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Overview of Ice Jams in Three Major US Rivers

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We investigated ice jams on the Yukon, the Platte, and the Connecticut Rivers. Information on the dates of jam occurrence and the latitude and longitude of each jam was found in the Ice Jam Database (www.crrel.usace.army.mil/icejams/). Information was available for 255 ice jams on the Platte River, 210 ice jams on the Yukon River; and 94 ice jams on the Connecticut River. Each ice jam was associated with the closest NWS meteorological station and the closest downstream USGS gaging station for which there were consistent records. The daily discharge and the accumulated freezing degree days (AFDD) associated with each ice jam event along with the changes in discharge and AFDD in the time period immediately prior to each event were determined. As the majority of entries in the database have been entered with "Unknown" type, the type of jam was determined independently for each ice event based on the flow conditions immediately prior to the jam formation and the time of year that the jam occurred. Ice jams were classified as freezeup jams if the river discharge decreased prior to the ice jam formation, as indicated by the change in discharge over the previous 5 days. Any jam not classified as a freezeup jam was classified as a breakup jam. Surveys of the day-of-year and discharge for each ice jam location along the entire length of each river are presented. Information on the day-of-year was used to classify the jam formation as progressive (Yukon), semi-progressive (Platte) or non-progressive (Connecticut). Histograms of freezeup and breakup jams by the day-of-year and discharge show that the classification of jam type by discharge produces consistent and rational results

Introduction

The goal of this report is to survey ice jam formation at a three major rivers across the continental United States and Alaska where ice jams occur in a consistent manner, using parameters that are readily available at all locations. These rivers were the Yukon, the Platte, and the Connecticut Rivers. This report is part of a larger study that included a larger number of rivers. Three sources of information were used in this study. The first was the Ice Jam Database (IJDB) (White and Eames 1999) which includes information on ice jams reported by various sources in the United States. The IJDB provided two primary pieces of information: the dates of jam occurrence and their specific locations (the latitude and longitude of almost every jam is included in the IJDB). The second source of information was the NWS daily meteorological records for all CO-OP and first-order stations (NOAA 1950-present). The third and final source of information was the United States Geological Survey quality-assured records of daily average surface-water stream flow (USGS 2007). These records provided information on the discharge in the rivers and streams where the ice jams occurred. Generally the nearest downstream gage to the ice jam location was used to estimate the flow at the time of the ice jam. In this report, we concentrate on the location, timing, and discharges associated with the recorded ice jams.

Classification of freezeup and breakup ice jams.

Each ice jam was classified as either a breakup jam or a freezeup jam. The first screen for determining freezeup jams was to select all ice jams for which the discharge had been consistently declining prior to the ice jam formation. This selection was made by including only those jams that had a change in daily average discharge over the prior five days, $DelQ5 = Q_i - Q_{i-5}$, less than zero. This indicated that the discharge on the day of the jam was less than the discharge five days before the jam had occurred. As will be shown below, this criterion produces consistent results when the meteorological and other data is compared between the freezeup and breakup ice jams. All jams that were not classified as freezeup jams were classified as breakup jams.

Platte River

At the time of this study, there were 255 entries in the IJDB for the Platte River (Figure 1) and its two tributaries, the North Platte and the South Platte Rivers, making it one of the best-documented rivers for ice jams in the United States. The active data collection program of the State of Nebraska Department of Natural Resources undoubtedly contributed to the large number of IJDB entries. The dates of the jams recorded in the IJDB range more or less uniformly from the 1940's to the early 2000's. The day-of-year recorded in the IJDB ranges from early December through the middle of March (Figure 2). The Platte also has a relatively large number of discharge gages located along its length (Figure 1) and NWS meteorological stations (Figure 1) providing good documentation of the discharge and air temperature conditions during the winter.

The first step was to classify all IJDB entries as either freeze-up or breakup jams. Freezeup jams were found to occur along the entire river length but the large majority of freezeup jams occurred in the North Platte. Breakup jams also occurred along the entire river length. Breakup ice jam formation on the Platte River can be considered to be semi-progressive as shown by the average day-of-year when breakup ice jams occurred (Figure 3); the vertical bars indicating the standard deviation of the data show the ranges of recorded ice jam dates. . There is a definite trend in formation starting upstream form Overton through Grand Island to Duncan but there is no consistent progression in the reaches downstream of Duncan. The average day-of-year for breakup jam occurrence is approximately 24 February downstream of Duncan. The average discharge associated with breakup ice jams increases from upstream to downstream (Figure 4). In every case, the discharge was increasing prior to the formation of a breakup ice jam at the gage associated with the jam. Comparing the *DelQ10* ($DelQ10 = Q_i - Q_{i-10}$) (red line) and *DelQ2* ($DelQ2 = Q_i - Q_{i-2}$) (black line) with the average discharge provides insight into the rate of increase of discharge prior to breakup ice jam formation. It can be seen that the increase in flow over the previous ten days (*DelQ10*, red line) formed a large portion of the discharge at the time of the jam. The increase over the previous two days (*DelQ2,* black line) formed a relatively small portion. The average discharge associated with breakup jams can also be compared to the long-term annual average discharge (pink triangles). This shows that breakup ice jam formation in the upstream reaches tends to occur at an average discharge approximately equal to the long-term annual average discharge; and at discharges much greater than the long-term annual average discharge in the downstream reaches. This result is consistent with the relative time of year at which the breakup jams occur. In the downstream reaches the jams tend to occur later and are associated with the general spring rise in discharge. The discharges associated with the spring rise tend to the largest discharges of the year, typically larger than the annual average discharge.

The dates when all ice jams occurred on the Platte River is shown using a histogram that combines both the freezeup jams and breakup jams (Figure 5). The histogram of freezeup jams peaks in late December and early January, although freezeup jams can occur throughout the winter season, from mid November through March. The histogram of breakup jams peaks in late February through late March. Breakup jams can also occur throughout the winter season, starting in mid December through early April. The histogram of discharges associated with freezeup jams peaks between 28-57 cms (1000-2000 cfs) (Figure 6) [cms = m^3s^{-1}; cfs = ft^3s^{-1}]. The histogram of discharges associated with breakup jams peaks between 85-113 cms (3000-4000 cfs). The range of discharges for breakup jams is much larger than that of freezeup jams, extending from 14 cms (500 cfs) to 650 cms (23,000 cfs), while the range for freezeup jams is much smaller, extending from 14 cms (500 cfs) to about 156 cms (5,500 cfs). In summary, freezeup jams tend to occur earlier in the winter season, at fewer seasonal AFDD, and at lower discharges than breakup jams. However, there is considerable overlap of the ranges for all three of these parameters between freezeup and breakup jams.

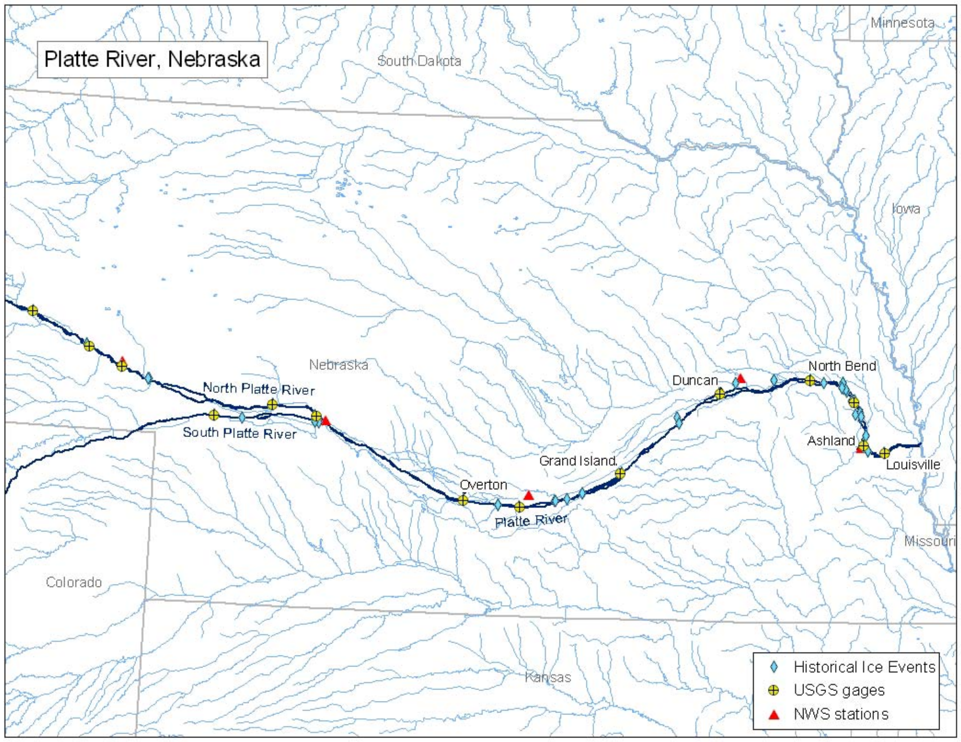

Figure 1. Platte River

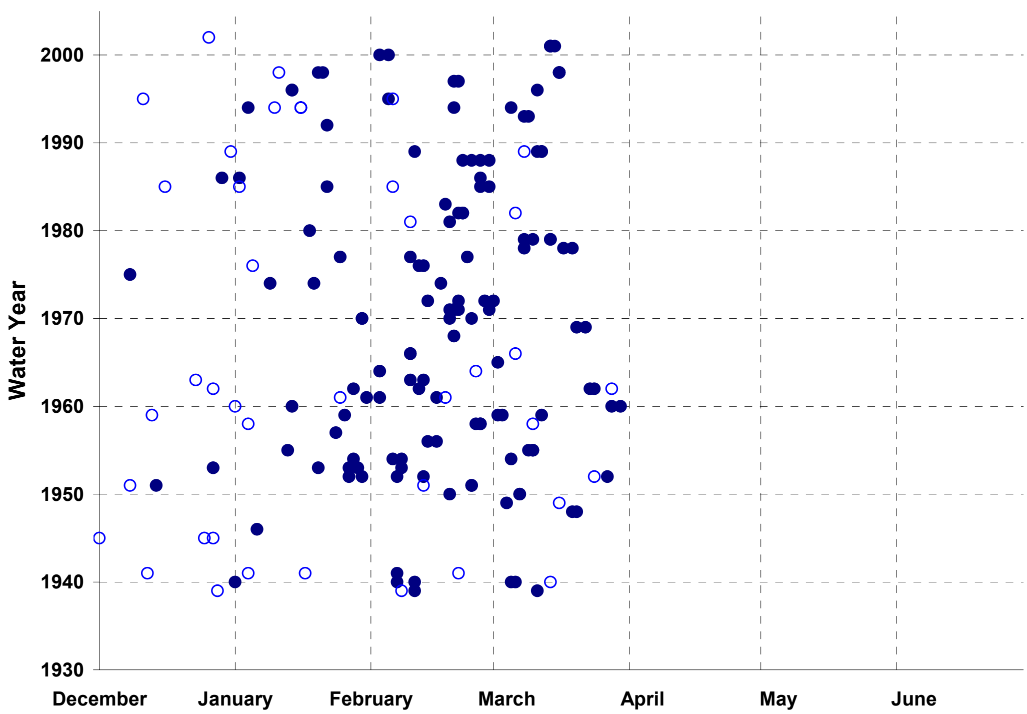

Figure 2. All ice jam data for the Platte River. Freeze up jams are open circles, breakup jams are solid.

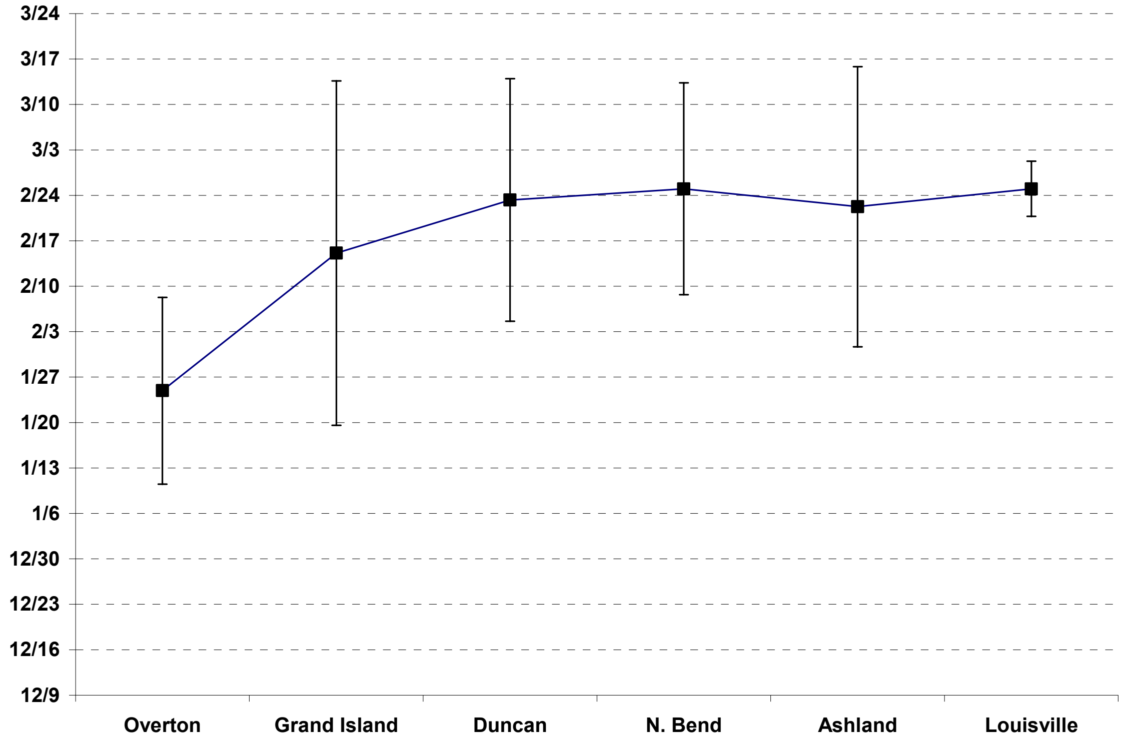

Figure 3. Dates of Ice Events along the Platte River

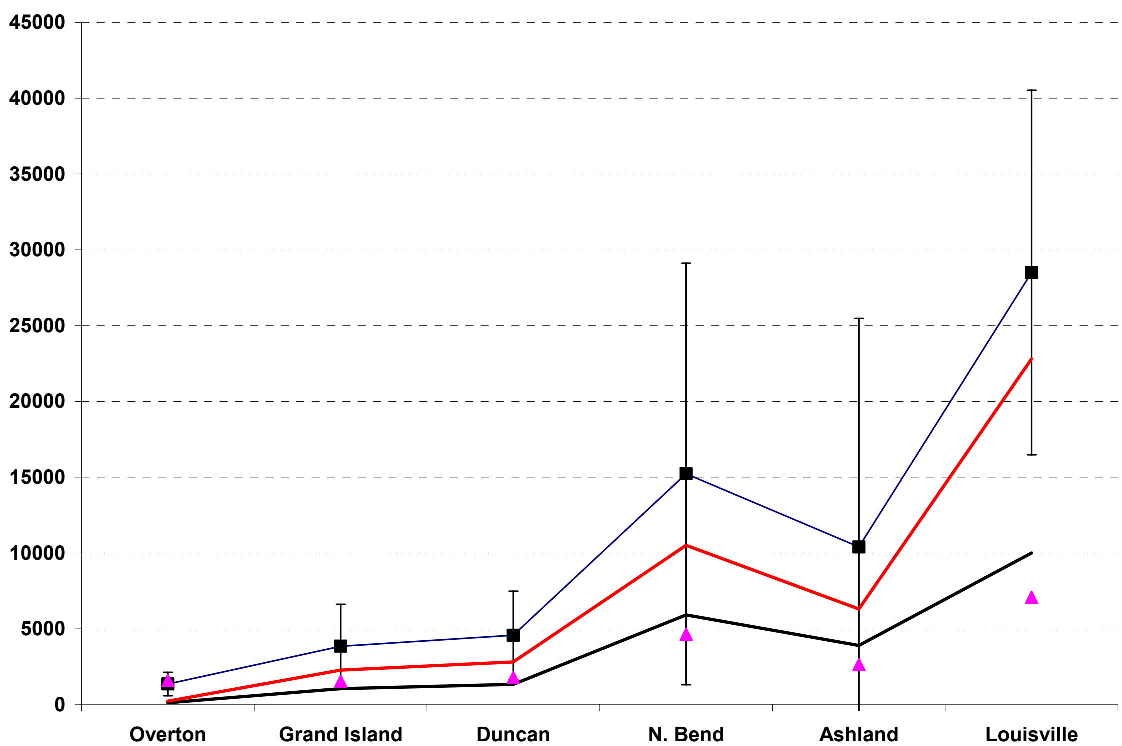

Figure 4. Discharges associated with Ice Events along the Platte River (cfs) (1000 cfs = 28.3 cms). Shown are the average discharge and standard deviation associated with the events, the average DelQ10 (red line), DelQ2 (black line), and annual average discharge each location (pink triangle).

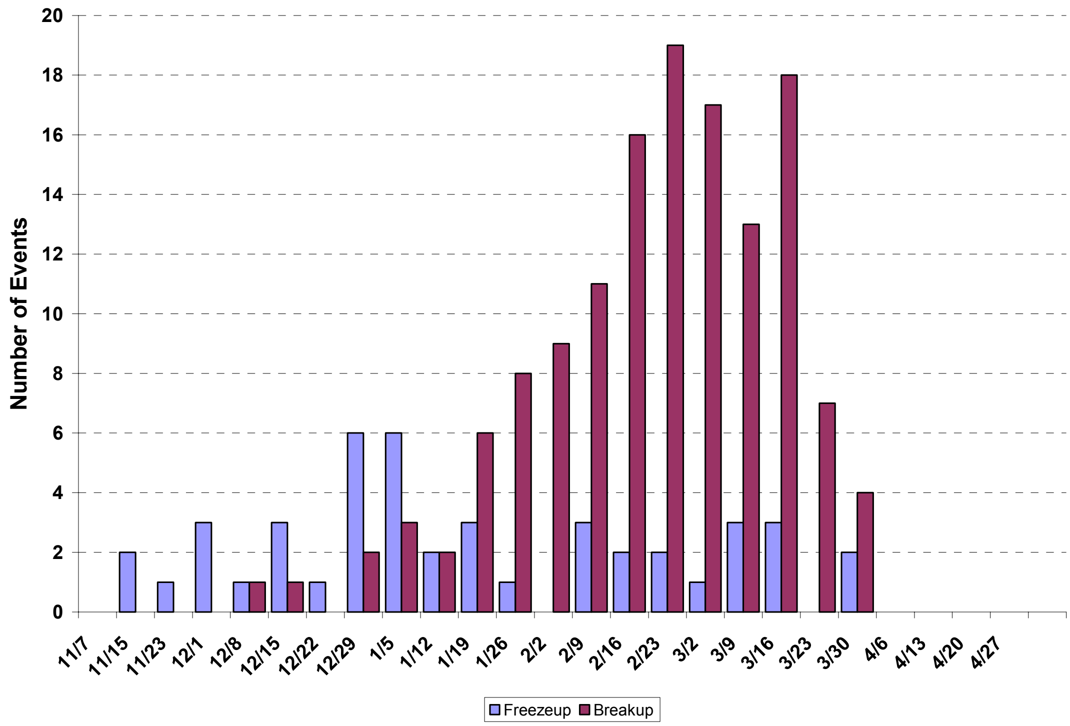

Figure 5. Histogram of Ice Events on the Platte River by date

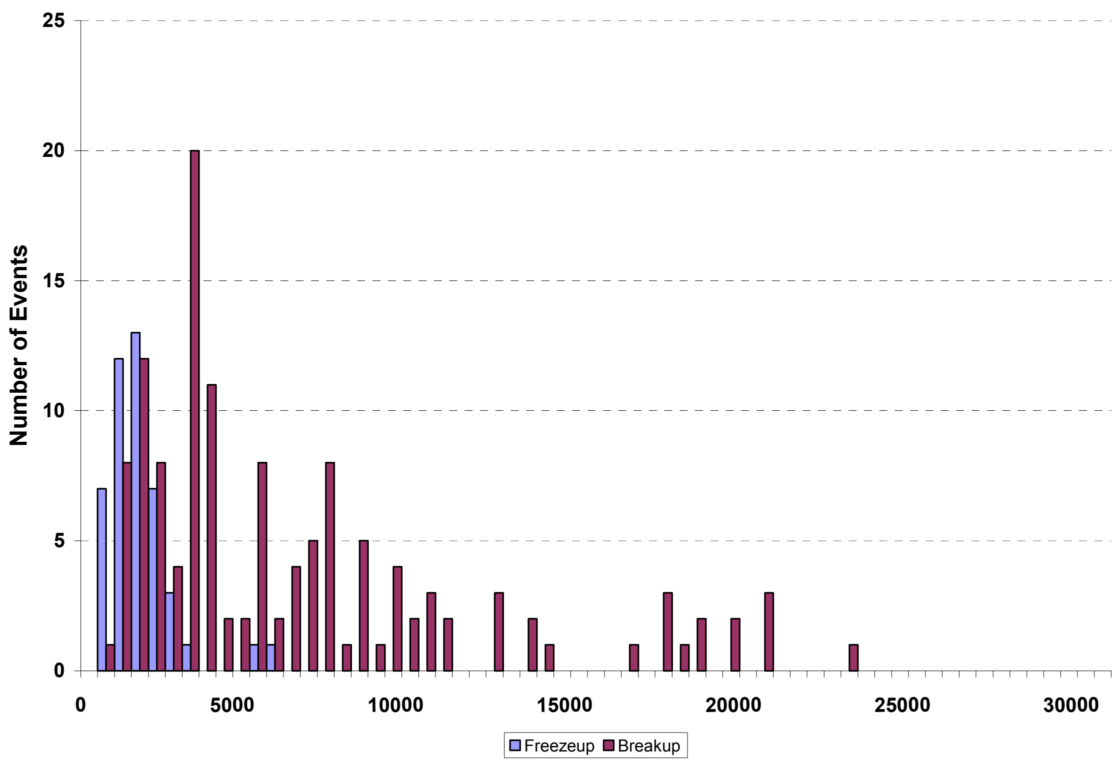

Figure 6. Histogram of Ice Events on the Platte River Watershed by Discharge (cfs) (1000 cfs = 28.3 cms)

Yukon River

At the time of this study, there were 210 entries in the IJDB for the Yukon River making it one of the better-documented rivers for ice jams in the United States. The dates of the jams recorded in the IJDB range more or less uniformly from the 1970's to the mid 1990's with a few jams recorded in the 2000's. The day-of-year recorded in the IJDB occurs exclusively in May (Figure 8). All jams recorded in the IJDB for the Yukon River were classified as breakup jams as discussed below. The Yukon has only three discharge gages located along its length (Figure 7) and few NWS meteorological stations (Figure 7) providing documentation of the discharge and air temperature conditions during the winter. The relatively few discharge gages makes it difficult to estimate the discharge occurring at the jam locations when the location may be a considerable distance (hundreds of miles) from the nearest gage.

None of the events included in the IJDB were identified as freezeup jams. This was due to the fact the all events included in the IJDB for the Yukon River occur in May, when there is little likelihood of a freezeup jam occurring. Breakup jams occurred along the entire river length. Breakup ice jam formation on the Yukon River can be considered to be progressive as shown by the average day-of-year when breakup ice jams occurred (Figure 9); the vertical bars indicate the standard deviation of the data. There is a definite trend in breakup ice jam formation starting upstream at Eagle and Circle and proceeding downstream with some small variation to Alakanuk and Emmonak. The average day-of-year for breakup jam occurrence is approximately 8 May at the upstream reaches to 24 May at the downstream reaches. The progressive nature of ice jams on the Yukon has been remarked upon previously. It should be noted that while the average day-of-year recorded in the IJDB show the progressivity of the Yukon, a progressive breakup does not occur every year on the Yukon. In fact, there can be a wide year-to-year variation in the pattern of breakup.

The average discharge associated with breakup ice jams increases from upstream to downstream (Figure 10). The discharge at the jam location was estimated by linearly interpolating between the recorded discharges at gages located upstream and downstream of the jam location and accounting for the travel time of the hydrographs.

$$Q_j^i = \frac{Q_{upstream}^{i-u_{travel}} \left(D_{us}\right)^{-1} + Q_{downstream}^{i+d_{travel}} \left(D_{ds}\right)^{-1}}{\left(D_{us}\right)^{-1} + \left(D_{ds}\right)^{-1}}$$

where Q_j^i = the discharge at location j along the Yukon River on the ith day; $Q_{upstream}^{i-u_{travel}}$ = the discharge recorded at the upstream gage on the i-u_{travel} day, where u_{travel} is the travel time from the upstream gage to the jam location in days; $Q_{downstream}^{i+d_{travel}}$ = discharge recorded at the downstream gage on the i+d_{travel} day, where d_{travel} is the travel time from the jam location to the downstream gage in days; and D_{us} and D_{ds} are the distances from the jam location to the upstream and downstream gages, respectively. The travel times were based on the ice jam occurrence matrix developed by White (1999). For locations downstream of the Pilot Station gage, there was obviously no downstream gage available, so only the travel time from the Pilot Station gage was taken into account. The mean discharge increases uniformly in the downstream direction to approximately the Nulato location, and then is more or less constant downstream of that location, ranging between 8500 and 11300 cms (300,000 and 400,000 cfs).

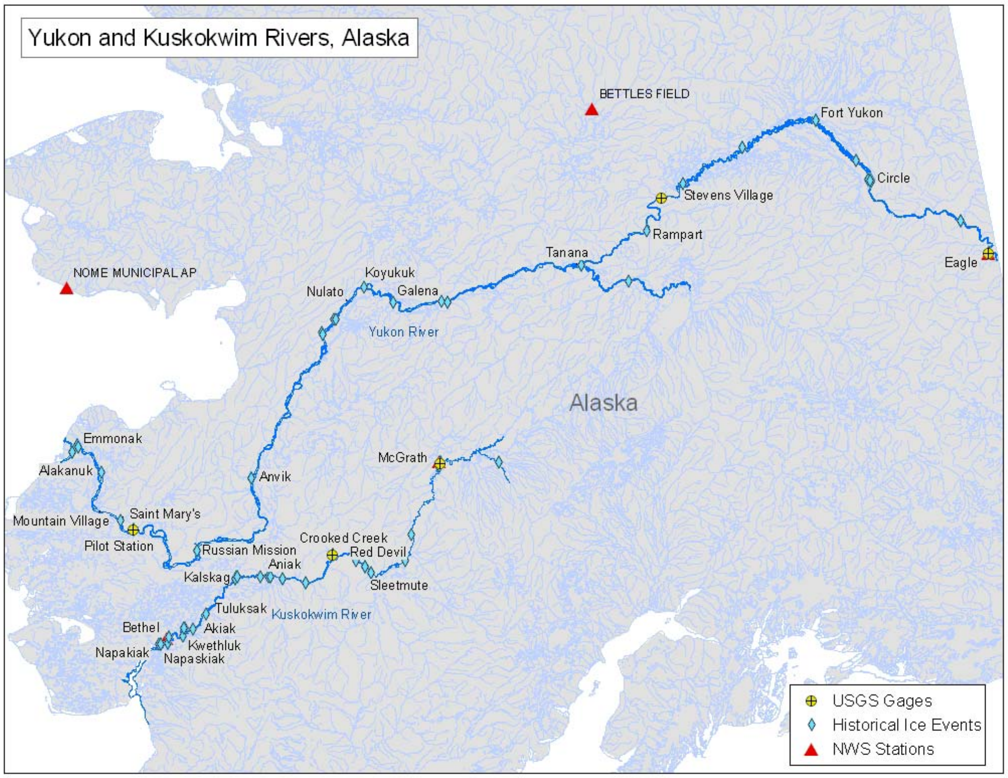

Figure 7. Yukon River

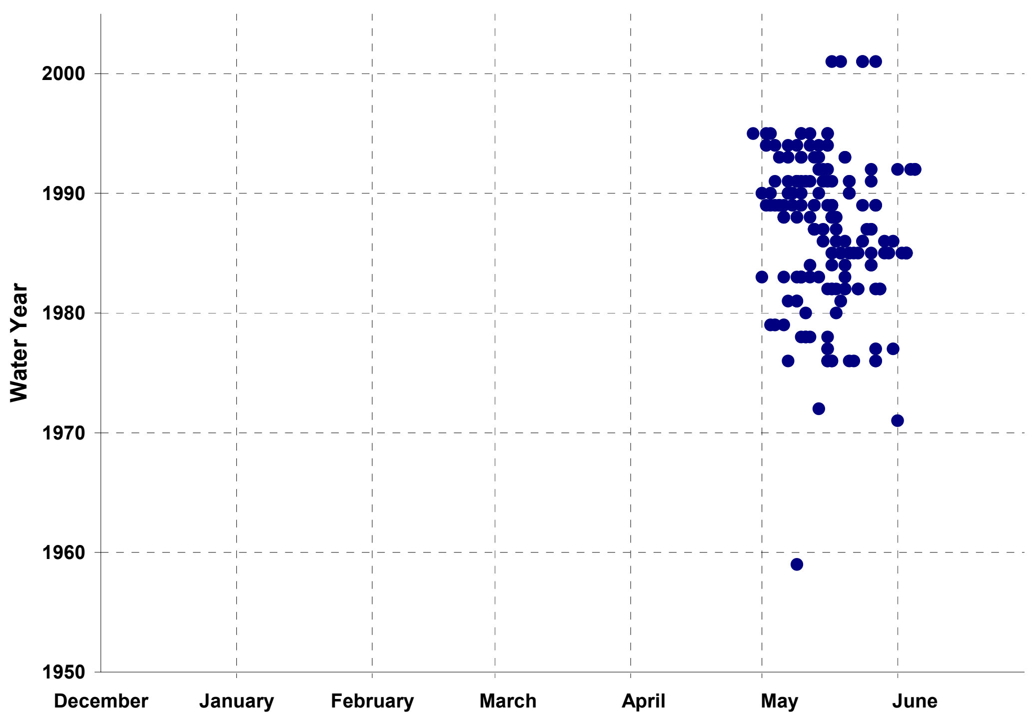

Figure 8. All ice jam data for the Yukon River. All events are breakup jams.

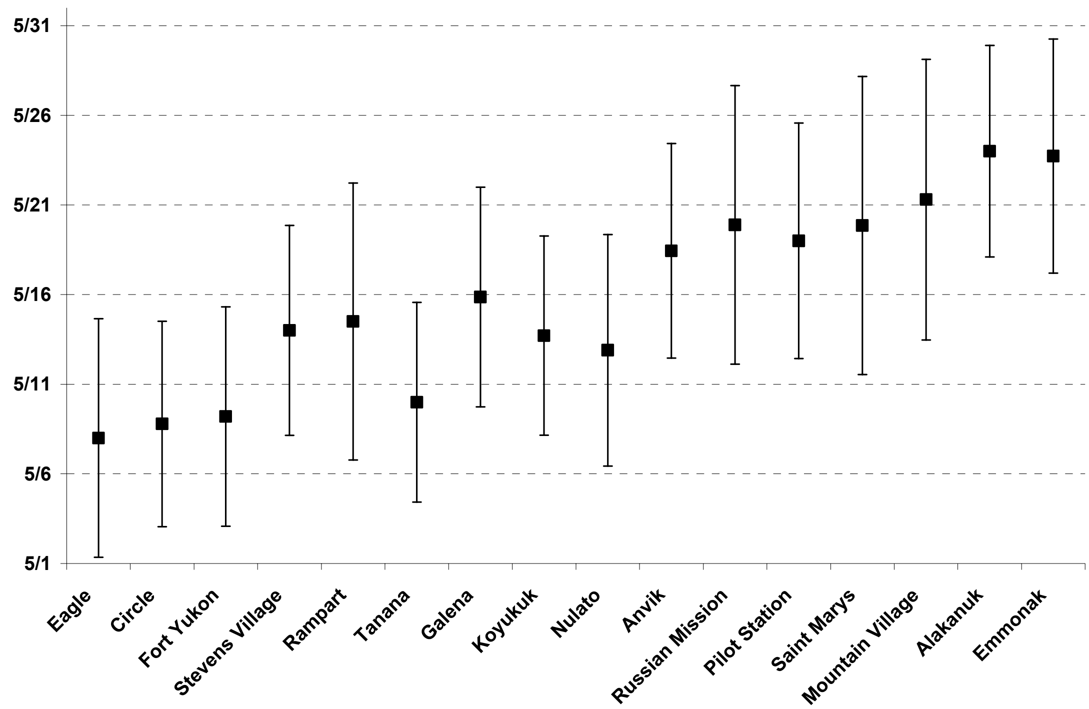

Figure 9. Dates of Ice Events along the Yukon River

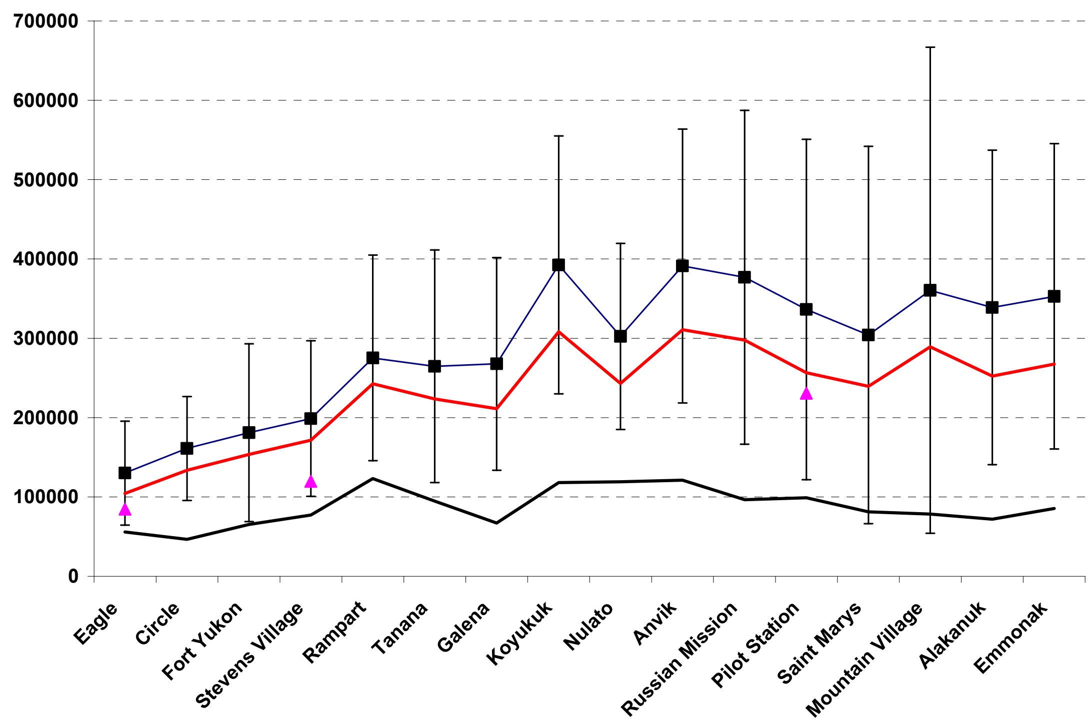

Figure 10. Discharges (cfs) associated with Ice Events along the Yukon River. Shown are the average discharge and standard deviation associated with the events, the average DelQ10 (red line), DelQ2 (black line), and annual average discharge each gage location (pink triangle). (1000 cfs = 28.3cms)

Connecticut River

At the time of this study, there were 91 entries in the IJDB for the Connecticut River north of the state of Massachusetts of which 83 were useable. There were very few entries for the Connecticut River south of the northern border of Massachusetts, and the reaches of the river south of that line was not included in this study. (Vuyovich et al 2005). The dates of the jams recorded in the IJDB range more or less uniformly from the mid 1930's to the early 2000's (Figure 12). The day-of-year recorded in the IJDB ranges throughout the winter from early December through the middle of March. The Connecticut River also has a number of discharge gages located along its length (Figure 11) and NWS meteorological stations (Figure 11) providing good documentation of the discharge and air temperature conditions during the winter.

Freezeup jams were found to occur along the entire river length but the large majority of freezeup jams occurred in the northern reaches. Breakup jams also occurred along the entire river length. Overall, breakup ice jam formation on the Connecticut River can not be considered to be progressive as shown by the average day-of-year when breakup ice jams occurred (Figure 13). There is a trend in formation starting downstream at Hartford/White River Junction and proceeding upstream but there is no consistent progression downstream of Hartford/White River Junction. This upstream progression probably reflects the general north to south orientation of the river. The average discharge associated with breakup ice jams generally increases from upstream to downstream (Figure 14), with an anomalous peak in West Lebanon. In every case, the discharge was increasing prior to the formation of a breakup ice jam at the gage associated with the jam. It can be seen that the increase in flow over the previous ten days (*DelQ10*, red line) and the increase over the previous two days (*DelQ2,* black line) formed a large portion of the discharge at the time of the jam. This suggests the relatively rapid rise in flow before the formation of the jams. The average discharge associated with breakup jams can also be compared to the long-term annual average discharge (pink triangles). This shows that breakup ice jam formation in the upstream reaches tends to occur at an average discharge greater than the long-term annual average discharge. This result is not consistent with the relative time of year when breakup jams occur, but rather suggests that the discharges during ice jams are relatively large events.

The dates when all ice jams occurred on the Connecticut River are shown using a histogram that combines both the freezeup jams and breakup jams (Figure 15). The location of the breakup jams, either northern (upstream of Lebanon, NH) or southern (downstream of Lebanon, NH) is indicated. The histogram of freezeup jams peaks in early January, although freezeup jams can occur throughout the winter season, from mid December through early March. . Breakup jams can also occur throughout the winter season, starting in mid December through late April. The histogram of breakup jams peaks appears to have two peaks, one in early January and a second in late March. The first peak, in January, corresponds with the period of the "January thaw" a period of highly variable weather. The second peak corresponds with the spring rise due to precipitation and snowmelt. The histogram of discharges associated with freezeup jams peaks between 28-57 cms (1000-2000 cfs) (Figure 16). The histogram of discharges associated with breakup jams peaks around 127 cms (4500 cfs). The range of discharges for breakup jams is much larger than that of freezeup jams, extending from 424 to 850 cms (1500 to 30,000 cfs), while the range for freezeup jams is much smaller, extending from 28.3 to about 170 cms (1000 cfs to about 6000 cfs). In summary, freezeup jams tend to occur earlier in the winter season, at fewer seasonal AFDD, and at lower discharges than breakup jams. However, there is considerable overlap of the ranges for all three of these parameters between freezeup and breakup jams.

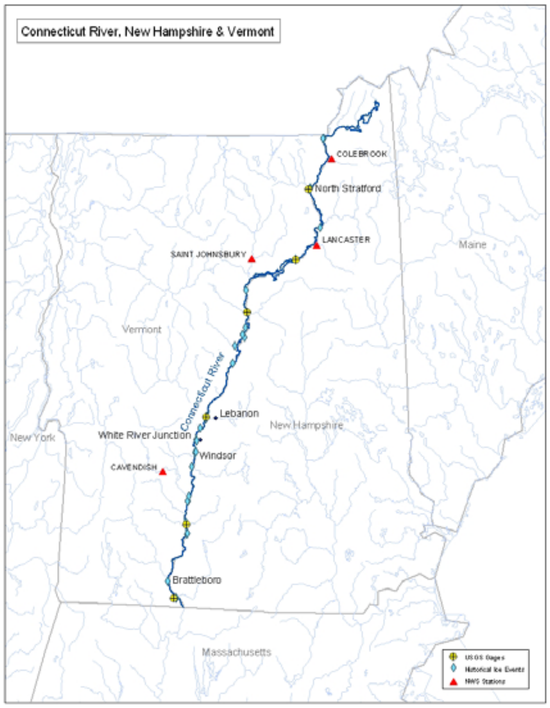

Figure 11. Connecticut River

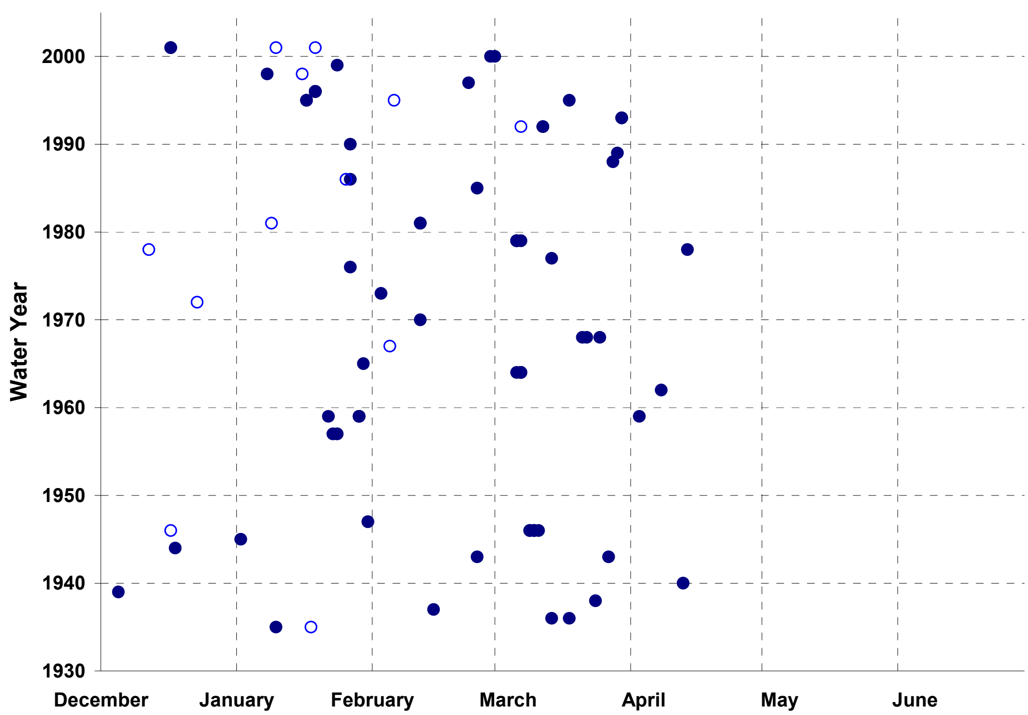

Figure 12. All ice jam data for the Connecticut River. Freeze up jams are open circles, breakup jams are solid.

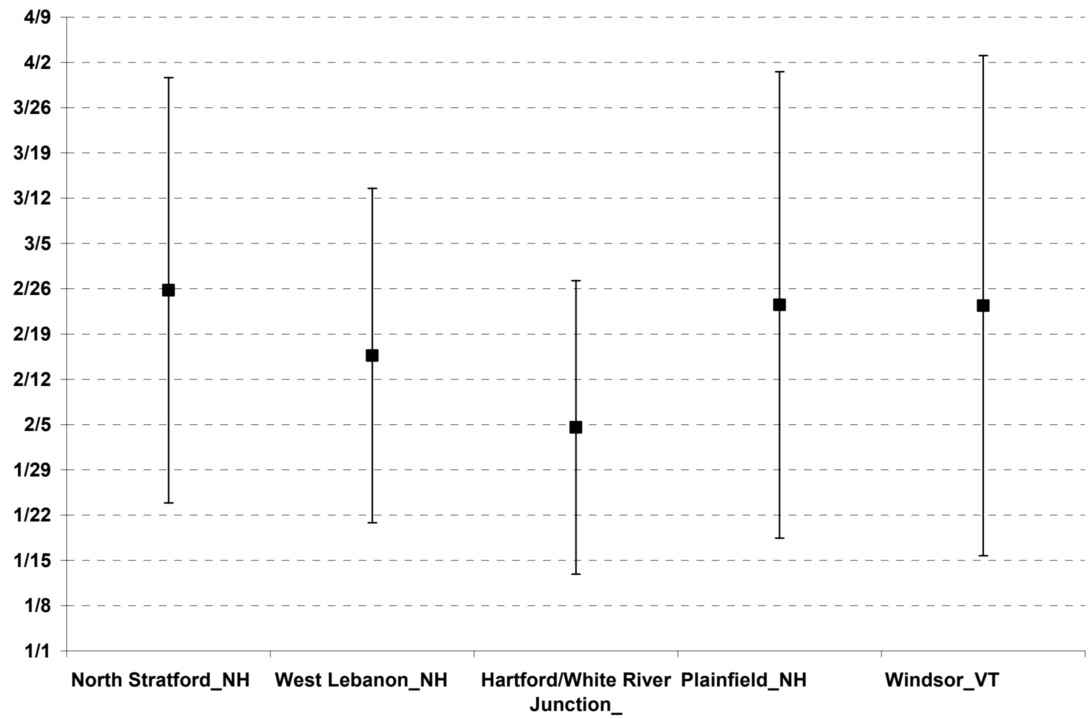

Figure 13. Dates of Ice Events along the Connecticut River

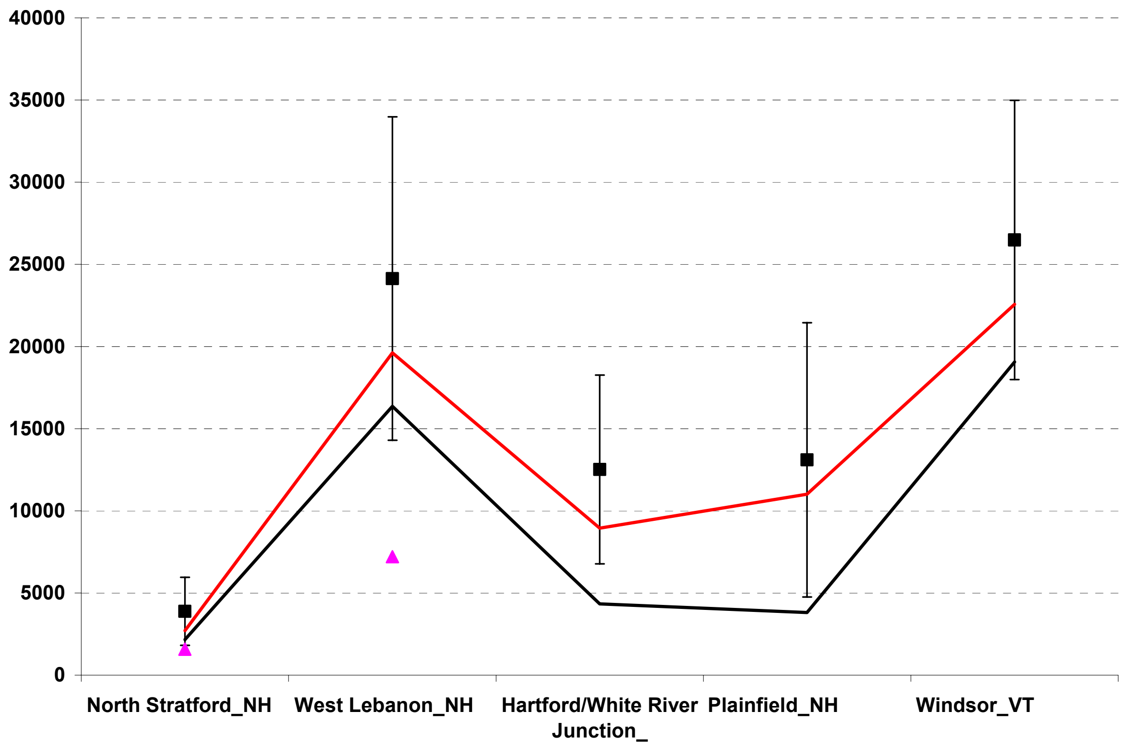

Figure 14. Discharges associated with Ice Events along the Connecticut River. (cfs) (1000 cfs = 28.3cms) Shown are the average discharge and standard deviation associated with the events, the average DelQ10 (red line), DelQ2 (black line), and annual average discharge each location (pink triangle).

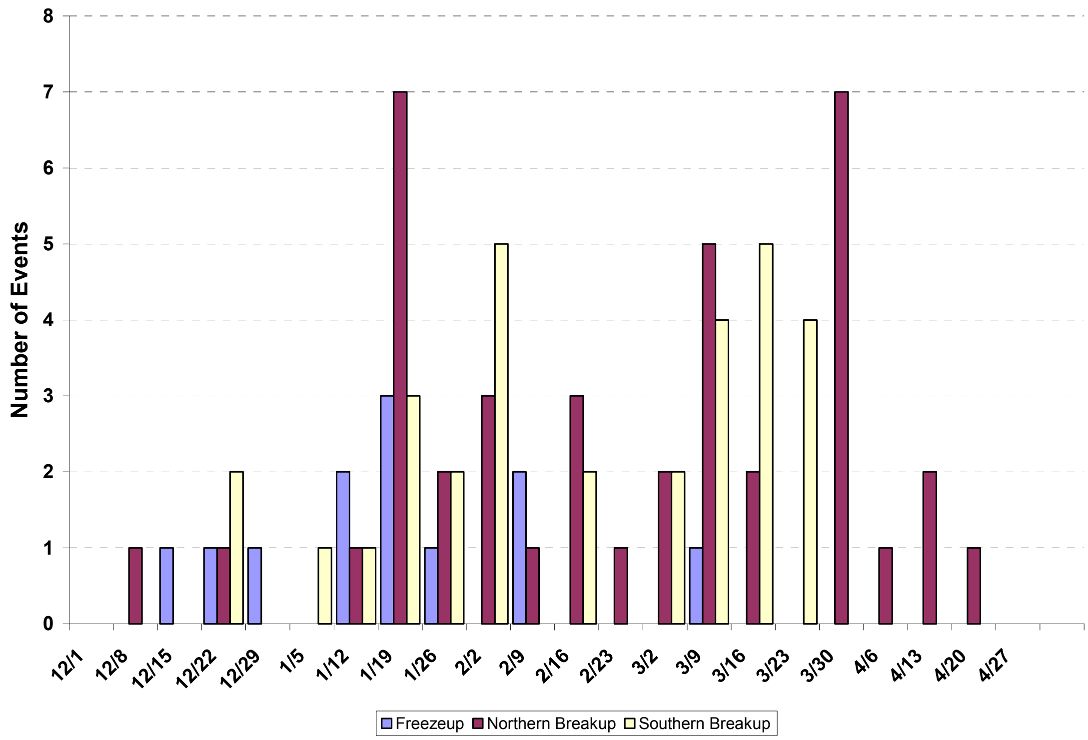

Figure 15. Histogram of ice events on the Connecticut River by date

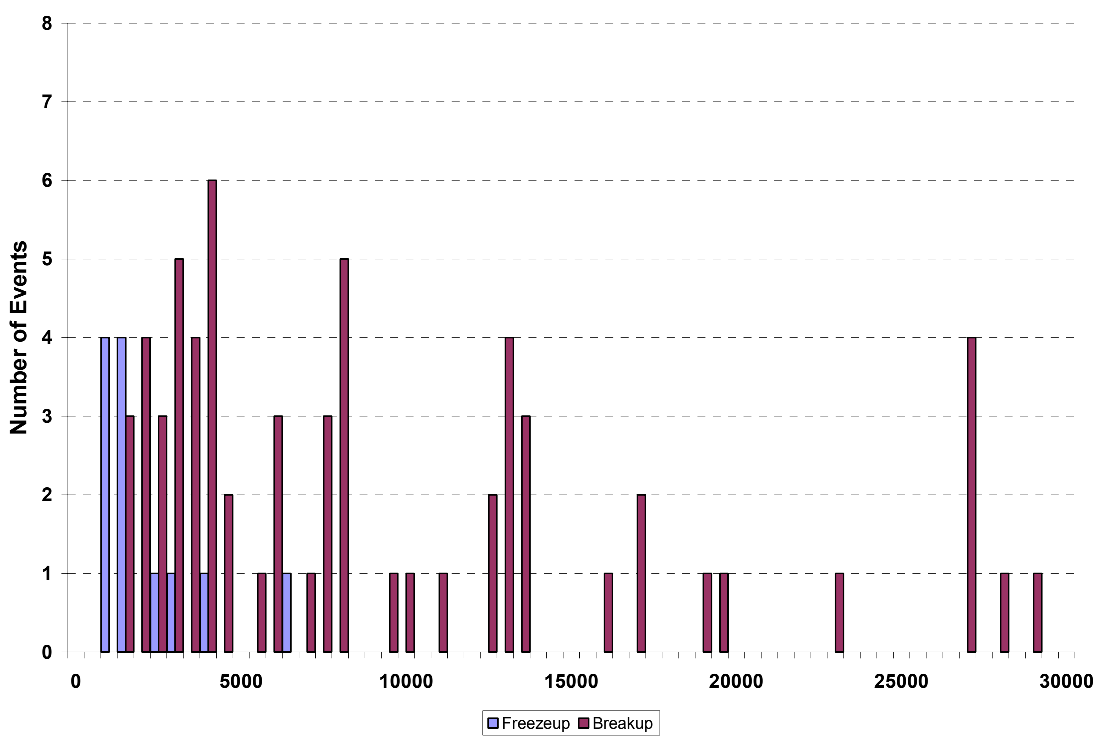

Figure 16. Histogram of ice events on the Connecticut River Watershed by discharge (cfs) (1000 cfs = 28.3cms)

Summary
We investigated ice jams on the Yukon, the Platte, and the Connecticut Rivers. These three rivers provide a useful comparison of the range of ice jam formation characteristics. Ice jams were classified as freezeup jams if the river discharge decreased prior to the ice jam formation, as indicated by the change in discharge over the previous 5 days. Any jam not classified as a freezeup jam was classified as a breakup jam. Histograms of freezeup and breakup jams by the day-of-year and discharge show that the classification of jam type by discharge produces consistent and rational results. Surveys of the day-of-year and discharge for each ice jam location along the entire length of each river are presented. Information on the day-of-year was used to classify the jam formation as progressive (Yukon), semi-progressive (Platte) or non-progressive (Connecticut). The distribution of the recorded dates of breakup jams on the Platte River covered the entire winter period and displayed a single peak that corresponded to the peak of the spring discharge. In contrast, the recorded dates of breakup jams on the Connecticut River also covered the entire winter period but displayed two peaks, one at mid to late January, corresponding to the period of the "January thaw" and the second to the peak of the spring discharge. The dates of breakup jams on the Yukon River corresponded to the spring peak flows and were confined to the month of May. Freezeup jams on the Platte and Connecticut Rivers tended to occur early in the winter. Both rivers displayed peaks in early January. No freezeup jams were recorded for the Yukon River. On the Platte River and Connecticut River the range of discharges for breakup jams is much larger than that of freezeup jams. The mean discharge increases uniformly in the downstream direction to approximately the Nulato location, and then is more or less constant downstream of that location. The Platte and Connecticut Rivers also show a trend for discharges associated with breakup jams to increase in the downstream direction, but there are notable exceptions to this trend on both rivers.

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