CHAPTER III

ON-LINE SIMULATION OF HOURLY RIVER FLOWS FOR RUN-OF-THE RIVER HYDRO-ELECTRIC PLANT

CHAPTER III

ON-LINE SIMULATION OF HOURLY RIVER FLOWS FOR RUN-OF-THE RIVER HYDRO-ELECTRIC PLANT

3.0 Introduction

Assessment of the present state of the hydropower generation in India indicates that the huge water power of the rivers flowing through the Himalayan regions is virtually untapped. A realistic estimate of the availability of water power of the river Teesta in North Bengal in the Himalayan region in the up-stream of Coronation Bridge point as a single generating station of the run-of-the river type suggests the generation in the range of 1000 MW. Complexities of the hydrological characteristics of the Teesta watershed region in the mountain necessitates the on-line monitoring of hourly river flow and real time control of hydraulic structures of the power plant in conjunction with the monitored variables.

Computer based digital supervisory system needs a highly realistic hourly flow simulation model to be incorporated in the ROM of the respective processor. Small general purpose microcomputer can be used as peripheral controllers with preprogrammed estimation algorithm in conjunction with computer control supersystem. The present investigation develops the hourly flow simulation technique with the cybernetical method of recursive least square instrument variable algorithm with parameter tracking adaptiveness in the estimation of instrument variables. The effectiveness of the developed technique has been demonstrated in obtaining an on-line simulation model of the hourly flows of the hilly river Teesta in North Bengal at Coronation Bridge Point on the basis of the observed data at different up-stream gauging stations.

3.1.0 Modelling of Hourly River Flows by Recursive Least Square Instrument Variable Algorithm

3.1.1 Development of Recursive Algorithms

The recursive technique has been defined as a technique in which an estimate is updated on receipt of fresh information.

Systems Dynamic Equation

A strong correlation of the down-stream flows with that at up-stream flows, particularly at the confluence of the tributaries, suggests that the process may be represented in the form of a non-stationary time series with a probability that the current value of the output $Y(t_k)$ is a function of the previous output observations, the autoregressive terms $Y(t_{k-1})$, $Y(t_{k-2})$, ..., the past values of the highly correlated deterministic inputs

$$U_1(t_{k-r_1}), U_2(t_{k-r_2}), \ldots, U_1(t_{k-r_1-1}), U_2(t_{k-r_2-1}), \ldots$$

together with a current unknown realization of the noise process $\eta(t_k)$. The process can be represented as

$$Y(t_k) = \sum_{i=1}^{n} \beta_i Y(t_{k-i}) +$$

$$\sum_{j=1}^{m} \sum_{i=0}^{n} \delta_{ji} U_j(t_{k-r_j-i}) + \eta(t_k) \qquad (3.1.1)$$

Determination of n is known as the model order determination. It is suggested that the output correlation is an intuitive consideration for model determination which is also the model structure identification.

With backward shift operator $q^{-1}(.)$ defined as $q^{-1} Y(t_k) = Y(t_{k-1})$, equation (3.1.1) transforms to

$$Y(t_k) = \left[\sum_{i=1}^{n} \beta_i q^{-i} \right] Y(t_k) +$$

$$\sum_{j=1}^{m} \left[\sum_{i=0}^{n} \delta_{ji} q^{-i} \right] U_j(t_{k-rj-i}) + \eta(t_k) \qquad (3.1.2)$$

Here, $\eta(t_k)$ may be expressed in a moving average sequence as

$$\eta(t_k) = \sum_{p=1}^{P} \eta(t_{k-p}) + v(t_k) \qquad (3.1.3)$$

where $v(t_k)$ is a white noise innovation process with

$$\mathcal{E}\left\{v(t_k) \;\; v(t_j)\right\} = 0 \quad \text{for} \quad j \neq k$$

$$\mathcal{E}\left\{v(t_k) \;\; v(t_j)\right\} \simeq \rho^2 \quad \text{for} \quad j = k \qquad (3.1.4)$$

This model is quite flexible since it requires that the equations should be linear in parameters.

Equation (3.1.2) may be represented as

$$Y(t_k) = z^T(t_k)\,\alpha + \eta(t_k) \qquad (3.1.5)$$

where α is the parameter vector with the property of slowly varying with time and amenable to recursive adaptiveness, and

$$z^T(t_k) = \left[Y(t_{k-1}),\ldots, Y(t_{k-n}), U_1(t_{k-r_1}),\ldots, U_1(t_{k-r_1-n}),\ldots, U_m(t_{k-r_m}),\ldots, U_m(t_{k-r_m-n}) \right] \quad (3.1.6)$$

where r_j, $j = 1,2,\ldots\ldots\ldots, m$ stands for the lag time instant of up-stream flows which have the strongest correlation with the down-stream flow $Y(t_k)$.

3.1.2 Least Square Estimation of Parameters

The parameter values of equation (3.1.5) are estimated by minimizing a loss function defined as the sum of the square errors as

$$J \triangleq \sum_{k=1}^{N} \left[Y(t_k) - z^T(t_k)\hat{\alpha} \right]^2 \quad (3.1.7)$$

The estimates $\hat{\alpha}$ of α that minimize J are called least squares estimates. Thus, for minimization,

$$\frac{\delta J}{\delta \hat{\alpha}} = 0$$

$$= 2\left[\sum_{k=1}^{N} z(t_k)z^T(t_k) \right] - 2\left[\sum_{k=1}^{N} z(t_k)Y(t_k) \right]$$

Hence the well known equations for least squares parameter estimation as

$$\hat{\alpha} = \left[\sum_{k=1}^{N} z(t_k) z^T(t_k) \right]^{-1} \left[\sum_{k=1}^{N} z(t_k) Y(t_k) \right] \qquad (3.1.8)$$

3.1.3 Algorithms for Recursive Least Square Estimation of Parameters

If it is assumed that the estimate $\hat{\alpha}$ of α is a slowly varying function of time, the new value of $\hat{\alpha}$ defined as $\hat{\alpha}(t_k)$ will appear as each information is serially processed recursively.

The algorithms for least square recursive estimation of parameters have been obtained as

$$\hat{\alpha}(t_k) = \hat{\alpha}(t_{k-1}) + P^*(t_{k-1})\, z(t_k) \left[1 + z^T(t_k) P^*(t_{k-1}) z(t_k) \right]^{-1} Y(t_k) - z^T(t_k)\, \hat{\alpha}(t_{k-1}) \qquad (3.1.9)$$

$$P^*(t_k) = P^*(t_{k-1}) - P^*(t_{k-1}) z(t_k) \left[1 + z^T(t_k)\, P^*(t_{k-1}) z(t_k) \right]^{-1} z^T(t_k) P^*(t_{k-1}) \qquad (3.1.10)$$

with $$P^*(t_k) \triangleq \left[\sum_{j=1}^{k} z(t_j) z^T(t_j) \right]^{-1}.$$

From least square estimation $\hat{\alpha}(.)$ and $P^*(.)$ may be initialised for a block of data or for the whole data set.

The parameter estimation algorithms of equations (3.1.9) and (3.1.10) do not overcome the problem of bias. The conditions for unbiased estimates have been stated in equation (3.1.4). For most cases of practical interest, $v(t_k)$ is not a white Gaussian sequence and estimates of α are not unbiased.

To overcome the problem of bias many variants of recursive parameter estimation algorithms have been suggested. Of which the recursive instrument variable algorithms are found to be easily amenable to simulation with rapid convergent properties.

3.1.4 Recursive Instrument Variable Algorithms for Parameter Estimation

The most likely source of biased estimate is the presence of significant noise sequence correlation between noise sequence and the past values of the output.

Referring to equation (3.1.2) with suitable estimates of the parameters, an auxiliary time series model can be computed as

$$\hat{Y}(t_k) = \left[\sum_{i=1}^{n} \beta_i q^{-i} \right] \hat{Y}(t_k) +$$

$$\sum_{j=1}^{m} \left[\sum_{i=0}^{n} \delta_{ji} q^{-i} \right] U_j(t_{k-r_j-i}) \qquad (3.1.11)$$

Equations (3.1.2) and (3.1.11) suggest that any variation in $\hat{Y}(t_k)$ should be strongly correlated with variations in the noise corrupted output observations $Y(t_k)$, but the variations in $\hat{Y}(t_k)$ should be uncorrelated with $\eta(t_k)$ provided $\eta(t_k)$ is not correlated with the measured input sequences $U_j(t_{k-r_j})$, i.e.,

$$\mathcal{E}\left\{ \left(U_j(t_{k-r_j}) \, \eta(t_l) \right\} = 0 \quad \text{for all } j, k \text{ and } l.$$

The sequence $\hat{Y}(t_k)$ is called the sequence of instrument variables. Consequently, the vector $z^T(t_k)$ is modified as $\hat{z}^T(t_k)$, defined by

$$\hat{z}^T(t_k) = \left[\hat{Y}(t_{k-1}),\ldots,\hat{Y}(t_{k-n}),U_1(t_{k-r_1}),\ldots,\right.$$

$$\left. U_1(t_{k-r_1-n}),\ldots, U_m(t_{k-r_m}),\ldots,U_m(t_{k-r_m-n}) \right]$$

The conditions of unbiased estimates are modified as

$$\mathcal{E}\{z(t_k)\ \eta(t_k)\} = 0 \quad \text{for all} \quad k$$

with $\mathcal{E}\{v(t_k)\ v(t_j)\} = 0 \quad \text{for} \quad k \neq j$

$$= \rho^2 \quad \text{for} \quad k = j$$

Replacing $z(t_k)$ by $\hat{z}(t_k)$ and not $z^T(t_k)$ by $\hat{z}^T(t_k)$, the recursive instrument variable algorithms are given as

$$\hat{\alpha}(t_k) = \hat{\alpha}(t_{k-1}) + \hat{P}^*(t_{k-1})\,\hat{z}(t_k)\,[1 + z^T(t_k)\,\hat{P}^*(t_{k-1})\,\hat{z}(t_k)]^{-1}\,\{y(t_k) - z^T(t_k)\,\hat{\alpha}(t_{k-1})\}$$

$$\hat{P}^*(t_k) = \hat{P}^*(t_{k-1}) - P^*(t_{k-1})\,\hat{z}(t_k)\,[1 + z^T(t_k)\,\hat{P}^*(t_{k-1})\,\hat{z}(t_k)]^{-1}\,z^T(t_k)\,\hat{P}^*(t_{k-1}) \qquad (3.1.18)$$

with

$$\hat{Y}(t_k) = \left[\sum_{i=1}^{n} \beta_i\, q^{-i}\right] \hat{Y}(t_k) + \sum_{j=1}^{m} \left[\sum_{i=0}^{n} \delta_{ji}\, q^{-i}\right] U_j(t_{k-r_j-i})$$

and $$\hat{P}^*(t_k) \triangleq \left[\sum_{j=1}^{k} \hat{z}(t_j)\,z^T(t_j)\right]^{-1}.$$

$\hat{\alpha}(.)$ and $\hat{P}^*(.)$ have been initialised by the least square method using the whole data set or a block of data.

The instrument variables $\hat{Y}(.)$ in $\hat{z}(.)$ are obtained through a separate parameter tracking algorithm as detailed below.

$$Y(t_k) = \sum_{i=1}^{n} \beta_i Y(t_{k-i}) + \sum_{j=1}^{m} \sum_{i=0}^{n} \delta_{ji} U_j(t_{k-rj-i})$$

$$+ \sum_{q=1}^{Q} C_{t_{k-q}}(Y(t_{k-q}) - Y(t_{k-q})) + \sigma(t_k) \qquad (3.1.13)$$

where the third component is the moving average component, $\sigma(t_k)$ is the error sequence.

$\hat{Y}(t_k)$, the estimate of $Y(t_k)$ can be written as

$$\hat{Y}(t_k) = a^T(t_{k-1})\, z(t_{k-1}) \qquad (3.1.14)$$

where

$$a^T(t_{k-1}) = \left[\beta_1, \beta_2, \ldots, \delta_{10}, \delta_{11}, \ldots, \ldots, \delta_{mn}, C_{t_{k-1}}, C_{t_{k-2}}, \ldots \right]$$

$$z(t_{k-1}) = \left[Y(t_{k-1}), Y(t_{k-2}), \ldots, U_1(t_{k-r1}) \ldots, \ldots, U_m(t_{k-rm-n}) \right] \qquad (3.1.15)$$

The co-efficient vector 'a' can be estimated by minimizing the quadratic performance criterion $J_k(a)$, defined as,

$$J_k(a) \overset{\Delta}{=} \sum_{j=1}^{k} \left(Y(t_j) - a^T z(t_{j-1}) \right)^2 +$$

$$+ (a - a(t_0))^T S^{-1}(t_0) (a - a(t_0)) \qquad (3.1.16)$$

where $a(t_0)$ is the available a priori estimate of the co-efficient vector 'a' and $S(t_0)$ is the positive definite weighting matrix of the order $m1 \times m1$ where $m1 = n + m(n+1) + Q$.

For minimization,

$$\frac{\delta J_k(a)}{\delta a} = -2 \sum_{j=1}^{k} z(t_{j-1}) (Y(t_j) - a^T z(t_{j-1}))$$

$$+ 2 S^{-1}(t_0) (a - a(t_0)) \qquad (3.1.17)$$

It follows from equation (3.1.17)

$$\sum_{j=1}^{k} z(t_{j-1}) Y(t_j) + S^{-1}(t_0) a(t_0) = \sum_{j=1}^{k} z(t_{j-1}) z^T(t_{j-1})$$

$$+ S^{-1}(t_0)\, a \qquad (3.1.18)$$

Let

$$S^{-1}(t_k) = \sum_{j=1}^{k} z(t_{j-1})z^T(t_{j-1}) + S^{-1}(t_0) \qquad (3.1.19)$$

and

$$d(t_k) = \sum_{j=1}^{k} z(t_{j-1})Y(t_j) + S^{-1}(t_0)a(t_0) \qquad (3.1.20)$$

Denoting the co-efficient vector 'a' as $a(t_k)$ at the time instant t_k,

$$S^{-1}(t_k)\,a(t_k) = d(t_k)$$

or $\qquad (3.1.21)$

$$a(t_k) = S(t_k)\;d(t_k).$$

From equations (3.1.19) and (3.1.20) the following recursive equations are obtained,

$$S^{-1}(t_{k+1}) = S^{-1}(t_k) + z(t_k)z^T(t_k) \qquad (3.1.22)$$

$$d(t_{k+1}) = d(t_k) + z(t_k)\,Y(t_{k+1}) \qquad (3.1.23)$$

By matrix inversion lemma the recursive parameter estimation algorithms to obtain the instrument variables $Y(t_k)$ are,

$$a(t_{k+1}) = a(t_k) + S(t_{k+1})z(t_k)\left[Y(t_{k+1}) - a^T(t_k)z(t_k)\right] \qquad (3.1.24a)$$

$$S(t_{k+1}) = S(t_k) - S(t_k)z(t_k)z^T(t_k)S(t_k)\left[1 + z^T(t_k)S(t_k)z(t_k)\right]^{-1}$$

... (3.1.24b)

The algorithms are initialised with

$$s(t_0) \overset{\Delta}{=} I \quad (\text{ unit matrix }) ; \quad a(t_0) = 0$$

$$Y(t_j) = 0 \quad \text{for} \quad j = 0, -1, -2, \ldots,$$

and $$\hat{\delta}(t_j) = 0 \quad \text{for} \quad j = 0, -1, -2, \ldots).$$

3.2.0 Details of Investigation Sites

The river Teesta, its catchment and the observation sites are described below.

3.2.1 The Teesta, its Catchment and the Observation Sites

The river Teesta rising from the Himalayan ranges in north Sikkim and passing through the deep gorges for nearly 128 Kms. debouches upon the plain of West Bengal near Sevoke. The Teesta is a very fast flowing river. Its average velocity is 6.2 metre per second. In winter its water is seagreen. In summer and in rainy season when the ice in the glacier melts quickly and when its catchment is bathed in torrential rains the milky white water flows through the river surging its narrow Himalayan fluvial course.

The accompanying map, Fig. 3.2.1 depicts the Teesta river and its catchment. A brief description of the river is given. The river Lohnak originates from the snow line in North Sikkim at a height of about 6401 metres.

The river Pokichu originates from the Zemu glacier at a height of 4968 metres. These two rivers combine at Lachen, after which it is known as the Zemuchu river. At Chungthang Lachen Chu river joins the Zemu Chu from the north eastern side. This combined flow is further augmented by the river Lachung Chu at down-stream of Chungthang to form the river Teesta. Thus the Teesta, is Bengali Language called Trisrota meaning that three flows have combined together, is formed by the rivers Zemu Chu, Lachen Chu and the Lachung Chu. At Sankalan the river Talung Chu originating from the Talung gracier in north western Sikkim at a height of about 5873 metres, joins the river Teesta. Upto Sankalan length of the river from the origin is about 70 K.m. and the catchment area is about 4200 sq. K.m.

From Sankalan the river Teesta flows through the narrow Himalayan gorges and comes to Singtam. About 15 K.m. up-stream of Singtam the river Dik Chu joins the Teesta. At Singtam from the easternside the river Rongni Chu joins the Teesta. Upto Kantitar the length of the river is approximate 114 K.m. from the origin and the catchment area is approximate 4874 sq.K.m. from the origin.

At Rongpo the river Rongpo Chu from the eastern catchment region joins with the Teesta. The length of the river from the origin upto Rongpo is approximate 118 K.m. and the total catchment area of the river including its tributaries upto Rongpo is approximately 5406 sq.K.m. from the origin.

Near Singlabazar the river Great Rangit combines with the river Raman and the river Little Rangit and flows as the Great Rangit river. This combination of three rivers bring in an addition of about 1966 sq. K.m. of catchment area to the Teesta catchment. At about 3 K.m. up-stream of Teestabazar the Great Rangit joins the Teesta. The confluence of the Great Rangit and the Teesta is unforgettable. The clear sea green water of the Great Rangit mixes with the milky white water of the Teesta and thus creating a wonderful cocktail of nature. The length of the river from the origin upto Teestabazar is about 134 K.m. and the catchment is (approx.) 7714 sq. K.m.

Upto Coronation Bridge the length of the Teesta from the origin is (approx.) 158 K.m. and the catchment area is about 8147 sq.K.m. Upto Sevoke its length from the origin is (approx.) 160 K.m. and the catchment area is about 8179 sq. K.m.

In the plains the important tributaries of the Teesta are the Lish, Ghish, Chel, Neora and the Karla. Upto Domohani Road Bridge the length of the Teesta from the origin is (approx.) 206 K.m. and the catchment area is (approx.) 9432 sq. K.m.

The Teesta mixes with the Brahmaputra.

3.2.2 The Main Observation Stations

The main observation stations from where the data for the investigation reported in this chapter were collected have been shown in the map. A brief description of the stations are given below.

Sitewise brief note of various observation stations

1. SANKALAN BRIDGE

a) Location	:	Lat.-27° 30'N, Long.-88° 38'E, on river Teesta in hilly terrain of North Sikkim down-stream of confluence of Lachenchu, Lachungchu and Talungchu. National Highway 31 A is about 3 K.m. from the site.
b) Nature of Station	:	Gauge and Discharge with 25 Watt H.F. Wireless facilities.
c) Mode of observation	:	Hourly gauge observed round the clock during monsoon. Discharge observation thrice a day at 0800, 1200 and 1600 hrs. using wooden float and a float run of 30 m. Cross-section taken once a month using sounding of 15 Kg.wt.

d) Length of river from
origin up to site : 70 K.m. (approx.)

e) Catchment area up to
site from origin : 4200 sq. K.m. (approx.)

f) Date of commencement
of gauge/discharge : 12.10.72/ 2.12.72

g) Maxm. observed gauge/
Discharge during : 759 m. on 2.7.79 (1900 Hrs.)
monsoon of 1979 1433.64 Cumecs on 12.7.79 (1600 hrs.)

h) Maxm. ever recorded
gauge/Discharge : 762.30 m on 12.6.73 (0100 hrs.)
1729.07 Cumecs on 12.7.73 (0700 hrs.)

i) Type of Raingauge : NIL.

2. KHANITAR

a) Location : Lat.- 27° 10.5'N, Long.- 88° 30'E in Sikkim on Teesta. NH-31 A is about 1 K.m. from the site.

b) Nature of Station : Gauge and Discharge with 15 Watt. H.F. wireless facilities.

c) Mode of observation : Hourly gauge observed round the clock during monsoon. Discharge observation thrice a day at 0600, 1200 and

1600 hrs. using Wooden float and a float run of 30 M. Cross-section taken once a week using sounding of 26 Kg.wt.

d) Length of river from origin upto site : 114 K.m. (approx.)

e) Catchment area upto site from origin : 4874 Sq.K.m. (approx.)

f) Date of commencement of observation of Gauge/Discharge : 12.6.70/12.6.70

g) Maxm.observed gauge/Discharge during monsoon of 1979 :
296.79 m.on 2.7.79 (2000 hrs.)
1784.49 Cumecs on 23.7.79 (0700 hrs.)

h) Maxm. ever recorded Gauge/Discharge :
297.50 m.on 13.10.73 (0500 hrs.)
2197.74 Cumecs on 18.6.79 (1200 hrs.)

i) Type of raingauge : One S.R. Raingauge and one ordinary raingauge.

3) RONGPO

(1) ON RIVER RANGPO CHU :

(a) Location : Lat.-27° 10' N, Long.-88° 32' E, on river Rongpo chu i.e. tributary of river Teesta near the junction of L.R.P. Road at NH - 31 A is about 1 K.M. from the site.

(b) Nature of Station : Gauge and Discharge with 15 Watt. H.F. Wireless facilities.

(c) Mode of observation : Hourly Gauge observed round the clock during monsoon. Discharge observation thrice a day at 0800, 1200 and 1600 hrs. using wooden float and a float run of 30 m. Cross-section taken once a week using sounding of 20 Kg.wt.

(d) Date of commencement of observation of Gauge/Discharge : 5.6.70/ 1.7.70

(e) Maxm. observed Gauge/Discharge during monsoon of 1979 : 304.608 Mtr. on 3.8.79 (0800 hrs.) / 603.25 Cumecs on 23.7.79 (1200 hrs.)

(f) Maxm. ever recorded
Gauge/Discharge : $\frac{\text{304.608 Mtr.on 2.8.79 (0900 hrs.)}}{\text{732.016 Cumecs on 26.9.72 (1800 hrs.)}}$

(g) Type of Raingauge : One ordinary raingauge.

4) <u>SINGLABAZAR</u>

(a) Location : Lat.- 27° 07' N and Long. 88° 14' E, on river Great Rangit i.e. tributary of river Teesta, is 2 K.m. from the site.

(b) Nature of Station : Gauge with 15 Watt. H.F. Wireless facilities.

(c) Mode of observation : Hourly gauge observed round the clock during the monsoon.

(d) Date of commencement of observation of Gauge/Discharge : 11.12.69

(e) Maxm. observed Gauge/Discharge during monsoon '79 : 310.00 Mtr. on 24.7.79 (0900 hrs.)

(f) Maxm. ever recorded Gauge/Discharge : 310.35 Mtr. on 12.10.73 (2100 hrs.)

(g) Type of raingauge : One S.R. Raingauge and one ordinary raingauge.

(ii) **ON RIVER RAMAN**

(a) Location : Lat.-27°7.5'N, Long. 88° 18.5'E on river Raman i.e. tributary of river Teesta, is 1 K.m. from the site.

(b) Nature of Station : Gauge and Discharge.

(c) Mode of Observation : Hourly gauge observed round the clock during monsoon. Discharge observation thrice a day at 0800, 1200 and 1600 hrs. using wooden float and a float run of 30 Mtr. Cross-section taken once a week using sounding of 25 Kg.wt.

(d) Length of river from origin upto site : 32 K.m. (approx.)

(e) Catchment area upto site from origin : 385 Sq.K.m. (approx.)

(f) Date of commencement of observation of Gauge/Discharge : 11.12.69/ 1.6.73

(g) Maxm. observed Gauge/Discharge during monsoon of 1979 : $\frac{\text{320.00 Mtr. on 29.7.79 (1000 hrs.)}}{\text{140.63 Cumecs on 29.7.79 (1200 hrs.)}}$

(h) Maxm. ever recorded Gauge/Discharge : $\frac{\text{320.15 Mtr. on 12.10.73 (2200 hrs.)}}{\text{421.488 Cumecs on 16.8.78 (0700 hrs.)}}$

(i) Type of Raingauge : NIL.

(iii) ON RIVER LITTLE RANGIT

(a) Location : Lat.- $27^{\circ} 5 \frac{5}{6}$ 'N, Long. $88^{\circ} 15 \frac{1}{2}$ 'E on river Little Rangit i.e. tributary of river Teesta, is about 3 K.m. from the site.

(b) Nature of Station : Gauge and Discharge with Non-exchange telephone facilities with Singlabazar.

(c) Mode of observation : Hourly gauge observed round the clock during monsoon. Discharge observation thrice a day at 0800, 1200 and 1600 hrs. using wooden float and a float run of 30 Mtr. Cross-section taken once a day using sounding of 25 Kg.wt.

(d) Length of river from origin upto site : 25 K.m. (Approx.)

(e) Catchment area upto site from origin : 184 Sq. K.m. (Approx.)

(f) Date of commencement of observation of Gauge/Discharge : 21.6.72/ 1.7.72.

(g) Maxm. of observed Gauge/Discharge during monsoon of 1979 :

$$\frac{\text{321.53 Mtr. on 8.8.79 (2400 hrs.)}}{\text{88.60 Cumecs on 30.8.79 (0700 hrs.)}}$$

(h) Maxm. ever recorded Gauge/Discharge :

$$\frac{\text{314.30 Mtr. on 12.10.73 (1800 hrs.)}}{\text{288.57 Cumecs on 7.9.75 (1700 hrs.)}}$$

(i) Type of Raingauge : NIL.

5) **TEESTABAZAR**

(a) Location : Lat.-27° 03' N, Long. 88° 26' E on river Teesta down-stream of the confluence of the Great Rangit with river Teesta NH-31A is about 3 K.m. from the site.

(b) Nature of Station : Gauge and Discharge with 15 Watt. Wireless facilities observation made on the suspension bridge on river Teesta on NH-31A. Also having non-exchange telephone line between camp shed and bridge point.

(c) Mode of observation : Hourly Gauge observed round the clock during the monsoon. Discharge observation thrice a day at 0800, 1200 and 1600 hrs. using wooden float and a float run of 50 Mtr. Cross-section taken once a month through sounding of 25 Kg.wt.

(d) Length of river from origin upto site : 134 K.m. (approx.)

(e) Catchment area upto site from origin: 7714 Sq.K.m. (approx.)

(f) Date of commencement of observation of Gauge/Discharge : 1.6.69/ 22.8.74

(g) Maxm.observed Gauge/ Discharge during monsoon of 1979 : 211.80 Mtr.on 24.7.79 (0400 hrs.) / 2906.17 Cumecs on 24.7.79 (0700 hrs.)

(h) Maxm. ever recorded Gauge/Discharge : 217.00 Mtr.on 12.10.73 (0800 hrs.) / 7642.45 Cumecs on 12.10.73 (0600 hrs.)

(i) Type of Raingauge : One S.R. Raingauge and one ordinary raingauge.

6) **CORONATION**

(a) Location : An important forecasting point on river Teesta on NH-31.

(b) Nature of Station : Gauge and Discharge with 15 Watt. Wireless facilities and non-exchange telephone line between Camp shed and bridge point and camp shed to Sevoke site.

(c) Mode of observation : Hourly gauge observed round the clock during monsoon. Discharge observation thrice a day at 0800, 1200 and 1600 hrs. using wooden float and a float run of 70 Mtr. Cross-section taken once a month through sounding of 25 Kg.wt.

(d) Length of river from origin upto site : 188 K.m. (approx.)

(e) Catchment area upto site from origin : 8147 Sq.K.m. (approx.)

(f) Date of commencement of observation of Gauge/Discharge: 10.8.74/ 1.8.74.

(g) Maxm. observed Gauge/Discharge during monsoon of 1979 : 151.40 Mtr. on 24.7.79 (0800 hrs.) / 2751.38 Cumecs on 24.7.79 (0700 hrs.)

(h) Maxm. ever recorded Gauge/Discharge : 156.500 Mtr. on 12.10.73 (0800 hrs.) / 5080.00 Cumecs on 12.10.73 (0700 hrs.)

(i) Type of Raingauge : NIL.

Table showing the distance of various gauge observation in various basin from the forecasting stations and their travel time.

Sl. No.	Base Station	F/C Station	River distance between base station to F/C station in K.M.	Approx. Travel time
	TEESTA CATCHMENT			
1.	Sankalan Bridge	Coronation Bdg.	84	10 Hrs.
2.	Kantitar	Coronation Bdg.	44	4 Hrs.
3.	Rongpo	Coronation Bdg.	42	4 Hrs.
4.	Singlabazar	Coronation Bdg.	54	4 Hrs.
5.	Mayabazar	Coronation Bdg.	54	4 Hrs.
6.	Teestabazar	Coronation Bdg.	22	2 Hrs.

3.2.3 Results of Investigation

Data from 14.00 hr. on July 23, 1979 to 18.00 hr. on July 26, 1979 were observed at the gauging stations at Sankalan, Great Rangit (Singlabazar), Rongo (Teesta), Teestabazar and Coronation Bridge. The stations are shown in Fig. 3.2.2.

Table 3.2.1 shows the correlation co-efficients of the hourly river flow at Coronation Bridge with flows at the up-stream gauging stations. Input variables are selected on the basis of the strongest co-efficient of correlation with flows at Coronation Bridge.

Table 3.2.2 shows the input-output variables rationalized in accordance with

$$x(k) = \frac{X(k) - X_{min}}{X_{max} - X_{min}} \quad \text{(ii)}$$

where $X(.)$ is the observed value and the values and X_{max} and X_{min} are the maximum and the minimum values of the data sequence. The co-efficient of correlation has been defined as

$$\phi_{yx}(\lambda) = \frac{\sum_{i=1}^{N-\lambda}\left[y(i)-\frac{1}{N}\sum_{i=1}^{N}y(i)\right]\left[x(i+\lambda)-\frac{1}{N}\sum_{i=1}^{N}x(i)\right]}{\left[\sum_{i=1}^{N-\lambda}\left[y(i)-\frac{1}{N}\sum_{i=1}^{N}y(i)\right]^{2}\sum_{j=1+\lambda}^{N}\left[x(j)-\frac{1}{N}\sum_{i=1}^{N}x(i)\right]^{2}\right]^{\frac{1}{2}}} \quad \ldots (3.2.1)$$

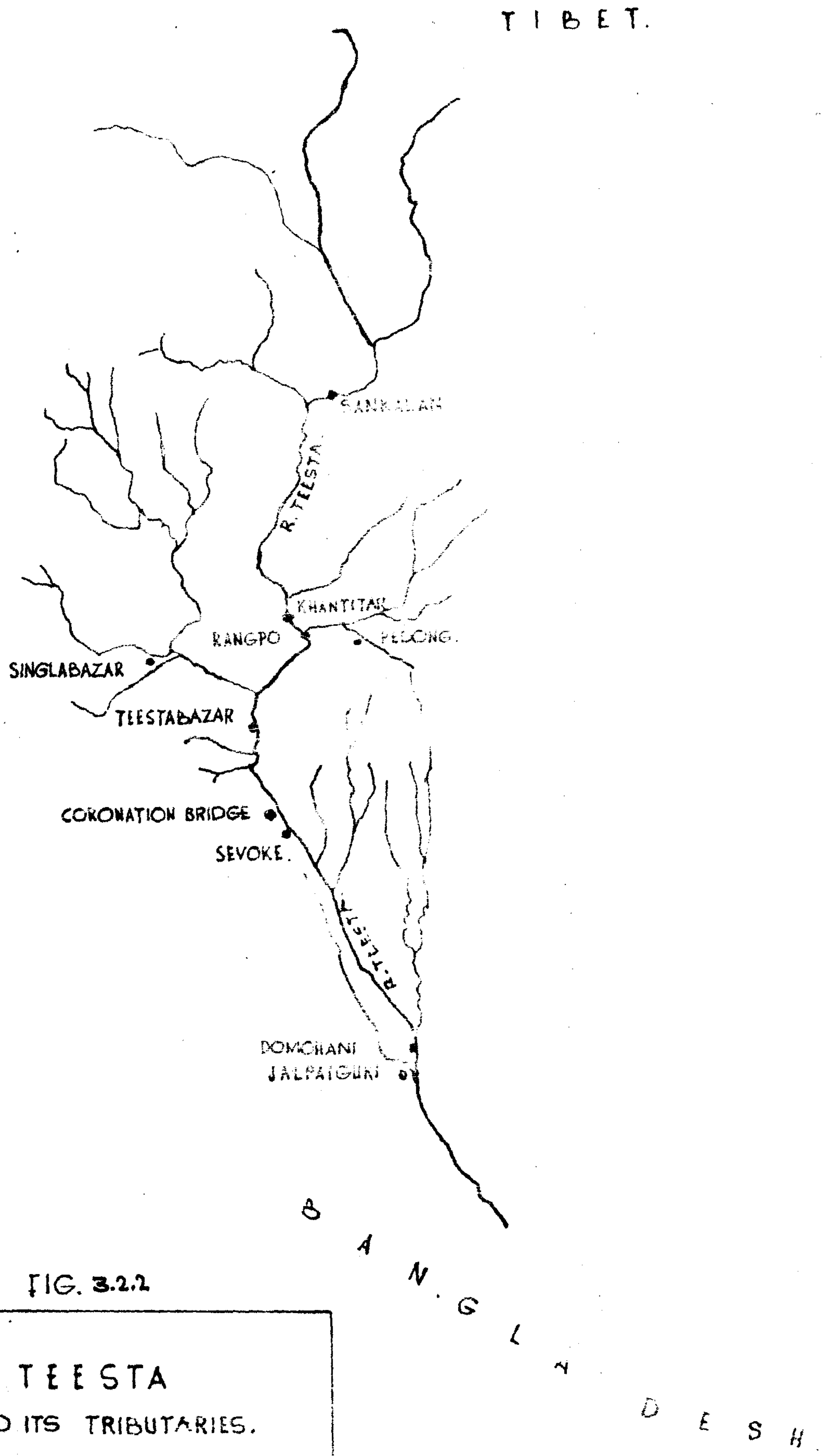


FIG. 3.2.2

TEESTA
AND ITS TRIBUTARIES.
SCALE : 1 INCH = 16 MILES.

TABLE 3.2.1

Correlation Co-efficient against Timeshift Coronation Bridge, Teestabazar, Rongpo (Teesta), Great Rangeet, Sankalan.

Instant	Coronation Teestabazar	Coronation Rongpo (Teesta)	Coronation Great Rangeet	Coronation Sankalan
0	0.9421	0.7586	0.7574	0.6534
1	0.9726	0.8306	0.7765	0.7078
2	0.9540	0.8748	0.7908	0.7482
3	0.8886	0.8879	0.7854	0.7828
4	0.7891	0.8628	0.7426	0.7886
5	0.6737	0.8066	0.6649	0.7473
6	0.5516	0.7342	0.5728	0.6690
7	0.4343	0.6493	0.4697	0.5698
8	0.3263	0.5609	0.3584	0.4531
9	0.2300	0.4760	0.2494	0.3201
10	0.1550	0.4015	0.1503	0.2082

TABLE 3.2.2

OUTPUT-INPUT VARIABLES IN RATIONALIZED UNITS

DATE	TIME, hr	CORONATION $Y(t_k)$	TEESTA-BAZAR $U_1(t_{k-1})$	RONGPO (TEESTA) $U_2(t_{k-3})$	GREAT RANGEET $U_3(t_{k-2})$	SANKALAN $U_4(t_{4-4})$
July 23,	14.00	0.318681	0.266666	0.444444	0.086956	0.068181
1979	15.00	0.450549	0.444444	0.644444	0.086956	0.090909
	16.00	0.604395	0.711111	0.800000	0.217391	0.090909
	17.00	0.736263	0.822222	1.000000	0.391304	0.090909
	18.00	0.692307	0.688888	1.000000	0.347826	0.090909
	19.00	0.637362	0.666666	1.000000	0.304347	0.113636
	20.00	0.582417	0.622222	0.977777	0.304347	0.113636
	21.00	0.560439	0.577777	0.888888	0.260869	0.090909
	22.00	0.472527	0.555555	0.800000	0.304347	0.090909
	23.00	0.417582	0.422222	0.622222	0.304347	0.068181
	24.00	0.362637	0.377777	0.533333	0.304347	0.068181

TABLE 3.2.2 (Continued)

DATE	TIME, hr	CORONATION $Y(t_k)$	TEESTA - BAZAR $W_1(t_{k-1})$	RONGPO (TEESTA) $W_2(t_{k-3})$	GREAT RANGEET $U_3(t_{k-2})$	SANKALAN $W_4(t_{4-4})$
July 24, 1979	01.00	0.340659	0.377777	0.488888	0.282608	0.068181
	02.00	0.340659	0.355555	0.466666	0.282608	0.090909
	03.00	0.318681	0.355555	0.444444	0.434782	0.090909
	04.00	0.428571	0.444444	0.400000	0.434782	0.136363
	05.00	0.527472	0.533333	0.444444	0.434782	0.181818
	06.00	0.571428	0.577777	0.577777	0.456521	0.272727
	07.00	0.604395	0.600000	0.622222	0.521739	0.318181
	08.00	0.692307	0.644444	0.644444	0.565217	0.409090
	09.00	0.747252	0.777777	0.644444	0.782608	0.500000
	10.00	0.714285	0.933333	0.666666	1.000000	0.636363
	11.00	0.956043	1.000000	0.800000	1.000000	0.863636
	12.00	1.000000	0.911111	0.800000	0.782608	1.000000
	13.00	0.912087	0.822222	0.844444	0.565217	0.772727
	14.00	0.824175	0.711111	0.800000	0.521739	0.636363
	15.00	0.736263	0.666666	0.711111	0.478260	0.579545
	16.00	0.659340	0.600000	0.622222	0.434782	0.488636
	17.00	0.571428	0.555555	0.622222	0.434782	0.409090
	18.00	0.494505	0.511111	0.577777	0.434782	0.295454
	19.00	0.450549	0.488888	0.522222	0.413043	0.181818
	20.00	0.428571	0.444444	0.422222	0.434782	0.181818
	21.00	0.384615	0.433333	0.400000	0.434782	0.181818
	22.00	0.373626	0.422222	0.400000	0.478260	0.181818
	23.00	0.417582	0.422222	0.355555	0.478260	0.261363
	24.00	0.439560	0.466666	0.311111	0.456521	0.272727

TABLE 3.2.2 (Continued)

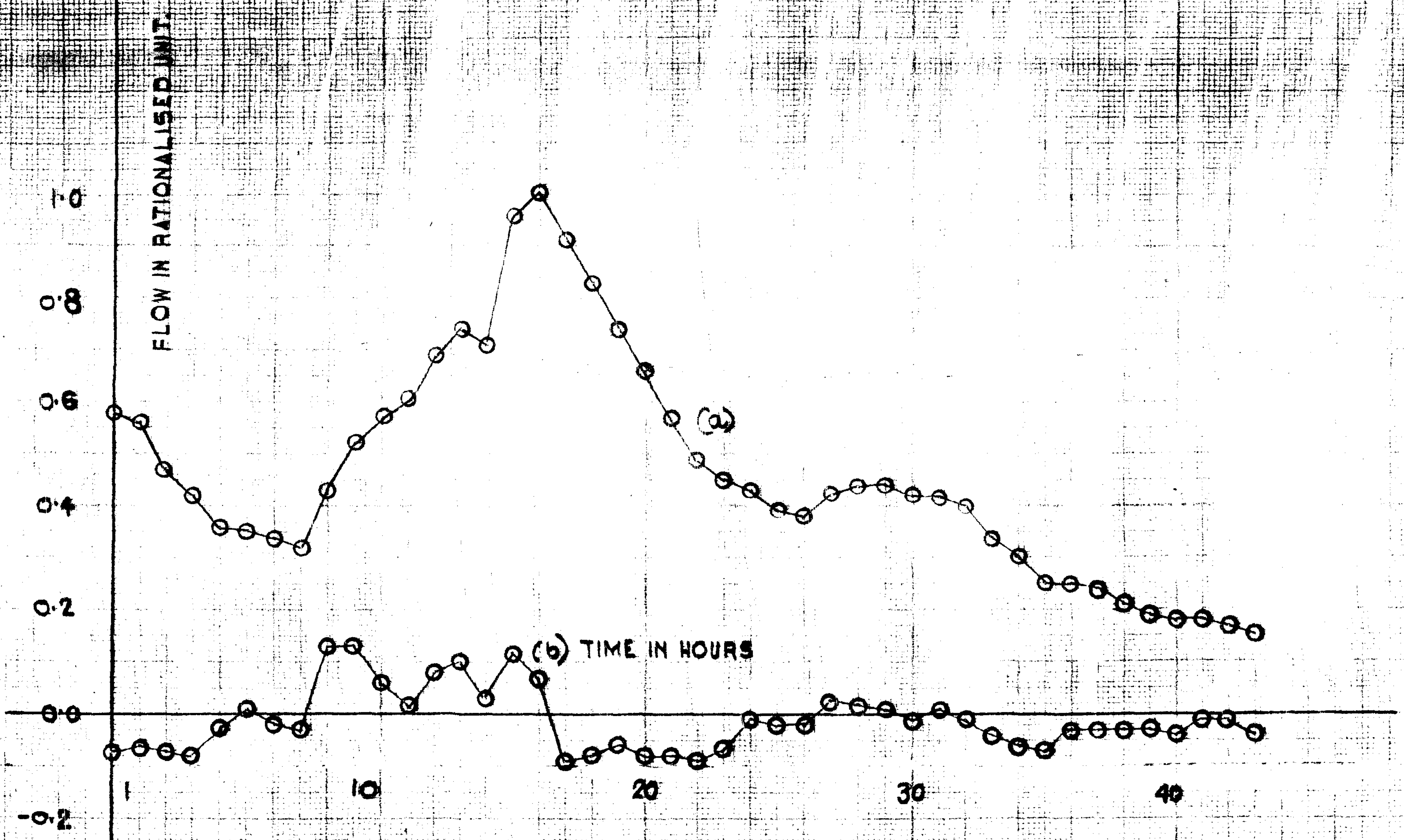
DATE	TIME, hr	CORONATION $Y(t_k)$	TEESTA - BAZAR $U_1(t_{k-1})$	RONGPO (TEESTA) $U_2(t_{k-3})$	GREAT RANGEET $U_3(t_{k-2})$	SANKALAN $U_4(t_{4-4})$
July 25,	01.00	0.439560	0.466666	0.266666	0.391304	0.272727
1979	02.00	0.428571	0.466666	0.266666	0.391304	0.272727
	03.00	0.423076	0.444444	0.222222	0.347826	0.238636
	04.00	0.395604	0.422222	0.222222	0.369565	0.238636
	05.00	0.340659	0.400000	0.222222	0.413043	0.238636
	06.00	0.296703	0.377777	0.222222	0.434782	0.238636
	07.00	0.252747	0.377777	0.222222	0.434782	0.181818
	08.00	0.252747	0.377777	0.200000	0.434782	0.181818
	09.00	0.241758	0.333333	0.200000	0.423043	0.181818
	10.00	0.219780	0.288888	0.177777	0.369565	0.181818
	11.00	0.197802	0.266666	0.177777	0.326086	0.181818
	12.00	0.186813	0.244444	0.177777	0.304347	0.181818
	13.00	0.186813	0.244444	0.155555	0.282608	0.136363
	14.00	0.164835	0.222222	0.133333	0.260869	0.136363
	15.00	0.142857	0.222222	0.133333	0.260869	0.102272

Using recursive instrument variable algorithm with parameter tracking adaptiveness for estimation of instrument variables the mean error and the integral square error for $n = 2$ and $Q = 2$ were found as 0.013475 and 0.014917 respectively. The integral square error has been defined as,

$$ISE = \frac{\sum_{j=1}^{N} \left[Y(t_j) - \hat{Y}(t_j) \right]^2}{\sum_{j=1}^{N} \left[Y(t_j) \right]^2} \qquad (3.2.2)$$

For a moving average sequence of $P = 2$, $\eta(t_k)$ was found to have a mean error of 9.250282 E-03 and a variance of the error sequence $v(k)$ as 0.934175. Observed and the errors between the observed and modelled values of the hourly river flows are shown in Fig. 3.2.3a and 3.2.3b respectively. Parameter vector '$\hat{\alpha}$' and the matrix P^* have been initialised for block of data using least square technique. Table 3.2.3 and Table 3.2.4 show the initial values of the parameter vector '$\hat{\alpha}$' and the P^* matrix respectively.

Thus, the recursive instrumental variable algorithms have been found to simulate adequately the observed hourly flows for real time operation [88]. The computer programmes in BASIC language are given in the Appendix as A1.1 - A1.5.



FLOW OF RIVER TEESTA AT CORONATION BRIDGE FROM 20·00 HOUR ON JULY 23, 1979 - 15·00 HOUR ON JULY 25, 1979

FIG 3.2.3a & 3.2.3b

TABLE 3.2.3

INITIAL VALUES OF THE PARAMETER VECTOR " $\hat{\underset{\sim}{\alpha}}$ "

Element	Value
1	0.399774
2	0.014683
3	0.488142
4	-0.088370
5	-0.247403
6	0.213479
7	0.082824
8	-0.128437
9	-0.209974
10	0.241120
11	0.168889
12	0.220721
13	-0.328690
14	0.166041

TABLE 3.2.4

INITIAL VALUES OF $P^*(. , .)$ MATRIX

Column / Row	1	2	3	4	5
1	58.880664	-8.829053	-40.030619	-33.521385	-38.186045
2	- 8.829053	42.177748	5.355676	13.017608	-22.537688
3	-40.030619	5.355676	73.677836	23.761898	54.834963
4	-33.521385	13.017608	23.761898	71.448512	7.330765
5	-38.186045	-22.537688	54.834963	7.330765	94.575968
6	37.562782	-13.953667	-68.268940	-45.479030	-39.470863
7	-16.391836	9.196837	15.698047	0.450839	- 2.882897
8	15.003694	-11.202067	-14.154664	- 2.338086	-12.157318
9	0.987203	-10.415648	-17.542602	- 2.414112	1.880186
10	38.029081	0.235984	-37.433986	-46.712746	-40.959651
11	-14.871545	6.358026	9.629415	19.934608	- 3.078808
12	6.120561	1.193587	- 7.605047	- 2.480554	- 2.551819
13	- 6.585247	4.076049	- 2.720300	- 3.768396	0.046091
14	6.494409	-12.988852	- 8.330788	- 2.911984	1.032974

TABLE 3.2.4 (Continued)

Column / Row	6	7	8	9	10
1	37.562788	-16.391936	15.003694	0.987203	30.089081
2	-13.953667	9.196837	-11.208057	-10.415648	0.236924
3	-62.268940	15.698047	-14.154664	-17.543508	-37.432986
4	-45.479030	0.450839	- 2.338026	- 2.414112	-46.712746
5	-39.470863	- 2.582897	-12.157318	1.880156	-40.959551
6	86.771294	-30.972607	18.657976	15.318287	47.790582
7	-30.972607	47.886238	-22.121179	- 1.996982	- 7.449749
8	18.657976	-22.121179	19.164287	1.333767	8.713446
9	15.318287	- 1.996982	1.333767	16.445804	- 7.199783
10	47.790582	- 7.449749	8.713446	- 7.199783	65.210142
11	-16.687083	10.421918	- 5.727901	0.572893	-22.645643
12	6.024589	- 1.466709	3.596923	- 1.512034	- 1.167621
13	2.840896	1.696162	- 0.275096	5.388988	3.787456
14	14.064357	- 3.282177	4.766638	3.231064	7.722280

TABLE 3.2.4 (Continued)

Column Row	11	12	13	14
1	-14.271545	6.120561	-6.585247	6.494409
2	6.358026	1.193687	4.076049	-12.926262
3	9.629415	-7.605047	-2.720300	-5.330783
4	12.934606	-2.420654	-3.763396	-8.911984
5	-3.078806	-8.551819	0.046091	1.032974
6	-16.687083	6.034589	3.840696	14.064357
7	10.421918	-1.466709	1.696162	-3.282177
8	-5.727801	3.596923	-0.275096	4.766636
9	0.872293	-1.518034	5.385928	3.231054
10	-22.645643	-1.167621	3.787456	7.782280
11	20.258990	1.900406	-8.207861	-0.987570
12	1.900406	12.380408	-17.247785	4.283845
13	-8.207861	-17.247785	37.880206	-16.887294
14	-0.987570	4.283845	-16.887294	20.010960