Modeling overbank flows during ice-jam flood events on the Lower Red River

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This study focuses on modelling overbank flows during ice-jam flood events on the Lower Red River. The lower reach of the Red River is a region between the city of Winnipeg and Lake Winnipeg that is prone to seasonal ice jam flooding. This particular stretch of the Red River runs along a low lying flood plain and drains into an inland delta before exiting into Lake Winnipeg. During ice jams, backwater levels rise and as a result, water flows over the low lying banks and drains excess water into the inland delta that surrounds the river. Accurately calibrating overbank flow is a key step in creating an accurate ice-jam flood forecasting system that will help provide flood managers with essential information for preparedness and flood mitigation strategies. For this study, RIVICE, a one-dimensional, fully dynamic wave model embedded with river ice processes was used. Backwater levels that occurred during ice jam events of 2009, 2010 and 2014 were simulated using RIVICE. Through these simulations, the relationship between volumetric discharge and overbank flow has been calibrated. This research is an extension of a previous paper (Lindenschmidt et al. 2012) that first modelled Lower Red River ice jam events of 2010. Some excerpts from the 2012 paper have been reused in this paper to be consistent with past research. In the near future, it is hoped that additional years of backwater levels during ice jamming events will be simulated to further refine this relationship.
1. Introduction

Ice jam is a common seasonal phenomena occurring during the beginning of spring flooding on many rivers in Canada, with some even experiencing annual peak water levels as a result of ice jam events (EC 2013a). On the Lower Reach of the Red River ice jams have been occurring frequently for the entire recorded history (Acres 2004; Farlinger and Westdal, 2010), and the severity and frequency of ice jams have increased in recent decades (Lindenschmidt et al. 2010). Ice-jam flooding events pose serious problems in regards to water damage and therefore, more accurate ice-jam forecasting methods are needed for better flood management.

Ice cover break-up and ice jamming processes on rivers are controlled by site specific river morphology, hydro-meteorological conditions, and water control structures such as bridges and culverts. Such complexities make accurate ice-jam forecasting a difficult and challenging task. A data driven ice jam backwater forecasting system would aid in addressing the stochastic nature of ice jams. The primary step in developing a data driven ice-jam forecasting system is establishing properly calibrated parameters and boundary conditions of a river ice model. For this study, RIVICE (EC 2013b), a one-dimensional, fully dynamic wave model developed by Environment Canada was used. RIVICE is embedded with river ice processes and can be used to simulate stage frequency distributions of backwater elevations during ice jam events.

A novelty of this work is using data from past ice jam events to calibrate the relationship between overbank flow and downstream discharge. Ice jam events of 2010 had already been modelled to develop this relationship (Lindenschmidt et al. 2012), however, the nuance of this research is using the result of two additional years of modelled ice jams to create a more robust relationship between the two boundary conditions. The Lower Red River runs along a low lying flood plain and drains into an inland delta before exiting into Lake Winnipeg. During ice jams, backwater levels rise and consequently, water flows over the low lying banks and allows excess water into the inland delta neighboring the river. Widths of negative inflows were introduced into the models to replicate overbank flows and were adjusted until simulated water levels matched well with observed water levels. Similar modelling work has been implemented on the Peace-Athabasca River using distributed sinks to simulate overland flow (Beltaos 2018). Observed water levels during ice jam events of 2009, 2010 and 2014 were used for developing this relationship.

The objective of this research is to model lateral overbank flows during ice-jamming events on the Lower Red River to better calibrate the relationship between volumetric flow and overbank flow.

This research project is a collaboration between the Global Institute for Water Security at the University of Saskatchewan, and the Government of Manitoba’s Department of Infrastructure. Both organizations are proficient in river-ice modeling and have expertise of the Lower Red River. It is hoped that this collaboration will be successful in modelling lateral overbank flows during ice jam events and in determining the relationship between downstream discharge and overbank flow during such events. This paper is a continuation of work first presented in an earlier paper by Lindenschmidt et al., 2012, that successfully modelled ice jam events of 2010 (accessible at https://www.researchgate.net/publication/266286200_Ice_Jam_Modelling_of_the_Lower_Red_River). Excerpts from the 2012 paper were reused in this paper to remain consistent throughout
the project. This paper presents initial results and it is expected that additional ice jam events will be used to further calibrate the relationship between downstream discharge and overbank flow.

2. Site Background

2.1 The Lower Red River

The Lower Red River (see Figure 1) is the furthest downstream stretch of the Red River starting from the Assiniboine River convergence in the city of Winnipeg and ending at the river’s outlet into Lake Winnipeg, accumulating to roughly 77 km in length. The total drainage area of Red river Basin above Lake Winnipeg is approximately 287,500 km². At the Lockport station, the average stream discharge is 244 m³/s, and the recorded maximum and minimum discharges are 4,330 m³/s and 14 m³/s respectively.

At Lockport, a lock and dam is present for navigation over five separate sets of rapids, including a 4 m decrease in elevation near Lister Rapids. The Camere style dam completed in 1910 has steel curtains that dam the river to regulate water levels upstream. The curtains can roll up to allow spring flood waters to safely pass. Less than a kilometer downstream of Lockport is the outlet of the Floodway, a man-made channel that diverts spring freshets from the Red River upstream of Winnipeg to protect the city from potentially high water levels. Downstream from Lockport are two bridges; Selkirk Bridge located in the city of Selkirk and PTH 4 Bridge further downstream. As well, between these two bridges, is a small island known as Sugar Island. At the most downstream stretch of the river between Selkirk and Lake Winnipeg, is a very flat delta system known as Netley-Libau Marsh. Several small waterbodies are connected by a network of channels with the Red River. A 400 m long section called Netley Cut short-circuits water from the river into Netley Lake.

Figure 1. The Lower Red River between the Assiniboine River confluence and Lake Winnipeg, adapted from Lindenschmidt et al. (2012).
Figure 2 portrays a longitudinal profile of the Lower Red River’s thalweg and ice cover level that is normally experienced during the end of winter. At the end of winter, the water level typically experiences a low slope between Lockport and Lister Rapids (≈ 0.00005 m/m). The water level and the river bed get steeper (≈ 0.00015 m/m) from Lister Rapids to Lockport during this same time of year. In the Netley-Libau Marsh area downstream of Lockport and Selkirk, backwater effects from Lake Winnipeg typically create an almost flat water gradient (less than 0.00001 m/m).

Figure 2. Longitudinal Profile of the Lower Red River’s thalweg and typical winters’ end ice cover level, adapted from Lindenschmidt et al. (2012).

2.2 Lower Red River Ice

Ice is normally present on the Lower Red River from mid-November to April. The ice cover in this area is usually smooth, and once thick enough, remains the entire winter. Spring flooding is often intensified by mechanical breakup and ice jamming, especially during premature and rapid melt events. Ice jamming is promoted by thick river ice, and in the case of the Lower Reach of the Red River, ice has been measured to be as thick as 1 m. Thick ice is able to develop on this stretch because of the low flow velocities associated with the shallow slope of the Netley-Libau Marsh.

3. Break-Up on the Lower Red River

River ice breakup is typically a brief event that entails the transition of a full ice cover to open water conditions. On the Lower Red River near Selkirk, ice breakup has been recorded to typically occur when the discharge is in the range of 990 m$^3$/s and 1,420 m$^3$/s. Downstream, in the Breezy Point and Netley Creek area, break-up has been seen to occur at relatively higher flows, even up to 2,690 m$^3$/s because the ice in this stretch is usually higher strength lake ice (Acres 2004).

Selkirk and the stretch of river downstream of Selkirk are the two regions most prone to ice jam flooding. The presence of Sugar Island may restrict movement of ice and favors ice jamming in Selkirk. Likewise, the Selkirk and PTH 4 Bridge piers can also restrict movement of winter ice. When Lake Winnipeg is frozen a backwater effect takes place and increases the likelihood of ice jamming near Breezy Point. Articles from historical newspapers show that severe ice jams occurred on the Red River near Selkirk as early as the mid to late 1800s (Manitoba Government 2010). In anticipation of severe jamming and flooding, the Government of Manitoba adopted an artificial ice breaking and cutting program in 2006. Ice breaking and cutting has been utilized every spring since then.
Ice cover is generally seen to first break at the North Perimeter Bridge at the northern limits of Winnipeg. In the days following initial breakup, ice is free to move between North Perimeter Bridge and Selkirk. Ice movement is then usually arrested at Selkirk to form an ice jam. Jamming may initially occur at the sharp bend at the Selkirk golf course or further downstream against the Selkirk Bridge piers or Sugar Island. Jams located in this stretch tend to cause flooding on the east banks of the river at Selkirk Bridge and often require the bridge to be closed. Eventually the initial jam will move downstream to PTH 4 Bridge.

Simultaneously, ice cover may also break up downstream of the PTH 4 Bridge and cause jamming in certain sections up to the Netley Creek confluence. During the initial surge of the ice jam, water typically short-circuits through the Netley Cut into Netley Lake. Jamming in this area is often accompanied by local flooding, so often that severe ice-jam flooding has occurred in 1996, 2004, 2007, 2009, 2010, 2011, and 2016. Attention will be focused on ice jam events that took place in 2009, 2010 and 2014 because data and imagery was most readily available for 2009 and 2014, and events from 2010 had already been modelled successfully in a past paper (Lindenschmidt et al. 2012).

3.1 Break-up of Ice in 2009

The autumn of 2008 brought approximately 43% more rain than usual, which saturated the soil right before freezing occurred in early December. This unfortunately left little room for spring snow melt to be absorbed into the soil. The nearly saturated ground was accompanied by an exceedingly snowy winter in southern Manitoba, and both of these conditions were met with a cold spring (EC 2017). As a result, the Red River was not able to handle the excess water, leading to extremely high water levels in some locations.

The winter of 2009 and spring of 2010 was the first winter where remote sensing images were used to monitor ice processes on the Lower Red River. Instead, for the spring ice break up of 2009, helicopter images were used to observe these events. Helicopter images were taken from April 10th to April 12th, 2010, and captured the majority of the ice break-up that occurred on the Lower Red River. On the morning of April 10th, 2009, between 8:30 and 9:00, images show that the ice cover was open from the Kidonan Settlers Bridge in Winnipeg downstream to the Selkirk Golf Course. A minor ice jam had formed at the golf course, the front reaching approximately 1.5 km upstream. Additional helicopter images taken April 10th, 2009, between 14:25 and 14:45, indicate that the jam moved downstream just past the Selkirk Generating Station, with the front just upstream of the Selkirk Golf Course. Furthermore, the ice cover opened downstream of Selkirk bridge. The latter jam can be seen in the map featured in Figure 3.

On April 11th, 2010, two more sets of helicopter images were taken of the Lower Red River; once in the morning between 7:55 and 8:50, and another in the evening between 18:30 and 19:00. On the morning of April 11th, 2009, the previous jam had released and lodged downstream between Sugar Island and PTH 4 Bridge. The front of the jam stretched upstream to Sugar Island. By the evening of April 11th, the front of the jam moved downstream past Sugar Island, whereas the toe of the jam remained intact approximately 1 km upstream of PTH 4 Bridge. A small amount of rubble ice flowed past the PTH 4 Bridge but juxtaposed against the intact ice cover. The ice-jam that occurred on the evening of April 11th, 2009 is shown in Figure 4, and was one of the ice jam events that was simulated using RIVICE.
Figure 3. Selkirk ice jam captured through helicopter images April 10\textsuperscript{th}, 2009, from 14:25 to 14:45.

Figure 4. Ice jam just upstream of PTH 4 Bridge captured through helicopter images April 11\textsuperscript{th}, 2010, from 18:30 to 19:00.
On April 12\textsuperscript{th}, 2009 two more sets of helicopter images were taken: once between 7:40 and 8:00, and another from 11:20 to 11:45. By 7:40 on April 12\textsuperscript{th}, 2009, the jam of the previous day had released and another jam had formed downstream at Breezy Point. The front of the ice jam stretched 1.2 km upstream, and images from midday indicate the jam stayed intact throughout the morning of April 12\textsuperscript{th}. The Breezy Point ice jam that occurred on April 12\textsuperscript{th}, 2009 is shown in Figure 5, and was also simulated using RIVICE. Images also indicate that high backwater levels resulted in large amounts of overbank flow during the Breezy Point jam.

![Image of ice jam](image.jpg)

**Figure 5.** Breezy Point ice jam captured through helicopter images April 12\textsuperscript{th}, 2010 from 11:20 to 11:45.

### 3.2 Break-up of Ice in 2010

March 10\textsuperscript{th}, 2010 was welcomed with a rainfall event and was followed by a week of greater than 0°C daytime temperatures. As a result, snowmelt occurred rapidly, and by the 18\textsuperscript{th} of March there was no snow recorded at the Oakbank weather station. The increase in runoff from the rainfall event and higher temperatures triggered the ice cover to open at North Perimeter Bridge. The breakup proceeded downstream until the front reached St. Andrews on March 16\textsuperscript{th}, 2010. The front reached south Selkirk on March 23\textsuperscript{rd}, 2010 and Figure 6 shows a SPOT-5 image with the ice accumulation at this location.

The ice jam at south Selkirk released on March 24\textsuperscript{th}, 2010 and the ice cover began to break-up until Selkirk Park. This jam remained in place until March 27\textsuperscript{th}, 2010, and during this time, disjointed ice from upstream collected at the ice jam, whose front juxtaposed upstream past the Selkirk Bridge. Figure 7 displays a SPOT-5 image of the ice jam from its toe at Selkirk Park to its front just upstream of the generating station captured on March 26\textsuperscript{th}, 2010. This ice jam was one of the 2010 events modelled using RIVICE.
Figure 6. Multispectral SPOT-5 image of ice accumulation front at St. Andrews on March 16th, 2010 (SPOT-5 image © 2010 CNES, Licensed by Iunctus Geomatics Corp, www.terraengine.com).

Figure 7. SPOT-5 image of the ice jam at Selkirk on March 26th, 2010 (SPOT-5 image © 2010 CNES, Licensed by Iunctus Geomatics Corp, www.terraengine.com).

The ice jam at Selkirk Park released on March 28th, 2010, and the ice flowed further to jam again, temporarily at Netley Cut. The ice jam resulted in the highest stages on record along the east bank between Selkirk and Breezy Point. By March 31st, all the ice cleared from the river up to Lake Winnipeg. An aerial photograph of the ice jam at Netley Cut can be seen in Figure 8, and was the other 2010 event that was modelled with RIVICE.
3.3 Break-up of Ice in 2014

The break-up of ice on the Lower Red River in 2014 took place from approximately April 16th to April 23rd. Two separate RADARSAT-2 images were used to capture some of the events of the 2014 spring breakup. The initial RADARSAT-2 image taken at midday on April 16, 2014 (see Figure 9) indicated that the ice cover was still intact on most of the Lower Red River. The image shows that open water conditions were present upstream of the Lockport Dam at this time and that break up of ice was beginning to occur just downstream of the dam.

Figure 8. Aerial image of the ice jam at Netley Cut on March 29th, 2010.

Figure 9. RADARSAT-2 image of the beginning of spring break up at Lockport along the Lower Red River on April 16th, 2014 (RADARSAT Data Products © MacDonald, Dettwiler and Associates Ltd (2014) – All Rights Reserved \ RADARSAT is an official mark of the Canadian Space Agency).
Records that were provided from Manitoba Infrastructure indicate that by April 18th, 2014, ice break up had made its way downstream from Lockport Dam to St. Clement (roughly 2.5 km upstream of Selkirk Golf course) where a jam had produced. This jam stayed in place until April 20th, 2014, in which break up pressed further downstream. By April 21st, 2014, another jam had formed between Sugar Island and PTH 4 Bridge. This jam remained in place until sometime on April 22nd, 2014. Following the release of this jam, the ice travelled further downstream to lodge briefly, just North of PTH 4 Bridge until the evening of April 22nd, 2014.

The other RADARSAT-2 image was captured during the first hour of April 23rd, 2014, and shows that ice cover had broken up all the way downstream from Lockport up to Breezy Point. The image captured a jam between Breezy Point and the Netley Creek confluence that raised the backwater level of the jam enough to force water over the west bank of the river. This jam was the only 2014 event modelled using RIVICE and can be seen featured in Figure 10.

The models were run in wide-jam mode where the ice-jam thickens through the shoving of ice in the jam. Shoving occurs as a result of the increased forces from the flow of water thrusting on the ice jam front, the drag force on the underside of the jam cover and the weight of the ice.

4. RIVICE Model

For this study, RIVICE, a one-dimensional, fully dynamic wave computer model with embedded river ice processes was used. The model uses an implicit finite-difference scheme to simulate ice processes along rivers. Some of these processes include border ice advancement, ice transportation, hanging ice dams, and the break up and formation of ice jams. The model was used to simulate ice jam events at Selkirk during 2009 and 2010, and at Breezy Point during 2009, 2010 and 2014.
accumulation in the jam. These three forces are opposed by the friction encountered by the ice cover edges shearing against the river banks and the internal resistance of the thickening ice volume at the jam. Widths of negative inflows were added along the model domain to replicate abstraction into the flood plain and leakage of water into channel storage and diversions. Volumes of ice lost to the floodplains was not accounted for as this is not a process available within the RIVICE model. A more detailed account of the RIVICE model can be found in supplementary publications (ECCC 2013; Lindenscheid 2017). All events simulated in this study were replicated with minimal differences in parameter values, minus the different boundary conditions experienced during each event. This was in attempt to perform a multi-jam calibration to best determine the relationship between downstream discharge and overbank flow without other parameters impacting results.

5. Data for Model Setup

The model stretched from the upper boundary located just downstream of both the Lockport Dam and the outlet of the Red River Floodway, to its lower boundary at the Red River’s entry into Lake Winnipeg (see Figure 1). River bed cross-sections from the upper boundary to just upstream of the Breezy Point gauge spaced at an average 250 m were available from a bathymetric survey. Additional bathymetric measures of the Netley Creek confluence, Delta forks and the outlet of the Red River into Lake Winnipeg were obtained from Public Works and Government Services Canada.

Gauge locations that were used for model data can be seen in Figure 1. Volumetric flow readings recorded at the Water Survey of Canada gauging station Red River at Selkirk Bridge (05OJ005) were used as the upstream model boundary for all simulated events. Water elevations recorded at Gimli on Lake Winnipeg (05SB006) were used as the downstream model boundary for all simulated events. Water level data from the gauges operated by Environment and Climate Change Canada’s Water Survey Office were used for 2009, 2010 and 2014 ice jam events. Additional water levels were obtained from Manitoba Infrastructure for the 2014 events. Helicopter photos were used to estimate ice volumes during the reconstruction of events that occurred in 2009, whereas remote sensing imagery was used to estimate ice thicknesses to be used in modelling the 2010 and 2014 ice jam events.

6. Results and Discussion

6.1 2009 Ice Jam Events

Figure 11 shows for a discharge of 2,940 m$^3$/s that was experienced on April 11$^{th}$, 2009, at the Environment Canada gauge station located at Selkirk Bridge, the longitudinal water level profiles along the modeled study site. The modelled jam was first set up with an ice cover (red line) whose front was located where the toe of the jam was observed. Open water remained upstream (blue line). Ice flow was then inserted into the model and lodged at the ice front. The volume of ice inserted into the model was continually refined until the resulting ice jam front matched the observed ice jam front (black triangle). Abstraction in the open water portion of the jam profile and leakage in the ice cover portion of the jam profile was introduced and varied until the simulated water level was below the banks and coincided with the observed water levels (orange circles). Calibration of the simulated water levels recorded during the Selkirk jam on April 11$^{th}$, 2009, resulted in a total abstraction and leakage of 67 % of the total inflow at the upper boundary (2,940 m$^3$/s) of the model.
By April 12\(^{th}\), 2009, the jam that had formed at Selkirk released and another jam formed at Breezy Point. This can be seen in Figure 12, as there’s a drop in the water elevation at Selkirk Generating Station on April 11\(^{th}\) and an increase in the level at Breezy Point. The discharge upstream of the jam that was recorded on April 12\(^{th}\), 2009, was 3,090 m\(^3\)/s, which was used as the upstream boundary condition for this event. The downstream boundary water level was approximately the same as the previous day. The process of inserting an ice flow of appropriate volume to match the observed ice jam front was done again. Figure 13 shows the observed and simulated longitudinal water level profiles along the modeled study site. The amount of water abstracted upstream of the jam and the amount of leakage downstream of the jam was altered until the simulated profile coincided best with the observed water levels. The total abstraction and leakage equaled to approximately 69\% of the upstream boundary flow of 3,090 m\(^3\)/s.

![Observed Water Levels](image)

Figure 11. Observed and simulated longitudinal profiles for ice cover and ice cover with an ice jam at Selkirk on April 11\(^{th}\), 2009, with diffuse abstraction and water leakage equivalent to the volume of water leaving the main channel.

![Water Levels](image)

Figure 12. Water levels recorded at Selkirk generating station and Breezy Point gauges during the ice jam events of 2009.
Figure 13. Observed and simulated longitudinal profiles for ice cover and ice cover with an ice jam at Breezy Point on April 12th, 2009, with diffuse abstraction and water leakage equivalent to the volume of water leaving the main channel (legend as in Figure 11).

6.2 2010 Ice Jam Events

Figure 14 displays, for a discharge of 1,000 m$^3$/s, the longitudinal water elevation profiles along the modeled Lower Red River for three different cases: open water, ice cover, and an ice cover with a jam in Selkirk. A different approach was taken for calibrating the 2010 ice jam events and can be seen in full detail in an additional publication (Lindenschmidt et. al 2012). Simulations for 2010 events were first run in open water conditions until steady states were reached (blue line). Ice covers were then introduced and the models were run until additional steady states were achieved causing backwater levels to rise (red line). Appropriate volumes of ice were then inserted to simulate the actual jam events. Models were ran until a third steady state was reached. The ice jam profile (black line) and thickness of the jam and ice cover (black infills) for the 2010 Selkirk event are present in Figure 14. Simulations of both Selkirk and Breezy Point jams were reiterated for increasing discharges on subsequent days and results are compared on hydrographs in Figure 15. This image shows good agreement between simulated and observed levels.

The discharge of 1,000 m$^3$/s that was recorded on March 25th, 2010, at the Water Survey of Canada gauge at Selkirk Bridge was used as the upstream boundary condition for this event. The downstream boundary water level at Lake Winnipeg remained nearly the same throughout all 2010 events. A width of outflow (leakage) was inserted between the Netley Cut and Lake Winnipeg to recreate the amount of water short-circuiting from the primary river channel. A water leakage amount of 65% of the total discharge at the upper boundary (1,000 m$^3$/s) was needed to calibrate the modelled water profile to the recorded levels (Lindenschmidt et al. 2011).
Figure 14. Simulated longitudinal profiles for open water, ice cover and ice cover with ice jam at Selkirk on March 25\textsuperscript{th}, 2010, with water leakage equivalent to the volume of water leaving the main channel (image adapted from Lindenschmidt et al. (2012) with elevation legend as in Figure 11).

Figure 15. Water levels recorded during the spring break-up period of 2010. Simulation results are from the ice jam modelled at Selkirk Park (image adapted from Lindenschmidt et al. (2012)).

The jam at Selkirk Bridge released on March 28\textsuperscript{th}, 2010 and caused the downstream water level to rise abruptly at Breezy Point approximately six hours later (see Figure 16). The ice from the Selkirk jam flowed downstream and was arrested at Netley Cut where another ice jam formed until the mid-day of March 29, 2010. A flow of approximately 1,750 m\textsuperscript{3}/s was recorded during the jam release and was used as the upstream boundary condition. A volume of ice equal to the ice at the Selkirk jam plus the ice that covered the river from Selkirk Bridge to Netley Cut was input for the Breezy Point ice jam event. Volumes of water were removed from the main channel to recreate both abstraction into the flood plain and leakage of water into channel storage and
diversions (Lindenschmidt et al. 2011). Resultant water level profiles are portrayed in Figure 17. The amount of water abstracted from upstream of the jam was increased until simulated backwater levels were roughly the same elevation of the most downstream river bank elevations. The total abstraction and leakage equaled to approximately 66% of the upstream boundary flow of 1,750 m³/s.

Figure 16. Water levels recorded at Selkirk generating station and Breezy Point gauges during the ice jam events of 2010 (image adapted from Lindenschmidt et al. (2012)).

Figure 17. Simulated longitudinal profiles for open water conditions, ice cover and ice cover with ice jamming at Netley Cut on March 29th, 2010 with diffuse abstraction and leakage of water equal to the volume of water leaving the main channel (image adapted from Lindenschmidt et. al (2012) with elevation legend as in Figure 11).
6.3 2014 Ice Jam Event

Figure 18 shows for a discharge of 1,970 m$^3$/s that was experienced on April 23rd, 2009 at the Environment Canada gauge station located at Selkirk Bridge, the longitudinal water level profiles along the modeled study site. The modelled jam was first set up with an ice cover (red line) whose front was located where the toe of the jam was observed via Radarsat-2 images. Open water remained upstream (blue line). Ice flow was then inserted into the model and lodged at the ice front. The volume of ice inserted into the model was continually refined until the resulting ice jam front best matched the observed ice jam front (black triangle).

Observed water levels were obtained from Manitoba Infrastructure and it is clear these readings have some uncertainty, especially the readings upstream of the jam which were surveyed to be lower than the downstream levels. As a result, abstraction in the open water portion of the jam profile and leakage in the ice cover portion of the jam profile was varied until the simulated water level coincided at the jam (locations 6, 7 and 8) but not upstream of the jam (locations 1 to 5). Calibration of the simulated water levels recorded during the Breezy Point jam on April 23rd, 2014, resulted in a total abstraction and leakage of 68% of the total inflow at the upper boundary (1970 m$^3$/s) of the model.

![Figure 18. Observed and simulated longitudinal profiles for ice cover and ice cover with an ice jam at Breezy Point on April 23rd, 2014 with diffuse abstraction and water leakage equivalent to the volume of water leaving the main channel (elevation legend as in Figure 11).](image)

6.4 Establishing the relationship between discharge and overbank flow

To analyze the relationship between downstream discharge and total overbank flow, simulated ice jam events were separated into two different categories: (1) ice jams occurring in the Selkirk area and (2) ice jams occurring in the Breezy Point area. Figure 19 shows the relationship between the discharge used for the upstream boundary and the overbank flow for the two separate categories of jams simulated. Overall, two events were simulated in the Selkirk area (events of 2009 and 2010) and three events were simulated in the Breezy Point area (events of 2009, 2010 and 2014).
Both sets of data best fit linear trend lines, but this was expected with such few data points. Equations for each trend line representing bank full flows can be seen as well.

![Figure 19. Plot of the relationship between downstream discharge and overbank flow for simulated ice jam events in both Selkirk and Breezy Point areas.](image)

Jamming events that took place in both Selkirk and Breezy Point areas yielded very similar relationships between downstream discharge and overbank flow. For the two ice jam events simulated at Selkirk, lateral flow ranged from 65 to 67% of the downstream discharge. Similarly, for the three ice jam events simulated at Breezy Point, lateral flow ranged from 66 to 69% of the downstream discharge. The minimally higher percentage of lateral flow associated with the jams simulated at Breezy Point may be a result of greater ice volumes being able to juxtapose at the further downstream location. As this research progresses, it is hoped that additional ice jam events that have occurred in either of these two locations will be calibrated in order to continually refine the relationship between downstream discharge and overbank flow. In the meantime, the relationship that has been thus far established will be used in a preliminary ice jam backwater forecasting system for the Lower Red River.

7. Conclusion

Ice jams continue to be a seasonal challenge for the low-lying area and river delta located in the Lower Red River. These natural events are problematic in terms of local flooding and therefore, more accurate ice jam forecasting methods are needed. Accurately modelling ice jam events with 1-D RIVICE model and establishing properly calibrated parameters and boundary conditions for these systems remains an essential step.

The focus of this study was to model lateral overbank flows during ice-jamming events on the Lower Red River to calibrate the relationship between volumetric flow and overbank flow. Data from 2009, 2010, and 2014 ice-jam events were used to calibrate this relationship. Widths of negative inflows were introduced into the models to simulate overbank lateral flows until simulated water levels matched well with observed water levels. With two ice jam events modelled in Selkirk, total under-ice leakage and diffuse abstraction from the Red River main channel was
estimated through calibration to be as high as 67% of the upstream discharge. Likewise, with three ice jam events simulated in the Breezy Point area, total under-ice leakage and diffuse abstraction from the Red River main channel was estimated through calibration to be as high as 69% of the upstream discharge. Future work may include a sensitivity analysis to determine how these overbank flow percentages change with other varying parameters such as ice roughness. This would optimistically differentiate the effect overbank flow has on other parameters as well. It is hoped that in the near future, additional years of ice jam events will be simulated and the relationship between downstream discharge and overbank flow will become more robust and refined for the Lower Red River study site.

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9. References


