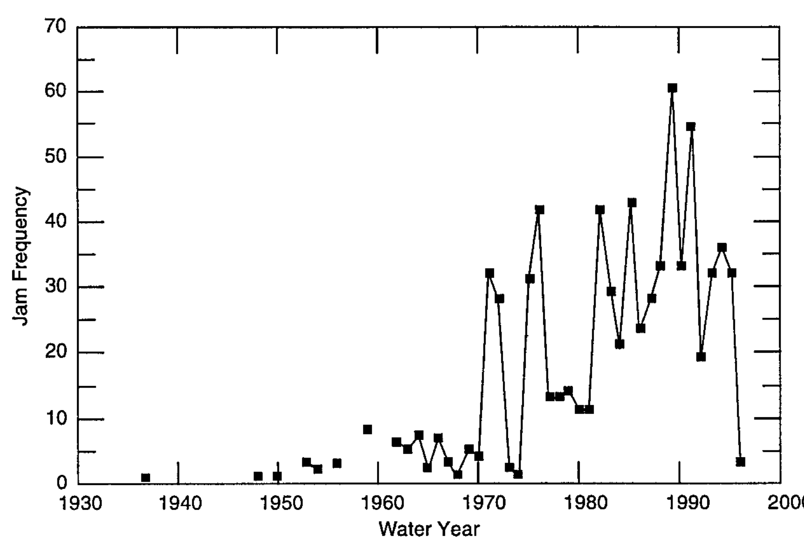

Figure 8. Number of ice events recorded annually for Alaska.

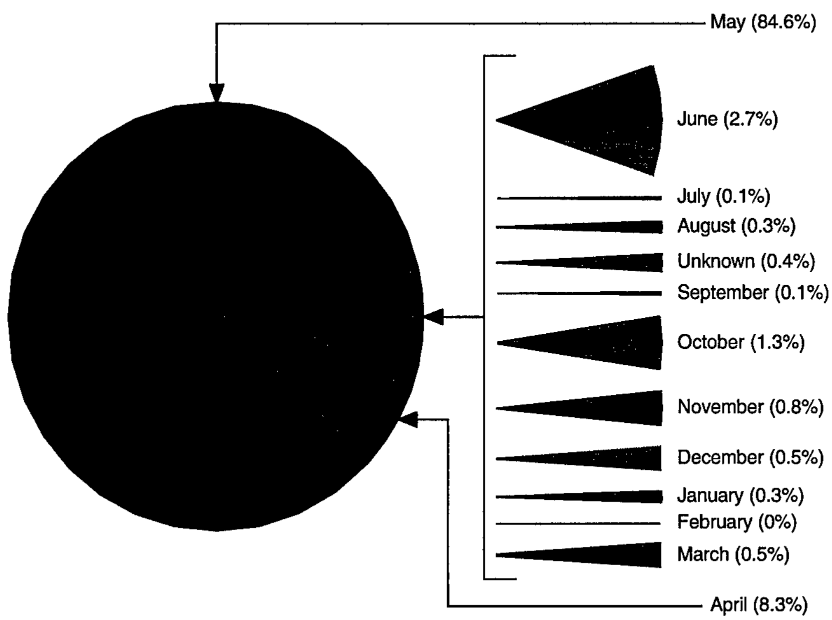

Figure 9. Monthly distribution of ice events in Alaska.

experienced extensive ice jam flooding. As a result, news stories and other publications emphasized ice jam occurrences everywhere in Alaska more than usual that year.

Ice jam occurrence also depends on the season. Of the 747 ice jam events in the Alaskan database, 663 took place in May, which is typically when the rivers begin to break up (Fig. 9). From these data, we can conclude that Alaskan ice jams are largely breakup ice events. Freezeup events do occur, though less frequently.

For many Alaskans, the breakup of river ice means the end of frozen highways and the start of open water transportation (Fountain 1984). Most people who live along rivers expect flooding during the time of breakup, and simply move to higher ground (Hunt 1991). In Emmonak on the Yukon River, flooding is a way of life. All homes are on pilings and during high water the power plant is shut down and people visit each other in skiffs (Hunt 1991). Says the City Manager, "Nobody really gets excited. Everything is put away and everything raised up, and we deal with it" (Hunt 1991). However, ice jams can take towns by surprise with rapid flooding and extensive damage caused by ice floes that are carried out of the river banks. In 1971, a very rapid rise in water level at Alakanuk damaged every structure in the village and residents were forced to await rescue from rooftops and boats (*Newsminer* 1971).

Ice jams can also have damaging effects on wildlife (Fig. 10) and the natural environment, as well as humans and their associated structures. For example, in 1989, an ice jam on the Nowitna River created a lake hundreds of square miles in area, and high water marks 40 miles (64 km) upstream were 9 ft (3 m) above the riverbank (Hunt 1991). A fly-over of the flooded area found nine moose trapped on a small knoll (Hunt 1991). The effects of such a catastrophic event on the environment are unknown. In general, ice-related losses of fish, wildlife, and riverine habitat, and their effects on local economies, are not well documented in Alaska.

As is the case for the database as a whole, many of the sources of information on ice jams in Alaska lack specific data on damages. However, damages have recently been reported by the Alaska Division of Emergency Services Preliminary Damage Assessment Team, with the result that 146 of the reported Alaskan ice events (19.5%) have known damages, a much higher percentage than the whole database (about 2%). The most common damages reported are lowland flooding, bank erosion, flooded homes, and road damage, such as a 1989 ice jam flood in Alakanuk on the Yukon River, in which ice took two homes off of their pilings (Hunt 1991). Some ice jam floods can cause extensive damage and be quite costly for communities. In 1971, ice jam damage in the

Figure 10. Moose trapped on an ice floe during breakup, Yukon River.

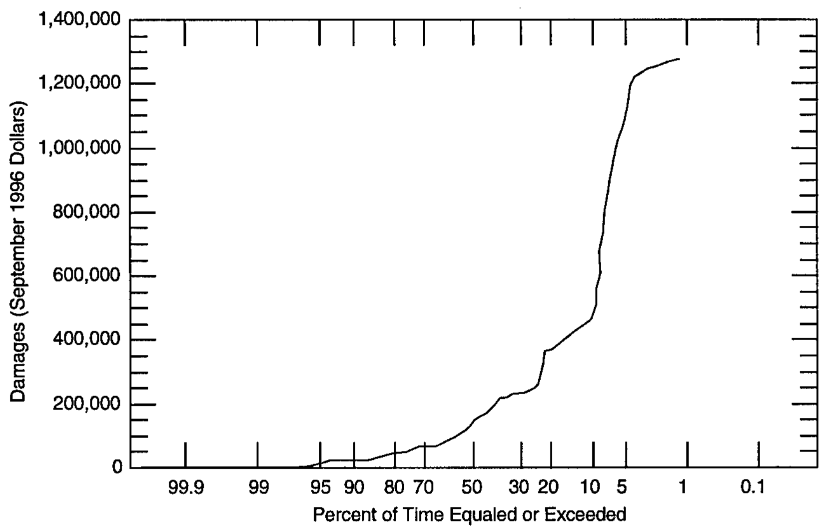

Figure 11. Damage-frequency curve for reported ice-related damages in Alaska between 1982 and 1994 in September 1996 dollars (from Eames and White 1997).

towns of Akiak and Napakiak on the Kuskokwim River, and the towns of Galena and Sheldon Point on the Yukon River, totaled about $7 million (September 1996 dollars). More recently, in 1994, an ice jam on the Yukon River in the town of Galena caused $380,000 in damage (September 1996 dollars). These damages can be presented in the form of a damage-frequency curve (Fig. 11), which shows reported damages for the period 1982 through 1994 in 1996 dollars. The figure indicates that during the 13-year period, damages exceeded $150,000 about half the time.

USING THE ICE JAM DATABASE TO CHARACTERIZE ICE JAM EVENTS IN A REGION

Overview

Characterizing ice jams on a regional basis provides some of the same information as the example for a single state above. Summaries can be prepared for groups of states (e.g., New England), and for river basins or other areas whose boundaries can be described by hydrologic unit areas. For example, ice events in the Susquehanna

River Basin, which encompasses parts of Pennsylvania, New York, and Maryland (White 1999b), can be searched using hydrologic unit code 0205. Similarly, a summary of ice events in the U.S. Army Engineer District, St. Louis, can be developed by searching the hydrologic unit areas in Missouri and Illinois that lie within it (White 1999a). Such general knowledge about the spatial distribution of ice jams can be useful (e.g., prioritizing the allocation of resources for further study of ice events).

Example of regional characterization: New Hampshire and Vermont

An example of a regional characterization is provided by White (1995) for New Hampshire and Vermont, which are joined by the Connecticut River. In this example the goal is to determine in general when and where ice events occurred and what the damages were, so that ice events can be compared to open-water events. It is assumed that the accuracy of database information is acceptable, broadly characterizing ice jams in the two states, and that the bias attributable to the unfinished nature of the database will be negligible.

A search of the database revealed 1097 ice events: 667 in 90 towns or cities in Vermont and 430 in 80 towns or cities in New Hampshire. Ice events were reported at 248 locations on 146 different streams in New Hampshire and Vermont. Almost 34% of all reported ice events occurred on just 5% of these streams, while 35% of the 146 rivers had only one reported ice event. Ice events were reported in all of the primary drainage basins in the two states: the Androscoggin (7), Saco (26), Piscataqua (32), and Merrimack (154) basins in New Hampshire, and the Hudson (2) and St. Lawrence (399) basins in Vermont. There were 453 reported ice events in the Connecticut River basin, which includes both states (261 in Vermont and 192 in New Hampshire).

USGS documents, such as those by Green (1964) and Wiitala (1965), and annual streamflow records, are the data sources for about 74% of these ice events, somewhat less than for the entire database (over 85%). Among the other sources listed are newspapers dating back to the 1800s and detailed ice investigations by the Corps of Engineers. The higher percentage of non-USGS sources means that the entries for New Hampshire and Vermont may be slightly less spatially and temporally biased than for the database as a whole. Perception stage bias remains.

There has been at least one ice event in New Hampshire or Vermont every year since 1932. A plot of the distribution of ice event entries over time (Fig. 12) illustrates some of the temporal biases in the database. For example, the high number of ice events reported for 1992 is the result of a survey of ice-related damage that occurred during ice cover breakup in March 1992 rather than an extremely unusual regional event. Similarly, the small number of ice events reported before 1935 is more a reflection of the data sources rather than actual event frequency. There were few USGS gages in operation before

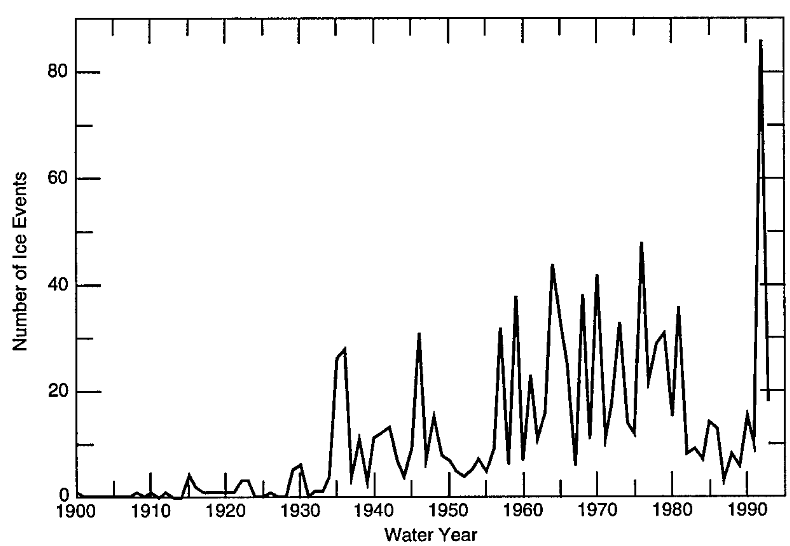

Figure 12. Number of ice events recorded annually for New Hampshire and Vermont (from White 1995).

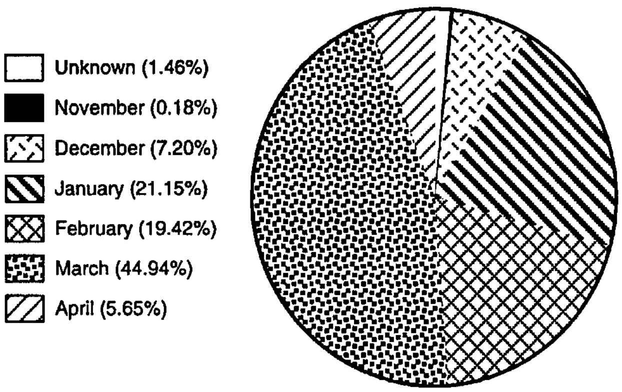

Figure 13. Monthly distribution of ice events in New Hampshire and Vermont (from White 1995).

that time, so less information is available from the primary data source and the reliance on other, less readily available data sources is higher.

It would be a mistake, however, to assume that all of the trends apparent in this figure are simply attributable to bias. For instance, both newspaper records and USGS sources confirm that there were relatively few ice events in New Hampshire and Vermont during the early 1940s and early 1950s, while they were frequent in the late 1960s through the 1970s. These trends may prove to be related to long-term meteorological cycles, or they may reflect population growth and development patterns that affect perception stages. Both are subject areas that would benefit from further research.

The database entries show that ice events can happen at any time during the winter in New Hampshire and Vermont, but are most frequent in March (Fig. 13). Of New Hampshire ice events, 78% are not specifically classified by type (e.g., freezeup, breakup, combination) and 72% are unclassified in Vermont. One damaging ice event in New Hampshire was attributed to the thermal expansion forces generated in a lake ice cover. Virtually all ice events that are type-classified are positively identified as breakup events. Breakup ice events were reported as early as 6 December and as late as 7 April, and there have been multiple breakup events during a single winter. In 1964, for example, there were 13 reported breakup events in late January after a rainstorm associated with rising air temperatures. Thirty more breakup events, many with significant damage and some on the same rivers experiencing breakup jamming in January, occurred in early March 1964.

Identification of ice event damage is clearly the most difficult task in the continued expansion of the database, and yet damage done is one of the most important pieces of information for the end user. For the United States as a whole, 22 ice-event related deaths are reported in the database. Two of these were in Vermont: one in 1867, the other in 1936. In New Hampshire, 7 deaths occurred along the Merrimack River during the March 1936 ice event that preceded the very large open water flood of March 1936, and one in Claremont in 1981. Ice-related damage, including agricultural, residential, and commercial flooding, road closures, mitigation costs, and bridge failure, was reported for 186 (17% of total) ice events. The 37 New Hampshire and Vermont ice events with damage estimates in dollars (3.4%) are all ice jams that involved flooding. A very rough probability distribution for these 37 jams shows that about nine of every ten exceed $1000 in damage, half of the ice jams exceeded $50,000, and that when ice-jam related damages occur, costs can be expected to exceed $1 million 20% of the time (Fig. 14).

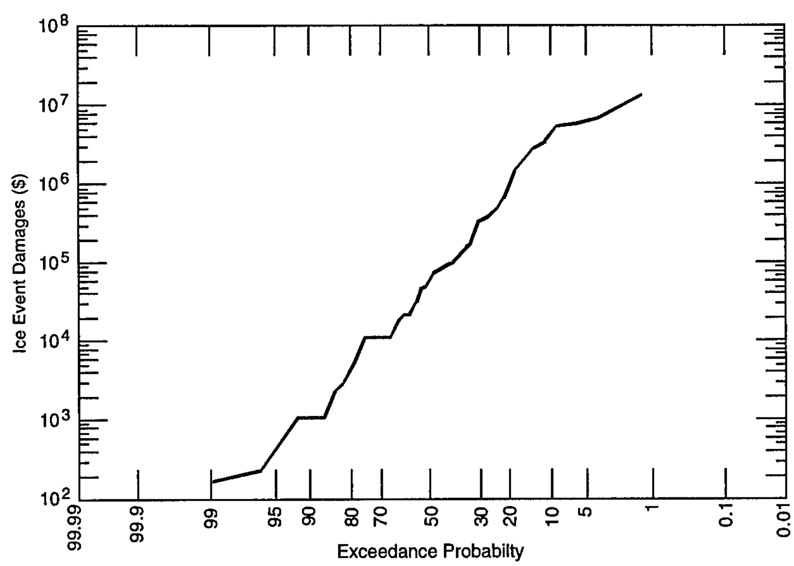

Figure 14. Damage-frequency curve for 37 reported ice-related damages in New Hampshire and Vermont in 1995 dollars (from White 1995).

USING THE ICE JAM DATABASE TO CHARACTERIZE ICE JAM EVENTS BY YEAR

Overview

In addition to a series describing ice events throughout a state or region, CRREL has also initiated an annual report of ice jams, beginning with 1996. An example of an annual summary of ice event data in the CRREL Ice Jam Database for water year 1996 (the period 1 October 1995 through 30 September 1996) is presented here (Eames 1997).

Example of annual jams: Water year 1996

The CRREL Ice Jam Database contains 272 entries in the database for water year 1996, the highest number of annual ice jams recorded since 1960, a year with 326 ice events. A substantial amount of the information on ice jams in 1996 originated from the National Weather Service. In 1996, 54.8% have some reported damages, including flooding and other damages to homes, roads, and buildings. Only 3.3% of the entries for 1996 provide dollar amounts for damages.

Ice jams during water year 1996 affected 25 states, with Montana, New York, Vermont, and Pennsylvania most affected (Fig. 15). The rivers with the most reported ice events were the Missouri, Connecticut, Yellowstone, and Allegheny. Montana experienced the most extensive damage ascribable to ice jams during water year 1996. Damage in just ten of Montana's counties totaled $1.8 million (Jones and Mclaughline 1996). On 7 February 1996, Governor Marc Racicot declared Montana a disaster area because of ice jam flooding in 21 of the state's 56 counties (Gallagher 1996).

January and February saw the greatest number of ice jams in 1996 (87%). During January 1996, the most ice jams were reported on the nineteenth (25.6%) and during February the most ice jams were reported on the ninth (Fig. 16). Weather patterns during January created favorable conditions for ice jams; record early January snowfalls in the Northeast resulted in more than 20 in. (51 cm) of precipitation. Widespread flooding resulted as snowpacks melted because of warm weather and heavy rain between 18 and 20 January, creating rapid runoff leading to ice cover breakup and ice jams.

A major contribution to the formation of ice jams in the Northwest was the above average snowfall. At the Stevensville Ranger Station (Montana), over 25 in. (64 cm) of snow was measured in January, with 20.5 in. (52 cm) between 19 and 29 January (Breeding 1996). In most major river drainages in western Montana, mountain snowpack levels were above the 30-year average; the Bitterroot drainage area reported 21% more snow than the 30-year norm and 35% more than the previous year (*Missoulian* 1996). Following the snowfall, there were subzero temperatures as low as –33°F (–36°C), which formed thick ice covers. A February warm spell that kept temperatures well above freezing for a week resulted in rapid

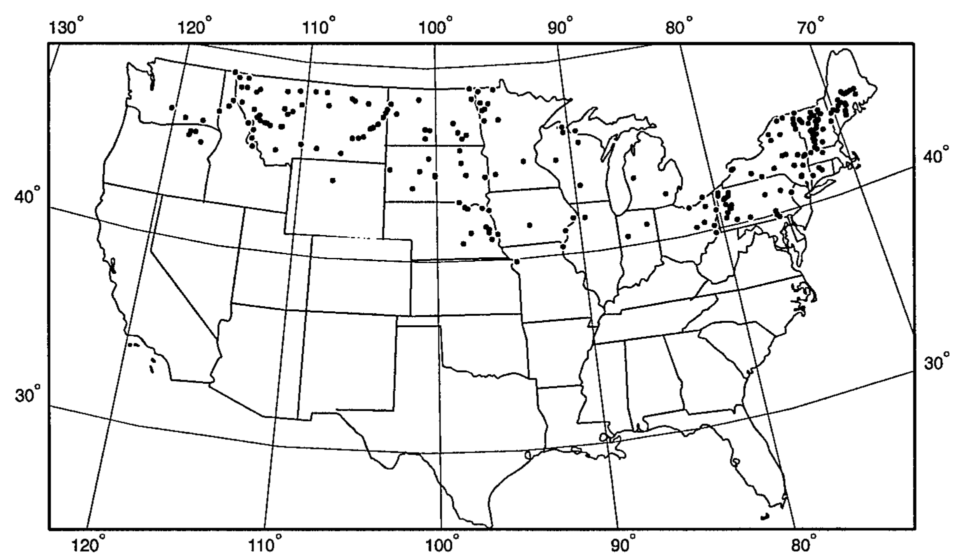

Figure 15. Locations of reported ice events in water year 1996 (from Eames 1997).

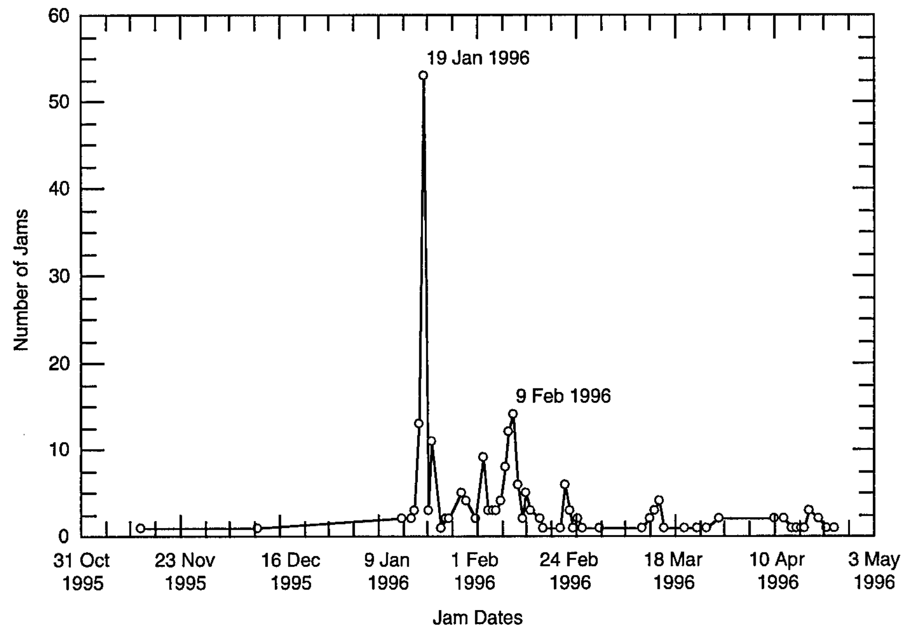

Figure 16. Number of reported ice events in January and February 1996. January events were primarily located in the Northeast, while February events were primarily located in the Northwest (from Eames 1997).

breakup of river ice covers and the formation of jams (Breeding 1996).

Weather conditions were similar in the New York and Pennsylvania portions of the Susquehanna River Basin. Snowstorms in early January dumped about 2–3 in. (5–8 cm) above normal snowfall throughout the 27,000-mile^2 (70,000-km^2) Susquehanna River Basin, with a water equivalent of 3 to 4 in. (8–10 cm) (Kelley 1996). Massive runoff began 18 and 19 January, when strong winds and dew points reaching into the 50s (10s in degrees Celsius) melted the snowpack covering the entire Mid-Atlantic region. Conditions were exacerbated when a cold front moved in on 19 and 20 January, along with rainfall, with the result that Pennsylvania experienced the most severe statewide flooding since tropical storm Agnes in June 1972 (USGS 1996). In approximately 50 locations throughout the state, the magnitude of floods was increased by ice jams (USGS 1996). On the Susquehanna River at Safe Harbor, the 75-year average flow was 38,300 ft^3/s (1085 m^3/s) (Kelley 1996). An ice jam that broke at Turkey Point on 20 January sent water and ice toward Safe Harbor, where flood gates at the dam were opened to deal with the average daily discharge of 826,000 ft^3/s (23,384 m^3/s). Damage to the Safe Harbor Dam was reported to be approximately $20 million, and the ice jam caused $14 million in damage to a mill project (Safe Harbor Power Corp. 1996). Downstream from the Safe Harbor Dam, the Conowingo Dam was next to be affected by the wave of water and eventually the City of Port Deposit, Maryland. Port Deposit experienced severe flooding and was reported to only have had 1/2 hour of warning time.

The CRREL Ice Jam Database reports over $5 million of ice-related damage in New York for 1996. According to contemporary Corps Emergency Operations Situation Reports (SITREPS), preliminary damage figures for the ice-jam-affected counties of Lewis, Jefferson, St. Lawrence, and Erie totaled over $1.1 million, with more than 350 homes affected.

Vermont reported 27 ice events in the Ice Jam Database for 1996. The high frequency of ice jams in Vermont during 1996 was influenced by above average snowfall followed by heavy rains and warm weather (Stahl 1996), with 74% of these jams occurring between 18 and 20 January. Damages on 19 January included the Route 12 bridge failure in Woodstock and extensive ice damage in Middlesex that was caused by the failure of a jam on the Winooski River upstream in Montpelier. An ice jam between Bellows Falls, Vermont, and Charlestown, New Hampshire, on the Connecticut River resulted in the closing of Routes 12 and 5 and the evacuation of 18 families on the same date.

During the 1996 ice jam flooding, the U.S. Army Corps of Engineers provided resources and technical assistance to alleviate flood damage to affected communities. According to contemporary Corps Emergency Operations Situation Reports (SITREPS), the Corps deployed more than 360,000 sandbags to counties affected by ice jams in the Buffalo, New York, area and the St. Paul District. CRREL provided technical assistance in the form of advice, referrals, and trips to visit ice jams in the New England Division (now District) and the following districts: Buffalo, Chicago, Detroit, Kansas City, New York, Omaha, Philadelphia, Sacramento, Seattle, and Walla Walla. Specific examples of the Corps and CRREL responses as described in the database are presented below.

In February 1996, an ice jam formed on the Oswegatchie River, affecting the towns of Antwerp and Oxbow, New York. The Corps assisted with the construction of a semi-permanent sand berm to reduce of flood threats (Lever 1996). An engineer from CRREL visited the site at the request of Buffalo District to assess the potential for short- and long-term ice-mitigation measures to reduce ice jam flooding in Oxbow.

As noted previously, ice jams on the Susquehanna River were severe and in particular caused significant damage to the Safe Harbor Dam, Conowingo Dam, and the town of Port Deposit in Maryland. The Governors of Pennsylvania and Maryland sought to improve forecasting and warning for ice jams to reduce future damages. A meeting of the Baltimore District, USGS, FEMA, the Susquehanna River Basin Commission, and CRREL was held to discuss ice jam mitigation, how to predict locations where ice jams are likely, and whether monitoring river conditions can help to predict ice jams and improve warning time.

In the lower Lolo Creek area at Lolo, Montana, the Corps flood team provided technical assistance at several locations and participated in flood fighting (Berg 1996). Corps involvement included sandbagging, construction of two diversion levees, construction of temporary earth berms, plugging various irrigation ditches, removing ice, moving an ice jam, and draining a flooded area (Berg 1996). The location of these operations included Drummond, Clinton, and Lolo, Montana.

SUMMARY AND CONCLUSIONS

The CRREL Ice Jam Database is a compilation of data on a variety of known ice events, ranging from damaging ice jams to ice cover formation that decreases downstream discharge. Because of its heavy reliance on one data source, USGS records, the database is spatially and temporally biased toward ice events that occurred at USGS gaging stations during the period of USGS records. A third bias affecting the database is perception or stage-related; ice events with maximum stage less than the perception stage may not be reported.

Despite its biases, the database can be used to characterize ice events by region, to locate ice event sites, and to identify a seasonal frequency distribution of ice events. Ice event frequency information can be used to guide a search of other sources for material on unreported ice events. In addition, apparent trends in ice event data may shed light on their causes. Although ice event damages are important, damage information is largely unavailable. As yet, statistical analyses of reported damages have a high degree of uncertainty but may still provide useful information if the data biases are considered. The database is useful directly and indirectly in emergency response to ice events and can be used to guide detailed studies of ice problems and future research efforts. It is hoped that users of the CRREL Ice Jam Database will continue to provide information on ice events not in the database, as well as corrections to existing entries.

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