ANALYSIS OF DEPENDABILITY CRITERIA IN RESERVOIR PLANNING - A CASE STUDY

A DISSERTATION

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By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "ANALYSIS OF DEPENDABILITY CRITERIA IN RESERVOIR PLANNING – A CASE STUDY" in partial fulfillment of the requirement for the award of the degree of Master of Technology in Water Resources Development (Civil) submitted in the Water Resources Development Training Centre of Indian Institute of Technology Roorkee is an authentic record of my own work carried out during a period from July, 2002 to November, 2002 under the supervision of Dr. U.C. CHAUBE, Professor at WRDTC, Indian Institute of Technology Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Place : Roorkee

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

The practice followed in India is to plan a project for a target demand of not more than 75% dependable yield (with associated temporal distribution) and then test the performance of the system so planned to ensure 75% success of the project. Thus the two concepts namely planning for utilization 75% dependable yield and planning to achieve 75% success of the project are two different concepts.

Prevalent criteria for irrigation planning have several drawbacks as given below.

- Planning is based on annual reliability only. Seasonal reliability is also important, as crops having different economic value to farmers and to the society are grown in different seasons.
- Quantum of failure (water deficit), time length of failure, period of failure vis a vis planned growth, crop specific failure (sustenance crop, cash crop), are not reflected in the prevalent criteria.
- Region specific characteristics (drought proneness, differences in hydrologic characteristics of catchment and location of storage site) may necessitate adoption of different planning criteria.

The comparative of capacity utilisation in six existing reservoirs in India was carried out. Considerable quantity of live storage is available in carry over storage schemes even at minimum annual condition compared to "within year" storage schemes. Variability of the annual minimum storages over the years is large and for a large number of years, the near full condition is not achieved as compared to "within year" storage.

Yield series of Mahanadi river at Manibhadra dam site has been synthesised and dependability of inflows analysed and compared with previous studies. The purpose was to adopt an appropriate yield series for reservoir simulation study.

The estimated annual yields of 70% dependability are within 95% confidence limits of 75% dependable flow. Similarly estimated 65% dependable flow (3894.47 Th. ha.m) is within 95% confidence limits of 75% dependable flow. In other words, water utilisation planning with 70%, 65% or 60% dependable flows (estimated) may in reality have higher dependability upto 80%, 75%, 70% respectively in consideration of 95%

confidence limits. This aspect also needs to be kept in view while planning for dependable utilisation of flows as per prevailing procedure.

It is generally thought that dependable yields in hypothetical years of various dependability are too conservative and therefore should not be used in planning. The study shows that it need not necessarily be so. Therefore while planning for dependable water utilisation on the basis of actual monthly flows in 75% dependable year, the coefficient of variability of flows in each month should be taken into account. Dependable flows of hypothetical years should be used unless estimates happen to be too conservative.

It is also observed that annual flow series shows periodicity over the years. It will be useful to carry out analysis of periodicity using upto date data.

Synthesised monthly inflows at Manibhadra dam site were used in simulation study. In the project report proposed storage capacity is 580 Th. ha.m and annual irrigation withdrawal is 1650 Th. ha.m. (31.20% of mean annual flow) corresponding to 75% annual dependability.

Annual reliability, time reliability, Kharif season reliability, Rabi season reliability at different annual withdrawal levels (with given monthly distribution) and storage capacities have been worked out. Seasonal reliability appears to be a better criteria as compared to annual reliability as reliable irrigation water supply is crucial for irrigated agriculture in rabi season and may not be so crucial in Kharif season. It is suggested that in case of Manibhadra storage scheme, design irrigation areas could be different for Kharif season crops and Rabi season crops with Kharif design area being more and having lesser reliability (say 67%) and Rabi season area being less but higher reliability (79.17%).

Cost and benefit have been evaluated as function of reservoir capacity and annual irrigation withdrawals. Storage, withdrawal reliability relationship were converted to cost, benefit, reliability relations. Effect of increase in height of reservoir on economic parameters has been evaluated for (i) fixed annual withdrawal and for (ii) fixed annual reliability of 75%.

Long term simulation study is preferred over Gould's probability matrix method in case of Manibhadra reservoir.

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Notation	
A, B, C, D	regression constant
b	$\sqrt{1+1.3K+1.1K^2}$
B/C	benefit cost ratio
C_l	reservoir capacity estimate
D^t	irrigation water diversion
D_t	the release during the t^{th} month
Δ Et	the net evaporation loss during the t^{th} month.
e	exponential
$f(c)$	function of confidence probability c determined by using the table of normal variates
G^t	net gain (+ve) or net loss (-ve) due to rainfall over reservoir area and evaporation from reservoir area
H^t	inflow
$I.D^t$	irrigation demand in period t
JR	July runoff
K	number of zones
K_T	frequency factor which depend upon the return period T
MR	monsoon runoff
m	positive integer large enough for the resulting matrix to be equivalent to steady state conditions
N	number of years of data
N.A.	not available
P_e	probability of failure
R	correlation determination
r	coefficient of correlation
S_e'	probable error
S_{max} and S_{min}	maximum and minimum storage limits (usually corresponding to storage capacity and dead storage).

S_n	reduced standard deviation in Gumbel's extreme value distribution
σ_{n-1}	standard deviation of the sample of size N
S^{t+1}, S^t	storage at the beginning and end of period t
T	return period
[T]	transition matrix
W	the volume of each zone
W^t	water available for utilisation in period t
X	reservoir capacity in Th. ha.m
x	monthly yield at Hirakud in Thousand ha.m
$\bar{x}$	mean of the variate
X_t	the inflow during the t^{th} month
x_T	value of the variate X of a random hydrologic series with a return period
$x_{1/2}$	the confidence interval of the variate x_T is bounded by values x_1 and x_2
X^t	downstream release
X_1	annual irrigation requirement in Th. ha.m.
Y	cost of reservoir in Crores of rupees
Y_1	cost of irrigation work
Y_2	benefit of irrigation in Crores of Rupees
y	monthly yield at Tikarapara in Thousand ha.m
y_n	reduced mean in Gumbel's extreme value distribution
y_T	reduced variate, a function of T
Z_t, Z_{t+1}	the storage content at the beginning and end of the t^{th} month

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Water is a prime natural resource, a basic human need and a precious national asset. The growth process and the expansion of economic activities inevitably lead to increasing demands for water for diverse purposes: domestic, industrial, agricultural, hydropower, navigation, recreation, etc. So far, the principal consumptive use of water in India has been for irrigation.

Due to the particular characteristics of the tropical monsoon, about 80% of the annual river runoff occur in the three to four monsoon month of the year. During this period maximum utilization of the water can be made from the river flows with small regulation and very little storage. However for use in subsequent dry seasons, there is need to store surplus water of monsoon season in reservoirs and tanks.

Sizing of storage and diversion capacity for the purpose of water utilization is an important component of the water resources development studies. If the planned storage and or division capacity is not sufficient, project may not serve the purpose effectively, for which it has been designed and may cause wastage of scarce water resources. On the other hand, over estimation of the storage capacity can result in considerably high cost of the project rendering the project to be an uneconomical alternative.

It is usually seen that in large catchments, the average annual flows are about 10% to 20% more than the 75% dependable annual flows. However, in respect of small catchments of 100 km^2 to 1000 km^2, average annual flow are observed to be much higher, about 15-35% more than the 75% dependable flows. It means depending upon the size of the catchment and hydrological conditions, 10 to 35% excess water in comparison to 75% dependable flow may be available for half the period (50% dependable flow). There is variation of flows within the year as well and 70 to 90% of annual flows occur during a short period of 3 to 4 monsoon months. With such wide variability in the occurrence of flows, both within year and year to year, a considerable amount of water goes waste if adequate storage capacity is not planned. And this reduces the availability of utilisable water. Storage helps in increasing reliability of water utilisation. Higher flows of lesser dependability can be made more dependable through storage.

1.2 BACKGROUND OF STUDY

The present criteria requires the system capability in delivering water to be underutilized in three years out of four years, which perhaps a developing country can ill afford particularly in regard to the drought areas. However, for various reasons, the planned annual reliability of irrigation supplies is kept at 75% dependability. The minimum modification, which can be considered in this regard, is to ignore minor shortages experienced in some years and considering those years also as success years instead of the usual practice of including them in the list of failure years. Also in addition to annual reliability, seasonal reliability (Rabi and Kharif) can also be specified in consideration of the importance of crops.

In conventional procedure annual planned utilization of water is kept approximately equal to 75% dependable flow. It is an empirical decision based on experience and judgement. The controversy on this issue stems from this empirical nature of the criteria. Water resources systems vary widely in their characteristics with respect to the pattern of the flow in the river within the year, and year to year variation of flow and range of flow. The design of reservoir capacity and their level of utilization also vary accordingly from system to system. With availability of fast computational methods and analytical tools it is possible to carry out long term simulation studies for different levels of utilization and assess physical, and economic performance.

1.3 STUDY AREA

Mahanadi River is one of major rivers in India flowing east and draining into Bay of Bengal. Among the Peninsular rivers, it ranks second to Godavari in terms of its water potential and flood producing capacity. The river originates in Raipur district of Madya Pradesh. Total length of the river from head to its outfall into the sea is 851 km of which 357 km are in Madya Pradesh and 494 km are in Orissa. Hirakud dam in Orissa intercepts 83400 km^2 catchment area which 95% of the total area drained by Mahanadi river.

This study deals with the Manibhadra dam project proposed 180 km downstream of the Hirakud dam on Mahanadi river for the purpose of irrigation, flood control and hydropower generation. The dead storage, live storage and specific provision for flood storage are 171 Th. ha.m, 409 Th. ha.m and 260 Th. ha.m respectively as proposed in the project report.

1.4 OBJECTIVE AND SCOPE OF STUDY

1.4.1 Objective

Main objective of this study are to critically examine various parameters of irrigation reliability in reservoir planning and carry out hydrologic analysis of a storage type river valley project to evolve storage size – withdrawal – dependability relationships so as to provide more realistic and meaningful information for taking decisions on storage size and irrigation withdrawals.

1.4.2 Scope of Study

i) Literature survey to examine dependability criteria for reservoir planning for the purpose of irrigation and hydropower.

ii) Analysis of monthly storages over a ten year period for six reservoirs (3 within year storage schemes and 3 carry over storage schemes) to examine capacity utilisation of existing reservoirs.

iii) Synthesis of long term series of inflows at Manibhadra reservoir site on Mahanadi river and analysis of dependability.

iv) Long term simulation study of Manibhadra reservoir for several combinations of storage size and irrigation withdrawal targets and analysis of physical reliability parameters.

v) Analysis of economic parameters (Benefit, Net Benefit, Benefit/Cost Ratio) for storage size and irrigation withdrawals for the Manibhadra reservoir at different levels of reliability.

vi) Reliability analysis by probability matrix method for a given storage size and annual withdrawal level for illustration.

CHAPTER 2
CRITERIA FOR RESERVOIR PLANNING

2.1. INTRODUCTION

Sizing of storage and diversion capacity for the purpose of water utilization is an important component of the water resources development studies. If the planned storage and or division capacity is not sufficient, project may not serve the purpose effectively, for which it has been designed and may cause wastage of scarce water resources. On the other hand, over estimation of the storage capacity can result in considerably high cost of the project rendering the project to be an uneconomical alternative. In India, irrigation projects are being planned to provide 75% dependable yield. This is considered by many planners to be a very conservative planning and is stated to have been leading to under-utilization of the available water resources in the river systems (IWRS 1999). Hydropower projects are planned for 90% dependability and water supply projects are planned for 100% dependability.

A criticism of the prevalent 75% reliability criteria seems to stem from two considerations. Firstly it is due to presumption which makes this irrigation reliability synonymous with the dependability of the inflow into the system. Under this forced synonimity, the criteria is criticized for its undue restriction on the scale of storage development, which gets limited to that required to regulate 75% dependable annul flow. The other consideration for the criticism is that the present criteria requires the system capabilities in giving water to be under utilized in three years out of four, by restricting irrigated area or cropping pattern (Mohanty, G.Y. 1990). This imposes some restriction on the quantum of water in a river basin or at a project site for which firm plans can be made.

This Chapter deals with critical examination of dependability criteria and the discussion is based on IWRS (1999).

2.2. LITERATURE REVIEW ON DEPENDABILITY CRITERIA

Most of the early development had been in the lower reaches of the rivers. Simple diversion structures (for example original weir on Ganga at Hardwar, original weir on Yamuna at Tajewala, etc.) were sufficient to get the required supply. In such situations the supply was almost always ensured and the question of dependability of supply never arose.

As the demand increased and demand areas also shifted to upper reaches of the river, availability of supply in comparison to the demand became a deciding factor. Since supply varies from year to year and from season to season, it became difficult to predict whether the demand will be met in a year or not, thus introducing an element of uncertainty in the planning process. This uncertainty gave rise to the concept of dependability of the project in meeting the planned demand.

2.2.1 The Indian Standard Institution Guidelines

The Indian Standard Institution (now Bureau of Indian Standards) in 1969 adopted the following as one of the general factors for design of live storage.

"The storage provided in an irrigation project should be able to meet the demand of 75 percent of the time whereas in power and water supply projects the storage should meet the demand for 90 percent and 100 percent of the time respectively".

2.2.2 Second Irrigation Commission (1972)

The Second Irrigation Commission (1972) had gone into the question of utilization of flows of lower dependability. The Commission observed that "At present, the practice is to design the projects to utilize river flows of 75% dependability. It means that in 75 years there is some surplus in the river and in 25 years some shortage, ranging from marginal to substantial. It is obvious that the higher the dependability, the lesser the quantity of water available for utilization. Availability can, however, be improved by providing an extra capacity in the reservoir for carrying over supplies from surplus year to lean year. By adopting this device, a project can be designed on river flows of lower dependability to provide a larger volume of water to irrigators, with the same degree of assurance. But the provision of carry over capacity in a reservoir entails additional cost, and it becomes a matter of evaluating the additional supply against the additional cost. The more precious is water in an area, as in drought areas, the greater is the justification for providing a carry-over.

"We consider that the farmer should be assured of getting the designed supply in 75% of the years, and the existing practice of planning irrigation scheme on the basis of 75% dependability should continue. Where a carry-over is provided, the 75% dependability can be figured out, taking into account the carry-over water".

2.2.3 Ministry of Agriculture and Irrigation (1975)

The question of relaxing the planning criterion for drought prone area was considered by The Ministry of Agriculture and Irrigation (1975). The Ministry of Agriculture and Irrigation, as stated in IWRS (1999) relaxed the criteria of 75% dependability for planning irrigation projects to 50% dependability in case of medium irrigation projects in drought prone districts. This was further relaxed in 1983 to include major projects also IWRS (1999).

2.2.4 Guidelines for Preparation of Detailed Projects Reports (DPR)

As per the "Guidelines for Preparation of Detailed Project Reports of irrigation and Multipurpose Projects, Ministry of Irrigation (1980)", projects can be classified by storage behind the structures.

While planning for storage capacity, the guidelines stipulate that in case annual carry-over capacity is provided, its basis may be given. Further, in so far as data requirement is concerned, where carry-over storage is involved, it is desirable and necessary to consider a long term series containing cycle of dry years.

Regarding dependability of output, the checklist contained in the Guidelines implies that the supplies available should be sufficient to ensure 75 percent success.

Thus, it would be seen that the criteria has been evolved over a time. Although the dependability of inflows was considered as the basis in the early days, both the Indian Standard and the Irrigation Commission clearly brought out, in 1969 and 1972, that the criteria apply only to the dependability in the meeting the demands in 75 percent of the year. The same is also reflected in the Guidelines for Preparation of Project Reports.

2.3 SIMULATION AND RELIABILITY

The criterion of 75% dependability is considered to have two concepts implicit in it. One is that a project be planned for an annual utilization of not more than 75% dependable annual flow. The second is that the planning should ensure 75% success of the project in meeting the targeted demand over the economic life of the project. The practice followed in India is to plan a project for a target demand of not more than 75% dependable yield (with associated temporal distribution) and then test the performance of the system so planned to ensure 75% success of the project. Thus the two concepts namely planning for utilization 75% dependable yield and planning to achieve 75% success of the project are two different concepts.

Planning of water resources projects is based on simulation study. Trial and error 'simulation' or 'working table' procedure generally forms the kernel of the planning. In this the trial design of the system is subject to various hydrologic and other inputs and its likely performance is brought out.

For irrigation, apart from the quantum of failure, the time length of the failure, the period of the failure vis-à-vis the planned growths are important. Failure in sustenance crop could hurt a farmer more than that of marketed cash crop. A few random failures may not hurt as much as sequence of failures where his meager savings have been wiped out earlier. Many of these complications are not reflected in the performance index. However no performance index can be perfect, and each could have some advantage.

Following physical performance indices can be used to evaluate project performance.

1. Annual reliability: any year in which there is even a short failure i.e. failure in any 10 daily/monthly releases for runoff the river/storage scheme is taken as failure year. The number of successful years divided by the total period of simulation in years would indicate the annual reliability.
2. Reliability by crop seasons: This is similar to annual reliability except that the decision of success is done not for the year as a whole but for each relevant crop seasons (Kharif, Rabi, hot weather).
3. Monthly and 10 daily reliability: This is similar to the annual reliability but the counting of the success is done on monthly/10 daily basis as the case may be.

4. Quantitative reliability: the ratio of the average annual water delivered or irrigation use for the plan average annual use. Deliveries beyond planned use are not counted since they may not have much significance.

Out of the above, at the present in India, the annual reliability is the normally used criteria. An annual reliability of near 100% for water supply, 90% for hydropower and 75% for irrigation is generally desired.

2.4 RATIONALE FOR FIXING ACCEPTABLE RELIABILITY LEVEL

In the case of irrigated agriculture, unpredicted failure would lead to loss of inputs, loss of labour and more importantly the loss of the alternative opportunity of growing the unirrigated crop which would have been the fall back strategy of the farmer, had the irrigation not been promised. Further, small shortages can be managed more easily either by distributing the shortage in space equitably or by allowing large failure on some hardly or low cost crops. But large shortages during critical crop periods may lead the complete failure of the crop and total disaster.

Even when irrigation deliveries of a storage project are 75% dependable, on annual basis, for the aggregate of the project, the average 'on farm' dependability may be lower. This is due to existing maldistribution practices where in head reach farmers get water at near 75% reliable and at larger than required level, and middle and tail end farmers suffer with undependable supplies even in good years. Better management can reduce such inequitability.

A good amount of research work has been done in recent years to relate the crop yield reduction to the inadequacy in the quantity and timing of irrigation water supply. Relaxation in the implementation of reliability criteria can be thought of with a clear understanding that in the years in which marginal deficit in supplies is ignored, the net value of produce in the project command will also be less than what has been projected in a normal year.

2.5 RELIABILITY FOR DROUGHT PRONE AREAS

A failure in a low rainfall drought area in general is likely to cause larger loss to the farmers as compared to the normal areas. This would be particularly so for Kharif crops where in a normal area the effective rainfall itself may sustain the crop planned for irrigation although yields would be lower, while in a drought area that crop is likely to be lost totally. It is, therefore, likely that the loss function in a drought area would be steeper than that in a normal area. Thus the criteria of 75% annual reliability is equally applicable to drought prone areas. Contentious issue, therefore, is not the criteria of 75% reliability of output but 75% dependability of inflow, which restricts the utilisation to 75% dependable annual yield. Considering the scarcity of water in drought prone areas the restriction of utilisation of 75% dependable yield has been relaxed and projects are accepted even up to 50% dependable yield provided adequate carry-over storage capacity has been provided to ensure 75% reliability to irrigation besides meeting others demands at prescribed reliability.

2.6 PLANNING FOR STORAGE

As stated in the introduction, the dependability of the inflows and the reliability of the supplies are two related but different parameters. Although no authoritative source has sought to restrict the water resources development to 75% dependable inflows, this has been done in a large number of medium as well as major projects as a routine.

Optimum size of development is site specific depending mainly upon how good a storage site is available and how difficult is the command topography. Perhaps it has been traditionally presumed that optimum for the storage development would lie at the point of the largest 'within the year' development, without considering carry over storage. However, even for preliminary planning purposes the water of a river that can be utilized need not be depicted by 75% dependable annual flow alone. The preliminary estimate of utilizable water is related to the type of development envisaged. For example, if irrigation development with reliability of 75% is envisaged then the annual water utilization can be approximated as follows:

(1) For runoff the river project, the water available in hypothetical year in which each ten daily or month flow has reliability of 75%. The total annual flow in such cases of hypothetical year would be much less then the 75% dependable annual inflow;

(2) For largest within the year storage development 75% dependable annual flows; and

(3) For carry over development – A figure between 75% dependable annual flow and mean flow depending on the extent of carry over available.

The carry over storage can be better option, if hydrological data indicates that there is a large fluctuation in annual flows. Mean flows in such case are generally much higher than 75% dependable flow. By providing carry over storage in such cases proportionately larger irrigation benefits can be derived with reliability. As stated in IWRS (1999) the aspect of carry over storage was considered by The Krishna Water Disputes Tribunal also (KWDT). The expert generally agreed that it is possible to utilize surplus water flowing above 75% dependability in 75% years by constructing over the year storage's in which excess water in particular year may be stored for use in succeeding years.

2.7 PRACTICE FOLLOWED IN OTHER COUNTRIES

Different countries have different criteria for planning water resources projects. The concept of percentage dependability likes 75% or 80% where a certain level of failure is voluntary acceptable seems to be adopted mostly in developing countries. The financial resources of such countries are usually limited and the economic feasibility is of paramount importance in investment decisions. On the contrary in western countries like USA, the criterion is to meet the requirements of a particular purpose at nearly 100% success. A number of large reservoirs in USA provide carry over storages to enable full utilisation of available water. The projects are planned for "firm yield" that is 'fully dependable output', which can be committed to users at 100% dependability. However, the reservoirs may be planned for a higher capacity and any excess water available over and above the committed firm yields are referred to as "secondary yield" or "non dependable outputs". The additional water is provided to users at a reduced rate. Thus the firm yield and the secondary yield (even tertiary yield in case of flood flows) have different values attached to them.

Practice followed in Indonesia is similar to practice followed in India. 80% dependability criteria is followed for irrigation planning. There are two crop seasons: wet season and dry season and the main crop is paddy. Unlike in India, annual rainfall is more, storage sizes are smaller and only a few large storage schemes exist or being planned. Dependability criteria as followed in Indonesia is subject to critical examination on the same basis as for irrigation schemes in India.

Practice followed in countries of South Asian region such as Nepal, Bangladesh, Pakistan, Srilanka is more or less similar to the practice followed in India as the entire region is characterised by the tropical monsoon hydrologic condition with a wet monsoon season and remaining year being dry.

2.8 NEED FOR REVISION

It is seen that in the respect of large catchments, the average annual flows are in general about 10% to 20% more than the 75% dependable annual flows. However, in the respect of small reservoirs having catchment of 100 km^2 to 1000 km^2, average annual flow are observed to be much higher, about 15-35% more than the 75% dependable flows. It means depending upon the size of the catchment and hydrological conditions, 10 to 35% excess water will be available for half the period. There is variation within the year flows as well and 70 to 90% of flows occur during a short period of 3 to 4 monsoon months. With such wide variability in the occurrence of flows, both within year and year to year, a considerable amount of water goes waste if adequate storage capacity is not planned. And this reduces the availability of utilisable water.

At present, annual planned utilization of water is kept approximately equal to 75% dependable flow. It is an empirical decision based on experience and judgement. The controversy on this issue raised from time to time stems from this empirical nature of the criteria. Water resources system varies widely in their characteristics with respect to the pattern of the flow in the river within the year to year variation of flow and range of flow. The design of reservoir capacity and their level of utilization also vary accordingly from system to system. It is possible to carry out simulation studies for different levels of utilization and for system of different hydrologic characteristics and assess and compare the techno-economic performance. It seems prudent to plan the terminal sites in a river basin for maximum possible storage capacity especially in water scarce regions.

2.9 IMPLICATION OF ADOPTING LOWER DEPENDABILITY

For a given hydrologic inflow series and operating criteria, the reservoir capacity (C), the quantum of planned deliveries for utilization (U), and the dependability of these deliveries (D) are inter-related. These relations would be of the following types:

i) For a given D, U will increase with C, starting from the possible U min (runoff the river utilisation) for a zero C, to a U max less than the average inflow for infinite C. The curve would show a slope reducing with U.

ii) For a given C, U will decrease with decreasing D.

The maximum utilisation possible in the best year will have a near zero dependability and the utilisation possible for the worst year for the given capacity would have near 100% dependability.

If the 'C' is so small that the reservoir spills in almost every year and if the dry period flows are also very small, then the possible utilisation would show only small variability with dependability.

Utilisation of yield of lower dependability requires larger storages. It is often argued that provision of such carry over storages result in more loss through reservoir evaporation, especially in shallow reservoirs. Evaporation takes place in reservoirs even without carry over storages and the extra evaporation due to higher level of reservoir may not be significant compared to the additional utilization obtained through carry over. In USA, a number of large reservoirs provide carry over storages to enable full utilization of the water available and it has taken several years to fill the reservoirs.

Some of the inter-state agreements in India consider only 75% yield for allocation between States. Adoption of criterion of lower dependability will require reconsideration of inter-States agreement already finalized for allocation of the additional flow at lower dependability's.

Large storages are being criticised for adverse submergence affect especially relating to problems of large number oustees.

The height of the dam and therefore the cost would be more in case of dam built on the basis of lower dependability. Every additional one-meter height of the dam over that designed for 75% dependability would involve additional cost and additional benefit. The additional cost involved in driving the benefit of a unit quantum of water depends on the frequency and persistence of lean flow years and the incremental cost of creating a unit storage. Therefore, the utilization of flows of lower dependability should depend on the economic viability of impounding the additional waters to meet the anticipated deficit in subsequent lean flow years as happens in drought areas as well as environmental cost.

2.10 OTHER STRATEGIS TO IMPROVE RELIABILITY

2.10.1 Conjunctive use of surface and ground water

Conjunctive use of the two resources in time can be considered as one of the alternatives to planning for carry over especially in drought prone areas. Ground water resources provide evaporation free reserve storage and can supplement the surface supplies whenever shortages are experienced. A 'within the year' surface water storage may be planned on say 60% dependability so that in good year the entire utilization is through surface sources. Under the 40% probability of the inflows being deficient the surface flows would be supplemented by ground water flows. The ground water utilisation can be so planned that provides an overall desired level of reliability. In this design the ground water storage is used entirely as a carry over storage. More acceptable combination of conjunction in space and time can also be worked out.

2.10.2 Integrated operation of multiple projects

It is observed that integrated operation of the projects in a basin as a single system may result in higher availability of dependable flows. This is so because the dependable flow for any given dependability of 60%, 75% and 90% etc. of sub-catchments taken individually and added, is likely to be smaller than dependable flow of entire basin. This behavior of dependable flow is different from that of average flows, where, if leakages/additions are ignored, average of the whole is the same as the sum of the average of the parts.

By integrated operation of the various projects in the basin, the common downstream demands can be met with the help of different release pattern of upstream reservoirs. Integrated working table can be made for this type of operation. This type of operation can also average out any short fall in the annual yield in an individual reservoir.

2.10.3 Inter-basin transfer of water

Inter-basin transfer of water from water surplus region to water short regions, where good storage sites are available can also be considered as one of the options for optimum utilization of available water resources. Flood flow canals can be constructed in areas of surplus water to tap floodwater. These canals can be linked to existing reservoirs in deficit areas, which normally do not get filled up. If in planning stage, some carry over storage can be provided in these reservoirs depending upon the availability of water from surplus basin, utilization could be enhanced.

2.10.4 Firm wet season and non-firm dry season irrigation

An unscheduled irrigation shortage can lead to significant loss to the farmer in view of both the loss of inputs and loss of number of growing unirrigated crops. Shortage as such, may not be catastrophic provided sufficient forewarning is available.

In drought areas storage type irrigation schemes can be planned mainly for Kharif use. The planned annual reliability for Kharif should be at the desire level of, say, 75%. The canal network and the irrigated area should be designed based on desired reliability in Kharif. However, depending on the storage available the end of Kharif season a non-firm Rabi irrigation may be allowed from year to year. Since about one month would be available to the farmers to know the area to be planned under the Rabi in that year, the losses due to any change in seasonal water allocation plan would be low and farmers can derive a small but significant additional benefit in Rabi.

CHAPTER 3
ANALYSIS OF STORAGE IN "WITHIN YEAR" AND "CARRY OVER" RESERVOIRS

3.1 GENERAL

It has been traditionally presumed that optimum for storage development would lie at the point of the largest "within the year" development without considering carry over storage. Thus annual water utilisation in case of irrigation project planned for largest within the year storage would be 75% dependable, annual flow. Annual water utilisation planned with carry over storage would be some where between 75% dependable flow and mean annual flow depending on the extent of planned carry over storage.

Similarly for hydropower project 90% dependable output would correspond to storage planned to 90% dependable hydrologic year. In case of carry over storage, 90% dependable output would have to be determined by long-term waterpower studies with upper limit corresponding to utilisation of long term average annual flow.

The purpose of providing carry over storage is to achieve wherever economically feasible higher utilisation of the inflows which change not only from month to month in a year but over the years also. The carry over storage type hydropower projects are normally designed (subject to topographical, geological and other economical) to enable regulation of 90 to 95% of average flow and benefit of firm power are assessed on 90% dependability criteria.

In case of multi purpose (irrigation and hydropower) storage projects, where major benefit is irrigation, the releases are made primarily in the interest of irrigation and power generation follows the pattern of irrigation. Since 75% dependability criteria is being followed in case of irrigation, the power benefit in such a year would be higher than in 90% dependable year. It is desirable to assess the power benefits corresponding to irrigation releases made in a 90% dependable year. Studies should be carried out for 90%, 75% and average dependable condition.

This chapter is continuation of chapter 2. Variation in monthly storages in some of the existing reservoirs in India is examined on the basis of available data so as to compare capacity utilisation pattern

3.2 THE DATA

Ten years data on monthly storage in six reservoirs have been examined in the present study. Table 3.1 shows salient features of these reservoirs. In addition monsoon end storage data for 19 years for the Gandhi Sagar and Rana Pratap Sagar Reservoirs on Chambal River have also been analysed.

Tungabhadra, Hirakud and Koyna reservoirs have been planned for "within year" storage. Rihand, Bhakra and Srisailam reservoirs have been planned with carry over storage. All these reservoirs are used for hydro-electricity generation. Hirakud, Gobind Sagar and Tungabhadra reservoirs are also used for irrigation purpose.

The data on monthly storage built up and depletion during 10 water years from 1988-89 to 1997-98 in respect of these projects have been derived from the graphs given in IWRS discussion paper "Dependability Criteria for Water Resources Development Projects".

It is observed from Table 3.1 that there is discrepancy with regard to live storage capacity of the six reservoirs. The IWRS discussion paper shows smaller live storage capacity compared to those given in CBIP (1979). Assuming that live storage capacity of these reservoirs has decreased over the year due to siltation, live storage capacities as given in IWRS discussion paper have been taken for further analysis.

3.3 ANALYSIS OF HIRAKUD RESERVOIR

This reservoir has been planned as a "within year storage" scheme on Mahanadi River in Orissa State of India. Besides hydropower generation it provides irrigation benefits also (Table 3.1).

Monthly storages and monthly increment/depletion as percentage of live storage capacity have been worked out in Table 3.2. Live storage capacity at the beginning of water year 1988-89 has been assumed to be 5.4 billion m^3 (IWRS 1999) instead of 5.843 billion m^3 as envisaged earlier (CBIP 1979). Reservoirs get fill up in the month of July, August and September; high increments generally occur in the month of July and August. Depletion generally starts in the month of October and continues upto June.

In view of tropical monsoon hydrology each water year has single peak and single trough. There are clearly defined filling and depletion periods. Figure 3.1 shows graphical depletion of storage built up and depletion.

The average annual minimum live storage is 4.13% of the live storage capacity and the year to year variability of annual minimum storage is also small. The reservoir has been asked to attain full live storage in all the ten years examined. Reservoir has been depleted to zero live storage in 50% of the year examined but in remaining 50% of the years the depletion was almost upto zero capacity as is clear in figure 3.1.

Monthly storages over different years are compared in Table 3.3. Mean monthly storage is highest in September (5.36 billion m^3) and lowest in June (0.391 billion m^3). Variability is lowest (0.007) for September storages and highest (0.934) for June storages. Standard deviation is highest (0.716) for storages in February and lowest (0.038) for storages in September.

Releases from Hirakud reservoir are utilised for the purpose of irrigation and hydropower generation. In such multi purpose reservoirs, the water releases are primarily made in the interest of irrigation and power generation follows the pattern of irrigation releases Hirakud reservoir has a large catchment and significant inflows continues to occur upto the month of December enabling storage to be maintained at high level as is evident from small depletions from October to December.

3.4 COMPARATIVE STUDY OF WITHIN YEAR STORAGE SCHEME

Hirakud, Tungabhadra and Koyna reservoirs have been planned as within year storage schemes. Salient features of these schemes are given in Table 3.1. Monthly storage built up and depletion of Hirakud reservoir has been analysed in section 3.3. A brief analysis of Tungabhadra and Koyna compared with Hirakud reservoir.

3.4.1 Tungabhadra Reservoir

Live storage capacity is 3.33 billion m^3. Storage built up and depletion during various water years is graphically depicted in Figure 3.2. Monthly storages in different years are analysed in Table 3.4 (mean, standard deviation, and coefficient of variation).

Analysis of storage increment/depletion on monthly basis and as percent of live storage capacity was carried out similar to that for Hirakud Reservoir as in Table 3.2.

Storage increment starts occurring in May but highest increments in storage generally occur in the month of July. Depletion generally starts from the month of October but sometimes there has been depletion in September also. Storages in June show highest variability and storages in September show the smallest variability as indicated by the coefficient of variation (Table 3.4). Ten year average of annual maximum storages is 98.018% of live storage capacity and ten year average annual minimum as percent of capacity is 2.093% (Table 3.10).

3.4.2 Koyna Reservoir

Live storage capacity is 2.66 billion m^3. Storage built up and depletion during the ten water years under examination is graphically depicted in Figure 3.3. Monthly storages in different years are analysed in Table 3.5.

Analysis of storage increment/depletion on monthly basis and as percent of storage capacity was carried out. Storage built up starts in June/July and highest increment generally occurs in the month of July. Depletion starts in September/October and continues upto June. Storages in June show highest variability. Average annual minimum storage is 13.947% of live storage capacity. Average annual maximum storage is 94.707% live storage capacity.

3.4.3 Comparison of within year storage schemes

Koyna being only a hydropower reservoir, (planned for 90% dependability) has higher average annual minimum storage (13.947% of its capacity) compared to Hirakud (2.093% of capacity) and Tungabhadra (4.131% of capacity).

Whereas Hirakud and Tungabhadra reservoirs show small year to year variability of the minimum storage, it is not so in case of Koyna reservoir. The analysis that for within year reservoirs serving the purpose of irrigation (as single purpose or as one of the purpose in multi purpose reservoir scheme) have (a) annual minimum live storage is small and (b) year to year variability of minimum storage is small and (c) except for bad years reservoirs attain near full condition.

But similar conclusion cannot be arrived at for a single purpose hydropower scheme planned as "within year storage" scheme. It is because power generation depends not only on discharge but also on head available for power generation.

Therefore it is not necessary to deplete the reservoir for 90% dependable power generation if power generation is the only purpose of reservoir.

3.5 COMPARATIVE STUDY OF "CARRY OVER" RESERVOIR

Rihand, Bhakra and Srisailam reservoirs have been planned with carry over storage. All three reservoirs are used for hydro electricity generation. Bhakra (Gobind Sagar) is also for the purpose of irrigation. Salient features of these reservoirs are given in Table 3.1.

3.5.1 Rihand Reservoir

Live storage capacity is 8.99 billion m^3. Storage built up and depletion during various water years is graphically depicted in Figure 3.4. Monthly storage over ten years period are analysed for mean, standard deviation and coefficient of variation in Table 3.6. Analysis of storage increment/depletion on monthly basis and as percent of live storage capacity shows that storage increment generally starts occurring in July month. Highest increments occur either in July or August. Depletion starts occurring in October. Coefficient of variability is highest in July month and lowest in the month of April (Table 3.6). Ten year average of annual maximum storages as percent of live storage capacity is 88.446% and average annual minimum storage is 44.813% of live storage capacity.

The minimum storage in Rihand reservoir in all the ten years is significantly higher than in other reservoirs. Reservoir could be filled upto FRL only in three years out of ten years examined. Its capacity has remained under utilise in most of the years. Storage built up and depletion in water year June 1992 to May 1993 is unusual (Figure 3.4.). Storage capacity of this reservoir appears to be much high in consideration of the dependable flows in the river. It would be interesting to carry out detailed hydro-economic performance analysis of this reservoir.

3.5.2 Gobind Sagar (Bhakra) Reservoir

Live storage capacity of this reservoir is 6.70 billion m^3. Storage built up and depletion is shown graphically in Figure 3.5. Monthly storages over ten year period are given in Table 3.7. Unlike other reservoirs, this reservoir is on a snow fed Perennial

River. The reservoir releases are made in consideration of irrigation requirements in addition to power generation.

Storage built up starts occurring in June. Highest increments generally occur in July. October storages in the ten years period have the lowest variability. May storages have the highest variability (Table 3.7). Average annual maximum storage is 90.09% of its capacity. Average annual minimum storage is 14.436% of its capacity.

3.5.3 Srisailam Reservoir

Live storage capacity of this reservoir is 8.29 billion m^3. Storage built up and depletion is graphically depicted in Figure 3.6. June 1993 to May 1994 and June 1997 to May 1998 are an unusual water years maximum storages. In these years are significantly lower than the live storage capacity of the reservoir. The reservoir has been depleted to zero level only once.

Monthly storages over ten year period are given in Table 3.8. Storage built up starts in June but highest increments occur in August. Depletion starts in November month. Coefficient of variability is lowest for storages in October and it is highest for the month of June. Average annual maximum storage is 99.334% of its capacity and average annual minimum is 8.631% of its capacity (Table 3.10).

3.5.4 Comparison of "Carry Over" Storage Scheme

Table 3.9 and Table 3.10 show the comparison. Rihand reservoir generally has lower dependability in its monthly storages compared to Gobind Sagar and Srisailam reservoirs. Srisailam reservoir shower significantly high variability in its storages.

Considerable quantity of live storage is available in carry over storage schemes even at minimum annual condition compared to "within year" storage schemes. Variability of the annual minimum live storages is large and for a large number of years, the near full condition is not achieved as compared to "within year" storage.

3.6 GANDHI SAGAR AND RANA PRATAP SAGAR RESERVOIRS

Monthly storage data for these reservoirs are not available. Therefore these reservoirs could not be compared with other carry over storage projects discussed above. However 19 years data on storage achieved at end of monsoon season are available.

These hydropower projects are located in series on Chambal River a tributary of Gandhi Sagar Reservoir (GSR) and Rana Pratap Sagar (RPS) are 7595.25 MCM and 1566 MCM respectively. The reservoirs have been planned as over the year storages. Release from Gandhi Sagar is stored in RPS and after power generation goes downstream to Kota Barrage where water is diverted in irrigation canal. Ideally with two upstream over a year storage projects and diversion barrage at downstream should have resulted in optimum utilisation for hydropower and irrigation. Irrigation water utilisation has been poor. 75% dependable water utilisation should have been much higher than actually achieved (Shah 1990).

The 19 years data taken from Shah (1990) indicates that GSR has been filled to its live storage capacity in 19 years and R.P.S has filled upto its storage capacity only in 4 years at the end of monsoon season each year (Figure 3.7). In spite of this there has been a considerable spillage downstream of Kota barrage in monsoon as well as in non-monsoon season (lean season).

The GSR and RPS have been operated solely with consideration of power generation to meet seasonal variation as well as diurnal variation in power demand. Pond level of Kota barrage was raised by 0.6 m in 1986 to absorb day to day fluctuation in releases from RPS, which resulted in marginal improvement in water utilisation for irrigation.

Figure 3.1
LIVE STORAGE BUILD-UP & DEPLETION DURING VARIOUS WATER YEARS IN HIRAKUD RESERVOIR (ORI)

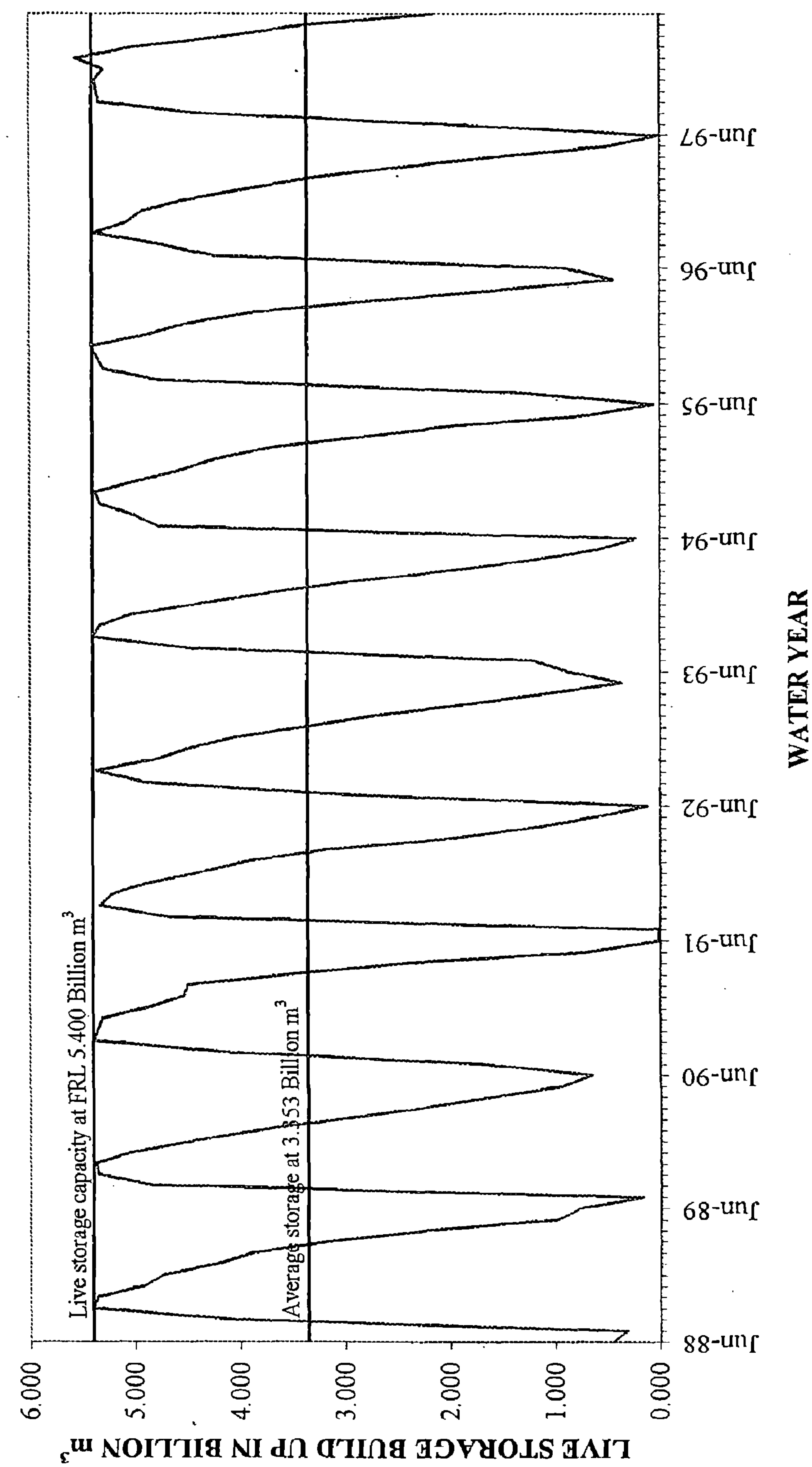


Figure 3.2
LIVE STORAGE BUILD-UP & DEPLETION DURING VARIOUS WATER YEARS IN TUNGABHADRA RESERVOIR (KAR)

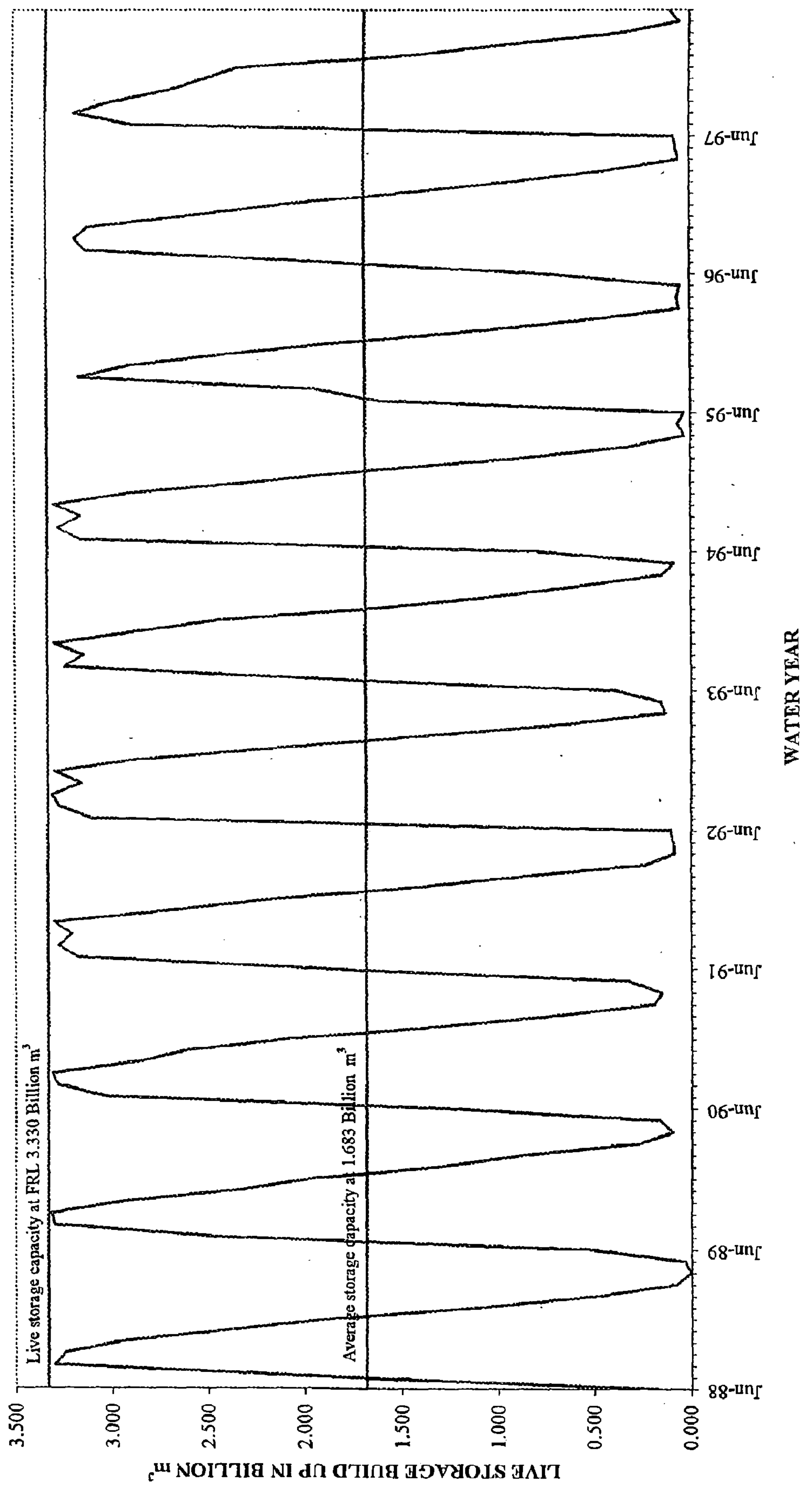


Figure 3.3

LIVE STORAGE BUILD-UP & DEPLETION DURING VARIOUS WATER YEARS IN KOYNA RESERVOIR (MHA)

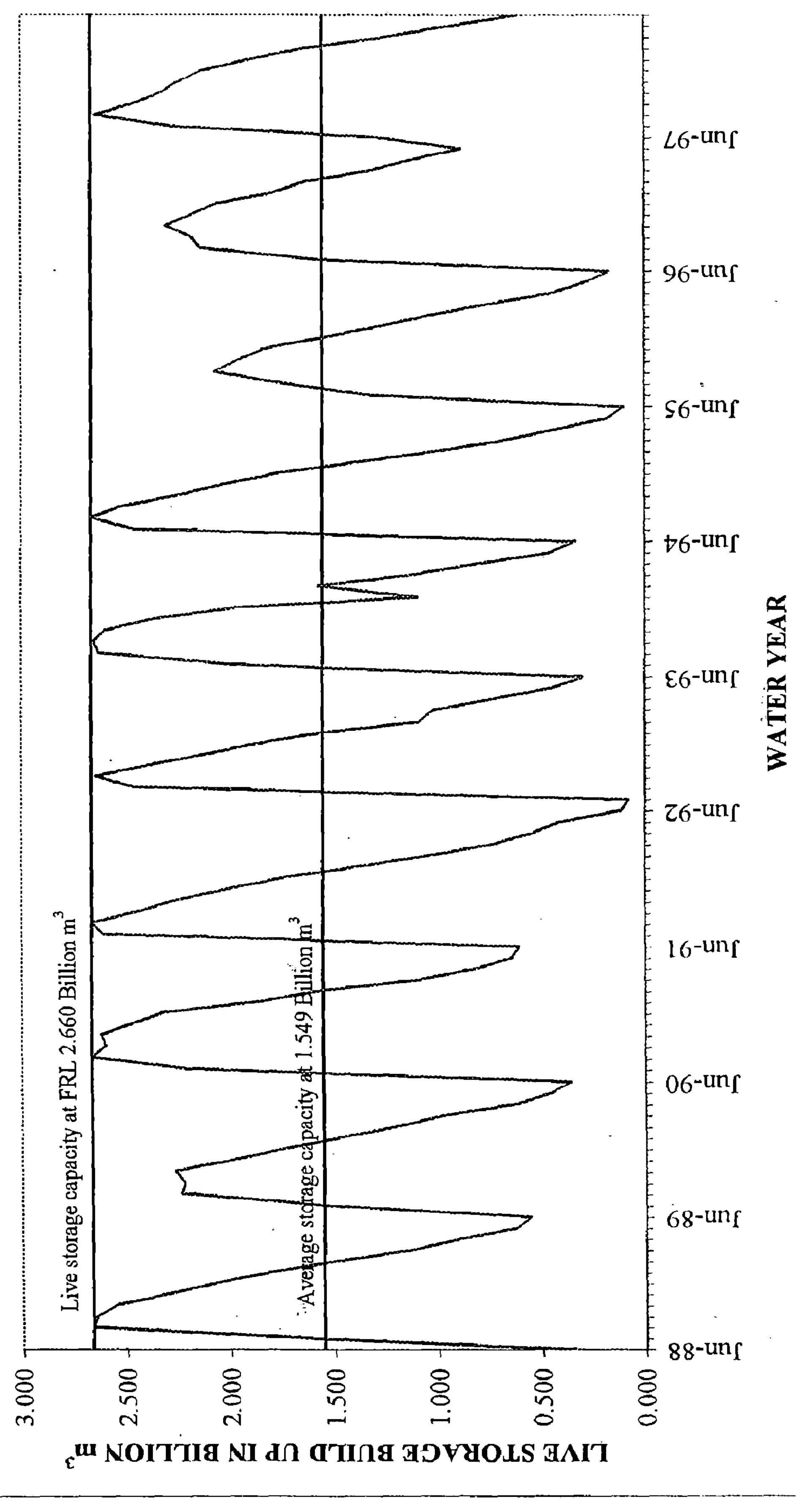
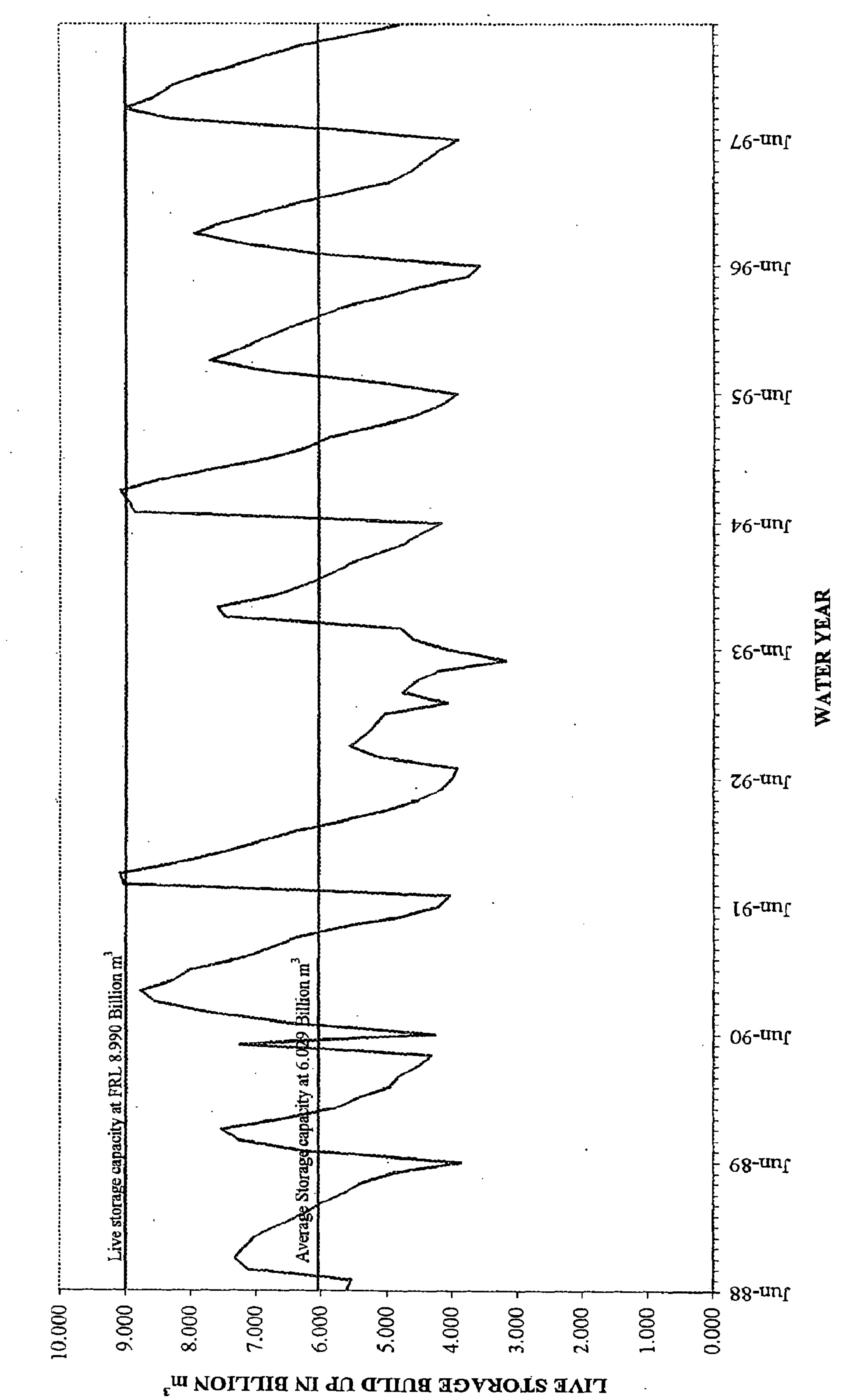


Figure 3.4
LIVE STORAGE BUILD-UP & DEPLETION DURING VARIOUS WATER YEAR IN RIHAND RESERVOIR (U.P.)



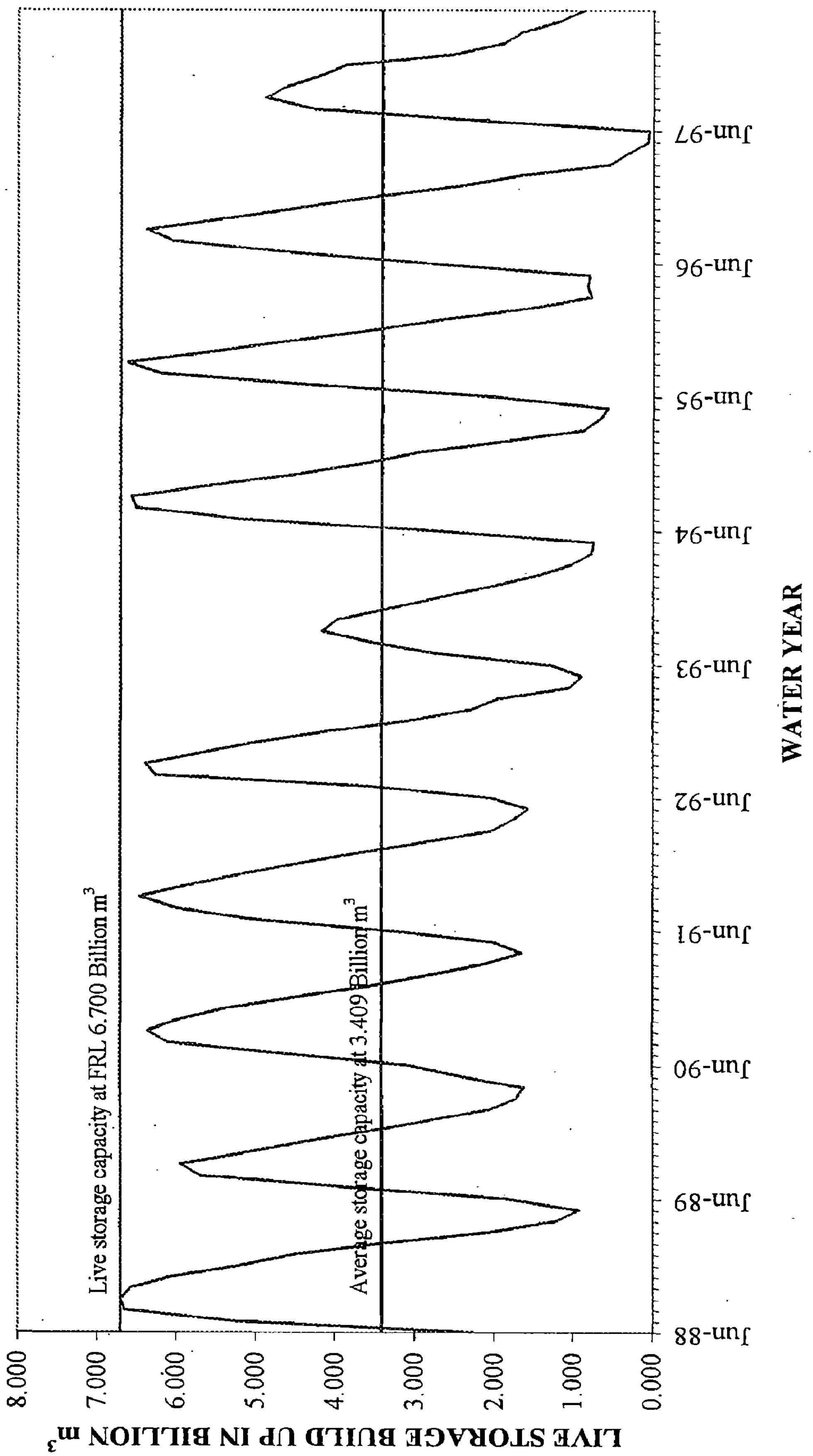
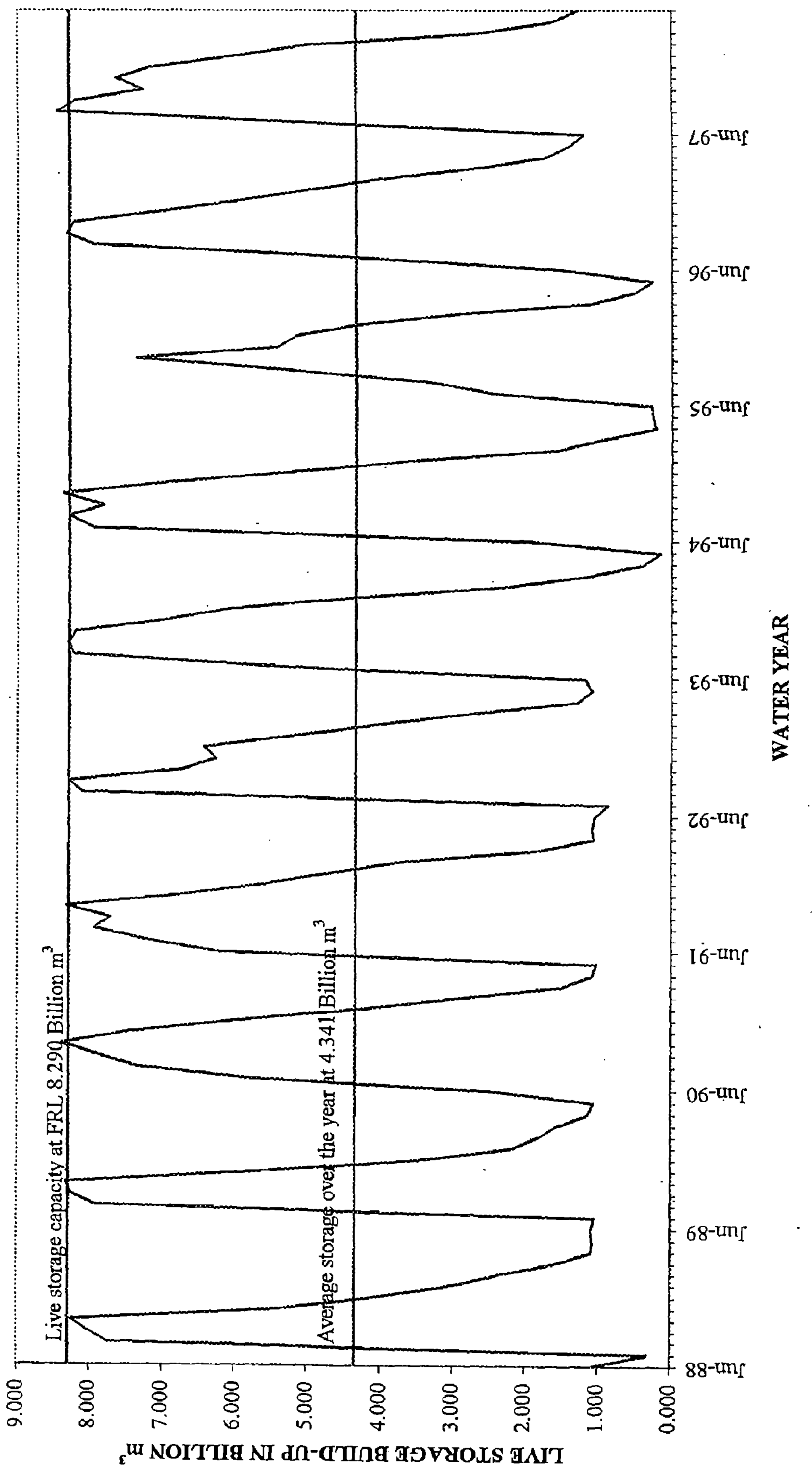


Figure 3.5
LIVE STORAGE BUILD-UP & DEPLETION DURING VARIOUS WATER YEARS IN GOBIND SAGAR RESERVOIR (H.P.)

Figure 3.6

LIVE STORAGE BUILD-UP & DEPLETION DURING VARIOUS WATER YEARS IN SRISAILAM RESERVOIR (A.P.)



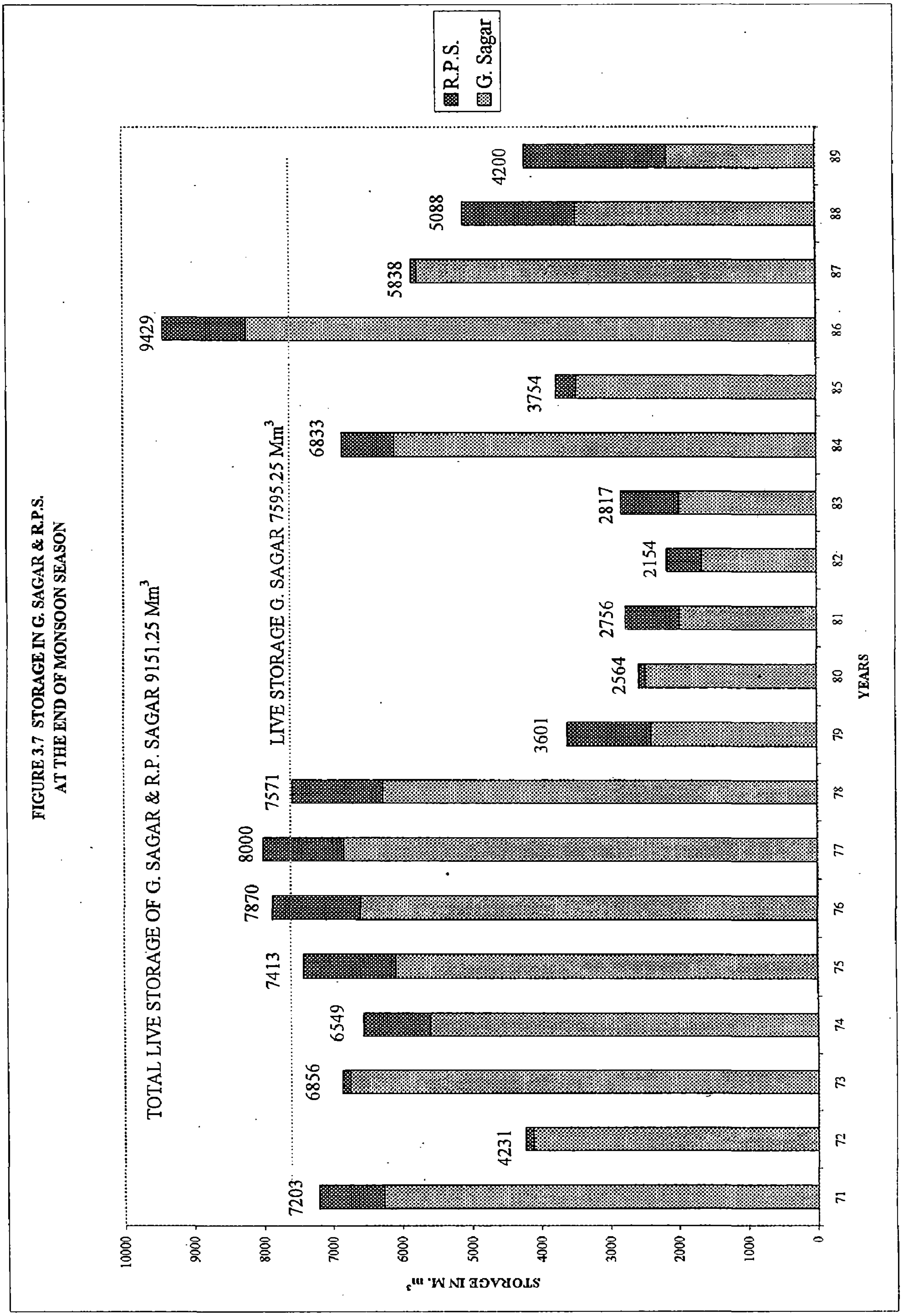


FIGURE 3.7 STORAGE IN G. SAGAR & R.P.S. AT THE END OF MONSOON SEASON

Table 3.1
Salient Features of the Reservoirs

No.	Name of Project	Year of Completion	River	State	Gross Capacity 10^6 m^3	Live Storage Capacity 10^6 m^3	Spillway Capacity m^3/sec	Irrigation Potential
1	Tungabhadra	1957	Tungabhadra	Karnataka	3767	3701 (3300)	18408	364900 ha
2	Hirakud	1957	Mahanadi	Orissa	8105	5843 (5400)	824.2	260781 ha
3	Koyna	1961	Koyna	Maharastra	2796.5	2622 (2660)	3823	H.P.
4	Rihand	1962	Rihand	U.P.	10600	9060 (8990)	515.2	H.P.
5	Gobind Sagar	1963	Satluj	Himachal Pradesh	9621	7191 (6700)	8372	2880000 ha
6	Srisailam	1981	Krishna	A.P.	8722	7080 (8290)	37400	H.P.

H.P. : Hydropower
Source : Register of Large Dams in India Central Board of Irrigation and Power, New Delhi October 1979

Note : Figures in bracket for effective storage capacity are as per unpublished IWRS discussion paper "Dependability Criteria for Water Resources Development Project"

Table 3.2
Live Storage Build-up & Depletion During Various Water Years
for Hirakud Reservoir (Orissa)

Live Storage Capacity : 5.400 Billion m^3
Av. storage over the year : 3.354 Billion m^3

Year	Month	Storage (Billion m^3)	Percent of Capacity (%)	Storage increment (% of cap.)	Storage depletion (% of cap.)	Highest/ Lowest
1988	June	0.440	8.148	8.148		
	July	0.311	5.759		-2.389	Lowest
	August	4.067	75.315	69.556		
	September	5.400	100.000	24.685		Highest
	October	5.356	99.185		-0.815	
	November	4.911	90.944		-8.241	
	December	4.733	87.648		-3.296	
1989	January	4.200	77.778		-9.870	
	February	3.867	71.611		-6.167	
	March	3.133	58.019		-13.593	
	April	2.222	41.148		-16.870	
	May	0.977	18.093		-23.056	
	June	0.751	13.907		-4.185	
	July	0.156	2.889		-11.019	Lowest
	August	4.867	90.130	87.241		
	September	5.356	99.185	9.056		
	October	5.378	99.593	0.407		Highest
	November	5.000	92.593		-7.000	
	December	4.445	82.315		-10.278	
1990	January	3.791	70.204		-12.111	
	February	3.031	56.130		-14.074	
	March	2.267	41.981		-14.148	
	April	1.578	29.222		-12.759	
	May	0.924	17.111		-12.111	
	June	0.636	11.778		-5.333	Lowest
	July	1.689	31.278	19.500		
	August	4.089	75.722	44.444		
	September	5.400	100.000	24.278		Highest
	October	5.356	99.185		-0.815	
	November	5.311	98.352		-0.833	
	December	4.867	90.130		-8.222	

Tabel 3.2. .....continued

1991	January	4.533	83.944		-6.185	
	February	4.489	83.130		-0.815	
	March	3.489	64.611		-18.519	
	April	2.400	44.444		-20.167	
	May	0.698	12.926		-31.519	
	June	0.0	0.0		-12.926	
	July	0.0	0.0		0.000	Lowest
	August	4.689	86.833	86.833		
	September	5.333	98.759	11.926		Highest
	October	5.222	96.704		-2.056	
	November	4.867	90.130		-6.574	
	December	4.356	80.667		-9.463	
1992	January	3.911	72.426		-8.241	
	February	3.178	58.852		-13.574	
	March	2.044	37.852		-21.000	
	April	1.200	22.222		-15.630	
	May	0.600	11.111		-11.111	
	June	0.111	2.056		-9.056	Lowest
	July	3.236	59.926	57.870		
	August	4.916	91.037	31.111		
	September	5.364	99.333	8.296		Highest
	October	4.800	88.889		-10.444	
	November	4.489	83.130		-5.759	
	December	4.053	75.056		-8.074	
1993	January	3.378	62.556		-12.500	
	February	2.720	50.370		-12.185	
	March	1.867	34.574		-15.796	
	April	1.111	20.574		-14.000	
	May	0.356	6.593		-13.981	Lowest
	June	0.844	15.630	9.037		
	July	1.200	22.222	6.593		
	August	4.444	82.296	60.074		
	September	5.400	100.000	17.704		Highest
	October	5.333	98.759		-1.241	
	November	5.044	93.407		-5.352	
	December	4.356	80.667		-12.741	

Tabel 3.2. .....continued

1994	January	3.711	68.722		-11.944	
	February	2.978	55.148		-13.574	
	March	2.044	37.852		-17.296	
	April	1.244	23.037		-14.815	
	May	0.568	10.519		-12.519	
	June	0.222	4.111		-6.407	Lowest
	July	4.782	88.556	84.444		
	August	5.022	93.000	4.444		
	September	5.333	98.759	5.759		
	October	5.378	99.593	0.833		Highest
	November	4.964	91.926		-7.667	
	December	4.564	84.519		-7.407	
1995	January	4.222	78.185		-6.333	
	February	3.733	69.130		-9.056	
	March	2.813	52.093		-17.037	
	April	1.956	36.222		-15.870	
	May	0.657	12.167		-24.056	
	June	0.044	0.815		-11.352	Lowest
	July	1.347	24.944	24.130		
	August	4.769	88.315	63.370		
	September	5.289	97.944	9.630		
	October	5.356	99.185	1.241		
	November	5.413	100.241	1.056		Highest
	December	4.880	90.370		-9.870	
1996	January	4.489	83.130		-7.241	
	February	3.858	71.444		-11.685	
	March	2.742	50.778		-20.667	
	April	1.556	28.815		-21.963	
	May	0.435	8.056		-20.759	Lowest
	June	0.889	16.463	8.407		
	July	4.244	78.593	62.130		
	August	4.756	88.074	9.481		
	September	5.387	99.759	11.685		Highest
	October	5.067	93.833		-5.926	
	November	4.920	91.111		-2.722	
	December	4.533	83.944		-7.167	

Tabel 3.2. .....continued

1997	January	3.933	72.833		-11.111	
	February	3.356	62.148		-10.685	
	March	2.578	47.741		-14.407	
	April	1.573	29.130		-18.611	
	May	0.489	9.056		-20.074	
	June	0.013	0.241		-8.815	Lowest
	July	2.022	37.444	37.204		
	August	4.298	79.593	42.148		
	September	5.333	98.759	19.167		
	October	5.351	99.093	0.333		
	November	5.378	99.593	0.500		Highest
	December	5.289	97.944		-1.648	
1998	January	5.556	102.889	4.944		Highest
	February	4.996	92.519		-10.370	
	March	4.102	75.963		-16.556	
	April	3.364	62.296		-13.667	
	May	2.147	39.759		-22.537	

Table 3.3
Monthly Storages During Various Water Years
for Hirakud Reservoir (Orissa)

Live Storage Capacity : 5.400 Billion m^3
Av. storage over the year : 3.353 Billion m^3

Year	Monthly Storages (Billion m^3)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988						0.440	0.311	4.067	5.400	5.356	4.911	4.733
1989	4.200	3.867	3.133	2.222	0.977	0.751	0.156	4.867	5.356	5.378	5.000	4.445
1990	3.791	3.031	2.267	1.578	0.924	0.636	1.689	4.089	5.400	5.356	5.311	4.867
1991	4.533	4.489	3.489	2.400	0.698	0.000	0.000	4.689	5.333	5.222	4.867	4.356
1992	3.911	3.178	2.044	1.200	0.600	0.111	3.236	4.916	5.364	4.800	4.489	4.053
1993	3.378	2.720	1.867	1.111	0.356	0.844	1.200	4.444	5.400	5.333	5.044	4.356
1994	3.711	2.978	2.044	1.244	0.568	0.222	4.782	5.022	5.333	5.378	4.964	3.711
1995	4.222	3.733	2.813	1.956	0.657	0.044	1.347	4.769	5.289	5.356	5.413	4.880
1996	4.489	3.858	2.742	1.556	0.435	0.889	4.244	4.756	5.387	5.067	4.920	4.533
1997	3.933	3.356	2.578	1.573	0.489	0.013	2.022	4.298	5.333	5.351	5.378	5.289
1998	5.556	4.996	4.102	3.364	2.147							
Mean	4.172	3.621	2.708	1.820	0.785	0.395	1.899	4.592	5.360	5.260	5.030	4.522
Standard deviation	0.602	0.716	0.711	0.692	0.518	0.360	1.687	0.345	0.038	0.188	0.278	0.450
Coeff. Of variation	0.144	0.198	0.262	0.380	0.659	0.912	0.889	0.075	0.007	0.036	0.055	0.099

Table 3.4
Monthly Storages During Various Water Years
for Tungabhadra Reservoir (Karnataka)

Live storage capacity : 3.330 Billion m^3

Av. storage over the year : 1.683 Billion m^3

Year	Monthly Storages (Billion m^3)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988						0.167	1.859	3.295	3.244	2.949	2.400	1.846
1989	1.090	0.492	0.072	0.000	0.031	0.526	2.436	3.295	3.315	2.946	2.346	1.949
1990	1.308	0.877	0.269	0.090	0.159	1.244	3.031	3.282	3.308	2.862	2.608	2.077
1991	1.359	0.718	0.185	0.146	0.321	1.885	3.179	3.274	3.205	3.295	2.705	2.167
1992	1.449	0.872	0.231	0.082	0.087	0.103	3.103	3.269	3.308	3.154	3.295	2.872
1993	2.159	1.462	0.692	0.128	0.154	0.385	1.923	3.244	3.141	3.297	2.882	2.456
1994	1.679	1.064	0.582	0.144	0.079	0.782	3.162	3.274	3.154	3.297	2.910	1.679
1995	1.654	0.910	0.326	0.028	0.059	0.026	1.618	1.936	3.167	2.910	2.395	1.808
1996	1.123	0.538	0.049	0.059	0.044	0.731	1.897	3.128	3.179	3.115	2.603	2.115
1997	1.513	0.936	0.436	0.051	0.064	0.077	2.885	3.179	2.987	2.692	2.513	2.333
1998	1.487	0.949	0.359	0.049	0.095							
Mean	1.482	0.882	0.320	0.078	0.109	0.593	2.509	3.118	3.201	3.052	2.666	2.130
Standard deviation	0.309	0.274	0.207	0.050	0.086	0.597	0.631	0.419	0.101	0.211	0.295	0.353
Coeff. Of variation	0.208	0.311	0.647	0.639	0.783	1.007	0.251	0.134	0.031	0.069	0.110	0.166

Table 3.5
Monthly Storages During Various Water Years
for Koyna Reservoir (Maharasthra)

Live storage capacity : 2.660 Billion m^3
Av. storage over the year : 1.549 Billion m^3

Year	Monthly Storages (Billion m^3)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988						0.341	1.560	2.660	2.644	2.549	2.308	2.070
1989	1.802	1.495	1.138	0.895	0.620	0.550	1.534	2.229	2.215	2.264	1.978	1.736
1990	1.473	1.198	0.967	0.626	0.451	0.352	2.211	2.660	2.593	2.615	2.462	2.308
1991	1.835	1.560	1.077	0.813	0.637	0.604	2.604	2.660	2.440	2.253	2.011	1.736
1992	1.400	1.037	0.736	0.539	0.407	0.110	0.075	2.462	2.640	2.393	2.110	1.868
1993	1.550	1.088	1.011	0.736	0.440	0.292	1.989	2.626	2.648	2.593	2.360	1.967
1994	1.088	1.571	1.132	0.802	0.451	0.330	2.462	2.660	2.517	2.242	2.022	1.088
1995	1.407	1.000	0.670	0.418	0.176	0.092	1.319	1.736	2.066	1.952	1.824	1.560
1996	1.286	1.044	0.758	0.451	0.281	0.165	1.593	2.132	2.176	2.297	2.171	2.055
1997	1.780	1.626	1.323	1.114	0.879	1.281	2.275	2.637	2.462	2.319	2.242	2.121
1998	1.903	1.637	1.264	0.939	0.607							
Mean	1.552	1.326	1.008	0.733	0.495	0.412	1.762	2.446	2.440	2.348	2.149	1.851
Standard deviation	0.270	0.273	0.225	0.224	0.199	0.349	0.736	0.317	0.215	0.200	0.197	0.346
Coeff. Of variation	0.174	0.206	0.223	0.306	0.403	0.847	0.418	0.129	0.088	0.085	0.092	0.187

Table 3.6
Monthly Storages During Various Water Years
for Rihand Reservoir (Uttar Pradesh)

Live Storage Capacity : 8.990 Billion m^3
Av. storage over the year : 6.029 Billion m^3

Year	Monthly Storages (Billion m^3)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988						5.587	5.524	7.111	7.302	7.175	7.016	6.667
1989	6.286	6.032	5.651	5.365	4.889	3.841	6.286	7.238	7.524	6.540	5.778	5.397
1990	4.952	4.825	4.508	4.317	7.238	4.254	6.476	7.683	8.540	8.762	8.254	8.000
1991	7.238	6.794	6.381	5.683	4.794	4.190	4.025	9.016	9.079	8.190	7.524	6.952
1992	6.381	5.651	5.003	4.508	4.159	4.000	3.924	5.111	5.556	5.302	5.175	5.035
1993	4.063	4.762	4.571	4.190	3.175	4.063	4.603	4.781	7.460	7.581	6.730	6.254
1994	5.892	5.575	5.143	4.762	4.476	4.159	8.857	8.952	9.079	8.476	7.683	5.892
1995	6.235	5.841	5.175	4.571	4.171	3.924	5.016	6.730	7.702	7.270	6.889	6.489
1996	6.063	5.683	5.029	4.508	3.746	3.556	5.905	7.161	7.937	7.518	6.908	6.317
1997	5.632	4.952	4.635	4.419	4.190	3.905	5.746	8.279	8.991	8.552	8.318	7.905
1998	7.340	6.844	6.286	5.524	4.806							
Mean	6.008	5.696	5.238	4.785	4.564	4.148	5.636	7.206	7.917	7.537	7.028	6.491
Standard deviation	0.978	0.735	0.669	0.537	1.077	0.544	1.437	1.423	1.085	1.056	0.998	0.959
Coeff. Of variation	0.163	0.129	0.128	0.112	0.236	0.131	0.255	0.197	0.137	0.140	0.142	0.148

Table 3.7
Monthly Storages During Various Water Years
for Gobind Sagar Reservoir (Himachal Pradesh)

Live Storage Capacity : 6.700 Billion m^3
Av. storage over the year : 3.409 Billion m^3

Year	Monthly Storages (Billion m^3)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988						2.234	5.259	6.650	6.701	6.548	6.041	5.188
1989	4.492	3.401	2.030	1.218	0.904	1.827	3.797	5.685	5.939	5.152	4.391	3.579
1990	2.766	2.056	1.726	1.609	2.386	3.096	4.619	6.091	6.345	5.970	5.371	4.508
1991	3.563	2.817	2.132	1.650	2.005	3.391	5.076	5.990	6.447	5.863	5.178	4.467
1992	3.706	2.843	2.031	1.751	1.563	2.030	3.553	6.244	6.371	5.685	5.000	4.086
1993	3.071	2.274	1.929	1.041	0.888	1.269	2.741	3.553	4.162	3.959	3.325	2.690
1994	2.056	1.472	1.015	0.761	0.736	2.741	5.152	6.498	6.558	5.533	4.492	2.056
1995	2.944	1.904	0.863	0.660	0.558	1.980	4.188	6.193	6.599	5.584	4.569	3.553
1996	2.640	1.574	0.761	0.812	0.787	2.792	4.558	6.041	6.365	5.406	4.442	3.553
1997	2.437	1.650	0.533	0.305	0.051	0.036	2.284	4.264	4.873	4.619	4.188	3.858
1998	2.513	1.878	1.650	1.168	0.863							
Mean	3.019	2.187	1.467	1.098	1.074	2.140	4.123	5.721	6.036	5.432	4.700	3.754
Standard deviation	0.721	0.639	0.608	0.475	0.703	0.977	1.023	1.005	0.843	0.725	0.741	0.906
Coeff. Of variation	0.239	0.292	0.415	0.433	0.654	0.457	0.248	0.176	0.140	0.133	0.158	0.241

Table 3.8
Monthly Storages During Various Water Years
for Srisailam Reservoir (Andhra Pradesh)

Live Storage Capacity : 8.290 Billion m^3

Av. storage over the year : 4.341 Billion m^3

Year	Monthly Storages (Billion m^3)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988						1.048	0.317	7.746	8.000	8.254	5.352	4.127
1989	3.048	2.368	1.587	1.079	1.060	1.073	1.035	7.905	8.254	8.318	5.619	3.460
1990	2.190	1.810	1.556	1.124	1.048	2.476	5.778	7.365	7.873	8.381	7.460	6.000
1991	4.318	2.889	1.492	1.079	1.016	6.222	7.206	7.937	7.714	8.317	6.762	5.556
1992	4.667	3.651	1.841	1.048	1.079	1.035	0.857	8.095	8.286	6.730	6.254	6.425
1993	5.175	4.032	2.762	1.270	1.079	1.175	5.460	8.222	8.298	8.190	6.984	6.063
1994	4.381	2.286	1.143	0.381	0.140	1.905	7.937	8.292	7.810	8.368	6.952	4.381
1995	3.619	1.556	0.952	0.203	0.254	0.273	2.413	3.302	5.206	7.365	5.429	5.143
1996	4.317	2.921	1.111	0.508	0.254	1.492	4.286	7.937	8.317	8.229	7.048	5.968
1997	4.984	4.032	2.730	1.714	1.397	1.206	4.857	8.444	8.197	7.270	7.632	7.175
1998	6.006	4.952	2.692	1.638	1.270							
Mean	4.271	3.050	1.787	1.004	0.860	1.791	4.015	7.525	7.796	7.942	6.549	5.430
Standard deviation	1.093	1.094	0.700	0.503	0.460	1.662	2.721	1.514	0.937	0.592	0.836	1.146
Coeff. Of variation	0.256	0.359	0.392	0.501	0.535	0.928	0.678	0.201	0.120	0.074	0.128	0.211

Table 3.9
Coefficient of Variation in Six Reservoirs

Name of Project	Coefficient of Variation											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Within year storage scheme												
1. Tungabhadra	0.208	0.311	0.647	0.639	0.783	1.007	0.251	0.134	0.031	0.069	0.110	0.166
2. Hirakud	0.144	0.198	0.262	0.380	0.659	0.912	0.889	0.075	0.007	0.036	0.055	0.099
3. Koyna	0.174	0.206	0.223	0.306	0.403	0.847	0.418	0.129	0.088	0.085	0.092	0.187
Carry over storage scheme												
4. Rihand	0.163	0.129	0.128	0.112	0.236	0.131	0.255	0.197	0.137	0.140	0.142	0.148
5. Gobind Sagar (Bhakra)	0.239	0.292	0.415	0.433	0.654	0.457	0.248	0.176	0.140	0.133	0.158	0.241
6. Srisailam	0.256	0.359	0.392	0.501	0.535	0.928	0.678	0.201	0.120	0.074	0.128	0.211

Table 3.10
Annual Performance of Reservoirs

Name of Project	No. of Years of record	No. of Years FRL attained	Percent (%)	No. of Years depletion upto zore capacity	Percent (%)	Av. Annual max as % of capacity	Av. Annual min as % of capacity
Within year storage scheme							
1. Tungabhadra	10	7	70	2	20	98.018	2.093
2. Hirakud	10	10	100	6	60	100.017	4.230
3. Koyna	10	7	70	2	20	94.707	13.947
Carry over storage scheme							
4. Rihand	10	4	40	0	0	88.446	44.813
5. Gobind Sagar (Bhakra)	10	5	50	1	10	90.090	14.436
6. Srisailam	10	9	90	3	30	99.334	8.631

CHAPTER 4

GENERATION OF YIELD SERIES OF MAHANADI RIVER AND DEPENDABILITY ANALYSIS

4.1 INTRODUCTION

As already stated in Chapter 2, irrigation projects in India are planned to provide 75% dependability of the outflow on annual basis. At the same time present criteria for reservoir planning also specifies that the utilisation of river water be limited to a 75% dependable yield. The two concepts namely planning for utilising 75% dependable yield and planning to achieve 75% success of the project are two different concepts but planners have many times considered these to be synonymous. Although no authoritative source has sought to restrict the water resources development to 75% dependable inflows, this has been done in a large number of medium as well as major projects as a routine. Traditionally maximum size of storage for irrigation development is limited to the use of 75% dependable inflows fully to provide 75% reliability of surplus (outflow).

This chapter deals with synthesis of yield series of Mahanadi at Manibhadra dam site and analysis of dependability of inflows. A comparative study with earlier studies is carried out. The purpose is to adopt an appropriate yield series for reservoir simulation study in Chapter 5.

4.2 THE MAHANADI RIVER

Mahanadi, the Sixth largest river of India originates in Satpura hills of Raipur district of Madya Pradesh. The total length of river is 851 km. It flows for a distance of 357 km. in Madya Pradesh State before entering to Orissa State and falls in Bay of Bengal at Paradip in Orrisa.

To mitigate the hazards of flood, Hirakud dam project was completed in the year 1957. Hirakud dam intercepts a catchment of 83400 km^2, which works out to be 59% of total area (141720 km^2), drained by the river.

Even after construction of Hirakud dam the peak flood in the river is not reduced to safe flood in the delta region, due to unfavourable characteristics of the river basin in relation to the storm movement (Mohanty 1990). The catchment area of 58320

km^2 downstream of Hirakud dam is sufficient to create damaging floods during the period of heavy storm.

In order to reduce the submergence and for providing direct irrigation from the reservoir, Manibhadra dam project was proposed 180 km downstream of Hirakud dam and 32 km downstream of Tikarapara to harness the river Mahanadi for the benefit of irrigation, flood control and power generation. The catchment area of Mahanadi River at Manibhadra dam site is 126120 km^2. Line diagram of Mahanadi River system is shown in Figure 4.1. The salient features of the Manibhadra dam are given below (Mohanty 1990).

Annual Yield (Th. ha.m)

Percent Dependability	Initial stage	Ultimate stage after utilisation by upstream projects
75%	3255.64	2545.95
90%	1936.24	1278.32
Maximum	13070.40	12328.10
Minimum	1619.90	1317.90
Average	5314.10	4556.00

Reservoirs Particulars

	Level in meters	Capacity in Th. ha.m
Dead Storage Level (D.S.L.)	73.15	171.00
Full reservoir Level (F.R.L.)	86.00	580.00
Maximum Water Level (M.W.L.)	91.50	840.00

Irrigation

G.C.A.	9,74,000 ha
C.C.A.	6,82,000 ha
Kharif area	6,82,000 ha
Rabi area	4,83,000 ha

Power	
Installed capacity	960 MW
Firm power of 100% load factor	297 MW
Cost	
Total cost of the project	110312.46 lakhs.
Benefit	
Firm power	297 MW
Production of annual energy	2620 million units
Net revenue from power/year	114.3
Flood protection area	6,57,432 ha
Benefit cost ratio for flood control	4.28
Percentage return of power Component (10th year)	168%

4.3 DATA AVAILABILITY

No discharge observation has been done at Manibhadra. But there are number of sites in the Mahanadi river basin where discharge observation are being made. The two nearest sites of discharge observations on the upstream of Manibhadra (i.e. one at Hirakud dam and other at Tikarapara) have been considered.

At Hirakud, the inflow into reservoir and outflow from the reservoir are available from the date of the Hirakud project i.e. from 1958 to onwards.

Monthly inflow of Hirakud reservoir for the period 1958 to 1982 from its catchment corrected for the post dam period i.e. after 1956 have been taken from NIH Report 1986 and are given in Table 4.1.

Central Water Commission has been conducting discharge observations at Tikarapara sites from 1972 onward. Table 4.2 shows monthly flows from 1972 to 1982 at Tikarapara site. W.B. Longbien's Log Deviation Method was used for fill missing record of July 1972 as explained in Table 4.3.

4.4 COMPUTATION OF MONTHLY MONSOON YIELD AT TIKARAPARA

Outflow from Hirakud reservoir consists of releases made for power generation spill from reservoir and return from irrigated area assumed as 20% of irrigation diversion from reservoir. This outflow was reduced from observed yield at Tikarapara to obtain yield from virgin catchment between Hirakud and Tikarapara (40920 km^2) as shown in Table 4.4. In some months observed yield at Tikarapara was found to be less than release from Hirakud reservoir. In such months irrigation yield from interim catchment has been assumed to be zero.

4.5 SYNTHESIS OF MONTHLY MONSOON YIELD AT TIKARAPARA

4.5.1 Correlation Between Monthly Runoffs

Concurrent data on monthly runoff at Hirakud (Table 4.1) and at Tikarapara (Table 4.4) for the monsoon months (June to October) during 1972-73 to 1981-82 are used to develop best-fit regression equations between flows at these two sites. Table 4.5 shows five relationships for each month. The regression equation having highest coefficient of correlation is selected separately for each month as shown below. 'y' is monthly yield at Tikarapara and 'x' is monthly yield at Hirakud both in units of Thousand ha.m. Figure 4.2 shows the graphical regression analysis for various relationships for each month. Outliers which were not considered are also indicated.

Month	Best fit equation	Coeff. of correlation	Remark
June	$y = A + Bx$ $A = 0.2976$ $B = -0.7881$	$r = 0.930$	Thought Polynomial equation has higher value but it gives negative or abnormally high values in some years. Hence not adopted (applies to June and July)
July	$y = A + Bx$ $A = 0.7374$ $B = -182.75$	$r = 0.793$	
August	$y = A + Bx + Cx^2$ $A = 740.8$ $B = -0.7679$ $C = 0.0005352$	$r = 0.728$	
September	$y = B * x^A$ $A = 0.9005$ $B = 1.2324$	$r = 0.859$	

October $y = A + Bx + Cx^2 + Dx^3$ $r = 0.932$

$A = -28.9753424$

$B = 1.0514224$

$C = -0.0021741$

$D = 0.0000014$

4.5.2 Synthesis of Monthly Monsoon Yield

Using these regression equations for different months and monthly runoff of catchment upstream of Hirakud (Table 4.1) for the period 1958 to 1971, the monthly yield at Tikarapara during monsoon months for the period 1958 to 1971 have been computed as shown in Table 4.6.

4.6 COMPUTATION OF MONTHLY YIELD AT MANIBHADRA

4.6.1 Computation of Monsoon Yield at Manibhadra

Monsoon yield at Manibhadra Dam site is computed from the computed monsoon yield at Tikarapara in proportion to the catchment area.

From this, the yield of intercepted catchment (3240 km^2) by the Medium Projects between Hirakud and Manibhadra (in proportion to catchment area) are deducted to get yield of free catchment and to this yield of free catchment, Hirakud spill, power release and assumed 20% regeneration from Hirakud irrigated area have been added to find out yield at Manibhadra dam site at the initial stage (Table 4.7).

4.6.2 Computation of Non-Monsoon Yield at Manibhadra Dam Site

The non-monsoon yield at Tikarapara has been computed from the available record at Tikarapara from the period of 1972 to 1982. Percentile relationship between the total monsoon yield and total non-monsoon yield has been found out from the above observed period. The total average non-monsoon yield in term of percentage of total monsoon yield was found out. Again for each individual month for the period 1972 to 1982, the average figures for non-monsoon yield was found out. Thus, for each individual month for the same period the average figures for non-monsoon yield in the terms of percentage yield was found out from already calculated percentile total non-monsoon yield. The figures for November to May obtained in the terms of percentages are 2.41%, 1.55%, 1.61%, 1.67%, 1.94%, 1.86%, 1.31%, and for total 12.35% as shown in Table 4.8.

From the above relationship monthly data for non-monsoon periods i.e. from 1958 to 1971 have been generated and annual yield for the period from 1958 to 1971 are found at Manibhadra Dam site as shown in Table 4.9. The complete series of monthly flows for 24 years from 1958-59 to 1981-82 is presented in Table 4.10.

The annual yield as computed from the monsoon yield and non-monsoon yield, have been arrived at after making adjustments earlier for monsoon yield as discussed below.

The water requirement from this catchment (below Hirakud and Manibhadra) for the on-going and future projects will have to be kept reserved. Hence from the initial yield, the water requirement for the above projects will have to be deducted to get the ultimate yield at Manibhadra Dam site. Since data on on-going and future projects are not available, this exercise could not be carried out.

4.7 ANALYSIS OF THE DEPENDABILITY

From this yield series for Mahanadi at Manibhadra at initial stage (i.e. without consideration of ongoing future projects), dependability analysis of annual flow has been carried out as shown in Table 4.11 and Figure 4.3.

Table 4.12 shows a comparison of early studies (Project Report and NIH Study) with present study. 75% dependable annual flow (3204.71 Th. ha.m) is lower than estimated in previous studies however standard deviation of the series by present study is higher.

4.7.1 Ninety Five Percent Confidence Limits for Dependable Yield

For the annual yield series at Manibhadra, mean annual runoff is 5288.58 Th. ha.m, standard deviation is 2627.38 Th. ha.m and coefficient of skewness is 1.14. It is assumed that annual yield series follows Gumbel's probability distribution as skewness is 1.14. Accordingly, 95% confidence limits have been worked out for flows of various dependabilities (probability of exceedence or return period) as per procedure explained as follows:

Confidence limit calculation:

N = 24

σ_{n-1} = 2627.38

Reduced mean y_n in Gumbel's extreme value distribution, y_n = 0.5296, and Reduced standard deviation S_n in Gumbel's extreme value distribution, S_n = 1.0864; for N = 24.

$$y_{1.33} = -\left[\ln\ln\left(\frac{1.33}{0.33}\right)\right]$$

$$= -0.3321$$

$$K_{1.33} = \frac{(y_t - y_n)}{S_n}$$

$$= \frac{(-0.3321 - 0.5296)}{1.0864}$$

$$= -0.7931$$

$$x_{1.33} = \bar{x} + K_{1.33}.\sigma_{n-1}$$

$$= 5288.58 + (-0.7931) \times 2627.38$$

= 3204.71 Th. ha.m.

$$b = \sqrt{1 + (1.3x(-0.7931)) + (1.1x(-0.7931)^2)}$$

$$= 0.8130$$

$$S_e = \frac{bx\sigma_{n-1}}{\sqrt{N}}$$

$$= \frac{0.8130x2627.38}{\sqrt{24}}$$

= 436.00 Th. ha.m.

$$x_{1/2} = x_T \pm f(c).S_e$$

$$= 3204.71 \pm 1.96x436.00$$

x_1 = 4059.26 Th. ha.m

x_2 = 2350.15 Th. ha.m

Similarly upper and lower limits of 95% confidence for estimated yields of various dependabilities have been worked out as shown in Table 4.13. Figure 4.4 shows confidence band in which true values of dependable yield for different return periods are expected to lie with 95% confidence.

The estimated annual yields of 80% dependability (2856.89 Th. ha.m) and 70% dependability (3563.54 Th. ha.m) are within 95% confidence limits of 75% dependable flow (4059.26 Th. ha.m to 2350.15 Th. ha.m).

Similarly estimated 65% dependable flow (3894.47 Th. ha.m) is within 95% confidence limits of 75% dependable flow (4059.26 to 2350.15 Th. ha.m) and estimated 60% dependable flow (4227.11 Th. ha.m) is within 95% confidence limits of 70% dependable flow (4391.67 Th. ha.m to 2735.41 Th. ha.m). In other words, water utilisation planning at 70%, 65% or 60% dependable flows (estimated) may in reality have higher dependability upto 80%, 75%, 70% respectively. This aspect also needs to be kept in view while planning for dependable utilisation of flows as per prevailing procedure.

65% dependable flow is 21.52% higher than 75% dependable flow and 70% dependable flow is about 11.20% higher than 75% dependable flow.

Planning irrigation water utilisation on the basis of 75% dependability means there will be three out of four years (on an average basis over long term) during monsoon season (kharif crop season). It would be worthwhile to consider utilisation of flows of dependability lesser than 75% in monsoon season.

4.7.2 Dependability Analysis on Monthly Basis

Flow duration curves for each of the 12 calendar months are shown in Figure 4.5. Calculation procedure is shown in Table 4.14. Monthly flow duration curves have been used to estimate monthly yields in hypothetical years of 75%, 70% and 60% dependable monthly flows (Table 4.15). These dependable monthly yields of hypothetical years have been compared with actual monthly yields obtained in 75%, 70% and 60% dependable years (1966-67, 1969-70, 1976-77) in Table 4.15.

It is generally thought that dependable yields in hypothetical years of various dependability are too conservative and therefore should not be used in planning. The comparison in Table 4.15 shows that it need not necessarily be so as indicated by annual figures in the Table 4.11.

Differences in monthly yield are highest in September for 75% dependability. It is possible that rainfall in September 1966 (the 75% dependable annual year) might have been low resulting in low runoff 224.55 Th. ha.m whereas 75% monthly runoff in

September (of hypothetical year) is 562.50 Th. ha.m which is the expected figure and more reliable.

Therefore while planning for dependable water utilisation on the basis of actual monthly flows in 75% dependable year, the coefficient of variability of flows in each month should be taken into account. Dependable flows of hypothetical years (90% dependable monthly flows) should be used unless estimates happen to be too conservative.

4.8 PERIODICITY IN ANNUAL FLOW SERIES

Synthesised annual flow series from 1958 – 59 to 1981 – 82 is graphically depicted in Figure 4.7. It is observed that the annual flow series shows periodicity over the years. Bad water years rarely occur in succession and are often preceded by good water years. With the provision of over the year storage, higher utilisation of available water is possible.

Figure 4.1
LINE DIAGRAM OF MAHANADI RIVER SYSTEM

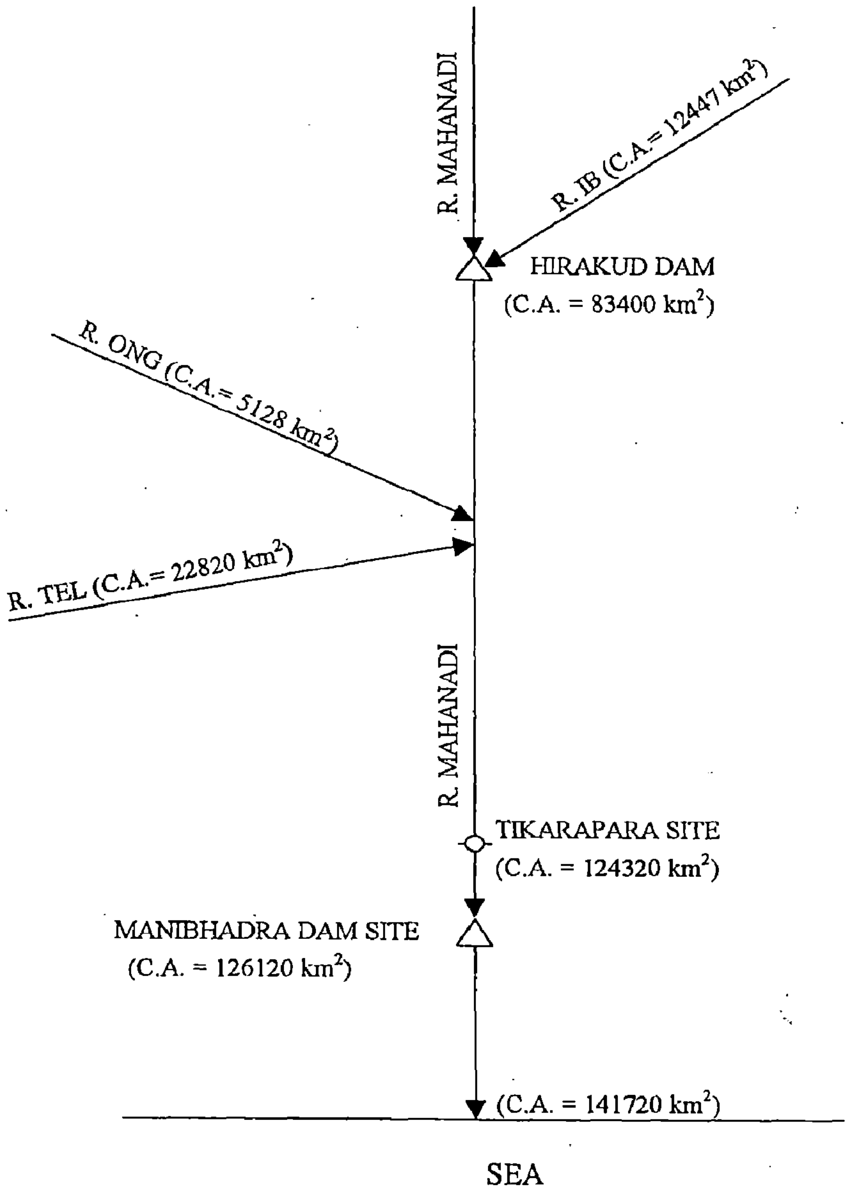


Table 4.1

Corrected Hirakud Inflow from 1958 to 1882 in Thousand ha-m

Year	Month												Monsoon	Non-Monsoon	Annual
	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May			
1958	44.40	1,433.20	886.20	1,240.90	599.00	111.40	43.10	28.10	17.20	6.30	10.30	5.20	4,203.70	221.60	4,425.30
1959	30.70	625.50	1,816.70	1,708.90	273.00	72.30	40.30	28.80	10.00	19.60	9.30	9.90	4,454.80	190.20	4,645.00
1960	62.80	797.90	2,219.70	495.00	453.90	76.80	40.90	32.00	40.10	13.40	12.30	8.40	4,029.30	223.90	4,253.20
1961	675.70	2,762.10	1,896.30	2,990.90	719.40	150.60	86.60	41.90	19.90	16.70	8.90	8.60	9,044.40	333.20	9,377.60
1962	59.70	406.10	753.50	555.20	131.20	61.90	34.30	16.10	15.20	19.90	2.50	3.50	1,905.70	153.40	2,059.10
1963	96.30	611.90	1,352.30	1,370.20	265.60	93.70	40.90	21.70	12.10	17.20	3.40	4.90	3,696.30	193.90	3,890.20
1964	165.90	1,566.60	2,168.00	863.00	510.10	113.70	19.90	29.20	11.80	26.00	13.80	7.50	5,273.60	221.90	5,495.50
1965	45.20	389.20	395.40	558.80	113.80	43.10	23.90	21.20	16.60	6.80	2.50	11.20	1,502.40	125.30	1,627.70
1966	266.90	555.00	1,044.30	202.90	90.00	37.70	33.40	11.40	6.80	8.30	11.80	7.40	2,159.10	116.80	2,275.90
1967	58.70	689.80	2,059.60	930.80	172.20	57.10	52.70	33.90	32.50	19.80	5.70	9.80	3,911.10	211.50	4,122.60
1968	61.30	552.00	1,393.00	337.50	176.50	55.60	31.00	17.10	12.40	11.90	5.10	9.40	2,520.30	142.50	2,662.80
1969	34.30	603.50	1,264.90	448.40	131.70	59.70	33.40	21.80	12.50	19.50	4.50	3.50	2,482.80	154.90	2,637.70
1970	176.40	1,305.10	1,726.40	1,016.80	241.50	56.80	35.00	23.60	18.80	14.80	8.60	9.10	4,466.20	166.70	4,632.90
1971	579.00	1,297.80	1,680.50	850.90	309.70	87.20	45.50	25.40	19.50	10.20	3.90	3.50	4,717.90	195.20	4,913.10
1972	14.90	530.60	896.60	603.80	175.80	86.70	55.20	18.80	17.30	10.00	8.60	3.50	2,221.70	200.10	2,421.80
1973	11.60	1,043.90	1,492.80	1,588.30	939.60	252.80	56.90	31.30	19.30	6.90	2.90	3.50	5,076.20	373.60	5,449.80
1974	26.90	355.70	1,047.70	123.20	147.10	53.60	30.60	12.50	9.80	7.30	3.60	3.50	1,700.60	120.90	1,821.50
1975	46.30	846.30	1,836.60	825.00	482.90	135.70	47.30	26.30	18.50	9.90	5.00	3.50	4,037.10	246.20	4,283.30
1976	14.60	662.30	1,600.50	774.40	82.90	38.10	23.60	11.10	6.80	6.20	2.50	3.50	3,134.70	91.80	3,226.50
1977	198.70	966.30	1,419.10	924.90	234.50	75.00	42.50	18.70	21.50	18.90	3.70	3.50	3,743.50	183.80	3,927.30
1978	109.40	683.70	1,857.70	701.40	154.50	73.80	49.90	23.30	23.80	6.20	2.50	3.50	3,506.70	183.00	3,689.70
1979	20.50	283.70	769.60	81.50	120.20	33.00	24.20	9.20	6.80	6.20	2.50	3.50	1,275.50	85.40	1,360.90
1980	272.60	1,199.80	1,012.90	1,816.60	163.90	61.70	31.10	21.20	10.00	6.20	6.00	3.50	4,465.80	139.70	4,605.50
1981	35.50	523.90	1,109.30	434.00	228.60	60.90	23.10	24.30	25.80	26.80	2.50	3.50	2,331.30	166.90	2,498.20
1982	31.20	254.60	1,421.60	468.90	157.10	65.10	32.10	15.40	20.60	8.60	2.50	4.30	2,333.40	148.60	2,482.00
Mean	125.58	837.86	1,404.85	876.49	282.99	80.56	39.10	22.57	17.02	12.94	5.80	5.65	3,527.76	183.64	3,711.40
Std. Dev.	173.13	554.01	493.38	656.51	221.54	47.37	14.67	8.08	8.11	6.65	3.65	2.78			1,732.26
Coff. Var.	1.38	0.66	0.35	0.75	0.78	0.59	0.38	0.36	0.48	0.51	0.63	0.49			0.47

Source : Water Availability Studies for Mahanadi Basin - Final Report Volume I & Volume II National Institute of Hydrology 1986

Table 4.2
Observed Monthly Discharge of Mahanadi
at Tikarapara from 1972 - 1982 in Thousand ha-m

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	2	3	4	5	6	7	8	9	10	11	12	13
1972	N.A.	N.A.	N.A.	N.A.	N.A.	26.63	260.31 *	724.26	1,196.84	319.20	173.56	99.84
1973	111.27	96.44	106.58	113.00	55.33	4.22	1,601.62	1,689.45	1,823.53	1,028.97	404.16	98.39
1974	92.04	83.09	77.18	70.31	56.04	65.28	106.36	1,222.46	163.14	103.19	33.06	23.66
1975	32.87	36.39	32.78	29.07	19.46	40.17	840.34	2,249.04	822.72	525.38	195.56	70.87
1976	73.55	67.94	68.28	70.06	68.50	64.24	889.85	2,380.81	1,132.47	110.36	64.89	44.43
1977	52.10	73.11	87.88	78.85	45.21	147.86	1,077.80	1,909.79	2,024.73	291.17	107.87	74.77
1978	71.19	68.65	94.10	79.95	74.12	71.73	738.40	2,968.21	1,067.34	211.74	106.84	81.89
1979	83.41	72.65	76.44	97.03	73.33	99.50	288.94	1,093.88	122.78	97.25	42.74	12.94
1980	46.01	42.16	68.00	47.82	17.09	147.40	1,901.06	1,064.72	2,950.00	198.85	96.07	61.34
1981	69.98	78.07	98.27	85.22	42.67	75.64	325.81	1,568.36	812.43	355.05	92.40	65.71
1982	26.26	65.20	86.42	91.21	87.00	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

* Estimated using W.B. Longbien's log deviation method

Table 4.3
Estimation of Missing Record of Monthly Discharge at Tikarapara
by W.B. Longbien's Log Deviation Method

Year	Monsoon Runoff	Log MR	X	X^2	July Runoff	Log July Runoff	Y	Y^2	X * Y
1973	6,147.79	3.7887	0.2015	0.0406	1,601.62	3.2046	0.3980	0.1584	0.0802
1974	1,660.43	3.2202	(0.3670)	0.1347	106.36	2.0268	(0.7797)	0.6080	0.2862
1975	4,477.65	3.6511	0.0638	0.0041	840.34	2.9245	0.1179	0.0139	0.0075
1976	4,577.73	3.6607	0.0734	0.0054	889.85	2.9493	0.1428	0.0204	0.0105
1977	5,451.35	3.7365	0.1492	0.0223	1,077.80	3.0325	0.2260	0.0511	0.0337
1978	5,057.42	3.7039	0.1167	0.0136	738.40	2.8683	0.0618	0.0038	0.0072
1979	1,702.35	3.2310	(0.3562)	0.1269	288.94	2.4608	(0.3457)	0.1195	0.1231
1980	6,262.03	3.7967	0.2094	0.0439	1,901.06	3.2790	0.4725	0.2232	0.0990
1981	3,137.29	3.4966	(0.0907)	0.0082	325.81	2.5130	(0.2936)	0.0862	0.0266
Σ		32.2854	(0.0000)	0.3996		25.2587	(0.0000)	1.2846	0.6741
Av.		3.5873				2.8065			
1972	2,266.93	3.355			260.31	2.4155			

$X = \text{Log MR} - \overline{\text{Log MR}}$

$Y = \text{Log JR} - \overline{\text{Log JR}}$

Linear Regression : $Y = A + BX$

$A = (\Sigma Y - B\Sigma X) / n$

$= 0.0000$

$B = (n \,.\, \Sigma XY - \Sigma X \,.\, \Sigma Y) / [n \,.\, \Sigma X^2 - (\Sigma X)^2]$

$= 1.6867$

$r = (n \,.\, \Sigma XY - \Sigma X \,.\, \Sigma Y)/((n \,.\, \Sigma X^2 - (\Sigma X)^2) \,.\, (n \,.\, \Sigma Y^2 - (\Sigma Y)^2))^{0.5}$

$= 0.9408$

$Y = BX$

$\text{Log JR} - \overline{\text{Log JR}} = B(\text{Log MR} - \overline{\text{Log MR}})$

$\text{Log JR} - 2.8065 = 1.6867(3.355 - 3.5873)$

$\text{Log JR} = 2.4155$

$\text{JR} = 260.31$ Th. ha.m.

Table 4.4
Monthly and Cumulative Monsoon Yield of Mahanadi at Tikarapara
from Its Virgin Catchment below Hirakud Dam (1972 - 1981) in Thousand ha-m

Year	Month	Observed Yield at Tikarapara	Contribution from Hirakud*	Yield from Virgin Catchment Col (3 - 4)	Cumulative Yield
1	2	3	4	5	6
1972	June	26.63	41.11	0.00 **	0.00
	July	260.31	311.26	0.00 **	0.00
	August	724.26	387.51	336.75	336.75
	September	1,196.84	575.84	621.00	957.75
	October	319.20	115.53	203.67	1,161.42
		2,527.24		1,161.42	
1973	June	4.22	25.66	0.00 **	0.00
	July	1,601.62	767.17	834.45	834.45
	August	1,689.45	1,134.82	554.63	1,389.08
	September	1,823.53	1,402.37	421.16	1,810.24
	October	1,028.97	864.71	164.26	1,974.50
		6,147.79		1,974.50	
1974	June	65.28	62.78	2.50	2.50
	July	106.36	80.45	25.91	28.41
	August	1,222.46	861.86	360.60	389.01
	September	163.14	109.93	53.21	442.22
	October	103.19	49.84	53.35	495.57
		1,660.43		495.57	
1975	June	40.17	25.78	14.39	14.39
	July	840.34	593.29	247.05	261.44
	August	2,249.04	1,539.86	709.18	970.62
	September	822.72	583.56	239.16	1,209.78
	October	525.38	401.06	124.32	1,334.10
		4,477.65		1,334.10	
1976	June	64.24	58.36	5.88	5.88
	July	889.85	497.60	392.25	398.13
	August	2,380.81	1,216.77	1,164.04	1,562.17
	September	1,132.47	488.66	643.81	2,205.98
	October	110.36	63.40	46.96	2,252.94
		4,577.73		2,252.94	

Table 4.4 .....continued

Year	Month	Observed Yield	Contribution from Hirakud*	Yield from Virgin Catchment Col (3 - 4)	Cumulative Yield
1	2	3	4	5	6
1977	June	147.86	86.60	61.26	61.26
	July	1,077.80	834.59	243.21	304.47
	August	1,909.79	1,076.90	832.89	1,137.36
	September	2,024.73	723.94	1,300.79	2,438.15
	October	291.17	176.56	114.61	2,552.76
		5,451.35		2,552.76	
1978	June	71.73	62.56	9.17	9.17
	July	738.40	425.77	312.63	321.80
	August	2,968.21	1,499.83	1,468.38	1,790.18
	September	1,067.34	595.36	471.98	2,262.16
	October	211.74	101.93	109.81	2,371.97
		5,057.42		2,371.97	
1979	June	99.50	45.84	53.66	53.66
	July	288.94	80.72	208.22	261.88
	August	1,093.88	470.80	623.08	884.96
	September	122.78	43.22	79.56	964.52
	October	97.25	30.19	67.06	1,031.58
		1,702.35		1,031.58	
1980	June	147.40	62.07	85.33	85.33
	July	1,901.06	1,073.47	827.59	912.92
	August	1,064.72	666.03	398.69	1,311.61
	September	2,950.00	1,709.49	1,240.51	2,552.12
	October	198.85	102.18	96.67	2,648.79
		6,262.03		2,648.79	
1981	June	75.64	50.20	25.44	25.44
	July	325.81	220.11	105.70	131.14
	August	1,568.36	789.04	779.32	910.46
	September	812.43	453.80	358.63	1,269.09
	October	355.05	174.42	180.63	1,449.72
		3,137.29		1,449.72	

* Includes power drafts, spill, and 20% of irrigation drawing from the reservoir.

** Assumed to be zero as observed yield at Tikarapara is less than release from Hirakud

Table 4.5 Regression Equations

Month	W.B. Longbien's Log Deviation Method		Linear		Polynomial		Exponential		Power	
	Regression Equation	Coefficient of correlation	Regression Equation	Coeff. Of Correlation r	Regression Equation	Coeff. Of Correlation r	Regression Equation	Coeff. Of Correlation r	Regression Equation	Coeff. Of Correlation r
Jun	$\text{Log T} - \overline{\text{Log T}} = B(\text{Log H} - \overline{\text{Log H}})$ B = 0.9208	r = 0.7899	$y = A + Bx$ B = 0.2976 A = -0.7881	**0.930**	$y = A + Bx + Cx^2 + Dx^3$ A = 16.3843383 B = - 0.3272526 C = 0.00401659 D = -0.00000686	0.956	$y = B * e^{Ax}$ A = 0.0103 B = 5.6234	0.813	$y = B * x^A$ A = 0.9208 B = 0.3519	0.790
Jul	$\text{Log T} - \overline{\text{Log T}} = B(\text{Log H} - \text{Log H})$ B = 1.5693	r = 0.7238	$y = A + Bx$ B = 0.7374 A = - 182.75	**0.793**	$y = A + Bx + Cx^2 + Dx^3$ A = 55.322 B = 0.3953 C = -0.0007 D = 0.0000008	0.850	$y = B * e^{Ax}$ A = 0.0026 B = 37.119	0.754	$y = B * x^A$ A = 1.5693 B = 0.0091	0.724
Aug	$\text{Log T} - \overline{\text{Log T}} = B(\text{Log H} - \text{Log H})$ B = 1.0929	r = 0.6866	$y = A + Bx$ B = 0.6614 A = - 139.86	0.709	$y = A + Bx + Cx^2$ A = 740.8 B = - 0.7679 C = 0.0005352	**0.728**	$y = B * e^{Ax}$ A = 0.0009 B = 202.97	0.710	$y = B * x^A$ A = 1.0929 B = 0.2672	0.687
Sep	$\text{Log T} - \overline{\text{Log T}} = B(\text{Log H} - \text{Log H})$ B = 0.9005	r = 0.859	$y = A + Bx$ B = 0.5028 A = 147.14	0.653	$y = A + Bx + Cx^2 + Dx^3$ A = - 213.9 B = 2.6987 C = -0.0028 D = 0.00001	0.720	$y = B * e^{Ax}$ A = 0.0013 B = 129.19	0.708	$y = B * x^A$ A = 0.9005 B = 1.2324	**0.859**
October	$\text{Log T} - \overline{\text{Log T}} = B(\text{Log H} - \text{Log H})$ B = 0.4704	r = 0.849	$y = A + Bx$ B = 0.1155 A = 63.563	0.843	$y = A + Bx + Cx^2 + Dx^3$ A = -28.9753424 B = 1.0514224 C = -0.0021741 D = 0.0000014	**0.932**	$y = B * e^{Ax}$ A = 0.0011 B = 64.616	0.743	$y = B * x^A$ A = 0.4704 B = 7.2294	0.849

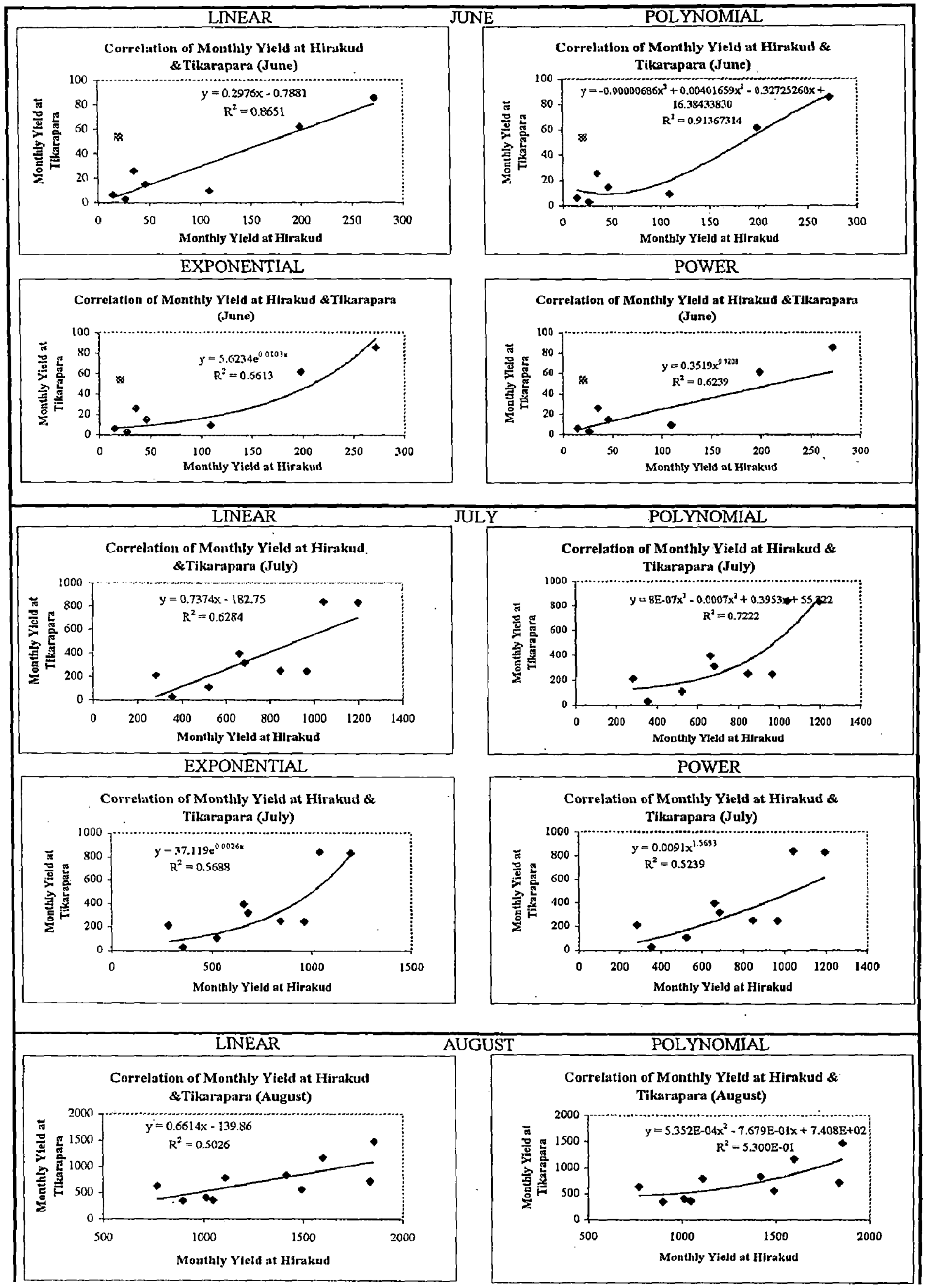


Figure 4.2 Regression Analyisis for months between Hirakud and Tikarapara

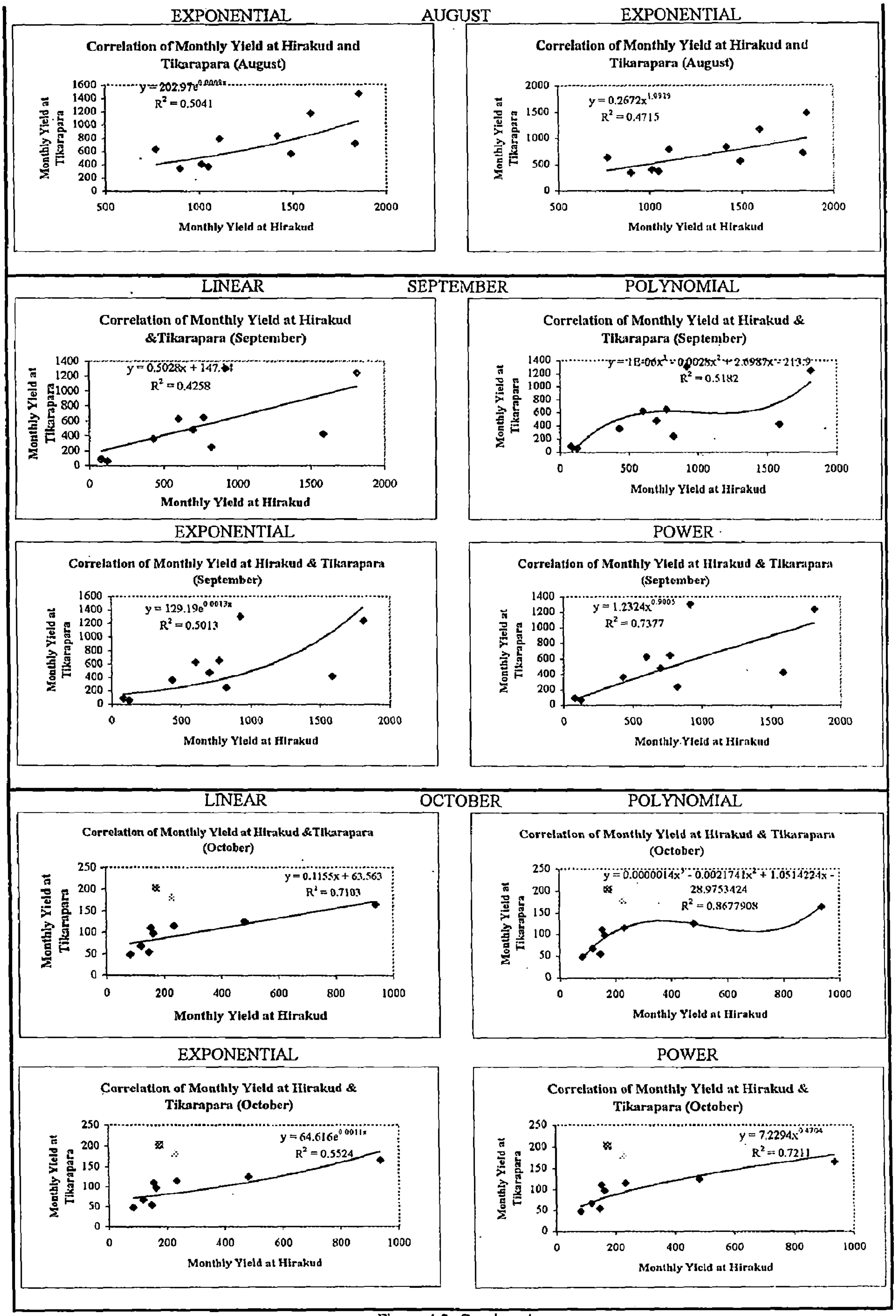


Figure 4.2 Continued

Table 4.6

Virgin Monsoon Yield at Tikarapara and Hirakud in Thousand ha-m

Year	Upstream flow of Hirakud from Its Virgin Catchment (x)						Monsoon yield at Tikarapara from virgin catchment below Hirakud (y)					
	Jun.	Jul.	Aug.	Sep.	Oct	Total	Jun.	Jul.	Aug.	Sep.	Oct	Total
1	2	3	4	5	6	7	8	9	10	11	12	13
1958	44.40	1,433.20	886.20	1,240.90	599.00	4,203.70	12.43	874.09	480.61	752.77	121.65	2,241.54
1959	30.70	625.50	1,816.70	1,708.90	273.00	4,454.80	8.35	278.49	1,112.13	1,004.18	124.51	2,527.67
1960	62.80	797.90	2,219.70	495.00	453.90	4,029.30	17.90	405.62	1,673.26	329.04	131.27	2,557.08
1961	675.70	2,762.10	1,896.30	2,990.90	719.40	9,044.40	200.30	1,854.02	1,209.19	1,662.31	123.48	5,049.30
1962	59.70	406.10	753.50	555.20	131.20	1,905.70	16.98	116.71	466.05	364.86	74.71	1,039.31
1963	96.30	611.90	1,352.30	1,370.20	265.60	3,696.30	27.87	268.47	681.10	823.05	123.14	1,923.63
1964	165.90	1,566.60	2,168.00	863.00	510.10	5,273.60	48.58	972.46	1,591.55	542.79	127.47	3,282.85
1965	45.20	389.20	395.40	558.80	113.80	1,502.40	12.66	104.25	520.85	366.99	64.58	1,069.33
1966	266.90	555.00	1,044.30	202.90	90.00	2,159.10	78.64	226.51	522.55	147.39	49.06	1,024.15
1967	58.70	689.80	2,059.60	930.80	172.20	3,911.10	16.68	325.91	1,429.53	581.04	94.76	2,447.92
1968	61.30	552.00	1,393.00	337.50	176.50	2,520.30	17.45	224.29	709.64	233.06	96.57	1,281.02
1969	34.30	603.50	1,264.90	448.40	131.70	2,482.80	9.42	262.27	625.79	301.01	74.99	1,273.47
1970	176.40	1,305.10	1,726.40	1,016.80	241.50	4,466.20	51.71	779.63	1,010.24	629.17	117.86	2,588.61
1971	579.00	1,297.80	1,680.50	850.90	309.70	4,717.90	171.52	774.25	961.79	535.93	129.71	2,573.20
1972	14.90	530.60	896.60	603.80	175.80	2,221.70	0.00	0.00	336.75	621.00	203.67	1,161.42
1973	11.60	1,043.90	1,492.80	1,588.30	939.60	5,076.20	0.00	834.45	554.63	421.16	164.26	1,974.50
1974	26.90	355.70	1,047.70	123.20	147.10	1,700.60	2.50	25.91	360.60	53.21	53.35	495.57
1975	46.30	846.30	1,836.60	825.00	482.90	4,037.10	14.39	247.05	709.18	239.16	124.32	1,334.10
1976	14.60	662.30	1,600.50	774.40	82.90	3,134.70	5.88	392.25	1,164.04	643.81	46.96	2,252.94
1977	198.70	966.30	1,419.10	924.90	234.50	3,743.50	61.26	243.21	832.89	1,300.79	114.61	2,552.76
1978	109.40	683.70	1,857.70	701.40	154.50	3,506.70	9.17	312.63	1,468.38	471.98	109.81	2,371.97
1979	20.50	283.70	769.60	81.50	120.20	1,275.50	53.66	208.22	623.08	79.56	67.06	1,031.58
1980	272.60	1,199.80	1,012.90	1,816.60	163.90	4,465.80	85.33	827.59	398.69	1,240.51	96.67	2,648.79
1981	35.50	523.90	1,109.30	434.00	228.60	2,331.30	25.44	105.70	779.32	358.63	180.63	1,449.72

Note: The above monthly yield (from 1958 - 71) at Tikarapara have been computed taking the help of best fitted Regression Equation (from Table No. 2) using Linear, Polynomial and Power Regression

Taking the help of the above data (from 1972 - 81), the best fitted Regression equation have been found out monthwise (from Table No. 4)

Table 4.7
Yield Series (Th. ha.m) at Manibhadra during Monsoon (Initial Stage)
for the period 1958 - 1981

Year	Month	Computed net yield at Tikarapara from virgin catchment	Yield at Manibhadra dam site Col. 3 x 42720 / 40920	Yield at Manibhadra dam site at initial stage Col. 4 x 39480 / 42720	Hirakud Contribution: Hirakud Spill Observed	Hirakud Contribution: Powerhouse release and 20% regeneration for Hirakud irrigation	Regeneration from catchment between Hirakud and Manibhadra (Initial Stage)	Total yield at Manibhadra dam site the initial stage Col.(5+6+7+8)	Cumulative annual monsoon yield at Manibhadra dam site
1	2	3	4	5	6	7	8	9	10
1958	Jun.	12.43	12.97	11.99	1.23	29.83	3.24	46.29	46.29
	Jul.	874.09	912.54	843.33	1,281.85	35.13	9.95	2,170.26	2,216.55
	Aug.	480.61	501.75	463.69	607.87	34.52	11.89	1,117.97	3,334.52
	Sep.	752.77	785.88	726.28	1,069.44	29.71	13.84	1,839.27	5,173.79
	Oct.	121.65	127.00	117.37	454.30	31.72	16.46	619.85	5,793.64
1959	Jun.	8.35	8.72	8.05	0.12	68.81	3.24	80.22	80.22
	Jul.	278.49	290.74	268.69	449.12	75.39	9.95	803.15	883.38
	Aug.	1,112.13	1,161.05	1,072.99	1,560.13	74.72	11.89	2,719.73	3,603.11
	Sep.	1,004.18	1,048.36	968.85	1,406.56	64.65	13.84	2,453.90	6,057.01
	Oct.	124.51	129.99	120.13	103.49	60.56	16.46	300.64	6,357.65
1960	Jun.	17.90	18.69	17.27	0.00	74.15	3.24	94.66	94.66
	Jul.	405.62	423.46	391.35	700.87	66.78	9.95	1,168.95	1,263.61
	Aug.	1,673.26	1,746.86	1,614.38	1,996.67	57.90	11.89	3,680.84	4,944.44
	Sep.	329.04	343.51	317.46	118.05	59.48	13.84	508.83	5,453.27
	Oct.	131.27	137.04	126.65	322.93	59.94	16.46	525.98	5,979.25
1961	Jun.	200.30	209.11	193.25	536.33	75.86	3.24	808.68	808.68
	Jul.	1,854.02	1,935.58	1,788.78	2,562.10	69.59	9.95	4,430.42	5,239.10
	Aug.	1,209.19	1,262.38	1,166.63	343.65	68.66	11.89	1,590.83	6,829.93
	Sep.	1,662.31	1,735.43	1,603.81	2,679.41	58.89	13.84	4,355.95	11,185.88
	Oct.	123.48	128.92	119.14	558.05	78.65	16.46	772.30	11,958.18
1962	Jun.	16.98	17.73	16.38	0.00	90.56	3.24	110.18	110.18
	Jul.	116.71	121.84	112.60	315.28	106.25	9.95	544.08	654.26
	Aug.	466.05	486.55	449.65	450.23	97.64	11.89	1,009.41	1,663.68
	Sep.	364.86	380.91	352.02	131.12	82.70	13.84	579.68	2,243.36
	Oct.	74.71	78.00	72.08	0.00	78.45	16.46	166.99	2,410.35
1963	Jun.	27.87	29.10	26.89	20.60	67.37	3.24	118.10	118.10
	Jul.	268.47	280.27	259.02	386.70	96.85	9.95	752.52	870.62
	Aug.	681.10	711.06	657.13	1,057.83	86.81	11.89	1,813.66	2,684.28
	Sep.	823.05	859.25	794.09	804.47	92.31	13.84	1,704.71	4,388.98
	Oct.	123.14	128.56	118.81	99.42	62.88	16.46	297.57	4,686.55
1964	Jun.	48.58	50.72	46.87	109.53	74.30	3.24	233.94	233.94
	Jul.	972.46	1,015.24	938.24	1,396.17	91.55	9.95	2,435.91	2,669.85
	Aug.	1,591.55	1,661.56	1,535.54	1,721.10	86.79	11.89	3,355.32	6,025.18
	Sep.	542.79	566.66	523.69	544.71	78.75	13.84	1,160.99	7,186.16
	Oct.	127.47	133.08	122.98	343.04	79.85	16.46	562.33	7,748.50

Table 4.7. .....continued

1	2	3	4	5	6	7	8	9	10
1965	Jun.	12.66	13.22	12.22	0.62	71.44	3.24	87.52	87.52
	Jul.	104.25	108.83	100.58	186.38	87.28	9.95	384.19	471.71
	Aug.	520.85	543.76	502.52	11.35	87.38	11.89	613.14	1,084.84
	Sep.	366.99	383.13	354.08	180.34	73.17	13.84	621.43	1,706.27
	Oct.	64.58	67.43	62.31	4.07	73.54	16.46	156.38	1,862.65
1966	Jun.	78.64	82.10	75.87	146.54	47.56	3.24	273.21	273.21
	Jul.	226.51	236.47	218.54	244.48	80.17	9.95	553.14	826.35
	Aug.	522.55	545.54	504.16	841.62	83.52	11.89	1,441.19	2,267.54
	Sep.	147.39	153.87	142.20	0.00	68.51	13.84	224.55	2,492.09
	Oct.	49.06	51.22	47.34	0.00	68.93	16.46	132.73	2,624.82
1967	Jun.	16.68	17.41	16.09	0.00	25.66	3.24	44.99	44.99
	Jul.	325.91	340.24	314.44	508.57	76.63	9.95	909.59	954.58
	Aug.	1,429.53	1,492.41	1,379.22	1,684.10	96.33	11.89	3,171.54	4,126.12
	Sep.	581.04	606.60	560.59	511.78	71.82	13.84	1,158.03	5,284.16
	Oct.	94.76	98.93	91.43	37.87	65.18	16.46	210.94	5,495.09
1968	Jun.	17.45	18.22	16.84	0.00	69.08	3.24	89.16	89.16
	Jul.	224.29	234.16	216.40	345.33	67.97	9.95	639.65	728.81
	Aug.	709.64	740.86	684.67	1,110.89	72.58	11.89	1,880.03	2,608.84
	Sep.	233.06	243.31	224.86	0.00	66.28	13.84	304.98	2,913.82
	Oct.	96.57	100.82	93.17	0.00	66.83	16.46	176.46	3,090.28
1969	Jun.	9.42	9.83	9.09	53.29	44.38	3.24	110.00	110.00
	Jul.	262.27	273.81	253.04	245.84	74.82	9.95	583.65	693.65
	Aug.	625.79	653.32	603.77	996.54	85.08	11.89	1,697.28	2,390.93
	Sep.	301.01	314.25	290.41	39.97	85.97	13.84	430.19	2,821.12
	Oct.	74.99	78.28	72.35	0.00	83.17	16.46	171.98	2,993.10
1970	Jun.	51.71	53.98	49.89	0.00	84.72	3.24	137.85	137.85
	Jul.	779.63	813.93	752.20	1,104.60	102.18	9.95	1,968.93	2,106.77
	Aug.	1,010.24	1,054.68	974.69	1,261.36	111.01	11.89	2,358.95	4,465.72
	Sep.	629.17	656.85	607.03	87.21	90.81	13.84	798.89	5,264.61
	Oct.	117.86	123.05	113.72	71.54	95.30	16.46	297.02	5,561.62
1971	Jun.	171.52	179.07	165.49	405.70	83.65	3.24	658.08	658.08
	Jul.	774.25	808.31	747.00	1,083.01	92.04	9.95	1,932.00	2,590.08
	Aug.	961.79	1,004.10	927.95	1,357.47	99.13	11.89	2,396.44	4,986.51
	Sep.	535.93	559.50	517.07	543.48	106.98	13.84	1,181.37	6,167.88
	Oct.	129.71	135.42	125.15	0.00	85.29	16.46	226.90	6,394.78
1972	Jun.	0.00	0.00	0.00	0.00	41.11	3.24	44.35	44.35
	Jul.	0.00	0.00	0.00	225.48	85.78	9.95	321.21	365.56
	Aug.	336.75	351.56	324.90	277.78	109.73	11.89	724.30	1,089.86
	Sep.	621.00	648.32	599.15	485.38	90.46	13.84	1,188.83	2,278.69
	Oct.	203.67	212.63	196.50	16.78	98.75	16.46	328.49	2,607.18
1973	Jun.	0.00	0.00	0.00	0.00	25.66	3.24	28.90	28.90
	Jul.	834.45	871.16	805.09	678.43	88.74	9.95	1,582.21	1,611.11
	Aug.	554.63	579.03	535.11	1,026.27	112.54	11.89	1,685.81	3,296.92
	Sep.	421.16	439.69	406.34	1,303.54	98.83	13.84	1,822.55	5,119.47
	Oct.	164.26	171.49	158.48	771.92	92.79	16.46	1,039.65	6,159.12
1974	Jun.	2.50	2.61	2.41	0.00	62.78	3.24	68.43	68.43
	Jul.	25.91	27.05	25.00	7.28	73.17	9.95	115.40	183.83
	Aug.	360.60	376.46	347.91	756.61	105.25	11.89	1,221.66	1,405.49
	Sep.	53.21	55.55	51.34	0.00	109.93	13.84	175.11	1,580.60
	Oct.	53.35	55.70	51.47	0.00	49.84	16.46	117.77	1,698.37

Table 4.7. .....continued

1	2	3	4	5	6	7	8	9	10
1975	Jun.	14.39	15.02	13.88	0.00	25.78	3.24	42.90	42.90
	Jul.	247.05	257.92	238.36	489.94	103.35	9.95	841.60	884.50
	Aug.	709.18	740.38	684.22	1,426.30	113.56	11.89	2,235.97	3,120.47
	Sep.	239.16	249.68	230.74	477.12	106.44	13.84	828.14	3,948.62
	Oct.	124.32	129.79	119.95	312.08	88.98	16.46	537.47	4,486.08
1976	Jun.	5.88	6.14	5.67	0.00	58.36	3.24	67.27	67.27
	Jul.	392.25	409.50	378.45	387.94	179.16	9.95	955.50	1,022.77
	Aug.	1,164.04	1,215.24	1,123.08	109.59	121.18	11.89	1,365.74	2,388.51
	Sep.	643.81	672.13	621.15	367.95	120.71	13.84	1,123.65	3,512.16
	Oct.	46.96	49.03	45.31	0.00	63.40	16.46	125.17	3,637.33
1977	Jun.	61.26	63.95	59.10	25.78	60.82	3.24	148.94	148.94
	Jul.	243.21	253.91	234.65	705.07	129.52	9.95	1,079.19	1,228.14
	Aug.	832.89	869.53	803.58	942.89	134.01	11.89	1,892.37	3,120.51
	Sep.	1,300.79	1,358.01	1,255.01	590.50	133.44	13.84	1,992.79	5,113.30
	Oct.	114.61	119.65	110.58	67.72	108.84	16.46	303.60	5,416.90
1978	Jun.	9.17	9.57	8.85	0.00	62.56	3.24	74.65	74.65
	Jul.	312.63	326.38	301.63	317.38	108.38	9.95	737.34	811.99
	Aug.	1,468.38	1,532.97	1,416.71	1,363.63	136.20	11.89	2,928.43	3,740.41
	Sep.	471.98	492.74	455.37	469.10	126.26	13.84	1,064.57	4,804.98
	Oct.	109.81	114.64	105.95	0.00	0.00	16.46	122.41	4,927.39
1979	Jun.	53.66	56.02	51.77	0.00	45.84	3.24	100.85	100.85
	Jul.	208.22	217.38	200.89	0.00	80.72	9.95	291.56	392.41
	Aug.	623.08	650.49	601.15	338.84	131.96	11.89	1,083.84	1,476.26
	Sep.	79.56	83.06	76.76	0.00	43.22	13.84	133.82	1,610.08
	Oct.	67.06	70.01	64.70	0.00	30.19	16.46	111.35	1,721.43
1980	Jun.	85.33	89.08	82.33	20.11	41.69	3.24	147.37	147.37
	Jul.	827.59	863.99	798.47	901.57	171.89	9.95	1,881.88	2,029.24
	Aug.	398.69	416.23	384.66	478.60	187.43	11.89	1,062.58	3,091.82
	Sep.	1,240.51	1,295.08	1,196.86	1,549.28	160.21	13.84	2,920.19	6,012.01
	Oct.	96.67	100.92	93.27	0.00	102.18	16.46	211.91	6,223.92
1981	Jun.	25.44	26.56	24.54	0.00	50.20	3.24	77.98	77.98
	Jul.	105.70	110.35	101.98	75.37	144.24	9.95	331.54	409.53
	Aug.	779.32	813.60	751.90	597.63	191.41	11.89	1,552.83	1,962.35
	Sep.	358.63	374.41	346.01	263.60	190.20	13.84	813.65	2,776.00
	Oct.	180.63	188.58	174.27	51.07	123.35	16.46	365.15	3,141.15

Note:

1. For entire Col. 3 refer the Table No. 5
2. Catchment of Mahanadi at Hirakud is 83,400 sq.km. at Tikarapara (gauge Discharge Observation site) is 1,240,320 sq.km. and at Manibhadra is 1,260,120 sq.km. Thereore, free catchment at Tikarapara is 40,920 sq.km. and at Manibhadra is 42,720 sq.km. Catchment intercepted by reservoir across tributaries between Hirakud and Manibhadra during initial phase of irrigation development is 3,240 sq.km. Leaving free the reminder of 39,480 sq.km.
3. Col. 4 = Col. 3 x 42720 / 40920
4. Col. 5 = Col. 4 x 39480 / 42720
5. Col. 6 to 8 = from Manibhadra Project Report

Table 4.8
Precentile relationship between Non-Monsoon Yield and Monsoon Yield at Tikarapara
in Th. ha.m

Year	Monthwise Non-Monsoon Yield							Total non-Monsoon Yield	Total Monsoon Yield
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May		
1	2	3	4	5	6	7	8	9	10
1972-73	173.56	99.84	111.27	96.44	106.58	113.00	55.33	756.02	2,527.24
1973-74	76.60	98.39	92.04	83.09	77.18	70.31	56.04	553.65	6,147.79
1974-75	33.06	23.66	32.87	36.39	32.78	29.07	19.46	207.29	1,660.43
1975-76	195.56	70.87	73.55	67.94	68.28	70.06	68.50	614.76	4,477.65
1976-77	64.89	44.43	52.10	73.11	87.88	78.85	45.21	446.47	4,577.73
1977-78	107.87	74.77	71.19	68.65	94.10	79.95	74.12	570.65	5,451.35
1978-79	106.84	81.89	83.41	72.65	76.44	97.03	73.33	591.59	5,057.42
1979-80	42.74	12.94	46.01	42.16	68.00	47.82	17.09	276.76	1,702.35
1980-81	96.07	61.34	69.98	78.07	98.27	85.22	42.67	531.62	6,262.03
1981-82	92.40	65.71	26.26	65.20	86.42	91.21	87.00	514.20	3,137.29
Total	989.59	633.84	658.68	683.70	795.93	762.52	538.75	5,063.01	41,001.28
Average	98.96	63.38	65.87	68.37	79.59	76.25	53.88	506.30	4,100.13
% of Col. 10	2.41	1.55	1.61	1.67	1.94	1.86	1.31	12.35	

Note : Yield during Nov-1973 of 404.16 has been limited to the Hirakud contribution of 76.60 for getting average yield for making percentile relationship.

Table 4.9

Non-Monsoon and Annual Yield Series for Mahanadi at Manibhadra (Initial Stage) in Th. ha.m

Year	Monsoon Yield	Non-Monsoon Yield 12.35 % x Col. 2	Monthwise breakup of non-monsoon yield							Annual Yield
			Nov. 2.41 % x Col. 2)	Dec. 1.55 % x Col. 2)	Jan. 1.61 % x Col. 2)	Feb. 1.67 % x Col. 2)	Mar. 1.94 % x Col. 2)	Apr. 1.86 % x Col. 2)	May 1.31 % x Col. 2)	(Col. 2 + Col. 3)
1	2	3	4	5	6	7	8	9	10	11
1958-59	5,793.64	715.42	139.83	89.56	93.07	96.61	112.47	107.75	76.13	6,509.06
1959-60	6,357.65	785.07	153.45	98.28	102.13	106.01	123.42	118.24	83.54	7,142.72
1960-61	5,979.25	738.34	144.31	92.43	96.06	99.70	116.07	111.20	78.57	6,717.59
1961-62	11,958.18	1,476.65	288.62	184.86	192.11	199.40	232.14	222.39	157.13	13,434.83
1962-63	2,410.35	297.64	58.18	37.26	38.72	40.19	46.79	44.83	31.67	2,707.99
1963-64	4,686.55	578.72	113.11	72.45	75.29	78.15	90.98	87.16	61.58	5,265.27
1964-65	7,748.50	956.82	187.01	119.78	124.48	129.21	150.42	144.10	101.81	8,705.32
1965-66	1,862.65	230.01	44.96	28.79	29.92	31.06	36.16	34.64	24.47	2,092.66
1966-67	2,624.82	324.12	63.35	40.58	42.17	43.77	50.95	48.81	34.49	2,948.94
1967-68	5,495.09	678.56	132.63	84.95	88.28	91.63	106.67	102.19	72.20	6,173.65
1968-69	3,090.28	381.60	74.59	47.77	49.64	51.53	59.99	57.47	40.61	3,471.88
1969-70	2,993.10	369.60	72.24	46.27	48.08	49.91	58.10	55.66	39.33	3,362.70
1970-71	5,561.62	686.77	134.23	85.98	89.35	92.74	107.96	103.43	73.08	6,248.40
1971-72	6,394.78	789.65	154.34	98.86	102.73	106.63	124.14	118.93	84.03	7,184.43
1972-73	2,607.18	321.95	62.93	40.30	41.88	43.47	50.61	48.49	34.26	2,929.12
1973-74	6,159.12	760.55	148.65	95.21	98.95	102.70	119.56	114.54	80.93	6,919.67
1974-75	1,698.37	209.72	40.99	26.26	27.28	28.32	32.97	31.59	22.32	1,908.09
1975-76	4,486.08	553.96	108.27	69.35	72.07	74.81	87.09	83.43	58.95	5,040.04
1976-77	3,637.33	449.15	87.79	56.23	58.43	60.65	70.61	67.65	47.79	4,086.48
1977-78	5,416.90	668.90	130.74	83.74	87.02	90.33	105.15	100.74	71.18	6,085.80
1978-79	4,927.39	608.45	118.93	76.17	79.16	82.16	95.65	91.64	64.75	5,535.84
1979-80	1,721.43	212.57	41.55	26.61	27.65	28.70	33.42	32.01	22.62	1,934.00
1980-81	6,223.92	768.56	150.22	96.22	99.99	103.78	120.82	115.75	81.78	6,992.47
1981-82	3,141.15	387.88	75.81	48.56	50.46	52.38	60.98	58.42	41.27	3,529.04

Note : For entire col. 2 , refer yearwise total of col. 10 of Table 4.7

Table 4.10 Monthly Yield at Manibhadra Dam Site (Th. ha.m)

Year	Monthly Yield												Annual
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	yield
1958-59	46.29	2,170.26	1,117.97	1,839.27	619.85	139.83	89.56	93.07	96.61	112.47	107.75	76.13	6,509.06
1959-60	80.22	803.15	2,719.73	2,453.90	300.64	153.45	98.28	102.13	106.01	123.42	118.24	83.54	7,142.72
1960-61	94.66	1,168.95	3,680.84	508.83	525.98	144.31	92.43	96.06	99.70	116.07	111.20	78.57	6,717.59
1961-62	808.68	4,430.42	1,590.83	4,355.95	772.30	288.62	184.86	192.11	199.40	232.14	222.39	157.13	13,434.83
1962-63	110.18	544.08	1,009.41	579.68	166.99	58.18	37.26	38.72	40.19	46.79	44.83	31.67	2,707.99
1963-64	118.10	752.52	1,813.66	1,704.71	297.57	113.11	72.45	75.29	78.15	90.98	87.16	61.58	5,265.27
1964-65	233.94	2,435.91	3,355.32	1,160.99	562.33	187.01	119.78	124.48	129.21	150.42	144.10	101.81	8,705.32
1965-66	87.52	384.19	613.14	621.43	156.38	44.96	28.79	29.92	31.06	36.16	34.64	24.47	2,092.66
1966-67	273.21	553.14	1,441.19	224.55	132.73	63.35	40.58	42.17	43.77	50.95	48.81	34.49	2,948.94
1967-68	44.99	909.59	3,171.54	1,158.03	210.94	132.63	84.95	88.28	91.63	106.67	102.19	72.20	6,173.65
1968-69	89.16	639.65	1,880.03	304.98	176.46	74.59	47.77	49.64	51.53	59.99	57.47	40.61	3,471.88
1969-70	110.00	583.65	1,697.28	430.19	171.98	72.24	46.27	48.08	49.91	58.10	55.66	39.33	3,362.70
1970-71	137.85	1,968.93	2,358.95	798.89	297.02	134.23	85.98	89.35	92.74	107.96	103.43	73.08	6,248.40
1971-72	658.08	1,932.00	2,396.44	1,181.37	226.90	154.34	98.86	102.73	106.63	124.14	118.93	84.03	7,184.43
1972-73	44.35	321.21	724.30	1,188.83	328.49	62.93	40.30	41.88	43.47	50.61	48.49	34.26	2,929.12
1973-74	28.90	1,582.21	1,685.81	1,822.55	1,039.65	148.65	95.21	98.95	102.70	119.56	114.54	80.93	6,919.67
1974-75	68.43	115.40	1,221.66	175.11	117.77	40.99	26.26	27.28	28.32	32.97	31.59	22.32	1,908.09
1975-76	42.90	841.60	2,235.97	828.14	537.47	108.27	69.35	72.07	74.81	87.09	83.43	58.95	5,040.04
1976-77	67.27	955.50	1,365.74	1,123.65	125.17	87.79	56.23	58.43	60.65	70.61	67.65	47.79	4,086.48
1977-78	148.94	1,079.19	1,892.37	1,992.79	303.60	130.74	83.74	87.02	90.33	105.15	100.74	71.18	6,085.80
1978-79	74.65	737.34	2,928.43	1,064.57	122.41	118.93	76.17	79.16	82.16	95.65	91.64	64.75	5,535.84
1979-80	100.85	291.56	1,083.84	133.82	111.35	41.55	26.61	27.65	28.70	33.42	32.01	22.62	1,934.00
1980-81	147.37	1,881.88	1,062.58	2,920.19	211.91	150.22	96.22	99.99	103.78	120.82	115.75	81.78	6,992.47
1981-82	77.98	331.54	1,552.83	813.65	365.15	75.81	48.56	50.46	52.38	60.98	58.42	41.27	3,529.04
Mean	153.94	1,142.24	1,858.33	1,224.42	328.38	113.61	72.77	75.62	78.49	91.38	87.54	61.85	5,288.58
Std. Dev.	188.77	959.14	840.33	986.04	236.31	56.44	36.15	37.57	39.00	45.40	43.49	30.73	2,627.38
Coff. Var.	1.226	0.840	0.452	0.805	0.720	0.497	0.497	0.497	0.497	0.497	0.497	0.497	0.497
Coff. Skew.	2.821	1.946	0.639	1.616	1.569	1.144	1.144	1.144	1.144	1.144	1.144	1.144	1.144

Table 4.11
Yield Series for Mahanadi at Manibhadra (Initial)
Abstract of Annual Yield and Percent Dependability

Year	Yield (Th. ha.m)	Order	Year	Yield (Th. ha.m) arranged in descending order	Rank	Percent Dependability
1	2	3	4	5	6	7
1958-59	6,509.06	8	1961-62	13,434.83	1	4.00
1959-60	7,142.72	4	1964-65	8,705.32	2	8.00
1960-61	6,717.59	7	1971-72	7,184.43	3	12.00
1961-62	13,434.83	1	1959-60	7,142.72	4	16.00
1962-63	2,707.99	21	1980-81	6,992.47	5	20.00
1963-64	5,265.27	13	1973-74	6,919.67	6	24.00
1964-65	8,705.32	2	1960-61	6,717.59	7	28.00
1965-66	2,092.66	22	1958-59	6,509.06	8	32.00
1966-67	2,948.94	19	1970-71	6,248.40	9	36.00
1967-68	6,173.65	10	1967-68	6,173.65	10	40.00
1968-69	3,471.88	17	1977-78	6,085.80	11	44.00
1969-70	3,362.70	18	1978-79	5,535.84	12	48.00
1970-71	6,248.40	9	**1963-64**	5,265.27	13	**52.00**
1971-72	7,184.43	3	1975-76	5,040.04	14	56.00
1972-73	2,929.12	20	1976-77	4,086.48	15	60.00
1973-74	6,919.67	6	1981-82	3,529.04	16	64.00
1974-75	1,908.09	24	1968-69	3,471.88	17	68.00
1975-76	5,040.04	14	1969-70	3,362.70	18	72.00
1976-77	4,086.48	15	**1966-67**	2,948.94	19	**76.00**
1977-78	6,085.80	11	1972-73	2,929.12	20	80.00
1978-79	5,535.84	12	1962-63	2,707.99	21	84.00
1979-80	1,934.00	23	1965-66	2,092.66	22	88.00
1980-81	6,992.47	5	**1979-80**	1,934.00	23	**92.00**
1981-82	3,529.04	16	1974-75	1,908.09	24	96.00

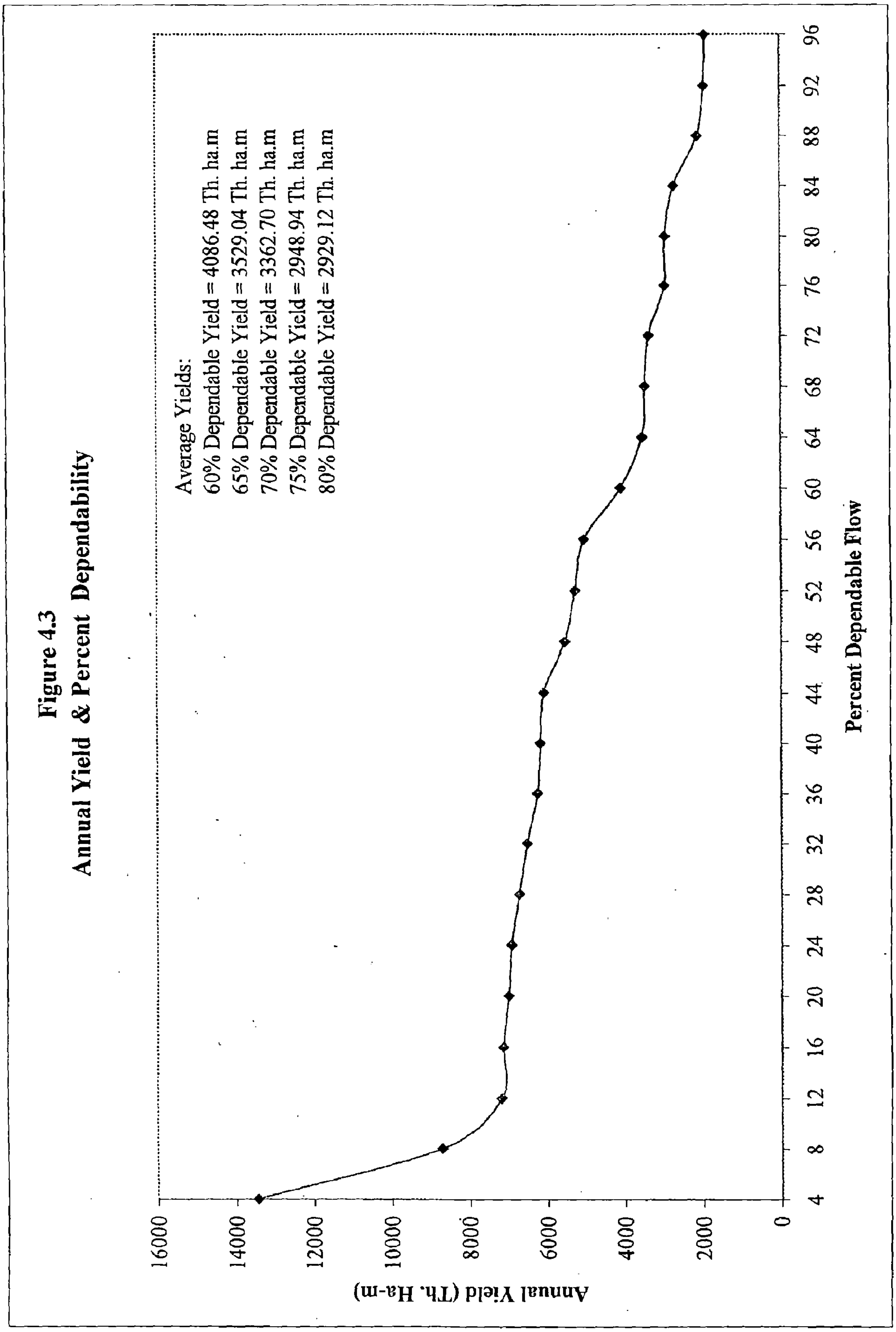


Figure 4.3
Annual Yield & Percent Dependability

Table 4.12
Comparative Study of Annual Yields as obtained from the Project Report, NIH Study and Present Study

Sl. No.	Items	Yield series at Manibhadra (Th. ha.m)		
		As per Project Report	As per NIH Study	As per Present study
1	Period of data considered for Hirakud	1958-82	1902-57 (generated) 1958-82 (available)	1958-82
2	Period of data considered for Tikarapara	1972-82	1972-83	1972-82
3	Duration of yield series for Manibhadra	1958-82	1902-82	1958-82
4	Mean flow of yield series at Manibhadra	5330.76	6246.80	5,288.58
5	75% dependable annual flow at Manibhadra	3255.64	3926.12	2,948.94 3,204.71 *
6	Maximum annual flow of yield series at Manibhadra	13070.40 (1961-62)	12252.03 (1961)	13,434.83 1961-62
7	Minimum annual flow of yield series at Manibhadra	1619.85 (1965-66)	2089.23 (1974)	1,908.09 1974-75
8	Standard deviation of annual yield series at Manibhadra	2610.07	1730.51	2,627.38

* Based on Gumbel's probability distribution

Table 4.13 95% Confidence Limits

Dependability	Return period (T)	y_T	K_T	x_T (10^3) (Th. ha.m)	b	Se	x_1 (10^3) (Th. ha.m)	x_2 (10^3) (Th. ha.m)
80	1.25	(0.4759)	(0.9255)	2.86	0.8597	461.06	3.76	1.95
75	1.33	(0.3321)	(0.7931)	3.20	0.8130	436.00	4.06	2.35
70	1.43	(0.1837)	(0.6566)	3.56	0.7878	422.51	4.39	2.74
65	1.54	(0.0469)	(0.5306)	3.89	0.7873	422.26	4.72	3.07
60	1.67	0.0907	(0.4040)	4.23	0.8089	433.83	5.08	3.38
50	2	0.3665	(0.1501)	4.89	0.9108	488.50	5.85	3.94
20	5	1.4999	0.8932	7.64	1.7432	934.88	9.47	5.80
10	10	2.2504	1.5839	9.45	2.4122	1,293.70	11.99	6.91
5	20	2.9702	2.2465	11.19	3.0776	1,650.58	14.43	7.96
2	50	3.9019	3.1041	13.44	3.9541	2,120.61	17.60	9.29
1	100	4.6001	3.7468	15.13	4.6166	2,475.96	19.99	10.28
0.5	200	5.2958	4.3872	16.82	5.2797	2,831.57	22.37	11.27
0.2	500	6.2136	5.2320	19.03	6.1573	3,302.24	25.51	12.56
0.1	1000	6.9073	5.8704	20.71	6.8220	3,658.73	27.88	13.54

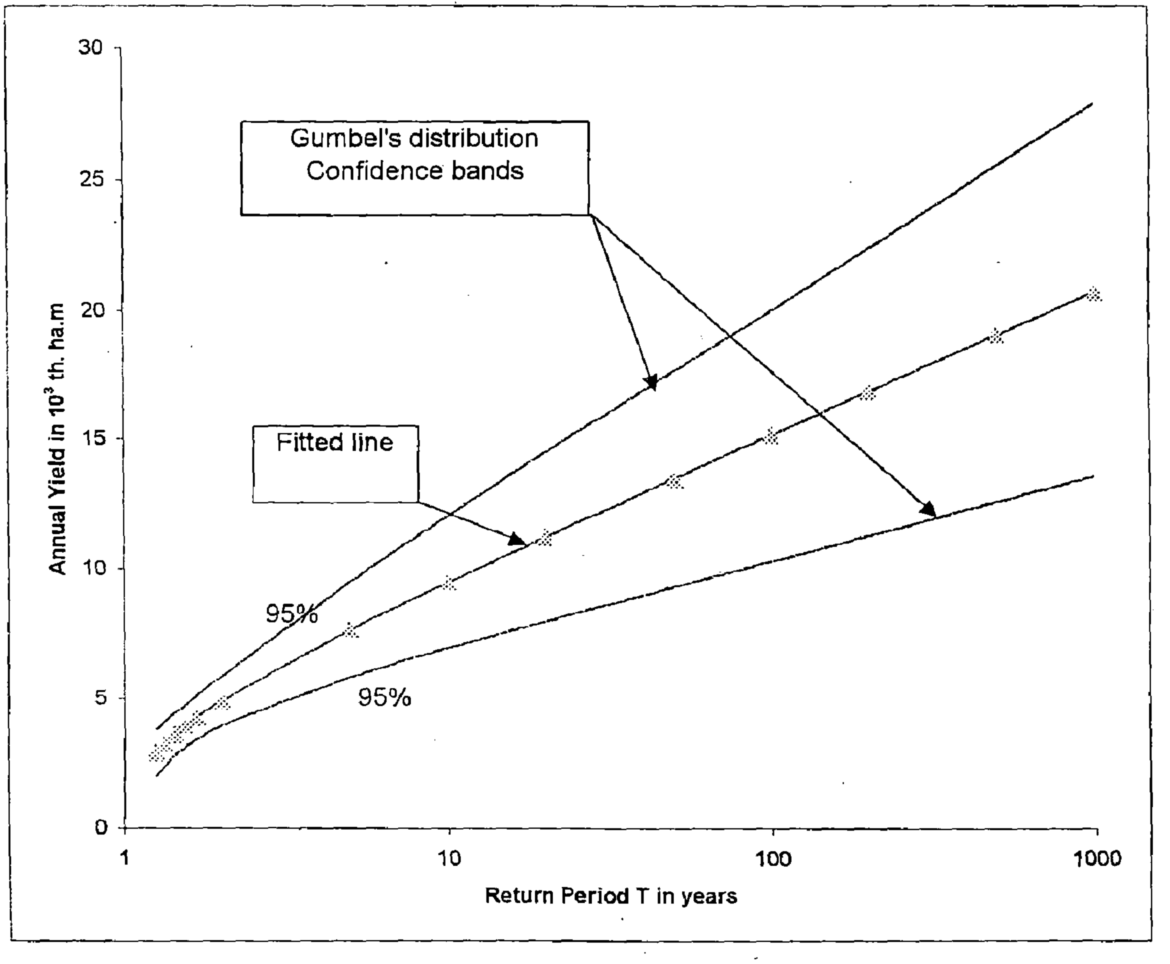


Figure 4.4 : Confidence Band for Time Value of Annual Yield of Various Dependabilities

Table 4.14 Calculation Procedure of Flow Duration Curves

Monthly yield (Th. ha.m)	Median monthly yield	**January** Yield	Cumulative	Percentage Time
1	2	3	4	5
200 - 130.1	165	1	1	4.00
130 - 110.1	120	1	2	8.00
110 - 100.1	105	2	4	16.00
100 - 90.1	95	4	8	32.00
90 - 80.1	85	3	11	44.00
80 - 70.1	75	3	14	56.00
70 - 50.1	60	2	16	64.00
50 - 40.1	45	4	20	80.00
40 - 30.1	35	1	21	84.00
30 - 20.1	25	3	24	96.00
20 - 10.1	15	0	24	96.00
10 - 0.1	5	0	24	96.00
Total		24		

Monthly yield (Th. ha.m)	Median monthly yiled	**February** Yield	Cumulative	Percentage Time
1	2	3	4	5
200 - 130.1	165	1	1	4.00
130 - 120.1	125	1	2	8.00
120 - 100.1	110	4	6	24.00
100 - 90.1	95	5	11	44.00
90 - 80.1	85	1	12	48.00
80 - 70.1	75	2	14	56.00
70 - 60.1	65	1	15	60.00
60 - 50.1	55	2	17	68.00
50 - 40.1	45	4	21	84.00
40 - 30.1	35	1	22	88.00
30 - 20.1	25	2	24	96.00
20 - 10.1	15	0	24	96.00
10 - 0.1	5	0	24	96.00
Total		24		

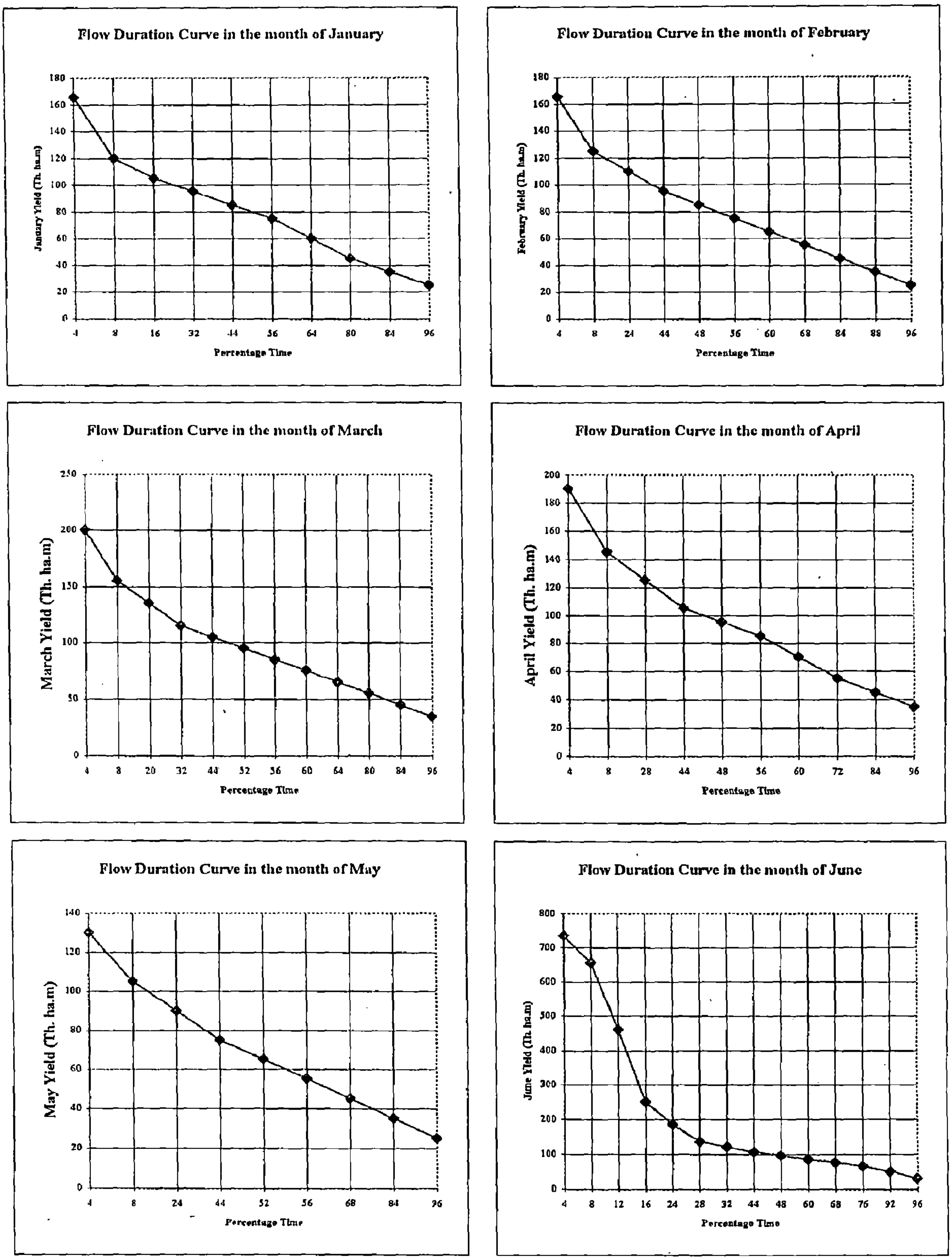


Figure 4.5 Monthly Flow Duration Curves January to June

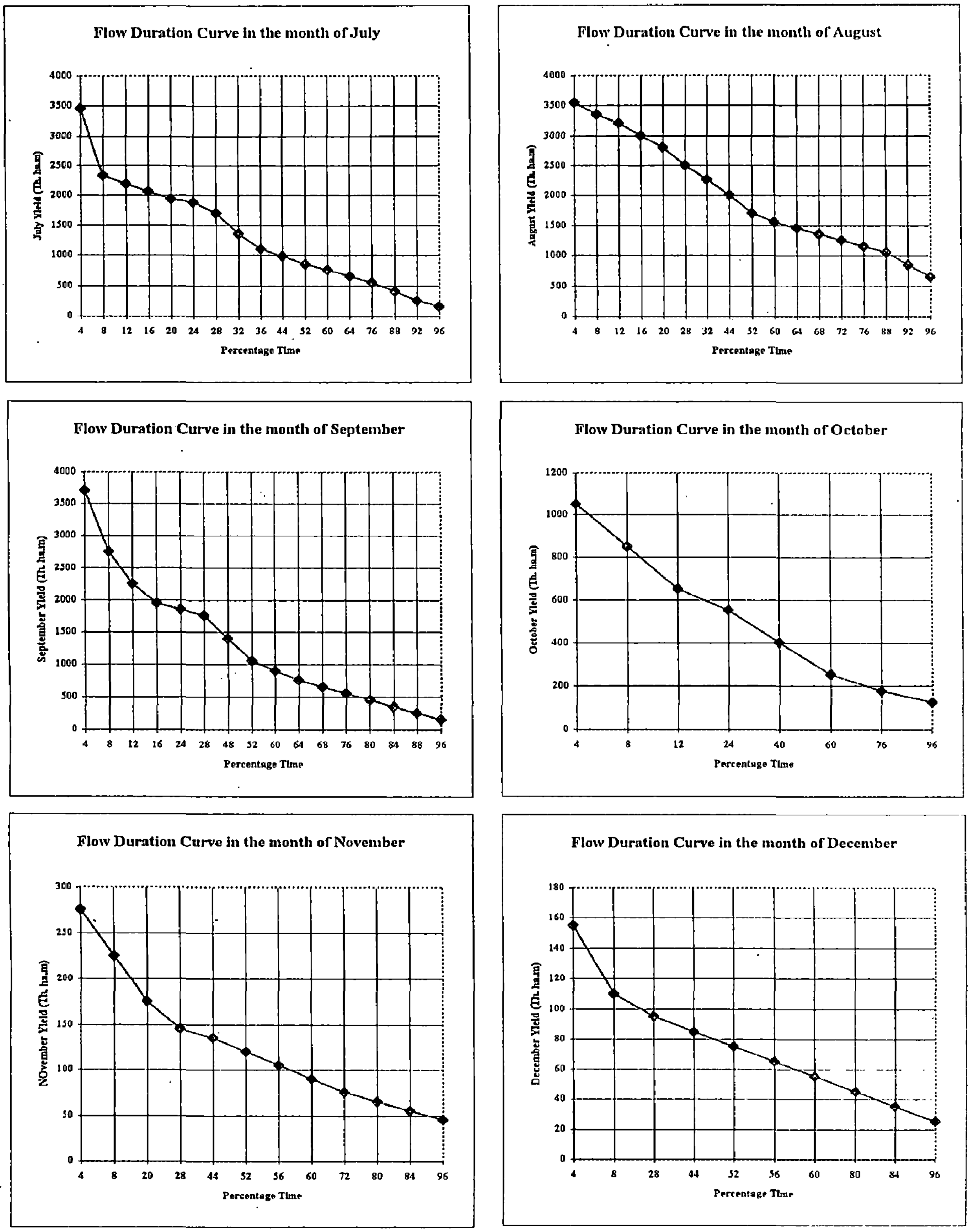


Figure 4.6 Monthly Flow Duration Curves July to December

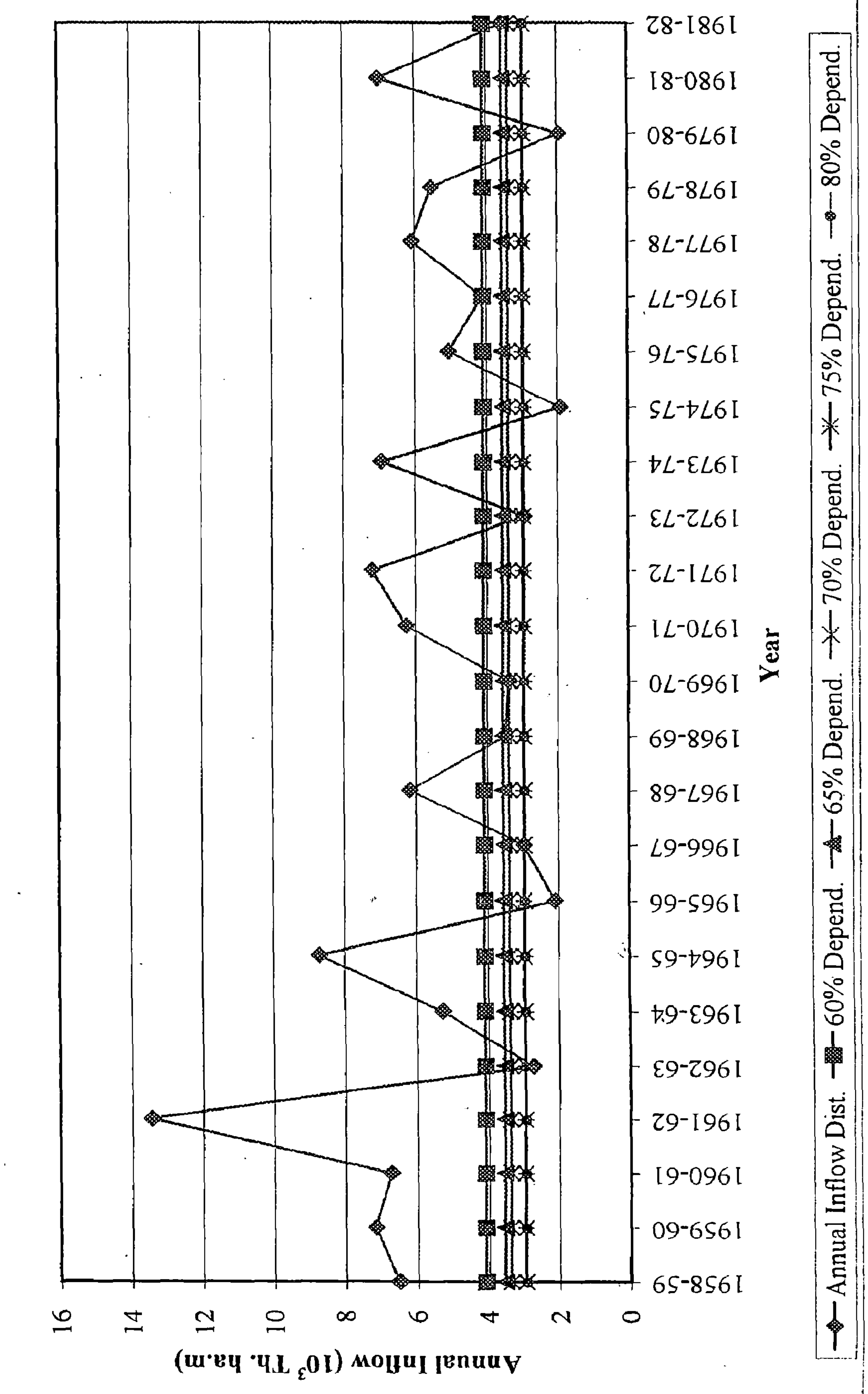
Table 4.15

Monthly Yield Corresponding to 75%, 70% and 60% Dependable Years and Hypothetic Years

(In Thousand ha.m)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Yield
75 % Dependability Monthly yields in 75% dependable year (1966-67)	42.17	43.77	50.95	48.81	34.49	273.21	553.14	1,441.19	224.55	132.73	63.35	40.58	2,948.94
Monthly yields in hypothetical year of 75% depend. monthly flow	49.69	50.63	58.13	52.50	40.63	66.25	558.33	1,175.00	562.50	179.69	71.25	57.50	2,922.08
70 % Dependability Monthly yields in 70% dependable year (1969-70)	48.08	49.91	58.10	55.66	39.33	110.00	583.65	1,697.28	430.19	171.98	72.24	46.27	3,362.70
Monthly yields in hypothetical year of 70% depend. monthly flow	54.38	53.75	61.25	57.50	43.75	72.50	600.00	1,300.00	625.00	203.13	77.50	50.00	3,198.75
60 % Dependability Monthly yields in 60% dependable year (1976-77)	58.43	60.65	70.61	67.65	47.79	67.27	955.50	1,365.74	1,123.65	125.17	87.79	56.23	4,086.48
Monthly yields in hypothetical year of 60% depend. monthly flow	67.50	65.00	75.00	70.00	51.67	85.00	750.00	1,550.00	900.00	250.00	90.00	55.00	4,009.17

Figure 4.7 Periodicity in Annual Flow Series of Mahanadi River at Manibhadra



CHAPTER 5
ASSESSMENT OF RELIABILITY THROUGH LONG TERM SIMULATION

5.1 GENERAL

Dependability analysis of river flows at Manibhadra dam site suggests that 75% dependability criteria should not be followed rigidly particularly in monsoon season (Kharif crop season). Analysis of 95% confidence limits for flows of different dependability indicates that water utilisation based on 70%, 65% or 60% dependability may in reality have higher dependability (about 10% more).

Storage helps in increasing reliability of water utilisation. Higher flows of lower dependability can be made more dependable through storage. Conventional procedure for deciding size of storage is based on flows occurring in 75% dependable year of annual flow. Central Water Commission (CWC) has recommended long term simulation study as the basis for fixing size of reservoir. But water utilisation criteria remains to be 75% dependability for irrigation. In this Chapter, it is proposed to work out and examine storage capacity, water withdrawal and reliability relationship for Manibhadra reservoir.

5.2 THE DATA

Synthesized monthly inflows at the Manibhadra Dam for 24 years (1958-59 to 1981-82) are given in Table 9 of Chapter 4. Elevation – Capacity Curve is shown in Figure 5.1. Elevation – Area curve is not available therefore average monthly evaporation losses have been considered based on known trend of reservoir filling and depletion and known evaporation rates for each month (Table 5.1). Monthly water requirements for irrigation and other utilities are shown in Table 5.2.

5.3 SIMULATION STUDY

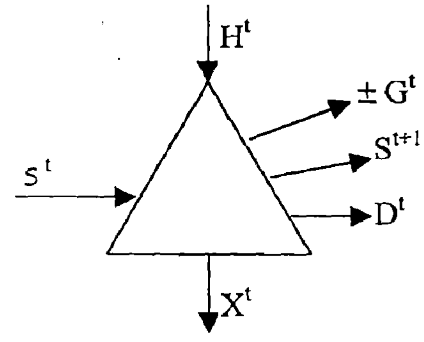
Water balance study of reservoir of given storage capacity on monthly basis and over a long term period duly considering inflows and outflows is termed as long term simulation study.

$S^{t+1} = S^t + H^t \pm G^t - D^t - X^t$

$D^t \leq I.D^t$

$S^t \leq S_{max}$

$S^t \geq S_{min}$



S^{t+1}, S^t are storage at the beginning and end of period t. H^t is inflow, G^t is net gain (+ve) or net loss (-ve) due to rainfall over reservoir area and evaporation from reservoir area. D^t is irrigation water diversion, $I.D^t$ is irrigation demand in period t and X^t is downstream release. S_{max} and S_{min} are maximum and minimum storage limits (usually corresponding to storage capacity and dead storage).

Water available for utilisation in period t can be defined as

$W^t = S^t + H^t \pm G^t$

Reservoir operation policy can be stated as

$D^t = W^t$ if $W^t \leq I.D^t$

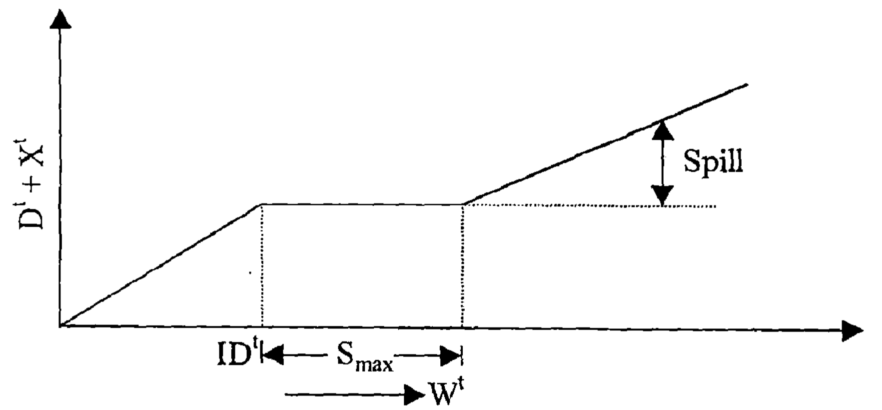
$X^t = 0$

$D^t = I.D^t$ if $W^t > I.D^t$ and $W^t < I.D^t + S_{max}$

$X^t = 0$

$D^t = I.D^t$ if $W^t > I.D^t + S_{max}$

As X^t = spill



Synthesized monthly flows for 24 years have been used. Evaporation losses and rainfall gain for different years are not available. Therefore net evaporation losses could not be varied from year to year.

Monthly irrigation demands in an average year were available. Total annual demand in an average year is 1650 Th. ha.m, which is 31.20% of mean annual flow. This is termed as withdrawal of mean annual flow.

For a given storage size and specified withdrawal, long term simulation study (24 years) on monthly basis is carried out and reliability is worked out as follows

$$\text{Annual Reliability (A.R.)} = \frac{\text{Number of success years}}{\text{Total number of years (N)}} \times 100$$

Where success year is defined as the year in which monthly deficits if any are not more than 10% of monthly demands.

$$\text{Time Reliability (T.R.)} = \frac{\text{Number of success months}}{\text{Total number of months (12N)}} \times 100$$

Where success months = 12N – Σ failure months

Failure month is that month in which deficit in meeting monthly demand is more than 10% of monthly demand.

$$\text{Kharif Season Reliability (K.S.R.)} = \frac{\text{Number of successful Kharif seasons}}{\text{Total number of Kharif seasons}} \times 100$$

Successful Kharif season is defined as the Kharif season of a year without any failure month as defined above. Total number of Kharif seasons simulated is equal to N.

Kharif Season Time Reliability (K.S.T.R.)

$$= \frac{12NK - \Sigma\text{failure months in Kharif season}}{12NK} \times 100$$

Where NK is number of months in a Kharif season.

Similarly Rabi season reliability and Rabi Time Reliability are worked out

$$\text{Rabi Season Reliability (R.S.R.)} = \frac{\text{Number of successful Rabi seasons}}{\text{Total number of Rabi seasons}} \times 100$$

Rabi Season Time Reliability (R.S.T.R.)

$$= \frac{12NR - \Sigma\text{failure months in Rabi season}}{12NR} \times 100$$

Where NR is number of months in a Rabi season.

Table 5.3 shows long term simulation study when annual withdrawal is equal to 31.20% of mean annual flow. It corresponds to annual irrigation demand with given monthly demand distribution in an average year.

Storage capacity is equal to 565.00 Th. ha.m. The simulation study shows following reliabilities AR = 75%; TR = 93.06%; KSR = 75%; KSTR = 95.14%; RSR = 79.17% and RSTR = 90.97%.

5.4 STORAGE – WITHDRAWAL – RELIABILITY STUDY

Simulation study as explained in section 5.3 was carried out for different annual withdrawals and different storage sizes. For each combination of storage capacity and annual withdrawal, reliabilities were worked out.

Table 5.4 shows monthly irrigation demand distribution for different levels of annual irrigation demand (withdrawal) in term of 31.20%, 35%, 40%, 45% and 50% of mean annual flows. Mean annual flow is 5288.58 Th. ha.m. Proportionate distribution of annual demand over different months is kept same for varying annual demand.

Table 5.5 shows storage capacity required for different combinations of annual withdrawal and annual reliability. It is prepared on the basis of simulation study for different combinations of annual withdrawal and storage capacity.

Table 5.6 shows time reliability and seasonal reliabilities corresponding to annual reliability levels of 60% to 80% as obtained from long term simulation studies.

Figure 5.2 shows withdrawal, storage size and reliability relationship in graphical form.

The relationship between storage – withdrawal – annual reliability (Table 5.5) and storage – withdrawal – seasonal reliability (Table 5.6) is much more useful in planning of Manibhadra reservoir compared to conventional procedure in which storage capacity is worked out only for 75% dependable utilisation on annual basis.

As analysed in Chapter 3, confidence limits of a particular dependable flow (say 75% dependable flow) encloses dependable flows of lower dependability. In terms of reliability with storage, a storage planned for 70% annual reliability of water utilisation could as well be 75% reliable at 95% confidence level.

Seasonal reliabilities are higher than annual reliability (Table 5.6). For the purpose of irrigation, Rabi season reliability is more important compared to Kharif season reliability as rainfall in monsoon season is the additional positive factor. Reliability of irrigated agriculture is more important in Rabi season as rainfall is almost negligible in Rabi season. Storage planned for 65% annual reliability would still make Rabi season reliability to be 79.17%.

The Manibhadra reservoir has been designed for gross storage of 580 Th. ha.m (409 Th. ha.m live storage capacity) for multipurpose use of water (irrigation and hydropower). Present study is confined for irrigation use of the reservoir.

According to the simulation study a reservoir of 565 Th. ha.m (including 171 Th. ha.m dead storage) gross storage or 394 Th. ha.m live storage would provide 1650 Th. ha.m of regulated irrigation water at 75% annual reliability level (75% Kharif season reliability and 79.17% Rabi season reliability). A gross storage capacity of 565 Th. ha.m (394 Th. ha,m) would have been adequate to provide 79.17% reliability for irrigated agriculture in Rabi season. Annual reliability would be 65%.

Annual reliability does not appear to be a sound basis for reservoir planning as even one-month failure in meeting irrigation demand of that month is considered as a failure year. 75 percent annual reliability means that the command area designed to be served by the storage scheme should not suffer for more than one year in a cycle of four years. Here, the area is assumed to suffer even if marginal deficits occur in one or more months in a year.

Seasonal reliability appears to be a better criteria as compared to annual reliability as reliable irrigation water supply is crucial for irrigated agriculture in Rabi season and not so crucial in Kharif season. It is suggested that in case of Manibhadra storage scheme, design irrigation areas should be different for Kharif season crops and Rabi season crops with Kharif design area being more and having lesser reliability (say 67%) and Rabi season area being less but higher reliability (79.17%).

5.5 ANALYSIS OF MANIBHADRA RESERVOIR

Monthly storage built up and depletion for Manibhadra reservoir during 24 years from 1958-59 to 1981-82 have been worked out in Table 5.3 at 75% reliability to meet irrigation demand. Reservoir gets fill up in the month of July and August.

Depletion generally starts in the month of October and continues upto June. Figure 5.5 is graphical presentation of storage built up and depletion.

The average of annual minimum storage is 64.25% of the live storage capacity. The reservoir has been depleted to zero live storage in 33% of the years examined This shows that the reservoir behavior is similar to that of a carry over reservoirs examined in Chapter 3.

Monthly storages over different years are compared in Table 5.9. Mean monthly storage is highest in August (565 Th. ha.m) and lowest in February (382.31 Th. ha.m). Variability is lowest (0.00) for August and September storages and highest (0.47) for May Storages. Standard deviation is highest (178.77) for storages in May and lowest (0.00) for storages in August.

Releases from Manibhadra reservoir have been considered for the purpose of irrigation only as the purpose of this study is analysis of dependability criteria in reservoir planning for irrigation.

5.6 ANALYSIS OF ECONOMIC RELIABILITY

The height of the dam and therefore the cost would be more in case of dam built on the basis of lower dependability. Every additional one-meter height of the dam over that designed for 75% dependability would involve additional cost and additional benefit. The additional cost involved in driving the benefit of a unit quantum of water depends on the frequency and persistence of lean flow years and the incremental cost of creating a unit storage. Therefore, the utilization of flows of lower dependability should depend on the economic viability of impounding the additional waters to meet the anticipated deficit in subsequent lean flow years as happens in drought areas as well as environmental cost.

5.6.1 Estimation of Cost and Benefit of Irrigation

Patra, K.C. (1978) has developed following regression equation relating cost and benefit with capacity of reservoir and annual irrigation withdrawal.

Reservoir cost: $Y = 11.3981 + 0.747822X - 0.00004785X^2$

Cost of reservoir has been allocated between irrigation and flood based on allocation of capacity for irrigation and flood control. The allocated cost of reservoir for irrigation is:

$$Y = 51.67/100*(11.3981 + 0.747822X - 0.00004785X^2)$$

Even though the Project serves the purpose of hydropower generation also, its cost is included in irrigation cost.

Cost of irrigation work:

$$Y_I = 0.868 + 0.78764X_I$$

Where Y_I is cost of irrigation works in Crores of Rupees (10^7 Rupees) and X_I is annual irrigation withdrawal in Th. ha.m.

Cost of irrigation works was added to cost of reservoir allocated for irrigation to arrive at total cost.

Benefit of irrigation:

$$Y_2 = 0.432092 + 1.647385\ X_I$$

Where Y_2 is benefit in Crores of Rupees (10^7 Rupees) and X_I is annual irrigation withdrawal in Th. ha.m.

5.6.2 Benefit, Cost and Reliability Analysis

Table 5.10 shows benefit and cost for 75% dependable annual withdrawal and required capacities. Figure 5.6 shows variation in cost and benefit with storage. Net benefit increases with increase in storage capacity but benefit cost ratio decreases marginally.

The analysis was extended to estimate benefit and cost at different reliability levels of withdrawal and required storage capacities as shown in Table 5.11. Relationship between storage, B/C ratio and reliability for 60%, 65%, 70%, 75% and 80% reliability levels are depicted in Figure 5.7. As the storage size increases, B/C ratio decreases at the considered reliability levels. For higher levels of reliability a given storage size gives lower B/C ratio; reduction in B/C ratio being significant from 60% reliability level to 65% reliability level. Reduction in B/C ratio for reliability levels of 65%, 70%, 75% and 80% is not significant for storage upto 600 Th. ha.m (Figure 5.7). Therefore with a storage of less than 600 Th. ha.m annual irrigation withdrawal at 65% reliability and at 80% reliability would result in nearly same B/C ratio (1.78 to 1.80).

As discussed in section 4.7 of chapter 4 estimated dependable flows at 70%, 65%, 60% reliability may in reality have dependability upto 80%, 75%, 70% respectively. Therefore it is desirable to plan water utilisation for a reliability of 65% to 70% instead of planning for 75% annual reliability in conventional procedure.

Table 5.12 shows change in economic parameters with change in height of reservoir from 83.94 m to 88.94 m at interval of one meter. Corresponding change in reservoir capacity is from 501.85 Th. ha.m to 710.15 Th. ha.m. The cost of reservoir, cost of irrigation works and total cost are shown in column 4, column 6 and column 7 respectively. The annual irrigation requirement (column 5) has been kept same therefore irrigation benefits are same (column 8). The B/C ratio changes from 1.82 to 1.73 (column 9) and annual reliability changes from 62,5% to 87,5% (column 3). For 75% reliability in annual withdrawal of 1650 Th. ha.m, a storage capacity of 565 Th. ha,m is adequate. The B/C ratio of 1.79 will be 75% reliable. Following the argument given in section 4.7 of chapter 4 that computed reliability of 65% may in reality could be 75%, a storage capacity of 540.3 Th. ha.m could provide 1650 Th. ha.m at 66.67% computed reliability which could in reality be 75% or even more and benefit cost ratio would be 1.8.

Table 5.13 shows change in economic parameters with every one meter increment in height of reservoir above 85.94 m corresponding to 580 Th. ha.m storage capacity as proposed in the project report. Reliability is fixed at 75% and possible annual irrigation withdrawals at 75% reliability due to increase in storage capacity are worked out (column 5). Both cost (column 7) and benefit (column 8) increase with every one meter increase in reservoir height. The Benefit Cost ratio is affected only marginally. However as seen in column 10, the net benefit increases with the reliability is maintained at 75% level.

The Manibhadra reservoir being located in lower reach of Mahanadi should be planned for higher utilisation of flows even if reliability in utilisation happens to be lower than the prevalent criteria of 75% annual dependability.

The Manibhadra project has a power generation component also cost of which was not separated from allocated cost of reservoir to irrigation. Therefore net benefit and benefit cost ratio for irrigation would be higher than as stated in the paragraph above.

Table No. 5.1
Monthly evaporation,
precipitation and temperature at Dam site.

Month	Evaporation		Precipitation	Temperature
	(mm)	(Th. ha-m)	(mm)	(°C)
January	100.00	3.80	14.90	20.90
February	100.00	3.55	23.40	23.70
March	180.00	5.79	17.80	27.10
April	230.00	6.77	20.10	31.80
May	250.00	6.18	28.90	38.80
June	180.00	3.85	214.90	26.90
July	150.00	4.54	404.90	24.80
August	150.00	5.79	390.00	26.10
September	150.00	5.79	227.80	27.90
October	130.00	4.33	70.60	26.60
November	100.00	4.34	16.80	22.30
December	100.00	4.05	4.30	20.20
Total	1820.00		1,434.40	

Source : Govt. of Orissa (1984)

Table No. 5.2
Monthwise water requirement
for irrigation and other utilities (Th. ha.m)

Month	Industrial & drinking water requirement	Salinity central requirement	Irrigation Requirement			Total monthly requirement
			Left Canal Command	Right Canal Command	Total	
January	5.00	31.00	50.05	34.68	84.73	120.73
February	5.00	31.00	48.95	34.19	83.14	119.14
March	5.00	31.00	14.85	10.52	25.37	61.37
April	5.00	31.00	28.45	20.14	48.59	84.59
May	5.00	31.00	17.05	12.07	29.12	65.12
June	5.00	-	47.90	19.40	67.30	72.30
July	5.00	-	235.60	92.90	328.50	333.50
August	5.00	-	93.60	72.70	166.30	171.30
September	5.00	-	120.90	48.00	168.90	173.90
October	5.00	31.00	126.85	89.82	216.67	252.67
November	5.00	31.00	43.45	34.93	78.38	114.38
December	5.00	31.00	26.35	18.65	45.00	81.00
Total	60.00	248.00	854.00	488.00	1,342.00	1,650.00

Source : Govt. of Orissa (1984)

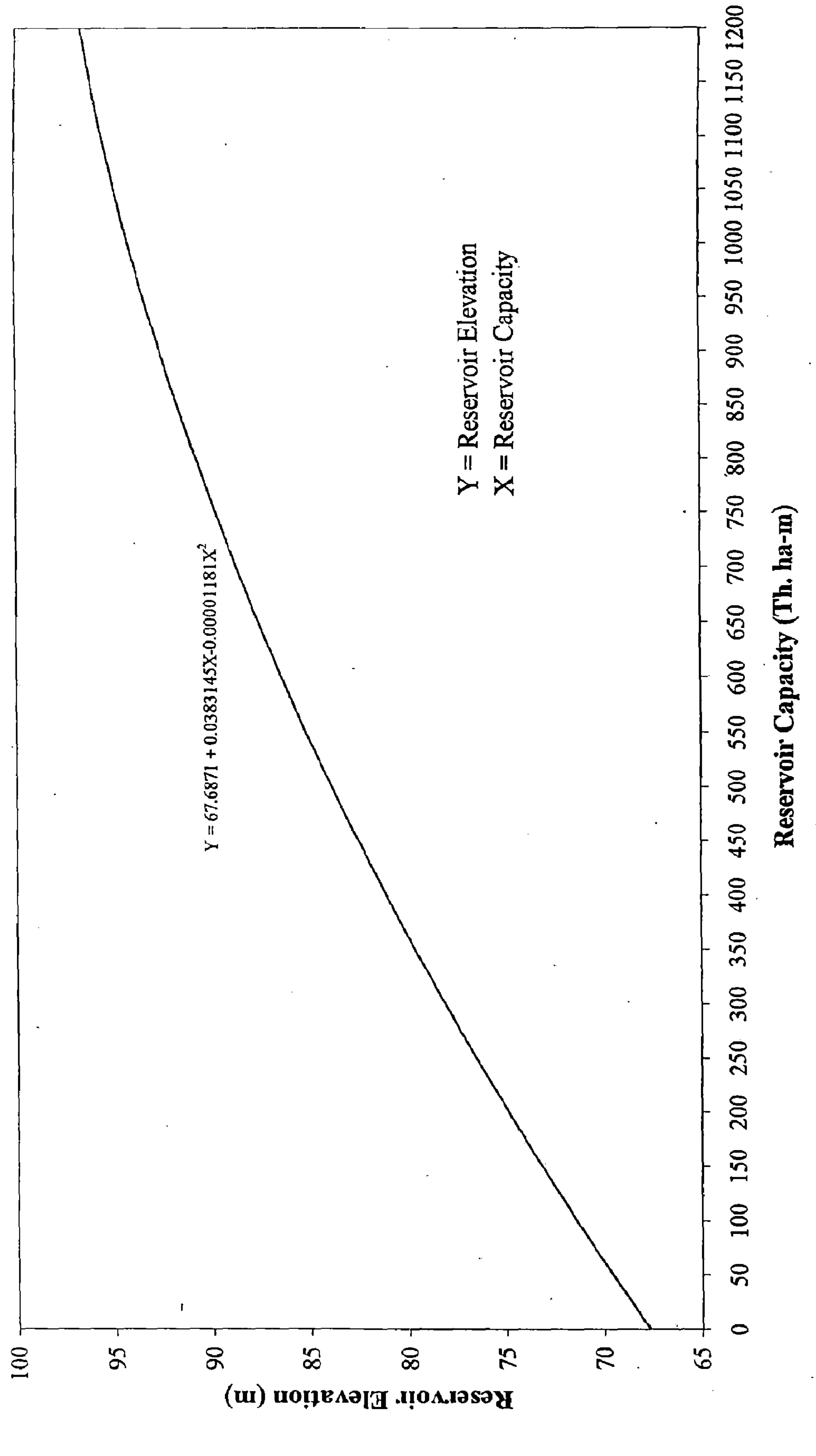


Figure 5.1
Reservoir Capacity vs Reservoir Elevation Curve

Table 5.3

ASSESMENT OF RELIABILITY FOR LIVE STORAGE CAPACITY OF RESERVOIR FOR MEETING IRRIGATION DEMAND

Storage Capacity at FRL : 565.00 (Th. Ha-m)
Storage Capacity at MDDL : 171.00 (Th. Ha-m)

Normal Reservoir Level : 85.56 m
MDDL : 73.89 m

No.	Year	Month	Reservoir at beginning of Month		Monthly Inflow	Total Available Water	Irrigation & other Demand	Evapo. Losses	Spill Out	Reservoir at the end of month		Deficit
			Elevation	Storage						Storage	Corresponding Elevation	
			(m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(m)	(Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
1	1958-59	July	73.89	171.00	2,170.26	2,341.26	333.50	4.54	1,438.22	565.00	85.56	0
2		August	85.56	565.00	1,117.97	1,682.97	171.30	5.80	940.87	565.00	85.56	0
3		September	85.56	565.00	1,839.27	2,404.27	173.90	5.80	1,659.57	565.00	85.56	0
4		October	85.56	565.00	619.85	1,184.85	252.67	5.34	361.84	565.00	85.56	0
5		November	85.56	565.00	139.83	704.83	114.38	4.67	20.78	565.00	85.56	0
6		December	85.56	565.00	89.56	654.56	81.00	4.54	4.02	565.00	85.56	0
7		January	85.56	565.00	93.07	658.07	120.73	4.25	0.00	533.09	84.76	0
8		February	84.76	533.09	96.61	629.70	119.14	4.04	0.00	506.52	84.06	0
9		March	84.06	506.52	112.47	618.99	61.37	6.76	0.00	550.86	85.21	0
10		April	85.21	550.86	107.75	658.61	84.59	8.20	0.82	565.00	85.56	0
11		May	85.56	565.00	76.13	641.13	65.12	8.12	2.89	565.00	85.56	0
12		June	85.56	565.00	46.29	611.29	72.30	4.54	0.00	534.45	84.79	0
13	1959-60	July	84.79	534.45	803.15	1,337.60	333.50	4.54	434.56	565.00	85.56	0
14		August	85.56	565.00	2,719.73	3,284.73	171.30	5.80	2,542.63	565.00	85.56	0
15		September	85.56	565.00	2,453.90	3,018.90	173.90	5.80	2,274.20	565.00	85.56	0
16		October	85.56	565.00	300.64	865.64	252.67	5.34	42.63	565.00	85.56	0
17		November	85.56	565.00	153.45	718.45	114.38	4.67	34.40	565.00	85.56	0
18		December	85.56	565.00	98.28	663.28	81.00	4.54	12.74	565.00	85.56	0
19		January	85.56	565.00	102.13	667.13	120.73	4.25	0.00	542.15	84.99	0
20		February	84.99	542.15	106.01	648.17	119.14	4.04	0.00	524.99	84.55	0
21		March	84.55	524.99	123.42	648.41	61.37	6.76	15.28	565.00	85.56	0
22		April	85.56	565.00	118.24	683.24	84.59	8.20	25.45	565.00	85.56	0
23		May	85.56	565.00	83.54	648.54	65.12	8.12	10.30	565.00	85.56	0
24		June	85.56	565.00	80.22	645.22	72.30	4.54	3.38	565.00	85.56	0
25	1960-61	July	85.56	565.00	1,168.95	1,733.95	333.50	4.54	830.91	565.00	85.56	0
26		August	85.56	565.00	3,680.84	4,245.84	171.30	5.80	3,503.74	565.00	85.56	0
27		September	85.56	565.00	508.83	1,073.83	173.90	5.80	329.13	565.00	85.56	0
28		October	85.56	565.00	525.98	1,090.98	252.67	5.34	267.97	565.00	85.56	0
29		November	85.56	565.00	144.31	709.31	114.38	4.67	25.26	565.00	85.56	0
30		December	85.56	565.00	92.43	657.43	81.00	4.54	6.89	565.00	85.56	0
31		January	85.56	565.00	96.06	661.06	120.73	4.25	0.00	536.08	84.83	0
32		February	84.83	536.08	99.70	635.78	119.14	4.04	0.00	512.60	84.22	0
33		March	84.22	512.60	116.07	628.67	61.37	6.76	0.00	560.54	85.45	0
34		April	85.45	560.54	111.20	671.74	84.59	8.20	13.95	565.00	85.56	0
35		May	85.56	565.00	78.57	643.57	65.12	8.12	5.33	565.00	85.56	0
36		June	85.56	565.00	94.66	659.66	72.30	4.54	17.82	565.00	85.56	0

No.	Year	Month	Reservoir at beginning of Month		Monthly Inflow	Total Available Water	Irrigation & other Demand	Evapo. Losses	Spill Out	Reservoir at the end of month		Deficit
			Elevation	Storage						Storage	Corresponding Elevation	
			(m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(m)	(Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
37	1961-62	July	85.56	565.00	4,430.42	4,995.42	333.50	4.54	4,092.38	565.00	85.56	0
38		August	85.56	565.00	1,590.83	2,155.83	171.30	5.80	1,413.73	565.00	85.56	0
39		September	85.56	565.00	4,355.95	4,920.95	173.90	5.80	4,176.25	565.00	85.56	0
40		October	85.56	565.00	772.30	1,337.30	252.67	5.34	514.29	565.00	85.56	0
41		November	85.56	565.00	288.62	853.62	114.38	4.67	169.57	565.00	85.56	0
42		December	85.56	565.00	184.86	749.86	81.00	4.54	99.32	565.00	85.56	0
43		January	85.56	565.00	192.11	757.11	120.73	4.25	67.13	565.00	85.56	0
44		February	85.56	565.00	199.40	764.40	119.14	4.04	76.22	565.00	85.56	0
45		March	85.56	565.00	232.14	797.14	61.37	6.76	164.01	565.00	85.56	0
46		April	85.56	565.00	222.39	787.39	84.59	8.20	129.60	565.00	85.56	0
47		May	85.56	565.00	157.13	722.13	65.12	8.12	83.89	565.00	85.56	0
48		June	85.56	565.00	808.68	1,373.68	72.30	4.54	731.84	565.00	85.56	0
49	1962-63	July	85.56	565.00	544.08	1,109.08	333.50	4.54	206.04	565.00	85.56	0
50		August	85.56	565.00	1,009.41	1,574.41	171.30	5.80	832.31	565.00	85.56	0
51		September	85.56	565.00	579.68	1,144.68	173.90	5.80	399.98	565.00	85.56	0
52		October	85.56	565.00	166.99	731.99	252.67	5.34	0.00	473.98	83.19	0
53		November	83.19	473.98	58.18	532.16	114.38	4.67	0.00	413.11	81.50	0
54		December	81.50	413.11	37.26	450.37	81.00	4.54	0.00	364.83	80.09	0
55		January	80.09	364.83	38.72	403.55	120.73	4.25	0.00	278.57	77.44	0
56		February	77.44	278.57	40.19	318.76	119.14	4.04	0.00	195.58	74.73	0
57		March	74.73	195.58	46.79	242.37	61.37	6.76	0.00	174.24	74.00	0
58		April	74.00	174.24	44.83	219.07	84.59	8.20	0.00	171.00	73.89	44.72
59		May	73.89	171.00	31.67	202.67	65.12	8.12	0.00	171.00	73.89	41.57
60		June	73.89	171.00	110.18	281.18	72.30	4.54	0.00	204.34	75.02	0
61	1963-64	July	75.02	204.34	752.52	956.86	333.50	4.54	53.82	565.00	85.56	0
62		August	85.56	565.00	1,813.66	2,378.66	171.30	5.80	1,636.56	565.00	85.56	0
63		September	85.56	565.00	1,704.71	2,269.71	173.90	5.80	1,525.01	565.00	85.56	0
64		October	85.56	565.00	297.57	862.57	252.67	5.34	39.56	565.00	85.56	0
65		November	85.56	565.00	113.11	678.11	114.38	4.67	0.00	559.06	85.42	0
66		December	85.42	559.06	72.45	631.51	81.00	4.54	0.00	545.97	85.09	0
67		January	85.09	545.97	75.29	621.26	120.73	4.25	0.00	496.28	83.79	0
68		February	83.79	496.28	78.15	574.43	119.14	4.04	0.00	451.25	82.57	0
69		March	82.57	451.25	90.98	542.23	61.37	6.76	0.00	474.10	83.20	0
70		April	83.20	474.10	87.16	561.25	84.59	8.20	0.00	468.46	83.04	0
71		May	83.04	468.46	61.58	530.05	65.12	8.12	0.00	456.81	82.72	0
72		June	82.72	456.81	118.10	574.91	72.30	4.54	0.00	498.07	83.84	0

No.	Year	Month	Reservoir at beginning of Month		Monthly Inflow	Total Available Water	Irrigation & other Demand	Evapo. Losses	Spill Out	Reservoir at the end of month		Deficit
			Elevation	Storage						Storage	Corresponding Elevation	
			(m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(m)	(Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
73	1964-65	July	83.84	498.07	2,435.91	2,933.97	333.50	4.54	2,030.93	565.00	85.56	0
74		August	85.56	565.00	3,355.32	3,920.32	171.30	5.80	3,178.22	565.00	85.56	0
75		September	85.56	565.00	1,160.99	1,725.99	173.90	5.80	981.29	565.00	85.56	0
76		October	85.56	565.00	562.33	1,127.33	252.67	5.34	304.32	565.00	85.56	0
77		November	85.56	565.00	187.01	752.01	114.38	4.67	67.96	565.00	85.56	0
78		December	85.56	565.00	119.78	684.78	81.00	4.54	34.24	565.00	85.56	0
79		January	85.56	565.00	124.48	689.48	120.73	4.25	0.00	564.50	85.55	0
80		February	85.55	564.50	129.21	693.71	119.14	4.04	5.53	565.00	85.56	0
81		March	85.56	565.00	150.42	715.42	61.37	6.76	82.29	565.00	85.56	0
82		April	85.56	565.00	144.10	709.10	84.59	8.20	51.31	565.00	85.56	0
83		May	85.56	565.00	101.81	666.81	65.12	8.12	28.57	565.00	85.56	0
84		June	85.56	565.00	233.94	798.94	72.30	4.54	157.10	565.00	85.56	0
85	1965-66	July	85.56	565.00	384.19	949.19	333.50	4.54	46.15	565.00	85.56	0
86		August	85.56	565.00	613.14	1,178.14	171.30	5.80	436.04	565.00	85.56	0
87		September	85.56	565.00	621.43	1,186.43	173.90	5.80	441.73	565.00	85.56	0
88		October	85.56	565.00	156.38	721.38	252.67	5.34	0.00	463.37	82.91	0
89		November	82.91	463.37	44.96	508.33	114.38	4.67	0.00	389.28	80.81	0
90		December	80.81	389.28	28.79	418.07	81.00	4.54	0.00	332.53	79.12	0
91		January	79.12	332.53	29.92	362.46	120.73	4.25	0.00	237.48	76.12	0
92		February	76.12	237.48	31.06	268.54	119.14	4.04	0.00	171.00	73.89	25.64
93		March	73.89	171.00	36.16	207.16	61.37	6.76	0.00	171.00	73.89	31.97
94		April	73.89	171.00	34.64	205.64	84.59	8.20	0.00	171.00	73.89	58.15
95		May	73.89	171.00	24.47	195.47	65.12	8.12	0.00	171.00	73.89	48.77
96		June	73.89	171.00	87.52	258.52	72.30	4.54	0.00	181.68	74.26	0
97	1966-67	July	74.26	181.68	553.14	734.81	333.50	4.54	0.00	396.77	81.03	0
98		August	81.03	396.77	1,441.19	1,837.97	171.30	5.80	1,095.87	565.00	85.56	0
99		September	85.56	565.00	224.55	789.55	173.90	5.80	44.85	565.00	85.56	0
100		October	85.56	565.00	132.73	697.73	252.67	5.34	0.00	439.72	82.25	0
101		November	82.25	439.72	63.35	503.07	114.38	4.67	0.00	384.02	80.66	0
102		December	80.66	384.02	40.58	424.60	81.00	4.54	0.00	339.06	79.32	0
103		January	79.32	339.06	42.17	381.22	120.73	4.25	0.00	256.24	76.73	0
104		February	76.73	256.24	43.77	300.01	119.14	4.04	0.00	176.83	74.09	0
105		March	74.09	176.83	50.95	227.79	61.37	6.76	0.00	171.00	73.89	11.34
106		April	73.89	171.00	48.81	219.81	84.59	8.20	0.00	171.00	73.89	43.98
107		May	73.89	171.00	34.49	205.49	65.12	8.12	0.00	171.00	73.89	38.75
108		June	73.89	171.00	273.21	444.21	72.30	4.54	0.00	367.37	80.17	0

No.	Year	Month	Reservoir at beginning of Month		Monthly Inflow	Total Available Water	Irrigation & other Demand	Evapo. Losses	Spill Out	Reservoir at the end of month		Deficit
			Elevation	Storage						Storage	Corresponding Elevation	
			(m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(m)	(Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
109	1967-68	July	80.17	367.37	909.59	1,276.96	333.50	4.54	373.92	565.00	85.56	0
110		August	85.56	565.00	3,171.54	3,736.54	171.30	5.80	2,994.44	565.00	85.56	0
111		September	85.56	565.00	1,158.03	1,723.03	173.90	5.80	978.33	565.00	85.56	0
112		October	85.56	565.00	210.94	775.94	252.67	5.34	0.00	517.93	84.36	0
113		November	84.36	517.93	132.63	650.55	114.38	4.67	0.00	531.50	84.72	0
114		December	84.72	531.50	84.95	616.45	81.00	4.54	0.00	530.91	84.70	0
115		January	84.70	530.91	88.28	619.19	120.73	4.25	0.00	494.21	83.74	0
116		February	83.74	494.21	91.63	585.84	119.14	4.04	0.00	462.66	82.89	0
117		March	82.89	462.66	106.67	569.33	61.37	6.76	0.00	501.20	83.92	0
118		April	83.92	501.20	102.19	603.40	84.59	8.20	0.00	510.61	84.17	0
119		May	84.17	510.61	72.20	582.81	65.12	8.12	0.00	509.57	84.14	0
120		June	84.14	509.57	44.99	554.57	72.30	4.54	0.00	477.73	83.30	0
121	1968-69	July	83.30	477.73	639.65	1,117.38	333.50	4.54	214.34	565.00	85.56	0
122		August	85.56	565.00	1,880.03	2,445.03	171.30	5.80	1,702.93	565.00	85.56	0
123		September	85.56	565.00	304.98	869.98	173.90	5.80	125.28	565.00	85.56	0
124		October	85.56	565.00	176.46	741.46	252.67	5.34	0.00	483.45	83.45	0
125		November	83.45	483.45	74.59	558.04	114.38	4.67	0.00	438.99	82.23	0
126		December	82.23	438.99	47.77	486.76	81.00	4.54	0.00	401.22	81.16	0
127		January	81.16	401.22	49.64	450.87	120.73	4.25	0.00	325.89	78.92	0
128		February	78.92	325.89	51.53	377.42	119.14	4.04	0.00	254.24	76.66	0
129		March	76.66	254.24	59.99	314.23	61.37	6.76	0.00	246.10	76.40	0
130		April	76.40	246.10	57.47	303.57	84.59	8.20	0.00	210.78	75.24	0
131		May	75.24	210.78	40.61	251.38	65.12	8.12	0.00	178.14	74.14	0
132		June	74.14	178.14	89.16	267.30	72.30	4.54	0.00	190.46	74.56	0
133	1969-70	July	74.56	190.46	583.65	774.11	333.50	4.54	0.00	436.07	82.15	0
134		August	82.15	436.07	1,697.28	2,133.35	171.30	5.80	1,391.25	565.00	85.56	0
135		September	85.56	565.00	430.19	995.19	173.90	5.80	250.49	565.00	85.56	0
136		October	85.56	565.00	171.98	736.98	252.67	5.34	0.00	478.97	83.33	0
137		November	83.33	478.97	72.24	551.21	114.38	4.67	0.00	432.16	82.04	0
138		December	82.04	432.16	46.27	478.43	81.00	4.54	0.00	392.89	80.92	0
139		January	80.92	392.89	48.08	440.97	120.73	4.25	0.00	315.99	78.61	0
140		February	78.61	315.99	49.91	365.90	119.14	4.04	0.00	242.72	76.29	0
141		March	76.29	242.72	58.10	300.82	61.37	6.76	0.00	232.69	75.96	0
142		April	75.96	232.69	55.66	288.36	84.59	8.20	0.00	195.57	74.73	0
143		May	74.73	195.57	39.33	234.90	65.12	8.12	0.00	171.00	73.89	9.34
144		June	73.89	171.00	110.00	281.00	72.30	4.54	0.00	204.16	75.02	0

No.	Year	Month	Reservoir at beginning of Month: Elevation (m)	Reservoir at beginning of Month: Storage (Th. Ha-m)	Monthly Inflow (Th. Ha-m)	Total Available Water (Th. Ha-m)	Irrigation & other Demand (Th. Ha-m)	Evapo. Losses (Th. Ha-m)	Spill Out (Th. Ha-m)	Reservoir at the end of month: Storage (Th. Ha-m)	Reservoir at the end of month: Corresponding Elevation (m)	Deficit (Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
145	1970-71	July	75.02	204.16	1,968.93	2,173.08	333.50	4.54	1,270.04	565.00	85.56	0
146		August	85.56	565.00	2,358.95	2,923.95	171.30	5.80	2,181.85	565.00	85.56	0
147		September	85.56	565.00	798.89	1,363.89	173.90	5.80	619.19	565.00	85.56	0
148		October	85.56	565.00	297.02	862.02	252.67	5.34	39.01	565.00	85.56	0
149		November	85.56	565.00	134.23	699.23	114.38	4.67	15.18	565.00	85.56	0
150		December	85.56	565.00	85.98	650.98	81.00	4.54	0.44	565.00	85.56	0
151		January	85.56	565.00	89.35	654.35	120.73	4.25	0.00	529.37	84.66	0
152		February	84.66	529.37	92.74	622.11	119.14	4.04	0.00	498.93	83.86	0
153		March	83.86	498.93	107.96	606.89	61.37	6.76	0.00	538.76	84.90	0
154		April	84.90	538.76	103.43	642.19	84.59	8.20	0.00	549.40	85.17	0
155		May	85.17	549.40	73.08	622.48	65.12	8.12	0.00	549.24	85.17	0
156		June	85.17	549.24	137.85	687.09	72.30	4.54	45.25	565.00	85.56	0
157	1971-72	July	85.56	565.00	1,932.00	2,497.00	333.50	4.54	1,593.96	565.00	85.56	0
158		August	85.56	565.00	2,396.44	2,961.44	171.30	5.80	2,219.34	565.00	85.56	0
159		September	85.56	565.00	1,181.37	1,746.37	173.90	5.80	1,001.67	565.00	85.56	0
160		October	85.56	565.00	226.90	791.90	252.67	5.34	0.00	533.89	84.78	0
161		November	84.78	533.89	154.34	688.23	114.38	4.67	4.18	565.00	85.56	0
162		December	85.56	565.00	98.86	663.86	81.00	4.54	13.32	565.00	85.56	0
163		January	85.56	565.00	102.73	667.73	120.73	4.25	0.00	542.75	85.00	0
164		February	85.00	542.75	106.63	649.38	119.14	4.04	0.00	526.20	84.58	0
165		March	84.58	526.20	124.14	650.34	61.37	6.76	17.21	565.00	85.56	0
166		April	85.56	565.00	118.93	683.93	84.59	8.20	26.14	565.00	85.56	0
167		May	85.56	565.00	84.03	649.03	65.12	8.12	10.79	565.00	85.56	0
168		June	85.56	565.00	658.08	1,223.08	72.30	4.54	581.24	565.00	85.56	0
169	1972-73	July	85.56	565.00	321.21	886.21	333.50	4.54	0.00	548.17	85.14	0
170		August	85.14	548.17	724.30	1,272.47	171.30	5.80	530.37	565.00	85.56	0
171		September	85.56	565.00	1,188.83	1,753.83	173.90	5.80	1,009.13	565.00	85.56	0
172		October	85.56	565.00	328.49	893.49	252.67	5.34	70.48	565.00	85.56	0
173		November	85.56	565.00	62.93	627.93	114.38	4.67	0.00	508.88	84.13	0
174		December	84.13	508.88	40.30	549.18	81.00	4.54	0.00	463.64	82.91	0
175		January	82.91	463.64	41.88	505.52	120.73	4.25	0.00	380.54	80.56	0
176		February	80.56	380.54	43.47	424.02	119.14	4.04	0.00	300.84	78.14	0
177		March	78.14	300.84	50.61	351.45	61.37	6.76	0.00	283.32	77.59	0
178		April	77.59	283.32	48.49	331.81	84.59	8.20	0.00	239.02	76.17	0
179		May	76.17	239.02	34.26	273.28	65.12	8.12	0.00	200.04	74.88	0
180		June	74.88	200.04	44.35	244.39	72.30	4.54	0.00	171.00	73.89	3.45

No.	Year	Month	Reservoir at beginning of Month		Monthly Inflow	Total Available Water	Irrigation & other Demand	Evapo. Losses	Spill Out	Reservoir at the end of month		Deficit
			Elevation	Storage						Storage	Corresponding Elevation	
			(m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(m)	(Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
181	1973-74	July	73.89	171.00	1,582.21	1,753.21	333.50	4.54	850.17	565.00	85.56	0
182		August	85.56	565.00	1,685.81	2,250.81	171.30	5.80	1,508.71	565.00	85.56	0
183		September	85.56	565.00	1,822.55	2,387.55	173.90	5.80	1,642.85	565.00	85.56	0
184		October	85.56	565.00	1,039.65	1,604.65	252.67	5.34	781.64	565.00	85.56	0
185		November	85.56	565.00	148.65	713.65	114.38	4.67	29.60	565.00	85.56	0
186		December	85.56	565.00	95.21	660.21	81.00	4.54	9.67	565.00	85.56	0
187		January	85.56	565.00	98.95	663.95	120.73	4.25	0.00	538.97	84.91	0
188		February	84.91	538.97	102.70	641.67	119.14	4.04	0.00	518.49	84.38	0
189		March	84.38	518.49	119.56	638.05	61.37	6.76	4.92	565.00	85.56	0
190		April	85.56	565.00	114.54	679.54	84.59	8.20	21.75	565.00	85.56	0
191		May	85.56	565.00	80.93	645.93	65.12	8.12	7.69	565.00	85.56	0
192		June	85.56	565.00	28.90	593.90	72.30	4.54	0.00	517.06	84.34	0
193	1974-75*	July	84.34	517.06	115.40	632.46	333.50	4.54	0.00	294.42	77.94	0
194		August	77.94	294.42	1,221.66	1,516.08	171.30	5.80	773.98	565.00	85.56	0
195		September	85.56	565.00	175.11	740.11	173.90	5.80	0.00	560.41	85.45	0
196		October	85.45	560.41	117.77	678.18	252.67	5.34	0.00	420.17	81.70	0
197		November	81.70	420.17	40.99	461.16	114.38	4.67	0.00	342.11	79.41	0
198		December	79.41	342.11	26.26	368.37	81.00	4.54	0.00	282.83	77.58	0
199		January	77.58	282.83	27.28	310.11	120.73	4.25	0.00	185.13	74.38	0
200		February	74.38	185.13	28.32	213.45	119.14	4.04	0.00	171.00	73.89	80.73
201		March	73.89	171.00	32.97	203.97	61.37	6.76	0.00	171.00	73.89	135.16
202		April	73.89	171.00	31.59	202.59	84.59	8.20	0.00	171.00	73.89	61.20
203		May	73.89	171.00	22.32	193.32	65.12	8.12	0.00	171.00	73.89	50.92
204		June	73.89	171.00	68.43	239.43	72.30	4.54	0.00	171.00	73.89	8.41
205	1975-76	July	73.89	171.00	841.60	1,012.60	333.50	4.54	109.56	565.00	85.56	0
206		August	85.56	565.00	2,235.97	2,800.97	171.30	5.80	2,058.87	565.00	85.56	0
207		September	85.56	565.00	828.14	1,393.14	173.90	5.80	648.44	565.00	85.56	0
208		October	85.56	565.00	537.47	1,102.47	252.67	5.34	279.46	565.00	85.56	0
209		November	85.56	565.00	108.27	673.27	114.38	4.67	0.00	554.22	85.29	0
210		December	85.29	554.22	69.35	623.57	81.00	4.54	0.00	538.03	84.88	0
211		January	84.88	538.03	72.07	610.10	120.73	4.25	0.00	485.12	83.49	0
212		February	83.49	485.12	74.81	559.93	119.14	4.04	0.00	436.75	82.17	0
213		March	82.17	436.75	87.09	523.83	61.37	6.76	0.00	455.70	82.69	0
214		April	82.69	455.70	83.43	539.13	84.59	8.20	0.00	446.34	82.44	0
215		May	82.44	446.34	58.95	505.29	65.12	8.12	0.00	432.05	82.04	0
216		June	82.04	432.05	42.90	474.95	72.30	4.54	0.00	398.11	81.07	0

No.	Year	Month	Reservoir at beginning of Month		Monthly Inflow	Total Available Water	Irrigation & other Demand	Evapo. Losses	Spill Out	Reservoir at the end of month		Deficit
			Elevation	Storage						Storage	Corresponding Elevation	
			(m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(m)	(Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
217	1976-77	July	81.07	398.11	955.50	1,353.61	333.50	4.54	450.57	565.00	85.56	0
218		August	85.56	565.00	1,365.74	1,930.74	171.30	5.80	1,188.64	565.00	85.56	0
219		September	85.56	565.00	1,123.65	1,688.65	173.90	5.80	943.95	565.00	85.56	0
220		October	85.56	565.00	125.17	690.17	252.67	5.34	0.00	432.16	82.04	0
221		November	82.04	432.16	87.79	519.95	114.38	4.67	0.00	400.90	81.15	0
222		December	81.15	400.90	56.23	457.13	81.00	4.54	0.00	371.59	80.29	0
223		January	80.29	371.59	58.43	430.02	120.73	4.25	0.00	305.04	78.28	0
224		February	78.28	305.04	60.65	365.69	119.14	4.04	0.00	242.51	76.28	0
225		March	76.28	242.51	70.61	313.12	61.37	6.76	0.00	244.99	76.36	0
226		April	76.36	244.99	67.65	312.64	84.59	8.20	0.00	219.85	75.54	0
227		May	75.54	219.85	47.79	267.64	65.12	8.12	0.00	194.40	74.69	0
228		June	74.69	194.40	67.27	261.67	72.30	4.54	0.00	184.83	74.37	0
229	1977-78	July	74.37	184.83	1,079.19	1,264.02	333.50	4.54	360.98	565.00	85.56	0
230		August	85.56	565.00	1,892.37	2,457.37	171.30	5.80	1,715.27	565.00	85.56	0
231		September	85.56	565.00	1,992.79	2,557.79	173.90	5.80	1,813.09	565.00	85.56	0
232		October	85.56	565.00	303.60	868.60	252.67	5.34	45.59	565.00	85.56	0
233		November	85.56	565.00	130.74	695.74	114.38	4.67	11.69	565.00	85.56	0
234		December	85.56	565.00	83.74	648.74	81.00	4.54	0.00	563.20	85.52	0
235		January	85.52	563.20	87.02	650.22	120.73	4.25	0.00	525.24	84.55	0
236		February	84.55	525.24	90.33	615.57	119.14	4.04	0.00	492.39	83.69	0
237		March	83.69	492.39	105.15	597.54	61.37	6.76	0.00	529.41	84.66	0
238		April	84.66	529.41	100.74	630.15	84.59	8.20	0.00	537.36	84.87	0
239		May	84.87	537.36	71.18	608.54	65.12	8.12	0.00	535.30	84.81	0
240		June	84.81	535.30	148.94	684.25	72.30	4.54	42.41	565.00	85.56	0
241	1978-79	July	85.56	565.00	737.34	1,302.34	333.50	4.54	399.30	565.00	85.56	0
242		August	85.56	565.00	2,928.43	3,493.43	171.30	5.80	2,751.33	565.00	85.56	0
243		September	85.56	565.00	1,064.57	1,629.57	173.90	5.80	884.87	565.00	85.56	0
244		October	85.56	565.00	122.41	687.41	252.67	5.34	0.00	429.40	81.96	0
245		November	81.96	429.40	118.93	548.32	114.38	4.67	0.00	429.27	81.96	0
246		December	81.96	429.27	76.17	505.44	81.00	4.54	0.00	419.90	81.69	0
247		January	81.69	419.90	79.16	499.06	120.73	4.25	0.00	374.08	80.37	0
248		February	80.37	374.08	82.16	456.25	119.14	4.04	0.00	333.07	79.14	0
249		March	79.14	333.07	95.65	428.72	61.37	6.76	0.00	360.59	79.97	0
250		April	79.97	360.59	91.64	452.23	84.59	8.20	0.00	359.44	79.93	0
251		May	79.93	359.44	64.75	424.18	65.12	8.12	0.00	350.94	79.68	0
252		June	79.68	350.94	74.65	425.59	72.30	4.54	0.00	348.75	79.61	0

No.	Year	Month	Reservoir at beginning of Month		Monthly Inflow	Total Available Water	Irrigation & other Demand	Evapo. Losses	Spill Out	Reservoir at the end of month		Deficit
			Elevation (m)	Storage (Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	(Th. Ha-m)	Storage (Th. Ha-m)	Corresponding Elevation (m)	(Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
253	1979-80	July	79.61	348.75	291.56	640.31	333.50	4.54	0.00	302.27	78.19	0
254		August	78.19	302.27	1,083.84	1,386.11	171.30	5.80	644.01	565.00	85.56	0
255		September	85.56	565.00	133.82	698.82	173.90	5.80	0.00	519.12	84.39	0
256		October	84.39	519.12	111.35	630.47	252.67	5.34	0.00	372.46	80.32	0
257		November	80.32	372.46	41.55	414.01	114.38	4.67	0.00	294.96	77.96	0
258		December	77.96	294.96	26.61	321.57	81.00	4.54	0.00	236.03	76.07	0
259		January	76.07	236.03	27.65	263.68	120.73	4.25	0.00	171.00	73.89	32.30
260		February	73.89	171.00	28.70	199.70	119.14	4.04	0.00	171.00	73.89	94.48
261		March	73.89	171.00	33.42	204.42	61.37	6.76	0.00	171.00	73.89	34.71
262		April	73.89	171.00	32.01	203.01	84.59	8.20	0.00	171.00	73.89	60.78
263		May	73.89	171.00	22.62	193.62	65.12	8.12	0.00	171.00	73.89	50.62
264		June	73.89	171.00	100.85	271.85	72.30	4.54	0.00	195.01	74.71	0
265	1980-81	July	74.71	195.01	1,881.88	2,076.89	333.50	4.54	1,173.85	565.00	85.56	0
266		August	85.56	565.00	1,062.58	1,627.58	171.30	5.80	885.48	565.00	85.56	0
267		September	85.56	565.00	2,920.19	3,485.19	173.90	5.80	2,740.49	565.00	85.56	0
268		October	85.56	565.00	211.91	776.91	252.67	5.34	0.00	518.90	84.39	0
269		November	84.39	518.90	150.22	669.12	114.38	4.67	0.00	550.07	85.19	0
270		December	85.19	550.07	96.22	646.28	81.00	4.54	0.00	560.74	85.46	0
271		January	85.46	560.74	99.99	660.73	120.73	4.25	0.00	535.75	84.82	0
272		February	84.82	535.75	103.78	639.53	119.14	4.04	0.00	516.35	84.32	0
273		March	84.32	516.35	120.82	637.17	61.37	6.76	4.04	565.00	85.56	0
274		April	85.56	565.00	115.75	680.75	84.59	8.20	22.96	565.00	85.56	0
275		May	85.56	565.00	81.78	646.78	65.12	8.12	8.54	565.00	85.56	0
276		June	85.56	565.00	147.37	712.37	72.30	4.54	70.53	565.00	85.56	0
277	1981-82	July	85.56	565.00	331.54	896.54	333.50	4.54	0.00	558.50	85.40	0
278		August	85.40	558.50	1,552.83	2,111.33	171.30	5.80	1,369.23	565.00	85.56	0
279		September	85.56	565.00	813.65	1,378.65	173.90	5.80	633.95	565.00	85.56	0
280		October	85.56	565.00	365.15	930.15	252.67	5.34	107.14	565.00	85.56	0
281		November	85.56	565.00	75.81	640.81	114.38	4.67	0.00	521.76	84.46	0
282		December	84.46	521.76	48.56	570.32	81.00	4.54	0.00	484.78	83.49	0
283		January	83.49	484.78	50.46	535.24	120.73	4.25	0.00	410.26	81.42	0
284		February	81.42	410.26	52.38	462.64	119.14	4.04	0.00	339.46	79.33	0
285		March	79.33	339.46	60.98	400.44	61.37	6.76	0.00	332.31	79.12	0
286		April	79.12	332.31	58.42	390.73	84.59	8.20	0.00	297.94	78.05	0
287		May	78.05	297.94	41.27	339.21	65.12	8.12	0.00	265.97	77.04	0
288		June	77.04	265.97	77.98	343.96	72.30	4.54	0.00	267.12	77.08	0

Table 5.4 Irrigation Water Demand

Mean Annual Flow (Th. Ha-m)	Annual Irrigation Demand (Th. Ha-m)	Percent of Mean Annual Flow
5288.58	1650.00	31.20
	1851.14	35.00
	2115.30	40.00
	2380.13	45.00
	2644.29	50.00

	Annual Irrigation Demand	Annual Irrigation Demand increment			
		1.1219	1.282	1.4425	1.6026
	333.50	374.15	427.55	481.07	534.47
	171.30	192.18	219.61	247.10	274.53
	173.90	195.10	222.94	250.85	278.69
	252.67	283.47	323.92	364.48	404.93
	114.38	128.32	146.64	164.99	183.31
	81.00	90.87	103.84	116.84	129.81
	120.73	135.45	154.78	174.15	193.48
	119.14	133.66	152.74	171.86	190.93
	61.37	68.85	78.68	88.53	98.35
	84.59	94.90	108.44	122.02	135.56
	65.12	73.06	83.48	93.94	104.36
	72.30	81.11	92.69	104.29	115.87
Total	1650.00	1851.14	2115.30	2380.13	2644.29

Table 5.5 Storage Capacity for different combination of withdrawal and reliability

Percent of mean annual flow	Storage Capacity (Th. ha.m)				
	60% Annual Reliability	65% Annual Reliability	70% Annual Reliability	75% Annual Reliability	80% Annual Reliability
31.20	467.00	548.00	552.00	565.00	570.00
35.00	542.00	649.00	661.00	662.00	678.00
40.00	663.00	763.00	804.00	816.00	820.00
45.00	808.00	918.00	963.00	970.00	971.00
50.00	962.00	1,075.00	1,116.00	1,125.00	1,126.00

Table 5.6 Time Reliability and Seasonal Reliability corresponding to Annual Reliability

Annual Reliability (%)	Time Reliability (%)	Reliability in Kharif Season		Reliability in Rabi Season	
		Seasonal (%)	Time (%)	Seasonal (%)	Time (%)
60	85.76	62.50	91.67	62.50	79.86
65	91.32	66.67	93.75	79.17	88.89
70	92.01	70.83	94.44	79.17	89.58
75	93.06	75.00	95.14	79.17	90.97
80	93.40	79.17	93.06	83.33	93.75

Figure 5.2
Storage Size - Withdrawal - Reliability Relationship

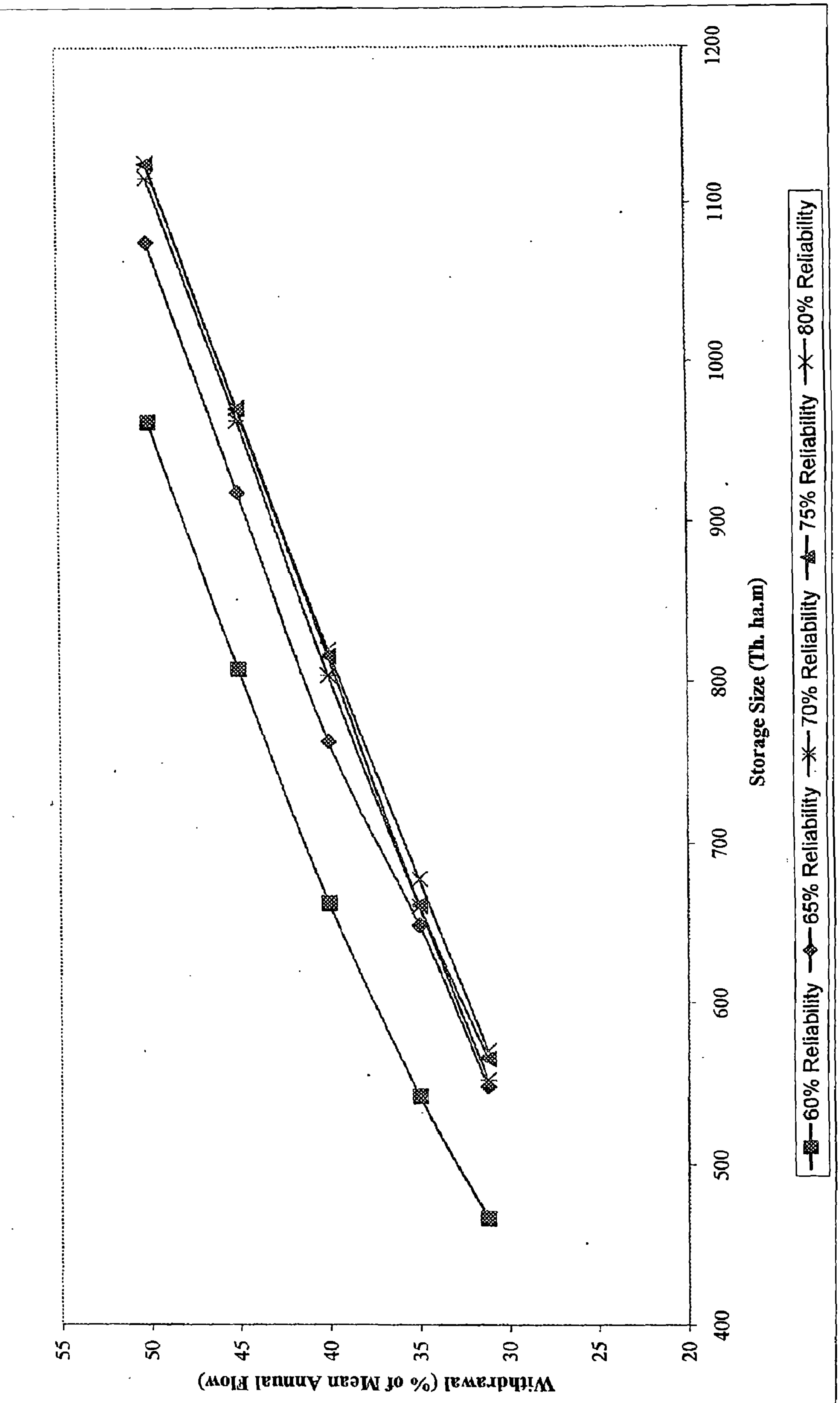


Table 5.7 Storage Capacity for different combination of Kharif withdrawal and reliability

Percent of mean annual flow	Storage Capacity (Th. ha.m)				
	60% Kharif Season Reliability	65% Kharif Season Reliability	70% Kharif Season Reliability	75% Kharif Season Reliability	80% Kharif Season Reliability
31.20	467.00	548.00	552.00	565.00	570.00
35.00	542.00	649.00	661.00	662.00	678.00
40.00	663.00	763.00	804.00	816.00	820.00
45.00	808.00	918.00	963.00	970.00	971.00
50.00	962.00	1,075.00	1,116.00	1,125.00	1,126.00

Figure 5.3
Storage Size - Withdrawal - Reliability Relationship

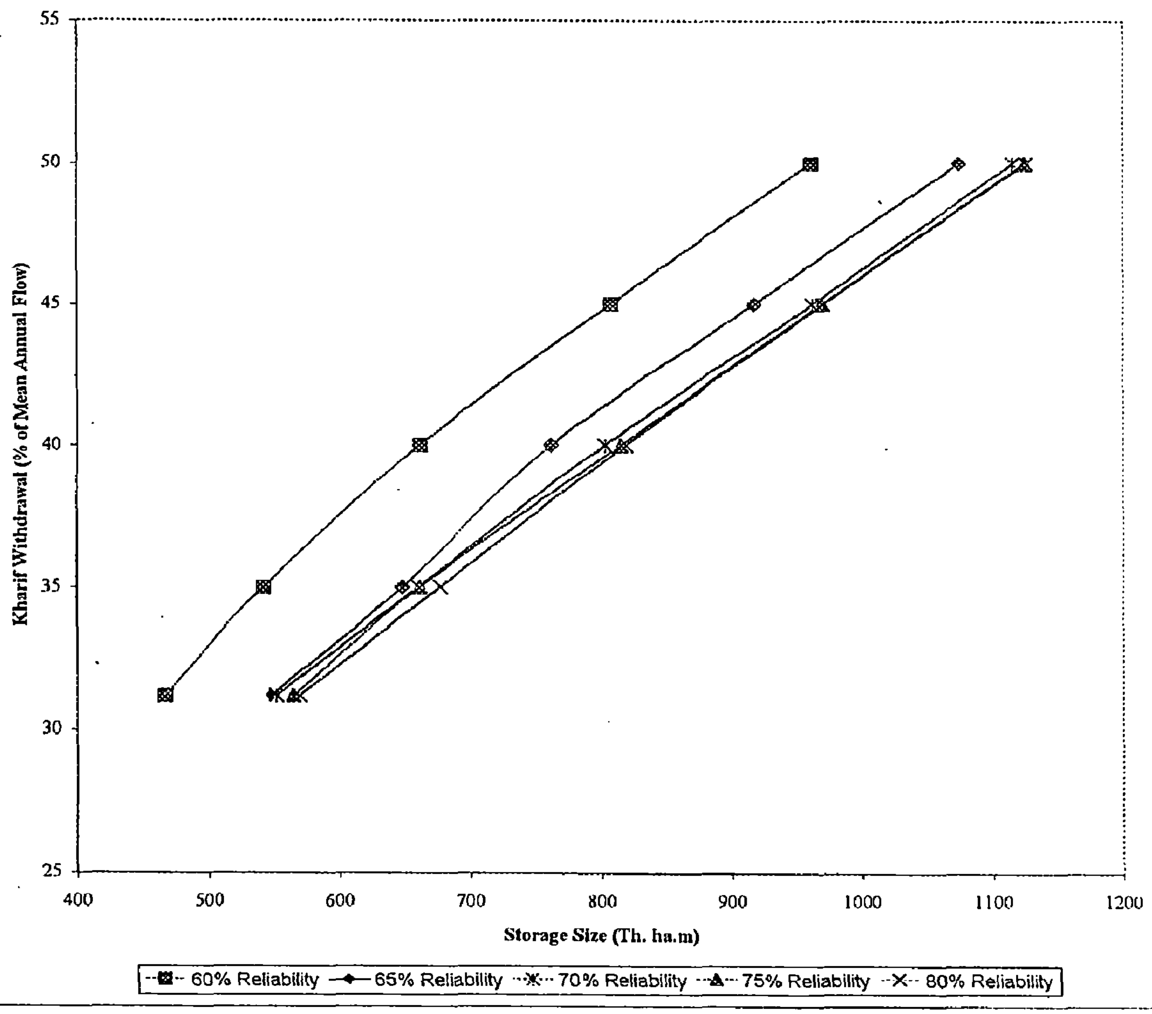


Table 5.8 Storage Capacity for different combination of Rabi withdrawal and reliability

Percent of mean annual flow	Storage Capacity (Th. ha.m)				
	60% Rabi Season Reliability	65% Rabi Season Reliability	70% Rabi Season Reliability	75% Rabi Season Reliability	80% Rabi Season Reliability
31.20	431.00	490.00	509.00	518.00	533.00
35.00	500.00	560.00	609.00	618.00	634.00
40.00	602.00	658.00	743.00	752.00	766.00
45.00	735.00	784.00	875.00	883.00	899.00
50.00	850.00	918.00	1,007.00	1,015.00	1,031.00

Figure 5.4
Storage Size - Withdrawal - Reliability Relationship

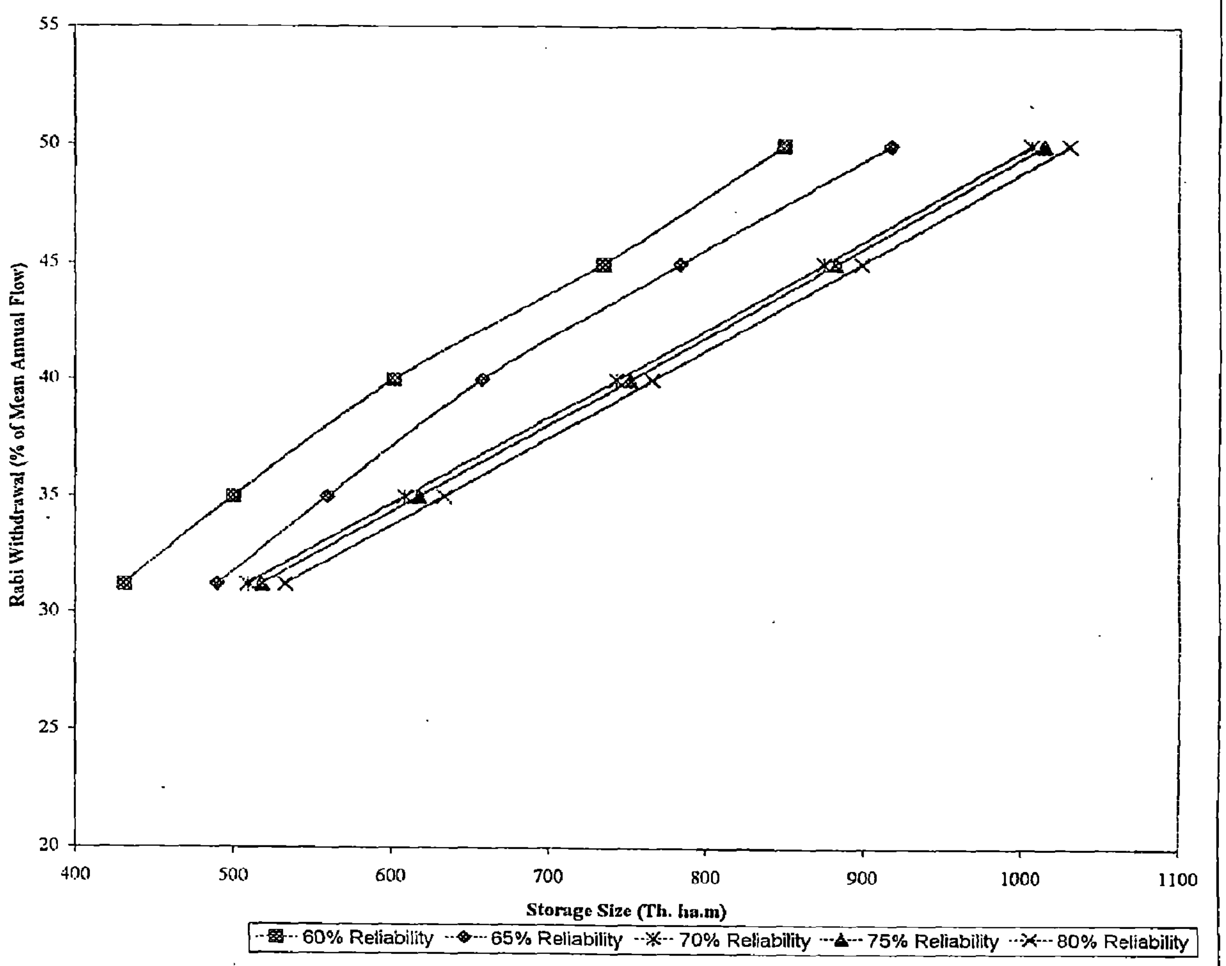


FIGURE 5.5 LIVE STORAGE BUILD-UP & DEPLETION DURING VARIOUS WATER YEARS IN MANIBHADRA DAM FOR 75% RELIABILITY

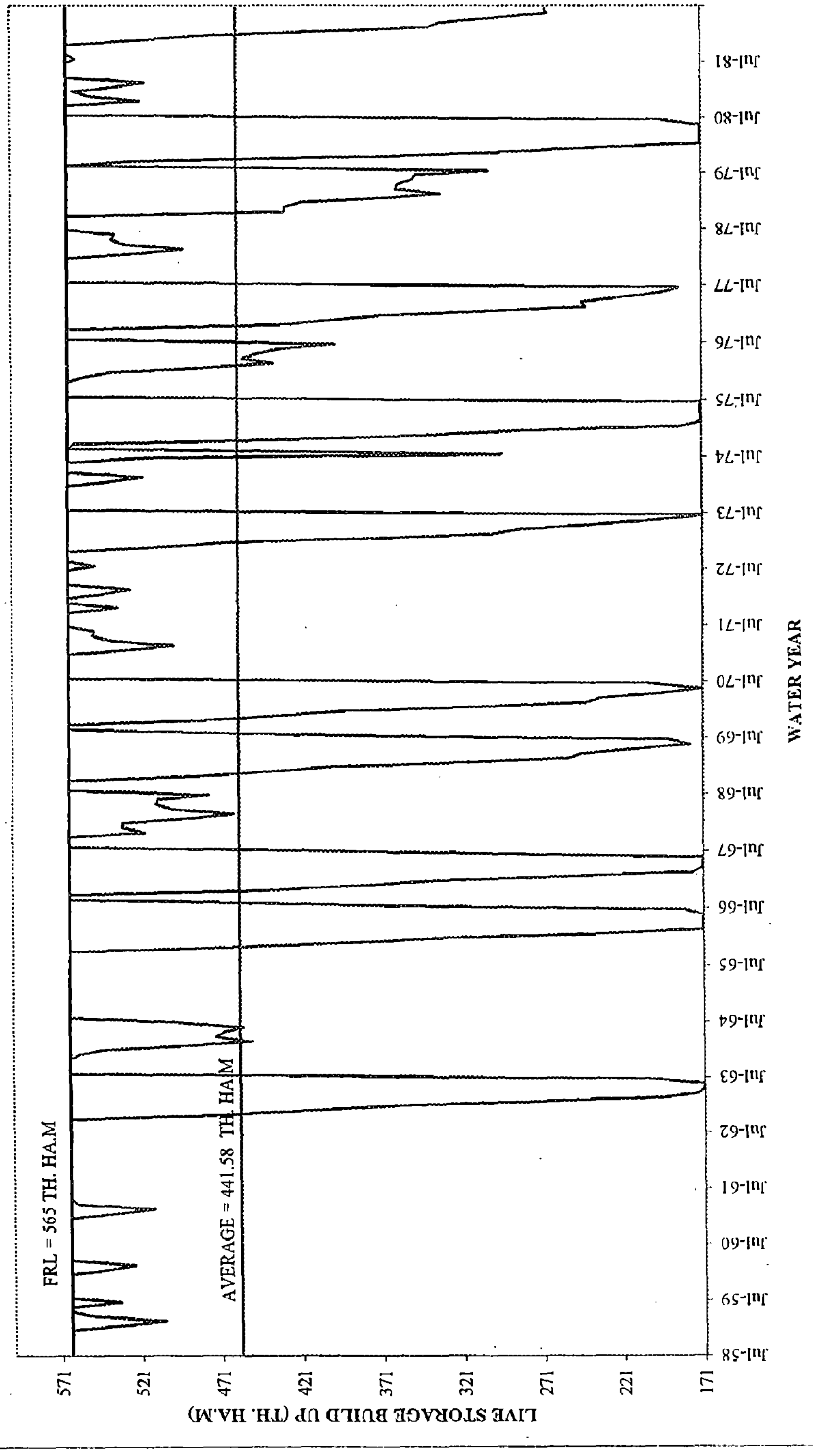


Table 5.9
Monthly Storage During Various Water Years
for Manibhadra Reservoir

Storage Capacity : 565.00 Th. ha.m.
Av. storage over the year : 459.12 Th. ha.m.

Year	Storage Capacity (Th. ha.m)											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1958							565.00	565.00	565.00	565.00	565.00	565.00
1959	533.09	506.52	550.86	565.00	565.00	534.45	565.00	565.00	565.00	565.00	565.00	565.00
1960	542.15	524.99	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00
1961	536.08	512.60	560.54	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00
1962	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	473.98	413.11	364.83
1963	278.57	195.58	174.24	171.00	171.00	204.34	565.00	565.00	565.00	565.00	559.06	545.97
1964	496.28	451.25	474.10	468.46	456.81	498.07	565.00	565.00	565.00	565.00	565.00	565.00
1965	564.50	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	463.37	389.28	332.53
1966	237.48	171.00	171.00	171.00	171.00	181.68	396.77	565.00	565.00	439.72	384.02	339.06
1967	256.24	176.83	171.00	171.00	171.00	367.37	565.00	565.00	565.00	517.93	531.50	530.91
1968	494.21	462.66	501.20	510.61	509.57	477.73	565.00	565.00	565.00	483.45	438.99	401.22
1969	325.89	254.24	246.10	210.78	178.14	190.46	436.07	565.00	565.00	478.97	432.16	392.89
1970	315.99	242.72	232.69	195.57	171.00	204.16	565.00	565.00	565.00	565.00	565.00	565.00
1971	529.37	498.93	538.76	549.40	549.24	565.00	565.00	565.00	565.00	533.89	565.00	565.00
1972	542.75	526.20	565.00	565.00	565.00	565.00	548.17	565.00	565.00	565.00	508.88	463.64
1973	380.54	300.84	283.32	239.02	200.04	171.00	565.00	565.00	565.00	565.00	565.00	565.00
1974	538.97	518.49	565.00	565.00	565.00	517.06	294.42	565.00	560.41	420.17	342.11	282.83
1975	185.13	171.00	171.00	171.00	171.00	171.00	565.00	565.00	565.00	565.00	554.22	538.03
1976	485.12	436.75	455.70	446.34	432.05	398.11	565.00	565.00	565.00	432.16	400.90	371.59
1977	305.04	242.51	244.99	219.85	194.40	184.83	565.00	565.00	565.00	565.00	565.00	563.20
1978	525.24	492.39	529.41	537.36	535.30	565.00	565.00	565.00	565.00	429.40	429.27	419.90
1979	374.08	333.07	360.59	359.44	350.94	348.75	302.27	565.00	519.12	372.46	294.96	236.03
1980	171.00	171.00	171.00	171.00	171.00	195.01	565.00	565.00	565.00	518.90	550.07	560.74
1981	535.75	516.35	565.00	565.00	565.00	565.00	558.50	565.00	565.00	565.00	521.76	484.78
1982	410.26	339.46	332.31	297.94	265.97	267.12						
Mean	422.03	382.31	398.28	392.07	384.10	398.44	529.43	565.00	562.90	514.35	493.14	472.84
S. Deviation	131.57	146.55	164.56	172.80	178.77	167.70	82.65	0.00	9.37	61.21	86.16	106.94
Coeff. Of var.	0.31	0.38	0.41	0.44	0.47	0.42	0.16	0.00	0.02	0.12	0.17	0.23

Table 5.10 Benefit, Cost, and Storage Relationship at 75% Reliability in Withdrawal

Reservoir Capacity at 75% Reliability (Th.ha.m)	Reservoir cost Y = 51.67/100* (11.3981 + 0.747822X - 0.00004785X^2) (Crores of Rs.)	Annual Irr. Requirement (Th.ha.m)	Irr. Work Cost Y = 0.868 + 0.78764X (Crores of Rs.)	Total Cost (Crores of Rs.)	Irrigation Benefit Y = 0.432092 + 1.647385X (Crores of Rs.)	Benefit Cost Ratio
1	2	3	4	5 = 2 + 4	6	7 = 6 / 5
565.00	216.31	1650.00	1300.47	1516.79	2718.62	1.79
662.00	250.85	1851.14	1458.90	1709.75	3049.96	1.78
816.00	304.73	2115.30	1666.96	1971.69	3485.15	1.77
970.00	357.43	2380.13	1875.55	2232.98	3921.41	1.76
1,125.00	409.30	2644.29	2083.62	2492.91	4356.60	1.75

Fig. 5.6 Benefit, Cost, and Storage Capacity Relationship at 75% Reliability in Withdrawal

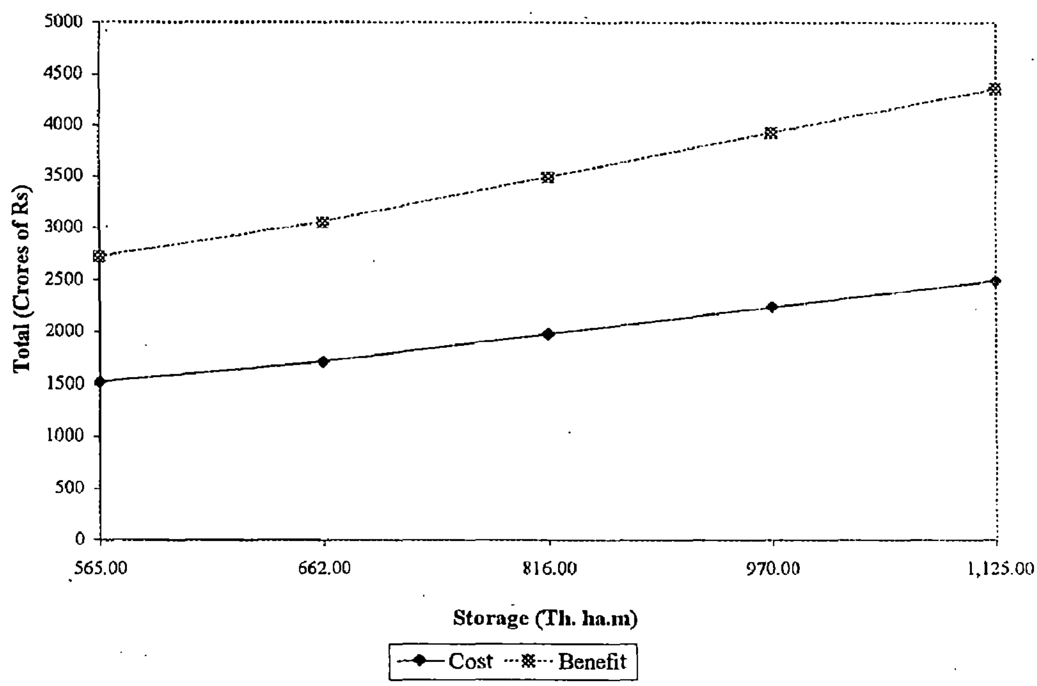


Table 5.11 Benefit Cost Ratio , Storage and Reliability Relationship

Reservoir Capacity (Th.ha.m)	Reservoir cost Y = 51.67/100* (11.3981 + 0.747822X - 0.00004785X²) (Crores of Rs.)	Annual Irr. Requirement (Th.ha.m)	Irr. Work Cost Y = 0.868 + 0.78764X (Crores of Rs.)	Total Cost (Crores of Rs.)	Irrigation Benefit Y = 0.432092 + 1.647385X (Crores of Rs.)	Benefit Cost Ratio
1	2	3	4	5 = 2 + 4	6	7 = 6 / 5
60% reliability						
467.00	180.95	1650.00	1300.47	1481.42	2718.62	1.84
542.00	208.05	1851.14	1458.90	1666.95	3049.96	1.83
663.00	251.20	2115.30	1666.96	1918.17	3485.15	1.82
808.00	301.96	2380.13	1875.55	2177.51	3921.41	1.80
962.00	354.73	2644.29	2083.62	2438.34	4356.60	1.79
65% reliability						
548.00	210.21	1650.00	1300.47	1510.69	2718.62	1.80
649.00	246.25	1851.14	1458.90	1705.14	3049.96	1.79
763.00	286.32	2115.30	1666.96	1953.28	3485.15	1.78
918.00	339.77	2380.13	1875.55	2215.32	3921.41	1.77
1,075.00	392.70	2644.29	2083.62	2476.31	4356.60	1.76
70% reliability						
552.00	211.65	1650.00	1300.47	1512.12	2718.62	1.80
661.00	250.50	1851.14	1458.90	1709.39	3049.96	1.78
804.00	300.57	2115.30	1666.96	1967.54	3485.15	1.77
963.00	355.06	2380.13	1875.55	2230.61	3921.41	1.76
1,116.00	406.32	2644.29	2083.62	2489.94	4356.60	1.75
80% reliability						
570.00	218.10	1650.00	1300.47	1518.58	2718.62	1.79
678.00	256.50	1851.14	1458.90	1715.40	3049.96	1.78
820.00	306.11	2115.30	1666.96	1973.08	3485.15	1.77
971.00	357.77	2380.13	1875.55	2233.32	3921.41	1.76
1,126.00	409.63	2644.29	2083.62	2493.24	4356.60	1.75

Fig. 5.7 STORAGE, B/C RATIO AND RELIABILITY RELATIONSHIP

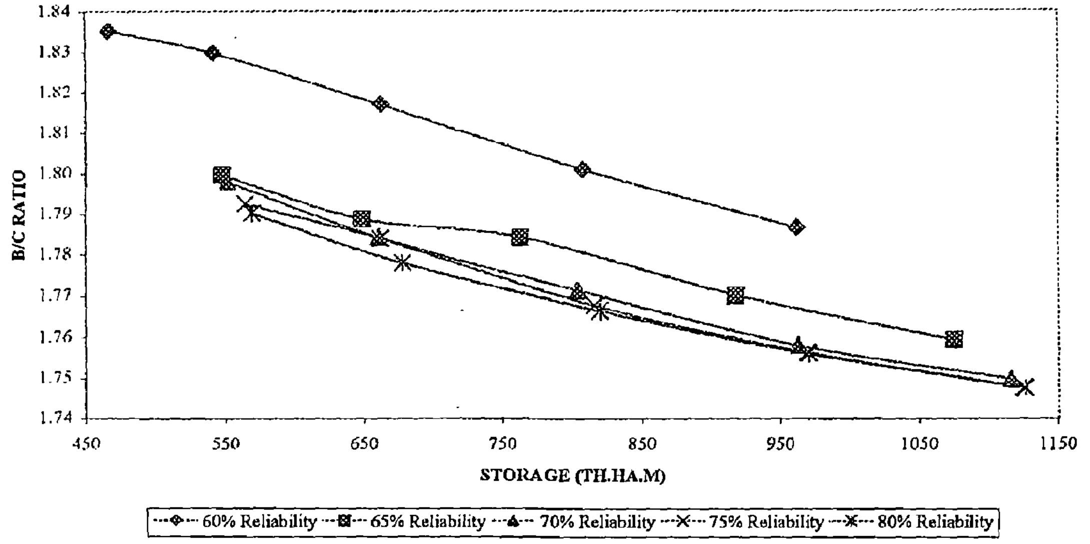


Table 5.12 Benefit Cost Ratio, and Resevoir Level Relationship for Fixed Withdrawal

Reservoir Level (m)	Reservoir Capacity (X) (Th.ha.m)	Annual Reliability (%)	Reservoir cost $Y = 51.67/100*(11.3981 + 0.747822X - 0.00004785X^2)$ (Crores of Rs.)	Annual Irr. Withdrawal (X_1) (Th.ha.m)	Irr. Work Cost $Y = 0.868 + 0.78764X_1$ (Crores of Rs.)	Total Cost (Crores of Rs.)	Irrigation Benefit $Y = 0.432092 + 1.647385X_1$ (Crores of Rs.)	Benefit Cost Ratio	Net Benefit (Crores of Rs.)
1	2	3	4	5	6	7 = 4 + 6	8	9 = 8 / 7	10 = 8 - 7
83.94	501.85	62.50	193.58	1650.00	1,300.47	1,494.05	2,718.62	1.82	1,224.57
84.94	540.30	66.67	207.44	1650.00	1,300.47	1,507.92	2,718.62	1.80	1,210.70
85.56	565.00	75.00	216.31	1650.00	1,300.47	1,516.79	2,718.62	1.79	1,201.83
85.94	**580.00**	80.00	221.68	1650.00	1,300.47	1,522.16	2,718.62	1.79	1,196.46
86.94	621.60	80.00	236.52	1650.00	1,300.47	1,537.00	2,718.62	1.77	1,181.62
87.94	664.85	87.50	251.86	1650.00	1,300.47	1,552.33	2,718.62	1.75	1,166.28
88.94	710.15	87.50	267.82	1650.00	1,300.47	1,568.30	2,718.62	1.73	1,150.32

Table 5.13 Benefit Cost Ratio, and Resevoir Level Relationship for Fixed Reliability

Reservoir Level (m)	Reservoir Capacity (X) (Th.ha.m)	Annual Reliability (%)	Reservoir cost $Y = 51.67/100*(11.3981 + 0.747822X - 0.00004785X^2)$ (Crores of Rs.)	Annual Irr. Withdrawal (X_1) (Th.ha.m)	Irr. Work Cost $Y = 0.868 + 0.78764X_1$ (Crores of Rs.)	Total Cost (Crores of Rs.)	Irrigation Benefit $Y = 0.432092 + 1.647385X_1$ (Crores of Rs.)	Benefit Cost Ratio	Net Benefit (Crores of Rs.)
1	2	3	4	5	6	7 = 4 + 6	8	9 = 8 / 7	10 = 8 - 7
85.94	580.00	75.00	221.68	1691.15	1,332.89	1,554.57	2,786.41	1.79	1,231.84
86.94	621.60	75.00	236.52	1778.59	1,401.76	1,638.28	2,930.45	1.79	1,292.18
87.94	664.85	75.00	251.86	1854.49	1,461.54	1,713.40	3,055.49	1.78	1,342.09
88.94	710.15	75.00	267.82	1932.03	1,522.61	1,790.43	3,183.23	1.78	1,392.79

CHAPTER 6

RELIABILITY ANALYSIS BY PROBABILITY MATRIX METHOD

6.1 GENERAL

While long term simulation study is now the accepted procedure for reservoir planning, it is also subject to certain assumptions/limitations. This chapter illustrates an alternate procedure available in literature for reliability analysis of reservoir.

Long term simulation study of Manibhadra reservoir was used in chapter 5 to establish relationship between storage size and annual withdrawal for physical reliability at seasonal and annual level. Economic parameters were also evaluated and related with reliability simulation study also known as reservoir behavior analysis is based on certain assumptions and has certain limitations as discussed below.

i) In the simulation study reservoir is initially assumed to be full. This may have significant effect on storage size, which can be checked by examining a behavior diagram for various starting conditions.

ii) Non continuous records can not be easily handled because of difficulties of assigning the initial reservoir condition after a break in the stream flow.

iii) Demands (and hence releases) that are related to growth rates in time (increased irrigation and urban water demand) are not easily taken into account because of difficulty of relating the demand in a future year to a specific year of the historical flow record used in the simulation study and assumed to be representative of future river flows.

iv) When the analysis is based on the historical record, the sequencing of flows may not be representative of the population of flows.

Mc. Mahon and Mein (1978) recommended Gould's Probability Matrix Method for establishing single reservoir capacity – yield – reliability relationship. Following are the advantages of this method.

i) The procedure samples all years of data without reference to the historical sequencing of inflow.

ii) Computed storage estimates are independent of the initial reservoir condition.

iii) As annual flow are assumed to be independent, the sequencing of flows is unimportant and so records with missing annual data can be used as effectively as continuous records.

iv) Monthly parameters and monthly serial correlations, except that between the last month of year i and the first month of year i+1, are automatically taken into account as yearly flow sequences are routed on a monthly basis through the reservoir.

v) Probability of failure is computed either at steady state or as a time dependent function of starting conditions. The latter attribute is a most important characteristic of probability matrix methods.

vi) Varying drafts and complicated release rules can be handled easily.

6.2 GOULD'S PROBABILITY MATRIX METHOD

In the approach storage capacity and draft are given, and probability of failure of the reservoir is determined. If draft or storage size is to be determined then a trial and error method needs to be utilised.

The procedure to determine storage capacity for given draft and probability of failure criteria is as follows:

i) Decide on the releases (D_t) required from the reservoir in volume units per month and how they are to vary from month to month throughout the year. It is usual that releases are seasonal, although the method requires that *annual* releases are not time variant. Operating policy may require the releases to be reduced if the stored contents fall below some predetermined values; thus the release rule needs to be defined at this stage. In addition, net evaporation loss from the reservoir, which is a function of surface area (hence stored content) needs to be defined.

ii) Decide on the design probability of failure (P_e) which is defined as the probability of the reservoir running dry in any month.

iii) Assume a first trial, reservoir capacity C_1 (volume units).

iv) Set up a tally sheet to construct the transition matrix. It is shown here for descriptive purposes. With the computations being done on a computer, the "tally sheet" is actually a computer matrix. Divide the trial reservoir capacity C into K zones. As a general rule twenty is sufficient. The volume of each zone including the top and bottom ones is given as follow:

$$\text{Volume (W)} = \frac{C_1}{K-2}$$

0	1,2, ... 18,	19
↑	↑	↑
empty zone of zero volume	18 zones of equal volume	full zone (C_1) of full volume

v) Apply the continuity equation (same as for behavior analysis) on a monthly basis taking one year of data at a time as described below.

$Z_{t+1} = Z_t + X_t - D_t - \Delta E_t$

Where, Z_t, Z_{t+1} = the storage content at the beginning and end of the t^{th} month,

X_t = the inflow during the t^{th} month,

D_t = the release during the t^{th} month, and

ΔEt = the net evaporation loss during the t^{th} month.

The net evaporation loss is the difference between the evaporation from the proposed reservoir and the evapotranspiration from the proposed reservoir site and will be a function of water surface area which in turn is a function of volume of water in active storage plus dead storage capacity.

For each year of data (there are a total of N years). Equation above is applied month by month to determine the zone in which the reservoir finishes at the end of the year. This is done for each possible starting zone, and the element corresponding to the starting and finishing zone in a tally sheet is incremented by one. Any failures (reservoir emptying) that occur during the year also noted.

In applying the continuity equation, the seasonal variability of D_t should be taken into account in conjunction with any restrictions imposed on the release as a result of the present state (Z_t) of the storage and also the ΔE_t losses.

6.3 PROBABILITY MATRIX ANALYSIS OF MANIBHADRA RESERVOIR

In the Gould's probability matrix method annual flows are assumed to be independent. However as discussed in chapter 4 (section 4.8) the annual flow series at

Manibhadra reservoir site shows periodicity. Therefore serial correlation present in the series is ignored when Gould's probability matrix method is used.

Storage capacity 565 Th. ha.m, and release requirements and net evaporation loss same as in simulation study continuity equation is applied on monthly basis within a year and independently for 24 years (Table 6.1). Live storage is divided in 20 zones to set up "tally sheet" for transition matrix (Table 6.1). Table 6.2 shows the number of years of reservoir content at beginning of year (Z_t) and reservoir content at end of year (Z_{t+1}) in each zone after yearly routing by Gould's Procedure (Table 6.2). Table 6.3 shows tally sheet for transition probability matrix. Transition matrix is obtained by dividing each column by 24 to convert the element contents to probability. The matrix expresses the state of the reservoir contents at the end of a year as a probability relationship of the state of the reservoir contents at the beginning of that year. The probability of failure is obtained by dividing number of failure months with 12 x 24 years as shown in Table 6.2.

Steady state probability is computed by using three alternative methods (i) power up the transition matrix $[T]^{2^m}$ by squaring this matrix five times, (ii) set up simultaneous equations and solve by Gauss Seidel Method, and (iii) compute the stored content year by year starting initially with the reservoir empty (Table 6.4). By using three methods the results on steady state probability are found to be same. Probability of failure of 565 Th. ha.m storage capacity in meeting the target irrigation withdrawal is 47.57% by using Gould's procedure as shown in Table 6.5 and corresponding reliability is 52.43%.

Thus 565 Th. ha.m storage capacity will meet target irrigation requirements 1650 Th. ha.m at 75% reliability level (annual) as per long term simulation study but the reliability as per Gould's probability matrix method is only 52.43%. Main reasons for this difference could be:

i) Annual flows are assumed to be independent of each other in Gould's probability matrix method which may not be true in view of observed periodicity of annual flows (see section 4.8, chapter 4).

ii) Only 24 years data is used in the analysis to arrive at transition probability matrix and steady state probability.

iii) In consideration of large flows in monsoon months reservoir usually gets filled upto the storage capacity at the end of August or September an it is depleted to lowest level by end of dry season (end of June). Therefore it is not necessary to consider possibility of reservoir being in any one of 20 zones as done in the Gould's method

Table 6.1 BEHAVIOR ANALYSIS BY APPLYING CONTINUITY EQUATION WITHIN A YEAR

Trial Storage Capacity : 269.50 (Th. Ha-m)
Storage Capacity at MDDL : 171.00 (Th. Ha-m)

Normal Reservoir Level : 77.16 m
MDDL : 73.89 m

No.	Year	Month	Reservoir at beginning of Month (Z_t)		Monthly Inflow	Total Available Water	Release/ Irr. & other Demand	Evapo. Losses	Spill Out	Reservoir at the end of month		Deficit
			Zone	Storage (Z_t) (Th. Ha-m)	(X_t) (Th. Ha-m)	(Th. Ha-m)	(D_t) (Th. Ha-m)	ΔE_t (Th. Ha-m)	(Th. Ha-m)	Storage (Z_{t+1}) (Th. Ha-m)	Zone	(Th. Ha-m)
1	2	3	4	5	6	7= 5+6	8	9	10	11	12	13
1	**1981-82**	July	5	269.50	331.54	601.04	333.50	4.54	0.00	263.00	5	0
2		August	5	263.00	1,552.83	1,815.83	171.20	5.80	1,369.33	269.50	5	0
3		September	5	269.50	813.65	1,083.15	173.90	5.80	633.95	269.50	5	0
4		October	5	269.50	365.15	634.65	252.67	5.34	107.14	269.50	5	0
5		November	5	269.50	75.81	345.31	114.38	4.67	0.00	226.26	3	0
6		December	3	226.26	48.56	274.82	81.00	4.54	0.00	189.28	1	0
7		January	1	189.28	50.46	239.74	120.73	4.25	0.00	171.00	0	56.24
8		February	0	171.00	52.38	223.38	119.14	4.04	0.00	171.00	0	70.80
9		March	0	171.00	60.98	231.98	61.37	6.76	0.00	171.00	0	7.15
10		April	0	171.00	58.42	229.42	84.59	8.20	0.00	171.00	0	34.37
11		May	0	171.00	41.27	212.27	65.12	8.12	0.00	171.00	0	31.97
12		June	0	171.00	77.98	248.98	72.30	4.54	0.00	172.14	1	0

Zone	Storage Cap.(Th.ham)	Zone	Storage Cap.(Th.ham)	Zone	Storage Cap.(Th.ham)
0	171	7	324.222>=Z>302.333	14	477.444>=Z>455.556
1	192.889>=Z>171	8	346.111>=Z>324.222	15	499.333>=Z>477.444
2	214.778>=Z>192.889	9	368.000>=Z>346.111	16	521.222>=Z>499.333
3	236.667>=Z>214.778	10	389.889>=Z>368.000	17	543.111>=Z>521.222
4	258.556>=Z>236.667	11	411.778>=Z>389.889	18	565>Z>302.333
5	280.444>=Z>258.556	12	433.667>=Z>411.778	19	565
6	302.333>=Z>280.444	13	455.556>=Z>433.667		

Table 6.2 Yearly Routing Result in Gould's Procedure

1958-59			1959-60			1960-61			1961-62			1962-63			1963-64			1964-65		
Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze
0	3	0	0	2	0	0	2	0	0	0	0	0	8	0	0	6	0	0	1	0
1	3	0	1	2	1	1	2	1	1	0	1	1	8	1	1	4	1	1	0	1
2	1	1	2	1	2	2	1	2	2	0	2	2	8	2	2	2	2	2	0	2
3	1	2	3	0	3	3	0	3	3	0	3	3	8	2	3	2	3	3	0	3
4	0	3	4	0	4	4	0	4	4	0	4	4	8	2	4	1	3	4	0	4
5	0	4	5	0	5	5	0	5	5	0	5	5	7	2	5	1	3	5	0	5
6	0	5	6	0	6	6	0	6	6	0	6	6	7	2	6	0	3	6	0	6
7	0	6	7	0	7	7	0	7	7	0	7	7	7	2	7	0	4	7	0	7
8	0	7	8	0	8	8	0	8	8	0	8	8	6	2	8	0	5	8	0	8
9	0	8	9	0	9	9	0	9	9	0	9	9	6	2	9	0	6	9	0	9
10	0	9	10	0	10	10	0	10	10	0	10	10	5	2	10	0	7	10	0	10
11	0	10	11	0	11	11	0	11	11	0	11	11	5	2	11	0	8	11	0	11
12	0	11	12	0	12	12	0	12	12	0	12	12	5	2	12	0	9	12	0	12
13	0	12	13	0	13	13	0	13	13	0	13	13	5	2	13	0	10	13	0	13
14	0	13	14	0	14	14	0	14	14	0	14	14	4	2	14	0	11	14	0	14
15	0	14	15	0	15	15	0	15	15	0	15	15	4	2	15	0	12	15	0	15
16	0	15	16	0	16	16	0	16	16	0	16	16	4	2	16	0	13	16	0	16
17	0	16	17	0	17	17	0	17	17	0	17	17	4	2	17	0	14	17	0	17
18	0	17	18	0	18	18	0	18	18	0	18	18	3	2	18	0	15	18	0	18
19	0	18	19	0	19	19	0	19	19	0	19	19	2	2	19	0	15	19	0	19

1965-66			1966-67			1967-68			1968-69			1969-70			1970-71		
Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze
0	8	0	0	8	0	0	6	0	0	8	0	0	8	0	0	3	0
1	8	1	1	8	1	1	4	0	1	8	1	1	8	1	1	2	1
2	8	1	2	8	2	2	4	0	2	8	1	2	8	2	2	2	2
3	8	1	3	8	3	3	2	1	3	8	1	3	8	2	3	1	3
4	8	1	4	8	4	4	1	1	4	8	1	4	8	2	4	0	4
5	8	1	5	8	5	5	1	1	5	7	1	5	7	2	5	0	5
6	7	1	6	8	6	6	0	2	6	7	1	6	7	2	6	0	6
7	7	1	7	7	7	7	0	3	7	6	1	7	6	2	7	0	7
8	7	1	8	7	8	8	0	4	8	5	1	8	6	2	8	0	8
9	6	1	9	6	9	9	0	5	9	5	1	9	5	2	9	0	9
10	6	1	10	6	9	10	0	6	10	5	1	10	5	2	10	0	10
11	6	1	11	5	9	11	0	7	11	5	1	11	5	2	11	0	11
12	5	1	12	5	9	12	0	8	12	4	1	12	4	2	12	0	12
13	5	1	13	5	9	13	0	9	13	4	1	13	4	2	13	0	13
14	5	1	14	5	9	14	0	10	14	4	1	14	4	2	14	0	14
15	5	1	15	4	9	15	0	11	15	3	1	15	4	2	15	0	15
16	4	1	16	4	9	16	0	12	16	2	1	16	2	2	16	0	16
17	4	1	17	4	9	17	0	13	17	1	1	17	2	2	17	0	17
18	4	1	18	4	9	18	0	14	18	1	1	18	1	2	18	0	18
19	4	1	19	3	9	19	0	15	19	0	1	19	1	2	19	0	19

Zs The storage capacity at the beginning of routing in a year (Zone)

Ze The storage capacity at the end of routing in a year (Zone)

* No. of months of failure

Table 6.2 .... Continued

1971-72			1972-73			1973-74			1974-75			1975-76			1976-77			1977-78			1978-79			1979-80			1980-81			1981-82			No. of months	Probability
Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	Zs	*	Ze	of failure	of failure
0	3	0	0	9	0	0	3	0	0	11	0	0	7	0	0	8	0	0	4	0	0	8	0	0	10	0	0	3	0	0	8	0	137	0.476
1	3	1	1	9	0	1	3	0	1	10	0	1	5	0	1	8	0	1	2	1	1	6	0	1	10	1	1	3	1	1	7	1	123	0.427
2	1	2	2	8	0	2	2	0	2	10	0	2	4	0	2	8	0	2	2	2	2	5	1	2	10	2	2	2	2	2	7	1	110	0.382
3	0	3	3	8	0	3	0	1	3	10	0	3	4	0	3	8	0	3	1	3	3	5	1	3	8	2	3	0	3	3	6	1	96	0.333
4	0	4	4	7	0	4	0	2	4	10	0	4	4	0	4	8	0	4	0	4	4	5	1	4	8	2	4	0	4	4	6	1	90	0.313
5	0	5	5	7	0	5	0	3	5	10	0	5	3	0	5	8	0	5	0	5	5	5	1	5	8	2	5	0	5	5	5	1	85	0.295
6	0	6	6	6	0	6	0	4	6	10	0	6	3	0	6	8	0	6	0	6	6	5	1	6	8	2	6	0	6	6	5	1	81	0.281
7	0	7	7	6	0	7	0	5	7	10	0	7	1	0	7	7	0	7	0	7	7	3	1	7	8	2	7	0	7	7	5	1	73	0.253
8	0	8	8	6	0	8	0	6	8	9	0	8	1	0	8	6	0	8	0	8	8	2	1	8	8	2	8	0	8	8	4	1	67	0.233
9	0	9	9	5	0	9	0	7	9	9	0	9	0	1	9	6	0	9	0	9	9	2	1	9	8	2	9	0	9	9	4	1	62	0.215
10	0	10	10	5	0	10	0	8	10	9	0	10	0	2	10	5	0	10	0	10	10	1	1	10	7	2	10	0	10	10	4	1	58	0.201
11	0	11	11	5	0	11	0	9	11	7	0	11	0	3	11	5	0	11	0	11	11	1	1	11	7	2	11	0	11	11	3	1	54	0.188
12	0	12	12	5	0	12	0	10	12	7	0	12	0	4	12	5	0	12	0	12	12	0	2	12	7	2	12	0	12	12	2	1	49	0.170
13	0	13	13	4	0	13	0	11	13	7	0	13	0	5	13	4	0	13	0	13	13	0	3	13	6	2	13	0	13	13	1	1	45	0.156
14	0	14	14	3	0	14	0	12	14	6	0	14	0	6	14	4	0	14	0	14	14	0	4	14	6	2	14	0	14	14	0	1	41	0.142
15	0	15	15	3	0	15	0	13	15	6	0	15	0	7	15	4	0	15	0	15	15	0	5	15	6	2	15	0	15	15	0	1	39	0.135
16	0	16	16	2	0	16	0	14	16	6	0	16	0	8	16	3	0	16	0	16	16	0	6	16	5	2	16	0	16	16	0	2	32	0.111
17	0	17	17	2	0	17	0	15	17	6	0	17	0	9	17	2	0	17	0	17	17	0	7	17	5	2	17	0	17	17	0	3	30	0.104
18	0	18	18	1	0	18	0	16	18	5	0	18	0	10	18	0	0	18	0	18	18	0	8	18	5	2	18	0	18	18	0	4	24	0.083
19	0	19	19	1	0	19	0	16	19	5	0	19	0	11	19	0	0	19	0	19	19	0	9	19	5	2	19	0	19	19	0	5	21	0.073

Zs The storage capacity at the beginning of routing in a year (Zone)
Ze The storage capacity at the end of routing in a year (Zone)
* No. of months of failure

Table 6.3 Tally Sheet for Transition Matrix in Gould's procedure

Z_t (Beginning of year); rows: Z_{t+1} (End of year)

Zone	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	24	8	6	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
1	0	16	5	6	5	5	4	4	4	5	4	4	3	3	3	3	2	2	2	2
2	0	0	13	4	4	3	4	3	3	3	4	3	4	3	3	3	4	3	3	3
3	0	0	0	10	2	2	1	1	0	0	0	1	0	1	1	0	0	1	0	0
4	0	0	0	0	9	1	1	1	1	0	0	0	1	0	1	1	0	0	1	0
5	0	0	0	0	0	9	1	1	1	1	0	0	0	1	0	1	1	0	0	1
6	0	0	0	0	0	0	9	1	1	1	1	0	0	0	1	0	1	0	0	0
7	0	0	0	0	0	0	0	9	1	1	1	1	0	0	0	1	0	1	0	0
8	0	0	0	0	0	0	0	0	9	1	1	1	1	0	0	0	1	0	1	0
9	0	0	0	0	0	0	0	0	0	9	2	2	2	2	1	1	1	2	1	2
10	0	0	0	0	0	0	0	0	0	0	8	1	1	1	1	0	0	0	1	0
11	0	0	0	0	0	0	0	0	0	0	0	8	1	1	1	1	0	0	0	1
12	0	0	0	0	0	0	0	0	0	0	0	0	8	1	1	1	1	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	1	1	1	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	1	1	1	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	1	1	2
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1	1	1
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8

Table 6.4 Computation of Steady State Matrix (The Storage Initial Empty)

Transition Matrix																					The storage initial empty		Steady State
1.000	0.333	0.250	0.167	0.167	0.167	0.167	0.167	0.167	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125		1		1
0.000	0.667	0.208	0.250	0.208	0.208	0.167	0.167	0.167	0.208	0.167	0.167	0.125	0.125	0.125	0.125	0.083	0.083	0.083	0.083		0		0
0.000	0.000	0.542	0.167	0.167	0.125	0.167	0.125	0.125	0.125	0.167	0.125	0.167	0.125	0.125	0.125	0.167	0.125	0.125	0.125		0		0
0.000	0.000	0.000	0.417	0.083	0.083	0.042	0.042	0.000	0.000	0.000	0.042	0.000	0.042	0.042	0.000	0.000	0.042	0.000	0.000		0		0
0.000	0.000	0.000	0.000	0.375	0.042	0.042	0.042	0.042	0.000	0.000	0.000	0.042	0.000	0.042	0.042	0.000	0.000	0.042	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.375	0.042	0.042	0.042	0.042	0.000	0.000	0.000	0.042	0.000	0.042	0.042	0.000	0.000	0.042		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.375	0.042	0.042	0.042	0.042	0.000	0.000	0.000	0.042	0.000	0.042	0.000	0.000	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.375	0.042	0.042	0.042	0.042	0.000	0.000	0.000	0.042	0.000	0.042	0.000	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.375	0.042	0.042	0.042	0.042	0.000	0.000	0.000	0.042	0.000	0.042	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.375	0.083	0.083	0.083	0.083	0.042	0.042	0.042	0.083	0.042	0.083	X	0	=	0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.042	0.042	0.042	0.042	0.000	0.000	0.000	0.042	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.042	0.042	0.042	0.042	0.000	0.000	0.000	0.042		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.042	0.042	0.042	0.042	0.000	0.000	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.042	0.042	0.042	0.000	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.042	0.042	0.042	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.042	0.042	0.083		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.042	0.042	0.042		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.042	0.000		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.042		0		0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333		0		0

Table 6.5 Combining Steady State Probability with the conditional failure probability in Gould's procedure

Zone (1)	Probability of starting in a particular zone (steady state) (2)	Conditional Probability of failure in any month within any year for that zone (3)	Product of Probabilities (4) = (2) x (3)
0	1	0.476	0.4757
1	0	0.427	0.0000
2	0	0.382	0.0000
3	0	0.333	0.0000
4	0	0.313	0.0000
5	0	0.295	0.0000
6	0	0.281	0.0000
7	0	0.253	0.0000
8	0	0.233	0.0000
9	0	0.215	0.0000
10	0	0.201	0.0000
11	0	0.188	0.0000
12	0	0.170	0.0000
13	0	0.156	0.0000
14	0	0.142	0.0000
15	0	0.135	0.0000
16	0	0.111	0.0000
17	0	0.104	0.0000
18	0	0.083	0.0000
19	0	0.073	0.0000
		Σ	0.4757

CHAPTER 7
SUMMARY AND CONCLUSION

Sizing of storage and diversion capacity for the purpose of water utilisation is an important component of water resources development. The practice followed in India is to plan a project for a target demand of not more than the yield of river corresponding to 75% dependability on annual basis (with associated temporal distribution) and then test the performance of the system so planned to ensure 75% success of the project. Thus ***the two concepts namely planning for utilization 75% dependable yield and planning to achieve 75% success of the project are two different concepts.***

Prevalent criteria for irrigation planning have several drawbacks as given below.

- Planning is based on annual reliability only. Seasonal reliability is also important, as crops having different economic value to farmers and the society are grown in different seasons.
- Quantum of failure (water deficit), time length of failure, period of failure vis a vis planned growth, crop specific failure (sustenance crop, cash crop), randomness and sequential failure are not reflected in the prevalent criteria. Similarly spatial distribution of reliability in head reach, middle reach and tail reach occurs due to existing maldistribution practices.
- Region specific characteristics such as drought proneness, differences in hydrologic characteristics of catchment and location of storage site (upper catchment or terminal site of basin) may necessitate adoption of different planning criteria.

Analysis of Within Year and Carry Over Storage

Variation in monthly storages of seven existing reservoirs in India has been examined to compare capacity utilisation pattern based on ten year data.

The analysis shows that for within year reservoirs serving the purpose of irrigation (as single purpose or as one of the purpose in multi purpose reservoir scheme)

(a) annual depletion is large (b) year to year variability of minimum storage attained is small and (c) except for bad years reservoirs attain near full condition.

But similar conclusion cannot be arrived at for a single purpose hydropower scheme planned as "within year storage" scheme. It is because power generation depends not only on discharge but also on head available for power generation. Therefore it is not necessary to deplete the reservoir for 90% dependable power generation if power generation is the only purpose of reservoir.

Considerable quantity of live storage is available in carry over storage schemes even at minimum annual storage condition compared to "within year" storage schemes. Variability of the annual minimum storages over the years is large and for a large number of years, the near full condition is not achieved as compared to "within year" storage.

Synthesis Yield Series of Mahanadi river at Manibhadra site

Yield series of Mahanadi river at Manibhadra dam site has been synthesised and dependability of inflows analysed and compared with previous studies. The purpose was to adopt an appropriate yield series for reservoir simulation study.

Concurrent data on monthly runoff at Hirakud and yield at Tikarapara from catchment between Hirakud and Tikarapara for the monsoon months were used to develop best-fit regression equations for each month. Monsoon yield at Manibhadra dam site is computed from the computed monsoon yield at Tikarapara in proportion to the catchment area.

From this, the yield of intercepted catchment (3240 km^2) by the Medium Projects between Hirakud and Manibhadra (in proportion to catchment area) are deducted to get yield of free catchment and to this yield of free catchment, Hirakud spill, power release and assumed 20% regeneration from Hirakud irrigated area have been added to find out yield at Manibhadra dam site at the initial stage.

The non-monsoon yield at Tikarapara has been computed from the available record at Tikarapara from the period of 1972 to 1982. Percentile relationship between the total monsoon yield and total non-monsoon yield has been found out from the above observed period. The total average non-monsoon yield in term of percentage of total monsoon yield was found out. Again for each individual month for the period

1972 to 1982, the average figures for non-monsoon yield was found out. Thus, for each individual month for the same period the average figures for non-monsoon yield in the terms of percentage yield was found out from already calculated percentile total non-monsoon yield.

Dependability Analysis

The estimated annual yields of 80% dependability (2856.89 Th. ha.m) and 70% dependability (3563.54 Th. ha.m) are within 95% confidence limits of 75% dependable flow (4059.26 Th. ha.m to 2350.15 Th. ha.m). ***Similarly estimated 65% dependable flow (3894.47 Th. ha.m) is within 95% confidence limits of 75% dependable flow (4059.26 to 2350.15 Th. ha.m)*** and estimated 60% dependable flow (4227.11 Th. ha.m) is within 95% confidence limits of 70% dependable flow (4391.67 Th. ha.m to 2735.41 Th. ha.m). In other words, ***water utilisation planning with 70%, 65% or 60% dependable flows (estimated) may in reality have higher dependability upto 80%, 75%, 70% respectively. This aspect also needs to be kept in view while planning for dependable utilisation of flows as per prevailing procedure.***

Monthly flow duration curves have been used to estimate monthly yields in hypothetical years of 75%, 70% and 60% dependable monthly flows. These dependable monthly yields of hypothetical years have been compared with actual monthly yields obtained in 75%, 70% and 60% dependable years (1966-67, 1969-70, and 1976-77). It is generally thought that dependable yields in hypothetical years of various dependability are too conservative and therefore should not be used in planning. The comparison in Table 4.15 shows that it need not necessarily be so.

Therefore ***while planning for dependable water utilisation on the basis of actual monthly flows in 75% dependable year, the coefficient of variability of flows in each month should also be taken into account. Dependable flows of hypothetical years should be used unless estimates happen to be too conservative.***

It is also observed that annual flow series shows periodicity over the years. It will be useful to carry out analysis of periodicity using upto date data so that the same is taken into consideration in generation of series and its use in reservoir planning and operation.

Storage – Withdrawal – Reliability Analysis

Synthesised monthly inflows at Manibhadra dam site were used in simulation study. In the project report proposed storage capacity is 580 Th. ha.m and annual irrigation withdrawal is 1650 Th. ha.m. (31.2% of mean annual flow) corresponding to 75% annual dependability.

Annual reliability, time reliability, Kharif season reliability, Rabi season reliability at different annual withdrawal levels (with given monthly distribution) and for different storage capacities have been worked out. These relationships are useful in deciding trade off between irrigation withdrawal, reliability level and storage size.

According to the simulation study a reservoir of 565 Th. ha.m gross storage (including 171 Th. ha.m dead storage) or 394 Th. ha.m live storage would provide 1650 Th. ha.m of regulated irrigation water at 75% annual reliability level (75% Kharif season reliability and 79.17% Rabi season reliability). The gross storage capacity of 548 Th. ha.m (377 Th. ha,m live storage) would have been adequate to provide 79.17% reliability for irrigated agriculture in Rabi season. However annual reliability would be 65%.

Annual reliability does not appear to be a sound basis for reservoir planning as even one month failure in meeting irrigation demand of that month is considered as a failure year. 75 percent annual reliability means that the command area designed to be served by the storage scheme should not suffer for more than one year in a cycle of four years. Here, the area is assumed to suffer even if marginal deficits occur in one or more months in a year.

Seasonal reliability appears to be a better criteria as compared to annual reliability as reliable irrigation water supply may be crucial for irrigated agriculture in rabi season and not so crucial in Kharif season. It is suggested that in case of Manibhadra storage scheme, design irrigation areas could be different for Kharif season crops and Rabi season crops with Kharif design area being more and having lesser reliability (say 67%) and Rabi season area being less but higher reliability (79.17%).

Economic Parameters and Reliability

The height of the dam and therefore the cost would be more in case of dam built the basis of lower dependability. Every additional one-meter height of the aibhadra dam over that designed for 75% dependability would involve additional and additional benefit. The additional cost involved in driving the benefit of a unit ntum of water depends on the frequency and persistence of lean flow years and the remental cost of creating a unit storage. Therefore, the utilization of flows of lower endability should depend on the economic viability of impounding the additional ers to meet the anticipated deficit in subsequent lean flow years as happens in ught areas as well as environmental cost.

Cost and benefit functions have been taken from Patra, K.C. (1978). These cost nctions may not be accurate now however the same have been used to illustrate the ocedure for economic interpretation of the physical reliability parameters.

Cost of reservoir was allocated to irrigation and flood control only. The llocated cost of reservoir for irrigation was added with irrigation works cost to arrive at total cost of irrigation as a function of storage size and annual irrigation withdrawal. Irrigation benefit is evaluated as a function of annual irrigation withdrawal. Relationship between storage size, economic parameters and reliability has been worked out. Reliability analysis in economic terms has also been carried out for variation in dam height at one meter interval. Reduction in B/C ratio from reliability levels of 65% to 80% is not significant for storage upto 600 Th. ha.m (Figure 5.7). ***For a fixed annual withdrawal of 1650 Th. ha.m, change in reliability of economic parameters with change in storage height from 83.94 m to 88.94 m at one meter interval have been worked out. For 75% reliability in annual withdrawal of 1650 Th. ha.m, storage capacity of 565 Th. ha.m is adequate. The B/C ratio is 1.79. For a fixed reliability of 75%, possible annual withdrawal with increase in storage height (at interval of 1 m height) and corresponding costs and benefits were also worked out. The B/C ratio is affected marginally however net benefits increase significantly. The economic parameters would have been much better if cost of power component were not included in reservoir cost, which has been allocated between irrigation and flood control only.***

Probability Matrix Method

Reliability analysis has also been carried out using Gould's probability matrix method in view of certain assumptions/limitations of the long term simulation study. However in the probability matrix method, annual flows are assumed to be independent which may not be true for the data series of Mahanadi river which shows periodicity. Further there is no break in the data series and assumption of reservoir being full in the initial month of simulation period is also reasonable. Therefore result obtained from long term simulation study are considered to be more accurate.

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