Hydrograph Travel Time Analysis

Introduction

Alberta Infrastructure and Transportation (AIT) monitors its stream crossing infrastructure closely during large runoff events. This is done both to enhance the safety of the travelling public and to collect data that will be of use on future designs. The best time to be at a site for data collection is soon after the peak of the flow, to maximize the likelihood of obtaining accurate highwater marks and observing and documenting flow conditions at relatively high water levels.

Alberta Environment operate real-time rainfall and runoff gauges that are valuable in knowing where large runoff events are likely to occur and how significant they may be. However, due to the complex relationship between rainfall and runoff on large natural basins, it can be difficult to predict when the peak of an event will occur at a given site. However, analysis of data from past runoff events should provide useful information on the typical range of timings observed between certain gauges, and possibly help identify simple techniques to assist in prediction of timing on un-gauged streams.

Available Data

As part of development work on the current AIT hydrotechnical design guidelines, runoff hydrographs were developed based on published mean daily and peak instantaneous flow data for over 3800 events measured at over 500 gauges in Alberta. Also, stream profiles generated from DTM data have been prepared for most streams in the province, from which the station and elevation of all WSC gauges can be extracted. Rating curve data for the gauges has also been compiled and can be used to estimate the typical hydraulic characteristics of the reach between gauges.

Methodology

The rising limbs of all hydrographs were systematically sampled at various points to ascribe a time value to the front of each hydrograph. Combinations of multiple gauges on the same stream covering the same runoff event were then determined and the timing difference noted. Tools were developed using VBA in Excel to automate much of this process.

The mean speed of the runoff event front travelling between gauges was then calculated for each of these timings. Some simple statistics were then done for each reach to identify those that show consistent results. Filtered results were then compared with typical reach parameters such as flow depth, channel slope, and mean velocity. The mean reach flow depth was based on the average of the range of the rating curves for the gauges at the ends of the reach. The mean reach slope was determined from the difference in elevation and station between the two gauges. The mean reach velocity was based on application of the AIT open channel flow equation to the mean flow depth and the overall reach slope.

Results

This process resulted in about 1800 differential hydrograph timings calculated on about 270 reaches on about 50 streams. These results have been entered into a database for easy reference on the range of timings observed for any given reach. Statistics were performed on about 170 reaches which had multiple timings, excluding obvious outliers. About 45 reaches had more than 10 timings. The coefficient of variation was in the 0.1 to 0.3 range for most of these reaches.

The mean hydrograph front speeds for these reaches were typically in the 1.5 – 3.0m/s range. No significant relationship was observed between these front speeds and mean physical parameters for the reach, including flow depth, channel slope, and mean velocity. It was observed that the ratio of front speed to mean reach velocity was in the range of 0.5 to 1.2, averaging about 0.8.

Reaches with multiple timing results typically cover a range of magnitude and shape of runoff events. However, analysis of timings for some of the reaches with the most data points did not show a strong relationship between hydrograph timing and key hydrograph indicators such as runoff volume, peak flow, or ratio of flow rise to time to peak.

Potential Error

There are several reasons for the significant scatter observed in the results. These cover both accuracy issues with the data and integrated complex physical processes included in the data.

One source of inaccuracy is the hydrograph creation process. The hydrographs are recreated using mean daily peak instantaneous flow values, using a volume balance with a graphical process. Although these hydrographs should be quite accurate in terms of runoff volume and overall shape, the value at any given point is an estimate, and it is expected that the accuracy of any given point is in the 3 – 6 hours range.

Additional inaccuracy is due to the front timing sampling process. Several points along the front were sampled for each hydrograph and used to calculate a mean value for the time of the hydrograph front. However, many hydrographs have complex shapes, with multiple fronts within one overall rise, and error is introduced in characterizing this front with one value for analysis.

Another source of inaccuracy, affecting the analysis, is the determination of mean reach parameters. In many cases, the hydraulic parameters at the two gauges at the ends of a reach are not similar, and an average of these parameters may not be indicative of the overall reach. Also, each runoff event has a different magnitude and shape with some variance from the mean hydraulic parameters used in the analysis.
The process of sampling the fronts of the hydrographs at different stations picks up the net effect of several physical processes, including translation (routing) of the hydrograph

along the channel and additional inflow to the system between the gauges. An attempt to quantify this based on change in hydrograph volume between the two gauges was undertaken. The scatter in results was somewhat reduced when timings with large differences in volume were filtered out. However, no significant relationship between hydrograph timing and volume ratio was observed. This is likely due to the impact of other factors such as change in shape of the hydrograph.

Discussion

Although no significant relationships with key physical indicators were observed, it does appear that the hydrograph front travel speed does scale on the mean velocity for the reach. This appears reasonable as the unsteady flow nature of natural runoff events, as evidenced by the increase in hydraulic slope on the front of the hydrograph, is relatively minor compared to the overall slope of the stream. For example, if the time to peak of a hydrograph is about 20 hours, the increase in stage at the peak is 5m, and the hydrograph travel speed is about 2m/s, the increase in slope on the hydrograph front is about 0.00003. This value is quite small compared to most channels in Alberta.

The key observations from this study can be of some use in managing flood chasing activities. The database of hydrograph timings can be consulted for typical responses for many of the larger reaches in the province. For reaches with known hydraulic properties but limited historic gauging information, travel times can be estimated based on the mean velocity for the reach. For less known reaches, hydrograph travel times can be roughly estimated using a mean speed of about 2m/s.

Conclusions

This study of differential hydrograph timing shows significant scatter in the results and no significant correlation with key physical parameters. However, the developed database and observation that hydrograph travel speeds tend to scale on the mean reach velocity will be useful in estimation of the timing of runoff response in downstream areas. This will be of value in managing flood chasing activities.