REVIEW OF CLEVER MODEL'S PERFORMANCE FOR GRANBY RIVER NEAR GRAND FORKS DURING MAY 10, 2018 FLOODING

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Abstract. The Granby River near Grand Forks (08NN002), British Columbia, Canada recorded a historical record-breaking flood on May 10, 2018. The CLEVER Model is the major flood forecasting tool used in the BC River Forecast Centre since 2015. In this paper, the CLEVER Model is introduced and the model's performance during the flooding event is reviewed. The model forecast the flood peak and peaking time with a high degree of accuracy two days before the hydrometric station recorded the peak flow. In the forecasts issued on May 8, 9, and 10, 2018, the forecast errors of peak are only 10.3%, -1.5% and 4.7%, respectively, and the forecast errors of peaking time are only 12, 8 and 12 hours later than the actual peaking time, respectively.

Keywords: real-time flood forecasting, hydrologic model, watershed modelling

1. Introduction

Floods are common in British Columbia (BC), Canada and flood risks are even higher for BC's riverside communities. E.g., on May 10, 2018 after about a week of high temperatures over 20 ^{o}C and three days of rainfall with a total amount about 50 mm, Grand Forks, BC, a community about 520 kilometres east of Vancouver, was hit by the worst flood in 70 years according to the CTV online news (CTV, 2018a). Homes were submerged in brown, murky flood water, and the water level was about 0.6 metres higher than that had ever been recorded. As a direct consequence of this high water level, thirty people were rescued by boats in the town (CTV, 2018a). This worst flood in Grand Forks since 1948 forced the community to evacuate about 3,000 homes (CTV, 2018b). Accurate flood forecasting always plays an important role in helping riverside communities prepare for flooding and mitigate flood hazards. This requires a sophisticated real-time flood forecasting system. The core element of such a system is a numerical computer model or a hydrologic model.

Over the past decades, many hydrologic models have been developed, and especially in the recent 15 years, flood forecasting techniques have advanced considerably. Data-driven models, particularly the neural networks (NN) models have been widely used in flow forecasting due to their simplicity. The disadvantages of data-driven models for flood forecasting are their requirements of long-term data records and the site specificity of the derived relationships (Hapuarachchi et al., 2011). Besides the data-driven models, recently developed lumped models are also used for flood forecasting. One of the limitations of using lumped models for flood forecasting is their coarse resolution (Hapuarachchi et al., 2011). On the other hand, a number of physics-based, distributed hydrologic models have been developed in recent years. However, the physics-based, distributed models require intensive watershed data and much longer computing time, which limit their application to real-time flood forecasting.

The majority of BC watersheds are located in the interior and streamflows of these watersheds belong to the snowmelt-dominated (nival/nivo) regime (Bonsal et al., 2019). Some may be snow-and-glacier- (nivo-glacial) dominated, e.g. the Upper Columbia River, and some snow-and-rain- (nivo-pluvial) dominated, e.g. the Peace River (Jost and Weber, 2012). Most of these watersheds in BC are large-scale watersheds. Hydrologic models for large-scale watersheds are always more complicated and consume longer computing time in order to address the heterogeneity issues posed by the large watershed scale. On the other hand, real-time flood forecasting must be very time efficient; or the shorter computing time, the better. Any hydrologic models for real-time flood forecasting in BC must be capable of tackling the conflict between the large watershed scale and time efficiency required by real-time flood forecasting.

Lyons (1976) presented a computer program - SIMPAK, which is probably the first computer model that was applied to the Fraser River, the largest watershed in BC, for the purpose of flood forecasting. The methodology of SIMPAK is the simple curvature-slope method applied to the observed hydrograph and thus large errors were present in the forecasts. A relatively sophisticated model - the UBC Watershed model (Quick and Pipes, 1977) was developed for daily streamflow forecasting in the Fraser River system. The model was recommended to run for a complete annual hydrological cycle. It does not include an open channel routing component and if it is required, a very simple lag-and-route model relying on the wave travel time was recommended. These characteristics of the UBC Watershed Model limit its application to real-time flood forecasting in the entire province of BC.

The Channel Links EVolution Efficient Routing (CLEVER) Model was developed in the BC River Forecast Centre in 2013 and has been the major real-time flood forecasting tool for the freshet season in the BC River Forecast Centre since 2015 (Luo, 2015). It has been developed for specific regions/basins and shown to be suitable for western snowmelt-dominated watersheds, mountains and Prairie region (Zahmatkesh et al., 2019). The CLEVER Model is a very time-efficient model, which requires only 4 minutes for a run and 15 minutes to generate a color-coded map and charts with a hydrograph and a table for a total of 108 stations/sub-basins on a desktop computer with a CPU clock of 3.20GHz. More details about the CLEVER Model are given in the next section.

There are two rivers flowing across Grand Forks, the Kettle River and the Granby River. However, the latter is the only river that Water Survey of Canada (WSC) has a hydrometric station installed near the town; that is the Granby River near Grand Forks (08NN002). Therefore, the discharge data from this station was used to evaluate the performance of the CLEVER Model during the historical record-breaking flooding event on May 10, 2018. The CLEVER Model had been run daily and consecutively during this unprecedented flooding event and all the model data and outputs had been saved on the modelling computer. This provides all the necessary information for the post-event evaluation of model performance.

In the coming sections, the CLEVER Model, data assimilation, model calibration and verification, the forecasting process, the Granby River watershed and model set-up and the May 10, 2018 flooding event at the Granby River near Grand Forks (08NN002) are given briefly, and the model performance during this flooding event is reviewed in detail.

2. The CLEVER Model

The CLEVER Model is a real-time flood forecasting system developed for BC watersheds (Luo, 2015). The model is capable of tackling the modelling conflict between the large watershed scale and time efficiency required by real-time flood forecasting. According to the classification in Aral and Gunduz (2006), the CLEVER Model is a hybrid model, which is a semi-distributed watershed model including a lumped sub-model and a distributed sub-model which are linked to each other. In the CLEVER Model, a large-scale watershed is split into a number of relatively homogeneous sub-basins which are further simplified into individual nodes. A lumped and conceptual watershed routing sub-model is applied to the sub-basin nodes, which are connected to the channel links. A one-dimensional, distributed open channel routing sub-model is applied to the channel links. The two sub-models are integrated in the model and the watershed routing sub-model provides inputs as boundary conditions to the open channel routing sub-model.

In the lumped, conceptual watershed routing sub-mode, the water balance of each sub-basin is calculated at the centre of the sub-basin, and is given by Equation (1):

$$W = R + M + G - E - I \tag{1}$$

in which W (≥0) is the net water input to the sub-basin in mm/hour, and this unit is used for all terms on the right-hand side of the equation, R is the rainfall, M is the snowmelt, G is the groundwater seepage to the system or the channel link, E is the evapotranspiration, and I is the infiltration to the unsaturated soil and the recharge to the groundwater.

The revised temperature-index method that is adapted to the hourly time step is used for the snowmelt simulation in this study and is given by Equation (2):

$$M = c_a c_d M_f (T_i - T_b)^\beta \tag{2}$$

where M is the snowmelt in an hour (mm/hour), M_f is the melt factor, T_i is the air temperature at the time step (hour), T_b is the base temperature, at which snow starts to melt, c_a is a correction factor related to the snowpack coverage area over the sub-basin, c_d is the correction factor related to the ordinal date in year, and β has a value between 0 and 1.

In the open channel routing sub-model, the kinematic wave simplification of the Saint-Venant Equations is employed to govern the open channel flow and is given by Equations (3):

$$\begin{cases} \frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \\ S_0 = \frac{n^2 Q^2}{A^2 R^{4/3}} \end{cases} \tag{3}$$

in which Q is the flow, x and t are the spatial and temporal coordinates, respectively, A is the section area, S_0 is the friction slope, n is the Manning roughness coefficient, and R is the hydraulic radius and is given by $R = A/P$ where P is the wet perimeter.

Using the temporal average forward-difference approximation for the first term and the spatial averaged forward-difference approximation for the second term, the continuity equation in Equations (3) becomes:

$$\frac{1}{\Delta x}\left[\frac{Q_{i,j}+Q_{i,j-1}}{2} - \frac{Q_{i-1,j}+Q_{i-1,j-1}}{2}\right] + \frac{1}{\Delta t}\left[\frac{A_{i,j}+A_{i-1,j}}{2} - \frac{A_{i,j-1}+A_{i-1,j-1}}{2}\right] = 0 \tag{4}$$

in which *i* and *j* denote the spatial and temporal points on the coordinates, respectively, (i, j) is the unknown node, and Δx and Δt are the spatial and temporal steps.

Discretizing and rearranging the momentum equation in Equations (3) produces:

$$Q_{i,j} = \frac{1}{n}\sqrt{S_0} R_{i,j}^{2/3} A_{i,j} \tag{5}$$

Assuming:

$$V_{i,j} = \frac{1}{n}\sqrt{S_0} R_{i,j}^{2/3} \tag{6}$$

and substituting Equation (6) into Equation (5), it becomes:

$$Q_{i.j} = V_{i,j} A_{i,j} \tag{7}$$

Substituting Equation (7) into Equation (4) with some rearrangements gives:

$$A_{i,j} = \frac{\Delta t\left(Q_{i-1,j}+Q_{i-1,j-1}-Q_{i,j-1}\right)+\Delta x\left(A_{i,j-1}+A_{i-1,j-1}-A_{i-1,j}\right)}{\Delta t V_{i,j}+\Delta x} \tag{8}$$

Equation (8) is unsolvable because $V_{i,j}$ on the right-hand side is also an unknown. An efficient numerical scheme similar to the Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) (Patankar and Spalding, 1972; Luo, 2007) is introduced so that Equation (8) can be solved iteratively. Because of the scope of this paper, details of the solution of Equation (8) is not given here and can be found in Luo (2015).

The spatial step for a channel link is set to a distance between 1 km to 20 km dependent on the length of a channel link so that the channel link has as few spatial grids as possible but no fewer than two. And, in order to capture the flood peaking time on a day, an hourly time step is adopted for both the distributed open channel routing sub-model and the lumped watershed routing sub-model.

3. Data assimilation

There are three categories of input data for the model, (1) observed flow data, (2) observed climate data, and (3) forecast climate data.

The observed flow data, mostly discharges but also water levels for some stations, are the provisional real-time hydrometric data which are downloaded from WSC's DataMart site. These data have different time steps for different stations, from 5 minutes to several hours. Missing data are always present. The model requires both hourly and daily time series for 20 days immediately before the forecasting day for the model calibration. Flow data pre-processing systems, which are independent of the model, were developed for data download and treatment.

There are three sources for the observed climate data, XML data from Environment and Climate Change Canada (ECCC), and climate data from automated snow weather stations and fire weather stations from the province of BC. These climate data include daily precipitation and maximum and minimum temperatures. Missing data are also always present. Independent systems for observed climate data download and missing data treatment were also developed. The daily data are distributed into hourly series in the model by using historical typical distributions for temperatures and precipitation.

The forecast climate data is the10-day numerical weather prediction (NWP) GRIB2 data from the regional and global models of Canadian Meteorological Centre (CMC), ECCC. Scripts were written to download these data from ECCC's DataMart site automatically. These data are downscaled to the locations of the climate stations used in the CLEVER Model by using the wgrib2, which provides a tool of "regridding, interpolating to new grids" (NOAA, 2016). The default method of this tool is the bilinear method for interpolation.

4. Model calibration and verification

There are three categories of model parameters which are subject to the model calibration. The first category includes the snowmelt parameters in Equation (2), the melt factor (M_f), correction factor related to the snowpack coverage (c_a), correction factor related to the ordinal date in year (c_d), and power of temperature (β). The second category is related to the input precipitation, including a factor (P_f) and an increment (dP) which are used to modify the input precipitation for each of the climate stations. The third category is watershed parameters related to Equation (1), including the infiltration rate (i), evapotranspiration rate (e), and groundwater seepage rate (g). In the CLEVER Model, each of the watersheds or sub-basins has its own set of parameters which are subject to the model calibration.

During the real-time forecasting, the model is calibrated visually for each of the watersheds for every run on each day. A 20-day series of observed flow immediate before the modelling day is compared with the simulated hydrograph. The above parameters are changed manually based on the comparison. Statistical analysis for model calibration is conducted after the freshet season by using the coefficient of model efficiency (C_e), the coefficient of determination (C_d) and the percentage volume difference (dV) (Nash and Sutcliffe, 1970). For the 2018 freshet (from April 1 to August 1, 2018), the statistical analysis of model calibration shows that 70% of the 100 modelled stations (excluding the regulated stations) have a C_e greater than or equal to 0.85, 73% have a C_d greater than or equal to 0.85, and 88% have a dV smaller than or equal to 10%. This shows that the model was well calibrated.

The model produces a 10-day hourly forecast, for which observations are not available when the forecast is produced. Therefore, verification of accuracy of the 10-day model forecast is carried out statistically only after the freshet season comes to an end by using the relative mean absolute error (E_{ra}) and the square of the Pearson product moment correlation coefficient (r^2) (Lettenmaier and Wood, 1992). For the 2018 freshet, the statistical analysis of model forecast shows that 61% of the 100 modelled stations have an E_{ra} smaller than or equal to 30%, and 36% have an r^2greater than or equal to 0.5. These results are not as good as the calibration but good enough because that the 10-day trend of streamflow is difficult to forecast (Luo et al., 2015).

5. Forecasting process

In order to incorporate the latest observation data, such as the observed flow data up to 7 a.m. on the forecasting day, into the model, the data downloading and processing systems are scheduled to finish running by 9:30 a.m., and then the CLEVER Model begins to run. The running period of the model is 30 days, including 20 days of observation and 10 days of forecast. This means that the model parameters are maintained constant in 30 consecutive days. However, interim values of all the model variables at all time steps are saved in a temporary file since the first run of the model in the year. Any new run of the model within 30 days will picked up the interim values of the model variables from the previous runs. A consecutive estimated hydrograph for each of the watersheds from the first run to the last run is generated for the model calibration.

After the model is calibrated for each run, a 10-day forecast hydrograph at an hourly interval starting from the last hour, at which observed flow data are available, is generated. It is usually difficult to match perfectly the simulated and observed discharges (water levels for some stations) at a specific point of time through model calibration. In order to acquire such a perfect match, the simulated hydrograph has to be shifted by a constant increment, which is the calibration bias at this point of time. Details of forecast process can be found in Luo (2015). In 2018, the model produced and issued the 10-day hourly forecasts for a total of 108 stations across the province by 11 a.m. on most days when the model was run.

6. Granby River watershed

The Granby River is a tributary of the Kettle River which is originated in BC. The Kettle River runs across the Canada-US border flowing south into Washington State, USA, then runs back to BC, Canada at Grand Forks just upstream of the confluence with the Granby River, crosses the Canada-US border again flowing south into Washington State, and finally joins the Columbia River. The length of the Granby River is about 100 km and the watershed area is about 2,100 km^2, most of which is covered by vegetation. The elevation of this mountainous watershed ranges from 500 m to 2,200 m. During the freshet season, the streamflow of the Granby River belongs to the snowmelt-dominated (nivo) regime, and some years it may be snow-and-rain- (nivo-pluvial) dominated.

There is a WSC hydrometric (flow) station located at the watershed outlet, the Granby River near Grand Forks (08NN002). There are two fire-weather station stations, Nicoll (NCL, ID: 157, elevation 866 m) and Eight Mile (ETM, ID: 110, elevation 1338 m), located in the watershed. Figure 1 shows the Granby River watershed and the locations of the flow station and the two climate stations.

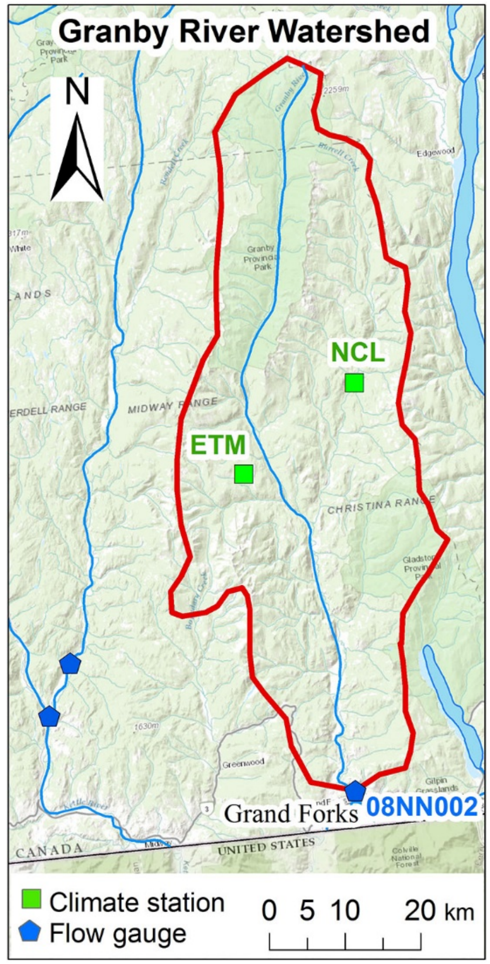

Figure 1. Granby River watershed and flow and climate stations.

7. May 10, 2018 flooding event at Granby River near Grand Forks

Based on observations during this period, continuous high temperatures up to 26.6 ^{o}C from May 3 to May 8, 2018 and about 50 mm three-day total rainfall from May 8 to 10, 2018 triggered historical record-breaking flood at the WSC hydrometric station, the Granby River near Grand Forks (08NN002), which recorded a flood of 524 m^3/s at 3:55 p.m. (PST), May 10, 2018. This station has a long history of flow observation since 1914, however the observation had been carried out inconsecutively. There is a total of 58 years of daily discharge data. However, annual instantaneous peaks have been recorded only since 2005. The estimated historical instantaneous maximum flow is 420 m^3/s, which occurred on June 4, 1914. The recent recorded maximum annual instantaneous flood is 396 m^3/s, which occurred at 12:00 noon (PST) May 21, 2006. The flood on May 10, 2018 surpassed both these records and is slightly greater than the 500-year return period flood (522.1 m^3/s).

Figure 2 shows the plots of hydrographs from May 1 to May 30, 2018 of (1) BC River Forecast Centre's record of provisional observed discharge data downloaded from WSC's DataMart site, and (2) the provisional observed discharge data downloaded from the WSC real-time hydrometric data site as of October 11, 2018. WSC may change/correct the provisional observation data after site measurements are carried out or other quality control measures are taken. The figure also shows the estimated historical maximum instantaneous flow (420 m^3/s) and the 500-year return period flood (522.1 m^3/s) for comparison. The value of the 500-year return period flood was obtained from the frequency analysis using all the available data before 2018.

This unprecedented flooding event in the Granby River provided a rare opportunity to examine the model's capability to its full extent.

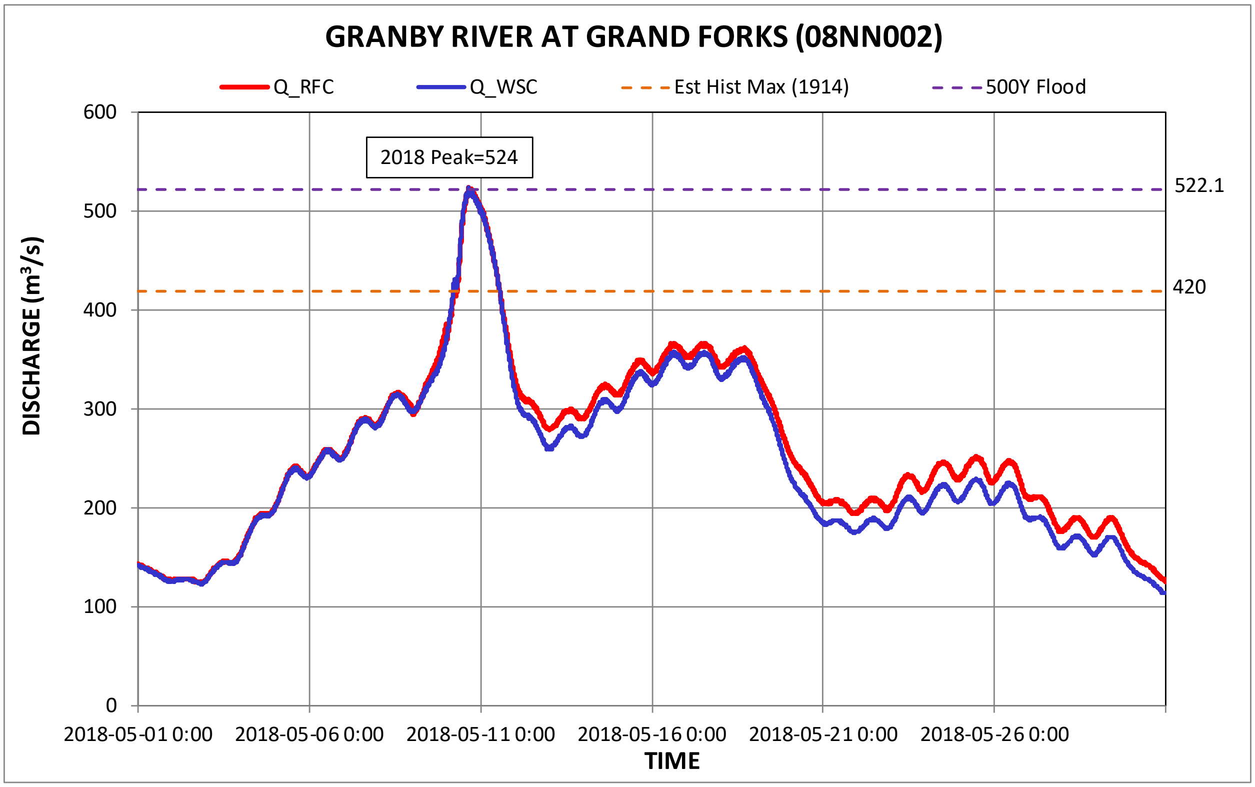

Figure 2. Provisional discharges for Granby River near Grand Forks (08NN002) from May 1 to May 30, 2018.

Note: Q_RFC – BC River Forecast Centre's data record of WSC's real-time provisional discharge. Q_WSC – Provisional data downloaded from Water Survey of Canada's real-time hydrometric data website as of October 11, 2018. Est Hist Max (1914) – Estimated historical maximum instantaneous flow occurred on June 4, 1914. 500Y Flood – 500-year return period flood.

8. Model performance of real-time forecasting during May 10, 2018 flooding

The CLEVER Model had been run from January 21 to August 1, 2018 on most weekdays and daily during the critical periods of the 2018 freshet season (from April to June). Post-freshet statistical analysis shows that the model was well calibrated for the Granby River watershed (Ce = 0.945, Cd = 0.946 and dV = -2.268%). Figure 3 shows the hydrographs of model calibration of hourly output and hourly-average provisional observed discharge from April 1 to June 30, 2018. It can be seen from this figure that the estimated hydrograph (red dash line) fits the provisional observed hydrograph (blue line) well.

The CLEVER Model had been run daily consecutively from May 1 to May 25, 2018. Figure 4 shows the model outputs of forecast from May 1 to May 10, 2018. These outputs are the actual/real-time products from the model as they were generated on the forecasting days rather than ones re-constructed afterward. From Figure 4, it can be seen that, from May 2, 2018, the model started forecasting a high peak for May 9 to May 12. From May 6, 2018, the model started forecasting a very high peak (463.2 m^3/s) in the early morning of May 11, 2018, which surpassed both the recorded maximum annual instantaneous flow (396 m^3/s, May 21, 2006) and the estimated historical maximum instantaneous flow (420 m^3/s, June 4, 1914).

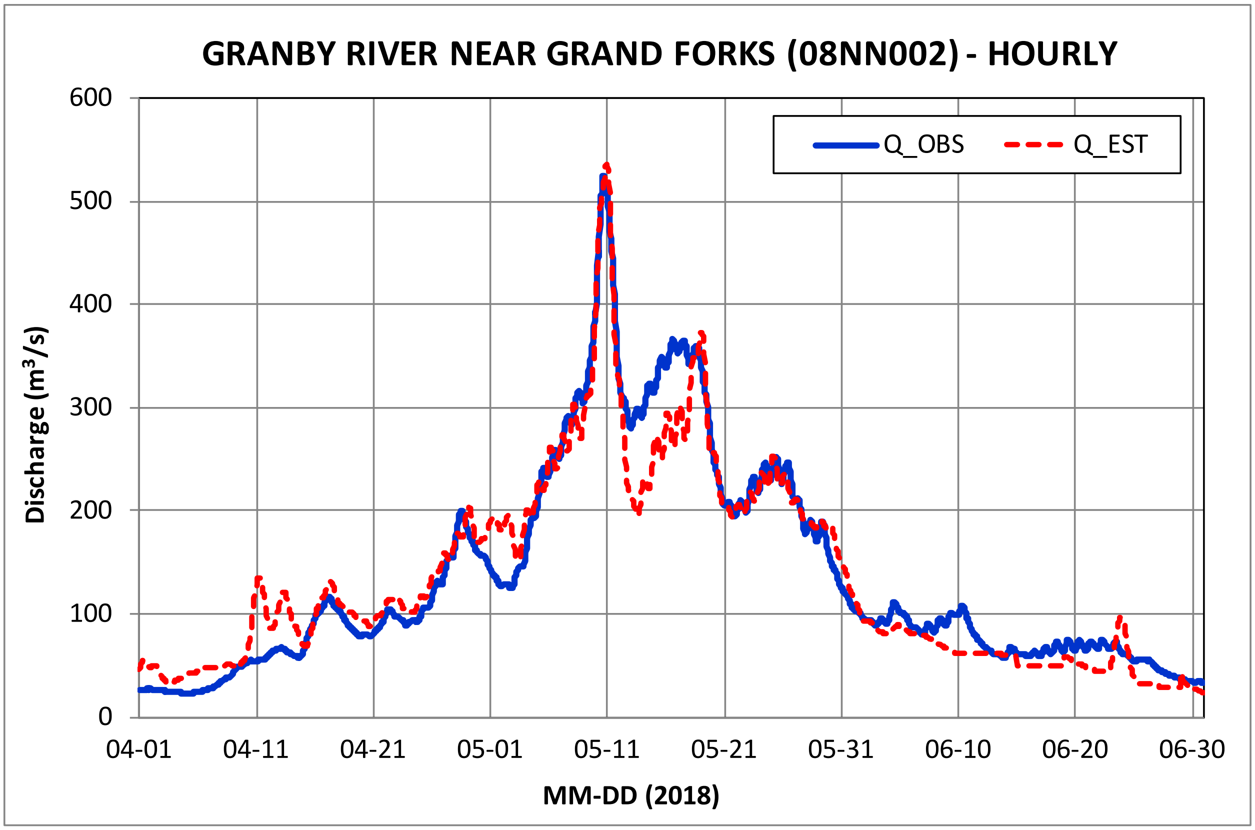

Figure 3. Model calibration (hourly averages) for Granby River near Grand Forks (08NN002) from April 1 to June 30, 2018. Note: Q_OBS – provisional observed discharge (blue line); Q_EST – model estimated discharge (red dash line).

Table 1 shows the model forecasts of peak, percent of error relative to the provisional observed peak (524 m3/s), peaking time, and error of peaking time.

Table 1. Model forecasts of peak, error, peaking time, and error of peaking time.

Date of Forecast (YYYY-MM-DD)	Peak (m^3/s)	Error of Peak (%)	Remark	Peaking Time (MMM/DD HH:MM)	Error of Peaking time (hour)
2018-05-01	308.3	-41.1		May/07 10:00	-78
2018-05-02	356.3	-32.0		May/09 07:00	-33
2018-05-03	366.4	-30.1		May/12 12:00	+44
2018-05-04	346.3	-33.9		May/09 09:00	-31
2018-05-05	388.1	-25.9		May/11 09:00	+17
2018-05-06	463.2	-11.6	>1914 peak ≈100Y Flood	May/11 04:00	+12
2018-05-07	427.1	-18.5	>1914 peak	May/11 05:00	+13
2018-05-08	578.1	10.3	>1914 peak >500Y Flood	May/11 04:00	+12
2018-05-09	516.3	-1.5	>1914 peak >200Y Flood	May/11 00:00	+8
2018-05-10	548.6	4.7	>1914 peak >500Y Flood	May/11 04:00	+12

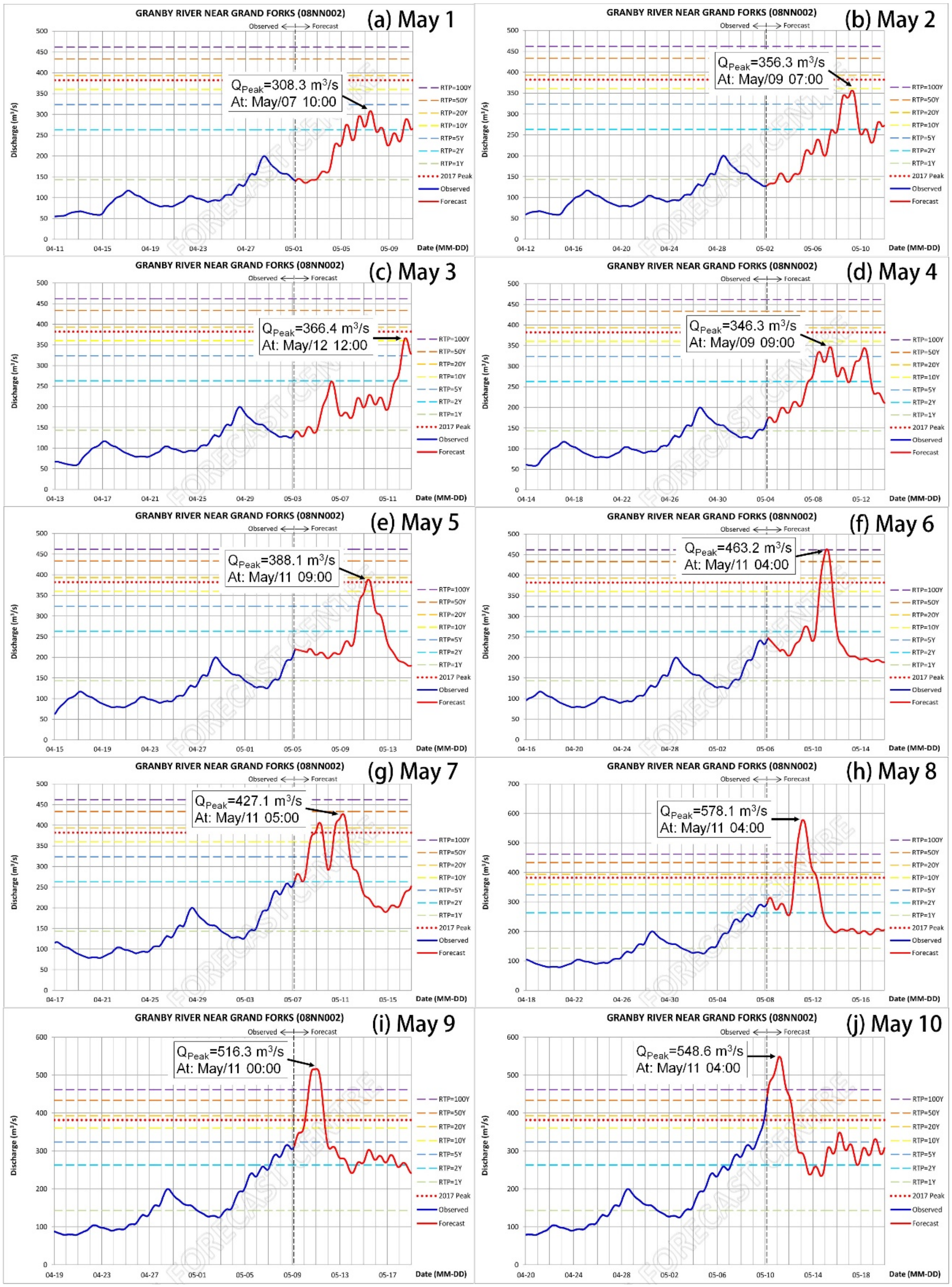

Figure 4. Model outputs of real-time forecast for Granby River near Grand Forks (08NN002) from May 1 to May 10, 2018.
(a) May 1, (b) May 2, (c) May 3, (d) May 4, (e) May 5, (f) May 6, (g) May 7, (h) May 8, (i) May 9, (j) May 10.

Table 2. Observed and forecast maximum temperatures (Tmax) and precipitation (P) at climate station NCL from May 1 to 10, 2018.

NCL	Tmax (°C)										
	Obs	Forecast									
Date		May-01	May-02	May-03	May-04	May-05	May-06	May-07	May-08	May-09	May-10
May-01	18.0	11.1									
May-02	21.6	15.7	15.5								
May-03	23.5	17.0	18.3	18.5							
May-04	24.1	15.1	17.6	16.3	18.0						
May-05	23.2	16.0	13.8	16.1	16.1	16.1					
May-06	26.6	16.1	16.2	15.1	15.8	17.8	19.0				
May-07	22.1	18.0	14.8	13.1	16.6	14.4	19.7	17.7			
May-08	24.4	19.5	14.6	17.2	15.5	14.5	17.6	18.0	19.3		
May-09	16.3	20.5	18.0	19.5	17.7	17.6	17.3	14.6	11.7	9.6	
May-10	13.8	20.2	20.9	20.6	18.3	14.2	11.4	10.6	11.8	12.0	6.7
	P (mm)										
	Obs	Forecast									
Date		May-01	May-02	May-03	May-04	May-05	May-06	May-07	May-08	May-09	May-10
May-01	0.0	1.7									
May-02	0.0	0.0	0.0								
May-03	0.0	0.0	0.0	0.3							
May-04	0.0	0.3	0.7	20.1	1.2						
May-05	0.0	0.0	0.0	0.0	3.2	0.5					
May-06	0.0	0.0	0.6	0.6	10.9	0.1	0.0				
May-07	0.0	0.0	15.1	0.0	9.9	1.4	8.6	23.7			
May-08	12.2	0.0	0.0	0.0	0.0	0.4	1.4	0.0	0.0		
May-09	30.6	0.0	0.0	0.0	1.2	12.4	28.0	17.4	43.3	36.2	
May-10	7.4	18.0	2.2	9.1	14.0	7.9	0.0	5.7	15.5	2.4	24.6
Total May-8 to May 10	50.2	18.0	2.2	9.1	15.2	20.7	29.4	23.1	58.8	50.8	67.4

Note: Three-day total precipitation (for May 8, 9 and 10) for the forecast on May 9 and 10 includes the observations before the forecasting day.

From Table 1, it can be seen that the forecast errors of peak on May 8, 9 and 10 are only 10.3%, -1.5%, and 4.7%, respectively, and the forecast errors of peaking time are only 12, 8, and 12 hours later than the actual peaking time, respectively. This forecast accuracy of peak and peaking time is very high. These accurate forecasts gave the local community enough time to prepare for the flooding. From Table 1, it also can be seen that the forecast peak varies from day to day. This phenomenon can be explained by the variability of the input forecast climate data, the maximum and minimum temperatures and precipitation.

Table 2 lists the observed and forecast maximum temperatures and observed and forecast precipitation. The freshet usually starts from early April and the soil moisture has been saturated in May. During rainfall events, evapotranspiration is always negligible. Therefore, the model forecast of flow was mainly the combined result of snowmelt and rainfall. From Table 2, it can be seen that, on May 8, 9 and 10, the three-day total forecast rainfall (for May 8, 9 and 10) is closest to the observation. May 9, 2018 is the day that the forecast peak and peaking time have the smallest errors. On this day (May 9), the forecast maximum temperature for May 10, 2018 and the forecast three-day total rainfall are the most accurate. One may also notice that the forecast three-day total rainfall on May 10 is 8.6 mm more than that forecast on May 8, but the forecast peak on May 10 is 29.5 m^3/s lower than that forecast on May 8. This is because that the forecast maximum temperature on May 10 is 5.1 ^oC lower than that forecast on May 8. And thus, the total amount of rainfall and snowmelt in the model run on May 10 is smaller than that on May 8.

The accuracy of forecast water volume was not evaluated in this paper because that it was less important to flood preparedness and flood hazard mitigation.

9. Conclusion

Based on the above analysis and description, it can be concluded that the CLEVER Model performed at a very high level of satisfaction during the unprecedented flooding event recorded at the WSC hydrometric station - the Granby River near Grand Folks (08NN002). The model forecast the May 10, 2018 flood with a high degree of accuracy in respect of both magnitude and peaking time two days before the actual peak passed the above hydrometric station. Of course, flood forecasting accuracy first relies on accuracy of the forecast climate data. However, the high level of satisfaction of the CLEVER Model performance of real-time flood forecasting should also be accredited to the model accuracy, which depends on sophisticated and robust modelling techniques and good model calibration.

Acknowledgements. The author would like to thank all staff members in the BC River Forecast Centre for their contributions when the CLEVER Model was running during the 2018 freshet season and when this manuscript was prepared.

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