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LOW FLOW FORECASTING USING STATISTICAL APPROACH

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PREFACE

The availability of water resources is highly variable both in space and time in India. 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.

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. Reasonably accurate estimation of the water resources available during lean period and also its possible forecast will go a long way 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 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 M.E. Haque and Rakesh Kumar, Scientists of the Institute.

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(S.M. Seth)
DIRECTOR

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1.0 INTRODUCTION

The average annual surface runoff from the various river basins of our country is assessed to be about 188 million ha m. But 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, the western regions of India receive less than 10 cms and Cherapunji in the east receives over 1000 cms per year. Similarly the ratio of maximum and minimum discharges at a particular site is found to be more then 5000 in some of the perennial rivers of coastal regions. Even the variations in flows during the non monsoon months are quite considerable. The above features lead to occurrence of flood-drought-flood syndrome in various parts of the country.

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.

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. In addition to this, low flow modelling is also necessary for dealing with the problems of environmental evaluation and stream pollution. The analysis of low flows is equally important for Municipal and Industrial water supply schemes, both from the view points of quantity and quality.

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 India, 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.

1.1 Importance and Need for Low flow Studies

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 availability of water resources, particularly during the non-monsoon period generally remains unaltered. As a matter of fact, some of the studies indicate a gradual reduction in the availability of water during the non-monsoon period due to various factors such as deforestation and urbanisations etc.

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.

Low flow in natural rivers is qualitatively indicated by a low water level. 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.

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.

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;

(j) Urban water treatment systems;
(k) Recharge of ground water aquifer;
(l) Drought management; and
(m) In-stream flow maintenance.

The wide range of application further stresses the necessity and need for elaborate low flow studies.

1.2 Low flow Forecasting - Applications and Limitations

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.

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.

In view of distinct characteristics of the river systems, the choice of a model for low flow forecasting easier.

2.0 LOW FLOW FORECASTING METHODS

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 consideratton;

- 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.

2.1 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.

2.2 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 & 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 considerations.

3.0 LOW FLOW FORECASTING USING STATISTICAL APPROACH

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.

3.1 Model for Low flow Forecasting

The forecast of 10-day period flow for a larger river system is assumed to be dependent on previous four 10-daily flows at the same site, i.e.:

$$Q_i = a_{i,1} Q_{i-1} + a_{i,2} Q_{i-2} + a_{i,3} Q_{i-3} + a_{i,4} Q_{i-4} + b_i \qquad (1)$$

Where,

Q_i is the average flow during i *th* 10-daily period, say first 10-daily period of November;

Q_{i-1} is the average flow during the previous 10-daily period i.e. average flow during the third 10-daily period of October;

Q_{i-2} is the average flow during second 10-daily period of October;

Q_{i-3} is the average flow during first 10-daily period of October;

Q_{i-4} is the average flow during third 10-daily period of September; and

$a_{i,1}$, $a_{i,2}$, $a_{i,3}$, $a_{i,4}$, and b_i are regression coefficients in which i refers to the various 10-daily periods for which forecasts are required i.e. first 10-daily period of November, Second 10-daily period of November up to third 10-daily period of May.

For the purpose of issuing forecasts of low flows different values of parameters viz. $a_{i,1}$, $a_{i,2}$, $a_{i,3}$, $a_{i,4}$ and b_i for each value of i i.e. for all the twenty one 10-daily periods from first 10-daily period of November to third 10-daily period of May are estimated.

4.0 RESULTS AND DISCUSSION

For the purpose of illustrating the model efficacy a 10-daily sample data of 30 years has been used to estimate the model parameters. The forecast for the flow during November to May has been prepared and compared with the observed data of next 3 years.

4.1 Model Parameters

As illustrated in eq.(1) there are 5 parameters $a_{i,1}$,$a_{i,2}$ $a_{i,3}$,$a_{i,4}$, and b_i .These parameters have been estimated by multiple linear regression analysis. Least square technique has been adopted for parameter estimation.

To begin with, the initial forecast is prepared for the period from first 10-day of November for which the flow data of previous four 10-daily periods i.e. third 10-daily period of October,second 10-daily period of October, first 10-daily period of October and the third 10-daily period of September have been used. For the forecast of flow during the second 10-daily period of November, the forecast value of the flow of first 10-daily period of November is taken as input. Similarly the forecasts are estimated for the subsequent 10-daily periods up to the third 10-daily period 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 10-day as soon as the additional observed data is available. However for the purpose of illustrating the methodology, the following sets of forecasts have been formulated for three years.

a) Forecast for the period November I to May III, based on 10-daily observed discharges for October III, October II, October I and September III;

b) Forecast for the period December I to May III, based on 10-daily observed discharges for November III, November II, November I and October III;

c) Forecast for the period January I to May III, based on 10-daily observed discharges for December III, December II, December I and November III;

d) Forecast for the period February I to May III, based on 10-daily observed discharges for January III, January II January I and December III.

e) Forecast for the period March I to May III, based on 10-daily observed discharges for February III, February II. February I and January III;

f) Forecast for the period April I to May III, based on 10-daily observed discharges for March III, March II, March I and February III; and

g) Forecast for the period May I to May III,based on 10-daily observed discharges for April III, April II, April I and March III.

4.2 Discussion Of Results

The observed and forecasted discharges are shown in Table-1 to Table-3 for the 3 test years respectively.

Figures 1 to 7 show the observed and forecasted discharges for the first test year; figures 8 to 14 show the observed and forecasted discharges for the second test year and figures 15 to 21 show the observed and forecasted discharges for the third test year for the above cases (a to g) respectively.

It is observed from Table-1 that when the forecasts are formulated for the period November I to May III, based on the observed data for October III, October II, October I and September III the percentage error is -15.9% for 10-daily period of November I and around 6% for November II and November III. The percent error between observed and forecasted discharges in general decreases for the period January to April I. After April I, again the percent errors between observed and forecasted flows show a little increase. Table -2 shows that percent error between the observed and forecasted discharges are much less i.e. -1.4% for November I, -2.6% for November and 0 for November III. The percent error is quite low for rest of the period except for February II and March I. Table-3 shows that the percent error is a little high except for the period from December to March.

Table 1: Comparison of forecast and observed flows for test year 1

S. No.	10-Daily Period	Obser. Disch.	Forecast discharge and Percentage error for different 10-Daily periods from November-I to May-III											
1	Nov.I	419	486	-15.9										
2	II	402	427	-6.2										
3	III	365	387	-6.0										
4	Dec.I	326	351	-7.6	336	-3.1								
5	II	294	318	-8.2	306	-4.1								
6	III	267	293	-9.7	284	-6.4								
7	Jan.I	264	271	-2.6	264	0.0	254	3.8						
8	II	249	256	-2.8	250	-0.4	244	2.0						
9	III	228	245	-7.5	240	-5.3	235	-3.0						
10	Feb.I	217	239	-10.1	234	-7.8	229	-5.5	223	-2.7				
11	II	199	233	-17.1	229	-15.1	224	-12.6	220	-0.5				
12	III	209	229	-9.6	223	-6.7	217	-3.8	220	4.1				
13	Mar.I	221	222	-.5	217	1.8	211	4.5	214	3.2	206	6.8		
14	II	216	215	0.5	210	2.8	205	5.1	204	5.5	192	11.1		
15	III	209	210	-0.5	207	0.9	203	2.9	202	3.3	189	9.5		
16	Apr.I	210	210	0.0	207	1.4	204	2.9	203	3.3	192	8:6	207	1.4		
17	II	216	211	2.3	208	3.7	206	4.6	205	5.1	194	10.2	208	3.7		
18	III	221	214	3.2	212	4.0	210	4.9	209	5.4	200	9.5	212	4.1		
19	May I	229	221	3.5	220	3.9	218	4.8	218	4.8	211	7.9	219	4.3	228	0.4
20	II	238	229	3.8	228	4.2	227	4.6	227	4.6	223	6.3	227	4.6	236	0.8
21	III	295	242	17.9	241	18.3	240	18.6	239	18.9	234	20.6	240	18.6	251	14.9

Table 2: Comparison of forecast and observed flows for test year 2

S. No.	10-Daily Period	Obser. Disch.	Forecast discharge & Percentage error for different 10-Daily periods from November-I to May-III													
1	Nov.I	556	564	-1.4												
2	II	457	469	-2.6												
3	III	413	413	0.0												
4	Dec.I	362	369	-1.9	369	-1.9										
5	II	325	330	-1.5	332	-2.2										
6	III	297	302	-1.7	303	-2.0										
7	Jan.I	272	278	-2.2	279	-2.6	276	-1.5								
8	II	271	261	3.7	262	3.3	260	4.1								
9	III	262	250	4.6	251	4.2	249	4.9								
10	Feb.I	240	243	-1.3	244	-1.7	242	-0.8	252	-5.0						
11	II	222	238	-7.2	239	-7.6	237	-6.8	244	-9.9						
12	III	207	235	-13.5	235	-13.5	233	-12.6	241	-16.4						
13	Mar.I	196	228	-16.3	229	-16.8	227	-15.8	234	-19.4	203	-3.6				
14	II	206	219	-6.3	220	-6.8	218	-5.8	225	-9.2	202	1.9				
15	III	202	214	-5.9	214	-5.9	213	-5.4	218	-7.9	200	0.9				
16	Apr.I	205	213	-3.9	213	-3.9	212	-3.4	216	-5.4	200	2.4	198	3.4		
17	II	218	213	2.3	214	1.8	213	2.3	216	0.9	202	7.3	201	7.8		
18	III	215	216	-0.4	216	-0.4	216	-0.4	219	-1.8	207	3.7	207	3.7		
19	May I	220	222	-0.9	222	-0.9	222	-0.9	224	-1.8	216	1.8	215	2.3	221	0.5
20	II	232	230	0.9	230	0.9	229	1.3	230	0.9	225	3.0	223	3.9	232	0.0
21	III	239	243	-1.7	243	-1.7	243	-1.7	244	-2.1	238	0.4	237	0.8	247	-3.3

Table 3: Comparison of forecast and observed flows for test year 3

S. No.	10-Daily Period	Obser. Disch.	Forecast discharge & % error for different 10-Daily periods from Nov.-I to May-III											
1	Nov.I	375	442	-17.8										
2	II	330	393	-19.0										
3	III	314	363	-15.6										
4	Dec I	301	335	-11.3	300	0.3								
5	II	290	307	-5.9	284	2.1								
6	III	283	285	-0.7	268	5.3								
7	Jan.I	284	264	7.0	251	11.6	262	7.7						
8	II	272	251	7.7	241	11.3	247	9.2						
9	III	249	241	3.2	232	6.8	237	4.8						
10	Feb.I	232	235	-1.3	227	2.2	232	0.0	242	-4.3				
11	II	227	230	-1.3	222	2.2	227	0.0	236	-3.9				
12	III	221	224	-1.4	214	3.2	221	0.0	241	-9.0				
13	Mar.I	206	218	-5.8	208	-0.9	214	3.9	235	-14.1	215	-4.4		
14	II	197	211	-10.6	203	-3.0	208	-5.5	221	-12.1	208	-5.6		
15	III	186	207	-11.3	201	-8.1	205	-10.2	214	-15.1	205	-10.2		
16	Apr.I	180	208	-15.5	203	-12.7	206	-14.4	214	18.8	206	-14.4	183	-1.7		
17	II	184	209	-13.5	204	-10.8	207	-12.5	214	-16.3	207	1.0	187	-1.6		
18	III	189	212	-12.2	209	-10.5	211	-11.6	216	-14.3	211	-11.6	194	-2.6		
19	May I	199	220	-10.6	217	-9.0	219	-10.0	222	-11.6	219	-10.0	205	-0.3	200	-0.5
20	II	201	228	-13.4	227	-12.9	228	-13.4	230	-14.4	228	-13.4	216	-7.5	211	-4.9
21	III	208	241	-15.8	239	-14.9	241	-15.8	243	-16.8	241	-15.8	228	-9.6	223	-7.2

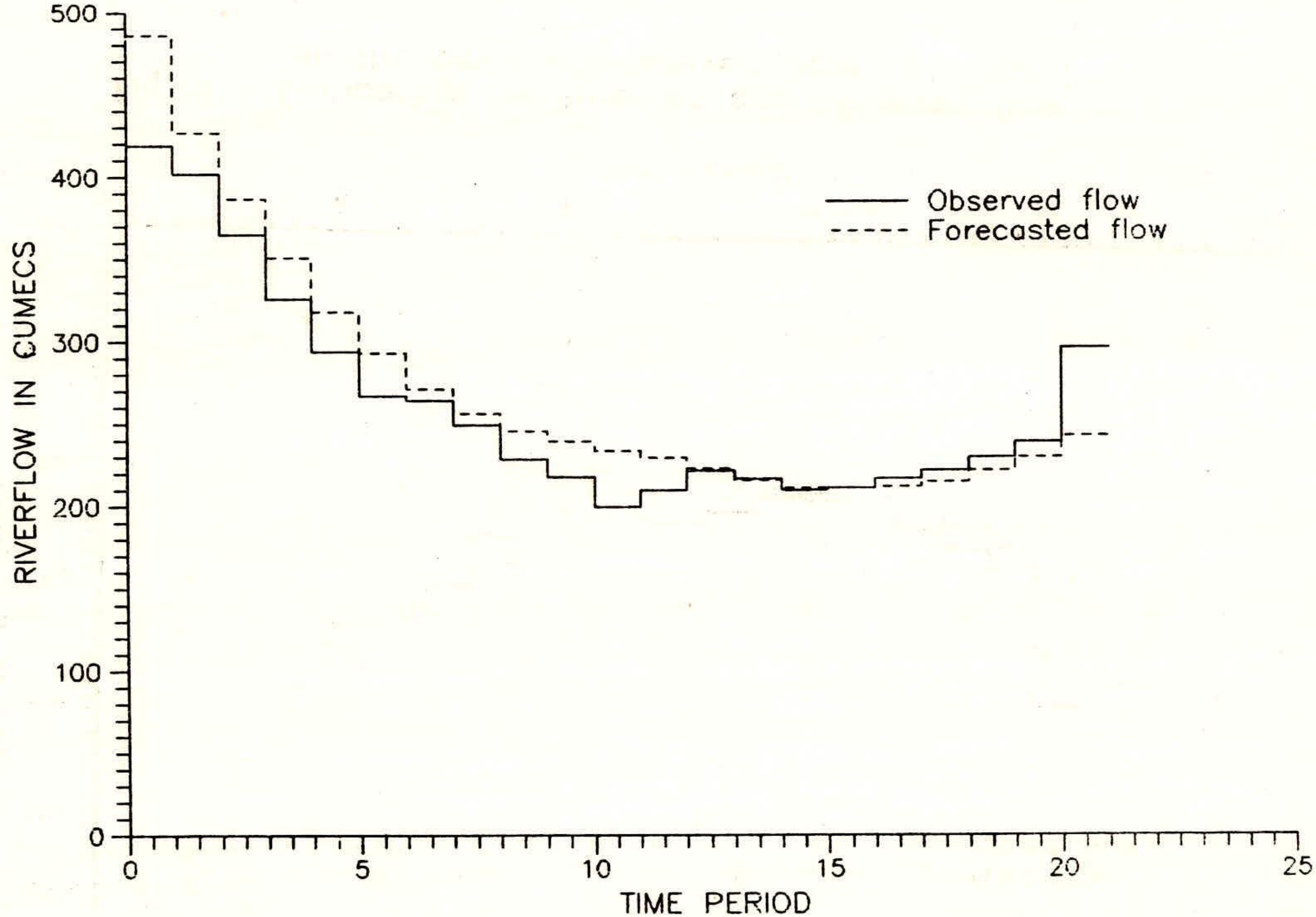

Fig. 1 : Comparison of forecast and observed flow (on the basis of observed data upto Oct.)

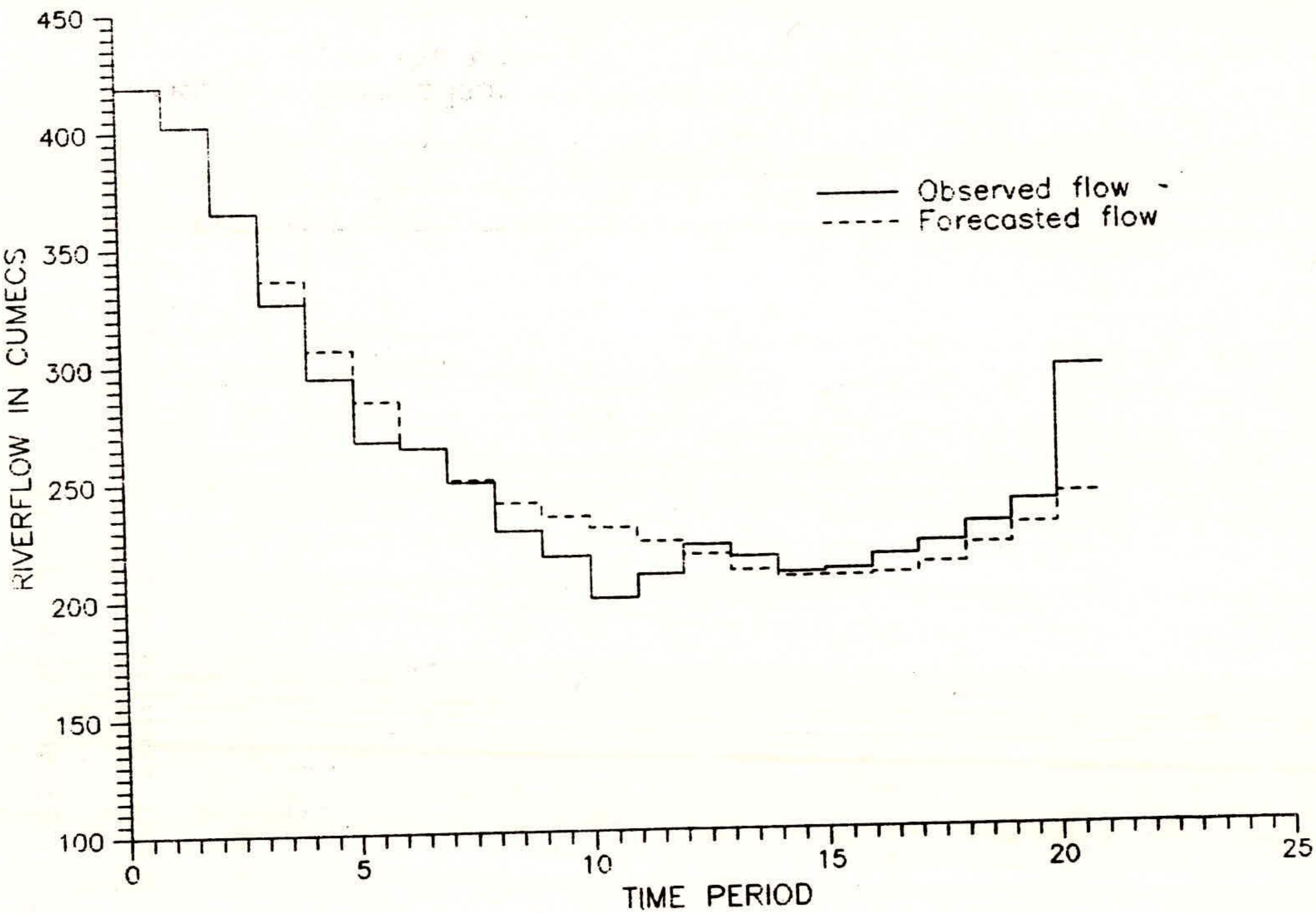

Fig. 2 : Comparison of forecast and observed flow (on the basis of observed data upto Nov.)

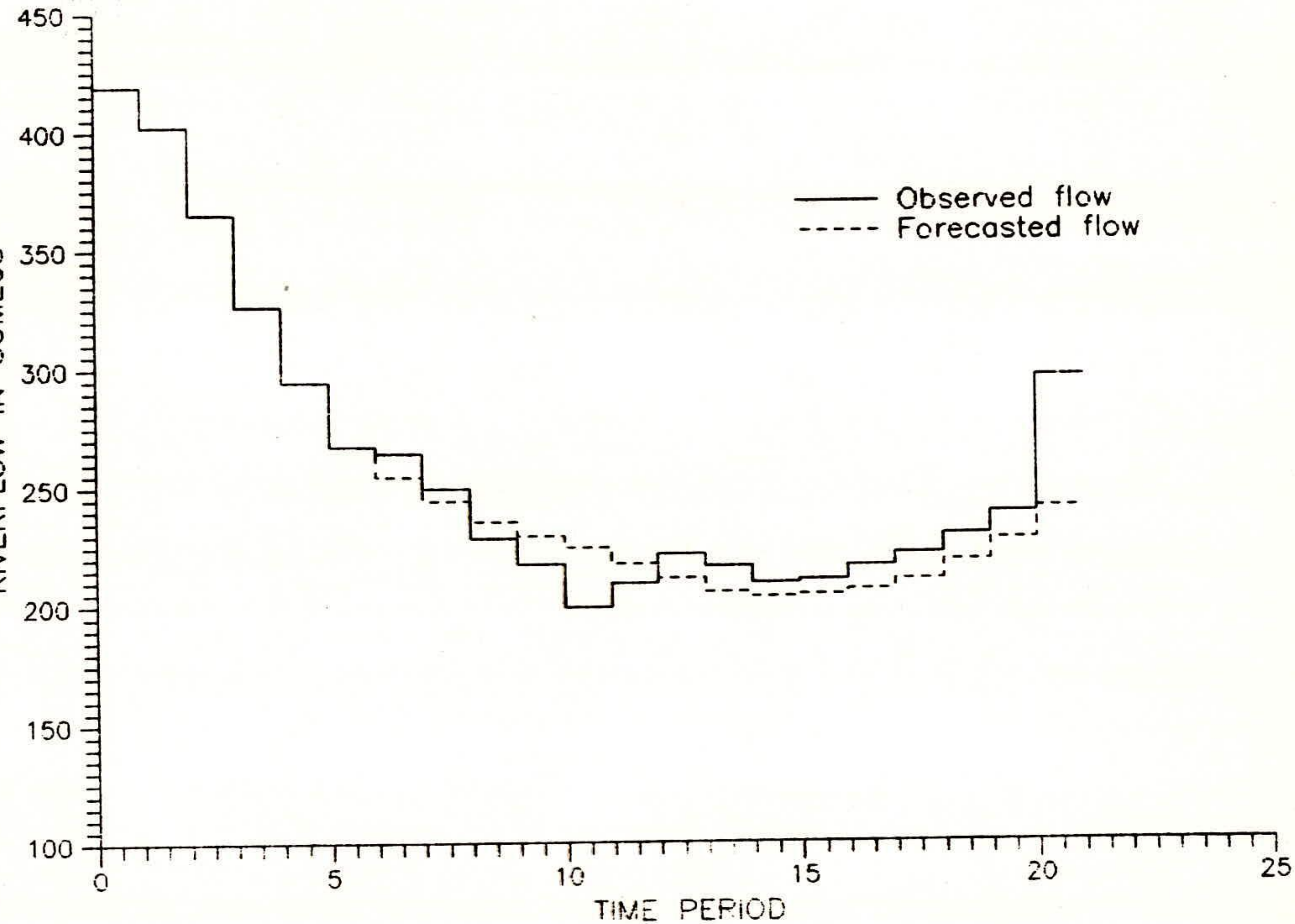

Fig. [illegible] : Comparison of forecast and observed flow
(on the basis of observed data upto Dec.)

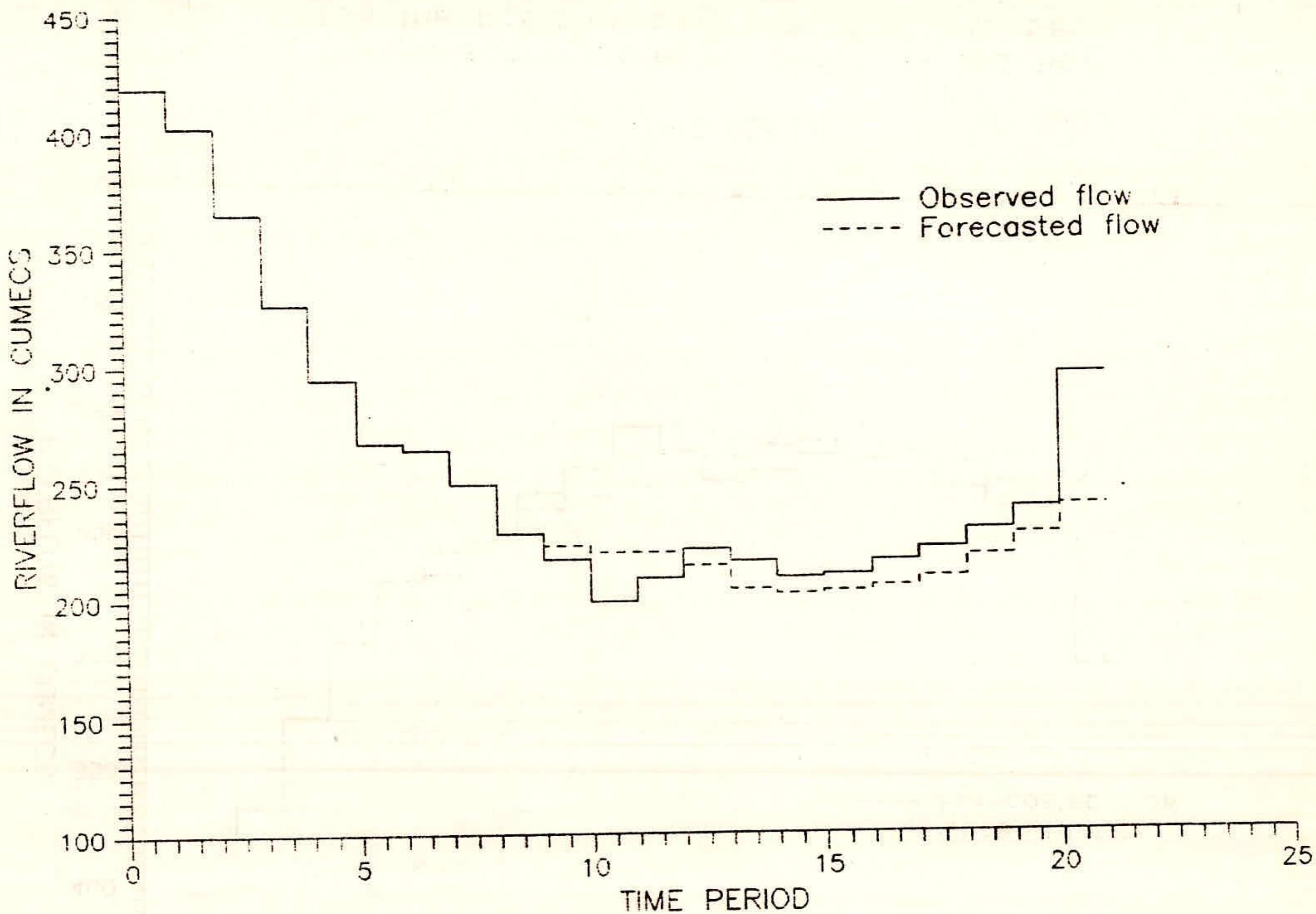

Fig. 4 : Comparison of forecast and observed flow (on the basis of observed data upto Jan.)

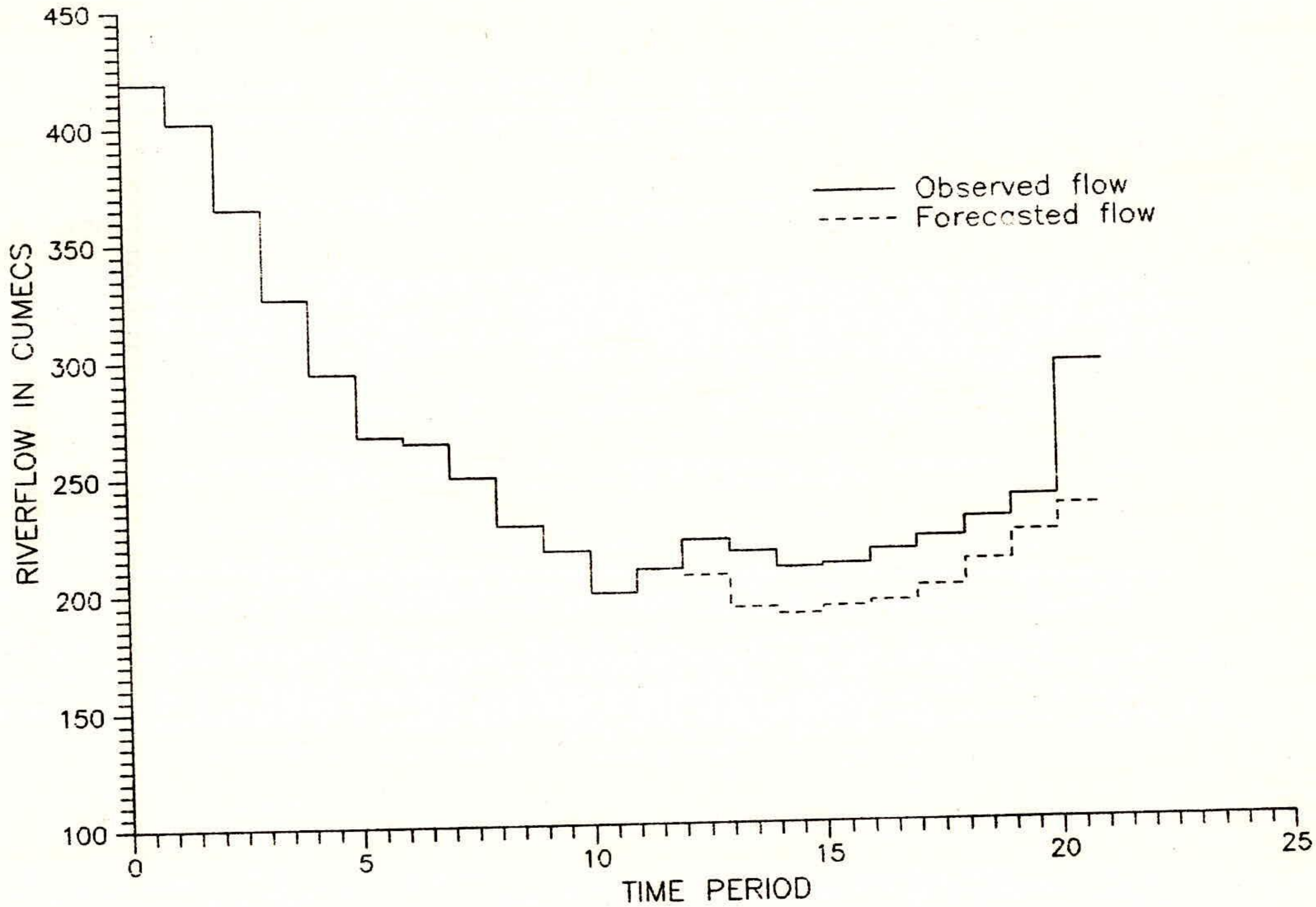

Fig. 5 : Comparison of forecast and observed flow
(on the basis of observed data upto Feb.)

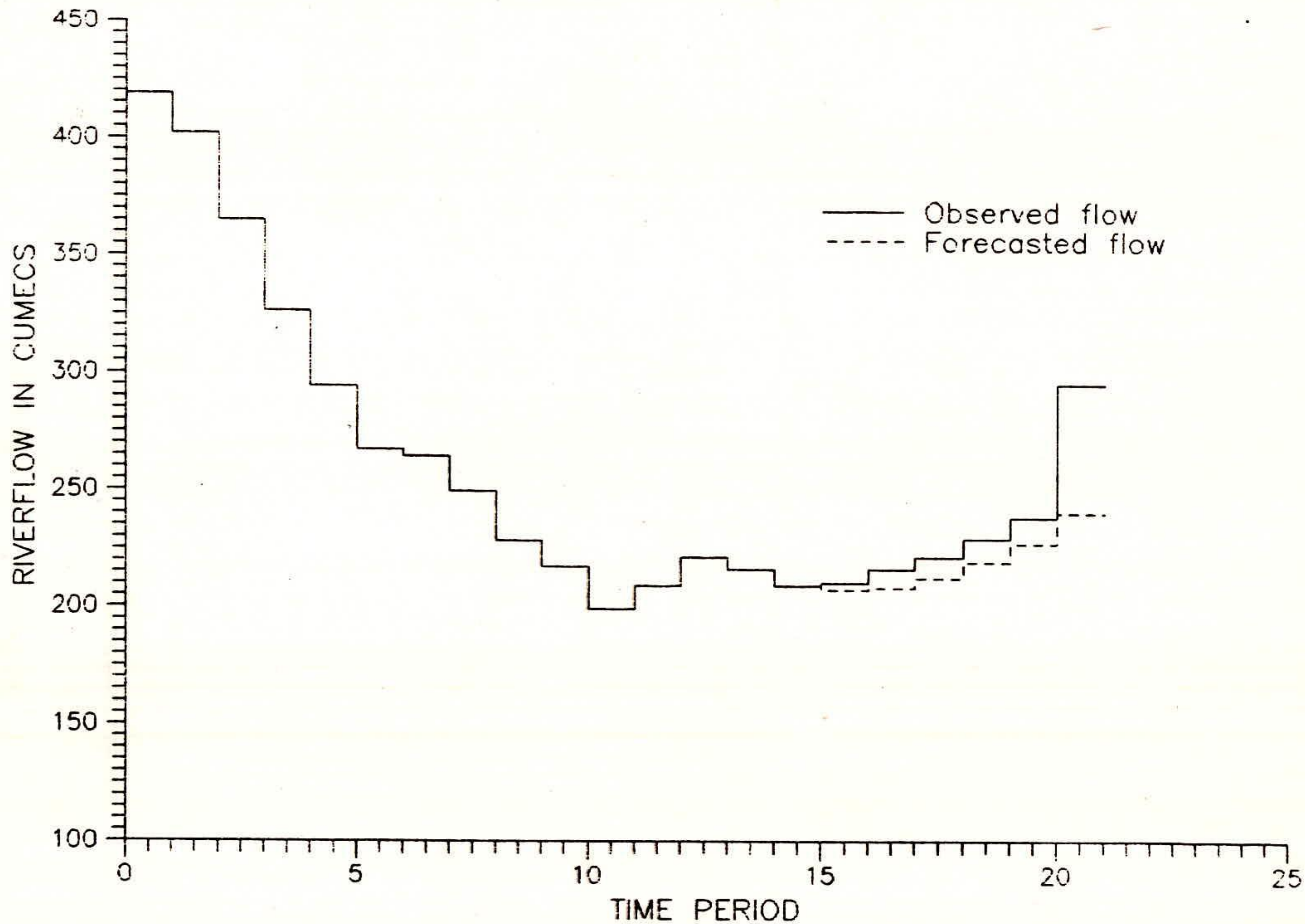

Fig. [illegible] : Comparison of forecast and observed flow (on the basis of observed data upto Mar.)

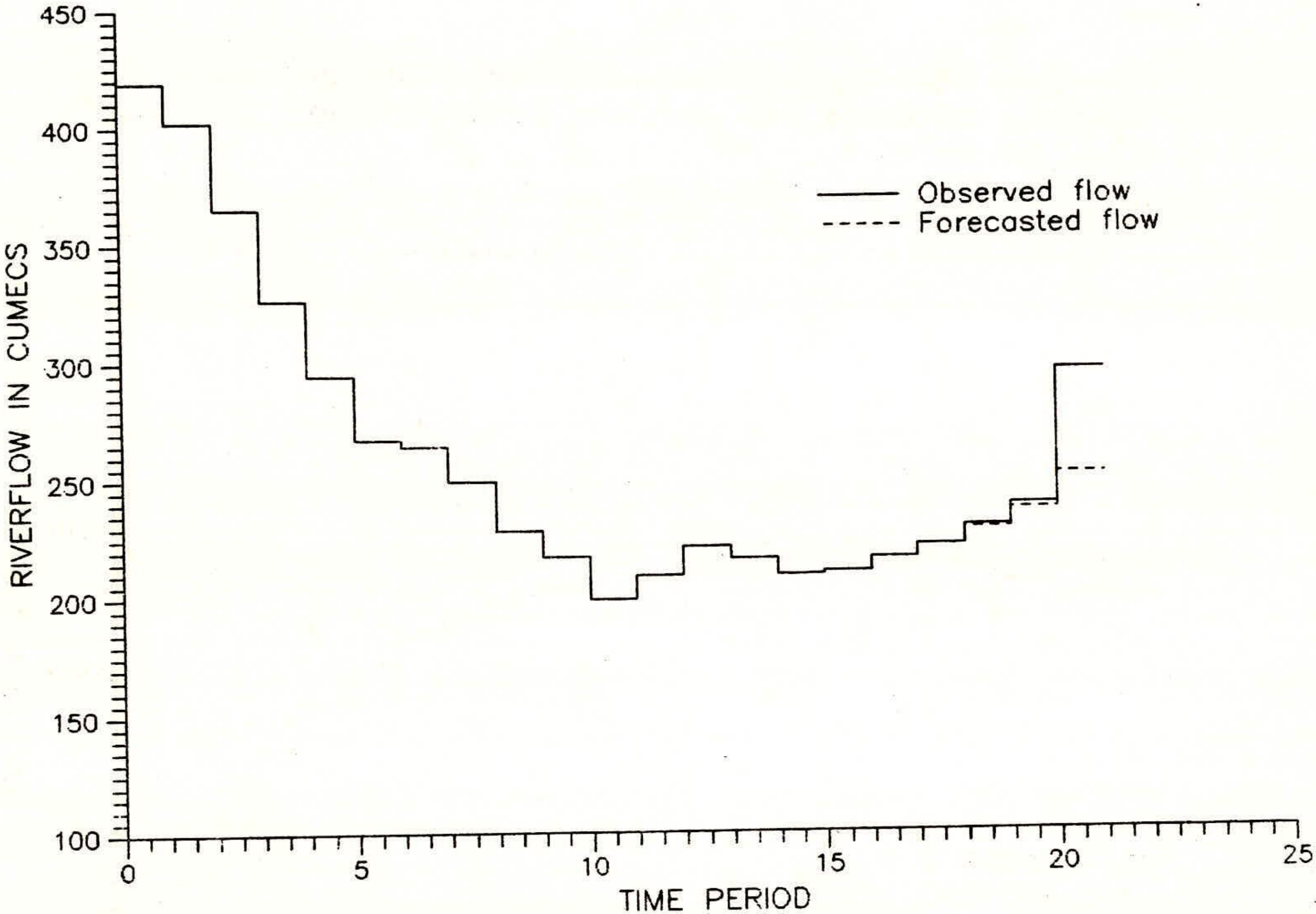

Fig. 7 : Comparison of forecast and observed flow (on the basis of observed data upto Apr.)

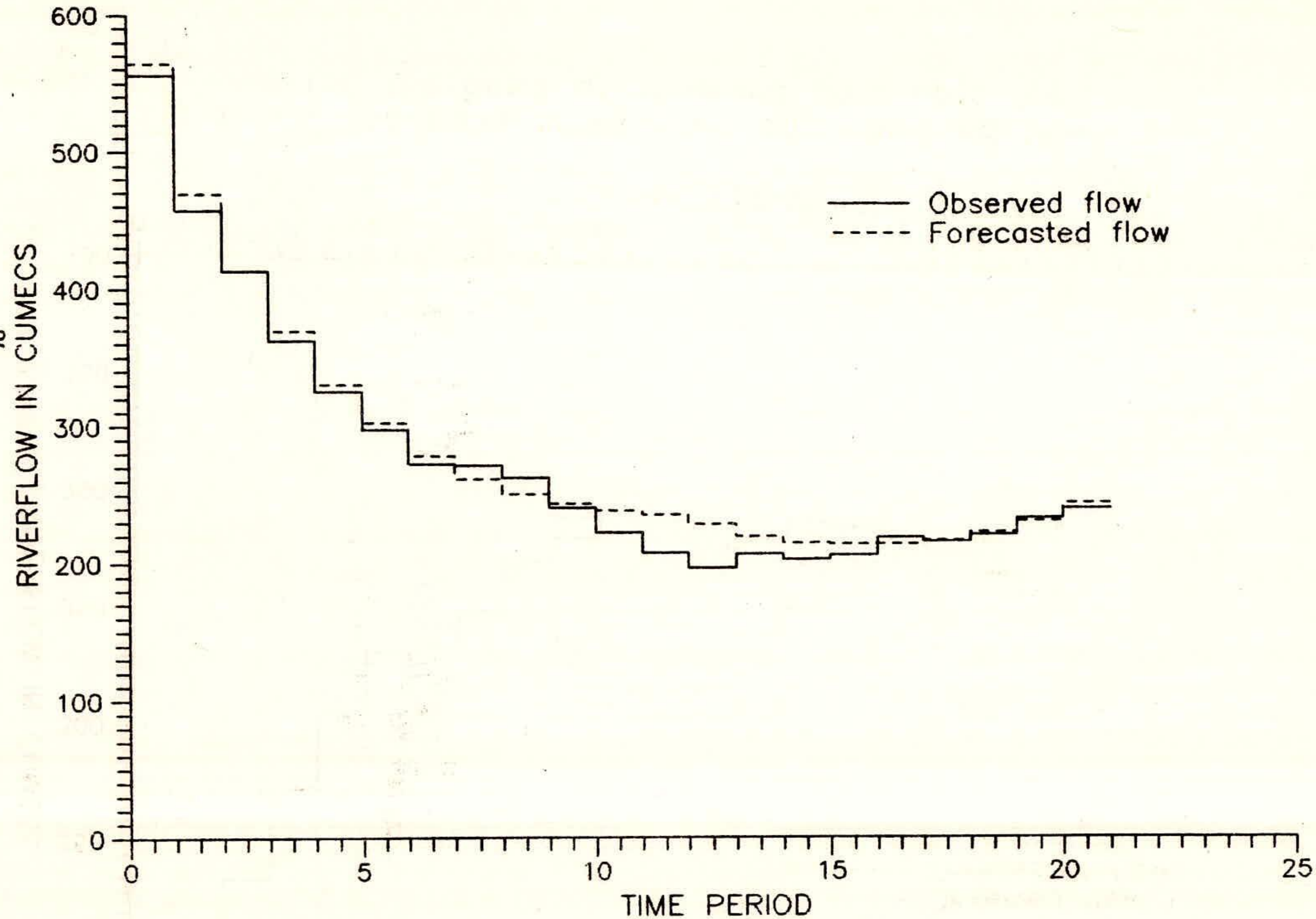

Fig. 8 : Comparison of forecast and observed flow
(on the basis of observed data upto Oct.)

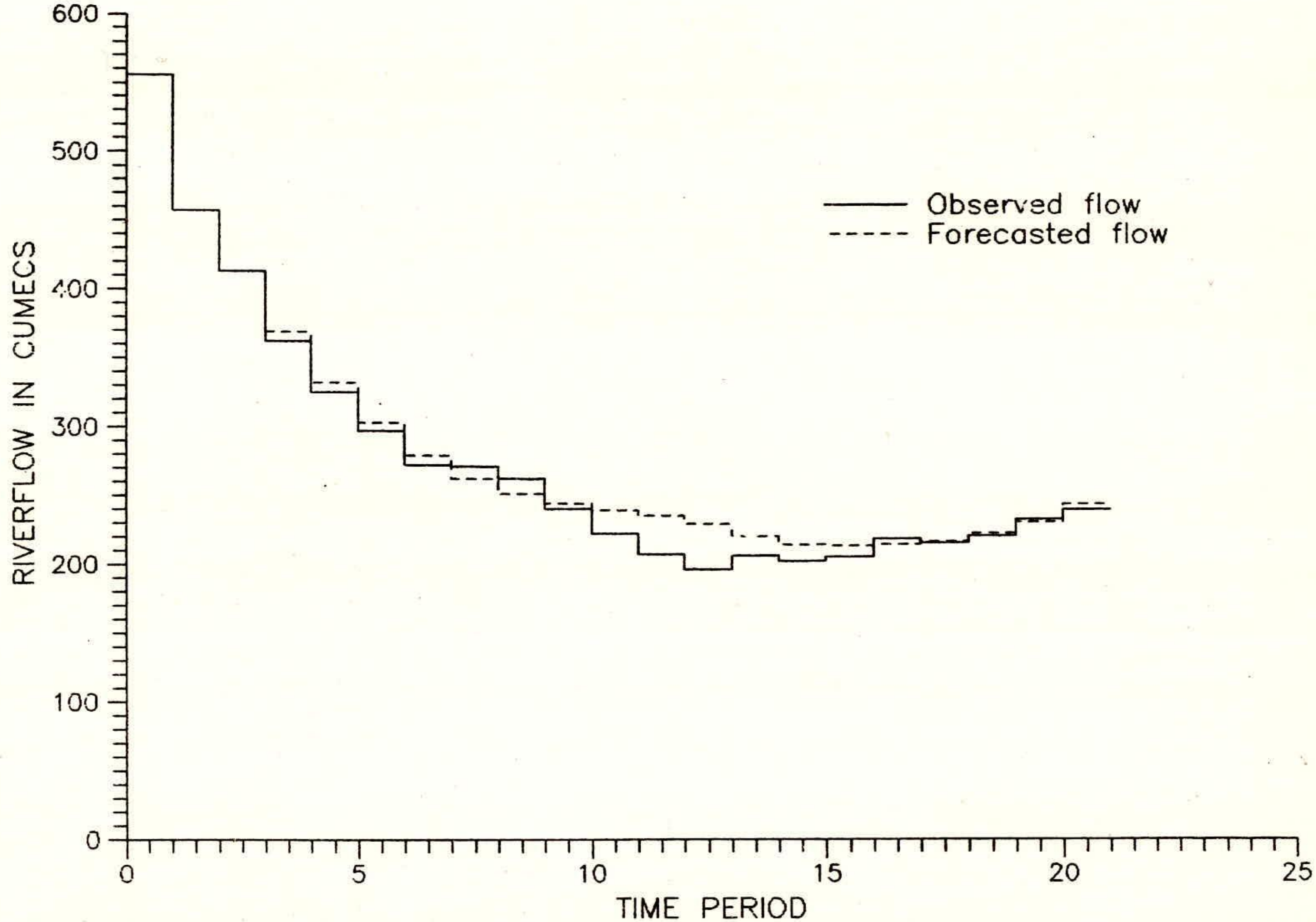

Fig. 9 : Comparison of forecast and observed flow
(on the basis of observed data upto Nov.)

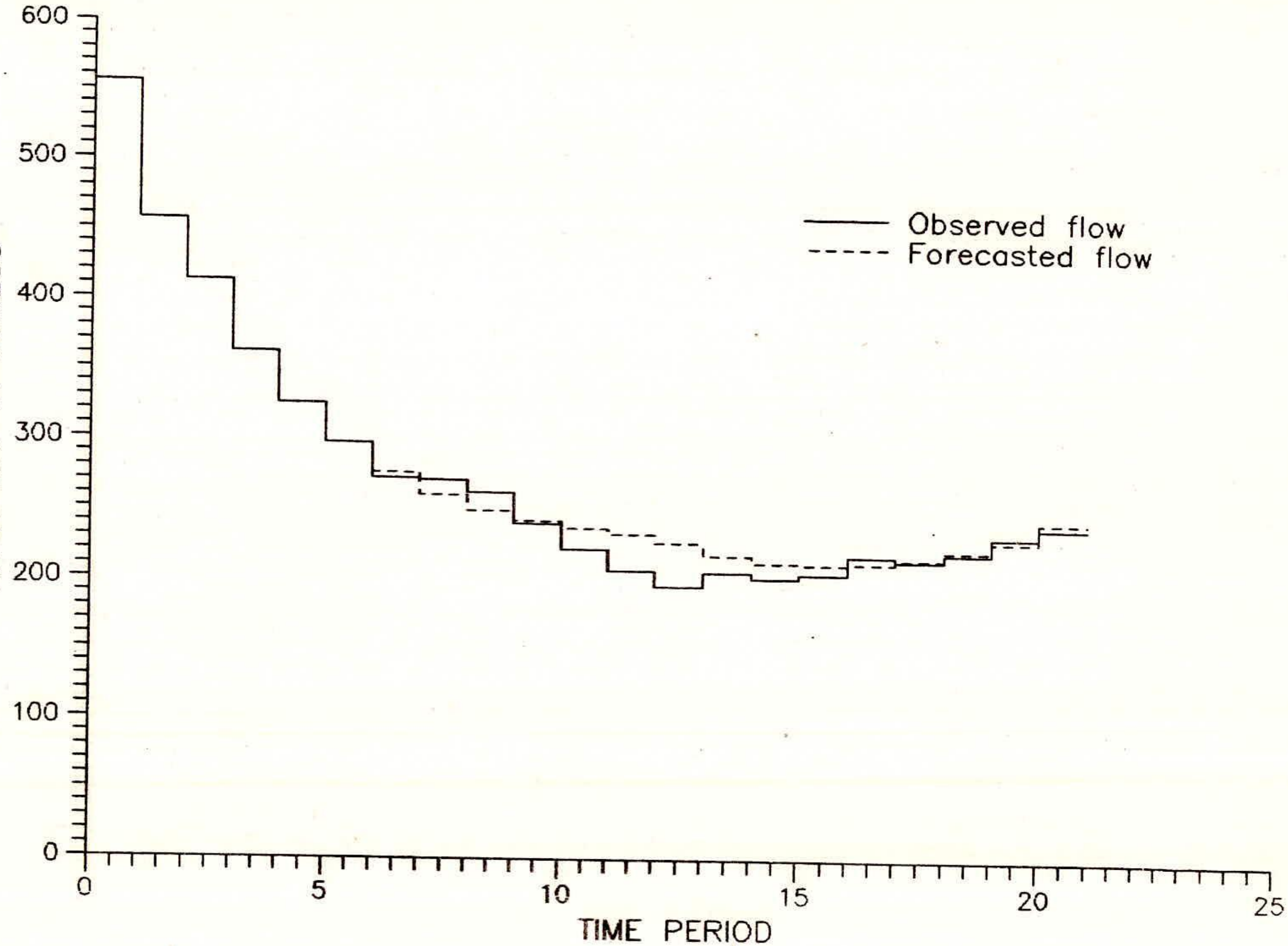

Fig. 10 : Comparison of forecast and observed flow
(on the bcsis of observed data upto Dec.)

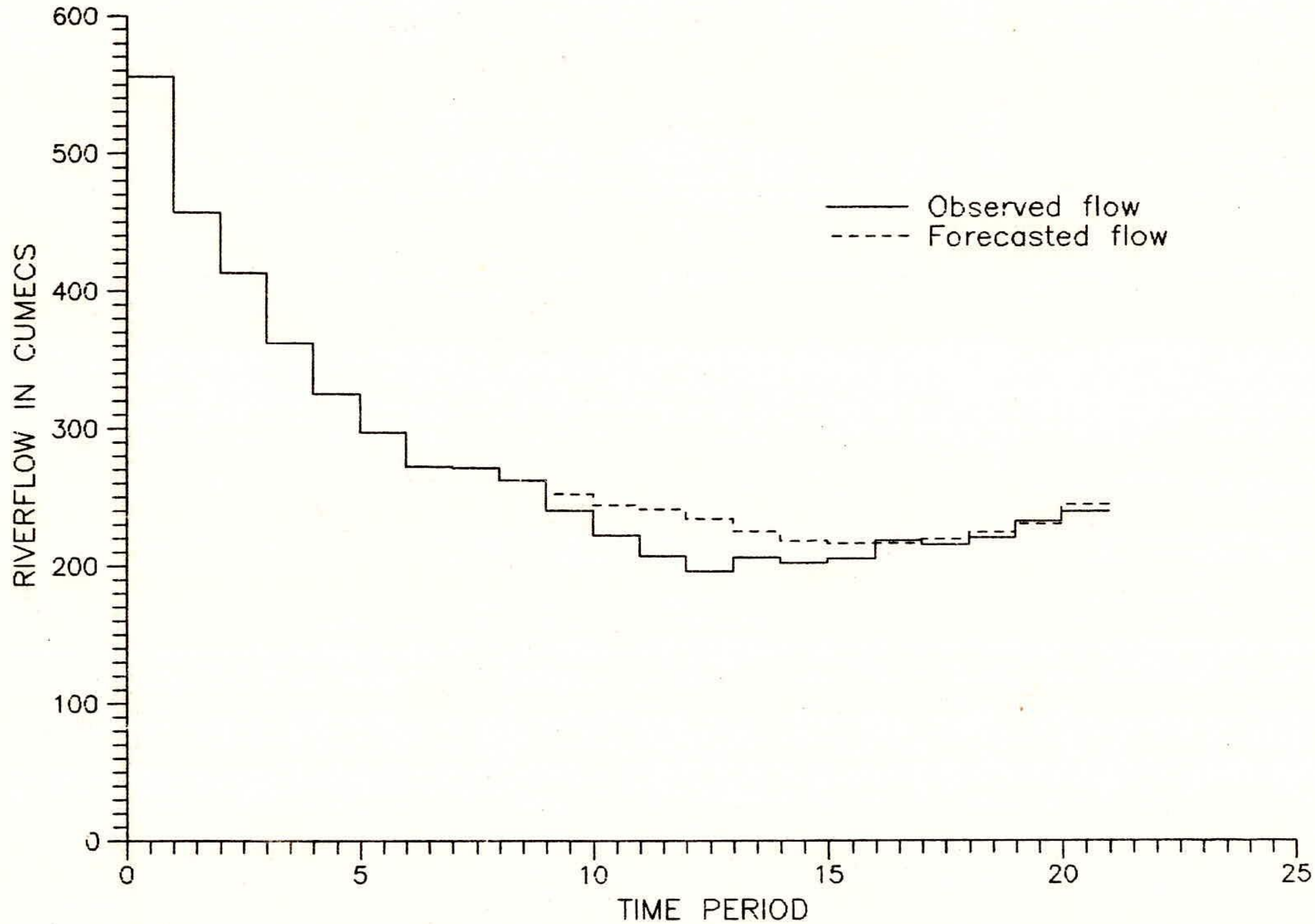

Fig. 11 : Comparison of forecast and observed flow (on the basis of observed data upto Jan.)

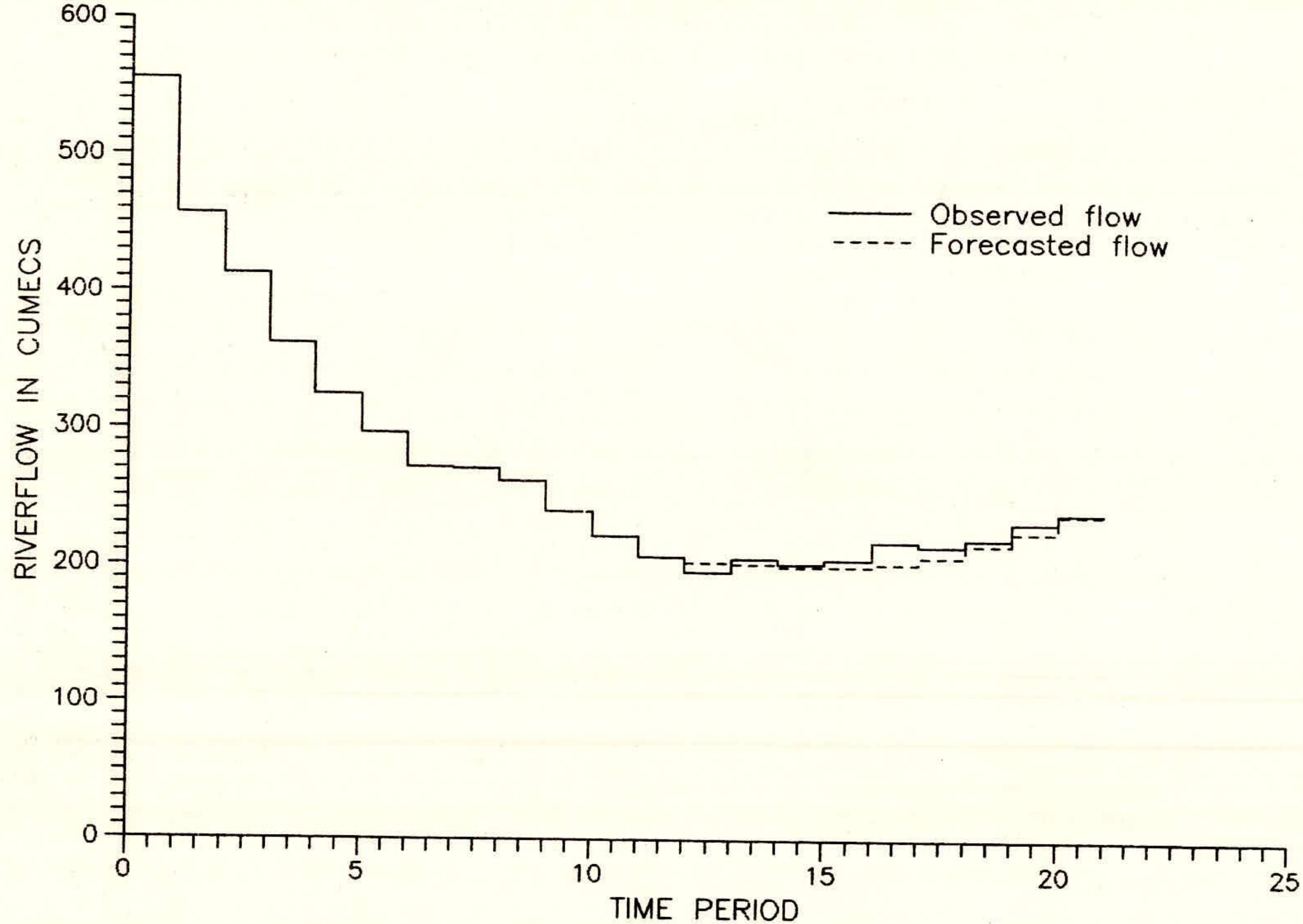

Fig. 12 : Comparison of forecast and observed flow
(on the basis of observed data upto Feb.)

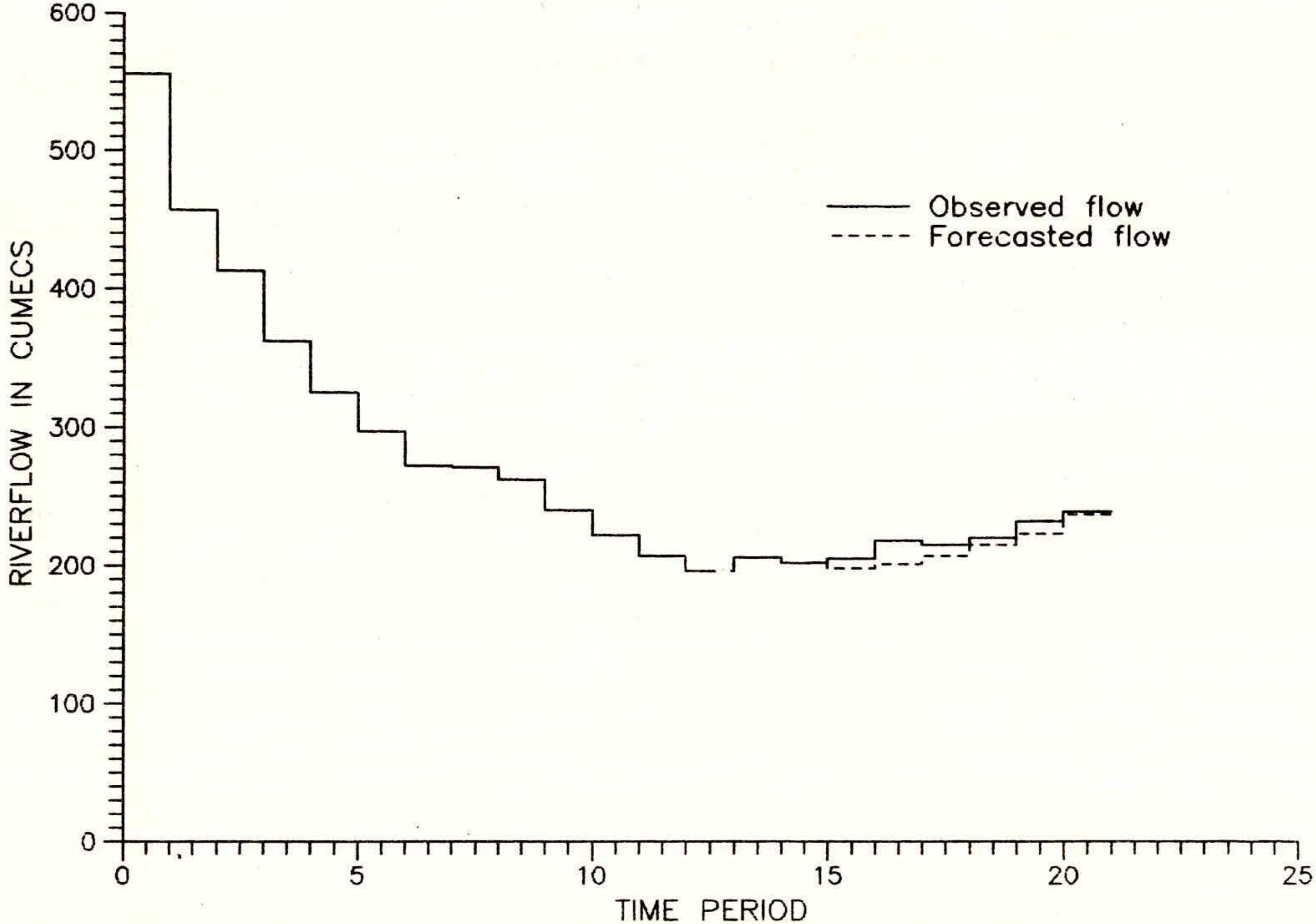

Fig. 13 : Comparison of forecast and observed flow (on the basis of observed data upto Mar.)

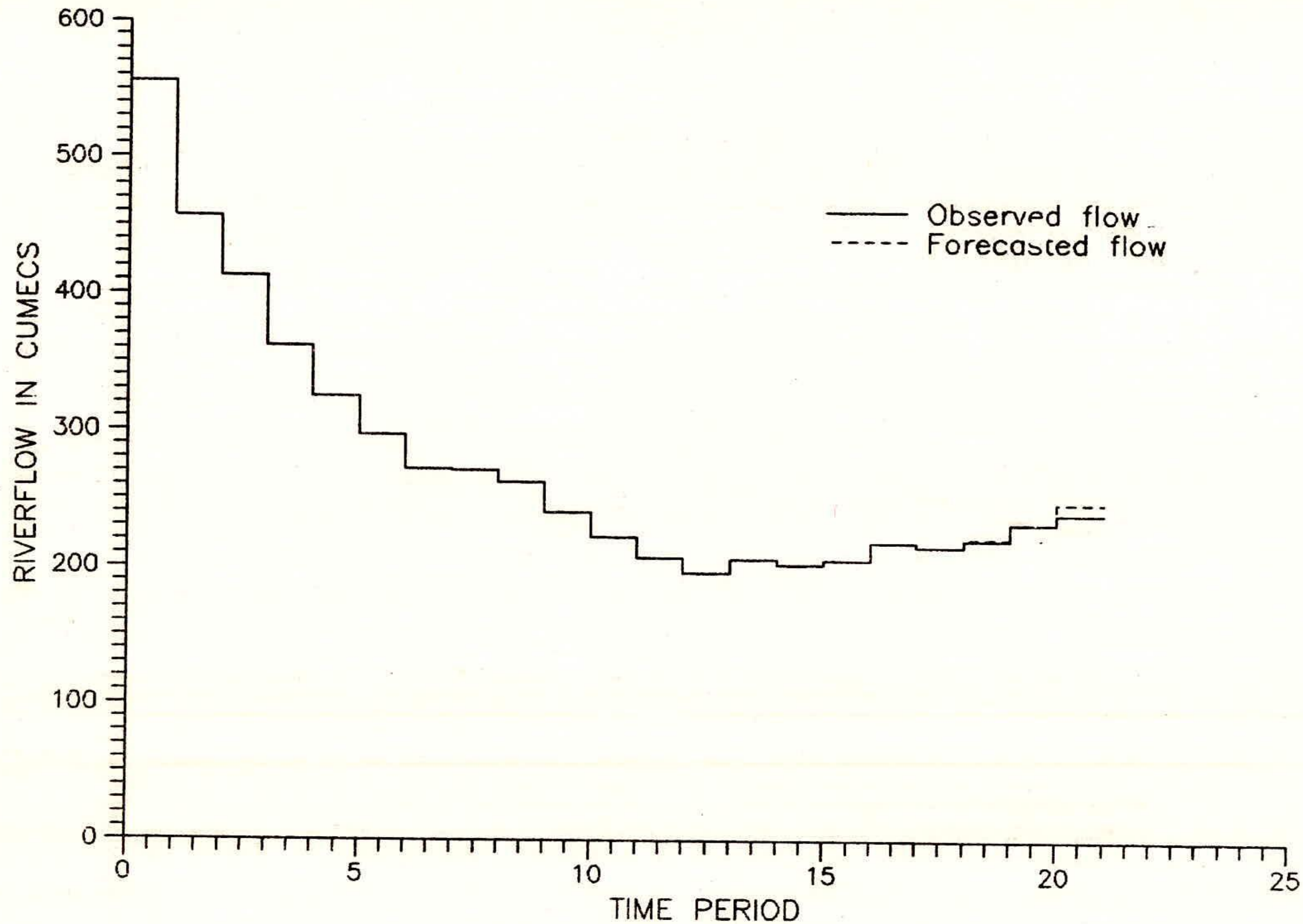

Fig.14 : Comparison of forecast and observed flow (on the basis of observed data upto Apr.)

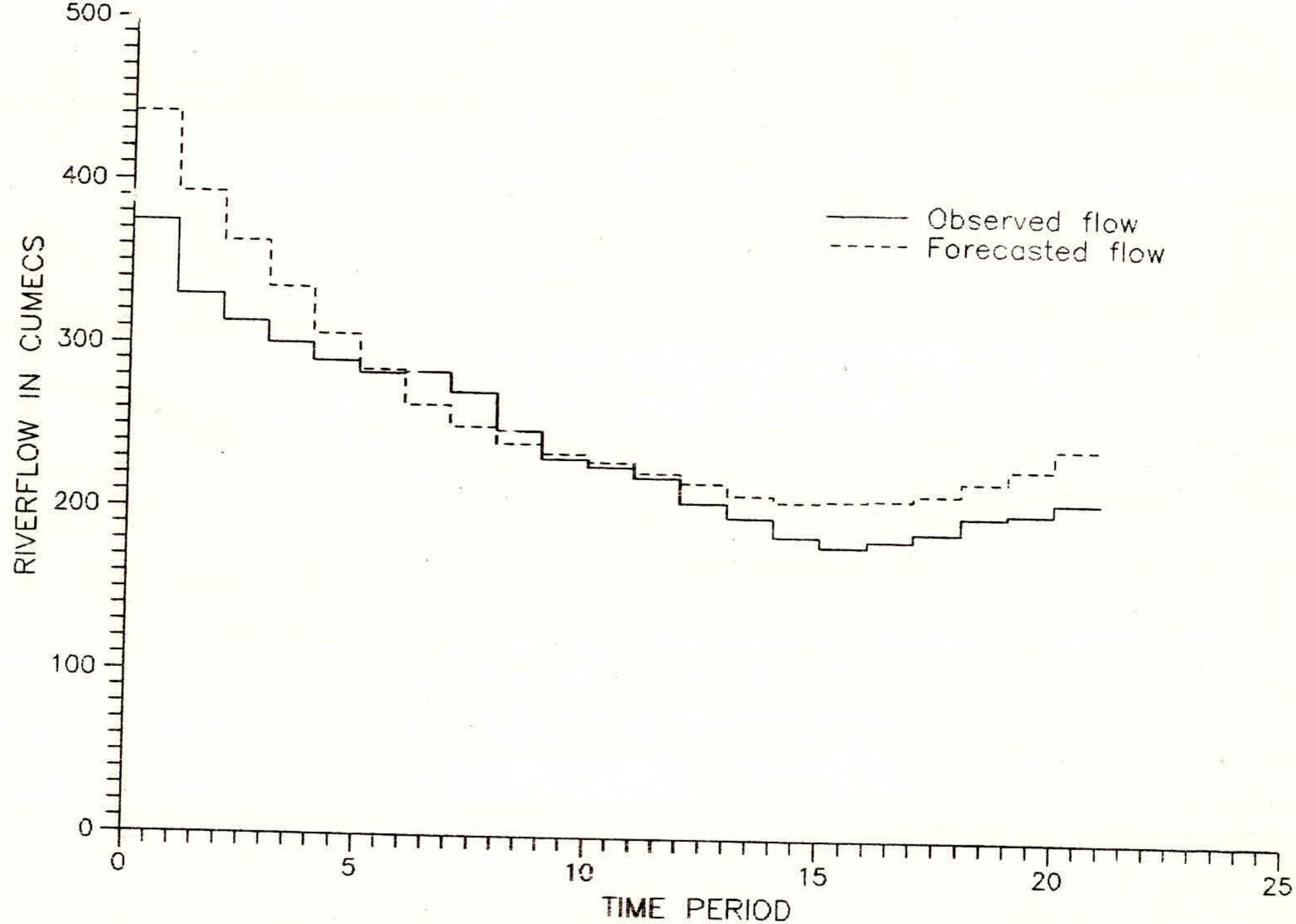

Fig. 15 : Comparison of forecast and observed flow
(on the basis of observed data upto Oct.)

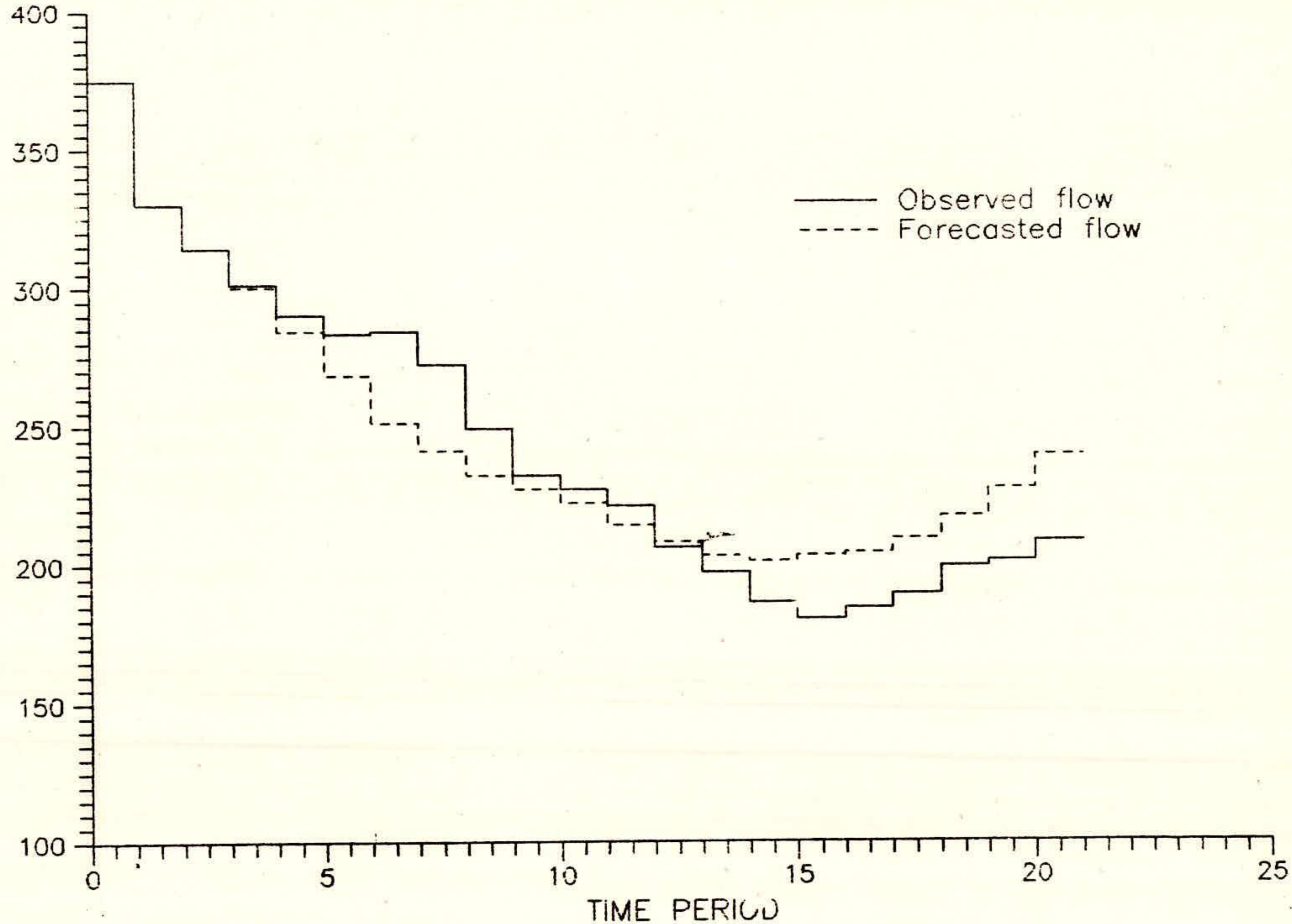

Fig. 16 : Comparison of forecast and observed flow
(on the basis of observed data upto [illegible])

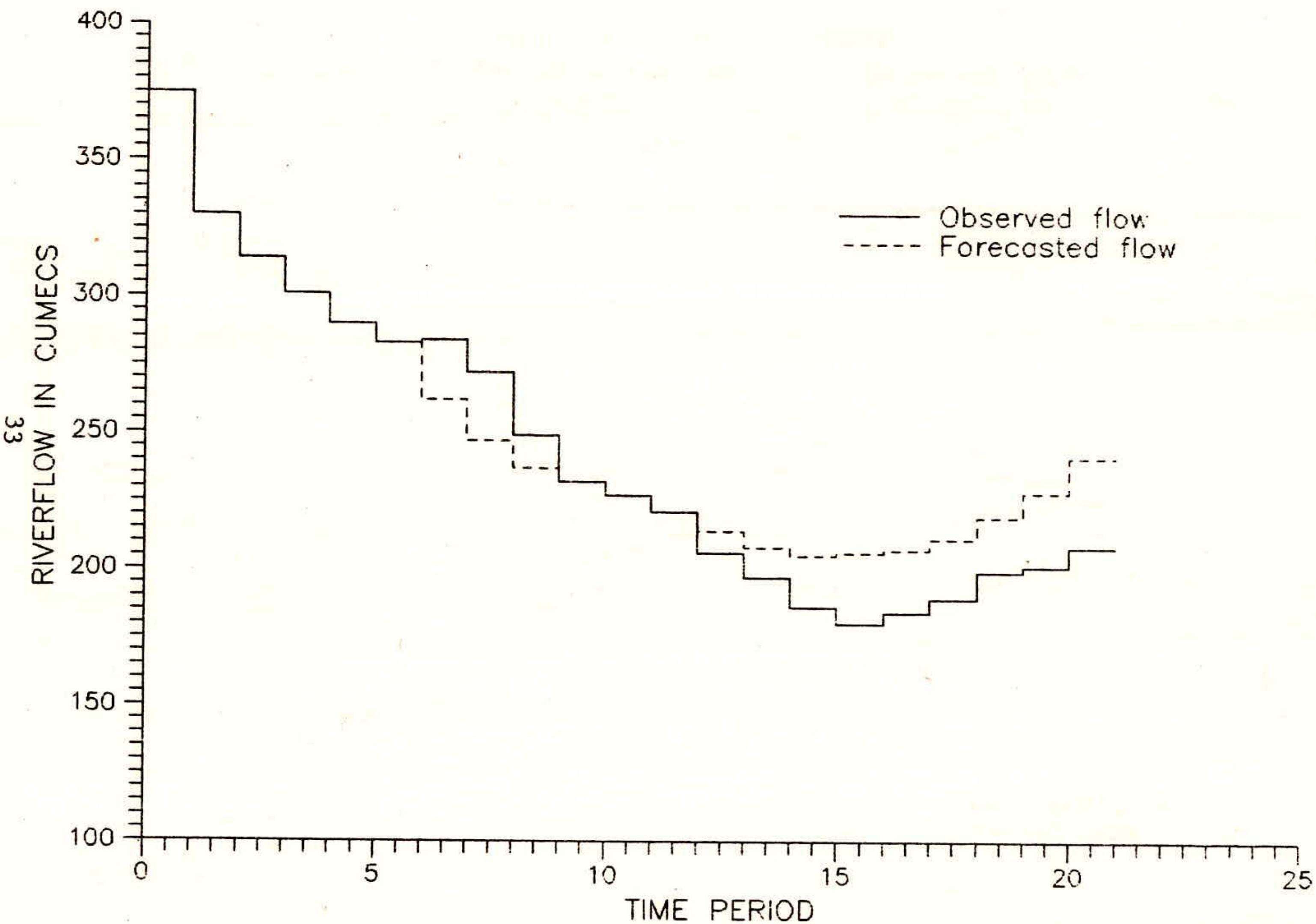

Fig. 17 : Comparison of forecast and observed flow (on the basis of observed data upto [illegible].)

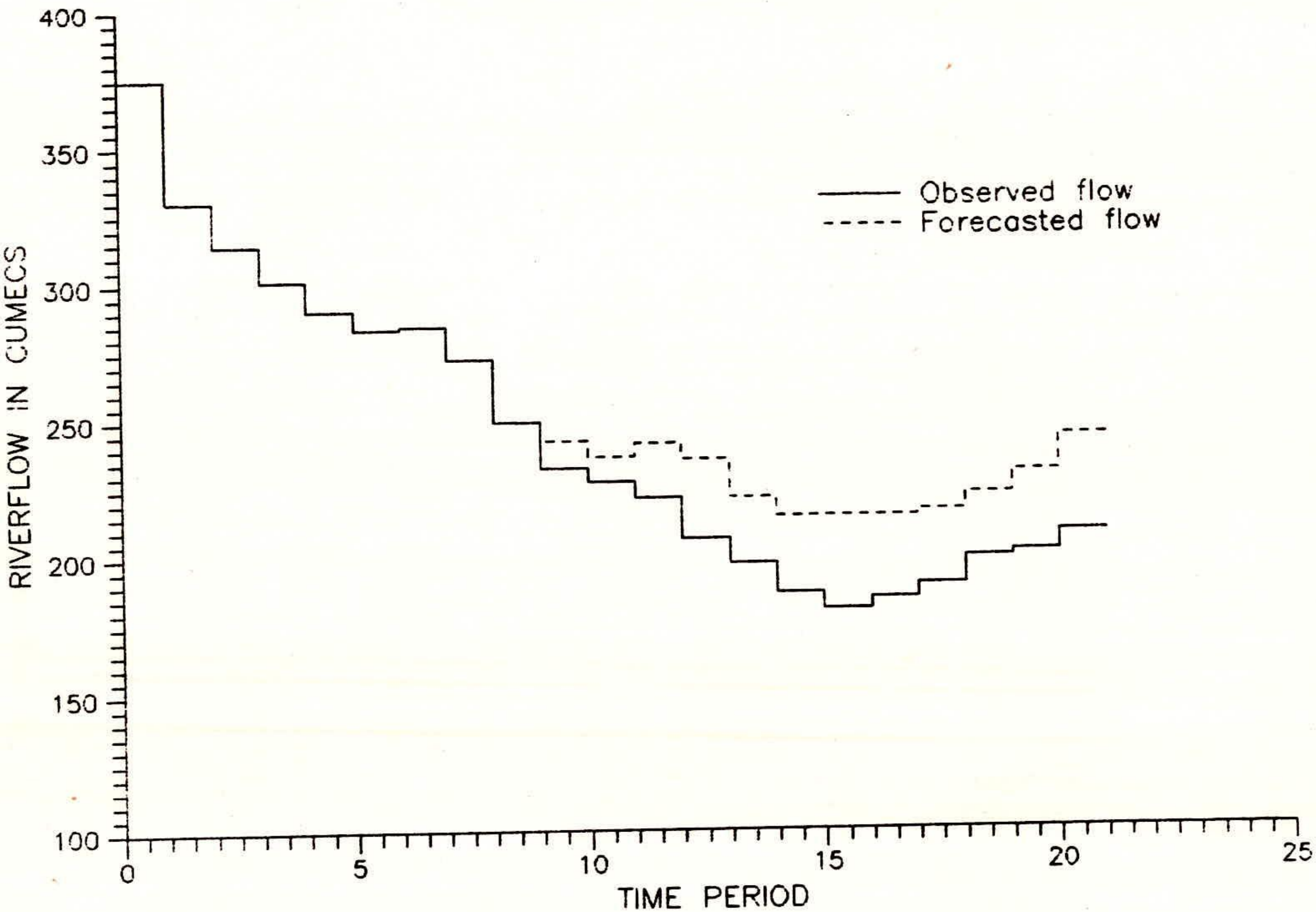

Fig. [illegible] : Comparison of forecast and observed flow
(on the basis of observed data upto Jan.)

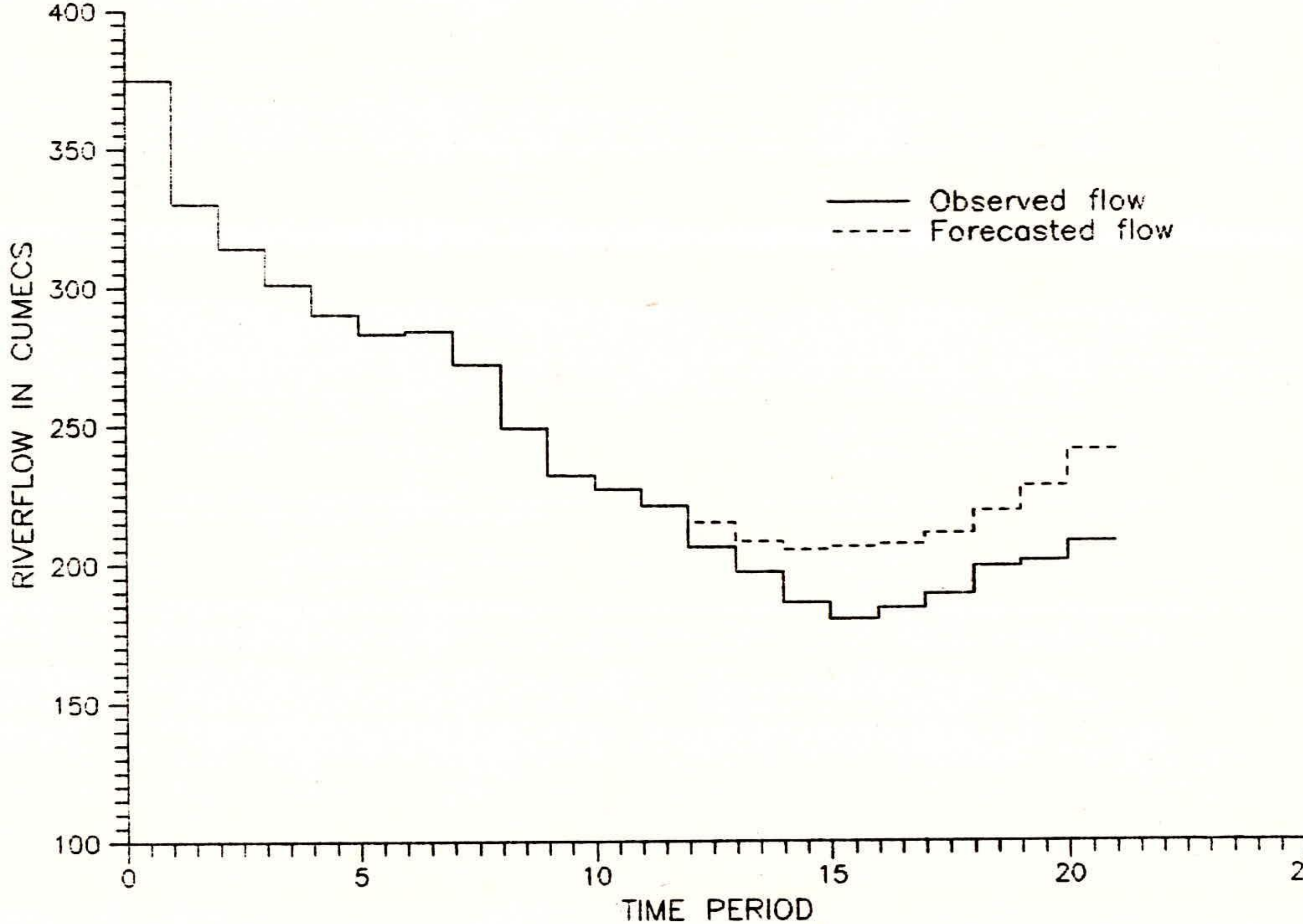

Fig. 19 : Comparison of forecast and observed flow
(on the basis of observed data upto Feb.)

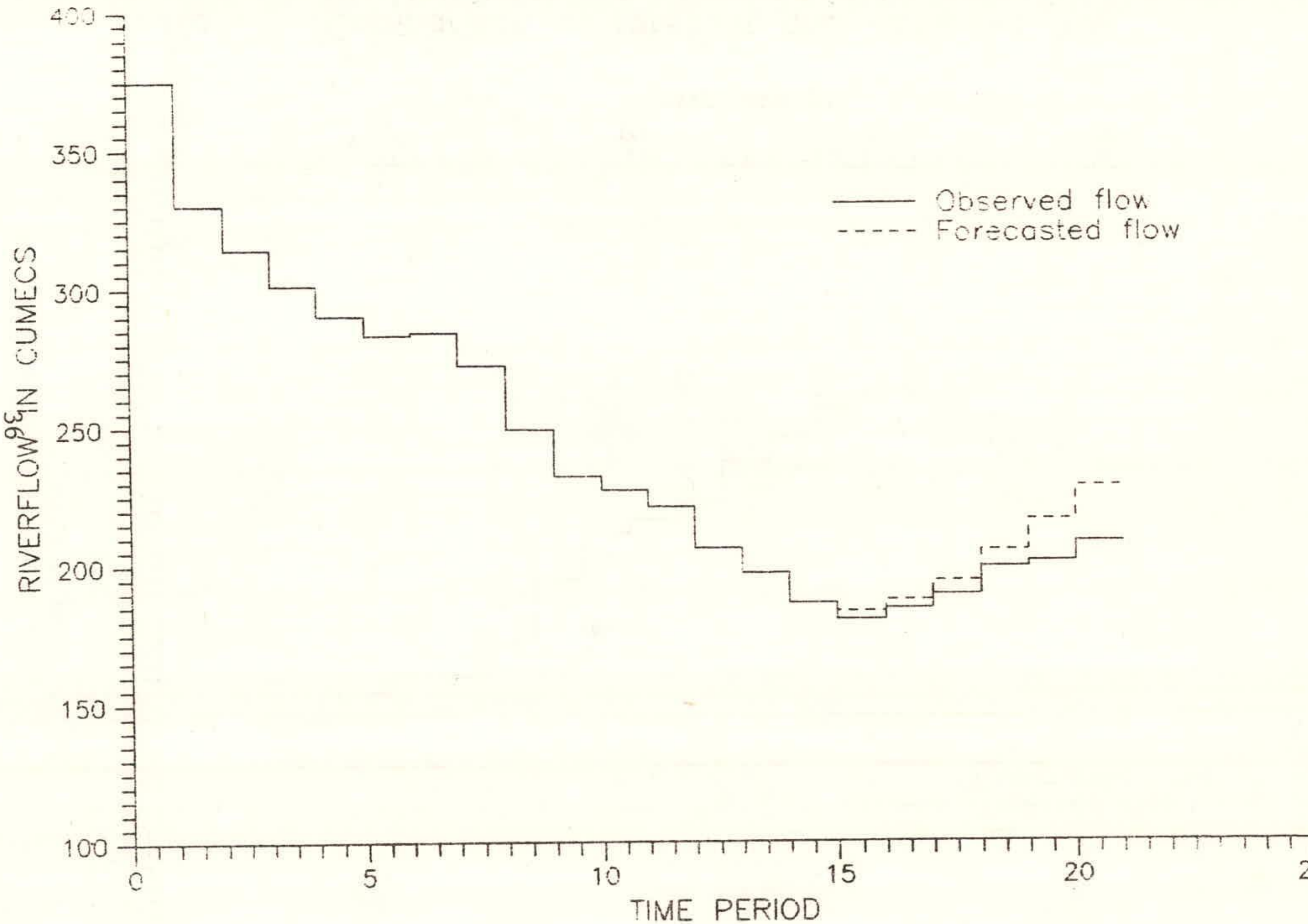

Fig. [illegible] : Comparison of forecast and observed flow (on the basis of observed data upto Mar.)

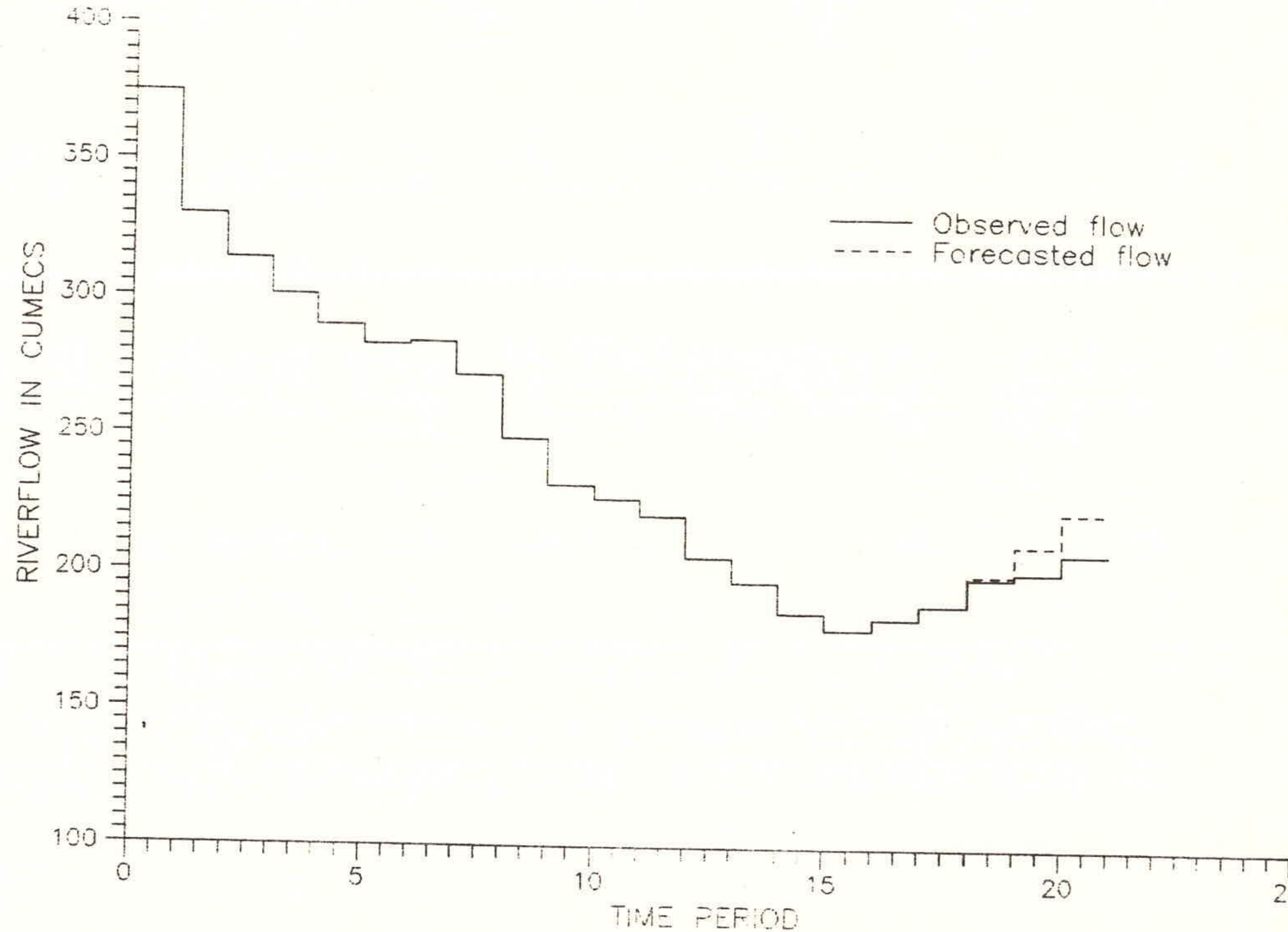

Fig. 21 : Comparison of forecast and observed flow
(on the basis of observed data upto Apr.)

When the forecasts are formulated for the period December to May on the basis of data for November III, November II, November I and October III; it is observed that in general percent error decreases for the first year. Similar pattern is observed for second and third years as well.

5.0 REMARKS

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 variation 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 result in boundary conditions changing with respect to time. The statistical method, not withstanding all its constraints, provides the only practical solution for the medium and long range forecasting for a basin having above referred features.

No doubt, the recommended exponentially decay function depicting the ground water flow can be very conveniently adopted provided:

a) The contribution during non-monsoon period is through ground water and the contribution from other factors such as rainfall, snow melt etc. are negligible;

b) The basin is of reasonably small size; and

c) The basin characteristics do not exhibit marked variations both in space and time.

Such ideal conditions can be rarely met under field conditions and therefore use of statistical approaches is rather unavoidable. This study shows that a suitable statistical method can be very effectively used for low flow forecasting with reasonably accurate results.

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