THE SIMPAK PROGRAM

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APPLICATION TO SIMPLIFIED STREAMFLOW FORECASTING

By

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Introduction

This paper is presented with a twofold purpose; firstly to introduce the SIMPAK computer program for streamflow modelling and, secondly, to outline a novel method of forecasting freshet discharges using the program. The concepts used in both SIMPAK and the forecasting technique are simple and they have been found to be useful both in reconstitution-type studies of proposed projects and in actual flood situations. Although the procedures do not deal directly with snow hydrology the program's facility for streamflow modelling and its use in analysing the effects of snowmelt will be of interest to the hydrologists assembled at this Western Snow Conference.

The SIMPAK program was developed to aid in flood-control studies undertaken jointly by the Province of British Columbia and the Government of Canada in the Fraser River basin of British Columbia. The program was patterned after the well known SSARR program and indeed was intended as a simplified alternative to carry out only the river routing functions of that program. The forecasting procedure also originated as a study tool. Both the program and the forecasts, however, have found wider application and have been used in real-time situations.

General Description of SIMPAK

This "simulation package for river modelling" (SIMPAK) is a truly modular computer program. It consists of a basic framework that reads the input instructions, sets up the logistics of the computer operations and controls the calling of the many separate program modules that each perform an individual hydrologic computation or data manipulation. In developing the program the modular concept was adhered to as closely as possible so that changes could easily be made or parts could easily be added or subtracted. The program has been written so as to be completely general in nature, and can be applied to any river basin.

Each of the individual modules or subroutines do a specific operation on a set of time dependent data representing river flows, elevations, storage and change in storage values for each day of a simulation period. Each set of such data is handled in the main program as a "station" having a unique identification number. The various individual subroutines are then called from an input list of operation instructions, each instruction telling the type of operation to be performed and the parameter values to be used. Most of the functional information about the station is held within this single instruction.

The program was developed using the 370/165 computer at the University of British Columbia, but it can easily be adapted to any medium to large scale computer system.

Some of the main features and capabilities of the SIMPAK program are discussed below:

a) Data Input

There are several classes of data that are input to the program:

(i) The model control data that specify the stations for the model and the operations that are to be performed at each station. This constitutes "the model" and is normally input directly on cards or at a remote keyboard terminal but can be held on a computer disc file.

(ii) Tables of relationships such as correlation curves, stage/storage curves etc. These are input on a separate data file that is set up externally to the program and that is automatically searched for the required tables.

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(iii) Hydrologic data such as records of discharges and elevations. The program will read the required hydrologic data for the model from several different sources such as card-image computer disc files, magnetic tape, and disc files holding unformatted data. Data can presently be handled in any of three different data formats. These are:

- "W.S.C." format, used by the Water Survey of Canada on their computer data tapes;
- "SSARR" format, used in the SSARR (Streamflow Synthesis and Reservoir Regulation) program for data input;
- "long records" format, made up of data records consisting of unformatted (i.e. machine code form) data.

Input instructions to the program specify from which source the data is to be read and in what format the data will be on each of the source units. The program automatically searches all the data held in each specified source for data required by the model. SIMPAK is completely convertible between English and Metric units of measurement and mixtures of both types are handled automatically.

b) Data Output

SIMPAK outputs data in several forms. The most common is a listing of the discharges for each station in tables showing eight stations for one month on each page.

The complete set of data for a station (i.e. discharge, elevation, storage and change in storage) can be printed on a separate page is specified. The program will also output data to computer files in either SSARR format or the long record format.

Two different types of plotting can be accomplished. The most flexible type is the printer-plot, in which the printer output sheet is scaled and a hydrograph is "plotted" using printer symbols. This provides a fast inexpensive plot of any specified data. Several stations can be plotted together to give clear comparisons.

The second type of plot is the line plot produced by a Calcomp Plotter. The program will plot any desired data, using either a specified scale or an automatic scaling feature.

c) Model Time Control

The program works on a fixed time increment of one day except in the "REACH" routing operation in which calculations are made for shorter time periods under certain conditions. All flow data are considered to be mean daily discharges with values of elevation and storage being end-of-day values.

The time boundaries for any run are input in the model control instructions. In its usual form the program handles up to 200 days in any cycle, however, this can easily be extended by redimensioning the programs. Several cycles can be run at one time, and the data for each cycle will automatically be fetched from the data file.

d) Organization of the Program

Each set of data within the program is indexed according to a unique station number and operations of the program are then made by reference to that station number. Each step in the model is specified by an operation card which tells SIMPAK what type of operation to carry out and specifies the stations and parameters to use. Each operation takes the data held in one or more stations, uses that data in carrying out the specified operation, and stores the computed values under another specified station. In this way the operation cards specify the configuration of the river and can be considered as the "model". If an operation requires table data, SIMPAK automatically finds the table having the station number as its identification in the file of table data. All operation cards follow a standard format, making the coding of the model a relatively easy matter.

e) Operations of SIMPAK

The several operations that can be carried out by SIMPAK are summarized below. Each of these operations are initiated by an entry in the operation card list. In many of these operations only one type of data for the station is operated on; the type may be selected in many cases. In other operations, such as lake routing, all types of data are used. The operations available in SIMPAK are:

(i) "LAKE" routes flows through a lake, using the Modified Puls Method of routing;

(ii) "RESEV" routes flows through a reservoir based on a target rule curve, with constraints for upper and lower reservoir limits, minimum flows and discharge capacity;

(iii) "REACH" routes flows through a river channel reach using the SSARR method of channel routing (see Ref 1);

(iv) "WAVE" routes river flows or reservoir holdouts to a downstream point using a polynomial method of routing similar to a unit hydrograph (see Ref 3 and 5);

(v) "ADD" sums the data from two or more stations;

(vi) "SUBT" subtracts the data for one station from another;

(vii) "TRSF" transfers data from one station to another and multiplies by any specified constant;

(viii) "EXTN" extends records on the basis of a correlation curve, using a specified station as a base record;

(ix) "RATIO" computes daily ratios between stations' data;

(x) "MULT" extends records on the basis of input daily ratios between the base station and the extended station;

(xi) "MEAN" computes monthly means and totals of data values;

(xii) "LOOK" computes elevations from discharges or vice-versa;

(xiii) Many of the above operations can be accomplished under backwater conditions.

In addition to these operations, there is a dummy operation "USER" that allows a hydrologist to program his own routine to fit into the SIMPAK structure. Any other program may be called in the operation card list by identifying it with the name "USER" and attaching it to the SIMPAK program. This is a very handy feature that allows a great deal of flexibility.

Forecasting with SIMPAK

With the USER facility, several forecast tests were made in developing the algorithm described here. The SIMPAK program automatically found and retrieved the required data, printed and plotted the results and compared changes in the trial methods, while the USER routine carried out all the specialized forecast computations.

The forecast algorithm was originally intended only as a simulator of present hydrometeorological forecast techniques. It was used in reservoir regulation studies to provide simulated forecasts for past years hydrometric records for which matching meteorological records were unavailable. The purpose for the simulated forecasts was to determine when to begin and end storage at upstream reservoirs to effect efficient flood control at points far downstream. Thus the main concern was to never be too low on the forecast.

The Fraser River basin covers an area of about 87,000 square miles in central British Columbia. A map of the basin is shown in Figure 2. The main sources of freshet flows are the mountainous areas along the eastern edge of the basin, about three to four days lag time from the largest flood concern in the lower Fraser valley, and the Coast Mountains in the south-west portion of the basin. The point at which target levels for flood control were to be maintained was Mission City, a central point in the populous lower Fraser valley.

Because a large portion of the flows originate from the far upstream portions of the basin and require considerable time to reach the lower valley, much of the water that will affect the Mission flow four days in the future is already in the river. This flow information greatly simplifies the forecasting.

Two methods which would make use of the available flow information were proposed and tested. The first method involved a linear regression analysis in which flows on two or three days at several stations in the basin were correlated with the flow at Mission four days later. The second method involved choosing a set of stations and local inflows, producing one through four day forecasts for each of those stations by projecting the trends of the hydrograph, then computing the forecast flow at Mission by routing and summing the combined recorded and forecast flow from each of the upstream points.

The regression method produced forecast hydrographs which closely resembled the true hydrograph shape, but consistently lagged behind it. The second method produced forecast hydrographs which are quite peaky, which are high at peaks and on falling limbs of the hydrograph, but which are very good on the steep rising limbs of the hydrographs. Because of this latter consideration which is vital to flood-control operation of reservoirs, this second method was chosen.

The Forecast Algorithm

The basin was first divided into areas as shown in Figure 2 and where necessary, local inflows were computed by routing flows at the upstream area boundary to the downstream boundary and subtracting from the flow at the downstream station. This resulted in twelve "stations" for each of which forecasts were computed.

The algorithm was developed and tuned to meet certain specific requirements. These were that the forecast should seldom, if ever, be below the actual flows, it should not be significantly high for any length of time prior to the peak, and peaks and valleys of the hydrograph should be forecast with as little delay as possible.

At each of the twelve stations the hydrographs were projected ahead according to simple rules keyed to the hydrograph slope and curvature;

i.e. $$\text{slope} = S_j = Q_j - Q_{j-1}$$

$$\text{curvature} = DS_j = (Q_j - Q_{j-1}) - (Q_{j-1} - Q_{j-2})$$

Different projections are made for each of four conditions:

a) Curvature negative, slope positive
In this case the slope normally continues to turn down, or at least does not turn upwards. The projection is made as a straight line extension of slope S.

b) Curvature negative, slope negative
As in case 1, the slope normally continues to turn down, and the projection is made as a straight line extension of slope S.

c) Curvature positive, slope positive
Here the slope normally continues to increase. A rate of change of slope DLRISE(2) was selected at each station equal to about one-quarter to one-third of the maximum rate of rise for each station. The slope S was increased by this factor and the new slope projected for the four days of the forecast.

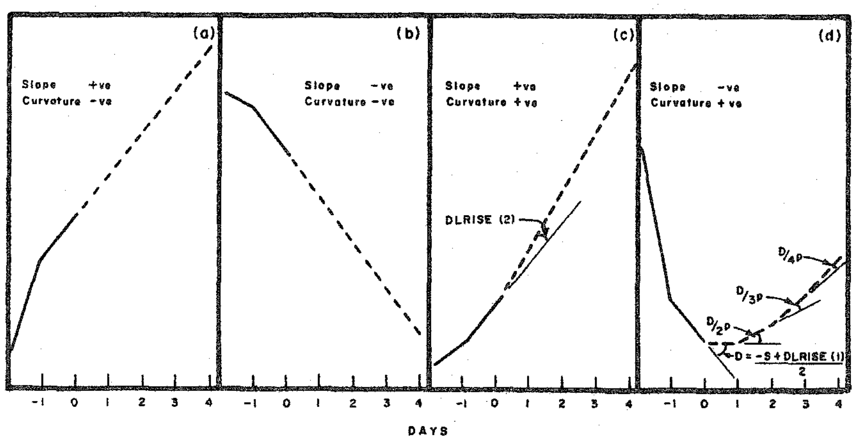
d) Curvature positive, slope negative
Here the slope very often rapidly turns around and becomes positive so the algorithm is designed to protect against missing such a rapid turnaround. The change in slope is computed according to the equation;

$$D = D_i/N^P$$

where: $D_i = \frac{-\text{slope} + \text{DLRISE(1)}}{2}$

- DLRISE(1) is a parameter for each station
- N is the forecast day number
- P is a parameter at each station

These four rules are illustrated below:



All projections made under the above rules were constrained within maximum rates of rise and fall. The limiting rates of rise were obtained by examining plots of the station hydrographs for several large years and taking at each station the steepest slope which occurred for at least four consecutive days. These limiting rates were subsequently all multiplied by a reduction factor, as it was found that using the full values gave forecasts which were too high at Mission.

Comments on Forecasts

A sample of the forecasts is shown in Figure 3. Although there are large forecast errors during falling stages, the forecasts are nevertheless quite useful for reservoir operations or for flood warnings. The forecast errors are consistantly high by design since they are the highest flows that can be expected regardless of weather conditions. The forecasts are seldom too low and seldom miss an upturning point on the hydrograph.

The method was found to be useful in real-time flood predictions as an indicator of the worst that could be expected during the forecast period. When tempered with judgement and a knowledge of the weather forecasts over an area, such a forecast can be quite useful. Once calibrated for a basin, the method can be applied easily and quickly each day or can be applied to a large number of years of past flow data to simulate forecasts for simulation-study purposes.

Most of the forecast error was due to the projection of flows in the most downstream sub-basin. The results could be greatly improved if weather and snow information were added to the analysis only for that area. If this method of forecasting were to be

EXAMPLE OF A SIMPAK MODEL

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DEMONSTRATION RUN, SHOWS MANY FEATURES OF SIMPAK
     3161008          1          INFLOW TO HOBSON RESERVOIR
       61069          9          RESERVOIR ROUTE, HOBSON LAKE RES
     3162806          1          LOCAL INFLOW, HOBSON TO CLEARWATER LAKE
       62808          1          TOTAL RUNOFF UPSTREAM OF CLEARWATER L.
       62859          1          LAKE ROUTE, CLEARWATER LAKE
       64926          1          LOCAL INFLOW, CLEARWATER L. TO HEMP CR.
       65069          1          RESERVOIR ROUTE, HEMP CREEK RES. CH STOR SPEC.
       69049          1          ROUTE N. THOMPSON R., CLEARWATER TO MCLURE
       67609          1          CLEARWATER RIVER NR CLEARWATER STA  OBS.
     5069049          1          ROUTE N. THOMPSON R, CL. TO MCLURE FOR LOCAL
       69009          1          N. THOMPSON RIVER AT MCLURE OBS.
       69006          1          DERIVED LOCAL, CLEARWATER TO MCLURE
       69019          1          SUM POINT, N. THOMPSON AT MCLURE
       73049          1          ROUTE N. THOMPSON, MCLURE TO KAMLOOPS
     5073049          1          ROUTE N. THOMPSON, MCLURE TO KAM, FOR LOCAL
       72009          1          S. THOMPSON R. AT MONTE CREEK OBS.
       72549          1          ROUTE S. THOMPSON, MONTE CR. TO KAMLOOPS
       74019          1          SUM POINT, THOMPSON R. AT KAMLOOPS
     5074009          1          NATURAL FLOW, THOMPSON R. AT KAMLOOPS
       74033          1          CHANGE IN FLOW AT KAMLOOPS (HOLDOUTS)
       18079          1          WAVE ROUTE, KAMLOOPS TO MISSION (HOLDOUTS)
       18009          1          FRASER RIVER AT MISSION OBS.
       18019          1          COMPUTED DISCHARGE AT MISSION
       19029          1          COMPUTED DISCHARGE AT NEW WESTMINSTER
$END
 1  9 1972  31  7 1972      0   2   1   0          0   1
RESEV     61069   3161008                    500. 2 0 0  314000.      2800.     2810.
ADD       62808   3161008   3162806              1
LAKE      62859     61069   3162806
TRSF      64926     62808                        1 1       0.56
RESEV     65069     62859   64926 -95999999 4 9 9  945000.
REACH     69049     65069                        2          0.2        38.0
REACH   5069049     67609                        2          0.2        38.0
SUBT      69006     69009   5069049              1 1 1
ADD       69019     65049     69006              1
REACH     73049     65019                        2          0.2        44.
REACH   5373049     69009                        2          0.2        44.
REAC      72549     72009                        3          0.2        27.0
ADD       74019     73049     72549              1
ADD     5074009   5073049     72549              1
SUBT      74033     74019   5074009              1 1 1
WAVE      18079     74033                        0 3
  .08   .35   .42   .15
ADD       18019     18079     18009              1
LOOK      18019     18019                        2 1
EXTN      19029     18019
PRINT     65065                                  9
MEAN      18019                                  0 1
 0 0 0 0 1 1 1 0 0 0 0 0
PLOT                                             2
          74019     1    C        0    150000
        5074009     1    R        0    150000
PLOT                                             2
          18019     1    R        0    600000
          18009     1    C        0    600000
FILE      18019                                  1
$END
```

FIGURE 1

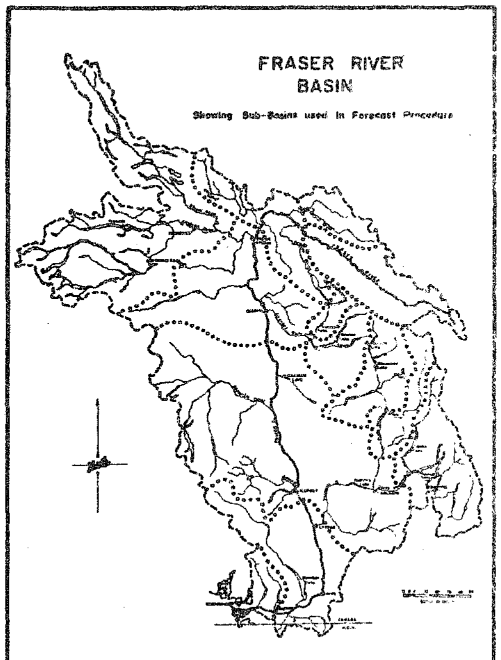

FIGURE 2

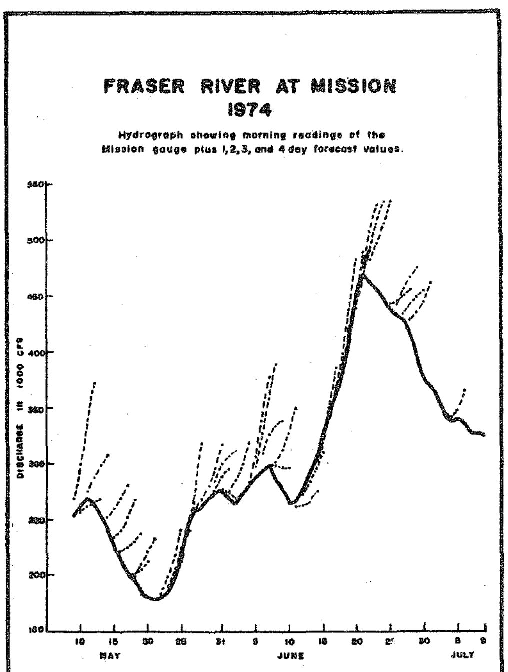

FIGURE 3

used extensively for real-time forecasting it is recommended that it be extended to include detailed hydrometeorological forecasting in the lower (small lag) portions of the basin.

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The SIMPAK program has evolved over the past three years to its present form and has received input from several individuals within the Inland Waters Directorate as well as from other agencies. Particular adknowledgement is due to the U.S. Army Corps of Engineers, North Pacific Division, who made available the SSARR program, after which the concept of SIMPAK was patterned. Individual acknowledgement must go to Mr. K. G. Waldie and Mr. N. A. Dowds who have done the bulk of the programming for SIMPAK, and to Mr. D. R. Flavell who, under the direction of the author, developed the forecasting algorithm.

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