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NICOLA LAKE INFLOW FORECASTING MODEL REVIEW

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INTRODUCTION

Nicola Lake is located northeast of Merritt in the Southern Interior of British Columbia. Figure 1 shows the location of Nicola Lake and the contributing watershed. The catchment area includes 2990 km^2 of the interior plateau, varying from semi-arid valley bottom to temperate mountains rising 2000 m above sea-level. Nicola Lake water levels have been controlled by a dam since the 1920's. The dam was rebuilt in 1986 to store more spring runoff for summer irrigation and maintaining fisheries flows though the fall and winter. The dam does not provide significant flood control benefits as average freshet inflow volumes far exceed the live storage capacity of the reservoir. It can, however, reduce peak discharge in the Nicola River downstream in moderate flood years if inflow forecasts are accurate and snowmelt is not too rapid.

BC Environment operates the new dam which was funded mainly by the BC Ministry of Environment with contributions from the Department of Fisheries and Oceans Canada, Agriculture Canada, and BC Ministry of Agriculture. Effective operation of the dam depends on accurate forecasts of lake inflows, particularly during the freshet period when most of the annual runoff occurs. The inflow forecasts are done by BC Environment's River Forecast Centre in Victoria. Inflow prediction has been good, with the exception of years like 1990 or 1991 when extremely high rainfall in May and June resulted in inflows much higher than forecast. The problems associated with the unexpectedly high releases in the spring of both 1990 and 1991 sparked a search for improved flow forecasting methods.

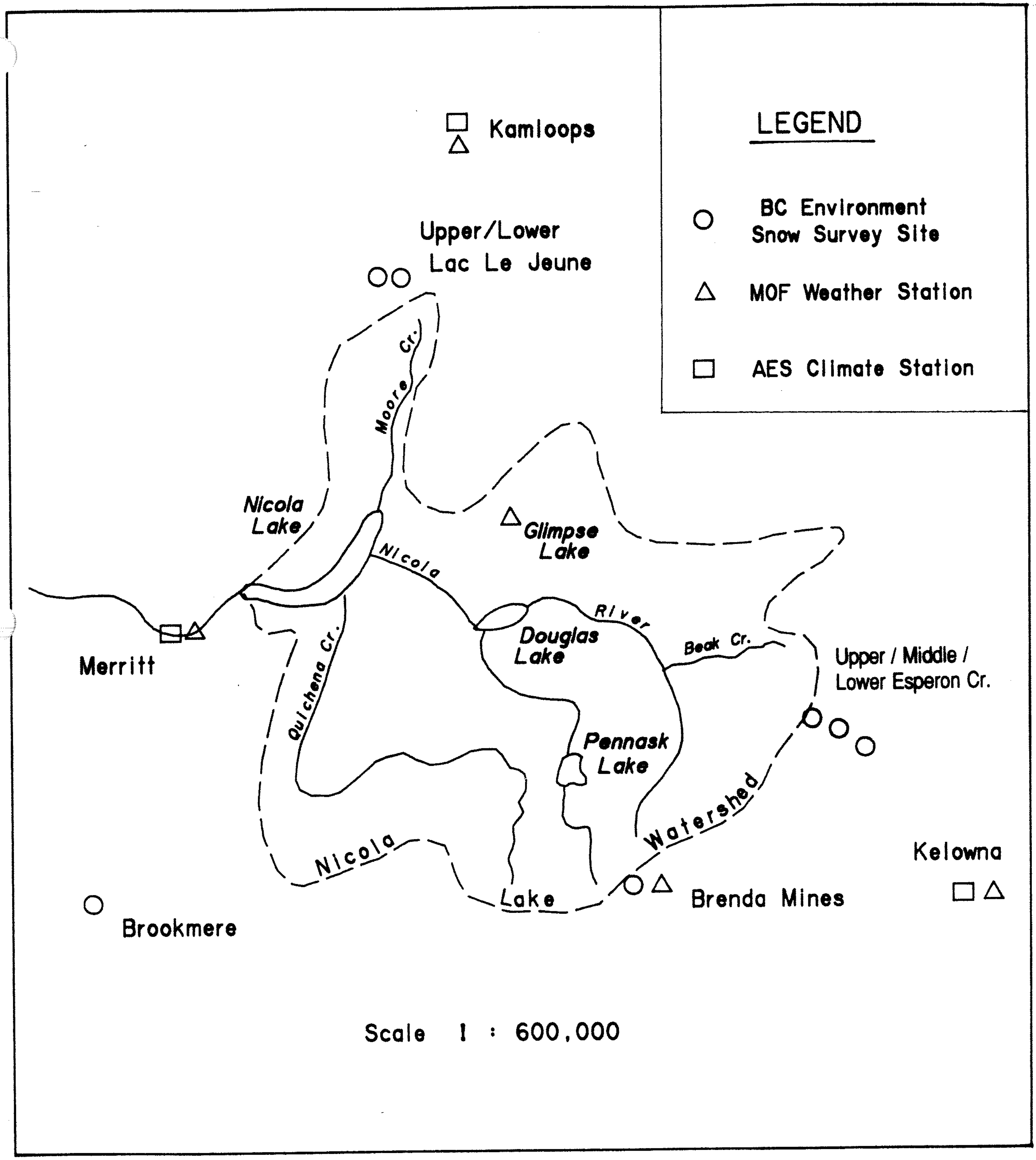

Figure 1. Nicola Lake Watershed and Meteorological Sites in and around the watershed

DATA ANALYSIS

All local snow course, precipitation, and Nicola Lake inflow, outflow and lake level data were assembled for the period from 1965 to 1991. The meteorological data collection sites used are shown in Figure 1. The snow course data used were the April 1 snow water equivalents for the following stations: Brenda Mines; Brookmere; Lower, Middle and Upper Esperon Creek; Lower and Upper Lac Le Jeune. Atmospheric Environment Services rainfall data were available for the following stations: Merritt (1965-66); Merritt STP (1968-91); Kelowna (1965-68), Kelowna Airport (1969-91); and Kamloops (1965-91). Net inflows to Nicola Lake were calculated from lake levels and outflows (1983-91), or estimated from the difference in Nicola and Coldwater River discharges measured downstream (1965-82). All the precipitation and snow water equivalent values are given in millimetres. The net inflows are expressed in millions of cubic metres.

Data analysis consisted of many multiple linear regressions relating freshet runoff volumes (April to June Nicola Lake net inflows) to a subset of the snow course, precipitation, and antecedent discharge variables. The computer software used was the Statistical Analysis System (SAS) on the VAX mainframe computer.

In 1986 the River Forecast Centre used these techniques to develop the following equation to predict freshet volumes ($Vol_{Apr\text{-}Jun}$) based on data to 1985.

$$Vol_{Apr\text{-}Jun} = -81.3 + 0.113(UpEsp + Brook) + 0.838(Kel_{Nov\text{-}Mar}) \quad \text{.........(1)}$$

where $UpEsp$ = April 1 Snow Water Equivalent at Upper Esperon snow course

$Brook$ = April 1 Snow Water Equivalent at Brookmere snow course

$Kel_{Nov\text{-}Mar}$ = Total November to March precipitation at Kelowna

This equation fits the data to 1985 very well and has a correlation coefficient (R^2) of 0.93. Repeating this analysis independently with data to 1985 resulted in an R^2 of 0.89. This minor difference may be due to different precipitation data being use for Kelowna during overlap in station operation. Also there may be minor differences in estimated net inflows in the late 60's due to revised streamflow record.

When the data to 1991 is added, the River Forecast Centre's model shows R^2 dropping to 0.67. The high, rainfall-generated, 1990 flow is largely responsible for this drop in degree of correlation. Since this equation uses Kelowna rainfall data to 1991 it will be referred to as "Kelowna to 1991", and is as follows:

$$Vol_{Apr\text{-}Jun} = -52.7 + 0.105(UpEsp + Brook) + 0.71(Kel_{Nov\text{-}Mar}) \quad \text{..........(2)}$$

Using any combination of the input data available, for all years to 1991 the best R^2 that can be produced is 0.73. This equation will be referred to as "Merritt to 1991", and is as follows:

$$Vol_{Apr\text{-}Jun} = -39.5 + 0.131(UpEsp) + 0.442(Mer_{Nov\text{-}Mar}) + 4.6(Vol_{Mar}) \quad \text{.....(3)}$$

where

where	UpEsp	=	April 1 Snow Water Equivalent at Upper Esperon snow course
	$Mer_{Nov\text{-}Mar}$	=	Total November to March rainfall at Merritt
	Vol_{Mar}	=	March net inflow volume to Nicola Lake

Although the "Merritt to 1991" model does explain more of the variation in net inflows it consistently over-estimates the low inflows. The errors, or residuals, for equations (2) and (3) for each year are plotted in Figures 2 and 3. The years are arranged from lowest to highest flow. Figure 3 clearly shows that the "Merritt to 1991" equation over-estimates the inflow for all years with inflows less than 1981's 109 x 10^6 m^3. This is a serious flaw in that the dam was constructed for water

Nicola Lake Inflow Forecasting
Equation (2) "Kelowna to 1991"

$$Vol_{Apr-Jun} = -52.7 + 0.105(Brook + UpEsp) + 0.71(Kel_{Nov-Mar})$$

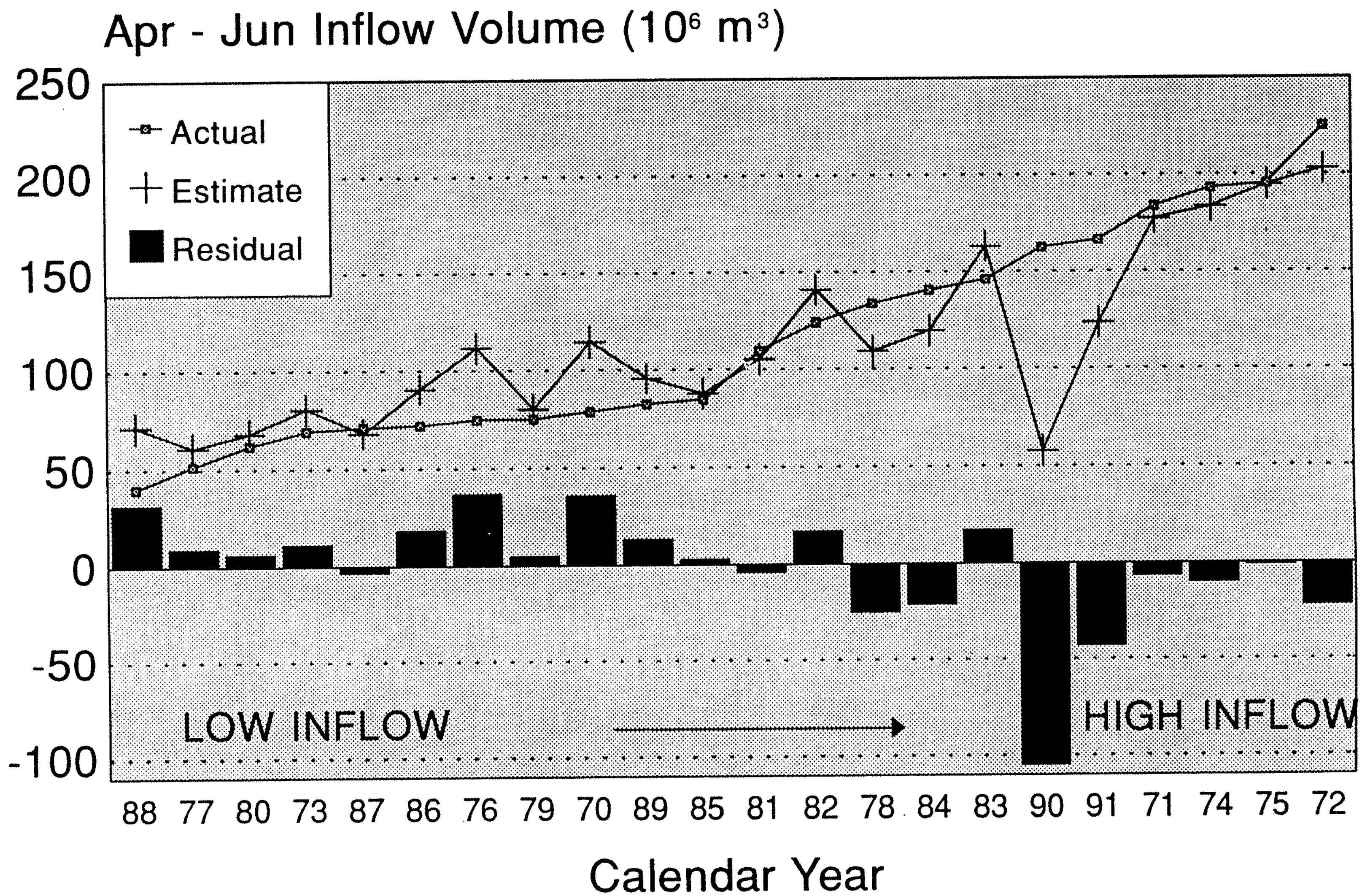

Figure 2

Nicola Lake Inflow Forecasting
Equation (3) "Merritt to 1991"

$$Vol_{Apr\text{-}Jun} = -39.5 + 0.131(UpEsp) + 0.442(Mer_{Nov\text{-}Mar}) + 4.6(Vol_{Mar})$$

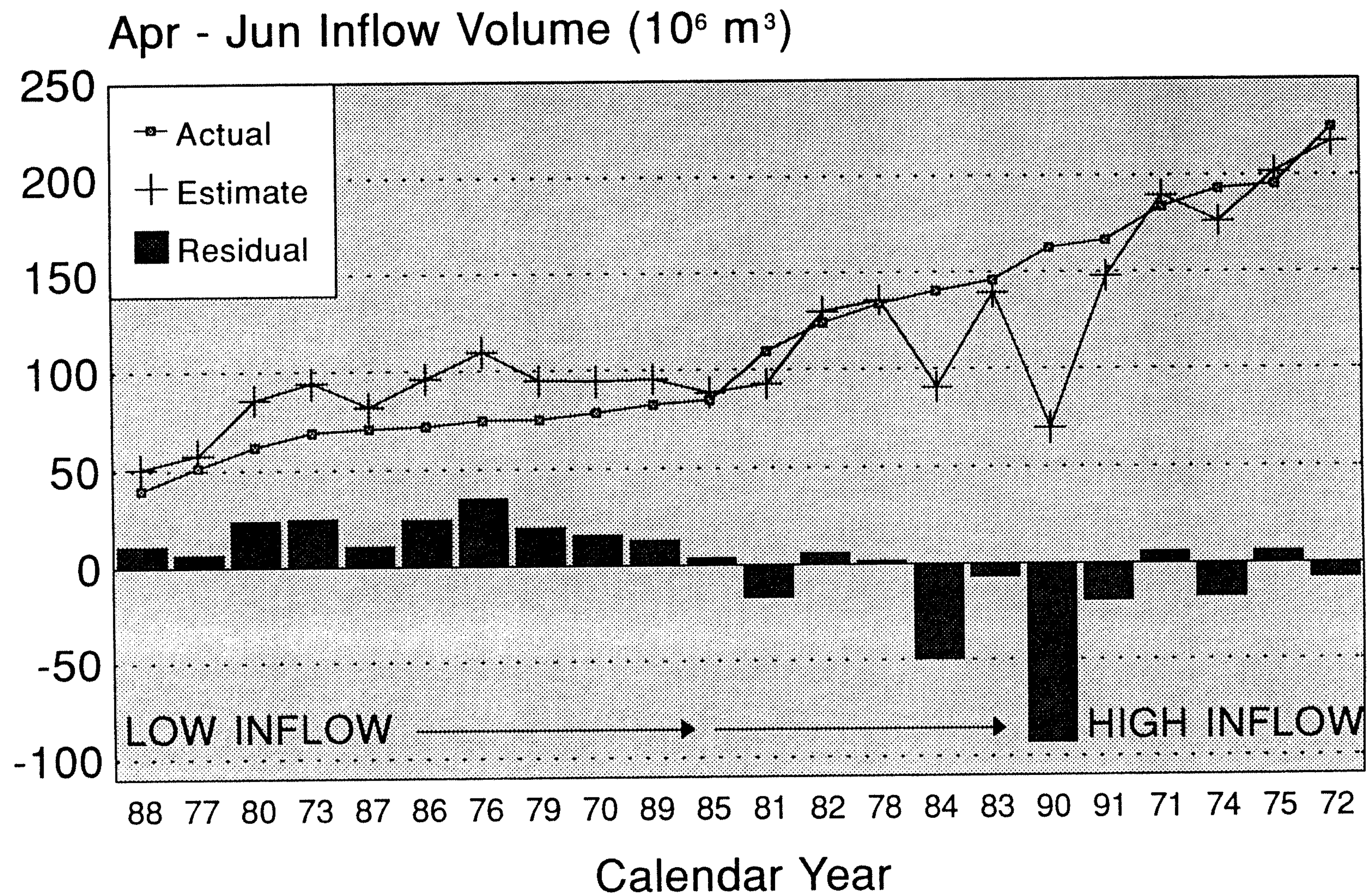

Figure 3

supply, and the estimates should be as good as possible during low flow years when water may be in short supply. A prediction method which over-estimates the inflow would lead to larger storage releases than necessary, and consequently the reservoir might not fill. The "Merritt to 1991" model predicts high inflows better than the "Kelowna to 1991" model. While it is desirable to have advance warning of high inflows, the storage capacity of Nicola Lake is insufficient to provide significant flood control benefits which makes the "Merritt to 1991" model only useful during minor flood years.

If the regression using the independent variables in Equation (3) is repeated without the 1990 data ("Merritt w/o 1990") the result is Equation (4) having an R^2 of 0.89.

$$Vol_{Apr\text{-}Jun} = -61.2 + 0.165(UpEsp) + 0.463(Mer_{Nov\text{-}Mar}) + 4.4(Vol_{Mar}) \quad \text{.....(4)}$$

The River Forecast Centre's model has $R^2 = 0.86$ with the 1990 data omitted ("Kelowna w/o 1990") and is shown as Equation (5).

$$Vol_{Apr\text{-}Jun} = -83.8 + 0.114(UpEsp + Brook) + 0.855(Kel_{Nov\text{-}Mar}) \quad \text{..........(5)}$$

The errors resulting from Equation (5) are slightly greater than those of Equation (4) but the error distribution appears to be more random than Equation (4). The results and error distributions for equations (4) and (5) are shown in Figures 4 and 5, respectively. Equation (5) is almost identical to equation (1), which demonstrates that the 1990 freshet volume was largely responsible for shifting the curve to try to account for high inflows.

NICOLA LAKE INFLOW FORECASTING
Equation (4) "Merritt w/o 1990"

$$Vol_{Apr-Jun} = -61.2 + 0.165(UpEsp) + 0.463(Mer_{Nov-Mar}) + 4.4(Vol_{Mar})$$

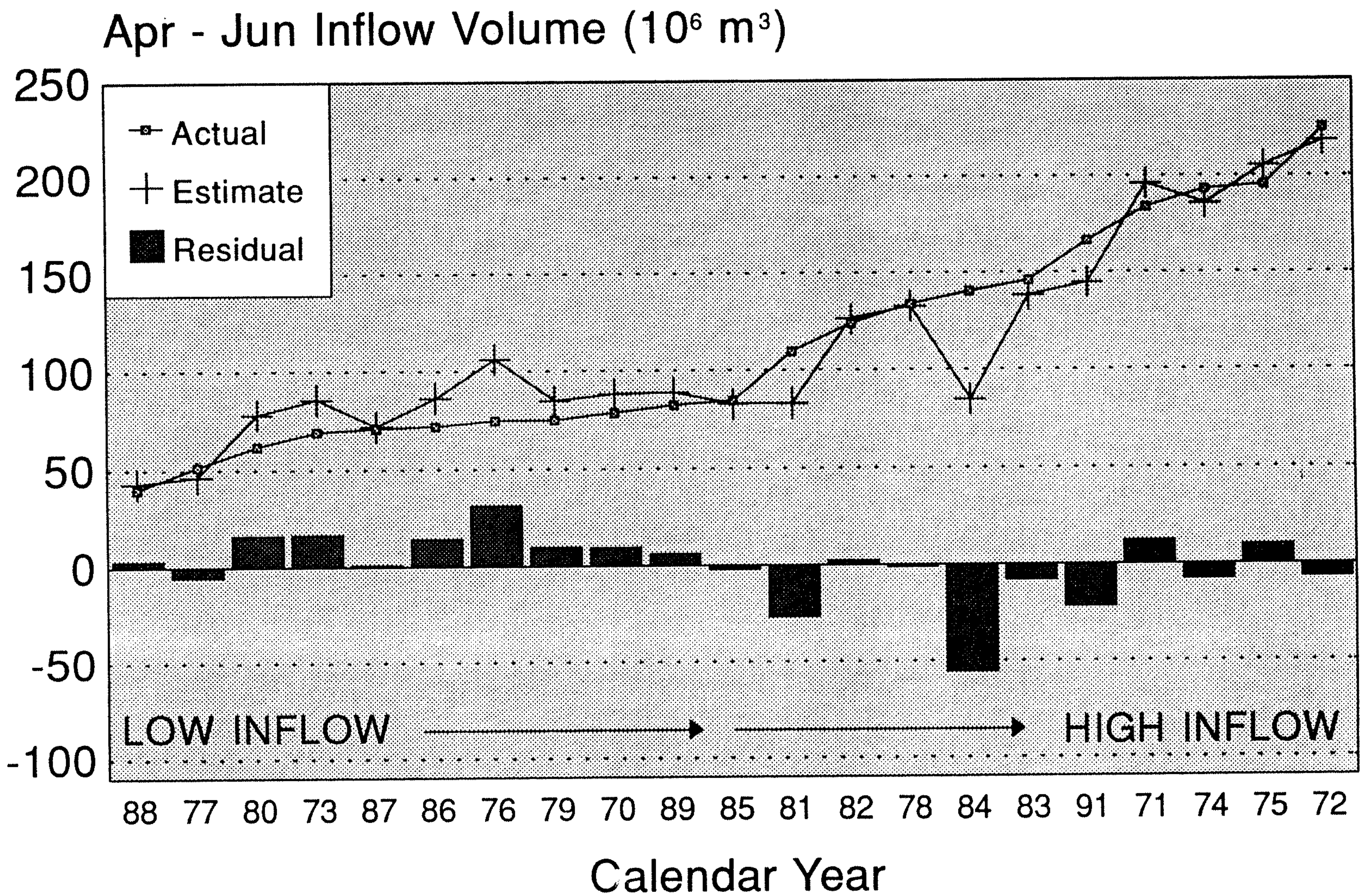

Figure 4

Nicola Lake Inflow Forecasting
Equation (5) "Kelowna w/o 1990"

$$Vol_{Apr\text{-}Jun} = -83.8 + 0.114(Brook + UpEsp) + 0.855(Kel_{Nov\text{-}Mar})$$

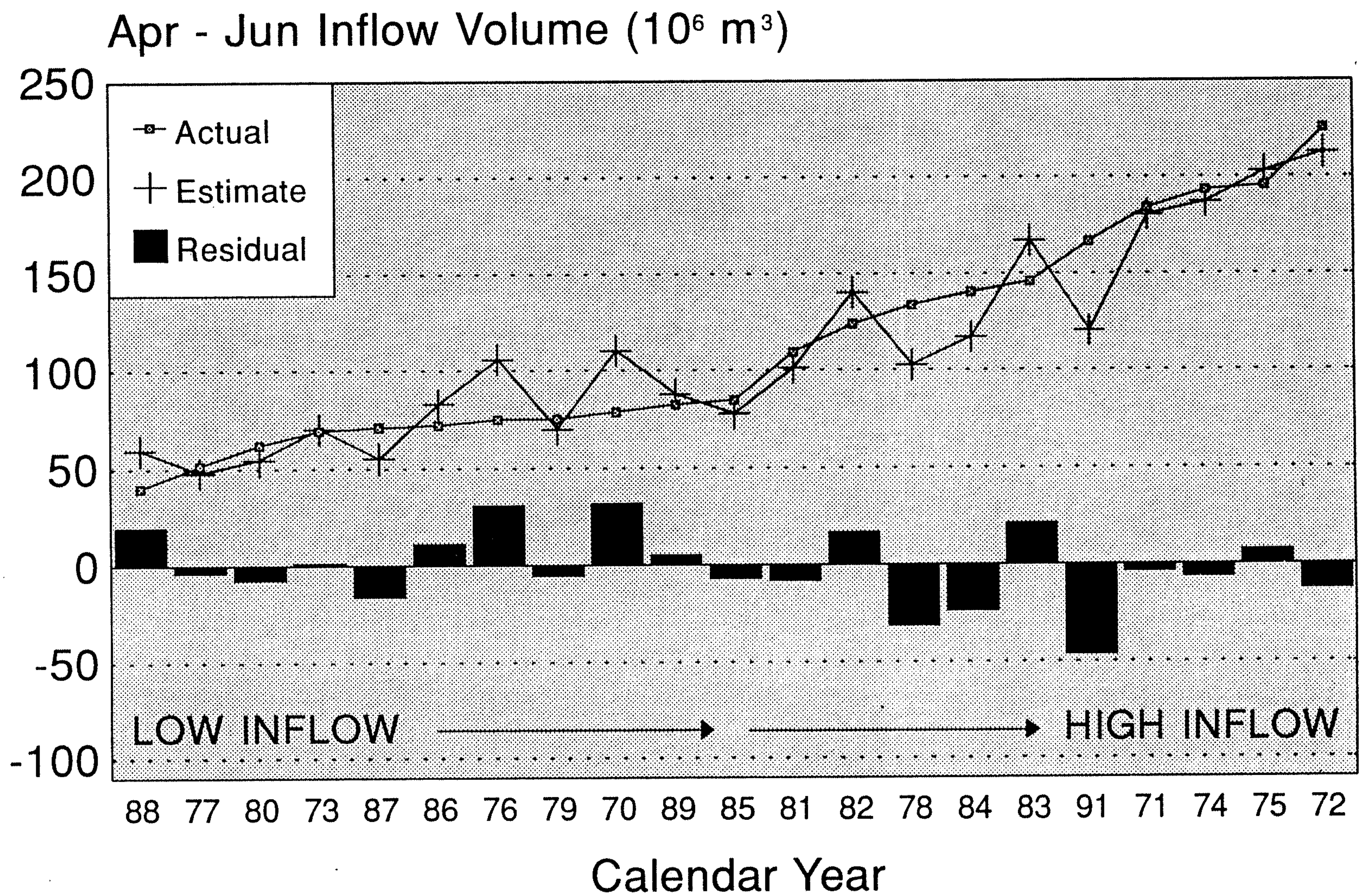

Figure 5

Consideration was given to using rainfall data for Merritt, Kelowna, or Brenda Mines for the freshet period April to June. It was hoped that a benefit of this approach could be that the impact of actual rainfall could be entered into the model, and the forecast updated as soon as it became apparent that the rainfall was significantly different than normal. An attempt was made to incorporate the 12 years of May to June rainfall data for Brenda Mines. This data provided no improvement in correlation if the 1990 data was excluded. It does, however, almost double the R^2 (0.38 to 0.72) if 1990 is included. The resulting model is unreliable though, as it uses no snow course data. It is interesting to note the effect of adding a Kelowna April to June rainfall term to equations (2) to (5): Equations (2) and (3), which are based on all data to 1991, have correlation coefficients increased 10%, whereas equations (4) and (5), which omit the 1990 data, show no improvement in correlation. Therefore, equation (5) remains the best predictive equation, even though common sense tells us that freshet rainfall does affect freshet runoff volume.

An attempt was also made to relate the error (residual) in the model (equation 5) to the May to June rainfall at Brenda Mines. For years of heavy spring rainfall, the rainfall in excess of normal was compared to the inflow in excess of that predicted by equation (5). The relationship is evident, but weak due to variations in rainfall intensity, precipitation, infiltration and extent. This relationship may be better defined when there is more data available at the Brenda Mines station, or when the Glimpse Lake station has a longer period of record, and can be included in the analysis.

Another idea to improve inflow prediction was to fit two curves, one for high inflows and one for low. However, these equations both had correlation coefficients lower than the single regression line.

Recently all the data for 1992 and 1993 freshet periods have become available. These can be used as a further test of the various equations. The predicted and actual inflows are shown in Table 1.

Table 1. Comparison of Inflow Prediction Models Using 1992 and 1993 Data

REGRESSION EQUATION	1992 INFLOW ($m^3 \times 10^6$)	1993 INFLOW ($m^3 \times 10^6$)
Kelowna to 1991, Equation (2)	61	134
Merritt to 1991, Equation (3)	81	82
Merritt w/o 1990, Equation (4)	71	75
Kelowna w/o 1990, Equation (5)	44	130
ACTUAL INFLOW	**45**	**120**

These two years provide examples of years with low to normal snowfall, and low (1992) to high (1993) spring rainfall. The "Kelowna w/o 1990" model clearly provides the best prediction of the low inflow in 1992. It also is the closest estimate for the moderate 1993 inflow. 1993 also was a good example of a year in which high inflows continue well beyond June, and therefore considerable flow was excluded from the "Freshet Volume". Inflow to Nicola Lake stayed high well into August. The influence of spring and summer rain on lake inflows is difficult to quantify in any given year and remains a matter of hydrologic judgment.

DISCUSSION

In the future, improvements may be made to the forecasting method by using the real time meteorological data available at Ministry of Forests high elevation weather stations in the watershed such as Brenda Mines and Glimpse Lake. It should be possible to use this data to update the forecast as actual April to June precipitation is recorded. One such attempt was unsuccessful in this analysis, but it may be possible as the period of high elevation rainfall record is extended.

Uncharacteristically high and/or prolonged rainfall during May, June and July in 3 of the past 4 years in the Nicola watershed has underlined the need to include a real-time term in any successful predictive equation during wet springs. Some consideration might also be given to including July in the high inflow period since flows have been significant in July when spring rainfall is heavy.

CONCLUSIONS

An attempt to improve the forecasting of annual freshet inflow volumes to Nicola Lake has been made. In the process, the 1986 River Forecast Centre's Nicola Lake Inflow Model has been updated. While a small increase can be made in the 1986 model's correlation coefficient, it is not possible to improve this model in any meaningful way. The model should continue to be used unchanged as it best predicts freshet inflows during the low flow years. These forecasts are most important in helping BC Environment operate the dam in a way that meets the dam's primary purpose of water supply. Other snow course and precipitation data are useful in evaluating how well the data represent conditions in the entire watershed. In very wet springs judgment and experience will still be needed to decide on the least damaging schedule of releases from the dam as the weather situation unfolds.