Guidance for Flood Risk Analysis and Mapping

Ice-Jam Analyses and Mapping

February 2018

FEMA

Requirements for the Federal Emergency Management Agency (FEMA) Risk Mapping, Assessment, and Planning (Risk MAP) Program are specified separately by statute, regulation, or FEMA policy (primarily the Standards for Flood Risk Analysis and Mapping). This document provides guidance to support the requirements and recommends approaches for effective and efficient implementation. Alternate approaches that comply with all requirements are acceptable.

For more information, please visit the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage (www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping). Copies of the Standards for Flood Risk Analysis and Mapping policy, related guidance, technical references, and other information about the guidelines and standards development process are all available here. You can also search directly by document title at www.fema.gov/library.

Table of Revisions

Affected Section or Subsection	Date	Description
First Publication	February 2018	Initial version of newly transformed guidance. The content was derived from the Guidelines and Specifications for Flood Hazard Mapping Partners, Procedure Memoranda, and/or Operating Guidance documents. It has been reorganized and is being published separately from the standards.

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1.0 Overview

An ice jam may be defined as an accumulation of ice in a river, stream or other flooding source that reduces the cross-sectional area available to carry the flow and increases the water-surface elevation. Ice usually accumulates at a natural or manmade obstruction or a relatively sudden change in slope, alignment or cross-section shape or depth. Ice jams are common in locations where the channel slope changes from relatively steep to mild and where a tributary stream enters a large river. Ice jams often cause considerable increases in upstream water-surface elevation, and the flooding often occurs quite rapidly after the jam forms.

In the northern United States, where rivers can develop relatively thick ice covers during the winter, ice jams can contribute significantly to flood hazards. Although flow discharges may be low relative to free flow flood, the stages of ice jam flooding may be among the highest on record. Ice jams typically occur repeatedly in the same locations, and ice jam flooding tends to be local and highly site specific.

In areas likely to be selected for an enhanced study by FEMA or one of FEMA's Mapping Partners, historical documentation will usually indicate if ice-jam flooding is a significant factor warranting consideration. In regions of the United States where ice jams are typical, the Mapping Partner that performs an enhanced study for a FEMA-contracted Flood Risk Project or community-initiated map revision shall investigate historical floods for evidence of ice-jam contribution as part of the reconnaissance effort.

2.0 Ice-Jam Types

Ice jams have been classified in numerous ways by various investigators. In the U.S. Army Cold Regions Research and Engineering Laboratory Technical Note entitled "Methodology for Ice Jam Analysis" (1980), ice jams were classified as freezeup-, breakup-, floating- or grounded-type jams. Each type is discussed in more detail in Subsections 2.1 through 2.4.

Additional information on the characteristics of ice jams is provided by the National Research Council of Canada in Chapter 10 of *Hydrology of Floods in Canada—A Guide to Planning and Design* (National Research Council of Canada, 1989) and by the U.S. Army Corps of Engineers in Engineering Pamphlet 1110-2-11, *Engineering and Design Ice Jam Flooding: Causes and Possible Solutions* (U.S. Army Corps of Engineers, 1994).

2.1 Freezeup-Type Jams

Freezeup-type jams are associated with the formation and accumulation of frazil ice which eventually forms a continuous ice cover. Freezeup jams typically occur during early winter to midwinter. The Mapping Partner that performs the enhanced study usually will not be required to address freezeup-type jams in performing an enhanced study for National Flood Insurance Program (NFIP) purposes because freezeup-type jams are not associated with large discharge events. However, the Mapping Partner shall be aware of possible exceptions.

2.2 Breakup-Type Jams

Breakup-type jams are frequently associated with rapid increases in runoff and rises in river stage resulting from rainfall and/or snowmelt. Breakup-type jams usually occur during the late winter or early spring. Because of the large volumes of ice that may be involved and the greater discharges associated with them, breakup-type jams are predominant in ice-jam-caused flooding. Therefore, breakup-type jams are the type that the Mapping Partner that performs the enhanced study for a FEMA-contracted Flood Risk Project or community-initiated map revision will typically need to investigate.

2.3 Floating-Type Jams

Floating-type jams are considered to be those where the ice is not grounded to the channel bottom and significant flow takes place beneath the ice cover. Floating-type jams are typical of deeper rivers. Because floating-type jams can cause significant backwater effects, the Mapping Partner that performs the enhanced study must address them as part of the enhanced study for a FEMA-contracted Flood Risk Project or community-initiated map revisions when such conditions exist.

2.4 Grounded-Type Jams

Grounded-type jams are characterized by an ice cover that is partially grounded to the bed of the channel with most of the flow being diverted into the overbank and floodplain areas. Grounded-type jams are typical of shallow, confined stream sections. Because grounded-type jams can cause significant backwater effects, the Mapping Partner that performs the enhanced study must address them as part of the enhanced study for a Flood Risk Project when such conditions exist.

3.0 Reconnaissance

When the Mapping Partner that performs the enhanced study determines that ice jamming has historically resulted in flooding within the community that is the subject of the Flood Risk Project, the Mapping Partner shall intensify the reconnaissance effort. Through the intensified reconnaissance effort, the Mapping Partner will be able to acquire as much data as possible concerning ice-jam events in the community, on the streams being studied, and in the region. Such data shall include, but not be limited to, the following:

- Locations of ice jams,
- Dimensions,
- Ice volumes,
- Causes,
- Associated river stages and discharges,
- Frequency of occurrence,
- Lateral and upstream extent of flooding, and
- Season of occurrence.

The Mapping Partner that performs the enhanced study also shall investigate the nature of ice jamming common to the site; that is, whether freezeup- or breakup-type jams are typical and whether grounded- or floating-type jams are typical. Because very limited documentation data are usually available, the Mapping Partner that performs the enhanced study shall investigate all possible sources of information, including the following:

- Photographs,
- Local residents,
- Newspapers,
- Community officials, and
- State and Federal agencies.

During the field reconnaissance, the Mapping Partner that performs the enhanced study also shall investigate physical evidence of ice jams (e.g., high-water marks, damage to structures, scars on trees) that may provide useful data for the analysis.

4.0 Analysis Approaches

Different methods may be used for establishing flood elevations in areas subject to ice-jam flooding depending on the availability of data and the nature of the ice-jamming phenomena that occur at the site of interest. The methods outlined herein are applicable primarily to stationary-type ice jams that occur during periods of ice breakup. When conditions warrant alternate analytical methods, the Mapping Partner that performs the enhanced study must seek approval of the alternate methods from the FEMA Regional Project Officer (RPO) before proceeding.

The approaches in Subsections 4.1 and 4.2 are based on the development of stage-frequency relationships for two different populations (ice-jam flood stages and free-flow flood stages) which are then combined into a single composite frequency curve for flood stages at a site under study. Depending on the availability of ice-jam stage information, ice-jam frequency relationships may be determined directly or indirectly as discussed in Subsections 4.1 and 4.2. For NFIP purposes, the direct method is preferred where sufficient data are available.

4.1 Direct Approach

If sufficient data exist at the site of interest, the Mapping Partner that performs the enhanced study shall establish an ice-jam stage-frequency distribution directly by analyzing the historical ice-stage data. This approach is preferred where ice-jam stages are available for three or more significant events (i.e., overbank flooding) that span more than a 25-year period of record and where hydraulic conditions have not changed appreciably since those events.

Limited data on historical ice-jam stages are usually available at ungaged locations, and the Mapping Partner that performs the enhanced study may obtain these data from a variety of sources including

- Community officials,
- Resident recollections,
- Newspaper accounts,
- High-water marks,
- Tree damage or scars,

- Vegetation trim lines, and
- Disturbed bank material.

If historical records of stage are sufficient, the Mapping Partner that performs the enhanced study may use the graphical frequency analysis method to compute plotting positions and fit a frequency curve on a probability graph. Because of their simplicity, FEMA recommends using the Weibull plotting positions for this purpose although other plotting positions are also applicable. However, the Mapping Partner shall be aware that any extrapolation beyond the range of the observed data is risky when the graphical frequency analysis is performed, because the ice-affected stages are primarily governed by the regime of ice and its interaction with channel geometry. Additional guidance on graphical frequency analysis and the use of exceedance thresholds for ice-jam flooding is provided in *Hydrology of Floods in Canada—A Guide to Planning and Design* (National Research Council of Canada, 1989).

If the enhanced study reach includes a gaging station where historical ice jams have occurred, the Mapping Partner that performs the enhanced study shall perform a stage-frequency analysis using the stage data at the gaging station. The Mapping Partner shall obtain the stage data necessary for this analysis from streamflow records published by the U.S. Geological Survey (USGS) and other agencies. An example of stage data archived and published by the USGS is shown in Table 1 for the Platte River at North Bend, Nebraska (station no. 06796000).

Table 1: Example of Annual Peak Discharges and Stages Available for the Platte River at North Bend, NE (Station No. 06796000)

Date	Annual Peak Discharge (cfs)	Stage for Annual Peak Discharge (ft)	Date	Annual Peak Stage(ft)
June 2, 1949	21000	7.05[a]		
July 12, 1950	25000	7.30	March 7, 1950	8.00[b]
May 31, 1951	30800	7.65	February 24, 1951	7.80[b]
March 28, 1952	18000	6.65	February 13, 1952	10.17[b]
May 11, 1953	20900	7.05	February 8, 1953	7.14[b]
June 18, 1954	22800	7.33[a]		
March 10, 1955	12700	7.65	March 9, 1955	8.20[b]
June 17, 1957	44200	8.06[a]		
February 26, 1958	29100	7.59	February 26, 1958	8.26[b]
August 2, 1959	21700	7.04	March 12, 1959	7.55[b]
March 29, 1960	112000	10.04[a]		
May 23, 1961	15700	6.02	February 16, 1961	6.93[b]
March 26, 1962	39000	7.78	March 23, 1962	8.78[b]
June 24, 1963	37300	7.78	December 24, 1962	8.53[b]
June 17, 1964	30200	7.35[a]		
June 29, 1965	35800	7.84[a]		
August 14, 1966	72500	9.01[a]		
June 16, 1967	75200	9.56[a]		
June 25, 1968	29200	7.52[a]		
March 22, 1969	42100	8.23[a]		
February 25, 1970	12000	5.94	February 24, 1970	7.66[b]
March 11, 1971	28000	8.27	February 20, 1971	12.24[b]

[a]annual maximum peak stage resulting from a free-flow event

[b]annual maximum peak stage resulting from an ice-jam event

The annual-maximum stage can occur as the result of either a free-flow event or an ice-jam event. For the ice-jam events, the annual-maximum peak stages can occur at a different time than the annual-maximum peak discharge as illustrated in Table 1.

If detailed data are available, the Mapping Partner that performs the enhanced study may follow two approaches for the direct analysis of stage data: (1) annual-event series and (2) annual-maximum series. The Mapping Partner shall use the annual-event series approach when data are available for both the maximum peak stage during the ice-jam season and the maximum peak stage during the free-flow season for each year (two values per year). The Mapping Partner shall use the annual-maximum series approach when only data for the annual-maximum peak stages are available for each year.

In both approaches, the Mapping Partner that performs the enhanced study shall develop separate frequency curves for the ice-jam events and the free-flow events and then combine them into a single composite frequency curve to determine the percent chance that a given stage will be exceeded in a year. Weibull plotting positions are preferred for determining the individual stage-frequency curves. However, when there are more than 10 years of ice-jam or free-flow stages, the Mapping Partner may fit a frequency distribution such as the log-Pearson Type III (Interagency Advisory Committee on Water Data, 1982) to the stage data or their logarithms to help define or extend the stage-frequency curve based on plotting positions. The Mapping Partner should determine if the analytical frequency curve is applicable and consistent with the plotting positions. An example of analyzing both annual-event and annual-maximum series is given in "Discussion of Techniques for Analysis of Ice-Jam Flooding" (Thomas, Crockett and Johnson, 1998).

4.1.1 Annual-Event Series

To develop the annual-event series, the Mapping Partner that performs the enhanced study shall develop peak stages for the ice-jam season and for the free-flow season for each year of record. However, most often, the available data will not be sufficient to develop the annual-event series. In many years, only a single peak stage is reported. To develop the annual-event series for these years, the Mapping Partner shall determine the peak stage through a search of the historical stage records. FEMA does not recommend estimating the peak stage, because this approach introduces uncertainty in the analysis, particularly when estimating the missing ice-jam stages. Even though a search of historical stage records is usually time consuming, the Mapping Partner that performs the enhanced study shall use this approach for developing the complete annual-event series.

For the annual-event series, the Mapping Partner that performs the enhanced study shall compute stage-frequency curves for each season and combine them using the following equation:

$$P(s) = P(si) + P(sq) – P(si) * (P(sq) \qquad (1)$$

Where

P(s) = Probability of the annual-maximum stage exceeding a given stage "s" in any year, by either type of event

P(si) = Probability of the annual-maximum stage exceeding a given stage “s” in the ice-jam season (not all events in the ice-jam season will necessarily be affected by backwater from ice)

P(sq) = Probability of the annual-maximum stage exceeding a given stage “s” in the free-flow season

P(si) * P(sq) = Joint probability of the annual-maximum stage exceeding a given stage “s” in any year from both types of events

For the annual-event analysis, the Mapping Partner that performs the enhanced study shall determine a peak stage for each season each year and combine the seasonal frequency curves into a single composite frequency curve assuming the two populations are independent of one another. The Mapping Partner shall not use Equation 1 if the two populations are not independent, if it is impossible to compile an annual-event series or if it is impossible to segregate the peak stages into populations based on distinct hydrologic causes. When these conditions cannot be met, the Mapping Partner that performs the enhanced study shall use an alternate approach that uses only the annual-maximum peak stages in the frequency analysis.

4.1.2 Annual-Maximum Series

In the annual-maximum series, the Mapping Partner that performs the enhanced study shall identify the annual peak stage in each year of record as resulting from either an ice-jam or free-flow event. The Mapping Partner that performs the enhanced study shall then develop a stage-frequency curve using all annual-maximum stages that are ice-jam events and a separate stage-frequency curve using all the annual-maximum stages that are free-flow events. Each frequency curve is called a “conditional-frequency curve”.

The ice-jam conditional-frequency curve is “conditioned” in the sense that only annual-maximum peak stages that are ice-jam-related are used in the frequency analysis. To obtain the probability of an ice-jam event exceeding a given stage “s” in any year, the Mapping Partner that performs the enhanced study shall multiply the exceedance probabilities from the conditional-frequency curve by the fraction of time that ice-jam events produce annual-maximum peak stages.

The free-flow conditional-frequency curve is “conditioned” in the sense that only annual-maximum peak stages that are free-flow events are used in the frequency analysis. To obtain the probability of a free-flow event exceeding a given stage “s” in any year, the Mapping Partner performing the enhanced study shall multiply the exceedance probabilities from the conditional-frequency by the fraction of time that free-flow events produce annual-maximum peak stages.

The Mapping Partner that performs the enhanced study shall then combine the seasonal-frequency curves into a single composite frequency curve to obtain the probability of the annual-maximum stage exceeding a given stage “s” in any year for either a free-flow or an ice-jam related event. For the annual-maximum series, the Mapping Partner that performs the enhanced study shall compute the stage-frequency curves for each season and combine them using the following equation:

P(s) = (P(s) | s = free-flow event) * P(s = free-flow event) +

(P(s) | s = ice-jam event * P(s = ice-jam event) (2)

Where

P(s) = Probability of the annual-maximum stage exceeding a given stage “s” in any year by either type of event

(P(s) | s = free-flow event) = Conditional probability of the annual-maximum stage exceeding a given stage “s” in any year, when only free-flow events that are annual-maximum peak stages are used in the analysis

(P(s = free-flow event) = Fraction of years for which the annual-maximum peak stage was a free-flow event

(P(s) | s = free-flow event) * P(s = free-flow event) = Joint probability of the annual-maximum stage exceeding a given stage “s” in any year and the seasonal free-flow event is an annual maximum

(P(s) | s = ice-jam event) = Conditional probability of the annual-maximum stage exceeding a given stage "s" in any year, when only ice-jam events that are annual-maximum peak stages are used in the analysis

P(s = ice-jam event) = Fraction of years for which the annual-maximum peak stage was an ice-jam event

(P(s) | s = ice-jam event) * P(s = ice-jam event) = Joint probability of the annual-maximum stage exceeding a given stage “s” in any year and the seasonal ice-jam event is an annual maximum

4.1.3 Summary

Equations 1 and 2 provide two different approaches for combining stage-frequency curves when stage data are directly available, when stage data are determined by the indirect approach described in Subsection 4.2 or for a combination of the two approaches. For example, the Mapping Partner that performs the enhanced study may use Equation 1 where limited historical stage data are available for ice-jam analysis and where the stage data for free-flow conditions are determined using the indirect approach. The Mapping Partner may estimate the probability of the annual-maximum stage exceeding a given stage “s” in any year from an ice-jam event (P(si)) from limited stage data such as three events occurring over at least a 25-year period.

As discussed earlier in this Guidance document, the Mapping Partner that performs the enhanced study shall perform a graphical analysis using Weibull plotting positions or other applicable plotting positions and combine the probability (P(si)) with the free-flow probabilities (P(sq)) using Equation 1. The Mapping Partner shall determine the free-flow probabilities (P(sq)) using discharge-frequency analysis for the free-flow season and standard hydraulic modeling procedures as described in Subsection 4.2.

Equation 2 is more convenient for directly computing stage-frequency curves for enhanced study reaches where detailed information is available, such as at gaging stations. This approach requires the fraction of time that annual-maximum stages are caused by either ice-jam or free-flow events and uses just the annual-maximum stages for the two types of events. This information is usually not available or easy to determine for ungaged locations.

The Mapping Partner that performs the enhanced study shall use the direct approach rather than the indirect approach as discussed below, because the joining probabilities of various hydrologic and hydraulic factors (e.g., discharges, ice volumes, and ice thickness) are inherently included in the frequency analysis. However, available data are often not sufficient for direct analysis or when hydraulic conditions in the enhanced study reach are different from gaging stations located upstream or downstream of the reach. In those instances, the Mapping Partner that performs the enhanced study shall use the indirect approach.

4.2 Indirect Approach

The Mapping Partner that performs the enhanced study may use the indirect approach to ice-jam stage-frequency analysis where available data are insufficient to establish a stage-frequency distribution directly.

4.2.1 Assumptions

The indirect approach to ice-jam stage-frequency analysis makes use of the following assumptions:

- Ice-jam stage frequency is a function of ice-jam season-discharge frequency.
- Ice jams are of the breakup type.
- Ice jams are of the stationary type.
- For all ice jams, the ice thickness will be given by the equilibrium relationship developed in “Formation of Ice Covers and Ice Jams in Rivers” (Pariset, Hauser and Gagnon, 1966).
- For all ice jams, the stage-discharge relationship will be determined by adjusting the standard step-backwater technique for flow under an ice cover of equilibrium thickness.
- For grounded-type jams, the stage-discharge relationship at the point of ice-jam formation will be that resulting from complete or nearly complete blockage of the normal channel, with flow being carried in the overbank floodplain areas.

4.2.2 General Procedures

To apply the indirect approach, the Mapping Partner that performs the enhanced study shall use the procedures discussed below.

The Mapping Partner that performs the enhanced study shall establish a free-flow stage-frequency distribution for each cross section by using standard backwater modeling to establish stage-discharge relationships. Usually, the five standard (10-, 4-, 2-, 1- and 0.2-percent-annual-chance) flood discharges will provide sufficient points for establishing the stage-frequency curve for each cross section on a normal probability graph.

The Mapping Partner that performs the enhanced study shall separate the water year into an "ice-jam season" and a "free-flow season" based on the historical occurrence of ice jams in the region and, in particular, in the flooding source that is the subject of the enhanced study. The season shall encompass the period when breakup-type ice jams normally occur and will likely vary with the latitude and elevation of the flooding source. Ice jams tend to be associated with one of the seasonal peak flows, because ice jams typically form during rises in river stage that break up the ice sheet.

Where peak flow data are available at gaging stations, the Mapping Partner that performs the enhanced study shall perform discharge-frequency analyses for the ice-jam and free-flow seasons using procedures described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) or subsequent updates. If the logarithms of the peak-flow data do not fit a Pearson Type III distribution, then the Mapping Partner may use other frequency distributions or the appropriate plotting position formulas for this purpose. The reasons for deviating from Bulletin 17B procedures or any subsequent update of those procedures shall be documented.

For ungaged streams, the Mapping Partner that performs the enhanced study shall establish seasonal discharge-frequency relations by performing a regional analysis of seasonal flows for the gaged streams in the region. Usually, the establishment of regional seasonal discharge-drainage-area relations will be sufficient for this purpose.

The Mapping Partner that performs the enhanced study shall then use standard hydraulic techniques to establish corresponding stage-frequency curves for each cross section in the reach where ice jams are to be considered. Usually, the analyses of the standard percent chance of exceedance used for a FEMA-contracted Flood Risk Project or community-initiated map revision (i.e., 10-, 4-, 2-, 1- and 0.2-percent-annual-chance) will be sufficient to establish the stage-frequency curves. For ice-jam analysis, this is typically accomplished using hydraulic modeling software approved for use on NFIP projects that is capable of analyzing ice cover. The list of approved software entitled "Hydraulic Numerical Models Meeting the Minimum Requirement of National Flood Insurance Program" can be found at fema.gov.

These options take into account the hydraulic aspects of flow under ice, such as a reduction in flow area, increased wetted perimeter and ice roughness. The inputs required to use this option include the following:

- Normal hydraulic modeling software input,
- Thickness of the ice in the channel and overbank,
- Manning's "n" value for the underside of the ice cover, and
- Specific gravity of the ice.

The recommended ranges for "n" values are from 0.015 to 0.045 for unbroken ice and from 0.04 to 0.07 for ice jams. The specific gravity of normal ice is approximately 0.92 and is the recommended value for this analysis.

Where major floods are caused by ice jams, the assumption of equilibrium ice thickness is probably reasonable, because sufficient upstream conditions exist to generate the ice volumes needed. Unless there is strong evidence to the contrary, the Mapping Partner that performs the enhanced study shall use the approximate equilibrium thickness as defined in "Formation of Ice Covers and Ice Jams in Rivers" (Pariset, Hauser and Gagnon, 1966) as the ice thickness for the analysis. Where equilibrium ice thickness is not appropriate, the Mapping Partner that performs the enhanced study shall provide written justification to the RPO for the thickness used in the analysis.

The Mapping Partner that performs the enhanced study shall calibrate for floating-type jams by assuming equilibrium ice thickness at the location where the ice-jam stage-frequency curve is needed and use a combination of discharge, equilibrium ice thickness and roughness that would correspond to that stage. The Mapping Partner shall calibrate grounded-type jams by assuming complete blockage of the main channel at the point of obstruction, with equilibrium ice thickness, discharge and roughness that would correspond to that stage. This will permit the Mapping Partner to use the ice cover option in the approved hydraulic modeling software to estimate corresponding ice-jam stages upstream or downstream of the point where historical data are available.

The Mapping Partner that performs the enhanced study shall document that grounded-type ice jams have occurred historically before grounded-type jam behavior is assumed. Grounded-type jams may occur at confined sections, such as bridges, and at shallow sections. The hydraulic analysis assumes that a high percentage of the normal flow area of the channel (or bridge) is obstructed and that most of the flow is in the overbank areas.

At the point of obstruction, the Mapping Partner that performs the enhanced study shall use an actual or hypothetical bridge section to permit the special bridge routine in the HEC-2 or HEC-RAS computer program to facilitate the analysis. The Mapping Partner shall then adjust the low chord of the bridge and the net flow area to achieve different degrees of blockage of the main channel.

The Mapping Partner that performs the enhanced study shall normally assume between 95- and 100-percent blockage of the main channel unless sufficient evidence exists to support another assumption. In that case, the Mapping Partner shall document and justify the alternative. Upstream from the site of the grounding, the Mapping Partner shall assume the equilibrium ice thickness, as computed according to the Pariset formulation (Pariset, Hauser and Gagnon, 1966), unless alternative thickness can be justified.

The Mapping Partner that performs the enhanced study shall establish a stage-frequency curve for the ice-jam and free-flow events by plotting the stages from the approved hydraulic modeling software analyses at each cross section. The Mapping Partner shall plot stages for the 10-, 4-, 2-, 1- and 0.2-percent-annual-chance floods on a normal (or log-normal) probability graph and fit smooth curves through these points.

Not every flood event during the ice-jam season is affected by ice. If sufficient ice-jam data are available, then the Mapping Partner that performs the enhanced study shall incorporate the fraction of time that ice-jam season peak stages are affected by ice in the analysis. If the discharge-frequency relation in the ice-jam season is independent of ice conditions, then the 10-

, 4-, 2-, 1- and 0.2-percent-annual-chance flood discharges are essentially the same for those years when jams occur and when they do not occur.

Under these conditions, the Mapping Partner shall develop water-surface profiles for ice-affected and free-flow conditions in the ice-jam season. A modified version of Equation 1 for combining the stage-frequency curves is as follows:

$$P(s) = [P(sw) * P(si = \text{ice-jam event}) + P(so) * P(si = \text{free-flow event})] + P(sq) - [P(sw) * P(si = \text{ice-jam event}) + P(so) * P(si = \text{free-flow event})) * P(sq)] \quad (3)$$

Where P(s) and P(sq) are as defined in Equation 1

P(sw) = Probability of exceeding a given stage "s" in the ice-jam season developed using the discharge-frequency relationship for the ice-jam season and ice-affected hydraulic conditions

P(si = ice-jam event) = Fraction of years during the ice-jam season that peak stages are affected by ice jams

P(so) = Probability of exceeding a given stage "s" in the ice-jam season developed using the discharge-frequency relationship for the ice-jam season and free-flow hydraulic conditions

P(si = free-flow event) = Fraction of years during the ice-jam season that peak stages are free-flow events

The assumption in Equation 3 is that the conditional distribution of peak discharges for the ice-jam season is the same for ice-affected and free-flow conditions. If ice jams only occur when peak discharges are large or, conversely, if large peak discharges do not occur under free-flow conditions, Equation 3 is not applicable.

4.2.3 Summary

For the indirect approach, the Mapping Partner that performs the enhanced study shall obtain the composite stage-frequency curve for the various percent-chance-exceedance floods at each cross section. This shall be done by combining the free-flow and ice-jam stage-frequency curves using Equations 1, 2 or 3, depending on the available data and analysis procedures used in establishing the discharge-frequency relationship. The various conditions are summarized below.

If the discharge-frequency analysis was performed using the annual-event approach (two discharge values per year), the Mapping Partner that performs the enhanced study shall use Equation 1 to combine the ice-jam and free-flow stage-frequency curves. Equation 1 also applies for combining the stage-frequency curves if regional seasonal discharge-drainage-area relations are used to determine the discharge-frequency curves. Seasonal discharge-frequency curves developed in this manner represent the probabilities of the annual-maximum discharge exceeding a given discharge value during either the ice-jam or free-flow season. These exceedance probabilities are not conditioned or related to the fraction of time that the annual-maximum discharges are either ice-jam or free-flow events; therefore, the conditional-frequency approach of Equation 2 is not appropriate.

If the Mapping Partner that performs the enhanced study based the discharge-frequency estimates of the 10-, 4-, 2-, 1- and 0.2-percent-annual-chance floods solely on annual-maximum discharge events, then the Mapping Partner shall use Equation 2 for combining the stage-frequency curves. This implies that the discharge-frequency curves used for this analysis are based on either ice-jam or free-flow annual-maximum discharges and that these frequency curves have NOT been adjusted for the fraction of time that the ice-jam or free-flow events are annual maximums.

If the discharge-frequency relationship during the ice-jam season is the same under the ice-affected and free-flow conditions and sufficient ice-jam data are available, the Mapping Partner that performs the enhanced study shall use Equation 3 to account for the fraction of time that the peak stages in the ice-jam season are actually affected by backwater from ice.

5.0 Presentation of Results

Requirements for presenting the results of the ice-jam analyses in the Flood Insurance Study (FIS) report, on the Flood Insurance Rate Map (FIRM) and in the Technical Support Data Notebook (TSDN) are presented in Subsections 5.1, 5.2 and 5.3.

5.1 Flood Insurance Study Report

The Mapping Partner that performs the enhanced study shall submit the information summarized in Subsections 5.1.1 and 5.1.2 for inclusion in the FIS report. For additional information on the development or revision of FIS reports, see the Flood Insurance Study (FIS) Report Technical Reference.

5.1.1 Information To Be Included in Tables

The Mapping Partner that performs the enhanced study shall submit the information summarized below for inclusion in the tables that appear in the FIS report.

- The Mapping Partner that performs the enhanced study shall submit information for Table 10, Summary of Discharges that is based on an analysis of the full year and footnote the table to that effect.
- The Mapping Partner that performs the enhanced study shall submit information for Table 13, Summary of Hydrologic and Hydraulic Analyses and note that ice jam analyses were used in the Special Considerations.
- The Mapping Partner that performs the enhanced study shall submit information for all columns of the Floodway Data Table using the 1-percent-annual-chance flood elevations established from the composite stage-frequency curves and footnote the table to that effect.

5.1.2 Flood Profiles

The Mapping Partner that performs the enhanced study shall submit Flood Profiles that are based on the elevations established from the composite stage-frequency analysis.

5.2 FIRM Panels and Database

The Mapping Partner that performs the enhanced study and the Mapping Partner that prepares the Preliminary and final versions of the FIRM for FEMA shall ensure the information shown on the FIRM is based on the elevations established from the composite stages-frequency analyses performed at each cross section. The Mapping Partner also shall ensure that the regulatory floodways are established and plotted based on the 1-percent-annual-chance flood discharges and hydraulics established from the composite stage-frequency analysis. For additional information on the development or revision of FIRM panels, see the Flood Insurance Rate Map (FIRM) Panel Technical Reference.

The Mapping Partner that performs the enhanced study shall document the inclusion of ice-jam analyses in the SPEC_CONS1 and SPEC_CONS2 fields of S_Profil_Basln in the FIRM database. These fields are used to populate Table 13 in the FIS Report which is discussed in Subsection 5.1.1. For additional information on the development or revision of the FIRM database, see the Flood Insurance Rate Map (FIRM) Database Technical Reference.

5.3 Technical Support Data Notebook (TSDN)

The Mapping Partner that performs the enhanced study shall submit the information summarized below for inclusion in the TSDN. The Mapping Partner that performs the enhanced study is responsible for submitting the relevant TSDN components at the conclusion of each task. TSDN submittals are uploaded to FEMA's Mapping Information Platform (MIP). For additional information on study documentation, see the Data Capture Technical Reference.

The Mapping Partner that performs the enhanced study shall submit the information summarized below for inclusion in the TSDN Hydraulics Report.

- The Mapping Partner that performs the enhanced study shall provide a discussion of historic ice jams.
- The Mapping Partner that performs the enhanced study shall provide a discussion of any discharge-frequency analysis for the ice-jam season, if used, and the statistical treatment of stage-frequency analysis for the ice-jam and non-ice-jam events. In this discussion, the Mapping Partner that performs the enhanced study shall reference the historical data used in the analyses along with its source and how it was used.
- The Mapping Partner that performs the enhanced study shall provide a discussion of how free-flow and ice-jam stages were computed and whether stages were computed directly from stage-frequency analyses or indirectly analyzed. The Mapping Partner that performs the enhanced study shall include the following topics in this discussion:
    1. Approximate channel blockage and ice thickness assumed, if used,
    2. The relationship of the computed ice-jam stages to historic floods,
    3. An example of stage-frequency curves for combined floods for the point of obstruction, or a representative cross section within the community if the former is outside the corporate or county limits, and

4. An explanation of how the regulatory floodways were established using the composite frequency analysis.

The Mapping Partner that performs the enhanced study may indicate the lateral extent of a major historic ice jam on the work map if it is well-documented, does not hamper interpretation and is appropriately annotated as such.

6.0 References

Interagency Advisory Committee on Water Data, Office of Water Data Coordination, Hydrology Subcommittee, Bulletin 17B, “Guidelines for Determining Flood Flow Frequency,” September 1981, Revised March 1982.

National Research Council of Canada, *Hydrology of Floods in Canada—A Guide to Planning and Design*, Ottawa, Ontario, 1989.

Pariset, E., R. Hauser and A. Gagnon, “Formation of Ice Covers and Ice Jams in Rivers,” *Journal of the Hydraulics Division, American Society of Civil Engineers*, November 1966.

Thomas, W. O., Jr., K. L. Crockett and A. A. Johnson, “Discussion of Techniques for Analysis of Ice-Jam Flooding,” *Association of State Floodplain Managers, Proceedings of the 22nd Annual Conference*, Milwaukee, Wisconsin, May 18-22, 1998, pp. 457-464.

U.S. Department of the Army, Cold Regions Research and Engineering Laboratory, Technical Note, “Methodology for Ice Jam Analysis,” D. J. Calkins, October 1980.

U.S. Department of the Army, Corps of Engineers, Engineering Pamphlet 1110-2-11, *Engineering and Design of Ice Jam Flooding: Causes and Possible Solutions*, November 1994.