



# **Ice Jam Flooding and Mitigation**

## **Lower Platte River Basin, Nebraska**

Kathleen D. White and Roger L. Kay

January 1996

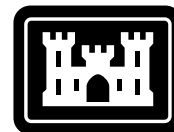
### **Abstract**

This report presents the results of the Corps of Engineers' Section 22 study of ice jam flooding in the Lower Platte River basin. The purpose of the study was to gather and analyze historical data relating to ice jams, with the intent of developing guidance that can be used to alleviate ice jam flooding at seven sites within the study area. Ice event and related information is summarized for each site. Ice event characteristics for the study area are identified and analyzed. A model for predicting the occurrence of ice jams or other ice events within the study area was developed based on data for the Platte River at North Bend, Nebraska. The model provides the minimum discharge associated with ice events for a given date, assuming a threshold value of accumulated freezing degree-days has been reached. A data collection program for future field observations was developed and placed in operation during the winter of 1993-94. General information on ice jam mitigation measures, as well as specific information on such operations as dusting and blasting, is provided. Specific recommendations include increased monitoring of ice conditions, installation of ice motion detectors and water stage recorders, and further study of nonstructural and structural mitigation measures. The use of dusting and blasting as mitigation measures is also presented. The study was divided into six phases. Phase 1 involved collection of historical information from all available data sources, published and oral. Site visits were made to each identified site. Phase 2 entailed analysis and assessment of the collected hydrological, hydraulic, meteorological and ice data. Aerial reconnaissance of each of the seven sites was also made during the ice-covered season. The third phase involved the design of the data collection program and database. Personnel from CRREL conducted a workshop to train ice observers and other interested parties in data collection, while the database design was done by the Nebraska Natural Resources Commission. Phase 4 was the assessment of mitigation and prediction techniques. Various mitigation techniques were evaluated for feasibility, and several were recommended for further study. A model was developed to forecast the occurrence and severity of ice jams utilizing collectable data. The fifth phase involved the development of guidance on the application of specific preventive measures, such as dusting and blasting. The final phase involved the compilation of all work into this report.

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Engineering Laboratory

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Kathleen D. White and Roger L. Kay

January 1996

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## **PREFACE**

This report was prepared by Kathleen D. White, Research Hydraulic Engineer, Ice Engineering Research Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL); and Roger L. Kay, Hydraulic Engineer, Hydrologic Engineering Branch, Engineering Division, U.S. Army Engineer District, Omaha (CEMRO). Project funding was provided by the U.S. Army Engineer District, Omaha, by the State of Nebraska Governor's Emergency Fund and by the State of Nebraska Natural Resources Commission.

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# Ice Jam Flooding and Mitigation Lower Platte River Basin, Nebraska

KATHLEEN D. WHITE AND ROGER L. KAY

## INTRODUCTION

Severe flooding due to the combination of ice jams and rapid snowmelt occurred within the Lower Platte River basin in Nebraska during March 1993. The two areas most affected were along the south side of the Loup River at Columbus and just downstream from the confluence of the Elkhorn and Platte Rivers near Ashland (Fig. 1). Stages at Columbus exceeded the previous peak stage set in August 1966, an open-water event

with a discharge of 119,000 cubic feet per second (cfs) and a gage height of 14.42 ft. The 1993 event caused flooding in the area between the Loup and Platte Rivers and nearly overtopped the levee on the north bank of the Loup River. At Ashland, two major levee breaks occurred, flooding about 14,000 acres of farmland on the east side of the Platte River. A number of houses were destroyed along the west side of the river, and the well fields for the city of Lincoln were threatened. Fourteen counties were included in the disaster area.

The overall basin damages during the March 1993 event were more than \$25 million, including road closures; road failures; damage to bridge abutments and water supplies; flooding of residential, agricultural, industrial and commercial areas; and damage to levees, dikes and other river-training structures. Over 74,000 acres were damaged by sediment deposited during the floods (USAED, Omaha 1993).

The March 1993 ice event was the most damaging event since February 1978, when over \$18 million in damages resulted from ice-jam flooding (USAED, Omaha 1978). Flood damages in 1978 were particularly severe in the Valley-Fremont area, when an ice jam overtopped and breached the Union Dike, flooding 27,000 acres in Dodge and Douglas Counties. Substantial damages were also incurred that year due to an ice jam that formed just downstream from the confluence of the Platte and Elkhorn Rivers near Ashland. In all, over 60,000 acres were flooded, and 20 counties were included in the disaster area for the 1978 event.

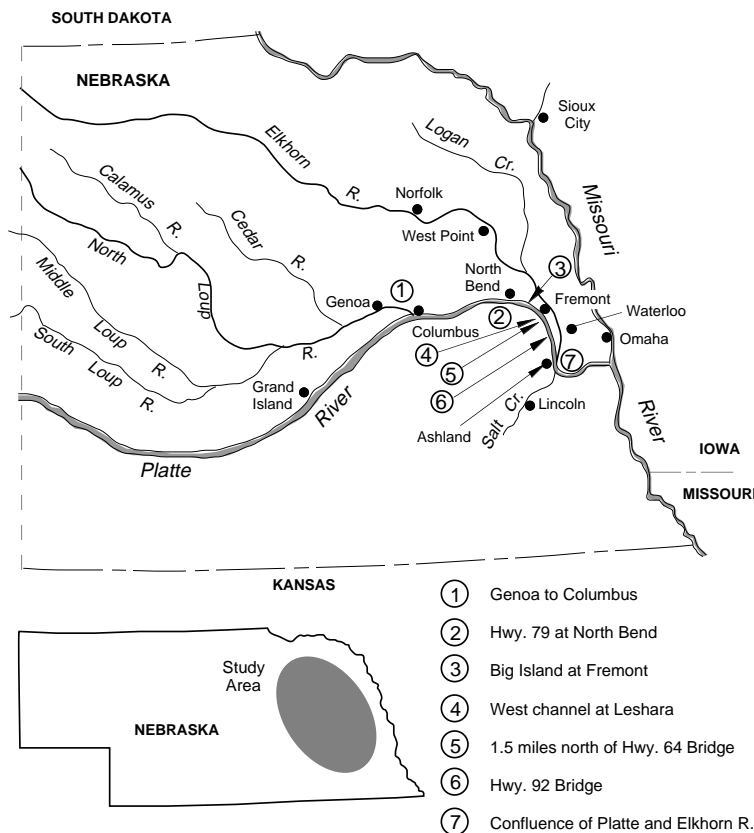


Figure 1. Lower Platte River Section 22 study sites.



Following the March 1993 ice event, the Federal Emergency Management Agency (FEMA), Region VII, as required by 44 CFR Part 206, formed an Interagency Hazard Mitigation Team to review the flood events and suggest measures which might be implemented to mitigate similar events in the future. At the suggestion of representatives from State agencies, Work Element 3 called for a comprehensive investigation by the Corps of Engineers to gather historical ice data with the intent of developing guidance that could be used to mitigate or alleviate recurring ice-jam-related flooding on the Lower Platte, Loup and Elkhorn Rivers.

The Governor enthusiastically supported the concept, and after a series of meetings, the planned scope of the Section 22 study was defined. The State's share of the funding was provided by the Governor's Emergency Fund and the Natural Resources Commission. The present study is the result of this hazard mitigation coordination.

The objective of the Corps' year-long Section 22 study (authorized by Section 22 of the Water Resources Development Act of 1974, as amended) was to investigate the recurring ice-jam problems in the Lower Platte, Loup and Elkhorn Rivers with the goal of developing general guidance on the likelihood of ice-jam occurrence and evaluating potential ice-jam flood mitigation measures. Seven locations of recurring ice jams were chosen for study following the recommendations of the Interagency Hazard Mitigation Team. These locations are shown in Figure 1.

There are a number of sites which experience ice jams and ice-jam-related flooding in addition to the seven sites identified above, including Schuyler, Ames and Louisville on the Platte River and Norfolk, Waterloo and West Point on the Elkhorn River. Many of these sites have also experienced damaging open-water flood events and have put into place mitigation measures ranging from nonstructural measures such as detection, monitoring, warning and emergency response plans to structural measures such as levees and dikes. These mitigation measures have been primarily designed for open-water events, although they may provide some protection during ice events as well.

Ice events, however, present hazards that may not be adequately addressed using mitigation measures designed for open-water events only. Consequently one major purpose of this study was to provide general guidance to facilitate adequate warning and response to ice-jam events.

This guidance is applicable to the overall study area as well as to the seven sites shown in Figure 1. In addition, the study includes an assessment of possible mitigation measures that may be suitable for implementation at different locations. Based on an analysis of past ice, meteorological and hydrological records, an initial predictive model of ice-jam occurrence and severity was developed. Because data collection is important in detection, warning and the refinement of the predictive model for ice jams, a plan for collecting future ice-related data was designed.

## HISTORICAL DATA

Collection of data from past ice events is necessary in order to characterize the ice jams or other ice events at the chosen sites as well as those occurring within the region as a whole. Analysis of historical ice records and meteorological and hydrological data enables us to determine which parameters affecting jam formation and progression are most important. Although ice events are usually highly site-specific, there may be similarities between ice events that occur within a region. It is these similarities that allow development of general guidance on mitigation measures as well as a regional ice-jam predictive model.

Ice event records are often more difficult to obtain than open-water flood records. Information on ice events is lacking because most ice events occur less frequently than open-water floods, ice events are often short-lived and may affect only a short reach of river, and access or weather conditions can make it difficult to make observations. Ice events can include:

- Ice jams that cause flooding (overbank);
- Ice jams that do not cause flooding (within bank) that may not be identified as ice jams;
- Ice covers that raise water levels upstream or decrease water levels downstream;
- Initial ice cover formation; and
- Ice cover breakup and movement.

Ice jams include those which occur in the early winter as ice formation begins (freeze-up jams), those which form as a result of the breakup of ice covers (breakup jams), and those which contain characteristics of both (combination jams). Historical ice records may not differentiate between types of ice events, making it difficult to characterize them.

Historical ice records for the Lower Platte, Loup and Elkhorn Rivers were obtained through a liter-

ature search, an examination of various State and Federal agency records, and a series of local public meetings. Weather records and river discharge and stage records were also collected from the National Weather Service (NWS) and the U.S. Geological Survey (USGS). The Nebraska Civil Defense Agency also made available a number of documents which provided additional information on ice events within the study reach.

### Ice records

The initial search for records of ice events in the study area utilized the Ice Jam Data Base\* developed at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). Some ice-jam events included in the database are well documented, while only sketchy information exists for others. The database relies heavily on USGS sources (e.g. USGS 1989) and, in particular, on data collected for the USGS report series on the magnitude and frequency of floods (Matthai 1968). As a result the most frequently reported ice events are those which occurred at the sites of USGS water-stage gages between the mid-1930s (when many gage records were begun) and the early 1960s. Ice events that occur away from USGS gages are not well represented as yet. While gage records often include such useful data as the local stage and discharge, they rarely provide information on the thickness, extent, likely causes or damages associated with a particular ice event.

The ice events that can be identified through a review of peak USGS records are most commonly associated with the peak annual gage height (or discharge) at a particular location. It is not always

clear whether the reported value is the actual peak or the average value that occurred on the peak day. Also, it is possible that ice events that did not cause an annual peak gage height will not be reported. In some cases a gage height is reported as being caused by an ice jam. Generally, without further information, we assume that an ice jam must have been observed at or very close downstream from the gage when this form of reporting is used. In other cases the gage height might be reported as being affected by backwater from ice. We assume in these cases that an ice cover located at or downstream from the gage is causing backwater effects to be felt at the gage. The ice cover may range from smooth to rough or even a jam.

Ice thickness is measured by the USGS whenever possible during winter discharge measurements at gaging stations. Written ice thickness data that have been collected in Nebraska are located at the USGS office in Lincoln. Obtaining all of the historical ice thickness measurements made by the USGS within the study area would be beyond the scope of this study; however, records for particular locations for particular years were obtained (Table 1).

Once a number of ice events had been identified through literature searches and agency contacts, the Corps contacted local residents and agencies to corroborate and expand on the information. A series of meetings was held in October 1993 with the objective of identifying additional sources of information and learning more about the ice jams which occur at the seven sites identified in Figure 1. The meetings were held at Columbus (26 October), Gretna (27 October) and Fremont (28 October). For convenience these meetings were held in two parts: first, a meeting with local, State and Federal agencies; and second, a meeting with the general public. The agency portions of the meetings were attended by city and county officials, representatives of irrigation districts and

\* The CRREL Ice Jam Data Base (White 1992) is a database of ice events in the United States. It is updated periodically; the latest version can be found at [www.usace.army.mil/crrel](http://www.usace.army.mil/crrel) on the World Wide Web.

**Table 1. Locations and water years of ice thickness measurements obtained from USGS.**

<i>USGS gaging station number</i>	<i>USGS gaging station location</i>	<i>Water years</i>
06793000	Loup River near Genoa	1948, 1969, 1978, 1979, 1987, 1993
06794500	Loup River at Columbus	1948, 1969, 1978
06799000	Elkhorn River at Norfolk	1966, 1969, 1978, 1979, 1987, 1993
06800500	Elkhorn River at Waterloo	1966, 1969, 1978, 1979, 1987, 1993
06770500	Platte River near Grand Island	1971, 1978, 1979, 1987, 1993
06796000	Platte River at North Bend	1971, 1978, 1979, 1987, 1993
06805500	Platte River at Louisville	1971, 1978, 1979, 1987, 1993

**Table 2. USGS data sources.**

<i>Gaging station number</i>	<i>Gaging station location</i>	<i>Period of wintertime record available</i>
06793000	Loup River near Genoa	1930–1991
06792500	Loup River Power Canal near Genoa	1937–1990
06794500	Loup River at Columbus	1935–1979
06799100	North Fork Elkhorn River near Pierce	1961–1992
06798000	South Fork Elkhorn River at Ewing	1948–1953, 1961–1972, 1978–1992
06797500	Elkhorn River at Ewing	1948–1991
06798500	Elkhorn River at Neligh	1931–1958, 1961–1992
06799000	Elkhorn River at Norfolk	1946–1992
06799350	Elkhorn River at West Point	1973–1992
06800500	Elkhorn River at Waterloo	1929–1991
06770000	Platte River near Odessa	1939–1991
06770500	Platte River near Grand Island	1935–1992
06796000	Platte River at North Bend	1950–1992
06801000	Platte River near Ashland	1929–1960, 1989–1992
06805500	Platte River at Louisville	1954–1991

Natural Resources Districts, members of the Civil Defense network, National Weather Service observers, Corps of Engineers personnel and a representative from CRREL. A number of sources of information were identified in the meetings, and several additional ice events were revealed.

### Hydrological data

In addition to the stage data and ice notes discussed previously, USGS gaging station data also provided information about water discharge throughout the winter. Discharge is important in characterizing ice jams for several reasons. First, discharge at freeze-up determines the stage at which the ice cover initially forms. Second, as the discharge rises or falls throughout the winter, the corresponding changes in stage may result in ice conditions that are either more or less likely to break up and jam. Third, large increases in discharge and stage, such as those due to rainfall, snowmelt or a combination of both, may increase stages to the point that the ice cover begins to break up. The discharge at breakup can determine whether the ice is transported downstream or whether it is likely to jam at a particular location.

Fortunately there are several gages within the study area which have long-term discharge records. Many of these gages are located within jam areas or are affected by backwater from ice jams, depending on the jam length. Average daily discharge records were obtained for several USGS gaging stations, both within the study reach and in the contributing drainage basins, for the months of January through April. Table 2 lists the gaging stations selected and the period of winter

records available. Important discharge parameters examined for each site include the maximum average daily discharge  $Q_{\max}$  and the date on which it occurred. For ease in data handling, dates were converted from a month–day format to a Julian Day format, with Day 1 being 1 October, the start of the water year. Thus, the date of  $Q_{\max}$  would be termed JD  $Q_{\max}$ .

### Meteorological records

The NWS operates a number of gages that collect meteorological data. Records obtained from gages within the Lower Platte River basin (Table 3) included minimum and maximum air temperature, snowfall and precipitation. From these records we calculated average daily air temperature (ADAT), freezing degree-days (FDD), accumulated freezing degree-days (AFDD) and accumulated thawing degree-days (ATDD) for the winter, all of which are described in detail below. Meteorological data, like discharge data, are tracked by Julian Day (JD) starting with 1 October, the start of the water year. Average daily air

**Table 3. National Weather Service meteorological data sources.**

<i>NWS station location</i>	<i>Period of record</i>
Columbus	1949–1991
Genoa	1948–1991
North Platte	1948–1991
Grand Island	1900–1991
Omaha (Eppley)	1948–1991
West Point	1892–1991
Ewing	1948–1991

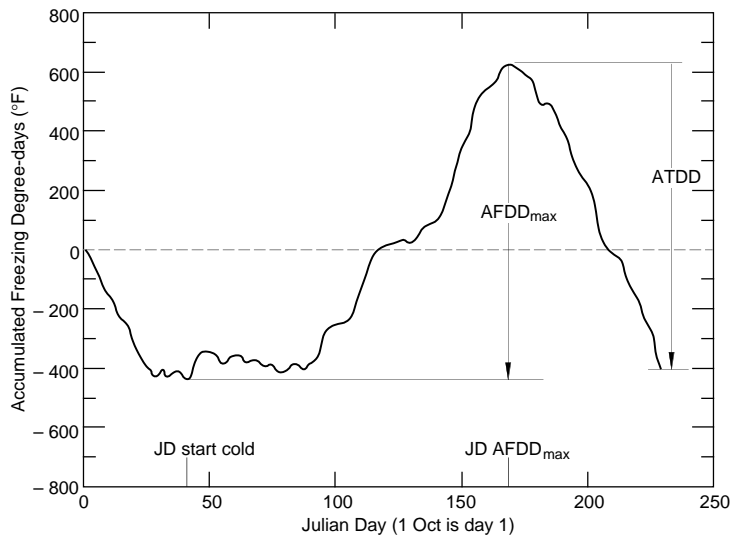


Figure 2. AFDD at the National Weather Service Station at North Platte, Nebraska, during water year 1960.

temperature is simply the average of the minimum ( $T_{\min}$ ) and maximum ( $T_{\max}$ ) air temperatures:

$$\text{ADAT} = \frac{T_{\max} + T_{\min}}{2}. \quad (1)$$

Freezing degree-days (FDD) are calculated from the ADAT using the relation

$$\text{FDD} = 32 - \text{ADAT}. \quad (2)$$

A positive value of FDD means that the average daily air temperature is lower than 32°F, while a negative value means that the average daily air temperature is higher than 32°F. Accumulated freezing degree-days (AFDD) are the sum of the freezing degree-days during the winter, beginning 1 October (the start of the water year). Since air temperatures are still relatively high in October in Nebraska, however, AFDDs are summed until some minimum value is reached. The date of the minimum AFDD is called the JD start cold. Upon reaching the JD start cold, AFDD is reset to zero and begins accumulating again until some maximum value is reached (AFDD<sub>max</sub>). The date of the AFDD<sub>max</sub> is called JD AFDD<sub>max</sub>. The AFDD<sub>max</sub> marks the change from generally colder weather (average daily air temperature below freezing) to weather where the average daily air temperature is above freezing. After the AFDD<sub>max</sub> is reached, FDDs continue to be accumulated until they drop below zero. Figure 2 illustrates the parameters derived from the minimum and maximum temperature data.

Negative freezing degree-days are termed thawing degree-days (TDD). Thawing degree-days are of interest because they can be an indica-

tor of ice thickness and rapidity of snowmelt. They are calculated using the equation

$$\text{TDD} = \text{ADAT} - T_b \quad (3)$$

where  $T_b$  is the base temperature at which snowmelt and ice deterioration are considered to begin. Because snowmelt and ice deterioration can occur when the average daily air temperature is less than 32°F, the base temperature can range from about 25° to 32°F. Thawing degree-days accumulated after the JD start cold are called ATDD. If the ATDD drops below zero, accumulation ends and ATDD is considered to be equal to zero until the next positive TDD.

Snowfall data are important because the presence of snow can affect ice thickness. Snow on top of an ice cover will insulate the ice, slowing its growth during cold weather. Conversely, if there is no snow on top of the ice, the ice will thicken more quickly during cold periods. Snowfall is also an indicator of the amount of snowpack available during the snowmelt. The combination of deeper snowpacks and rapid snowmelt causes larger increases in stage and discharge than shallower snowpacks under the same conditions. Also, the timing of snowfall can be important since late snows are more likely to still be on the ground when the breakup season arrives. Finally, heavy snowfall on ice can cause a depression of the ice cover that allows water to flood the ice cover. The saturated snow can freeze into snow ice, increasing the overall ice thickness. Data on precipitation other than snowfall are also collected because precipitation combined with snowmelt can result in rapid runoff and sharp increases in stage that

lead to ice breakup. Precipitation amounts less than 0.05 inch were designated trace amounts.

### Summary of historical data collected

A review of the historical records collected during the initial phase of the study indicated that ice events are relatively frequent on the Lower Platte, Loup and Elkhorn Rivers. Some locations have reported more ice-related damage than others, and many of the locations are also subject to occasional open-water flood damages. Records are good at some locations and sketchy at others. Historical data collected for the seven sites shown in Figure 1 are summarized below and discussed in the section *Analysis of Historical Data*.

#### Site 1. Loup River from Genoa to Columbus

Several sites along the Loup River between Genoa and Columbus have recurring ice-jam problems. Unfortunately, little specific data are available for jams which occur upstream from Columbus. Local residents and agency representatives identified the sites shown in Figure 3.

The uppermost site is just downstream from the USGS gaging station on the Loup River near Genoa, which has operated continuously since 1944. Although no detailed ice-jam information was reported at the site, the gaging station records do confirm the presence of downstream ice jams, which can cause significant backwater effects at the gage. The maximum annual (water year) gage height for the station was caused by backwater from ice 22 times between 1962 and 1991, or about 73% of the time (Table 4). There were no reported

ice effects at the gage between 1944 and 1962. This can be interpreted in several ways:

- There actually were no ice events between 1944 and 1962;
- There were ice events but subsequent open-water events in the same year had higher stages than the ice events; or
- The ice events that occurred were not reported or were reported as open-water events.

**Table 4. Maximum annual gage heights associated with ice at the USGS gage on the Loup River near Genoa (period of record 1944–1991, flood stage 9 ft).**

Date	Ice-related annual maximum stage (ft)
16 February 1962	10.0
18 December 1963	7.83
1 April 1965	10.33
19 March 1969	10.8
23 February 1970	8.59
19 February 1971	10.37
28 February 1972	9.21
21 January 1973	8.36
15 February 1974	9.12
3 March 1975	8.36
9 February 1976	8.79
23 February 1977	10.2
18 March 1978	12.12
15 March 1979	10.87
18 January 1980	10.79
30 December 1981	11.83
21 February 1982	12.35
17 February 1983	9.35
27 February 1985	9.43
27 January 1986	10.14
24 February 1988	8.99
10 March 1989	9.4

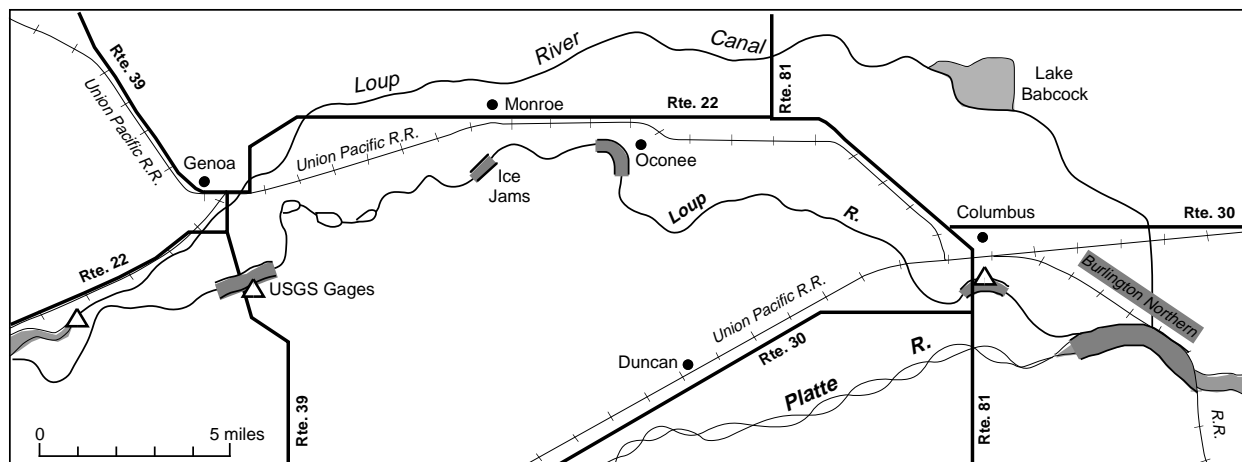


Figure 3. Identified recurring ice jam sites on the Loup River between Genoa and Columbus.

The flood stage at the gage (9 ft) was exceeded by ice events occurring in 1962, 1965, 1969, 1971, 1972, 1974, 1977–1983, 1985, 1986 and 1989. The 1988 ice event may have exceeded flood stage; the precision of ice-jam stage measurement is larger than 0.01 ft. The maximum open-water stage at the Genoa gage was 13.93 ft during the storm of August 1966. In comparison, the peak ice-related stage of 12.35 ft at the gage on 21 February 1982 was caused by an ice jam. According to Nebraska Civil Defense records, this jam was about one mile long and resulted in lowland flooding. The next-highest ice-related stage was 12.12 ft on 18 March 1978. Civil Defense records indicate that ice jams causing flooding in 1978 were located both east and west of the bridge.

Two ice jams at Genoa were reported by other sources. On Thursday, 20 March 1969, the *Columbus Daily Telegram* reported that the ice jam at Genoa was still in place and water was 1 ft lower than Wednesday, 19 March, but still “slightly” out of bank. According to Nebraska Civil Defense records (1971), a 5-mile-long ice jam formed at Genoa during the storm of February 1971. No information about water stages, or the exact location in reference to the gage, was provided. Although the date of jam formation was not specified, the jam was in place and causing flooding at least between 24 February and 6 March 1971, and perhaps for a longer period.

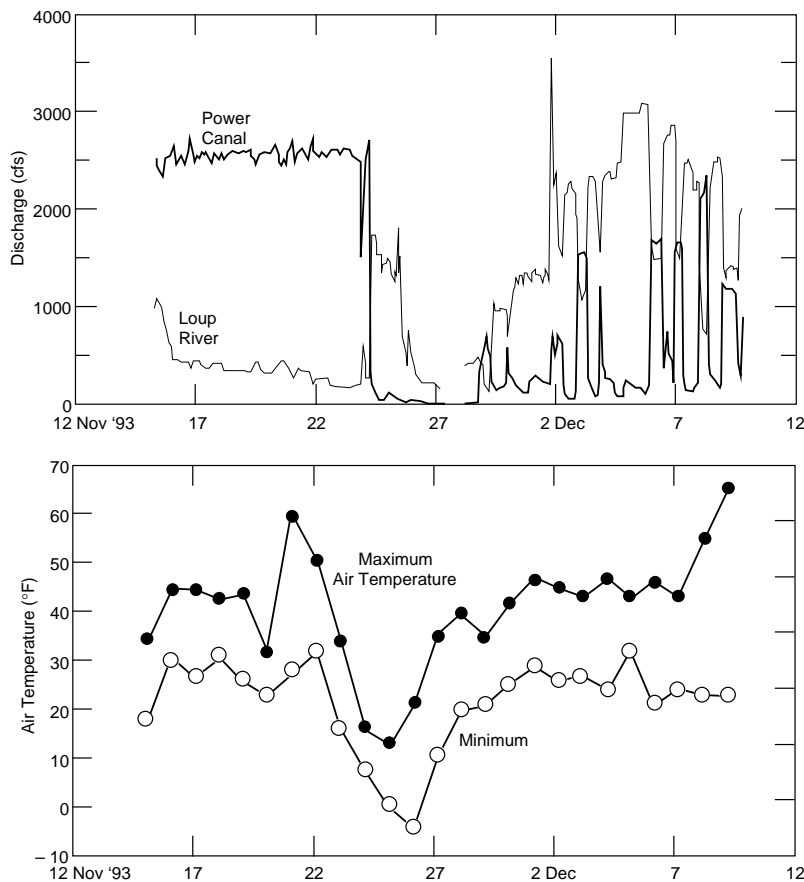
The Loup River Power Canal diversion structure, consisting of a gated dam and gated canal headworks, is located on the Loup River about six miles upstream from the USGS gage on the Loup River near Genoa. Outflow from the canal enters the Platte River below Columbus. The canal system, which began diversions in December 1936, includes a settling basin, two hydro-power plants and Lake Babcock.

A USGS gage is located at the settling basin weir two miles downstream from the headworks. No ice jams were reported at the Loup River Power Canal gage. Canal operations, however, are suspended in early winter when heavy frazil ice discharge might adversely impact power production. Regular canal operations resume when frazil ice concentrations are low or a sheet ice cover forms on the canal. The average flow for the period 1938–1989 at this gage was 1600 cfs, in contrast to the average daily flow at the Loup River gage near Genoa, which is about 680 cfs for the period 1944–1989. Instantaneous Loup River Power Canal flows during the period January through March have varied from essentially zero to 3160 cfs.

The effects of these fluctuations in Loup River Power Canal diversions on discharge, ice formation and ice transport in the Loup River below the diversion structure have not been quantified. Some local residents have expressed the opinion that the resulting fluctuations in water level cause or exacerbate ice jams in the Loup River downstream from the canal diversion. However, it would only be possible to evaluate the situation after a detailed study. A quantitative analysis would be difficult given the lack of good ice records. A qualitative analysis might address such issues as the potential effects of raising and lowering water levels on the formation of border ice, frazil production, frazil ice transport and the effects of sudden decreases in river flow on ice movement (e.g. stranding ice blocks, increased frazil deposition). Changes in the sediment regime of the river resulting from canal operations may also have impacted ice formation and transport processes. The difficulties involved in evaluating Loup River Power Canal operations are illustrated in Figure 4, which presents measured flows at the Loup River Power Canal gage, the Loup River gage near Genoa, the combined flow in the canal and the river, and air temperatures at Columbus during the period 15 November through 9 December 1993. The canal operated at fairly steady flows between 15 and 23 November, while the river flows were slowly decreasing. Canal flow decreased sharply on 23 November and remained very low until 28 November, when flows were increased. The increased canal flow fluctuated roughly diurnally. In most cases, increases in canal flows are associated with decreases in river flows (see, for example, 6 December 1993).

The rather marked decrease in river flow measured at the Loup River gage on 26, 27 and 28 November may actually reflect water going into storage when the frazil ice produced during the low temperatures experienced during this period increased flow resistance due to shore ice and anchor ice buildup and the formation of freeze-up jams. A transient peak flow of the magnitude and duration experienced on 1 December is unusual. This high flow might be attributable either to the release of water from storage as a result of rising temperatures, or it could be an artifact of increased stage due to backwater from ice accumulations downstream from the gage.

Ice jams and associated flooding have been reported in the vicinity of the Monroe Bridge, south of Monroe. One jam was reported at this location on 19 March 1969 in the *Columbus Daily Telegram*.



a. Flows measured at USGS gages on the Loup River near Genoa and the Loup River Power Canal near Genoa.

b. Minimum and maximum daily air temperatures measured at Columbus.

Figure 4. Loup River flows and daily air temperatures, 15 November through 9 December 1993.

Nebraska Civil Defense records indicate that ice-jam-related flooding also occurred at the Monroe Bridge in January 1980. This ice jam resulted in lowland flooding for several days before breaking up.

According to local residents, severe ice jams also occur downstream at Oconee Bend, east of Monroe and about a mile west of Oconee (Fig. 3). The ice jam at this location is said to be a recurring one, with the toe at the downstream end of the bend. On 14 March 1978, Nebraska Civil Defense records indicated that ice-related overbank flooding was taking place at this location.

Some residents reported an ice jam at Oconee Bend in March 1993. The *Columbus Daily Telegram* reported overbank flooding at Oconee Bend on Monday, 9 March 1993, but ice was not specifically mentioned. No other specific data on jam dates, length of jam, stages or damages due to ice jams at Oconee Bend were given.

The most damaging ice jams on the lower portion of the Loup River have occurred at Columbus. The presence of a recurring ice jam that forms

about 0.8 mile downstream from the Highway 30-81 bridge is reflected in the records of the USGS gaging station that was operated at the bridge from 1935 through 1978. Gage records revealed that peak stages due to backwater from ice (i.e. the ice jam was downstream from the gage but raised water levels at the gage) occurred in 1936, 1958, 1961, 1963, 1969–1971 and 1973–1977 (Table 5). The records also showed that the ice jam itself extended beyond the gage in 1978.

Local residents provided information on an additional jam that occurred in February 1948, causing \$72,000 in damages. This jam caused high stages during the week of 14–21 February 1948, but the maximum stage (not reported) did not occur until 28 February 1948. An additional ice jam was reported in Nebraska Civil Defense records\* on 15 February 1966. This ice jam, located in the Wagner Lake–Sand Pit area west of Co-

\* Memorandum of aerial reconnaissance, William J. Clark, 16 February 1966.

**Table 5. Maximum annual gage heights associated with ice at the USGS gage on the Loup River at Columbus (period of record 1934–1979, flood stage 11 ft).**

<i>Date</i>	<i>Ice-related annual maximum stage (ft)</i>
5 March 1936	6.57
26 February 1958	7.53
5 March 1959	6.18
17 February 1961	6.38
16 February 1963	6.04
21 March 1969	11.2
3 January 1970	8.0
20 February 1971	9.3
20 January 1973	7.4
10 January 1974	6.7
11 January 1975	7.46
3 January 1976	8.58
24 February 1977	6.36
15 March 1978	8.87
7 March 1993	>12.5

lumbus (upstream from the gage), caused overbank flooding. No other more specific information regarding jam formation or extent was given.

The flood stage at the Columbus gage is considered by the USGS to be 11 ft. The maximum open-water gage height of record was 14.42 ft on 14 August 1966. Prior to 1993 the peak ice-related stage at the Columbus USGS gage was 11.2 ft on 21 March 1969, with an average daily discharge of about 16,500 cfs. This ice jam resulted in extensive flooding along the route of the present Highway 81 and the area between the Loup and Platte Rivers. The *Columbus Daily Telegram* reported that the jam began forming east of the Highway 81 bridge at about 6:30 p.m. on Tuesday, 17 March, and eventually extended about one-half mile upstream and downstream of the bridge. Within two hours water levels had risen enough to begin overbank flooding. According to newspaper reports, blasting was done in the vicinity of the Highway 81 bridge. The blasting was eventually successful in removing the jam, which went out about 7 p.m. on 21 March 1969.

According to Nebraska Civil Defense records (1971), the ice jam that occurred in 1971 formed about five miles east of Columbus and extended for three miles. The jam flooded low-lying areas southeast of Columbus. Blasting was initially unsuccessful, but it finally caused the release of the jam on 24 February 1971.

The ice jam of 7–10 March 1993, which extended a short distance upstream from the Highway

30-81 bridge, resulted in a stage of greater than 12.5 ft at the gage, based on high-water marks. Local residents described the 1993 event as being the worst in memory, with a local farm implement dealer noting that the high-water marks on his building were 4.5–5 ft higher than during the August 1966 flood, which had a stage of 14.42 ft recorded at the USGS gage. High-water marks set by Corps personnel indicated that the stages produced by the ice jam at Columbus were equivalent to those that might be expected from an open-water event of about 200,000 cfs (USAED, Omaha 1993).

Ice jams which form on the Platte River between the Burlington Northern Railroad bridge and the tailrace of the Loup River Power Canal (Fig. 3) can also affect Loup River stages at Columbus and cause lowland flooding along the Loup and Platte Rivers. Jams are known to have formed in this area in March 1978, March 1979, February 1982 and late November 1993. The jam of February 1971, which extended for five miles up the Loup River, probably also formed in this area.

On 30 November 1993, a freeze-up ice jam formed upstream from the Burlington Northern Railroad bridge (Fig. 3) following a sudden drop in temperature beginning about 22 November (Fig. 4b). The sudden drop in discharge through both the river and the canal coincident with low temperatures is indicative of significant frazil ice formation and blockage upstream. The jam extended upstream to the water plant on the north bank of the Loup River. Lowland flooding was experienced on both sides of the river. With rising temperatures the jam eventually went out on its own. Small ice accumulations typical of ice breakup and movement were evident on the Loup River upstream from the jam area. It is probable that the Loup River was the primary source of ice which formed this jam.

On 14 March 1979, an ice jam formed upstream from the Union Pacific Railroad bridge (Fig. 3). This jam extended about one-half mile above the bridge and caused lowland flooding. The jam eventually failed and moved downstream, rejamming downstream from the Highway 81 bridge. Backwater from the jam reached bank level at the bridge before the jam failed on 15 March 1979.

*Site 2. Platte River:  
Highway 79 at North Bend*

The Platte River in the vicinity of Highway 79 at North Bend was also identified as a site of



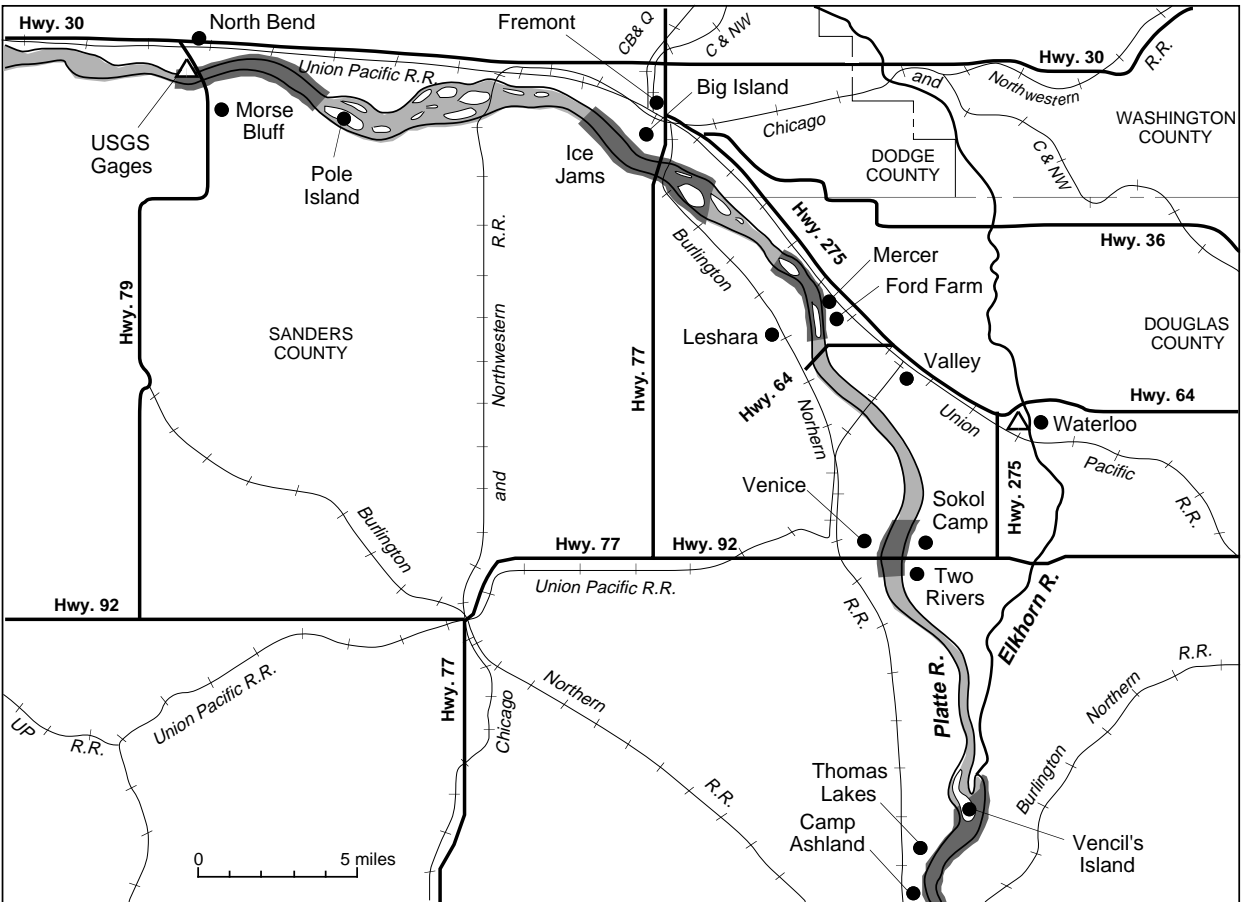


Figure 5. Identified recurring ice jam sites on the Platte River between North Bend and Ashland.

recurring ice jams. According to local residents the jams initiate at a point about 2–2.5 miles downstream from the Highway 79 bridge, in the reach upstream from Pole Island (Fig. 5). Ice-jam-related flooding occurs primarily in the Morse Bluff area, but lowland flooding could occur on both sides of the river. Ice jams have also been noted upstream from the Highway 79 bridge, but data are sketchy. For example, Nebraska Civil Defense records report that an ice jam located about 1.75 miles upstream from the bridge in February 1980 resulted in lowland flooding, but no other information about the jam (i.e. location of toe, length, stages) was available. In February 1982, ice jams were located both upstream and downstream from the bridge. Sandbagging of the levee in the McGinn’s Lake area about four miles west of North Bend was begun when backwater from the jam(s) approached within six inches of the top of the levee.

A USGS gaging station is located on the left bank of the river just upstream from the Highway 79 bridge. This gage has been operated continu-

ously since 1949. Ice jams have been reported at the gage in 1971, 1972 and 1978. In addition, peak annual stages caused by backwater from downstream ice have occurred at the North Bend gage relatively frequently—in 1950–1953, 1955, 1958–1963, 1970, 1974, 1976–1977, 1979–1980, 1982–1983, 1985–1986 and 1988–1989.

The flood stage at this gage, 8 ft, has been exceeded during the period of record by 14 ice-related events, 11 of which occurred between 1971 and 1989 (Fig. 6, Table 6). Using the difference between recorded stage and flood stage as a measure of severity, it appears there has been a trend toward more severe ice events in recent years. However, more detailed information about events within and outside the period of record, as well as changes in observers and observation methods, would be required to verify this apparent trend. In addition, changes in river morphology and property development patterns may also affect stages.

The maximum stage recorded at the North Bend gage was 15.55 ft on 19 March 1978, during

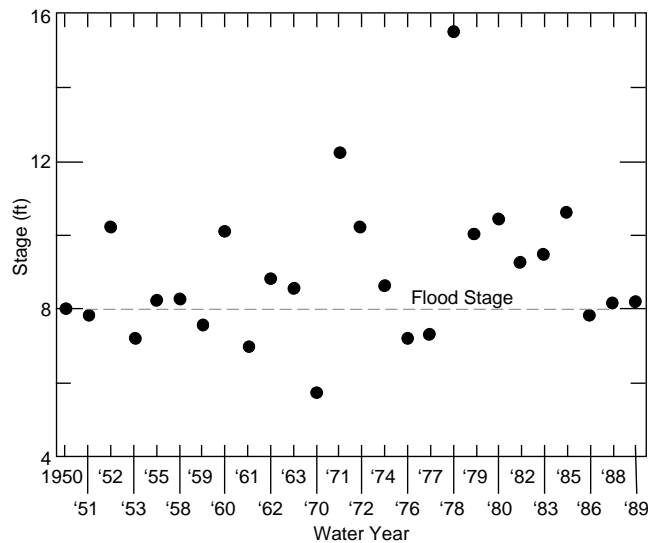


Figure 6. Ice-related peak annual stages at the USGS gage for the Platte River at North Bend for the period 1949 through 1992. Ice jams were reported in 1971, 1972 and 1978; all other stages were affected by backwater from downstream conditions.

an ice-jam event. This stage resulted in flooding along both sides of the river. The *Omaha World-Herald* reported that one person died in North Bend during this event and another was injured when a basement wall caved in. Highway 79 was overtopped with water and ice. The average daily discharge reported on this day was 54,000 cfs, and the maximum instantaneous discharge was calculated to be about 80,000 cfs, including the

main channel discharge and an indirect measurement of flow over the roadway.

In contrast to this ice-jam event, the maximum open-water stage was 5.51 ft lower at 10.04 ft. This stage occurred on 29 March 1960, with a reported discharge of 112,000 cfs. The gage height was reported to be affected by backwater, however, so although it is reported as an open-water event, it may have been related to a downstream ice jam, which would also have affected discharge calculations. The maximum open-water stage of 10.04 ft was exceeded by several other ice events in addition to the March 1978 event, including ice events that occurred on 13 February 1952 (10.17 ft, ice jam reported downstream from gage); 20 February 1971 (12.24 ft, ice jam at gage); 19 February 1972 (10.19 ft, ice jam at gage); 18 January 1980 (10.44 ft, ice jam downstream from gage); and 28 February 1985 (10.59 ft, ice jam downstream from gage). During the 1980 event the Department of Roads operated a crane equipped with a wrecking ball from the Highway 79 bridge to break ice in the jam. NWS records indicate that lowland flooding along the south bank resulted from the 1985 event.

Ice jams formed about two miles west and one mile east of the Highway 79 bridge at North Bend on 13 March 1979. By 14 March the upstream jam was located one-half to three-quarters of a mile upstream from the bridge. Backwater from this jam eventually breached a dike along the south

Table 6. Summary of ice events at North Bend with a stage greater than the flood stage of 8 ft.

Date	Stage (ft)	Description
13 February 1952	10.17	ice jam at gage
29 March 1960	10.04	gage affected by backwater from ice
20 February 1971	12.24	ice jam at gage
19 February 1972	10.19	ice jam at gage
17 February 1974	8.6	gage affected by backwater from ice
19 March 1978	15.55	ice jam at gage, maximum gage height of record, one dead, many evacuated
14 March 1979	10.0	gage affected by backwater from ice, upstream jam flooded Hwy 79 and Morse Bluff
18 January 1980	10.44	ice jam downstream from gage, lowland flooding reported, crane and wrecking ball operated from bridge
22 February 1982	9.25	gage affected by backwater from ice, sandbagging of levee at McGinn's Lake, Wolf Lake roads flooded
18 February 1983	9.49	gage affected by backwater from ice
28 February 1985	10.59	ice jam downstream from gage, lowland flooding south bank
24 February 1988	8.14	gage affected by backwater from ice
12 March 1989	8.19	gage affected by backwater from ice
8 March 1993	10.97	ice jams upstream and downstream from Hwy 79 bridge

**Table 7. Summary of ice-related flooding at Big Island.**

<i>Date</i>	<i>Description</i>
6–15 March 1949	overbank flow 0.5 to 4 miles upstream from Highway 77 bridge
6–24 March 1950	possible overflow into Big Island
March 1978	100 evacuated by airboat
11–16 March 1979	lowland flooding, jam near BNRR Bridge
22 February 1982	jam three-quarters of a mile downstream from Highway 77 bridge
14–18 February 1984	roads flooded, residents evacuated
7 January 1985	evacuations due to ice-related high water
late February-early March 1989	minor ice-related flooding

side of the river, resulting in flooding on Highway 79 and in the Morse Bluff area.

In February 1982, ice jammed intermittently at the upstream side of the bridge, and a jam formed about three-quarters of a mile downstream from the bridge. Blasting was considered, but the jam failed before blasting could be started. The McGinn’s Lake and Wolf Lake areas were flooded. NWS records indicate that lowland flooding along the south bank also resulted from the February 1985 event. Jamming upstream and downstream from the bridge caused lowland flooding in March 1993.

*Site 3. Platte River:  
Big Island at Fremont*

Big Island is located along the north bank of the Platte River to the southwest of Fremont (Fig. 5) and includes several residential developments built around lakes. There is some anecdotal evidence that an ice jam occurs in the reach along Big Island, with the jam toe about 1 mile upstream from the Highway 77 bridge.\* According to local residents, ice blocks which pile up at the Burlington Northern Railroad bridge can also raise the water level sufficiently to cause backwater to flow into the Big Island area. In most cases the backwater is probably formed by jams which form in several places downstream from Fremont. One recurring jam initiation location is about a half mile downstream from the Highway 77 bridge, and another is in the vicinity of Mercer, about 3–3.5 miles downstream from the Burlington Northern Railroad bridge. Known ice-jam-related flooding events are summarized in Table 7.

In a review of ice-related flooding within the Papio–Missouri Natural Resources District, Wehr-

span (1978) reported ice-related flooding at Big Island during the floods of 6–15 March 1949, when overbank flow was observed between about one-half mile downstream from the Highway 77 bridge and a point about 4 miles upstream from the bridge. It is possible that the area was flooded again on 6–24 March 1950, although Big Island was not specifically mentioned by Wehrspan, who reported that “ice jams caused moderate overbank flow on the Platte River in the vicinity of Fremont, Linwood, Schuyler and North Bend” during this event.

Big Island was flooded in 1978, and 100 people were evacuated by airboat, according to the *Oma-ha World-Herald*. No other details about the ice jam causing this flood were given, although it is probable that the ice jams at Mercer and downstream, which flooded the Valley area, contributed to elevated water levels at Big Island. In March 1979, Nebraska Civil Defense records reported lowland flooding in the Big Island area due to ice movement and jamming at the Burlington Northern Railroad bridge.

An ice jam formed about three-quarters of a mile downstream from the Highway 77 bridge on 22 February 1982. This jam raised water levels in the Big Island area, prompting some evacuations. Nebraska Civil Defense records indicate that the jam moved out by itself late in the afternoon but rejammed between the Ford Farm and the Highway 64 bridge in the same location as the major jam of 1978.

The NWS indicated that minor ice-related flooding was affecting Big Island on 14 February 1984. By the next day, roads in the area were flooded, and on 16 February 1984, a number of residents were evacuated from the area. The jam was not described, but it appears to have extended at least as far as Ridge Road from an unknown point downstream. The jam was observed from the air

\* Marlin Petermann, personal communication.

on 17 February and reported to be 0.5 mile long. The exact locations of the upstream and downstream ends of the jam were not identified. The ice jam went out on 18 February 1984.

Nebraska Civil Defense records report evacuations in Big Island due to ice-related flooding on 7 January 1985. NWS records indicate that the ice jam was located between the Burlington Northern Railroad bridge and the Highway 77 bridge. There was also minor ice-related flooding in Big Island at the end of February and into early March 1985.

*Site 4. Platte River:  
West Channel at Leshara*

Leshara has been plagued by open-water flooding as well as ice-related flooding. Because there is no gage or large settlement near the jam area, little has been reported about ice jams in the vicinity. However, it is thought that the jams which adversely affect Leshara occur within the west channel of the river. The jam that occurs north of the Highway 64 bridge (see below) may also affect stages and ice conditions at Leshara. For example, a large ice jam that formed in the west channel upstream from the Highway 64 bridge on 16 March 1979 resulted in a dike breach and flooding at Leshara the next day. This dike breach may have been located in the same place as the one that occurred in March 1978. The 1978 breach was not specifically identified as being due to ice action, but the presence of ice jams at the Highway 64 bridge that year and subsequent jamming and flooding of the east channel of the river make it highly likely that the 1978 event was, in fact, ice related.

An ice jam in the Woodcliff area resulted in lowland flooding and eventually in the failure of a dike at Leshara on 27 February 1980. According to Nebraska Civil Defense records, more extensive flooding occurred after the dike breached, and some evacuations were necessary. The west channel was plugged by a mile-long jam in February 1982, which caused lowland flooding through the breach, which had not yet been fully repaired.

A 28 February 1986 *Omaha World-Herald* news article reported that residences in the Woodcliff area were flooded during an ice event when the dike failed at Leshara. According to the article, the dike was originally breached during the 1978 ice jam event and had not been completely repaired by 1986.

*Site 5. Platte River: 1.5 miles north  
of the Highway 64 bridge*

Details of this ice jam are sketchy. It is possible that this ice jam is the one commonly described as being located at the Ford Farm about 2.5 miles upstream from the Highway 64 bridge, since the upstream end of a jam is usually of more concern to local observers than the downstream end.

The ice jam near the Ford Farm was associated with the Union Dike breach, which resulted in extensive flooding in the Valley area during the March 1978. The jam was blasted in an effort to release the jam and decrease flooding. A similar event occurred in March 1929: "... Valley, Nebraska, residents were prepared early today for the second time within 24 hours to abandon their homes as a huge ice gorge was forming six miles above the town. A gorge that caused water to break through a dike near the village Tuesday night and threatened the city was blasted away yesterday."

On 1 March 1979, the ice in the vicinity of the Ford Farm was dusted with fly ash in hopes of increasing the rate of deterioration of the ice and preventing the occurrence of an ice jam similar to the 1978 jam (USAED, Omaha 1979). Although ice jammed intermittently near the Ford Farm between 11 and 18 March 1979, no flooding occurred.

Nebraska Civil Defense records reveal that an ice jam formed between Highway 64 and the Ford Farm on 22 February 1982. The jam was reported to be in the same place as the 1978 jam, which caused so much flooding in Valley. The jam eventually failed naturally on 24 February before flooding occurred.

A minor jam was noted by Nebraska Civil Defense spotters upstream from the Highway 64 bridge on 12 February 1984. The NWS indicated that the jam had caused overflows onto bottomlands and had flooded several cabins near Leshara on 16 and 17 February 1984. A minor jam upstream from the Highway 64 bridge was again reported by the Nebraska Civil Defense on 26 February 1985.

The *Omaha World-Herald* reported that water levels had come within 3 ft of overtopping the Union Dike in the Ford Farm area on 27 February 1986, as a result of an ice jam. The location and extent of the jam were not described, but it appar-

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\* *Montpelier* (Vermont) *Evening Argus*, Thursday, 14 March 1929.

ently formed somewhere upstream from the Highway 64 bridge. Ice was pushed up onto the top of the dike during this event.

*Site 6. Platte River: Highway 92 bridge*

The recurring ice jam in the vicinity of the Highway 92 bridge appears to form both upstream and downstream from the bridge and generally affects the reach of river between the Two Rivers State Recreation Area downstream from the bridge and Sokol Camp upstream from the bridge. No specific information regarding the usual locations of the downstream end of the jam or the jam extent was obtained. Known ice-related flood events are summarized in Table 8.

According to Nebraska Civil Defense records, an ice jam formed near the Highway 92 bridge at Venice in February 1971. The jam was first noted on 23 February 1971, and the Highway 92 bridge was closed soon after. Flooding occurred in the Two Rivers area downstream from the bridge as a result of this ice jam.

A 21 March 1978 *Omaha World-Herald* article reported that an 80-ft-long section of dike was washed away north of the Highway 92 bridge near Yutan. No other details were given. An ice jam formed downstream from the Highway 92 bridge, causing flooding at Sokol Camp and the Two Rivers area.

On 14 March 1979, Civil Defense records report that ice began jamming on the west side of the Highway 92 bridge. An ice jam also formed downstream from the bridge. On 15 March, blasting took place both downstream and upstream from the bridge. The blasting was reported to be relatively unsuccessful, since little ice moved away from the blasted areas.

Nebraska Civil Defense records reported an ice bridge near Two Rivers on 22 February 1982. Overbank flow was observed in the Two Rivers area, but no other specific information was given for this ice event.

The NWS noted a minor ice blockage occurring upstream from the Highway 92 bridge between Venice and Sokol Camp on 13 February 1984. On 14 February, local ice jam flooding was reported in the Sokol Camp area. No other information on this jam was located.

Nebraska Civil Defense records reported an ice jam on 26 February 1985 just upstream from the Highway 92 bridge; the jam was threatening the Lake Platte View development on the east bank. No further mention was made of the jam or of actual flooding.

*Site 7. Platte River-Elkhorn River confluence near Ashland*

Ice jams frequently occur in the reach of the Platte River between its confluence with the Elkhorn River and the Highway 6 bridge. The jams are formed by ice originating in the lower Elkhorn River and the Platte River (probably downstream from Highway 92). Flooding associated with these jams affects the Thomas Lakes development, Camp Ashland (operated by the National Guard) and Vencil's Island, located between the Platte and Elkhorn Rivers. In addition, several levee breaks have occurred along the east bank during ice jams, flooding many acres. Known ice events are listed in Table 9.

An ice jam formed in the Thomas Lakes area on the Platte River in early February 1966. The jam extended upstream beyond the Platte River's confluence with the Elkhorn River, with ice jamming both the Platte River and the Elkhorn River. One major levee break occurred on the left bank of the Elkhorn River, allowing Elkhorn River flows to flood thousands of acres and damage the Interstate 80 (I-80) bridges over the Platte River. I-80 remained closed for several days while the damage was repaired. Because so much of the Elkhorn River flow was diverted through the break in the levee, Platte River water levels did not rise to flood levels. Over 6500 lb of dynamite were re-

**Table 8. Summary of ice-related flood events near the Highway 92 Bridge over the Platte River.**

<i>Date</i>	<i>Description</i>
23 February 1971	Two Rivers area flooded, Highway 92 bridge closed
21 March 1978	80-ft-long section of dike washed out near Yutan
14 March 1979	blasting upstream and downstream from Highway 92 bridge
22 February 1982	Two Rivers area flooded
13–14 February 1984	Sokol Camp area flooded
26 February 1985	Lake Platte area threatened

portedly used to open a channel along the east bank of the Platte and Elkhorn Rivers.

In March 1978, ice jams formed in many places along the Platte River. Ice jams in the Elkhorn–Platte confluence area flooded both sides of the river and Vencil’s Island. A crane equipped with a wrecking ball was operated from the Highway 6 bridge to facilitate ice movement through the bridge. Blasting was done on 19 and 20 March in an attempt to increase flow conveyance through the area.

Nebraska Civil Defense records indicate that on 24 February 1980 an ice jam was located between Memorial Hall and the north edge of Camp Ashland. High stages caused by the jam were entering both Camp Ashland and the Thomas Lakes development. The jam broke up on its own at noon on 25 February.

Lowland flooding was first reported on 19 February 1982, in the vicinity of Highway 6 and the Guard Camp. On 20 February it was reported that an ice jam on Salt Creek was backing water up into the Thomas Lakes area. Ice jammed in the Thomas Lakes area and near Camp Ashland on 21 February 1982. According to Civil Defense reports, a number of homes were evacuated from Thomas Lakes and from Vencil’s Island farther upstream. Blasting of the ice jam began on 23 February but was cut short due to bad weather. The jam failed soon after.

On 14 February 1984, an ice jam in the vicinity of the Thomas Lakes development again forced water into the development, flooding some cabins. There was solid ice between the jam and the Highway 6 bridge downstream, with water flowing over the ice. A minor ice jam at the mouth of the Elkhorn River was reported by the NWS on 16 February 1984. This jam was apparently affecting

the Vencil’s Island area. It is possible that the two jams reported were actually the same jam.

In 1993 an ice jam formed in the vicinity of the Thomas Lakes development on 7 February, following the breakup of the ice cover on the lower Elkhorn River. The ice cover on the Platte River below the confluence with the Elkhorn River did not break up, and a solid ice cover extended about two miles downstream from the Thomas Lakes development (USAED, Omaha 1993). A jam formed in this area when the movement of the broken ice was stopped by the competent ice cover. This jam did raise stages slightly, and levees along the east bank were monitored. However, the water stage remained within bank and the jam eventually froze in place.

This jam was still in place when the rising temperatures, precipitation and snowmelt of early March caused both an increase in discharge and the breakup of additional ice upstream on the Platte and Elkhorn Rivers. The jam both lengthened and thickened at this time, and by 8 March the ice jam was about 2.5 miles long, causing water to overtop a levee on the east bank (Sarpy County) and a levee on the west bank (Saunders County). The Sarpy County levee failure reportedly occurred in the same general area as a break during the 1966 and 1969 events. In addition, a second levee failure occurred on the east bank somewhat downstream from the first. The Thomas Lakes development and Camp Ashland were flooded, and the City of Lincoln’s well field was threatened, with two pipelines washing out. East bank flooding caused the closure of I-80 for at least a day, and two Highway 6 bridges were damaged. The discharge during the March 1993 event was estimated at 130,000 cfs (FEMA 1993), but only about 55,000 cfs was measured at the

**Table 9. Summary of ice-related flood events at the confluence of the Platte and Elkhorn Rivers near Ashland.**

<i>Date</i>	<i>Description</i>
February 1966	levee break on Elkhorn River; I-80 damaged; blasting done
March 1978	flooding along east and west banks of the river; blasting done; wrecking ball used at Highway 6 bridge
24 February 1980	flooding in Camp Ashland and Thomas Lakes
21 February 1982	flooding of Camp Ashland, Thomas Lakes, east side of river, and Vencil’s Island; blasting done
14 February 1984	flooding in Thomas Lakes and Vencil’s Island
February–March 1993	Thomas Lakes flooded; levee break in same place as 1966 and 1969 and a second break downstream; Highway 6 bridges damaged; blasting done

Ashland gage; the remainder of the flow was estimated in the overbanks. The previous maximum discharge at the Ashland USGS gage was 107,000 cfs on 12 June 1944.

## ANALYSIS OF DATA

### Historical data

The available historical hydrological, meteorological and ice records presented previously were examined to determine general characteristics or trends associated with ice events in the study area. Since it is difficult to quantify ice event occurrence at sites which are not gaged, the historical analysis concentrates on gaged sites within the study area. These sites include the Loup River near Genoa, the Loup River at Columbus (until

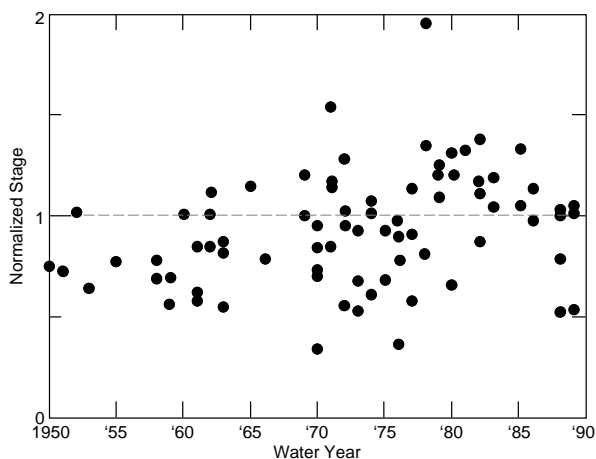


Figure 7. Normalized stage for ice events between 1950 and 1990 for the gages in the study area plus the Elkhorn River at Waterloo.

1978) and the Platte River at North Bend and Louisville. Gaged sites outside of the study area on the Elkhorn River are of value because of the Elkhorn River contribution to ice jamming problems near Ashland, one of the more frequent and costly jam sites within the study. Data from the Elkhorn River at Waterloo are also included in this preliminary analysis. The period included in the historical analysis is 1950–1990.

Graphical analysis allows general characterization of various combinations of ice event data. Parameters examined in the analysis are shown in Table 10. Discharge at each gage can be compared by normalizing it as runoff per square mile of contributing drainage area. Stages at different locations are more difficult to compare because they are a result of site-specific conditions such as jam conformation, cross-sectional shape, width, water slope and presence or absence of levees. As a result, ice and discharge conditions that might cause ice-related flooding at one location may not cause flooding at another. However, stage is still a valuable tool in comparing the severity of jamming at one locations vs. another. Therefore, we have chosen to normalize stage at different locations by the reported flood stage for each location. The normalized stage, which is the maximum stage divided by the flood stage, is shown in Figure 7 for each water year between 1950 and 1990. A normalized stage of 1.0 is at flood stage, and normalized stages greater than 1.0 are above flood stage. Table 11 lists the ice events for which the normalized stage is greater than 1.0.

Figure 7 shows that about 44% of the known ice events that occurred during the period 1950–1990 resulted in water levels greater than flood stage at Genoa, Columbus, North Bend and Lou-

Table 10. Parameters used in characterization of ice events in the Lower Platte River basin study area.

Parameter	Abbreviation	Definition
Maximum stage	max stage	recorded ice-affected stage (ft), generally a maximum annual gage height either due to an ice jam or to backwater from downstream ice jams
Julian Day of maximum stage	JD max stage	the date when the maximum stage occurred, in Julian Days, where day 1 = 1 October, the start of the water year
Flood stage	flood stage	reported flood stage (ft)
Normalized maximum stage	normalized stage	ratio of maximum stage to flood stage
Maximum discharge	max Q	recorded maximum average daily discharge (cfs) between 1 January and 31 March
Julian Day of maximum Q	JD max Q	the Julian Day when the maximum discharge occurred
Maximum AFDD	max AFDD	the maximum absolute value of the accumulated freezing degree-days since the start of cold
Julian Day of maximum AFDD	JD max AFDD	the Julian Day when the maximum AFDD was reached

**Table 11. Ice events with normalized stage greater than 1.0.**

<i>Location</i>	<i>Flood stage (ft)</i>	<i>Date(s)</i>	<i>Normalized stage</i>
Loup River at Genoa	9	16 February 1962	1.11
Loup River at Genoa	9	1 April 1965	1.15
Loup River at Genoa	9	19 February 1971	1.15
Loup River at Genoa	9	28 February 1972	1.02
Loup River at Genoa	9	15 February 1984	1.01
Loup River at Genoa	9	23 February 1977	1.13
Loup River at Genoa	9	18 March 1978	1.35
Loup River at Genoa	9	15 March 1979	1.21
Loup River at Genoa	9	18 January 1980	1.20
Loup River at Genoa	9	30 December 1980	1.31
Loup River at Genoa	9	21 February 1982	1.37
Loup River at Genoa	9	17 February 1983	1.04
Loup River at Genoa	9	27 February 1985	1.05
Loup River at Genoa	9	27 January 1986	1.13
Loup River at Genoa	9	10 March 1989	1.04
Loup River at Columbus	11	21 March 1969	1.02
Platte River at North Bend	8	13 February 1952	1.02
Platte River at North Bend	8	29 March 1960	1.01
Platte River at North Bend	8	20 February 1971	1.53
Platte River at North Bend	8	29 February 1972	1.27
Platte River at North Bend	8	17 February 1974	1.07
Platte River at North Bend	8	19 March 1978	1.94
Platte River at North Bend	8	14 March 1979	1.25
Platte River at North Bend	8	18 January 1980	1.31
Platte River at North Bend	8	22 February 1982	1.16
Platte River at North Bend	8	18 February 1983	1.19
Platte River at North Bend	8	28 February 1985	1.32
Platte River at North Bend	8	24 February 1988	1.02
Platte River at North Bend	8	12 March 1989	1.02
Platte River at Louisville	9	28 March 1962	1.01
Platte River at Louisville	9	19 February 1971	1.17
Platte River at Louisville	9	3 March 1979	1.09
Platte River at Louisville	9	22 February 1982	1.11

Note: There were no normalized stages greater than 1.0 at Waterloo

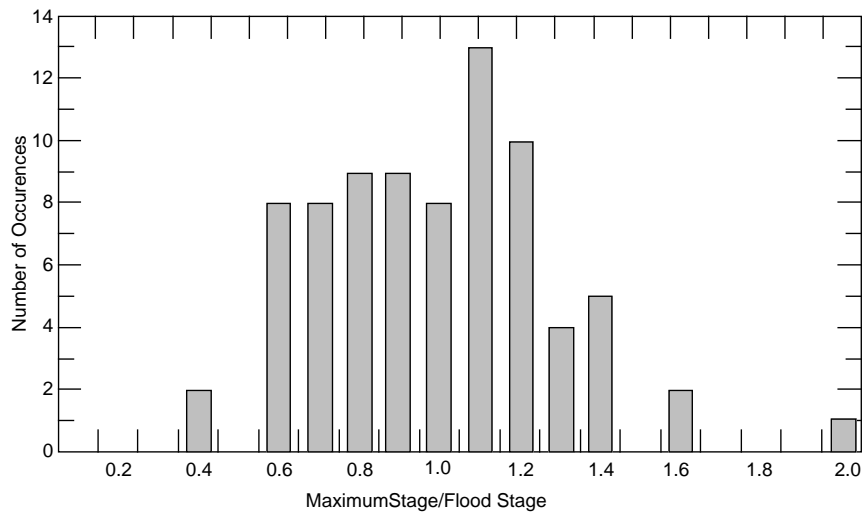
isville. Stages greater than flood stage occurred most frequently at Genoa (73%), followed by Louisville (50%) and North Bend (46%). Normalized stages ranged between 0.34 and 1.94, with a mean of 0.93 and standard deviation of 0.28. The frequency distribution of the normalized stages is given in Figure 8a. The most frequently occurring normalized stages fall between 1.0 and 1.1 (16.7%), followed by 12.8% between 1.1 and 1.2. Assuming a log-normal distribution, the exceedance probability of a given normalized stage is given in Figure 8b. Flood stage is equaled or exceeded about 40% of the time at the gaged sites in the study area; however, factors unique to each site may cause it to experience a significantly greater or smaller probability of exceeding flood stage.

Although the ice events shown in Figure 7 which result in flooding appear to occur more frequently after 1970, this may actually be more a reflection of the quality and availability of data

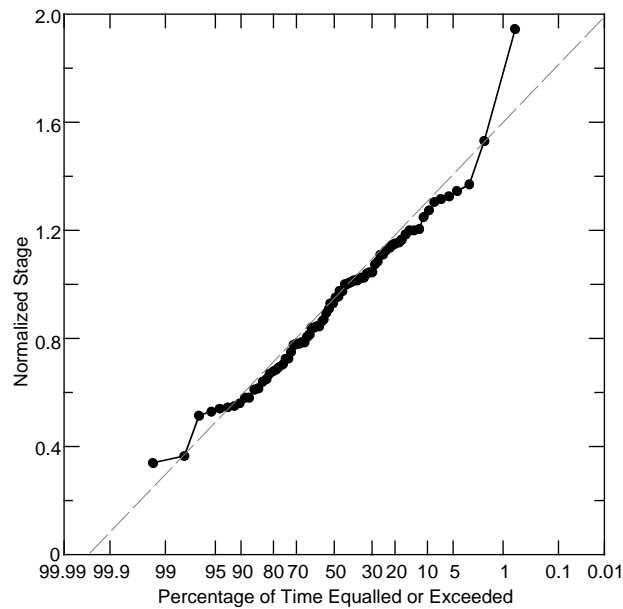
than of actual ice event occurrence. For example, ice jams occurred at ungaged sites in 1966 and 1969. They may also have occurred at gaged sites, but stages associated with large flows during the summertime, particularly in 1966 (USAED, Omaha 1966), may have obscured high ice-related stages. A review of archived winter USGS stage and discharge measurement records for the gaged sites could be useful in identifying and verifying ice event information. Large-scale climatic variations, increased development, modification of land-use practices, and changes in the sediment regime of the rivers may also affect the apparent frequency of flooding, in addition to data uncertainties.

In addition to characterizing the frequency and stage of ice events, it is also important to characterize the hydrological and meteorological conditions associated with ice events. The probability distributions for the occurrence of discharge events or temperatures can be developed with greater





a. Frequency distribution.



b. Exceedance probability.

Figure 8. Statistics for the ice events shown in Figure 7.

confidence than for ice-related stages; therefore, it is helpful to develop some idea of the relationships between them. From Figure 9 it appears that normalized stage is roughly proportional to both maximum discharge and maximum AFDD. However, significant scatter in the data prevents a clear relationship. There does not appear to be any correlation between maximum discharge and AFDD.

A comparison between the date of the maximum stage and the date of the maximum discharge shows a stronger correlation. In this case

(Fig. 10a) it is evident that the maximum ice-related stage almost always occurs on or before the date of the maximum discharge. This is because ice jams generally form on the rising limb of the hydrograph, and although a large-discharge event is required to break up the ice and cause a jam, an even larger discharge will cause the jam to fail and wash out.

The relationship between the date of the maximum stage and the date of the maximum AFDD is less clear (Fig. 10b). The maximum stage associated with ice events can occur either before and

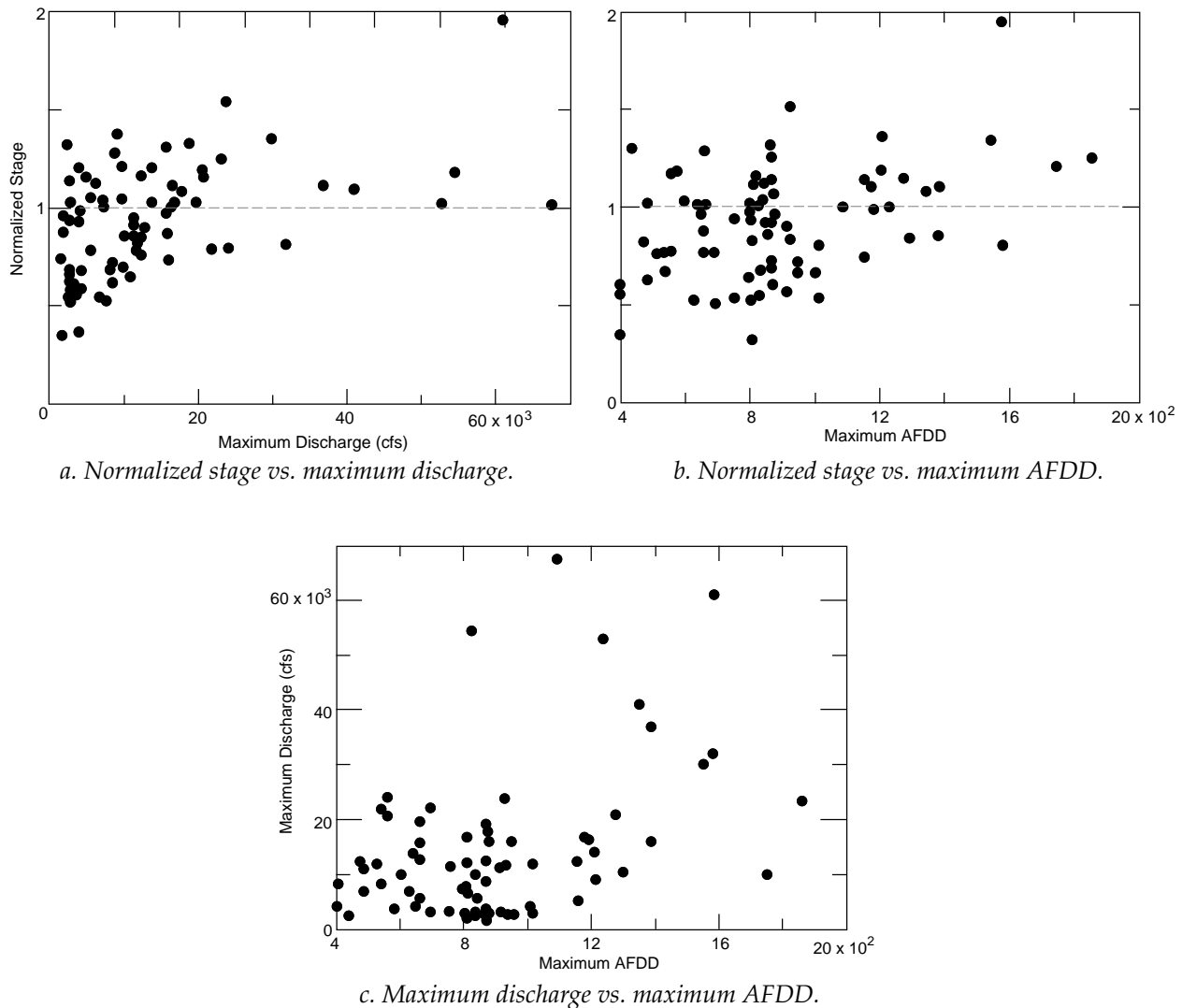
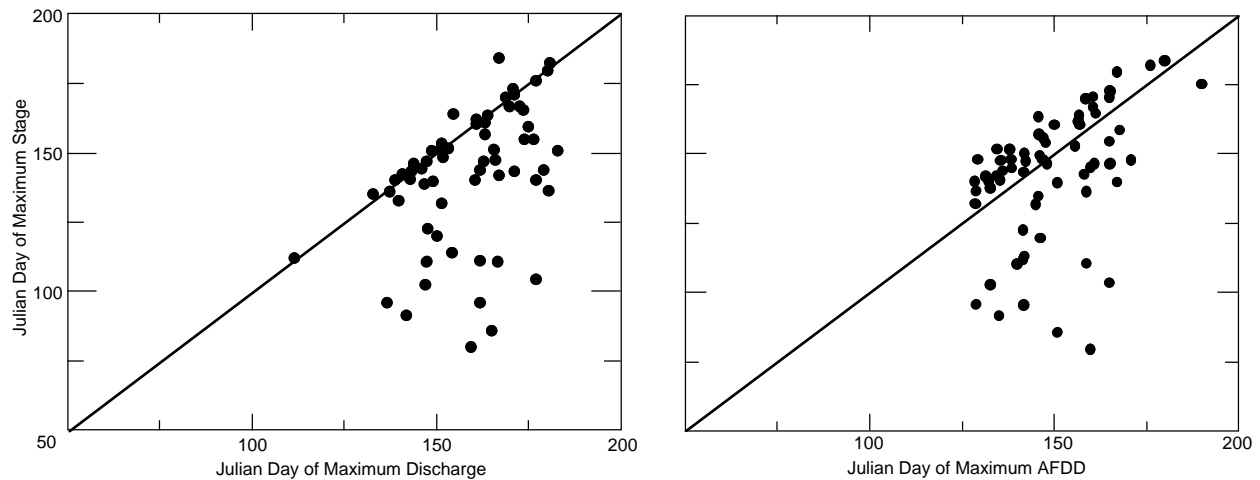


Figure 9. Relationships among normalized stage, maximum discharge and maximum AFDD for January through March, water years 1950 through 1990.

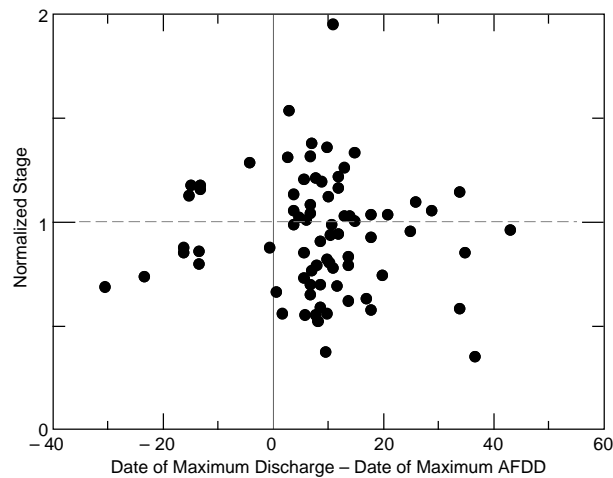
after the weather begins to warm. Ice events occur before the maximum AFDD 42% of the time, but 64% of these events are below flood stage. Although not documented, it is possible that some of the earlier events, say those occurring prior to JD 100 (8 January), may be freeze-up events rather than breakup events. In addition, ice events that occur before the maximum AFDD may also have lower discharges, as snowmelt will not be a significant component of the discharge. Figure 10c presents the same data in another fashion. In this figure the normalized stage is plotted against the difference between the dates of the maximum stage and the maximum AFDD. Negative values indicate that ice events occur before the maximum cold, and positive values indicate that ice

events occur after the weather begins warming. For values close to zero, the maximum stage occurs near the time of the maximum AFDD, when the ice would be thick, competent and most likely to cause a damaging ice jam. However, the data show that flood events (normalized stage greater than 1) occur both before and after this date. Again, values much lower than zero may indicate freeze-up jams.

Ice events in the study area occur between late December and late March, with ice events occurring most frequently between about 15 February and 1 March. However, ice jams with significant flood stages have occurred as early as late December and as late as the end of March. Ice events most commonly cause stages within the range



a. Date of occurrence of the maximum ice-related stage vs. the date of the maximum discharge. b. Date of occurrence of the maximum ice-related stage vs. the date of the maximum AFDD.



c. Normalized stage vs. the difference between the date of maximum stage and the date of the maximum AFDD.

Figure 10. Relationships among dates of occurrence of maximum ice-related stage, maximum discharge and maximum AFDD for January through March, water years 1950 through 1990 (October 1 = Julian Day 1).

plus or minus 50% of the flood stage at a given location (normalized stage 0.5–1.5). However, ice events may result in stages that are almost double flood stages under worst-case conditions, such as those experienced on the Platte River at North Bend in 1978. In general, ice events occur only after at least 400 FDD have accumulated.

### Hydraulic analysis

Hydraulic analyses of ice-affected rivers can often reveal possible causes of jam formation at particular locations. According to profiles developed for the Platte River Basin Level B Study

(Missouri River Basin Commission 1975), the average Platte River water slope decreases from 4.6 ft/mile upstream of the Elkhorn confluence to 3.9 ft/mile downstream of the Elkhorn to the mouth. The change in slope corresponds closely with historic jam locations and may be a contributing factor in the formation of breakup jams downstream of the Elkhorn confluence. A second marked change in slope occurs at a point approximately 2.5 miles upstream of the Highway 64 bridge, where the stream slope decreases from 5.1 to 4.6 ft/mile. This location also corresponds closely with the observed jamming location along Union

Dike. The third significant change in slope is at the confluence of the Loup and Platte Rivers, where the slope decreases from approximately 6 to 4.6 ft/mile. This location coincides also with a historical jam location on the Platte River.

Using available HEC-2 models, we performed a hydraulic analysis of two reaches within the study area to determine whether any obvious hydraulic conditions conducive to ice jam formation could be detected. The two locations were the Platte and Loup Rivers at Columbus and the Platte River near its confluence with the Elkhorn River. We first developed open-water profiles, which can be used to identify critical changes in water surface slope often associated with ice jam initiation. We then modeled freeze-up jam conditions because frazil ice accumulations can result in areas of localized thick ice that may be significant during breakup jam formation. Finally a stable ice cover was modeled in both locations, and an equilibrium breakup ice jam was modeled for the lower Platte River location. Open-water and stable ice cover profiles were modeled with the HEC-2 step backwater program (USACE 1990). Freeze-up and breakup jam profiles were modeled using HEC-2 and the ICETHK utility (Wuebben and Gagnon, in prep.).

#### *Loup River near Columbus*

The reach modeled extended from a point on the Platte River from 0.5 mile downstream from the Loup confluence to the Loup confluence and then up the Loup River to about 7.25 miles upstream of the confluence. The HEC-2 model used available cross-sectional geometry for a limited map and maintenance study of the Loup River at Columbus, Nebraska, performed for FEMA.\* However, while overbank information was relatively detailed, for many cross sections only one point below the surveyed water surface was used to describe the channel bottom. The computation of water surface profiles at high discharges is not significantly affected by the lack of detailed channel geometry but may decrease accuracy at low discharges such as those used in this study. Channel geometry (cross-sectional area, top width, etc.) fluctuates between adjacent sections within the reach but not significantly. The overall bed slope decreases from about 5 to 4 ft/mile downstream of the Highway 81/30 bridge as the Loup enters the Platte River valley, although local bed slopes differ significantly from that.

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\* LMMP study not yet published.

Open-water, freeze-up and stable ice-cover profiles were developed for a number of discharges ranging up to 3500 cfs, which is about the maximum discharge experienced during freeze-up. Open-water conditions show a flattening of the profile near the downstream end of Wagners Lake and about 3000 ft downstream of the Highway 81/30 bridge, as did profiles for a stable ice cover and freeze-up conditions. The freeze-up ice thicknesses computed by ICETHK ranged from 0.5 to 3.6 ft thick, with Manning's  $n$  values ranging from 0.02 to 0.036. The stable ice cover was represented by 1-ft-thick ice and a Manning's  $n$  value of 0.015. As can be seen in Appendix A, the open-water profiles were lowest and the freeze-up profiles were highest, as expected. This appendix includes profiles for 750, 2500 and 3500 cfs, although many other intermediate discharges were modeled.

The thickest accumulations of ice computed for the freeze-up case, up to 3.3 ft, were generally located between the Highway 81/30 bridge and the water treatment plant at all discharges. This might be expected since the stream slope flattens out slightly near the highway bridge. Significant ice thickening was computed for all discharges about 0.5 mile downstream of the highway bridge. This location would correspond closely to the toe of the 1969 ice jam. Another area of ice thickening approximately 2000 ft upstream from the water-treatment plant was seen at discharges between 2000 and 3000 cfs. This location corresponds closely to the toe of the 1993 jam. Other discharges showed slightly thicker ice in this area, but the increase in stage was most noticeable for discharges between 2000 and 3000 cfs. Field observations of the November 1993 freeze-up jam showed that frazil accumulations upstream of the actual jam were thickest from about 0.25 mile upstream of the water treatment plant to just downstream of the UPRR bridge west of Wagners Lake, with accumulations of up to 3 ft on top of sandbars and along shore common. Ice accumulations of greater than 3 ft in thickness may be possible during freeze-up due to river level fluctuations associated with Loup River Power Canal operations. The formation of thick ice accumulations in the areas with reduced slope would appear to contribute to later breakup ice-jam formation near Columbus.

#### *Platte River from its mouth to near Highway 92*

The area modeled on the Platte River extended from its confluence with the Missouri River up-

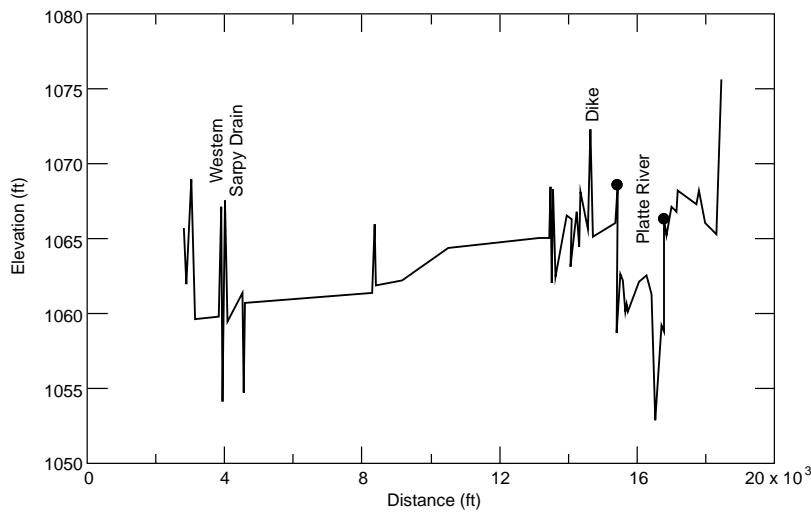


Figure 11. Typical Platte River partial valley cross section upstream of Highway 6 in Sarpy County.

stream to near the Douglas–Sarpy County line. The HEC-2 model was developed from available HEC-2 input used for an ongoing Platte River floodplain study performed by R. Michael Breneman for the Nebraska NRC. Conditions modeled included open-water, freeze-up, stable ice cover and breakup. Discharges used were approximately equal to the 50%, 25% and 1% seasonal flow duration values shown in Table 12 for open-water, freeze-up and stable ice-cover profiles and the 1% seasonal flow duration value for the breakup profile. ICETHK was used in conjunction with HEC-2 for the freeze-up and breakup profiles. Plots of the modeled profiles are shown in Appendix B.

Some problems were encountered with the HEC-2 input data. The numerous geometry errors found in the model, especially at bridges, required correction before the model would run properly. Some cross sections had channel and valley dimensions that did not correspond well with the location shown on the maps provided. Other cross sections had detailed survey information within the channel, while others had only two points below the bank line. As a result the following dis-

cussion of results is qualitative, reflecting the uncertainty found in the model. Figure 11 shows a typical cross section between the Elkhorn River confluence and Highway 6 that illustrates why floods are so damaging below the Elkhorn confluence. The overbank near the Western Sarpy Drain is up to 5 ft lower than the Platte River high bank and as much as 10 ft lower than the top of the levee along the river. Once the levee is overtopped or breached, it is evident that the depth of water in the overbank can be quite large.

The thickest accumulations of ice shown in the model correspond closely to observed ice-jam locations. The most noticeable areas of ice accumulation were immediately downstream of the Highway 6 bridge, near the north end of Camp Ashland and north of Thomas Lakes. Ice thicknesses modeled for the 1% duration flow exceeded 3 ft for freeze-up and 5 ft for breakup. However, not enough field data are available to verify the thickness and locations. The profiles for open water and stable ice cover show localized decreases in water surface slope near each of these three locations, but greater decreases were modeled just upstream of the Elkhorn and just upstream of Salt

Table 12. Discharges used in HEC-2 model of lower Platte River.

Location	50% exceedance probability discharge (cfs)	25% exceedance probability discharge (cfs)	1% exceedance probability discharge (cfs)
Platte River downstream of Elkhorn River	4500	8000	12000
Platte River upstream of Elkhorn River	3500	6000	9000

Creek. The jam profiles are up to several feet higher than the open-water and stable-ice-cover profiles as expected, but in some locations the breakup profile approaches the open-water profile because there is no ice. Better analysis of Platte River ice jams could be accomplished with more detailed geometry and field data relating to ice volume and thickness.

## PREDICTIVE MODEL FOR ICE JAM OCCURRENCE

### Past methods

The ability to forecast the occurrence and severity of an ice jam would provide early warning, which could decrease damages due to ice jams within the study area. As a result the Interagency Hazard Mitigation Team requested the development of some type of model that could be used to forecast ice jams in the study area. While models have been developed for use in predicting open-water flood events, there are few existing models that can be used to predict the occurrence and severity of breakup ice jams. There have been a number of attempts to develop a prediction scheme for ice breakup, the prelude to breakup ice-jam formation. For the most part these methods address the formation of cracks in the ice as a result of increases in stage over the freeze-up stage (see, for example, Beltaos 1990). The cracks, combined with increased stage and discharge, result in ice-cover breakup and movement. The thickness and deterioration of the ice and the rate of the stage increase are often considered, as well as river geometry and meteorological and hydrological conditions.

Unfortunately, while ice-cover breakup is necessary for breakup ice-jam formation, the prediction of breakup alone is not sufficient to predict the occurrence and severity of breakup ice jams. The few methods to predict breakup ice-jam formation that presently exist are based on probabilistic or statistical analyses of past ice events and the parameters associated with ice jams at a particular location. Shuliakovskii (1963) presented two cases in which the probability of a breakup ice jam occurring can be predicted based on a statistical analysis of historical events. The predictions are based on the maximum stable ice stage in one case and on the rise in water stage and the air temperature during jam formation in the second case.

Shuliakovskii also presented a technique for forecasting the severity of a breakup ice jam using the incremental increase in stage due to an ice jam

as the index of severity. His method assumes that this incremental increase in stage is a function of the ice thickness, the depth of snow, the rate of rise of stage prior to ice jamming, the accumulated freezing degree-days during the ice breakup or simply the existence of subfreezing temperatures, the character of the ice, the difference in time between ice breakup on the main stem and significant tributaries, and the ratio of total heat input per unit surface area in the ice-jamming region and the total heat input per unit surface area in the flood-formation region.

Because detailed, long-term data for many of these parameters may be difficult to obtain, Shuliakovskii presented a simplified application of the prediction technique. For the case where no significant tributaries are present, the time of breakup on tributaries vs. the main stem may be neglected. If the ice-jam region is either coincident with or very similar to the source of runoff in terms of heat input, the heat terms may be neglected. Ice thickness may be estimated using AFDD. The term describing the character of the ice is neglected if the thickness and condition of the ice cover contributing to the jam are relatively uniform. Finally the temperature statistic of interest may be modified to more closely reflect conditions at the prediction site.

Zhukova (1979) discussed some important parameters to consider in developing a method to predict the occurrence of an ice jam. Working with long-term stage and discharge data for several river basins, she developed a method to predict stages due to ice jams in particular river reaches. This method utilizes an observed relationship between the long-term average normalized increase in stage due to ice jams and the ratio between long-term average ice-jam stages and open-water stages for the basins examined.

The prediction method relies on determining the increase in stage due to ice over the long-term average low-flow stage. The method for determining the long-term average low-flow stage was not specified. Zhukova assumed that the total increase in stage due to an ice jam is the sum of the incremental increase in stage due to the ice and the increase in stage attributable to the jam discharge alone. For comparison between different sites, the incremental stage increase due to ice is normalized by the total increase in stage due to an ice jam, and the stage increase due to discharge during an ice jam is normalized by the stage increase due to the maximum open-water discharge.

Once these parameters are computed, long-

term average values can be determined. For Zhukova's sites a plot of the long-term average values of the normalized stage parameters exhibits a general relationship which can then be used to develop an expression useful in predicting ice-jam stages. Within each basin or other subarea, the data could be further analyzed to determine the probability that a given increase in stage due to ice will occur, assuming that an ice jam occurs at a given discharge.

Galbraith (1981) developed a method for predicting the occurrence of significant ice jams on the Saint John River in New Brunswick. His method was based on a review of data associated with historical ice-jam formation. Three factors were assumed to be important in the formation of ice jams: the characteristics of the ice (e.g. strength, piece size, quantity), its movement and river channel properties that restrict the movement of the ice. Meteorological factors were thought to have a major impact on both the characteristics and movement of ice, particularly the rate of snowmelt and rainfall during the ice breakup period.

Galbraith's method requires the determination of indices for several meteorological parameters following the start of the breakup period. These include the number of days to reach an ATDD of 50, the rate of heat transfer over the breakup period, the number of days to reach a snowmelt index of 90 mm, and the accumulated precipitation in mm water equivalent. The rate of heat transfer can be calculated from the incident solar radiation or hours of sunlight, incident atmospheric radiation, air temperature, cloud cover, long-wave radiation emitted from the surface and its emissivity, surface temperature, estimated conductive heat transfer and wind speed. The snowmelt index is estimated from the mean daily wind speed, air temperature (if greater than 0°C) and water vapor pressure.

From past records the meteorological indices were calculated for the years available and then ranked in ascending (length of breakup period, number of days to reach ATDD = 50 and snowmelt index = 90) and descending (rate of heat transfer and accumulated precipitation) order. In general, high-ranking or extreme values of the indices were associated with damaging ice jams. The time to ATDD = 50 and the snowmelt indices were the best predictors of damaging ice jams. Because these terms are related, Galbraith suggested that the snowmelt index might be the better predictor. Accumulated precipitation was not useful in predicting the occurrence of ice jams. A

method using these four indices was developed that rates the relative potential for significant (i.e. damaging) ice jams.

Recently CRREL has been involved in several attempts to develop prediction schemes for ice events based on historical ice data. Wuebben and Gagnon (1995), for example, developed a model based on an evaluation of historical discharge, stage and meteorological information for a reach of the Missouri River near Williston, North Dakota. Ranges of parameters associated with low and high potential for ice jams were identified, and a method to predict ice-jam occurrence within this reach was proposed.

Winter parameters examined were AFDD, the Julian date of the maximum AFDD, the maximum discharge, the Julian date of the maximum discharge, the difference in time between the maximum discharge and the maximum AFDD, the stage of the downstream reservoir (which controls backwater levels affecting ice jamming), the total snowfall, and the timing of the snowfall (i.e. early or late in the season). Each parameter was weighted and assigned a positive or negative rating factor according to its correlation with ice-jam events.

Wuebben's prediction method involves calculating each parameter, determining the weight and rating factor, and summing positive and negative weighting factors. The ratio of positive to negative factors is used to predict the occurrence of a breakup ice jam. During the winter of 1993-94, when the method predicted a high ice-jam potential, the most damaging ice-jam flood on record occurred.

#### **Lower Platte River predictive model**

The approach taken in developing an initial predictive model of ice-jam occurrence within the Lower Platte River basin study reach is similar to the methods above in that it relies on an analysis of hydrological and meteorological data associated with historical ice jams. The data presented in the previous section, which encompasses the entire study area, do provide some information on general trends and interrelationships between parameters. However, for various reasons it is not possible to develop a model applicable to the entire study area at this time. These reasons include uncertainties in the data, which might be rectified over time as archived USGS records and old newspapers are searched. Also, the causes of ice-jam formation at the different locations vary, along

with such important parameters as river hydraulics and geometry. We used both the regression approach and the threshold approach to develop a prediction model.

To select a site on which to base the predictive model, the ice events described previously are summarized in Table 13 for the period 1950–1990. Of the seven sites chosen for detailed analysis in the Section 22 Study, the Platte River at North Bend provides the best combination of ice data and long-term stage, discharge and meteorologi-

cal records. Ice jams at North Bend are often associated with ice jams at other study locations, and few jams occur at other locations in the absence of some ice event at North Bend. Therefore, the predictive model developed for this study is based on USGS gaging station records for gage #0679600 (Platte River at North Bend) and NWS data for Columbus, Nebraska.

The normalized stage (i.e. the ratio between the stage and flood stage) was used as an indicator of the severity of a given ice event. A high

**Table 13. Known ice events during the period 1950 through 1990.**

<i>Water Year</i>	<i>Loup River between Columbus</i>	<i>Loup River at Columbus and Genoa</i>	<i>Platte River at North Bend</i>	<i>Platte River at Big Island</i>	<i>Platte River at Leshara</i>	<i>Platte River North of Hwy 64</i>	<i>Platte River at Hwy 92</i>	<i>Platte/Elkhorn Confluence</i>
1950			X	XX				
1951			X					
1952			XX					
1953			X					
1954								
1955			X					
1956								
1957								
1958		X	X					
1959		X	X					
1960			XX					
1961		X	X					
1962	XX		X					
1963	X	X	X					
1964								
1965	XX							
1966		X						XX
1967								
1968								
1969	XX	XX						
1970	X	X	X					
1971	XX	XX	XX				XX	
1972	XX		XX					
1973	X	X						
1974	XX	X	XX					
1975	X	X						
1976	X	X	X					
1977	XX	X	X					
1978	XX	X	XX	XX	XX	XX	XX	XX
1979	XX	XX	XX	XX	XX	X	XX	X
1980	XX		XX		XX			XX
1981	XX							
1982	XX	X	XX	X		X	XX	XX
1983	XX		XX					
1984				XX		X	XX	XX
1985	XX		XX	XX		X	X	
1986	XX		X		XX	X		
1987								
1988	X		XX					
1989	XX		XX	X				
1990								

Note: X = recorded ice event below flood stage  
 XX = recorded ice event above flood stage (not necessarily significant flooding)



normalized stage would be an indicator of a severe or damaging ice event. For example, the most damaging ice event at North Bend occurred in March 1978. This event had a normalized stage of more than 1.9, almost double the listed flood stage of 8 ft. Using the regression approach, we examined the relationships between a variety of meteorological and hydrological parameters, including air temperature and discharge on the day of the ice event, AFDD, ATDD, accumulated precipitation and accumulated snowfall. Because we thought that the rate of increase in discharge (and hence stage) might be important in ice-cover breakup and jam formation, we also looked at the difference between the average daily discharge on the day of the event and one, two, three, four and five days before the event.

An examination of the data showed that accumulated precipitation, accumulated snowfall and air temperature on the day of the event were weakly correlated with the normalized stage of ice events at North Bend. We also found little relationship between stage and the difference between the discharge on the day of the ice event and one, two, three, four and five days previously. ATDD was slightly better correlated with the normalized stage. A stepwise linear regression selected Julian date, AFDD and the discharge on the date of the ice event ( $Q$ ) as significant parameters. The resulting model is:

$$NS = 1.60799 - 5.832 \times 10^{-3} JD + 2.59 \times 10^{-4} AFDD + 1.1 \times 10^{-5} Q$$

where  $NS$  is the normalized stage. The  $r^2$  for the model is 0.5419. Most of the variation is due to the model rather than random error.

By definition a regression equation will overpredict and underpredict some values. Figure 12 is a graph of the normalized stages at North Bend predicted for ice-event years by the regression relationship vs. observed normalized stages. As can be seen in the figure, the regression tends to overpredict stage, but in eight cases it underpredicts stages. The most serious shortcoming is illustrated by the two cases in which the regression predicts a stage less than flood stage, but stages greater than flood stage occurred (1980 and 1955). The normalized stage was underpredicted by 19% and 32%, respectively, in these cases. In the remaining six cases the predicted normalized stage was above flood stage but was between 7% (1983) and 23% (1978) lower than the observed normalized stage. It is possible that an improved regression

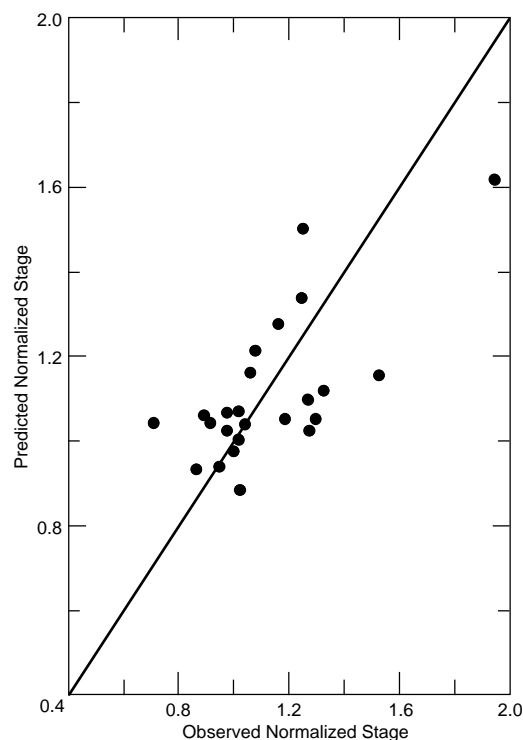


Figure 12. Relationship between the observed and predicted values of normalized stage at North Bend.

might be developed in the future with the inclusion of additional ice-event data. If so, this could provide a useful prediction of the stages that might be expected for an ice event at North Bend.

Although the regression does not result in a conservative prediction of the occurrence or severity of ice jams, it does identify the important parameters (date, AFDD and discharge) that should be considered in developing a prediction model. It also provides a mean value of expected stage, which, if the uncertainty is recognized, can be used to provide warning that damage is likely or very likely.

The AFDD, discharge and Julian date of the ice jam were considered in a threshold analysis, which confirmed the conclusion reached during the evaluation of historic data for the study area—that AFDD must reach at least 400 before an ice event will occur. Similarly discharges must exceed at least 6000 cfs for an ice event to occur. Also, ice events occurred between Julian Day 131 and Julian Day 182. From an examination of average daily discharges at the time of maximum ice stages, a relationship between ice-event discharge and Julian date was developed:

$$Q = 0.39 (JD)^{1.96} \quad (4)$$

where  $Q$  is the average daily discharge corresponding to ice events in cfs and  $JD$  is the Julian Day (day 1 is 1 October of a given water year). This relationship, shown in Figure 13, describes the minimum average daily discharge required for an ice event to occur on a given date. From Figure 13 we can see that the relationship reasonably describes the minimum discharge conditions associated with ice events at North Bend, at least while the AFDD criterion is met. After examina-

tion of data for ice events at North Bend, the following criteria were then chosen to characterize these ice events:  $AFDD > 400$  and  $Q > 6000$  cfs or  $Q = 0.39 (JD)^{1.96}$ , whichever is larger. Once these criteria had been arrived at, they were applied to the data for 1950–1990 to evaluate the effectiveness of this classification system. The first date that met the criteria in a given year was selected as an ice event.

Table 14 presents the results of application of the criteria to the historic data. The second column identifies water years in which there was a

**Table 14. Results of applying AFDD and discharge criteria to historic data at North Bend.**

<i>Water year</i>	<i>Recorded maximum ice stage</i>	<i>Predicted ice event ± one week of maximum ice stage</i>	<i>False prediction</i>	<i>Negative prediction</i>	<i>False negative prediction</i>
1950	√	√			
1951	√	√			
1952	√	√			
1953	√	√			
1954				√	
1955	√	√			
1956				√	
1957			√		
1958	√	√			
1959	√	√			
1960	√		√		
1961	√				√
1963	√		√		
1964				√	
1965			√		
1966			√		
1967			√		
1968			√		
1969			√		
1970	√	√			
1971	√	√			
1972	√	√			
1973	√		√		
1974	√		√		
1975			√		
1976	√	√			
1977	√	√			
1978	√	√			
1979	√	√			
1980	√		√		
1981				√	
1982	√	√			
1983	√	√			
1984			√		
1985	√	√			
1986	√		√		
1987				√	
1988	√		√		
1989	√		√		
1990			√		

Note: Water year 1962 was omitted due to significant amounts of missing meteorological data.

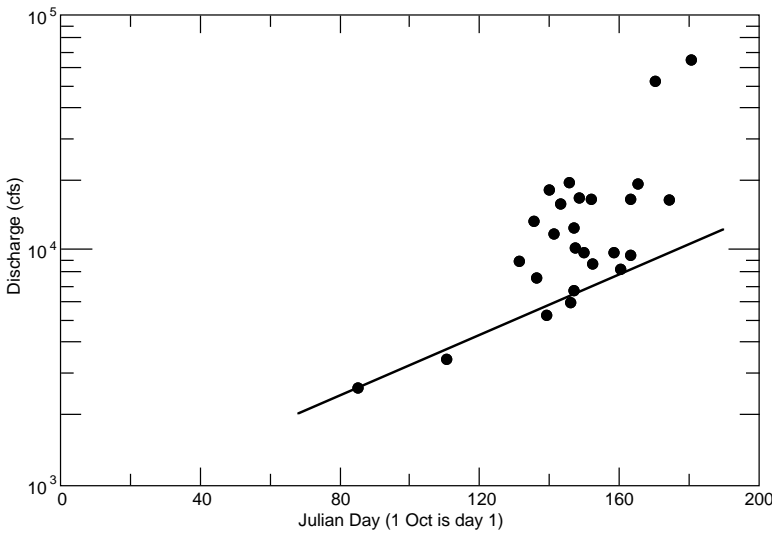


Figure 13. Average daily discharge at the time of the maximum ice stage vs. Julian Day. The line represents the relationship  $Q = 0.39 (JD)^{1.96}$ .

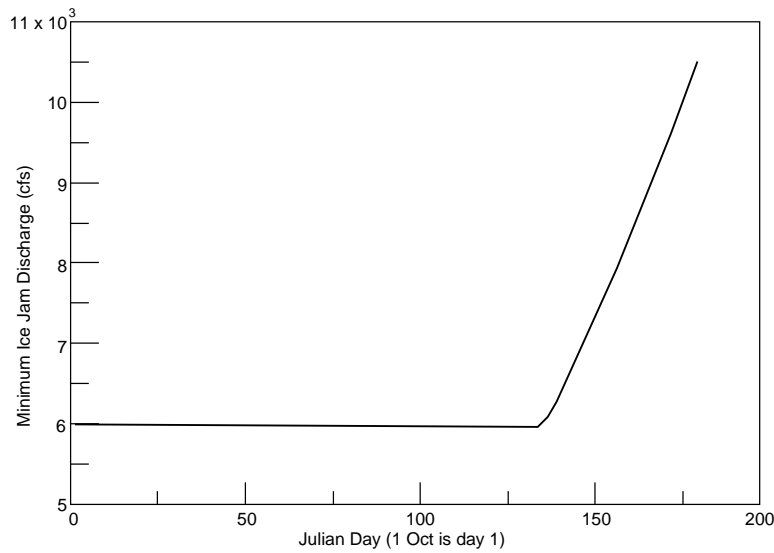


Figure 14. Minimum discharge required for ice jam vs. Julian Day.

recorded maximum ice stage. The third column indicates whether the criteria predicted an ice event within one week of the actual recorded maximum ice stage. A false prediction is defined as predicting a date farther than one week from the actual date, or predicting an event and none occurred (such as in 1957). A negative prediction is defined as predicting no ice event and none occurred. A false negative prediction is defined as predicting no ice event and an ice event did occur.

For years when a maximum ice stage was recorded, the criteria identified 65% of the ice events within one week of the time they actually occurred. For the whole period the criteria predicted 55% of the ice events within one week of occurrence or correctly predicted that no ice events would occur. Also, 41% of the time, the criteria either predicted the wrong date (more than seven days dif-

ferent from the actual event) or that an ice event would occur and one did not occur. Only once (in water year 1961) did the criteria predict that no ice event would occur and one actually did occur. The ice-related stage of 6.93 ft in 1961, the second smallest ice-related stage in the 26 years with ice events, was more than a foot below flood stage and may be considered a nondamaging ice event.

Considering the lack of detailed ice data, the model performed quite well in hindcasting ice events. This is particularly true if one considers that the model may have accurately predicted ice events for years where ice data at North Bend was particularly sketchy, such as 1966 and 1969, when serious ice jams occurred elsewhere in the study area (Table 13). The model overpredicts the occurrence of ice jams at North Bend. However, it does provide good initial predictive model capa-

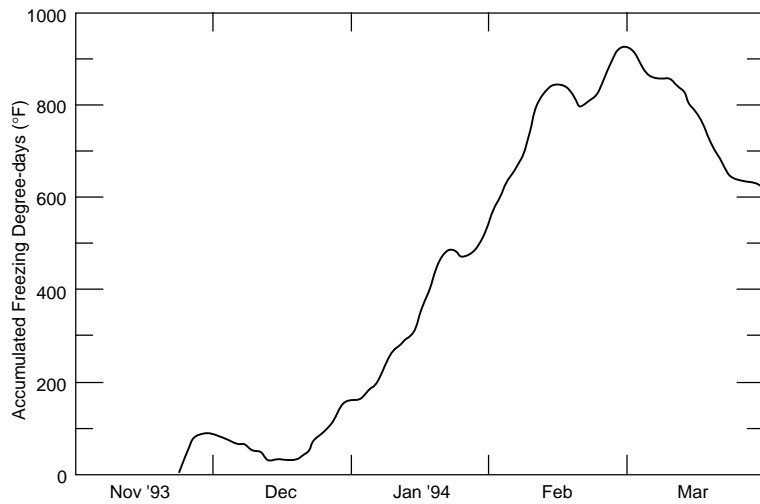


Figure 15. AFDD at Columbus vs. date for winter 1993-94.

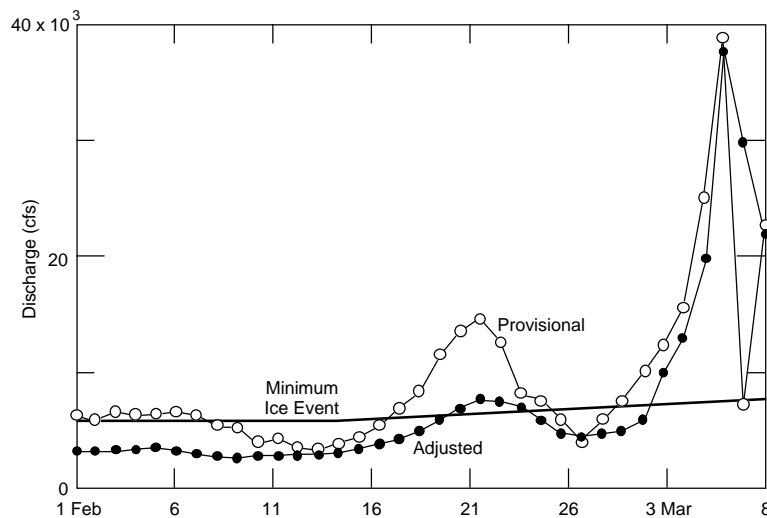


Figure 16. Minimum discharge required for ice jam for 1 February to 8 March, 1994.

bilities that may be enhanced by the addition of missing ice data.

Using the model to predict an ice jam requires the calculation and updating of AFDD using observed minimum and maximum daily air temperatures at Columbus; also, some estimate of discharge at North Bend is necessary. Once the minimum AFDD criterion of 400 has been met, forecast discharges can be compared to the minimum discharge associated with an ice jam for a given date, which can be estimated using Figure 14. If the AFDD criterion has been exceeded, and the forecast discharge is greater than the discharge for that date shown in Figure 14, there is a high probability that an ice jam will occur in at least one location in the study area.

Calculating or forecasting AFDD is relatively simple. For example, the AFDD at Columbus during the winter of 1993-94 had exceeded 400 by

17 January 1994 and remained above 400 through the end of March (Fig. 15). The peak AFDD (924) occurred on 1 March 1994. Forecasting discharge, or even simply monitoring discharge, however, is more complicated. The discharge criteria for the prediction model are based on the reported discharges at North Bend, which are actually adjusted from the real-time, provisional discharges. The provisional discharges are calculated from the stages reported at the gage, which include the effect of ice and are therefore too high. At the end of each winter season, the provisional discharges are adjusted to reflect the presence of ice and are revised downward. The difference between the provisional and adjusted discharges can be significant (Fig. 16).

If the minimum ice event discharge criteria were applied to the provisional discharges, several ice events would have been predicted begin-

ning in early January 1994. Using the adjusted discharges would result in ice-event predictions for 19 February and 2 March 1994. Although no ice jams formed at North Bend during 1994, an ice jam formed on the Platte River downstream of the confluence with the Elkhorn River on 20 February 1994. Jams also reportedly formed on the Platte River at Schuyler and upstream from Highway 64 on 5 March 1994.

Using the prediction criteria to predict ice jams in the study area during 1994 was successful; however, the experience underscored the importance of obtaining and forecasting real-time ice-affected discharge. Before the model can be applied with any confidence, a reliable method to adjust provisional discharges on a nearly real-time basis must be developed. CRREL personnel are continuing to develop a method to convert the provisional ice-affected discharges into actual discharges for use in the model.

## **DATA COLLECTION PROGRAM DESIGN**

The primary objective of an ice-data collection program in the Lower Platte River basin is to develop information useful in developing advance or emergency response measures to ice jams. The secondary objective is to collect future data for input into the predictive model. The data collection program design for the Lower Platte River basin is based on the guidelines presented in White and Zufelt (1994). Table 15 lists the types of data that should be obtained to meet the objectives of the data collection program. They may be categorized as either (1) historical, or background, data or (2) physical data that must be collected in the field. Historical data collection performed to date and the analysis of those data have been discussed in previous sections. Any additional historical data revealed during the course of the ice data collection program should be added to the database. Collection of field data, described in more detail below, may be categorized in chronological order: freeze-up conditions, ice cover characteristics, breakup details, and ice-jam formation, progression and release.

Ice observations over a number of years will be necessary to refine the predictive ice-jam model. Ice observations will also be a key part of an ice-jam detection and warning system. The conditions which do not lead to jamming are as impor-

tant to determine as those that do, so observations should be made carefully even during winters in which jamming is unlikely. Observations of ice breakup and transport are particularly important, whether or not a jam forms. The characteristics of a jam which does not result in flooding should be documented as completely as those of a jam which does cause damaging floods.

Primarily because of safety constraints, the field data collection portion of the program is to be limited to visual observations and measurements that can be made on shore or from the air. The USGS, the Corps of Engineers, the Papio-Missouri River Natural Resources District (NRD) and CRREL have personnel trained in making ice measurements. These are the only persons who should attempt to make any measurements from the surface of the ice. Ice measurements should never be made alone. Ice observers should be aware of the possible safety hazards that are associated with data collection and should both minimize their exposure to these hazards and be prepared to deal with any hazards that might occur. Ice-data-collection efforts may have to be suspended during particularly hazardous weather or flooding conditions, so it is best to plan alternatives if it is not possible to obtain data using the ideal method. Other constraints affecting the type and quantity of data collected are budgetary limitations, time (e.g. events may occur rapidly), large geographic area and difficulty of access.

Representatives from the Omaha District office of the Corps of Engineers, CRREL, NWS (Omaha), USGS (Lincoln), Nebraska Natural Resources Commission (NRC) and Nebraska Civil Defense were involved in creating a network of observers to make ice observations in the study area. In January 1994, CRREL personnel presented a two-day workshop to the observers and others involved in ice-jam detection or response. The workshop presented information on ice characteristics, river and ice hydraulics, mitigation options and data collection.

The observation form used by the observers, the Nebraska Ice Report, is shown in Figure 17. The form was developed mainly with input from the NRC, CRREL, Corps of Engineers and Civil Defense. Ice information collected using the Ice Report is incorporated into the NRC database and is available for use by the Nebraska Civil Defense, Corps of Engineers, NWS and others. In addition, the USGS forwards information on ice thickness measurements, which are also included in the database.

**Table 15. Data to be collected in ice data collection program.**

---

<b>Historical data</b>
past flood-fighting efforts
stages
discharges
meteorological conditions
ice records
<b>Physical (field) data</b>
<i>Freeze-up conditions</i>
general ice conditions in river
predominant ice type
location of main channel at freeze-up
<i>Ice cover characteristics</i>
general appearance
location of upstream and downstream boundaries
ice cover roughness
presence of leads or cracks
changes in water level affecting ice cover
<i>Breakup details</i>
thermal effects on ice cover
presence and growth of leads or cracks
changes in water level leading to breakup
breakup process
<i>Jam formation and evolution</i>
type of jam
location of jam toe
jam extent
ice characteristics
upstream ice supply
jam progression or regression with time
river geometry and hydraulics affecting jam
water stage
ice thickness
actual and potential ice jam flood areas

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**Freeze-up conditions**

Visual observations of the freeze-up process are quite valuable. In particular, the date of initial ice formation and when and where the ice freezes across the channel to form an ice cover are important. Border ice growth, as well as the types and relative amounts of moving ice observed, should be documented. The manner in which the ice cover actually forms in a reach where jams are known to form would be of special value. It may also be possible to determine whether the ice cover is made up primarily of sheet ice or frazil ice through observations of ice-cover formation and freeze-up conditions. Identifying the type and the relative quantity of each type of ice that constitutes the ice cover or jam can help both in estimating its possible effects and in evaluating suitable mitigation measures.

Ground-based observations of freeze-up conditions at selected locations are usually adequate, but if conditions are rapidly changing or if safety

concerns limit ground-based observations, aerial reconnaissance would be desired. A particularly useful application of aerial reconnaissance would be to monitor the location of the main flow channel in the rivers at freeze-up, since effective application of some mitigation measures requires this information. Ideally the channel should be videotaped to record the location of the main channel, and the main channel location should be transferred to maps. In the future, as technology further develops, it may be possible to “mark” the main channel directly on the videotape. Ideally observations of freeze-up conditions should be made in a consistent manner by the various ice observers. It should be emphasized that the observers should include as many additional observations and comments as they desire when using data collection forms. It is often the unexpected observation that provides the most information.

**Ice cover characteristics**

As the winter continues, periodic observations of general ice conditions should be made at selected locations. Observations of general ice conditions include monitoring the locations of the downstream and upstream ends of the ice cover, if possible, and any changes over time. Aerial reconnaissance is the easiest way to obtain this information, but with an adequate network of observation stations, ground-based observations may be suitable. This is the case at several of the seven recurring ice-jam locations, such as the Loup River at Columbus and along the Union Dike, where levees and dikes provide good access and visibility along the jam reaches.

The relative roughness of the ice-cover surface should be monitored over time, along with the locations and sizes of open-water areas (leads) within the ice cover. Changing water levels may affect the ice cover in various ways. If the water level drops after freeze-up, the ice cover may also drop, forming a hinge crack along the shoreline. It is important to note the presence of such cracks parallel to the shore since they have a direct impact on breakup processes. The appearance and location of cracks perpendicular to the shore should also be noted. Since snow insulates an ice cover, the dates of significant snowfall and the change in estimated snow depths with time should be reported.

The ice cover will begin to deteriorate as the air temperature, length of day and sun angle increase during late winter and spring. The surface of a formerly smooth ice cover may become pit-

# ICE REPORT

## Section A

DATE: \_\_\_\_\_ mm/dd/yy TIME: \_\_\_\_\_ AM/PM RIVER NAME: \_\_\_\_\_

OBSERVER'S NAME: \_\_\_\_\_

LOCATION OF OBSERVATION (See attached map grid):

Area/Site #: \_\_\_\_\_ or Lat: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" Long: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_"

Location of nearest roads: \_\_\_\_\_

Location of nearest bridge: \_\_\_\_\_

Name of town: \_\_\_\_\_ County: \_\_\_\_\_

Is this a changed condition?  Yes  No Photographs:  Yes  No

### LOCAL WEATHER

Temperature: Air: \_\_\_\_\_°F Water: \_\_\_\_\_°F  
Precipitation: Rain: \_\_\_\_\_in. Snow: \_\_\_\_\_in.  
Wind: Average speed: \_\_\_\_\_mph Direction: (circle one) NW N NE  
W ↑ E  
SW S SE

### RIVER CONDITION

Bankfull \_\_\_\_\_ft  Estimate less than bankfull \_\_\_\_\_ft  Nearest gage reading \_\_\_\_\_ft

## Section B

### FREEZEUP

Border ice: Growth from shore \_\_\_\_\_ft \_\_\_\_\_% of channel remaining open

Moving ice: Types  Frazil slush  Frazil pans

(Check all that apply)  Fragmented sheet ice  Large sheets

Other: \_\_\_\_\_

Percentage of open channel surface occupied by moving ice: \_\_\_\_\_%

Ice cover complete \_\_\_\_\_ (mm/dd/yy)

### CHARACTER OF INTACT ICE COVER

Location of downstream end of ice cover: Lat: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" Long: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" or River Mi: \_\_\_\_\_

Location of upstream end of ice cover: Lat: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" Long: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" or River Mi: \_\_\_\_\_

Surface roughness (check one):

Smooth  < 0.5 ft  < 1.0 ft  < 1.5 ft  > 1.5 ft

Evidence of decay:  Yes  No  Snow covered

If yes, check:  Melting snow  Melting ice  Canded ice

Cracks in ice cover:  Yes  No

If yes, check:  Parallel to shore Distance from shore: \_\_\_\_\_ft  Estimate  Measured  
 Perpendicular to shore

Evidence of fracturing along banks  Yes  No

If yes, check:  (a) Ice thickness when fracture occurred: \_\_\_\_\_ft  Estimate  Measured

(b) Displacement: \_\_\_\_\_ft  Estimate  Measured

(c) Distance from shore: \_\_\_\_\_ft  Estimate  Measured

### BREAKUP

Cracks (check one):  Parallel to shore Distance from shore: \_\_\_\_\_ft  Estimate  Measured  
 Perpendicular to shore

Average distance between cracks: \_\_\_\_\_ft

Water on top of ice:  Pooled  Flowing  None

Time ice started to more: \_\_\_\_\_AM/PM \_\_\_\_\_mm/dd/yy

Time water was clear of ice: \_\_\_\_\_AM/PM \_\_\_\_\_mm/dd/yy

Post movement: Height of shear walls along bank: \_\_\_\_\_ft

### ICE JAMS

Cause (check one):  Freezeup  Breakup

Condition at ice jam initiation point (check all that apply):

Solid ice sheet  Bend  Bridge  Island  Constriction

Reduction in water slope  Other: \_\_\_\_\_

Jam length: \_\_\_\_\_mi (approx)

Location of ice jam toe (downstream end), if known: Lat: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" Long: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" or River Mi: \_\_\_\_\_

Location of ice jam head (upstream end), if known: Lat: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" Long: \_\_\_\_\_° \_\_\_\_\_' \_\_\_\_\_" or River Mi: \_\_\_\_\_

Height of shear walls along bank after jam release: \_\_\_\_\_ft

Figure 17. Nebraska ice report data collection form.

Section C

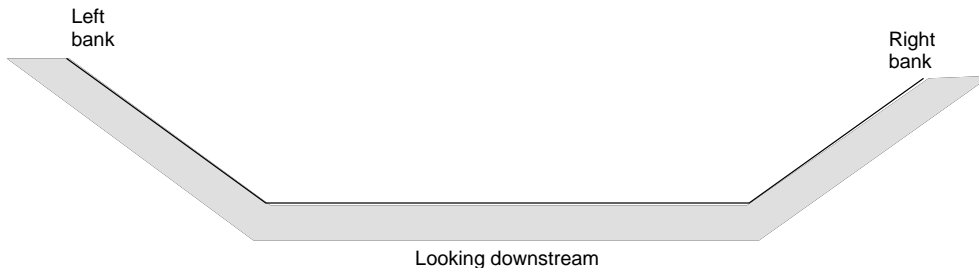
Observer: \_\_\_\_\_ Date: \_\_\_\_\_ Time: \_\_\_\_\_

River Name: \_\_\_\_\_

Location: \_\_\_\_\_

Sketches: Include approximate scale.  
Illustrate character of ice cover, ice coverage, water level, etc.

1. River cross section:



2. River reach (use copy of map if available; show flow direction).

Comments on any aspect of ice quantity, quality, freezeup, breakup, jamming, weather, etc.:

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CONTACT #1:  
(Local)

CONTACT #2:  
(Corps)

CONTACT #3:  
Ice Engineering Research Division  
CRREL  
72 Lyme Road  
Hanover, NH 03755-1290  
(603) 646-4378

Figure 17 (cont'd). Nebraska ice report data collection form.



ted or slushy in appearance. Deteriorated ice may often appear darker. Pools of water may form on top of the ice, enhancing the deterioration process. Water may also run over the top of the ice as water levels increase. The shape and size of leads and cracks change as ice melts because of contact with warmer air and water. Changes in water level may also expose vertical sections of ice that can provide information on the condition of the ice. Sheet ice which has begun to deteriorate has a characteristic appearance, termed candling. Candling will occur soon after exposure to sunlight though, so it is best to check for candling soon after an ice piece is exposed.

The ice cover may be monitored remotely by satellite, although current technology is expensive, images are only occasionally available, and the resolution of the images may not be desirable. Two major satellites that could be used are Landsat (U.S.) and SPOT (European). The Landsat imagery covers an area roughly  $100 \times 100$  miles, at an approximate cost of \$4400, while the SPOT image covers an area roughly  $40 \times 40$  miles at an approximate cost of \$2500. The SPOT image offers higher resolution (or in other words, the size of the smallest distinguishable object) at 33–66 ft, while the Landsat satellite offers resolution of only 100 ft. Cloud cover can obscure the target area, rendering the collected image useless. The satellites also only pass over a specific area once every 16–18 days. A new radar system is being tested that should be able to detect areas of river ice with flowing water underneath. This technology may prove useful for detecting the location of the main channel for some mitigation techniques. However, the cost of this is unknown, and an image may not be available in time to be of use.

### **Jam formation and evolution**

Observations of ice-jam formation processes are important in evaluating the effectiveness and timing of mitigation measures. Important parameters include the location of the downstream end of the jam; conditions at the jam initiation point, such as stage, discharge and condition of ice cover, if any; any obvious cause for jam initiation, such as obstruction to ice transport by a competent ice cover; and the time of jam formation relative to the occurrence of other events such as precipitation and increases in discharge.

It is important to identify the type of ice jam at the different jam sites because different mitigation measures are suited to different types of ice

jams. Freeze-up ice jams generally occur during the early to middle part of winter, during periods of very cold weather and relatively steady discharge. Breakup jams occur from mid- to late winter and are usually associated with sudden large increases in discharge due to snowmelt or precipitation or a combination of both. Breakup jams commonly occur during periods of higher air temperatures and thaws. The dates and times of jam formation should be recorded.

Locating the downstream end of the jam (the jam toe) is essential because knowledge of the conditions at the jam initiation point (e.g. open water, solid ice cover, bridge) can help in identifying the cause(s) of the jam and in evaluating possible mitigation measures. Variability or lack of variability of the jam toe location from year to year is also important to note, since some long-term mitigation measures may rely on jam initiation at a particular location. Locating the upstream and downstream ends of an ice jam may be difficult for a ground-based observer in the Lower Platte River system, since the rivers cover a large area and access may be limited. Aerial reconnaissance would be particularly useful in obtaining this information as well as information about the appearance of the jam and locations of flooded areas.

The rate of upstream progression of an ice jam should be monitored, if possible. The location of the upstream end of the jam should be noted periodically, both to estimate progression between reaches and to aid in emergency response decision-making. Again, aerial reconnaissance provides the most complete data on ice-jam progression when access is limited. River geometry and hydraulic conditions affecting jam progression should be noted. For example, it may take several hours longer for the ice to progress upstream past a riffle than through a relatively uniform reach.

### **Other useful data**

Knowledge of the potential upstream ice supply is useful in estimating the extent, thickness and possible stages associated with an ice jam. Important parameters include the length and average width of the ice cover upstream from the jam, the extent of open water between the jam and the upstream ice cover, and the presence and stability of upstream ice jams which might be additional sources of ice to the jam. Estimates of the thickness and relative competence of any upstream ice should be made, if possible. Again, actual ice thickness measurements from the surface of an

ice cover should only be made by USGS, Corps of Engineers or CRREL personnel. The competence of an upstream ice cover might be assessed by noting the existence of cracks or leads, the presence of water on top of the ice, and whether candling is visible.

Information on stage data at different locations along an ice jam is extremely important because it is stage that determines the level of flooding. Stage data are collected at USGS gages, but it would be more useful to develop a system of staff gages within the jam reaches so that stage could be measured at several locations for each jam. A staff gage could be as simple as painted markings on a bridge pier that are monitored or photographed, or it could be as complicated as a pressure transducer connected to a data acquisition system capable of relaying the information via telephone. Monitoring of stages could be incorporated into a detection and warning system as well as the data-collection program.

Stage data can also be obtained indirectly, assuming that ice levels can be related to water levels. Ice jams can damage trees, leaving scars that can indicate the level of the ice. When ice jams move downstream, they can leave behind walls of ice along the bank, termed shear walls. The height of these shear walls can also indicate the ice levels, although if the river geometry is favorable for pushing ice upwards, the shear walls may be higher than the actual ice level. If the ice-jam flooding occurs during freezing weather, a collar of ice may form around trees or other objects. When the water recedes, the ice collar may remain. Photographs of buildings or other objects showing water or ice levels may also be used to determine stage.

## DATABASE STRUCTURE

The Nebraska Natural Resources Commission (NRC) was tasked with providing a database structure to allow easy entry and retrieval of information collected by the ice observers. The NRC will set up each branch site and provide training for entering the ice data, transferring the data to the home base, and retrieving data on-line or through file transfer. The Commission will also serve as the long-term ice-data repository. A conceptual overview of the connectivity between the NRC (the home base) and other agencies responsible for data collection and retrieval (branch sites) is shown in Figure 18.

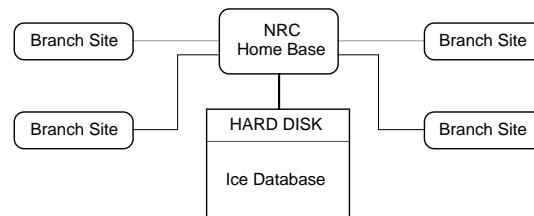


Figure 18. System connectivity.

The home base will act as the repository for the Ice Report data. The database format and design is standardized by the home base. It provides the means (using Microsoft Access) for all the branch sites to enter their local ice data. These local files uploaded by the branch sites to the home base are merged into one main database. The home base also is responsible for system administration, log tracking, data backups and security of the main database. The minimum requirements for the home base are a 486/66-MHz PC with 16 mb of RAM, a 500-mb hard disk, a 14.4-kbps modem, Internet connectivity using a bridge/router with TCP/IP software, Microsoft Access software (version 2.0) and PC Anywhere software (version 4.5).

Observers at the branch sites will enter their Ice Report data on their local PC using the Microsoft Access program provided by the home base. That program also allows them to automatically transfer the updated and newly added data to the home base. The branch sites have the capability to retrieve both raw and processed data from the home base. The branch site is responsible for the system administration, security and backup of their local data. Minimum requirements for a branch site are a 386/33-MHz PC, with 8 mb of RAM, a 200-mb hard disk, a 14.4-kbps modem or Internet connectivity using a bridge/router with TCP/IP software, Microsoft Access software (version 2.0) and PC Anywhere software (version 4.5).

Figure 19 shows how data transfer can be achieved from the branch site to the home base using either a modem or Internet connection. Each branch site is assigned a directory at the home base. The branch site will transfer updated or newly added data to the home base over the modem or through the Internet to an assigned directory. The home base monitors these branch directories and merges the uploaded data into the main database automatically.

The two ways for a branch site to retrieve data from the home base are by on-line access or by downloading the complete database. Each method has its advantages and disadvantages. Access-

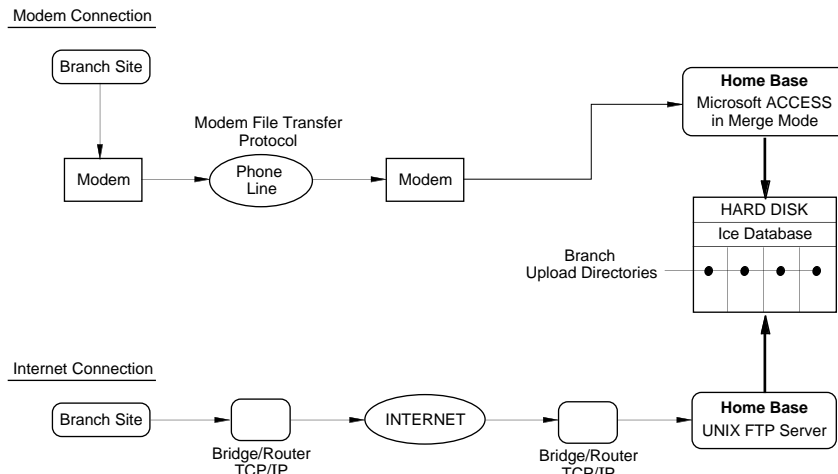


Figure 19. Schematic of data transfer from branch site to home base.

ing data on line allows the branch site to work directly with the data residing at the home base. It can be done over a modem using software such as PC Anywhere, which allows the branch site to control the home base PC, transferring only screen outputs and keyboard and mouse inputs instead of the entire data set. All the data processing is done at the home base.

The data can be accessed over the Internet through the Network File System (NFS) mechanism. This technique of remote access makes the database files at the home base appear as local files to the branch site, which can be directly processed by the Microsoft Access software at the branch site. A schematic of each method is included in Figure 20. The advantages of on-line access through the Internet are that direct access to the latest data at the home base is possible, any

number of users on the Internet can share the database, and session time is reduced because the entire data set is not transferred. The disadvantages of on-line access are that only one user can use the modem link at a time, on-line communication cost is based on the session time over the modem link, and processing data over a slow Internet link (56 bps) for queries and reports can be time consuming.

Figure 21 is a schematic of the second method of working with data at the branch site: transferring the main database file from the home base to the branch site and then processing it locally without being connected to the home base. The advantages of a complete data transfer are that data are available locally for fast searches, data can be modified and processed locally for custom reports, and there is only a one-time

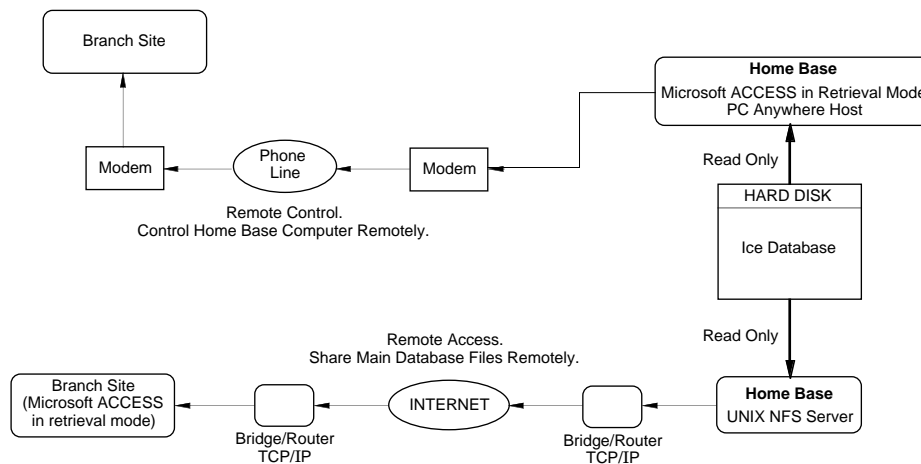


Figure 20. Schematic of on-line data retrieval at branch site.

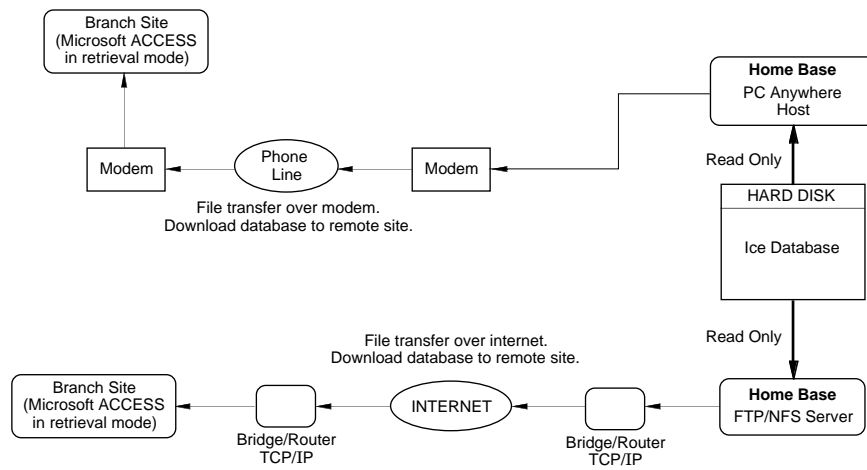


Figure 21. Schematic of complete data download before processing.

communication cost for downloading (no session costs). The disadvantages are that data may need to be downloaded repeatedly to stay current, and local changes to the database are not reflected at the home base.

## ICE JAM MITIGATION MEASURES

A number of ice jam flood mitigation measures are possible, depending on the type, length, thickness and accessibility of the jam and the available equipment, personnel and budget. These measures may be broadly labeled as structural or nonstructural; as measures appropriate to control breakup or freeze-up jams; and finally, as measures that are permanent, deployed in advance of an anticipated flood threat, or deployed under emergency conditions when a jam has formed and flooding has occurred. A brief overview of possible mitigation measures is followed by a discussion of measures that might be applied in the study area.

Structural measures for ice-jam control, such as levees, dikes and floodwalls, may incorporate features that can be used to alleviate open-water flooding as well. The costs of such measures include construction, operation and land acquisition, as well as costs associated with recreation and environmental mitigation. Unfortunately, while they are often very successful, structural solutions tend to be expensive, and current budget climates make their funding less likely. They remain appropriate for rivers where chronic or particularly serious threats persist and where the

extent of damages justifies their cost. Although the majority of the structural mitigation techniques are, by their very nature, permanent, some are designed to be removable. These removable structures are usually installed at the beginning of winter and removed after spring breakup, when the threat of ice-jam flooding no longer exists.

Nonstructural measures are those that modify vulnerability to flooding or reduce the severity of ice-jam-related floods. They are generally less expensive than structural solutions. The majority of the nonstructural techniques are used for advance and emergency measures when serious ice-jam flooding is imminent or already occurring. For example, ice weakening (ice cutting or dusting) may be implemented before an ice jam occurs, if sufficient warning is provided, while blasting and mechanical removal are often employed as emergency mitigation measures once ice jams have occurred. On the other hand, the creation of ice-storage zones upstream from a known jam site (to minimize the amount of ice reaching the jam site) can be considered a permanent measure, since these areas, once established and properly maintained, can be used year after year.

Freeze-up ice-jam control usually targets the production and transport of the frazil ice which makes up the jam. This may be accomplished by encouraging the growth of an ice cover, which insulates the water beneath, decreasing the production of frazil ice. The ice cover can also incorporate frazil ice which is transported from upstream production areas, decreasing the supply available to jam or deposit beneath a downstream ice cover.

**Table 16. Ice-jam mitigation methods.**

<i>Technique</i>	<i>Jam type</i>	<i>Type of mitigation</i>
<b>a. Structural</b>		
Dikes, levees, floodwalls	F,B	P
Dams and weirs	F,B	P
Ice booms	F,B	P,A
Retention structures	F,B	P
Channel modifications	F,B	P
Floodproofing	F,B	P,A
Ice storage zones	B	P,A
<b>b. Nonstructural</b>		
Forecasting	F,B	A,P
Monitoring and detection	F,B	E,A,P
Thermal control	F,B	E,A,P
Land management	F,B	P
Ice cutting	B	A
Operational procedures	F,B	E,A,P
Dusting	F,B	E,A
Ice breaking	F,B	E,A
Mechanical removal	F,B	E,A
Blasting	F,B	E,A
<b>c. Traditional techniques</b>		
Floodproofing		P
Sandbagging		A,E
Evacuation		A,E
Levee closing		A,E

F = Freeze-up jam  
 B = Breakup jam  
 P = Permanent measure  
 A = Advance measure  
 E = Emergency measure

Breakup ice-jam control focuses on affecting the timing of the ice-cover breakup (thereby reducing the severity of the resulting jam to the point where little or no flooding occurs) or controlling the location of the ice jam by forcing the jam to occur in an area where flooding damages will be inconsequential, or at least acceptable.

Table 16 summarizes the currently available jam mitigation techniques. In the following sections, these methods are described in some detail. Traditional flood-fighting methods, namely floodproofing, sandbagging, levee closing or evacuation, are obviously applicable to ice-jam floods. Table 17 lists common ice-jam mitigation strategies and corresponding techniques.

**Permanent measures**

Dikes, levees and floodwalls physically separate the river from property to be protected. These are used to protect against open-water floods as well as ice-jam floods. However, designs adequate for open-water protection may not be adequate for the stages and physical damage caused by ice jams.

**Table 17. Ice-jam mitigation strategies.**

1. Protect surrounding areas from flood damages
  - Dikes, levees, and floodwalls
  - Floodproofing
  - Floodplain land use management
  - Flow diversion
  - Sandbagging
  - Levee closing
  - Evacuation
2. Reduce ice supply
  - Thermal control
  - Revised operational procedures
  - Ice booms
  - Dams and weirs
  - Ice storage zones
  - Ice retention
3. Increase river ice and water conveyance
  - Channel modifications
  - Revised operational procedures
4. Control ice breakup sequence
  - Detection and prediction
  - Ice booms
  - Ice retention
  - Dusting
  - Ice cutting
  - Icebreaking
  - Revised operational procedures
5. Displace ice jam initiation location
  - Dams and weirs
  - Ice piers, boulders and cribs
  - Ice booms
  - Channel modifications
  - Dusting
  - Ice cutting
  - Icebreaking
6. Remove ice
  - Thermal control
  - Ice breaking
  - Mechanical removal
  - Blasting

Ice booms are the most widely used type of ice-control structure. They are relatively inexpensive and can be placed seasonally, thus decreasing environmental impacts. Booms are most commonly used to stabilize or retain an ice cover in areas where surface water velocities are 2.5 ft/s or less and relatively steady. Ice-control booms are also used to promote ice-cover formation during freeze-up as an ice-jam mitigation effort. They can be placed to direct ice pieces away from an intake or navigation channel.

Breakup ice-jam frequency and flood levels can be reduced by storing ice upstream from damage-prone areas. Ice-storage zones reduce the volume and/or rate of ice moving to a downstream jam

location. By developing low overbank areas where ice can easily leave the channel during breakup, perhaps supplemented by dikes or booms to redirect ice movement, the volume of ice passing downstream can be substantially reduced. The ice left behind settles in side channels, on floodplains or on the riverbanks.

Diversion channels can be built to bypass ice and water flow around the normal jamming sites, lowering the upstream stage. If such diversion channels are used, they should be designed to remain dry except during flood events so they will be available to function as open-water channels and not add to the ice supply reaching downstream ice-jam sites.

Ice-retention structures are used to control freeze-up or breakup jams by promoting the initiation of an ice jam at a suitable location where flooding will create little or no damage. Fragmented ice is captured and retained upstream from the retention structure to create the ice jam. A variety of structures can serve as ice-retention structures, ranging from suspended structures such as a submarine net, to structures that project from the streambed, such as concrete piers placed at regular intervals across the stream. Provision for ice-storage zones or diversion channels may also be required to limit the rise in upstream water level and corresponding load on the structure elements as well as the upstream flooding potential. Suspended structures are generally more suited to smaller rivers and streams. Bed and bank scour must be considered in the design of ice-retention structures.

Thermal control of ice jams uses an existing source of warm water to melt or thin a downstream ice cover or ice jam. Water even a fraction of a degree above freezing can be quite effective in melting ice over a period of days or weeks (Wuebben and Gagnon 1995). External heat sources include cooling water effluent from thermal power plants, wastewater treatment plant effluent and groundwater. The thermal reserve provided by water in nearby lakes and large reservoirs may also be a source of warm water for thermal control. Because water reaches its maximum density at about 39°F, colder water in lakes tends to stratify above warmer water. An ice cover can form on the water surface even though the water at depth is still well above freezing. Warm water can be brought to the surface using air bubbles, pumps or flow enhancers, or a low-level outlet in a dam may be used to release warm water.

Perhaps the best strategy for reducing flood losses is to keep people and property out of the floodplains. Proper land-use planning would dramatically reduce the flood damage potential. This is particularly valuable in areas which experience chronic flooding. If such land-use regulation is not feasible, floodproofing should be considered. There are four basic types of floodproofing to minimize damage to individual structures during floods: raising or relocating a building, barrier construction, dry floodproofing and wet floodproofing. Specific techniques of floodproofing are presented in the U.S. Army Corps of Engineers manual on floodproofing, *Flood Proofing Techniques, Programs and References* (USACE 1991).

#### **Advance measures**

Mitigation measures that are put into place in anticipation of actual ice-jam flooding are known as advance measures. Some emergency measures, such as ice removal, may also be initiated in advance of flooding. Monitoring and detection should be addressed in any ice-jam mitigation effort. Ice-cover breakup, jam formation and jam progression are particularly important processes to monitor. Simple remote gages to collect data on river-ice movement and breakup are useful. Water-level gages can be monitored to detect rapid increases in river stage, which often precede ice breakup. Automated temperature sensors help to verify whether conditions are conducive to ice-jam formation or breakup.

Ice motion detectors can be imbedded in intact ice covers prior to breakup to warn of the initiation of breakup upstream from a likely jam site. These can be connected to inexpensive burglar alarm units that will automatically dial preselected telephone numbers when the unit detects ice motion (Fig. 22), or existing USGS gages can be augmented with telemetry transmitters that send ice motion data directly to a local monitoring center or to State and Federal agencies (e.g., NWS or USGS) either through telephone, radio or satellite (Zufelt 1993).

Ice cutting involves creating slots in the ice, either mechanically, using a chainsaw, trenching machine, backhoe or other convenient device, or thermally, using warm water or a substance that reacts chemically with the ice, melting it. The slots can be made to a partial depth or can extend the full depth of the ice. They may follow the natural thalweg of the river channel, be cut along the edges of the channel to facilitate movement of the ice sheet, or be cut into the ice in a pattern de-

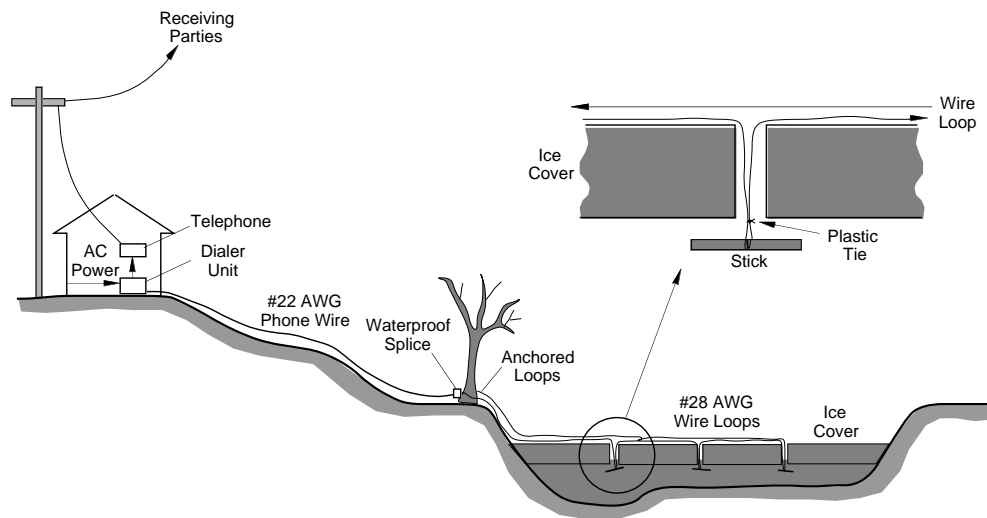


Figure 22. Ice motion detector.

signed to weaken it. Ice cutting must be carefully timed to avoid refreezing of the slots. This technique may be used to cause a stable ice sheet to break up earlier than normal, preventing it from obstructing the movement of upstream ice. Ice cutting in selected locations can also create a flow path for ice and water at breakup, reducing the probability of jamming.

Ice covers can be broken prior to natural breakup using icebreaking vessels or construction equipment. The downstream movement of the broken ice should be enhanced to prevent localized breakup ice jams. Air cushion vehicles (ACVs) can be used to break large extents of relatively smooth sheet ice covers, usually in areas where the sheet ice may stop the ice run and initiate a jam. The advantages of an ACV are its speed and maneuverability and its ability to operate in shallow areas. The disadvantages are that it simply breaks the ice but does not move it, it cannot operate over rough ice accumulations because of potential damages to its flexible skirts, and operations in cold weather can lead to severe icing of the propulsion system. Also, the ACV must be quite large; the smaller 2- or 4-person ACVs will not break ice of average thickness in the Platte River.

Dusting, or covering ice surfaces with a thin layer of dark material, induces more rapid melting and ice weakening. Conventional materials include coal dust, fly ash, topsoil, sand or riverbed material. Initial tests with biodegradable materials such as leaves, mulch and bark show promising results. This type of material is more easily spread by commercially available seeders and

spreaders than sand or coal dust. These materials must be dry enough to flow freely for even distribution and to avoid freezing. Wind can be a problem, causing the fine materials to drift or the snow to drift over the dust (Moor and Watson 1971).

The dusting material is usually applied two to three weeks prior to breakup. The degree of melting depends on the quantity and properties of the material deposited, solar radiation and snowstorms. In areas where late snowstorms occur, several applications may be necessary, although snow of moderate depth over a dark material will melt at an accelerated rate. The melting period may be too short for significant reduction in ice volume or weakening if breakup occurs soon after application. Whatever material is used, the possible adverse environmental impacts of dusting must be considered prior to application. The use of dusting as a mitigation measure within the study area is discussed in detail below.

#### Emergency measures

Emergency measures are those that are taken after an ice jam has formed and flooding is imminent or already occurring. The effectiveness of emergency response may be reduced unless an emergency action plan exists that specifically refers to ice jams. Comprehensive emergency management includes four phases: preparedness, response, recovery and mitigation. Emergency planners should have a clear line of command for multi-governmental management of ice-jam flooding events. Plans should be tested in advance to be sure that all phases can be carried out and that all necessary materials and equipment are avail-

able when needed. The Nebraska Disaster and Civil Defense Act is attached in Appendix C for reference. The act defines the legislated powers and duties of the Nebraska State Civil Defense Agency. Appendix D contains a legal opinion drafted by the State indicating that both the State and its political subdivisions are essentially protected from liability if emergency measures are in accordance with the Nebraska Disaster and Civil Defense Act and an emergency has been declared.

Prior to implementing emergency measures, it is necessary to monitor the river ice conditions upstream as well as downstream from the jam site to select the best measures and to eliminate those that may only displace the flooding problem to another location. Early ice monitoring can also provide some lead time to allow other emergency measures to be taken. Downstream ice conditions also need to be assessed, if only to determine whether there is sufficient open-water area to receive ice when the jam releases.

If ice-jam flooding has been predicted, levees should be closed immediately and interior drainage pumps should be prepared for possible activation. Again, winter weather conditions such as snowdrifts or frozen valves, which can hinder levee closing, should be identified. Monitoring of water levels at levees may aid in identifying possible overflow sites before serious damage can occur.

Although ice can cause significant damage to sandbags used as protective barriers, the use of sandbagging as an emergency response measure can be very effective in reducing damages at particular facilities or locations. For example, sandbagging around sewage treatment plants or low points on roads or riverbanks can significantly reduce flood losses. Overbank flow may be channeled away from flood damage areas using temporary levees constructed of sandbags.

Ice-jam emergency response measures include icebreaking, mechanical ice removal and ice blasting, in addition to the traditional flood-fighting efforts of evacuation, levee closing and sandbagging, all of which also qualify as advance measures. The principle behind evacuation is to move people at risk from a place of relative danger to a place of relative safety via a route that does not pose significant danger. Local law enforcement departments usually serve as lead organizations and have standard operating procedures. Winter weather conditions should be taken into account when planning evacuation timing, equipment and routes.

Construction equipment can be used to break up an ice cover or an existing jam, either from the shore or, if the ice is safe, from the river itself. It is generally best to begin working from the downstream end of the ice cover toward the upstream end so that the broken ice will be carried away. A heavy weight or wrecking ball can be dropped repeatedly on the ice surface to break up the ice. Ice can be broken either to form a channel or to weaken the ice in specific locations.

Mechanical removal involves taking the ice out of the river and placing it elsewhere using bulldozers, backhoes, excavators or draglines, starting from the downstream end of the ice accumulation. This approach is most effective on small rivers and streams because of the time required to excavate and because of additional safety concerns associated with wide or deep rivers. Mechanical removal can be expensive and slow but also quite effective. Access to the jam site by heavy equipment is frequently an impediment to mechanical removal of ice.

Often a popular solution to ice-jam problems, blasting breaks up an ice cover or loosens an ice jam so that it is free to move. Absolute prerequisites to successful blasting are that enough flow is passing down the river to transport the ice away from the site and that sufficient open-water area exists downstream to receive the ice. Otherwise, the ice will simply rejam elsewhere and cause problems for another community. Blasting has been used to create a relief channel within a grounded jam to pass water and decrease the upstream water level. As with icebreaking and mechanical removal, it is recommended that blasting proceed upstream from the toe of the jam. Safety and environmental concerns must be addressed before implementation (USACE 1982).

#### **Specific mitigation options within the study area**

The choice of mitigation options for a particular ice-jam location depends on a number of factors, including the characteristics of the ice jam, weather, access and budget. Local residents and officials, who are most familiar with the jam, should be involved in selecting appropriate mitigation measures. Applying traditional flood mitigation techniques (e.g. floodproofing, sandbagging, evacuation and levee closing) should be considered for areas affected by ice-jam flooding.

Increased monitoring and detection of ice conditions, breakup and jamming is a nonstructural mitigation option that should be implemented at



every ice-jam location within the study area. The ice monitoring conducted under the aegis of the Nebraska NRC should prove useful in the early detection of ice breakup. The use of ice-motion detectors will provide warning at a number of locations in the study area. For example, a series of ice-motion detectors on the Loup River upstream from Columbus will provide information on the timing and location of ice breakup, which can contribute to damaging jams at Columbus. Knowledge of ice conditions on the Loup and Platte Rivers downstream from Columbus and estimates of broken ice volumes could be used to assess the damage potential of a jam. The additional lead time provided by ice-motion detectors will increase the effectiveness of early warning and other advance measures, such as sandbagging or evacuation. Emergency measures such as blasting or ice removal are most effective if they are begun soon after a jam has formed, so early detection is very important if such measures are contemplated. Particular locations that would benefit from the use of ice-motion detectors include the Loup River near Columbus and the Platte River and lower Elkhorn River in the vicinity of their confluence.

Water-stage recorders can also be used to alert authorities when the stage reaches a certain level or increases rapidly. Water-stage recorders could be used singly or in conjunction with ice motion detectors to provide early warning. Placing water-stage recorders both upstream and downstream from a known ice-jam location will allow the observer to detect the formation of a jam which causes backwater. If such an installation is not possible, jam formation can also be detected by combining discharge data from USGS gages and information from a single water-stage recorder upstream from a known jam location. Two likely sites for water-stage recorders are Big Island and Columbus.

Other nonstructural ice-jam mitigation measures that are suitable for application within the study area are dusting, icebreaking, mechanical removal and blasting. The formation and progression characteristics of a particular jam must be known in order to design an effective plan of application. Dusting is best used when the ice jam is caused by a competent ice sheet that impedes the movement of broken ice. Icebreaking, mechanical removal and blasting can be used to create a channel through a competent ice cover or through a jam to increase flow and ice conveyance.

The application of structural ice-jam mitigation

techniques within the study area requires more detailed analysis than is possible within the scope of the present study. The available information suggests that levees could prove effective in the Big Island area. The existing levee at Leshara should be evaluated to see what improvements might increase its level of protection. An ice boom located just upstream from the Loup River Power Canal headworks could provide frazil-ice control, which would decrease somewhat the amount of ice available to downstream jams and might result in more efficient operation of the canal. The effects of the canal operation must be studied in detail before any conclusion can be reached as to the impacts of fluctuations in stage and discharge on the Loup River.

#### *Ice dusting as a mitigation alternative*

Ice dusting refers to the practice of spreading solid material on top of the ice surface to accelerate melting and decay of the ice. Dusting was performed on the Platte River in 1979 at four locations (USAED, Omaha 1979). The dusting operation was done under the direction of the Nebraska Civil Defense Office and the Omaha District Corps of Engineers; the Cold Regions Research and Engineering Laboratory (CRREL) provided technical assistance. The ice on the Platte River just prior to breakup was as much as 3 ft thick in 1979, and the snowpack water equivalent was estimated at 2.5–3 inches in late February. The results of the dusting were inconclusive because of the insufficient time between dusting and breakup, especially at the mouth of Salt Creek, where breakup occurred two days after application. The report noted that there may have been some positive effect in that no significant jamming problems occurred at the dusting sites, which had historically been problem areas, and jamming occurred at other sites that were not dusted. The report did conclude that dusting will reduce the strength of river ice and reduce the problem of jamming if an adequate time elapses between dusting and breakup.

*Materials.* The material used in 1979 for dusting was black-bottom slag from the Nebraska Public Power District power plant at Hallam, Nebraska. This material was chosen because of its dark color and relatively low cost. The target application rate was 0.5 lb/yd<sup>2</sup>, and it was applied using airplanes equipped with crop-dusting equipment. The material was chemically analyzed for environmental reasons (Table 18). If this material is

**Table 18. Constituents of 1979 dusting material.**

<i>Ingredient</i>	<i>Amount % by weight</i>
Silica	50.00
Phosphorus pentoxide	0.25
Ferric oxide	7.50
Alumina	21.30
Titania	1.07
Lime	7.50
Magnesia	2.24
Sulfur trioxide	7.70
Potassium oxide	1.70
Sodium	0.20
Undetermined	0.54

used again for dusting, it should be chemically analyzed again, since plant operations or fuel source have changed since 1979.

Small-diameter particles are more desirable because, for a given weight, the smaller particles will cover a larger ice area than larger-diameter particles. However, if particles are too small, they may be blown off the target area before penetrating the ice cover. If particles are too large, they may clog the spreader on the airplane. Bolsenga (1968) cited Williams and Gold (1963), who stated that field experience had shown the practical range in particle size was 0.004–1.0 inches. The material used in 1979 had fewer than 1% by weight outside this size range. Bolsenga also cited Konov-alov and Miasnikov (1956), who recommended particle sizes of 0.008–0.02 inches. However, it would probably be prohibitively expensive to screen bottom slag to this fine gradation (only 15% of the material used in 1979 was this fine). The areal concentration in the past has varied from 0.01 to 0.08 lb/ft<sup>2</sup> (Bolsenga 1968); for comparison, the application rate in 1979 was 0.02 lb/ft<sup>2</sup>. Generally the lighter application rates were associated with smaller-diameter and less-dense particles.

Materials used in the past have included sand, soil, coal dust, soot, fly ash, bottom slag, foundry loam, phosphate fertilizer, potassium salt, calcium chloride, ammonium nitrate or mixtures of the above (Bolsenga 1968). Some of these materials may not be environmentally acceptable today. Dyes and powders in the form of a spray could be used in areas where the cost of transporting and applying dust is high, but these materials are not as effective. Recently various agricultural products, such as grain, feed and fertilizer, have been approved in certain areas, as these items are found

in waterways from non-point pollution sources in nonharmful levels. Another material that has recently been tried is leaf mulch (Haynes et al. 1994).

*Equipment.* The dust was applied by means of crop-dusting airplanes in 1979. This was considered the only practical means of distributing the material on the ice in a short time. Aircraft have been the most commonly used method of application in other areas of the country and world as well. Dusting in Alaska has been done with B-25 (USAED, Alaska 1968, 1969) and B-26 (Meyer 1976) aircraft outfitted with gravity-flow hoppers. Helicopters have also been used, with the helicopter carrying a hopper-type spreader. The crop-dusting airplanes used in 1979 were outfitted with rectangular-shaped venturi-type funnels.

It is necessary to secure a means by which to load the aircraft. In 1979 the material was put into a plastic funnel-shaped bag with a 6-in. circular bottom discharge port, which was hoisted above the airplane hopper with a crane. The report on the 1979 dusting recommended using augers to load the material into the airplane; however, the material may be excessively abrasive on auger flights. Another option which may be less affected by abrasive material may be a portable elevator flight.

The areas to be dusted must be marked for the pilots' benefit. In the 1979 dusting operation, flight paths were delineated with neon orange road cones by using two cones to mark the beginning and end of the path and individual cones at several intermediate points. The cones were placed by helicopter.

*Timing of application.* The 1979 Platte River dusting operations were performed from 28 February to 2 March, which was about a week later than initially recommended based on experience. The date will vary from year to year, depending on weather conditions, such as snowfall or rainfall, amount of sun and temperature. The recommended time of application in 1979 was for three weeks prior to breakup. The report concluded that dusting should be done three to four weeks prior to breakup, with trouble spots dusted even earlier.

Cavan (1969) stated that dusting should generally be carried out just before natural break-up starts and that dusting is most effective when the air temperature is 32°F or higher. Williams (1967), as cited by Bolsenga (1969), reported that dusting much before breakup is usually not worthwhile because periods of freezing weather following dusting freezes the meltwater produced. However, others have noted that the particles create tun-

nels in the ice surface, which, if filled with water and then frozen, tend to further break the ice since water expands when frozen. Most dusting in the past has been done much farther north than Nebraska, so it is difficult to extrapolate timing since Nebraska warms up quicker and the sun angle gets higher sooner. The most critical aspects of timing, though, appear to be adequate sunshine, near- or above-freezing temperatures and lack of snowfall for several days following application. It is best to study past climate data to determine the earliest that dusting can be effective.

Dust can be applied far in advance of breakup if the intent is to weaken a midwinter jam that freezes in place. Midwinter jams may not be very damaging at the time of formation but can cause great damage at normal breakup if they freeze in place and block a large portion of the flow channel. Dusting can weaken the ice and reduce the volume in a midwinter jam enough so that it does not pose a problem later. The rate of melting will not be as effective as later, but since jams tend to be several times thicker than the ice blocks composing it, more time is required to thin the ice. Multiple applications may be necessary because of the thickness and subsequent snowfalls. The ice in some rivers may contain sediment that gives it a dirty appearance and will accelerate the melting of this ice in a jam. Dusting to melt normal spring breakup jams has not proven very effective because it generally takes too long to thin the ice before damaging flooding occurs.

*Planning an ice-dusting operation.* Planning for an ice-dusting operation is essential since weather conditions may limit the window of opportunity for applying dust. It is important to have the

material and equipment lined up ahead of time. This does not mean actually having the equipment on hand but being able to mobilize operations in a short time. It is imperative to identify the sites most likely requiring dusting ahead of time, as resources and time are likely to be limited. Plans for dusting the Platte have been developed twice since 1979. The State of Nebraska requested initial technical planning assistance for dusting operations from the Corps of Engineers in 1980 and 1982. Dusting was not carried out in either year because weather conditions became favorable for natural melting prior to breakup, although some ice jamming did occur. Table 19 summarizes the sites and materials required for the ice-dusting operation planned in 1982. Eventually shorter or fewer strips were planned to reduce the cost of dusting, but dusting was not done. The dusting strips were chosen on the basis of historical ice-jamming problems. The effort that went into planning these two proposed ventures should serve as a guide for planning future dusting operations. Other items should be incorporated to form an overall plan of action for dusting. The following is intended as a checklist in planning dusting operations, and a chart for estimating the cost of the operation is also included.

1) *Identify sites for dusting.* Sites of recurring historical jamming problems should always be identified as possible dusting sites. The need for dusting these various sites may vary from year to year, depending on conditions such as ice thickness and amount of open water. If possible, these recurring jam sites should have aerial photography done just prior to freeze-up to identify the location of the main channel or channels. Dusting

**Table 19. Example dusting plan for the lower Platte River based on the 1982 plan. All flight information is based on using Wahoo Airport as a base of operations.**

Site no.	Location	Strip length (ft)	Cinder (tons)*	Distance one way (miles)	Number of passes (3 planes)	Time for each pass†	Total time (3 planes)
1	Louisville	9,000	7.5	27	4	47.4 min	3 hr 10 min
2**	I-80\Salt Creek	16,000	13.3	22	7	41.4 min	4 hr 50 min
3**	HWY #6 Bridge	5,200	4.4	19	2	37.8 min	1 hr 15 min
4**	Elkhorn Exit	6,500	5.4	17	3	35.4 min	1 hr 45 min
5	Two Rivers	6,000	5.0	12	3	29.4 min	1 hr 28 min
6**	Ford Farm	14,000	12.0	13	6	28.6 min	2 hr 52 min
7	Fremont	10,500	8.8	14	5	31.2 min	2 hr 36 min
8	C&NW Bridge	10,600	8.8	13	5	30.6 min	2 hr 33 min
9	North Bend	6,000	5.0	18	3	36.6 min	1 hr 50 min

\* Based on concentration of 0.5 lb per sq yard.

† Includes 15 minutes for landing, taxiing, loading, fueling, etc.

\*\* Sites dusted in 1979.

should be done from just downstream of the usual jam location to upstream of the jam location, so maps showing the probable maximum upstream and downstream ends of dusting should be prepared and on file. Maps showing the proposed 1982 dusting sites are on file in the Hydraulics Section of U.S. Army Engineer District, Omaha.

2) *Identify dusting material, availability and suitability.* There are many suitable materials available for dusting, but not all may be available as needed on short notice. A ready source of dusting material should be identified. Dry material works best, so it is important that a means of drying the material be secured if necessary. The selected source of material should be contacted every year to assure that the required material can be delivered if needed. Alternate materials should be identified ahead of time in case the selected material is unexpectedly unavailable or is designated as environmentally unacceptable.

3) *Identify needed equipment.* Equipment needs and availability should be identified ahead of time. This includes airplanes or helicopters equipped for dusting, a means of conveying the dusting material into the aircraft holding bay, and a means of marking the dusting strips. An airport that is central to the dusting sites should be identified as a base of operations, and permission to use the airport should also be secured.

4) *Estimate the cost of planned dusting operations.* Unit costs of materials and equipment should be periodically verified and updated if necessary. Table 20 is designed to be used to assist in estimating operation costs. It is also helpful for identifying areas where dusting efforts can be cut back if funding is limited.

5) *Secure any applicable permits prior to the operation.* Permit requirements will vary state by state but will generally include some review by local, state and Federal environmental agencies. USAED, Omaha (1994) provided a complete discussion on potentially applicable Federal regulations. In this case the Nebraska Department of Environmental Quality determined that the planned 1994 dusting would have no significant environmental impact and did not require a permit.

#### *Summary of 1994 ice dusting*

Three locations on the Platte River were dusted on 3 and 4 March 1994. The locations dusted were:

- From Highway 64 bridge to about 3 miles upstream;
- Both channels upstream of the Highway 92

bridge to about 1.25 miles upstream; and

- About 1 mile downstream of the Highway 92 bridge to about 1.5 miles downstream of the Highway 92 bridge.

These three sites were selected based on previous jamming locations and on aerial reconnaissance flights on 5, 16 and 25 February. A brief warm-up in mid-February broke up the lower Elkhorn River ice and cleared most of the Platte below the Elkhorn. However, the river remained mostly ice-covered above the Elkhorn, and the ice showed few signs of deterioration at that time. By the end of February, river-ice thickness still exceeded 2 ft along Union Dike.

A decision to dust was made on 28 February, and plans were finalized by 2 March. A rapid warm-up began on 1 March and continued for several days. The ice began to rapidly deteriorate with the warmup as the remaining snow cover melted and began to crack following completion of the dusting operation. The dusting operation used material from the same source as in 1979. Three aircraft were used to apply the material. Larger pieces of material applied after noon on 3 March were observed to have penetrated the ice surface by as much as 4 inches by 5:00 p.m. the same day. Smaller particles did not penetrate as rapidly but made up the bulk of the material applied. The dusted strips showed significant decay, but the surrounding ice deteriorated rapidly as well. The Platte River above the Elkhorn began breaking up on 6 March with increasing flows, and no ice jams were reported in the areas dusted, although an ice jam causing minor overbank flows was reported about one mile upstream of the uppermost dusting site.\* No damage was reported.

#### *Blasting as a mitigation alternative*

Blasting should be considered only as a last alternative to ice-jam removal because of cost and safety reasons. Explosives have been widely used in ice and ice-jam removal in many countries, with widely varying results. Explosives used in the past have included TNT, dynamite, C-4, C-3, tetrytol, ammonium nitrate-fuel oil (ANFO), ammonite, black powder, thermite and even bombs and rockets. The relative effectiveness of various explosives varies. Often the explosive used has been

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\* Information from DATACOL (now called HYDRO-MET), the daily output of the NWS River Forecast Center and Pleasant Hills, Kansas.



chosen as a matter of convenience, in terms of availability and cost. This report will discuss previous uses of explosives in Nebraska, steps to take before and during blasting operations, selecting proper charge sizes and placement, and estimating the quantity of explosives needed and the time required.

The use of explosives to clear ice can be dated back to Germany in 1758, when bombs were affixed below the ice and exploded (Bolsenga 1968). Several researchers have studied blasting effects on floating ice sheets (Van der Kley 1965, Mellor 1986, 1987), but there is little quantitative information available regarding blasting of ice jams. Duego (1973) noted that thermally grown ice is relatively easy to break up by blasting, while frazil ice is more difficult to break up since it absorbs much of the blast energy. The guidance available for blasting ice sheets can be useful in designing an ice jam blasting plan, as long as the additional difficulties posed by ice jams are taken into account. These include the fact that placement of charges will be more difficult and hazardous, and less exact, in an ice jam than in a stable ice sheet. Also, the varying thickness, ice strength and porosity in an ice jam will cause more of the explosive energy to be absorbed than would be the case in a uniform ice sheet, and therefore the crater size will be smaller. At a minimum, one would expect to use more and larger charges to achieve the same effect in an ice jam as in an ice sheet.

Explosives have been used to break up ice jams in Nebraska and surrounding states since at least the 1920s, with varying degrees of success. Some known applications of blasting for ice jam mitigation in Nebraska and the results, if known, are presented below.

*Missouri River, 1946.* Tests were conducted in 1946 by several agencies, including Corps of Engineers employees in the Omaha District, to test the effectiveness of ice-jam removal on the Missouri River by means of various explosives. Moran (1946) described efforts to remove an ice jam near Corning, Missouri, on 8 and 9 February 1946. Weights and then live charges were dropped from a helicopter to demonstrate the feasibility and safety of such an operation. Following this, 15 charges of Composition C-3 ranging from 36 to 160 lb were dropped on the ice jam from a helicopter. However, the jam was resting on a bar, and Moran observed "there was little or no flow under or through the ice to aid its movement when loosened." Following this, tests were conducted to determine the accuracy of dropping charges

from an airplane flying at about 65 mph at an altitude of less than 20 ft. The accuracy of dropping charges in this manner was not as good as when a helicopter is used, although accuracy improved with practice.

An ice jam in DeSoto Bend (prior to the bend cut-off) was broken up using T37 rockets (7.2-inch demolition rockets) and hand charges of Composition C-3. The rockets carried a 32.5-lb charge of explosive in a steel casing, propelled by a motor unit. The rockets had a maximum range of 300 yd and exploded upon impact. Eight rockets were used on 23 February to break up the ice jam. Four rockets were used on sheet ice 6–8 inches in thickness. No appreciable effect was noticed from the first three rockets, but immediately following the fourth rocket the sheet ice broke loose 1000 ft upstream of the target area, and a 1500-ft section of sheet ice approximately 500 ft wide moved out. Hand charges were then used on the remaining sheet ice below the jam. The ice was too rotten to walk on, so the charges were cast out onto the ice from the shore. One 10-lb charge and 13 charges from 4.5 to 6.75 lb were tossed 50–100 ft out onto the ice at one- to five-minute intervals. Following a series of two to four charges, a crack would open up across the channel at a distance 100–300 ft upstream of the last hole produced, and a large section of ice would then break away. Rockets were then fired at the heavier jammed ice upstream (six hand charges had been tried but they had no discernible effect). The first two rockets produced no discernible breaking effect, but the third rocket started ice movement approximately 1500 ft upstream. A fourth rocket was used merely to hasten the breakup.

Rockets and hand charges were also used on an ice jam on 26 and 27 February at Tieville Bend near Decatur but with less success. The hand charges were thrown from the bank and were used along a dike system. The ice was loosened but did not move out. Charges were then placed from a skiff, and the ice began moving through the dike system. The next day fifty-two 18.5-lb charges were used to break the ice clear of the dike system. Hand charges were also used to clear 1.14 miles of the main channel of sheet ice. The charges broke the ice, but the flow was very slow, so it was necessary to start the broken ice downstream from the propeller wash of the outboard motor on the skiff. It was also necessary to place additional charges downstream along the dike system to prevent the ice from jamming there. Additional charges were placed from the motorboat when the

charges could not be thrown far enough out onto the ice. Eleven rockets were fired on the 26th before a determination was made that a bar formation precluded movement in the desired direction. A twelfth rocket was fired in a different location, but it failed to detonate and had to be destroyed by means of a hand-placed charge. On the 27th, nine more rockets were fired, and a small area was cleared of ice. However, two of the rockets failed to explode, and the testing was suspended. It was also noted that the explosion of each rocket threw steel fragments from the casing and motor as much as 600 yd, which posed a safety hazard for anyone in the area.

An attempt was made to remove an ice jam at Black Bird Bend on 1 and 2 March using hand-placed charges of Composition C-3. The jam was 800–1000 ft wide and 1 mile long and was composed of ice 10–34 in. thick and piled 5–6 ft above the water surface. The jam was caused by a bar formation over which the ice could not pass. Most of the water was bypassing the toe of the jam, so an effort was made to loosen the ice along one shore so that a rise in stage would carry the ice downstream. Eight-hundred and fifty pounds of explosives were used over 1500 ft to loosen the ice. Overnight a rise of approximately 2 ft cleared the lower 300 ft of the ice that had been blasted, but additional ice from upstream increased the length of the jam to 1.5 miles. Approximately 1400 lb of explosives were used to clear a channel approximately 0.5 mile long, but the ice again jammed at the lower end of the jam. The experiment was then stopped as there was insufficient flow to carry the ice downstream.

*Platte River near Ashland, 9–11 February 1966.* Runoff from a rainfall event in early February caused a breakup of the ice cover on the lower Platte and its tributaries. An ice jam formed below the confluence of the Elkhorn and Platte Rivers, and private agricultural levees on both banks were overtopped. Local interests spent about \$6000 to remove the ice jam by blasting. The effort was deemed unsuccessful in a Corps post-flood report. The floodwaters in the overbank froze in place after temperatures dropped. Floodwaters caused damage to the Interstate 80 bridge abutments, in excess of \$30,000. The levees were repaired at a cost of \$162,250 after it was determined that the river would not return to its channel even after removal of the ice jam. Little else is known of the blasting effort.

*Columbus, Loup River, 18–21 March 1969.* An ice jam formed at Columbus on the Loup River at

about 6:30 p.m. on 18 March 1969, and within two hours, it sent water spilling over the banks to the north and south. A decision to blast the ice jam was made by city officials on 21 March, according to the 21 March *Columbus Telegram*, but the 22 March *Columbus Telegram* stated that the Platte County Board of Supervisors decided late 20 March to blast. The ice jam extended 0.5 mile upstream and downstream from the Highway 81 bridge. Blasting operations began at 1:00 p.m. and lasted until about 6:45 p.m. on 21 March. A total of 1100 lb of explosives were used, but the length of channel blasted was not reported. The *Columbus Telegram* reported that 12–30 sticks of dynamite were placed in 1- to 5-gallon cans weighted with sand or bricks, which were then dropped in holes in the ice jam from a helicopter. The helicopter pilot and explosives expert reported progress in the blasting effort after each drop. Fifteen minutes after the blasting operation was suspended, the water level began to drop. Water levels had dropped 3–4 ft by the next morning.

*Platte and Elkhorn River west of Gretna and Platte River near Yutan and near Ames, February 1971.* Ice-jam flooding in late February caused breaks in several private levees between Ashland and Fremont. A situation report describing the flooding mentions local officials and private interests placing dynamite by helicopter west of Gretna and near Yutan in efforts to break up ice jams on the Platte and Elkhorn Rivers, but little else is known of the blasting efforts or success. A long-time resident near Fremont also recalled blasting from a helicopter near Ames for the same flood event.

*Platte River, 15 March 1979.* Blasting operations were conducted by the State of Nebraska downstream of the Highway 92 bridge for two days. The blasting was reported to be relatively unsuccessful as little ice movement was observed in the blast areas.

*Confluence of Elkhorn and Platte Rivers, 8–18 March 1993.* An ice jam formed near Thomas Lakes in early February when the Elkhorn River ice broke up and was stopped by an intact ice cover on the Platte. Discharges soon dropped and temperatures dropped, and the jam stayed in place until breakup in early March. A large increase in discharge and a large volume of ice from upstream combined to overtop private levees and create numerous breaches on both sides of the river near and just below the mouth of the Elkhorn on 8 March 1993. The breaches on the left bank allowed flow to destroy two bridges on Highway 6 and close Interstate 80 for parts of three days. The Sarpy

County Board of Supervisors gave the Western Sarpy Drainage District permission to blast the ice jam on 16 March.

Blasting began the afternoon of the 16th and continued until the 18th. At the peak of the flooding, the jam extended nearly four miles, but it was about 2–2.5 miles when blasting began. Initial blasting efforts began at the upstream end of the jam in the hope of creating a channel to a small levee breach at about the midpoint of the jam, so that water levels would drop enough to allow repair of other breaches. On the 17th, however, blasting began at the toe of the jam near Thomas Lakes. According to the *Omaha World-Herald*, charges up to 25 lb were used initially. Charge sizes were reduced while blasting near Thomas Lakes. A channel was blasted through the jam on the 18th, and water levels began to decrease gradually. Overflows through the breaches, however, were not stopped until the breaches were repaired. An estimated 10,000 lb of explosives were used during the blasting operations.

Some other uses of explosives about which little is known include:

- Near Columbus on the Platte River near the Burlington Northern Railroad bridge on or about 24 February 1971;
- On the Platte River near Ashland on or around 20 March 1978;
- Near the mouth of the Elkhorn River in February 1981; and
- Near Valley on the Platte River on or around 12 March 1929.

#### *Suggested steps to take for blasting operations*

Blasting operations are hazardous because of the potential for disaster if something goes wrong. Untimely detonation of the charge could lead to serious injury or death to one or more individuals. Blasting can also cause property damage to facilities in the vicinity of operations. Explosives can also have an adverse impact on the environment.

For these reasons, certain general steps and precautions listed below (not in any particular order) should be taken before initiating blasting operations. Other guidelines for blasting operations are contained elsewhere in the report. These guidelines should be incorporated into an emergency response plan so that exact details of each step are known ahead of time so that blasting can readily be accomplished.

- Obtain the services of an explosives expert to advise on use and placement of explosives.

- Obtain the services of a professional helicopter pilot and use of a helicopter.
- Obtain necessary permits for explosives and necessary quantities of explosives.
- Advise the Federal Aviation Administration so that aircraft can be kept away from the blast area.
- Contact the U.S. Fish and Wildlife Service to determine if any endangered species are in the blasting area.
- Designate an area reasonably close to the blast site as a base of operations. All operations should be done from this site, including charge preparation and charge loading.
- Follow all safety precautions when handling explosives. A good set of safety precautions for ANFO has been developed by the U.S. Bureau of Mines (1963).
- Notify those in the blasting area prior to blasting so that nobody is in the proximity of blasting.
- Have another helicopter or emergency rescue vehicle available at all times in case the helicopter carrying explosives goes down.
- Coordinate with local law enforcement officials to keep “sightseers” out of the area.

*Estimating charge size, total charge quantity and time of blasting operation.* Research on the use of explosives on ice jams in rivers such as the Platte is quite limited. However, the results of research elsewhere can be used for estimating the size of a blast crater created with a charge of a given weight. For shallow rivers such as the Platte, complete removal of an ice jam by using explosives is difficult, especially if flows are bypassing the jam. It is possible to blast a “pilot” channel through the length of the jam to allow more water back into the main channel. In turn, this may help slowly remove more ice from the jam. The selection of charge size is often best based on experience but will vary depending on the ice thickness and the proximity to dwellings or other structures. It may be necessary to adjust charge sizes after a few drops. One guide for selecting the smallest effective charge size can be found in theoretical research done by Van der Kley (1965). Van der Kley developed a relationship for the minimum charge of TNT placed at varying depths below the ice surface required to break ice of a given thickness (Fig. 23).

Usually the ice thickness will not be known but must be estimated by judging the amount of ice above and below the water surface. Once the ice thickness is estimated, then the depth below



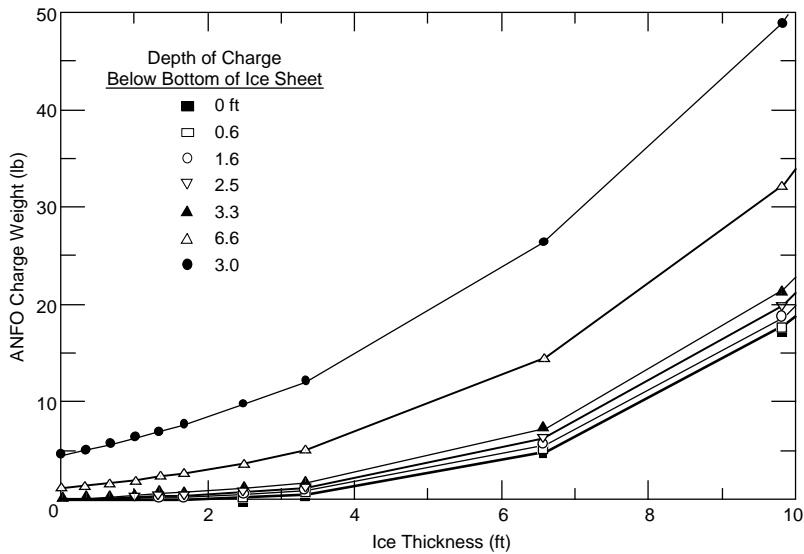


Figure 23. Minimum charge placed below ice surface required to break ice. (After Van der Kley 1965.)

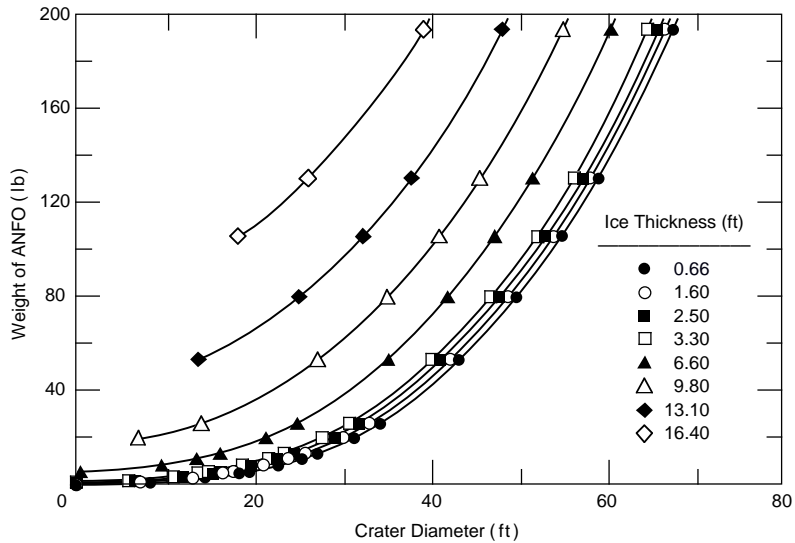


Figure 24. Crater diameter for ANFO charges placed just below the underside of the ice. (After Van der Kley 1965.)

the bottom of the ice surface at which the charge will explode must be estimated. It is important to be sure the charge is below the bottom surface of the ice because blasting above the ice takes a substantially larger charge to accomplish the same thing. From Figure 23, the minimum charge required is found by first going to the appropriate ice thickness and drawing a line straight up until it intersects the curve for the depth at which the explosive will detonate. A straight line is then drawn to the left to find the minimum charge weight required to break the ice. A larger charge

is required to break ice as the charge depth increases. However, this is just a minimum charge; larger charges can be used. Van der Kley also developed curves for determining the crater diameters for various charge sizes and ice thicknesses. Figure 24 illustrates the crater diameters for charges that explode just below the bottom surface of the ice.

The crater diameter is defined as the distance across the approximately circular hole from which most ice is thrown clear. Larger charges create larger craters, and larger charges are needed to

create a crater of equal diameter as ice thickness increases. The crater diameter for a given charge is determined by finding the appropriate charge weight on the left side of the figure and drawing a straight line to the right until it intersects the curve representing the estimated ice thickness. A straight line is then drawn straight down to find the expected crater diameter. The crater diameter is important because it determines the length and width of the channel created through the jam. It also determines the distance between charges. It is recommended that charges be placed a distance apart equal to the diameter of the crater those charges create. Thus, if a charge creates a crater 50 ft in diameter, slightly over 100 charges would be required to clear a channel one mile long and 50 ft wide.

If blasting is to be done, some quick computations can help determine a proper charge size. Several items must be determined before doing these computations. The extent of the ice jam must be determined so that the length of channel to be blasted is known. A plat map or USGS quadrangle map would be best for determining jam lengths, since the pilot channel to be blasted is not likely to be straight. Since access to the jam is likely to be poor, the charges will need to be placed from a helicopter. It would be necessary to know how many charges a pilot will allow on his helicopter for either weight or space reasons. It is also necessary to know how long it takes to complete one round trip with the helicopter to load the charges, drop the charges and return to the base of operations. This can be estimated either from experience or from the distance from the base of operations to the blasting site. The last two items are the cost of explosive per pound, including the booster charge, and the cost of the helicopter per hour, including the use of the helicopter, the pilot's time and the blaster's time.

Two examples are given below to illustrate the methodology used to estimate quantities and time. These are only examples and should not be used for an actual blasting event. Diagrams illustrating the use of the two figures above are shown, as well as a chart for computing explosive quantities and costs.

*Example 1.* An ice jam one mile in length is to be blasted. The cost of explosives is \$1.50 per pound, and the use of helicopter is \$350 per hour. You would like to use charges of about 25–35 lb and can take three charges per trip. The pilot estimates that one round trip will average ten minutes. You think the charges will detonate just below the ice bottom. The ice jam is estimated to

average 6 ft thick. What size of charge should be used and what is the expected cost?

Step 1. Determine the minimum charge size that can be used.

- From Figure 23, the minimum charge size that could be used is approximately 7 lb. This is less than the size of charge planned, so the planned charge size can be used.

Step 2. Determine the cost of several charge sizes. Compare costs for charges of 20, 30 and 40 lb.

- Use Table 21 and fill in columns 1, 3, 7, 9, 11 and 12 for charge size, length of channel to blast, number of charges per trip, time for one round trip, cost of explosives per pound and cost of helicopter per hour.
- Use Figure 24 to estimate the crater diameter. The crater diameter is 22 ft for the 20-lb charge, 27 ft for the 30-lb charge and 31 ft for the 40-lb charge. Enter these values in column 2 in the chart. You can now complete the chart to compare costs.
- Complete column 4 by dividing column 1 by column 2. Column 5 is equal to column 3 times column 4 times 5280. Compute the number of charges, column 6, by dividing column 5 by column 1, and compute column 8 by dividing column 6 by column 7. Column 10 is equal to column 8 times column 9 divided by 60. The cost of the explosives is determined by multiplying columns 5 and 11, the cost of the helicopter is determined by multiplying columns 10 and 12, and the total cost is the sum of columns 13 and 14. Any miscellaneous costs can be added on to determine the true total cost.

As can be seen, using 20-lb charges is the least expensive alternative by about \$750, but it takes the most time by at least 2.5 hours. If time is important, it may be worthwhile to spend more for larger charges.

*Example 2.* An ice jam 2 miles long needs to be removed by blasting. You estimate the jam thickness to be 8 ft in the lower 0.5 mile and 3 ft in the upper 1.5 miles. Explosives will cost \$1.25 per pound and the helicopter will cost \$400 per hour. The helicopter pilot will allow 80 lb of explosives each trip and says each trip will take 10 minutes. You think the explosives will explode just under

**Table 21. Sample calculations for blasting costs.**

Col (1)	Col (2)	Col (3)	Col (4)	Col (5)	Col (6)	Col (7)	Col (8)	Col (9)	Col (10)	Col (11)	Col (12)	Col (13)	Col (14)	Col (15)
Weight of charge (lb)	Diameter of crater (ft)	Distance to blast (mi)	Pounds per foot	Total pounds	Number of charges	Charges per trip	Number of trips	Round trip flight time (min)	Total flight time (hr)	Cost of explosives (\$/lb)	Cost of helicopter (\$/hr)	Total cost of explosives (\$)	Total cost of helicopter (\$)	Total costs (\$)
	from Figure A2	from observation	$\frac{col(1)}{col(2)}$	$col(4) \times col(3) = 5280$	$\frac{col(5)}{col(1)}$	at pilot's discretion	$\frac{col(6)}{col(7)}$	Based on experience	$\frac{col(9) \times col(8)}{60}$			$col(5) \times col(11)$	$col(10) \times col(12)$	$col(13) \times col(14)$
<b>Example 1</b>														
20	22	1	0.91	4800	240	3	80	10	13.33	1.50	350	7200.00	4666.67	11866.67
30	27	1	1.11	5867	196	3	65	10	10.86	1.50	350	8800.00	3802.47	12602.47
40	31	1	1.29	6813	170	3	57	10	9.46	1.50	350	10219.35	3311.83	13531.18
<b>Example 2</b>														
<i>Lower 1/2 mile</i>														
20	8	0.5	2.50	6600	330	4	83	10	13.75	1.25	400	8250.00	5500.00	13750.00
25	14	0.5	1.79	4714	189	3	63	10	10.48	1.25	400	5892.86	4190.48	10083.33
40	22	0.5	1.82	4800	120	2	60	10	10.00	1.25	400	6000.00	4000.00	10000.00
80	36	0.5	2.22	5867	73	1	73	10	12.22	1.25	400	7333.33	4888.89	12222.22
<i>Upper 1-1/2 miles</i>														
10	21	1.5	0.48	3771	377	8	47	10	7.86	1.25	400	4714.29	3142.86	7857.14
15	25	1.5	0.60	4752	317	5	63	10	10.56	1.25	400	5940.00	4224.00	10164.00
20	28	1.5	0.71	5657	283	4	71	10	11.79	1.25	400	7071.43	4714.29	11785.71
25	31	1.5	0.81	6387	255	3	85	10	15.61	1.25	400	7983.87	6245.16	14229.03

the ice. What will be the most effective charge size or sizes?

Step 1. Since the ice is considerably thicker at the downstream end, larger charges will probably be required, so compute separately for the lower 0.5 mile and the upper 1.5 miles.

- Divide the chart into two areas for the lower 0.5 mile and upper 1.5 miles. Fill in column 3 for 0.5 mile and 1.5 miles in the two separate groups. Fill in columns 9, 11 and 12 for round trip time, explosive cost and helicopter cost, using the same numbers for each group.

Step 2. Determine the minimum charge weight required.

- From Figure 23 the minimum charge size is about 18 lb for 10-ft-thick ice and about 1–2 lb for 3-ft-thick ice.

Step 3. Determine the number of charges per trip for various sizes of charges to blast the 10-ft-thick ice.

- Since the load is limited to 80 lb, you could have four 20-lb charges, three 25-lb charges, two 40-lb charges or one 80-lb charge. Put these numbers in columns 1 and 7.

Step 4. Determine the blast crater for the 10-ft-thick ice.

- From Figure 24, find that a 20-lb charge has an 8-ft-diameter crater, a 25-lb charge has a 14-ft crater, a 40-lb charge has a 22-ft crater and an 80-lb charge has a 36-ft crater. Fill in column 2 with the blast craters for the appropriate size of charge.

Step 5. Fill in the remainder of the chart for the lower 0.5 mile.

- Compute columns 4, 5, 6, 8, 10, 13, 14 and 15 as in the previous example. As can be seen, the 40-lb charges are the least expensive, but the 25-lb charges only cost about \$80 more and take only about 30 minutes longer to blast the lower part of the jam. The larger charge may be better because they will clear a wider channel; the smaller charges may be more convenient for handling.

Step 6. Determine the number of charges per trip for various sizes of charges to blast the 3-ft-thick ice.

- Since the ice is much thinner in the upper 1.5 miles, smaller charges can be used. You could have eight 10-lb charges, five 15-lb charges, four 20-lb charges or

three 25-lb charges. Put these values in columns 1 and 7 for the upper jam part of the table.

Step 7. Determine the blast crater diameter for the 3-ft-thick ice.

- From Figure 24, the crater size is 21 ft for 10-lb charges, 25 ft for 15-lb charges, 28 ft for 20-lb charges, and 31 ft for 25-lb charges. Fill in column 2 with the appropriate crater diameter.

Step 8. Complete the rest of Table 21.

- Compute the values for columns 4, 5, 6, 8, 10, 13, 14 and 15 as before. As can be seen, the 10-lb charges result in the lowest cost. Even if the pilot limited the load to four charges per trip for safety reasons due to the time it takes to light more charges, the 10-lb charges would still be slightly less expensive.

These examples illustrate how effective charge sizes can quickly be determined. It is best if only a few charge sizes are considered to reduce computation time, so it is important to have a good idea of what charge sizes may be effective. It is also important to remember that the cheapest alternative to getting the job done is not necessarily the best alternative if it takes considerably longer to accomplish.

## CONCLUSIONS

The historical data-collection effort found much available information, both published and oral. Some information, such as ice-thickness measurements from USGS stream-gaging records, is very time consuming to compile, while other information, such as USGS discharge records, is relatively easy to access. In general, information about the physical characteristics of ice and ice jams is the most difficult to obtain, simply because there has not been a concerted effort in the past to collect such information, the information available is widely scattered, and most people do not take particular notice of the ice until it is causing problems. The data-collection program initiated as a result of this study should begin to provide better ice information.

The analysis of the collected data attempted to find relationships or trends among the various hydrological, meteorological and ice records pertaining to ice events in the study area. The results of the analysis were used to develop an ice-jam predictive model based on hydrologic and meteorological data that are relatively easy to access.

Future refinement of the model, and development of a separate model for each site, should be possible with additional data collected as part of the ice-data-collection program.

Meetings with local citizens often yielded good information on ice events but also some commonly mentioned themes. Many said there was not enough communication between state agencies, civil defense, local governments and the general public. Many also expressed an interest in volunteering to help make ice observations—many more than were needed. A number of people said they were unfamiliar with or unaware of emergency procedures, didn't know who has the authority to declare an emergency, and didn't know who has authority and assumes liability during an emergency. The Nebraska Disaster and Civil Defense Act (App. C) describes the role and responsibility of the State and its political subdivisions in dealing with disaster emergencies, among other matters.

Local governments are the first agencies responsible for dealing with disasters. Advance planning for disasters by county, city and other local governments, and coordination of this planning between various governments, is important for dealing with disasters when they begin, not after they have reached great proportions. Appendix D contains a legal opinion drafted by the State indicating that both the State and its political subdivisions are essentially protected from liability if emergency measures are in accordance with the Nebraska Disaster and Civil Defense Act and an emergency has been declared.

The Nebraska Ice Report will be an ongoing effort and should be maintained for use in future studies, as well as being able to provide "real-time" warnings of conditions upstream. The observations recorded on the data collection forms will be reported to and stored in the ice database to be maintained by the Nebraska Natural Resources Commission. The information collected on the ice report will be able to be used to refine the predictive model sometime in the future, perhaps leading to the development of models for each individual site, rather than a generalized model. Future studies will be able to utilize the additional information collected by the ice report. Perhaps more importantly the information contained in the database will be able to be called up by various entities to check on ice conditions upstream that may impact conditions downstream.

The section of this report on specific mitigation options contains recommendations for specific measures that could be utilized at individual

locations for either controlling ice or monitoring ice. More detailed studies would be required at individual sites to determine the appropriateness of specific structural measures. As mentioned in the previous paragraph, the information collected by the ice report will provide much valuable information on ice processes and characteristics, which are presently very sketchy. Nonstructural measures, such as monitoring, would not require detailed study to implement, although some coordination efforts may be needed. A recommended future study would be to evaluate the impact, if any, of the operation of the Loup Power Canal on ice conditions downstream.

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APPENDIX A: MODEL RESULTS FOR THE LOUP RIVER NEAR COLUMBUS

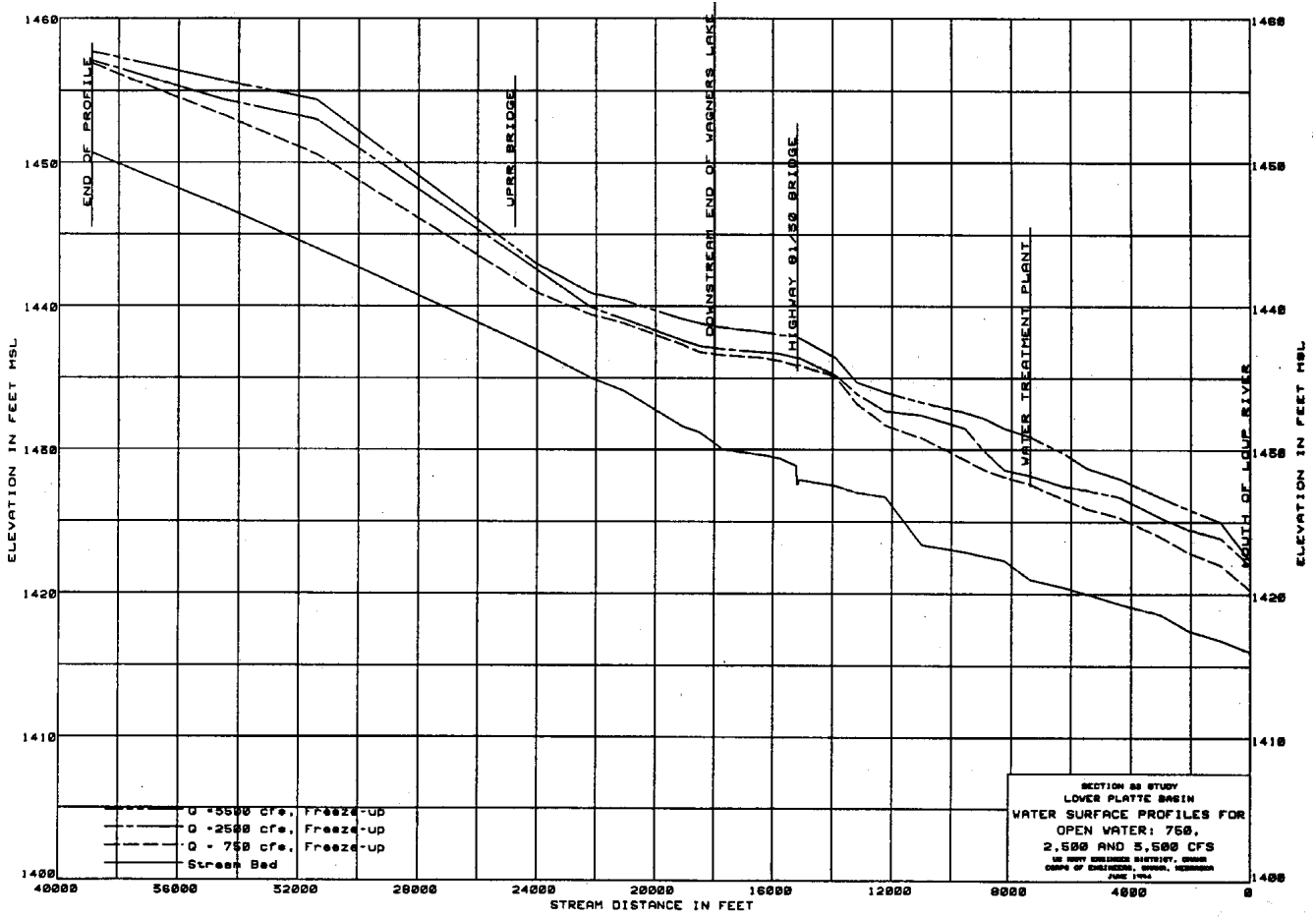


Figure A1. Open-water profiles.

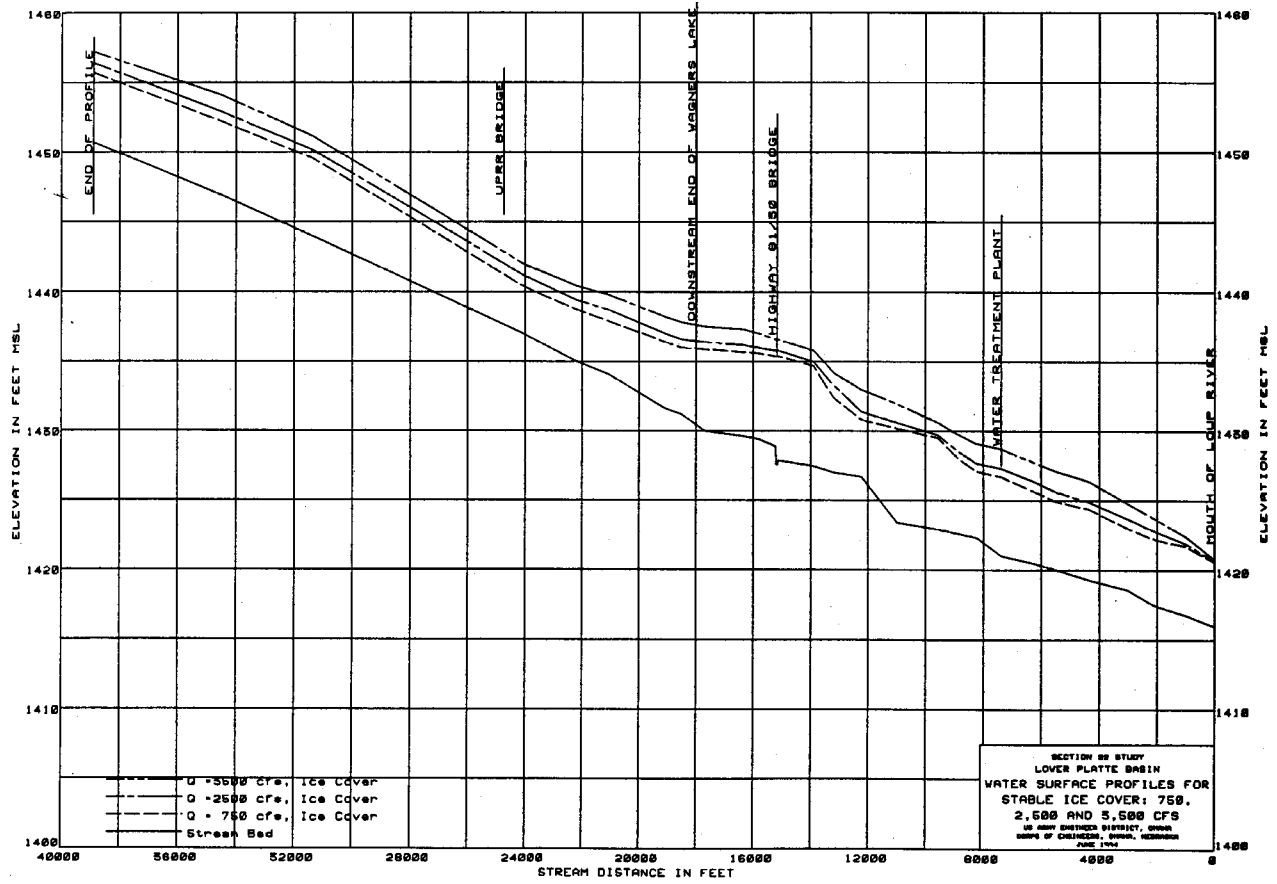


Figure A2. Ice-flow water profiles.

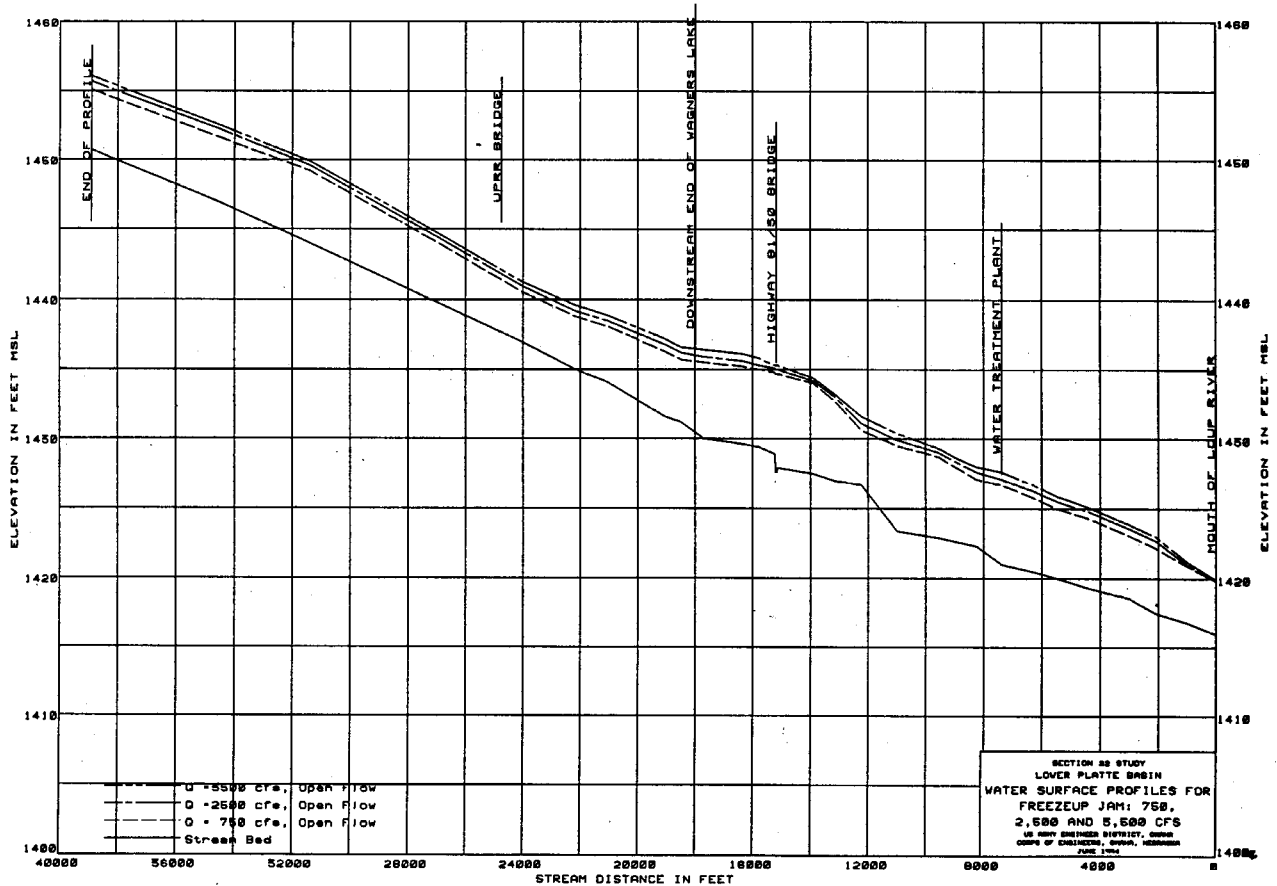
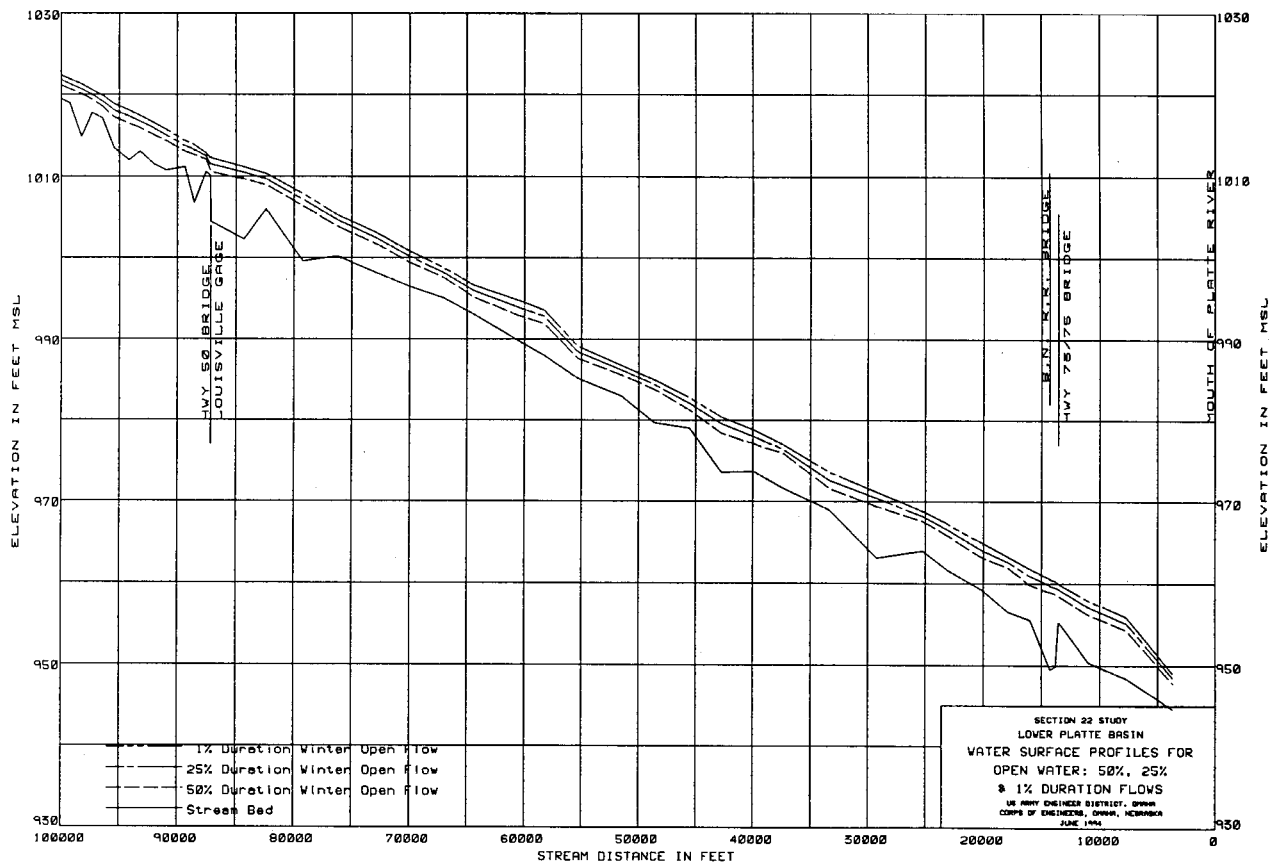


Figure A3. Freeze-up water profiles.



**APPENDIX B. MODEL RESULTS FOR  
THE PLATTE RIVER ALONG SARPY COUNTY, NEBRASKA**



*Figure B1. Open-water flow profiles for the eastern section.*

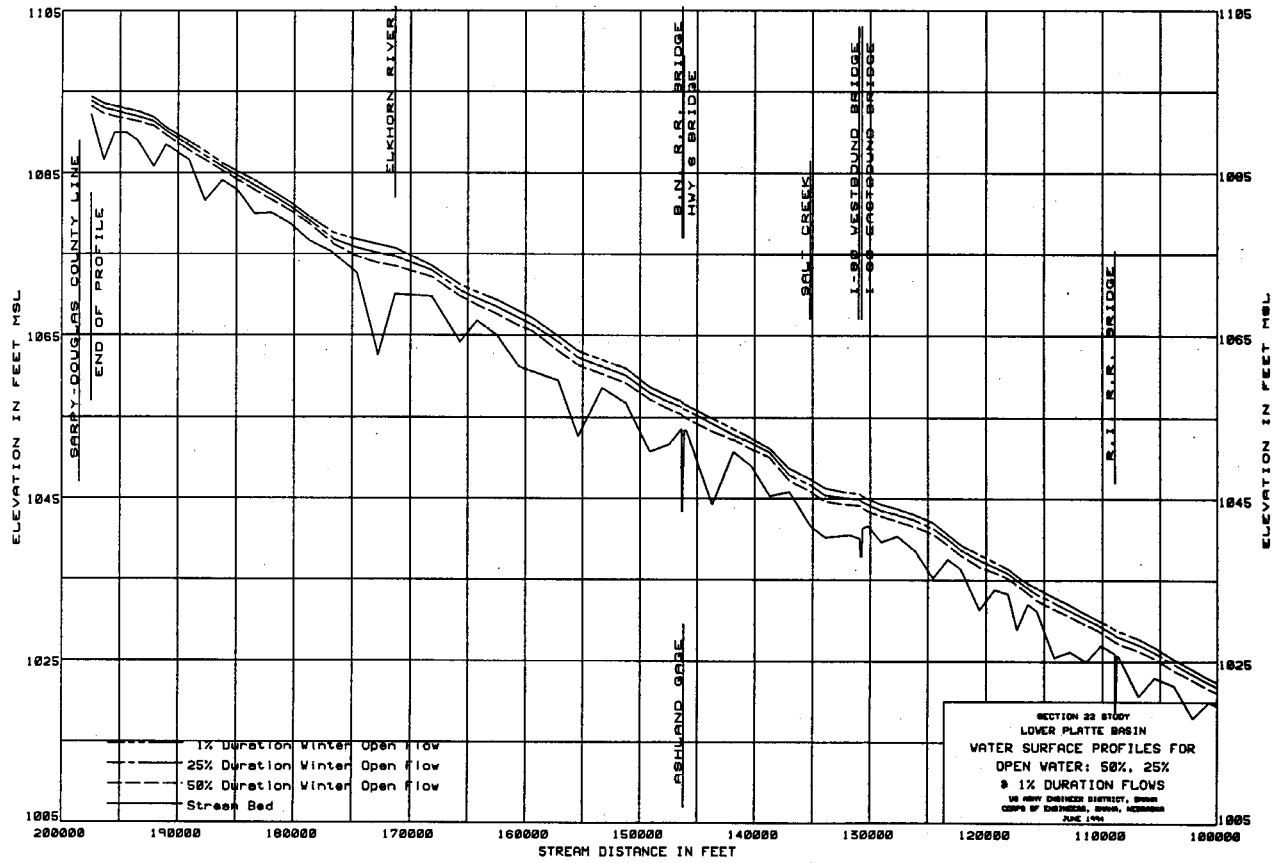


Figure B2. Open-water flow profiles for the western section.

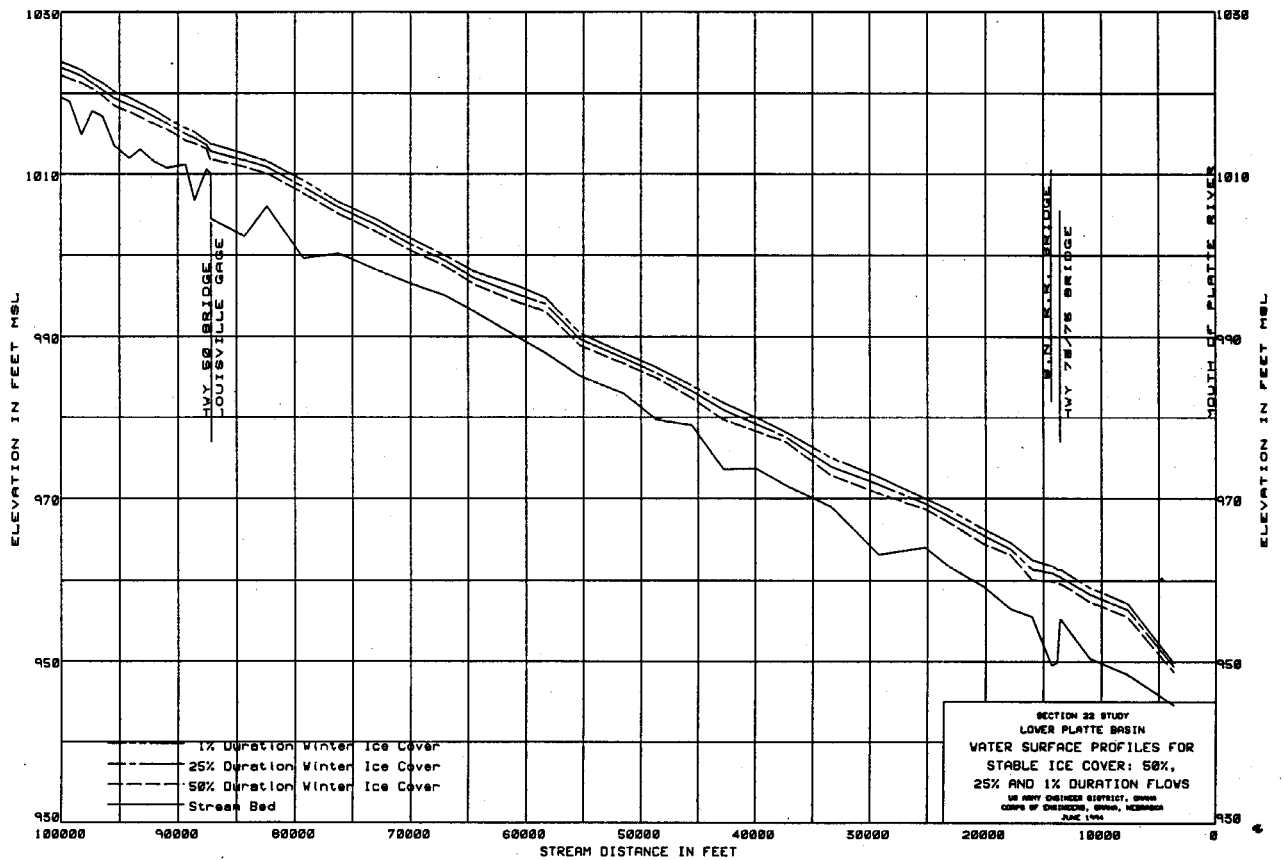


Figure B3. Solid-ice-cover flow profiles for the eastern section.

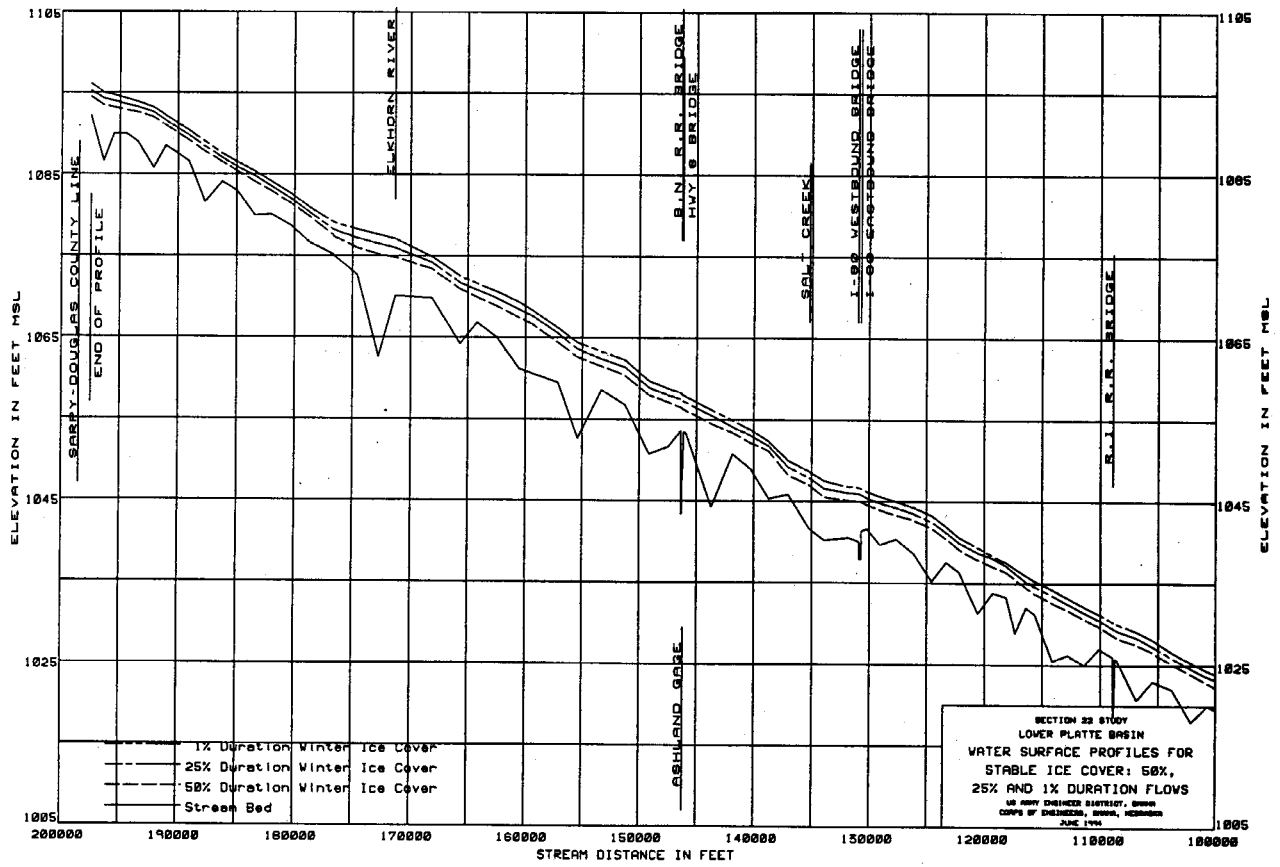


Figure B4. Solid-ice-cover flow profiles for the western section.

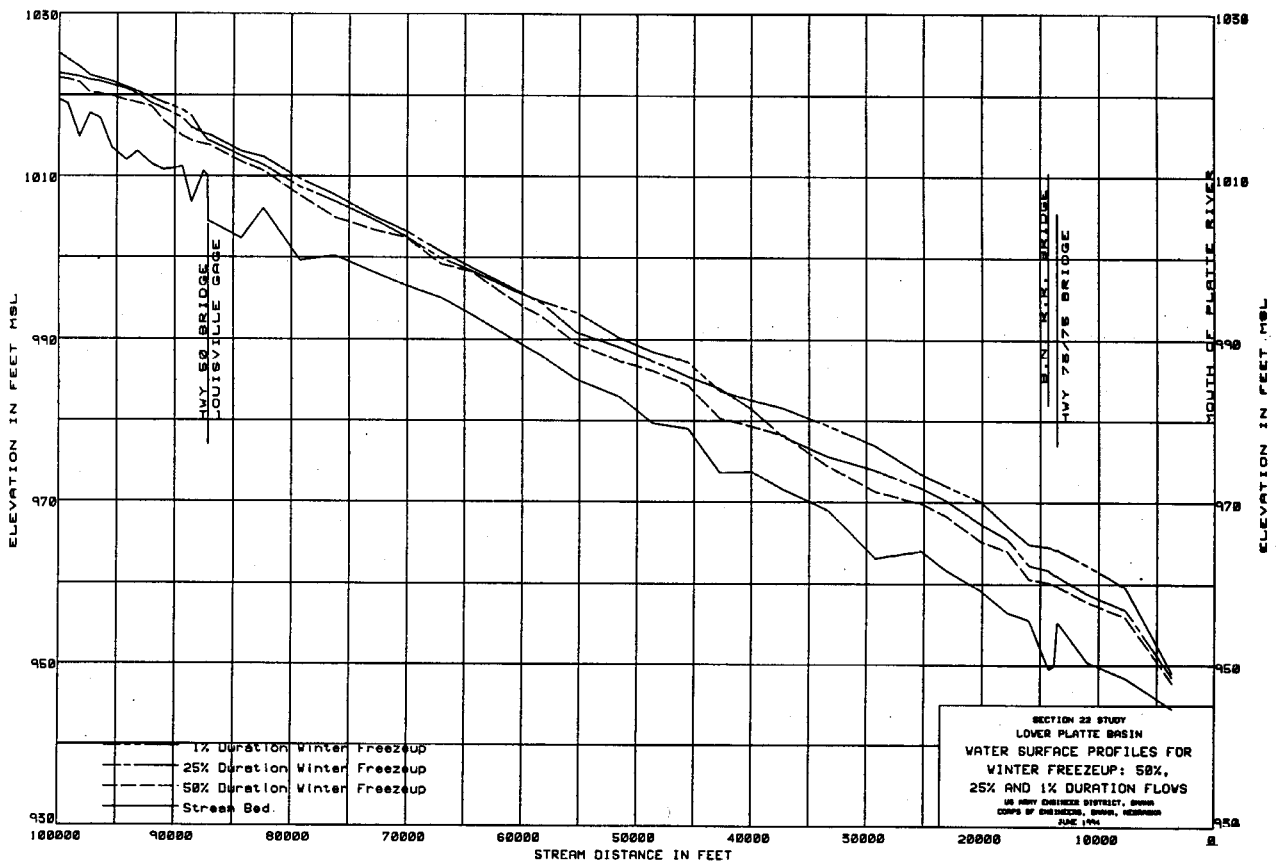


Figure B5. Freeze-up flow profiles for the eastern section.

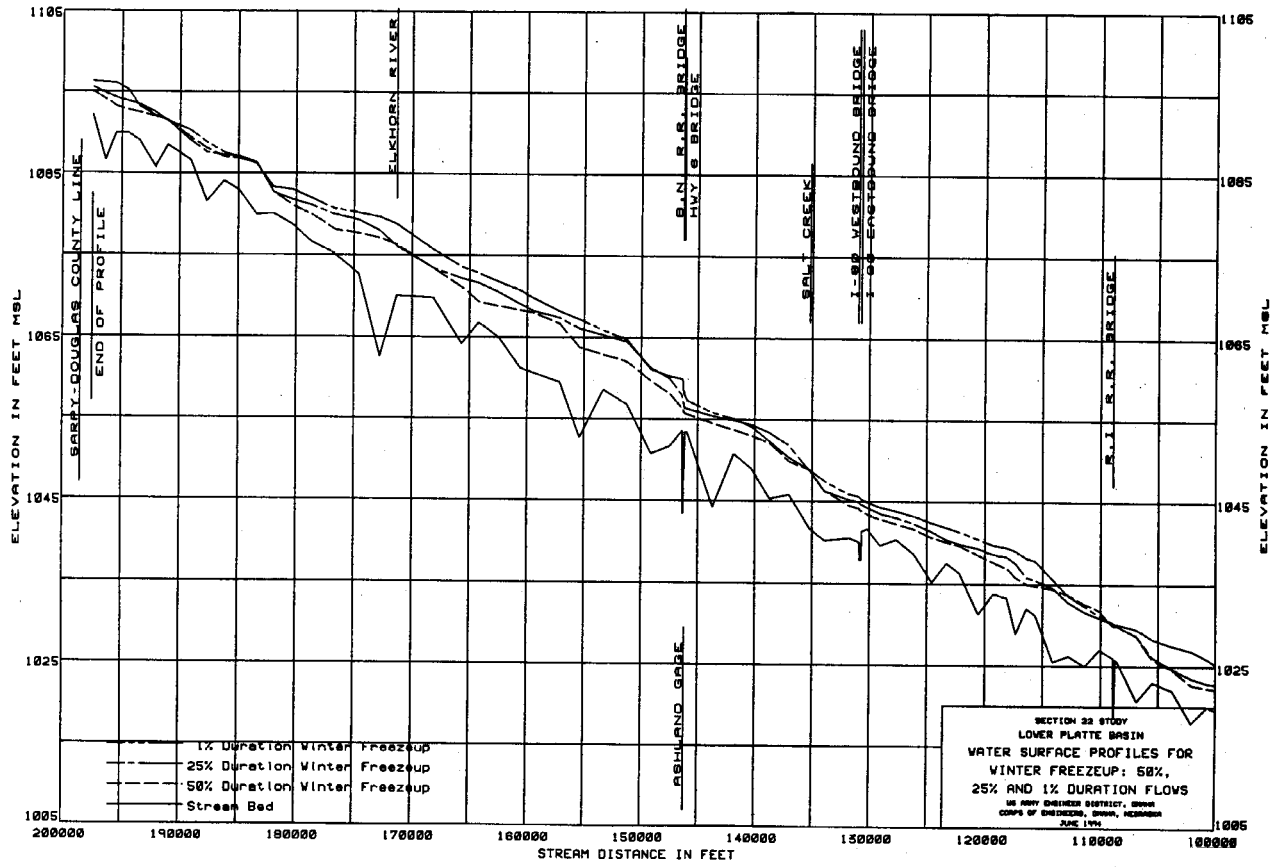


Figure B6. Freeze-up flow profiles for the western section.

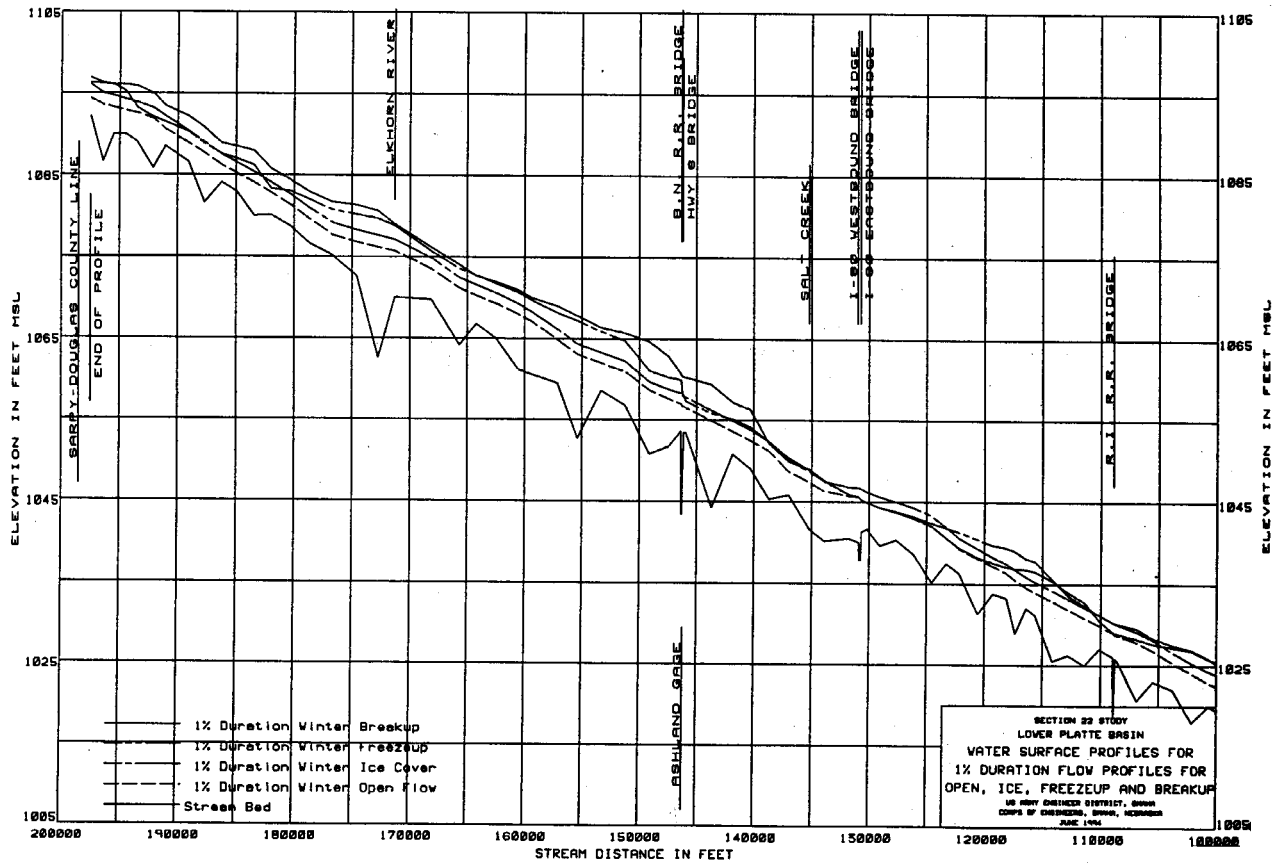


Figure B7. One-percent-duration flow profiles for open water, ice cover, freeze-up and breakup for the eastern section.

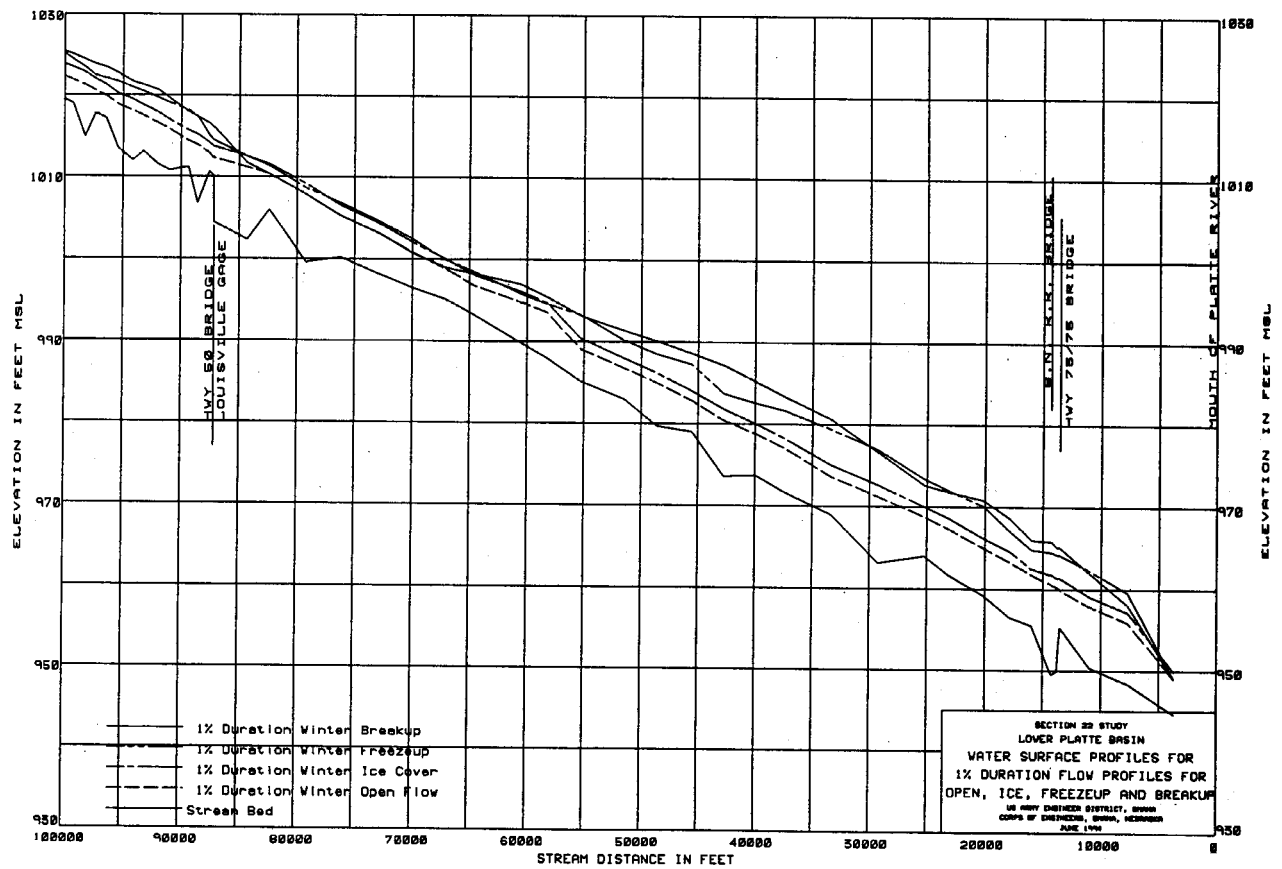


Figure B8. One-percent-duration flow profiles for open water, ice cover, freeze-up and breakup for the western section.

**APPENDIX C: NEBRASKA DISASTER AND CIVIL DEFENSE ACT**  
**(Sections 81-829.31, 81-829.37 to 81-829.74 reproduced from the**  
**Revised Statutes of Nebraska 1943, 1982 Supplement)**

**(c) DISASTER AND CIVIL DEFENSE**

**Cross Reference**

Vital resource crises, see section 84 162 et seq.

**81-825 to 81-829. Repealed.** Laws 1947, c. 179 sec. 9.

**81-825.01 to 81-828.01. Repealed.** Laws 1953, c 336, sec. 5.

**81-829.01 and 81-829.02.** Expiration of act.

**Note:** According to the provisions of section 81-829.01, these sections expired by their own limitation on March 1, 1945. They have therefore been omitted.

**81-829.03. Repealed.** Laws 1953, c. 336, sec. 5.

**81-829.04. Repealed.** Laws 1951, c. 315, sec. 16.

**81-829.05. Transferred to section 81-829.36.**

**81-829.06. Transferred to section 81-829.37.**

**81-829.07. Transferred to section 81-829.38.**

**81-829.08. Transferred to section 81-829.39.**

**81-829.09. Transferred to section 81-829.40.**

**81-829.10 to 81-829.12. Repealed.** Laws 1973, LB 494, sec. 34.

**81-829.13. Transferred to section 81-829-52.**

**81-829.14. Transferred to section 81-829-53.**

**81-829.15. Transferred to section 81-829-54.**

**81-829.16 and 81-829.17. Repealed.** Laws 1953, c. 336, sec. 5.

**81-829.18. Transferred to section 81-829-46.**

**81-829.19. Transferred to section 81-829-48.**

**81-829.20. Repealed.** Laws 1973, LB 494, sec. 34.

**81-829.21. Transferred to section 81-829.55.**

**81-829.22. Transferred to section 81-829.49.**

**81-829.23. Transferred to section 81-829.51.**

**81-829.24. Transferred to section 81-829.58.**

**81-829.25. Transferred to section 81-829.59.**

**81-829.26. Transferred to section 81-829.60.**

**81-829.27. Transferred to section 81-829.61.**

**81-829.28. Transferred to section 81-829.62.**

**81-829.29. Transferred to section 81-829.63.**

**81-829.30. Transferred to section 81-829.64.**

**81-82931. Adjutant General; civil defense agency; administer.** There is hereby created in the office of the Adjutant General a civil defense agency. The Adjutant General shall administer the provisions of sections 81.829.36 to 81.829.40, 81.829.46, 81-829.48, 81-829.49, 81-829.51 to 81-829.55, and 81-829.59 to 81-829.64.

**Source:** Laws 1953, c. 336, sec. 2, p. 1106.

#### **Cross Reference**

For provisions relating to the Adjutant General, see Chapter 55, article 1.

**81-829.32. Transferred to section 81-829.65.**

**81-829.33 and 81-829.34. Repealed.** Laws 1971, LB 105, sec 1.

**81-829.35. Transferred to section 81-829.66.**

**81-829.36. Act, how cited.** Sections 81-829.36 to 81-829.68 may be cited as the Nebraska Disaster and Civil Defense Act of 1973.

**Source:** Laws 1951, c. 315, sec. 1, p. 1073; R.R.S.1943, sec. 81-829.05; Laws 1973, LB 494, sec. 1.

**81-82937. Nebraska Disaster and Civil Defense Act; policy.** The purposes of sections 81-829.36 to 81-829.68 and the policy of the state are to:

(1) Reduce the vulnerability of people and communities of this state to damage, injury, and loss of life and property resulting from natural or man-made disasters, civil disturbances, or hostile military or paramilitary actions;

(2) Prepare for prompt and efficient rescue, care, and treatment of persons victimized or threatened by disasters;

(3) Provide a setting conducive to the rapid and orderly start of restoration and rehabilitation of persons and property affected by disasters;

(4) Clarify and strengthen the roles of the Governor, state agencies, and local governments in the prevention of, preparation for, and response to and recovery from disasters;

(5) Authorize and provide for cooperation in disaster prevention, preparedness, response, and recovery;

(6) Authorize and provide for coordination of activities relating to disaster prevention, preparedness, response, and recovery by agencies and officers of this state, and similar state, local interstate, federal-state, and foreign activities in which the state and its political subdivisions may participate;

(7) Provide a disaster management system embodying all aspects of preparedness and response;

(8) Assist in prevention of disasters caused or aggravated by inadequate planning for and regulation of public and private facilities and land use; and

(9) Provide for the funding of activities incidental to carrying out the purposes of sections 81-829.36 to 81-829.68.

**Source:** Laws 1951, c. 315, sec. 2(1), p.1074; R.R.S.1943, sec. 81-829.06; Laws 1973, LB 494, sec. 2.

**81-829.38. Nebraska Disaster and Civil Defense Act; purpose.** Nothing in sections 81-829.36 to 81-829.68 shall be construed to:

(1) Interfere with the course or conduct of labor dispute, except that actions otherwise authorized by sections 81-829.36 to 81-829.68 or other laws may be taken when necessary to forestall or mitigate imminent or existing danger to public health or safety;

(2) Interfere with dissemination of news or comment on public affairs, but any communications facility or organization, including but not limited to radio and television stations, wire services, and newspapers, may be required to transmit or print public service messages furnishing information or instructions in connection with a disaster emergency;

(3) Affect the jurisdiction or responsibilities of police forces, fire fighting forces, units of the armed forces of the United States, or of any personnel thereof, when on active duty, but state, local, and interjurisdictional disaster emergency plans shall place reliance upon the forces available for performance of functions related to disaster emergencies; or

(4) Limit, modify, or abridge the authority of the Governor to proclaim martial law or exercise any other powers vested in him under the Constitution, statutes, or common law of this state independent of, or in conjunction with, any provisions of sections 81-829.36 to 81-829.68.

**Source:** Laws 1951, c. 315, sec. 2(2), p. 1074; R.R.S. 1943, sec. 81-829.07; Laws 1973, LB 494, sec. 3.

**81-829.39. Terms, defined.** As used in sections 81-829.36 to 81-829.68 unless the context otherwise required:

(1) Civil Defense shall mean the preparation for and the carrying out of all emergency functions, other than functions for which military forces are primarily responsible, to prevent, minimize, and repair injury and damage resulting from disasters caused by enemy attack, sabotage or other hostile action; or by fire, flood, earthquake, or other natural causes. These functions include, without limitation, fire fighting services, police services, medical and health services, rescue, engineering, air raid warning services, communications, radiological, chemical and other special weapons defense, evacuation of persons from stricken area, emergency welfare services, civilian war aid, emergency transportation, existing or properly assigned functions of plant protection, temporary restoration of public-utility services, and other functions related to civilian protection, together with all other activities necessary or incidental to the preparation for and carrying out of the foregoing functions.

(2) Civil defense emergency shall mean an emergency declared by the President of the United States or Congress pursuant to applicable federal law finding that an attack upon the United States has occurred or is anticipated and that the national safety therefore requires the invocation of the emergency authority provided for by federal law. Such emergency also shall exist in the event of an enemy attack or other hostile action within the State of Nebraska, or when the President determines that any attack has been made upon or is anticipated within a designated geographic area which includes all or a part of the State of Nebraska. Any such emergency shall terminate in the manner provided by federal law, or by proclamation of the governor, or by resolution of the Legislature, terminating such emergency.

(3) Disaster shall mean occurrence or imminent threat of widespread or severe damage, injury, or loss of life or property resulting from any natural or man-made cause,



including but not limited to fire, earthquake, wind, storm, wave action, oil spill, or other water contamination requiring emergency action to avert danger or damage, volcanic activity, epidemic, air contamination, blight, drought, infestation, explosion, riot, civil disturbance, or hostile military or paramilitary action.

(4) Mobile support unit shall mean an organization for civil defense established in accordance with the provisions of sections 81-829.52 by state or local authority to be dispatched by the Governor to supplement local organizations for civil defense in a stricken area.

(5) Local government shall mean counties, villages, and cities of all classes.

(6) Civil defense worker shall include any full-time or part-time paid, volunteer, or auxiliary employee of this state or other states, territories, possessions, or the District of Columbia, of the federal government or any neighboring country, or of any political subdivision thereof, or of any agency or organization performing civil defense services at any place in this state subject to the order or control of, or pursuant to a request of, the state government or any political subdivision thereof and shall also include instructors and students in recognized educational programs where civil defense services are taught. A recognized educational program where civil defense services are taught. A recognized educational program shall include programs in educational institutions duly existing under the laws of this state and such other educational programs as shall be established by the state Civil Defense Agency or otherwise under the provisions of sections 81-829.36 to 81-829.68.

**Source:** Laws 1951, c. 315, sec. 3, p. 1074; R.R.S. 1943, sec. 81-829.08; Laws 1973, LB 494, sec. 4.

**81-829.40. Disaster and Civil Defense Agency; Governor; control.**

(1) The Governor shall be responsible for meeting the dangers to the state and people presented by disasters, and in the event of disaster beyond local control, he/she may assume direct operational control over all or any part of the civil defense functions within this state. He/she shall have general direction and control of the disaster response and the state Civil Defense Agency and shall be responsible for carrying out the provisions of sections 81-829.36 to 81-829.68.

(2) In order to effect the policy and purposes of sections 81-829.36 to 81-829.68, the Governor may issue proclamations and make, amend, and rescind the necessary orders, rules, and regulations to carry out the provisions of sections 81-829.36 to 81-829.68.

(3) A disaster emergency shall be declared by proclamation of the Governor if he/she finds that a disaster has occurred or that the occurrence or threat thereof is imminent. The state of disaster emergency shall continue until the Governor finds that the threat or danger has passed or the disaster has been dealt with to the extent that emergency conditions no longer exist and terminates the state of disaster emergency by proclamation, but no state of disaster emergency may continue for longer than thirty days unless renewed by the Governor. The Legislature by resolution may terminate a state of disaster emergency at any time, whereupon the Governor shall issue a proclamation ending the state of disaster emergency. All proclamations issued under this subsection shall indicate the nature of the disaster, the area or areas threatened, and the conditions which have brought it about or which make possible the termination of the state of disaster emergency. All proclamations shall be disseminated promptly by means calculated to bring its contents to the attention of the general public and, unless the circumstances attendant upon the disaster prevent or impede, shall be promptly filed with the state Civil Defense Agency, the Secretary of State, and the clerks of the local governments in the area to which it applies.

(4) Proclamation of a state of disaster emergency shall activate the disaster response and recovery aspects of the state, local, and interjurisdictional disaster and civil defense plans applicable to the political subdivision or area in question and be the authority for the deployment and use of any forces to which the plan or plans apply and for use or

distribution of any supplies, equipment, and materials and facilities assembled, stockpiled, or arranged to be made available pursuant to sections 81-829.36 to 81-829.68 or any other provision of law relating to disaster emergencies.

(5) During the continuance of any state of disaster emergency the Governor shall be commander-in-chief of the organized and unorganized militia and of all other forces available for emergency duty. To the greatest extent practicable, the Governor shall delegate or assign command authority by prior arrangement embodied in appropriate proclamations, orders, rules, and regulations, but nothing shall restrict his/her authority to do so by orders issued at the time of the disaster emergency.

(6) In addition to any other powers conferred upon the Governor by law, he/she may:

(a) Suspend the provisions of any regulatory statute prescribing the procedures for conduct of state business, or the orders, rules, or regulations of any state agency, if strict compliance with the provisions of any statute, order, rule, or regulation would in any way prevent, hinder, or delay necessary action in coping with the emergency;

(b) Utilize all available resources of the state government and of each political subdivision of the state as are reasonably necessary to cope with the disaster emergency;

(c) Transfer the direction, personnel, or functions of state departments and agencies or units thereof for the purpose of performing or facilitating disaster response;

(d) Subject to any applicable requirements for compensation under section 81-829.57, commandeer or utilize any private property if he/she finds this necessary to cope with the disaster emergency;

(e) Direct and compel the evacuation of all or part of the population from any stricken or threatened area within the state if he deems this action necessary for the preservation of life or other disaster mitigation, response, or recovery

(f) Prescribe routes, modes of transportation, and destinations in connection with evacuation;

(g) Control ingress and egress to and from a disaster area, the movement of persons within the area, and the occupancy of premises therein;

(h) Suspend or limit the sale, dispensing, or transportation of alcoholic beverages, firearms, explosives, and combustibles; and

(i) Make provisions for the availability and use of temporary emergency housing.

(7) In the event of a civil defense emergency, as defined in section 81-829.39, the Governor shall assume direct operational control overall or any part of the civil defense functions within this state.

**Source:** Laws 1951, c. 315, sec. 4(1), p. 1076; R.R.S. 1943, sec. 81-829.09; Laws 1973, LB 494, sec. 5.

**81-829.41. Civil Defense Agency; Adjutant General; act; administer.**

(1) The state Civil Defense Agency shall be maintained in the office of the Adjutant General. The Adjutant General shall administer the provisions of sections 81-829.36 to 81-829.68, subject to the direction and control of the Governor, and shall receive such compensation for these services as shall be determined by the Governor. The agency shall have an assistant director and such other professional, technical, secretarial, and clerical employees as are necessary for the performance of its functions.

(2) The agency shall maintain a state disaster plan and keep it current, which plan may include:

(a) A history of Nebraska disasters;

(b) An analysis of past and potential disasters, including an identification of the functions and resources required to cope with such disasters. The expected frequency of occurrence of disasters, along with the severity of their effect, shall indicate the priority of preparedness efforts of the disaster agencies of the state;

(c) Measures to be undertaken to accomplish disaster damage assessment and situation analysis, warning, direction and control, coordination of operating forces, emergency resource management, emergency information and official instructions, communications

and other necessary support to disaster response operations, and coordination and cooperation of federal, state, local, and nongovernmental agencies so as to provide a prompt and effective response to disaster situations to prevent and minimize the injury and damage caused by disasters;

(d) The provision of disaster relief and assistance to individuals, political subdivisions of the state, and state agencies;

(e) Identification of areas of the state particularly vulnerable to a disaster;

(f) Recommendations for preventive and preparedness measures designed to eliminate or reduce disasters or their impact, such as zoning, building, and other land-use control, and safety measures for securing mobile homes or other nonpermanent or semipermanent structures;

(g) Authorization and procedures for the erection or other construction of temporary works designed to protect against or mitigate danger, damage, or loss from flood, conflagration, or other disaster;

(h) Assistance to local officials in designing local disaster response plans;

(i) Preparation and distribution to the appropriate state and local officials of catalogs of federal, state, and private disaster assistance programs; and

(j) Other necessary matters.

(3) The agency shall take an integral part in the development and revision of local and interjurisdictional disaster and civil defense plans prepared under section 81-829.46. To this end, it shall employ or otherwise secure the services of professional and technical personnel capable of providing expert assistance to political subdivisions, their disaster and civil defense agencies, and to interjurisdictional disaster and civil defense agencies. Such personnel shall consult with subdivisions and agencies on a regularly scheduled basis and shall make field examinations of the areas, circumstances, and conditions to which particular local and interjurisdictional disaster and civil defense plans are intended to apply, and may suggest or require revisions.

(4) In preparing and revising the state disaster plan and other civil defense plans, the agency shall seek the advise and assistance of other agencies of government and the private sector. In advising local and interjurisdictional agencies, the agency shall encourage them to also seek advise from these sources.

(5) The state disaster and other civil defense plans or any part thereof may be incorporated in rules or regulations of the agency.

(6) The state Civil Defense Agency shall:

(a) Determine the requirements of the state and its political subdivisions for basic necessities such as food, clothing, shelter in various disaster situations;

(b) Procure and preposition supplies, medicines, materials, and equipment;

(c) Promulgate standards and requirements for local and interjurisdictional disaster and civil defense plans;

(d) Periodically review local and interjurisdictional disaster and civil defense plans;

(e) Provide for mobile support units;

(f) Establish and operate or assist political subdivisions, their disaster and civil defense agencies, and interjurisdictional disaster and civil defense agencies to establish and operate training programs and programs of public information;

(g) Make surveys of industries, resources, and facilities within the state, both public and private, as are necessary to carry out the purposes of sections 81-829.36 to 81-829.69;

(h) Plan and make arrangements for the availability and use of any private facilities, services, and property and, if necessary and if in fact used, provide for payment for use under terms and conditions agreed upon;

(i) Establish a register of persons with types of training and skills important in disaster prevention, preparedness, response, and recovery;

(j) Establish a register of mobile and construction equipment and temporary housing available for use in a disaster emergency;

(k) Prepare, for issuance by the Governor, proclamations, orders, rules, and regulations

as are necessary or appropriate in coping with disasters;

(l) Cooperate with the federal government and any public or private agency or entity in achieving any purpose of sections 81-829.36 to 81-829.68 and in implementing programs for disaster prevention, preparation, response, and recovery; and

(m) Do other things necessary, incidental, or appropriate for the implementation of sections 81-829.36 to 81-829.68.

**Source:** Laws 1973, LB 494, sec. 6.

**81-829.42. Governor's Emergency Fund; established; use.**

(1) While annual appropriations are adequate to meet the normal needs, the Legislature recognizes the necessity for anticipating and making advance provision to care for the unusual and extraordinary burdens imposed on the state and its political subdivisions by disasters or a civil defense emergency as defined in section 81-829.39. To meet such situations, it is the intention of the Legislature to confer emergency powers on the Governor, acting through the Adjutant General and the state Civil Defense Agency, and vesting him with adequate power and authority within the limitation of available funds in the Governor's Emergency Funds to meet any such emergency or disaster.

(2) There is hereby established a fund to be known as the Governor's Emergency Fund. It shall be expended, upon direction of the Governor, for any state of emergency. The emergency declaration shall set forth the emergency and shall state that it requires the expenditure of public funds to furnish immediate aid and relief. The Adjutant General shall administer such fund. Any money in the fund available for investment shall be invested by the state investment officer pursuant to the provisions of sections 72-1237 to 71-1259.

(3) It is the legislative intent that the first recourse shall be to funds regularly appropriated to state and local agencies. If the Governor finds that the demands placed upon these funds are unreasonably great, he/she may make funds available from the Governor's Emergency Fund. Expenditures may be made upon direction of the Governor for any or all of the civil defense functions as defined in section 81-829.39, or to meet the intent of the state disaster plans as outlined in section 81-829.41. Expenditures may also be made to state and federal agencies to meet the matching requirement of any applicable assistance programs.

(4) Assistance shall be provided from the Governor's Emergency Fund to political subdivisions of this state which have suffered from a disaster to such an extent as to impose a severe financial burden exceeding the ordinary capacity of the subdivision affected. Applications for aid under this section shall be made to the state Civil Defense Agency on such forms as shall be prescribed and furnished by the agency and which shall require the furnishing of sufficient information to determine eligibility for aid and the extent of the financial burden incurred. The agency may call upon other agencies of the state in evaluating such applications. The Adjutant General shall review each application for aid under the provisions of this section and recommend its approval or disapproval, in whole or in part, to the Governor. If the Governor approves, he/she shall determine and certify to the Adjutant General the amount of aid to be furnished. The Adjutant General shall thereupon issue his voucher to the Director of Administrative Services, who shall issue his warrants therefor to the applicant.

(5) When a disaster emergency has been proclaimed by the Governor, or in the event of a civil defense emergency, the Adjutant General, upon order of the Governor, shall have authority to expend funds to meet but not be limited to the following situations:

(a) The purposes of sections 81-829.36 to 81-829.68 to include civil defense functions as defined in section 81-829.39, and the responsibilities of the Governor and the state Civil Defense Agency as outlined in sections 81-829.40 and 81-829.41;

(b) Employing for the duration of the emergency additional personnel and contracting or otherwise procuring all necessary appliances, supplies and equipment;

(c) Performing services for and furnishing materials and supplies to state government

agencies, counties and municipalities with respect to performance of any duties enjoined by law upon such agencies, counties, and municipalities which they are unable to perform because of extreme climatic phenomena, and receiving reimbursement in whole or in part from such agencies, counties, and municipalities able to pay therefor under such terms and conditions as may be agreed upon by the Adjutant General and any such agency, county, or municipality;

(d) Performing services for and furnishing materials to any individual in connection with alleviating hardship and distress growing out of extreme climatic phenomena, and receiving reimbursement in whole or in part from such individual under such terms as may be agreed upon by the Adjutant General and such individual;

(e) Performing services to counties and municipalities with respect to quelling riots and civil disturbances;

(f) Opening up, repairing, and restoration of roads and highways;

(g) Repairing and restoration of bridges;

(h) Furnishing transportation for supplies to alleviate suffering and distress;

(i) Restoration of means of communication;

(j) Furnishing medical services and supplies to prevent the spread of disease and epidemics;

(k) Quelling riots and civil disturbances;

(l) Training of individuals or governmental agencies for the purpose of perfecting the performance of emergency assistance duties as defined in the state disaster plans;

(m) Procurement and storage of special emergency supplies or equipment, determined by the Adjutant General as required to provide rapid response by state government to assist counties and municipalities in impending or actual emergencies;

(n) Clearing or removing from publicly or privately-owned land or water, debris and wreckage which may threaten public health or safety; and

(o) Such other measures as are customarily necessary to furnish adequate relief in cases of catastrophe or disaster.

(6) The Governor may receive such voluntary contributions as may be made from any source to aid in carrying out the purposes of this section and shall credit the same to the Governor's Emergency Fund.

(7) All obligations and expenses incurred by the Governor in the exercise of the powers and duties vested in him/her by the provisions of this section shall be paid by the State Treasurer out of available funds in the Governor's Emergency Fund, and the Director of Administrative Services shall draw his warrants upon the State Treasurer or the payment of such sum, or so much thereof as may be required, upon receipt by him of proper vouchers duly approved by the Adjutant General.

(8) The provisions of this section shall be liberally construed in order to accomplish the purposes of sections 81-829.36 to 81-829.68 and to permit the Governor to adequately cope with any emergency which may arise, and the powers vested in the Governor by this section shall be construed as being in addition to all other powers presently vested in him/her, and not in derogation of any existing powers.

(9) Such funds as may be made available by the government of the United States for the purpose of alleviating distress from disasters may be accepted by the State Treasurer, and shall be credited to the Governor's Emergency Fund unless otherwise specifically provided in the act of Congress making such funds available.

**Source:** Laws 1973, LB 494, sec. 7; Laws 1975, LB 612, sec. 2.

#### **81-829.43. Disaster prevention, procedure.**

(1) In addition to disaster prevention measures as included in the state, local, and interjurisdictional disaster plans, the Governor shall consider on a continuing basis steps that could be taken to prevent or reduce the harmful consequences of disasters. At his or her direction, and pursuant to any other authority and competence they have, state agencies, including but not limited to those charged with responsibilities in connection

with flood plain management, stream encroachment and flow regulation, weather modification, fire prevention and control, air quality, public works, land use and land-use planning, and construction standards, shall make studies of disaster prevention-related matters. The Governor, from time to time, shall make recommendations to the Legislature, local governments, and other appropriate public and private entities as may facilitate measures for prevention or reduction of the harmful consequences of disasters.

(2) The appropriate state agencies, in conjunction with the state Civil Defense Agency, shall keep land uses and construction of structures and other facilities under continuing study and identify areas which are particularly susceptible to severe land shifting, subsidence, flood, or other catastrophic occurrence. The studies under this subsection shall concentrate on means of reducing or avoiding the dangers caused by any such occurrence or the consequences thereof.

(3) If the state Civil Defense Agency believes on the basis of the studies or other competent evidence that an area is susceptible to a disaster of catastrophic proportions without adequate warning, that existing building standards and land-use controls in that area are inadequate and could add substantially to the magnitude of the disaster, and that changes in zoning regulations, other land-use regulations, or building requirements are essential in order to further the purposes of this section, it shall specify the essential changes to the Governor. If the Governor upon review of the recommendation finds after public hearing that the changes are essential, he or she shall so recommend to the agencies or local governments with jurisdiction over the area and subject matter. If no action or insufficient action pursuant to his recommendations is taken within the time specified by the Governor, he shall so inform the Legislature and request legislative action appropriate to mitigate the impact of disaster.

(4) The Governor, at the same time that he or she makes recommendations pursuant to subsection (3) of this section, may suspend the standard or control which he finds to be inadequate to protect the public safety and by regulation place a new standard or control in effect. The new standard or control shall remain in effect until rejected by resolution of the Legislature or amended by the Governor. During the time it is in effect, the standard or control contained in the Governor's regulation shall be administered and given full effect by all relevant regulatory agencies of the state and local governments to which it applies. The Governor's action may be appealed, and the appeal shall be in accordance with the Administrative Procedure Act.

**Source:** Laws 1973, LB494, sec. 8; Laws 1988, LB352, sec. 168.

Operative date July 1, 1989.

#### Cross Reference

Administrative Procedure Act, see section 84-920.

**81-829.44. State Civil Defense Agency; duties.** The state Civil Defense Agency shall ascertain what means exist for rapid and efficient communications in times of disaster emergencies. The agency shall consider the desirability of supplementing these communications resources or of integrating them into a comprehensive state or state-federal telecommunications or other communications system or network. In studying the character and feasibility of any system or its several parts, the agency shall evaluate the possibility of multipurpose use thereof for general state and local governmental purposes. The agency shall make recommendations with respect there to the Governor as appropriate.

**Source:** Laws 1973, LB 494, sec. 9.

**81-829.45. State Civil Defense Agency; weather condition, continuously apprise; permits; issue; suspend.** The state Civil Defense Agency shall keep continuously apprised of weather conditions which present danger of precipitation or other climatic

activity severe enough to constitute a disaster. If the agency determines that precipitation that may result from weather modification operations, either by itself or in conjunction with other precipitation or climatic conditions or activity, would create or contribute to the severity of a disaster, it shall direct the officer or agency empowered to issue permits for weather modification operation to suspend the issuance of the permits, and thereupon no permits may be issued until the agency informs the officer or agency that the danger has passed.

**Source:** Laws 1973, LB 494, sec. 10.

**81-829.46. Civil Defense Agency; political subdivisions; suspension; Governor; director; salary; powers; duties; performance of functions.**

(1) Each political subdivision within this state shall be within the jurisdiction of and served by the state Civil Defense Agency and by a local or interjurisdictional civil defense organization which is headed by a director or coordinator who shall devote full time his duties, or shall be served by a part-time director or coordinator who has a full-time assistant or deputy who shall be qualified as set forth in subsection (5) of this section.

(2) Each county shall maintain a civil defense agency or participate in a local or interjurisdictional civil defense agency which, except as otherwise provided under the provisions of sections 81-829.36 to 81-829.68, has jurisdiction over and serves the entire county. Each city and village which is desirous of establishing a civil defense organization may do so in accordance with the state civil defense plan and program. Each such local or interjurisdictional civil defense organization shall have a director who shall be appointed by the governing body or bodies of such government or governments, and who shall have direct responsibility for the organization, administration, and operation of such local organization for civil defense, subject to the direction and control of the governing body or bodies of the political subdivision or subdivisions concerned. The director of any county civil defense organization may also be appointed director for any city or village within such county, and the director of any city or village civil defense organization may also be appointed county director. Each local or interjurisdictional organization for civil defense shall perform civil defense functions within the territorial limits of the political subdivision or subdivisions within which it is organized, except that the interjurisdictional and county organizations for civil defense shall perform no civil defense functions within the limits of a county or city which are already being performed by such county or city civil defense organizations, unless the approval of the respective county or city civil defense director be first obtained.

(3) The Governor may determine that some cities need civil defense organizations or agencies of their own. He/she shall, after making such determination, require that such civil defense organizations be established and maintained by issuing a directive in the form of a rule or regulation. He shall make his determination on the basis of a city's disaster vulnerability and capability of response related to population size and concentration. The civil defense agency of a county shall cooperate with the civil defense agencies of cities within the county but shall not have jurisdiction within a city having its own civil defense agency. The state Civil Defense Agency shall publish and keep current a list of cities required to have civil Defense agencies.

(4) Any provision of sections 81-829.36 to 81-829.68 or other law to the contrary notwithstanding, the Governor may require a local government to establish and maintain a civil defense agency and organization jointly with one or more contiguous local governments, if he/she finds that the establishment and maintenance of an agency or participation therein is made necessary by circumstances or conditions that make it unusually difficult to provide disaster prevention, preparedness, response, or recovery services under the other provisions of sections 81-829.36 to 81-829.68. Such interjurisdictional agencies shall be organized generally in accord with the Interlocal Cooperation Act and pursuant to the provisions of section 84-143.

(5) Local or interjurisdictional civil defense directors or coordinators, or their assistants or deputies, who are required by sections 81-829.36 to 81-829.68 or rules and regulations of the Governor to devote full time to their duties shall be qualified in accord with criteria established for the state by the Governor and announced by him in a rule or regulation. Such directors or coordinators shall be paid for their services in an amount comparable to other officers of local governments. A minimum annual salary for such local or interjurisdictional civil defense director or coordinator shall be based on the combined population of the jurisdictions served, as follows: Having a population of less than three thousand, five thousand five hundred dollars; having a population of three thousand but less than nine thousand, six thousand dollars; having a population of nine thousand but less than sixteen thousand, six thousand five hundred dollars; having a population of sixteen thousand but less than twenty thousand, seven thousand five hundred dollars; having a population of twenty thousand but less than sixty thousand, eight thousand dollars; and having a population of sixty thousand or more, comparable to other officer of local governments as determined by the governing body or bodies.

(6) Each political subdivision, except those directly managing a local or interjurisdictional civil defense agency, shall have a liaison officer designated to facilitate the cooperation and protection of that subdivision in the work of disaster prevention, preparedness, response and recovery.

(7) The principal executive officer of each political subdivision of the state shall notify the state Civil Defense Agency of the manner in which the subdivision is providing or securing civil defense and disaster services, identify the person who heads the agency from which the service is obtained, and furnish such additional information relating thereto as the state agency requires.

(8) Each local and interjurisdictional civil defense agency shall prepare and keep current a local or interjurisdictional disaster and civil defense plan for its jurisdiction. Such plans shall be in conformance with the requirements established in section 81-829.41.

(9) Each local or interjurisdictional civil defense agency shall prepare, keep current, and distribute to all appropriate officials in written form a clear and complete statement of the disaster responsibilities of all local agencies and officials and of the disaster chain of command.

**Source:** Laws 1951, c. 315, sec. 7, p. 1079; Laws 1963, c. 516, sec. 1, p. 1632; R.R.S.1943, sec. 81-829.18; Laws 1973, LB 494, sec. 11.

**81-829.47. Interjurisdictional arrangement;  
Governor; findings.**

(1) If the Governor finds that two or more adjoining counties would be better served by an interjurisdictional arrangement than by maintaining separate disaster and civil defense agencies and services, he may delineate by order or regulation an interjurisdictional area adequate to plan for, prevent, or respond to disaster in that area and direct steps to be taken as are necessary, including the creation of an interjurisdictional relationship, a joint disaster emergency plan, mutual aid, or an area organization for disaster planning and services. A finding of the Governor pursuant to this subsection shall be based on one or more factors related to the difficulty of maintaining an efficient and effective disaster prevention, preparedness, response, and recovery system without such interjurisdictional arrangement, such as:

- (a) Small or sparse population;
- (b) Limitations on public financial resources severe enough to make maintenance of a separate disaster agency and services unreasonably burdensome;
- (c) Unusual vulnerability to disaster as evidenced by a past history of disasters, topographical features, drainage characteristics, disaster potential, and presence of disaster-prone facilities or operations;
- (d) The interrelated character of the counties in a multi-county area; or



(e) Other relevant conditions or circumstances.

(2) If the Governor finds that a vulnerable area lies only partly within this state and includes: territory in another state or states and that it would be desirable to establish an interstate relationship, mutual aid, or an area organization for disaster, he/she shall take steps to that end as desirable. If this action is taken with jurisdictions that have enacted the Interstate Civil Defense and Disaster Compact, any resulting agreement or agreements may be considered supplemental agreements pursuant to Article VI of that compact.

(3) If the other jurisdiction or jurisdictions with which the Governor proposes to cooperate pursuant to subsection (2) of this section have not enacted that compacts he may negotiate special agreements with the jurisdiction or jurisdictions. Any agreement, if sufficient authority for the making thereof does not otherwise exist, shall become effective only after its text has been communicated to the Legislature and if the Legislature has not disapproved it prior to adjournment of the next session competent to consider it, or within thirty days of its submission, whichever is later.

**Source:** Laws 1973, LB 494, sec. 12.

**81-829.48. Civil defense; local organization; mutual aid arrangements; interjurisdictional agreement.**

(1) The director or coordinator of each local or interjurisdictional organization for civil defense shall, in collaboration with other public and private agencies within this state, develop or cause to be developed mutual aid arrangements for reciprocal civil defense aid and assistance in case of disaster too great to be dealt with unassisted. Such arrangements shall be consistent with the state civil defense plan and program, and in time of emergency it shall be the duty of each local or interjurisdictional organization for civil defense to render assistance in accordance with the provisions of such mutual aid arrangements.

(2) The director or coordinator of each local or interjurisdictional organization for civil defense may, subject to the approval of the Governor, enter into mutual aid arrangements with civil defense agencies or organizations in other states for reciprocal civil defense aid and assistance in case of disaster too great to be dealt with unassisted.

(3) In passing upon local disaster plans, the Governor shall consider whether they contain adequate provisions for the rendering and receipt of mutual aid.

(4) It shall be a sufficient reason for the Governor to require an interjurisdictional agreement or arrangement, pursuant to section 81-829.47, that the area involved and political subdivisions therein have available equipment, supplies, and forces necessary to provide mutual aid on a regional basis and that the political subdivisions have not already made adequate provision for mutual aid, but in requiring the making of an interjurisdictional arrangement to accomplish the purpose of this section, the Governor need not require establishment and maintenance of an interjurisdictional agency or arrangement for any other disaster purposes.

**Source:** Laws 1951, c.31S, sec. 8(1), p. 1080; R.R.S.1943, sec. 81-829.19; Laws 1973, LB 494, sec. 13.

**81-829.49. Civil defense; political subdivision; interjurisdictional agreements; appropriations.** Each political subdivision shall have the power to make appropriations in the manner provided by law for making appropriations for the ordinary expenses of such political subdivision for the payment of expenses of its local or interjurisdictional organization for civil defense and in furthering the purposes of sections 81-829.36 to 81-829.68.

**Source:** Laws 1951, c. 315, sec. 10(1), p. 1081; R.R.S.1943, sec. 81-829.22; Laws 1973, LB 494, sec. 14.

**81-829.50. Local disaster emergency; declared; principal executive officer of a political subdivision; effect; interjurisdictional agency; disaster emergency; when.**

(1) A local disaster emergency may be declared only by the principal executive officer of a political subdivision. It shall not be continued or renewed for a period in excess of seven days except by or with the consent of the governing board of the political subdivision. Any order or proclamation declaring, continuing, or terminating a local disaster emergency shall be given prompt and general publicity and shall be filed promptly with the clerk of the local government and the state Civil Defense Agency.

(2) The effect of a declaration of a local disaster emergency shall be to activate the response and recovery aspects of any and all applicable local or interjurisdictional disaster or civil defense plans and to authorize the furnishing of aid and assistance thereunder.

(3) No interjurisdictional agency or official thereof may declare a local disaster emergency unless expressly authorized by the agreement pursuant to which the agency functions, but an interjurisdictional disaster or civil defense agency or organization shall provide aid and services in accordance with the agreement and disaster or civil defense plan pursuant to which it functions.

**Source:** Laws 1973, LB 494, sec. 15.

**81-829.51. Civil defense; emergency; political subdivision; emergency expenditures; election; when.** In the event of a civil defense emergency, as defined in section 81-429.39, each local government may make emergency expenditures, enter into contracts, and incur obligations for civil defense purposes regardless of existing statutory limitations and requirements pertaining to appropriation, budgeting, levies, or the manner of entering into contracts; Provided, that in the event that any such expenditure, contract, or obligation will be in excess of or in violation of existing statutory limitations or requirements, then before any such expenditure, contract, or obligation is undertaken it shall be approved by a vote of the governing body of such county, city, or village, as the case may be; provided further, that such governing body may not vote its approval unless and until they shall have secured the certificate of the local or interjurisdictional civil defense director serving his government that such action is necessary in the public interest for civil defense purposes.

**Source:** Laws 1951, c. 315, sec. 10(2), p. 1081; R.R.S.1943, sec. 81-829.23; Laws 1973, LB 612, sec. 16.

**81-829.52. Civil defense; mobile support rules; Governor; establish; commander of unit; appointment; duties.** The Governor or his/her duly designated representative is authorized to establish such number of mobile support units as may be necessary to reinforce disaster and civil defense organizations in stricken areas and with due consideration of the plans of the federal government and of other states. He/ she shall appoint a commander for each such unit who shall have primary responsibility for the organization, administration and operation of such battalion. The commander shall keep and maintain a roster of members of said mobile support units, and only such persons whose names appear on said roster shall be deemed members of such mobile support units and entitled to the benefits provided by sections 81-829.53, and no political subdivision shall be entitled to reimbursement as provided in section 81-829.54 unless the individual on whose behalf reimbursement is sought was duly enrolled on the roster as provided herein at the time the obligation was incurred. Mobile support units shall be called to duty upon orders of the Governor and shall perform their functions in any part of the state, or, upon the conditions specified in mutual aid plans and agreements, in accordance with the Interstate Civil Defense and Disaster Compact, and in this section, in other states.

**Source:** Laws 1951, c. 315, sec. 6(1), p. 1077; R.R.S.1943, sec. 81-829.13; Laws 1973, LB 494, sec. 17.

**81-829.53. Civil Defense; mobile support units; personnel; powers; duties; rights; immunities; compensation.** Personnel of mobile support units while on duty, whether within or without the state, shall: (1) If they are employees of the state, have the powers, duties, rights, privileges, and immunities, and receive the compensation incidental to their employment; (2) if they are employees of a political subdivision of the state, and whether serving within or without such political subdivision, have the powers, duties, rights, privileges, and immunities, and receive the compensation incidental to their employment; and (3) if they are not employees of the state or a political subdivision thereof, be entitled to compensation by the state at rates to be established by the Governor, and shall be entitled to the same rights and immunities as are provided by law for the employees of this state. All personnel of mobile support units shall, while on duty, be subject to the operational control of the authority in charge of disaster and civil defense activities in the area in which they are serving, and shall be reimbursed for all actual and necessary travel and subsistence expenses in accordance with sections 84-306.01 to 84-306.05 for state employees.

**Source:** Laws 1951, c. 315, sec. 6(2), p. 1078; R.R.S.1943, sec. 81-829.14; Laws 1973, LB 494, sec. 18; Laws 1981, LB 204, sec. 176.

**81-829.54. Civil Defense; mobile support units; employees; expenses; political subdivisions; reimbursement by state; rental of equipment; payment; damages.**

(1) The state shall reimburse a political subdivision for (a) the compensation paid and actual and necessary travel, subsistence, and maintenance expenses of employees of such political subdivision while service as members of a mobile support unit as provided in Sections 84-306.01 to 84-306.05 for state employees, (b) all payments for death, disability, or injury of such employees incurred in the course of such duty, as provided in the Nebraska Workmen's Compensation Act, and (c) all losses of or damage to supplies and equipment of such political subdivision resulting from the operation of such mobile support unit.

(2) The state shall pay a fee for rental of privately-owned equipment used in the operation of a mobile support unit, and shall also pay for any loss or damage to privately-owned equipment used immobile support. The fee for rental of said privately-owned equipment shall be fixed, and any loss or damage to said equipment shall be assessed by a board consisting of three persons to be appointed by the Governor, one of whom shall be the State Purchasing Officer.

**Source:** Laws 1951, c. 315, sec. 6(3), p. 1078; Laws 1953, c. 336, sec. 3, p. 1107; R.R.S.1943, sec. 81-829.15; Laws 1973, LB 494, sec. 19; Laws 1981, LB 204, sec. 177.

**81-829.65. Civil defense; immunity from liability for activities; covered by Workmen's Compensation Act; licenses, not required; civil defense worker; powers, duties, immunities, privileges.**

(1) All functions provided for in sections 81-289.36. to 81-829.68 and all other activities relating to civil defense are hereby declared to be governmental functions. Neither the United States, the state, nor any political subdivision thereof nor other agencies of the United States, the state, or political subdivision thereof, nor, except in cases of willful misconduct, gross negligence or bad faith, any civil defense worker complying with or reasonably attempting to comply with the provisions of sections 81-829.36 to 81-829.68 or Public Law 93-288, or any order, rule or regulation promulgated pursuant to any ordinance relating to black-out or other precautionary measures enacted by any political subdivision of the state shall be liable for the death of or injury to persons, or for damage to property, as a result of any such activity. The provisions of this section shall not affect the right of any person to receive benefits to which he would otherwise be entitled under the provisions of section 81-829.36 to 81-829.68, or under the Nebraska Workmen's Compensation Act, or under any pension

law, nor the right of any person to receive any benefits or compensation under any act of Congress.

(2) Any requirement for a license to practice any professional, mechanical or other skill shall not apply to any authorized civil defense worker who shall, in the course of performing his duties as such, practice such professional, mechanical or other skill during a civil defense emergency or declared disaster emergency.

(3) Any civil defense worker, as defined in sections 81-829.36 to 81-829.68, performing civil defense services at any place in this state pursuant to agreements, compacts or arrangements for mutual aid and assistance, to which the state or a political subdivision thereof is a party, shall possess the same powers, duties, immunities and privileges he would ordinarily possess if performing his duties in the state, province or political subdivision thereof in which is a party, shall possess the same powers, duties, immunities and privileges he would ordinarily possess if performing his duties in the state, province or political subdivision thereof in which normally employed or rendering services.

**Source:** Laws 1951, c. 315, sec. 9, p. 1080; Laws 1963, c. 517, sec. 1, p. 1633; R.R.S. 1943, sec. 81-829.21; Laws 1973, LB 494, sec. 29; Laws 1975, LB 612, sec. 3.

**81-829.56. Interstate Civil Defense and Disaster Compact; enter into.**

(1) This state hereby enacts into law and enters into the Interstate Civil Defense and Disaster Compact with all states bordering this state which have enacted or shall hereafter enact the compact in the form substantially as adopted in this state.

(2) The Governor may enter into the compact with any state which does not border his state if he finds that joint action with the state is desirable in meeting common intergovernmental problems of emergency disaster planning, prevention, response, and recovery.

(3) Nothing in subsections (1) and (2) of this section shall be construed to limit previous or future entry into the Interstate Civil Defense and Disaster Compact of this state with other states.

(4) If any person holds a license, certificate, or other permit issued by any state or political subdivision thereof evidencing the meeting of qualifications for professional mechanical, or other skills, the person may render aid involving that skill in this state to meet an emergency or disaster, and this state shall give due recognition to the license, certificate, or other permit.

**Source:** Laws 1973, LB 494, sec. 21.

**81-829.57. Persons of state; conduct; personal services; compensation for property claim; file.**

(1) Each person within this state shall conduct himself and keep and manage his affairs and property in ways that will reasonably assist and will not unreasonably detract from the ability of the state and the public successfully to meet disaster emergencies. This obligation includes appropriate personal service and use or restriction on the use of property in time of disaster emergency. Sections 81-829.36 to 81-829.68 neither increases nor decreases these obligations but recognizes their existence under the Constitution and statutes of this state and the common law. Compensation for services or for the taking or use of property shall be only to the extent that obligations recognized in this subsection are exceeded in a particular case and then only to the extent that the claimant may not be deemed to have volunteered his services or property without compensation.

(2) No personal services may be compensated by the state or any subdivision or agency thereof, except pursuant to statute or local law or ordinance.

(3) Compensation for property shall be made only if the property was commandeered or otherwise used in coping with a disaster emergency and its use or destruction was ordered by the governor or a member of the disaster emergency forces of this state to whom the Governor has duly delegated such authority.

(4) Any person claiming compensation for the use, damage, loss, or destruction of

property under sections 81-829.36 to 81-829.68 shall file a claim therefore with the state Civil Defense Agency in the form and manner the agency provides.

(5) Unless the amount of compensation on account of property damaged, lost, or destroyed is agreed upon between the claimant and the state Civil Defense Agency, the amount of compensation shall be calculated in the same manner as compensation due for a taking of property pursuant to the condemnation laws of this state.

(6) Nothing in this section shall apply to or authorize compensation for the destruction or damaging of standing timber or other property in order to provide a fire break or to the release of waters or the breach of impoundments in order to reduce pressure or other danger from actual or threatened flood.

**Source:** Laws 1973, LB 494, sec. 22.

**81-829.58. Civil Defense; supplies; services; federal government; channeled through Governor; funds deposited in Military Department Cash Fund.** Whenever the federal government or any agency or officer thereof shall offer to the state, or through the state to any political subdivision thereof, services, equipment, supplies, materials, or funds by way of gift, grant, or loan, for purposes of disaster response and civil defense, the state, acting through the Governor, or such political subdivision, acting with the consent of the Governor of the state or executive officer or governing body of such political subdivision may authorize any officer of the state or such political subdivision, as the case may be, to receive such services, equipment, supplies, materials, or funds on behalf of the state or such political subdivision, and subject to the terms of the offer and the rules and regulations, if any, of the agency making the offer. All such funds received on behalf of the state shall be deposited in the state treasury and by the State Treasurer credited to the Military Department Cash Fund.

**Source:** Laws 1951, c. 315, sec. 10(3), p. 1081; Laws 1965, c. 342, sec. 2, p. 973, R.R.S.1943, sec. 81-829.24; Laws 1973, LB494, sec. 23.

**81-829.69. Civil Defense; supplies; services; channeled through Governor; funds deposited in Military Department Cash Fund.** Whenever any person, firm, or corporation shall offer to the state or to any political subdivision thereof, services, equipment, supplies, materials, or funds by way of gift, grant, or loan, for purposes of disaster response and civil defense, the state, acting through the Governor, or such political subdivision, acting through its executive officer or governing body, may accept such offer and upon such acceptance the Governor of the state or executive officer or governing body of such political subdivision may authorize any officer of the state or of the political subdivision, as the case may be, to receive such services, equipment, supplies, materials, or funds on behalf of the state or such political subdivision, and subject to the terms of the offer. All such funds received on behalf of the state shall be deposited in the state treasury and by the State Treasurer credited to the Military Department Cash Fund.

**Source:** Laws 1951, c. 315, sec. 10(4), p. 1082; Laws 1965, c. 342, sec. 3, p. 974; R.R.S.1943; sec. 81-829.25; Laws 1973, LB 494, sec. 24.

**81-829.60. Civil defense; services, equipment, and supplies; utilization of services, equipment, supplies, and facilities of existing departments and agencies of state.** In carrying out the provisions of sections 81-829.36 to 81-829.68, the Governor and the executive officers or governing bodies of the political subdivisions of the state are directed to utilize the services, equipment, supplies, and facilities of existing departments, offices, and agencies of the state and of the political subdivisions thereof to the maximum extent practicable, and the officers and personnel of all such departments, offices, and agencies are directed to cooperate with and extend such services and facilities to the Governor and to the disaster response and civil defense organizations of the state upon request.

**Source:** Laws 1951, c. 315, sec. 11, p. 1082; R.R.S.1943, sec. 81-829.26; Laws 1973, SB 494, sec. 25.

**81-829.61. Disaster response; civil defense; organizations; political activities prohibited.** No organization for disaster response and civil defense established under the authority of sections 81-829.36 to 81-829.68 shall participate in any form of political activity, nor shall it be employed directly or indirectly for political purposes.

**Source:** Laws 1951, c. 315, sec. 12, p. 1082; R.R.S.1943, sec. 81-829.27; Laws 1973, LB 494, sec. 26.

**81-829.62. Disaster response; civil defense; personnel; advocacy of subversive activities against government; employment prohibited; oath.** No person shall be employed or associated in any capacity in any disaster response and civil defense organization established under the provisions of section 81-829.36 to 81-829.68 who advocates or has advocated a change by force or violence in the constitutional form of the government of the United States or in this state or the overthrow of any government in the United States by force or violence, or who has been convicted of or is under indictment or information charging any subversive act against the United States. Each person who is appointed to serve in an organization for disaster response and civil defense, shall before entering upon his duties, take an oath, in writing, before a person authorized to administer oaths in this state; *Provided*, that the Adjutant General and any subordinate civil defense officer within this state, designated by the Adjutant General in writing, shall be qualified to administer any such oath within this state under such regulations as the Adjutant General shall prescribe. The oath shall be substantially as follows:

I ....., do solemnly swear (or affirm) that I will support and defend the Constitution of the United States and the Constitution of the State of Nebraska, against all enemies, foreign and domestic; that I will bear true faith and allegiance to the same; that I take this obligation freely, without any mental reservation or purpose of evasion; and that I will well and faithfully discharge the duties upon which I am about to enter. And I do further swear (or affirm) that I do not advocate, nor am I a member of any political party or organization that advocates the overgrowth of the government of the United States or of this state by (name of civil defense organization), I will not advocate nor become a member of any political party or organization that advocates the overthrow of the government of the United States or of this state by force or violence. So help me God.

**Source:** Laws 1951, c. 315, sec. 13, p. 1082; Laws 1953, c. 336, sec. 4, p. 1108; R.R.S. 1943, sec. 81.829.28; Laws 1973, LB 494, sec. 27.

**81-829.63. Civil defense; personnel; oath; affirmation.** Whenever an oath is required by section 81-829.62, the affirmation of a person conscientiously scrupulous of taking an oath shall have the same effect.

**Source:** Laws 1951, c. 315, sec. 14, p. 1083; R.R.S.1943, sec. 81-829.29; Laws 1973, LB 494, sec. 28.

**81-829.64. Disaster response and civil defense; organizations; enforce laws, orders, rules, and regulations.** It shall be the duty of every organization for disaster response and civil defense established pursuant to the provisions of sections 81-829.36 to 81-829.68 and of the officers thereof to execute and enforce such orders, rules, and regulations as may be made by the Governor under authority of sections 81-829.36 to 81-829.68. Each such organization shall have available for inspection at its office all orders, rules, and regulations made by the Governor, or under his authority.

**Source:** Laws 1951, c. 315, sec. 15, p. 1083; R.R.S.1943, sec. 81-829.30; Laws 1973, LB 494, sec. 29.

**81-829.65. Disaster or civil defense; fire departments; moving of equipment outside of political subdivisions; insurance.** The governing body of each political subdivision of this state shall take the necessary action to permit the movement of its emergency equipment and personnel, or such equipment and personnel as defined in the state, local, or

interjurisdictional disaster or civil defense plans, outside the limits of such political subdivision in order to render aid, in the event of major disaster or civil defense emergency, as such terms are defined in section 81-829.39, or in connection with any program of practice or training for such disaster or civil defense emergency when such program is conducted, or participated in by the state Civil Defense Agency or with any other related training program. Such movement may be to any point in this state, or may be into any adjoining state when mutual aid arrangements have been entered into on behalf of this state with such other state as authorized by section 81-829.56. Each political subdivision shall self-insure or contract for insurance against any liability for personal injuries or property damage that may be incurred by it or by its personnel, as the result of any movement made pursuant to this section. As used in this section, political subdivision shall not include a district as defined in section 70.601.

**Source:** Law 1957, c. 380, sec. 1, p. 1323; R.R.S.1943, sec. 81-829.32; Laws 1973, LB 494, sec. 30. Laws 1988, LB961, sec. 1.

**81-829.66. Civil defense or disaster; immunity from liability for licensors of shelter space.** Any person owning or controlling real estate or other premises who voluntarily and without compensation grants a license or privilege, or otherwise permits the designation or use of the whole or any part or parts of such real estate or premises for the purpose of sheltering persons during an actual, impending, mock or practice attack or disaster shall, together with his successors in interest, if any, not be civilly liable for negligently causing the death of, or injury to, any person on or about such real estate or premises, or loss of, or damage to, the property of such person, at any time such real estate or premises are actually used for such purpose.

**Source:** Laws 1963, c. 499, sec. 1, p. 1591; R.R.S.1943, sec. 81-829.35; Laws 1973, LB 494, sec. 31.

**81-829.67 and 81-829.68. Repealed.** Laws 1976, LB 847, sec. 2.

**81-829.69. Disaster emergency; proclaimed by Governor; powers.** Whenever the Governor has proclaimed a disaster emergency pursuant to section 81-829.40, the Governor shall be authorized:

(1) to enter into purchase, lease, or other arrangements with any agency of the United States for temporary housing units to be occupied by disaster victims and to make such units available to any political subdivisions of the state;

(2) To assist any political subdivision of the state which is the location of temporary housing for disaster victims to acquire sites necessary for such temporary housing and to do all things required to prepare such sites to receive and utilize temporary housing units; and

(3) Under such regulations as he shall prescribe, to temporarily suspend or modify for not to exceed sixty days any public health, safety, zoning, transportation, or other requirement of law or regulation within this state when by proclamation he deems such suspension or modification essential to provide temporary housing for disaster victims.

**Source:** Laws 1975, LB 612, sec. 4.

**81-829.70. Temporary housing units; powers of political subdivisions.** Any political subdivision of this state is expressly authorized to acquire, temporarily or permanently, by purchase, lease, or otherwise, sites required for installation of temporary housing units for disaster victims, and to enter into whatever arrangements are necessary to prepare or equip such sites to utilize the housing units.

**Source:** Laws 1975, LB 612, sec. 5.

**81-829.71. Major disaster; powers of Governor; apply for federal community disaster loans.** Whenever a major disaster has been declared to exist in this state, the Governor shall be authorized:

(1) Upon his determination that a local government of the state will suffer a substantial loss of tax and other revenue from a major disaster and has demonstrated a need for financial assistance to perform its governmental functions, to apply to the federal government, on behalf of the local government, for a loan, and to receive and disburse the proceeds of any approved loan to any applicant local government subject to the terms of the loan. The Governor shall determine the amount needed by any applicant local government to restore or resume its governmental functions, and certify such amount to the federal government; and

(2) To recommend to the federal government, based upon his review, the cancellation of all or any part of repayment when, in the first three full fiscal years following the major disaster, the revenue of the local government is insufficient to meet its v operating expenses, including additional disaster-related expense of municipal operation.

**Source:** Laws 1972, LB 612, sec 6.

**81-829.72. Major disaster; powers of Governor; accept federal grant for disaster victims, Adjutant General; rules and regulations.**

(1) Whenever a major disaster has been declared to exist in this state, the Governor is authorized, upon his determination that financial assistance is essential to meet disaster-related necessary expenses or serious needs of individuals or families adversely affected by a major disaster that may not be otherwise met from other means of assistance, to accept a grant by the federal government to provide such financial assistance, subject to such terms and conditions as may be imposed upon the grant.

(2) The Adjutant General shall make such regulations as shall be necessary to carry out the purposes of subsection (1) of this section, including, but not limited to: (a) Standards of eligibility for persons applying for benefits; (b) procedures for application and administration; (c) methods of investigating, filing, and approving applications; and (d) formation of local or statewide boards to pass upon applications and procedure for appeals. Such rules, regulations, and standards shall, upon approval thereof by the Governor, be promulgated so as to meet disaster-related necessary expenses and serious needs of individuals. For the purposes of this subsection, necessary expenses and serious needs shall mean those essential requirements of food, health, clothing, and shelter.

**Source:** Laws 1975, LB 612, sec. 7.

**81-829.73. Misstatement concerning financial assistance; penalties.** Any person who fraudulently or willfully makes a misstatement of fact in connection with an application for financial assistance under sections 68-703, 81-829.42, 81-829.55, and 81-829.69 to 81-829.74 shall, upon conviction of each offense, be subject to a fine of not more than five thousand dollars, or imprisonment in the county jail for not more than one year, or both.

**Source:** Laws 1975, LB 612, sec. 8.

**81-829.74. State of Nebraska; assents to federal law.** The State of Nebraska, by the adoption of sections 68-703, 81-829.42, 81-829.55, and 81-289.69 to 81-829.74, assents to the provisions of the Disaster Relief Act of 1974, P.L.93-288, 93rd Congress, insofar as such provisions are permissible under the Constitution of the State of Nebraska.

**Source:** Laws 1975, LB 612, sec. 9.



**APPENDIX D: LEGAL OPINION ON NEBRASKA LAW  
CONCERNING THE REMOVAL OF ICE JAMS**  
(Drafted by James R. Cook, February 15, 1994)

Nebraska law does not address specifically the questions of (1) who, if anyone, has authority to approve ice jam removal (including by dynamiting) in the state's watercourses, or (2) what liability exists for injury to person or damage to property as a result of any efforts extended toward such removal or as a result of the removal itself. However, the questions are answered in a general way through the Nebraska Disaster and Civil Defense Act (hereinafter called the Disaster Act) sections 81-829.36 to 81-829.68, R.R.S. 1943, as amended.\*

As is true for other emergency activities, if efforts to remove an ice jam take place in full accord with the Disaster Act, both the state and its political subdivisions are authorized to approve that activity and are essentially insulated from liability for any damages resulting therefrom. If such action is not taken in accord with the Disaster Act, the basis for such authority is unclear and the chances of liability are much higher. The questions are analyzed in more detail below.

**Authority to Approve  
Ice Jam Removal**

Section 82-829.39 of the Disaster Act defines the term "civil defense" in relevant part to mean

"...the preparation for and the carrying out of all emergency functions...to prevent, minimize...damage resulting from disasters caused by...flood.... These functions include, without limitation...other functions related to civilian protection, together with all other activities necessary or incidental to the preparation for and carrying out of the foregoing functions."

The same statute defines "disaster" to mean "...occurrence or imminent threat of wide spread or severe damage, injury, or loss of life or property resulting from any natural or manmade cause,

including but not limited to... flood..." Those two statutes authorize virtually any activity that the state or an appropriate local subdivision deems necessary to prevent or minimize the consequences of flooding. However, it is very important that the provisions of the Disaster Act be followed carefully to take advantage of the protection granted by that act. Part of that compliance involves the preparation of state and local disaster plans. The authority and requirement for the state disaster plan is section 81-829.41, R.R.S. 1943. The authority and requirement for local disaster plans is section 81-829.46(8), R.S. Supp, 1992. For disaster declarations made by the Governor, section 81-829.40(4), R.R.S. 1943 provides that "*proclamation of a state of disaster emergency shall activate disaster response and recovery aspects of the state, local, and interjurisdictional disaster and civil defense plans applicable to the political subdivision or area in question...*" (emphasis added). A local disaster emergency also may be declared by the principal executive officer of any political subdivision (81-829.50(1)), R.R.S. 1943. The effect of any such local declaration is to "...activate the response and recovery aspects of and all applicable local or interjurisdictional disaster or civil defense plan..." (emphasis added) (81-829.50(2)), R.R.S. 1943. It is important to note from these two statutes that whether the disaster declaration is by the Governor or by a local political subdivision, the effect is to authorize the carrying out of what is included in the applicable plan (state or local). It is therefore advisable for those plans to include provisions for relief from ice jams, including standards or criteria for when the existence of those ice jams will result in a disaster emergency declaration and also the proposed measures to respond to that situation. If it is anticipated that the response may include dynamiting, when and how that will be done must be addressed in the plan.

**Limitation of Liability**

If the activities undertaken are in accordance with the Disaster Act, section 81-829.55 provides extensive protection from liability. In relevant part, that section provides as follows:

"Neither the United States, the state nor any political subdivision thereof nor other agencies of the United States, the state

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\* NOTE: LB 1203, currently pending before the Nebraska Legislature, would rename the act the "Emergency Management Act" and would modify the laws upon which this paper is based. If LB 1203 or similar legislation passes, modifications to this paper will be needed.

or political subdivision thereof, nor, except in cases of willful misconduct, gross negligence or bad faith any civil defense worker complying with or reasonably attempting to comply with the provisions of [the Disaster Act]...or any order, rule or regulation promulgated pursuant to the provisions of [the Disaster Act]...shall be liable for the death of or injury to persons, or for damage to property, as a result of any such activity."

There are two different standards concerning liability in the quoted material. For the governments—federal, state, or local—there is *no* liability as long as the activity is conducted in accordance with the Disaster Act (which means pursuant to a state or local declaration and in accordance with the previously prepared disaster plan). For civil defense workers, which include employees, volunteers, and auxiliary employees of the government or "of any agency or *organization* performing civil defense services at any place in this state subject to the order or control of, or pursuant to a request of, the state government or any political subdivision thereof..." there would be liability only in the event there is willful misconduct, gross negligence, or bad faith.

Section 81-829.55, R.R.S. 1943 was used successfully to prevent the state and Department of Roads employees from being held liable for damages caused by the removal in 1978 of an ice jam on the Platte (Cain v. State, Case No. 10163, Saunders County, 1981). It is not clear whether this protection for civil defense workers extends to contractors although they may be included within the term "organization" as used in the statute. Private contractors may, however, want to secure insurance to protect them against an action based on a regular negligence standard.

### **Actions Taken Other Than in Accordance with the Disaster Act**

If action to dynamite or otherwise remove ice jams from rivers is taken and that is not in accordance with the Disaster Act, the defense of that action would be much more difficult. There is no separate and specific authority which the state, counties, or other political subdivisions could use for such action. And, it is clear that the rather considerable protection from liability granted by the Disaster Act would not be available. Without the limits on liability imposed by that act, governmental liability would be determined in accordance with the State or Political Subdivisions Tort Claims Act, whichever was applicable. The governing section of the Political Subdivision Tort Claims Act is section 13-910, R.S. Supp, 1993. For the state act, the governing section is section 81-8219, R.R. Supp, 1993. Both effectively establish a negligence test as the standard for liability. Under those statutes, the state and its political subdivisions are liable for damages to the same extent as private citizens would be for the same actions.

### **Nebraska Game and Parks Authority**

There is one other statute which deserves mention here. That is section 37-515, R.S. Supp, 1993, which relates to the necessity of obtaining approval from the Game and Parks Commission before exploding any dynamite in any lake, river, stream or other waters of the state. However, that section specifically provides that the requirement "... shall not apply where, to safeguard public or private property from damage by ice gorges, immediate use of explosives is necessitated." Unless there is a question about the immediacy of the action needed, approval by Game and Parks would not be needed.



13. ABSTRACT (cont'd).

each of the seven sites was also made during the ice-covered season. The third phase involved the design of the data collection program and database. Personnel from CRREL conducted a workshop to train ice observers and other interested parties in data collection, while the database design was done by the Nebraska Natural Resources Commission. Phase 4 was the assessment of mitigation and prediction techniques. Various mitigation techniques were evaluated for feasibility, and several were recommended for further study. A model was developed to forecast the occurrence and severity of ice jams utilizing collectable data. The fifth phase involved the development of guidance on the application of specific preventive measures, such as dusting and blasting. The final phase involved the compilation of all work into this report.