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Ice Jam Flood Risk Forecasting at the Kashechewan FN Community on the North Albany River

J. K. E. Shaw[1], S. T. Lavender[2], D. Stephen[3], and K. Jamieson[4]
[1]*Hatch, 4342 Queen St. Suite 500, Niagara Falls, ON L2E 7J7*
jshaw@hatch.ca

[2]*Water Resources & Power Planning Inc., 405188 Grey Road 4, RR 3, Priceville, ON   N0C 1K0*
wrapp@xplornet.com

[3]*Chief, Kashechewan First Nation, P.O. Box 240, Kashechewan, ON   P0L 1S0*
stephen-wayne@hotmail.ca

[4]*Northern Waterworks First Nations Operations Inc., Christian Island, ON L9M0A9*
kaljam@rogers.com

The Kashechewan First Nation (KFN) community is located on a floodplain of the north branch of the Albany River, on the west coast of James Bay. Each spring the town's residents face the uncertain prospect of evacuation to limit damages caused by ice-jam flooding. The community has been evacuated on a precautionary basis on seven occasions of ice-jam related flooding since 1976, the most severe of which occurred in the spring of 2006. In 2007, Hatch was retained by KFN to assist with developing a remedial action plan for reducing the risk of flooding due ice-jamming at the community. The work was divided into two phases: 1. High Priority Emergency Measures; 2. Option Development for Permanent Remedial Works.

A component of Phase 1 was the development of an ice breakup flood forecast tool. The key criteria for tool development dictated that indication of a high risk of flooding must be provided at least 10 days in advance. A systematic approach to developing such a tool would typically include the installation of an extensive and costly hydro-meteorological station network within the river basin plus the collection and analysis of data from this network over at least a 25-year period to acquire enough information to produce flood forecasts. Unfortunately, this approach would not meet the community's immediate need for assistance.

With only historical flow records having been collected 200 km upstream of the community, Hatch reviewed the available hydro-meteorologic data outside the river basin and identified correlative relationships based upon physical processes that provided a useful working algorithm for predicting snow melt and consequential ice jam flood risk using meteorological forecasts of temperature and rainfall. This work resulted in an innovatively simple relationship that provides a flood risk forecast with reasonable success. The tool complements and enhances the current flood monitoring program executed by the combined efforts of the Kashechewan community, the Mushkegowuk Council, Emergency Management Ontario, Ontario Ministry of Natural Resources, and Aboriginal Affairs and Northern Development Canada.

1. Introduction

Ice Jam Flood Risk Forecasting at the Kashechewan First Nation Community on the North Albany River uses a Flood Forecast Tool developed specifically for the Town Site.

The Flood Forecast Tool provides a 10-day advance notion of the degree of risk of an impending ice break-up event being severe enough to cause flooding of the KFN town site. A 10-day warning provides sufficient time to prepare for and implement a 5-day emergency air evacuation of the town site, with a 5-day allowance for unfavourable weather conditions. Although the tool is imperfect, it has proven to be a useful aid in assessing the likelihood of an impending ice break-up flood by formalizing the assembly and interpretation of all available relevant information.

The tool is a spreadsheet-based application and incorporates a simple data-entry interface with a graphical representation of the flood warning status.

2. Model Development

In early 2008, Hatch developed an algorithm using actual ‘to date’ stream flow, snowmelt and rainfall data only for assessing the likelihood of an ice jam flood magnitude great enough to put the community of Kashechewan at serious risk of inundation.

In its original form, the forecast tool provided a record of the estimated cumulative rainfall plus water equivalent snowmelt and an estimate of the flow in the Albany River at Hat Island. The temporal trajectories of these define the potential risk for ice jam flooding based on the criteria below.

Early warning criterion – Represented by daily rainfall and daily water equivalent of snow pack depletion accumulated from the end-of winter (March 1st). Should the cumulative rainfall plus snow pack depletion in a given year fall in the yellow zone as defined by a value of 150 mm and the three dates March 19, April 18 and April 28 as shown in Figure 1, there is a significant probability of impending runoff rates that will lead to ice jam flooding at Kashechewan. The greater the rate and persistence of accumulation, the more likely it is that ice jam flooding will occur. Conversely, low rates of accumulation that cross into the green zone Figure 1 indicates a very low probability of troublesome flow rates because flow is expected to be too low and the ice cover will have had greater time to warm up and lose both cohesive strength when broken, and volume. The ‘early warning’ arises from the natural time lag between the occurrence of rainfall and snowmelt and its appearance as flow in the river at Hat Island.

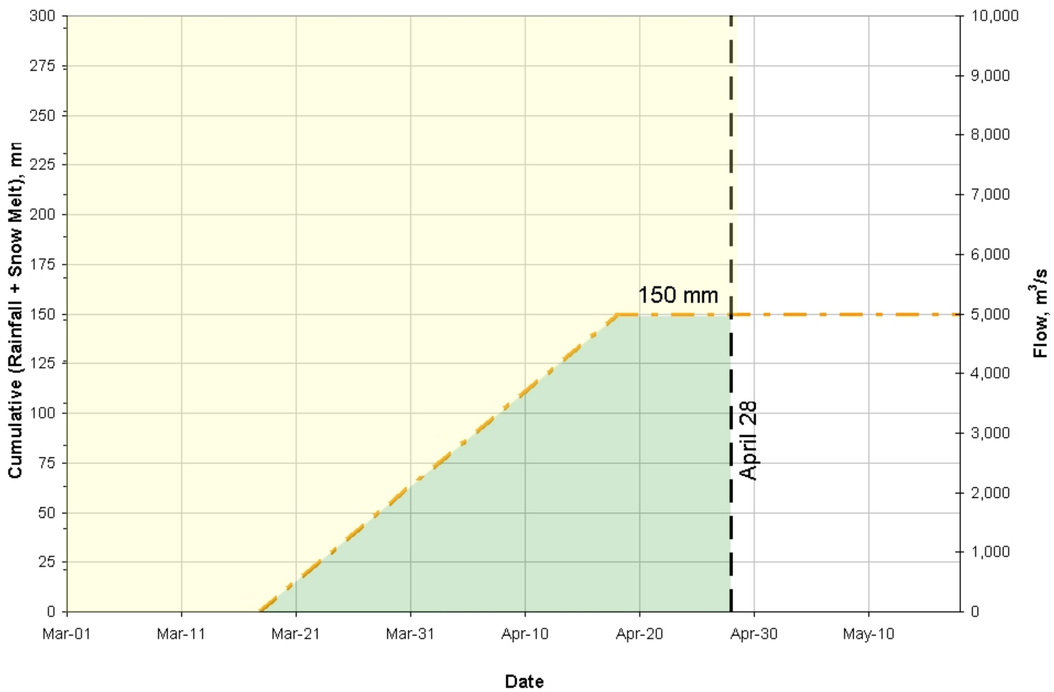


Figure 1- Forecast Tool Early Warning Zones

Late Warning Criteria – Based on the estimated flow at Hat Island, these criteria comprise:

- **The 3-day rate of increase in flow rate of 700 m^3/s/day** - A high rate of increase of flow in the river in excess of 700 m^3/s/day (over 3 days) indicates that the river levels are about to increase to levels that can lift the ice cover from its contact with the river banks so that the ability to transmit the body and hydraulic drag forces acting on the cover to the banks is lost. Consequently the cover will fail structurally and the broken cover can be transported downstream to accumulate at a river section through which the prevailing flow cannot transport the ice (e.g., too shallow and/or narrow a river cross-section and/or too gentle a river bed slope or retention by an as yet undisturbed section of ice cover).

- **A threshold flow rate of 4750 m^3/s** - The threshold flow rate of 4750 m^3/s at Hat Island is the magnitude of flow required to realize flooding of Kashechewan given the presence of an ice jam or jams in the river reaches downstream of and/or adjacent to the community. This value, deduced approximately from the analyses of historical events, could be refined with technical hydraulic analyses, but such analysis requires extensive river cross-section data throughout a reach of the river for some distance downstream of the Town Site to some distance upstream of the Town Site. Such data are currently not at hand.

- **A calendar date of April 28th** - The historic data indicate that no ice jam flooding has occurred in Kashechewan after the 28th of April even though the preceding two flow criteria are met after this date. This is considered to be the consequence of enough warming (weakening) and depletion of the ice cover having occurred that even though there may be ice present at this time, it has too little cohesion and is too small in quantity to be troublesome. This is not to say that ice jam flooding is not at all possible after this date, but that such an event is extremely unlikely. In addition, observation suggests that by this date, the south channels of the Albany River are relatively free of ice such that a significant portion of any water backed up behind a jam in the North Channel will divert through the south channel system thereby limiting the flow rate and therefore, water levels realized at Kashechewan.

In January 2009, it was deemed that a 10-day forecast, beyond a forecast based on the 'to date' data only (i.e., the advance warning time being only the rainfall-snow melt lag time), would be useful. It was also determined that the development of a snowmelt-rainfall-runoff model over a long period of time does not have a suitable time frame for immediate needs and would be very costly to realize as it would require the installation of an extensive hydro-meteorological station network within the Albany River Basin and the collection of data from this network over at least a 25-yr period to acquire enough data from which a detailed snow melt model could be developed[1]. Consequently, early in 2009, available data were reviewed to try to identify correlative relationships based upon physical processes that would provide a useful working algorithm for predicting snow melt from meteorological forecasts of temperature. This work did indeed result in a relationship that could provide a snowmelt forecast, albeit with a tenuous physical basis and considerable uncertainty. Nevertheless, a trial application of this algorithm using only Environment Canada's 7-day temperature forecasts at Moosonee was undertaken in the course of the 2009 break-up and, with modifications to include rainfall forecasts as the application proceeded, the application again yielded reasonable success.

In the course of the 2010 spring break-up, the basic tool and snow melt algorithm was again given a trial application, but this time with the introduction of temperature forecasts of up to 15-days and rainfall forecasts looking 7-days ahead. Trial of this version of the Tool continued each spring thereafter, including the 2013 breakup, with relatively no changes to the algorithm.

3. Tool Outline

The Severe Ice Break-up Flood Forecast Tool requires access to Microsoft® Excel 2007 (or later). In addition, the user is expected to have a good understanding of the flood warning criteria.

There are three main steps to using the Severe Ice Break-up Flood Forecast Tool:

1. Recorded data entry – the user obtains and enters recorded flow, rainfall and snowpack depth information into the tool.
2. Forecast data – the user obtains and enters forecast rainfall and temperature data from up to three sources into the tool.
3. Flood risk level determination – the level of flood risk is displayed for review.

[1] The history of ice jam flooding of the Kashechewan First Nation Community indicates flooding occurs 1 in 6 years, on average. Thus, a 25 year data set would be expected to provide but four flooding experiences with which to work.

3.1 Recorded Data

Recorded data are entered beginning March 1st of a given year and every day thereafter until there is no longer a flood risk due to an ice jam event. The required data are:

- average daily river gauge height on the Albany River near Hat Island (WSC 04HA001), in metres
- average daily river gauge height on the Albany River near Fishing Creek Island (WSC 04HA002) in metres
- total daily rainfall recorded at Moosonee UA 6075425 in millimetres
- total daily snow depth recorded at Moosonee UA 6075425 in centimetres.

3.2 Forecast Data

Up to 15 days of forecast temperature and rainfall data for Moosonee are entered to forecast the effect that future weather will have on the flood risk. Forecast data from multiple sources are used to cover the range of uncertainty of forecast future conditions. The sources for forecast information are Environment Canada, AccuWeather.com and The Weather Network.

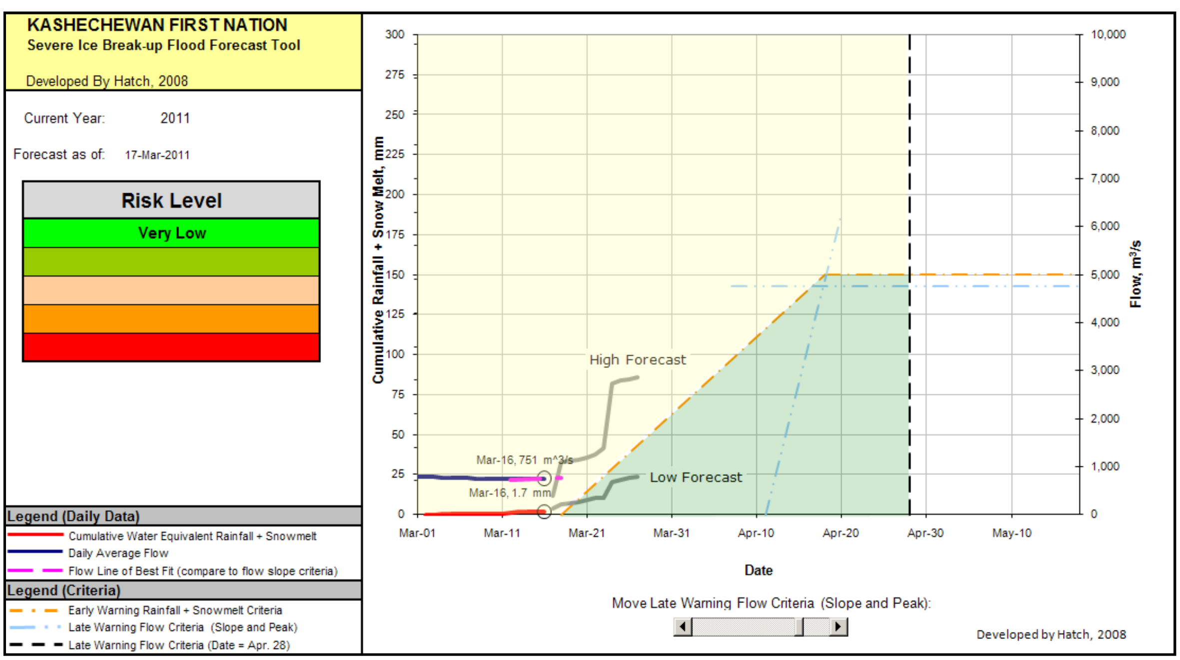
4. Tool Components

4.1 Introduction

The various functional components of the Forecast Tool are described in the following sections.

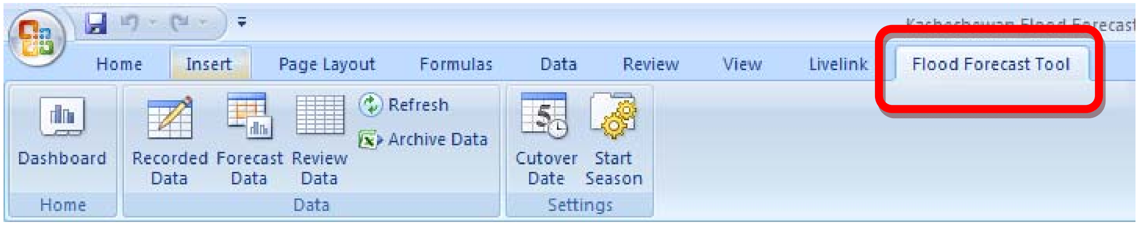
4.1.1 Dashboard

The Tool opens at the Dashboard, as shown below. The dashboard graphically illustrates the historical cumulative rainfall and snowmelt as well as the flow rate estimated at Hat Island. As the season progresses and additional data are entered, the level of flood risk is tracked and displayed.



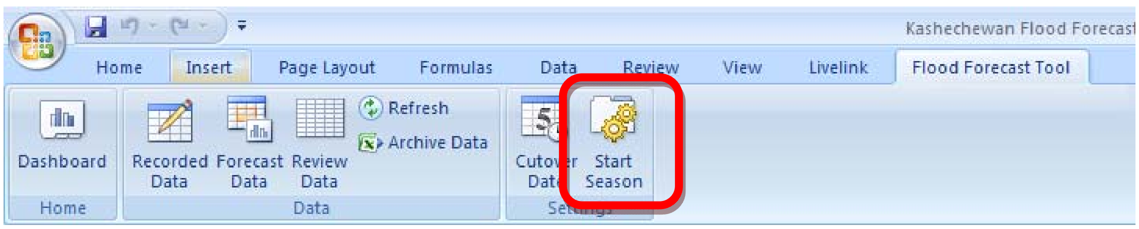
4.1.2 Microsoft® Excel Ribbon - Flood Forecast Tool Tab

When the Flood Forecast Tool is open in Microsoft® Excel 2007, the "Flood Forecast Tool" tab will become available, as shown below. This provides access to all of the functionality of the Flood Forecast Tool. Each of the buttons are discussed in the following sections.

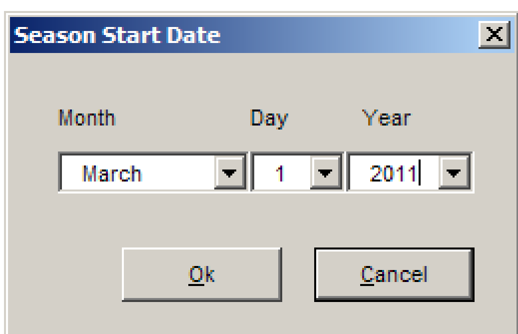


4.2 File Management

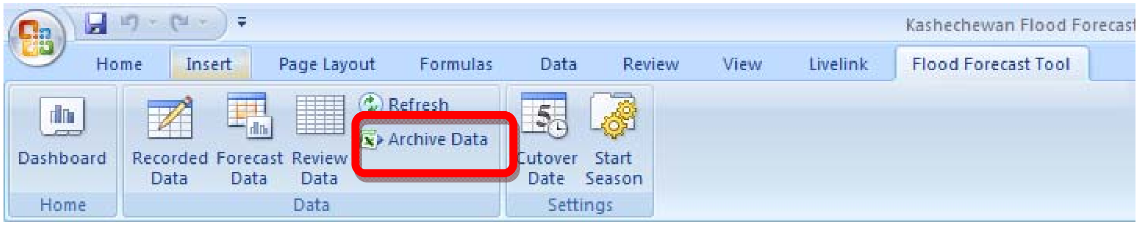
4.2.1 Start Season



At the beginning of the flood season, the tool is cleared of all of the data from the previous season and initiated to the correct start date. This is accomplished by clicking the "Start Season" button under the "Flood Forecast Tool" tab on the Microsoft® Excel ribbon. This action activates the "Start Season Date" graphical user interface (GUI) where the user enters the starting date for the new season (typically March 1st). As this action clears all of the current data, it is recommended that the user save the spreadsheet file with an appropriate name before proceeding.



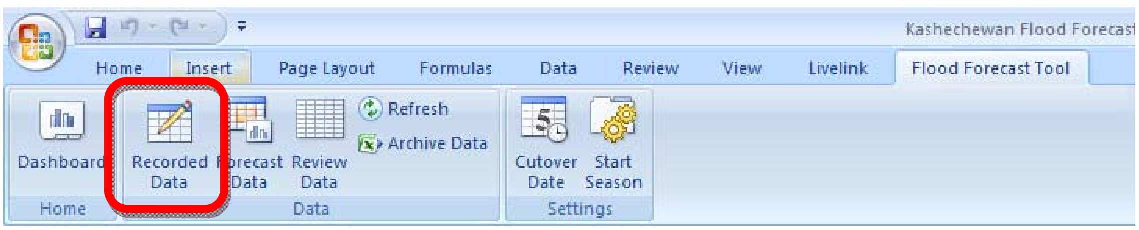
4.2.2 Archive Data



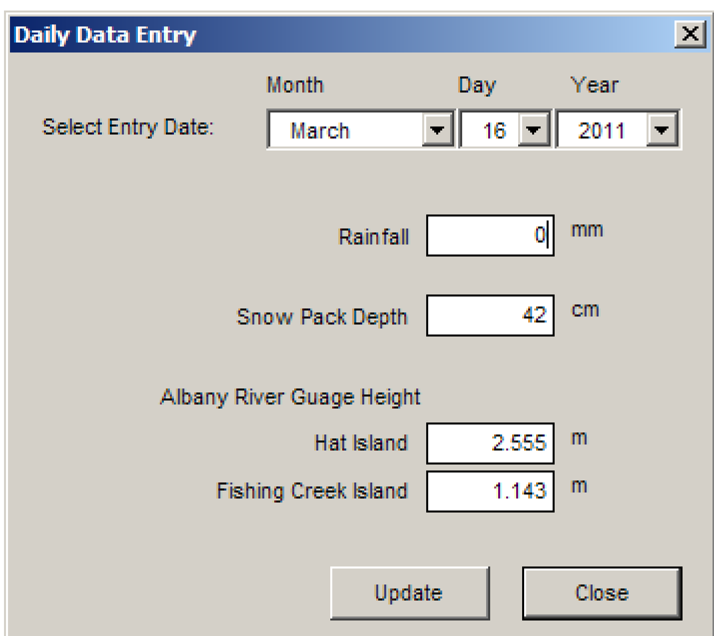
The “Archive Data” button creates a complete copy of the workbook, including all of the macros and worksheets. This allows the user to save the current state of the model as a reference point.

4.3 Data Entry and Review

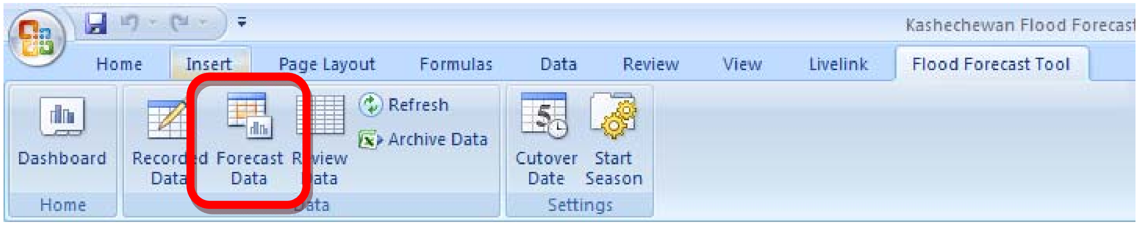
4.3.1 Recorded Data



The “Recorded Data” button under the “Flood Forecast Tool” tab on the Microsoft® Excel ribbon opens a GUI for the entry of the current date, recorded (to date) temperature, rainfall, snowpack and river level data using snow pack depth at Moosonee and the Albany River gauge heights for both the Hat Island and Fishing Creek Island stream flow gauges.



4.3.2 Forecast Data

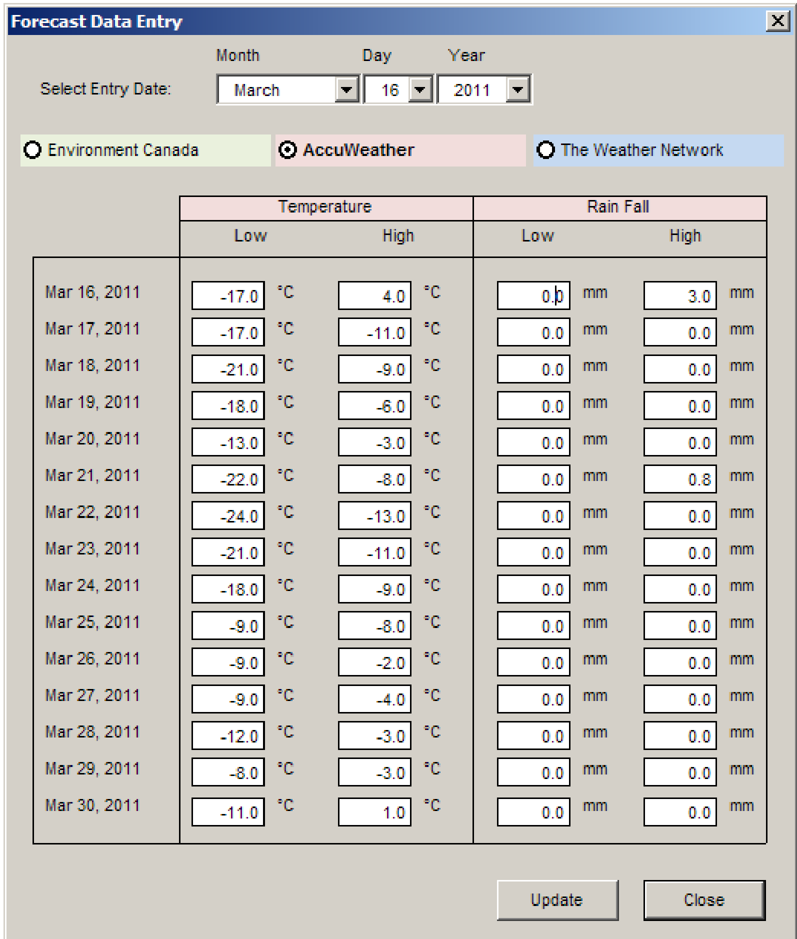


The “Forecast Data” button under the “Flood Forecast Tool” tab on the Microsoft® Excel ribbon activates the “Forecast Data Entry” GUI where the user can enter up to 15 days of forecast temperature and rainfall predictions from three sources; e.g., Environment Canada, AccuWeather.com and The Weather Network.

To begin, the user enters the day on which the forecast was obtained in the GUI’s drop down boxes. The user then selects the source of the forecast data and begins the data entry. There are four entry locations for each day:

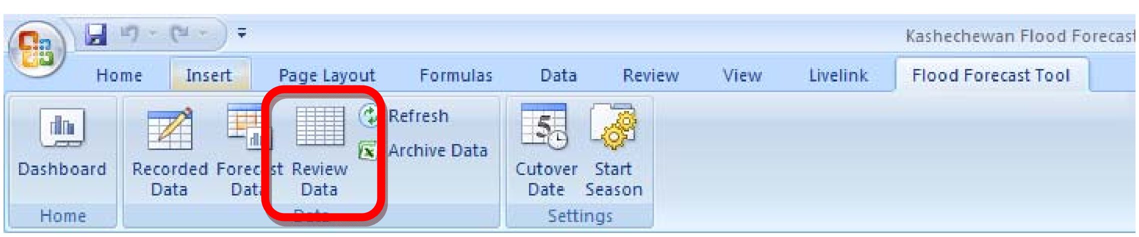
- low temperature – the forecast overnight low temperature, in °C
- high temperature – the daily high temperature, in °C
- low rainfall – the low prediction for rainfall, in mm
- high rainfall – the high prediction for rainfall, in mm.

EXAMPLE: Forecast data were obtained from AccuWeather.com on March 16, 2011. The user clicked the “Forecast Data” button under the “Flood Forecast Tool” tab on the Microsoft® Excel ribbon and entered the data as follows:



After the data entry task is complete, “Update” stores the data set and the GUI is closed to return to the dashboard. “Save” and “Refresh” secure the recently added data and update the plot on the dashboard.

4.3.3 Data Review



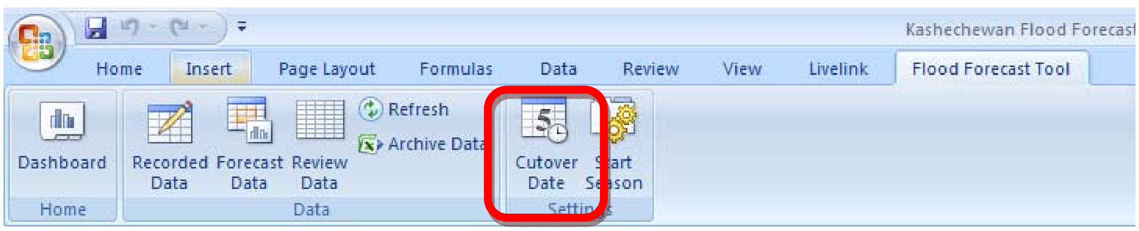
All of the data entered to date for the given year can be reviewed with the “Review Data” button under the “Flood Forecast Tool” tab on the Microsoft® Excel ribbon. This button closes the dashboard and opens the following worksheets for review:

- Daily Data – summarizes all of the recorded daily data that have been entered
- Daily Rainfall – summarizes the recorded rainfall data that have been entered
- Snowpack – summarizes the recorded snowpack data that have been entered

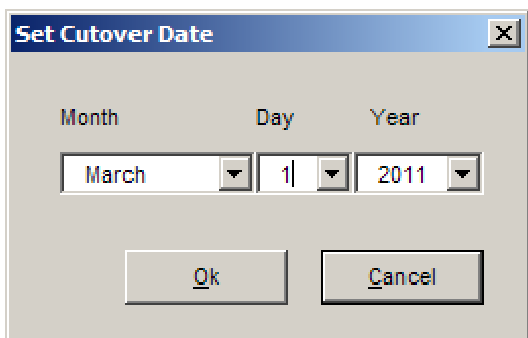
- Albany River Water Levels – summarizes the recorded Albany river water level that has been entered
- Temperature Forecast– summarizes all of the forecast temperature data that have been entered
- Rainfall Forecast – summarizes all of the forecast temperature data that have been entered
- Snow Melt Forecast – summarizes the forecast snowmelt calculations.

These worksheets are provided to allow checking of the data that have been input into the model. New data cannot be input and existing data cannot be modified in this location.

4.3.4 Cutover Date



The user can change the reference date of the tool by clicking the "Cutover Date" button.



Selecting a new Cutover Date has two effects:

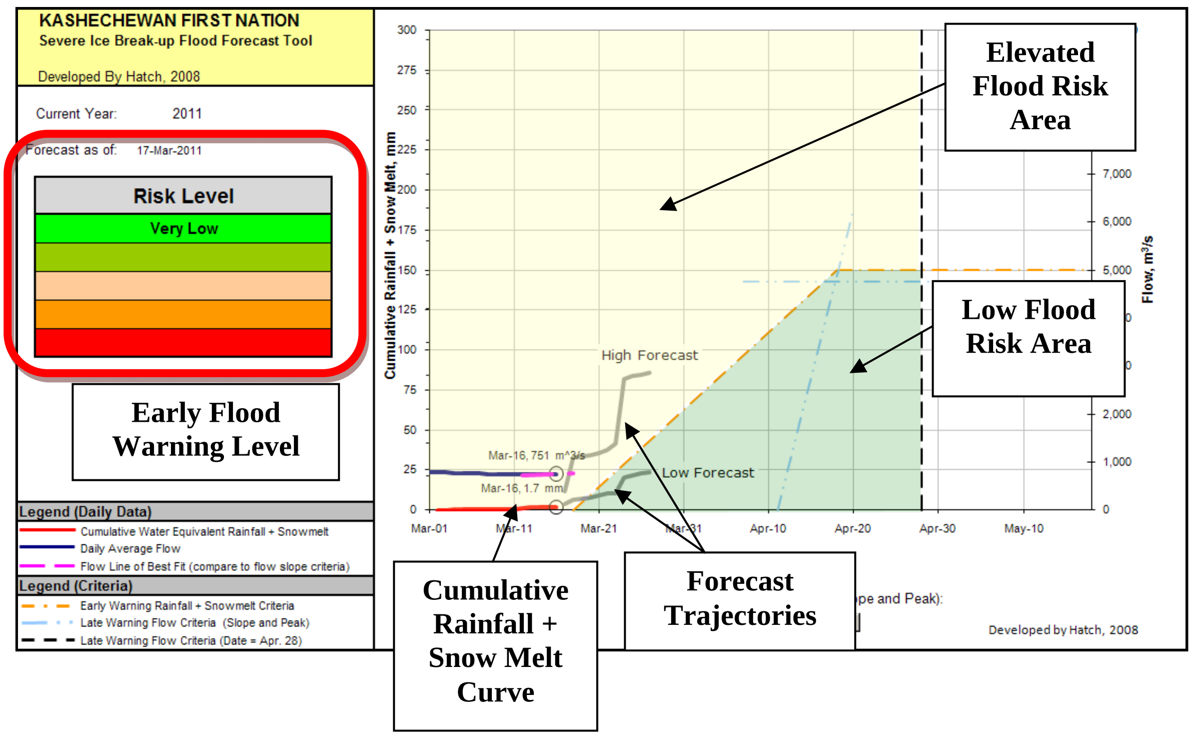
1. The default date on all data entry GUIs is set at the Cutover Date, and
2. The information presented on the Dashboard reflects the data entered up to this point. For example, this allows the user to review the forecast Cumulative Rainfall + Snow Melt trajectories for some date in the past for comparison to what actually occurred.

4.4 Display of Flood Risk Level on the Dashboard

The Flood Forecast Tool has two primary levels of flood risk warning; namely, the early warning criterion and the late warning criterion.

4.4.1 Early Warning

The early flood warning is based on cumulative rainfall plus snowmelt. This is shown on the Dashboard as a **RED** line. The GRAY High and Low Forecast lines show the forecasted trajectories of the line based on temperature and rainfall forecasts entered by the user. The green shaded area indicates the low risk area, while the yellow area indicates an elevated risk. The risk associated with the forecasted trajectory of the cumulative rainfall plus snowmelt curve is summarized on the Dashboard in the Risk Level Table to the left of the chart.



4.4.2 Late Warning

The late flood warning is based on the recorded flow in the Albany River at Hat Island. This is shown on the Dashboard as the **BLUE** line. There are three criteria used in determining the late warning level:

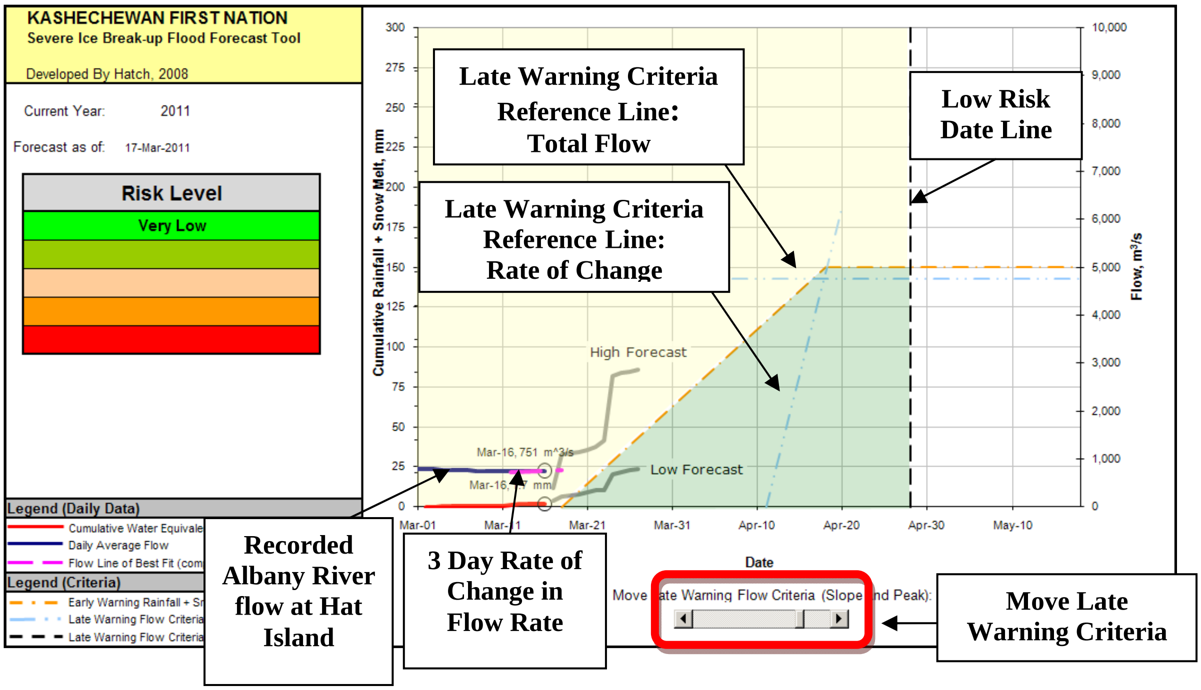
- The 3-day rate of increase in flow rate of 700 m^3/s/day
  - If the 3-day rate of change in flow rate (shown on the Dashboard by the **PINK** line) is above 700 m^3/s/day, there is a high risk of flooding.
- A threshold flow rate of 4750 m^3/s
  - If the flow in the Albany River exceeds 4750 m^3/s, there is a high risk of flooding.
- A calendar date of April 28th
  - Beyond April 28th, there is little risk of flooding due to ice jams.

The Late Warning Flow Criteria are shown graphically on the Dashboard. The **Dashed BLUE** lines indicate the critical slope for the rate of increase in flow as well as the critical total flow rate. The scroll bar below the chart can be used to position these lines to enable the user to check if the late warning criteria have been met.

If the PINK line (the actual rate of change of flow rate) is STEEPER than the **Dashed BLUE** line, then the first criterion is met and there is a high risk of flooding.

If the current flow in the river is above the horizontal **Dashed BLUE** line, then the second criterion is met and there is a high risk of flooding.

In both cases, if the date of April 28th is past, then there is a low risk of ice jam flooding.



5. Results of the Application of the Basic Tool in 2008 to 2013

The charts in the Figures 2 to 7 show the end result of application of the forecast tool for each year the tool has been in use. For comparison, Figure 8 shows the chart for the most severe flood of record; namely 2006.

The figures show the accumulation of rainfall and snowmelt (solid red line) relative to the previously described criterion (chain dotted yellow line), using the left ordinal scale. Also shown is a time series chart of daily flows in the Albany River at Hat Island (solid blue line) relative to the previously described flow criteria (double chain dotted faint blue line), using the right hand ordinal scale. It is important to note that the flows indicated in the figures are not the "official" Water Survey of Canada (WSC) flow estimates. They have instead been derived in "real time" from the WSC hourly levels (available in "real time") from the WSC internet web site using the open water rating curve for the station.

In 2008 (Figure 2), in which no flooding occurred at Kashechewan, both the early (150 mm) and late warning (4750 m^3/s) criteria are seen to have been exceeded 2 days before the 28th cut-off date, but in both cases by only a slight margin. This 'false positive' (i.e., criteria exceeded but no flood) is not surprising, given that the criteria were selected deliberately to err slightly on the safe side.

In 2009 (Figure 3), in which no flooding occurred, neither the early nor the late warning criteria was exceeded before the 28th cut-off date, although both values came close to their critical values immediately after the 28th. That is, the forecast tool yielded a 'true negative' result.

In 2010 (Figure 4), in which no flooding occurred, both the cumulative rainfall/snow melt and flow rate fell well short of their respective criteria. This occurrence was the consequence of there being less than half the normal snow pack depth at the beginning of the break-up season and the paucity of rainfall during the season.

In 2011(Figure 5), in which no flooding occurred, both the rainfall/snowmelt and flow rate again fell well short of their respective criteria. This benign flood season was also the result, in part, of the relatively low snow accumulation.

In 2012 (Figure 6), in which no flooding occurred, the cumulative rainfall/snow melt line tracked well below the critical value of 150 mm for the flood season. However, on March 23rd the estimated daily average flow rate at Hat Island exceeded the threshold rate of 4750 m^3/s, hitting 4913 m^3/s, and the 3-day rate of increase of flow prior to the 23rd was 1710 $m^3/s/day$ or 1010 $m^3/s/day$ greater than the criteria limit. The hourly peak water level on the Albany River at Hat Island was 7.259 m. While this level implied a flow rate over 8900 m^3/s under open water conditions, the increased level was likely due to ice movement and/or minor jamming in the vicinity of the gauge. A similar water level peak occurred above Fishing Creek Island approximately 12 hours later on March 24th and, again, was likely caused by local jamming in the vicinity of the water level gauge, not a real increase in flow. Following the peak on March 23rd the water level at Hat Island fell to 3.5 m at the end of April.

The 2012 event was another example of a 'false positive' where criteria were exceeded yet no flood resulted. With the presence of ice influencing the gauge levels, the forecast tool procedure over-estimates discharge values, thus yielding a conservative estimate for the purposes of ice jam flood forecasting for Kashechewan. That is, with this procedure flow values will appear to be approaching or exceeding the critical value when they are in reality somewhat less. This may in fact be a moot issue, as a perfunctory comparison of historic flow estimates unadjusted for the presence of ice and the corresponding WSC published values indicates the ice moves out of the Hat Island gauge site reach of the river when the flow exceeds about 3000 m^3/s. Thus, estimates of flow in excess of, say, 4000 m^3/s might reasonably be expected to be only a little biased by the influence of ice at the gauging site. This, however, requires verification.

In 2013 (Figure 7), in which no flooding occurred, the cumulative rainfall/snow melt line tracked well below the critical value of 150 mm for the entire flood season. This year was characterized by a late breakup with daily average temperatures lower than normal and persisting well into April. Snow pack accumulation this year was higher than average as illustrated on April 15th when the snow pack depth was recorded to be 50 cm; a depth which had only been equaled or exceeded 8% of the time between 1955 and 2012. Ice breakup occurred approximately two weeks later than previous years and continued beyond the calendar date criteria of April 28th. The 3-day rate of rise of flow ending May 5th exceeded the limit of 700 $m^3/s/day$ reaching 1004 $m^3/s/day$ and indicated a rapid water level increase. Although the cumulative rainfall over the previous 2 days was 14 mm, the cause of the water level increase was relatively uncertain until The Ministry of Natural Resources (MNR) conducted aerial observation of the river. On May 6th MNR provided a Flood Watch Report for the Albany River and indicated that the water level rise at Hat Island was the result of local jamming and not an increase in flow. Hat Island likely served to arrest ice movement (i.e., jamming) during breakup causing water to rise at the gauge upstream of the island. Therefore, the flow estimate, which was based on open water conditions, was likely overestimated and not be relied upon during the flood-monitoring program.

The monitored events of 2008 to 2013 realized no flooding of the town site. By contrast, the spring break up of 2006 produced a severe ice jam that flooded the community and prompted its evacuation. The trajectory of the cumulative rainfall and snowmelt and the runoff at Hat Island during the 2006 is illustrated in Figure 8. In this year, the cumulative rainfall and snowmelt was seen to exceed the indicated criterion by a large margin well before the realization of the previously noted critical flow rate of about 4750 m^3/s. Although this event occurred prior to the development of the tool, it never-the-less serves to illustrate the difference between a flood event and a non-flood event.

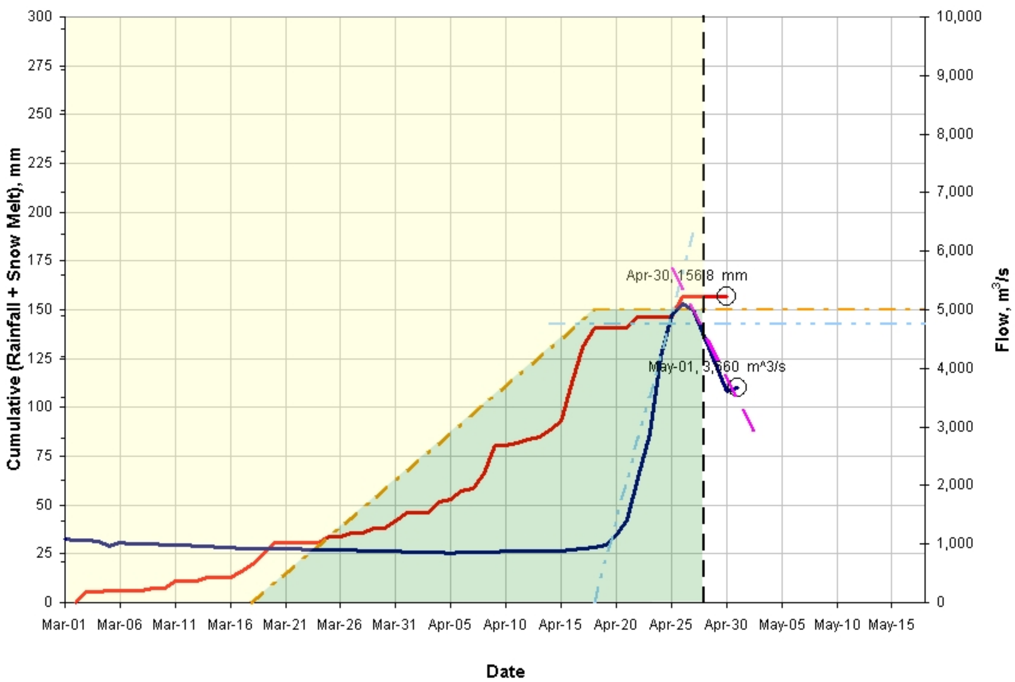


Figure 2 - 2008 Break-up Season Final Result

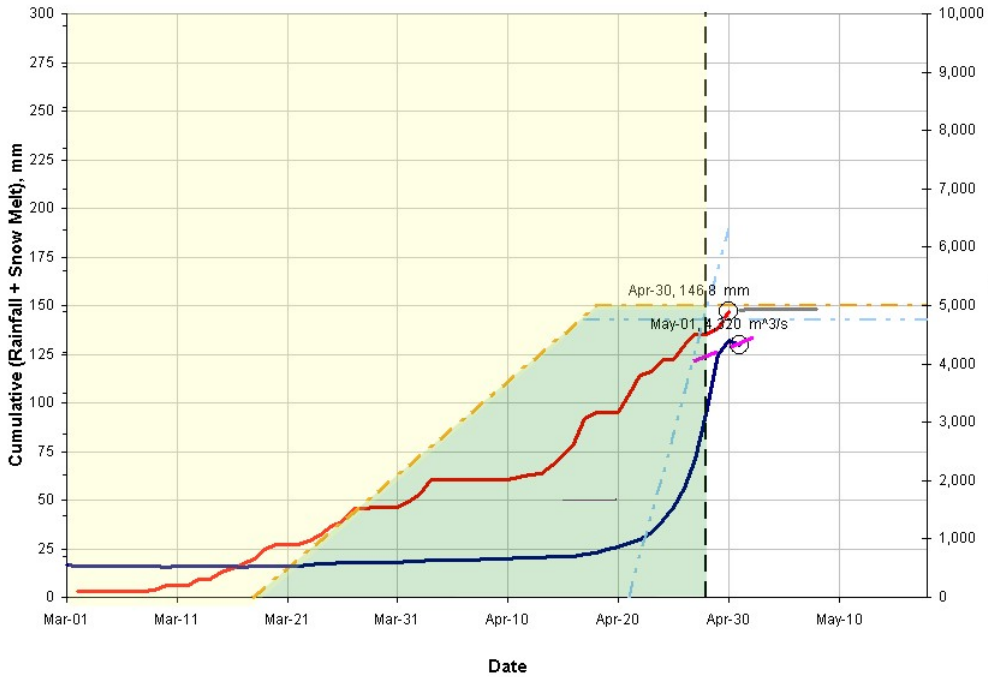


Figure 3 - 2009 Break-up Season Final Result

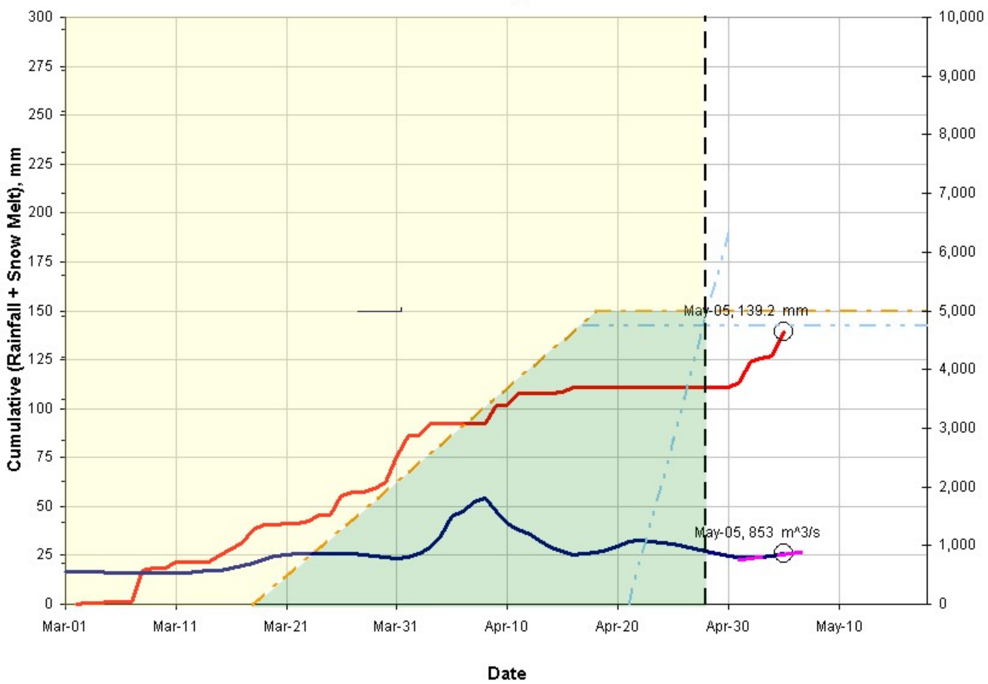


Figure 4 - 2010 Break-up Season Final Result

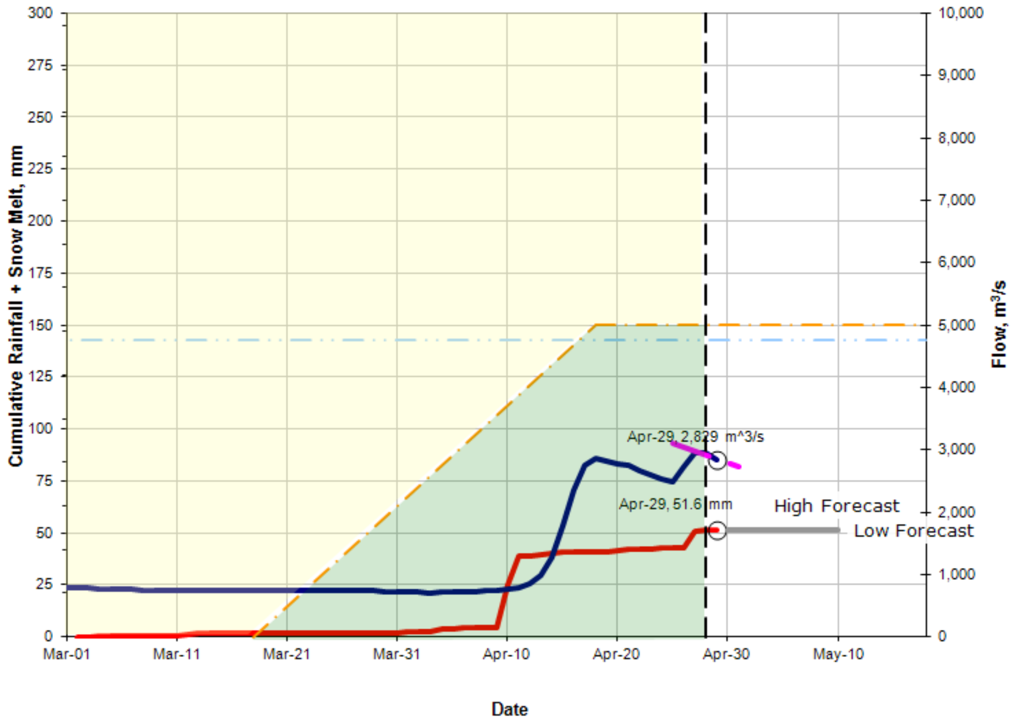


Figure 5 - 2011 Break-up Season Final Result

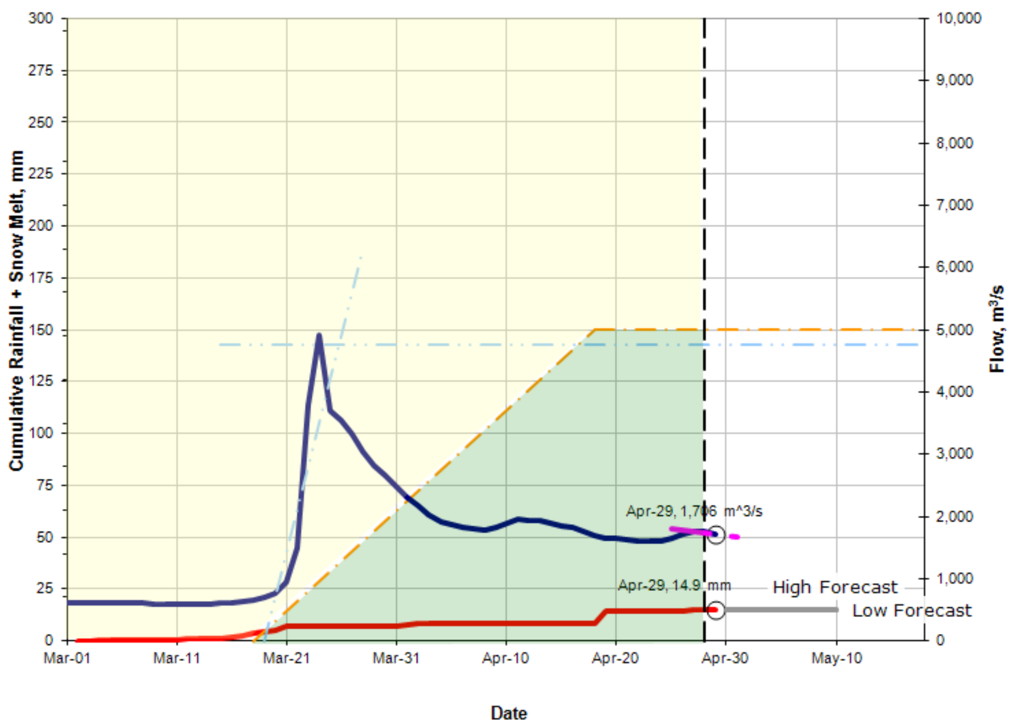


Figure 6 - 2012 Break-up Season Final Result

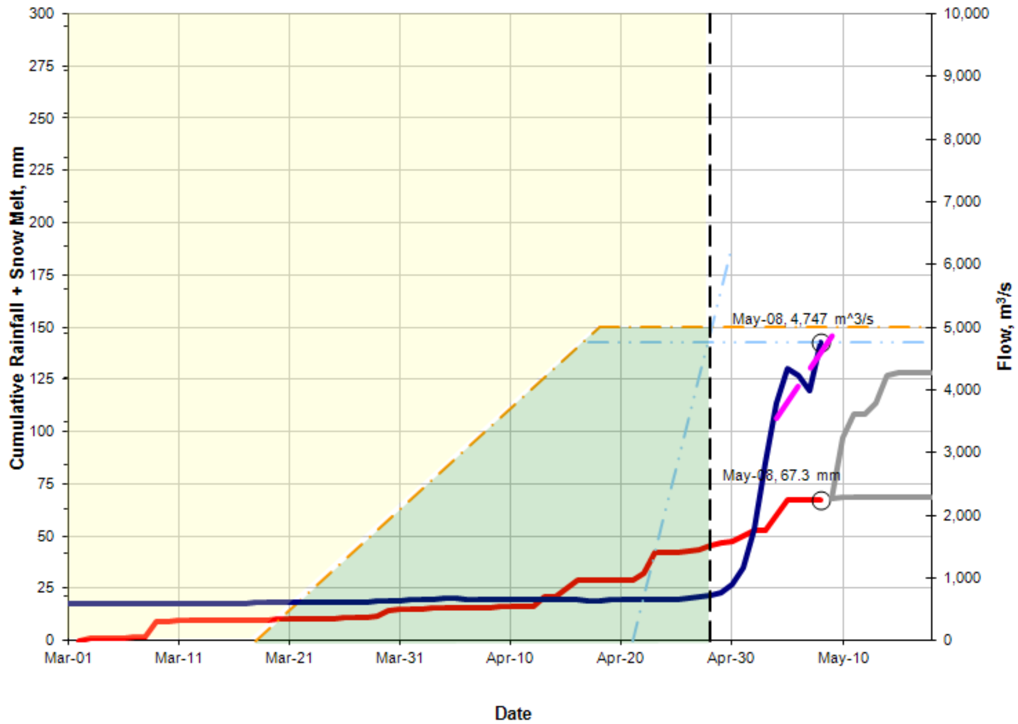


Figure 7 - 2013 Break-up Season Final Result

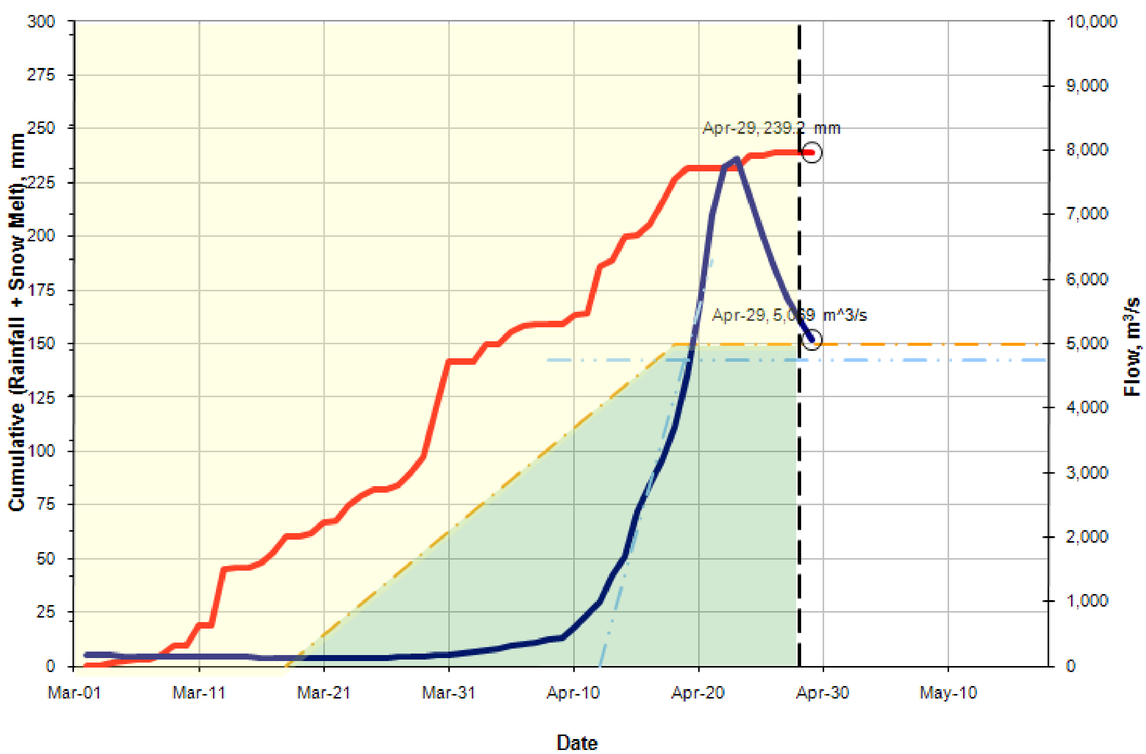


Figure 8 - 2006 Break-up Season Final Result

6. Discussion and Conclusions

Analysis of historic data and application of the flood forecast tool during the 2008 to 2013 break-up seasons strongly indicate that there will be serious risk of ice jam flooding of the Kashechewan Town Site only if the total snowmelt and rainfall accumulation exceeds 150 mm. While a total of more than 150 mm of snowmelt and rainfall is necessary to cause spring break-up flooding of the Kashechewan Town Site, it is not the only contributing factor to cause flooding.

The historic data also strongly indicate that there will be no ice jam flooding of the Kashechewan Town Site if the peak flow rate at the Hat Island metering station does not exceed 4750 to, say, 5000 m^3/s before the 28th of April. Corollary: The rate of snowmelt and rainfall accumulation must exceed a certain critical value in order to realize Hat Island flow rates in excess of the critical range of values.

Analysis of historic data indicates that to realize the critical flow rate, the accumulated snowmelt and rainfall must exceed the critical 150 mm value before April 18th. The 'near miss' flood experiences in 2008 and 2009 tend to support this criterion although the April 18th date may need to be adjusted on the basis of future experience, this date having been determined by drawing an envelope to a rather limited number of actual flood experiences.

The flood seasons of 2010 and 2011 were preceded by low snow accumulations and were relatively innocuous with little rain falling in the spring. The antecedent conditions of the 2012 event were similar to 2010 and 2011. However, much of eastern Canada including Ontario experienced above normal temperatures in March resulting in a depleted snow pack March 21st. The seemingly high flows at Hat Island on March 23rd could only have been the result of two things; namely, an ice jam downstream or a high rate of snowmelt and/or rainfall. Acknowledging that the snow pack was gone by the 23rd and no significant rainfall occurred in the preceding days, the likely cause of the high water level at Hat Island was ice jamming. Unfortunately, the condition of the river on the 23rd (to our knowledge) was not witnessed or recorded. Therefore, the ice jamming could not be confirmed and this lack of evidence served to illustrate the need to visually monitor the Albany River at Hat Island with a web camera.

A similar situation was witnessed in 2013 when the breakup event included a rapid water level increase at Hat Island in early May. With the snow pack depleted and only a nominal amount of rainfall the previous two days, the only plausible explanation for the water level increase was jamming at the gauge. MNR confirmed this hypothesis with photo evidence and this evidence emphasized the need to visually monitor the Albany River at Hat Island with a remote camera.

Forecasting of snowmelt and rainfall is fraught with uncertainties. In spite of the forecast uncertainties, experience to date suggests that the forecast tool provides a systematic procedure for assembling readily available data as the basis for making as rational an assessment as is possible of the ice jam flooding risk on the basis of clearly defined criteria.

While the forecast tool and the snowmelt and rainfall forecasts clearly comprise an imperfect procedure because of the inherent uncertainties in snowmelt and rainfall forecasts, they are deemed never the less to be a useful aid in preparing an assessment of the flood risk each break-up season and therefore, in reaching a timely decision on the need, or otherwise, for evacuation of the Kashechewan Town Site.