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DEVELOPMENT OF HYDROLOGICAL DROUGHT INDEX BASED ON RESERVOIR LEVEL FOR BARGI RESERVOIR

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PREFACE

The population growth in association with industrial and agricultural expansion has placed an increasing demand on water resources. The increased demand and high variability of rainfall necessitate the need for temporary storage of water to meet the demand during monsoon and non-monsoon period. During the period of deficiency in a normal year, the water from a temporary storage is supplied at a demand close to a value of its mean availability. The demand from a reservoir changes from year to year depending upon the prevailing conditions in a year. In a drought year, the demand increases, the availability of water in temporary storage reduces and, therefore, the water supply to meet the demand is not achieved during the period of its deficiency. The storage structures in such condition needs the nomograms to indicate the deficiency in meeting the demand discharge.

This report presents the nomograms in terms of reservoir level for actual demand and for different discharge to have an idea of reservoir level being in the situation of high flow, low flow or under drought. The nomograms not only give the drought index for a reservoir in terms of reservoir level, but also indicates the number of days, the water could be supplied at required demand discharge.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A drought index based on reservoir levels has been developed by the analysis of daily stream flow into the Bargi reservoir. The analysis has been carried out considering thirty six years daily flow data with different demand discharge as percentage of mean flow. The actual demand excluding the demands of right bank canal has also been used. The analysis include the annual flow departure analysis, analysis of maximum drought volume (storage volume), analysis of water available days and mean monthly available storage in terms of reservoir level. The results of the analysis are presented in the form of nomograms for the identification of high flow years, low flow years and drought years based on the existing reservoir level at actual and different demand discharges. Another drought index is presented, as mean reservoir level minus half of its standard deviation for low flow years and mean reservoir level minus its standard deviation for identification of drought years (moderate and severe drought) respectively.

It was observed that the availability of water was high in relation to the actual demand. In low flow years and even in moderate drought years, the demands from the reservoir could easily be met. It was proposed that the drought index should be developed also by considering the targeted demands of Right Bank Canal.

1.0 INTRODUCTION

The reservoirs are mainly built with the objective of storing the river flow to meet the water demand (total water requirement at any point of time) in arid and semi arid regions, during the periods of its deficiency. In such cases, it becomes important for the reservoir authorities to know an index for identification of drought, in terms of reservoir level. It is also necessary for authorities to know, the number of days for which water could be supplied at specific threshold discharge. At present, no specific guidelines are available and the authorities take decision either by their experience or through decisions based on the amount of rainfall and storage available or expected to arrive. However, the total rainfall alone exactly does not reflect the position of reservoir level. In view of this, it is necessary to have some nomograms in terms of reservoir level and for different demand discharge to have an idea of reservoir level being in normal, mild, or moderate drought situation and the number of days the water could be supplied at required demand discharge with no deficiency.

In arid and semi-arid regions, the water level in reservoirs frequently drops due to low availability of flow in streams. For such situation, it is important for reservoir authorities to know an index for identification of drought in terms of reservoir level. It also becomes important to know, the number of days for which water could be supplied at specific demand discharge.

The number of days water could be supplied is analysed as the period for which river flow combined with stored volume in reservoir is able to meet the demand discharge at different level of storage in the reservoir. The demand discharges are taken as the percentage of mean daily flow such that it covers the reservoir supply ranges of a normal year, low flow year and drought year. The similar analysis is also carried out for actual demand in order to compare with the other demands and to understand the actual situation of reservoir level under actual demand. The objectives of the study thus could be listed as below:

1. Development of nomograms for the estimation of water available days at different reservoir level for actual and other demands.

2. To develop nomograms for identification of high flow, low flow and drought year at different reservoir level.

2.0 REVIEW

The deviation of stream flow from the normal is videly accepted as an index to characterize the hydrological drought. The occurrence of such phenomena at certain regular intervals of time classify the area as drought prone. The C.W.C., 1982 has suggested that, the runoff, if found to be less than 75 percent of the normal runoff at a site, the year would be considered as drought year and if it occurs in 25 percent or more than 25 percent time of year, the area would be considered as drought prone.

Based on the guide lines, the NIH has analysed the river flow data of Krishna basin at eight different discharge measuring sites. Similarly the Godavari basin has been analysed for four different sites (NIH CS-37). The results in the form of flow duration curves, deficiency of the volume and dry spells are reported.

In low flow analysis, the drought volume and drought duration are normally estimated imposing a certain demand. This demand is usually a proportion of mean flow. The calculation procedure uses the Ripple Mass Diagram to calculate maximum annual drought volume/drought duration (Cunnane, 1981). In some cases the frequency analysis of drought volume and duration is also conducted. The analysis results in deciding the capacity of storage structure to meet a particular demand discharge at all times, when the river flow is not able to supply the demand.

The nomograms for drought index for the reservoir of Malaprabha and Ghataprabha in Belgaum district of Karnataka were developed applying the present methodology (NIH Report 1994-95). The results of the analysis are presented in the form of nomograms for the identification of drought based on the existing reservoir level at different demand discharge. Another drought index was presented, as mean reservoir level minus half of its standard deviation for mild drought and mean reservoir level minus its standard deviation for identification of moderate drought respectively.

3.0 BRIEF DESCRIPTION OF AREA

3.1 Narmada River Basin

The river Narmada rises in the Mikala range in Shahdol district in the Amarkantak plateau at an elevation of 1050 m.

Flowing generally in the south westerly direction in a narrow valley, the river takes a northerly turn near Mandla. After passing through the city of Jabalpur, the river flows through a deep narrow channel through the famous "Marble Rocks" of Bedaghat. The river system and the catchment area up to the Bargi reservoir is shown in Fig. 1.

After emerging from the gorge and continuing west, the river enters the fertile Narmada valley which is a long and narrow strip walled by Vindhyas on the north and Satpuras on the south. Coming out of the gorge, the river enters the plains of Gujarat and finally discharges into the Gulf of Khambat.

3.2 General Description of the Bargi Dam

In the series of major dams to be constructed on the Narmada river in Madhya Pradesh, the Bargi project is one of the major schemes which has been completed till date. The project consists of Bargi dam (later renamed as Rani Avanti Bai Sagar Project) which has been constructed on the river Narmada near village Bargi in the Jabalpur district. The dam is located 43 km. downstream of the Jabalpur city. The latitude and longitude of the dam are 22° 56' 30" N and 79° 55' 30" E respectively.

The Bargi dam is a composite earth and masonry dam, 5374.39 m long. The maximum height of the masonry dam is 69.80 m while that of earth dam is 29 m. The catchment area at the dam site is 14556 sq. km. The gross, live and dead storage capacities of the reservoir are 3.92 billion cubic meter (B.Cum.), 3.18 B.Cum. and

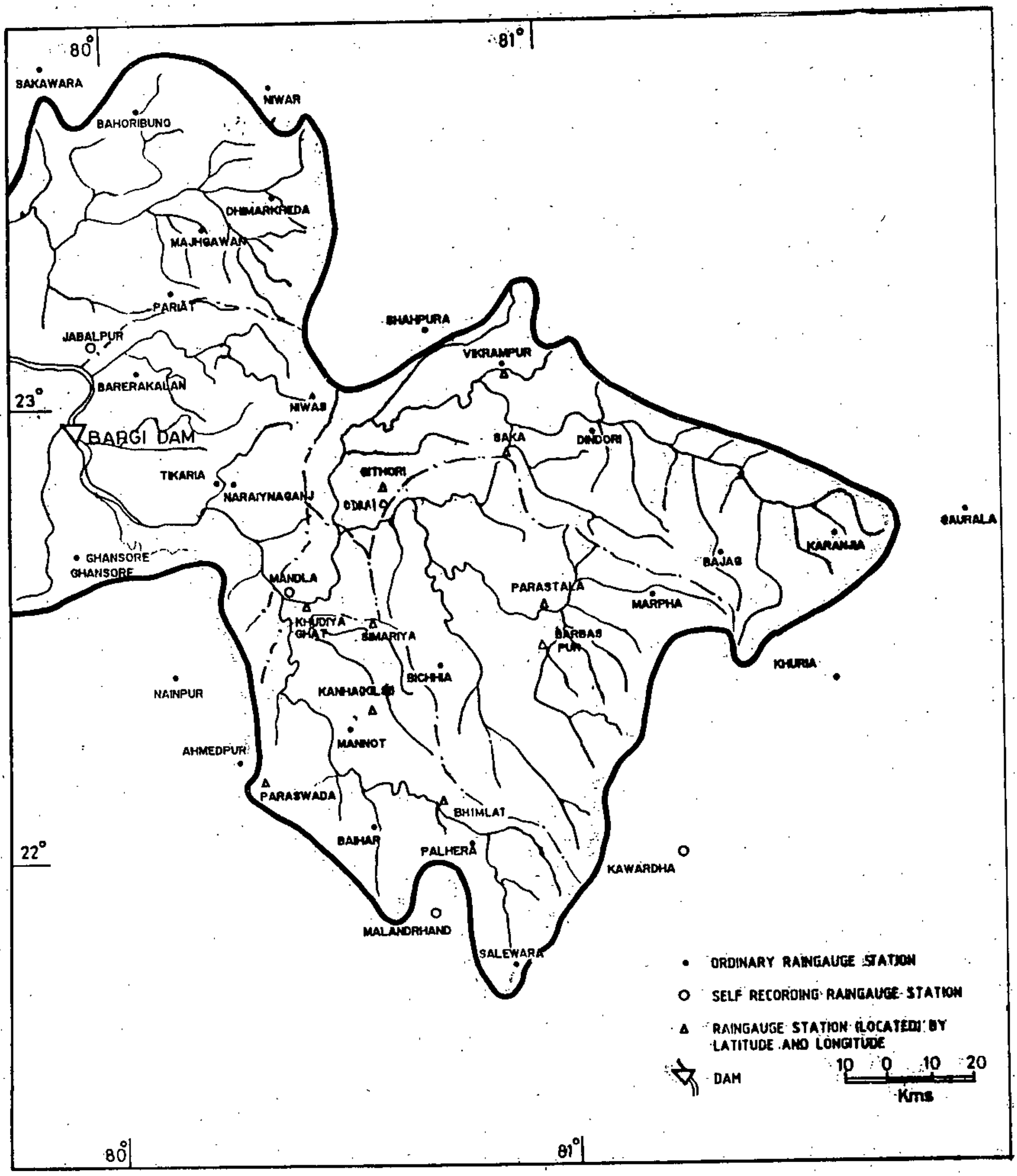

Fig. 1: Bargi reservoir and its catchment area in Upper narmada basin.

0.740 B.Cum. respectively. The maximum water level, full reservoir level and the dead storage level of the reservoir are at 425.70 m, 422.76 m and 403.55 m respectively. The estimated life of the reservoir is 100 years.

The project has been envisaged as a multipurpose scheme meant to serve for water supply for domestic and industrial purposes, irrigation and hydropower generation. One canal system (left bank canal system) is nearing completion and one power plant (River bed power plant) with capacity of 90 MW has already been completed for utilizing the stored water of the Bargi reservoir. The gross and cultivable command area of the left bank canal is 2.574 and 1.57 lakh ha. respectively. Other canal system (right bank canal system) is under construction. The purpose of right bank canal is to transport 116 M.Cum. of water for domestic use and around 2300 M.Cum. of water for irrigation and inter-basin transfer annually. One power house (Canal power house) with capacity of 15 MW is also proposed to be constructed in the left bank canal system. Annual water requirement from the reservoir through the left bank canal for domestic water supply and irrigation is 54 M.Cum. and 2160.1 M.Cum. respectively. In addition, annual firm energy requirement from the reservoir is 363 M.kwh. For discharging excess water during the flood season, a 385.72 m long spillway has been provided in the centre of the masonry section. Twenty one numbers of radial gates of size 13.71 m length and 15.25 m height have been provided on this spillway.

The water availability at the dam site has been based on the discharge data collected at the Jamtara gauge site. Jamtara gauge site is located 16 km. downstream of the Bargi dam site and has a catchment area of 16576 sq. km. Systematic gauging has been done at this site since 1949. The average annual inflow at the dam site is 7197 M.Cum. There are 13 raingauge stations in the catchment area. In some of the raingauge stations, rainfall data for nearly 89 years has been recorded. The average annual rainfall in the catchment up to Jamtara is 1414 mm. Rainfall in the basin mostly occurs during the monsoon months (July to October). During monsoon, 94.09 % of the total rainfall of the calender year occurs.

The reservoir has been classified as hilly according to the I.S. specification number 5477. The shape of the reservoir is almost longitudinal. Its longest periphery from the axis is about 80 km. The width at 16 km. and 25 km. from the axis is 16 km. and 3.2 km. respectively.

The salient features of Bargi reservoir are as below:

3.3 Demands from the Bargi Dam

The Bargi reservoir project is a multipurpose project meant to serve various purposes like water supply for domestic and industrial purposes, irrigation and hydropower generation. No additional storage has been provided for the purpose of flood control as the top of the gate level corresponds to the FRL of the dam. However, when the reservoir level is below the FRL, incidental flood control benefits can be achieved. Various demands which have been envisaged from the reservoir are detailed in the following section:

a) Water supply demands for domestic and industrial purposes.

The present policy of the Government of Madhya Pradesh is to supply water to the Jabalpur city for domestic and industrial purposes and to the urban and rural areas in the command area of the left bank canal irrigation projects. It has been planned that 54 M.Cum. of water will be supplied from the reservoir for domestic requirement of Jabalpur city. In the rural and urban areas under the command of left bank canal, 47 M.Cum. of water is required which will be met through the ground water reserve in the Jabalpur and Narasinghpur districts. Domestic supply for the Jabalpur city (54 M.Cum. annually) will be routed through the left bank canal. Further, there is also a provision of 116 M.Cum. of water for domestic purposes through the right bank canal which is under construction.

b) Irrigation demands

Bargi reservoir project is proposed to provide irrigation through its left bank canal system and right bank canal system. The Bargi left bank canal takes off from the left bank of the dam and runs up to the Shakkar river, covering a distance of 137.20 km. The command area under the Bargi L.B.C. lies in the Jabalpur and Narasinghpur districts. The gross command area of the L.B.C. system is 2.574 lakh ha. and the cultivable command area 1.570 lakh ha. Annual irrigation area with 140 % intensity of irrigation works out to be 2.198 lakh ha. The cropping pattern has been approved by the State Agriculture Department and the target monthly water requirements for irrigation at the left bank canal head are given in Table 1.

Table 1: Monthly demand of the Bargi reservoir.

Month	Irrigation $M.m^3$	Hydro power $M.m^3$	Water supply $M.m^3$	Total demand $M.m^3$	Total demand $M.m^3$	Ratio to mean demand m^3/sec	R.B.C. demand $M.m^3$
June	55.9	70	4.5	130.4	50.30	0.429	309.82
July	192.5	140	4.5	337.0	130.01	1.109	119.65
Aug.	69.3	210	4.5	283.8	109.49	0.934	132.76
Sept.	240.0	210	4.5	454.5	175.34	1.496	325.15
Oct.	435.9	210	4.5	650.4	250.92	2.141	465.20
Nov.	191.0	105	4.5	300.5	115.93	0.989	275.51
Dec.	274.7	105	4.5	384.2	148.24	1.265	285.94
Jan.	322.7	70	4.5	397.2	153.24	1.307	231.54
Feb.	200.4	70	4.5	274.9	106.05	0.905	157.49
Mar.	79.2	70	4.5	153.7	59.29	0.506	3.37
April	53.4	70	4.5	127.9	49.34	0.421	0.00
May	76.9	70	4.5	151.4	58.41	0.498	0.00
			Average	303.82	117.21		

The right bank canal of the Bargi reservoir has sill level of 410 m. The high intake level is kept in order to cross a ridge for inter-basin transfer. The annual water requirement from this canal is planned to be around 2300 M.Cum. This will include irrigation in the command area of the canal, water supply for domestic purposes and inter-basin transfer. In the present study, the demands from this canal system have not been accounted for as this canal system is in its initial phase of construction.

c) Hydropower demands

The project contemplates generation of 105 MW of hydropower by installation of 2 units of 45 MW power plants in the river bed and 2 units of 7.5 MW power plants in the left bank canal. At present, two units of river bed power plant are functioning. The power plant, with a total capacity of 90 MW, has been installed in the river bed at the right flank of the non-overflow section of the dam. The construction for the second power plant, with a total capacity of 15 MW, has not been started yet and has not been accounted for in the operation study. Firm power of the plants at 60 % load factor is 58 MW. The annual and firm energy requirement from the dam is 363 M kwh. For the river bed power plant, the invert level is 367.22 m. The maximum and minimum head for this plant are 57 m and 32 m respectively.

d) Flood control requirements

The detailed project report prepared by NVDD does not provide for flood protection through the operation of Bargi reservoir. However, through judicious and cautious reservoir operation, peak flood can be moderated to some extent, thereby reducing the damage and submergence of life and property downstream of the dam specially near Jabalpur town and Bedaghat area.

3.4 Salient Features of Bargi Reservoir

Location	Village - Bijora Dist. - Jabalpur State - M.P.
River	Narmada
Latitude	20° 56' 30"
Longitude	79° 55' 30"
Toposheet No.	55 N
Hydrology	
Catchment Area	14,556 sq.km.
Maximum Rainfall in the catchment	2311 mm.
Minimum Rainfall in the catchment	665 mm.
Average Rainfall in the catchment	1448 mm.

Maximum Annual yield	16.02 B.Cum.
Minimum Annual yield	3.67 "
Average Annual yield	7.19 "
50% dependable yield	8.07 "
75% dependable yield	5.29 "
90% dependable yield	4.10 "
100 yr. frequency flood at Jamtara	14744 cumec
1000 yr. frequency flood at Jamtara	19782 cumec
Maximum designed flood	51,510 cumec
Moderated flood	43,000 cumec

Reservoir data

River Bed level	RL 367.00 m.
Minimum draw down level (MDDL)	RL 403.55 m.
Spillway Crest level	RL 407.50 m.
Full Reservoir level (FRL)	RL 422.76 m.
Maximum Reservoir level (MWL)	RL 425.70 m.
Top of Dam Level (TBL)	RL 426.90 m.
Sill level (L.B.C.)	RL 401.00 m.
Sill level (R.B.C.)	RL 410.00 m.
Minimum Tail water level	RL 369.05 m.
Maximum Tail water level	RL 370.88 m.
Dead Storage Capacity at MDDL	740 $M.m^3$.
Gross Storage Capacity at Crest level	1140 $M.m^3$.
Gross Storage Capacity at FRL	3920 $M.m^3$.
Gross Storage Capacity at MWL	4806 $M.m^3$.
Live Storage Capacity at FRL	3180 $M.m^3$.
Area of Submergence at MDDL	30860 ha.
Area of Submergence at FRL	26797 ha.

Dam data

Type of Dam	Composite earthen & masonry
Length of masonry Dam	827 m.
Length of earthen Dam	2750.51 m.
Maximum height of masonry Dam	69 m.
Maximum height of earthen Dam	29 m.
Free Board above FRL	4.14 m.
Free Board above MWL	1.20 m.

Spillway

Length of Spillway	385.72 m.
Number of Gates	21 Nos.
Size of Gates	13.71 m x 15.25 m.
Type of Gates	Radial
Top level of Gates	422.76 m.

Outlets

Length of L.B.C.	135 km.
Size of L.B.C.	3 x 4 m.
Maximum discharge capacity of L.B.C.	127.8 cumec
Length of R.B.C.	95.5 km.
Size of R.B.C.	2.62 m x 2.62 m.

Power House		
Location		Right bank of Dam
Installed Capacity		2 x 45 MW 2 X 7.5 MW(Proposed)
Firm power & Load factor		58 MW at 60% Load factor
Head	Maximum	56.40 m.
	Minimum	35.67 m.
	Designed	47.85 m.

4.0 METHODOLOGY

The daily in flow to the reservoir is subjected to the analysis in order to prepare the nomograms for the identification of low flow and drought. The analysis carried out are as listed below.

1. Annual flow departure.
2. Maximum drought value.
3. Days of water availability.
4. Monthly mean available storage.

The objective of the study is to analyse the reservoir inflow to identify an index for low flow and drought in terms of reservoir level. With such an objective, it is important to know the limitation and applicability of above analysis. The analysis reported above are for the river flow with emphasis on low flow having objective to know about departure of low flow and reservoir storage to meet the demand during the lean flow period. The application of above analysis is therefore widely applicable to the conditions of arid to semi-arid regions. The above analysis are not intended for conditions where the regulation of the peak flow or routing through reservoir is to be considered. The flow departure analysis, results in the flow departure from its mean without giving any attention to the existing demand at that point of river.

The maximum drought volume at any site is analysed to decide the storage volume of a reservoir in order to supply the water during the period of deficiency for a given demand. In the present analysis of maximum drought volume, the demand is considered as the direct demand at that particular point. The direct water requirement includes (a) irrigation demand, (b) hydro power demands (c) water supply.

The analysis of water available days also considers the volume of water received in the river over and above the drought volume, which could be stored and utilized to compensate for the next drought volume. The analysis of mean monthly available storage also considers the drought volume as well as the demand as explained earlier.

4.1 Data

The analysis requires the daily inflow to the reservoir and reservoir level/capacity curve. In addition, the daily demand at the point is required if available. The elevation-area-capacity data of Bargi dam is reported in Table 2 as well of Fig. 2.

The actual irrigation, hydropower and water supply demand on the Right Bank Canal(R.B.C.) is given in Table 1. Total monthly demand and its ratio from the mean is represented in Fig.3. The analysis is also carried out for different demand as the percentage of mean available flow. The demand levels are 20%, 30%, 40%, 50%, 60% and 70% of mean available flow and are

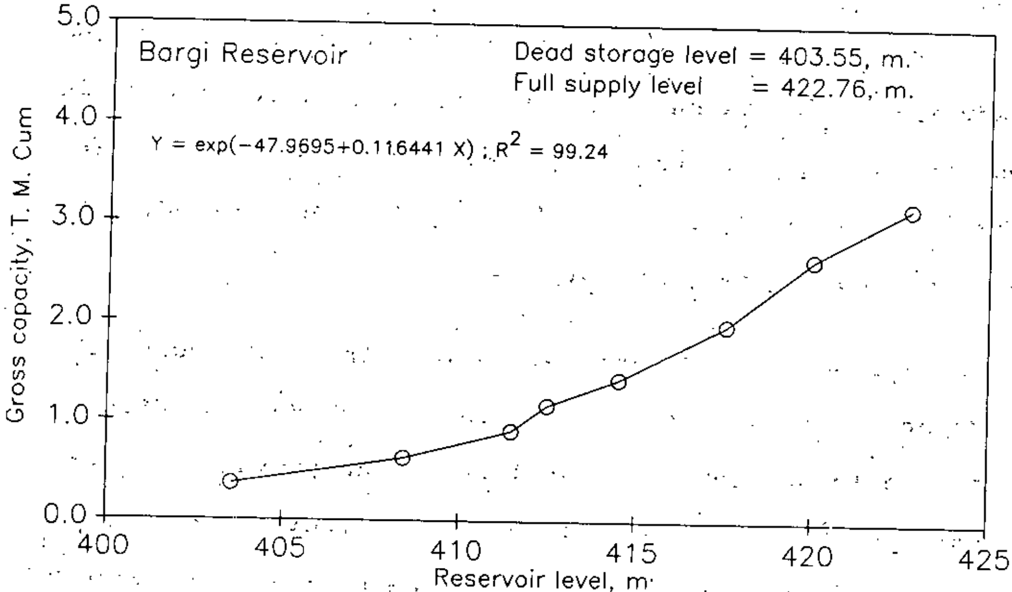

Fig. 2 : Elevation capacity curve for Bargi reservoir.

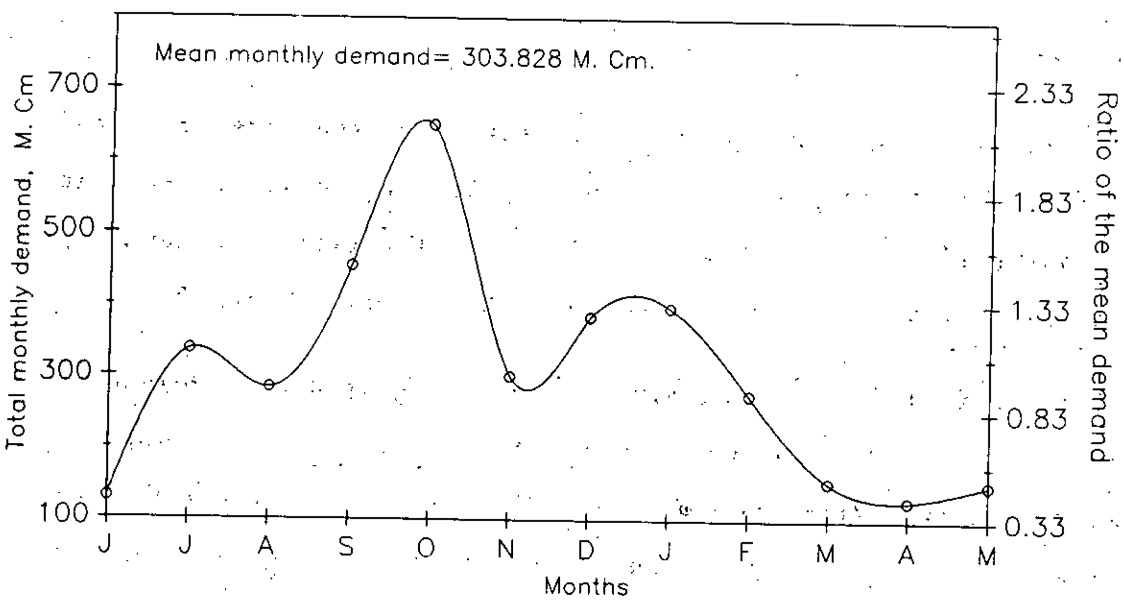

Fig.3 : Total actual demand to the Bargi reservoir excluding R.B.C.

considered constant in each month of the year.

Table 2: Elivation-area-capacity table for Bargi reservoir.

Sl. No.	Depth m	Elevation m	Area ha	Capacity T.M. m^3
1	0.00	381.56	0	0.000
2	0.48	382.04	48	0.000
3	8.54	390.11	560	0.018
4	14.67	396.24	2270	0.102
5	20.76	402.33	4246	0.299
6	21.98	403.55	5110	0.365
7	26.86	408.43	8585	0.634
8	29.91	411.48	2161	0.905
9	30.63	412.50	3625	1.164
10	32.96	414.52	6138	1.429
11	36.00	417.57	0119	1.980
12	38.45	420.02	4227	2.655
13	41.19	422.76	7296	3.181

The analysis is carried out using the daily river flow of thirty six years, starting from 1951-52 to 1986-87.

4.2 Selection of Base Period and Demand Discharge

The base period in the analysis is considered as a year and any carry over effect of drought volume from one year to next year is not considered to confirm with the assumption in estimation procedure of maximum drought volume. The assumption is that, all flows in the current base period are greater than the demand discharge. The assumption says that, at the end of each year there is one value of maximum drought volume.. The assumption is based on the fact that the reservoir is depleted to meet the demands due to drought in one year, at beginning of next year, there will be no storage in the reservoir to supply during deficiency. As such carry over of drought in case of reservoir physically has no meaning and finding an index for an empty reservoir has no significance. This carry over effect of drought could be true for an aquifer which is considered as a ground water reservoirs.

The other reason for not considering the carry over affect of drought volume from year to year is because of the nature of storage in the reservoir. The nature of storage in reservoir is limited by a minimum and maximum value, with an objective to utilise the storage most economically before the rains of next base period starts. The possibility of excess mining and its replenishment is not possible as such to the storage of reservoirs. Therefore, the carryover of drought volume from year to year is not considered in the analysis.

The decision of assigning a demand to be supplied by the reservoir is based on the purpose with which the reservoir is constructed. The demand at a point on a reservoir varies from year to year and on the local requirements. The demand in a year followed by a drought year also varies. The actual demand on the Bargi reservoir is reported in Table 1 along with the demands of R.B.C. not included in the analysis. The monthly mean demand comes to 3.64 T.M.M.[3] (thousand million metre cube) approximately 40% of mean flow. The analysis is also carried out for different constant demands . There constant demands are taken as the percentage of mean flow such that it covers the different reservoir supply ranges from normal to drought situations. The constant demands considered are 20%, 30%, 40%, 60% and 75% of mean flow.

4.3 Annual Flow Departure

The percent departure on annual basis is the departure of annual flow from its long term mean. The analysis highlights the year of high flows, low flows and drought years. The drought years could be classified in drought scale as per the criteria of C.W.C. 1982. The analysis requires the long term flow data and does not consider the effects of demand on drought identification. The analysis has been carried out as per the procedure defined by C.W.C., 1982. The mean daily flow is converted to mean annual flow and is subjected to the departure analysis. A commonly used index as suggested by C.W.C., 1982 has been applied to classify the drought. The criteria says as follows;

If;

a. Percent departure is greater than 50 % (Severe drought)
b. Percent departure is in between 25-50 % (Moderate drought)

This analysis at present is carried out only to have an idea of pattern of yearly river flow to reflect the situation of flow in each year and to split the years in to high flow, low flow and drought years.

4.4 Maximum Drought Volume

The maximum drought volume is the storage volume required at the beginning of the drought to prevent water supply for falling below the demand for the duration of the drought in a base period of a year. The definition of drought volume itself defines the duration of drought for a particular demand during any period of stream flow record.

The drought volume in a single drought consist of a single deficit followed by a surplus which should make recovery of the deficit and if the flow drops below the demand discharge before the recovery can occur, the drought is continued into next time step till the recovery is obtained. The net deficit at each time step is calculated till the volume becomes surplus related to some specific demand discharge. At the end of each surplus the maximum deficit volume is the drought volume in one drought element. It is, therefore, at high demands, there may be more numbers of drought elements with high drought volume but for low demand the number of drought elements as well as drought volume will be low. The method estimates the maximum drought on annual basis as one base period. The base period ends when there is no further flow less than the demand discharge i.e. the next monsoon should have started. The procedure has been defined by Institute of Hydrology (1980). This procedure allows for the effect of possible carry over of a previous drought element in the same base period, but not considered in the present analysis.

The maximum drought volume is estimated for each year using the mean daily inflow and superimposing a demand as percentage of mean daily flow. The analysis results in maximum drought volume for a base period as one year. By statistical analysis of maximum drought volume of a number of years , the required maximum storage volume for different return period is also estimated. The analysis of drought duration, the duration of low flow, could also be carried out on the similar guidelines, but not considered in this report.

The maximum drought volume is obtained by viewing the flow record and deciding a common date as the start of monsoon to all years for which data has been considered. For different return period the drought volume is plotted against demand discharge as a percentage of mean flow for the purposes of interpolating the drought volume (storage required) for other demand. This maximum drought volume related to a demand are arranged in ascending order and there plotting position are marked using an Extreme Value Type 1 distribution.

The cumulative distribution function of the Extreme value 1 type distribution is;

$$F(q) = \exp[-e^{((q-u)/\alpha)}] \qquad \ldots\ldots(1)$$

where; u, α are the parameters of location and scale respectively and are determined from sample data. F(q) is the non exceedable probability of q (data) in the series.

By replacing $(q-u)/\alpha = Y$, the equation (1) reduces to:

$$\ln\{F(Y)\} = -e^{-Y} \qquad \ldots\ldots(2)$$

where; Y is called the Extreme Value 1 standardized normal variate or reduced variate and has parameters u=o and α=1. An appropriate expression for probability value F_i corresponding to Y_i has been given by Gringorten as:

$$F_i = (i - 0.44)/(N + 0.12) \qquad \ldots\ldots(3)$$

where; N is the sample and i is the rank counted from the smallest value. The values of F_i is used with equation (2). Thus the drought volume (S) can be represented by plotting position (Y) as a line 'S = a + b Y' and the constants are estimated by a lest square analysis of 'S' on 'Y'. The return period (T_p) could be estimated by $Y = -\ln(1/T_p)$.

4.5 Water Available Days

The duration for which the supply is greater than the demand is considered as the water available day. The days water available from a reservoir is dependent on the storage volume of the reservoir and demand. An analysis for water available days at actual and at different constant demand has been carried out in order to yield a series of graphs relating the above parameters for Bargi reservoir at different storage. For the case, when the storage volume at the beginning is sufficiently high, such that, to prevent the supply from falling below a demand, there will be no day with shortage of water supply. The stored volume will be utilized to prevent the supply to fall below demand. Such a condition could only happen when either storage volume is very high or the demand is very low, i.e. the condition of uneconomical management of storage. For the conditions, when the storage at the beginning is not sufficient, the water supply normally goes down resulting in shortage of water supply and turns to the situation drought. The water available days is defined as a situation when;

Available cumulative supply > Cumulative demand

4.6 Monthly Mean Available Storage

Monthly mean available storage is estimated at actual and at different constant demands from daily river flow data. The monthly mean storage volume is then converted to level of reservoir. Based on a number of years of data, the monthly mean level and its standard deviation is estimated. A criteria for low flow and drought is given by relating monthly mean level to its standard deviation and half of standard deviation as follows;

For low flow;

Storage level < Monthly mean level - Standard deviation/2

For drought;

Storage level < Monthly mean level - Standard deviation

Thus, the reservoir level estimated with above criterion is compared with the reservoir level estimated for the condition of high flow years, low flow years and drought years.

5.0 RESULTS AND DISCUSSION

The mean daily flow to Bargi reservoir based on the thirty six years data, starting from 1951-52 to 1986-87 is estimated as 281.8 m^3/sec (8.88 T.M.m^3). The actual demand excluding the demands of Right Bank Canal (R.B.C.) is 112.7 m^3/sec (3.64 T.M.m^3). This demand is around 40% of mean available flow. Since, the actual demand is only around 40% of mean available flow, a reduction of around 60% in mean availability of water may not effect the supply.

On the other hand, one half of the actual demand (1.85

T.M.m^3) is during the monsoon months (June to October). During this period, the incoming water is directly supplied to meet the demand without using the storage of the reservoir. Thus, in relating, the storage of reservoir meets the demands of around 20% of mean available flow. Tnerefore, even in the years of moderate drought, when the stream flow departure is in between -25 % to -50 %, the demand of the reservoir could be met.

Keeping in view, the high availability of water, the river flow has been classified into three groups as the high flow years, the low flow years and the drought years. The guide lines to form the above grouping is kept such that, it should not effect the drought definition reported by C.W.C. for the case of river flow. The guidelines for the above grouping is as below.

(a) High flow years:

Percent departure less than -10%.

(b) Low flow years:

Percent departure -10% to -25%.

(c) Drought years:

Percent departure is greater than - 25% (It covers mild drought {-25% to 50%} and Severe drought {greater than -50%}.

The flow departure analysis indicates a high flow in twenty years, a low flow in seven years and nine years as drought years. The seven years out of nine drought years faced moderate drought and two years faced severe drought (Table 3). For the development of drought index, each group has been analysed separately.

In the analysis of maximum drought volume, the first step is to decide the time of on set of monsoon, such that, all the flows beyond this time is above the demand in order to fulfil the limitation of the procedure. The daily river flow of all the years, indicates that no exact date of start of monsoon could be assigned but on an average it starts in the month of June. Therefore, June 1 is considered as the date beyond which all flows in the river are assumed to be greater than the demand.

Table 3: Departure of annual inflows to Bargi reservoir.

Sl. no.	Year	Percent departure	Remarks	Sl. no.	Year	Percent departure	Remarks
1	1951-52	-47.56	M.D.	19	1969-70	1.65	H.F.
2	1952-53	-14.97	L.F.	20	1970-71	35.90	H.F.
3	1953-54	-24.28	L.F.	21	1971-72	39.18	H.F.
4	1954-55	-23.02	L.F.	22	1972-73	-15.55	L.F.
5	1955-56	28.78	H.F.	23	1973-74	35.56	H.F.
6	1956-57	62.20	H.F.	24	1974-75	-45.87	M.D.
7	1957-58	-10.57	L.F.	25	1975-76	27.71	H.F.
8	1958-59	-9.64	H.F.	26	1976-77	-42.67	M.D.
9	1959-60	36.07	H.F.	27	1977-78	36.24	H.F.
10	1960-61	-6.58	H.F.	28	1978-79	.22	H.F.
11	1961-62	95.59	H.F.	29	1979-80	-65.75	S.D.
12	1962-63	-32.99	M.D.	30	1980-81	46.67	H.F.
13	1963-64	-12.30	L.F.	31	1981-82	-45.73	M.D.
14	1964-65	25.49	H.F.	32	1982-83	-19.83	L.F.
15	1965-66	-69.65	S.D.	33	1983-84	24.48	H.F.
16	1966-67	-48.65	M.D.	34	1984-85	14.65	H.F.
17	1967-68	46.17	H.F.	35	1985-86	10.52	H.F.
18	1968-69	-33.36	M.D.	36	1986-87	2.54	H.F.

L.F: Low flow, H.F: High flow,
M.D: Moderate drought, S.D: Severe drought.

The maximum drought volume (Storage required) for the constant demands of 20%, 30%, 40%, 50%, 60% and 70% of mean flow and for actual demand has been estimated and reported in Fig. 4. In general, the drought volume increases with demand and return period. Comparison of drought volume at 40% of constant demand and at actual demand indicates an increase in drought volume with

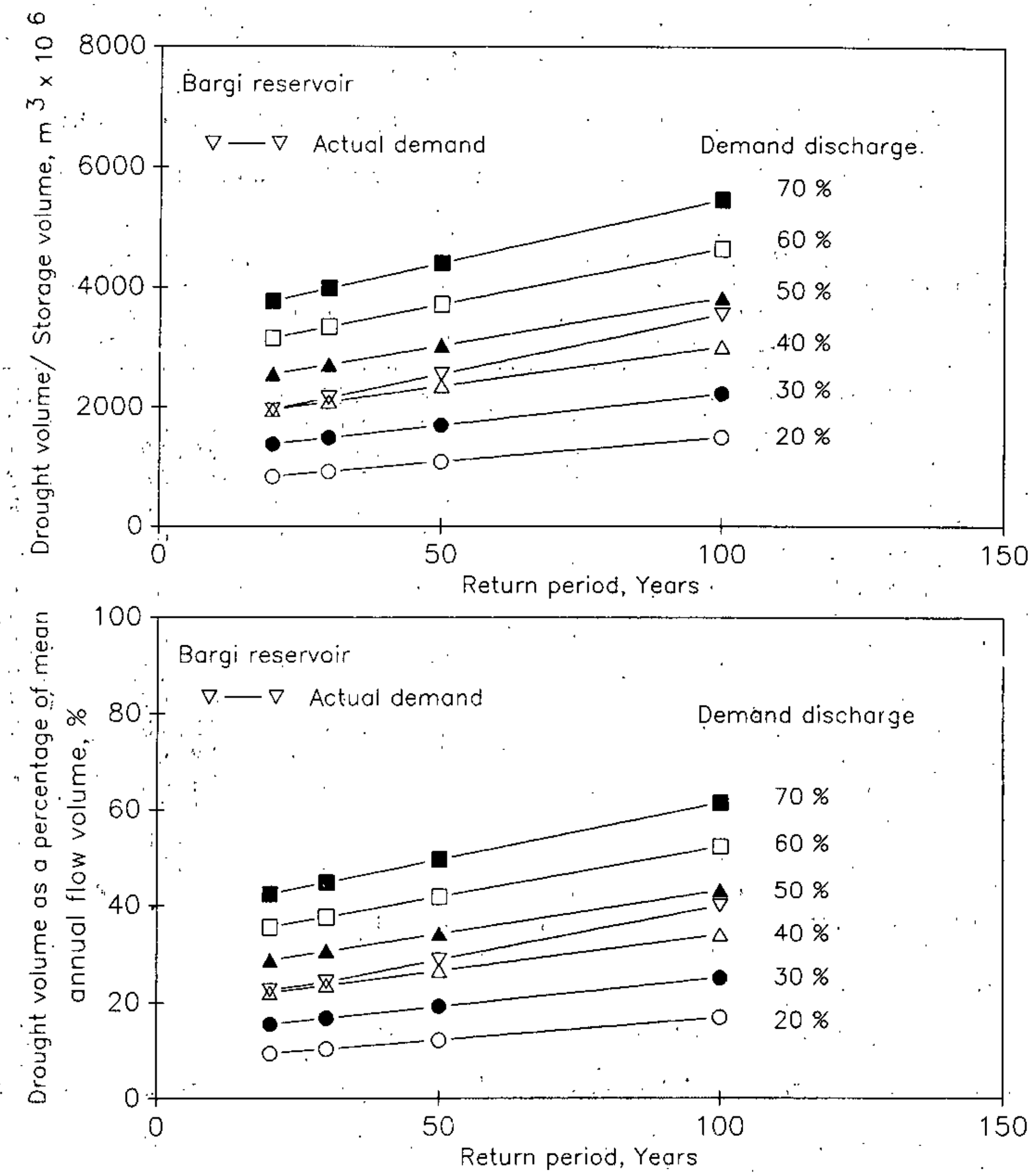

Fig. 4: Estimated drought volume and drought volume as a percentage of mean annual flow volume at different demand discharges and return period.

return period. The maximum drought volume at constant demand of 40% of mean flow and at hundred years return period is 3.017 T.M.m^3 and it increases to 3.55 T.M.m^3 when the same demand 40% of mean flow is actual demand. The similar observation are for the drought volume as a percentage of mean annual flow volume.

By looking at the actual monthly demand (Table 1), it can be seen that nearly half of the demand is during the months of June to October when water availability is sufficiently high and for meeting this demand the reservoir storage is not utilized. Thus the actual demand on the storage of reservoir is nearly half of that reported and in the months of November to May. In case the demand on the storage of reservoir is assumed around half of the present demand, the maximum drought value (required storage) should have been 1.708 T.M.m^3. When this required storage is compared with the actual reservoir storage as 3.18 T.M.m^3, the storage of reservoir is quite high compared to storage required.

Water available days for six different demand and for the actual demand at different reservoir level is estimated. The estimated average number of water available days in a year is reported in Fig.5. It can be observed that the reservoir level at F.R.L. will meet a constant demand of 40 percent of mean flow on an average 336 days of the year. When this demand is varied as per the actual demand, the water available days comes to 335.

Two conclusions could be drawn out of the above. Firstly, that the variable and the constant demand makes no difference in number of water available days. Secondly, the reservoir will not

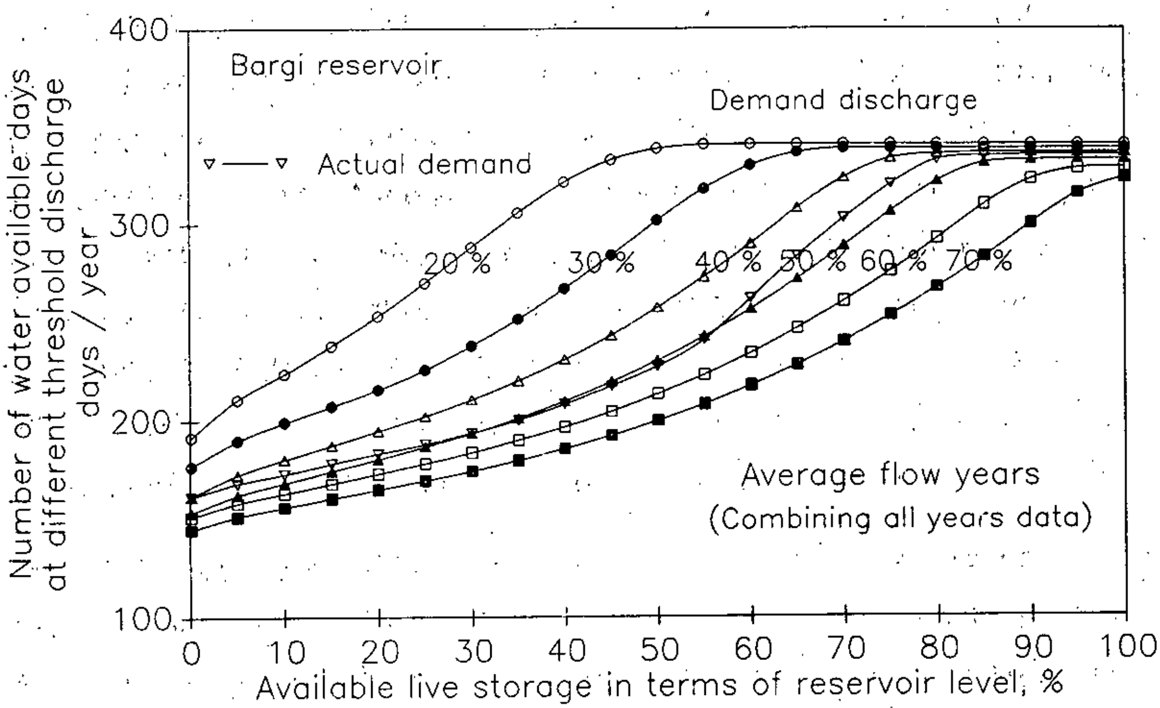

Fig5: Average number of water available days at different demand discharges for Bargi reservoir.

be able to supply water for around 30 or less days in a year. It is happening so, because of the following two reasons.

1. Since the demand is too less as compared to water availability, the variation of demand in different months makes no difference in water available days.

2. The analysis assumes that the reservoir is empty at the start of each year in the month of June. This assumption may not be true to some extent for reservoirs like Bargi where the demand is very less as compared to average water availability.

3. The analysis also assumes that the monsoon starts on June 1, which may not be true because of the natural variation of the arrival of monsoon. The results suggest that the analysis should be carried out also by considering the carry over of storage from year to year.

Average number of water available days is also estimated for the data in three groups (high flow years, low flow years and drought years) for both constant demands and actual demand. Fig.6. The water available days of high flow years, low flow years and drought years, are almost similar. It indicates that a reduction of mean water availability during the high flow years to low flow years to drought years has not significantly effected the water availability from the reservoir.

The water available days by imposing actual demand for the three conditions of flow and for the average flow years is reported in Table 4. The average number of water available days

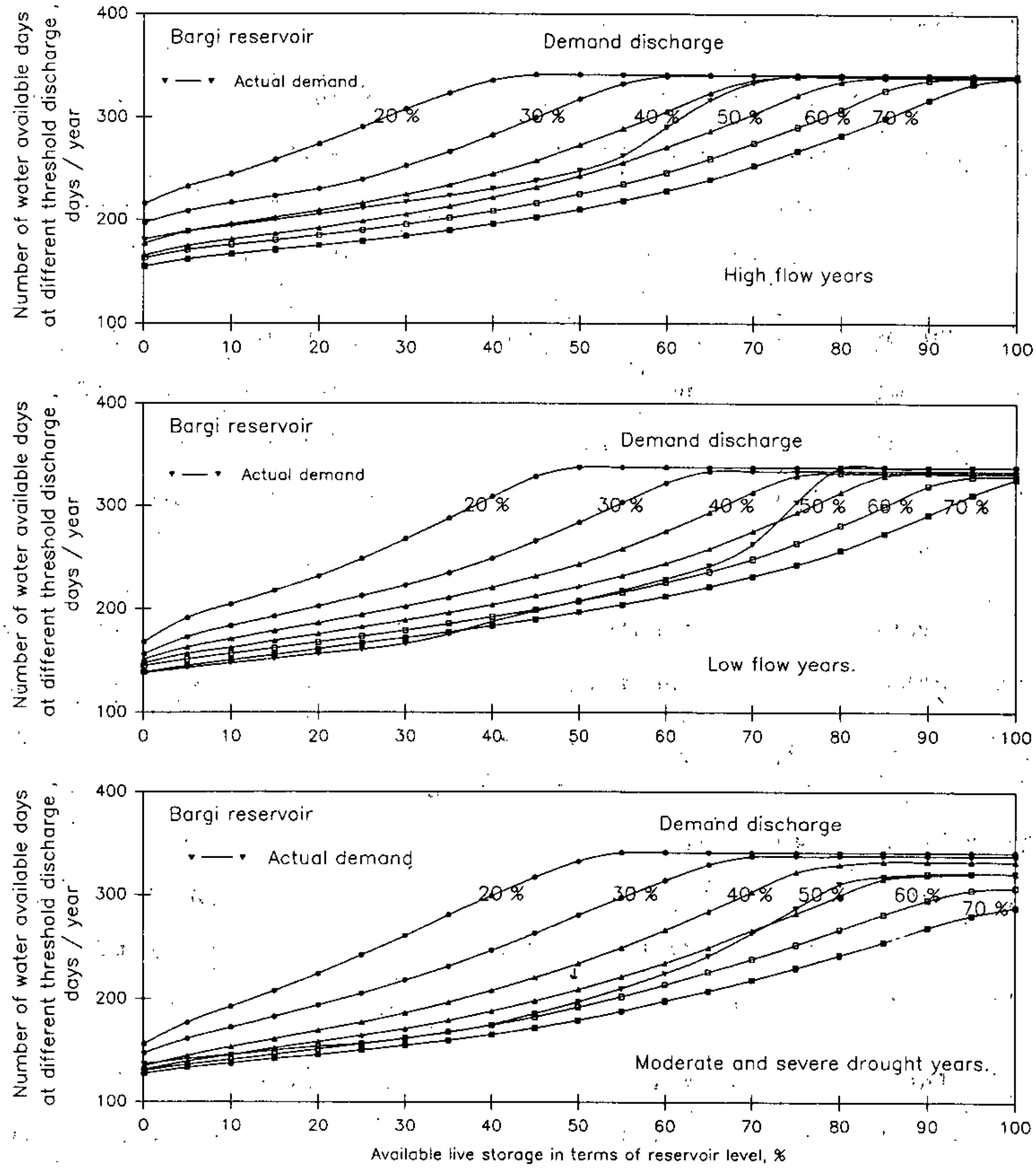

Fig. 6: Number of water available days at different demand discharges for different condition of flow.

for the average flow years, high flow years, low flow years and drought years are not significantly different as compared to the change in water availability in high to low to drought years. It again suggests that the demand is too low compared to water availability.

Table 4: Average minimum number of water available days from Bargi reservoir under actual demand (around 40 % of the mean flow).

Sl. no.	Reservoir level	Reservoir level	Average minimum number of water available days			
	%	m	Average flow years	Highflow years	Lowflow years	Drough years
1	100.0	422.8	335	341	337	320
2	95.0	421.8	335	341	337	320
3	90.0	420.8	335	341	337	320
4	85.0	419.9	334	341	337	318
5	80.0	418.9	332	341	337	310
6	75.0	418.0	320	340	304	287
7	70.0	417.0	302	334	263	263
8	65.0	416.0	283	317	242	241
9	60.0	415.1	262	290	229	224
10	55.0	414.1	241	263	218	209
11	50.0	413.2	227	248	207	197
12	45.0	412.2	217	238	198	185
13	40.0	411.2	208	230	187	175
14	35.0	410.3	200	224	175	167
15	30.0	409.3	193	218	166	161
16	25.0	408.4	188	211	161	156
17	20.0	407.4	183	205	156	153
18	15.0	406.4	178	200	152	150
19	10.0	405.5	173	194	147	145
20	15.0	404.5	168	188	143	141
21	.1	403.6	161	180	138	137

It can also be observed that the average number of water available days at constant demand of 40% of mean flow and at full reservoir level is 340, 332, 332 respectively for high flow years, low flow years and drought years. (Fig.6) and the same is 341, 337 and 320 for actual demand (Table 4). A similarity is again observed between the two.

The values presented in Table 4 could be used for low flow and drought identification and indexing, by knowing the available storage. The values also reflect the number of days when the water will not be available at actual demand. The situation when the number of water available days at actual demand are less than that reported reflects the condition of drought. Since, the water availability to Bargi reservoir is very high compared to demand, a difference in water available days for different conditions of flow could not be observed. The results suggest towards the possibility of imposing higher demands on the reservoir.

The mean reservoir level is also estimated and reported by splitting the data in to high flow years, low flow years and drought years for both constant demands and the actual demand (Fig.7).

It can be seen (Fig.7) that mean reservoir level for the year of high flow is followed by low flow year and drought years. Also for high flow years the reservoir is able to supply water up to 70% of constant demand and in low flow years and drought years it could supply water up to 60% of constant demand, without being empty in the month of April and May. The reservoir levels at the end of year in May for the case of actual demand remains quite above from the dead level at the level of 418.6 m, 416.2 m and 413.2 m respectively for high flow year, low flow years and drought years. Table 5.

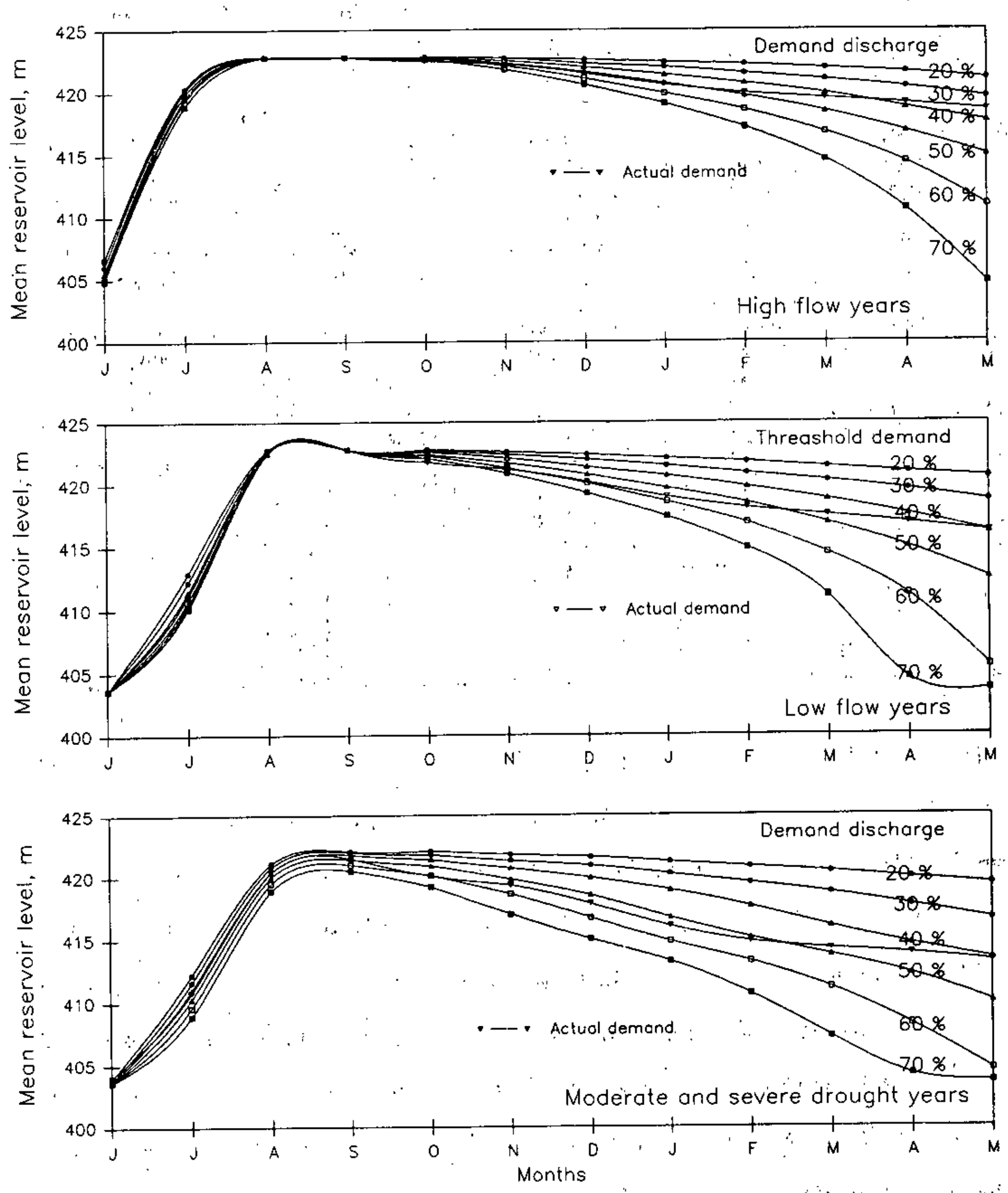

Fig.7 : Monthly mean reservoir level at different demand discharges and actual demand for different flow years.

The mean reservoir level at different demands and at actual demand for different months are presented in Fig.8 along with the mean reservoir level minus half of its standard deviation and mean reservoir level minus its standard deviation.

Table 5: Mean reservoir level for different condition of flow at actual demand of Bargi reservoir.

Month	Mean monthly reservoir level, m					
	Highflow years	Lowflow years	Drought years	Mean	Mean-SD/2	Mean-SD
June	406.6	403.6	403.6	405.4	403.7	402.1
July	419.8	411.1	410.8	415.9	412.8	409.8
Aug.	422.8	422.7	420.4	422.2	421.2	420.2
Sept.	422.8	422.8	421.5	422.5	421.9	421.2
Oct.	422.5	421.8	420.1	421.8	420.9	420.0
Nov.	422.2	421.2	419.3	421.3	420.2	419.2
Dec.	421.5	420.2	417.8	420.3	419.0	417.6
Jan.	420.6	419.0	416.0	419.1	417.4	415.7
Feb.	419.9	418.1	414.8	418.3	416.4	414.6
Mar.	419.5	417.5	414.2	417.8	416.0	414.1
April	419.1	416.9	413.8	417.4	415.6	413.8
May	418.6	416.2	413.2	416.8	415.0	413.3

The results in Fig.8 are for identification and indexing of low flow years and drought years. Again, it can be said that for the mean flow years the reservoir could meet 70 % of mean flow demand and for the condition of mean-S.D./2 and Mean-S.D. The reservoir could meet 60% of mean flow demand. The reservoir levels at the end of year in the month of may for the case of actual demand remains quite above from the dead level at the level of 416.8 m, 415.0 m and 413.3 m respectively for the conditions of mean, mean-SD/2 and mean-SD.

A similarity could be seen between the reservoir levels for the condition of mean-SD/2 and low flow years (Table 5).

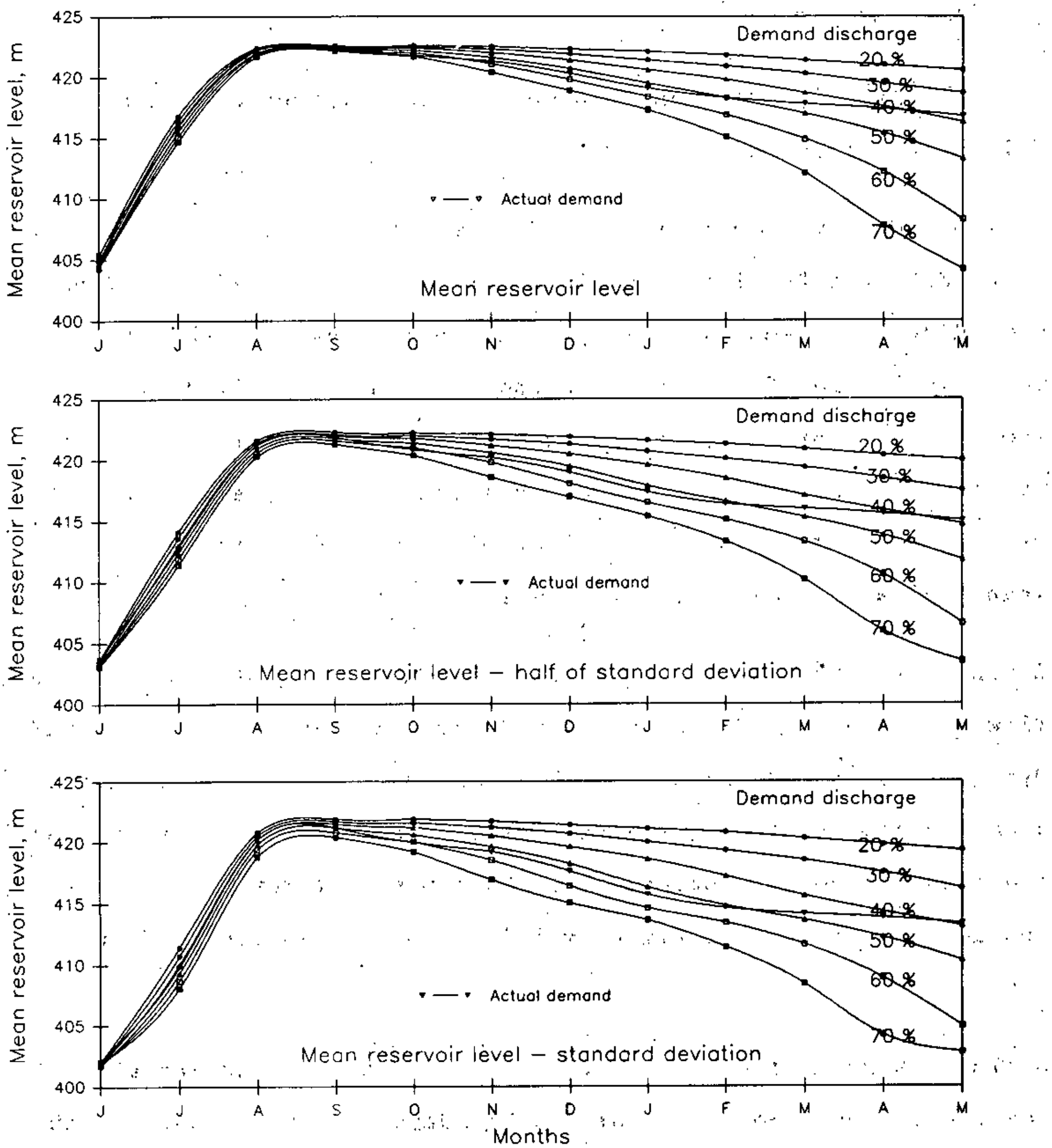

Fig. 8 : Mean reservoir level for different conditions of drought at different demand discharges for Bargi reservoir.

Similarly the reservoir levels for the condition of Mean-SD correspond to the drought years. Therefore, a reservoir level equal or lower than the condition of Mean - SD/2 and mean-SD will index the condition of low flow years and drought years.

6.0 CONCLUSIONS

The results discussed in the preceeding section led to the following conclusion.

1. The mean available flow based on the thirty six years daily flow data is 281.8 m^3/sec (8.88 T.M.m^3) and the actual demand excluding the demands of R.B.C. is nearly less than half of the mean available flow and is around 112.7 m^3/sec (3.64 T.M.m^3). Around half of this demand (1.85 T.M.m^3) is met during the monsoon season with out using the storage of the reservoir. The results suggest that a reduction of around 60 % or greater in mean available flow will not effect the demands.

2. The maximum drought volume for constant demand of 40% of mean flow is 3.017 T.M.m^3 and for the actual demand the maximum drought value is 3.55 T.M.m^3. However nearly half of the actual demand does not utilize the storage of the reservoir. The maximum drought volume corresponding to the demands of November to May should have been approximately 1.7 T.M.m^3, it is observed quite high.

3. The water available days even at the lowest demand and at full reservoir level does not come to 365 days. It is because of the assumption of considering the reservoir empty at the start of

each year in the month of June and also because of assuming the arrival of monsoon on June 1 in each year.

4. The water available days at different demand and at actual demand and for different condition of flow has not indicated a remarkable difference in the number of water available days. It suggested that in low flow year and even in drought years, the actual demands could be met without creating a drought condition. However, for severe drought years a shortage of water may exist which needs to be analysed to be sure.

5. The mean reservoir level in all three condition of flow (high flow years, low flow years and in drought years) never reaches below 413.2 m. It suggests for a further utilization of storage and increasing the demands with different level in high flow years, low flow years and in drought years.

6. A reservoir level below the level of mean - SD/2 and mean - SD represents the condition low flow years and drought years with respect to present existing demand.

7.0 . SUGGESTION

From the study it appears that the waters of the reservoir are under utilised even a reduction of around 60% in the mean available flow will not effect the demands. The demands on the reservoir could be increased subjectrd to the analysis for upper section water requirements and evaporation losses from reservoir. The project wise dependability should be checked for the designed demands (i.e., 100 % for water supply, 90 % for hydropower, and

75 % for irrigation). Further analysis is required by considering the following:

1. Considering the actual demands of link bank canal.

2. Considering the demands under two groups i.e. the demands of the monsoon season (June to October) when storage is not utilized and demand of non-monsoon season (November to May) when the storage of reservoir is utilized to meet the demand.

3. Further analysis is also required by considering the carryover of the storage from year to year with the case of new increased demand.

8.0: REFERENCES

1. Cunnane, C. (1981). Lecture notes for M. Sc. course in stochastic hydrology. Department of Engineering Hydrology, University College, Gelway, Ireland.

2. Central Water Commission (1982). Report on identification of drought prone areas for 99 districts, New Delhi.

3. Institute of Hydrology. (1980). Low flow studies. Wallingford, Oxon, Research report.

4. National Institute of Hydrology, (1989-90). Hydrological aspects of drought up to 1987-88. CS-37, Roorkee, U.P., India.

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