Forecast of Winter Flow in the Blue Nile*1

By El-Fatih A.B. El-Tahir*2
Department of Civil Engineering, University of Khartoum,
P.O. Box 321, Khartoum.

ABSTRACT

A reliable forecast of the flow volume in the Blue Nile during the winter months, October to December, is an important input to the management of irrigation land in the Gezira Scheme, Sudan. In this paper we focus on this problem with the objective of developing simple and reasonably accurate models for providing forecasts of the winter flow based on information available at the 1st of September. Different models and sources of information are compared objectively and it is found that the simple linear reservoir model combined with a random flow component provides satisfactory representation of the Blue Nile system. The results of the study are presented in a graphical form in August and the output is the winter flow foracst for a range of risk levels. The methodology presented in this paper can be used for deriving similar forecasting charts for the flow in other months.
The reliability of winter flow for long term planning purposes is also investigated. The winter flow data fits reasonably the normal distribution model.

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**2 Current address: Room 48-320, M.I.T., Cambridge, MA, 02139, U.S.A.*

Forecast of Winter Flow, Blue Nile.

Introduction :

The Blue Nile is the main tributary of the Nile. The mean annual flow of the Nile is 83 milliard cubic metres (m.c.m). The Blue Nile supplies about 60% of this volume. Most of this water comes from the Ethiopian plateau. Figure 1 shows the Nile basin. Nile water is the source of life in Sudan and Egypt.

Since the rainfall pattern in Ethiopia is highly seasonal, the flow in the Blue Bile is also highly seasonal with most of the water flowing in the period between May and September. Figure 2 is a plot of the mean monthly flows in the Blue Nile calculated for the period 1912-1973.

The Blue Nile water is used in irrigating large areas in Sudan. Irrigation of these lands depends on the natural flow of the river. During summer season, April to September, flow in the river exceeds the demand and most of this water is stored downstream in Lake Nasir. However in the winter months, October to March, the flow in the river is less than the demand. Hence the size of the area to be irrigated in Sudan depends mainly on the volume of water available for irrigation. The present paper describes simple techniques applied in forecasting of the volume of winter flows in the Blue Nile.

Background about the Study Area :

Agriculture is the major economic activity in Sudan. It has two sectors irrigated lands and rained lands. Gezira Scheme, located between the White Nile and the Blue Nilke, is the largest irrigation scheme in Sudan. It is described as the backbone of the Sudanese economy. The irrigated lands in this Scheme amounts to around 2 millions feddans (1 feddan = 4200 square meters).

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The main crops in Gezira Scheme are cotton, peanuts and syrgum in summer season and wheat in winter season.

Description of the Problem :

The problem addressed in this study is the forecast of the volume of flow in the Blue Nile at station Roseiris in winter season. More specifically how much is the volume of flow in the months of October, November and December given the measured flow in the river up to August. This forecast is to be issued by early September. In the following the total flow in october, November And december is referred to as winter flow.

Since water is the only limiting constraint in winter, the size of the area to be prepared for cultivation can be directly derived from the forecast of the water available for irrigation. Accurate forecasts of the river flow means more economical management of the irrigation project.

The answer to the forecast question is a major input to water resources management of the Gezira scheme. For long term planning purposes, simple statistical analysis is done on the winter flow series to investigate the reliability of the natural flow for irrigation.

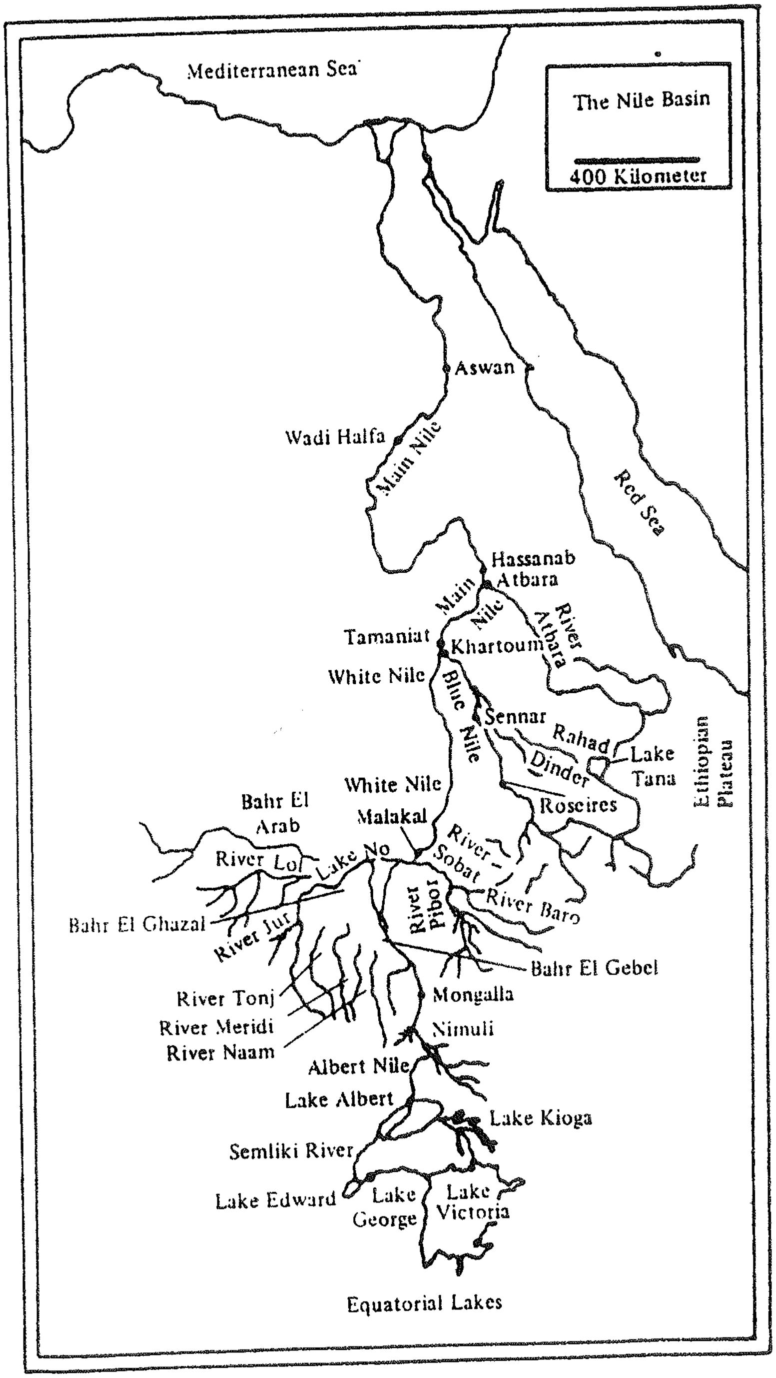
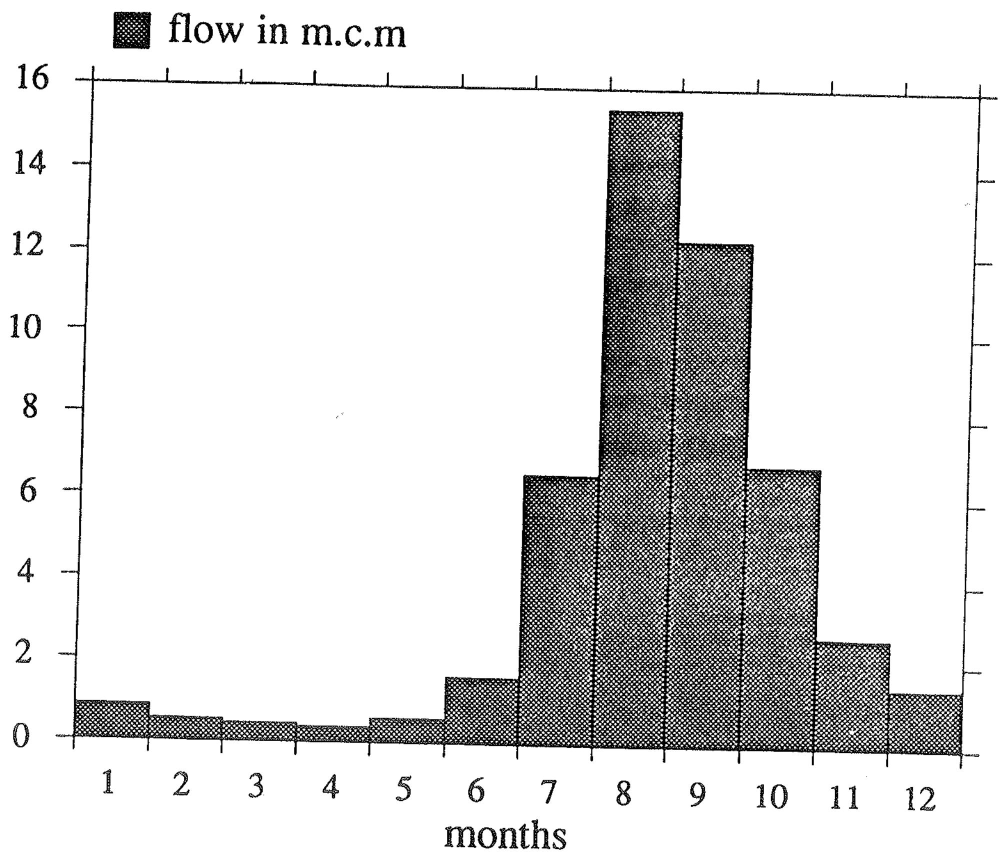


Figure 1 The Nile Basin

Figure 2 Mean Monthly Flows



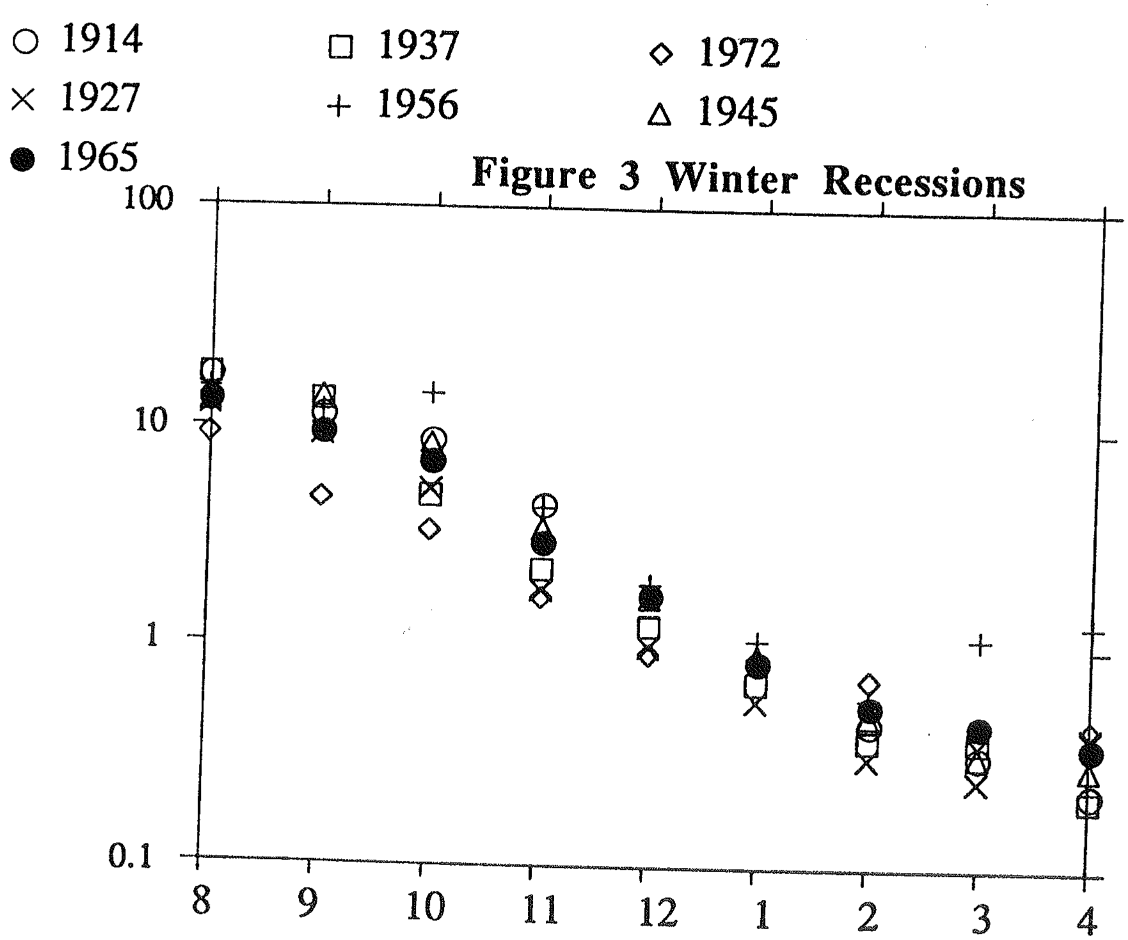


Figure 3 Winter Recessions

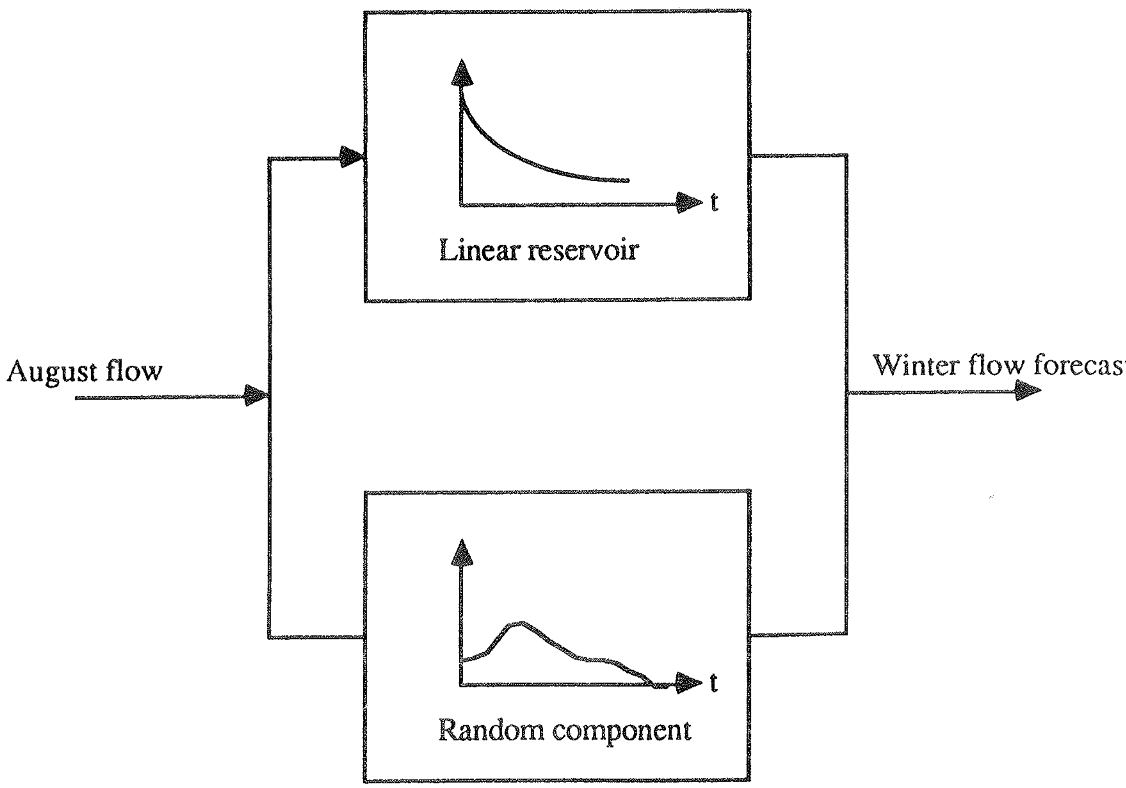


Figure 4 Model Description

Data :

The data used in this study is the monthly river flow of the Blue Nile at Roseiris which extends for the period 1912-1973, Shahin (1985). Rainfall data from Addis Ababa which is at the boundary of the Blue Nile basin is used as an indicator of rainfall levels in the Ethiopian plateau.

Model :

The flow of the Blue Nile in winter has two components: the discharge from the water stored in the basin after the floooding season and runoff due to rainfall which occurs in winter months. The model suggested for modelling the winter flow of the Blue Nile reflects this structure.

First the flow during winter months of the Blue Nile, in some representative years, was plotted as shown in figure 3. The plots show exponential recession for most of the years. A simple model which describes this kind of behavior is the linear reservoir, Ven Te Chow et. al. (1987). The linear reservoir model describes adequately the storage mechanism of many hydrological systems, particularly those with slow responses.

The basic assumption of the linear reservoir model is that :

$$S(1) = K \cdot Q(1) \quad \text{.......................} (1)$$

where,

S (I) : the storage in the system at time step I.

Q (I) : the discharge of the system at time step I.

K : a time constant characteristic of the system. It is the only parameter of the model.

Considering continuity and assuming zero inflow results in,

$$Q(1) = Q_0 . e^{(-I/K)} \quad \text{.......................} (2)$$

where,

Q_0: discharge at I=0.

The component of flow due to winter rainfall is difficult to forecast. In this study it is intended to correlate this component with the flood volume. This correlation implicity assumes a relation between summer rainfall and winter rainfall. Another possibility is to correlate this component of flow with rainfall in Addis. If no significant correlations exist then it will be treated as a random component. The following section describes the results of these investigations.

Results :

Estimation of the linear reservoir parameter K was the first step. The winter recessions (from October to february) were fitted to the model of equation (2) with Q_0 as the flow in August. Using simple linear regression for each year, values of K and R^2 (coefficient of determination) were obtained. R^2 is a measure of how good is the model fit. For 25 years R^2 was found greater than 98%. K was estimated as the mean of the K's calculated from those years. Table (1) shows the estimation of K.

Using the estimated value of K and measured Q (8), the storage contribution to winter flow was calculated as,

$$V'_1 = Q'(10) + Q'(11) + Q'(12) \quad \text{.......................} (3)$$

where Q' (10), Q' (11) and Q' (12) were obtained according to equation (2). The winter rainfall contribution V'_2 was estimated by,

$$V'_2 = V - V'_1 \quad \text{.......................} (4)$$

where V is the total measured flow in October, November and December.

No significant correlation was found between V'_2 and the flood volume (flow in April to July). This seems to confirm the Markovic nature of storage in the basin, all the information about storage in the system is contained in August flow.

The correlation between the rainfall in Addis during August and V'_2 was also tested. It was thought that August rainfall in Addis can be used in the forecast of winter flow. The percentage of the explained variance by this regression was 5% and hence it was considered insignificant. Based on these results it was decided to model V'_2 as a random component.

Figure 4 shows the structure of the model used. It consists of a storage component which is a linear reservoir and a random component. The random nature of this component is due to the fact that it is the runoff due to winter rainfall which is totally random.

The normal distribution was chosen for modelling V'_2. The data points were plotted in a normal probability paper in figure 5. The normal distribution model fits the data fairly well. The mean and standard deviation of the model were estimated by the mean and the standard deviation of the data,

Now the forecast model in its final form is described by the following equation :

$$V'(O) = V'_1 + V'_2(O) \qquad (5)$$

where V'_1 is given by equation (3) and V'_2 O is normally distributed with a non-exceedence probability, O. The parameters of the normal distribution are given in figure 5.

Figure 6 summarizes in a graphical form the results of the forecasting model. The input to this graph is August discharge and O.O is the risk level, since it is the probability that the given forecast will not be satisfied. The output of the graph is a forecast of winter flow in the Blue Nile.

Simple statistical analysis was carried out to investigate the reliability of winter flow. This class of analysis is suitable for long-term planning purposes. Again the normal frequency model was fitted to the data. Figure 7 shows the data plotted in a normal frequency paper. The model fits the data fairly well. The mean and standard deviation of the model were estimated from the data by the model of moments. Figure 7 provides an idea about the reliability of winter flows and hence of the agricultural production which is dependent on those flows.

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Discussion and Conclusions :

The above results indicate that the simple linear reservoir model with a random component provide a reasonable technique for modelling the winter flow in the Blue Nile. The uncertainity in the forecast is due to the random nature of the winter runoff component. The information available up to the 1st of September is not useful in forecasting winter runoff. Hence the only way to model this component is by a stochastic approach.

In figure 5 the negative values of the random component resulted from the assumption that August flow is totally from the linear reservoir storage. In reality only part of the flow in August is from storage, the rest is runoff due to August rainfall.

The conclusions of this study are summarized by figures 6 and 7. Figure 6 provides useful and easy charts for use in winter flow forecasting. An acceptable risk level depends on many social and economic factors. Benefits are directly related to winter flow. Hence the charts are suitable for simple optimization analysis to decide on which combination of risk and benefits is optimum.

The results of this analysis confirm that the practice in handling this problem by the authorities in Sudan is an appropriate one. The charts of figure 6 provide an easier and more sophisticated procedure

for winter flow forecasting but the babsic concept is the same.

Figure 7 presents the winter flow data in a form suitable for long-term planning. It associates with each flow value a degree of reliability and helps in evaluating the long-term benefits of the natural resource.

References :

Shahin, M. (1985), Hydrology of the Nile Basin, Elsevier Science Publishing Co., New York, p. 572.

Ven Te Chow, Maidment D.R., Mays, L.W. (1988), Applied Hydrology, McGraw-Hill Book Co., New York, p. 572.

Years	Explained variance	K in months
1912	98.602	1.5648
1921	98.455	1.5094
1923	98.682	1.6143
1924	98.514	1.6666
1925	98.943	1.6493
1926	98.745	1.5308
1927	98.734	1.5358
1928	99.328	1.5663
1930	98.922	1.5273
1934	99.003	1.5815
1936	98.007	1.5719
1937	98.997	1.5071
1940	98.693	1.4331
1942	98.109	1.5195
1943	98.161	1.5204
1944	98.857	1.5249
1946	99.476	1.4878
1949	98.308	1.6167
1951	98.561	1.6052
1952	98.514	1.4676
1953	99.342	1.5542
1957	98.114	1.5242
1960	98.028	1.5831
1963	98.112	1.7381
1965	98.377	1.7874

Mean value of K = 1.567 months

Table 1 Estimation of K

Figure 5 Random Component Data

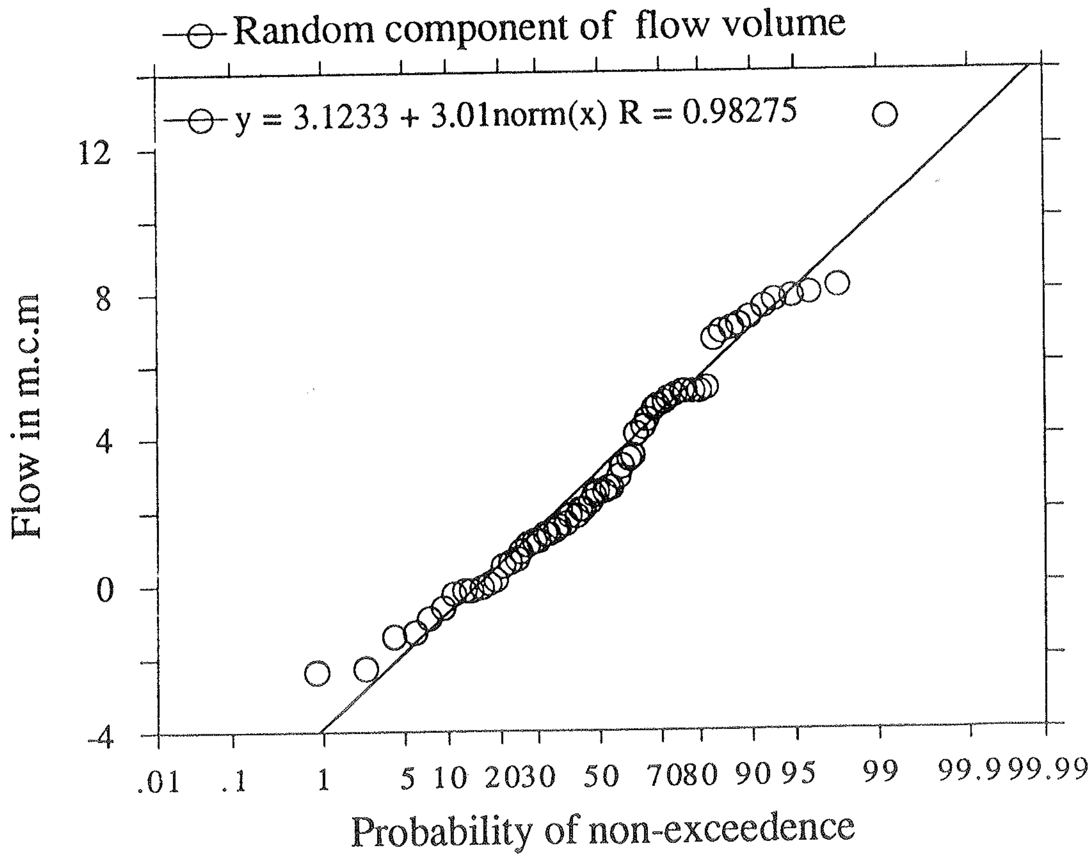

Figure 6 Winter Flow Forecasting Charts

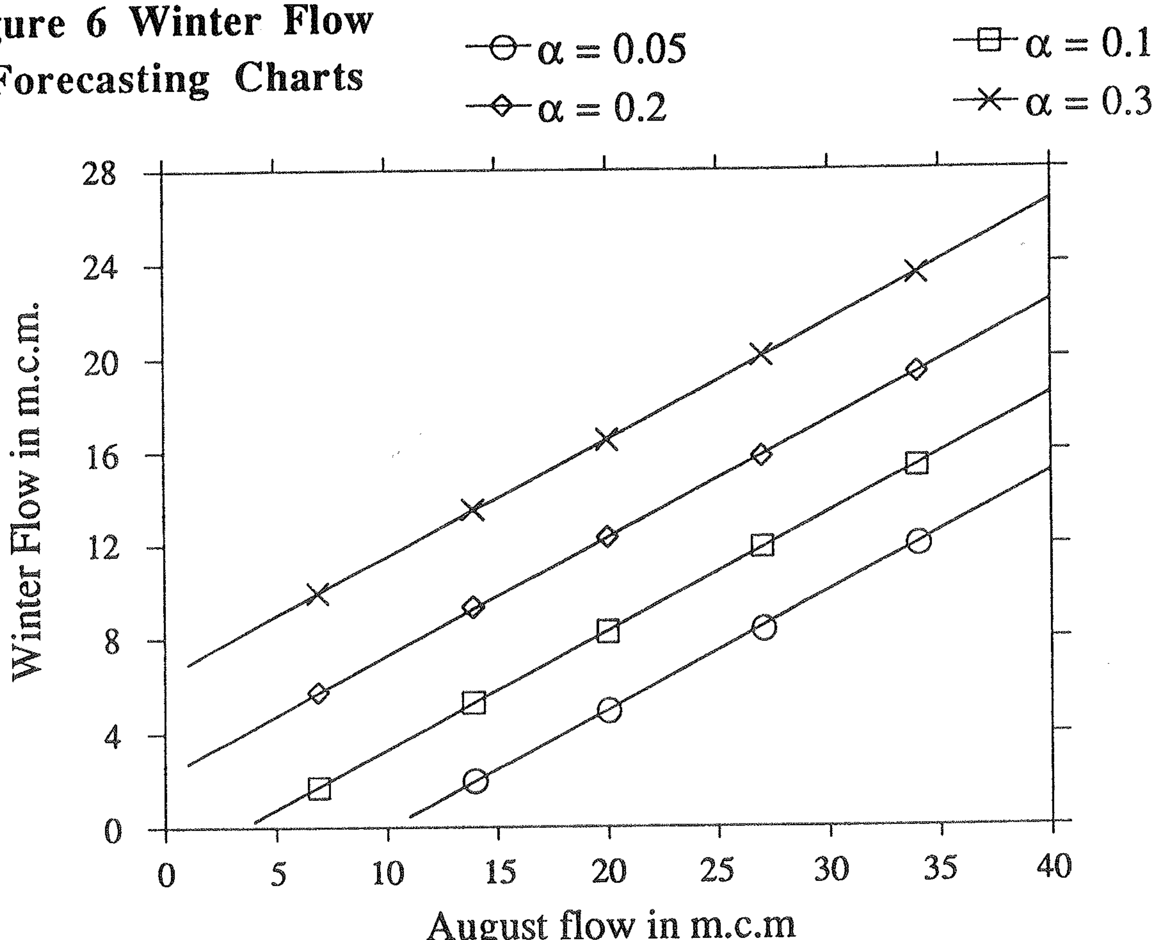

Figure 7 Winter Flow Data