TR (BR) 112

# FORECASTING OF LOW FLOWS FOR RIVER NARMADA AT MORTAKKA

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**1993-94**

# PREFACE

Assessment of river flow during non-monsoon months along with its time distribution is essential for planning and development of water resources and related schemes. Low flow modelling is also necessary for dealing with problems of stream pollution. The analysis of low flows is equally important for municipal and industrial water supply schemes, both from view points of quantity and quality.

The quantum of flows in the river in the lean season is generally very low - varying from about 15% in larger snow fed rivers to less than 1% in some of the smaller river systems in coastal areas. Although the availability of water during non-monsoon season is very low; it plays a vital role on the development and activities of the region. Accurate estimation of the water resources available during lean period and also its possible forecast helps in systematic developmental planning and utilization of the water resources. The importance of low flow forecasting is being increasingly felt for efficient management of the existing water resources projects as well as for optimal planning of the future projects.

A number of models have been suggested by various authors in the recent times for the flow forecasting but the statistical approach is still relevant and unavoidable under specific circumstances. In this report, a suitable statistical model for the low flow forecasting has been described.

This report is a part of work programme of Hydrologic Design Division and the study has been carried out by Shri Rakesh Kumar and Shri R.D. Singh, Scientists of the Institute. It is expected that the report would provide a suitable methodology for monthly low flow forecasting using the statistical approach.

(S.M. Seth)
DIRECTOR

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# ABSTRACT

For development of our agriculture based economy and to meet the demands of the growing population; in terms of irrigation, drinking water, hydropower generation and industrial use etc. modelling and forecasting of river flows during non-monsoon months is essential. Efficient management of existing water resources projects and optimal planning of the future projects also attach great importance to low flow modelling and forecasting.

Ideally, a distributed model based on the principle of physical laws representing the movement of water through its different phases should be developed for any modelling exercise for low flow forecast. However, it remains a fact that the physical laws for representing the formation and propagation of runoff through its various processes have not yet been perfected. No doubt, for the more complicated problems the use of physically based models acquires a great importance. But the physically based models require extensive data input and enormous computational facilities. On the other hand, there are many problems for which necessary solutions can be obtained with desired degree of accuracy required for the purpose, with relatively less sophisticated, lumped, conceptual or statistical models, which require very limited data generally available in the field.

In this study, a statistical model has been used to forecast the low flows (November to May) for the river Narmada at Mortakka, using the monthly data of previous month. To begin with, the forecast of flow from the month of November to May is formulated on the basis of observed data of October for a specific year. The forecast is updated after each month when additional data become available. The observed discharge and forecasts have been compared for the four test years and percentage errors between them have been computed.

## 1.0 INTRODUCTION

The availability of water resources in our country is highly variable both in space and time. The average annual surface runoff from the various river basins of the country is assessed to be about 188 million hectare meters. About 85% of the annual runoff is generated during the monsoon period of about four months only. As there is no sufficient provision for storage, a considerable portion of the runoff goes waste. Further, the availability of flow is highly variable both in space and time. For example, Cherapunji in the east receives average rainfall of the order of 1142 centimeters in a year and as much as 104 centimeters in a day, while western part of Rajasthan receives about 15 centimeters of rainfall per year. Similarly, the ratio of maximum and minimum discharges is found to be as high as 5000 in some of the perennial rivers of coastal regions. Even the variations in flows during the non-monsoon months, commonly known as low flows, are quite considerable. The above features lead to occurrence of flood-drought-flood syndrome in various parts of the country. Assessment of river flow during non-monsoon months along with its time distribution is essential for planning and development of water resources and related schemes for meeting the growing requirements of our developing society. Low flow modelling is also necessary for dealing with problems of stream pollution. The analysis of low flows is equally important for municipal and industrial water supply schemes, both from view points of quantity and quality.

There is no clearly defined term "Low flow" as such. Theoretically, whenever the river flow or the water level in the river is below a specific discharge or critical water level, the flows are called low flows. This is irrespective of the time of occurrence of such phenomenon. However, for all practical purposes, for Indian river basins, the term low flow applies to the flows in river during the non-monsoon period or during the lean season irrespective of the discharge during this period. Low flow periods in rivers are significant for various aspects of economy and ecology. The quantitative aspects include water supply for domestic, industrial and agricultural purposes, hydroelectric power generation and navigation. Chemistry and biology of the water courses and ecosystems constitute the qualitative aspects. Besides, efficient management of existing projects and optimal planning of the future projects attach great importance to low flow modelling and forecasting. Forecasting is concerned with predicting at some level of confidence the low flow state of a river in terms of stage or discharge at some specific time in the future conditional upon the present state.

In our country, river flow forecasting generally refers to either flood forecasting or the inflow forecast to the reservoir. But the river flow forecast covers the domains of low flow forecasts, the water quality forecasts, as also the forecast for the hydrological effects of the man-made changes in the river catchments. However, in India the organized forecast operation is generally limited to flood forecasts and inflow forecast to a few reservoirs. Only recently, the development of low flow forecast model has been taken up. In view of increasing importance of the forecasts for various purposes, the advanced countries are extensively using the river flow forecast services which includes the low flow forecast.

Low flow forecasts refer to the forecasts of river flow when the discharge the water level of a river is below a specific discharge or critical water level. In India, for major part of the country, the rainy season, commonly known as the monsoon season or non-rainy season are very clearly defined and for all practical purposes the forecast of the flow or the stage of the river during the non-monsoon period may be termed as low flow forecast. The role of low flow forecast becomes quite significant during the drought period when the water level is considerably depleted. The major objectives of the low flow forecast are: (a) Optimum utilization of scarce water.resources; (b) Deciding priorities in respect of various uses of water; (c) Assessment and evaluation of drought conditions and forecast for the possible drought situations; (d) Improvements in the operation policies for the water resources projects; (e) Solution of water sharing problems in respect of International and Interstate rivers; and (f) Pollution control and other environmental studies.

The cost effective reliable operation of watershed systems requires real time forecasts of river flows. Low flow forecasts are formulated round the year to plan or modify operating procedures keeping in view the available storage and the water use comprising hydro power generation, domestic water supply etc. Low flow forecasts are very much needed in planning seasonal utilization of water and periodic regulation schedule to match the plan of utilization. When the forecasting is extended to cover river flow throughout the year, it provides useful information for reservoir operations.

While hydrological data and their statistical analysis play very significant role in the planning of water resources projects; the low flow forecasts are necessary for efficient operation of these projects. The use of observed historic data serves to provide possible range and probable situations. Such exercises have got relevance in evaluating the economic viability of a project and formulating guidelines for reservoir operations regarding conservation. Timely evaluation and forecasting of flows greatly help in decision making processes on appropriate water uses. Both the demand for information concerning low flow and the need for a given accuracy of prediction may vary from case to case. It is desirable to have a prior knowledge of the amount of water available that could be drawn from reservoirs for various purposes in several months ahead, particularly for drought prone regions.

The wide range of application of low flow studies stresses the necessity and need for elaborate low flow studies. Some of the important fields of application of low flow studies and forecasting are:

(a) Domestic water supply;
(b) Irrigation;
(c) Hydro-power generation;
(d) Navigation;
(e) Industrial use of water;
(f) Reservoir operation;
(g) Ecosystems;
(h) Water quality management;
(i) Pollution control;
(j) Urban water treatment systems;
(k) Recharge of ground water aquifer;
(l) Drought management; and
(m) In-stream flow maintenance.

A hydrological forecast has following six main characteristics:

(a) the forecast variable;
(b) forecast period or lead time;
(c) computation methods;
(d) purpose of forecast;
(e) the form of presentation, like single expected value, total hydrograph, probability distribution etc; and

(f) the desired degree of accuracy for the forecast.

The two important features of the river flow forecasting are the accuracy and the availability of sufficient warning time. There are a number of models which are recommended for river flow forecasting. However, the choice of the model is generally governed by the objective of such forecast and the desired degree of the accuracy. In addition, the following ideal requirements of an effective model (Crawford & Linsley, 1966) should also be kept in view while identifying and developing a model. For practical purposes, a model should: (i) represent the hydrological regime on a wide variety of catchments with a high order of accuracy; (ii) be easily applied to any catchment for which hydrological data was available; and (iii) be physically realistic so that in addition to stream flow, estimates of other variables, such as soil moisture and ground water recharge are determined.

For the purpose of the development of a low flow forecasting model, the river systems in India can be broadly classified into following three categories.

i) the rivers originating from Himalayas in which snow melt contribution is quite considerable and its effects are dominant;

ii) the rain fed river having rains mostly concentrated during the monsoon season; and

iii) the coastal rivers of Tamil Nadu and Kerala where the contribution from the pre-monsoon and the post-monsoon rains are dominant.

Proper planning and efficient management of water resources systems are of vital importance. Inflow forecasts are major pre-requisite for all the operations necessary for the efficient management of the water resources. Seasonal stream flow models for forecasting are developed and utilized for the purpose. Utility of forecasts is dependant on the accuracy and the availability of warning time. Hence an adequate data network as well as dissemination facilities are very much desired in flow forecasting processes. The data network includes hydrological and hydrometeorological observations on the basis of an optimal design of such stations.

## 2.0 REVIEW

The factors affecting low flows and some of the low flow studies are briefly reviewed here under.

### 2.1 Factors Affecting Low flows

The regime and discharge during a lowflow period are affected by many factors. With present knowledge, the effects of majority of these factors can not be differentiated as a rule, since the laws governing them have not been adequately elucidated and their magnitudes are not, in general, known.

The factors affecting lowflows as described by McMahon and Arenas (UNESCO, 1982) are summarised below.

#### 2.1.1 Natural factors

The natural factors may be classified as:

**(a)** Climatic factors - (i)precipitation, (ii)evaporation, (iii)air and soil temperature, and (iv)humidity & wind;

**(b)** Hydrogeological factors - (i)geology of the basin, (ii)hydrogeological regime, and (iii)ground water (phreatic water, water in unconsolidated sediment, crack or fissure water, artesian water, karstic water and permafrost ground water);

(c) Morphological factors - (i)basin relief, (ii)presence of lake & swamps, and (iii)plant cover; and

(d) Morphometrical factors - (i)basin area, (ii)altitude, (iii)slope, (iv)orientation, and (iv)drainage densities etc.

#### 2.1.2 Factors due to human activity

The influence of man's activity on the regime and discharge of lowflows of a river varies in nature and intensity according to the level of development, type of economic activity involved, and the climatic conditions governing the basin & hydrological regime of the river. The various factors as a result of human activity such as urbanisation, irrigation, hydraulic works, water transfer schemes, hydro-electric stations, mining, navigation, treatment of urban and industrial effluents, drainage works and landuse changes etc. influence the flows during lean season.

## 2.2 Low Flow Studies

Some of the low flow studies are briefly reviewed below.

Institute of Hydrology(1980) developed the low flow estimation procedures for the rivers in United Kingdom. The philosophy underlying the study was that low flow indices extracted from flow records could be related statistically to catchment characteristics to yield formulae enabling low flows to be predicted at ungauged sites for preliminary design purposes. This study deals with statistical measures of low flows such are used in design work or in licensing abstractions or effluent discharges, and not with time series or rainfall-runoff models. Examples of low flow measures that are discussed are those concerned with the frequency of low flow events, the length of time below a threshold discharge, storage and yield and the rate of recession. Successful estimation at an ungauged site was found to depend very largely on the geology of the catchment. A new index, the base flow index has been developed for the purpose of quantifying catchment geology and the separate regional monographs describe how this index relates to and may be estimated from a knowledge of local geology.

Bingham(1982) developed a procedure for estimating the 7-day, 2-year and the 7-day, 10-year lowflow of ungauged Alabama streams based on geology, drainage area and mean annual precipitation. One equation for each of two lowflow frequencies was applied statewide to all natural flow streams; the equations did not apply to streams where flow was significantly altered by activities of man. The standard error of estimate of each equation was found to be 40 percent for 7-day, 2-year lowflow and 44 percent for 7-day, 10-year lowflow. The rate of streamflow recession has been used to account for the effects of geology on lowflow. Relations of lowflow discharge to geology, drainage area and mean annual precipitation have been analyzed by multiple regression techniques.

Rhue and Small(1986) illustrated the application of a lowflow assessment model for the Monogahela river Basin. The impact of reservoir operating rules and consumptive use limitation policies on lowflow frequency at downstream locations in the basin was simulated. Policies were evaluated using an observed flow sequence and synthetic flow inputs.

Seth and Singh(1988) described a methodology for forecasting the flows during non-monsoon season utilizing the base flow recession curves and incremental precipitation at various probability levels. This methodology was tested using monthly rainfall and flow data of non-monsoon season for Mahanadi river at Hirakud. Split sample approach was used in which part of data has been used for calibration and remaining part for testing the performance.

Nathan et al.(1988) presented a systems approach concerned with the investigation of lowflow hydrology of small ungauged rural catchments of Australia. A systems approach has been presented for the estimation of lowflow and yield parameters from ungauged catchments. A brief review of rationalization methodologies concluded that cluster analysis should be used to define regions of hydrological homogeneity, and that either stepwise regression or regression on principal components should be used for both prediction of hydrological characteristics and for examination of the underlying structure and relative importance of the variates. After a comparative investigation of a number of storage yield estimation techniques, the best estimation procedure was found to be based upon statistical regression analyses that relate storage size to rainfall and catchment characteristics. The directions of current research associated with the estimation of lowflow parameters and rainfall-runoff modelling techniques have also been discussed.

Manciola and Casadei(1988) suggested an estimation method of lowflows, to individuate the best places of minihydro plants. The authors mention that the low flows of a river define the period of low productivity and they qualify the technical and economic feasibility of minihydro power plants.Particularly the localization of these plants needs large territorial investigation and for this purpose it is necessary to evaluate the hydrological droughts for ungauged rivers.The research suggests an estimation methodology of low flow based on the geomorphological and hydrological characteristics of a given basin, which can be evaluated by hydrogeological thematic maps.The method required the preliminary analysis of 53 gauged basins of a region and the definition of a functional relationship between lowflow and hydro-geomorphological parameters.

Vogel and Kroll(1990) mention that regional hydrologic procedures such as generalized least squares regression and streamflow record augmentation have been advocated for obtaining estimates of both flood flow and lowflow statistics at ungauged sites. While such procedures are extremely useful in regional flood flow studies, no evaluation of their merit in regional low flow estimation has been made using actual streamflow data. The authors developed generalized regional regression equations for estimating the d-day, T-year lowflow discharge $Q_{d,T}$, at ungauged sites in Massachusetts, where, d = 3, 7, 14, 30 days. A two parameter log normal distribution is fit to sequences of annual minimum d-day lowflows and the estimated parameters of the log normal distribution are then related to two drainage basin characteristics i.e. drainage area and relief. The authors mention that resulting models are general, simple to use and about as precise as most previous models that only provide estimates of a single statistic such as $Q_{7,10}$. Comparisons are provided of the impact of using ordinary least squares regression, generalized least squares regression and streamflow record augmentation procedures to fit regional lowflow frequency models in Massachusetts.

Arihood and Glatfelter(1991) presented equations for estimating the 7-day, 2-year and 7-day, 10-year lowflows at sites on ungauged streams in Indiana. Regression analysis was used to develop equations relating basin characteristics and lowflow characteristics at 82 gauging stations. Significant basin characteristics in the equations are drainage area and flow duration ratio, which is the 20-percent flow duration divided by the 90-percent flow duration. The predictive capability of the method was determined by tests of the equations and of the flow-duration ratios on the plate. The authors state that the method can be applied only at sites in the northern and central physiographic zones of the state. Lowflow characteristics cannot be estimated for regulated streams unless the amount of regulation is known so that the estimated lowflow characteristics can be adjusted. The method is found to be most accurate for sites having drainage areas ranging from 10 to 1,000 square miles and for predictions of 7-day, 10-year lowflows ranging from 0.5 to 340 cubic feet per second.

Detailed review of methodology for low flow forecasting is presented in NIH(1990-91) and NIH(1992-93) describes the low flow forecasting using statistical approach.

## 2.3 Low Flow Forecasting Methods

As discussed in NIH(1992-93) lowflow forecasts are generally based on the following principles:

- presence of a relationships between the river and its associated ground water storage;

- effect of the preceding hydrometeorological conditions upon the river discharge at the time under consideration;

- availability of stored water from natural storage on and below the ground surface for low flow replenishment.

In addition, the effects of existing regulatory structures are also to be given due consideration.

The hydrological modelling techniques are mathematical simulation of natural hydrological phenomena which are considered as processes or systems undergoing continuous changes in time. These models are broadly classified into two categories viz; the deterministic models and the probabilistic models based on the concept of certainty and probability criteria respectively.

The probabilistic models for low flow estimation are more suitable for the planning purposes. However, they can also be used for the forecasting. But the deterministic models which are based on concept of certainty are most commonly used foe forecasting.

The deterministic models for the low flow forecasting can be classified under two broad categories as follows.

a) Methods based on physical concepts; and
b) Methods based on statistical approaches.

### 2.3.1 Methods Based On Physical Concepts

A physically based model describes the system using the basin equations governing the flows of energy and water. This type of model, also called a white box model, comprises of a set of linked partial differential equations together with parameters which, in principle, have direct physical significance and can be evaluated by independent measurements.

Some of the typical fields of application of the physical based distributed models for which lumped conceptual models are not applicable are:

a) Catchment changes viz both natural and man made changes such as change in land use.

b) Interaction between surface and ground water such as conjunctive use, water management in irrigation command areas.

c) Water quality and soil erosion modelling, movement of pollutants and sediments etc.

A Conceptual Model is based on some consideration of the physical processes in the catchment. In a conceptual model physically sound structures and equations are used together with semi-empirical ones. However, the physical significance is not so clear that the parameters could be assessed from direct measurements. Instead, it is necessary to estimate the parameters from calibration, applying concurrent input and output time series. A conceptual model, which is usually lumped-type model, is often called a grey box model. These models occupy an intermediate position between empirical black box models and physically based-distributed models. Such models are formulated on the basis of a relatively smaller number of components each of which is simplified representation of one process element in the system being modelled.

### 2.3.2 Methods Based On Statistical Concepts

In the methods based on statistical approaches, relationship is developed between some of the observed flows i.e. independent variables and presents/future flows or as dependent variable.

Regression analysis is widely used for development of such relationships. There are many forms in which the statistical technique is used. In the simplest form, the forecasting variable is expressed as a simple function of time. But for practical purposes, seasonal stream flow should be expressed as a function of several explanatory variables.

Theoretically, this is not very ideal method as the relationship is developed without taking into account the processes which play actual role in the process of runoff generation from rainfall, which is the input for most of the basins in India.

Although a statistical relationship between the upstream or downstream flows or the flows observed at t *th* hour and observed at (t+n) *th* hours at a particular site may give a reasonably accurate result for all practical purposes, it is difficult to justify such relationship on the basis of physical laws or concepts governing the process of formation and propagation of runoff.

However, it remains a fact that:

i) the processes for formation of runoff are very complicated;

ii) they are influenced by a number of independent variables both natural as well as man made; and

iii) there is a considerable degree of variation in the input variables as well as in the boundary conditions both in space and time.

The above factors make the adoption of a purely physically based model impracticable, particularly for a large river system.

The traditional lumped, conceptional models are well suited to simulation of the following hydrological problems when sufficiently long term data are available.

a) Extension of short stream flow records and

b) Real-time rainfall runoff simulation e.g. river flow forecasting.

As discussed earlier, one of the most important factor in river flow forecasting is the availability of lead time. For a large river system the collection of representative rainfall data and other variables in time becomes extremely difficult. Further, we still do not have a very sound reporting system for hydrological and hydrometeorological stations during non-monsoon months and in most of the cases, it becomes very difficult to use data even if they are observed.

The representation of the physical processes involved in the formation and propagation of the river flow is possible only when real time information about precipitation, evaporation, snow melt and detailed basin and channel characteristics etc. are available. This can be definitely achieved with modern developments in instrumentation and computing technology. In mathematical models, simulation of processes with certain amount of conceptualization, has been brought down to computational procedures. Such models require extensive data sets for calibration of various parameters, validation and for operational use at a later stage.

A number of hydrological models are available and are in use. The effectiveness of a model lies in the degree of extent to which the model simulates the natural processes. Generally, the hydrologic systems are so complex that no exact physical laws have yet been formulated to explain completely and precisely the natural development of a phenomenon.

However, in case of larger river systems, it becomes very difficult to separate out the contributions from various sources. Many a times, the contributions from snow melt, ground water reservoirs, irrigation recharge etc. cannot be estimated even qualitatively. The situation gets further complicated, where major regulatory structures exist. In view of above, a suitable statistical method may be conveniently adopted with very encouraging results. However, due care must be taken to separate out the effects of regulatory structures. Similarly the effects of local factors such as short duration and/or localized intense rainfall and natural or man made diversion of considerable magnitude are also to be given due consideration.

## 3.0 DESCRIPTION OF STUDY AREA

A brief description of the Narmada river and the Narmada basin is given below.

### 3.1 Narmada River

The Narmada river as described in Report of the Irrigation Commission, Vol.III part I (1972) rises in the Amarkanatak plateau of Maikala range in the Shahdol district of Madhya Pradesh at an elevation of 1058 m.a.s.l. The river travels a distance of 1312 km. before it falls into Gulf of Cambay in the Arabian Sea near Bharuch in Gujarat. The first 1079 km. are in Madhya Pradesh. In the next length of 35 km. the river forms the boundary between the states of Madhya Pradesh and Maharashtra. In the next length of 39 km., it forms the boundary between Maharashtra and Gujarat. The last length of 139 km. lies in Gujarat. The map of Narmada basin showing gauging sites on main river Narmada is shown in Fig. 1.

The river has a number of falls in its head reaches. At 8 km. from its source, the river drops 21 to 24 m. at Kapildhara falls; 0.4 km. further downstream, it drops by about 4.6 m. at the Dudhara falls. Flowing in generally south westerly direction in a narrow and deep valley, the river takes pin head turns at places. Close to Jabalpur, 404 km from the source, the river drops nearly 15 m at the Dhuandhara falls, after which it flows through a narrow channel carved through the famous marble rocks. After passing through the marble rocks, the Narmada enters the upper fertile plains, at Nandhar, 806 km from the source and at Dhardi, 47 km. further downstream, the river drops over falls of 12 m. at each place. At 966 km. from source, nearly 6.4 km downstream of Maheshwar, the Narmada again drops by about 6.7 m at the Sahastradhara falls.

Flowing further west, the river enters the lower hilly regions and flows through a gorge. The 113 km. long gorge is formed by the converging of the Vindhyas from the north and the Satpuras from the south towards the river. Emerging from the gorge, the river enters the lower plains and meanders in broad curves till it falls into Gulf of Cambay in the Arabian Sea near Broach.

The river has 41 tributaries of which 22 are on the left bank and 19 on the right, the important tributaries of the Narmada are

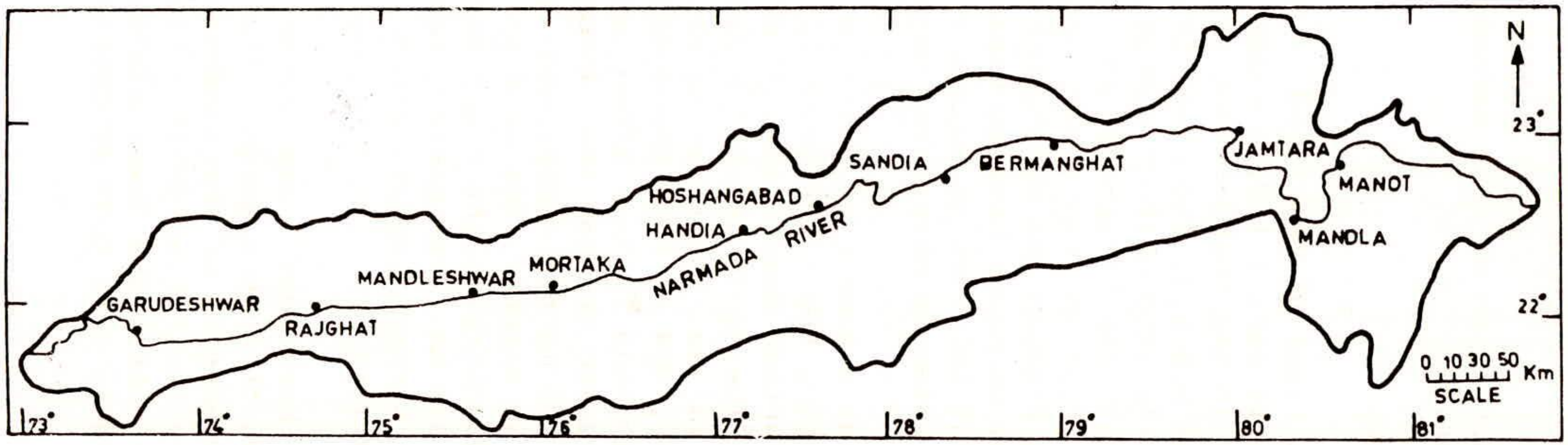


FIG.1- MAP SHOWING GAUGING SITES ON THE RIVER NARMADA

the Burhner, Banjar, Sher, Tawa, Chhota Tawa, Kundi, Shakkar, Dudhi, Ganjal, Goi, Karjan, Hiran, Tendoni, Barna, Kolar, Man, Uri, Hatni and Orsang.

### 3.2 Narmada Basin

The Narmada basin extends over an area of 98,796 sq. km. and lies between latitudes 21° 20'N to 23° 45' N and longitudes 72° 32' E to 81° 45' E. The catchment area of the basin up to Mortakka is 67,190 sq. km. The total the drainage area of the Narmada basin covers 85,859 sq. km. in Madhya Pradesh, 11,399 sq. km. in Gujarat, and 1,538 sq km. in Maharashtra.

The basin is bounded on the North by the Vidhyas, on the east by the Maikala range on the south by the Satpuras and on the west by the Arabian sea. Most of the basin is at an elevation of less than 500 m.a.s.l. A small area round Pachmarhi is at a height of more than 1000 m.a.s.l. The climate, soil types and land use of the Narmada basin are briefly discussed below.

#### 3.2.1 Climate

The climate of the basin is humid tropical ranging from sub-humid in the east to semi arid in the west with packets of humid or sub-humid climates around hill reaches. The normal annual rainfall for the basin works out to 1,178 mm. South West monsoon is the principal rainy season accounting for nearly 90% of the annual rainfall. About 60% of the annual rainfall is received during July and August months.

#### 3.2.2 Soils

The reconnaissance soil survey made by the Central Water and Power Commission in connection with the Bargi, Punasa, Barma and Tawa projects indicated that the Narmada basin consists mainly of black soils. The different varieties are deep black soil, medium black soil and shallow black soil. The addition mixed red and black soil, red and yellow soil and skeletal soil are also observed in pockets, of these deep black soil covers and major portion of the basin.

#### 3.2.3 Land Use

About 32% area of the basin is under forest and about 60% under arable land and remaining under grass land waste land etc.

## 4.0 DATA USED

Monthly discharge data of 16 years for the river Narmada observed at Mortakka gauging site from the year 1949-50 to 1965-66 have been used for estimation of the model parameters and data of the 4 years i.e. from the year 1966-67 to 1969-70 have been used for formulating the low flow forecasts. The forecasts formulated for each of the years have been compared with the observed data of those years.

## 5.0 METHODOLOGY

Low flow forecasting using statistical approach and the model for low flow forecasting are discussed below.

### 5.1 Low flow forecasting using Statistical Approach

As discussed in NIH(1992-93) for a rain fed river basin of moderate size, the major contribution during the non-monsoon period is from ground water and the other contributions are almost negligible. In such cases, an exponentially decaying curve may prove to be a very reasonable approximation of the river flow condition. However, in case of a larger river system, where snow melt contribution is also quite significant (in addition to ground water) adoption of the simple recession curve or a snow melt model may not give a reasonable forecast of low flow. Also in a large river system there are a number of factors contributing to the river flows and the interacting processes are very complicated. As a result, it becomes almost impossible to model the various components in accordance with the concepts of a physically based model.

In such cases, it is desirable to adopt a statistical model which may be either of the following two types:

a) Where the independent variables are mainly the element representative of different contributing factors such as rainfall, snow cover, temperature, ground water storage, vegetation, evaporation, humidity morphological factors, morphometrical factors,hydrogeological factors,factors due to human activity such as urbanisation, irrigation, hydraulic works, water transfer schemes, hydro-electric stations, navigation, drainage works and land use changes etc; or

(b) Where the previous state of the river flow is taken into consideration without identifying the various contributing factors.

It is quite difficult to get the adequate information in time about the factors influencing the low flow and determining their contributions at desired location, particularly for a large river basin. The contribution of rainfall during the non-monsoon season is very little. Also forecasts for rainfall during low flow period are not available, say, one has to forecast flow in a river for the month of May, well advance in November. Then, the contribution of rainfall as an input for forecast formulation is not available. Also it is very difficult to have information of desired level about the other elements affecting low flow.

On the other hand, quite precise information about the previous state of the river is always available as flow measurements are carried out for all the major rivers at different locations and the data are duly compiled and stored. Hence, it is very convenient to formulate the low flow forecast for any river on the basis of its prior state of flow.

5.2 Model for Low Flow Forecasting

The forecast of monthly flow for a river system is assumed to be dependent on the flow of previous month at the same site, i.e.:

$$Q_i = a_i \, Q_{i-1}^{b_i} \qquad (1)$$

Where, $Q_i$ is the monthly flow forecast for the ith month,

$Q_{i-1}$ is the flow for the month prior to the $Q_i$ th month,

$a_i$ and $b_i$ are the parameters of the model for the ith month; and the same are evaluated by least square regression analysis from the historical observed monthly data of the concerned gauging site.

## 6.0 RESULTS AND DISCUSSION

Procedure adopted for estimation of the model parameters and discussion of the results are presented here under.

### 6.1 Model Parameters

For the purpose of illustrating the model efficacy monthly sample data of 16 years i.e. 1949-50 to 1965-66 have been used to estimate the model parameters. The various equations developed for formulating the low flow forecasts for the seven months of the low flow period i.e. November, December, January, February, March, April and May using the historical data for the river Narmada at Mortakka are given below.

$$Q_{Nov} = 1.892\ Q_{Oct}^{0.744} \qquad (2)$$

$$Q_{Dec} = 3.635\ Q_{Nov}^{0.670} \qquad (3)$$

$$Q_{Jan} = 2.470\ Q_{Dec}^{0.761} \qquad (4)$$

$$Q_{Feb} = 2.120\ Q_{Jan}^{0.786} \qquad (5)$$

$$Q_{Mar} = 0.516\ Q_{Feb}^{1.078} \qquad (6)$$

$$Q_{Apr} = 0.669\ Q_{Mar}^{1.027} \qquad (7)$$

$$Q_{May} = 1.889\ Q_{Apr}^{0.735} \qquad (8)$$

To begin with, the initial forecast is prepared for the month of November for which the flow data of the month of October have been used. For the forecast of flow during the month of December, the flow forecast of month November is taken as input. Similarly the forecasts are estimated for the subsequent months up to the month of May.

The forecast have been updated every month with the availability of more and more observed data. As a matter of fact, the revision of forecast can be taken up after every month as soon as the additional observed data are available. However for the purpose of illustrating the methodology, the following sets of forecasts have been formulated for four years.

a) Forecast for the period November to May, based on monthly observed discharge of October.

b) Forecast for the period December to May, based on monthly observed discharge of November.

c) Forecast for the period January to May, based on monthly observed discharge of December.

d) Forecast for the period February to May, based on monthly observed discharge of January.

e) Forecast for the period March to May, based on monthly observed discharge of February.

f) Forecast for the period April to May, based on monthly observed discharge of March.

g) Forecast for the month of May, based on monthly observed discharge of April.

## 6.2 Discussion of Results

The forecast of flow for the period November to May has been prepared on the basis of the model parameters estimated using the historical data and compared with the observed data of next 4 years i.e. 1966-67, 1967-68, 1968-69 and 1969-70. The percent errors between the observed flows and the forecasts have also been computed. Tables 1 to 4 give the comparison of the observed flows and the forecasts along with the percentage of errors for the 4 years. Figs. 2 to 15 show comparison of the observed discharge and the forecasts for the first and the fourth test years.

Table-1 Comparison of monthly observed flows and forecasts for river Narmada at Mortakka for the year 1966-67 (in Cumec)

| S. No. | Month | Obser. Disch. | Flow forecasts (FF) and percentage errors (PE) based on monthly data of: Oct. | | Nov. | | Dec. | | Jan. | | Feb. | | Mar. | | Apr. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE |
| 1 | Nov. | 76.7 | 75.0 | 2.2 | | | | | | | | | | | | |
| 2 | Dec. | 64.3 | 65.6 | -2.0 | 66.6 | -3.5 | | | | | | | | | | |
| 3 | Jan. | 45.0 | 59.6 | -32.4 | 60.3 | -34.0 | 58.7 | -30.5 | | | | | | | | |
| 4 | Feb. | 34.9 | 52.7 | -50.8 | 53.2 | -52.1 | 52.1 | -49.0 | 42.2 | -20.9 | | | | | | |
| 5 | Mar. | 25.9 | 37.0 | -43.1 | 37.4 | -44.5 | 36.6 | -41.3 | 29.2 | -12.8 | 23.8 | -8.1 | | | | |
| 6 | Apr. | 43.0 | 27.3 | 36.5 | 27.6 | -35.9 | 27.0 | -37.3 | 21.4 | -50.3 | 17.3 | 59.7 | 18.9 | 56.0 | | |
| 7 | May | 16.7 | 21.5 | -28.3 | 21.6 | -29.3 | 21.3 | -27.1 | 17.9 | -7.2 | 15.4 | 8.1 | 16.4 | 2.1 | 30.0 | -79.2 |

Table-2 Comparison of monthly observed flows and forecasts for river Narmada at Mortakka for the year 1967-68 (in Cumec)

| S. No. | Month | Obser. Disch. | Flow forecasts (FF) and percentage errors (PE) based on monthly data of: Oct. | | Nov. | | Dec. | | Jan. | | Feb. | | Mar. | | Apr. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE |
| 1 | Nov. | 164.7 | 204.0 | -23.9 | | | | | | | | | | | | |
| 2 | Dec. | 203.8 | 128.2 | 37.1 | 111.1 | 45.5 | | | | | | | | | | |
| 3 | Jan. | 164.7 | 99.3 | 39.7 | 89.0 | 46.0 | 141.2 | 14.3 | | | | | | | | |
| 4 | Feb. | 88.7 | 78.7 | 11.4 | 72.2 | 18.6 | 103.8 | -17.0 | 117.2 | -32.0 | | | | | | |
| 5 | Mar. | 77.7 | 57.1 | 26.5 | 52.0 | 33.0 | 76.9 | 1.0 | 87.7 | -12.8 | 65.0 | 16.3 | | | | |
| 6 | Apr. | 38.5 | 42.6 | -10.7 | 38.7 | 0.7 | 57.9 | -50.5 | 66.2 | -72.1 | 48.7 | -26.5 | 58.4 | -52.0 | | |
| 7 | May | 24.3 | 29.8 | -22.4 | 27.8 | -14.1 | 37.3 | -53.3 | 41.2 | -69.2 | 32.8 | -35.0 | 37.6 | -54.4 | 27.6 | -13.5 |

Table-3 Comparison of monthly observed flows and forecasts for river Narmada at Mortakka for the year 1968-69 (in Cumec)

| S. No. | Month | Obser. Disch. | Flow forecasts (FF) and percentage errors (PE) based on monthly data of: Oct. | | Nov. | | Dec. | | Jan. | | Feb. | | Mar. | | Apr. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE |
| 1 | Nov. | 157.2 | 192.6 | -22.5 | | | | | | | | | | | | |
| 2 | Dec. | 101.5 | 123.4 | -21.6 | 107.7 | -6.1 | | | | | | | | | | |
| 3 | Jan. | 79.7 | 96.4 | -21.0 | 86.9 | -9.1 | 83.1 | -4.3 | | | | | | | | |
| 4 | Feb. | 54.8 | 76.9 | -40.3 | 70.9 | -29.3 | 68.4 | -24.8 | 66.2 | -20.7 | | | | | | |
| 5 | Mar. | 39.2 | 55.7 | -42.1 | 51.0 | -30.2 | 49.1 | -25.3 | 47.4 | -20.9 | 38.7 | 1.3 | | | | |
| 6 | Apr. | 27.2 | 41.5 | -52.5 | 37.9 | -39.4 | 36.5 | -34.0 | 35.2 | -29.2 | 28.5 | -4.9 | 28.9 | -6.9 | | |
| 7 | May | 18.2 | 29.2 | -60.7 | 27.3 | -50.4 | 26.6 | -46.1 | 25.9 | -42.2 | 22.2 | -22.0 | 22.4 | -23.2 | 21.4 | -17.8 |

Table-4 Comparison of monthly observed flows and forecasts for river Narmada at Mortakka for the year 1969-70 (in Cumec)

| S. No. | Month | Obser. Disch. | Flow forecasts (FF) and percentage errors (PE) based on monthly data of: Oct. | | Nov. | | Dec. | | Jan. | | Feb. | | Mar. | | Apr. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE | FF | PE |
| 1 | Nov. | 223.5 | 218.4 | 2.3 | | | | | | | | | | | | |
| 2 | Dec. | 127.8 | 134.2 | -5.0 | 136.3 | -6.7 | | | | | | | | | | |
| 3 | Jan. | 114.3 | 102.8 | 10.0 | 104.0 | 9.0 | 99.0 | 13.3 | | | | | | | | |
| 4 | Feb. | 86.8 | 80.9 | 6.9 | 81.6 | 6.0 | 78.5 | 9.6 | 87.9 | -1.2 | | | | | | |
| 5 | Mar. | 80.2 | 58.8 | 26.7 | 59.4 | 26.0 | 56.9 | 29.0 | 64.3 | 19.8 | 63.5 | 20.8 | | | | |
| 6 | Apr. | 43.7 | 43.9 | -0.4 | 44.3 | -1.4 | 42.5 | 2.8 | 48.1 | -10.1 | 47.5 | -8.7 | 60.4 | -38.1 | | |
| 7 | May | 29.7 | 30.4 | -2.4 | 30.7 | -3.1 | 29.7 | 0.1 | 32.6 | -9.5 | 32.3 | -8.5 | 38.5 | -29.4 | 30.3 | -2.1 |

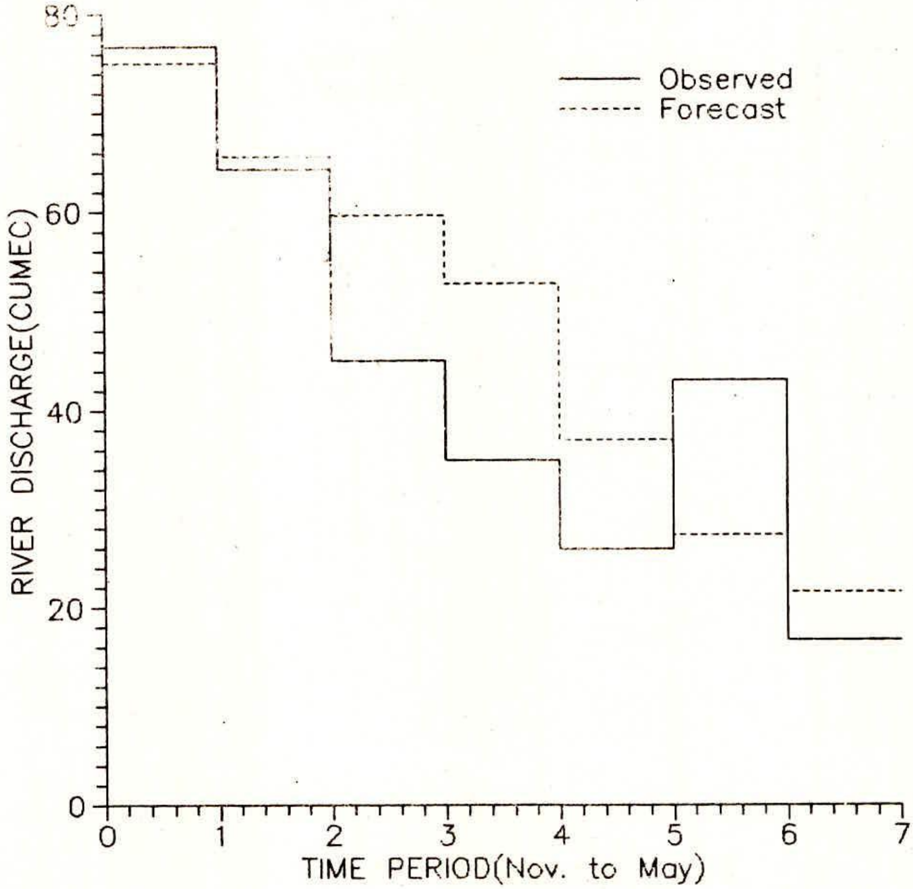


Fig. 2 Comparison of forecast & observed discharge for Narmada at Mortakka for 1966–67 (based on observed data of Oct. 1966)

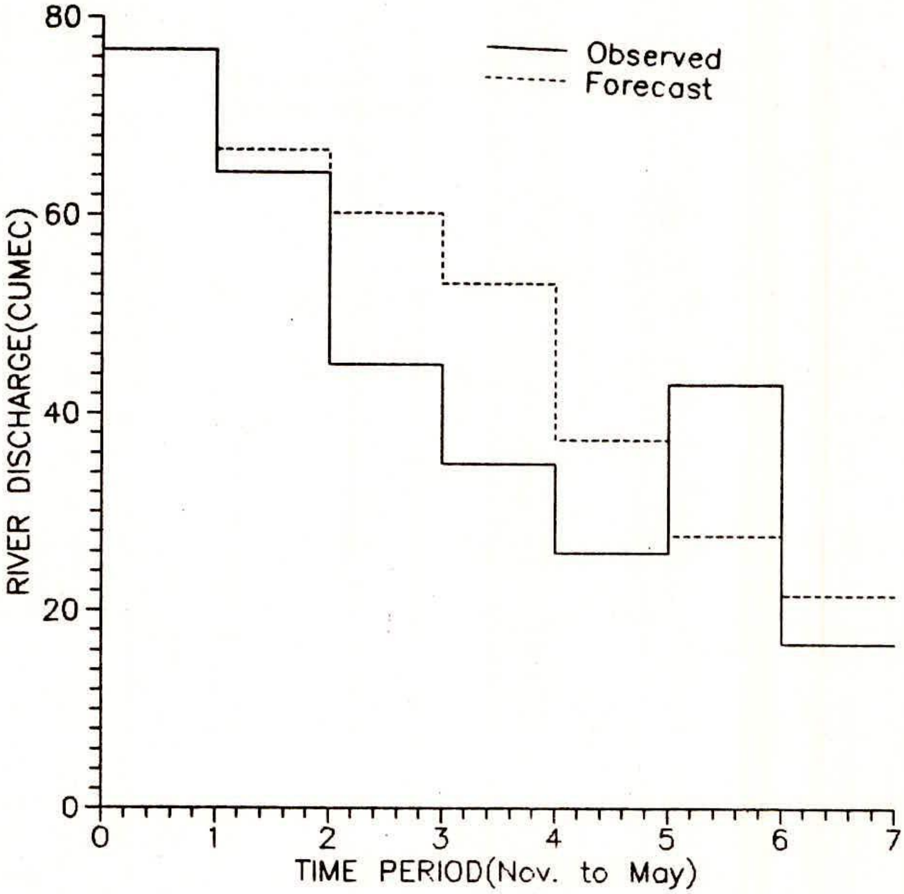


Fig. 3 Comparison of forecast & observed discharge for Narmada at Mortakka for year 1966–67 (based on observed data of Nov. 1966)

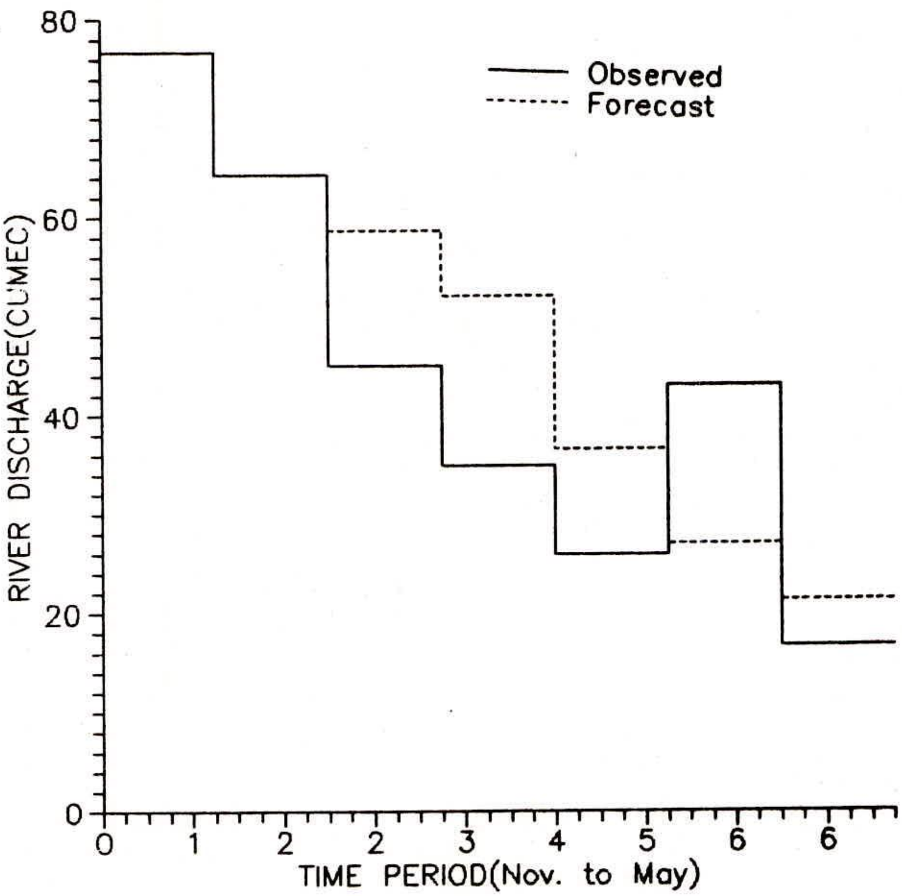


Fig. 4 Comparison of forecast & observed discharge for Narmada at Mortakka for year 1966–67 (based on observed data of Dec. 1966)

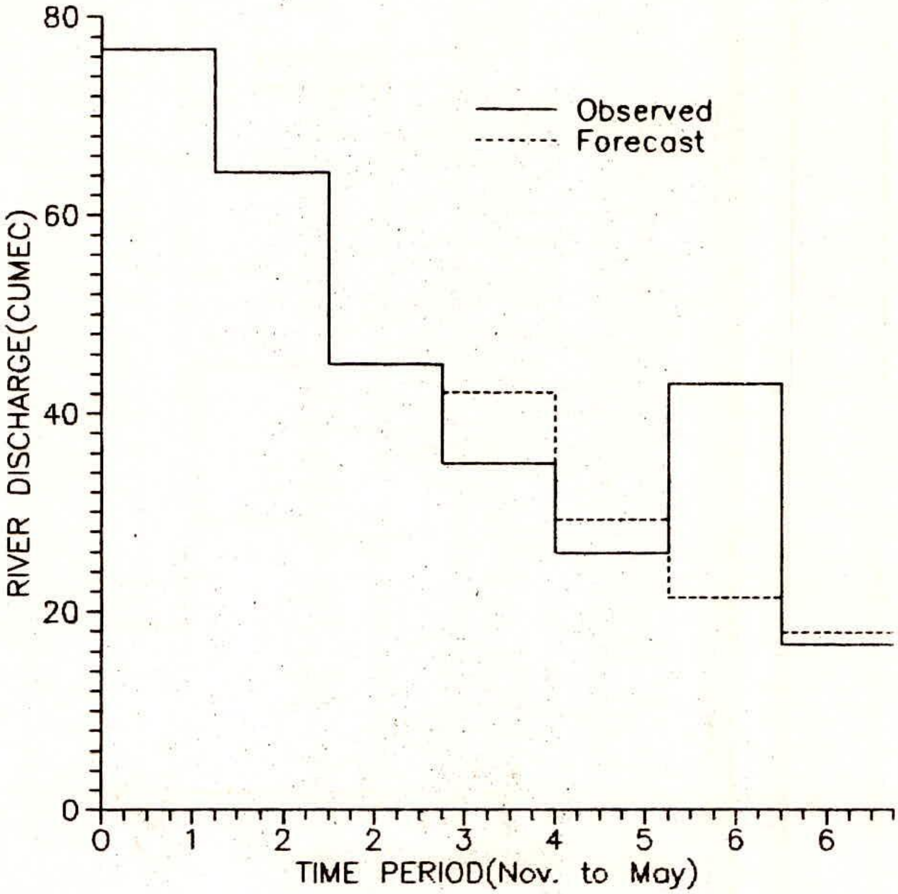


Fig.5 Comparison of forecast & observed discharge for Narmada at Mortakka for year 1966–67 (based on observed data of Jan. 1967)

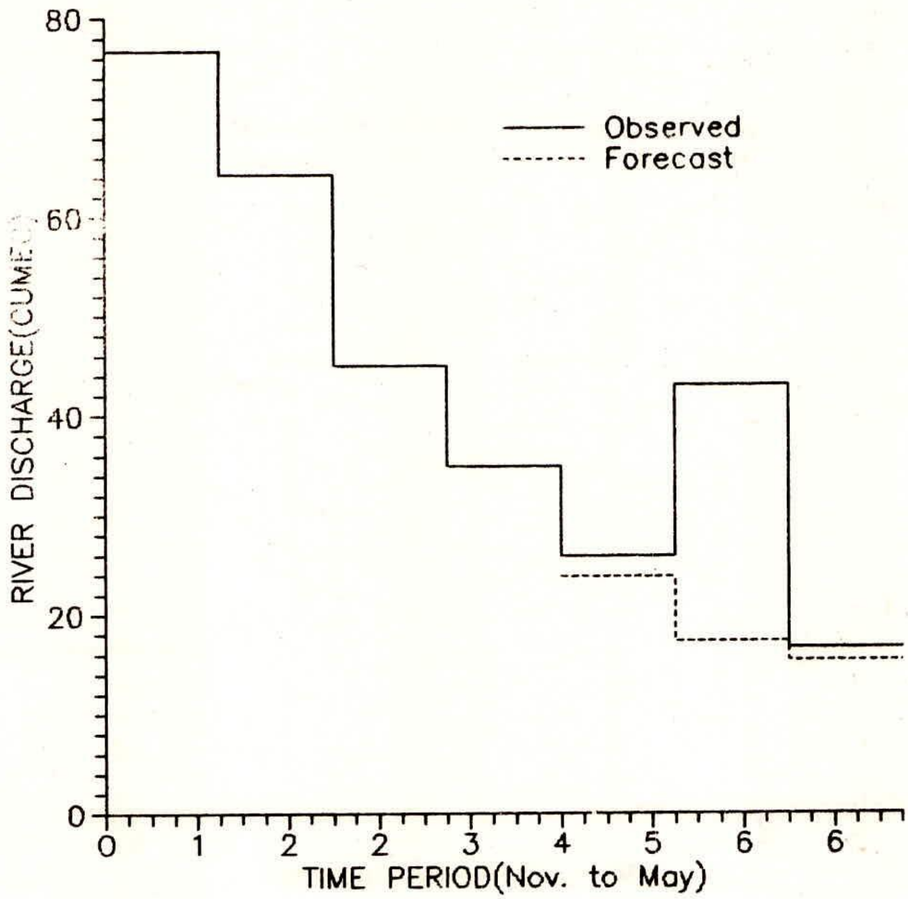


Fig.6 Comparison of forecast & observed discharge for Narmada at Mortakka for year 1966–67 (based on observed data of Feb. 1967)

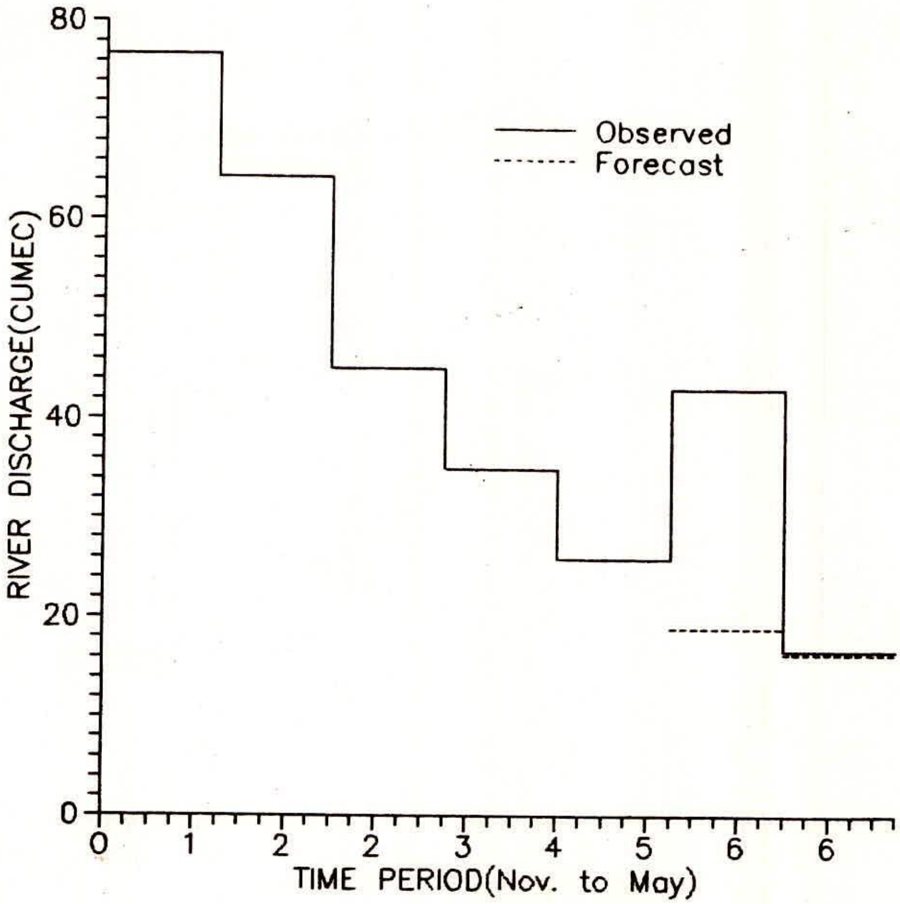


Fig. 7 Comparison of forecast & observed discharge for Narmada at Mortakka for year 1966–67 (based on observed data of Mar. 1967)

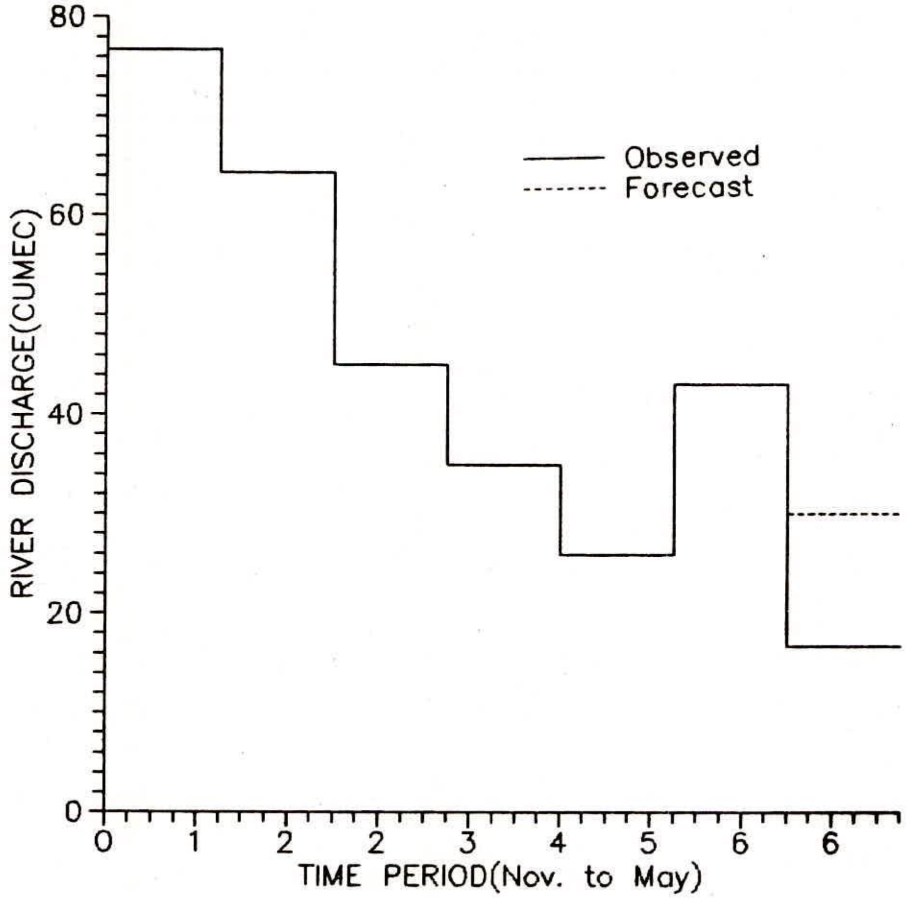


Fig.8 Comparison of forecast & observed discharge for Narmada at Mortakka for year 1966–67 (based on observed data of Apr. 1967)

d

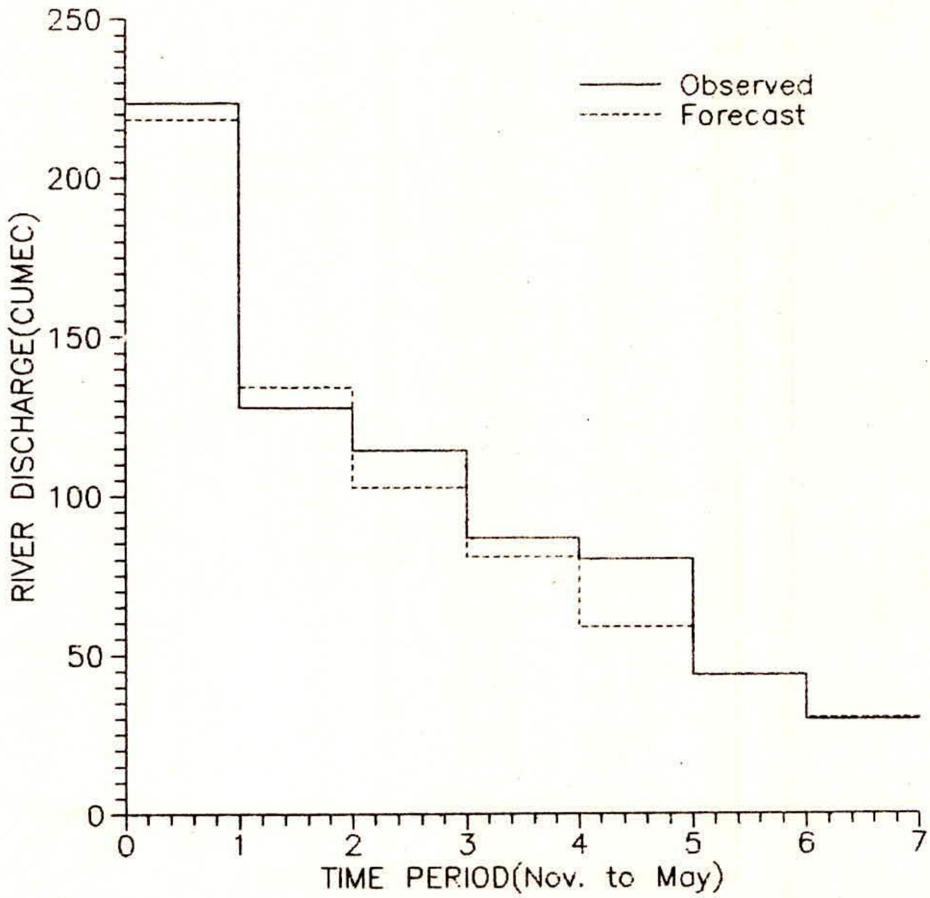


Fig. 9 Comparison of forecast & observed discharge for Narmada at Mortakka for 1969–70 (based on observed data of Oct. 1969)

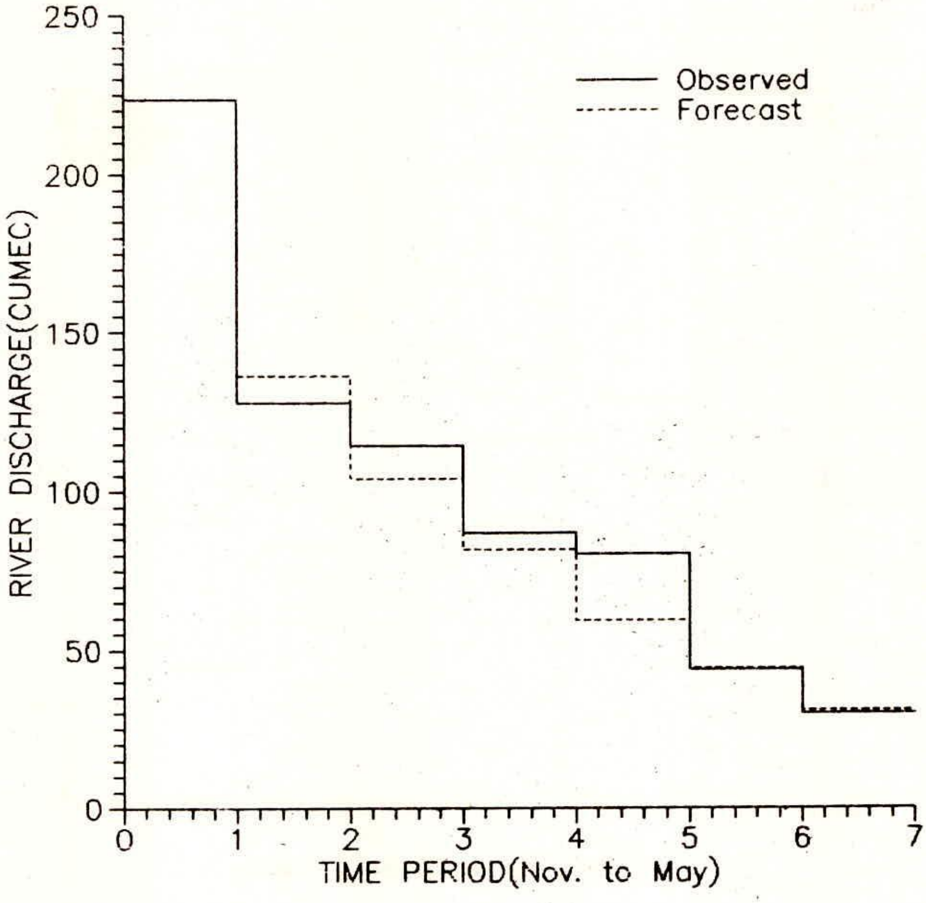


Fig.10 Comparison of forecast & observed discharge for Narmada at Mortakka for 1969–70 (based on observed data of Nov. 1969)

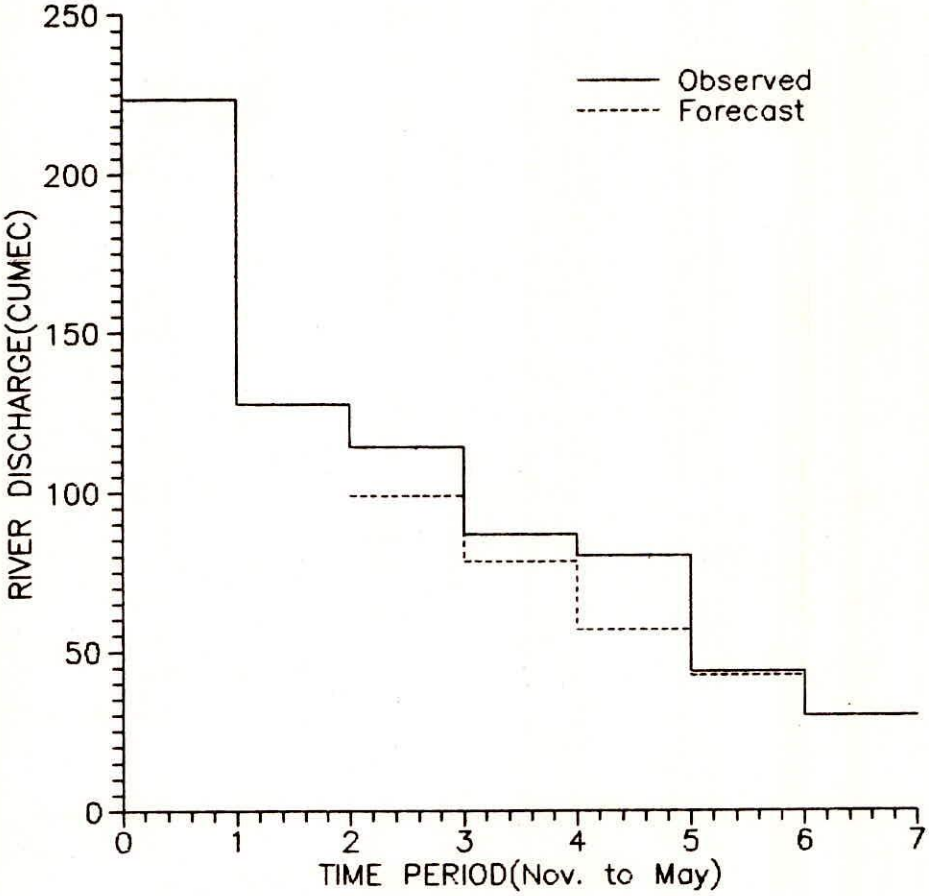


Fig.11 Comparison of forecast & observed discharge for Narmada at Mortakka for 1969-70 (based on observed data of Dec. 1969)

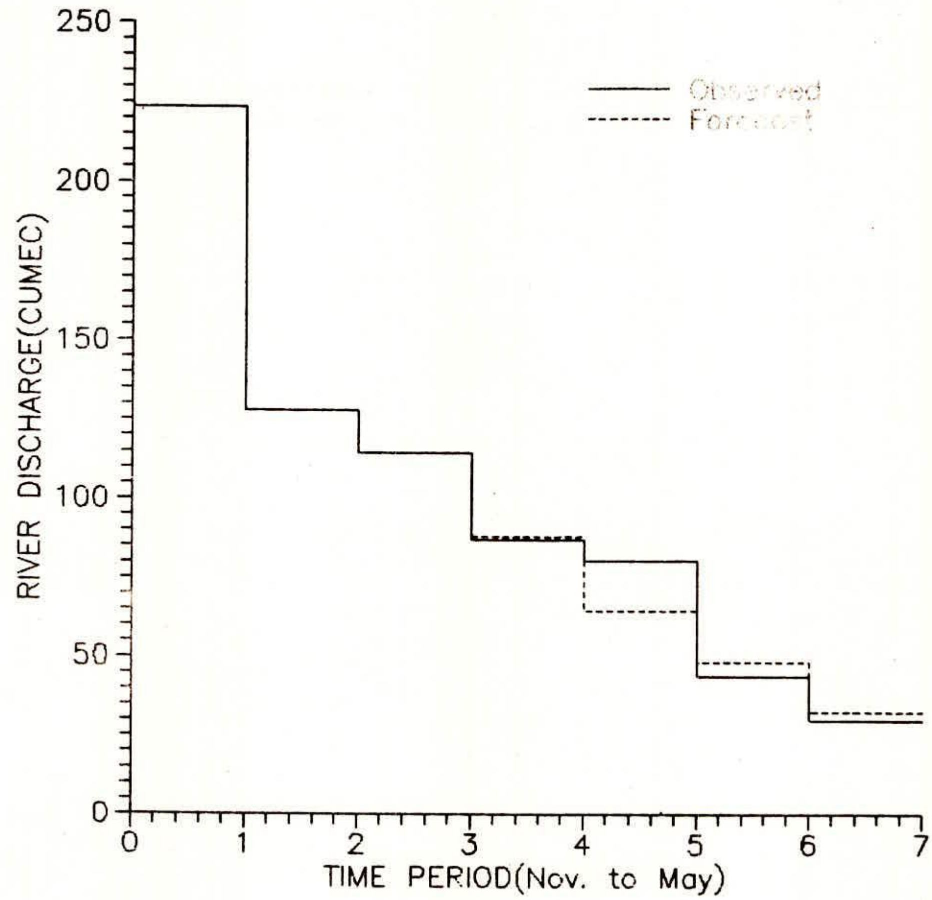


Fig.12 Comparison of forecast & observed discharge for Narmada at Mortakka for 1969-70 (based on observed data of Jan. 1970)

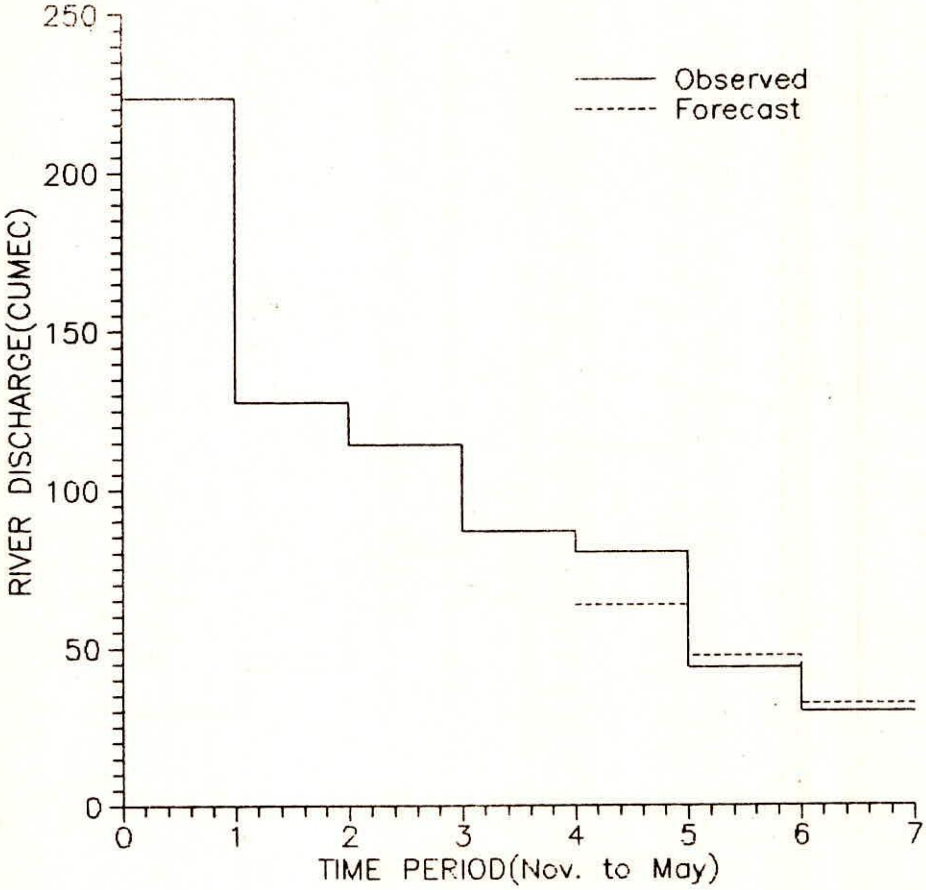


Fig.13 Comparison of forecast & observed discharge for Narmada at Mortakka for 1969–70 (based on observed data of Feb. 1970)

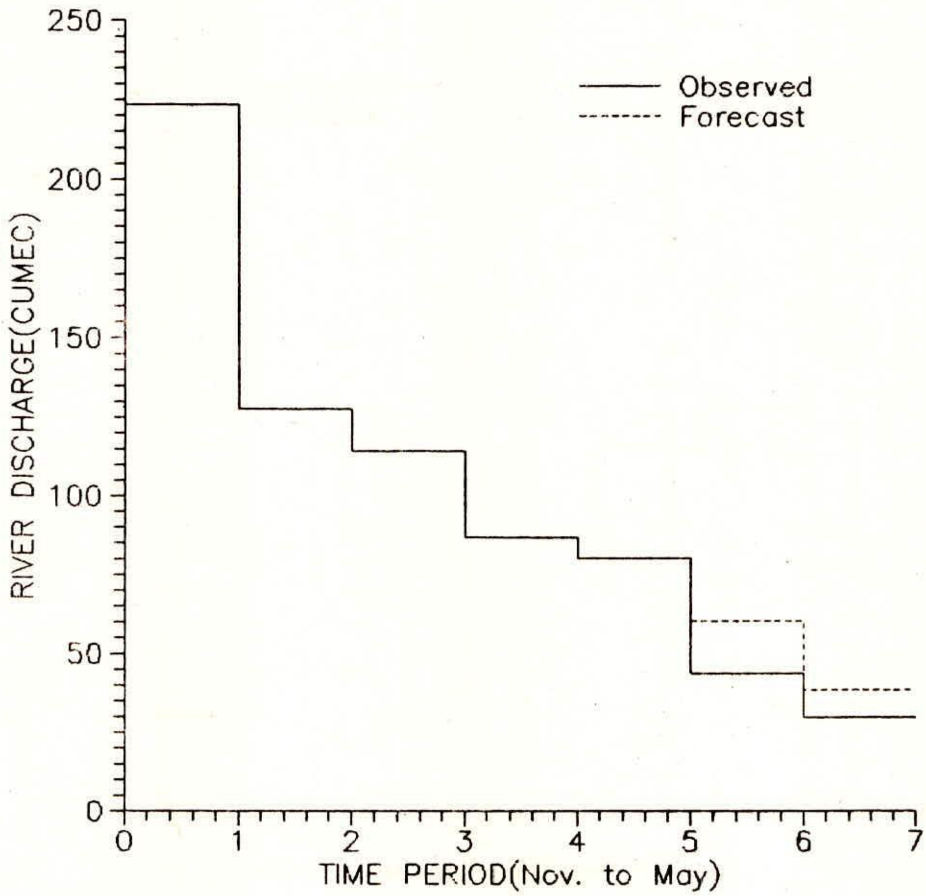


Fig.14 Comparison of forecast & observed discharge for Narmada at Mortakka for 1969–70 (based on observed data of Mar. 1970)

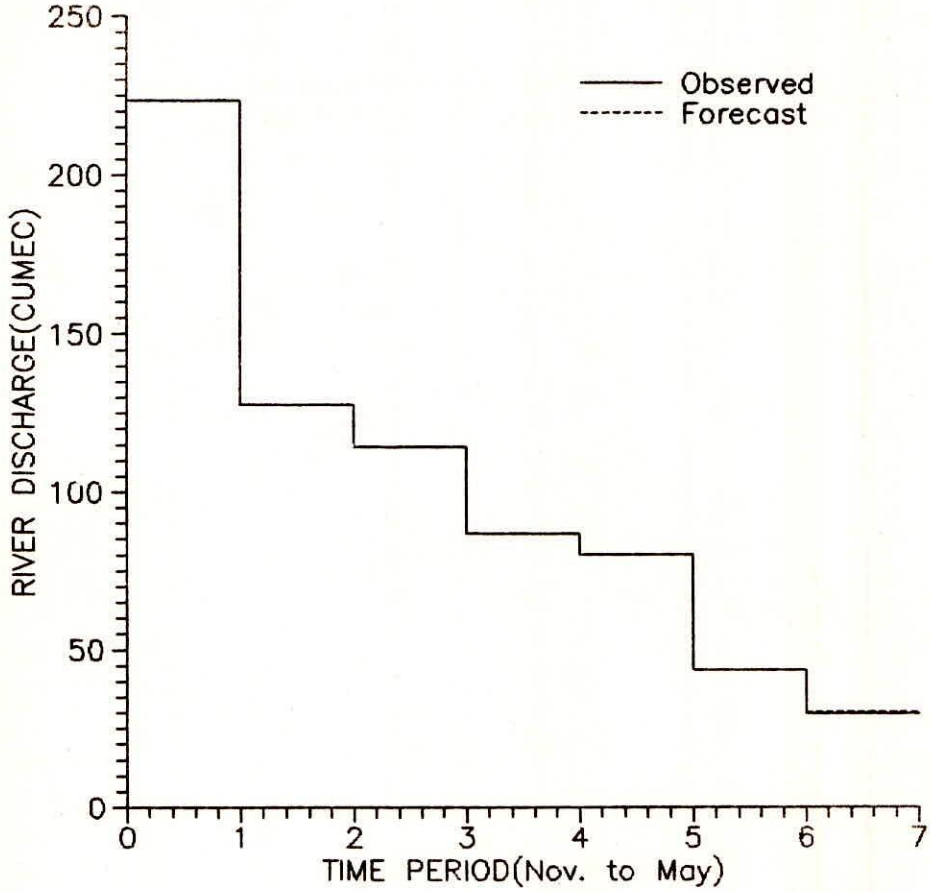


Fig.15 Comparison of forecast & observed discharge for Narmada at Mortakka for 1969–70 (based on observed data of Apr. 1970)

It is observed from Table-1 that in case of the first test year i.e. 1966-67, when the forecasts are formulated for the period November to May, based on the observed data of October the percentage errors between observed flows and the forecasts are 2.2% for the month of November, -2% for December, -32.4% for January, -50.8% for February, -43.1% for March, 36.5% for April and -28.3% for May. When the forecasts are formulated on the basis of the observed data of the month of November the errors are -3.5% for the month of December, -34.0% for the month of January, -52.1% for the month of February, -44.5% for the month of March, -35.9% for the month of April and -29.3% for the month of May. When the forecasts are formulated on the basis of the data of December the errors are -30.5% for the month of January, -49.0% for the month of February, -41.3% for the Month of March, -37.3% for the month of April and -27.1% for the month of May. When the forecasts are formulated on the basis of data for the month of January the errors are -20.9% for the month of February, -12.8% for the month of March, -50.3% for the month of April and -7.2% for the month of May. When the forecasts are formulated based on the data for the month of February the errors are -8.1% for the month of March, 59.7% for the month of April and 8.1% for the month of May. When the forecasts are issued based on the data for the month of March the errors are 56% for the month of March and 2.1% for the month of May and when the forecasts are formulated based on the data for the month of April the error is -79.2% for the month of May. The negative(-) sign of the percentage error for a month shows the the forecast has been over estimated and the observed discharge is less as compared to the forecast for a particular month. It is seen that in case of this test year the percentage errors, between the observed discharge and forecasts, in general, are quite low for the months of November and December. Whereas the errors are relatively high for the months of February and March.

Table 2 shows that in case of the second test year when the forecasts are formulated on the basis of the observed data for the month of October the errors vary from -10.7% for the month of April to 39.7 % for the month of January. When the forecasts are formulated on the basis of data for the month of November, the errors vary from 0.7% for the month of April to 46.0% for the month of January. When the forecasts are formulated on the basis of data for the month of December, the errors vary from 1.0% forthe month of March to -53.3% for the month of May. When the forecasts are formulated on the basis of data for the month of January, the errors vary from -12.8% for the month of February to -69.2% for the month of May. When the forecast are formulated on the basis of data for the month of February, the errors vary from 16.3% for the month of March to -35.0% for the month of May. When the forecasts are formulated on the basis of data for the month of March, the errors are -52.0% for the month of April and -54.4% for the month of May and when the forecast is formulated on the basis of data for the month of April, the error is -13.5% for the month of May.

Table 3 shows that in case of third test year, the percentage errors vary from -21.0% for the month of January to -60.7% for the month of May. When the forecasts are formulated on the basis of data for the month of November, the errors vary from -6.1% for the month of December to -50.4% for the month of May. When the forecasts are formulated on the basis of data for the month of December, the errors vary from -4.3% for the month of January to -46.1% for the month of May. When the forecasts are formulated on the basis of data for the month of January, the errors vary from -20.7% for the month of February to -42.2% for the month of May. When the forecasts are formulated on the basis of data for the month of February the errors are 1.3% for the month of March, -4.9% for the month of April and -22.0% for the month of May. When the forecasts are formulated on the basis of data for the month of March, the errors are -6.9% for the month of April and -23.2% for the month of May and when the forecast is formulated on the basis of data for the month of April, the error is -17.8% for the month of May.

Table 4 shows that when the forecasts are formulated on the basis of data for the month of October, the errors vary from -0.4% for the month of April to 26.7% for the month of March. When the forecasts are formulated on the basis of data for the month of November, the errors vary from -1.4% for the month of April to 26.0% for the month of March. When the forecasts are formulated on the basis of data for the month of December, the errors vary from 0.1% for the month of May to 29.0% for the month of March. When the forecasts are formulated on the basis of data for the month of January, the errors are -1.2% for February, 19.8% for March -10.1% for April and -9.5% for the month of May. When the forecasts are formulated on the basis of data for the month of February, the errors are 20.8% for the month of March, -8.7% for the month of April and -8.5% for the month of May. When the forecasts are formulated on the basis of data for the month of March the errors are -38.1% for the month of April and -29.4% for the month of May and when forecast is formulated on the basis of data for the month of April, error is -2.1% for the month of May.

The larger percent errors between the observed discharge and the forecasts formulated by the statistical model in this study may be attributed to the various factors affecting the low flows some of them include contribution from rainfall during the non monsoon season, withdrawls of water from the river, diversion of water to the river, errors associated with measurement of flows and occurrence of unusally less or more discharge in a particulr year than the discharge flowing during the the most of the years, whose data have used for estimating the parameters of the model. For example, the observed discharge in case of the first test year for the months of November to May is quite low in comparison to the other years; hence, considerable deviations are observed between the observed discharge and the forecasts for this year.

## 7.0 CONCLUDING REMARKS

Almost all the hydrologic system models which are continuous in nature include the suitable representation of flow conditions during the lean period. However the lowflow component of a comprehensive hydrological model generally gets poor treatment at the time of calibration of the model as a uniform criterion is generally adopted for the evaluation of the parameters. In view of the serious limitations in long term forecasting, particularly for the larger basins the use of a physically based approach virtually becomes infeasible for all practical purposes. The large spatial variations both in the basin characteristics as well as the inputs causing the runoff and the changes in the characteristics over time prove a major hurdle. The implementation of numerous water resources projects in the basin also results in boundary conditions changing with respect to time. The statistical method, not withstanding all its constraints, provides the practical solution for the medium and long range forecasting for a basin having above referred features.

The major contribution to the low flows in the river Narmada is from ground water storage and surface runoff due to non monsoon rainfall. Another important factor is the effect of man made regulatory structures which complicate the flow system to a great extent and particularly, the disturbance of the time distribution process is quite considerable. This results in great difficulty in identification of the characteristics of the lowflows and their proper representation through a physically based model. Many a time, simple statistical relations using limited number of variables have been found to give good results in case of larger river system.

The statistical model formulated in this study is a simple method, which yields reasonably good result inspite of the limitation that all the factors responsible for generation and propagation of low flows have not been taken into account in its structure. This model has been used to forecast the monthly flows for the river Narmada at Mortakka. For the present study only twenty years monthly discharge data were available, out of which, sixteen years data have been used for estimation of the parameters of the model and four years data have been used to formulate and compare the low flow forecasts. Generally the statistical models call for much longer term data. Better forecasts could have been obtained with longer term data. As the forecasts have been formulated based on the monthly discharge data without taking into consideration the effects of rainfall, withdrawls and/or diversions from the river and other factors; therefore the the percentage errors between the observed discharge and the forecasts are large for some of the months. The forecasts may be further improved by developing a model which takes into consideration all the factors affecting the low flows.

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