OPTIMAL SCALE OF HYDRO-DEVELOPMENT FOR LAKHWAR-VYASI SCHEME

A DISSERTATION
submitted in partial fulfilment
of the requirements for the award of the Degree
of
MASTER OF ENGINEERING
in
HYDROLOGY

By
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C E R T I F I C A T E

Certified that the dissertation entitled "OPTIMAL SCALE OF HYDRO-DEVELOPMENT OF LAKHWAR-VYASI SCHEME" which is being submitted by Sri Prasanta Kumar Ghoshal in partial fulfilment for the award of Degree of Master of Engineering in Hydrology of University of Roorkee is a record of candidate's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is to certify that he has worked for a period of more than 9 months since October 1973 for preparing this dissertation for Master of Engineering Degree of the University.

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INTERNAL GUIDE

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P. K. GHOSHAL

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CHAPTER I

INTRODUCTION

1.01 GENERAL

The development and prosperity of a Country is largely dependent on the availability of power. Growth of generation and utilisation of power is aptly taken as the index of economic development of any region or a country. For a developing country like ours, the need for generation and distribution of electricity is all the more as power is not only required for Industrial and domestic uses, it is also required for vast areas for tapping the ground water resources for Irrigation purposes. Rural electrification for village industry and Lift Irrigation too has gained momentum in the past few years. As a result of these development activities and the rapidly growing Industry and traction load, the demand for power has increased at an enormous rate and it become necessary to add a number of new schemes to augment power supply position in the plan period. While the installed generation capacity in the country under all the categories of power stations i.e. oil, thermal and Hydro was only a meagre 1363 MW at the time of independence (1947) it has risen to 12974 MW at the end of 1968-69[14]. Inspite of the tremendous stride made in the growth of generation, the supply of power has fallen short of demand at various parts of India, at different times resulting in huge losses to the nation by way of loss of production.

The conventional sources of power are the energy of falling water, coal, oil gas and nuclear energy from fissionable material (other sources of energy such as wind, tide geothermal & direct solar energy are not significant at the present stage of development). Out of the above conventional sources of energy water and coal forms the two most commonly tapped sources for large scale power generation in India.

In the past, the development of power took place mostly according to the necessity of the region. Depending on the facilities available, a hydro power or a Thermal plant was being taken up to cater to the needs of the particular region. But with the development activity becoming manifold and spreading over to wider areas under successive plans, it came to be realised, that to efficiently cater to the energy requirements within the available generation capacity, greater integration of the system over wider regions is necessary and thus came the idea of regional and supergrids. This is said to result in reduction of wastage of power and ensure better management and utilisation of existing power resources.

It will be seen that planning for power now has to take a wider perspective of the situation in view of the integrated operation of a number of plants namely Thermal and Hydro together. In this context, it is necessary to consider the system load, the load demand pattern and the part of the load curve the new plant is going to be assigned and its effect on existing plants in the system etc., and to know the characteristics of the two types of plants.

1.02 CHARACTERISTICS OF THERMAL PLANTS & OPERATION CRITERIA:

Thermal plants in India are mostly run with coal as fuel. Though nuclear fuel plants are also gradually coming up, till now the development made in that direction constitutes an insignificant fraction of the total installed capacity of the country. So it may be seen that by far it is coal that goes for almost the entire Thermal power generation in India at present and therefore for the purposes of this study, thermal plants are taken to mean those plants which use coal as fuel.

Though fortunately for us we have large coal reserves in our Country it is a consumable resource and its use in steam plants for power generation is only at the cost of other uses. Good variety of Coal require conservation for metallurgical purposes and therefore indiscriminate use of the same is likely to cause strain on resources in future. But as the present position exists, large number of steam generation plants have come up since pre-independence days throughout India usually near their load centres depending on the availability of Coal and water for the plant.

Though lately due to advancement in technology more efficient steam plants have come up, these are characterised in general by a decline in the effective capacity with age. For example some of the steam plants of U.P. like the Kanpur (river side), Harduaganj - A power house have lost about 47% and 16% of the initial capacity. Several other small stations like Agra, Lucknow, Varanasi await closure as soon as new power plants are added in the grid - Due to loss of efficiency of these plants the system reliability has also reduced.

Further, the cost of operating a steam plant is much higher than for a hydroelectric plant mainly because of the high cost involved in the fuel and cost of transportation of the fuel. A steam plant is also more difficult to operate and maintain and the cost of labour, maintenance and repairs is much higher than for a hydro electric plant[17]. Fuel cost with a steam plant varies with the unit price of fuel and the plant output. So the cost per unit of generation is directly related to the plant output. The situation gets wo\$se where a steam power station is held in reserve and utilised to carry peak loads. A substantial portion of the annual operating cost is incurred just to keep the plant ready to run if required, as it is not desirable to completely shutdown the plant when not in use. A steam plant performing the peaking duty will therefore have a very low capacity factor and consequently high cost of generation. Due to these reasons it is desirable to run a steam plant at a high capacity factor for greater economy. This is possible only by interconnecting a group of power stations so that at least some of the plants can be run at a high capacity factor and the others for peaking purposes. Here again those plants taking peak load will be at the same disadvantage as described earlier. Due to low capacity factor for them, the cost per unit of generation would be higher. This shows that steam plants are basically not suited for taking peak load from the consideration of efficiency and economy. Thus integrated operation of a group of steam power stations has only the main advantages like pooling of reserves, optimisation of overhaul scheduling etc. Stronger interconnection of the system with the adjacent system represents an additional alternative for meeting the load.[10]

1.03 CHARACTERISTICS OF HYDRO PLANTS & OPERATION CRITERIA

Hydroplants utilise the energy of falling water to generate power. So once a stream is harnessed through a power plant, it provides an inexhaustible source of energy. Though the initial cost may be higher than that of a steam plant of comparable capacity the cost of operation and maintenance of a Hydro plant is much less than for a steam plant. Since the input to the plant consists of water, there is no fuel cost for the plant and for this reason cost of hydro power generally works out to be cheaper. As water is a renewable resource , delay in utilising the resources to generate hydro power causes a wastage of resources, whereas in case of all other type of power stations the resources are consumable and costly. Hydro-generation directly saves upon these consumable fuel.

A hydro-electric plant can be put into operation in a very short time, the actual time will vary from a few seconds to 3 or 4 min. depending on the length of the conduit. So it is well adapted to provide reserve capacity at short notice as might be required if some other unit of the system fails. Due to its fast response and versatile operation characteristics, it is always cheaper to have reserve capacity in Hydro than in steam. Incremental cost for meeting peak demand is very little for hydro as the generation is achieved simply by drawing more water from the storage.

A hydro plant can be operated conveniently at any part of the load curve. It can run as a peak load or base load station or in any intermediate position. Running at a low capacity factor does not influence the cost of generation from a hydro plant as it does in case of a steam plant. However it has to be remembered that in case of Hydro, the capacity should not be reduced to below 40% of the rated capacity to avoid cavitation effect and damage to the turbine runner. In case of thermal the capacity should not be reduced below 60% in general.

A power plant, be it thermal or hydro would be seriously handicapped if run as an individual station so far as reliability of supply, reserve capacity, peak capability and maintenance is concerned. Economy and efficiency of the system vastly improves by interconnecting all the stations. Modern power systems therefore aim at integrated operation of all the stations in the system. Integration of hydro plants with thermal in the system provide additional advantages due to unique characteristics of hydro plant described above.

1.04 INTEGRATED OPERATION OF THERMAL & HYDRO POWER PLANTS

In general interconnection of power stations is intended to make the supply more reliable, efficient and economical. It provides flexibility of operation, pooling

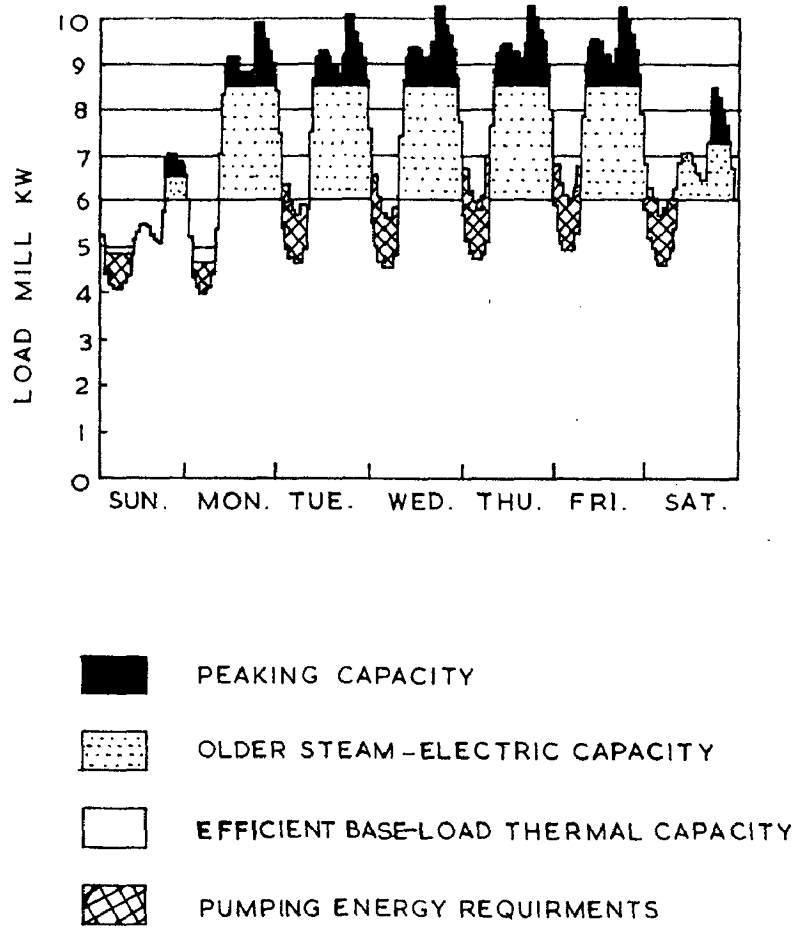

FIG. 2 - TYPICAL POWER SYSTEM WEEKLY LOAD CURVE

(AFTER J.G. THON-10)

of reserves and efficiency maintenance. Due to interconnection it becomes possible to put each power station to take that part of the load curve for which it is most suitable.

As the load varies throughout the day significantly it becomes necessary to use several classes of generating units to economically meet the load. In an integrated system large steam power units should be operated at near-constant, high capacity factor throughout the day. They should be assigned to the lowest part of the load curve (Fig.2) to take advantage of their characteristics. Peaking units are allowed to take large-power but low-energy short term peaks of the order of 1 hr. to 3 hr. at highly variable plant load factors. Between the base load and peak load operating ranges, Older and less efficient thermal plants of the system should be allowed to operate to carry a fairly large load of medium variability over time spans of 5 hr to 15 hr. Beyond this load requirements a fast-response spinning reserve should be kept to meet the forced and scheduled outages and unforeseen variations of load. Hydroplant is most suitable to meet this load due to its fast response characteristics which is instantaneous with load variation. So it can be seen that eventhough a storage hydro-power plant can operate at any part of the load depending upon the available storage, it can be assigned a place in the load curve where other classes of generating units are rather unsuitable for efficient and economical operation. Introduction of storage hydro plant therefore directly contributes to the improvement of economy of steam plant by enabling it to operate with a high capacity factor, which is otherwise not possible. Apart from this aspect, hydro plant goes further to improve the economy of thermal station when secondary power due to excess availability of water is absorbed in the grid by reduction of load on steam plant. This firming up of secondary power results in substantial economy by way of saving of fuel cost. Adequate storage hydro-backing is therefore essential for economic operation of steam plants, where as the converse is not true. A properly designed storage hydroplant which takes into account the stochastic nature of input, can operate efficiently and economically to take its designed load.

Apart from this aspect a storage hydroplant has additional benefits of integration which create large economies of scale. These have a direct effect on the plants downstream due to regulation of discharge as also of integration. Studies made on a portion of the T.V.A. hydroelectric systems as shown in Fig. 3 is a typical example in this regard.

"If only the Apalachia plant were constructed, 11,700 KW of firm power could be obtained. If the three upstream plants were constructed but operated independently, 33,700 KW could be generated at Apalachia. By co-ordinated operation, firm power can be increased to 42,800 KW. The change from 11,700 to 33,700 illustrates how upstream storage reservoirs increase the firm power potential of downstream plants by increasing low flows. An upstream storage facility such as that at Chatuge increased downstream power by several times the amount generated at the site. A downstream facility may

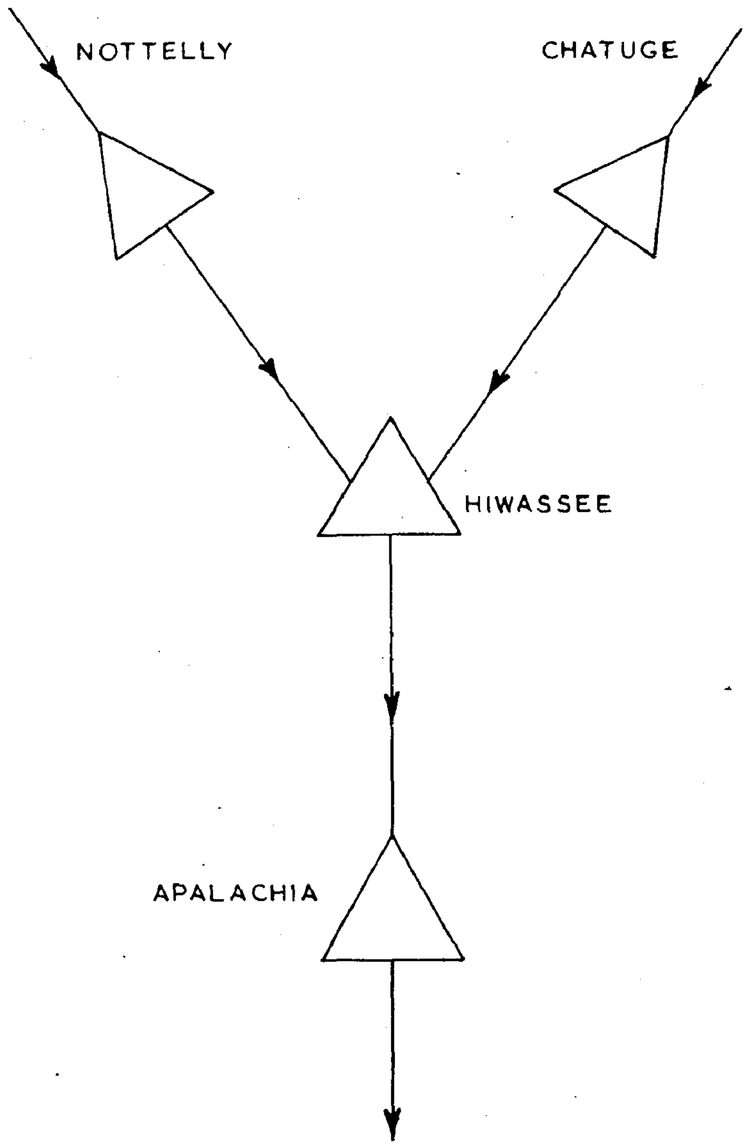

FIG. 3

(AFTER JAMES AND LEE)

depend almost entirely on upstream. The firm power could be increased further were the system operated with the sole objective of generating power rather than with additional purposes such as flood control and Navigation" (James & Lee-17).

TABLE 1

HYDROELECTRIC PLANT CONTRIBUTION TO SYSTEM PRIMARY POWER IN KILOWATTS

Power from	POWER AT Down-stream	Apalachia	Hiwassee	Nottely	Chatuge	Total power from
Apalachia	600	33700				34300
Hiwassee	3600	3900	20000			27500
Nottely	1800	1900	1100	3400		8200
Chatuge	3100	3300	1900		2400	10700
Total power at		42800	23000	3400	2400	

Another advantage that follows integrated operation of more than one storage hydroplant is that it gives scope to increase the firm energy over that could be obtained by individual operation. A typical example in this regard is the study of "Optimum Firm Power Output from a two reservoir system by incremental dynamic programming" done by Hall, Harboe, Yeh & Askew(18). The system optimised is shown in Fig.4.

It is reported that by joint operation of this system improvement of firm energy by 4.8% to 20% could be obtained depending upon annual firm water contract as given in Table 2.

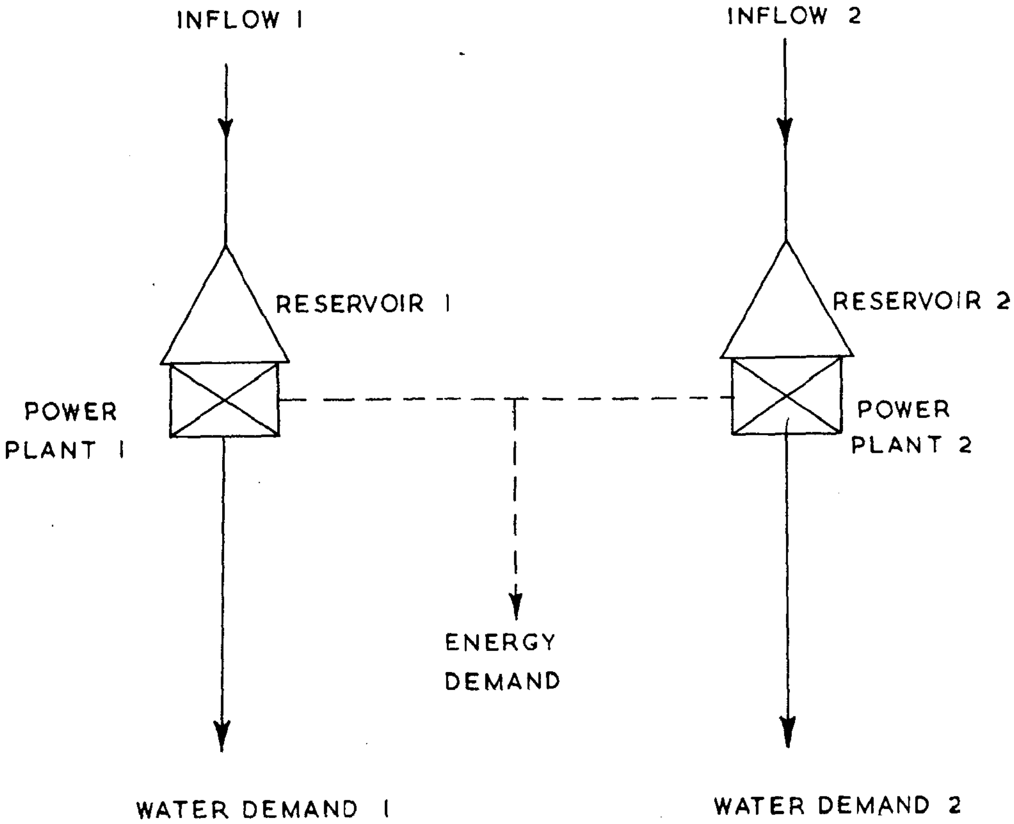

FIG. 4

(AFTER HALL ET. AL.-18)

TABLE 2

FINAL RESULTS AND IMPROVEMENTS OBTAINED THROUGH JOINT OPERATION

Annual firm water contract KAF/YEAR SHASTA	FOLSOM	Sum of individual optimum firm energy contracts MWH/YEAR	Joint Optimum firm energy contract MWH/YEAR	Improvement %
1	2	3	4	5
3500	700	961995	1007752	4.8
3500	800	948920	996587	5.0
3500	900	927316	979655	5.7
3600	700	888418	961551	8.2
3600	800	875343	951335	8.7
3600	900	853739	940387	10.1
3700	700	717718	845982	17.9
3700	800	704603	840470	19.3
3700	900	683039	818577	20.0

A storage hydroplant in the system will have a direct effect on the plants downstream due to regulation of discharges. In case of runoff the river plants, the pattern of generation will significantly change due to the upstream storage hydroplant. The generation in the nonmonsoon months will increase substantially in the downstream runoff the river plants. The water released from the storage hydropower plant, besides providing additional power in the downstream plant, provides additional irrigation.

From the above discussion it transpires that not only does a storage hydroplant produces its own power it has a significant effect on the entire system when interconnected.

1.05 COMPLEXITIES OF PLANNING OF HYDROPLANTS IN INTEGRATED SYSTEM

Planning now needs an in-depth study of all the aspects of integrated operation. The interaction between the system elements require careful evaluation before the optimal size of development can be arrived at. This makes the study extremely complex. Things get far more complex if, public, social, environmental and esthetic values require to be considered. In such a situation conventional methods of design cannot serve the requirement of optimal planning for hydroplants in an interconnected system, and it becomes necessary to go in for more sophisticated methods of analysis which take into account the interaction between the system elements as explained earlier. Utilising the most common objective of maximising the net economic benefits, techniques of mathematical modelling can be applied. But for a water resources system, it becomes usually necessary to simulate the detailed sequential operation of the system, representing the manner in which each element of the system will function under realistic conditions of inputs and requirements of the system.

1.06 SCOPE OF PRESENT STUDY

In this dissertation, determination of the optimal scale of hydro-development for a reservoir hydro scheme with runoff the river schemes on the downstream has been taken up for study. The reservoir scheme considered is the proposed Lakhwar-Vyasi complex under Yamuna Valley development scheme. This project on completion will be linked with the U.P. power system.

Since the project will be interconnected with the U.P. Grid the features and load characteristics of the grid have been taken into account in the study and the system load for the year 1972-73 has been considered.

It is presumed that the monthly distribution of energy on the system will remain the same when Lakhwar-Vyasi scheme comes into operation. A significant shift in the distribution pattern is not anticipated, even through the energy requirement may be higher.

of power will continue in the future as well. Eventually this would be a g big blow to the growth of Industry in the region.

Comparing the projected figures of 1972-73 with the actuals, the picture is even more disquieting.while the peak demand being 1588 mw reached nearly the projected target, the installed capacity and consequently the peak capability remained far short of the target, which means that the system fell short of both in its peak capacity as well as energy potential and not energy potential alone as reflected in the survey. The maximum and minimum daily load, average load and load factor of the U.P. Grid to which Yamuna Valley Power System will be connected are shown in Table. Two daily load curves for the Ganga Sarda Grid during peak periods are also shown in Figs. From these curves it is seen that there is a large gap between the demand and supply and if power potential is not rapidly developed in the region chronic shortages in future is not ruled out.

2.02 <u>BASIS OF PLANNING OF HYDRO PLANTS</u>

Out of the 8 hydro power stations only Rihand and Obra complex has storage hydro plant. Matatila power plant utilises the irrigation releases for power generation, and all the rest are run-of-the-river and canal plants. None of the power plant except Rihand Complex have any regulation facility. They are entirely dependent modelling can be applied. But for a water resources system, it becomes usually necessary to simulate the detailed sequential operation of the system, representing the manner in which each element of the system will function under realistic conditions of inputs and requirements of the system.

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CHAPTER - II

U.P. POWER SYSTEM & HYDROPLANTS

2.01 U.P. POWER SYSTEM

The power system as on 1.9.75 consisted of 9 hydropower stations and 15 thermal stations. The list of these power stations and their installed capacity is given in Table 3. The total installed capacity of the power system thus works out to about 1843 mw, which consisted of 790 mw of hydropower and 1152.5 mw of thermal power. The system load for the year 1972-73 is given in Table 4.

The installed capacity, peak capability, peak load, gross-margin, Energy potential and Energy requirements for the U.P. Power System as given in the 7th Annaul Electric Power Survey of India may be seen from Table 5. This makes a quite interesting study. The figures from 1968-69 to 1970-71 in the above survey represents the actuals over the years and these from 1971-72 to 1974-75 are projected figures. The survey indicates that there will be no shortfall in the peak capability of the system if the projected figures are achieved. But there has been shortage in the energy potential from 1971-72 onwards tough prior to that period energy potential had balanced the energy requirements. This is a grim picture for the state so far as growth of generation is concerned and if this unhappy trend is not arrested, chronic shortage of of power will continue in the future as well. Eventually this would be a g big blow to the growth of Industry in the region.

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Storage hydro plant usually take the peak load of the system. The basis of planning of the existing storage and run-of-river hydroplant in the system is as follows:

(i) RIHAND - OBRA

This is the largest and so called single storage hydroplant of U.P. power system located across river Rihand in the eastern part of the State. Rihand power plant has an installed capacity of 300 MW consisting of 6 machines of 50 MW each. It is designed for an annual load factor of 33%. The continuous power is 106 MW. The annual energy output is 900 mkwh.

Obra Power Plant which utilises the releases from Rihand Power House has an installed capacity of 99 MW consisting of 3 machines of 33 MW each. The annualload factor is the same as Rihand i.e. 33%. The annual energy output is 300 mkwh.

(ii) MATATILLA

This is a small storage hydro plant of 30 MW installed capacity with 3 machines of 10 MW each. It gets filled up with early rain and thereafter it is run as a base load station. For the 3 months, July, August & September it generates continuous power in accordance with the installed capacity and for the balance 9 months it generates power according to the availability of stream flow and Irrigation requirements which is the main purpose which Matatilla serves. When Irrigation requirement is more power generated is more and when the requirement for Irrigation is less, less power is generated. Subject to availability of water, power generation is guided by the requirements of Irrigation.

(iii) GANGA CANAL POWER HOUSES

This consists of a group of 8 small power houses on the Ganga Canal having a total installed capacity of 45 MW. The effective capacity of these power houses is only 30 MW. So even if more water is available in the canal the same cannot be utilised to produce power according to the installed plant capacity. The effective capacity of this group is decreasing every year. For the present for 6 months from May to October full power is generated subject to effective capacity of the plants and for the balance 6 months only about 50% power is produced. The annual load factor is around 70%.

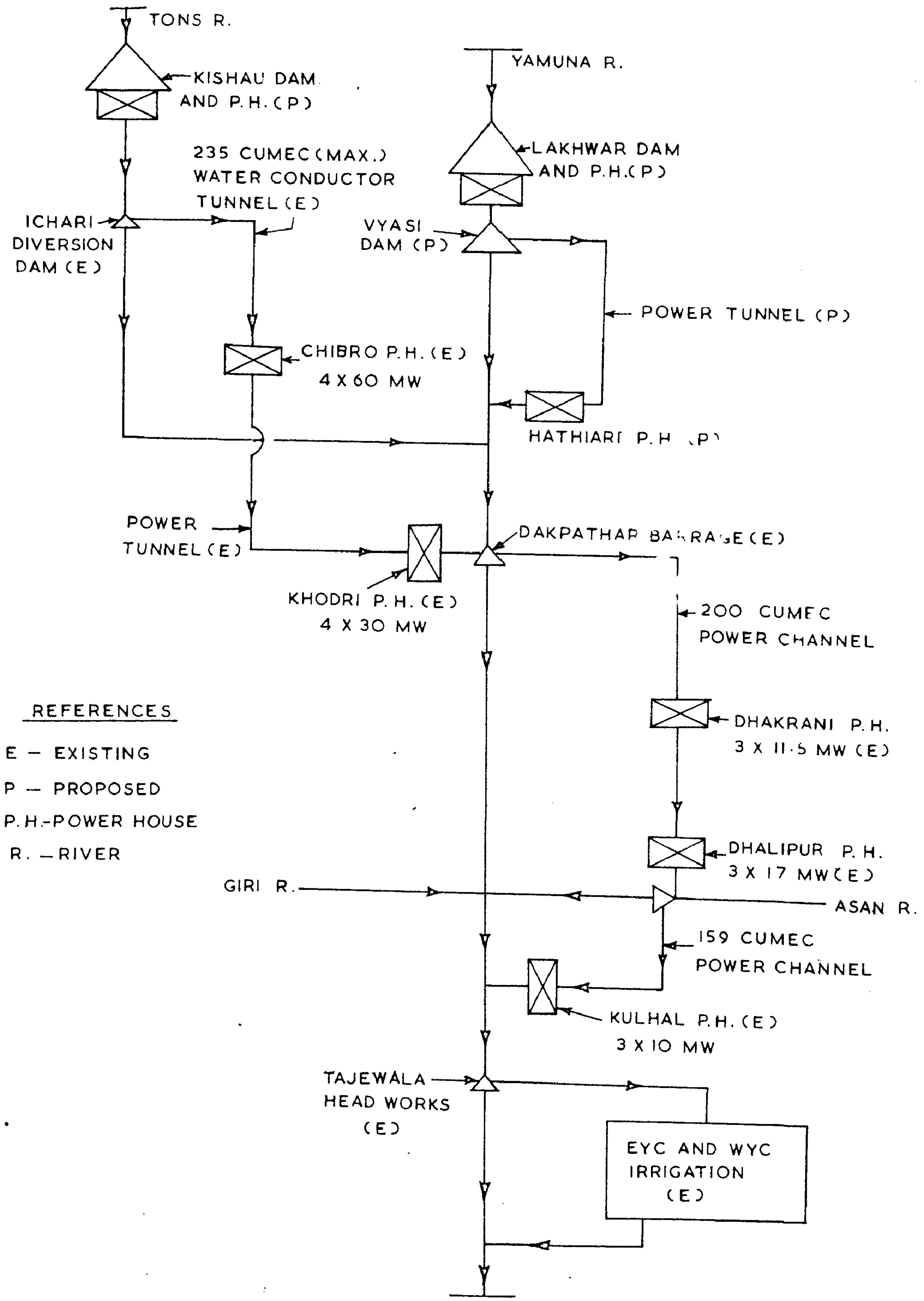


FIG. 1 – YAMUNA VALLEY PROJECTS SYSTEM

(iv) KHATIMA

This is a canal power house with installed capacity of 41.4 MW consisting of 3 machines of 13.8 MW capacity each. It generates full power during summer and rains i.e. for 6 months from May to October. For the rest part of the year it generates about 50% power.

2.03 PRESENT OPERATION

All the above hydro stations form part of the U.P. System. Presently they are run in integrated system comprising of mainly thermal and hydro stations in accordance with the system load.

Under such a situation individual design of a hydroplant is not relevant now. The system must be considered as a unit for any proposal for additional power station. Generation and transmission would now require evaluation and otp optimisation for the projected load. In this regard operation research techniques are particularly useful for systematically evaluating the decision variables.

In such a process, the installations that are already in existence would be mostly constrained by their characteristics and capacity etc. The installations which are under construction will also introduce constraints so far as optimisation from them is concerned

But for all proposed installations there would be a lot of flexibility and decision variables corresponding to the optimal design can be arrived at. This would require framing of a suitable operation model of the systems for simulation which is considered to be the best method for solving the overall problem. Other techniques such as linear programming and dynamic programming are not capable of solving the overall problems but can be applied to limited portions.

2.04 NEED FOR REVIEW OF OPERATION

The objectives of water resources system operation are usually fixed for any particular plan of development. These are expressed in terms of operation rules that specify quantities of water to be released and diverted, quantities of power to be generated, reservoir storages to be maintained, mandatory releases for downstream commitment etc. These systems operation rules will immediately get upset as soon as a new installation comes up in the system. So when a new scheme is proposed to be added to the system, it would be necessary to study again the overall problem and the effects that the new installation would have on the existing system. The entire system would again require optimisation to work out the optimal sizes of the proposed development. The process of review and optimisation is not only applicable for addition of new generation but transmission also.

TABLE

INSTALLED CAPACITY OF U.P. POWER SYSTEM

(as on 1.9.1975)

Name of Power Station	Hydro/ Thermal	Installed Capacity MW	REMARKS
Rihand	Hydro	6x50 = 300	Stage Scheme - 105 MW - firm 900 mkwh units per year
Obra	Hydro	3x33 = 99	
Chibro (Yamuna Stage II)	Hydro	3x60 = 180	One more unit of 60 MWwill be commissioned within a few months
Dhakrani	Hydro	3x11.25=33.75	
Dhalipur	Hydro	3x17 = 51	
Kulhal	Hydro	1x10 = 10	2 more 10 MW units will ~~by~~ be commissioned shortly.
8 Power stations of Ganga Canal	Hydro	45	These are small hydel power stations and the effective capacity is about 30 MW & is decreasing every year. ~~either water is available plant is not capable~~ L.F.50% approx.
Khatima	Hydro	3x13.8=41.4	
Matatila	Hydro	3x10 = 30	
	Total	790.15 MW	

N.B.

Small micro hydel sets installed in the hills aggregating to about 2000 KW have not heen included in the above figures.

Name of Power Station	Hydro/ Thermal	Installed Capacity in MW	REMARKS
Obra	Thermal	5x50 = 250	One more 100 MW set will be commissioned shortly
Renugagar	Thermal	2x62.5=125	
Panki	Thermal	2x32 = 64	
Kanpur (River side)	Thermal	87.5	Being old, effective capacity is only 50 MW
Mainpuri	THERMAL	10	These are old power stations and the effective capacity is only 35 MW
Mau Gorakh-pur Sohawal 10 MW each	Thermal	45	
Harduaganj			
A- Power House	Thermal	3x30 = 90	Being old effective capacity is only 75 MW
B- Power House	Thermal	2x50) 2x55) = 210	
Agra	Thermal	20)	These are small thermal Power Stations and may perhaps close down in a few years due to being old.
Lucknow	Thermal	20)	
Varanasi	Thermal	15)	
Allahabad		10)	
Chandausi		6)	

TOTAL 1152.5 MW

Old less efficient Thermal Stations	303.5 MW
Effective Capacity	210 MW
Efficient Thermal Stations	849 MW

LIKELY ADDITIONS TO THE SYSTEM FROM SCHEMES UNDER CONSTRUCTION

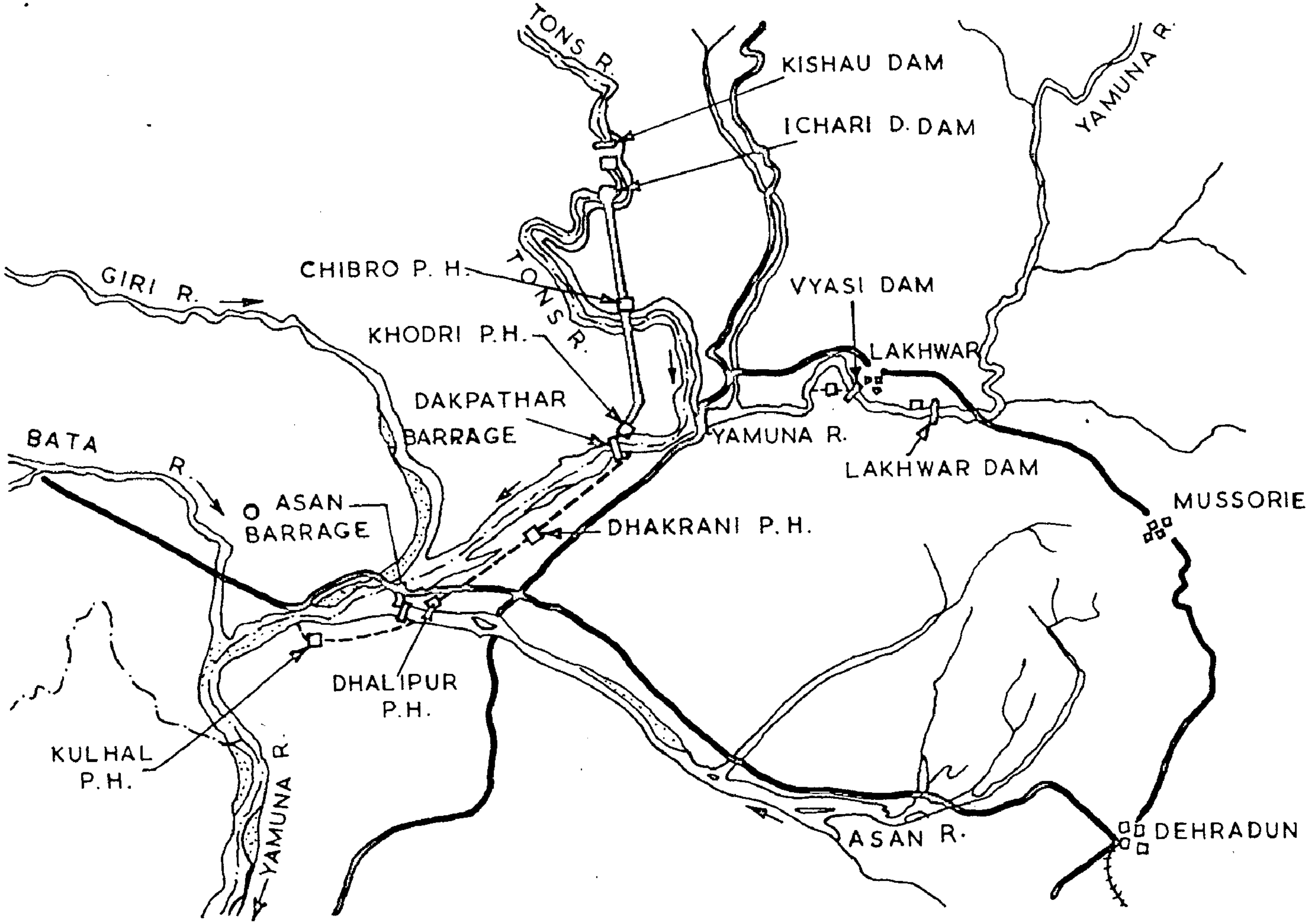
Name of Power Station	Hydro/ Thermal	Installed M.W.	Anticipated date of Commissioning
Ramganga	Hydro	3x65 = 195	Expected to be commissioned by 1975-76
Khodri	Hydro	4x30 = 120	Expected to be commissioned in next 2 years
Rishikesh Hardwar Scheme	Hydro	4x36 = 144	Expected to be completed in next 3 years
Manerivali Stage I	Hydro	3x33 = 99	"
Add for Chibro & Kulhal		80	
		638	
Panki	Thermal	2x110 = 220	Expected in next 2 years
Harduaganj B-Power House	Thermal	2x55) 1x110) = 220	Expected in next 2 years
Obra	Thermal	3x200 = 600	Expected to be completed in next 3 years
		2x200 = 400	Expected in next 5 years
		1440 MW	

INSTALLED CAPACITY, PEAK CAPABILITY, PEAK LOAD, GROSS MARGIN, ENERGY POTENTIAL AND ENERGY REQUIREMENTS IN UTTAR PRADESH

	1968-69 (Actual)	1969-70 (actual)	1970-71 (actual)	1971-72	1972-73	1973-74	1974-75
Installed Capacity MW	1310	1383	1537	1642	1935	2352	2462
Peak capability MW	1104	1168	1332	1354	1619	1986	2078
Peak Load MW	978	1117	@1246	1416	1605	1814	2061
Gross margin - MW/%	126/13	51/5	86/7	-62/4	14/1	172/9	17/1
Energy Potential mkwh	5317	5792	6563	6038	7153	8982	9686
Energy required mk mkwh	5317	5792	6563	7167	8095	8977	10096

@ There was load shedding of 34 MW at the time of annual peak load. The unrestricted peak in 1970-71 is assessed at 1280 MW. Figures from 1971-72 onwards are estimated figures.

Source: 7th Annual Electric Power Survey of India, 1972.



YAMUNA HYDEL SCHEME STAGE - I AND STAGE - II

FIG. 5

CHAPTER - III

LAKHWAR - VYASI SCHEME

3.01 YAMUNA VALLEY DEVELOPMENT FOR HYDRO POWER

In the Western parts of Uttar Pradesh, Yamuna Valley Development Schemes provide a large hydropower potential which is now being tapped for augmenting hydro-capacity of the system. Lakhwar - Vyasi project is one of the projects under this development programme. A brief description of the Yamuna Valley Development Program is given below. Fig. 5 may also be seen in this connection.

The river Yamuna and its major tributary Tons provide a large irrigation and power potential on account of their perennial flow and physiography. Presently almost the entire non-monsoon flow is utilised for irrigation from the headworks at Tajewala. The power potential which remained untapped previously is now being developed in a phased manner. Investigations have been made for the past two decades for a comprehensive development of the available water resources by construction of a series of run-of-the-river and storage schemes. As a result of this a number of power schemes have come up in series for maximum utilisation of the water resources for generation of power. The power houses which are already constructed are Dhakrani and Dhalipur, Against the power houses under construction Chhibro and Kulhal power houses are nearing completion and Khodri power house is in progress.

In the next phase the projects which are under active consideration is the Lakhwar-Vyasi Scheme. This project will affect the power generation from the Yamuna Hydel Scheme - Stage I projects of Dhakrani and Dhalipur, and Kulhal Power Station of Yamuna Hydro-Electric Scheme Stage IV.

3.02 YAMUNA HYDEL SCHEME STAGE I

Yamuna Hydel Scheme Stage I is a run-of-the-river scheme for generation of power utilising a drop of about 50 m available in the river Yamuna between Dakpathar and Dhalipur near the confluence of river Asan with Yamuna. This has been achieved by the construction of a barrage at Dhakpathar (just downstream of confluence of Tons with Yamuna) to divert the river supplies into a power channel and generation of power at two power stations. The releases from the power house join the river Asan a little upstream of its confluence with Yamuna. The Stage I scheme comprises the following works:

(i) Dakpathar barrage with 25 bays of 18.3 meters each across the river Yamuna to divert river water to the power channel leading to Dhakrani Power House.

(ii) Power channel 13.6 km long with a capacity of 200 cumecs for feeding the power houses at Dhakrani and Dhalipur.

(iii) Power Station at Dhakrani, 7.8 km from Dakpathar with installation of 3 machines of 11.5 mw each.

(iv) Power Station at Dhalipur, 13.6 km from Dakpather with installation of 3 machines of 17 MW each.

(v) Tail race channel 0.6 km long falling into the river Asan, 1.5 km above the confluence of rivers Asan & Yamuna.

(vi) Barrage across river Asan to divert its flow as well as the releases from Dhalipur Power House to generate further power. The barrage is 288 m long having 14 bays of 18.3 m length. This diverts ~~f~~ water through a power channel to Kulhal power house under construction which will utilise a fall of 18.4 m available between Asan barrage and village Kulhal on the left bank of river Yamuna. The barrage has pondage 1.6 mm^3 of water and is designed for 1500 cumecs discharge.

3.03 <u>YAMUNA HYDROELECTRIC SCHEME STAGE IV:</u>

It consists of Kulhal Power House with installation of 3 machines of 10 MW each. The tail race channel downstream of the power house is 0.35 km long and joins river Yamuna.

The above mentioned works under Stage I are already completed. Only one 10 mw unit at Kulhal power ~~hou~~ station has been commissioned so far. Apart from the above schemes, presently Stage II works are going on, a greater part of which is already completed.

A brief description of the Stage II scheme is given below.

3.04 YAMUNA HYDEL SCHEME STAGE II

Stage II Scheme comprises of those across river Tons, the major tributary of river Yamuna. Fundamentally it envisages the utilisation of a fall of 186 m available between Ichari & Dakpathar in river Tons. The scheme consists of two parts i.e. (a) Part I and (b) Part II.

PART I

(i) diversion dam across river Tons at Ichari, to divert the river flow to Chibro power house.

(ii) Underground power house at Chibro which utilises a head of 124 m for generation of power from the flow of Tons diverted at Ichari. It is proposed to instal 4 units of 60 mw capacity each in this power. Out of this 3 units have been already installed. The releases from this power house is taken in a syphon tunnel across Tons to Khodri power house for generation of power. The work is in progress for installation of the 4th unit at Chibro Power House.

PART II

The part II of the scheme consists of utilisation of the releases from Chibro power house for generation of power by utilising a head of 62 m available between Chibro and Dakpathar. A 7.5 m dia tunnel 5.9 km long and having a capacity of 235 cumecs conducts the water from the Chibro P.H. to the Khodri surface power house located just upstream of the barrage. It is proposed to instal 4 units of 30 mw capacity each in this power house.

Being on a separate river, Lakhwar Vyasi Scheme will not have any direct influence on their generation except through integration.

3.04 <u>PROPOSED LAKHWAR-VYASI PROJECT</u>

This scheme envisages construction of a storage dam at Lakhwar and pickup dam at Vyasi for generation of power. In case of Lakhwar dam, the power house will be located at the foot of the dam. The Vyasi dam which is located about 5 km downstream heading waters upto toe of Lakhwar dam will divert water through tunnels to feed a surface power house at Hathiari.

3.05 <u>THE PROJECT AS PROPOSED</u>

A 192 m high concrete dam has been proposed to store 580 mm^3 of water with full reservoir level at E.L. 796.00 m. The top of the dam has been fixed at E.L.800.0 m. This will create a maximum gross head of 166 m for power generation at the foot of the dam. Installed capacity of 300 mw consisting of two units of 150 mw each has been proposed for the power house. Another auxiliary concrete dam of height 61 m is proposed 5 km downstream of the Lakhwar dam near Vyasi. Waters collected at the proposed Vyasi dam will be conveyed through two 7 m dia. power tunnels each 2.5 km long to a surface power house at Hathiari with an installation of 240 mw consisting 4 units 60 mw each. Both the Lakhwar and Hathiari power houses are proposed to be run as peak load stations and a barrage at Katapathar, 2.5 km downstream of the proposed Hathiari power house, will serve for balancing the discharge from Hathiari. A uniform discharge will thus be released from Katapathar.

The Lakhwar Vyasi project would thus add 540 mw of peak power to the U.P.grid.

The gross storage of the reservoir behind the Lakhwar dam will be 0.47 m aft.(580 mm^3). The sediment load for 100 years life of the reservoir has been estimated to be 0.2 m aft (247 mm^3) which corresponds to E.L. 752.00 m. The live storage of the reservoir will thus be 0.27 m aft (333 mm^3) corresponding to E.L.796.0 m. It is stated that the Geological conditions are such that the depth of stripping increases considerably above E.L.800.00 along the left bank. The quantity of excavation and concrete would therefore increase disproportionately with the height of dam if it is carried higher than E.L.800.00.

The irrigation benefits from the project will be derived due to increased regulated flows through the power houses on account of storage created at Lakhwar reservoir.

3.06 OPERATION CRITERIA

Lakhwar-Vyasi project is essentially a power project for generation of peak power. The grid requirement of peak power is maximum during winter. The system load figures of 1972-73 shows that the maximum load during Winter was 1588 mw which is the annual peak for the year. The criteria for release of water from Lakhwar dam has been fixed for release of water in a manner that ensures generation of atleast a specified proportion of the annual energy output in accordance with the system load. This will enable the system to have the requisite load and energy capacity in different periods in conformity with the load curve. Water availability at Tajewala being more than irrigation requirement during the monsoon months of July to October, the status of Irrigation will remain unaffected during this part of the year so far as the effect of Lakhwar dam is concerned. But in the nonmonsoon months from November to June the utilisation of water for Irrigation is severely constrained by the stream flow. Therefore, at the least, the existing contribution from Lakhwar must be released during this period so as not to disturb the existing irrigation facility. The inflow at Lakhwar during the non-monsoon months from November to June therefore become mandatory. It has been ensured that the releases during this period did not fall below the inflow which is mandatory. The system load demand pattern will invariably meet this requirement because requirement for power in general is more than what the normal inflow can generate during this period. The additional water over the inflow released in this process produces additional power in the downstream The run-of-the river plants and additional irrigation from Tajewala head works.

With this background, the following criteria has been adopted for reservoir operation:

(1) Operation starts with reservoir full at the end of monsoon i.e. Ist November. The surplus water available during monsoon goes to fill up the reservoir.

(2) Reservoir will be empty at the end of nonmonsoon period i.e. at the end of June.

(3) The monthly releases from the reservoir are in accordance with the monthly energy distribution pattern of the system.

(4) Additional release during the nonmonsoon period produces additional power at the downstream run-of-the-river plants in accordance with their flow-energy relationship, the average head being nearly constant.

The reservoir operation studies have been made for 90% availability inflow.

CHAPTER - IV

SYSTEM DESCRIPTION OF THE PROBLEM FOR SOLUTION

4.01 HYDROLOGY

Discharge data of river Yamuna at Lakhwar is available for a short period of 7 years only from the year 1968 (Appendix 1) to 1974. This is not adequate for the purposes of design. Therefore it has been decided to use the extended data for Lakhwar as given in the project report (Appendix 2). 90% availability figures have been worked out from the above data in accordance with the dependability criteria for power supply schemes. These are shown at the end of Appendix 2. From the extended data the year 1939 has been discarded as an extreme event to arrive at the 90% availability figure. The annual inflow thus works out to 15550 cumec-day. The average inflow from extended data is 20,700 cumec-day and that from the observed data is 20,774 cumec-days. The lowest flow recorded within 7 years of observed data is 15,320 cumec-days.

4.02 RESERVOIR

The characteristics of the proposed Lakhwar reservoir is shown in Table 6 below :

TABLE - 6

E.L.	AREA	GROSS CAPACITY (mm^3)	CUMEC-DAY
750	511.5	235.49	2720
752	530.7	247.0	2860
778	780.0	407.05	4710
796	965.0	580.0	6710
800	1022.5	611.49	7080
806	1070.0	672.25	7780
810	1120.0	721.59	8350
814	1160.0	770.93	8930
817	1200.00	800.0	9260

The maximum possible dam height has been pre-decided on the basis of the following considerations :

(1) Geological Studies

"The Geological investigations carried out so far show that a dam with its top upto E.L.821.0 can be constructed at this site after taking proper precautions for the left bank spur. The height of the dam has been considered maximum possible on account of the rock and the topographic features of the left bank spur. There is however deep overburden of the order of 50 m at the highest elevation of the left spur at E.L.860.0 and a fair quality of rock can be expected at about E.L.810.0 m only. Hence a dam with top below elevation 810 m would be preferable from geological point of view"[20].

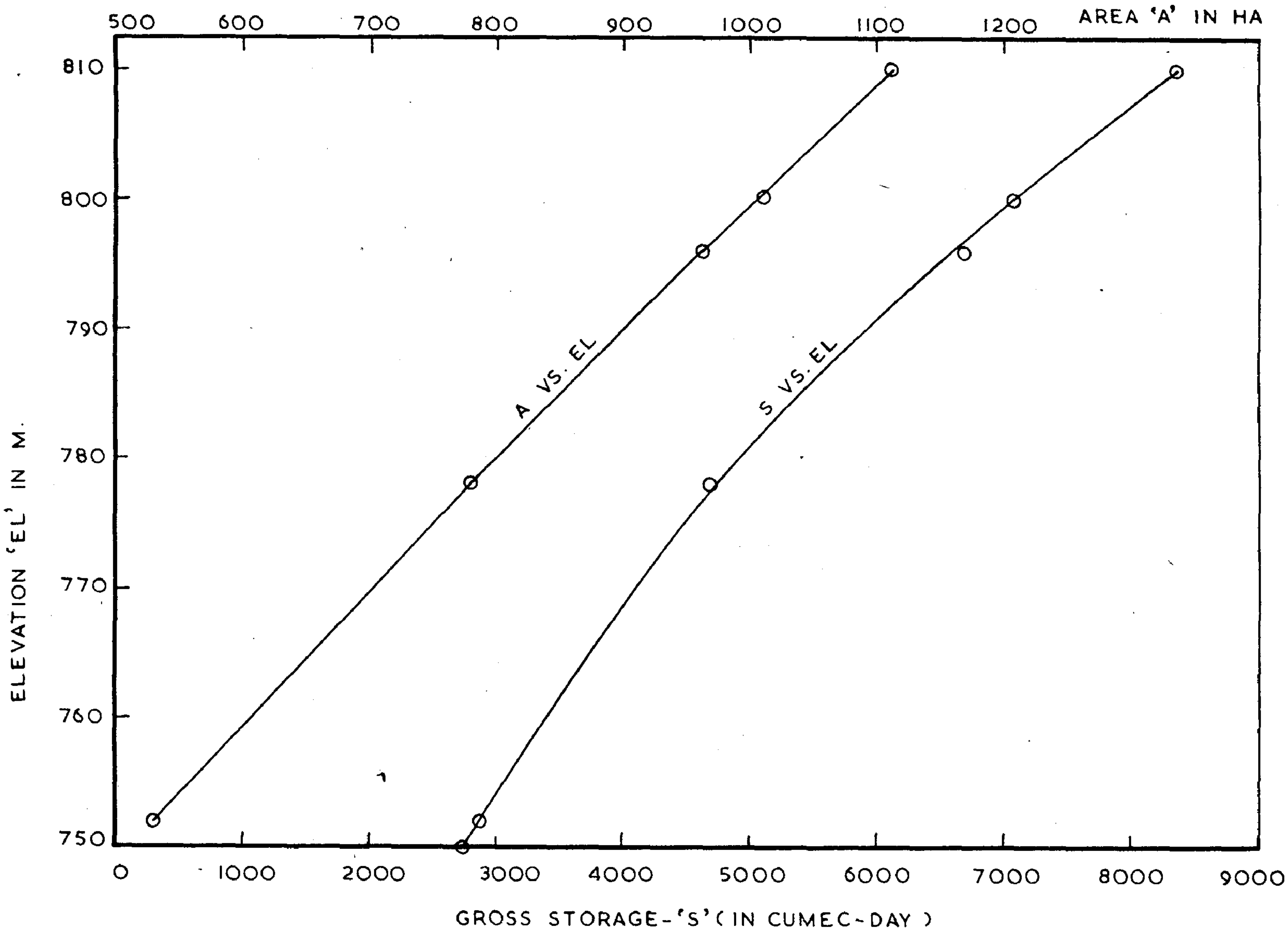

AREA 'A' IN HA
500
600
700
800
900
1000
1100
1200
ELEVATION 'EL' IN M.
810
800
790
780
770
760
750
A VS. EL
S VS. EL
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
GROSS STORAGE-'S'(IN CUMEC-DAY)

FIG. 6

(ii) Economic Studies

Economic studies included in the project report states that the concrete quantities above E.L.800.0 m increase at a faster rate in proportion to the benefits, derived from increased height. Accordingly the height of the dam is sought to be fixed with top at 800.0 m.

Due to above constraints maximisation of power output has not been attempted for higher levels of storage beyond 810.0 m.

The storage-elevation and area-elevation plot of the reservoir is shown in Fig.6.

RESERVOIR EVAPORATION

For arid and semiarid regions evaporation from the reservoir would be considerable and therefore this loss need be considered in the design. The procedure used to calculate evaporation losses is the use of evaporation coefficients which are the average monthly evaporation rates for various months of the year observed in the area. The amount of evaporation loss would be given by the equation

$$E\,V_t = A_t \cdot E\,C_t$$

Where $E\,C_t$ represents the evaporation coefficient or the depth of evaporation during the period t. But since A_t is a function of storage, flow, release and evaporation loss itself, a direct estimation of $E\,V_t$ is not possible.

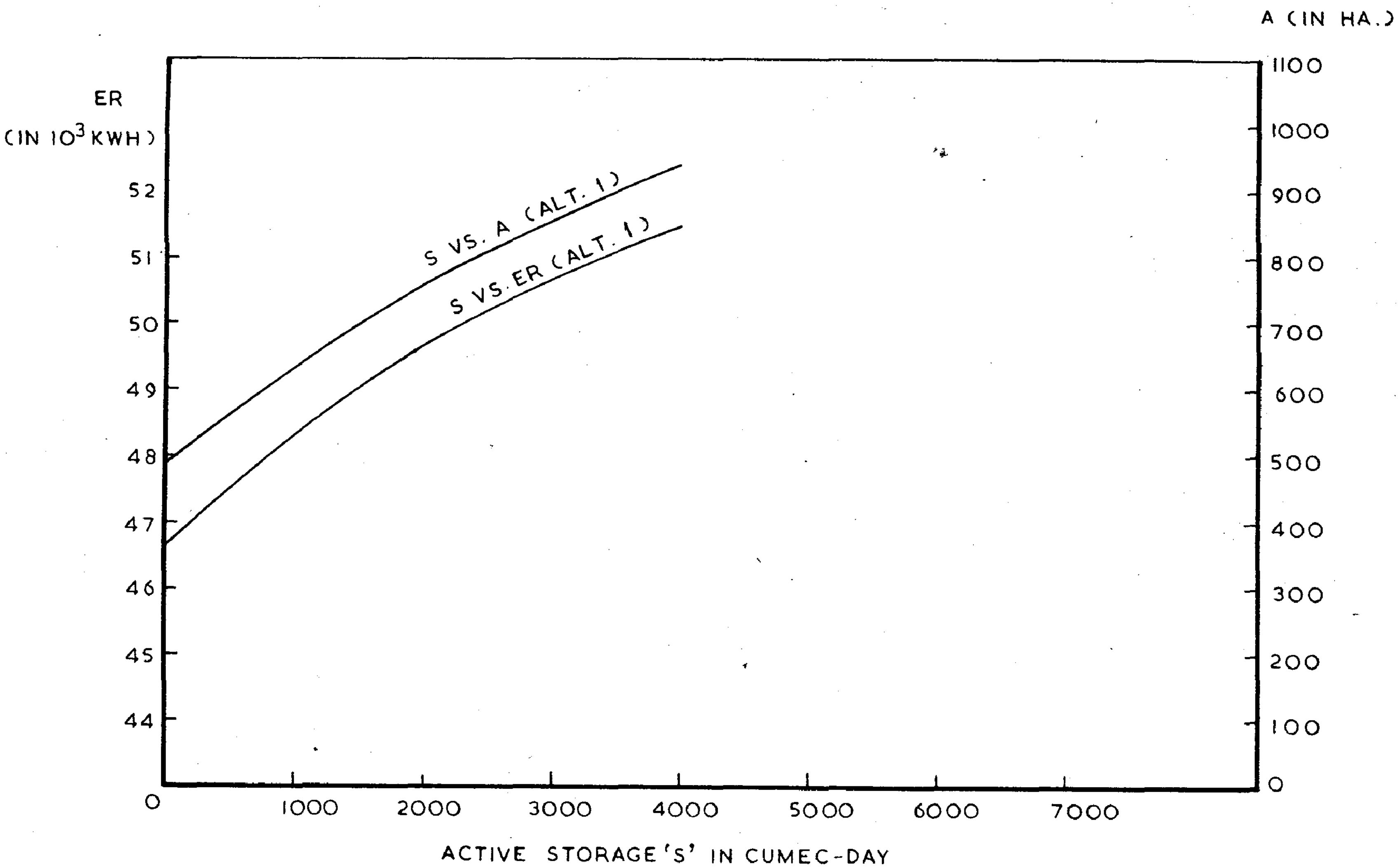

ER
(IN 10³ KWH)
A (IN HA.)
52
51
50
49
48
47
46
45
44
1100
1000
900
800
700
600
500
400
300
200
100
0
1000
2000
3000
4000
5000
6000
7000
S VS. A (ALT. 1)
S VS. ER (ALT. 1)
ACTIVE STORAGE 'S' IN CUMEC-DAY

FIG. 7

This is calculated by successive iteration in the operation model. The monthly evaporation coefficients as given in the Lakhwar project report are shown in Appendix 3.

4.03 PROPOSED POWER PLANT

The average tail water elevation for the power plant at Lakhwar dam is E.L. 630.0 m. The peak up dam at Vyasi located downstream of Lakhwar dam diverts the releases from Lakhwar power house to feed Hathiari power house. The average tail water level for Hathiari power house is E.L.513.5 m[20]. The two power houses have therefore been combined for purposes of calculation. Corresponding to different storage levels, Energy production rate has been worked out assuming the overall efficiency of the power plant as 85%. Energy production in kilowatt-hour per cumec day of water at different elevation is given in Appendix 6. In the operation studies these values have been used. Other factors such as variation of plant efficiency with head, turbine leakage, operating efficiency under partial load etc. have not been taken into consideration in the present study.

The storage-energy production rate and storage-area plot is shown in Fig.7. The relationship utilised is, power = 8.33 Q.H. where Q is the discharge in cumec and H is the head in meter.

The energy demand coefficients for different months are given in Appendix 4. In absence of daily load factor, these are arrived at by averaging the maximum and minimum load of each day and multiplying it with 24 for finding the daily energy requirement. The same has been added up for all the days of the month to arrive at the monthly requirement of energy. The ratio of monthly & the annual requirement has been foundout for each month. Though these coefficients are only approximate they may be taken as fairly indicative of the monthly energy distribution pattern of the system.

4.04 DIVERSION STRUCTURES

Dakpathar barrage across Yamuna located down-stream of Lakhwar-Vyasi project is relevant in this connection (Fig.1).

As already stated, this barrage diverts water to Dhakrani power house. The maximum water that can be diverted at this point is limited by the existing power channel capacity of 200 cumecs. The diversion is also constrained by the fact that water in excess of the installed plant capacity is of no use. The releases from Dhakrani power house is fed into Dhalipur power house and the releases from Dhalipur are let into Asan river upstream of Asan barrage for diversion to Kulhal power house. The power channel is 4 km long with base width of 11 m and side slope 1.5 : 1. The bed slope of the power channel is 0.15 m/km having a discharge carrying capacity of 300 cumec. A bye-pass for full discharging capacity is provided at the power house to escape water in the event of sudden closure of the power house.

4.06 EXISTING POWER PLANTS

Lakhwar storage scheme will have a direct effect on the three run-of-the-river power plants Dhakrani, Dhalipur and Kulhal. For the purposes of calculation of additional power on account of Lakhwar storage scheme, the three power houses have been combined. The total average head for the three plants is 68.4 m. Assuming 85% overall efficiency of plant one cumec-day will produce

$$\frac{8.33 \times 1 \times 68.4 \times 24}{10^6} \text{ mkwh}$$

= 1/73 mkwh of energy if passed through all the three plants. This relationship has been utilised in calculating the additional power that would be available from the three run-of-the-river plants due to regulation of discharge by Lakhwar storage scheme.

4.06 MANDATORY RELEASES

There is an established irrigation facility at a downstream point namely Eastern Yamuna Canal (EYC) and Western Yamuna Canal (WYC) Irrigation systems drawing water from Tajewala headworks. Any storage scheme taken up in the upstream, will affect the water availability at this diversion and consequently affect the existing Irrigation facilities. This is neither desirable nor is it tolerable by the beneficiaries of the facility. So it is mandatory on the part of the planner too see that the present rights are not disturbed at the downstream point due to construction of a reservoir scheme in the upstream. So far as Irrigation from EYC & WYC is concerned, no difficulty will be faced during monsoon months from July to October even if the inflow at Lakhwar is held up in the reservoir for use in the nonmonsoon months. Inflow at Tajewala is more than the requirement during monsoon. But inflow at Tajewala during non-monsoon months being less than requirement for Irrigation it is necessary to ensure that at the least, the entire inflow during the non-monsoon at the Lakhwar site is released to the downstream so as not to disturb the existing Irrigation facility. This has been ensured. In fact due to regulation of inflow, the releases during the non-monsoon period from November to June is invariably more than the inflow during that period. The mandatory releases from November to June are shown in the Table 7 below:

TABLE - 7

Month	Mandatory Releases (in cumec-days)
November	980
December	690
January	570
February	560
March	580
April	660
May	840
June	1475
Total:	6355

CHAPTER - V

ANALYSIS

5.01 CRITERIA ADOPTED FOR ECONOMIC ANALYSIS

Any planned effort is directed towards a set of development objectives which, supposedly, reflect Society's desire for some changes in physical economic & social environments. Formulation of a project proceeds in two directions. The first is the identification and elaboration of technically feasible alternatives. The second is the evaluation of such alternatives to select the most economical one. There are various measures of profitability such as the Benefit - Cost ratio Rate of return, present value of net benefits etc.which are utilised both by private and public sectors. The computational mechanics of each of these methods is universal, but what constitutes costs and benefits of a public project and how they could be measured and valued have been a controvertial subject among economists. It is said that the parameters for project evaluation for a developing country should in general reflect the social and economic environments. However in our case the traditional objective of maximising the net economic benefits has been employed. Other objectives involving social, political, ecological and envirionmental values have not been considered, because it is extremely difficult at the present stage to quantify these values in terms of money.

In general, water resources services are provided on a guaranteed basis. Services in excess of the commitment are usually of minor value; because the community is unprepared to utilise them effectively. On the other hand, shortages in such services can be extremely costly, because society has integrated these supplies into its delicate structure and shortages can disrupt social activities seriously.[9]

In case of storage hydroplants in an interconnected system with predominantly Thermal plants situation is a little advantageous. Here, in addition to the firm power, a large block of secondary power during the periods of higher inflows, can be effectively utilised to serve the system load. Absorption of secondary power in the system saves fuel cost of thermal plants and also improves the reliability of supply from integral system. The larger the system on which the power is used, the more valuable the secondary power may become for the reason that large systems have flexibility and diversity of use.

For fixing the scale of development maximisation of net economic benefits (B - C) is generally recommended. This criterion has been adopted to evaluate the different alternatives. Therefore the expression for the net economic benefit (B - C) would be of the form :

Z = Max. [Annual benefits from energy generated at Lakhwar-Vyasi project and from additional energy generated at Dhakrani, Dhalipur and Kulhal power houses due to increased supplies in lean months from Lakhwar-Vyasi Complex (B_1)

+ Annual Benefits from Secondary power (B_2)
+ Annual benefits from Additional Irrigation (B_3)
- Annual equivalent of capital cost of Lakhwar - Vyasi Complex (C_1)
- Annual maintenance cost of dam and appurtenant works (C_2)
- Annual operation and maintenance cost of Lakhwar - Vyasi power plants (C_3)
- Annual incremental operational cost of additional power from Dhakrani, Dhalipur & Kulhal Power Houses (C_4).
- Annual equivalent of capital cost of additional irrigation system (C_5)
- Annual maintenance cost of additional irrigation system (C_6)]

or $$Z \overset{MAX}{=} [B_1 + B_2 + B_3 - C_1 - C_2 - C_3 - C_4 - C_5 - C_6]$$

Where Z stands for the net annual benefit.

The above expression has been evaluated in the next para for four different levels of development considered. All benefits and costs refer to a common point of time that is the end of the construction period.

PROCEDURE FOR CALCULATION

(1) Annual Benefits from Energy Generated at Lakhwar-Vyasi Project (B_1)

Hydroelectric power may be evaluated (i) in terms of the cost of capacity and energy from the most economical alternative source usually thermal or sometime diesel power or (2) the highest price which the users are willing to pay. This has been taken as 12 paise per kwh. The energy benefits from Lakhwar-Vyasi project are taken to accrue on completion of the project and continue for a period of 100 years which is the designed life of the project. In economic evaluation 5% of the energy has been deducted towards losses.

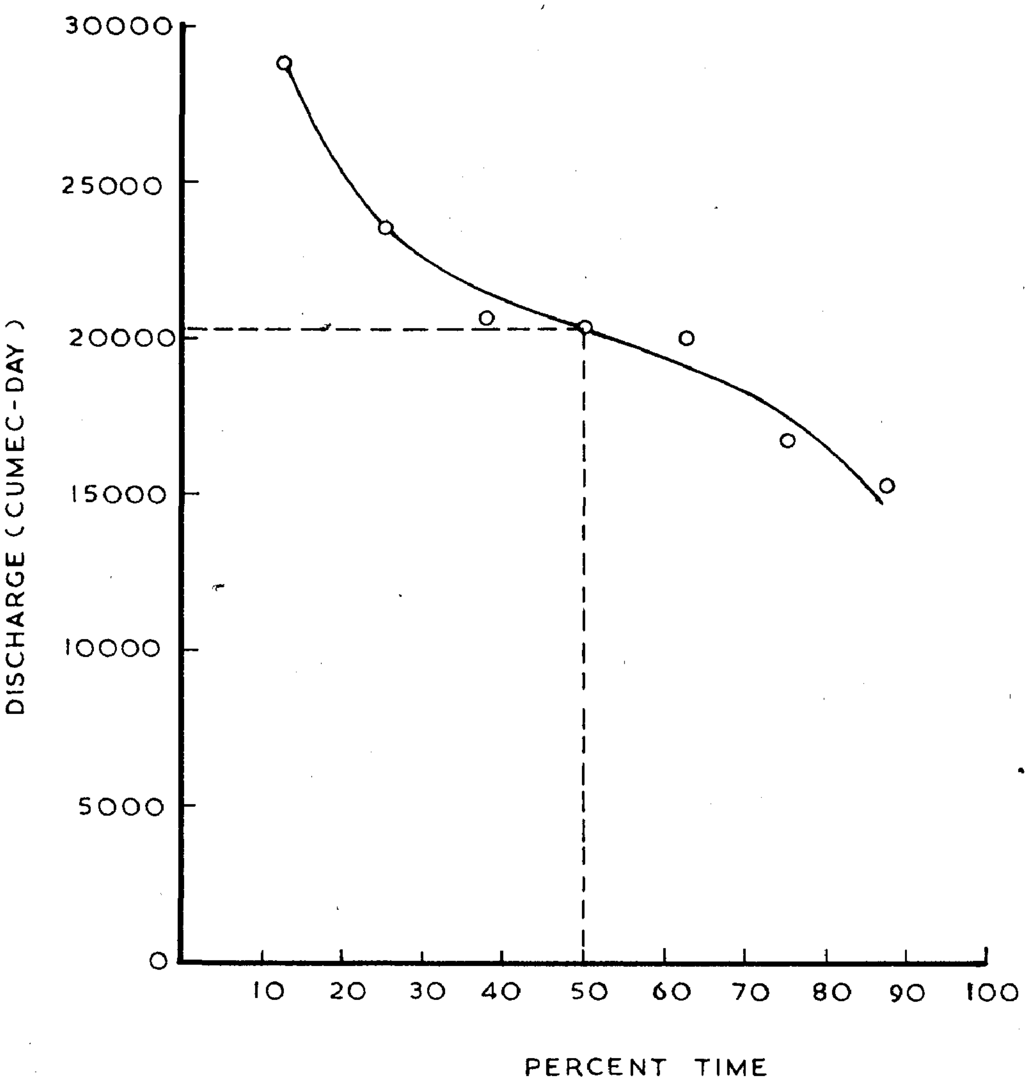
Annual benefits from additional energy generated at Dhakrani, Dhalipur & Kulhal due to Lakhwar-Vyasi complex:

The surplus water of river Yamuna at Lakhwar during monsoon will be utilised to fill up the Lakhwar reservoir. The inflow from Tons and the intermediate catchment would be sufficient to meet the needs of irrigation at Tajewala during this period. Releases from Lakhwar at any time will be in accordance with the requirements for power generation during that time. Due to this regulation at Lakhwar dam, flow in the nonmonsoon months will increase in the downstream (Table 8 to 11) and this additional flow will generate additional power in the three downstream power houses. It is seen that generally flow is more than release for the four monsoon months of July to October. For the balance eight months release is more than inflow. Thus the additional flow (R_t - I_t) will generate extra energy in the downstream run-of-the-river plants (Table 8 to 11) in accordance with their flow-energy relationship. For the purposes of calculation of benefits from this additional energy from Dhakrani, Dhalipur & Kulhal power houses on account of the Lakhwar Storage Scheme, the same rate of 12 paise per kwh has been adopted. Figures 9, 10, 11, 12 show the additional energy generated in the downstream power houses and that from Lakhwar-Vyasi complex for different levels of development.

However one important aspect which must be borne in mind is that, alongwith the additional benefits that accrue to Lakhwar-Vyasi Scheme on account of generation of additional power in the downstream run-of-the-river plants, there is also an element of indirect cost involved for the scheme, in as much as, it contributes to the reduction of plant factor of existing installations during rainy season. Energy requirements being less during this period, The available capacity cannot be utilised in full which result in reduced capacity factor. For arriving at this cost a detaile analysis of the available capacity, power potential, and system load is necessary. For the present study, a 25% reduction of the value of the additional benefits has been made to take into account this aspect. The percentage adopted is only qualitative.

(ii) Annual Benefits from Secondary Power (B_2)

The annual benefits discussed earlier are for primary power only. Besides the primary power there would be secondary power in years of higher inflows. The value of secondary power is equal to essentially the saving in fuel cost of a thermal plant on account of absorption



FLOW-DURATION CURVE

FIG. 8

of that energy in the system by shedding of load from thermal plants at such times.

Secondary power cannot be guaranteed but is available more than half the time. Besides the secondary power there will also be certain amount of dump power with reduced availability which has not been considered here. Since the secondary power is taken as available for 50% of the time, the present, value of the benefits have been found out over a time horizon of 100 years with interest rate of 6% and the annuity corresponding to this present value is taken as the annual benefit from secondary power. The details of economic evaluation may be seen in para 5.02. The availability of secondary power is indicated in Appendix 5. The saving towards fuel has been taken as 5 paise per kwh of energy. The flow duration curve for the actual observations is shown in Fig. 8.

(iii) Annual Benefits From Additional Irrigation (B_3)

As more flow would be available during the non-monsoon months from November to June, due to regulation of discharges at Lakhwar dam, Irrigation from the down-stream existing irrigation-system can be increased. It may be seen from Table 8 that the total inflow at Lakhwar from November to June before the construction of the dam (90% availability) is 6355 cumec-day and after construction of the dam the total releases for the above period is 10280 cumec-day on an average, for the four different levels of development studied (Table 8 to 11). During the nonmonsoon period therefore, 3925 cumec-day(33,900 ha.m.) more of water would be available for additional irrigation in the EYC command. From this amount, conveyance losses enroute may be deducted to arrive at the net additional quantity of water available at Tajewala from November to June. Adopting the same loss rate enroute as taken in Lakhwar-Vyasi project report the total loss works out as below:-

(i)	November to February @ 30 cumec-daily	= 3600 cusec-da
(ii)	March to April @40 cusec daily	= 2440 "
(iii)	May to June @ 50 cusec-daily	= 3050 "
	TOTAL	= 9090cusec-da
		= 2220 ha.m.

Net water available at Tajewala after deducting losses enroute = 33900 - 2220

= 31,680 ha.m.

Deduct 45% losses in the distribution system and field channels = 31,680 x 0.45

= 14,250 ha.m.

Water available for irrigation = 31680 - 14250

= 17,430 ha.m.

The direct benefits of new or additional irrigation are the difference between the annual net income from farm produce "with irrigation" and the annual net income "without irrigation". This increase in income has been taken as Rs.500 per acre. The cost stream consists of the annual equivalent of the capital cost for the additional irrigation system and its annual maintenance cost. Capital cost of the additional irrigation system has been taken as Rs.800 per acre and the cost of maintenance as Rs.10 per acre. Irrigation benefits will continue to accrue for 100 years from the time of completion of the project.

Assuming an average delta of 0.34 m, additional area that can be provided with irrigation

$$= 17430/0.34 = 51,300 \text{ ha.}$$

(126,000 ac.)

So the firm commitment for additional irrigation on the basis of the average delta adopted can be to the extent of 126,000 acres. There would be no change in the status of irrigation during monsoon. The additional surface water available for irrigation will be used in conjunction with ground water.

(iv) <u>Annual Equivalent of Capital Cost</u> : (C_1)

In water resources development projects, the annual equivalent of Capital cost is taken to include interest and depreciation. From the economic point of view, a given investment means a freezing of resources which might otherwise be used for meeting other needs or for other productive activities. If their use for such needs is postponed because of investment in the project there exists a social sacrifice, the value of which is expressed by means of the interest charge. The interest charge in this case has been taken as 6%.

Depreciation in water resources is the unavoidable loss in service value of a project due to physical deterioration. Depreciation depends to a large extent on the physical life of the engineering structures. The depreciation charge is intended to assume that the value of the goods and services used in the projectis returned to the national economy through the growth of income before the project wears out. It follows that the annual cost of the project should include an item equal to the depreciation of each of its parts in accordance with the life expectancy estimated for them based on the cost less the salvage value of the respective items. The sinking fund method is the most suitable and commonly used method for the depreciation of permanent works of water resources development project. For working out the depreciation in our case in accordance with the above method, interest rate of 3% and 90% recovery of the capital has been adopted.

As contemplated in the project report, the time of construction of Lakhwar-Vyasi complex is taken as 7 years. The capital cost will be incurred over this span of 7 years. The rate of investment will not be uniform during this period. After start, the project work gradually gets momentum and a peak rate of progress is achieved during which time most of the work is completed. After this period the rate of investment again decreases; Investment during this period is needed to complete the finishing items of work. The capital cost is taken to flow @ 5% for the Ist year, 10% for the 2nd year, 15% for the third year, 20% for the next three years and 10% for the last year. The single payment compound amount (SPCA) of these sums have been calculated to the end of 7th year with 6% interest. To arrive at the annual equivalent of capital cost, interest rate of 6% has been employed over 100 years. The life of the dam is taken as 100 years and power production is to continue upto 100 years from the time of completion. But depreciation for power plant and other structures has been taken in accordance with the life span recommended. The details of depreciation may be seen in Appendix 5A.

(v) Annual Maintenance Cost of Dam & Appurtenant Works (C_2)

This is taken as 0.25% of respective capital cost. This cost stream flows for a period of 100 years from the time of completion. The annual maintenance cost for the four levels of development is shown in Appendix A.

(vi) Annual Maintenance & Operation Cost of Lakhwar-Vyasi Power Plants (C_3)

The operation and maintenance expenses of a hydro-plant are generally classified under the following headings:-

1. Operating Labour
2. Maintenance Labour and Material
3. Supplies
4. Supervision

Operating Labour:

Attention to equipment in a power plant is a necessity. Even if the operation may be automatic,periodic inspections are necessary so that operating labour is not completely eliminated in any case. Since hydroplants have much lesser number of units of equipment requiring attention than thermal plants the cost of operating labour is much less and is likely to remain constant for all ranges of energy production[21].

Maintenance Labour and Materials:

Any well managed plant will generally follow a plan of preventive maintenance, inspecting cleaning overhauling apparatus on a regular schedule to fore-stall the possibility of break-down during service. This item of expenses is made up of two factors, materials used in making repairs and part replacement as required[1].

Supplies :

Supplies usually cover such items as lubricating oils, tools, wiping cloth etc. In case of thermal plants they may also include water treatment chemicals etc. In general any item that are not included in the categories of fuel(for thermal plants) or maintenance are charges to the supplies.

Supervision :

Supervision usually includes the salary of the regular establishment.

For estimating the operation and maintenance cost comprising of above items for Lakhwar-Vyasi power plant a rate of 0.5% of capital cost has been adopted. The annual maintenance and operation cost for different levels of development has been shown in Appendix 5A.

(vii) Incremental Operational Cost of Additional Power from Dhakrani Dhalipur and Kulhal Power Houses (C_4)

As already explained in para (vi) above, the incremental operation and maintenance cost of generating the additional power would be almost negligible. Only due to an increase in plant factor there may be same extra requirement of operating labour, maintenance labour and material and supplies. This has been taken as 20% of the normal operation cost. Normal operation cost for the additional power is worked out on pro-rata basis with Lakhwar-Vyasi power.

(viii) Annual Equivalent of Capital Cost of Additional Irrigation System (C_5)

The Capital cost of the additional irrigation system has been worked out on the basis of Rs.800 per acre. The total cost thus works out to Rs.1008 lakhs. The interest on capital has been taken as 6%. The amount of depreciation has been calculated with 3%

interest and 90% recovery. The depreciation amount worksout to Rs.1.5 lakhs. The economic life is taken as 100 years.

(ix) Annual Maintenance Cost of Additional Irrigation System (C_6)

The maintenance cost of the additional irrigation system as taken as Rs.10 per acre. This cost stream flows for a period of 100 years from the time of completion of the project.

5.02 EVALUATION OF ALTERNATIVE PLANS

(a) Alternative Plans :

A storage hydroelectric plant site will invariably offer scope for different levels of development at the same site. The reservoir storage would be constrained by the dead storage requirement as the lower limit and physically possible maximum storage for the site as its upper limit. The maximum possible storage is guided by the Geology of site, terrain condition and submergence etc. Between these two limits a large number of alternative plans of development are possible. As power is directly proportional to the height 'H' through which the water falls, the storage at a higher level would mean more power and consequently more benefits from the project. Side by side the cost also increases due to the necessity of building a higher dam for the purpose. So as the height of the dam increases both benefit and cost increases and as the height of the dam benefit and cost increases and as the height of the dam decreases cost and benefit decreases. There is, therefore a choice for selection of that particular plan of development which is optimal among large number of possible alternatives.

For Lakhwar dam, unsuitable Geological condition prevents making the dam higher than about EL 810.0 m. The dead storage is around EL 752.00 m. Within these two limits 4 alternatives have been studied corresponding to full reservoir levels at EL 795.0, EL 800.00, EL 805.0 and EL 810.0 m. The 90% availability inflow (Appendix 2) has been used for all the four cases. An active capacity at 400 cumec-day has been provided in each case. The minimum drawdown level in each case has been fixed from the consideration of the full reservoir levels stated above and the active capacity.

A computer program has been developed for operation of the reservoir for the four alternative levels of development. The flow chart is shown in Fig. 13 and the computer programme in Appendix 8. The following algorithm has been used for the operation of the reservoir.

$$S_{i+1} = S_i + I_i - R_i - EV_i$$

subject to

$$0 \quad S_{i+1} \quad Y$$

$0 \quad R_i \quad$ Man R_i - for 8 months from Nov. to June

$$E_i = C_i \, E$$

$E_i = E \, L_i + EDIK_i$ - for 8 months

& $\quad E_i = EL_i$ - for 4 months from July to October

$$EL_i = R_i \times EPR \left(\frac{S_i + S_{i+1}}{2}\right)$$

$$EV_i = ~~R~~\ EC_i \times AI \ \frac{(S_i + S_{i+1})}{2}$$

$$i = 1, \ldots\ldots 12$$

Where

S_i = Storage at the beginning of period i

I_i = Flow during the period i

R_i = Release during the period i

~~EV_i = Evaporation loss during the period i~~

Y = Active capacity

Man R_i = Mandatory release during the period i

E_i = Energy generated during the period i

C_i = Energy demand coefficient for the period i

E = Total energy generated over the period $i = 1, \ldots\ldots 12$

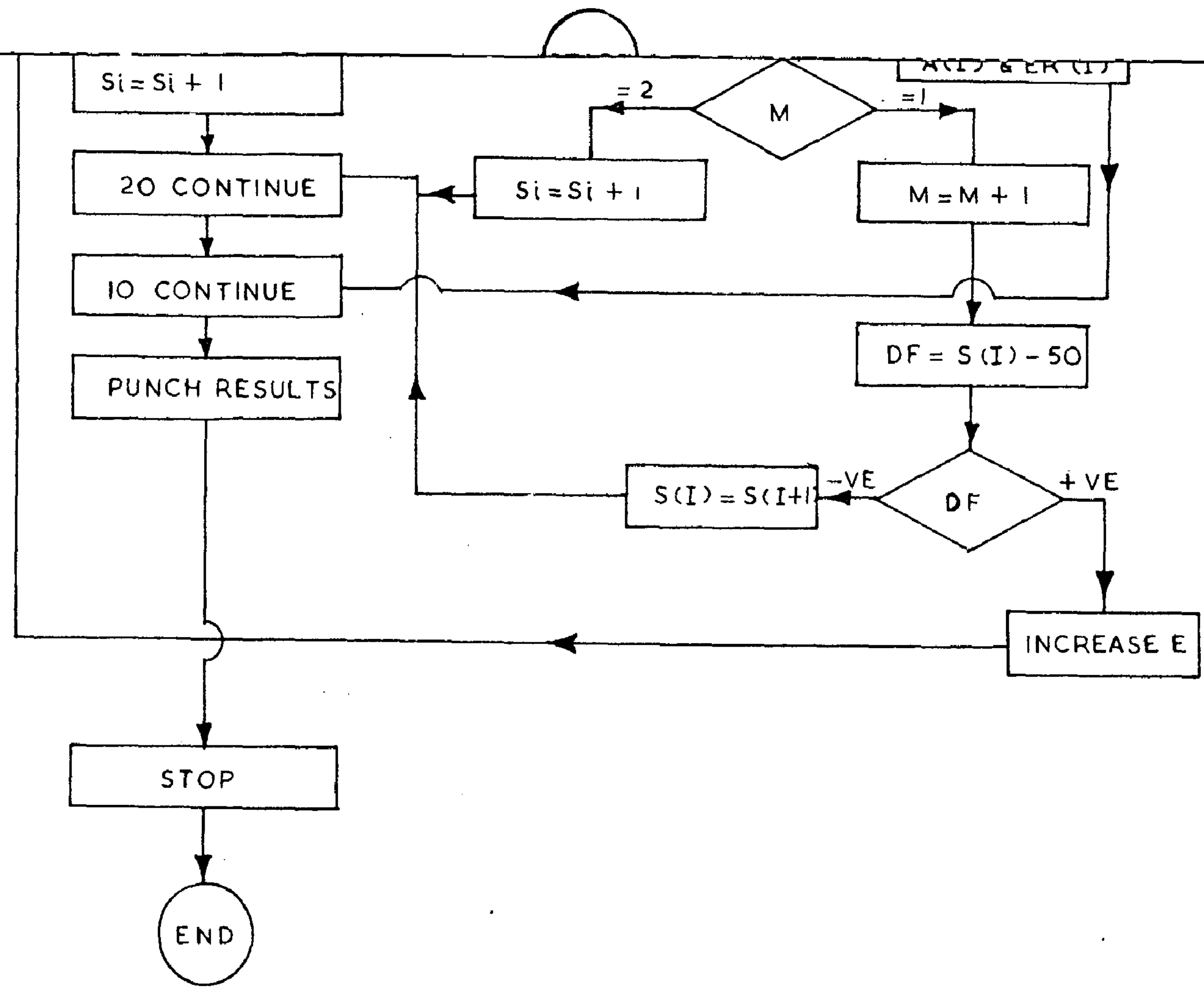
$EPR \frac{(S_i+S_{i+1})}{2}$ = Energy production rate, per unit vol. of water corresponding to S_i & S_{i+1} stage.

EL_i = Energy generated in Lakhwar-Vyasi power house during the period i

EV_i = Evaporation loss from the reservoir during the period i

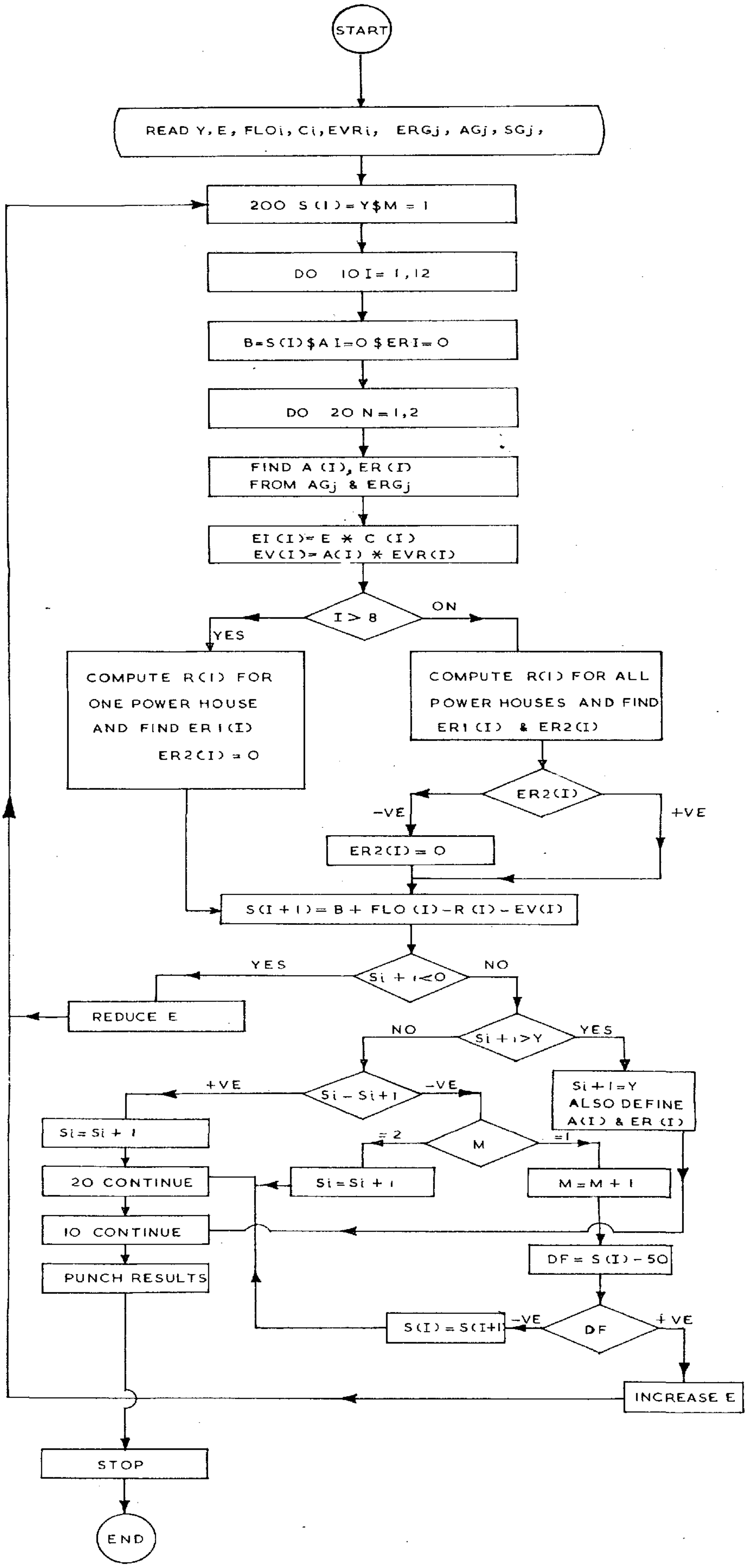
EC_i = Evaporation Coefficient for the period i

$AI \left(\frac{S_i+S_{i+1}}{2}\right)$ = Reservoir surface area corresponding to S_i & S_{i+1} stage.



FLOW CHART

FIG. 13



FLOW CHART

FIG. 13

To start with E is assumed. The reservoir is operated from full. The operation is carried out over 12 months with 90% runoff figures. The value of releases and storages for each period are found out. If the storage worked out to be significantly negative at any time, the entire cycle is repeated with reduced value of E. This continues till the value of storage is within the limit of permissible negative value. On the other hand if the storage remained signkficantly above the M.D.D.L. at the critical month, the entire cycle is repeated with increased value of E. The end value of storage is also checked. If S_{12} exceeded Y but has reached zero levels at the critical month, no further scope exists for increasing power. This indicates that active capacity required is more than that provided. If S_{12} remained less than Y, it shows capacity provided is larger than that required. An ideal solution is that which touches zero at the critical month and reaches Y at the end of the cycle.

The results of operation of the four alternatives have been tabulated in the following tables(Tables 8, 9 10,11). These show the releases during different months, total energy generated in each month and that individually from Lakhwar-Vyasi complex and the downstream run-of-the-river plants. Other details such as the evaporation losses and the additional water available during nonmonsoon are also shown in the table.

TABLE - 8

RESERVOIR OPERATION - ALTERNATIVE 1

F.R.L. = 795.0 m

Active capacity - 4000 cumec-day

M.D.D.L. - 747.0 m

Inflow - 90% availability

Assumed E = 861 mkwh

Month	Inflow Cumec-day	Release for Power cumec-day	Evaporation loss cumec-day	Energy generated at Lakhwar Vyasi mkwh	Mandatory release cumec-day	Additional water for power d/s cumec-day	Additional energy from Dhakrani Dhalipur & Kulhal p.h.	Total energy in mkwh	Total Power in mw	Power from Lakhwar-Vyasi mw
November	980	1267.49	9.64	65.12	980	287.49	3.94	69.06	96	90.5
December	690	1288.08	8.16	65.68	690	598.08	8.19	73.88	99.4	88.2
January	570	1412.89	6.66	71.16	570	842.89	11.55	82.71	111.1	95.7
February	560	1033.33	7.89	51.33	560	473.33	6.48	57.82	85	76.3
March	580	1203.43	10.25	58.91	580	623.43	8.54	67.45	90.5	79.2
April	660	1251.22	10.43	60.16	660	591.22	8.10	68.26	93.6	83.5
May	840	1350.13	15.92	63.68	840	510.13	6.99	70.66	95	85.5
June	1475	1477.63	13.63	69.02	1475	2.63	0.04	69.06	96	96
July	1775	1296.13	10.91	61.03	-	-	-	61.03	82	82
August	3760	1211.49	11.34	59.42	-	-	-	59.42	79.8	79.8
September	2040	1148.91	14.36	58.62	-	-	-	58.12	81.5	81.5
October	1620	1265.39	13.97	65.04	-	-	-	65.04	87.5	87.5
			133.16			3929.20	53.83	803		

Corrected E = 803.00

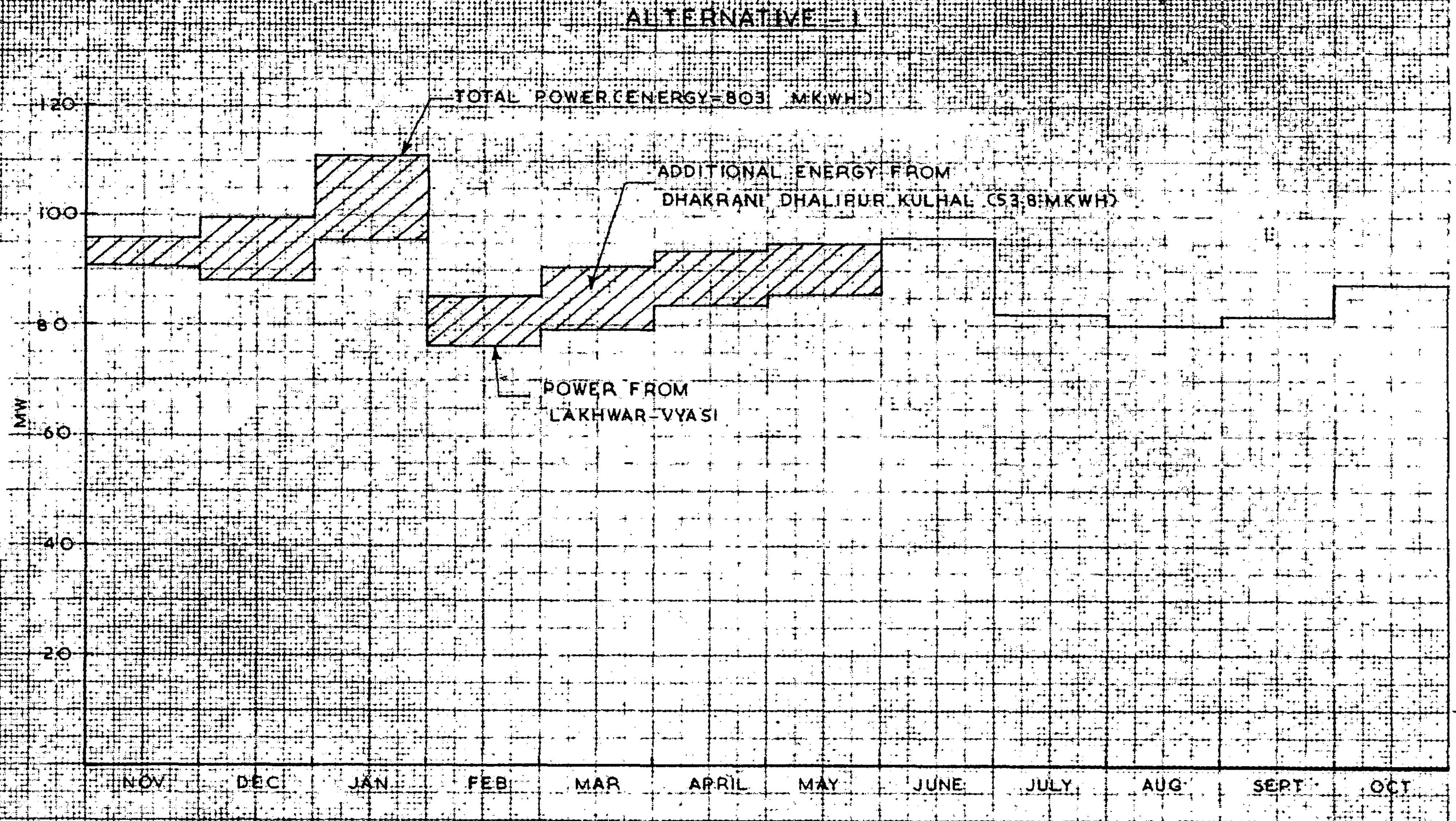

ALTERNATIVE – I
TOTAL POWER (ENERGY = 803 M.KWH)
ADDITIONAL ENERGY FROM
DHAKRANI DHALIPUR KULHAL (53.8 M.KWH)
POWER FROM
LAKHWAR-VYASI
MW
120
100
80
60
40
20
NOV
DEC
JAN
FEB
MAR
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT

FIG. 9

TABLE - 2

RESERVOIR OPERATION - ALTERNATIVE - 2

F.R.L. - 800.0 m

Active Capacity = 4000 cumec-day

M.D.D.L. - 755.0 m

Assumed E = 876 mkwh

Inflow = 90% availability

Month	Inflow cumec-day	Release for Power (cumec-day)	Evaporation loss (cumec-day)	Energy generated at Lakhwar-Vyasi mkwh	Mandatory release (cumec-day)	Additional water for power d/s (cumec-day)	Additional energy from Dhakrani, Dhalipur & Kulhal P.H.	Total Energy mkwh	Total Power mw	Power from Lakhwar Vyasi mw
November	980	1270.75	10.38	66.37	980	290.75	3.98	70.86	98.4	92.8
December	690	1292.78	8.65	67.53	690	603.78	8.27	75.80	102.0	91.9
January	570	1419.91	6.96	73.22	570	849.91	11.64	84.86	114.0	98.5
February	560	1035.80	8.38	52.80	560	475.80	6.52	59.32	88.2	78.5
March	580	1204.36	11.23	60.66	580	624.36	8.55	69.21	93.0	81.5
April	660	1250.16	11.49	61.95	660	590.16	8.08	70.03	97.2	86.0
May	840	1336.94	18.57	65.70	840	496.94	6.81	72.51	97.5	88.4
June	1475	1468.79	15.56	70.94	1475	-	0	70.86	98.4	98.4
July	1775	1286.04	12.21	62.62	-	-	0	62.62	84.2	84.2
August	3760	1207.93	12.15	60.97	-	-	0	60.97	81.8	81.8
September	2040	1150.75	15.33	60.15	-	-	0	60.15	83.5	83.5
October	1620	1267.25	15.10	66.74	-	-	0	66.74	89.6	89.6
			146.01	770.05	6355	3931.70	53.85	823.92		

Corrected E = 823.92 mkwh

Say 824 mkwh

ALTERNATIVE - 2

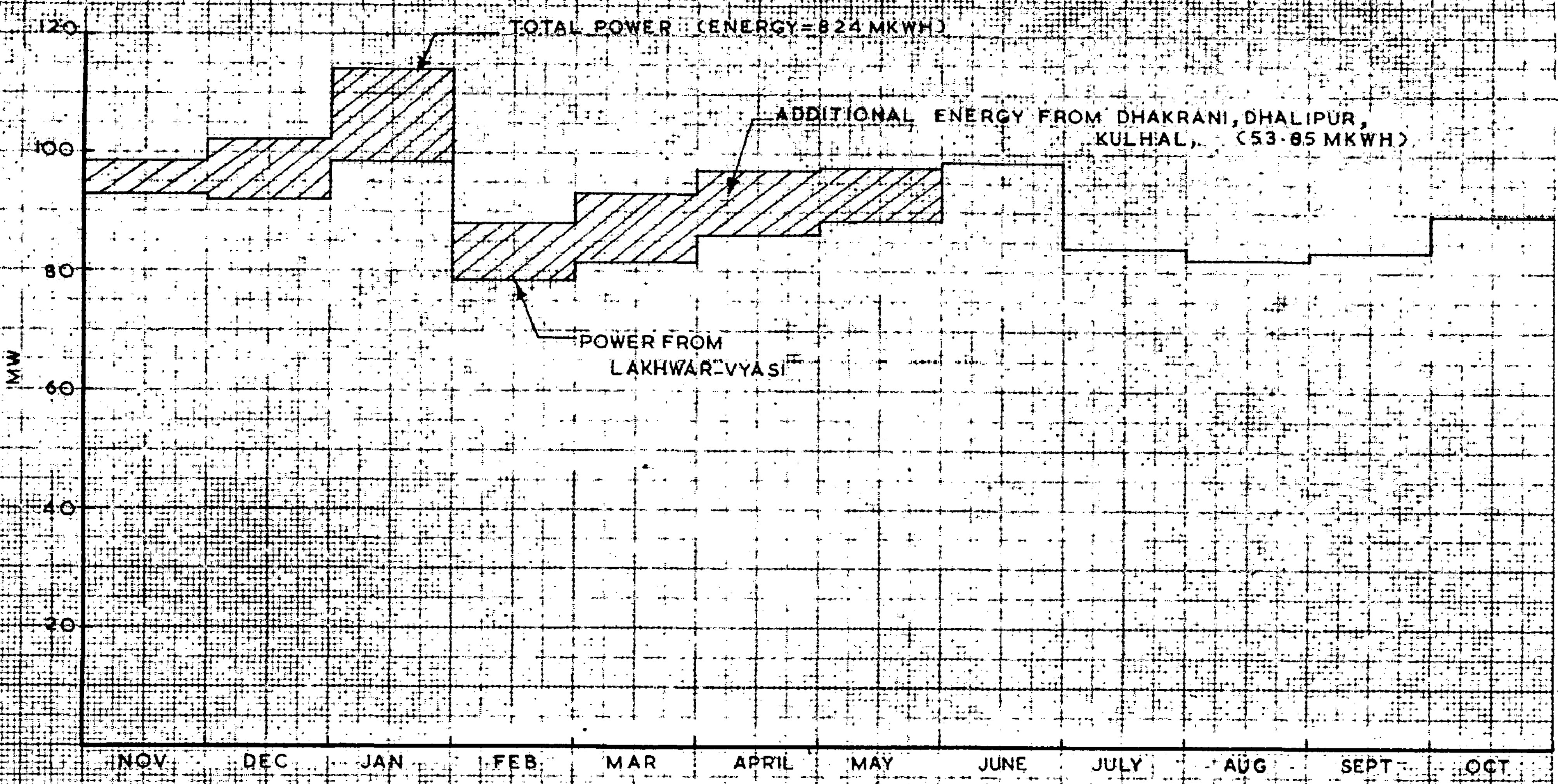


FIG. 10

TABLE - 10

RESERVOIR OPERATION - ALTERNATIVE - 3

F.R.L. - 805.0 m

Active capacity - 4000 cumec-day

M.D.D.L. - 762.0 m

Assumed E - 850 mkwh

Inflow - 90% availability

Month	Inflow cumec-day	Release for power (cumec-day	Evaporation loss(cumec-day)	Energy generated at Lakhwar-Vyasi mkwh	Mandatory release (cumec-day)	Additional water for power d/s (cumec-day)	Additional energy from Dhakrani, Dhalipur&Kulhal P.H.	Total Energy mkwh	Total power mw	Power from Lakhwar-Vyasi
November	980	1269.82	10.92	68.36	980	289.82	3.97	72.33	100.4	95
December	690	1294.62	9.21	69.09	690	604.62	3.28	77.37	104	93
January	570	1422.17	7.35	74.95	570	852.17	11.67	86.62	110	100.8
February	560	1036.63	8.77	54.02	560	466.63	6.53	60.55	90.1	80.5
March	580	1203.81	11.95	62.10	580	623.81	8.55	70.64	95	83.5
April	660	1246.46	12.68	63.45	660	586.46	8.03	71.49	99.4	88
May	840	1331.82	20.88	67.28	840	491.22	6.73	74.01	99.5	90.5
June	1475	1459.52	16.81	72.54	1475	-	-	72.33	100.4	100.4
July	1775	1275.68	13.50	63.92		-	-	63.92	86	86
August	3760	1202.55	13.21	62.23		-	-	62.23	83.7	83.7
September	2040	1148.75	16.15	61.39		-	-	61.39	85.2	85.2
October	1620	1264.16	15.84	68.12		-	-	68.12	91.6	91.6
					6355	3914.73	53.76	841		

Corrected E = 841 mkwh

ALTERNATIVE - 3

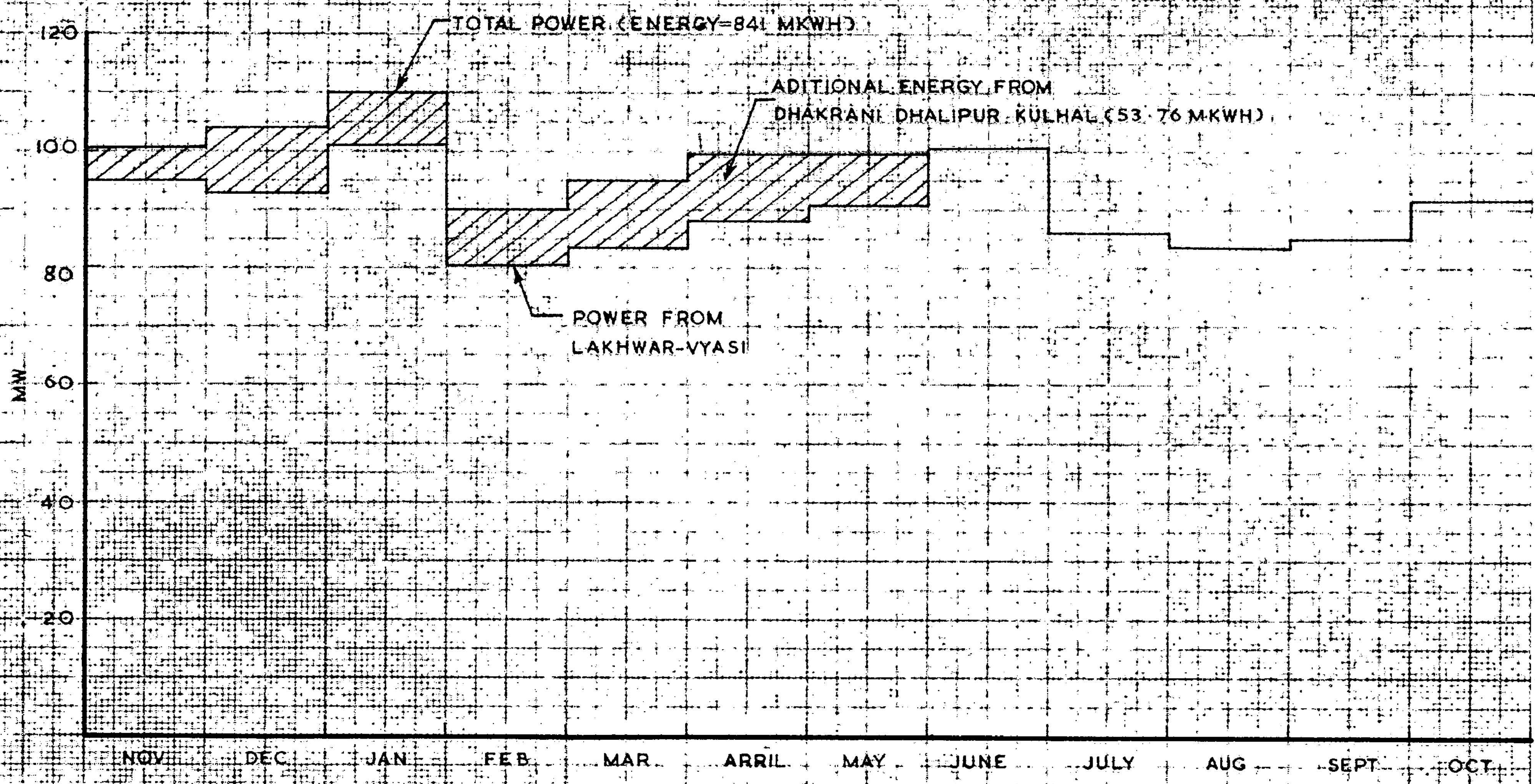


FIG. 11

TABLE - 11

RESERVOIR OPERATION - ALTERNATIVE - 4

F.R.L. - 810.0 m

Active Capacity - 4000 cumec-day

M.D.D.L. - 773.0 m

Inflow - 90% Availability

Assumed E = 880 mkwh

Month	Inflow (cumec-day)	Release for Power Cumec-day	Evaporation loss (cumec-day)	Energy generated at Lakhwar-Vyasi-mkwh	Mandatory release cumec-day	Additional water for power d/s cumec-day	Additional energy from Dhakrani, Dhalipur & Kulhal	Total Energy in mkwh	Total power in mw	Power from Lakhwar-Vyasi mw
November	980	1272.58	11.54	70.61	980	292.58	4.01	74.61	103.7	98.1
December	690	1296.76	9.94	71.51	690	606.76	8.31	79.82	107.3	96.1
January	570	1424.85	8.06	77.65	570	854.85	11.71	89.36	120	104.4
February	560	1038.04	9.50	55.92	560	478.04	6.55	62.47	92.9	83.2
March	580	1204.82	12.93	64.32	580	624.82	8.56	72.88	98	86.5
April	660	1244.04	14.06	65.75	660	584.04	8.00	73.75	102.4	91.3
May	840	1325.36	23.74	69.70	840	485.36	6.65	76.35	102.6	93.8
June	1475	1445.31	24.34	75.02	1475	-	-	74.61	103.7	103.7
July	1775	1261.84	15.86	65.94	-	-	-	65.94	88.6	88.6
August	3760	1194.80	14.88	64.20	-	-	-	64.20	86.3	86.3
September	2040	1147.01	17.52	63.33	-	-	-	63.33	88	88
October	1620	1265.15	16.77	70.28	-	-	-	70.28	94.5	94.5
						3926.45	53.79	867.60		

Corrected E = 867.60 mkwh

Say 868 mkwh

ALTERNATIVE - 4

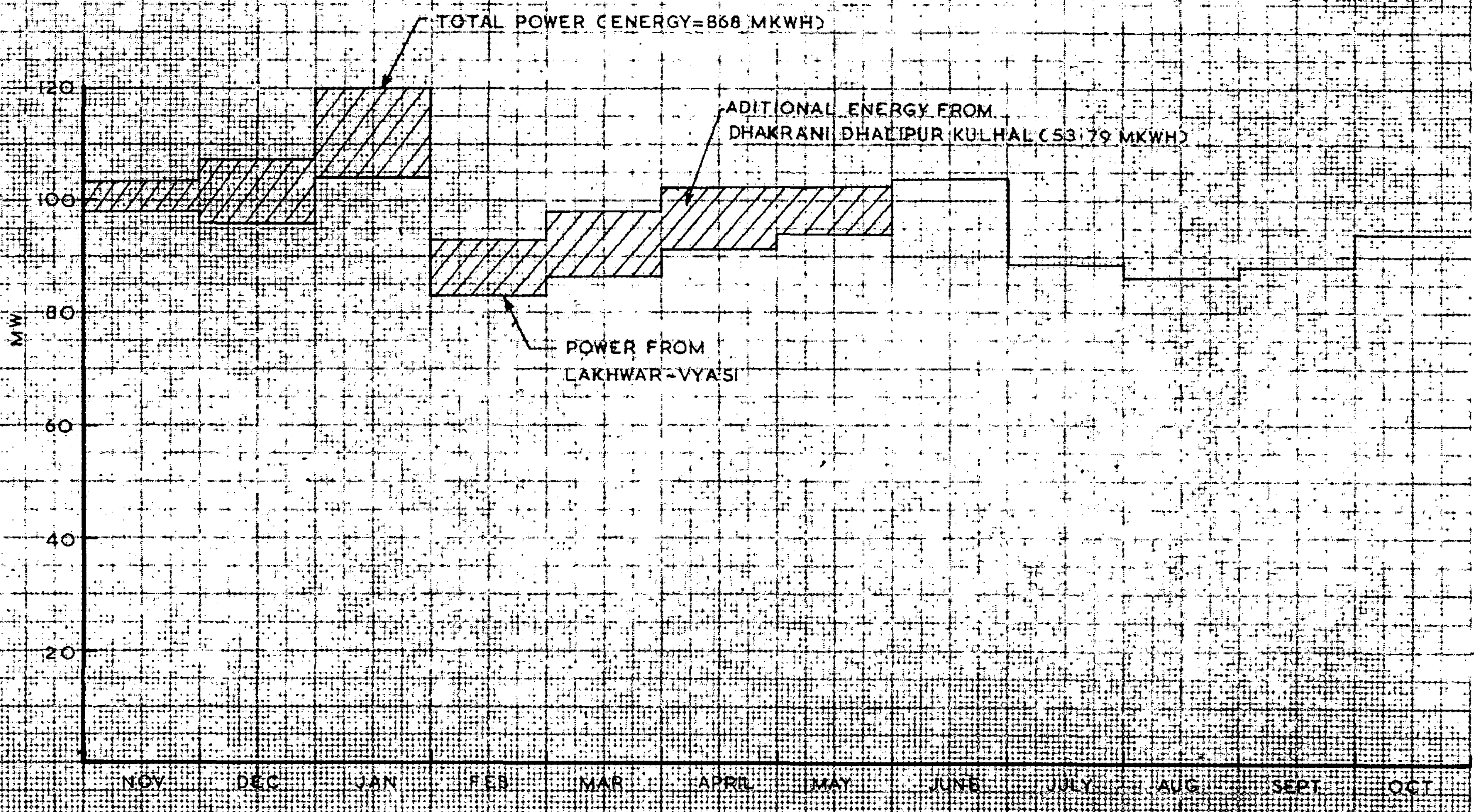


FIG 12

(b) Evaluation

C = Capital cost

C^*_1 to C^*_7 = Annual investment of capital

$(USCA)^n_i$ = Uniform Series Compound Amount for n years with interest i

$(USPV)^n_i$ = Uniform Series Present Value

S = Future sum

$(SPCA)^n_i$ = Single payment compound amount

PVB = Present Value of Benefits

Alternative 1

C = Rs. 13981 lakhs

C^*_1 = Rs.699 lakhs

C^*_2 = Rs. 1398 lakhs

C^*_3 = Rs.2098 lakhs

C^*_4 = Rs.2796 lakhs

C^*_5 = Rs.2796 lakhs

C^*_6 = Rs.2796 lakhs

C^*_7 = Rs.1398 lakhs

Annual Energy available for the size of the development considered = 803 mkwh (Table 8)

Deduct 25% of additional power from Dhakrani, Dhalipur & Kulhal due to reasons explained in para 5.01 = 13 mkwh

Gross annual energy considered for economic evaluation ~~Deduct losses 2%~~ = 803 - 13 = 790 mkwh.

DEDUCT LOSSES 5 %

$B_1 = (790 - 40) \times 0.12 \times 10^6$

$= 750 \times 0.12 \times 10^6$

= Rs.900 lakhs.

B_2 = Rs. 116.5 lakhs, 50% of the time.

$$PVB(B_2) = B_2 \times (SPPV)^{1}_{6} + B_2(SPPV)^{3}_{6} \; B_2 x(SPPV)^{5}_{6} + B_2(SPPV)^{7}_{6}$$

$$+ B_2 \times (SPPV)^{9}_{6} + \ldots\ldots\ldots + B_2 \; (SPPV)^{99}_{6}$$

$$= B_2 \times 8.614$$

$$= 116.5 \times 8.614$$

$$\therefore B_2 = \frac{116.5 \times 8.614}{(USPV)^{100}_{6}} = \frac{116.5 \times 8.614}{16.6175} = 60.5 \text{ lakhs}$$

$B_3 = 1.26 \times 500$ = Rs.630 lakhs.

$$C_1 = \frac{S}{(USPV)^{100}_{6}} + 111$$

$$S = C^*_7 + C^*_6 \; (USCA)^{3}_{6} \times (SPCA)^{1}_{6} + C^*_3(SPCA)^{4}_{6} + C^*_2(SPCA)^{5}_{6} + C^*_1 \; (SPCA)^{6}_{6}$$

$$= C^*_7 + 3.184 \times 1.060 \times C^*_6 + 1.262 \times C^*_3 + 1.338 x C^*_2 + 1.419 \times C^*_1$$

$$= 1398 + 3.184 \times 1.060 \times 2796 + 1.262 \times 2098 + 1.338 \times 1398 + 1.419 \times 699$$

$$= 1398 + 9440 + 2650 + 1870 + 990$$

= Rs. 16348 lakhs.

$$C_1 = \frac{16348}{16.6175} + 111$$

$= 985 + 111$

$=$ Rs. 1096 lakhs.

$C_2 =$ Rs. 34.95 lakhs

$C_3 =$ Rs. 69.90

$$C_4 = 0.20 \times \frac{54}{803} \times 69.9$$

$=$ Rs. 0.94 lakhs.

$$C_5 = \frac{1008}{(USPV)\frac{100}{6}} + 1.5$$

$$= \frac{1008}{16.6175} + 1.5$$

$= 60.2 + 1.5$

$=$ Rs. 61.7 lakhs.

$C_6 = 1.26 \times 10 =$ Rs. 12.6 lakhs.

$\therefore$ Benefit - Cost $= B_1 + R_2 + B_3 - C_1 - C_2 - C_3 - C_4 - C_5 - C_6$

$= 900 + 60.5 - 1096 - 34.95 - 69.90 - 0.94 - 61.7 - 12.6$

$= 1590.5 - 1276.09$

$=$ Rs. 314 lakhs (rounded)

ALTERNATIVE .2

C = Rs. 14537 lakhs.

C_1^* = Rs. 727 lakhs

C_2^* = Rs. 1454 lakhs

C_3^* = Rs.2181 lakhs.

C_4^* = Rs.2907 lakhs.

C_5^* = Rs.2907 lakhs

C_6^* = Rs. 2907 lakhs.

C_7^* = Rs. 1454 lakhs.

Annual energy available for the size of the development considered = 824 mkwh (Table 9)

Deduct 25% of additional power from Dhakrani, Dhalipur & Kulhal power house due to reasons explained in para 5.01
= 13 mkwh

Gross annual energy considered for economic evaluation
= 811 mkwh

Deduct losses 5% = 40 mkwh.

Net Annual energy considered = 811 - 40
= 771 mkwh.

$B_1 = 771 \times 0.12 \times 10^6$
= Rs. 925.2 lakhs

B_2 = Rs.120 lakhs, 50% of the time

$$PVB(B_2) = B_2 \times (SPPV)_6^1 + B_2 \times (SPPV)_6^3 + B_2 (SPPV)_6^5 + \ldots + B_2 (SPPV)_6^{99}$$

$$= B_2 \times 8.614$$

$$= 120 \times 8.614 = 1034$$

$$B_2 = \frac{1034}{(USPV)_6^{100}} = \frac{1034}{16.6175} = \text{Rs. } 62.2 \text{ lakhs}$$

$$B_3 = 1.26 \times 500 = \text{Rs.} 630 \text{ lakhs.}$$

$$C_1 = \frac{S}{(USPV)_6^{100}} + 111$$

$$S = C_7^* + C_6^* x (USCA)_6^3 (SPCA)_6^1 + C_3^* \; x (SPCA)_6^4 + C_2^* x (SPCA)_6^5 + C_1^* \; x (SPCA)_6^6$$

$$= C_7^* + 3184 \times 1.060 \times C_6^* + 1.262 \times C_3^* + 1.338 \times C_2^* + 1.419 \times C_1^*$$

$$= 1454 + 3.184 \times 1.060 \times 2907 + 1.262 \times 2181 + 1.338 \times 1454 + 1.419 \times 727$$

$$= 1454 + 9820 + 2750 + 1946 + 1031$$

$$= \text{Rs. } 17001 \text{ lakhs.}$$

$$C_1 = \frac{17001}{16.6175} + 114$$

$$= 1022 + 114$$

$$= \text{Rs. } 1136 \text{ lakhs.}$$

$$C_2 = \text{Rs. } 36.3 \text{ lakhs}$$

$$C_3 = \text{Rs.} 72.7 \text{ lakhs}$$

$$C_4 = 0.20 \times \frac{54}{824} \times 72.2$$

$$= \text{Rs.} 0.95 \text{ lakhs.}$$

$$C_5 = \frac{1008}{(USPV)_6^{100}} + 1.5$$

$$= \frac{1008}{16.6175} + 1.5$$

$$= 60.2 + 1.5 = \text{Rs.} 61.7 \text{ lakhs.}$$

$$C_6 = 1.26 \times 10 = \text{Rs. } 12.6 \text{ lakhs.}$$

$$\text{Benefit} - \text{Cost} = B_1 + B_2 + B_3 - C_1 - C_2 - C_3 - C_4 - C_5 - C_6$$
$$= 925.2 + 62.2 + 630 - 1136 - 36.3 - 72.7 - 0.95 - 61.7 - 12.6$$
$$= 1617 - 1320$$
$$= \text{Rs.}297 \text{ lakhs.}$$

Alternative 3

C = Rs.15033 lakhs

C_1^* = Rs.752 lakhs

C_2^* = Rs.1503 lakhs

C_3^* = Rs. 2254 lakhs

C_4^* = Rs. 3007 lakhs

C_5^* = Rs.3007 lakhs

C_6^* = Rs.3007 lakhs

C_7^* = Rs.1503 lakhs.

Gross energy = (841 - 13) = 828 mkwh

Deduct losses 5%

$$\therefore B_1 = (828 - 41) \times 0.12 \times 10^6$$
$$= 787 \times 0.12 \times 10^6$$
$$= \text{Rs.}944.4 \text{ lakhs}$$

B_2 = Rs.123 lakhs, 50% of the time.

$$PVB\ (B_2) = B_2 \times (SPPV)_6^1 + B_2 \times (SPPV)_6^3 + B_3\ (SPPV)_6^5 + B_2 (SPPV)_6^7 + \ldots\ldots + B_2 \times (SPPV)_6^{99}$$
$$= B_2 \times 8.614$$
$$= 123 \times 8.614$$
$$= 1060$$

$$R_2 = \frac{1060}{(USPV)_{6}^{100}} = \frac{1060}{16.6175}$$

$= Rs. 63.8$ lakhs

$B_3 = 1.26 \times 500 = Rs.\ 630$ lakhs

$$C_1 = \frac{S}{(USPV)_{6}^{100}} + 116.7$$

$$S = C_7^* + C_6^*(USCA)_6^3 \times (SPCA)_6^1 + C_3^*(SPCA)_6^4 + C_2^*(SPCA)_6^5 + C_1^*(SPCA)_6^6$$

$$= C_7^* + 3.184 \times 1060 \times C_6^* + 1.262 \times C_3^* + 1.338 \times C_2^* + 1.419 \times C_1^*$$

$$= 1503 + 3.184 \times 1.06 \times 3007 + 1.262 \times 2254 + 1.338 \times 1503 + 1.419 \times 752$$

$$= 1503 + 10140 + 2840 + 2015 + 1067$$

$$= 17565$$

$$C_1 = \frac{17565}{16.6275} + 116.7$$

$= 1057 + 116.7$

$= Rs. 1173.7$ lakhs

$C_2 = Rs. 37.58$ lakhs

$C_3 = Rs.\ 75.16$ lakhs

$$C_4 = 0.20 \times \frac{54}{841} \times 75.16$$

$= Rs. 0.96$ lakhs

$$C_5 = \frac{1008}{(USPV)_{6}^{100}} + 1.5$$

$= 60.2 + 1.5$

$= Rs. 61.7$ lakhs

$C_6 = 1.26 \times 10 = $ Rs. 12.6 lakhs

Benefit - Cost $= B_1 + B_2 + B_3 - C_1 - C_2 - C_3 - C_4 - C_5 - C_6$

$= 944.4 + 63.8 + 630 - 1173.7 - 37.58 - 75.16 -$

$0.96 - 61.7 - 12.6$

$= 1638.2 - 1361.7$

$=$ Rs. 276 lakhs (rounded)

Alternative 4

C = Rs. 15508 lakhs

C_1^* = Rs. 775 lakhs

C_2^* = Rs. 1552 lakhs

C_3^* = Rs. 2326 lakhs

C_4^* = Rs. 3101 lakhs

C_5^* = Rs. 3101 lakhs

C_6^* = Rs. 3101 lakhs

C_7^* = Rs. 1552 lakhs

Gross energy = (868 - 13) = 855 mkwh

Deduct losses 5%

$B_1 = (855 - 42) \times 0.12 \times 10^6$

$= 813 \times 0.12 \times 10^6$

= Rs. 975.6 lakhs

B_2 = Rs. 127.5 lakhs, 50% of the time

$$PVB\ (B_2) = B_2 \times (SPPV)_6^1 + B_2(SPPV)_6^3 + \ldots B_2(SPPV)_6^5 + \ldots\ldots + B_2 \times (SPPV)_6^{99}$$

$= B_2 \times 8.614$

$= 127.5 \times 8.614$

$= 1100$

$$B_2 = \frac{1100}{(USPV)_6^{100}} = \frac{1100}{}$$

$= Rs.\ 66.1\ lakhs$

$B_3 = 1.26 \times 500 = Rs.\ 630\ lakhs$

$$C_1 = \frac{S}{(USPV)_6^{100}} + 119$$

$$S = C_7^* + C_6^*(USCA)_6^3 \times (SPCA)_6^1 + C_3^*(SPCA)_6^4 + C_2^*(SPCA)_6^5 + C_1^*\ (SPCA)_6^6$$

$$= C_7^* + 3.184 \times 1.060 \times C_6^* + 1.262 \times C_3^* + 1.338 \times C_2^* + 1.419 \times C_1^*$$

$$= 1552 + 3.184 \times 1.06 \times 3101 + 1.262 \times 2326 + 1.338 \times 155 \ldots + 1.419 \times 775$$

$$= 1552 + 10500 + 2940 + 2080 + 1100$$

$= Rs.\ 18172\ lakhs$

$$C_1 = \frac{18172}{16.6175} + 119$$

$= 1091 + 119$

$= Rs.\ 1210\ lakhs$

$C_2 = Rs.\ 38.77\ lakhs$

$C_3 = Rs. 77.54\ lakhs$

$$C_4 = 0.20 \times \frac{54}{868} \times 77.54$$

$= Rs.\ 0.96\ lakhs$

$$C_5 = \frac{1008}{(USPV)_6^{100}} + 1.5$$

$$= \frac{1008}{16.6175} + 1.5$$

$= 60.1 + 1.5 = 61.7\ lakhs$

$C_6 = 1.26 \times 10 = Rs.\ 12.6\ lakhs$

$$\text{Benefit - Cost} = B_1 + R_2 + B_3 - C_1 - C_2 - C_3 - C_4 - C_5 - C_6$$

$$= 975.6 + 66.1 + 630 - 1210 - 38.77 - 77.54 - 0.96 - 61.7 - 12.6$$

$$= 1671 - 1401$$

= Rs. 270 lakhs (rounded).

TABLE - 12

ABSTRACT OF PROFITABILITY ANALYSIS FOR DIFFERENT LEVELS OF DEVELOPMENT

Alternatives	Level of development (F.R.L.)	B-C lakh Rs.
1	795.0 m	314
2	800.0 m	297
3	805.0 m	276
4	810.0 m	270

5.03 SELECTION OF THE OPTIMAL

From the results of the economic evaluation of the four alternatives given in Table 12 above, it may be seen that the first alternative with full reservoir level at E.L. 795.0 m yields maximum net benefits of Rs.314 lakhs. As the storage level is raised from E.L. 795.0 m to E.L. 810.0 m it is seen that the net benefit gradually diminishes.

From the above analysis it is therefore evident that the F.R.L. should be at E.L. 795 m to derive maximum net economic benefits from the project. The optimal scale of development corresponds to full reservoir level at E.L. 795.0 m. The top level of the dam in that case would be E.L. 799.0 m, considering 4 m as free board. The Lakhwar-Vyasi project report puts the F.R.L. at 796.0 m and top at 800.0 m. This study indicates that the above levels are fairly in conformity with the optimal scale of development.

CHAPTER - VI

DISCUSSION

6.01 SCALE OF DEVELOPMENT FOR DAM

Lakhwar - Vyasi hydro power scheme is proposed to be added to the U.P. Power grid in a near future. Therefore its planning and scale of development requires to be evaluated now. It was seen that planning for a power plant proposed to be run in an interconnected system needs consideration of the overall problem for arriving at the optimal decision. Accordingly to start with, a small truncated system excluding stage II works as shown in Fig. 1 has been considered in this study and optimal size of development has been sought to be found out by maximising benefits minus costs from a number of alternatives. Four different levels of development corresponding to E.L. 795, E.L. 800, E.L.805, E.L. 810 (reservoir levels) have been analysed. It is seen that the maximum net economic benefit is obtained when the full reservoir level is kept at E.L.795.0 m. In the project report it has been fixed at E.L. 796.0 m. That shows the peak point with regard to (B - C) and B/C lies somewhere in this region and below this level the net benefits and Benefit - Cost ratio would again tend to decrease. So the optimal scale of development may be taken as corresponding to reservoir level of E.L.795.0 m. Energy production for this height of reservoir with an active capacity of 4000 cumec-day is estimated to be 803 mkwh (Table 8).

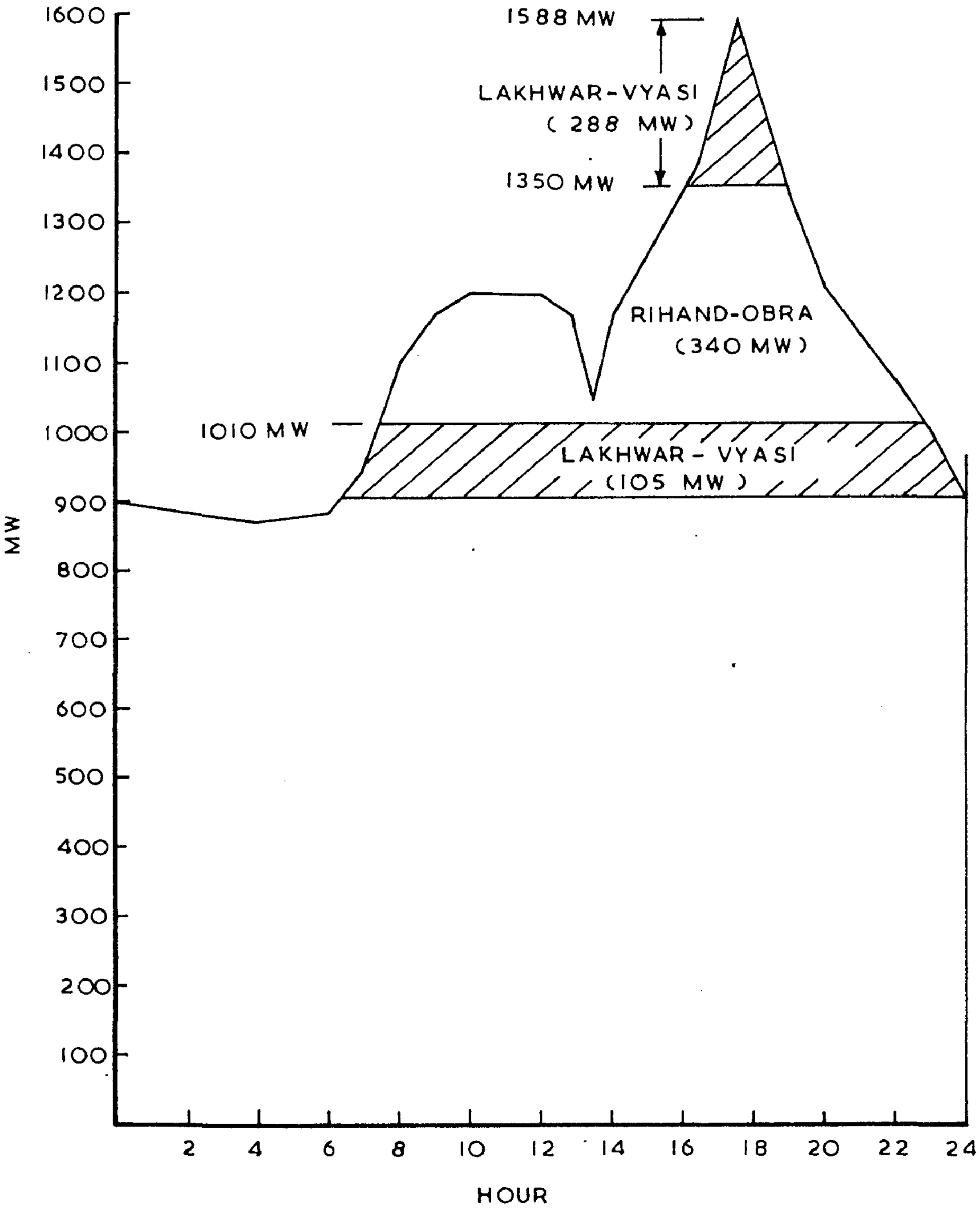


FIG. 14 – TYPICAL DAILY LOAD CURVE OF SYSTEM

6.02 ~~SIZE OF~~ POWER PLANT CAPACITY

This requires a study of the critical-day load curve of the system. From the 1972-73 system load (Table 4) it is seen that the annual peak occurred in the month of January and was equal to 1588 mw. Since the actual daily load curve for the annual peak day is not readily available an approximate daily load curve has been built up with a maximum load of 1588 mw and minimum load of 55% of the peak. Hourly loads as percentages of peak of Ganga-Sarda grid January-day load curve (Appendix 7) has been used as a rough guide to workout the distribution pattern. Unusual fluctuations which is only relevant to the particular grid and conditions on the particular day, have been ignored and general rise and fall in accordance with the expected demand is plotted (Fig. 14). From the daily load curve the load duration curve has also been plotted and shown in Fig. 15.

For allocation of the peak load of the system to the existing and proposed installation, the above daily load curve and load duration curve have been utilised which are taken as typical of the system. The Richard Rihand-Obra storage hydroplant which is the largest and the only storage hydroplant of significance for the system, has been considered first in the matter of allocation of peak load basing on the fundamental policy that maximum use of the existing installations must be ensured before new installation capacities are decided.

As explained in para 2.02 Rihand - Obra hydroplant has an installed capacity of 400 mw and the continuous capacity of the plant basing on designed inflow is 138 mw. The expected DAILY energy from the plant is therefore

$$= 138 \times 24$$
$$= 3312 \text{ mwh}$$

Assuming a peak capability of 85% for the plant, it may be taken that the plant is capable of taking a load of 340 mw at any time. This capacity and energy content has been sought to be fitted in the duration curve to ensure maximum utilisation of this plant first before considering Lakhwar-Vyasi. It is seen that in the load range of 1010 mw to 1350 mw (Fig. 15) almost the entire DAILY energy potential of the plant is contained. So Rihand - Obra hydroplant may be assigned this part of the load for effecive utilisation of its capacity and energy. Above 1350 mw, there still remains a load of 238 mw (1588 - 1350) for 14 percent of the time i.e. of 3 to 4 hrs. duration which, Rihand-Obra is not capable of meeting due to its installation constraint. This part of the load has to be taken by Lakhwar-Vyasi hydroplant. The energy content of this portion is 398 mwh. Even after meeting this demand the plant would be left with a substantial portion of its expected energy potential which is 803 mkwh annually (Table 8). On an average the daily energy potential is 2200 mwh. So after meeting the 14% peak load energy requirement of 398 mwh, the plant will have a further energy potential of 1802 mwh (2200 - 398). This requires running of the plant for more time to utilise the available energy potential in full. The area between 905 mw to 1010 mw in the duration curve contains 1792 mkwh. The capacity requirement for this portion is 105 mw (1010 - 905) which is required for about 82% of time. Therefore the capacity requirement of the new plant is

= 238 + 105

= 343 mw

Add reserve equal to the capacity of the largest unit in the system (1972-73 level) = 100 mw

∴ Total capacity requirement = 343 + 100

= 443 mw.

The installed capacity of the Lakhwar - Vyasi Scheme power plants should therefore, be of the order 443 mw. The project report puts the installed capacity at 540 mw which appears to be rather in the higher side. As the load requirement increases with time, more and more of new installations are added to the system to augment the capacity and energy potential. There is therefore a need and scope for constant review of operation with every new development proposed. The changes in the system requirement pattern can be conveniently taken care of at the time of designing the new power plant. As shown in Table 3, other storage hydroplants like Ramganga is going to be

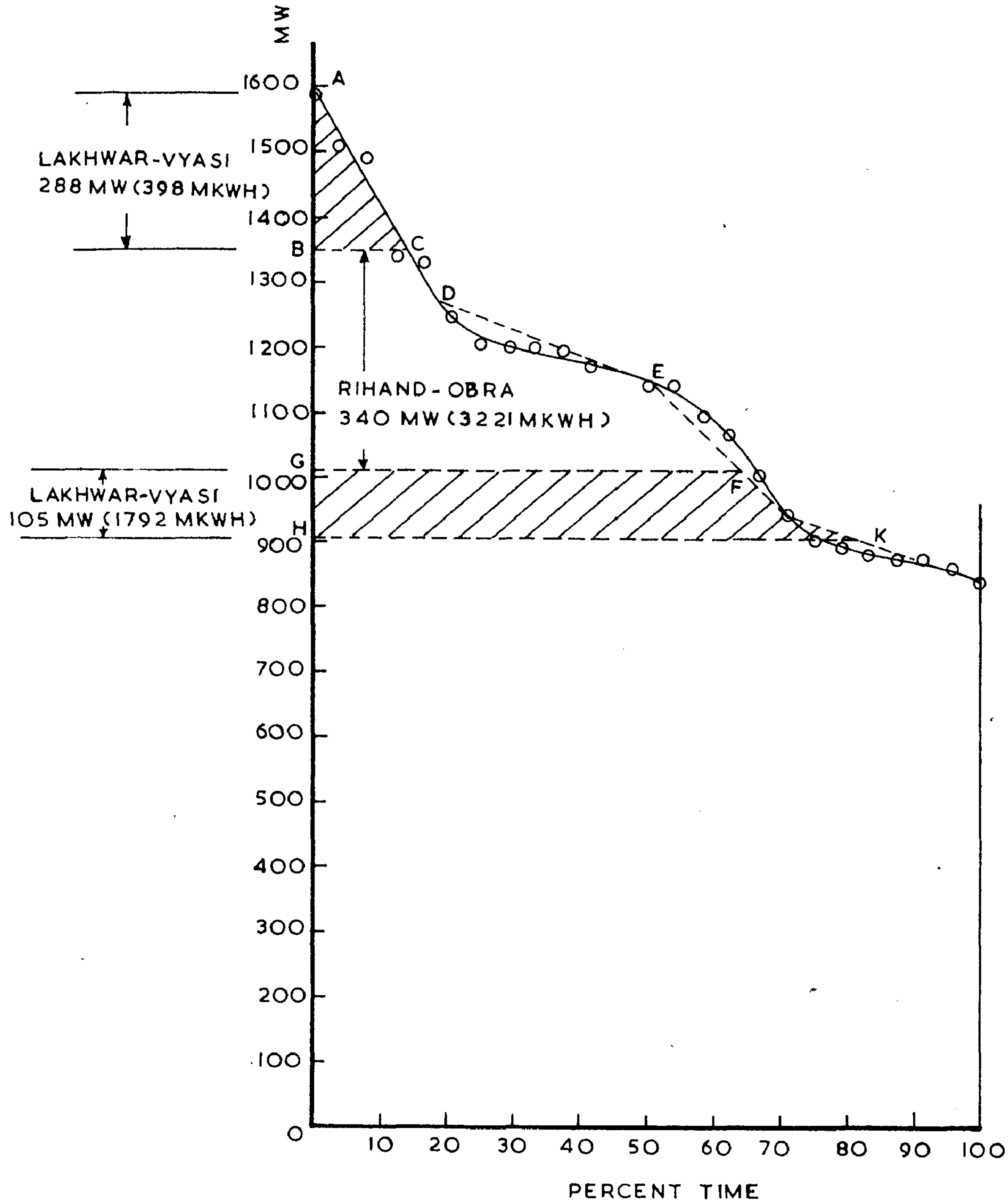


FIG. 15 - LOAD DURATION CURVE

added to the grid in a near future. Therefore the necessity of keeping unusually high capacity in one plant does not appear to be justified. The future plants can be designed to serve future needs.

SIZE OF UNITS FOR LAKHWAR - VYASI

The size of unit would in general depend upon availability of space, reliability of supply and cost considerations. In most cases interruption of service cannot be tolerated. So if the units are chosen radically larger than the existing units, it may be difficult to meet the load should any of such large units fail due to unforeseen reasons. The situation may be more critical if in addition to this, any of the large units is out of service for routine overhaul. So it may be seen that with the increase in the size of the unit, the probability of the system not meeting a particular load would be more than with smaller units. This aspect has to be weighed along with cost and availability of room for more number of units. As the number of units are increased more floor space is needed which makes the power house Civil structure costly. The equipment costs also increases.

For run-of-the-river plants there may be more wastage of water if units are large and they happen to go out of service for reasons as stated above. Of course the chances of wastage occurring with storage plant is rather remote; because except for the reservoir full condition, there would generally be sufficient storage space in the reservoir to absorb non-monsoon flow during the period of repair of unit running out of service due to unforeseen reasons.

Unless the details as explained are worked out it would not be possible to specify the size of the units that are most economical reliable under the situation. Prima-facie it appears 3 units of 90 mw each for Lakhwar-power house and 3 units of 65 mw each for Hathiari power house is suitable for the scheme. The installed capacity thus works out to 465 mw against the requirement of 443 mw. The present project report provides 2 units of 150 mw at Lakhwar Power House and 4 units of 60 mw each at Hathiari Power House making the total installed capacity equal to 540 mw. As already pointed out this capacity appears to be rather high and power plant design probably needs a review to exactly arrive at the capacity needed and unit sizes with reference to all relevant factors.

CHAPTER - VII

CONCLUSIONS

Techniques available for deriving optimum plans of development in water resources include Linear programming, Dynamic programming and a variety of search techniques. As already pointed out the above methods are not capable of solving the overall problem due to system non-linearities and unweildy size of the problem involving a large number of state variables. The physical constraints and relationship that exists in any water resources system probably introduce more non-linearities in the analysis than result from any other factor. For example curves of storage versus head, storage versus evaporation or storage versus energy production rate are highly nonlinear. So also are the curves of reservoir outlet capacity and power plant characteristics.

Due to these difficulties the above methods have not been adopted in this study and instead, reservoir operation has been carried out for different sizes of development to arrive at the optimal plan.

The reservoir operation has been carried out with 90% availability inflow. Adoption of deterministic inputs as this has been stated to be somewhat hazardous because basically the streamflow is stochastic in nature. Refinement is needed in this direction for finding out the system accomplishments for a particular level of development.

In the present study four different levels of development have been studied. To be more precise, some more alternatives require study to establish the rising part of the benefit-Cost curve and locate the optimal size of development corresponding to maximum net benefit. However the levels adopted in the project report sufficiently corroborates that the optimal size has been found.

The reservoir active capacity on the monthly operation basis appears to have been slightly less than that required, as spill to the extent of about 1½% of inflow occurs at the end as seen from the Computer outputs. A little refinement is necessary in this respect. Determination of the installation size require analysis of the critical day load curves of the system. The annual-peak day load curve alone may not be sufficient and it may be necessary to examine other daily curves also. The synthetic load curve considered in this study, in absence of actual load curves, only gives a fairly good picture of the situation. The actual position may be a little different from it. Study is, therefore, needed with the actual system load curves which are relevant to arrive at the exact capacity of installation and unit size.

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TABLE - 4

SYSTEM LOAD FOR 72-73

Day	April '72		May '72		June '72	
	Max. MW	Min. MW	Maximum MW	Minimum MW	Maximum MW	Minimum MW
1	2	3	4	5	6	7
1	1218	822	1175	871	1288	901
2	1156	811	1161	904	1279	905
3	1212	801	1216	853	1332	895
4	1051	804	1295	897	1207	893
5	1215	728	1232	872	1159	850
6	1121	801	1288	862	1201	781
7	1152	799	1172	859	1247	850
8	1204	830	1312	862	1262	791
9	936	845	1301	885	1269	847
10	1189	645	1181	900	1348	875
11	1178	799	1266	902	1356	896
12	1255	846	1297	976	1383	863
13	1213	849	1303	898	1391	878
14	1288	856	1232	900	1320	900
15	1271	886	1298	868	1342	866
16	1260	801	1374	866	1324	908
17	1244	802	1354	892	1371	920
18	1296	747	1240	932	1265	962
19	1283	879	1341	938	1355	876
20	1287	895	1321	917	1364	905
21	1315	903	1201	914	1307	946
22	1232	881	1266	870	1315	827

1	2	3	4	5	6	7
23	1190	892	1274	905	1289	917
24	1228	844	1273	843	1330	830
25	1204	916	1230	893	1064	844
26	1283	900	1265	879	1148	783
27	1245	934	1284	916	1072	795
28	1188	934	1248	877	1165	794
29	1184	907	1253	872	1149	821
30	1280	871	1320	883	1098	804
31			1275	879		

Day	July '72 Maximum MW	July '72 Minimum MW	August '72 Maximum MW	August '72 Minimum MW	September '72 Maximum MW	September '72 Minimum MW	October '72 Maximum MW	October '72 Minimum MW
1	8	9	10	11	12	13	14	15
1	1086	753	1414	1056	1067	751	1124	787
2	1088	749	1383	1092	1040	773	1097	795
3	1028	753	1327	1049	1019	732	1181	752
4	988	745	1305	1054	1060	719	1189	762
5	987	679	1268	964	1129	742	1156	772
6	935	716	1127	828	1082	747	1107	775
7	895	635	1127	775	1104	756	950	703
8	943	661	1178	724	1175	754	1056	660
9	848	650	1127	738	1049	761	1148	669
10	980	652	1083	722	1073	745	1170	717
11	955	703	1085	702	1084	737	1180	758
12	1011	699	1051	679	914	714	1180	774
13	1027	701	967	712	869	664	1152	801
14	1029	739	982	655	917	613	1164	740
15	1050	724	959	722	1010	627	1104	815
16	954	748	1081	701	1023	639	1125	762
17	999	700	1190	731	918	686	972	775
18	1077	714	1088	721	1053	620	1436	708
19	1123	717	1096	731	1099	691	1267	773
20	1115	716	1113	756	1067	714	1294	864
21	1159	777	1227	752	1111	734	1188	786
22	1189	796	1170	738	1090	726	1460	774

1	8	9	10	11	12	13	14	15
23	1176	826	1214	781	1024	737	1293	777
24	1272	813	993	751	997	728	1257	872
25	1213	865	956	705	1047	719	1233	815
26	1291	844	955	711	1112	701	1193	851
27	1276	921	958	689	1132	743	1271	844
28	1287	963	955	621	1139	748	1295	901
29	1317	934	1013	672	1168	783	1124	770
30	1302	962	1044	727	1175	798	1197	748
31	1406	984	986	721			1162	1011

Day	Maximum MW	Minimum MW	Maximum MW	Minimum MW	Maximum MW	Minimum MW
1	2	3	4	5	6	7
1	1203	850	1165	825	1554	939
2	1296	762	1222	808	1571	975
3	1318	893	1243	832	1564	956
4	1313	927	1285	781	1588	984
5	1128	927	1206	823	1514	1032
6	1164	831	1245	854	1530	995
7	1241	847	1250	848	1489	1007
8	1188	892	1303	843	1493	905
9	1379	873	1228	849	1553	975
10	1313	894	1268	770	1529	1003
11	1301	861	1283	799	1404	1023
12	1272	886	1273	838	1497	903
13	1340	882	1225	855	1482	1011
14	1334	900	1257	864	1508	1032
15	1380	882	1275	860	STRIKE PERIOD	
16	1360	905	1254	880		
17	1488	918	1308	872		
18	1445	954	1309	880		
19	1327	956	1329	911		
20	1158	923	1369	841		
21	1329	868	1445	928		
22	1292	927	1518	950		
	1326					

1	2	3	4	5	6	7
23	1326	933	1474	960	S T R I K E	
24	1386	945	1514	919		
25	1347	863	1419	903	P E R I O D	
26	1184	820	1516	950	1427	847
27	1148	793	1522	954	1428	915
28	1203	803	1548	929	1369	829
29	1264	822	1579	894	1453	964
30	1258	825	1540	974	1398	981
31			1496	988	1481	990

Day	February '72		March '72	
	Maximum MW	Minimum MW	Maximum MW	Minimum MW
1	8	9	10	11
1	1074	716	1149	675
2	1050	713	1188	768
3	986	699	1245	836
4	956	622	1111	807
5	911	635	1104	700
6	855	613	1160	748
7	971	598	1190	771
8	972	670	1165	769
9	986	690	1181	781
10	950	680	1219	790
11	980	697	1217	799
12	990	672	1119	785
13	890	648	1237	750
14	983	639	1290	772
15	1031	665	1284	805
16	1042	707	1256	824
17	1072	688	1280	845
18	1045	716	1281	839
19	1076	700	1192	781
20	1043	705	1284	752
21	1123	654	1274	813
22	1140	739	1307	804

1	8	9	10	11
23	1169	749	1234	812
24	1191	675	1301	832
25	1240	788	1282	850
26	1116	792	1226	791
27	1240	761	1265	922
28	1228	795	1270	854
29	979	765	1250	864
30			1210	835
31			1215	807

APPENDIX - 1

OBSERVED DISCHARGES OF RIVER YAMUNA AT LAKHWAR (in Cumec-days)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	In descending order	Plotting position m/n+1
1968	1074	1173	1328	1305	1315	1436	3259	4644	2087	1348	827	786	20582	28756	12.5
1969	809	670	778	929	1137	1107	2062	5237	3350	1716	1081	717	20093	23532	25
1970	619	420	625	659	706	862	1630	3918	2646	1561	934	740	15320	20582	37.6
1971	640	525	588	668	951	3590	6125	6812	5526	1619	989	723	28756	20308	50
1972	552	669	685	1031	1217	374	3057	4024	5368	1437	738	656	20308	20093	62.5
1973	654	620	1151	1272	951	1435	2945	5810	3940	2143	931	680	23532	16827	75
1974	579	460	480	570	530	755	2740	6420	1600	1421	710	562	16327	15320	87.5
											Average		20774		

SOURCE: Figures upto 1972 are taken from Lakhwar Project report and that for 1973-74 are from discharge data received by W.R.D.T.E.

ABSTRACT SHOWING MONTHLY INFLOW AT LAKHWAR,KISHAU & TAJEWALA

(90% Availability)

Month	Monthly inflows in Yamuna at Lakhwar	Monthly inflows in Tons at Kishau Dam	Monthly inflows at Tajewala
January	570	1030	2580
February	560	1090	2640
March	580	1730	2780
April	660	2940	3690
May	840	2900	4170
June	1475	3360	6550
July	1775	4900	11120
August	3760	10300	26400
September	2040	4320	12230
October	1620	3320	4450
November	980	1480	4450
December	690	1190	2740
	15,550	37,650	82,550

RUNOFF OF RIVER YAMUNA AT LAKHWAR

(in cumec-day)

Year	January	February	March	April	May	June	July
1938	977	1415	1263	1136	1426	1693	3048
1939	631	602	919	951	1095	1343	2262
1940	570	652	614	681	923	1265	2121
1941	566	520	568	598	805	1063	1661
1942	653	1207	1144	1054	1014	1163	3980
1943	1069	678	718	806	928	1199	3134
1944	748	673	882	1323	1209	1099	2554
1945	892	791	895	1035	1114	1158	2706
1946	708	701	717	897	953	1000	3841
1947	767	639	743	828	837	1142	1353
1948	732	798	1642	1294	1271	1009	2496
1949	734	1172	878	1099	1093	922	4998
1950	728	841	871	1033	1179	1340	4466
1951	815	733	817	818	1147	1049	1673
1952	862	633	835	995	1035	1283	2772
1953	748	625	730	754	890	1166	3666
1954	863	1824	1472	1326	1269	1276	2620
1955	869	780	989	816	923	1271	2252
1956	906	700	1120	1041	1418	1330	3799
1957	1230	972	984	1016	1468	1481	4857
1958	938	727	782	955	916	940	3476
1959	922	951	975	908	951	1115	3700
1960	946	803	784	884	975	979	1829

Year	August	September	October	November	December	Total
1938	3344	1530	1025	836	661	18354
1939	2141	1940	1046	0	0	12930
1940	4106	1516	918	662	623	14651
1941	3775	1597	1029	722	632	13536
1942	7064	4450	1396	935	833	24893
1943	6569	3820	1410	975	798	22104
1944	3053	2693	1055	752	681	16722
1945	4099	4085	2345	1118	880	2118
1946	3723	1785	1286	865	798	17274
1947	2537	2525	2759	1089	851	16070
1948	7220	4832	1498	970	860	24622
1949	5015	1878	1089	771	690	20339
1950	5872	3904	1567	959	826	23586
1951	4867	2663	1218	862	759	17421
1952	5994	2314	1138	798	695	19354
1953	4981	2353	1239	840	763	18755
1954	4788	3511	2436	1108	965	23458
1955	5567	3726	7668	1468	1059	27388
1956	4530	2352	7519	1621	1116	27452
1957	3929	4060	1896	1080	1021	23994
1958	5772	2901	2380	1159	980	21926
1959	5041	4720	2075	1177	938	23473
1960	4338	2303	1174	907	767	16689

1961	844	1508	1196	1106	1110	1395	3127
1962	908	978	1446	1241	1056	1221	1806
1963	748	571	866	753	763	964	1962
1964	845	714	834	896	948	1113	3450
1965	811	813	984	1332	1401	1270	2538
1966	536	484	558	537	778	1814	2825
1967	635	537	982	954	919	1042	3299
1968	1074	1173	1328	1305	1315	1436	3259
1969	809	670	778	929	1137	1107	2062
1970	619	420	625	659	706	862	1630
1971	645	525	588	668	951	3590	6125
1972	552	669	685	1031	1217	874	3057

1961	6482	3260	1473	1037	953	23491
1962	2924	13362	1806	995	931	28674
1963	6410	4740	1490	888	875	21030
1964	4323	4550	1932	1027	901	21533
1965	2796	1470	983	759	636	15793
1966	6712	2645	1293	916	755	19853
1967	7418	3950	1378	945	916	22975
1968	4644	2087	1348	827	786	20582
1969	5237	3850	1716	1081	717	20093
1970	3918	2646	1561	934	740	15320
1971	6812	5526	1619	989	723	28757
1972	4024	5368	1437	738	656	20308

CUMULATED RUNOFF

FIGURES IN CUMEC DAYS

Year	1 month	2 month	3 month	4 month	5 month	6 month
1938	977	2392	3655	4791	6217	7910
1939	631	1233	2152	3103	4198	5541
1940	570	1222	1836	2517	3440	4705
1941	566	1086	1654	2252	3057	4120
1942	653	1860	3004	4058	5072	6235
1943	1069	1747	2465	3271	4199	5398
1944	748	1421	2303	3626	4835	5934
1945	892	1683	2578	3613	4727	5885
1946	708	1409	2126	3023	3976	4976
1947	767	1406	2149	2977	3814	4956
1948	732	1530	3172	4466	5737	6746
1949	734	1906	2784	3883	4976	5898
1950	728	1569	2440	3473	4652	5992
1951	815	1548	2365	3183	4330	5379
1952	862	1495	2330	3325	4360	5646
1953	748	1373	2103	2857	3747	4913
1954	863	2687	4159	5485	6754	8030
1955	869	1649	2638	3454	4377	5648
1956	906	1606	2726	3767	5185	6515
1957	1230	2202	3186	4202	5670	7151
1958	938	1665	2447	3402	4318	5258

Year	7 month	8 month	9 month	10 month	11 month	12 month
1938	10958	14302	15832	16857	17693	18354
1939	7803	9944	11884	12930	12930	12930
1940	6826	10932	12448	13366	14028	14651
1941	5781	9556	11153	12182	12904	13536
1942	10215	17279	21729	23125	24060	24893
1943	8532	15101	18921	20331	21306	22104
1944	8488	11541	14234	15289	16041	16722
1945	8591	12690	16775	19120	20238	21118
1946	8820	12543	14328	15614	16479	17277
1947	6309	8846	11371	14130	15219	16070
1948	9242	16462	21294	22792	23762	24622
1949	10896	15911	17789	18878	19649	20339
1950	10458	16330	20234	21801	22760	23586
1951	7052	11919	14582	15800	16662	17421
1952	8415	14409	16723	17861	18659	19354
1953	8579	13560	15913	17152	17992	18755
1954	10650	15438	18949	21385	22493	23458
1955	7900	13467	17193	24861	26329	27388
1956	10314	14844	17196	24715	26336	27452
1957	12008	15937	19997	21893	22973	23994
1958	8734	14506	17407	19787	20946	21926

Year	1 month	2 month	3 month	4 month	5 month	6 month
1959	922	1873	2848	3756	4707	5822
1960	946	1749	2533	3417	4392	5381
1961	844	2352	3548	4654	5764	7159
1962	908	1886	3332	4573	5629	6850
1963	748	1319	2185	2938	3701	4665
1964	845	1559	2393	3289	4237	5350
1965	811	1624	2608	3940	5341	6611
1966	536	1020	1578	2115	2893	4707
1967	635	1172	2154	3108	4027	5069
1968	1074	2247	3575	4880	6195	7631
1969	809	1479	2257	3186	4323	5430
1970	619	1039	1664	2323	3029	3891
1971	645	1170	1758	2426	3377	6967
1972	552	1221	1906	2937	4154	5028
90% dependable inflow (cumulated)	570	1130	1710	2370	3210	4685
Monthly Inflow	570	560	580	660	840	1475

N.B. Year 1939 excluded as an extreme event.

Year	7 month	8 month	9 month	10 month	11 month	12 month
1959	9522	14563	19283	21358	22535	23473
1960	7210	11548	13851	15025	15932	16699
1961	10286	16768	20028	21501	22538	23491
1962	8656	11580	24942	26748	27743	28674
1963	6627	13037	17777	19267	20155	21030
1964	8800	13123	17673	19605	20632	21533
1965	9149	11945	14315	14398	15157	15793
1966	7532	14244	16889	18182	19098	19853
1967	8368	15786	19736	21114	22059	22975
1968	10890	15534	17621	18969	19796	20852
1969	7492	12729	16579	18295	19376	20093
1970	5521	9439	12085	13646	14580	15320
1971	9773	16585	22111	23730	24719	25442
1972	8085	12109	17477	18914	19652	20308
90% dependable inflow (cumulated)	6460	10220	12260	13880	14860	15550
Monthly Inflow	1775	3760	2040	1620	980	690

APPENDIX

RUNOFF OF RIVER TONS AT KISHAU (in m.a.ft.)

Year	January	February	March	April	May	June	July
1	2	3	4	5	6	7	8
1938	.1488	.2496	.2303	.2292	.3335	.4557	.6538
1939	.0861	.0863	.1553	.1822	.2406	.3728	.4731
1940	.0787	.1007	.0951	.1563	.1946	.3105	.2992
1941	.0776	.0708	.0835	.1004	.1627	.2557	.3270
1942	.0909	.2054	.2030	.2096	.2185	.2852	.9094
1943	.1681	.0989	.1153	.1485	.1792	.2950	.7912
1944	.1141	.1122	.1711	.2965	.2899	.2946	.7046
1945	.1005	.0845	.1556	.1870	.2167	.3224	.5996
1946	.0905	.0785	.1053	.1572	.1854	.2398	.5339
1947	.0889	.0765	.1029	.1479	.1982	.2305	.2452
1948	.0635	.0836	.3325	.3021	.2760	.2260	.5026
1949	.0878	.1250	.1277	.2015	.3174	.2272	1.0942
1950	.0837	.1161	.1216	.2025	.2926	.3543	.7624
1951	.1229	.1368	.1401	.1684	.2649	.2581	.4031
1952	.1233	.1054	.1505	.2148	.2412	.3504	.5040
1953	.1001	.0939	.1189	.1330	.1865	.3183	.8280
1954	.1225	.2660	.2517	.2434	.2832	.3241	.5045
1955	.1239	.1141	.1616	.1568	.1862	.3211	.7584
1956	.1766	.1268	.2605	.2995	.4681	.4174	.8595
1957	.1623	.1273	.1394	.2619	.3218	.3582	.8778
1958	.1225	.0992	.1091	.1615	.1574	.2195	.6723
1959	.1449	.1645	.1891	.2291	.2345	.2713	.6401
1960	.1289	.1290	.1203	.1356	.1616	.1736	.0445

Year	August	September	October	November	December	Total
1	9	10	11	12	13	14
1938	.6078	.2007	.1617	.1191	.0931	3.4833
1939	.3512	.3424	.1671	.1054	.0824	2.6449
1940	.7786	.2541	.1429	.0946	.0869	2.5922
1941	.6948	.2524	.1634	.1059	.0882	2.3824
1942	1.3838	.8712	.2429	.1490	.1242	4.8931
1943	1.2043	.6728	.2366	.1245	.1222	4.1566
1944	.7034	.4406	.1703	.1978	.0937	3.4988
1945	.6014	.7439	.4023	.1634	.1170	3.6916
1946	.6728	.3081	.2024	.1089	.0980	2.7808
1947	.3342	.5060	.5602	.1251	.1023	2.7179
1948	1.0224	.6230	.2419	.1263	.1061	3.9060
1949	1.0097	.3456	.1959	.0920	.0891	3.9131
1950	.7924	.7165	.2644	.1654	.1439	4.0158
1951	1.1635	.4769	.2160	.1430	.1161	3.6098
1952	1.1400	.3734	.2359	.1181	.0995	3.6565
1953	1.1781	.4559	.1977	.1406	.1152	3.8662
1954	.8314	.5668	.4539	.1764	.1313	4.1552
1955	.9557	.8127	1.0994	.5666	.2829	5.5394
1956	.9715	.4673	1.4490	.3047	.1853	5.9862
1957	.8262	1.0066	.2681	.1766	.1576	4.6838
1958	1.0706	.5117	.4814	.1875	.1550	3.9478
1959	.6680	.6104	.3036	.1539	.1353	3.7447
1960	.5006	.3699	.1950	.1975	.1133	2.2697

1	2	3	4	5	6	7	8
1961	.1524	.2592	.2768	.2602	.2689	.3752	.4817
1962	.1408	.1925	.2797	.2663	.2715	.3177	.4283
1963	.1229	.1046	.1334	.1262	.1378	.1877	.4041
1964	.0958	.1012	.1264	.1582	.1778	.2218	.8132
1965	.0916	.1109	.1570	.2652	.2550	.2620	.5518
1966	.0559	.0618	.0799	.0867	.1404	.4402	.6250
1967	.0691	0.0701	.1638	.1762	.1694	.2109	.7824
1968	.1020	.1513	.2370	.2173	.2198	.2908	.7877
1969	.0724	.0876	.1151	.1258	.2151	.2491	.4599

1	9	10	11	12	13	14
1961	.7485	.5758	.2807	.1920	.1545	4.0259
1962	.6585	1.0019	.3950	.2665	.1790	4.3977
1963	1.2224	.9859	.2259	.1094	.1000	3.8603
1964	.8234	.8732	.3173	.1346	.1014	3.9443
1965	.5192	.2350	.1091	.0904	.0682	2.7154
1966	1.3614	.5150	.2074	.1129	.0839	3.7705
1967	1.4580	.7088	.2731	.1262	.1073	
1968	.7807	.3147	.1596	.0805	.0722	3.4136
1969	.7641	.5112	.1578	.1111	.0842	2.9476

APPENDIX

RUNOFF OF RIVER YAMUNA AT TAJEWALA

(In maft)

Year	January	February	March	April	May	June	July
1	2	3	4	5	6	7	8
1933	.2776	.2485	.3326	.3082	.4766	.6010	1.9368
1934	.3210	.2866	.2796	.2830	.2916	.4434	1.5930
1935	.2630	.3398	.3286	.3102	.4388	.4094	1.3914
1936	.1834	.1696	.2076	.2712	.4294	.7568	1.2314
1937	.2598	.3845	.3974	.4716	.4759	.6864	1.7255
1938	.3204	.5294	.4424	.3936	.5176	.6534	1.3141
1939	.1872	.1816	.2980	.3134	.3740	.4976	.9510
1940	.1696	.2056	.1832	.2070	.3016	.4480	.8626
1941	.1671	.1530	.1663	.1719	.2531	.2674	.6306
1942	.1959	.4262	.3900	.3602	.3404	.4103	1.8448
1943	.3618	.2091	.2207	.2543	.3060	.4221	1.4200
1944	.2298	.2058	.3286	.4784	.4204	.3972	1.0974
1945	.2724	.1939	.2753	.3389	.3604	.4044	1.2522
1946	.2145	.2076	.2196	.2928	.3135	.4311	1.8862
1947	.2372	.1926	.2282	.2652	.3105	.3955	.4808
1948	.2242	.2402	.6659	.4586	.4460	.3439	1.1006
1949	.2232	.4243	.3060	.3789	.3991	.3020	2.3630
1950	.2245	.2602	.2806	.3521	.4092	.4878	2.1182
1951	.2556	.2295	.2608	.2607	.3966	.3601	.6437
1952	.2343	.1996	.2664	.3352	.3231	.4679	1.2149
1953	.2227	.1901	.2242	.2338	.2890	.4596	1.7088
1954	.2551	.7439	.5422	.4771	.4503	.4545	1.1305
1955	.2789	.2490	.3268	.2583	.3020	.4507	.9578

Year	August	September	October	November	December	Total
1	9	10	11	12	13	14
1933	2.4332	1.8952	.6464	.3736	.3098	9.8395
1934	3.0476	1.0914	.4290	.2920	.2684	8.6266
1935	2.5780	.7798	.3636	.2516	.2104	7.6646
1936	1.4312	1.4698	.4490	.2821	.2888	7.1703
1937	1.4565	2.0236	.5428	.3470	.2845	9.0555
1938	1.5260	.5754	.3334	.2714	.1986	7.0757
1939	.8764	.8232	.3516	.2214	.1876	5.2630
1940	1.9450	.5952	.3012	.1986	.1854	5.6030
1941	1.7379	.6093	.3440	.2223	.1883	4.9112
1942	3.4488	2.1103	.5116	.3127	.2650	10.6162
1943	3.1740	1.7943	.5124	.3168	.2501	9.2416
1944	1.3714	1.1900	.3607	.2336	.2054	6.5187
1945	1.9240	1.9660	.9900	.3852	.2760	8.6387
1946	1.7344	.6962	.4579	.2780	.2409	6.9727
1947	1.0911	3.8308	1.2198	.3738	.2702	8.8957
1948	4.0224	2.2910	.5552	.3210	.2731	10.9421
1949	2.3814	.7460	.3707	.2406	.2080	8.3432
1950	2.8541	1.7985	.5896	.3204	.2594	9.9546
1951	2.3177	1.1758	.4286	.2804	.2329	6.8424
1952	2.8905	1.0217	.3886	.2535	.2117	7.8074
1953	2.4079	.9992	.4336	.2731	.2343	7.6763
1954	3.3375	1.6090	1.0472	.3845	.3191	10.7509
1955	2.7165	1.7351	3.5366	.5470	.3610	11.7197

1	2	3	4	5	6	7	8
1956	.2951	.2149	.3843	.3536	.4902	.4791	1.6542
1957	.4185	.3311	.3270	.3468	.4492	.5484	2.2799
1958	.2855	.2087	.2229	.3002	.2752	.2891	1.6229
1959	.2922	.3251	.3179	.2882	.3228	.3887	1.7075
1960	.3076	.2520	.2424	.2780	.2962	.3231	1.0430
1961	.2638	.5802	.4154	.3851	.3790	.5052	1.4675
1962	.2962	.3998	.5316	.4314	.3614	.4274	.7094
1963	.2166	.1708	.2723	.2269	.2349	.3197	.7818
1964	.2652	.2293	.2604	.2834	.3032	.3790	1.6055
1965	.2520	.2509	.3216	.4789	.4362	.4476	1.0890
1966	.1546	.1399	.1623	.1562	.2406	.7463	1.2550
1967	.1903	.1587	.3333	.3132	.2899	.3595	1.4947
1968	.3116	.3117	.5241	.4165	.3787	.5099	1.9481
1969	.2099	.1941	.2326	.2308	.3505	.3968	.9978

1	9	10	11	12	13	14
1956	2.1645	.9944	3.5643	.6244	.3874	11.6064
1957	1.9444	1.8539	.7488	.3642	.3308	9.8430
1958	2.8124	1.2942	1.0358	.3900	.3152	9.0521
1959	2.4391	2.2426	.8425	.4118	.3043	9.8827
1960	2.0524	.9755	.4048	.2773	.2370	6.6893
1961	3.1340	1.5745	.5340	.3503	.3054	9.8944
1962	1.3319	2.4436	.7021	.3389	.2975	8.2712
1963	3.0090	2.3178	.5553	.2843	.2788	8.6682
1964	2.0538	2.0278	.7805	.3494	.2827	8.8202
1965	1.2475	.5597	.3117	.2351	.1905	5.8207
1966	3.3096	1.2123	.4587	.2944	.2326	8.3625
1967	3.6596	1.6391	.4952	.3112	.2897	9.5344
1968	2.0326	.5714	.3284	.2348	.2085	7.7763
1969	2.4314	1.6180	.4664	.2881	.2342	7.6506

APPENDIX - 3

Month	Evaporation depth in meter (EV_t)
January	0.07
February	0.09
March	0.13
April	0.15
May	0.26
June	0.24
July	0.18
August	0.14
September	0.14
October	0.13
November	0.09
December	0.08

APPENDIX - 4

Month	Energy Demand Coefficient (C_t)
January	0.103
February	0.072
March	0.084
April	0.085
May	0.088
June	0.086
July	0.076
August	0.074
September	0.073
October	0.081
November	0.086
December	0.092

APPENDIX 5

SECONDARY POWER CALCULATIONS

50% availability runoff	20,300 cumec day
90% availability runoff	15,500 "
Additional runoff	4,750 "

ALTERNATIVE I

Average rate of energy production per cumec-day of water $= \left(\frac{46.7 + 51.5}{2}\right) \times 10^{-3}$

$= \left(\frac{98.2}{2}\right) \times 10^{-3}$

$= 49.1 \times 10^{-3}$ mkwh.

$\therefore$ Total energy that would be available from the additional runoff of 4750 cumec day in a 50% year

$= 4750 \times 49.1 \times 10^{-3}$

$= 233$ mkwh.

ALTERNATIVE 2

Average rate of energy production $= \left(\frac{48.3 + 52.8}{2}\right) \times 10^{-3}$

$= \left(\frac{101.1}{2}\right) \times 10^{-3}$

$= 50.55 \times 10^{-3}$ mkwh.

$\therefore$ Total energy $= 4750 \times 50.55 \times 10^{-3}$

$= 240$ mkwh.

ALTERNATIVE 3

Average rate of energy production $= \left(\frac{49.7 + 54}{2}\right) \times 10^{-3}$

$= \left(\frac{103.7}{2}\right) \times 10^{-3}$

$= 51.85 \times 10^{-3}$ mkwh.

∴ Total energy $= 4750 \times 51.85 \times 10^{-3}$

$= 246$ mkwh.

ALTERNATIVE 4

Average rate of energy production $= \left(\frac{51.9 + 55.6}{2}\right) \times 10^{-3}$

$= \left(\frac{107.5}{2}\right) \times 10^{-3}$

$= 53.75 \times 10^{-3}$

∴ Total energy $= 4750 \times 53.75 \times 10^{-3}$

$= 255$ mkwh.

Taking saving in coal as 5 paise per kwh of energy, the benefit from saving in coal cost due to secondary power would be as follows:

1. For Alternative 1 $= 233 \times 0.05 \times 10^{6}$

   = Rs.116.5 lakhs

2. For Alternative 2 $= 240 \times 0.05 \times 10^{6}$

   = Rs.120 lakhs

3. For Alternative 3 $= 246 \times 0.05 \times 10^{6}$

   = Rs.123 lakhs

4. ForAlternative 4 $= 255 \times 0.05 \times 10^{6}$

   = Rs.127.5 lakhs.

APPENDIX - 5A

DETAILS OF DEPRECIATION

Item	Life in years	Cost in lakhs Rs.	Amount of depreciation Lakh Rs. (by sinking fined method) 3% interest & 90% recovery (Alternative 1)	(Alternative 2)	(Alternative 3)	(Alternative 4
1. Lakhwar dam, Vyasi Dam tunnel	100	5868	8.7	9	9.2	9.5
2. Surge Tank	40	66	0.8	0.8	0.8	0.8
3. Lakhwar & Hathiari Intake and Penstocks	40	299	3.6	3.6	3.6	3.6
4. Lakhwar & Hathiari P.H. and appurtenant works	35	633	9.9	9.9	9.9	9.9
5. Power Plant & equipment	35	4670	69.5	69.5	69.5	69.5
6. Permanent Buildings	50	71	0.6	0.6	0.6	0.6
7. Water Supply, fencing etc.	35	20	0.3	0.3	0.3	0.3
8. Land	Indefinite	102	-	-	-	-
		11759	93.4	93.7	93.9	94.2
9. Other expenditure		2222 prorata	17.6	20.3	22.8	24.8
		13981	111 lakhs	114	116.7	119

O & M COSTS

1. Capital cost (lakh Rs.)	13981	14537	15033	15508
2. Dam & Appurtenants works @0.25% of Capital Cost (lakh Rs.)	34.95	36.34	37.58	38.77
3. Power Plants @0.5% of capital cost (lakh Rs.)	69.90	[illegible]	75.16	77.54
(Total (2) + (3)	104.85	109.02	112.74	116.31

APPENDIX - 6

$$\text{Power Output, } P = \frac{Q.\,H \times 62.4 \times 0.85 \times 0.746}{550} \text{ kw}$$

$$= \frac{Q.\,H}{13.9} \text{ kw}$$

Where Q = Flow in cusecs

H = Average head acting on turbine in ft.

Combined efficiency of turbine & generator is taken as 85%.

In metric units

$P = 8.33$ Q. H. kw.

Where Q = Flow in cumecs

H = Average head acting on turbine in m.

ENERGY PRODUCTION RATE FOR ALTERNATIVE I AT EL 747.0 m

Average tailwater elevation of Hatiari P.H.=E.L.513.5 m

Gross head on turbine, H = (747 - 513.5) = 233.5 m

Neglecting head losses 1 cumec-day produces energy, E = 8.33 x 233.5 x 24

= 46,700 kwh.

At E.L. 750

H = (747 - 513.5) + 1/2 (750 - 747) = 235 m

E = 8.33 x 235 x 24

= 47,000 kwh.

At E.L. 755

$$H = (747 - 513.5) + 1/2\,(755 - 747) = 237.5 \text{ m}$$

$$E = 8.33 \times 237.5 \times 24$$

$$= 47{,}500 \text{ kwh}$$

At E.L. 760

$$H = (747 - 513.5) + 1/2\,(760 - 747) = 240 \text{ m}$$

$$E = 8.33 \times 240 \times 24$$

$$= 48{,}000 \text{ kwh.}$$

At E.L. 765

$$H = 233.5 + 1/2 \times 18$$

$$= 242.5 \text{ m}$$

$$\therefore \quad E = 8.33 \times 242.5 \times 24$$

$$= 48{,}500 \text{ kwh.}$$

At E.L. 770

$$H = 233.5 + 1/2 \times 23$$

$$= 245 \text{ m}$$

$$\therefore \quad E = 8.33 \times 245 \times 24$$

$$= 49{,}000 \text{ kwh.}$$

At E.L. 775

$$H = 233.5 + 14$$

$$= 247.5 \text{ m}$$

$$\therefore \quad E = 8.33 \times 247.5 \times 24$$

$$= 49{,}500 \text{ kwh.}$$

At E.L. 780

$H = 233.5 + 16.5 = 250$ m

$\therefore E = 8.33 \times 250 \times 24$

$= 50{,}000$ kwh.

At E.L. 785

$H = 233.5 + 19 = 252.5$ m

$\therefore E = 8.33 \times 252.5 \times 24$

$= 50{,}500$ kwh.

At E.L. 790

$H = 233.5 + 21.5 = 255$ m

$\therefore E = 8.33 \times 255 \times 24$

$= 51{,}000$ kwh

At E.L. 795

$H = 233.5 + 24 = 257.5$ m

$\therefore E = 8.33 \times 257.5 \times 24$

$= 51{,}500$ kwh.

Similarly for other 3 alternatives, the energy production rates are as follows (Figures in thousand kwh).

E.L.	755	760	762	765	770	773	775	780	785	790	795	800	805	810
ALT 2	48.3	48.8	-	49.3	49.8	-	50.3	50.8	51.3	51.8	52.3	52.8	-	-
ALT 3	-	-	49.7	50	50.5	-	51	51.5	52	52.5	53	53.5	54	-
ALT 4	-	-	-	-	-	51.9	52.1	52.6	53.1	53.6	54.1	54.6	55.1	55.[illegible]

APPENDIX - 7

HOURLY LOAD OF GANGA-SARDA GRID FOR 1.1.74

Hour	0	1	2	3	4	5	6	7	8	9	10	11	12
Load (mw)	416	364	348	346	350	354	356	476	524	406	506	486	478
%age of Peak	63.2	55.2	52.7	52.5	53.1	53.7	54	72.2	79.5	61.6	76.8	73.7	72.5

Hour	13	14	15	16	17	18	19	20	21	22	23	24
Load (mw)	496	498	482	542	550	628	648	656	628	440	406	360
%age of Peak	75.3	75.6	73.1	82.2	83.5	95.2	98.4	1.0	95.3	66.7	61.6	54.5

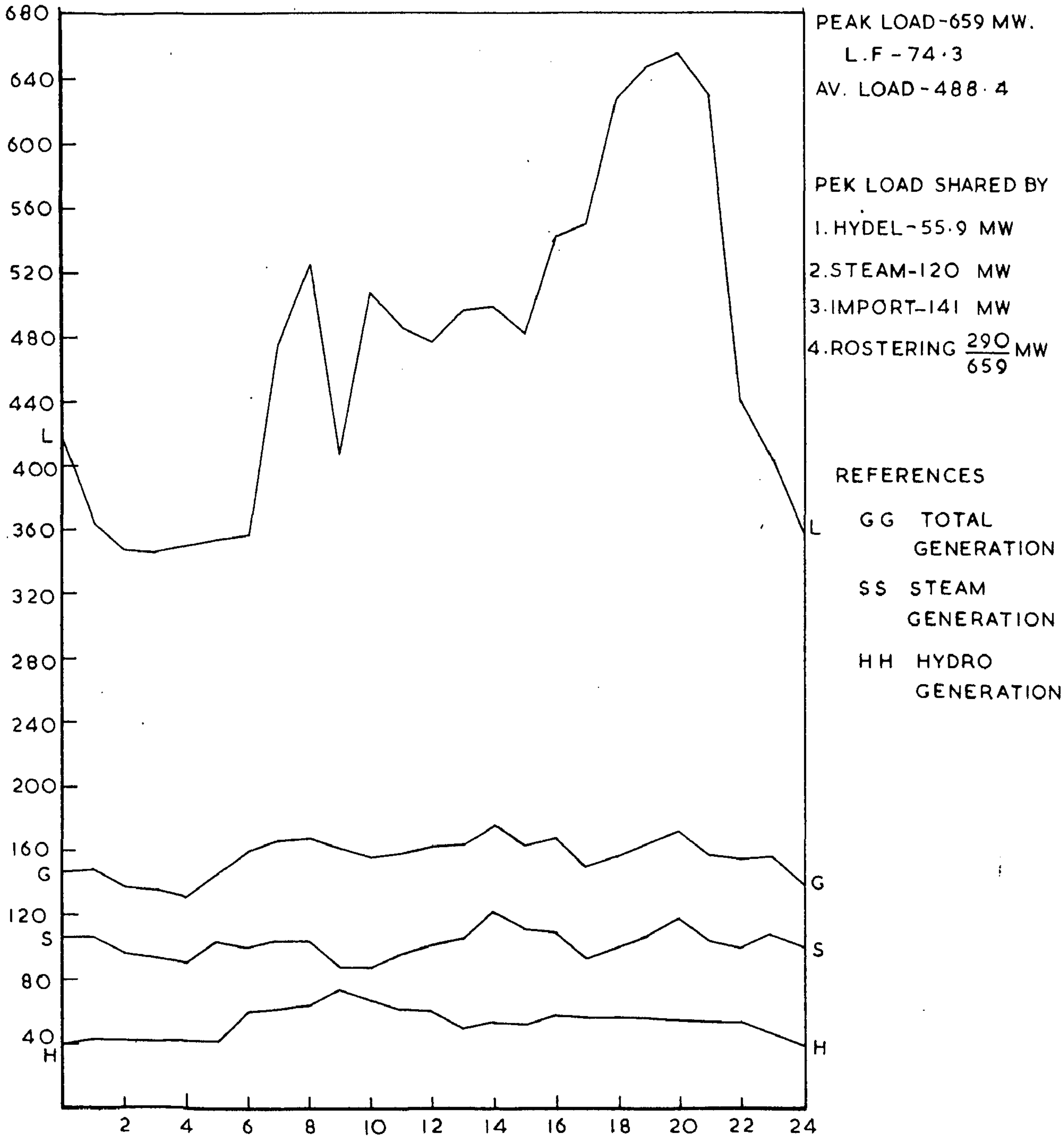

FIG. 16 - DAILY LOAD CURVE OF GANGA-SARDA GRID-1·1·74

```
C  C  OPERATION OF LA KHWAR RESERVOIR - P.K.GHOSHAL W.R.D.T.C
      DIMENSION FLO(1 2),C(12),EVR(12),ERG(25),AG(25),SG(25)
      DIMENSION S(13) ,R(12),EV(12),EI(12),A(12),ER(12),ER1(12),ER2(12)
      READ 99,Y,E
99    FORMAT(2F10.4)
      READ 100,(FLO(I ),I=1,12)
      READ 100,(C(I), I=1,12)
      READ 100,(EVR(I ),I=1,12)
      READ 100,(ERG(J ),J=1,11)
      READ 100,(AG(J) ,J=1,11)
      READ100,(SG(J), J=1,11)
100   FORMAT(8F10.4)
200   S(1)=Y
      M=1
      DO 10I=1,12
      AI=0. $ ERI=0.
      B=S(I)
      DO 20N=1,2
      DO 42 J=1,11
      IF(S(I)-SG(J))1 2,13,42
12    K=J
      KK=J-1
      ADE= ((ERG(K)-E RG(KK))*(S(I)-SG(KK)))/(SG(K)-SG(KK))
      D=ERG(KK)+ADE
      IF(N-1)22,22,23
22    ER(I)=D
      GOTO27
23    ER(I)=(ERI+D)/2 .
27    ADA=((AG(K)-AG( KK))*(S(I)-SG(KK)))/(SG(K)-SG(KK))
      AM=AG(KK)+ADA
      IF(N-1)25,25,26
25    A(I)=AM
      GO TO 28
26    A(I)=(AI+AM)/2.
28    GO TO 15
13    K=J
      IF(N-1)29,29,30
29    ER(I)=ERG(K)
      A(I)=AG(K) $ GO  TO 15
30    ER(I)=(ERG(K)+E RI)/2.
      A(I)=(AG(K)+AI) /2. $ GO TO 15
42    CONTINUE
15    EV(I)=(A(I)*EVR (I))/6.64
      PUNCH701,I,EV(I ),N
701   FORMAT(2HI=,I5, 2X,6HEV(I)=,F10.2,2X,2HN=,I5)
      EI(I)=E*C(I)
      PUNCH601,I,EI(I ),N
601   FORMAT(2HI=,I5, 2X,6HEI(I)=,F10.2,2X,2HN=,I5)
      IF(I-8)17,17,18
17    R(I)=(EI(I)+(FL O(I)/73.))/((ER(I)/1000.)+(1./73.))
      ER1(I)=R(I)*ER( I)/1000.
      ER2(I)=(R(I)-FL O(I))/73.
      IF(ER2(I))51,51 ,52
51    ER2(I)=0.
52    PUNCH703,I,R(I) ,ER1(I),ER2(I),N
703   FORMAT(2HI=,I5, 2X,5HR(I)=,F10.2,2X,7HER1(I)=,F10.2,2X,7HER2(I)=,
     1F10.2,2X,2HN=,I 5)
      GO TO 19
18    R(I)=(EI(I)*100 0.)/ER(I)
      ER1(I)=R(I)*ER( I)/1000.
      ER2(I)=0.
      PUNCH704,I,R(I) ,ER1(I),ER2(I),N
```

∴ Total energy $= 4750 \times 51.85 \times 10^{-3}$

$= 246$ mkwh.

ALTERNATIVE 4

Average rate of energy production $= (\frac{51.9 + 55.6}{2}) \times 10^{-3}$

$= (\frac{107.5}{2}) \times 10^{-3}$

$= 53.75 \times 10^{-3}$

∴ Total energy $= 4750 \times 53.75 \times 10^{-3}$

$= 255$ mkwh.

Taking saving in coal as 5 paise per kwh of energy, the benefit from saving in coal cost due to secondary power would be as follows:

1. For Alternative 1 $= 233 \times 0.05 \times 10^{6}$

   = Rs.116.5 lakhs

2. For Alternative 2 $= 240 \times 0.05 \times 10^{6}$

   = Rs.120 lakhs

3. For Alternative 3 $= 246 \times 0.05 \times 10^{6}$

   = Rs.123 lakhs

4. ForAlternative 4 $= 255 \times 0.05 \times 10^{6}$

   = Rs.127.5 lakhs.