SIMULATING SNOWMELT HYDROGRAPHS FOR THE FRASER RIVER SYSTEM

By

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Introduction

The Fraser is the largest and most important river in British Columbia. It has a drainage area of 90,000 sq. miles and a long-term average discharge of about 100,000 cfs. For the last 100 miles of its length the river flows through the lower Fraser Valley, an alluvial valley, which has been intensively developed for agriculture, and is now increasingly being developed for commercial and residential purposes, particularly in the vicinity of Vancouver.

Most of the runoff originates from snowmelt and, as a result, flows are generally low during winter, high during the snowmelt period of May and June, and decreasing thereafter. Peak floods occur in late May or June and on occasion these have been extremely damaging. The last major flood, which occurred in 1948, caused approximately $20,000,000 worth of damage, more than 80% of which occurred in the lower Fraser Valley. If a similar flood were to recur now, damage would be many times as great. To combat the flood threat in the Fraser Valley, the area most subject to damage, the dyking system is presently being extended.

The river system supports a valuable salmon fishery and the desire to protect this resource has inhibited construction of dams and reservoirs on the river and its major tributaries, despite the need for flood control and an estimated total hydro electric power potential of more than 5,000 average megawatts. There are dams on Bridge River and Nechako River, two tributaries of the Fraser, but since these two dams together could control peak discharges totalling only about 5% of the total flood peak there is, at present, no real possibility of controlling major floods by reservoir storage.

Volume forecasts of the total seasonal runoff in the Fraser and its major tributaries are made each year by the B. C. Water Resources Service. Attempts have also been made at forecasting flood hydrographs but since there is little possibility of controlling floods the resources devoted to forecasting flows in the Fraser have been meager. A forecasting model was proposed by Quick (1) and was used for forecasting during the high Spring freshet of 1964, and an empirical method for short range forecasts from limited data was developed by Muir (2) 1969. These methods were relatively simple and dealt with either the whole system or large sections of the river system in one step of the computation.

In the Civil Engineering Department at the University of British Columbia a Water Resources Group was recently formed for purposes of teaching and research in Water Resources. One of the group projects is the construction of a more elaborate simulation model of the Fraser system, for use in planning, teaching, research and forecasting. The model is a multi-purpose one and emphasis is placed on the development of techniques as well as on the building of a working model. The model has two main components, a streamflow routing, and a runoff simulation component. The streamflow routing model will be used for routing flows through the system, and the runoff simulation model will be used to provide inputs to the routing model. The two component models are still under development and they have not yet been combined. This paper describes their present status.

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Streamflow Routing Model

Although the ultimate aim is to develop a "multi-purpose" simulation model, it is usually simpler and more effective to first concentrate on one purpose and then generalise the model to meet other requirements as well. In the case of the streamflow routing component, efforts to date have been devoted to the development of the model for forecasting.

The underlying concept of the streamflow routing method is quite elementary and the method is specifically designed for streamflow routing through channel reaches in which the time interval of measurement is of the same order of magnitude as the travel time in the reach. In the Fraser system flows are normally recorded on a daily basis and one day is used as the basic time interval. This time scale is not fine enough for most traditional types of streamflow routing and a technique was developed to make the most of existing data but not place any demands for types of discharge data which are not readily available.

The model assumes monoclinal behaviour, namely translation through the reach, in a time period related to mean channel velocity. Linearity is assumed between day to day variations in the difference between the inflow to the reach on one day and the outflow from the reach on the next day, i.e.

$$O_{j+1} - I_j = K(O_j - I_{j-1})$$

where

O = outflow from reach

I = inflow to reach

K = proportionality constant

j represents day.

This can be expressed in prediction form -

$$O_{j+1} = I_j + KO_j - KI_{j-1}.$$

The method is best suited to large river basins with many channel reaches and subject to snowmelt floods with relatively slow day to day changes in the flow travel time. The "constant" K for a particular reach is reasonably stable over a large range of flow. Best values of "K" for each reach were determined by an optimization technique similar to that described by Beard (3), using the weighted sum of the differences between the recorded and "predicted" discharges during the period April to September as the objective function to be minimized. Values of K vary between 0.76 to 0.98 for different reaches of the river but tend to be quite stable from year to year.

In using the model lateral inflows are accounted for by increasing the recorded inflow ordinates through the flood season in proportion to their magnitude in order to make the total seasonal inflow equal the total seasonal outflow. For forecasting, the factors by which inflow ordinates are increased are obtained from past records. It was found that the method works satisfactorily even where there is substantial natural lake storage such as in the South Thompson tributary.

The method has been applied to the whole Fraser system using data from the network shown on Fig. 1. Because of the size of the basin and the number of reaches it is possible to get up to a 4 day forecast using only streamflow data. Typical results for 1964, the year with the third biggest river stage at Hope, the main Fraser River gauge, are shown in Fig. 2. The average error is some 6% or less than 10,000 cfs.

Runoff Simulation Component

The more accurately it is desired to simulate hydrologic phenomena the more complex must the model be. It is not difficult to construct a model to any desired degree of complexity but the more sophisticated it is, the more difficult it is to find the best values for the parameters in the model with some degree of objectivity. Too simple a model may be inherently incapable of simulating runoff to the required accuracy whereas if the model is

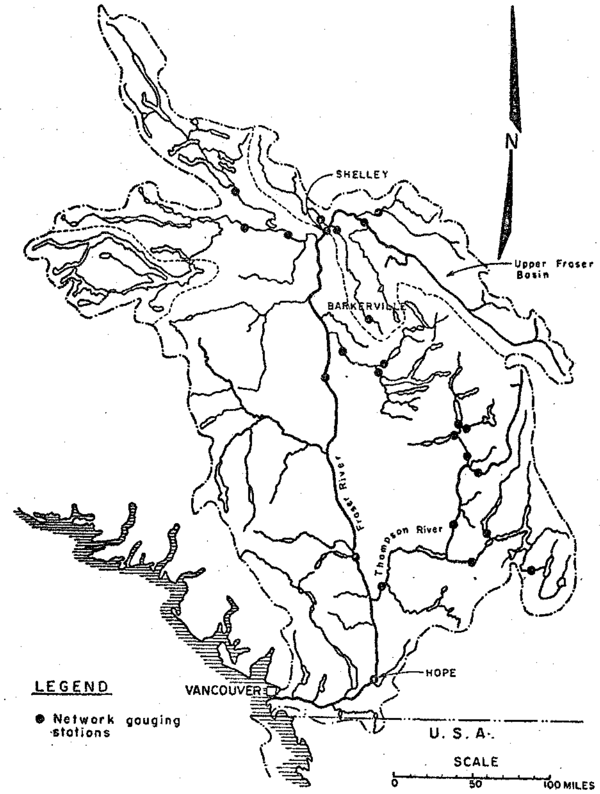

Figure I. FRASER RIVER BASIN.

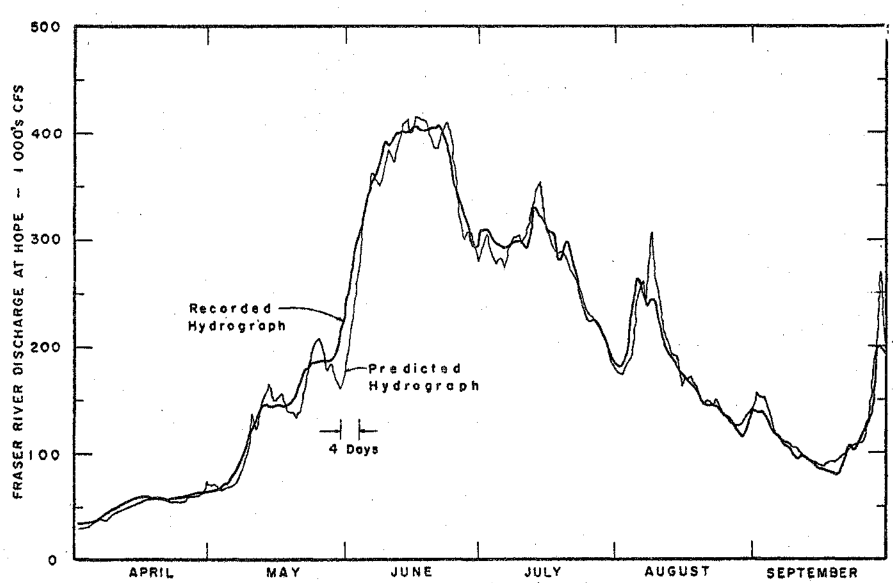

Figure 2. FOUR-DAY FORECAST-FRASER RIVER AT HOPE 1964.

too complicated there may be so many unknowns that it may not be possible to define the parameters. As with most problems in life, a good balance must be maintained.

In the present study, balance is being aimed at by starting with a relatively simple model and attempting to simulate runoff from a relatively large area. Additional relationships will be added to the model if required and a smaller, more homogeneous study area can be used if necessary. In the course of developing the model, considerable effort is being devoted to techniques for fitting the best values of the parameters, since the more automatic these are the simpler it will be to develop and test refinements to the model.

The Model

The model is designed to simulate runoff, which is almost entirely due to snowmelt, from daily temperature and precipitation data. It is similar to one which was developed for computation of design floods for the dams on the Canadian part of the Columbia River. The following simplifying assumptions are made:

1. There is a constant temperature lapse rate.

2. Daily melt at a point is proportional to the maximum temperature minus a base temperature.

3. Runoff can be accounted for by two components, ground water and surface runoff, each of which follows a simple exponential decay rate with a fixed time lag between time of melt and appearance as streamflow.

4. The snowline is horizontal, and the area still covered with snow and hence contributing to runoff is inversely proportional to the proportion of runoff already generated.

Calculations are made on a daily basis for the high flow months of May, June and July. The steps computing one day's flow are given below. "i" represents the day, "j" the elevation band and k_1 to k_8 the constants which must be determined for the study drainage basin.

1. Compute melt rate for each elevation band -

$$M_{i,j} = k_1(T_i - T_B) + P_i$$

$M_{i,j}$ = Daily melt on Day i in Elevation Band j; T_i = Daily maximum temperature at index station; T_B = Base temperature, and P_i = Daily Precipitation.

2. Allocate melt to ground water (MG) and surface runoff (MS).

$$MG_{i,j} = k_2\ M_{i,j} - K3$$

$$MS_{i,j} = M_{i,j} - MG_{i,j}$$

3. Compute groundwater (GG) and surface runoff (SG) generated.

$$GG_i = k_4 \sum_j A_j \cdot MG_{i,j}$$

$$SG_i = k_4 \sum_j A_j \cdot MS_{i,j}$$

Where A_j = area of elevation Band j

4. Compute groundwater (RG) and surface runoff (RS) contributions.

$$RG_i = k_5 \cdot RG_{i-1} \quad + \quad (1\ k_5)\ GG(i - k6)$$

$$RS_i = k_7 \cdot RS_{i-1} \quad + \quad (1\ k_7)\ SG(i - k8)$$

k_6 = groundwater lag and k8 = surface runoff lag.
k_5 = groundwater recession factor and k_7 = surface runoff recession factor.

5. Compute total runoff $R_i = RG_i + RS_i$.

6. Compute runoff generated to date (RSD).

$$RSD_i = RSD_{i-1} + GG_i + SG_i$$

7. Compute area covered with snow (AS).

$$AS_i = ASO \cdot RSD_i/RST$$

ASO = area covered with snow at beginning of season.
RST = total seasonal snowmelt.

At present, during the development and testing phase, the model is being used to simulate past floods using historical data for the Upper Fraser drainage basin at Shelley. The area is shown in Fig. 1 and typical results are shown in Fig. 3.

Next steps in refinement of this component of the overall model will involve changing it into an operational forecasting model by providing the capability to correct itself as discharge information becomes available, and extending it to other basins.

Determining the Parameters

To find the best values of the parameters in the above model three basic techniques are being used. The first is simply trial and error in which trial values of the various constants are used and the results, i.e. the computed hydrograph values are compared with recorded values. For this approach to be of value "turn around" time must be rapid and in the present study this is achieved by using an IBM 1100 computer with interference switches and an optical display. With the switches any parameter can be changed; and the resulting computed hydrograph is then plotted, together with the recorded hydrograph, on the oscilloscope screen. With this equipment it is possible to make many trial calculations, identify the parameters to which the model is most sensitive and provide a rapid education and good "feel" for the problem on the part of the hydrologist.

A second approach which is useful where there are interactions between parameters is one from Evolutionary Operations Research (4), a technique which was orininally developed for optimizing the operation of full scale plants without interrupting production. In this study the sum of the squares of the differences between the computed and recorded hydrographs is used as the objective function which has to be minimized. In each step four computations are made with two high and two low values of the parameters being investigated and all others held constant; the results are plotted as shown in Fig. 4. From the plotted results suitable values for the next trial can be determined. By itself this technique would be very slow but it is useful for showing up interactions between parameters and whether or not constant values are appropriate for the parameters.

Finally, Beard's univariate optimization method is used (3) again using the sum of the squares of the differences between the computed and recorded hydrographs as the objective function to be minimized. In this method the parameters are approximately optimized one at a time by the Newton-Raphson method and after all have been adjusted the cycle is repeated. Several iterations are usually required.

In the present study all of the above methods are used singly and in combination. No one method on its own is adequate, and it has been found that experience and judgement on the part of the hydrologist are extremely important. Paradoxically, one of the most important consequences of using modern efficient computer techniques is that the hydrologist can increase his understanding of hydrologic phenomena and skill in manipulating data much more rapidly than would otherwise be possible.

Summary

A computer simulation model of the Fraser system is presently being constructed in the Civil Engineering Department at the University of British Columbia for purposes of flood forecasting, planning, system evaluation, teaching and research. The model has two main components, a streamflow routing component and a runoff simulation component, both of which are under active development. The routing component model is presently oriented

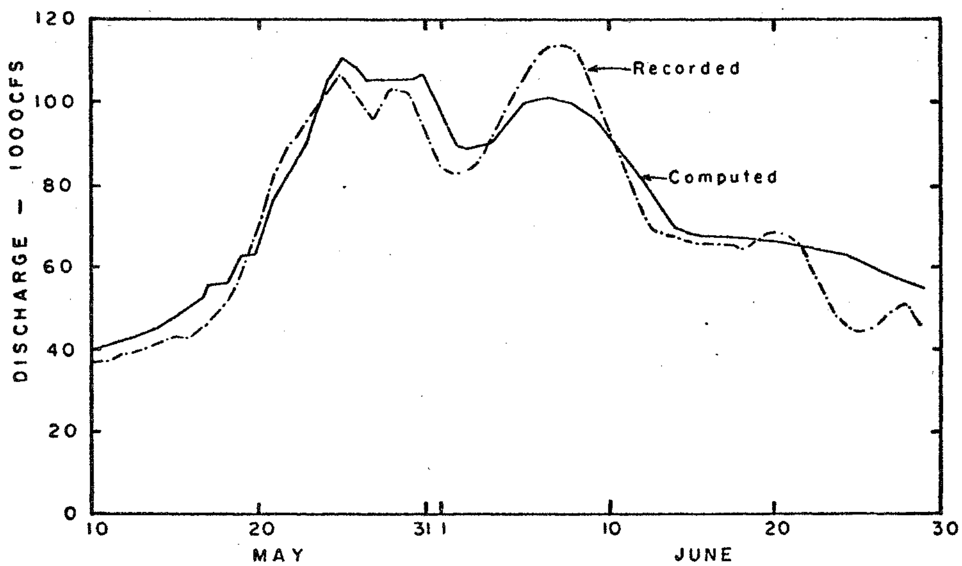

Figure 3. FRASER RIVER AT SHELLEY 1961.

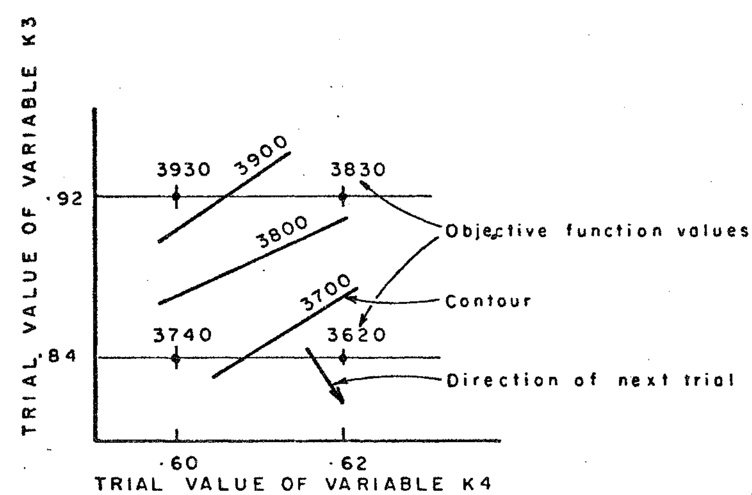

Figure 4. ILLUSTRATION OF "EVOP" APPROACH TO FINDING PARAMETERS FOR HYDROLOGIC MODEL.

towards flood forecasting using daily discharge data as input. Reasonably good four day forecasts are being achieved. The runoff simulation model computes runoff from meteorological data for eventual use as input to the streamflow model. As yet the two components have not been combined. Full use is being made of modern computer techniques in the development of both models. Computers are of great assistance in helping the hydrologist to build up his skill and judgement quickly but automatic optimization methods are not yet in sight.

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