MONTHLY RUNOFF MODEL

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1.0 Introduction

This report describes the development of a model which simulates monthly streamflows, and the application of this model to two topical drainage basins. These two basins, Ratchford Creek at the 600 m Contour and Flathead River at Flathead have streamflow records taken by the Water Survey of Canada. For the Ratchford basin the major question to be answered is to what accuracy can streamflows be synthesized from other data sources. For the Flathead basin the major question is to what extent are sub-basins of the Flathead such as Cabin Creek similar to the overall basin.

2.0 Background

The monthly runoff model upon which this present version is based was described in the 1970 Shawinigan report. This model allowed a distributed analysis of a basin through a 10 kilometre X 10 kilometre square grid sampling system of physiographic quantities. Modelling monthly values of runoff allowed for simplified representation of hydrologic processes. and required only moderate quantities of input data such as precipitation and temperature while still allowing some temporal variability to be studied.

As physiographic data from a 2 kilometre by 2 kilometre sampling scheme is becoming available for basins in B.C., this seemed an appropriate time to begin an examination of a spatially distributed model.

The key problem is the development of a model which incorporates established physical laws which still allow economy in data requirements. So as much as possible the model is intended to benefit from the guidance and constraints offered by physical laws.

The model was designed using difference equations to allow repersentation in state-space formalization. This will allow a Kalman filter routine to be developed for parameter optimization and examination of the contributions of data from various sources.

The model was also designed with consideration given to later using inputs from remote sensing data sources. These inputs would expand the present point meaurements of precipitation and temperature into area estimates.

In light of the above considerations attention has been paid to a spatially organized model, and the process representations have been kept simple and as observable as possible. Some modelling routines have been adapted from Martinec-Rango Snowmelt Runoff model and from Eagleson representation of hydrologic process.

3.0 Description of the Model

The model is initially based upon the Martinec-Rango SMR snowmelt runoff model. This model was developed for basins in which snowmelt is the major producer of runoff.

As Eagleson has pointed out, the thermal state of the snowpack governs the partition of moisture among evapotranspiration, runoff and storage. This state is easier to specify than the mositure state of near surface soil which controls the partitioning for rainfall inputs.

The flowchart of the model is shown in Figure 3.1.

SUBDIVIDE BASIN
  N SUBDIVIONS

ET MODEL PARAMETERS
  P(N,1) - SNOWMELT PARAMETER MELT AT 0 degrees C
  P(N,2) - TEMPERATURE ADJUSTMENT
  P(N,3) - SURFACE STORAGE
  P(N,4) - MAXIMUM RUNOFF COEFFICIENT

SET TLAPS
    PLAPS

SET INITIAL LAC
            SAC

FOR EACH MONTH M
READ TEMP, PREC

FOR EACH SUBDIVISION N
  LAPSE TEMP - TSN
  PREC - PSN

DECIDE ON DISTRIBUTION
OF FORMS OF PRECIP BASED ON TSN
SNOW-RAIN

FIND SAC SNOW

FIND SNOWMELT SM

FIRST ESTIMATE OF LAC
LACEND = LAC(N,M-1)+SM+RAIN

AEVAP
EVAPOTRANSPIRATION BY TURC
AVAILABLE WATER = 1/2 [LACEND +
  LAC(N,M-1)]

LACEND = LACEND-AEVAP

RUNOFF COEFFICIENT 1 BASED ON
 LAC(N,M-1)
 R01

LACEND = LACEND -R02

RUNOFF COEFFICIENT 2 BASE ON LACEND
 R02

LAC(N,M) LACEND -R02

Figure 3.1 Flowchart of the Model

3.1 Subdivision of the Basin

To simplify the model and reduce the number of model parameters, basins are subdivided by elevation. Martinec-Rango suggest 1500 foot bands, but because of shortage of data to help with estimating lapse rates, elevation bands greater than 1500 feet were used. Usually three elevation bands were used.

3.2 Lapsing Temperature and Precipitation

Temperature for each elevation band TSB was found from a temperature lapse late TLAPS.

TSB=TLAPS(ELEVATION OF SUBDIVISION
-ELEVATION OF MET STATION)

TLAPS=-0.0019 degrees C per foot was used as an initial value, as suggested by Martinec-Rango.

Precipitation was found for each elevation band PSB using the precipitation lapse rate PLAPS in a formula similar to that for temperature. Values of PLAPS were initially estimated from accumulated values of precipitation at lower level met stations and snow course water equivalent data. These were later modified in the calibration stages so that the synthesized longterm runoff was close to the observed long term runoff. TLAPS for the Ratchford basin using Revelstoke A data was 0.06 mm per foot; for the Flathead using Fernie precipitation data 0.03 mm per foot.

3.3 Form of the Precipitation

Once the temperature and precipitation for a subdivision were known, the form of the precipitation (rain or snow) was determined. The determination was made based upon a plot of Rain/Total precipitation versus temperature for a nearby met station, Figure 3.2. An equation is then developed for the amount of RAIN and SNOW.

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**************************************************************
*                                                            *
*                  Figure 3.2                                *
*                                                            *
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Precipitation in the form of snow is accumulated in storage, SAC, solid accumulation. The solid accumulation is given for each subdivision for each month, at the end of the month.

3.4 Snowmelt

Melt from the solid accumulation is modelled by a degree month approach. Martinec Rango suggest a degree-day factor in the range 0.25 to 0.60 cm per C degree day. As the months in which snowmelt occurs are usually either 30 or 31 days long, the monthly degree factor was taken to range from 75 mm per C degree month to 180 mm per C degree month.

The changes in degree day factor are related to increasing snow density. A greater density is usually associated with older snow with a lower albedo. Also high densities are associated with increased liquid water content and low thermal insulation of the snow. So high degree-day factors are generally realized toward the end of the melt season, i.e. months when the temperature is higher.
So the degree month factor was made a linear function of the mean monthly temperature. The melt factor was about 70 mm per C degree month when TSB^ 0 degrees C and was about 150 mm per C degree month when TSB^ 20 degrees C. The values were adjusted in the calibration stage so the synthesized runoff pattern matched the observed runoff pattern.

Two of the problems with degree day factor are that high winds will increase the degree day factor and new snow may temporarily decrease the degree day factor. Neither of these should affect the monthly degree day factor.

The melt (SM) from the solid accumulation is calculated by:

SM = MF*(TSB+P(N,2)+ CPT)

CPT is a coldpack temperature; it is a fraction of the previous month's temperature, provided this was below zero. P(N,2) is a parameter for subdivision N, a correction of the temperature TSB to allow for possible non-representativeness of the temperature lapse rate.

3.5 Rain and Liquid Accumulation

The snowmelt is added to the liquid accumulation carried over from the previous month LAC (N,M-1).

Precipitation in the form of rain is added to the liquid accumulation.

3.6 Evaporation

The monthly evaporation in each subdivision AEVAP is estimated using Turc's formula. The temperature is the temperature of the subdivsion TSB. The moisture available for evaporation is taken to be 1/2 [LAC(N,M01) + LACEND].

LACEND = LAC(N,M-1) +SM + RAIN

LACEND is an estimate of the liquid accumulation at the end of each month (M). Once AEVAP is estimated the estimate of LACEND is revised.

LACEND = LACEND - AEVAP

3.7 Runoff

The final step is estimating the runoff RLAC(N,M) for subdivision N for month M. Martinec-Rango advise that the runoff coefficient is the most difficult basin parameter to estimate accurately and should be closely examined. In this model the runoff coefficient RCOEF was made a function of the water available for runoff AVAL. This roughly allows for the effects of changing vegetation and soil moisture conditions.

$$RCOEF = P(N,4)*SINPI*\frac{AVAIL}{2*P(N,3)}$$

P(N,4) is a saturation runoff coefficient, maximum value 1.0 P(N,3) is the saturation value which depends upon the storage and steepness of the subdivision of the basin. Areas of lakes and swamps increase P(N,3) while steep slopes decrease its value. The length of stream channel, an index of drainage efficiency can also increase P(N,3) as more channel storage is available unless the subdivision is steep in which case the better drainage decreases storage.

Once the subdivision's maximum storage P(N,3) is reached, the runoff coefficient remains at P(N,4) for any increase in the AVAIL moisture.

To calculate the runoff, the month is divided in 2. For the first part AVAIL=LAC(N,M-1); for the second part AVAIL=LACEND-R01. The runoff RLAC(N,M)=R01+r02. The liquid accumulation is then updated and carried over to next month AAC(N,M)=LAC(N,M)-RLAC(N,M).

The runoff for the basin is a weighted sum of the runoff from each subdivision. Weighting is accomplished by ratio of drainage area of the subdivision to drainage area of the basin.

ROSYN=ROSYN+RLAC(N,M)*DASB
DA

The total synthetic discharge in cubic decametres (DAM) is then STDIS(M)=ROSYN*DA. The relative error in percent is
RELERR(M)= MTDIS(M)-STDIS(M) *100
MTDIS(M)

4.0 Procedure

The model was written in PRO-BASIC for interpretation on a DEC-350 computer. The program is stored on diskette RORY under the name MONRODF.11.

The input data are placed in files for the main program by the programs: METDATIN, which creates a file for the meteorological data, at present only one met station at a time is used for input; RODATIN, which sets up the observed total dischages for the basin; and PHYDATIN, which sets up the subdivisions of the basin and creates a file for the physiographic quantities of the basin. These programs are self exlaining and prompt the user for data and show the correct order for entering.

4.1 Ratchford Basin - Ratchford Creek at 600 m Contour

For the Ratchford basin the calibration sample was January 1973 to December 1977. The discharges from WSOC station 08LE086 were stored in RATCHR02 and the meteorologic data from Revelstoke Airport (1850 feet) were stored in REVAKLA2.

The physiographic data were taken from the 2 km X 2 km data bank and were stored in RATCHPHYS.

The area-elevation curve for the Ratchford basin is shown in Figure 4.1. The 2 X 2 representation of the Ratchford Basin is shown in Figure 4.2. The basin was subdivided in 3 parts with areas 72, 96 and 76 square kilometre areas. The centre elevations of the subdivisions are 3700 feet, 5200 feet and 6800 feet.

To get a first estimate of the precipitation lapse rate, snowcourse data from Mount Revelstoke (6000 feet), Kirbyville Lake (5140 feet) Watson Lake (5950 feet) and Mount Copeland (5570 feet) see Figure 4.3.

FIGURE 4.1

FIGURE 4.2

FIGURE 4.3

Consideration of accumulated precipitation at Revelstoke A and snow course data suggested a precipitation lapse rate of approximately 100 mm per 1000 feet.

For the first subdivision of the Ratchford basin the dot count for lakes and swamps is 19, for the second it is 167, and for the third it is 107, suggesting low storage in the first subdivision. The length of channel in subdivision 1 is 179.5, for subdivision 2 it is 267.5, and for subdivision 3 it is 137.0, so the second subdivision appears relatively well drained.

Some 30 runs of the program were made as procedures were changed and then values of parameters were tested. The final set is shown in Appendix I.

4.2 Flathead Basin [08NP001 Flathead River at Flathead]

The area-elevation curve for the Flathead basin in Canada is shown in Figure 4.4 The basin was subdivided into three elevation subdivisions: the first with mean elevation 500 feet (370 square kilometres), the second with mean elevation 5800 feet (370 square kilometres), and the third with mean elevation 6800 feet (370 square kilometres). The precipitation data was taken from Fernie elevation 3280 feet.

The calibration period was taken from January 1970 to December 1974, 60 months, and the validation from January 1978 to December 1981. The meteorologic data were placed in files FERNIE for calibration and FERNIE2 for validation. The physiographic data was in FLATPHYS and runoff in FLATHR01 and FLATHR02.

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*                                                          *
*                     FIGURE 4.4                           *
*                                                          *
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From examination of snowcourse records from Morrisey Ridge (6100 feet) a precipitation lapse rate of approximately 0.03 mm per foot was used as an initial estimate. As the

Flathead basin has very little surface storage in the form of lakes and swamps, the storage parameter (Parameter 3) was lowered from values used on the Ratchford basin. The Flathead does show a fairly high length of stream channels, i.e. it is well drained so the maximum runoff coefficient was set high, Parameter 4.

4.3 Cabin Creek [08NP004 Cabin Creek near the Mouth]

Cabin Creek (drainage area 93 square kilometres) is a tributary to the Flathead. The distribution of elevations is shown in Table 4.1. The basin was subdivided into three subdivisions: 5000, 6000, 6800 feet, and the model was applied to the basin over the period January 1978 to December 1981 with parameters as determined by the calibration of the Flathead. Fernie precipitations and temperatures were used. Detailed Results are presented in Appendix III.

****

4500-5000	3
5000-5500	1
5500-6000	9
6000-6500	6
6500-7000	3
7000+	1

Elevations taken from 2 km X 2 km database

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Table 4.1 Distribution of Elevations (in feet) for Cabin Creek Basin

4 Results

4.1 Ratchford Basin

For the Ratchford basin using Revelstoke A precipitation and temperature, the calibration results are summarized in Table 4.1. The relative error is the difference, observed discharge-synthesized discharge, divided by the observed discharge, times 100. There is a bias against high positive relative errors, as discharges are not allowed to be negative.

For the validation period, January 1973 to December 1978
TOTAL MEAS DISCHARGE .184686E+07 DAM
TOTAL SYN DISCHARGE .186322E+07 DAM

The model parameters used for this run are given in Appendix I.

Results for the validation run are given in Table 4.2.

DISTRIBUTION OF RELATIVE ERRORS		
BEYOND -100%	2	6.7%
BETWEEN -100% AND -75%	0	0
BETWEEN -75% AND -50%	2	6.7%
BETWEEN -50% AND -25%	6	10
BETWEEN -25% AND 0%	11	18.3
BETWEEN 0% AND 25%	20	33.3
BETWEEN 25% AND 50%	8	13.3
BETWEEN 50% AND 75%	9	15.0
BETWEEN 75% AND 100%	2	6.7
BEYOND 100%	0	0

Table 4.1 Ratchford Calibration

BEYOND -100%	4	8.3
BETWEEN -100% AND -75%	1	2.1
BETWEEN -75% AND -50%	2	4.2
BETWEEN -50% AND -25%	5	10.4
BETWEEN -25% AND 0%	5	10.4
BETWEEN 0% AND 25%	11	22.9
BETWEEN 25% AND 50%	8	16.6
BETWEEN 50% AND 75%	6	12.5
BETWEEN 75% AND 100%	6	12.5

Table 4.2 Distribution of Relative Errors
Ratchford Validation

Table 4.3 shows the relative errors from the estimates of 08LE086 Ratchford Creek monthly discharges made from simple regression with monthly discharges from 08ND019 Kirbyville River near the mouth. The period of record was January 1973 to December 1977 as for the calibration of the monthly flow model. The discharges were deseasonalized by subtraction of appropriate monthly mean values. The overall correlation coefficient (over the 60 months) was 0.84.

BEYOND -100%	3	5
BETWEEN -100% AND -75%	3	5
BETWEEN -75% AND -50%	2	4.2
BETWEEN -50% AND -25%	14	23.3
BETWEEN -25% AND 0%	15	25
BETWEEN 0% AND 25%	19	31.6
BETWEEN 25% AND 50%	4	8.3
BETWEEN 50% AND 75%	0	0
BETWEEN 75% AND 100%	0	0

Table 4.3 Distribution of Relative Errors
Ratchford-Kirbyville Correlation

4.2 Flathead

The calibration and validation results for the Flathead Basin are given in Tables 4.4 and 4.5. The model parameters are given in Appendix II.

For the calibration run,

TOTAL MEAS DISCHARGE .452668E+07 DAM
TOTAL SYN DISCHARGE .452641E+07 DAM

****

DISTRIBUTION OF RELATIVE ERRORS

BEYOND -100%	6	10
BETWEEN -100% AND -75%	0	0
BETWEEN -75% AND -50%	6	10
BETWEEN -50% AND -25%	4	6.7
BETWEEN -25% AND 0%	10	16.7
BETWEEN 0% AND 25%	17	28.3
BETWEEN 25% AND 50%	9	15
BETWEEN 50% AND 75%	6	10
BETWEEN 75% AND 100%	0	0

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Table 4.4 Flathead Calibration

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DISTRIBUTION OF RELATIVE ERRORS

BEYOND -100%	7	14.6
BETWEEN -100% AND -75%	0	0
BETWEEN -75% AND -50%	1	2.1
BETWEEN -50% AND -25%	6	12.5
BETWEEN -25% AND 0%	7	14.6
BETWEEN 0% AND 25%	10	20.8
BETWEEN 25% AND 50%	11	22.9
BETWEEN 50% AND 75%	4	8.3
BETWEEN 75% AND 100%	0	0

****

Table 4.5 Flathead Validation

4.3 Cabin Creek

Using the calibration parameters for Flathead and Cabin Creek Physiographic Quantities the following results were achieved:

****

DISTRIBUTION OF RELATIVE ERRORS

BEYOND -100%	9
BETWEEN -100% AND -75%	0
BETWEEN -75% AND -50%	2
BETWEEN -50% AND -25%	0
BETWEEN -25% AND 0%	7
BETWEEN 0% AND 25%	13
BETWEEN 25% AND 50%	11
BETWEEN 50% AND 75%	4
BETWEEN 75% AND 100%	1

MEAN DIFFERENCE	-259.09
ROOT MEAN SQUARE DIFFERENCE	3290.89
TOTAL MEAS DISCHARGE	245827 DAM
TOTAL SYN DISCHARGE	258263 DAM

****

Table 5 Cabin Creek

5.0 Discussion of Results and Conclusions

In general, the largest relative errors occur for low flow months. This is understandable as the model was designed for snowmelt and hence peak flows, for low flows runoff coefficients, storage and drainage of the basin become much more important. Validation generally produces more large errors than calibration. This was true for the Ratchford. But even for calibration errors greater than 25% occurred more than 50% of the months. Correlation with nearby stream produced approximately the same results as the monthly flow model. Apparently if data are required to

25% or better streams should be gauged.

Cabin Creek showed very similar error distribution to Flathead River and so for this model and sample period, Flathead River response and Cabin Creek response should be considered similar.

6.0 Recommendations

The monthly flow model should be applied to other basins first near to the original two to examine variability in parameters and then to basins in other hydrologic regimes such as the west coast of Vancouver Island and the Dry Interior.

The routines of the basin should be further refined to be made as efficient and with as much physical basis as possible.

The state-space approach should be developed for parameter optimization and assessment of the information content of various sources of data.

More extensive use should be made of the physiographic parameters and allowance must be made to distribute precipitation and temperature using more than one met station and remote sensing data.