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Mr. Terry Sargeant
Chairman, Manitoba Clean Environment Commission
305 155 Carlton Street
Winnipeg, Manitoba
R3C 3H8 CANADA

Dear Sir:

Re: Evaluation of the Effects of Expansion of the Winnipeg Floodway on Ice-related Water Levels Downstream of Floodway Outlet

Further to my telephone discussion with Mr. David Farlinger, and following up on the receipt of documents from Mr. Rick Carson, this letter report summarizes my opinion regarding the following two questions.

- How does the existing Floodway affect the severity of ice jams downstream of its outlet?
- How will the expanded Floodway affect the severity of ice jams downstream of the outlet?

Please refer to the summary of conclusions at the end of the letter for the salient findings of the report.

In addressing these questions, this letter provides a brief review and describes the following relevant background processes.

- Mechanics of breakup and hydraulic aspects of ice jams, including an assessment of breakup and ice jam levels at Selkirk.
- Operating practice related to the existing Floodway and the subsequent flow conditions downstream of the Floodway.
- Intended operating practice of the expanded Floodway and the expected flow conditions downstream of its outlet.

Furthermore, a brief assessment will be provided of options available for the mitigation of the effects of ice jams downstream of the Floodway.

It should be noted that as much of the following analysis as possible was based on independent data provided by Water Survey of Canada (WSC). However, in circumstances that did not allow for an independent check of complicated hydraulic simulations, use was also made of information provided by the various consultants involved in the design if the expanded Floodway.

northwest

hydraulic

consultants

4823 - 99th street
edmonton, alberta
canada T6E 4Y1

tel (780) 436-5868
fax (780) 436-1645
nhc@nhc-edm.com
www.nhcweb.com

Background

The Red River is a northward flowing river that rises in Minnesota, flows across the 49th parallel near Emerson, passes though the City of Winnipeg, and empties into Lake Winnipeg downstream of Breezy Point. A major tributary – the Assiniboine River – enters the Red River at Winnipeg. Flooding along the entire river has been a perennial problem since the early days of the Red River settlement [1] and the growth of Winnipeg in the 20th century has contributed to a significant increase in flood damages. The Winnipeg Floodway (the Floodway) was constructed in 1969 to mitigate high flood levels within the greater area of the City of Winnipeg, and with the combined effects of the Floodway and diking at selected locations throughout the city, flood damages have been reduced significantly. [2]

Upstream of St. Andrews, the Red River is essentially alluvial. It flows though lacustrine clays, the river width is about 200 m, the depth at bankfull is about 14 m, and the river slope averages about 0.00012 ~~m~~ (0.12 m per km). At St. Andrews the river cuts into bedrock, where it created rapids and a falls and it drops about 12 m over 10 km as it flows into the low plain that surrounds the south end of Lake Winnipeg. The river slope in the vicinity of St. Andrews is about 0.00035 (0.35 m per km) while the slope between there and Lake Winnipeg depends on the levels of the lake and the flow. At nominal flows that might be expected at breakup, and at low lake levels the river slope would be similar to that at Winnipeg. At high lake levels and higher flows that might occur during floods, the slope would decrease as low as 0.000076 (0.076 m per km) [3] or about 60% of the slope at Winnipeg. The nominal width of the river at Selkirk is about 250 m and the bankfull height is about 8 to ~~m~~ 10 m.

Mechanics of Breakup and Ice Jamming

The Breakup Process

Breakup on rivers is a complicated process that involves both thermal and hydraulic processes that operate on a basin-wide scale. These are superimposed on local antecedent ice conditions that have been established within the framework of the local channel characteristics. In general the breakup sequence on a river like the Red River would be as follows.

- Late winter ice would be present in the river channel. On the Red River that ice would have a thickness between 0.5 and 1 m and the pre-breakup flow at Lockport would be in the range of 30 to 100 m^3/s.
- With the onset of warm spring weather, the snow in the basin and on the ice surface begins to melt from the combined effects of warm air temperatures and increased solar radiation. Once the snow cover on the ice surface melts, the ice begins to thin and deteriorate internally.
- Concurrent with the melting of the snow on the ice surface and the deterioration of the ice, the snowmelt in the basin begins to contribute to local runoff. In areas where local

[1] Fleming, S., 1880.
[2] Acres Manitoba Ltd, April, 2004.
[3] Acres Manitoba Ltd, April, 2004.

runoff is significant (say like in a large urban area like Winnipeg) the inflow can melt the ice locally without necessarily lifting or breaking the ice cover.

- At some point, the effect of the snowmelt begins to be felt and the water levels start to increase. At Lockport this typically would start in about mid-March on the average, but this could vary from as early as mid-February to as late as mid-April.
- As the spring melt proceeds, the flow in the river increases, water levels increase, and the ice cover is lifted and dislodged from its late-winter confines. Concurrent with the increasing water levels, the ice cover continues to deteriorate. At some point, the increasing force on the ice cover, due to increasing discharges, overcomes the decreasing strength of the ice cover and the cover breaks up. Obviously, the date of incipient breakup depends on the strength of the ice cover, the flow in the river, and the local channel characteristics. The steep reach of the Red River at St. Andrews would produce breakup up prior to the milder sloped reach downstream, as has been observed.[4] It could take up to one month from the start of flow increases until the ice begins to move and subsequently is cleared from the river.
- Depending upon the antecedent conditions, two breakup extremes could occur.
    - For years with a low snow pack and/or a long drawn out melt period, there would be insufficient runoff generated from the snowmelt to mobilize the ice cover and the ice cover would melt in place without large increases in water levels. This type of breakup is benign and is termed a ***thermal breakup***.
    - For years with high snow pack and a rapid melt (perhaps augmented by rain) the snowmelt runoff would develop quickly, there would be sufficient runoff to mobilize the ice cover, breakup would be more violent, and significant water level increases would result. This type of breakup is called a ***dynamic or mechanical breakup***. Experience on the Red River suggests that if the spring peak flow is less than about 1,200 m^3/s (42,000 cfs), the corresponding flows on the rising limb of the spring hydrograph are low enough to tend towards a thermal breakup.
    - Although the above description would suggest a bi-modal distribution of breakup levels in any historical record (either very low or very high levels), given the year to year variability in flows and ice thicknesses that might be experienced at breakup, the historical record of breakup water levels is typically quite smooth and covers the entire range.
- Usually, but not always, the physiographic characteristics of large river basins like that of the Red River produce a rather long drawn out spring flood period. Since the breakup occurs early on the rising limb of the spring hydrograph ice is usually long gone by the time the peak flow event occurs. Thus, during years with significant spring flows and the occurrence of dynamic breakup, the highest flow during the spring flood period almost always occurs under open water conditions after ice has cleared from the river.

[4] Acres Manitoba Ltd, July 2004.

Ice Jams

Ice jams are more likely to form during a dynamic breakup. The process by which the broken ice cover produces jams can be described in a qualitative way, and the relationship between flow and ice jam levels can be quantified with a high degree of confidence. As the ice cover breaks up, the broken ice accumulates against intact ice and numerous short jams form with only a limited increase in water levels. As the flow increases, the short surface jams become unstable, small ice runs develop, and the short jams accumulate into longer jams that thicken as their length increases. This increases the local water levels and produces an accumulation that becomes unstable and itself contributes to the instability of the ice cover. Any time an ice is arrested for a significant length of time a jam is produced. Water levels can respond within minutes to changing ice conditions, but it usually takes a few hours for fully developed jam to form.

An ice jam is simply defined as an accumulation of ice. The thickness of the accumulation depends on a number of factors, but should a jam form in a steep reach it will be thicker than if it formed in a mild slope reach and if a jam forms under high flow conditions it will be thicker than if the flow would have been low. The peak levels associated with an ice jam are due both to the thickness of the jam and the depth of flow under the jam.

Water levels at a given location can be quite severe even without a jam developing precisely at that location. If a jam forms downstream of a given location, backwater effects may cause high water levels in spite of the reach being clear of ice. If a jam should form upstream, it could become unstable under rising discharges and produce a surge of ice and water that temporarily produces severe water levels as the ice run passes – again without a jam actually forming. Typically, however, over a long reach (say between Lockport and Breezy Point) high ice-related water levels (with or without ice jamming) at any location are associated with high flows. ***The more severe the spring runoff, the greater are the flows, and the greater are the ice-related water levels.***

There are a number of generalizations that can be made about the probabilities or risks of an ice jam forming at any particular location. The two main processes by which a jam forms are (1) congestion – the inability of moving ice to be passed though a reach as fast as it enters that reach and (2) surface blockage – the inability of moving ice to break through an intact ice cover or other type of structure without accumulating and forming a jam. Because a jam forms by the accumulation of ice, any physical feature along a river that contributes to that accumulation will predispose a location to ice jamming. Some notable morphologic factors that contribute to the formation of ice jams are the following.

- Sharp bend (congestion)
- Reduction in slope (congestion often associated with islands or shallows)
- Thick un-deteriorated ice downstream of the breakup front (surface blockage often associated with northward flowing rivers)
- Significant withdrawal of water (congestion)
- Backwater effects from lakes or reservoirs (congestion and surface blockage)

With respect to the situation in Selkirk (Sugar Island) it is likely that the channel pattern plays a significant role in the formation of ice jams. Downstream of Selkirk in the vicinity of Breezy Point it is likely that backwater effects initiate the jamming. In all instances, the presence of a solid ice cover exacerbates the tendency to produce a stable long lasting jam. However, it is unlikely that the Red River should be treated as a classic northward flowing river like the Peace River or the Mackenzie River, both of which span considerably greater latitude and more varied physiographic and climatic regions.

Exacerbation of Ice Jams

Frequency analysis can be undertaken of ice-related water levels to define the annual risks of a particular ice-related water level being exceeded. Typically, the risk of experiencing a given ice-related water level depends on (1) the risk of a jam occurring – that is if it would be a thermal or mechanical type of breakup – and (2) the discharge at which the jam would form. High ice-related water levels typically only occur if breakup is dynamic and the flows are high.

Ice-related water levels can be exacerbated on one hand by increasing the probability of a mechanical type of breakup. This could be achieved by artificially increasing the ice thickness or by more rapidly increasing the flow on the rising limb of the snowmelt hydrograph. On the other hand, if a mechanical breakup is developing and the flows would be increased, the height of the jam would increase and the net effect would be a higher or more severe ice-related water level regime. Typically, it is very difficult to change the risk of a mechanical breakup developing either for the better by weakening the ice or for the worse by strengthening it. Thus, the most significant way that ice conditions can be exacerbated is by increasing the flows at breakup.

Ice Conditions at Selkirk

There is limited quantitative information about ice-related water levels in the reach between Lockport and Breezy Point. This prevents undertaking a rigorous frequency analysis of ice-related water levels. It also prevents a direct comparison of pre and post-Floodway ice-related events. KGS Group [5] looked at ice jam levels in the reach as part of assessing the potential backwater at the exit of the Floodway. Acres Manitoba Ltd [6] assessed the possibility of Floodway operations exacerbating the breakup processes. Both drew heavily Water Survey of Canada flow and water level data from Lockport and Breezy Point and miscellaneous water levels measured at the Manitoba Hydro generation station at Selkirk. Only the 1996 and 2004 ice events had any quantitative information. In addition, Acres reviewed newspaper archives for those years in which high ice-related water levels were known to have occurred to quantify those levels. On the whole, there is not much information on ice-related water levels in the historical record.

The data described above was examined herein in some detail to develop an understanding of the ice conditions in the reach as reflected by the breakup data at Selkirk. The timing and magnitude of the flows that affected the breakup processes were quantified from the flow records at Lockport (from 1962 to 2002) and the resulting severity of ice related water levels was assessed

[5] Carson and Brown, 2004.
[6] Acres Manitoba Ltd, July, 2004.

from the data available at Selkirk. Unfortunately, most of the record length is contained within the post-1968 Floodway period, so there is limited pre-Floodway record.

Start of Runoff

The start of runoff from the basin becomes evident at the Lockport gauge on March 20, on the average. The earliest date that runoff became apparent was on February 13 in 2001 and the latest was on April 19 in 1963. The base flow prior to the start of runoff varies from about 30 to100 m^3/s. A cyclical trend in the late-winter (pre-breakup) flow is evident in Figure 1. There is about a 15 year cycle with minimums evident in 1962, 1977, and 1988. It appears that the base flows have been quite high over the past few years. If these base flows reflect antecedent moisture conditions in the basin, this might suggest that higher runoff could be anticipated during the spring in the year with the high base flows.

Flows at Breakup

Records of flow during the breakup period are extremely difficult to determine given the unpredictable way in which ice affect the rating curve. Reasonable flow estimates can be made early on in the runoff period before the ice cover mobilizes. In addition the flow estimate once the ice cover is gone is also reasonably accurate. Since many of the salient ice processes occur close to the start of open water, flows on the date of first open water are often used as an index of the severity of flow during the breakup period.

Table 1 summarizes the adopted flow for each year from 1962 to 2002. The flows are ranked from the highest to the lowest and the years in which significant ice-related water levels were noted are shaded. The median the flow is 1330 m^3/s with minimum and maximum of 144 and 2570 m^3/s, respectively. It is evident that the years with notable ice events all had flows greater than the median flow.

Figure 2 shows the time series of the date of first open water. On the average it would occur on April 13. The earliest was on March 28, in 2000 and the latest was on April 27 in 1967. There is a trend towards earlier dates of open water. Figure 3 shows the year to year variability in these flows. There is a somewhat cyclical trend in this data also, but the pattern is not as clear as that of the pre-breakup flows.

Given that the above flow record is rather short for the pre-Floodway period, it is difficult to discern what impact the Floodway may have had – at least from a statistical perspective – on the ice-related water levels. However, it is clear that the flow on the first day of open water correlates with the peak flow that occurs later on in the hydrograph (Figure 4) and thus it is possible to look at the longer record length of spring peak flows at James Avenue to infer any general differences in the pre and post-Floodway flows during breakup.

Table 1 **Summary of breakup flows at Lockport and years in which high ice-related levels were a concern**

Year	Discharge (m^3/s)
1966	2570
1997	2510
1996	2410
1979	2210
1987	2120
1974	2000
1970	1980
1965	1890
2001	1770
1978	1760
1986	1730
1995	1730
1967	1640
1976	1530
1962	1500
1998	1500
1969	1470
1983	1390
1971	1360
1992	1350
1999	1330
1982	1310
1972	1130
1975	1040
1984	1020
1980	1010
1994	957
1964	934
1993	863
1985	812
1963	782
2002	546
1973	535
2000	530
1988	440
1968	425
1990	362
1989	332
1991	292
1977	185
1981	144

Note: The shaded cells indicate years in which high ice-related levels were observed downstream of the Floodway. Also, the available data extends only to 2002. It is obvious that 2004 would likely rank near the top of the table.

Figure 5 compares the frequency curve of peak spring flows for the 30-year period with the Floodway to the 30-year period prior to the Floodway. It is evident that the peak flows (and hence severity of flows during breakup) in the post-Floodway period are generally greater than those in the pre-Floodway period. This may contribute to the perception that the Floodway has exacerbated ice-related flooding, but the overall increase in ice-related flooding in the post-Floodway period is more likely due to the more frequent occurrence of larger spring flows.

Ice-related Water Levels at Selkirk

As mentioned earlier, the most definite method to compare pre and post-Floodway ice-related water levels in the vicinity of Selkirk would be to compare actual peak water levels. Unfortunately the data does not exist. However, there is sufficient data to sketch out a mechanistic relationship between the flows at breakup and the subsequent water levels that would result and from this, draw conclusions about the peak levels that could have occurred.

Figure 6 compares the rating curves that would occur for three salient conditions on the river – (1) open water, (2) solid ice cover, and (3) a fully developed ice jam. The open water rating curve was simulated using a bed roughness of 0.030 and verified from historical measurements. The solid ice cover rating curve was developed using a representative ice thickness of 0.5 m and an ice cover roughness of 0.020, and also more or less verified from historical information. The ice jam rating curve was calculated using a jam roughness of 0.040. Given the sparse data, it is difficult to calibrate the parameters that go into the calculation of the ice jam rating curve, but reasonable values for the ice jam roughness were chosen on the basis of the expected thickness of the jam.

The validity of the ice jam rating curve was tested against two measured values – 1996 and 2004 and against estimated peak breakup levels measured in the early 1960's at the WSC gauge at Selkirk. It should be noted that the WSC data does not necessarily represent an ice jam condition, but rather a situation that could represent open water, a solid ice cover, or a surge of ice that would not develop into a stable jam. It would be expected, however, that the ice jam rating curve would form an upper bound to the WSC data because for a given flow, the ice jam level would be the highest that could possibly be attained.

A number of points are evident from the curves in Figure 6.

- The additional thickness and roughness of the solid ice cover typically increase the river levels by about 0.5 to 1.5 m at the higher flows that would be of concern.
- For a solid ice cover, flows would have to be in excess of 2500 m^3/s in order to reach the low chord of the highway bridge. It is very unlikely that the ice cover could remain intact at this flow and the ice cover would be dislodged prior to the development of such a flow.
- Should an ice jam form, the water levels would be 2 to 3 m higher than the open water level at the same flow.
- Depending on ice conditions, a wide range of water levels can occur, depending on the ice conditions in the river.

- Flow over the east approach to the bridge at Selkirk (approximate elevation 220 m) could occur at flows as low as 800 m^3/s if a stable ice jam was to form.
- A discharge of only 2500 m^3/s would be required to produce a jam that would attain a worst-case top of bank elevation of 222.5 m (730 ft). Once the levels exceeded bankfull it is unlikely that the jam could remain stable.
- It is evident, that high ice-related water levels can occur at relatively low flows should an ice jam form, and that these flows can occur quite frequently during breakup. There is no doubt that ice jams and ice-related flooding is an issue at Selkirk and downstream.

Effects of Floodway on Ice Jam Levels

Existing Floodway

The Floodway was constructed in the mid-1960's. The entrance to the Floodway is located upstream of St. Norbert and its outlet is located just downstream of Lockport. The Floodway is essentially trapezoidal in shape with a bottom width of about 120 to 160 m and a top width of 200 to 250 m. The side slopes of the Floodway are generally about 6H:1V, increasing to 9H:1V at bridges. The slope of the Floodway is 0.00012 – essentially the same as the Red River through Winnipeg. The length of the Floodway is about 46 km.

The elevation of the sill at the entrance to the Floodway is 228.6 m. Under open water conditions, water will naturally flow into the Floodway at a discharge of about 1200 m^3/s. Under an ice cover, that flow would be less - say about 1000 m^3/s, depending on the ice roughness. It should be noted that the elevation of the inlet was set to prevent significant ice from entering the Floodway (i.e. the ice would have gone out prior to flows reaching that level) and this appears to be the case.[7] Flow into the Floodway is controlled by gates located on the Red River just downstream of the inlet to the Floodway. The gates are operated according to certain rules to ensure that the effects of the Floodway on upstream water levels are minimized while still maintaining manageable water levels within Winnipeg (see later discussion). When the gates are raised, they are raised in small increments – say 0.3 m – at about 6 hour increments. This limits the rate at which water levels increase in the Floodway.

There are basically four rules that are followed in operating the Floodway – depending on the time of year and the flow upstream of the Floodway.[8] For the spring period, Rule 1 applies to flows upstream of the Floodway of up to about 4500 m^3/s, Rule 2 applies to flows between 4500 m^3/s and 5900 m^3/s, and Rule 3 applies to flows above 5900 m^3/s. Given that ice conditions downstream of the Floodway are typically affected by flows less than about 2500 m^3/s – perhaps as great as 3000 m^3/s – it is evident that only Rule 1 operating conditions would apply.

The Rule 1 operating criterion is as follows.

- The Floodway will be operated to maintain natural "state of nature" water levels upstream of the Floodway until water levels within Winnipeg reach a level of 0.6 m

[7] Rick Carson, personal communication
[8] Acres- KGS-UMA, July, 2004a.

below the so-called "Flood Protection Level". This is represented by a gauge height of 7.86 m (25.8 ft) at James Avenue and corresponds to a flow of about 2400 m^3/s (85000 cfs) [9] through Winnipeg (not including minor perturbations due to Assiniboine River flows).

To assist in visualizing how the water levels and flows at the entrance of the Floodway change during a flood event it is instructive to consult Figures 7 and 8. Figure 7 shows rating curves for the Red River upstream and downstream of the Floodway entrance and in the Floodway at its upstream end. These rating curves show the relationship between flows and water levels in the three reaches. Figure 8 shows the velocities for the range of expected flows in the three reaches. The following describes the passage of a hypothetical flood that has a peak flow of 4000 m^3/s (assuming open water in the Red River downstream of the Floodway).

- On the rising limb of the hydrograph the water levels increase at the Floodway entrance. All the flow goes down the Red River when water levels at the Floodway entrance are less than 228.6 m. At a flow of about 1250 m^3/s with the water level just at the crest of the Floodway entrance the mean velocity in the Red River would be about 1.3 m/s and the water arriving at the Floodway entrance will arrive at the Floodway exit about 14 hours later. No action at the inlet gates would be required to maintain water levels upstream of the Floodway at the "state of nature" level.
- As the flow continues to increase, the water level rises above the sill elevation of the Floodway and now the flow splits. At a total flow of 1500 m^3/s the water level will be 229.7 m upstream of the Floodway entrance, 200 m^3/s of flow enters the Floodway at a water level of 229.7 m at its entrance and the remaining 1300 m^3/s will go down the Red River. This will result in a water level downstream of the Floodway entrance of about 229.0 m, providing a net reduction on water level of about 0.7 m along the Red River through Winnipeg. ***With the flow split, there would be a tendency for the water levels upstream of the Floodway to drop below the "state of nature" level. The gates would be raised to counteract this tendency, thereby throttling back the flow that would go down the river.*** The flow entering the Floodway will travel at a velocity of 0.5 m/s and arrive at the outlet of the Floodway in about 24 hours and the flow in the Red River will travel at a velocity of 1.3 m/s and arrive at the Floodway exit in 14 hours after traveling the 64 km length between the entrance and exit of the Floodway. Both travel times are greater than the 13 hours that the full 1500 m^3/s, traveling at 1.4 m/s along the Red River through Winnipeg, would take to reach the Floodway exit. Obviously, the net effect would be a delay in the arrival of the flood wave into the reach of the Red River downstream of the Floodway exit.
- At the peak of the flood, with a total flow of 4000 m^3/s the water level upstream of the Floodway entrance will be 234.3 m, 1600 m^3/s of flow enters the Floodway with a water level of 234.3 m at its entrance and the remaining 2400 m^3/s will go down the Red River. This will result in a water level downstream of the Floodway entrance of about 232.5 m, providing a net reduction on water level of about 1.8 m along the Red River through Winnipeg. ***Again, with the flow split, there would be a tendency for the water levels upstream of the Floodway to drop below the "state of nature" level. The gates would be raised even higher to counteract this tendency, thereby throttling back more***

[9] Acres Manitoba Ltd, April, 2004.

the flow that would go down the river. The flow entering the Floodway will travel at a velocity of 1.2 m/s and arrive at the outlet of the Floodway in about 11 hours and the flow in the Red River will travel at a velocity of 1.6 m/s and arrive at the Floodway exit 11 hours after traveling the 64 km length between the entrance and exit of the Floodway. Both travel times are less than the 9 hours that the full 4000 m^3/s, traveling at 2.0 m/s along the Red River through Winnipeg, would take to reach the Floodway exit. The net effect still would be a delay in the arrival of the flood wave into the reach of the Red River downstream of the Floodway exit.

So, it is evident that in the Rule 1 operating mode there would be no increase of flows in the Red River downstream of the Floodway. Table 2 summarizes the travel time for various flow splits for a range of flows arriving at the entrance to the Floodway.

Table 2 Summary of travel times for various flow splits in the Floodway during open water on the Red River

Flow Upstream of Floodway (m^3/s)	Travel Time along River (hrs)	Flow Diverted to Floodway (m^3/s)	Travel Time along Floodway (hrs)	Flow in River (m^3/s)	Travel Time along River (hrs)	Potential Benefits in Flow Downstream of Floodway
1250	14.4	0	-	1250	14.4	None
1500	13.2	200	23.5	1300	14.1	Yes
2000	11.7	600	14.2	1400	13.6	Yes
2500	10.7	900	12.4	1600	12.8	Yes
3000	10.0	1200	11.4	1800	12.2	Yes
4000	9.1	1600	10.5	2400	10.9	Yes

A similar description as for the open water conditions can be undertaken for the situation with an ice cover on the river. It should be noted, however, that the presence of an ice cover would change the water levels in the river – increasing the levels both upstream and downstream of the Floodway, and affecting when the flow actually begins to be diverted into the Floodway. It is beyond the scope of this review to undertake such an analysis and the following description will be limited to the effects of an ice cover on the velocities and travel times in the river. Although not critical to the design and operation of the expanded Floodway, it would be instructive for an analysis to be carried out to illustrate the effects of an ice cover on river levels and the timing of flows into the Floodway early in the spring runoff period.

Not withstanding the impacts of an ice cover on flow splits at the entrance to the Floodway, a similar analysis of travel times can be untaken with a solid ice cover in the river. In general, an ice cover would result in overall reduction in the velocity of the flow in the river (see Figure 8) and because the Floodway would not be ice covered, the relative benefits of the flows being diverted to the Floodway would not be as great. The question is, however, what assumptions should be made regarding the extent of the ice cover and its roughness. Acres-KGS-UMA assumed a complete ice cover with a roughness of 0.015. The assumption of a complete ice cover is conservative, but the assumption of an ice roughness of 0.015 would appear to be somewhat aggressive. A more realistic value would be 0.020. However, it may be too conservative to adopt the higher ice roughness and assume a complete ice cover. On the balance, an assumed value of 0.015 is defensible. Table 3 summarizes the calculated travel times for various flow splits.

Table 3 **Summary of travel times for various flow splits in the Floodway with an ice cover on the Red River**

Flow Upstream of Floodway (m^3/s)	Travel Time along River (hrs)	Flow Diverted to Floodway (m^3/s)	Travel Time along Floodway (hrs)	Flow in River (m^3/s)	Travel Time along River (hrs)	Potential Benefits in Flow Downstream of Floodway
1250	16.3	0	-	1250	16.3	None
1500	15.0	200	23.5	1300	16.0	Yes
2000	13.2	600	14.2	1400	15.5	Yes
2500	12.1	900	12.4	1600	14.5	Yes
3000	11.4	1200	11.4	1800	13.8	Yes
4000	10.3	1600	10.5	2400	12.3	Yes

It is evident that the current Floodway does not increase flows downstream of the Floodway and thus it cannot have an impact on the ice regime downstream.

Expanded Floodway

The proposed Floodway expansion is relatively straight forward. The elevation of the inlet sill will not change, the channel invert will remain the same, and the slope will not change. However, the channel bottom width will be widened by about 70 to 90% to a width of 200 to 300 m and the top width will increase to between 250 to 350 m. The inlet will be changed to accommodate the need to allow more flow into the Floodway. The velocity in the Floodway cannot be changed dramatically because of the need to limit the erosion potential of the flow to what the original Floodway was designed to accommodate because the erodibility of the expanded Floodway channel will not be reduced. Overall, the expanded Floodway will convey only about 10% more flow for the same head ("state of nature" water level at its inlet) than the existing Floodway under the Rule 1 operating criteria at "state of nature" flows less than 2500 m^3/s. It is evident that the main attraction of the expanded Floodway is the benefits that it will provide at the very large floods when Rules 2 and 3 must be invoked.

The same process-based arguments can be made about the water levels, flow splits, and velocities and travel times for both open water and ice conditions in the river. Tables 4 and 5 summarize the effects for open water and ice covered conditions in the river, respectively.

Table 4 **Summary of travel times for various flow splits in the expanded Floodway during open water on the Red River**

Flow Upstream of Floodway (m^3/s)	Travel Time along River (hrs)	Flow Diverted to Floodway (m^3/s)	Travel Time along Floodway (hrs)	Flow in River (m^3/s)	Travel Time along River (hrs)	Potential Benefits in Flow Downstream of Floodway
1250	14.4	0	-	1250	14.4	None
1500	13.2	200	23.5	1300	14.1	Yes
2000	11.7	600	14.2	1400	13.6	Yes
2500	10.7	1000	12.0	1500	13.2	Yes
3000	10.0	1500	10.7	1500	13.2	Yes
4000	9.1	1800	10.2	2200	11.2	Yes

Table 5 **Summary of travel times for various flow splits in the expanded Floodway with an ice cover on the Red River**

Flow Upstream of Floodway (m^3/s)	Travel Time along River (hrs)	Flow Diverted to Floodway (m^3/s)	Travel Time along Floodway (hrs)	Flow in River (m^3/s)	Travel Time along River (hrs)	Potential Benefits in Flow Downstream of Floodway
1250	16.3	0	-	1250	16.3	None
1500	15.0	200	23.5	1300	16.0	Yes
2000	13.2	600	14.2	1400	15.5	Yes
2500	12.2	1000	12.0	1500	15.0	No
3000	11.4	1500	10.7	1500	15.0	No
4000	10.3	1800	10.2	2200	12.7	No

Comparing the travel times along the Floodway in Tables 2 and 4 (open water conditions) shows that the expanded Floodway will have virtually no impact on the pattern of flows downstream of the Floodway for inflows less than about 2000 m^3/s. Above those flows, the increased flow in the expanded Floodway will reduce the travel times in the Floodway by about 10% - a matter of only an hour or two. The flow differential in the Floodway will amount to at most 300 m^3/s (about

10% of the natural flow) over a period of only a couple of hours. However, these changes will be offset by the attendant reduction in flow and increase in travel times in the river. The changes to the flow rates downstream of the Floodway would be innocuous. Given that ice conditions last for a period of about a week, and that flow fluctuations greater than 300 m^3/s occur because of changes in channel storage due to changing ice conditions, the effects of the Floodway expansion would amount to no more than noise. There will be no affect on the ice regime.

It should be noted that the above conclusions are based on steady flow analysis. A hydraulic routing analysis of these flow splits should demonstrate that there would be even less of an effect on the flow patterns downstream of the Floodway outlet. Such an analysis was not in the scope of the analysis described herein. However, KGS has undertaken a more sophisticated unsteady analysis [10] that demonstrates that the effects of the Floodway are even less than what might be deduced from the steady flow analysis.

Effects in the Rule 2 Operating Range

The current operations under the Rule 2 operating criteria allow for an increase in water levels upstream of the Floodway. This reduces the downstream flows and reduces water levels through Winnipeg and downstream of the Floodway outlet. If ice jams downstream of the Floodway outlet were a concern at these very high flows, the net effect would be to lower ice jam levels.

Under the Rule 2 operating criteria, the expanded Floodway will have an effect on the flows downstream of the Floodway. The increased Floodway capacity will allow for more flow to leave the so-called Red Sea for the same water level upstream of the Floodway inlet. Typically, water levels will be reduced by about 0.8 to 1.0 m for a given natural flow, and at any given water level the flows will increase by about 500 m^3/s. However, operation under Rule 2 occurs at flows well above 5000 m^3/s, and by that late stage in the spring flood, all ice would have been cleared from the river. ***Flow increases in the Rule 2 operating stage will not exacerbate ice conditions.***

Miscellaneous Issues

A number of miscellaneous issues were noted in the review of the material that was provided (see References for the list). Mention was made of the historical overflow channel that extended from downtown Winnipeg to Stonewall, and entered Lake Winnipeg at Netley Lake. It is my understanding that infrastructure (roads, building, rail lines) has shut off this natural by-pass. It is also my understanding, and it appears reasonable, that this by-pass channel would only operate at extreme floods that are well beyond the Rule 1 operating scenarios and thus those events would not be coupled with any ice processes in the vicinity of Selkirk.

References have been made to the reduction in floodplain storage that would have resulted from the construction of dikes in Winnipeg between the entrance and exit of the Floodway. The Mike 11 analysis indicates that the changes in flows due to the loss of floodplain storage are

[10] KGS Group, July 6, 2004.s

relatively small, compared to the natural flows, suggesting that ice jamming downstream would not be exacerbated. It would be worthwhile to summarize the estimates of the changes in storage and explicitly identify the impacts on the flows downstream of the Floodway.

Acres suggests that in one instance the time of travel along the Floodway was as short as three hours [11](representing a mean velocity of 4 m/s, and reflecting a surge that could be as high as 1.6 m). This does not appear to fit into the gate operating protocols and does not reconcile with the steady state hydraulic calculations. It is difficult to understand how the travel time for a small flow (even if it was a surge) could be that short. This estimate of travel time should be checked.

Mitigation of Ice Jams at Selkirk

It is evident that serious ice-related flooding can occur at Selkirk and downstream even at relatively low flows if ice conditions are severe. ***It is also apparent that the Floodway does not and will not exacerbate this flooding.*** Never the less, it would be reasonable to examine methods to mitigate the flood damages.

Unfortunately, given the geomorphic and hydraulic characteristics of the Lower Red River, there is very little flexibility in controlling ice-related flooding. Any attempts to weaken, remove, or change the ice conditions will ultimately prove futile. Short of the entire removal of the ice cover, there will be little impact on flood levels by manipulating the ice characteristics.

Given the close proximity of Lake Winnipeg, and the backwater effects that it produces, considerable analysis would be required to confirm the technical feasibility of extending the Floodway, and the costs would likely be huge. This is beyond the scope of this review. On the other hand, diking may be a technically feasible flood control alternative if the social and economic issues can be resolved. However, due consideration should be given to the effects of removing the floodplain storage on the flow in the channel and how that could change the ice levels.

It is clear that there is no simple magic bullet to solve the ice problems on the Lower Red River.

Summary of Conclusions and Recommendations

Conclusions

The following are the most important conclusions developed from the above analysis.

- The morphology of the Red River (decreasing slope and lower bank levels) downstream of Lockport contributes to more frequent ice-related flooding than upstream of Lockport.
- Ice jamming downstream of Lockport is most likely due to the reduced river slope and the backwater effects of Lake Winnipeg.

[11] Acres Manitoba Ltd, July, 2004b, p 4-9.

- Breakup has tended to occur earlier over the last forty years, but since both the timing of runoff and the deterioration of the ice cover are driven by the same meteorological conditions this would not contribute an increase in the propensity for ice jams to form.
- Typical spring flood peaks have been about 50% greater in the 30 odd years of record since the construction of the Floodway than in the 30 years prior to the construction of the Floodway. This likely contributed to the perception that the Floodway has increased the likelihood of ice jams and contributed to higher ice-related levels.
- High ice-related water levels at Selkirk appear to occur in years when the flow exceeds about 1300 m^3/s. This is consistent with the general view of flood potential downstream of the Floodway.
- Should an ice jam form, over bank flooding at Selkirk could occur at flows as low as 800 m^3/s. Ice jams and ice-related flooding is a serious reality downstream of Selkirk.
- At flows greater than about 2500 m^3/s, ice jams become unstable due to loss of containment by the river channel and the river is cleared of ice.
- Ice issues downstream of the Floodway appear only to be evident at flows that would occur while the Floodway would be operated under the Rule 1 criteria.
- ***The concept of the so-called "Red Sea" being drained more efficiently because of the Floodway (two pipes versus one pipe) is false.*** In order to maintain the "state of nature" water levels upstream of the Floodway during natural flows less than about 4500 m^3/s, the flow in the Red River is throttled back by raising the gates at the Floodway inlet. This reduces flow in the Red River, and shunts flow over to the floodway. There are two pipes, but one is throttled.
- ***The Floodway does not exacerbate ice jamming and ice-related flood levels downstream of its outlet as long as adherence is made to the operating criteria established under Rule 1.***
- ***The expanded Floodway will not exacerbate ice jamming and ice-related flood levels downstream of its outlet as long as adherence is made to the operating criteria established under Rule 1.***
- There are no simple short term measures that can be taken on an annual basis to mitigate the effects of ice jams at Selkirk. Only a major investment in infrastructure (diking, etc.) is required to prevent ice-related flooding.

Recommendations

The following actions are recommended.

- A more extensive review of historical ice-related flood levels at Selkirk should be carried out – particularly identifying flooding thresholds within the context of the water levels at the Manitoba Hydro generating station.
- A field program to observe breakup and measure ice processes between the outlet of the Floodway and Lake Winnipeg be undertaken to better define the ice conditions around Selkirk. A rational processed-based description of the breakup process should be developed.
- The effects of ice on the water levels on the Red River at the Floodway entrance be quantified to determine how it affects the timing of inflows into the Floodway.

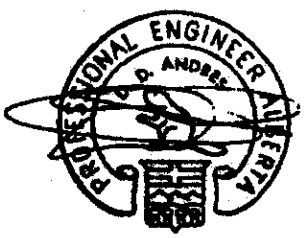
- A cursory estimate of the changes in channel storage cause by the construction of the dikes throughout Winnipeg should be undertaken.

I trust that the above is useful and I look forward to explaining these conclusions more fully, if required.

Yours truly,

northwest hydraulic consultants ltd.

Signed by: David Andres, M.Sc., P.Eng.



cc. Mr. David Farlinger, P. Eng.
Energy Consultants International Ltd.

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Figures

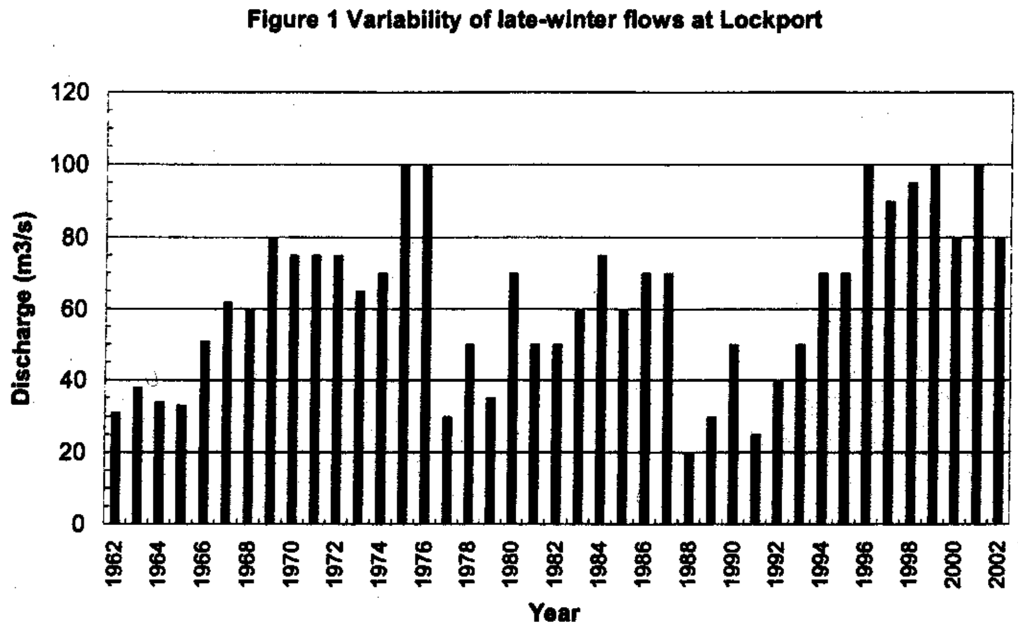


Figure 1 Variability of late-winter flows at Lockport
Discharge (m3/s)
120
100
80
60
40
20
0
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year

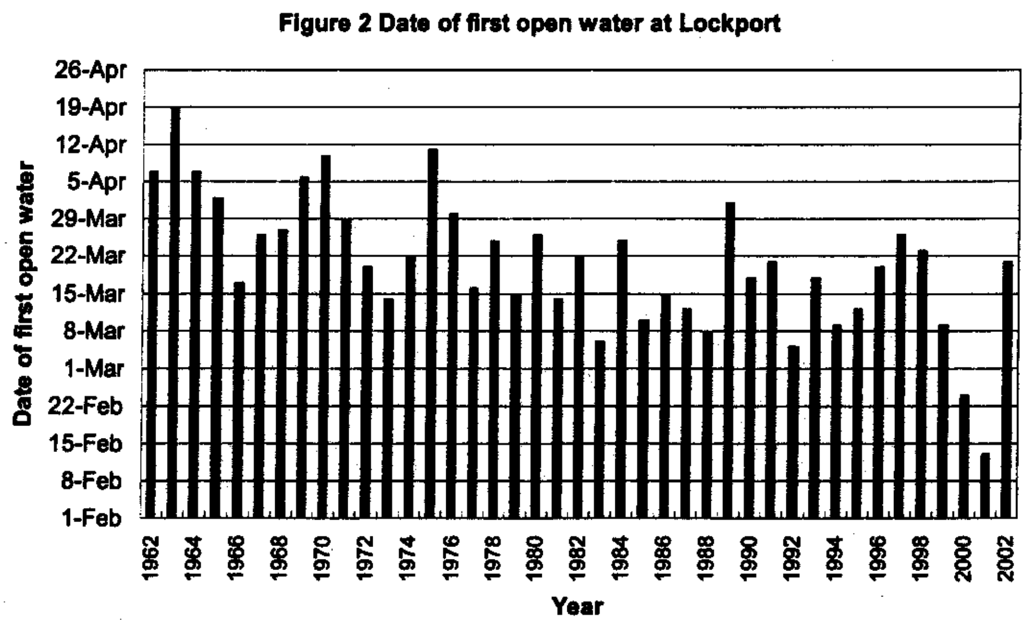


Figure 2 Date of first open water at Lockport
Date of first open water
26-Apr
19-Apr
12-Apr
5-Apr
29-Mar
22-Mar
15-Mar
8-Mar
1-Mar
22-Feb
15-Feb
8-Feb
1-Feb
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year

Figure 3 First open water flow at Lockport

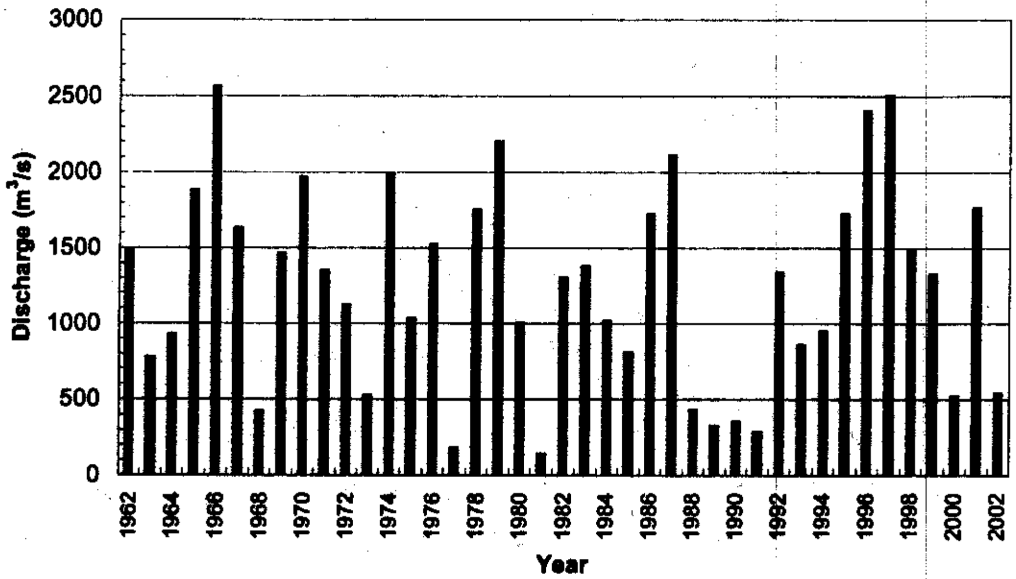


Figure 4 Comparison of flows at breakup to peak flow during spring flood

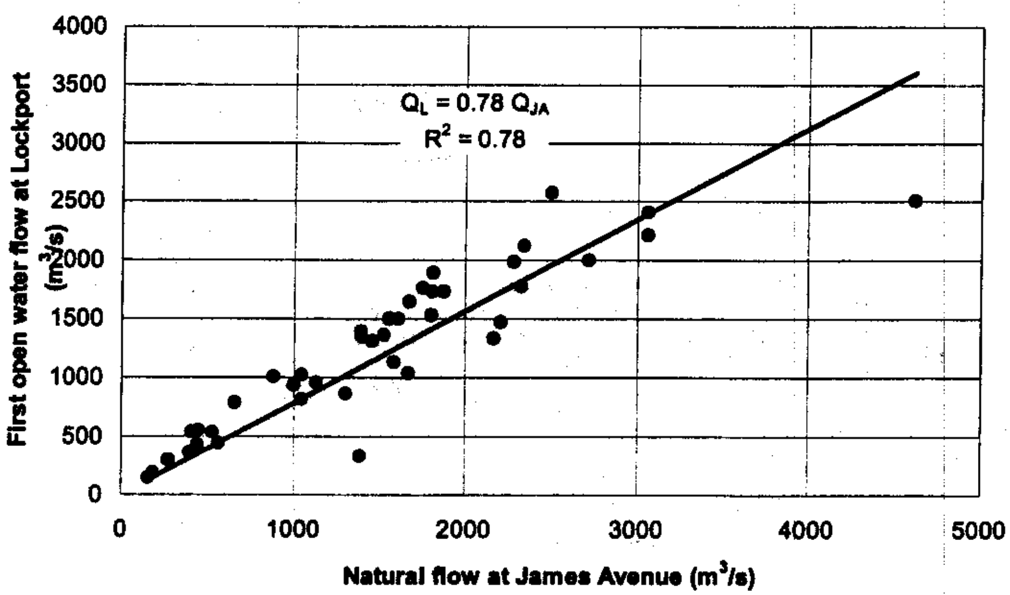


Figure 5 Comparison of peak flows pre and post-Floodway

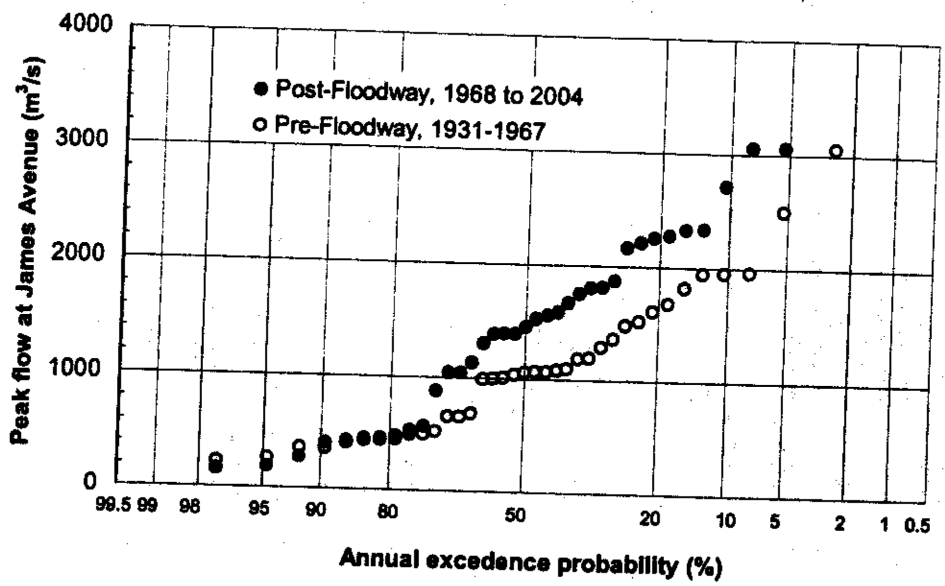


Figure 6 Rating curves for the Red River at Selkirk

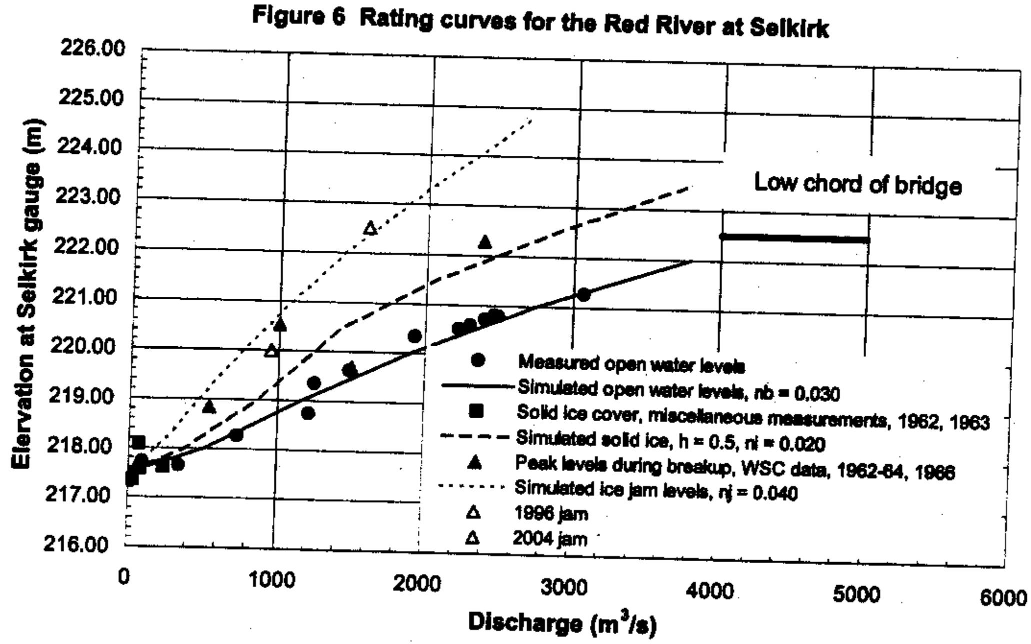


Figure 7 Rating curves at Floodway entrance

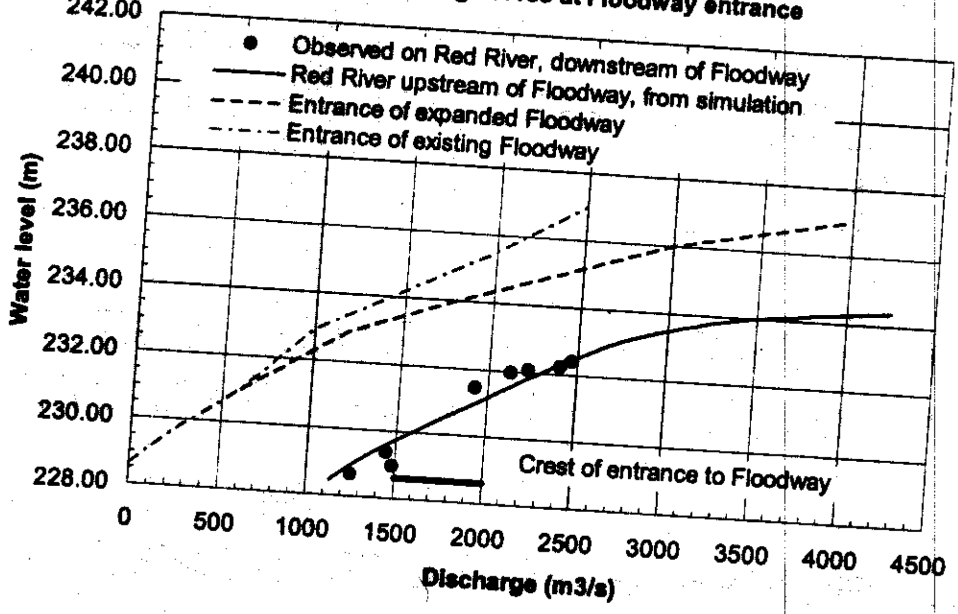


Figure 8 Mean velocities in Red River and Floodway for various conditions

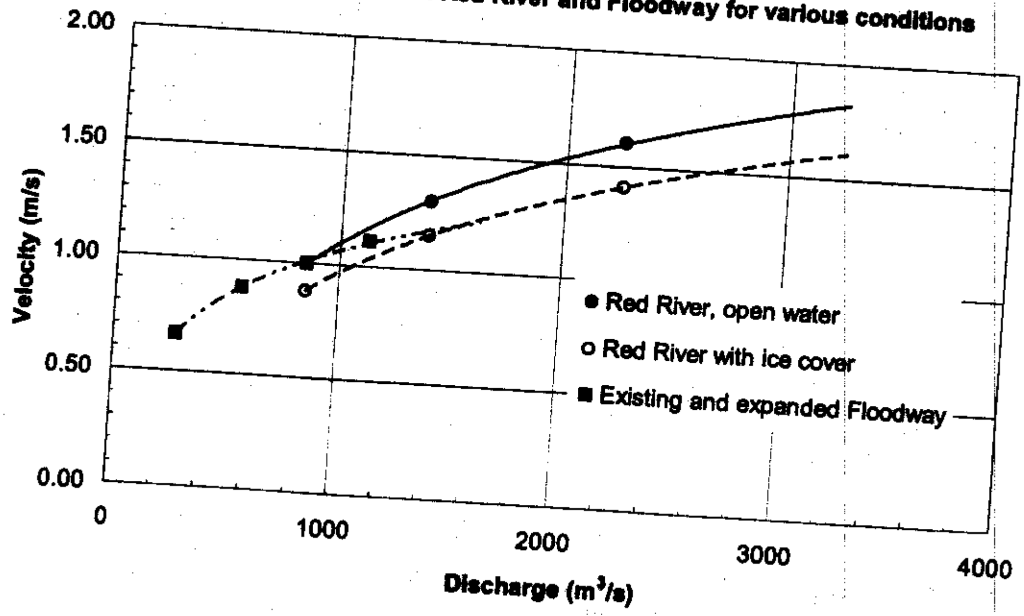
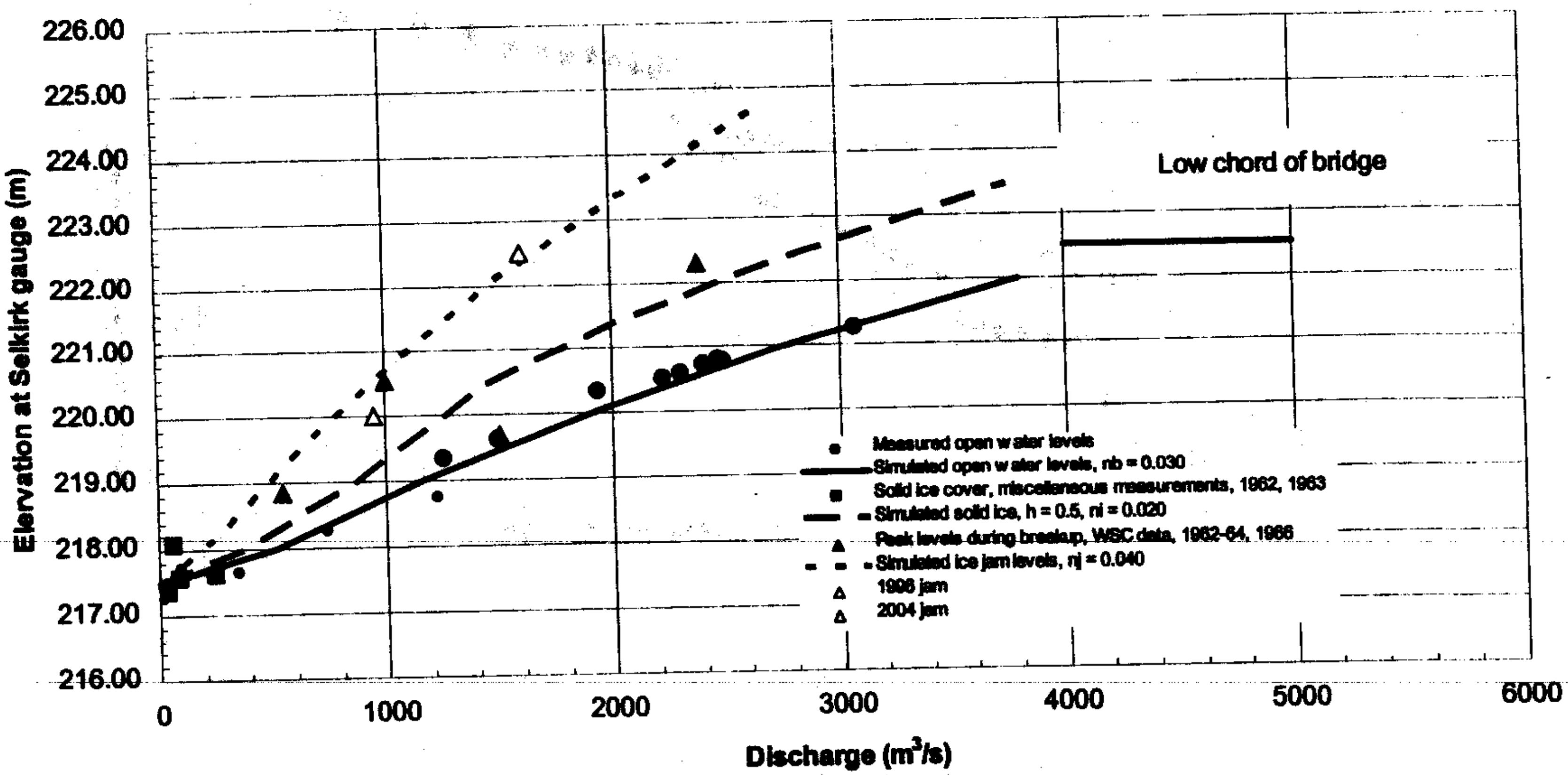


Table 1 **Summary of breakup flows at Lockport and years in which high ice-related levels were a concern**

Year	Discharge (m^3/s)
1997	2510
1979	2210
1987	2120
1974	2000
1970	1980
1965	1890
2001	1770
1986	1730
1967	1640
1976	1530
1962	1500
1998	1500
1983	1390
1992	1350
1999	1330
1982	1310
1972	1130
1975	1040
1984	1020
1980	1010
1994	957
1964	934
1993	863
1985	812
1963	782
2002	546
1973	535
2000	530
1988	440
1968	425
1990	362
1989	332
1991	292
1977	185
1981	144

Note: The shaded cells indicate years in which high ice-related levels were observed downstream of the Floodway. Also, the available data extends only to 2002. It is obvious that 2004 would likely rank near the top of the table.

Rating Curves for the Red River at Selkirk



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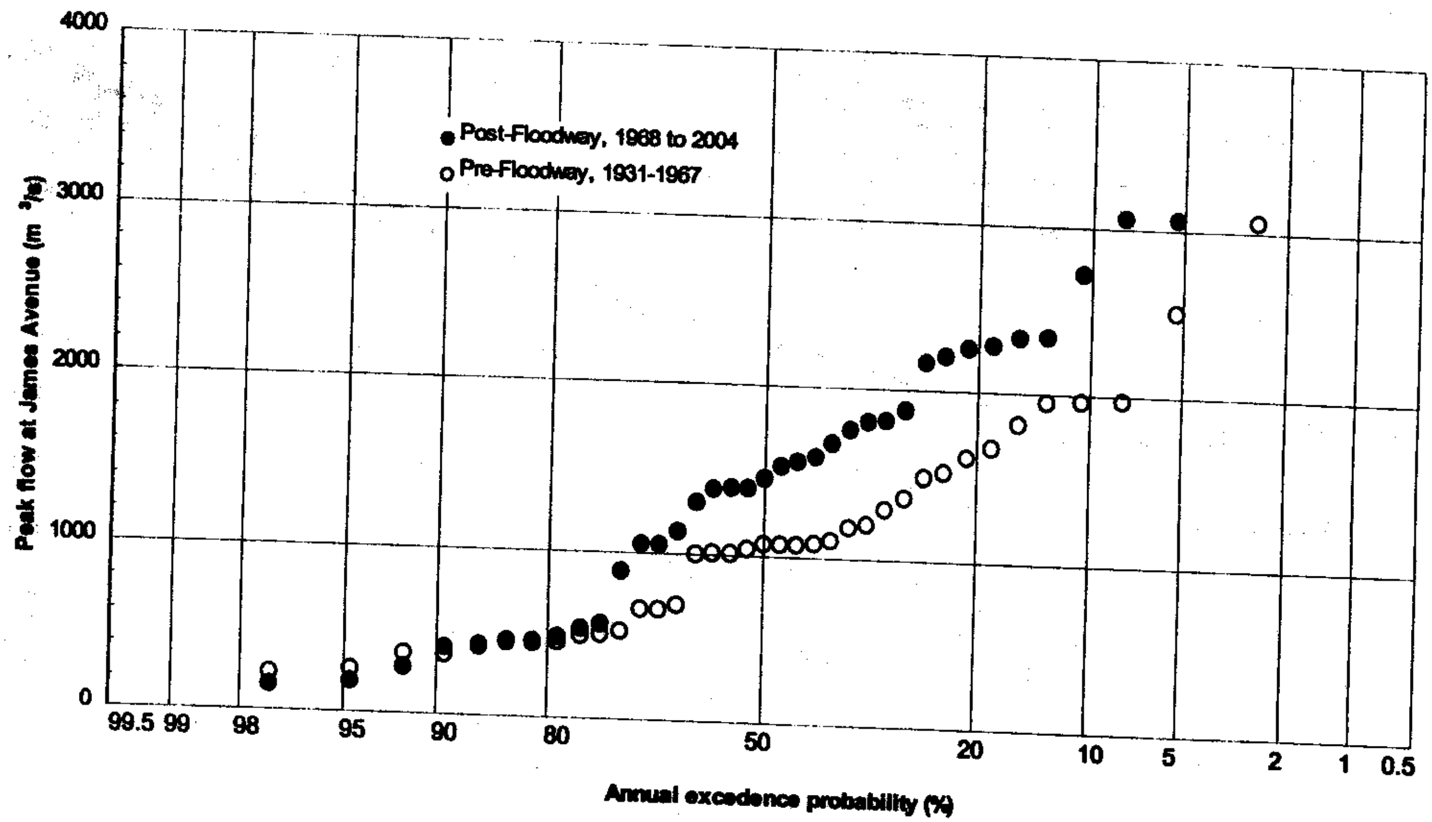
Frequency Curves of Pre and Post-Floodway Spring Flood Peaks



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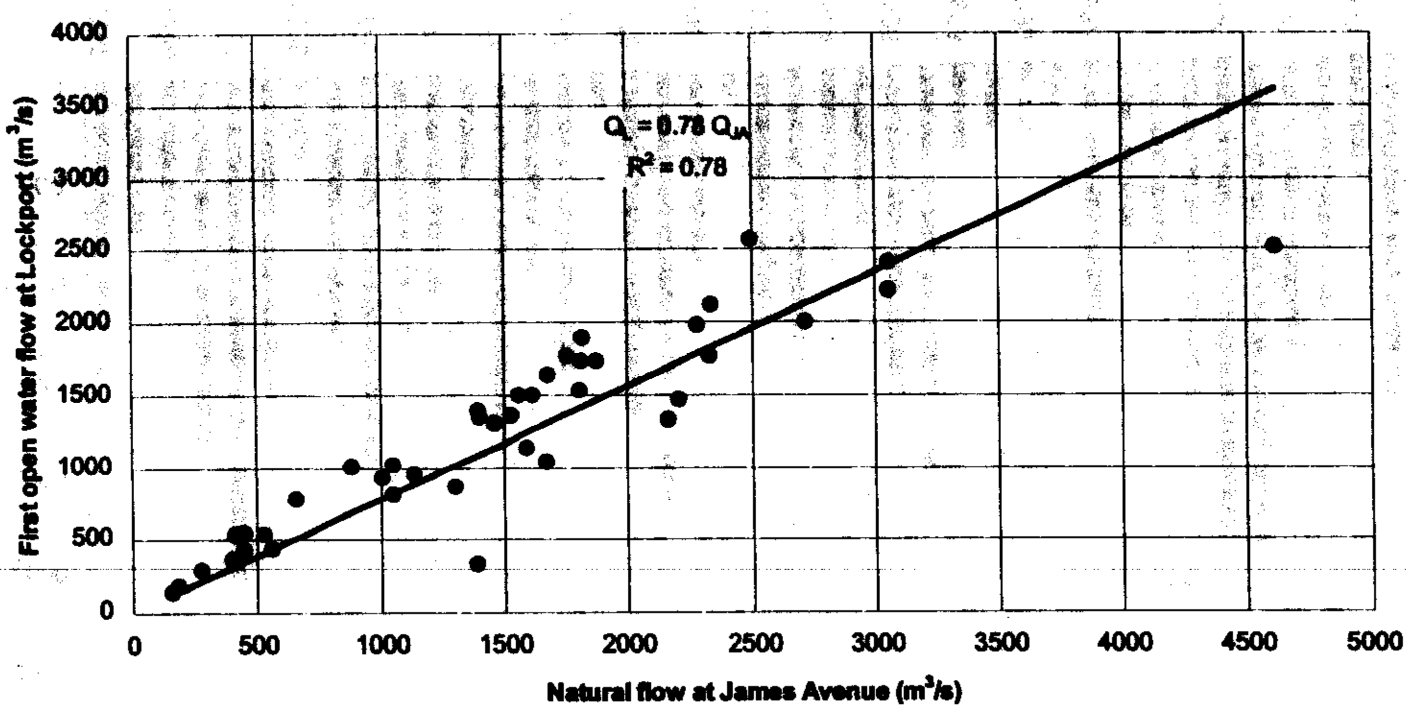
Relationship between Peak Spring Flow and Breakup Flow



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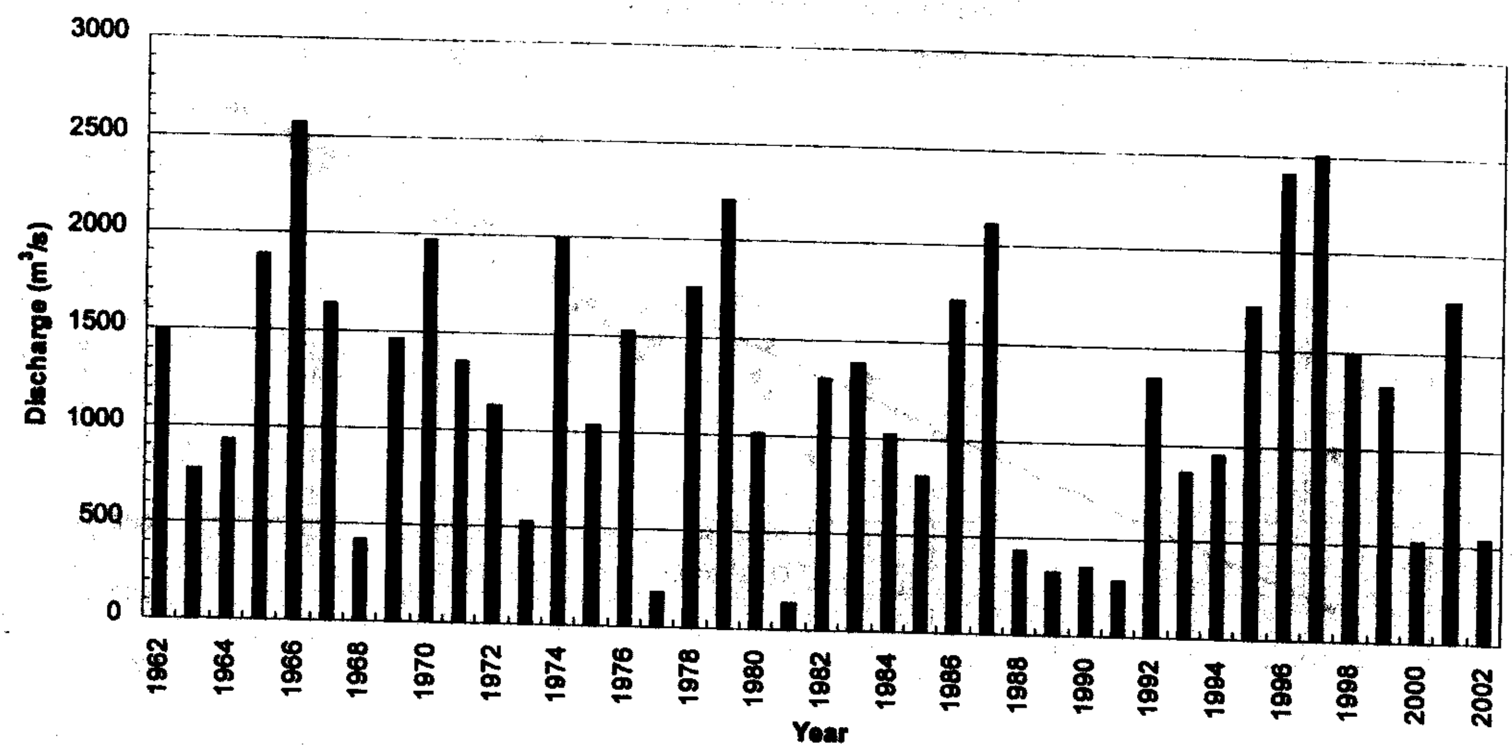
Year to Year Variability of Lockport Flows at Breakup



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Salient Recommendations

- Additional effort should be invested into more formally describing and characterizing the ice conditions at Selkirk and downstream
- A more extensive review should be undertaken of historical ice-related water levels at Selkirk to better quantify the extent of the flooding issue
- A more explicit assessment (or description) of ice conditions at the Floodway entrance should be carried out

Salient Conclusions (cont'd)

- The "two pipe" concept of increased flows downstream of Floodway is incorrect – gates on the Red River throttle back the flow in the river to offset extra conveyance gained from the Floodway
- The existing Floodway does not exacerbate ice-related flood levels downstream of the Floodway
- The expanded Floodway will not exacerbate ice-related flood levels downstream of the Floodway

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Salient Conclusions

- Channel morphology downstream of Floodway contributes to ice-related flooding
- Higher spring floods post-Floodway than pre-Floodway likely give the impression that the Floodway exacerbates ice-related flooding
- Ice-related flooding is a serious issue in the vicinity of Selkirk and upstream of Lake Winnipeg, with or without the Floodway
- There is no simple solution to preventing this flooding, short of building major infrastructure

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Rule 2 Floodway Operation

- At Q > 4500 m^3/s water levels upstream of Floodway are allowed to rise above natural levels for existing and expanded Floodway
- Increased in floodplain storage will reduce flows downstream, thus mitigating ice jam levels relative to the natural condition
- Expanded Floodway will produce higher flows than the existing Floodway
- Changes are moot because neither a stable ice cover or ice jams could exist at flows encountered under Rule 2 operation

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Rule 1 Expanded Floodway Operation

- No change in upstream water level relative to current Floodway
- As flow is shunted into Floodway, flow in river is throttled back
- Travel times for flow splits between Floodway and river are the same as those for the current Floodway at $Q < 2000\ m^3/s$
- Slightly shorter travel times along expanded Floodway at $Q > 2000\ m^3/s$ are offset by longer travel times on the river
- There will be no significant change in flows patterns

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Rule 1 Existing Floodway Operation

- No change in upstream water level relative to natural levels
- As flow is shunted into Floodway, flow in river is throttled back
- Travel times for flow splits between Floodway and river are longer than those for the river alone
- Longer travel times ensure flows do not cause premature breakup downstream
- Natural water levels upstream ensure no flow increase during period when jams present

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Exacerbation of Ice Conditions

- Increasing the external forces on the ice cover
  - Increasing the discharge during breakup to increase likelihood of dynamic breakup
  - Increasing discharge after jams form so that water levels increase
- Increasing the resistance of the ice cover
  - Increase thickness
  - Reduce slope of water surface (backwater from Lake Winnipeg)

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Salient Breakup Characteristics Downstream of Floodway

- Natural spring floods have been about 50% greater since Floodway constructed
- Ice-related issues appear to develop when flow exceeds 1300 m^3/s
- Noticeable flooding could occur if a jam forms at flows as low as 800 m^3/s
- Ice would be swept out of channel at flows in excess of 2500 m^3/s

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Ice Conditions Downstream of Floodway

- Both thermal and dynamic breakup can occur downstream of the Floodway
  - Low runoff usually produces a thermal breakup, $Q <$ 1200 to 1300 m^3/s
  - High runoff produces a dynamic breakup
- Ice jams can form due to the congestion of ice and by surface blockages – irrelevant which process dominates
- Channel conditions promote ice jamming

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Scope of Work

- Characterized channel geometry, flows, and mechanics of breakup downstream of Floodway
- Examined operating protocols of current and expanded Floodway and identified effects on flow conditions and ice processes downstream
- Briefly assessed options for mitigating high ice-related water levels downstream of Floodway

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Objectives

- Assess impact of current Floodway on ice-related water levels downstream of Floodway
- Assess impact of expanded Floodway on ice-related water levels downstream of Floodway
- Provide expert opinion on effects of existing and expanded Floodway

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Effects of Winnipeg Floodway on Ice Conditions Downstream of Floodway Outlet

Analysis of Historical Data and Review of Investigations into Effects of Floodway Expansion

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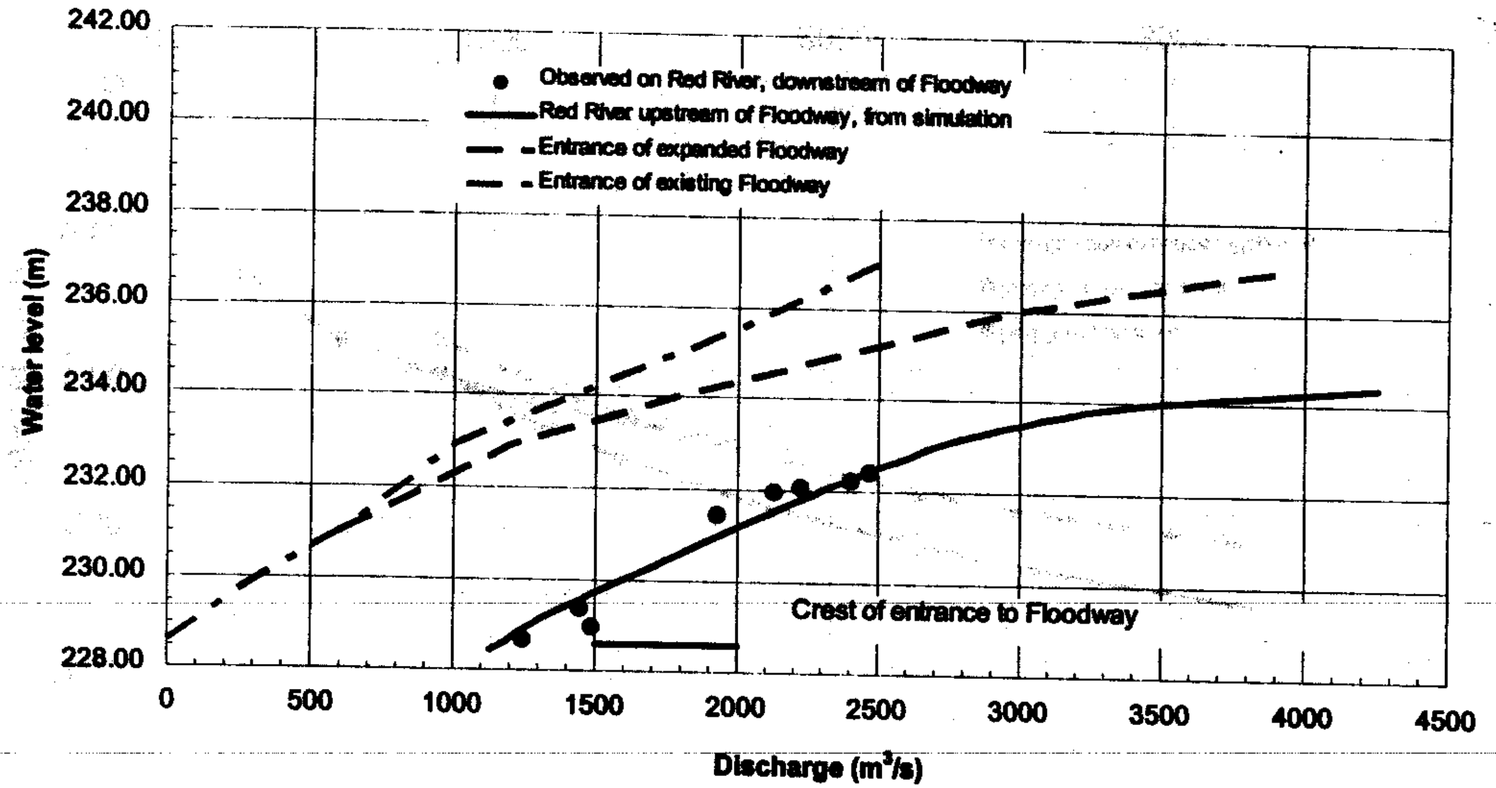
Rating Curves at Floodway Entrance



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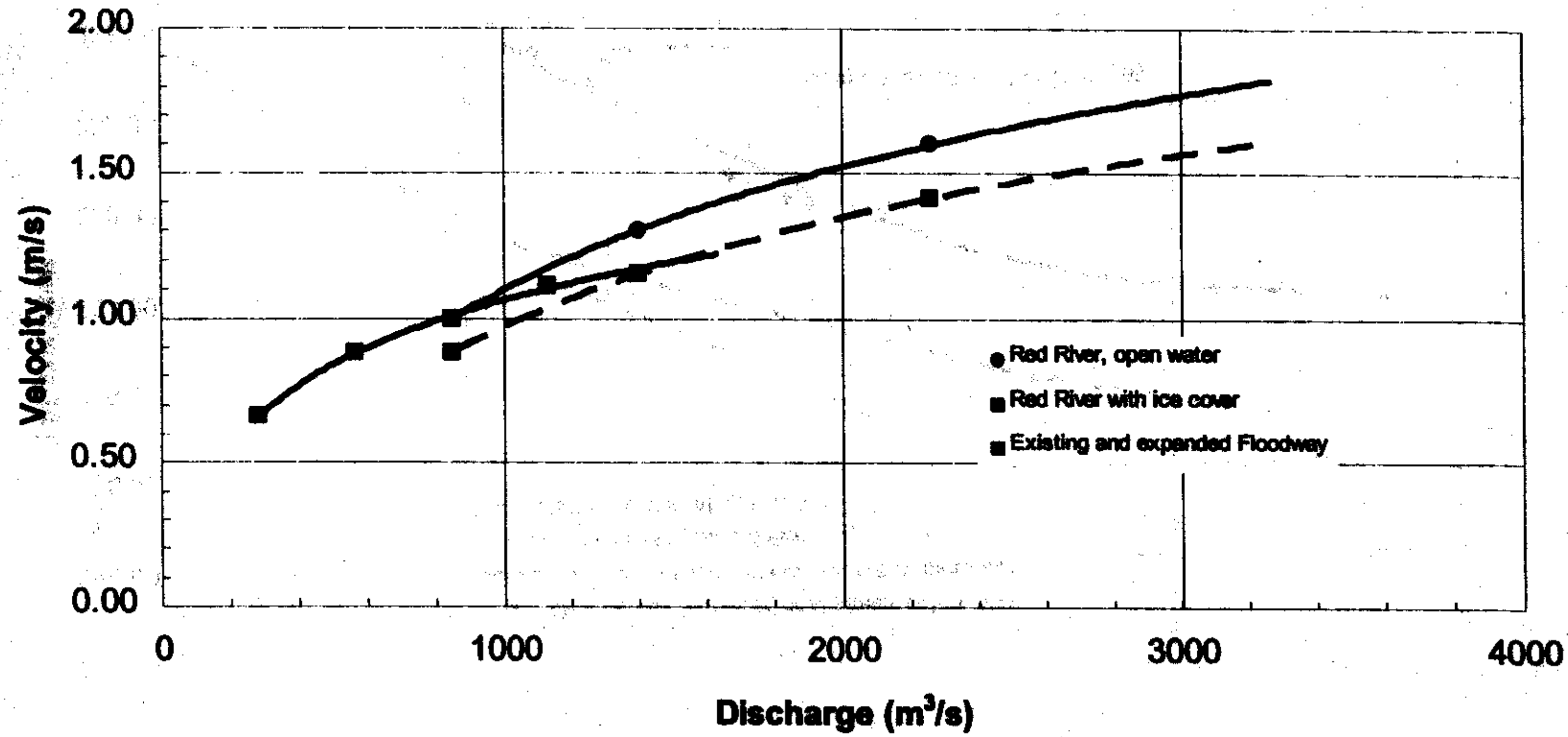
Flow-Velocity Relationship for River and Floodway



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