Winter Flow Measurements at the Mackenzie River

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Abstract

A winter flow monitoring system was developed for conducting discharge measurements at the Mackenzie River of Canada in the winter of 1998-1999, based on the request of the MAGS Hydrology Study Team for continuous stream discharge data over the entire ice-covered period. The monitoring system, which is composed of an instrument assembly for data collection and a discharge calculation scheme for data processing, was assembled with several flow measuring techniques and equipment currently available at WSB. The resulting records of continuous discharge measurements of the Mackenzie River at the Arctic Red is presented. The flow monitoring system has the potential to be used as an alternative technique for winter flow measurements of WSB's routine data acquisition operations with reducing the operational costs and enhancing the operational safety.

1. Introduction

This project is in response to a request from the MAGS Hydrology Study Team to provide enhanced stream discharge data at the Mackenzie River and the Liard River, with continuous near-real-time data over the entire ice-covered period including times when traditional on-the-ice measurements cannot be conducted due to fragility of ice cover (Wang, 1999). Due to the similarity of the operations at the two sites, only those at the Mackenzie River at the Arctic Red was reported here. A channel flow monitoring system, which combined various flow measuring techniques and equipment currently available at Water Survey Branch (WSB), was assembled to fulfil the requirements of the project.

The flow monitoring system is composed of two complementary phases: an instrument assembly for data collection and a discharge calculation scheme. The instrument assembly was used for recording and transferring, in real-time, the information of channel flow underneath ice cover. The data processing scheme for calculation of channel discharges with information collected with the instrument assembly is based on flow velocity distribution (FVD) model with three parameters, one representing the effects of channel bed roughness, another for the ice bottom roughness, and the third representing effects of hydraulic slope and viscosity. Channel discharge was calculated with the flow depth data and the estimated values of the model parameters that were derived with prior knowledge of the flow at the site as well as data collected with the assembly.

Demonstration of the resulting records of continuous discharge measurements of the Mackenzie River at the Arctic Red is presented in this paper. The flow monitoring system developed for this project worked successfully by producing continuous discharge data that were consistent with data obtained from the conventional measurements. In meeting the primary objectives of producing continuous discharge data over the entire ice-covered period, the flow monitoring system developed with this project can also be evaluated for the reduction of operational costs of the conventional winter flow measurement. The methods developed with this project have the potential to be used as an alternative technique for winter flow measurements of WSB's routine data acquisition operations.

2. Instrumentation

A variety of flow measuring techniques and equipment were assembled for this project. The instrumentation consists of a single-vertical monitoring assembly as well as complementary data transferring equipment, including acoustic transducers, water level pressure sensors, current meters, data loggers, data collection platform (DCP).

The single-vertical monitoring assembly was installed into the water by hanging on the ice cover and was capable of recording, in real-time, the information of the channel flows underneath the ice cover. Three modified propeller rotors of the SWOFFER velocity meters were mounted on a machined dyron housing where a read switch was inserted. The velocity meters provided continuous flow velocities measurements at three points underneath the ice cover. Two acoustic transducers were also mounted on the assembly, with one facing upwards reflecting on the bottom of the ice cover and the other facing downward reflecting on the river bed. The acoustic transducers were used to measure distances to the channel bed and to the bottom of ice cover, with which the net flow depth and the locations of the velocity meters could be derived. With the instrument assembly, flow velocities at three points with known locations in the flow were sampled continuously and in a real-time manner along with flow depth data. Pictures of the instrument assembly are shown in the following photographs. In addition, a HYDROLOGIC pressure transducer with built-in compressor was installed on the site to provide water level values. A data logger VEDAS II equipped with GOES satellite transmitter was used for data logging and data transmission to desktop in Ottawa office for processing. The assembly was also designed with intent to minimize any possible safety hazard.

Figure 1. Instrument Assembly Used for the Mackenzie Measurement Project

Figure 2. Instrument Assembly as Tested on the Gatineau River

3. Measurement Site on the Mackenzie River

The flow monitoring site is located at the regular winter measurement cross-section, about 3 km upstream of the WSB hydrometric station 10LC014 (Mackenzie River at the Arctic Red). At the site, the ice-covered period extends from mid November to late May in normal years. The measurement project was conducted during the period from March 12 of 1999 to May 18 of 1999. During this period, except a couple of weeks before the ice break-off, the average channel width is about 800 m, the average flow depth is about 12 m, the average discharge is about 3200 cm/s, and the mean flow velocity is about 0.4 m/s. There was little slush developed underneath the ice cover and the bottom surface of the ice cover is relatively flat. The cross-section is relatively symmetrical, the channel bed is composed of sand, silt, and gravel and the composition of channel bed is relatively homogeneity across the entire cross-section. A typical winter cross-section of the Mackenzie site was shown in the following graph.

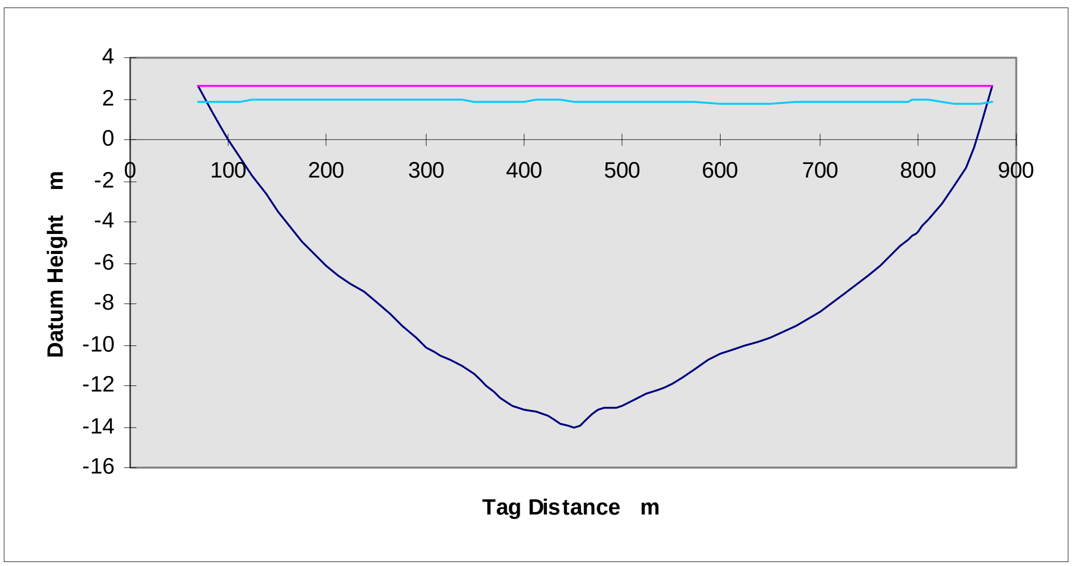

Figure 3. Channel Cross-Section of the Mackenzie River

The installation at Mackenzie consisted of a instrument assembly of 6.5 meters in length. The assembly was installed at the vertical with the tag-mark of 790 m, about 30 m from the right rank and with a normal flow depth of 6.3 m. A temporary instrument shelter was installed on the right bank, located some 250 meters from the installation. The area view of the Mackenzie monitoring site is illustrated in the following graph.

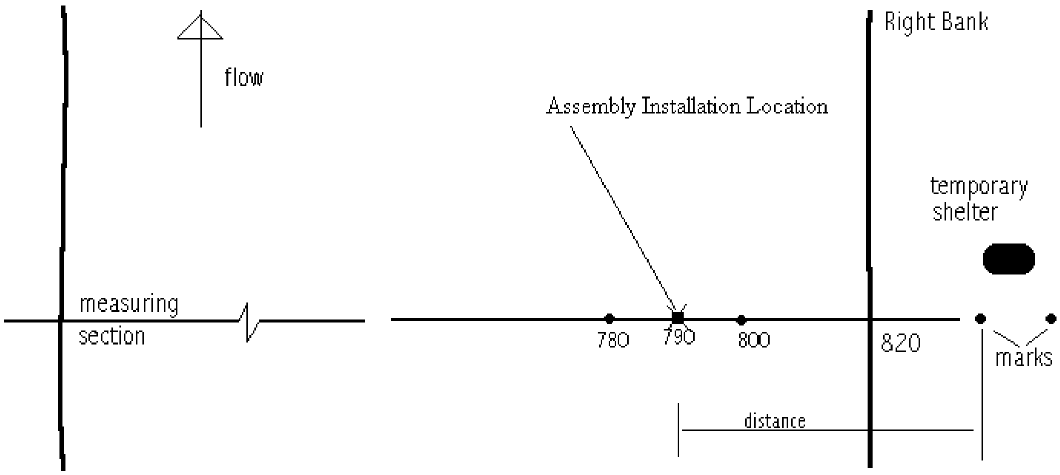

Figure 4. Plan View of Mackenzie River Monitoring Site

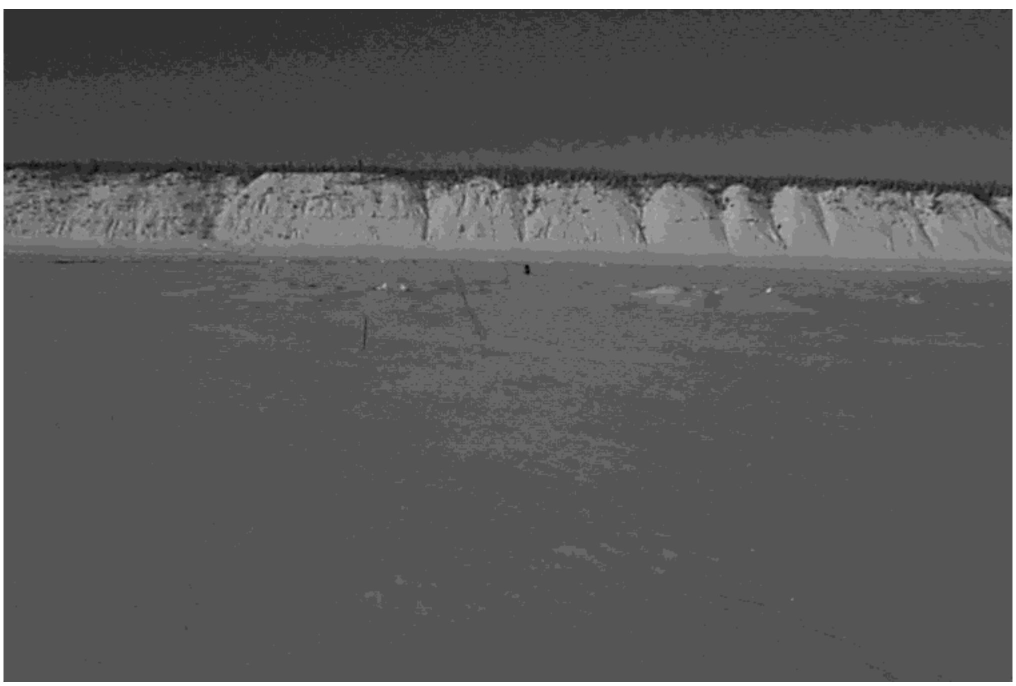

Figure 5. Mackenzie Monitoring Site as Seen from Left Bank

4. Data-Processing Scheme for Discharge Calculation

The channel discharges were determined with information collected with the instrument assembly via the data processing scheme that was based on the flow velocity distribution model (the FVD model) developed at the WRB (Chow, 1959; Wang, 1993; Wang et al, 2000; Wang, 2000). The background of the FVD model is briefed here in the following paragraphs.

The FVD models uses three parameters, namely, the bed roughness parameter y_{0b}, the ice roughness parameter y_{0i}, and the hydraulic parameter γ to describe the hydraulic properties of the flow regime under ice cover. The concept of cross-sectional velocity distribution model relies on the proposition that the roughness parameters are treated as cross-sectional properties. The composition of the channel bed and the bottom surface of the ice cover, as well as their resistance to the flow, often exhibit a certain degree of homogeneity, despite the existence of some local variation. This fact supports the treatment of the roughness parameters as cross-sectional properties as long as the composition of the channel bed and the ice cover is relatively homogeneous. Therefore, a unique value of the bed roughness parameter is applied to the entire cross-section for a specific site and the ice roughness parameter is handled in the same manner.

The values of parameters of the FVD model are estimated with the flow velocity profile data. It is proposed that the bed roughness parameter for a specific site would remain unchanged as long as the channel bed conditions did not change significantly. That is, the estimated value of the bed roughness parameter based on the previous flow measurements at the same site could be used in the current project. For the ice roughness parameter, its value would remain unchanged for the same winter season after the ice cover completely developed. This proposition was derived from analysis of previous measurements at the sites and was verified with data from concurrent conventional on-ice flow measurements.

Analysis of flow measurement data verifies the following assumptions about the properties of FVD model parameters:

- the hydraulic parameter for a cross-section varies with the stage (water level) at the site;
- the value of the bed roughness parameter for a specific cross-section does not change with respect to the various stage values at the site, and it does not change over the time period of the measurement project as long as the channel bed remains stable;
- the value of the ice roughness parameter for a specific cross-section does not change for most of the time in a winter season after the ice cover gets solidified; however, this value may vary in different winters as the ice formation process changes in successive winters.

With estimated values of the FVD model parameters, the channel discharge of a cross-section for flow under ice cover is calculated as:

$$Q = \gamma \bullet w \bullet \sum [D_i \bullet \ln(D_i) - D_i \bullet \ln(y_{0b}+y_{0i}) - D_i + y_{0b}+ y_{0i}] \quad (1)$$

where w is the equal panel width and D_i is flow depth of a vertical panel;
γ is model parameter reflecting effects of hydraulic slope and viscosity;
y_{0b} is model parameter reflecting the effects of channel bed roughness;
y_{0i} is model parameter reflecting the effects of roughness of ice bottom.

For this measurement project at the Mackenzie River, continuous channel discharges were calculated with the flow depth data, provided by the acoustic transducers fixed on the instrument assembly, as well as the estimated values of the model parameters. The roughness parameters of the FVD model were kept at the initial values estimated with the previous flow measurement data at the same sites. It was further assumed these values were assumed to remain unchanged during the course of the project. This assumption was verified with the flow velocity profile data collected at the sites with the verification flow measurements by the conventional on-ice procedure made three times during the course of this project.

The values of the roughness parameters were taken as:

$$y_{0b} = 0.018 \text{ m} \quad \text{and} \quad y_{0i} = 0.025 \text{ m} \quad (2)$$

The hydraulic parameter of the FVD model was estimated with point velocity data collected with the instrument assembly, together with the prior known values of the roughness parameters. Analysis conducted with this project indicated that the procedure used for estimating the hydraulic parameter provided a compensation effect such that the error in the calculated discharge values would be limited in an acceptable range despite the possible bias in the estimates of the roughness parameters. That is, the effect on the calculated discharge values caused by the possible bias in the estimates of roughness parameter was balanced off with the respective adjustment in the estimates of hydraulic parameter, since both parameters were inter-correlated through the same set of velocity profile data. This finding was further verified with sensitivity analysis. The sensitivity analysis also revealed that at least two points of the velocity data should be used for estimating the hydraulic parameter to avoid the possible error in the calculated discharge values.

5. Results of the Measurement Project

With the estimated values of FVD model parameters available, the channel discharge can be calculated using the algorithm as given by Eq. 1 of this report. The flow monitoring system developed for this project worked successfully in producing continuous discharge data that were consistent with data obtained from the conventional measurements. The resulting records of continuous discharge measurements of the Mackenzie River at the Arctic Red is presented with the hydrograph of the site as Figure 6 below, where the marks and figures appearing on the graph represent the discharge values produced by the convention on-ice measurements which was made as verification for the performance of the alternative winter flow monitoring system for continuous discharge measurements.

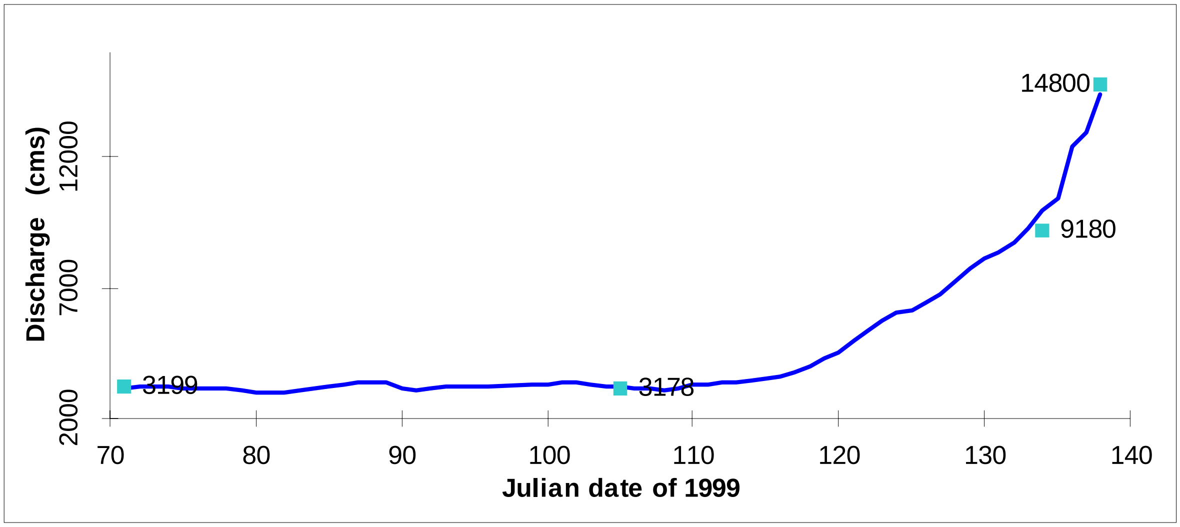

Figure 6. Hydrograph of Mackenzie River at Arctic Red for winter of 1998-1999

6. Conclusion

The flow monitoring system developed for this project worked successfully in producing continuous discharge data that were consistent with data obtained from the conventional measurements. In meeting the primary objectives of producing continuous discharge data over the entire ice-covered period, the flow monitoring system developed with this project can also be evaluated for the reduction of operational costs of the conventional winter flow measurement. The methods developed with this project have the potential to be used as an alternative technique for winter flow measurements of WSC's routine data acquisition operations.

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