Impact of the Ballville Dam on Ice Jams in Fremont, Ohio

Report Prepared by

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Executive Summary

This study investigated the impact of removal of the Ballville Dam on ice jams in Fremont, Ohio. The dam is located on the Sandusky River approximately 1.5 miles upstream of Fremont.

Fremont is located on the Sandusky River where a relatively steep section of river meets the backwater from Lake Erie. This is a location where ice jams can typically be expected. The Ballville Dam, located immediately upstream of the steep section, is ideally located to protect Fremont from damaging ice jams.

There are 58 recorded ice events on the Sandusky River near Fremont. Forty-seven jams were reported upstream of the Ballville Dam. The recorded stage of 18 of these ice events exceeded the flood stage of 10 feet at the gage. Four ice jams caused extensive damage and flooding in downtown Fremont prior to the dam construction; 1833, 1843, 1883 and 1904. Two ice jams caused flooding in downtown Fremont after the dam construction; in 1959 (when two separate flooding events occurred) and 1963. The remainder of the ice jams were relatively minor ice jams that occurred in Fremont and caused relatively little flooding. In 1972, flood walls were constructed to protect downtown Fremont from flooding and ice jam flooding has not been reported since that time.

The ice jams that occurred in downtown Fremont before the dam was constructed were very destructive. In three of the events, bridges in downtown Fremont were destroyed; the State Street Bridge twice (1833 and 1843) and the railroad bridge once, taking 37 cars with it (1883).

This analysis focused on the ability of the dam to retain ice during the most significant ice jam events. In historical accounts of ice jams before the dam was in place, ice was described as coming from miles upstream and piling many feet high in Fremont. After the Ballville Dam was constructed, ice upstream of the dam remained in place during the most significant events and did not contribute to the ice jams in town. It is likely that the Ballville Dam lessened the impact of the 1959 and 1963 ice jams by retaining the ice upstream of the dam

Based on this analysis, the Ballville Dam has had an impact on reducing damaging ice jams in Fremont, Ohio. Further investigation of the removal of the Ballville Dam on the formation of ice jams in the Sandusky River is recommended. The investigations should focus on the risk of flooding and ice damage to bridges and floodwalls caused by the additional ice carried from upstream of the current dam location to downtown Fremont. The two major alternatives for controlling ice in the absence of the Ballville Dam are described: ice piers and active river ice management.

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Introduction

The Ballville Dam on the Sandusky River in Ohio is currently being considered for decommissioning. A study to enhance the fishing industry on the Great Lakes has prompted efforts to investigate the environmental benefits of removing the dam. Without the dam in place it is expected that migratory fish, particularly walleye, would gain access to upstream reaches of the Sandusky River and increase their spawning ground (USACE 2007). There is a concern, however, that the Ballville Dam may have provided protection against damaging ice jam events in Fremont, Ohio, located approximately 1.5 miles downstream. Fremont has a long history of flooding events, some catastrophic, and many made worse by the presence of ice jams. This study investigates the role of the Ballville Dam in altering the ice process in the Sandusky River and determines whether future evaluations of the dam removal should address issues related to ice.

Dams can play a significant role in the ice formation and break up process on a river. To understand how the Ballville Dam affects ice on the Sandusky River, historical meteorological, hydrologic and ice event records were reviewed. The historical accounts provided information on the location of ice jams, the extent of damage and flooding in the surrounding areas and established a chronology of each event. Air temperature data were used to estimate the river ice thickness and, along with precipitation and discharge, used to evaluate conditions leading to ice jam formation. Ice-affected stage data was compared to open water stage data to examine the effects of ice on water levels in the Sandusky River. Significant ice jam events that occurred prior to the construction of the dam were compared to those that occurred after. This analysis focused on the difference in the amount of damage caused by ice jams in Fremont before and after the dam constructed and in the ability of the dam to retain ice during the most significant events.

Background

Ballville Dam

The Ballville Dam, located approximately 1.5 miles southwest of Fremont, OH on the Sandusky River was built in 1911 as a hydroelectric generating facility. In 1959 the dam was sold to the Town of Fremont. The pool created by the dam is the town's sole source of water. Sedimentation has severely limited the storage capacity of the dam and the town is currently investigating alternative water supply sources (Evans et al 2002). In addition, the dam is currently in need of repairs.

The Ballville Dam is a 34.4 foot high concrete overflow structure. There are two overflow sections separated by a 92.5 foot long water intake structure with 6 sluiceway passages (Figure 1). The right overflow section is 228 feet long and the left overflow section is 86.5 feet long. The crest elevation of the right overflow section is 624.68 feet; of the left overflow section is 625.1; and of the top of the intake structure is 634.68 feet. There is a 702 foot long retaining wall extending upstream on the left bank that has an elevation of 636.74 feet (USACE 1981).

Figure 1. Ballville Dam

Impacts of Dam Removal on Ice-Affected Rivers

Interest in dam decommissioning, including dam removal, has increased significantly throughout the United States over the past 20 years as older dams reach the end of their design life, and awareness of environmental, recreational and economical issues concerning dams increases (American Rivers et al. 1999). Before a dam can be decommissioned an analysis of the hydraulic impacts is often necessary. Dams alter the natural conditions of a river by changing the timing and peak values of flood hydrographs, causing sediment to accumulate in the impoundment, and impacting the ice regime (White and Moore 2002). As most dams remain in place for decades, the geography of the surrounding land, the habitat of the stream, and the population that lives along the river adjust to the new conditions. Removing a dam can result in a possible increase in ice jams, flooding or sedimentation in downstream areas. These effects need to be well understood prior to removal to prepare for and minimize future damages.

There are a number of examples of dam removals impacting and increasing the frequency and severity of damaging ice jam floods (Tuthill and White 1997, White and Moore 2002, Vuyovich and White 2006, Tuthill et al. 2007). One important way dam removal can modify the river ice conditions is by allowing ice at breakup to travel farther down river. Ice that was held upstream of the dam, either by the dam itself or by the solid ice cover formed on the impoundment, can contribute to ice jams downstream. As a result, development and infrastructure, such as bridges, may be susceptible to ice damage. Another way dam removal can affect river ice conditions is to increase frazil ice volume in downstream reaches (White and Moore 2002). Frazil ice is formed in steep turbulent reaches at sub-freezing temperatures. As they drift downstream, the frazil ice crystals adhere to each other and form "flocs" or slush which develop into larger floes. Frazil slush and floes may transport and deposit beneath the thermally grown ice, thickening and strengthening the ice cover, or they may accumulate upstream of the thermal ice in the form of a freezeup ice cover or ice jam. This common dynamic ice forming process is known as ice cover progression. The pools upstream of dams are favorable locations for frazil ice to accumulate on steep rivers. Once a dam is removed, the frazil ice can be transported farther downstream until another thermally grown ice cover is encountered. Significant frazil ice accumulations can result in freeze-up jams (USACE 2002).

Data Sources

Meteorological Data

Air temperature data were used to estimate ice thickness as well as to analyze historical ice events. Precipitation data were also used to analyze conditions that lead to ice jams. Daily maximum and minimum air temperature data and daily precipitation data for National Weather Service (NWS) meteorological stations were retrieved from National Climatic Data Center (NCDC 2007a). The station in Fremont, OH (No. 332974) was the primary source of meteorological data, and has a period of record from 1901 through the present. In years when data was missing at the Fremont station, the NWS station in Tiffin, OH (No. 338313) was used.

Hydrological Data

Average daily river discharge data were obtained from the USGS Gage Sandusky River near Fremont (No. 04198000), which is located approximately 2.2 miles upstream from the dam, and has a drainage area of 1,251 square miles. This gage has a period of record dating from 1923 through the present, though a gap in the data exists between 1935 and 1938. Stage records for this station are available for some high-water events, ice events and field observations (USGS 2007). Flood stage at this gage is 10 feet.

Stage records were also available for the National Weather Service (NWS) staff gage, located on the State Street Bridge in Fremont, OH. The NWS has been measuring the daily river stage at this location since 1904. During high-water events, hourly readings are taken. A database of historical records does not exist, though some of the observation sheets are available on the NCDC website (NCDC 2007b). Most of the historical data points were obtained from past reports and newspaper articles. Flood stage for this gage is still listed as 10 feet, though the flood protection system built in 1972 prevent any flooding until water levels overtop the flood walls at a design discharge of 50,000 cfs (USACE 1980).

Historical Accounts of Ice jams

The history of ice jam flooding along the Sandusky River is well recorded in the CRREL Ice Jam Database (IJDB), project reports, historical accounts, and local newspaper records. The IJDB (2007) lists 46 ice jam events, of which 43 were reported as the annual maximum gage height at the USGS gage upstream of the Ballville Dam. The other references provided further details on these events and identified 11 additional events. Six reports by the Buffalo District of the US Army Corps of Engineers were used in this analysis to gather information on flooding events (USACE 1963, 1964), characteristics of the watershed (USACE 1962, 1964), the dam (USACE 1981, 2007) and of the flood protection walls (USACE 1980, 2007). Online websites provided valuable information on the earliest ice jam records in Fremont (Rutherford B. Hayes Presidential Center, Sandusky County Scrapbook, Ohio Historical Center) and the March 2007 ice jam event

(Dietrich 2007). The floods of January and February 1959 were extensively chronicled by the local newspaper, the Fremont News-Messenger (1959) and the 1904 ice jam event was described in the New York Times (1904). A Fremont city official compiled all flood-related news articles into a large volume which thoroughly describes the events (Fremont Mayor John Overmyer, personal communication 2007).

Further research, particularly of local newspaper archives, may uncover additional ice jam events or additional information on known events, but it is expected that all of the major ice jam events of the last 100 years are listed in this report. Smaller ice jam events, that caused little or no flooding, often go unreported because of their lack of significance. The term *perception stage* describes the minimum stage at which an event is perceived (Gerard and Karpuk 1979). It is likely that additional ice jams have occurred on the Sandusky River which caused little or no significant damage and therefore were not reported.

Ice Formation on the Sandusky River

Ice formation on the Sandusky River is heavily influenced by the river's geomorphology, as shown in its profile (Figure 2) and its location in northern Ohio. The Sandusky River flows from south to north, traveling about 127 miles with a mean gradient of 0.00074 ft/ft (Evans et al 2002). The steepest portion of the river is a series of rapids with exposed bedrock between the Ballville Dam and downtown Fremont, with a mean gradient of 0.003 ft/ft. Fremont, OH is located near the downstream end of the Sandusky River, approximately 10 miles before the river empties into the Sandusky Bay of Lake Erie. The water surface between Fremont, OH and the Sandusky Bay is essentially flat, as the backwater from the bay reaches almost all the way to town. The channel bottom elevation at Fremont is below the mean lake level at Sandusky Bay (USACE 1963).

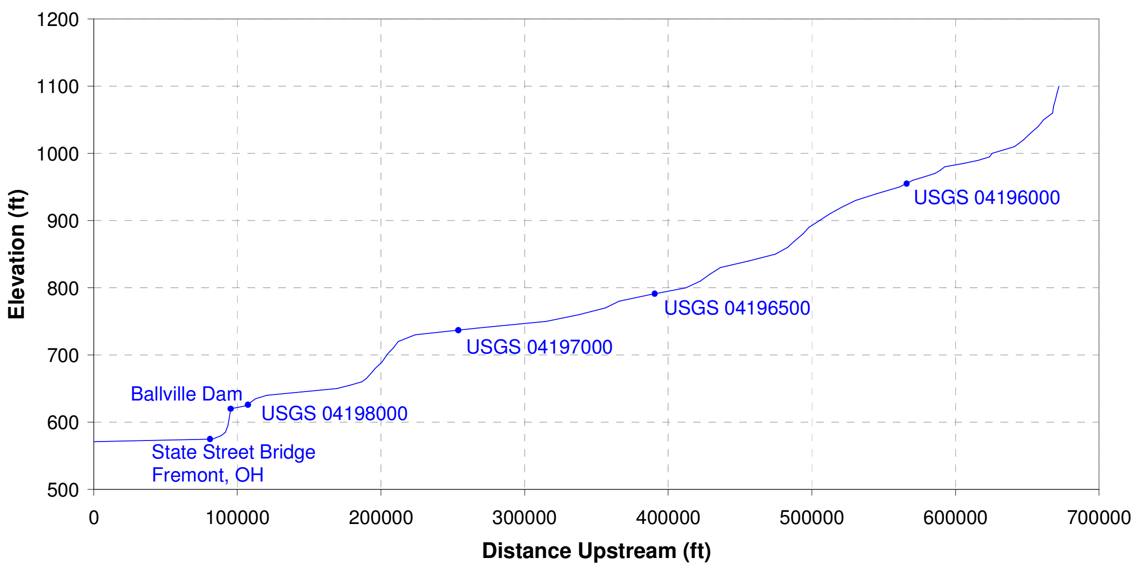

Figure 2. Profile of Sandusky River

The location of Fremont, at the upstream extent of the Sandusky Bay backwater is a likely location for ice jams to occur. A strong, thermal ice cover grows during the winter in the slow-moving backwater of the Sandusky Bay. Frazil ice generated in the steep section between the Ballville Dam and downtown Fremont can accumulate against and deposit beneath the thermally grown ice cover and contribute to the ice thickness in this reach.

Ice cover breakup results from thermal or mechanical processes (USACE 2002). Thermal breakup, caused when the cover melts and thins as a result of warming air and water temperatures, is largely benign, although it can result in the movement of ice pieces that later jam. A gradual rise in flow over many days or weeks will often weaken and melt the ice cover in place avoiding a dynamic breakup. Dynamic breakup occurs when the mechanical forces on the ice cover exceed the resisting forces of the ice. This usually occurs during rapid increases in discharge caused by heavy rain often accompanied by snowmelt. The rising stage lifts the ice. Once the ice cover has lifted, it fractures along the riverbanks and then rapidly breaks into smaller pieces, which begin to move downstream. If the concentration of the moving ice rubble exceeds the transport capacity of the river, an ice jam forms. Ice jams can occur when the breakup ice run impacts an intact ice cover or other obstacles such as bridges or dams. Jams can form as a result of hydraulic or morphological factors (e.g., decrease in energy slope, increase in channel depth or width). The ice thickness and ice strength at the time of break-up influences the severity of the ice jam. At some greater discharge the ice jam may release when it can no longer withstand the downstream forces acting on it. Figure 3 illustrates the stage-discharge relationship for an ice cover, including breakup, jamming, and finally ice jam failure.

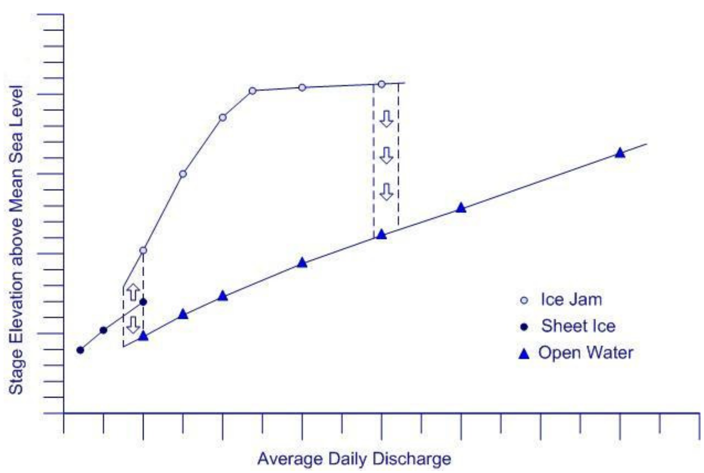

Figure 3. Open water and ice-affected stage-discharge (after Tuthill et al 1996)

In the case of the Sandusky River, the thicker ice in the backwater downstream of town stops the breakup progression and causes a jam to form. As ice accumulates the jam extends upstream, reducing the channel flow area and causing sudden rises in water level. The severity of flooding is a function of the volume of ice contributing to the ice jam, the ice strength, the discharge rate, and the riverbed geometry. More detailed descriptions of ice formation and breakup can be found in the Ice Engineering Manual (USACE 2002). A similar ice formation process occurs behind the Ballville Dam. A thermally grown ice cover forms behind the dam, which is likely thickened by frazil ice from upstream.

Break-up ice traveling downstream impacts the solid ice cover and forms an ice jam. A USGS stream gage, located approximately 2.2 miles upstream of the dam reports high stage due to ice jams about once every three years.

Estimation of Ice Thickness

Ice growth on a water surface is a function of heat transfer at the ice/water interface. Temperature data were used to estimate ice thickness on the Sandusky River based on accumulated freezing degree days (AFDD) (White 2004). In this method, thermally induced (but not frazil) ice thickness can be estimated on a given date during the winter using temperature data in the previous months. Freezing degree-days (*FDD*) represent the difference between the average daily air temperature (T_a) and 0°F, where a difference in temperature below freezing is positive. Accumulation of FDD begins in the fall when temperatures drop below freezing and continues throughout the winter. The peak annual AFDD is a good indicator of winter severity. AFDD can provide an estimate of ice thickness (t_{ice}) in inches on a particular day using the modified Stefan equation presented in USACE (2002):

$$t_{ice} = C\sqrt{AFDD} \tag{1}$$

where C is a coefficient, usually ranging between 0.3 and 0.6, and AFDD is in °F-days. A coefficient of 0.6 was used to calculate ice thickness on the Sandusky River based on observations of ice thickness during past events (Table 1).

Table 1. Calculated Coefficient for Estimating Ice Thickness

Date	Observed Ice Thickness (in)	Calculated Coefficient
10 Feb 1959	12-18	0.50[1]
6 Mar 1963	25-27	0.69[2]
2 Mar 2007	6-12	0.56[3]
Average Coefficient		0.59

While this method provides a reasonable estimate of ice growth due to heat transfer to the atmosphere, other factors, such as the presence of a snow cover on top of the ice or frazil ice deposition underneath the ice, may also affect the ice thickness. The estimated thermally grown ice thickness at the time of each ice event is shown in Figure 4. Based on the AFDD analysis, the average ice thickness during an ice event on the Sandusky River is 13.8 inches.

[1] USACE 1964, Fremont News-Messenger 1959
[2] USACE 1964
[3] Personal Communication Fremont Mayor Overmyer 2007, Detrich 2007

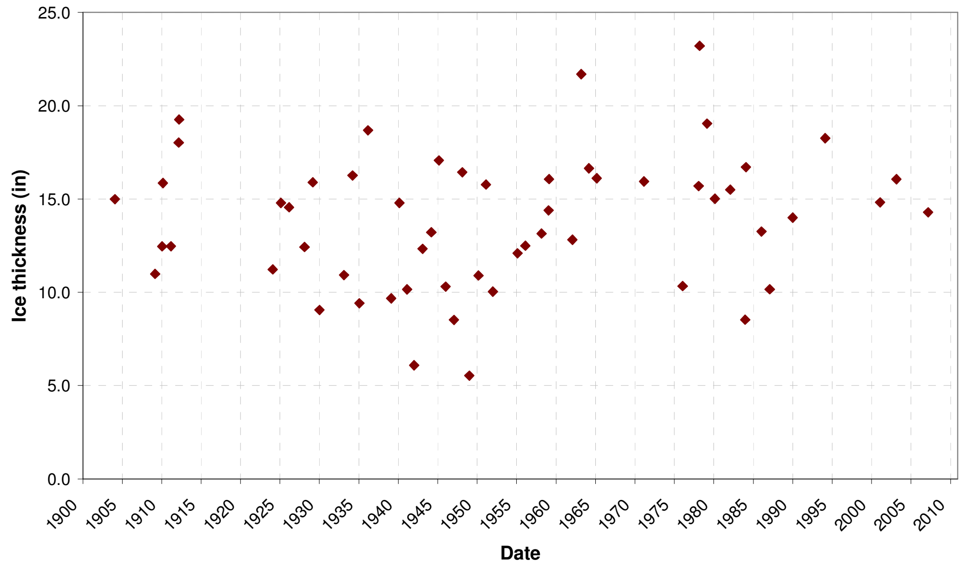

Figure 4. Calculated ice thickness for each ice event in Fremont, OH.

Ice Jams in Fremont, OH

Small ice jams have been reported at the USGS gage upstream of the Ballville Dam on the Sandusky River on average every three years. The orientation of the river, flowing from south to north may contribute to the frequency. Ice formed on the southern, warmer reaches upstream is likely to break up first and flow downstream until it impacts the stronger, intact ice sheet behind the dam. Most ice jams on the Sandusky River are minor and cause little or no flooding. Prior to construction of the dam these small, frequent events were reported downstream in Fremont (Thomas 1913). High water due to ice was recorded five times in downtown Fremont in the 7 years between when the stage gage was installed on the State Street Bridge in 1904 until the Ballville Dam was constructed in 1911.

Significant ice jam events, those that cause major flooding and extensive damage are less frequent. Six major ice jams were found in recorded history; 1833, 1843, 1883, 1904, 1959 and 1963. The earliest ice jams were found in a history of the Sandusky River written by Lucy E. Keeler (1904). According to the account, the first State Street Bridge, a timber bridge built in 1828, was destroyed by the extraordinary ice jam of 1833, which "bore it on a mass of ice and driftwood to the upper point of the island where it lodged and lay stretched almost from bank to bank." A second bridge built at the same location the following summer was destroyed by an ice jam in 1843. Unfortunately, no other data or information is available for the 1833 or 1843 ice jams. The following sections describe the other significant ice jam events in detail. Table 2 lists all of the recorded ice jams in Fremont, OH.

1883 Ice Jam Event

The 1883 ice jam may be the worst ice jam in Fremont history in terms of damage caused. A historical account describes the event:

> Before dawn on the Sunday morning of February 4, 1883, the Fremont fire bell aroused the citizens who found hundreds of their dwellings surrounded or already inundated by water. Heavy rains of two days, falling upon a frozen ground, with ice gorges formed below town, had caused a sudden rise of water in the river four or five feet above any previous high water mark. The water flowed through Front Street, the principal business street of the city, with a mighty current which no boats could stem. The whole third ward between the river banks and the foot of the hills was several feet under water; huge ice blocks floated in, packed and froze solid. Two thousand persons were driven from their homes. There were many narrow escapes and several deaths from drowning and exposure. Several bridges along the river were carried away, and that of the L. S. & M. S. Railway collapsed under a freight train, thirty-seven cars being precipitated into the river. The damage to property in Fremont alone amounted to about $100,000. (Keeler 1904)

No reliable measurement of stage exists for the 1883 event, but anecdotal evidence describes the water level as approximately 3 feet lower than the 1913 open water event of record, or 17.5 feet at the State Street Bridge (Thomas 1913). This is approximately the same level as the 1959 event. A newspaper clipping in 1959 described the 18 February 1883 ice jam event, “Ice was piled 6 or 8 feet high on State Street both east and west of the river…Traces of the flood remained for many months, even the huge cakes of ice did not melt and disappear entirely until the following May…Pressure of the enormous ice cakes caused the New York Central railroad to collapse…While the ice jam flood of 1883 was the worst of any ever to affect the city, water damage was not as great as that of the 1913 flood. (News-Messenger 1959)”

Figure 5. 1883 Ice Jam Event, Fremont, OH (Sandusky County Scrapbook)

1904 Ice Jam Event

On 23 January 1904, heavy rain caused increased discharge in the Sandusky River which led to an early ice breakup. The stage at the State Street Bridge was recorded at 16.5 ft. An article in the New York Times describes the event: “The ice in the Sandusky River is gorged from ten to twenty-five feet high in the very heart of the city, and the only channel the water has is through the main business street, where it rushes with great velocity. The water receded somewhat during the forenoon, but not enough to relieve the situation to any extent. “One-half the city is underwater, and no estimate of damage can be made at present. All day the ice has been coming down the Sandusky River and gorging until the gorges now extend to a point above the city, throwing all the back water over the low portions of the city. The entire east side, in the Third Ward, is under water.” (New York Times 1904)

Figure 6. 1904 Ice jam event, Fremont, OH (Sandusky County Scrapbook)

1959 Ice Jam Event

A summary of the 1959 floods is given below based on Fremont News-Messenger articles compiled by the City of Fremont.

On 19 January, 1959 four inches of snow fell in the Sandusky River Watershed. The following day, temperatures rose, the falling snow turned to rain and in a twenty-four hour period over 20-21 January 1.76 inches of rain fell in Fremont, OH. A mile-long ice jam formed approximately 1 mile downstream of Fremont. By 1:00 pm on the 21 January the stage began to rise in the Sandusky River in downtown Fremont. Early in the morning on 22 January the water levels reached flood stage of 12 feet at the State Street Bridge and downtown Fremont was flooded. For four days the water level remained above flood stage until finally receding on 26 January. The peak occurred on 24 January when water levels reached 17.2 feet in downtown Fremont (Figure 7).

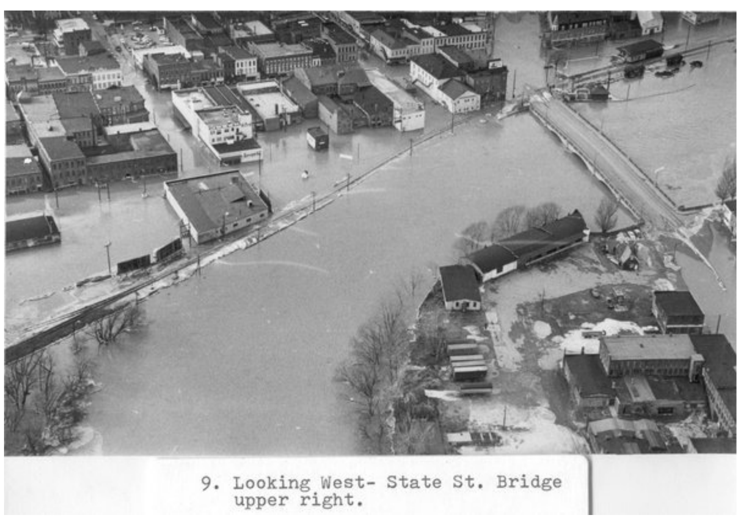

Figure 7. 1959 Ice Jam event, Fremont, OH (Sandusky County Scrapbook)

An ice jam was also reported upstream of the Ballville Dam, which remained in place throughout the January flooding event and afterwards was described as "more solid than ever…no sign of breaking up". The jam behind the sheet ice on the Ballville Dam was described as extending from Buckland Avenue to where Wolfe Creek emptied into the

Sandusky River. The locations of ice jams during the 1959 floods were estimated based on the published reports (Figure 8).

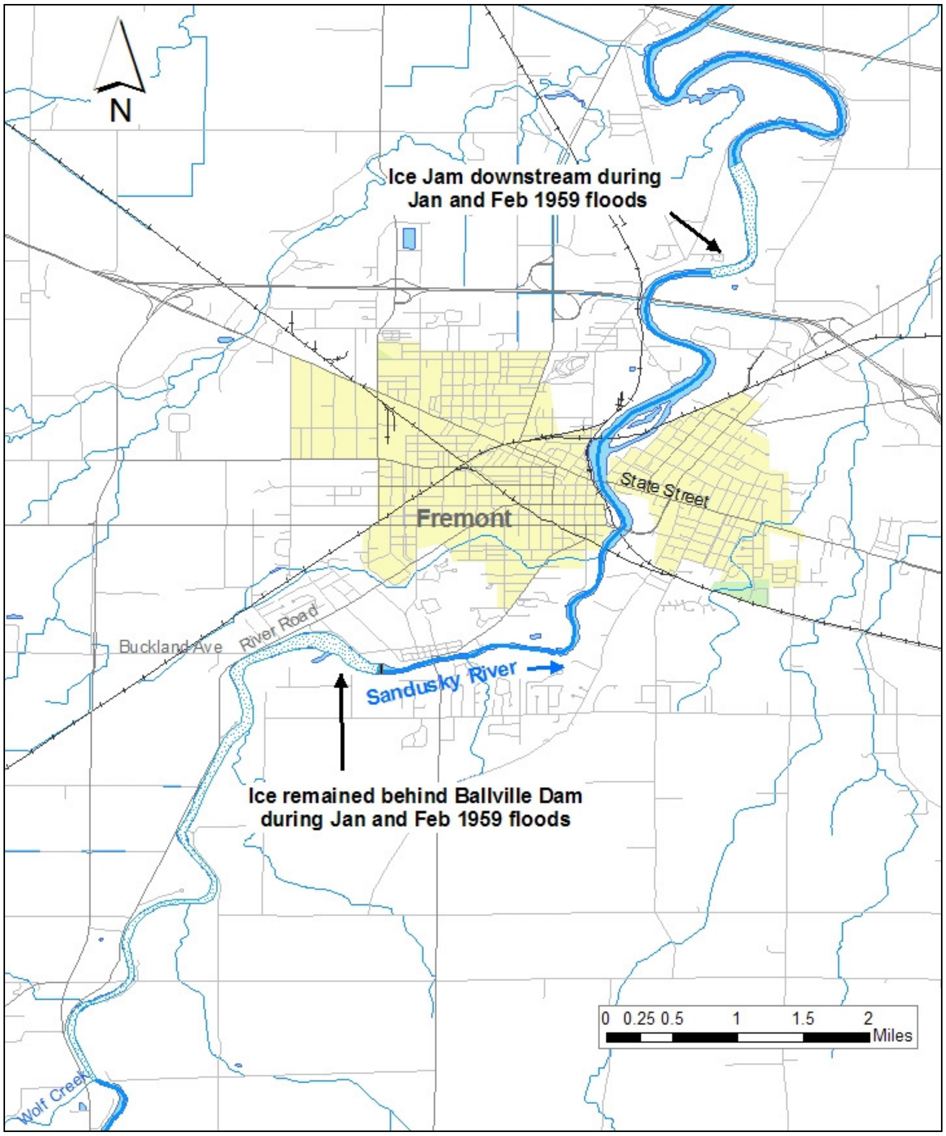

Figure 8. Map depicting ice events of 1959

Clean up efforts to remove the ice that had formed in downtown Fremont were hampered when the flooded water froze in place. In all, 1,650 people were displaced from their homes. Meanwhile there was still concern that another similar event could happen again since the ice jam was still in place downstream of town. Blasting the ice jam with dynamite was discussed, but because the slope is essentially flat between Fremont and the bay the ice would have no where to go if it were blasted. The decision was made to wait until discharge increased in the river before blasting. The jam was estimated to be 5 feet thick.

In the afternoon on 10 February 1959, discharge in the Sandusky River began to rise again. In twenty-four hours Fremont received 1.56 inches of rain, though other towns in the basin reported as much as 3 inches. The sheet ice holding the ice jam in place upstream of the Ballville Dam began to fracture, though it remained in place. Efforts were made to begin blasting the ice jam downstream of town, but had to be called off as the sun went down.

On 11 February, water levels continued to rise in Fremont reaching a peak stage of 18.0 feet at 7:00 am. A second flood of water was sent through downtown Fremont which was still cleaning up from the first flood. Water levels remained above flood stage until 13 February. Blasting operations resumed and the jam downstream of town shifted about 1000 feet downstream. A flight over the area revealed several ice jams between Fremont and the bay, including one just half a mile downstream from the ice jam causing the flooding. The flight also noted that the jam upstream of the Ballville Dam remained in place, though "the south ice pack did not appear as dangerous as it did Tuesday morning when it threatened to break away and add to the swirling ice and water pouring towards Fremont".

By 14 February ice in the Sandusky River began to rot away and was almost entirely gone by 15 February. Ice upstream of the Ballville Dam finally broke up and flowed over the dam during the night of the 13 February. An observer described the scene: "The ice broke up as it fell and ground up in the rapids below. In this respect the dam is of immense value to Fremont as well as a conserver of water."

Following the two floods event of 1959, a study of historical floods and future flood protection in Fremont, OH was undertaken by the Buffalo District Army Corps of Engineers. This flood was the impetus for construction of the flood walls in Fremont, built in 1972.

1963 ice jam event

A flood report by the Buffalo District of the US Army Corps of Engineers describes the ice jam of 1963. A major thunderstorm moved across the basin early on 4 March 1963, dropping 2.5 inches of rainfall on top of an estimated 1 inch of snow water equivalent on the ground. Cold air temperatures over the winter had resulted in a thick ice cover in the reach between Sandusky Bay and Fremont. Ice borings measured an ice thickness of 25 to 27 inches thick. An ice jam formed downstream of Fremont causing water to back up and flood the downtown area (Figure 9). On 8 March, the water level at the State Street Bridge gage reached a peak stage of 15.3 ft. An ice jam upstream of the Ballville Dam remained in place during the 1963 event. The following section describes the flooding upstream of the dam:

> "It is interesting to note that although the March 1913 flood is the flood of record (63,500 cfs), the water surface profile of the March 1963 flood is approximately the same at Ballville Dam and for a short distance upstream. This condition reflects the severe ice conditions in the river during the 1963 event and the fact that the Ballville Dam failed during the 1913 flood. The high ice jam stages inundated farm land and surrounded buildings on several agricultural properties upstream of the dam, although total damages were relatively minor (USACE, 1963)."

A flood hydrograph from the same report indicates that the peak stage at the USGS gage was 13.96 feet and occurred on 6 March at a discharge of approximately 13,000 cfs.

Immediately following, the stage dropped rapidly while the discharge continued to climb. This is typical of an ice jam release. When the discharge reached a peak of 21,500 cfs on 8 March, the stage upstream of the dam was approximately 10.8 ft, which is still higher than the open water stage for that discharge, indicating the effects of ice were still present. In an aerial image taken on 8 March 1963 (Figure 10), an intact ice cover is visible upstream of the dam. Ice rubble visible in the upper portion of the river is likely the start of the ice jam upstream of the dam extending further upstream. An open lead through the center of the ice cover is where some ice possibly released causing the drop in stage two days earlier.

Figure 9. Ice jam flood in Fremont, OH, 8 March 1963 (looking downstream)

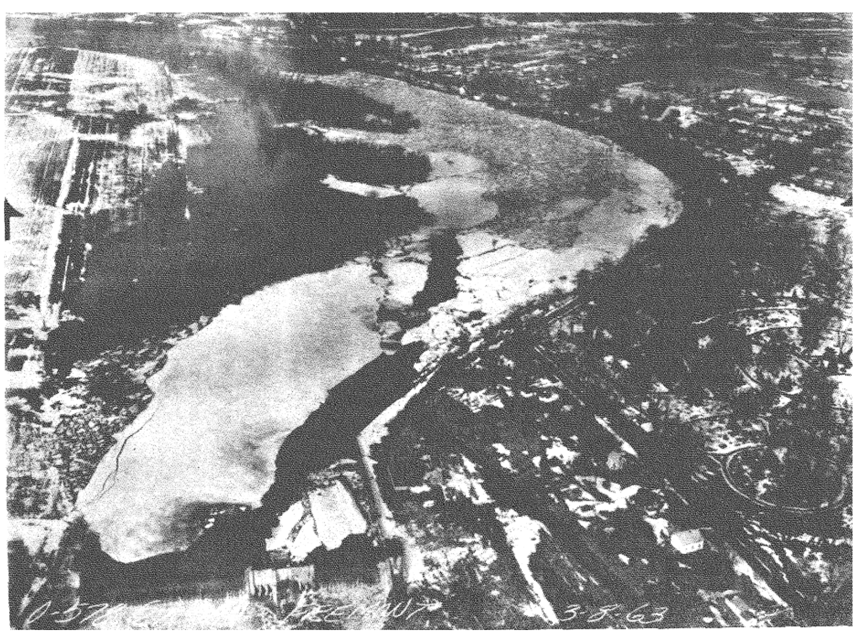

Figure 10. Ice Jam upstream of Ballville Dam, 8 March 1963 (looking upstream)

2007 Ice Jam Event

The ice jam event that occurred upstream of the Ballville Dam in March 2007 caused minor flooding on River Road and left large pieces of ice stranded in the area around the dam (Figure 11). No ice jams or high water were reported in Fremont during the ice jam. This event is significant because it is a recorded instance of an ice jam releasing and ice flowing over the dam. The ice jam occurred early in the morning on 2 March and reached a peak stage of 11.15 ft at 7:30 am at the USGS gage (04198000). Between 7:30 and 8:00 am the ice jam released and the ice floes were witnessed going over the dam[1]. Only stage data is reported for the 2007 event because discharge data is based on open water rating curve and has not yet been corrected for the effects of ice[2] (Figure 12).

Figure 11. Ice floe stranded on a stump near River Road (Detrich 2007)

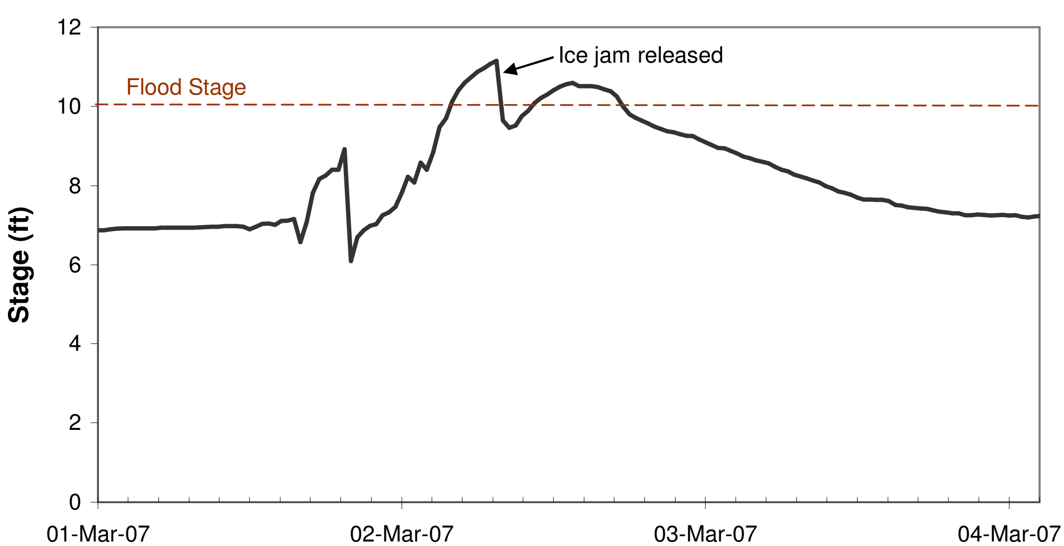

Figure 12. Stage reading at USGS gage during March 2007 ice jam (USGS 2007)

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[1] Personal communication with Fremont Mayor Overmyer 2007
[2] Personal communication with USGS, Ohio Water Science Center

Table 2. Recorded Ice Events in Fremont, OH

Date	Location	AFDD	Estimated ice thickness (in)	Daily Average Discharge (cfs)	Stage at State Street Bridge (ft)	Stage at USGS Gage (04198000) (ft)	Description
Feb 1833	Fremont						Destroyed first State Street Bridge[1]
Spring 1843	Fremont						Destroyed the second State Street Bridge[1]
04Feb1883	Fremont				17.5[3]		On 3 Feb, ice from miles up river came rushing down…and formed gorges downstream of town. Homes were flooded and damaged. The railroad bridge failed, taking 34 cars with it and 2000 people were evacuated.[2]
23Jan1904	Fremont	624.0	15.0		16.5		Ice jam in Fremont caused extensive flooding. Thickness of jam estimated between 10-25 feet.[3]
24Feb1909	Fremont	335.0	11.0		11.1		Break-up ice jam[3]
22Jan1910	Fremont	431.3	12.5		12.3		Break-up ice jam[3]
26Feb1910	Fremont	698.3	15.9		14.7		Break-up ice jam[3]
1-2Mar1911	Fremont	431.5	12.5		14.0		Break-up ice jam[3]
27Feb1912	Fremont	902.0	18.0		15.5		Break-up ice jam[3]
16Mar1912	Fremont	1030.5	19.3		12.6		Break-up ice jam[3]
30Jan1924	Ballville Dam	350.0	11.2	2150		9.8	Gage height due to backwater from ice[4]
7Feb1925	Ballville Dam	607.5	14.8	1110		8.4	Gage height due to backwater from ice[4]
26Feb1926	Ballville Dam	588.8	14.6	9310		7.1	Gage height due to backwater from ice jam[4]
6Feb1928	Ballville Dam	429.0	12.4	6000		8.2	Gage height due to backwater from ice[4]
26Feb1929	Ballville Dam	702.0	15.9	6000		14.0	Gage height due to backwater from ice[4]
10Feb1933	Ballville Dam	331.5	10.9	2800		7.4	Gage height due to backwater from ice[4]
10Mar1934	Ballville Dam	734.5	16.3	426		6.73	Gage height due to backwater from ice[4]
24Jan1935	Ballville Dam	2460	9.4	630		6.31	Gage height due to backwater from ice[4]
26Feb1936	Ballville Dam	969.5	18.7	28	13.0	15.34	Gage height due to backwater from ice[4]
3Feb1939	Ballville Dam	260.3	9.7	8800		7.37	Gage height due to backwater from ice[4]
20Feb1940	Ballville Dam	608.0	14.8	5000		11.4	Gage height due to backwater from ice[4]
9Feb1941	Ballville Dam	286.5	10.2	1000		5.53	Gage height due to backwater from ice[4]
6Jan1942	Ballville Dam	103.0	6.1	240		5.04	Gage height due to backwater from ice[4]

Date	Location	AFDD	Estimated ice thickness (in)	Daily Average Discharge (cfs)	Stage at State Street Bridge (ft)	Stage at USGS Gage (04198000) (ft)	Description
25Jan1943	Ballville Dam	422.0	12.3	4500		9.6	Gage height due to backwater from ice[4]
10Mar1944	Ballville Dam	485.5	13.2	1500		5.51	Gage height due to backwater from ice[4]
23Feb1945	Ballville Dam	809.5	17.1	9000		8.38	Gage height due to backwater from ice[4]
27Dec1945	Ballville Dam	295.0	10.3	2000		7.32	Gage height due to backwater from ice[4]
23Jan1947	Ballville Dam	201.5	8.5	3500		7.88	Gage height due to backwater from ice[4]
14Feb1948	Ballville Dam	750.0	16.4	4500		10.84	Gage height due to backwater from ice[4]
27Dec1948	Ballville Dam	85.0	5.5	480		5.33	Gage height due to backwater from ice[4]
3Mar1950	Ballville Dam	330.0	10.9	950		4.86	Gage height due to backwater from ice[4]
13Feb1951	Ballville Dam	691.0	15.8	3000		9.37	Gage height due to backwater from ice[4]
30Dec1951	Ballville Dam	279.5	10.0	5000		12.12	Gage height due to backwater from ice[4]
13Feb1955	Ballville Dam	406.5	12.1	3000		7.77	Gage height due to backwater from ice[4]
9Feb1956	Ballville Dam	434.0	12.5	4500		9.07	Gage height due to backwater from ice[4]
24Feb1958	Ballville Dam	480.5	13.2	3500		10.15	Gage height due to backwater from ice[4]
22Jan1959	Fremont	575.0	14.4	25000*	17.2	14.7	Ice jam about 1 mile downstream of town. Extensive residential & commercial flooding. 1300 people evacuated. Ice jam upstream of Ballville Dam held.[5]
10Feb1959	Fremont	717.5	16.1	28000*	18.0	15.2	Same ice jam from Jan event remained in place and caused a second, higher flood of downtown Fremont. Ice jam upstream of dam held.[5]
26Jan1962	Ballville Dam	456.0	12.8	3800		11.02	Gage height due to backwater from ice jam[4]
6Mar1963	Fremont	1307.5	21.7	21500*	15.3	13.96	Ice Jam downstream of State Street Bridge caused serious flooding which required evacuation of downtown. Ice jam held upstream of the Ballville Dam.[4]
29Feb1964	Ballville Dam	769.5	16.6	46			Maximum discharge of 4.4 cfs due to freeze-up[4]
26Feb1965	Ballville Dam	721.5	16.1	1700		8.08	backwater from ice jam[4]
23Feb1971	Ballville Dam	705.5	15.9	21000		13.89	backwater from ice jam[4]
15Jan1976	Ballville Dam	296.5	10.3	1600		10.33	backwater from ice jam[4]

Date	Location	AFDD	Estimated ice thickness (in)	Daily Average Discharge (cfs)	Stage at State Street Bridge (ft)	Stage at USGS Gage (04198000) (ft)	Description
27Jan1978	Ballville Dam	684.6	15.7	9000			ice jam reported at gage, stage unknown[4]
15Mar1978	Ballville Dam	1495.8	23.2	36000		15.88	Gage height due to backwater from ice jam[4]
24Feb1979	Ballville Dam	1007.0	19.0	1800		16.14	Gage height due to backwater from ice jam[4]
23Feb1980	Ballville Dam	626.0	15.0	4200		9.29	Gage height due to backwater from ice jam[4]
31Jan1982	Ballville Dam	667.0	15.5	5200		14.83	Gage height due to backwater from ice jam[4]
24Dec1983	Ballville Dam	202.0	8.5	1200		7.72	Gage height due to backwater from ice jam[4]
27Jan1984	Ballville Dam	775.5	16.7	6100		6.98	Gage height due to backwater from ice jam[4]
20Jan1986	Ballville Dam	488.0	13.3	5200	8.0	11.91	Gage height due to backwater from ice jam[4]
4feb1987	Ballville Dam	287.0	10.2	3000		6.52	Gage height due to backwater from ice jam[4]
01Jan1990	Ballville Dam	544.5	14.0	12000			ice jam reported at gage, stage unknown[4]
18Feb1994	Fremont	926.0	18.3	814	4.0		"Recent warm weather has caused the Sandusky River to start melting, jamming large blocks of ice up on the shore, as seen just down river from the State Street Bridge in Fremont" – News Herald[4]
31Jan2001	Ballville Dam	610.5	14.8	3000		7.21	Gage height of 7.21, due to backwater from ice jam[4]
23Feb2003	Ballville Dam	716.5	16.1	1100		10.94	Gage height of 10.94, due to backwater from ice jam[4]
2Mar2007	Ballville Dam	567.0	14.3		12.5	11.15	Ice jam behind Ballville Dam caused flooding of River Road. Ice went over the dam and downstream the following day[6]

[1] Keeler 1904
[2] Sandusky County Scrapbook 2007
[3] Thomas 1913
[4] IJDB 2007
[5] Fremont News-Messenger 1959
[6] Personal communication, Mayor Overmyer
* Peak Discharge (cfs)

Ice Jam Analysis

Historical ice jams were analyzed to understand to what degree the Ballville Dam influences the location and severity of ice jams in Fremont. Of the 58 recorded ice jams found, 47 occurred upstream of the Ballville Dam. In 18 of these ice events the stage exceeded the flood stage of 10 feet, but was only reported as maximum gage height due to ice at the USGS gage. A plot of calculated ice thickness and discharge, during events when data was available, indicates that most of the minor ice jams, with the exception of 1971 and 1978, had a discharge less than 15,000 cfs at the time of the event (Figure 13). The ice jams of 1971 and 1978 were both reported upstream of the Ballville Dam, and no record of an ice jam occurring in town during either of these years was found, though additional research might uncover more information. The major ice jams occurred when the ice thickness was greater than 13 inches and the discharge was greater than 20,000 cfs.

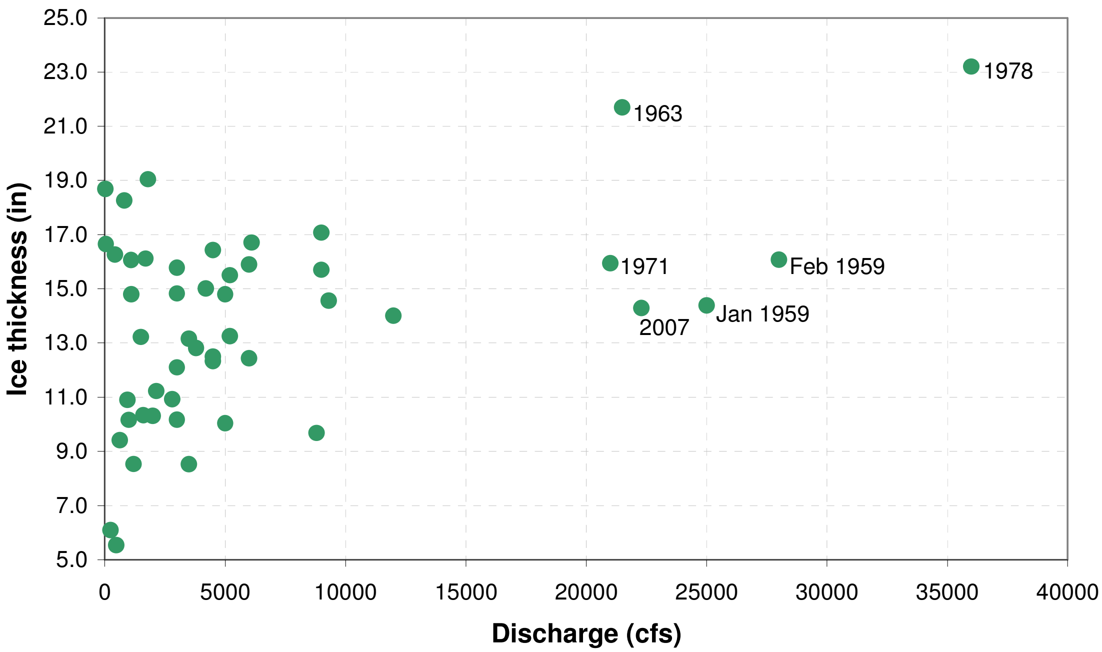

Figure 13. Discharge and estimated ice thickness during ice jam events

Of the six major ice jam events that caused extensive damage and flooding in Fremont (1833, 1843, 1883, 1904, 1959 and 1963), two occurred after the Ballville Dam was constructed; 1959 and 1963. According to historical accounts of both the 1959 and 1963, ice remained in place upstream of the Ballville Dam while flooding occurred in Fremont due to jams downstream. Typically an intact ice cover has been found to dynamically break up and release when the water level rises 3-4 times the thickness of the ice (Donchenko 1978). The stage upstream of the dam during both the 1959 and 1963 events was approximately 8-10 feet (USACE 1964) and still the ice remained in place. Other factors, such as the ice strength at the time of the event and the morphology and hydrography of the river likely play a significant role at this location. Graphs of the discharge and meteorological conditions (Figure 14-16) compare the 1959 and 1963 events to the 2007 ice jam when ice did overtop the dam. In 1959 heavy rains caused the discharge to rise sharply in January and again in February when the ice strength is typically highest due to cold temperatures. In 1963 the winter had been very cold with almost twice as many freezing degree-days accumulated as in 1959. Even though the 1963 ice jam occurred in March, the ice was still approximately 2 feet thick when the discharge again increased rapidly. In contrast, during the March 2007 ice jam air temperatures had been at or above freezing in the days leading up to the event. It is expected that the ice had already been weakened, facilitating break up and allowing the ice to flow over the dam.

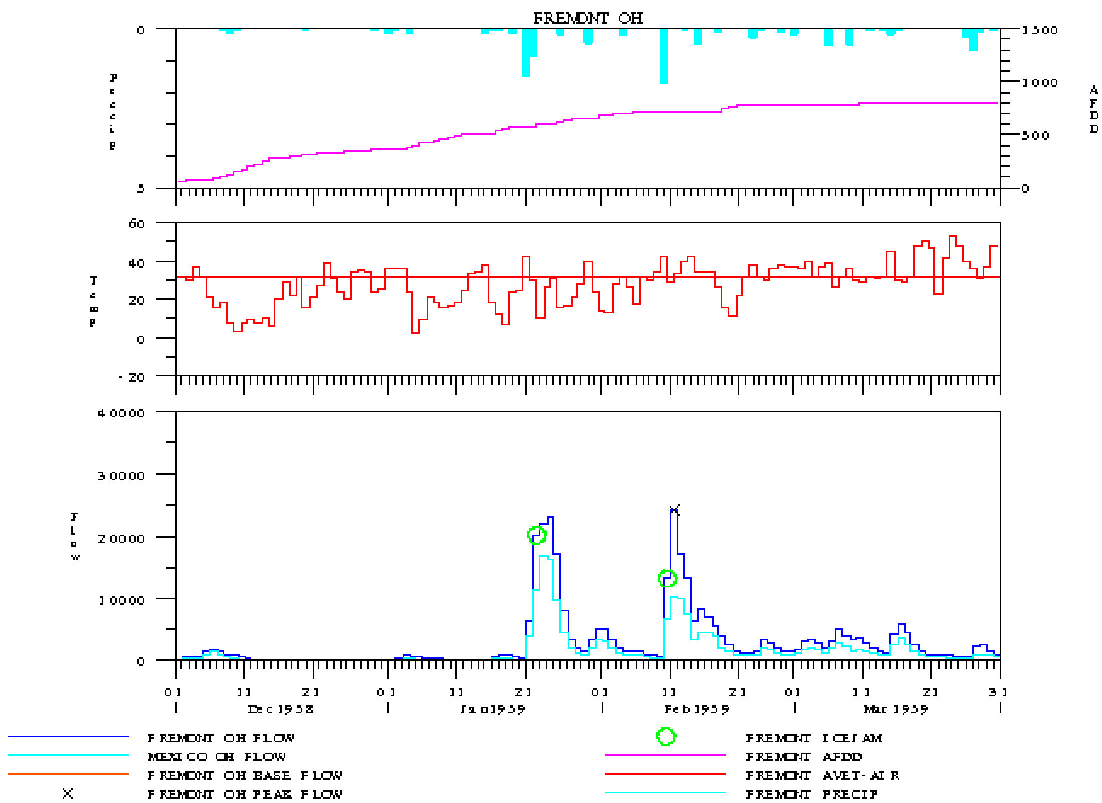

Figure 14. Plot of 1959 Precipitation, AFDD, Air Temperature and Discharge

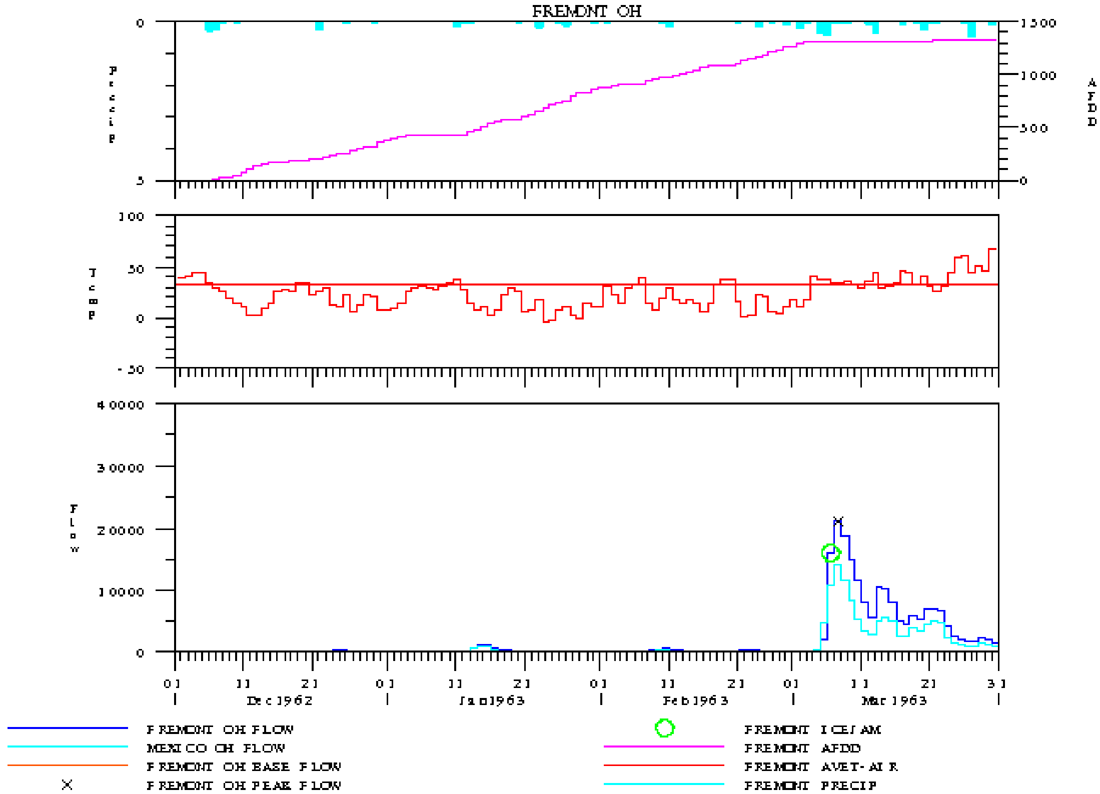

Figure 15. Plot of 1963 Precipitation, AFDD, Air Temperature and Discharge

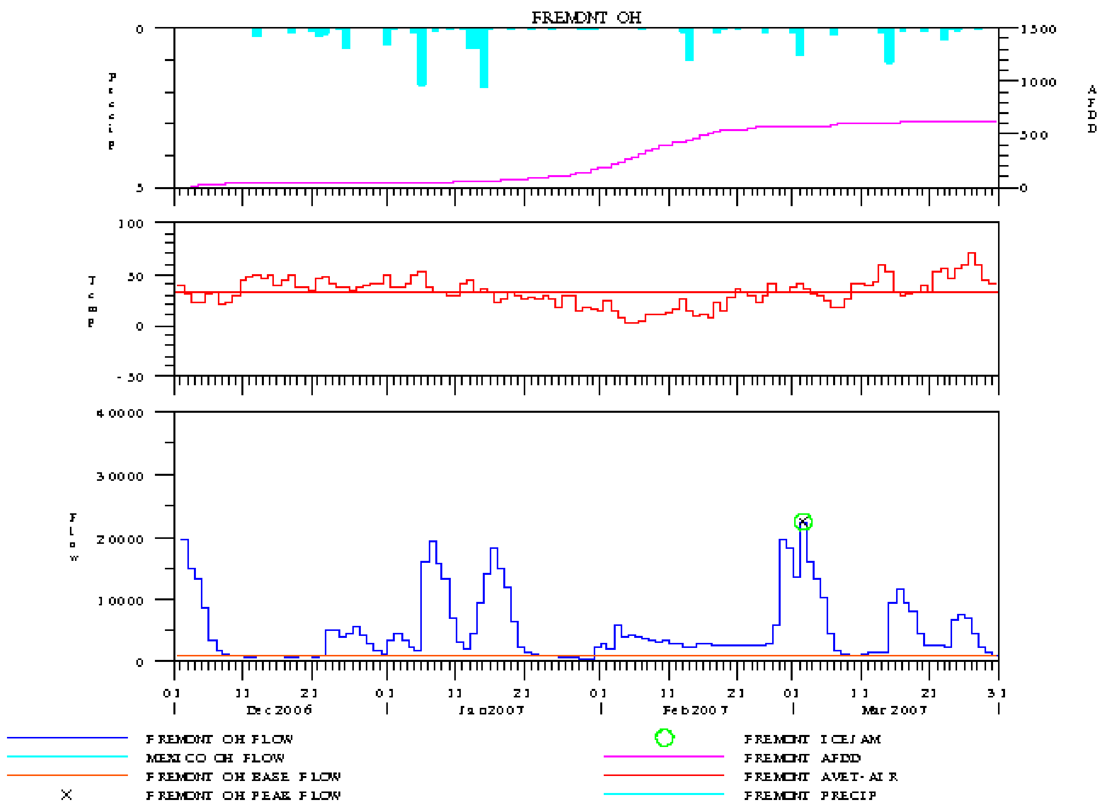

Figure 16. Plot of 2007 Precipitation, AFDD, Air Temperature and Discharge

The presence of ice behind the Ballville Dam causes water levels to rise higher than during open water conditions. The open water and ice-affected stage readings at the USGS gage upstream of the Ballville Dam are shown in Figure 17. Since the USGS gage was not installed until 1923, the 1913 stage and discharge were estimated using high water marks (USACE 1962). The stage during the 1913 flood of record is below the open water stage-discharge relationship because the dam failed during the event. Also shown on the graph is the stage-discharge rating curve for the Ballville Dam spillway (USACE 1981). The 2007 ice jam event is not shown on this graph because discharge measurements have not been corrected for the effects of ice at this time.

The 1978 event recorded the highest average daily discharge for an ice jam, 36,000 cfs on 15 March. At 7:30 pm on 15 March an ice jam was recorded upstream of the Ballville Dam which caused the maximum annual stage for that year of 15.88 feet. On 16 March 1978 a peak discharge of 36,500 cfs was reported, but the stage had dropped to 13.57 feet, which corresponds to the open water stage. It is possible that the ice overtopped the dam on 15 March after reaching a maximum discharge that the ice could withstand. If the ice overtopped the dam and traveled downstream either the discharge was sufficient to push the ice past Fremont so no jam occurred, or a jam occurred but because of the newly constructed flood walls no flooding was reported.

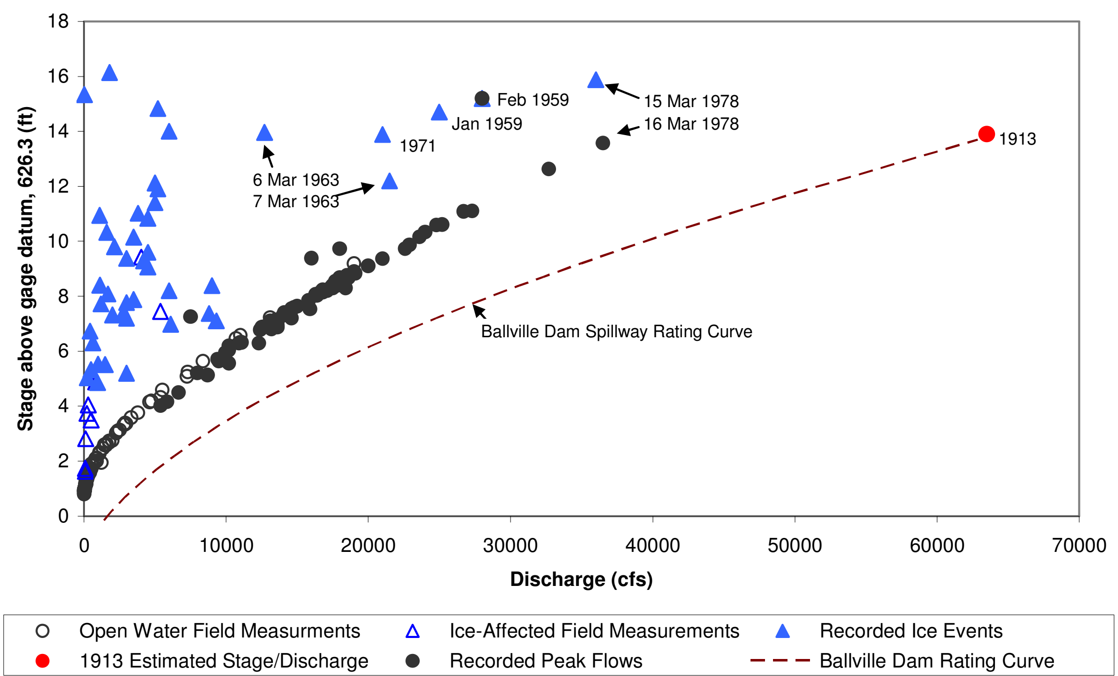

Figure 17. Open-water and ice-affected stage readings upstream of the Ballville Dam

The recorded stage readings at the NWS gage on the State Street Bridge are shown in Figure 18. Stage readings were obtained from Fremont News-Messenger articles (1959), USACE reports (1962, 1963 and 1964) and NWS observation sheets (NCDC 2007b). The indicated discharge is the average daily discharge from the USGS gage upstream of Ballville Dam, except for the three recorded ice events for which the peak discharge recorded was used (Jan and Feb 1959 and 1963). The stage-discharge relationship for this location was estimated by the US Army Corps of Engineers in a report on the proposed flood control of the Sandusky River in Fremont, OH (USACE 1962). The stage-discharge relationship for the improved conditions after the flood walls were built and the existing conditions are not significantly different at the State Street Bridge location. Unfortunately stage and discharge information is not available for the significant ice events which occurred during the 1800s for comparison. The 1913 event is below the rating curve because according the USACE 1962 report, the datum of the staff gage was lowered by 1.1 feet in 1925 and the stage of the 1913 event should be increased to 22.6 feet.

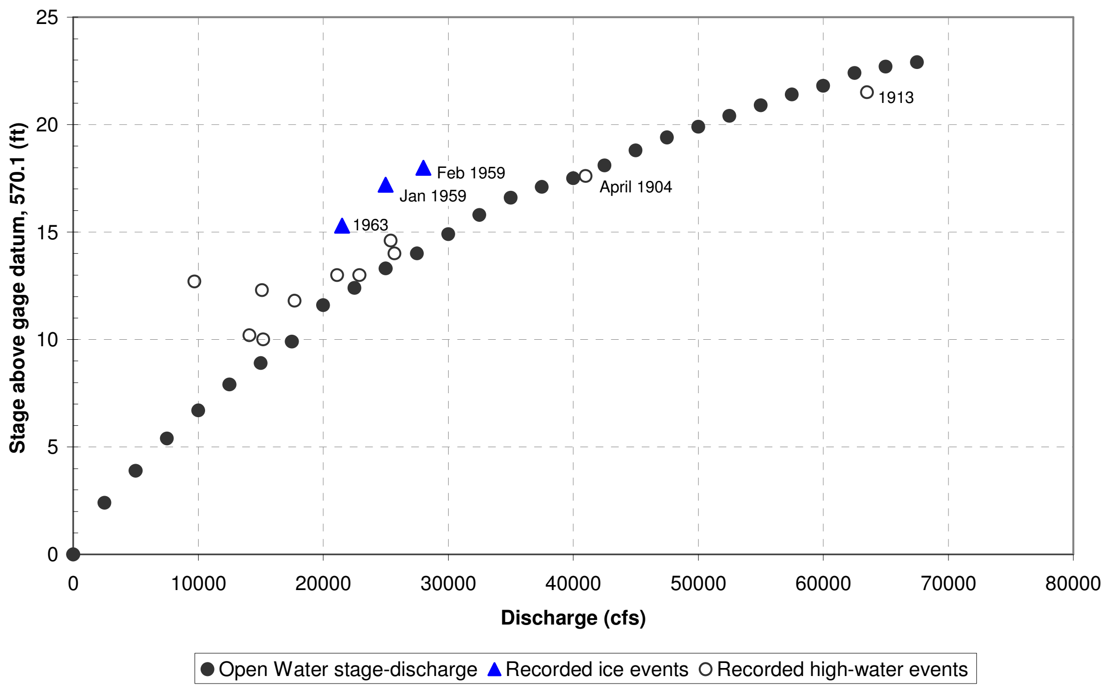

Figure 18. Open water and ice-affected stage readings at the State Street Bridge.

Impact of the Ballville Dam on Ice Jams

The Ballville Dam, built in 1911, has altered the ice formation and break up process on the Sandusky River. Water velocities in the pool are low enough to form a solid ice cover during the winter months. Ice jams form behind the Ballville Dam when break up ice encounters the solid ice cover on the pool. In the 84 years since the USGS gage was installed in 1923, 47 ice events have been recorded upstream of the Ballville Dam. The majority of these ice jams were minor and caused no flooding. Eighteen of these events caused water levels to rise above flood stage.

Before the dam was constructed, ice from upstream was transported farther downstream into Fremont where it was stopped at the solid ice cover on the backwater of the Sandusky Bay. High water due to ice was recorded 5 times at the State Street Bridge in the 7 years between when the stage gage was installed in 1904 and Ballville Dam was constructed. Four records of significant ice jam events in downtown Fremont before the dam was built were found (1833, 1843, 1883 and 1904). In three of those events, bridges in downtown Fremont were destroyed by the ice; the State Street Bridge in 1833, the State Street Bridge again in 1843, and the L.S & M.S Railroad Bridge in 1883. During both the 1883 and 1904 ice jam events, ice was described as coming from miles up river and jamming all the way through town.

Two of the most damaging ice jams in Fremont, 1959 and 1963, occurred after construction of the Ballville Dam. In both events, ice upstream of the dam remained in place and did not contribute to the ice jams in town. Newspaper accounts of the 1959 event record that citizens kept a constant watch on the ice cover upstream of the dam because of concerns that additional ice was going to exacerbate the flooding downstream (Fremont News-Messenger 1959). Water levels just beneath the roadway of the State Street Bridge can be seen in photos of the flooding during the 1959 event (Figure 6). Additional ice from upstream could have caused significant damage to the bridge had it impacted the roadway. In 1963, the ice jam was estimated to be 5 feet thick, compared to 10-25 feet estimated for the 1904 ice jam event.

Ice Jam Mitigation Alternatives

If the Ballville Dam is decommissioned, several alternatives exist for mitigating damaging ice jams in the future. The first step is to determine the risk of flooding and ice damage to bridges and floodwalls caused by the additional ice carried from upstream on the Sandusky River pass the current dam location. A hydraulic model of the ice conditions using HEC-RAS (USACE 2006) should be conducted to determine the water levels and flooding (Vuyovich and White 2007). Once the levels of risk were determined, a river ice control plan could be developed to reduce the probability of flooding to acceptable levels. The two major alternatives for controlling ice are listed below:

Permanent Ice Control Structure. Install a permanent ice control structure such as ice piers at the location of the dam (Tuthill and Lever 2006). The Ballville Dam is ideally located to protect the City of Fremont from damaging ice jams. Ice piers constructed at the same location would prevent upstream ice from contributing to an ice jam in downtown Fremont yet allow the floodwave to pass through. A structure of this type was constructed on Cazenovia Creek in Western New York State (Lever et al 2000). An image of the Cazenovia Creek ice control structure during an ice run in March 2007 was taken by a remote web camera installed at the site (Figure 19). Ice piers do not block upstream passage of fish, downstream passage of sediment, or passage of small recreational boats such as kayaks and canoes. The expected level of protection of permanent ice control structures, such as ice piers, can be quantitatively estimated with a high level of confidence based on laboratory tests, field performance of existing structures, and ice modeling. Generally, permanent structures can be expected to provide a high level of protection.

Figure 19. Ice jam at Cazenovia Creek ice control structure

River Ice Management. Institute active river ice monitoring and ice management strategies. Ice formation in the reach downstream of Fremont to Sandusky Bay would be monitored during the winter months. Active measures would be applied to reduce the ice strength and/or melt the ice in place, reducing the potential for damaging ice jams. These measures which include hole drilling, ice cutting and darkening the ice surface (Haehnel 1998). Active measures must be applied at the appropriate time, before an ice jam occurs but with enough lead time to be effective. It is often difficult to judge the appropriate time and degree of application. The expected level of protection of active measures is often hard to quantitatively estimate with confidence because of the difficulties is judging the level of performance in application. Active measures generally provide less protection than permanent structures.

What ever alternative is selected, new technologies can help monitor river ice conditions. Web-based cameras (Gagnon 2002) and satellite remote sensing (Gatto et al 1987) can take images of the ice remotely on a regular basis. Break up ice warning systems can be installed in the ice and set to provide an alarm when ice motion is detected (White et al 2000).

Conclusion

Ice jams are frequent events on the Sandusky River, which flows from south to north emptying into the Sandusky Bay and Lake Erie. Fremont, OH, located at the upstream extent of the Sandusky Bay backwater, has a history of major ice jam events causing extensive damage. This study investigated the role that the Ballville Dam, approximately 1.5 miles upstream of Fremont, has played in ice jams on the Sandusky River since it was constructed in 1911.

Historical ice jams were analyzed to determine to what degree the Ballville Dam influences the location and severity of ice jams in Fremont. The analysis of the ice impacts of the Ballville Dam has focused on the ability of the dam to retain ice during the most significant events. Major ice jam events that occurred before the dam was built were compared to events that occurred after to determine if the resulting flooding or damages were reduced.

Since the Ballville Dam was constructed, ice from upstream is stopped by the solid ice cover which forms in the pool. Of the 58 recorded ice jams found, 47 occurred upstream of the Ballville Dam. Six significant ice jam events have caused major damage and flooding in Fremont. The four ice jams that occurred in downtown Fremont before the dam was constructed, in 1833, 1843, 1883 and 1904, were very destructive destroying bridges in downtown Fremont including the State Street Bridge and the railroad bridge, which took 37 cars with it. During the two major ice jam events that occurred after construction of the dam, in 1959 and 1963, ice was retained upstream of the dam and did not contribute to the ice jam downstream of town. Ice-hydraulic modeling of the river is recommended to determine the degree to which flooding would have been worse had the additional ice contributed to the ice jam.

Based on this analysis, the Ballville Dam has had an impact on ice jam formation in Fremont, Ohio. Since construction of the flood protection walls in Fremont, there have been no reports of ice jams in the downtown area. Two possibilities exist; that conditions have not been conducive to cause an ice jam event in town; or that the flood walls prevented flooding and so an ice jam was not reported. Further investigation of ice jams in the Sandusky River is recommended to determine if the flood walls will protect Fremont from ice jam flooding and if the bridges in town will be at risk from additional breakup ice resulting from the removal of the Ballville Dam.

The two major alternatives for controlling ice in the absence of the Ballville Dam are described: ice piers and active river ice management. The expected level of protection of permanent ice control structures, such as ice piers, can be quantitatively estimated with a high level of confidence based on laboratory tests, field performance of existing structures, and ice modeling. The expected level of protection of active measures is often hard to quantitatively estimate with confidence because of the difficulties is judging the level of performance in application. Active measures generally provide less protection than permanent structures.

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