MATHEMATICAL MODELS FOR STREAM FLOW SIMULATION IN SRI LANKAN RIVERS

by

Mr. G.T. Dharmasena, Ms. H.V.D.P. Chandradasa
and Mrs. D. Priyani

Abstract

Numerical models for simulation of river flows are used in design and real time flood forecasting. Advances in computer technology in mathematical modeling of the processes in the hydrological cycle have recently improved our potential in this field. Such models are based on the observed point rainfall at selected locations of a river basin above a particular point in the river, selected for the modeling exercise. In most cases when a designer wants to obtain historical stream flow series to evaluate the reservoir capacity and spillway capacity of a proposed reservoir, it is not generally available, but rainfall data for long period is often available. In addition forecasting of flows for the future, either during floods or during droughts is still in a stage infancy in Sri Lanka. While it is possible to overcome this problem by development of mathematical models, it is very important to note that, these models have become increasingly significant, where land use and other changes have effected the hydrologic response of the basin. Under those circumstances, historical stream flow data, even if it is available are no longer representative of the basin characteristics and therefore irrelevant to be used in designs. This phenomena is clearly depicted in Fig. 1 for two rivers in Sri Lanka. Analyses of the variation of runoff rainfall ratio with time shows an upward trend.

1.0 Introduction

Attention has been focused in this paper on deterministic models in hydrology. Some of these models depend on the system theory, whose expression may be obtained by the application of system analyses methods. These models are time invariant and therefore the model outputs do not change with the time of occurrence of rainfall and therefore inherits a draw back. This is due to the assumed time invariant property in those model structures, which are based on Unit hydrograph. In order to overcome this problem in reality, as time invariant property does not exist in real world, the conceptual models are considered as an alternative. The paper deals with linear model, linear perturbation model (Nash and Barsi - 1983) and a model based on linear differential equation of ARMA type. (Box and Jenkins 1976). Among the conceptual models, this paper deals with soil moisture accounting and routing models (SMAR) developed by P.E.O'Connell in 1970 and NAM model developed by Danish Hydraulic Institute in Denmark. For testing of these models two major rivers in the country, namely Kulu Ganga and Kelani were selected.

2.0 Linearity and non linearity of Hydrological models:

If a catchment of a river is considered as a system, its behaviour can be described then by a linear differential equation of the form,

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\[
\frac{d^n y}{dt^n} + A_{n-1} \frac{d^{n-1} y}{dt^{n-1}} + \ldots + A_1 \frac{d y}{dt} + A_0 y = x
\]

then it is said to be a linear system.

In the above differential equation

\[ X = \text{model input (rainfall)} \]
\[ Y = \text{model output (discharge)} \]

\[ A_n, A_{n-1}, \ldots A_1, A_0 = \text{model parameters} \]

In the same equation products of constant terms with higher powers of \(y\) other than the first power or powers of differential exist, then the system becomes non-linear. The coefficients \(A_n, \ldots A_0\) may be constant in which case the linear system becomes time invariant. If the coefficients are varying with time then the model is time variant.

### 3.0 Aims of the study

Purpose of the study is to enhance the understanding and application of the recent developments in Mathematical modeling technique for flow simulation to be used in both design and forecasting. In this study daily discharges of Kalu Ganga at Ellagawa gauging station and Kelani Ganga at Glencourse (Avissawella) gauging station are simulated by calibrating several mathematical models in order to select the best.

Structure, application and results of the models used are given in details in the following paragraphs. A period is selected for model calibration and other part for the model verification.

### 4.0 Model efficiency criteria

To judge the performance of a model, there are number of statistical and graphical criteria available. But, none of these methods are free from drawbacks. Criteria which are used in this paper to verify model efficiencies are the sum of squares of differences between the observed discharge and the estimated discharge. This criterion is recommended by the World Meteorological Organisation (W.M.O.) - (Nash and Sutelife 1970).

\[ F = \varepsilon [Y_i - \hat{Y}]^2 \]

where

\[ Y_i = \text{Observed discharge} \]
\[ \hat{Y} = \text{Computed discharge} \]

\( F \) is an index of error which reflects the content to which a model is successful in reproducing observed discharge. In order to make this dimensionless, \( F_0 \) is defined as initial variance accounted by \( F \).

\[ F_0 = \varepsilon [Y_i - \bar{Y}]^2 \text{ and } \bar{Y} = \frac{1}{N} \varepsilon Y_i \]

where,

\[ N = \text{Number of observations} \]

\[ \bar{Y} = \text{Mean flow} \]

The efficiency criterion is now expressed as,

\[ R^2 = \frac{F_0 - F}{F_0} \]

### 5.0 River basins of Kalu and Kelani ganga

The Kalu and Kelani are the first and third largest rivers in Sri Lanka in the sense of annual volumes of flow. These rivers originate in the central hills at about 2000 meters M.S.L. and flow towards the Western coast, until they reach the sea in Kalutara and Colombo, respectively. These basins are entirely in the wet zone of the country, which is defined as the zone which receives an annual rainfall more that 2000 mm. The total drainage area of the basins are 2719 and 2292 sq. kms., with an annual runoff of 7635 and 5500 million cu.meters respectively. One third of the catchments are mountainous with very steep slopes, with shallow soil layers, featuring quick response to rainfall. The vegetation of the basins are mostly state owned tea and rubber plantations. These two river basins with the locations of hydrometric network used for modeling are shown in Fig. 2. The occurrence and distribution of rainfall is governed by the North East and South West monsoons, preceded by two inter monsoons. However, flow in these rivers are dominated by South West monsoons rains. Fig. 3 depicts the long term average flow distributions in these two rivers.

### 6.0 Hydrological information

There are about 60 ordinary raingauges and about 15 stream flow measuring stations in these catchments. However for the purpose of this study, six principal rainfall stations above Ellagawa stream flow gauging site were used for Kalu Ganga and five principal raingauges above Glencourse stream flow measuring station for Kelani were used. In Kelani, due to flow regulation in the upper catchment due to power reservoirs, stream flow data at the downstream gauging station in Kitulgala was used. This inflow was considered as an input to the model, in addition to the rainfall of intervening catchment. Drainage area above Ellagawa is 1377 sq.kms. and the area above
Glencourse is 1423 sq.kms. There is a scarcity of evaporation pans in these catchments and observations at Ratnapura and Colombo Evaporation Pans were used in this study. All models simulate daily mean flows and therefore time resolution of simulation is one day. Daily rainfall, stream flow and evaporation are used as inputs to the models. By considering the consistency of hydrological observation, 5 years of data from 1975 to 1979 were used for Kalu Ganga study and period of 15 years from 1961 to 1975 were selected for Kelani. Names of hydro meteorological stations and locations of these stations are shown in the Figure 2.

7.0 Modeling Approach

The flow in Kelani river cannot be considered as natural with high regulation in a part of the head catchment. This regulated catchment has an area of 376 sq. kms with Castlereigh and Maussakelle reservoirs intercepting 15% of the total catchment. Therefore, it is more appropriate to exclude this portion of the catchment for rainfall runoff modeling to obtain favorable results. This can be done by incorporating the reservoir releases from these two reservoirs as a model input, disregarding the rainfall runoff relationship in 376 sq. kms. catchment. This was possible as there is a stream flow measuring station to measure these releases at Kitulgala. When this regulated catchment is subtracted, the rainfall of the intervening catchment, which is 1043 can be taken as an input for rainfall runoff analysis, in addition to the discharge at Kitulgala. Therefore the model for Kelani has two inputs and one output. However, to apply conceptual models, part of a catchment cannot be considered. Therefore, for conceptual models full catchment is considered including the regulated part and therefore system was considered as a single input single output system.

For Kalu Ganga, there are five years of daily rainfall, stream flow and Evaporation data and 3 years of this was used for model calibration and 2 years was used for model verification. For Kelani, 6 years were used for model calibration and 4 years were used for model verification.

8.0 Linear models

8.1 Seasonal model

As a basis for comparison of the results obtained with other models, the mean flow of a day in the years of calibration, after suitably smoothing is called a seasonal model. This can be expressed as

\[
Y_{d} = \frac{1}{L} \sum_{r=1}^{L} Y_{d,r}
\]

where

\[ L = \text{Number of years}\]

\[ Y_{d,r} = \text{daily flow on the } d\text{ day of } r\text{th year.}\]

This series is smoothed by a Fourier series using the first few harmonics. Result of this analysis is shown in Fig. 3. It can be seen that the discharge hydrographs of these catchments are not in a seasonally predictable manner. The estimated Fourier series coefficients are also presented in Fig. 3 and it is clear that first few harmonics account for larger percentage of the total variance and therefore, it does not make any sense to increase the number of harmonics.

8.2 Linear Models

8.2.1 Theory of Unit Hydrograph

The theory of unit hydrograph (U.G.) is based on the principle of linearity and time invariant process. Simple linear model and linear perturbation models are directly founded on the U.G. theory. Rainfall runoff relationship in a catchment can be expressed as

\[
Y(t) = \int_{0}^{\infty} x(t) h(t-t') d t'
\]

where

\[ x(t) = \text{Precipitation}\]

\[ Y(t) = \text{Runoff}\]

\[ h(t-t') = \text{Ordinates of the instantaneous unit hydrograph}\]

The above integral is known as the convolution integral. In reality both rainfall and runoff are measured as discrete functions on daily basis and therefore convolution integral when expressed over successive short intervals of time, this relationship can be expressed as

\[
Y_i = x_{i,0} h_1 + x_{i-1,0} h_2 + \ldots + x_{i-m+1,0} h_m + \epsilon_i
\]

OR

\[
Y_i = \sum_{j=1}^{m} x_{i-j,0} h_j + \epsilon_i
\]

where

\[ h_j = j\text{th ordinate of TUH} ^{\wedge} \text{TU11} ^{83} \]

\[ m = \text{Memory length}\]

\[ H_i = \text{Rainfall}\]

\[ Y_i = \text{Runoff}\]

\[ \epsilon_i = \text{Model error}\]
8.2.2 The memory length

In many perennial streams discharge continues even for months after the cessation of the rainfall. The interval between the occurrence of the rainfall and the time when its effect on the stream flow finally ceases is known as the memory length.

This can be expressed in Matrix form as

\[ Y = XH + E \]

where
- \( Y \) is a \( N \) by 1 stream flow column vector
- \( H \) is a \( m \) by 1 pulse response column vector
- \( X \) is a \( N \) by \( m \) rainfall input matrix
- \( E \) is a \( N \) by 1 model error residual vector

By the application of Matrix transformation and inverting the matrix this can be rewritten in the form,

\[ H = [X^T X]^{-1} X^T Y \]

where
- \([X^T X]^{-1}\) transpose of matrix \( X \)
- \([X]^{-1}\) inverse of matrix \( X \)

From the above, the ordinates of the unit hydrograph matrix \( H \) or the impulse response function as generally termed by system engineers for continuous input functions can be found. As the input data in this exercise are discrete, corresponding discrete function is called pulse response, instead of impulse response. This model was calibrated by ordinary least square method assuming different memory lengths. Fig. 4 shows the estimated pulse response function and it is very satisfactory in shape as there are no negative ordinates. A vast improvement in efficiency from seasonal model to linear model can be seen.

8.3 Linear perturbation model

This model assumes that \( X_i \), the perturbation from the smoothed seasonal input rainfall and that of discharge \( Y_i \) are linearly related as,

\[ Y = \sum_{j=1}^{m} x_{i-j+1} h_j + e_i \]

where
- \( Y_i = Q_i - Q_d \) \quad \text{i} \quad 1, 2, \ldots, m
- \( X_i = I_i - I_d \) \quad \text{d} \quad 1, 2, \ldots, 365

Where \( Q_i, I_i \) are the observed discharge and rainfall. \( Q_d, I_d \) are the seasonal mean flow on the day \( d \).

In these catchments seasonal component of the linear perturbation model accounts for a small percentage and therefore there is no significant improvement on the efficiency from linear model to Linear Perturbation model. Pulse response functions of the L.P.M. model are shown in Fig. 4.

8.4 L.P.M. constrained by Nash model

After considerable investigations, Nash (1960) chose as a sufficiently adequate general model of \( N \) identical time invariant linear reservoirs in cascade, all having the same storage characteristics.

\[ S = K^*Y \]

where
- \( S \) = storage and \( Y \) = output discharge.

The impulse response of the Nash model is expressed by

\[ h(t) = \frac{1}{K} e^{-\left(\frac{t}{\alpha}\right)} \sum_{n=1}^{N} e^{-\left(\frac{t}{\alpha}\right)} \left(\frac{t}{\alpha}\right)^{n-1} \]

where
- \( N \) = Shape parameters or number of tanks in cascade
- \( K \) = Constant having time dimension

\[ \int_0^{\infty} e^{-x} X^{n-1} \, dx \]

Least square solutions for pulse response function in previous models have no constraints to its shape, but Nash model confines its shape to a Gamma function and therefore this approach is known as a parametric approach. This application involved, obtaining parameters of Nash model which are a number of linear reservoirs in cascade (N) and reservoir constant (K) by a search technique. The optimisation of these two parameters are done with Rosenbrock search method. Fig. 5 shows the pulse response functions obtained for two basins.

8.5 The linear difference equation - (Linear transfer function) L.T.F. Model

It is assumed that rainfall and river flow are related by the followings.

\[ Y_t = \sum_{j=1}^{m} \sum_{j=1}^{d} w_{j} Y_{t-j} + \sum_{j=1}^{365} w_{j} Y_{t-b-j+1} + e_t \]
where

\( f_j \) is the autoregression parameters and
\( w_j \) is the moving average parameters
\( b \) is the pure lag.

The model was applied to the catchments under the study. Ordinary least square was used for calibration. Model efficiencies found in both calibration and verifications, shows not much of a choice between the models. Puse response functions is given in Fig. 5.

### 8.6 Conceptual models

The deficiency in the models of the system approach explained earlier, depend on the assumption of time invariant property. But due to non linearity of catchment behaviour linear models might fail to provide satisfactory results, specially when subjects to prolong droughts. The discharge of a river at any particular time is dependent not only on recent rainfall, but also on evaporation. Unlike rainfall, the response of the evaporation is not immediate. This effect cannot be achieved by a linear relationship between the discharge and rainfall or evaporation. Therefore conceptual models permit the grouping together of the non linear operations and leave open the possibility of representing the subsequent transformation of the generated runoff by a linear routing component. In this situation, total water balance and the base flow dominates during the drought and therefore antecedent rainfall alone can be correlated to the stream flow without storage effects in the catchment. Therefore, its effect cannot be explained by a linear relation between the river discharge with combined effect of rainfall and Evaporation. This problem is overcome in conceptual models when it can be expressed by series operations.

The conceptual models dealt in this paper are the soil moisture according and routing models (SMAR) developed by O’Connell in 1970 and NAM Hydraulic model developed by the Danish Institute in Denmark.

### 8.6.1 SMAR Model

Schematic diagram of the model configuration is given in Fig. 6 and it is analogous to a vertical stack of horizontal soil layers. Evaporation from the top layer occurs at the potential rate and the layer below the top has an evaporation rate multiplied by a factor \( C \), which is a parameter in the model. There are 5 parameters in the model as explained below.

1. \( C \) - This controls the Evaporation rate from each soil layer.
2. \( Z \) - Total thickness of the soil layer.
3. \( Y \) - Infiltration capacity.
4. \( H \) - Runoff / Rainfall ratio.
5. \( T \) - Factor to correct pan Evaporation rate to Evapotranspiration rate.

Generated runoff from the above model is converted to discharge by a linear routing component. The search was conducted to find the optimum values of above parameters to minimize the objective function \( F \).

### 8.6.2 NAM Model

This model was originally developed by the hydrological section of the institute of Hyrodynamics and Hydraulic Engineering at the Technical University of Denmark (Nielson and Hanson 1973). During the past decade, it has been extensively applied and modified by the Danish Hydraulic Institute. Configuration of the model is shown in Fig. 6. There are 13 parameters in the NAM model and these parameters have to be optimized manually.

Results of the model calibration and verification are given in the Table 1 and 2. Among the models tested for Kuluganga and kelani ganga SMAR model and Linear Perturbation model gave the best results. When these two models were tested during the verification period, fitness of the models can be seen graphically from the Fig. 7.

### 9.0 Updating of model output during flow forecast

After calibration of a model, actually observed river flow data could be compared with generated flow by the model for the same period. The difference between the actual observations and estimated values from the model is called the residual error and the efficiency criteria is a measure to judge the lack of fitness of models. In general, it is possible to identify some persistence structure in the residual series from the output of a hydrological model. This persistence could be due to several reasons such as non linearity of the process, observation errors, existence of correlation between inputs and between input and outputs etc. The autoregression analysis provides the basis for an updating procedure, whereby previously obtained model output can be further refined prior to the issue of the flow forecast in real time. However, it should be noted that this updating of model output is possible only in case of flow forecasting and not in simulation. In forecasting, estimated flow has to be compared with actual observations and continuous updating procedure for future forecast has to be made, but such data is not available in simulation. It is essential to emphasise that updating is a corrective or salvage operation to compensate for system inadequacies in the structure of the main model.
9.1 Autoregressive updating component

If the residual at each time step is expressed as $U_t$ then,

$$U_t = \hat{\phi}_1 U_{t-1} + \hat{\phi}_2 U_{t-2} + \ldots + \hat{\phi}_p U_{t-p} + A_t$$

Where $\phi_1, \phi_2, \ldots, \phi_p$ are the parameters of the autoregressive model and $A_t$ is the uncorrelated model error. $p$ is the order of the autoregressive process. The parameters can be found during the calibration period by the application of the least square method. Then updated model forecast becomes,

$$\hat{O}_t = \hat{Y}_t + U_t$$

Where $\hat{Y}_t$ is the un updated model output and $\hat{O}_t$ is the updated output.

After obtaining the parameters of the updating model for one time step, it is possible to obtain the parameters of a updating model for several time steps ahead. In this paper observed historical data have been used to test the efficiency of the updated models for forecasting, but in practice actual observations after issuing the first forecast is used to feed the updating model.

9.2 Updated model for Kaluganga for forecasting

The efficiencies of the SMAR model for Kalu ganga were found to be $83.7\%$ efficient in calibration and $83.5\%$ efficient in verification. (See the Table 1). When the residuals errors of the model output during calibration was analysed in order to formulate an updating component for the model, following auto correlation coefficients were calculated from model output.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1</td>
<td>0.665</td>
<td>0.665</td>
</tr>
<tr>
<td>2</td>
<td>0.470</td>
<td>0.498</td>
</tr>
<tr>
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<tr>
<td>4</td>
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<td>0.078</td>
</tr>
<tr>
<td>5</td>
<td>0.357</td>
<td>0.168</td>
</tr>
<tr>
<td>6</td>
<td>0.321</td>
<td>0.008</td>
</tr>
<tr>
<td>7</td>
<td>0.274</td>
<td>0.007</td>
</tr>
</tbody>
</table>

The parameters of the auto regressive model can be found by the method of ordinary least square and first positive coefficients are estimated as 0.604, 0.007 and 0.001. Therefore model for updating the output from SMAR can be written as

$$U_t = 0.604 U_t + 0.007 U_t + 0.001 U_t$$

By using this model component with the un updated model for Kalu Ganga, forecasting was done for 1 day, 2 day and 3 days lead times and following are the results of efficiencies.

<table>
<thead>
<tr>
<th>Lead time in days</th>
<th>Calibration Eff.</th>
<th>Verification Eff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90.4</td>
<td>92.6</td>
</tr>
<tr>
<td>2</td>
<td>86.8</td>
<td>87.3</td>
</tr>
<tr>
<td>3</td>
<td>84.5</td>
<td>84.7</td>
</tr>
</tbody>
</table>

Table 3 shows the efficiencies of different models when adopted for both rivers in the forecasting mode.

10.0 Conclusions

1. In general, it can be concluded that even linear models provide a satisfactory tool for simulation of flows in Kalu and Kelani basins and therefore these models can be satisfactorily used in planning and designs, instead of complicated conceptual models.

2. However from the work done by the authors in catchments in the dry zone of Sri Lanka, it is known that satisfactory fitness of linear models in this study is due to the wetness of the catchments. Under conditions of prolonged droughts, conceptual models provide superior results and capability of these models cannot be under estimated. In this paper NAM model does not show any superior results, though the model is internationally accepted. This is due to inadequacy in calibration skills of the model, which will be improved in time to come.

3. Efficiencies obtained for Kelani are lower than that of Kalu ganga and this low efficiency is due to longer period of calibration. Period of calibration for Kelani is almost double and model calibration for a longer period results in lower efficiency.

4. Regarding the results obtained from updating, it is clear that most of the models provide similar efficiencies in the forecasting mode, irrespective of their previous rainfall runoff transformation model. This is due to the efficiency of the autoregressive updating model component in identifying the persistence in each model residuals.

5. From the efficiencies found in model fittings, it can be concluded that wide variety of models can be satisfactorily calibrated for wet zone rivers in Sri Lanka and it enhances our capability in design and forecasting. However flow forecasting can be implemented only after installation of suitable communication system in river basins to obtain real
time rainfall data in the head catchments. Therefore development of mathematical models will form the initial step of software development to implement a forecasting system on a future date.

6. It is expected to continue this work to cover some more rivers in the country, including rivers in the dry zone.

11.0 Acknowledgement

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12.0 References

FIG 1

RUN-OFF RAINFALL RATIOS

GIN GANGA

\[ y = 0.03x + 71 \]

KIRINDI OYA

\[ y = 15.92 + 0.91x \]
SEASONAL MEAN DISCHARGES

KELANI GANNA

<table>
<thead>
<tr>
<th>HARMONIC</th>
<th>a(J)</th>
<th>b(J)</th>
<th>VARIANCE</th>
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<tr>
<td>1</td>
<td>-2.8</td>
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<td>43.2</td>
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<td>-1.1</td>
<td>-3.1</td>
<td>15.4</td>
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<td>3</td>
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<td>0.5</td>
<td>1.8</td>
</tr>
<tr>
<td>4</td>
<td>1.3</td>
<td>1.3</td>
<td>5.4</td>
</tr>
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</table>

\[ Y = a + \sum_{j=1}^{p} A_j \cos\left(\frac{2\pi j d}{N}\right) + \sum_{j=1}^{q} B_j \sin\left(\frac{2\pi j d}{N}\right) \]

KALU GANNA

<table>
<thead>
<tr>
<th>HARMONIC</th>
<th>a(J)</th>
<th>b(J)</th>
<th>VARIANCE</th>
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<td>1.6</td>
</tr>
<tr>
<td>4</td>
<td>-2.0</td>
<td>-0.4</td>
<td>6.6</td>
</tr>
</tbody>
</table>
FIG 4

KALU GANGLA

LINEAR MODEL

LINEAR PERTURBATION MODEL
KALU GANGA

L.T.F MODEL

(LINEAR TRANSFER FUNCTION)

NASH MODEL
MODEL VERIFICATIONS

KALU GANGA
SMAR MODEL

OBSERVED
COMPUTED

DEPTH OF RUNOFF IN mm

1978 MAR APR MAY JUN JUL

KELANI GANGA
L.P.M MODEL

1968 MAR APR MAY JUN JUL
TABLE 1

MODEL CALIBRATION RESULTS OF KALY GANGA BASIN

1. STREAM FLOW MEASURING STATION - ELLAGAWA

2. CATCHMENT AREA - 1377 sq. kms

3. DATA BASE 5 YEARS 1975 to 1979 - CALIBRATION FOR 3 YEARS AND VERIFICATION FOR 2 YEARS

<table>
<thead>
<tr>
<th>NAME OF MODEL</th>
<th>EFFICIENCY IN CALIBRATION</th>
<th>EFFICIENCY IN VERIFICATION</th>
<th>REMARKS</th>
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<tr>
<td>1. SEASONAL MODEL</td>
<td>30.5</td>
<td>17.6</td>
<td>H = 5</td>
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<td>2. LINEAR MODEL</td>
<td>79.5</td>
<td>79.1</td>
<td>M = 17</td>
</tr>
<tr>
<td>3. LINEAR PERTURBATION MODEL</td>
<td>83.3</td>
<td>79.9</td>
<td>H1 = 4</td>
</tr>
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<td></td>
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<td></td>
<td>H2 = 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M = 25</td>
</tr>
<tr>
<td>4. L.P.M WITH NASH</td>
<td>80.1</td>
<td>81.1</td>
<td>M = 25</td>
</tr>
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<td></td>
<td></td>
<td>N = 1.5</td>
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<td></td>
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<td></td>
<td>K = 2.45</td>
</tr>
<tr>
<td>5. L.T.F (LINEAR TRANSFER FUNCTION)</td>
<td>79.3</td>
<td>78.8</td>
<td>M.A. = 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Au = 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M = 25</td>
</tr>
<tr>
<td>6. SMAR</td>
<td>83.9</td>
<td>83.4</td>
<td>C = 1.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Z = 250</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Y = 169</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>H = 0.76</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>T = 0.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>L = 25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M = 13</td>
</tr>
<tr>
<td>7. NAM</td>
<td>69.8</td>
<td>79.7</td>
<td>U max = 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>L max = 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CQ of = 0.99</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Ck1f = 3500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CK1 = 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CK2 = 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CAREA = 1.0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Sy = 0.1</td>
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<tr>
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<td>Ckbf = 5000</td>
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<tr>
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<td>GWLBFo = 10</td>
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</table>

Note: H = No of Harmonics
M = memory length
N = Nash n
K = Nash k
MA = moving average
Au = Auto regressive coeffe
C, Z, Y, H, T, L Parameters of SMAR model
### Table 2

**Model Calibration Results of Kelani Basin**

1. **Stream Flow Measuring Station - Glencourse**
2. **Catchment Area - 1423 sq.kms**
3. **Data Base: 10 Years from 1961 to 1970 - Calibration for 7 Years and Verification for 3 Years**

<table>
<thead>
<tr>
<th>Name of Model</th>
<th>Efficiency in Calibration</th>
<th>Efficiency in Verification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Seasonal Model</td>
<td>21.3</td>
<td>11.8</td>
<td>H = 5</td>
</tr>
<tr>
<td>2. Linear Model</td>
<td>70.7</td>
<td>85.8</td>
<td>M1 = 4, M2 = 20</td>
</tr>
<tr>
<td>3. Linear Perturbation Model</td>
<td>71.3</td>
<td>85.6</td>
<td>H1 = 4, H2 = 4, M1 = 4, M2 = 20</td>
</tr>
<tr>
<td>4. L.P.M with Nash</td>
<td>69.0</td>
<td>83.5</td>
<td>M1 = 3, M2 = 10, N = 1.15, K = 1.11</td>
</tr>
<tr>
<td>5. L.T.F</td>
<td>60.1</td>
<td>74.3</td>
<td>MA = 7, Au = 5, M = 5</td>
</tr>
<tr>
<td>6. SMAR</td>
<td>65.0</td>
<td>79.1</td>
<td>C = 2.26, Z = 755, Y = 177, H = 0.94, T = 1.05, L = 40, M = 25</td>
</tr>
<tr>
<td>7. NAM</td>
<td>55.3</td>
<td>65.3</td>
<td>U_max = 20, L_max = 100, C0 of = 0.6, Ck if = 1000, CK1 = 30, CK2 = 30, CAREA = 1423, Sy = 0.1, c_ki of = 2000, GWLB = 10</td>
</tr>
</tbody>
</table>

**Note:**
- H = No of Harmonics
- M = memory length
- N = Nash n
- K = Nash k
- MA = moving average
- AU = Auto regressive coeffs
- C, Z, Y, H, T, L = Parameters of SMAR model
### Table 3

#### Kalu Ganga

<table>
<thead>
<tr>
<th>Lead</th>
<th>Linear Model</th>
<th>LPM Model</th>
<th>NASH</th>
<th>SMAR</th>
<th>NAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>CAL</td>
<td>VAR</td>
<td>CAL</td>
<td>VAR</td>
<td>CAL</td>
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<tr>
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<td>86.6</td>
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<tr>
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<td>85.6</td>
<td>83.6</td>
<td>83.4</td>
</tr>
</tbody>
</table>

#### Kela Ganga

<table>
<thead>
<tr>
<th>Lead</th>
<th>Linear Model</th>
<th>LPM Model</th>
<th>NASH</th>
<th>SMAR</th>
<th>NAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>CAL</td>
<td>VAR</td>
<td>CAL</td>
<td>VAR</td>
<td>CAL</td>
</tr>
<tr>
<td>LEAD</td>
<td>78.5</td>
<td>87.8</td>
<td>78.7</td>
<td>87.8</td>
<td>74.9</td>
</tr>
<tr>
<td>LEAD</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>69.5</td>
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<tr>
<td>LEAD</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>67.2</td>
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</tbody>
</table>