SYSTEM STUDY OF PROPOSED GODAVARI-CAUVERY WATER TRANSFER LINK SYSTEM

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT

By

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SHANTI MANTRA

SAHANAAVAVTU, SAHANAU BHUNAKTU

SAHA VIRYAM KARVAAVAHAI

TEJASVINAH AVADHEETAMASTU, MAA VIDVISHAVAHAI

OM! SHANTI, SHANTI, SHANTI

May all of us unite together! May all of us enjoy together !

May all of us strive for great things together !

Let great minds flourish !

Let there be no misunderstandings !

The ultimate is Peace, Peace, Peace !

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation entitled, **"SYSTEM STUDY OF PROPOSED GODAVARI – CAUVERY WATER TRANSFER LINK SYSTEM"**, in partial fulfilment of the requirement for the award of the degree of Master of Technology in Water Resources Development, submitted in Water Resources Development Training Centre (WRDTC), Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out from 16th July, 2001 to 24th February, 2002 under the supervision of Dr. U.C. Chaube, Professor, WRDTC and Dr. S.K.Jain, Scientist 'F', National Institute of Hydrology (NIH), Roorkee.

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

Date: 25- 02-2002 **(NAGANATHAHALLI SIVA RAMA KRISHNA REDDY)**

CERTIFICATE

This is to certify that the above statement made by the candidate is true to the best of our knowledge.

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Dated: February 27 , 2002

(N.S.R.K.REDDY)

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SYNOPSIS

Distribution of water resources in India is highly uneven both spatially and temporally. The country's development planning shall, therefore, include conservation and development of water in the most scientific and efficient manner considering a basin / sub-basin as an hydrological unit. In such a comprehensive planning, intra-basin and inter-basin water transfer could be the possible options for sustainable development. A National Perspective Plan (NPP) comprising Himalayan and Peninsular rivers development components was framed by the Government of India and the National Water Development Agency (NWDA) was set up in 1982 to give concrete shape to the NPP after conducting detailed water balance studies. Mahanadi- Godavari- Krishna-Pennar-Cauvery –Vaigai link is the largest link system studied by NWDA with 9 links proposed for connecting 6 basins and a number of intermediate small basins. The study area pertains to Godavari-Cauvery part of this link system covering 4 basins besides 6 small basins in between.

In the present study, multi reservoir simulation for the 13 projects pertaining to Godavari-Cauvery link system has been carried out in four stages considering the ultimate development in the basins. The inflows at the reservoirs are the net inflows in the future scenario considering ultimate upstream development. In stage I of the study, sub system simulation has been carried out as per the existing/planned operation policies without considering inter basin water transfer. From this, the deficit/surplus basins could be identified. Then in stage II, optimization of performance of each reservoir is carried out through simulation considering no. of cases. The surface water balance after optimization in each basin has been arrived at. The Godavari basin is found to be surplus while the basins of Krishna, Pennar and Cauvery are found to be deficit.

There after in stage III, integrated resources planning considering conjunctive use in the water short project commands and ground water planning in the deficit tributary sub basins has been studied. ,It has been seen that Krishna basin can sustain the ultimate development from its own surface and ground water resources.The Upper Pennar sub-basin and Telugu Ganga command of Pennar basin, the Cauvery delta and five tributary sub-basins viz. Kabini, Suvarnavathi, Arkavathi, Bhavani and Amaravathi of Cauvery basin will still remain to be deficient to meet the projected needs and thus require supplementation from other basins. Finally in stage IV, inter basin water transfer links have been proposed to benefit the identified water short sub basins/ commands in three phases. The first phase of link proposal benefits the Upper Pennar sub-basin with 1757 Mm^3 of supplementation while the second phase of water transfer will provide 724 Mm^3 to the Telugu Ganga command. In the third phase, the link proposals are envisaged to divert 7540 Mm^3 to supplement Cauvery delta. Thus, it is seen that inter-linking proposals would be required to benefit the water short areas south of Godavari to ensure sustainable development in these areas, in the ultimate scenario. The deficits /surpluses arrived at from the multi-reservoir simulation study are more realistic compared to that worked out from conventional water balance studies since the simulation study takes into account net inflows and within year as well as carry over storage capacities of reservoirs in the system.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Water is the most precious gift of nature, next only to air. Its availability, in abundance, has made many countries to flourish. Water resources planning has acquired tremendous importance in countries like India, where distribution of water resources is highly uneven in both space and time. In the first two decades after independence, it was mostly individual project-wise planning. Later on, the impetus shifted to river basin planning and inter-basin supplementary planning in the overall interest of the basins, regions and the nation. Systems techniques such as simulation and optimization can play an important role in such a planning.

In our country rainfall is mostly confined to the monsoon season. As a result, some parts of the country are affected by frequent floods while some others by drought. Some rivers are blessed with enough water in excess of the needs in their basin, whereas some others are not fortunate even to meet their present needs. Creation of storage and inter-basin transfer of water from water surplus to water short regions is one option to overcome this anomaly. The basic philosophy of inter-basin transfer presumes the need to correct this natural imbalance leading to inequitable distribution of water resources.

1.2 NATIONAL PERSPECTIVE PLAN (NPP)

Suggestions for transferring surplus water from some regions to water deficit areas have been made from time to time. In the seventies the Garland Canal proposal of Capt. Dastur and the Ganga - Cauvery Canal proposal of Dr. K.L.Rao were received with considerable attention. These proposals were examined by experts from Central Water Commission and academic institutions. The Dastur Plan was found to be technically unsound and economically prohibitive and therefore was given up (IWRS 1996). Dr. K.L.Rao's proposal was observed to be grossly underestimated, requiring large blocks of power (5 to 7 Mkw) for lifting of water and had no flood control benefits (IWRS 1996). Therefore, the proposal was not pursued as such.

These proposals were, however, the stepping stones for more concrete and technically sound proposals to come later. The then Ministry of Irrigation (Now Ministry of Water Resources) formulated a National Perspective Plan (NPP) for Water Resources Development in August 1980. It comprises two components, viz.,

i) Himalayan Rivers Development; and

ii) Peninsular Rivers Development.

The main component of Peninsular Rivers Development is popularly known as "Southern Water Grid" which proposes to link Mahanadi, Godavari, Krishna, Pennar and Cauvery rivers. The distinctive feature of the NPP is that the transfer of water is essentially by gravity and only in small reaches by lifts (not exceeding 120 m). The scheme was prima-facie found to be technically feasible and economically viable (IWRS 1996)

The National water Development Agency (NWDA) was set up in 1982 by Government of India to study the feasibility of the National Perspective. The Agency has conducted water balance studies for all the 137 basins / sub-basins and at about 70 diversion points under Peninsular component considering present and projected needs (2050 AD). The studies have indicated that among peninsular rivers, Mahanadi and Godavari have sizeable surpluses of the order of 11176 Mm^3 and 15020 Mm^3 respectively after meeting the existing and projected needs of the States within these basins. As per these studies, the Krishna, Pennar and Cauvery rivers would be water deficient to the tune of 3235 Mm^3, 3820 Mm^3 and 16118 Mm^3 respectively (NCIWRDP 1999). The NWDA then came up with the revised proposal of Mahanadi – Godavari – Krishna – Pennar – Cauvery – Vaigai link system to utilize the surplus water of Mahanadi and Godavari in the water short basins down south.

In the present dissertation study, a part of this 'Southern Water grid' from Godavari to Cauvery has been taken up for system study.

1.3 NEED FOR SYSTEM STUDY ON INTER-BASIN WATER TRANSFER

Inter-basin transfer of water is an important and outstandingly large complex program of water management. NWDA has firmed up the NPP proposals based on sub-basin wise water balance studies. The water balance studies for the sub-basins / basins in Peninsular component have been completed by NWDA by the year 1990 considering the data available up to 1982-83.

These broad studies estimate the deficit / surplus based on consideration of annual water availability in a 75% dependable year and projected needs (2050 AD) for different purposes. Such studies do not consider the performance reliability of the system over a long period and also do not consider the effect of carry over capacities and operation policies of the major reservoirs in the system in making up the deficit or augmenting the surplus.

The system studies are required to evaluate the performance of the system over a long period duly considering the storage capacities and operation policies of major reservoirs for meeting various demands at desired degrees of reliability. Computer simulation models and systems analysis provide more refined and realistic studies compared to the dependable year water balance studies. Computer simulation models are required for intelligent and coordinated operation of a number of storage reservoirs already built or under construction in each basin. The National Commission for Integrated Water Resources Development, Government of India, Ministry of Water Resources in its report (NCIWRD 1999) has also emphasized the need for systems analysis of Inter-basin water transfer projects.

Link system: In the present dissertation, systems analysis of the proposed Godavari - Krishna - Pennar - Cauvery water transfer link system in Peninsular India, using a multi-reservoir simulation model has been undertaken. The link system consisting of seven inter-basin water transfer links are discussed in detail in Chapter: 3.

1.4 OBJECTIVES OF THE STUDY

The prime objective of the present study is to carry out multi - reservoir simulation for the existing, ongoing and proposed reservoirs pertaining to the Godavari – Krishna – Pennar – Cauvery link system to ascertain the necessity and extent of diversion from one basin to another for optimum water resources development of the region.

In order to achieve above mentioned objective, the study comprises of following tasks (stages.)

1. To carry out the long-term simulation for integrated operation of the reservoirs in each basin pertaining to the link system and finding out the operational reliabilities.
2. Optimization through simulation studies for each of these reservoirs considering the water utilization under the projects and downstream committed releases and also fixing

up the firm power and appropriate release pattern. Quantification of surface water surplus / deficit in each basin based on optimal reservoir operation policy.

3. Consideration of groundwater in meeting irrigation demands in surface water deficit basins identified above (stage II) and working out the net deficits and their locations.
4. Quantification of link diversions from surplus basins to deficit basins identified in stage III. Study the effect of the diversions on the performance of the reservoirs in each basin.

1.5 ORGANISATION OF THE THESIS

This dissertation work has been arranged in seven chapters as detailed below:

Chapter 1: INTRODUCTION

The basic philosophy of water transfer, the National Perspective Plan and the objectives of the study are discussed.

Chapter 2: MULTI-RESERVOIR SIMULATION MODEL

The basic principles of reservoir simulation, literature review, formulation of the mathematical model for multi-reservoir simulation and the details of sample input and output files are presented.

Chapter 3: THE GODAVARI – KRISHNA – PENNAR – CAUVERY LINK SYSTEM

The different river basins, the diversion points and the individual link projects of the inter-basin water transfer link system are discussed.

Chapter 4: STUDY APPROACH

The water transfer link system is decomposed into different sub-systems. There are four stages of study viz.

-Simulation study of each sub-system as per existing / planned operation policies to ascertain water deficit / surplus.

-Simulation study for optimizing sub-system performance.

-Simulation study considering groundwater in meeting irrigation water shortages and quantifying net deficits.

- Simulation study of each sub-system considering inter-basin water transfer in phases.

Chapter 5: SIMULATION STUDY OF SURFACE WATER USE WITHOUT INTER-BASIN TRANSFER

Multi-reservoir simulation model is applied for each of the four basins without considering inter-basin water transfer and groundwater use. Sub-system performance is optimized.

Chapter 6: SIMULATION STUDY CONSIDERING GROUNDWATER AND INTER-BASIN WATER TRANSFER

Groundwater use for meeting irrigation water deficits in project command areas is considered and simulation study of the deficit basins is carried out. Further, the net deficits in tributary sub-basins after considering groundwater is worked out. Based on this, Inter-basin water transfer is quantified and long term simulation is carried out to study the effect of inter-basin water transfer.

Chapter 7: CONCLUSIONS AND RECOMMENDATIONS

The conclusions from the analyses carried out and the recommendations for further improvement in the study are discussed.

MULTI - RESERVOIR SIMULATION MODEL

2.1 GENERAL

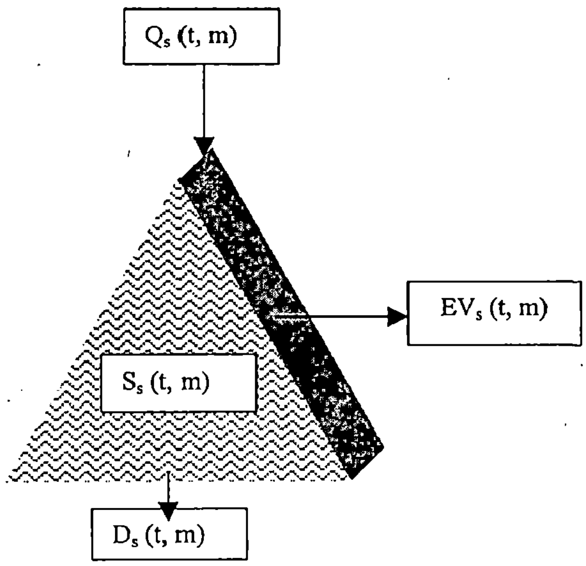
System engineering techniques have the potential of significantly improving the water resources planning and management. Simulation and Optimization are the most commonly used system techniques for evaluating the performance for a water resources system and problems associated with operation of reservoirs.

Simulation is the most widely used method for evaluating alternatives due to its mathematical simplicity and versatility (BIS 1994). The simulation model depicts the essence of a system or activity without actually attaining reality itself.

2.2 PRINCIPLES OF SIMULATION

The standard operating policy **(Fig:2.1)** in a simulation model is adopted under the important assumption that each reservoir operates independently (Lenton et al 1977).

FLOW VARIABLES



Let

V_s	= Active reservoir storage capacity
Q_s (t, m)	= Inflow to reservoir in period m of year t.
S_s (t, m)	= Reservoir storage at beginning of the period.
EV_s (t, m)	= Reservoir evaporation during the period.
D_s (t, m)	= Reservoir release.

OPERATING POLICY FOR MONTH 'm'

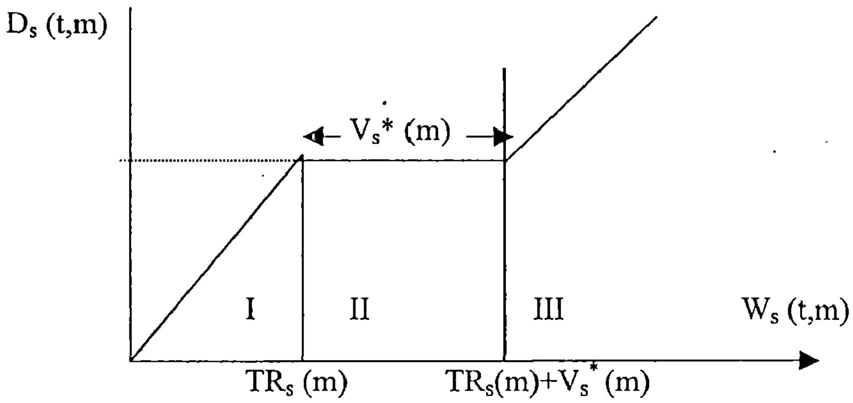


Fig :2.1 Reservoir standard operating policy

Available water W_s (t, m) $= S_s(t, m) + Q_s(t, m) - EV_s(t, m)$

Available Capacity V_s^* (m) $= S_{max}(m) - S_{min}(m)$

Let TR_s (m) = Target reservoir release during the period 'm'

Three cases can be visualized for determining the releases on the basis of available water W_s (t, m).

Case-I Water availability is insufficient to meet the target release requirement

The standard operating policy specifies that all available water will, therefore, be released from the reservoir in an effort to at least partially satisfy the demand.

Case-II Sufficient water to satisfy target release requirement

The target release requirement is met in full. All water not required for immediate use is stored in the reservoir for future use.

Case-III Water available exceeds demands and active storage capacity

All water in excess of active storage capacity is released from the reservoir.

The above considerations can be expressed in the following relations for the reservoir release $D_s(t, m)$.

$$D_s(t,m) = \begin{cases} W_s(t, m); & W_s(t,m) <= TR_s(m) \\ TR_s(m); & TR_s(m) < W_s(t,m) <= TR_s(m) + V_s \\ W_s(t, m) - V_s; & W_s(t,m) > TR_s(m) + V_s \end{cases}$$

Storage $S_s(t, m+1)$ at the beginning of the following period (m+1) can be represented by

$$\text{Storage } S_s(t, m+1) = \begin{cases} 0; & W_s(t, m) <= TR_s(m) \\ W_s(t,m) - TR_s(t,m); & TR_s(t,m) < W_s(t,m) <= TR_s(m) + W_s(t,m) \\ V_s; & W_s(t, m) > TR_s(m) + V_s \end{cases}$$

Reservoir storage is to lie within certain minimum and maximum storage levels, which can vary from period to period.

$$S_{min}(m) <= S_s(t, m) <= S_{max}(m)$$

This has the effect of reducing the value of V_s to V_s*. Ideally $S_{min}(m)$ should be set at a high level in the period preceding periods of low flow and $S_{max}(m)$ should be set at a low level in the periods preceding periods of high flow, when flooding may be a problem.

These are the basic principles that govern the simulation model of a reservoir system. In a simulation model, a fixed time interval is selected and the model examines the state of the system (flows, storage volumes, demands etc.) at successive time intervals. A judicious choice of the time increment is necessary keeping in view the desired accuracy and required computation time.

2.3 LITERATURE REVIEW:

A large number of models, generalized as well as system specific, have been developed during the last two decades. Some popular models include HEC-3 and HEC-5 of Hydrologic Engineering Centre, SIMYLD-II of Texas Water Development Board, the ACRES (Sigvaldason, 1976), the RESER (Simonovic1992) and the IRIS (Iris 1990).

Three criteria for evaluating the possible performance of water resources systems, viz., how likely a system is to fail (reliability), how quickly it recovers from failure (resiliency) and how severe are the consequences of failure (vulnerability) were discussed by **Hashimoto et al.** (1982). These criteria can be used to assist in the evaluation and selection of alternative design and operating policies for a wide variety of water resources projects.

Yeh (1985) reviewed the state-of-the- art of the mathematical models developed for reservoir operations including simulation. Simulation is different from a mathematical programming technique. Mathematical programming techniques find an optimum decision for system operation meeting all system constraints while maximizing or minimizing some objective. On the other hand, a simulation model provides the response of the system for certain inputs, which include decision rules, so that a decision maker is enabled to examine the consequences of various scenarios of an existing system or a new system without actually building it

Razavian et al. (1990) developed simulation, screening and optimization procedures to analyze multi-purpose water development opportunities for a complex river system. **Jain et al.** (1998) studied the operation of the Sabarmati system (India), consisting of four reservoirs and three diversion structures. The function of the system is to provide a municipal and industrial water supply, irrigation and flood control. For conservation and regulation of the system rule curves were derived for various reservoirs. Using the simulation analysis, the rule curves were fine-tuned to achieve the targets to the maximum possible extent.

The National Institute of Hydrology (NIH 1996-97) developed a generalized software for reservoir analysis as source code for the reservoir simulation program such as HEC-3, HEC-5, SIMYLD-II, ACRES, RESER and IRIS are not available.

2.4 MATHEMATICAL MODEL

A mathematical model has been formulated for simulation of the multi-reservoir nodes pertaining to the link system under study, for conservation operation. In all, there are 13 nodes in the link system situated in four basins, of which 10 are storage nodes. The nodes serve different purposes, viz., domestic, irrigation and power generation. Three non-storage nodes and one storage node cater to only irrigation, while six storage nodes serve both irrigation and power needs. One storage node is to meet domestic and irrigation needs- and two storage nodes are multi-purpose projects serving domestic, irrigation and power purposes. Software for Reservoir Analysis (SRA) developed by National Institute of Hydrology, Roorkee was modified to suit the link system configuration taken up for the study.

2.4.1 Concept and Capabilities

Concept: In the model, highest priority is given to the water supply demand for domestic purposes and the minimum flow requirement in the d/s channel. Priority between hydropower or irrigation can be specified by the user and may change from one period to another.

The quantum of water requirement for power generation is computed based on the mean elevation during a period. Five rule curve levels have been specified viz., the upper rule level, the first middle rule level, the second middle rule level, the lower rule level and the link rule level.

The upper rule level specifies the highest level up to which a reservoir should be filled if there is sufficient inflow to the reservoir. It can be either FRL or a level below FRL. If the reservoir overtops the upper rule level, then water is spilled into the downstream river.

The middle and lower rule levels are applicable in the situation when water is scarce and full supply for various demands can not be made. If the water level falls below first middle rule level, reduced supply based on curtail factors (user specified) is made for the low priority demands viz., irrigation and power while full supply is made for higher priority demands viz., domestic and minimum flow demands.

The second middle rule level comes into effect when water is so scarce that even after curtailing release for the least priority demand, releases for other higher priority demands can not be made in full. If the water level falls below this level, there will be no supply for the least priority demand and reduced supply for the second least priority demand is made, while full supply for top priority demands is ensured.

The lower rule level is critical for water supply demands and minimum flow requirements in the downstream river. If the water level in the reservoir falls below this level, supply is made only to meet water supply and minimum flow and no release is made either for irrigation or hydropower.

The model also incorporates the water transfer component from a surplus node to a deficit node. Ten-daily / monthly link diversions and link levels are required to be specified. If the water level in the reservoir after meeting its own demands in a period is above the link level, then release is made for diversion through link.

In the model, four possibilities of water release through the power plant have been considered. For this purpose, irrigation demand has been bifurcated into two parts, one, which passes through the power plant and the other, which does not. In the first case, all the releases from the reservoir including irrigation (partial or full), water supply and minimum flow pass through power plant. In the second case, the water supply and minimum flow bypass the power plant, while in the third case, irrigation releases bypass it. In the fourth case, only minimum downstream flow requirement passes through the power plant.

Capabilities: The model computes the total demands in a period to be met from a node. Then it calculates the total available water considering local flows, flow from upstream node (releases and spills) and link diversion from any other node, if applicable. Thereafter, it operates the reservoir in accordance with the specified trial rule curves and assesses the total quantum of release. Then, it apportions the total release among different purposes as per the indicated priorities. Accordingly, it computes the power flow and power generation at the node. It also checks whether the final water level after meeting its own demands is above link level and if so, releases water for link diversion to another node. This way, it carries out the simulation for all nodes in the system for each period. Finally, it computes several performance indices viz., the time, volume and annual reliabilities, resiliency and vulnerability for the node.

The model can carry out the simulation for monthly / ten-daily (as per the option) for any number of reservoirs for any length of period, subject to the memory requirement of computer. The model is capable of detecting the errors in the input data and displays the group of data items that have been read properly. This facility is very much helpful for the user in locating and correcting that distinct data of the particular reservoir, in a large set of input data. The model is capable of taking the period wise variations in priorities as well as demands of hydropower and irrigation.

2.4.2 Formulation of Model

The formulation of the model for a typical multi-purpose storage node is given below. All demands and releases are in Mm^3.

1. Estimation of total demands

(i) Power demand (Mm^3) $P_d = (P * 3600) / (9.81 * h * \eta)$ -----------**(2.1)**

where P = power demand in MU in the month

h = effective head (average level – tail water level) * 0.99. (losses @ 1 %)

η = efficiency (0.85 is considered in the study).

(ii) Downstream node demand $D_{ds} = T_{ds} * d_f + m_f$ --------- **(2.2)**

where T_{ds} = total demand of down stream node in a period

d_f = down stream demand factor

m_f = minimum flow.

(iii) Total demand in a period $T_d = \text{Max}(P_d, d_p) + d_o$ --------**(2.3)**

where d_p = demands routed through power plant

d_o = other demands not passing through power plant.

2. Estimation of inflow

(i) inflow from upstream node $f_u = r_{ds} + r_f * r_{iu} + s_u$. --------**(2.4)**

where r_{ds} = release from upstream node to the current node.

r_f = return flow factor (fraction)

r_{iu} = irrigation release from upstream node

s_u = spill from upstream node.

(ii) Available water at a node for allocation $a_w = S_i + f_u + l_f + l_d * s_f$ --------**(2.5)**

where S_i = initial storage.

f_u = flow from upstream node (s).

l_f = flow from local catchment.

l_d = Link diversion to this node, if any.

s_f = Supply factor considering conveyance losses in link.

3. Operation of the reservoir

(i) Normal condition (enough water to meet the demands):

Release $T_r = T_d$ --------(2.6)

(ii) Average level below first middle rule level.

$Tr = I_{d2} * f_i + (P_d - m_f)* f_p + W_s$ (subject to availability of water) --------(2.7)

Where I_{d2} = irrigation demand not passing through plant.

f_i = curtail factor for reducing irrigation demands.

f_p = curtail factor for reducing power demand.

W_s = water supply demand.

(iii) Average level below second middle rule level.

If irrigation priority $T_r = I_d * f_i + W_s + m_f$ ----------(2.8)

Where I_d = Total irrigation demand.

(power priority & domestic water supply through power plant).

$T_r = \max (P_d * f_p, W_s + D_{ds})$ or ----------(2.9)

$= \max (P_d * f_p + W_s, W_s + D_{ds})$ --------(2.10)

(iv) Average level below lower rule level.

$T_r = W_s + m_f$ --------(2.11)

(v) If average level is higher than link rule level

$l_d = D_{ld}$ ---------(2.12)

where D_{ld} = demand for link diversion

4. Evaporation losses e_l

$e_l = (a_i + a_f) * e_d/2$ -----------(2.13)

where a_i = surface area (m^2) at the beginning of the period

a_f = surface area (m^2) at the end of the period.

E_d = evaporation depth (m) in the period .

5. **Final storage**

$$S_f = a_w - e_l - T_r - l_d - s \qquad \text{-----------(2.14)}$$

Where s = spill from the node

$$S_{min} \leq S_f \leq S_{max} \qquad \text{-----------(2.15)}$$

6. **Power generation in MU**

$$P_{gen} = (\ 9.81 * h * \eta * P_r\ ) / 3600 \qquad \text{---------(2.16)}$$

Where P_r = power release in Mm^3.

7. **Performance indices**

(i) Time reliability $r_t = 1 - (\ f_p / T_p\ )$ -----------(2.17)

where f_p = no. of failure periods for a particular demand

T_p = Total no. of periods.

(ii) Volume reliability $r_v = \dfrac{\sum_{i=1}^{n} r}{\sum_{i=1}^{n} d}$ -----------(2.18)

where r = release for a particular use in period i.

d = demand for a particular use in period i.

(iii) Annual reliability $r_a = 1 - (F_y / T_y)$ -----------(2.19)

where F_y = no. of failure years when annual release is less than annual demand

T_y = total no. of years considered in simulation

The flow chart of the model is given in **Fig: 2.2**. The listing of the computer program in Fortran - 77 is given at **Appendix A.**

2.4.3 Input to the Model

The input data for the model pertains to the information about each structure viz., full reservoir level, dead storage level, elevation – area - capacity table, conservation demands, evaporation depths and local inflow from the intermediate / free catchment area. Data for defining the configuration of the system and rule curves are also required to be specified.

MAIN FLOW CHART

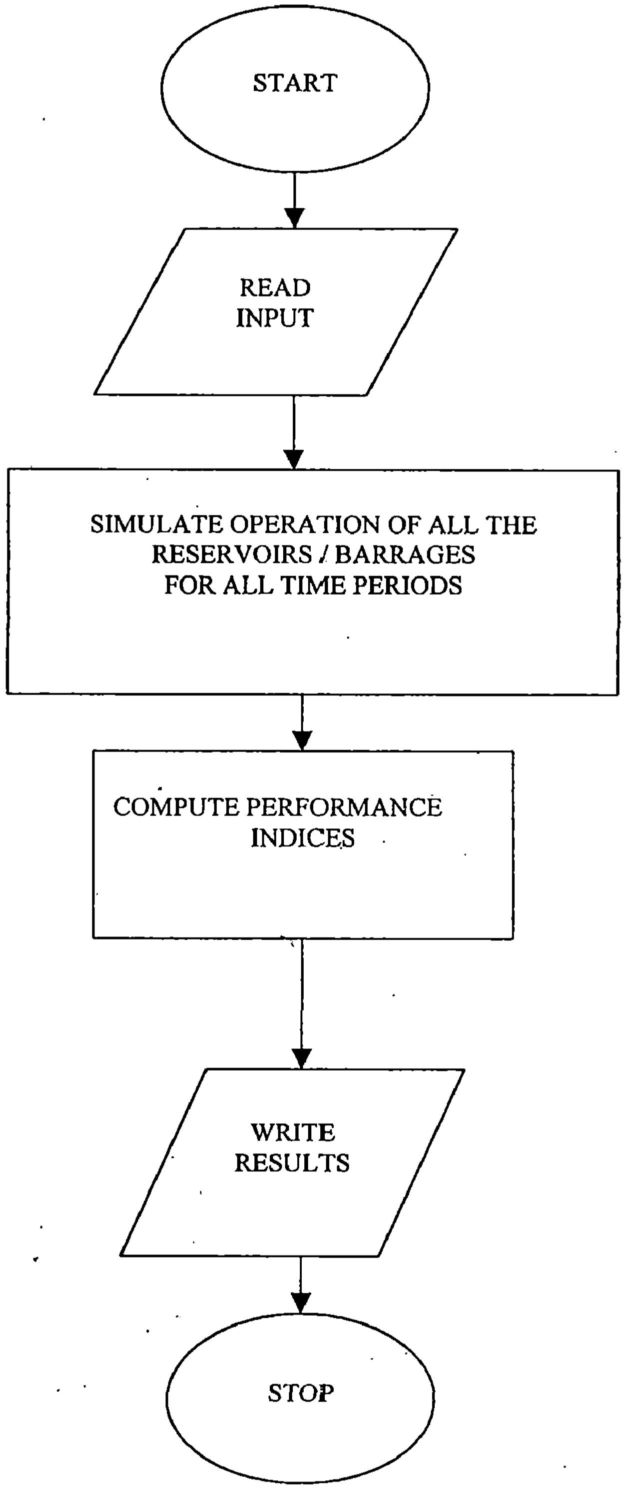


Fig:2.2 Flow chart of the Model

SUB-ROUTINE OPER (i, jm) **Fig:2.2 (contd)**

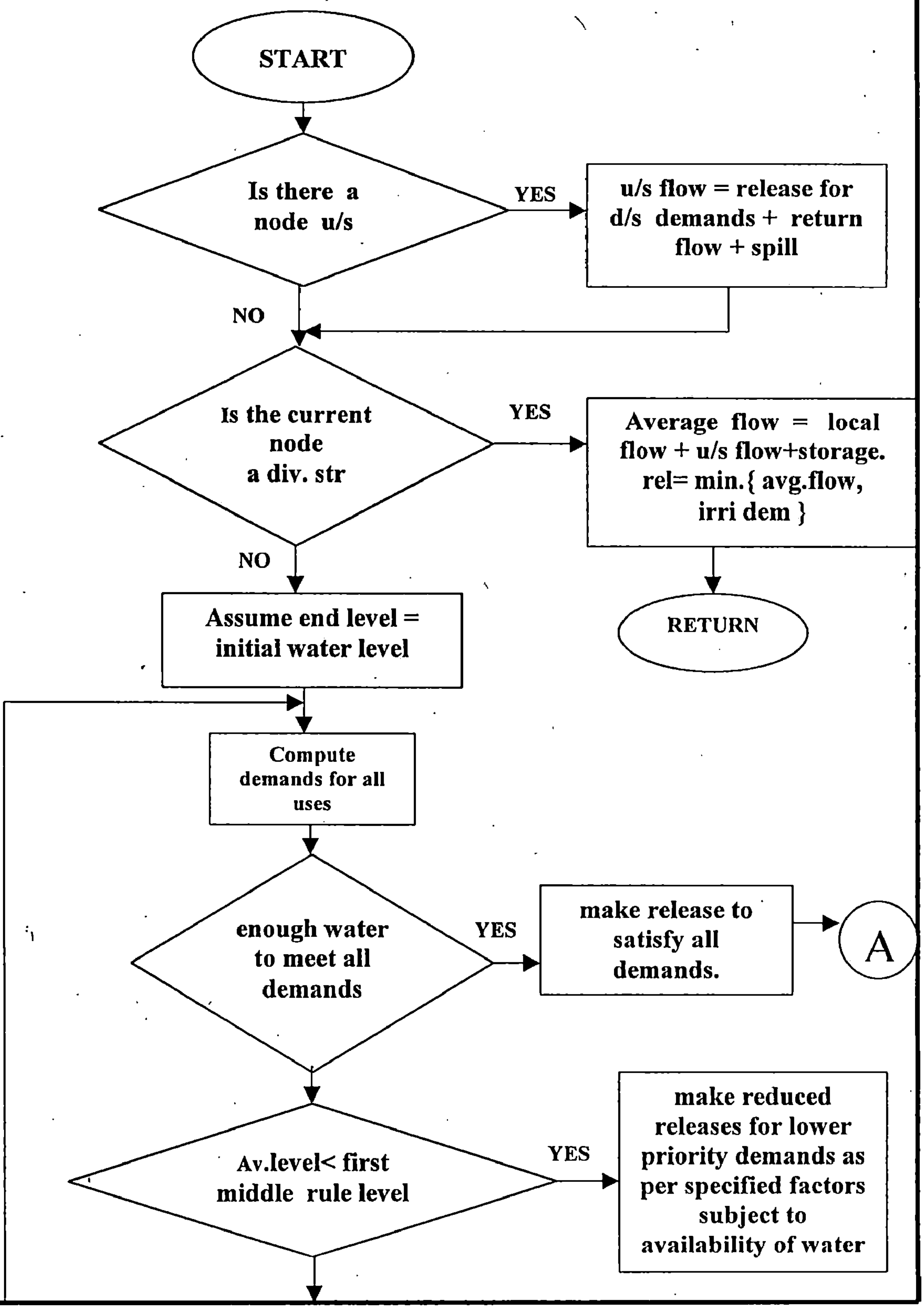
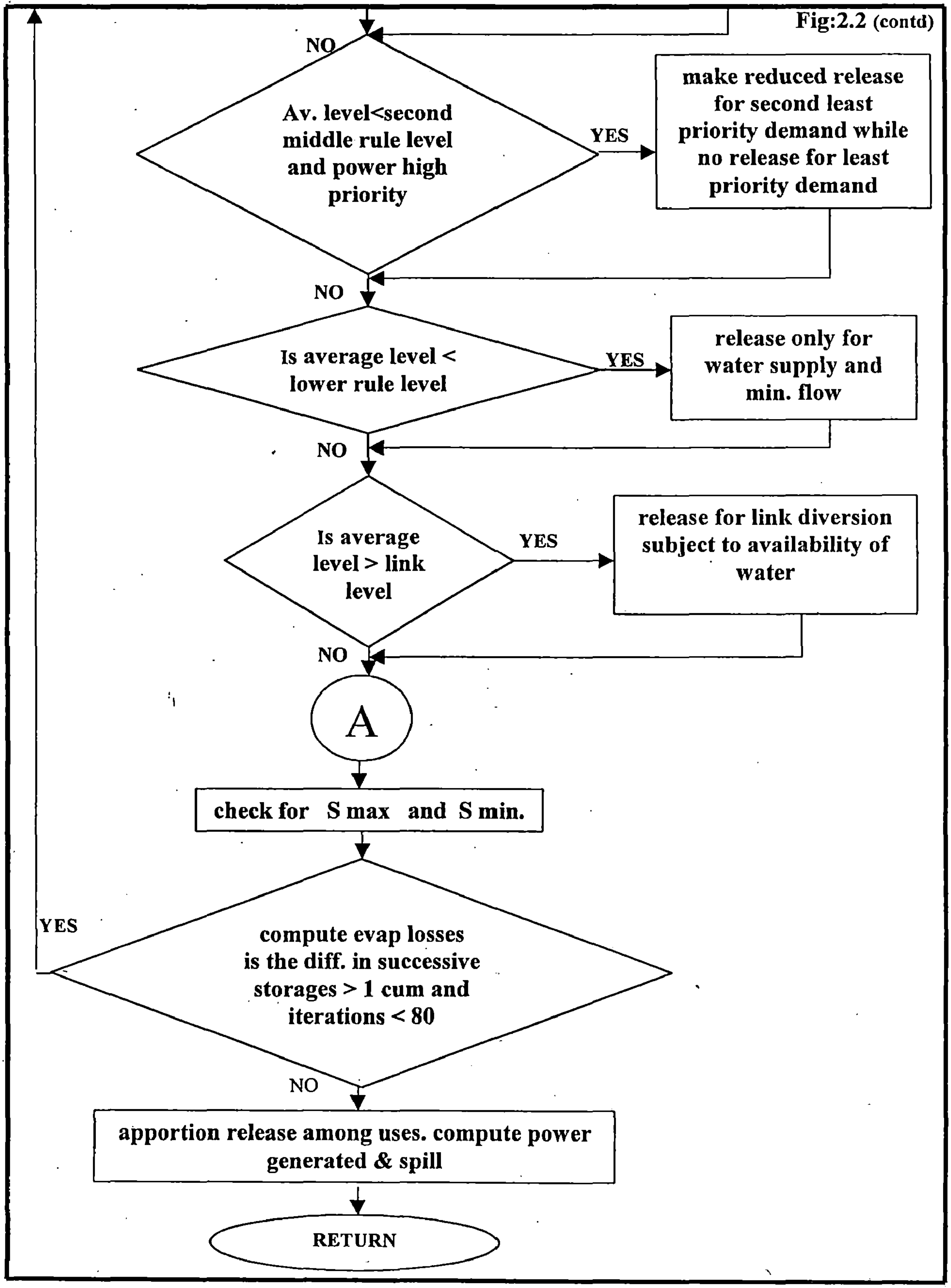


Fig:2.2 (contd)


NO
Av. level<second middle rule level and power high priority
YES
make reduced release for second least priority demand while no release for least priority demand
NO
Is average level < lower rule level
YES
release only for water supply and min. flow
NO
Is average level > link level
YES
release for link diversion subject to availability of water
NO
A
check for S max and S min.
YES
compute evap losses is the diff. in successive storages > 1 cum and iterations < 80
NO
apportion release among uses. compute power generated & spill
RETURN

For structures operated for hydropower generation, details regarding the method of water supply through the power plants, installed capacities, minimum level for power production, tail water level and efficiency of the plants are to be specified. In addition, critical factors for irrigation and hydropower, critical failure factor, options for monthly and ten-daily simulation and detailed / summary output, d/s node whose demands are to be met, d/s demand factors are required to be indicated. The input has to be entered in certain format and order to enable the model read it properly.

The required input data format and description along with a sample input data file for a storage node is given at **Annexure-I.**

2.4.4 Output of the Model

The output produced by the model has been designed to indicate the maximum amount of information from simulation and to present this information in an easily understandable way.

A detailed monthly operation table or an annual summary table for each structure is optionally prepared. For each period, the detailed operation table gives the year, month and period of operation, the initial storage, local flow, flow from upstream structure, irrigation, hydropower, downstream demands, actual releases made for these demands, power generated, link diversion, if any, spill from the structure, end level, middle and upper rule levels. The annual summary table depicts the yearly totals of all these flows, demands, releases, power generation and spills. The water supply and link demands, if any, are given on top of the tables.

The detailed output also indicates the water supply, irrigation, hydropower, link and critical failures with 'W', 'I', 'P', 'L' and 'C' respectively so that one can know as to failure for which use is taking place in a period and also which are critical periods.

A sample Annual Summary output and a Detailed Monthly output for a storage node are given at **Annexure-II.**

THE GODAVARI – KRISHNA – PENNAR – CAUVERY LINK SYSTEM

3.1 GENERAL

The study area pertains to the proposed Godavari – Krishna – Pennar – Cauvery link system in peninsular India. The system consists of the following link projects to inter connect nine storage / non-storage diversion points located in these four basins.

I GODAVARI TO KRISHNA

1. Polavaram – Prakasam Barrage(Vijayawada)
2. Inchampalli – Pulichintala
3. Inchampalli – Nagarjunasagar

II KRISHNA TO PENNAR

1. Almatti – Pennar
2. Srisailam – Pennar
3. Nagarjunasagar – Somasila.

III PENNAR TO CAUVERY

1. Somasila – Grand Anicut

Fig: 3.1 shows nine inter-basin transfer links as proposed by NWDA. Out of these, only seven links as mentioned above pertain to the study area.

In the present study, in addition to the above 9 storage and non- storage sites, three more storage sites and one non-storage site are considered for simulation. These are; Dowleswaram barrage on Godavari river (situated d/s of Polavaram reservoir), Narayanpur dam on Krishna river (d/s of Almatti reservoir) and Krishnarajasagar and Mettur dams on Cauvery river (situated u/s of Grand Anicut). These sites are important for this system study in view of the fact that Dowleswaram's committed demands are to be satisfied from Polavaram while the releases and spills from Krishnarajasagar and Mettur will add up to the inflows at Grand Anicut. Almatti dam and Narayanpur dam are the components of Upper

Krishna integrated project. Before proceeding with the actual analysis, a brief description of the basins, diversion sites and the link projects is given below so as to appreciate and understand the characteristics and issues involved in the link system.

3.2 THE BASINS

The four river basins of Godavari, Krishna, Pennar and Cauvery are important major river basins in Peninsular India. These rivers and their tributaries serve seven States viz., Maharashtra, Madhya Pradesh, Orissa, Karnataka, Andhra Pradesh, Kerala and Tamilnadu and the union territory of Pondicherry as lifeline systems.

3.2.1 The Godavari Basin

The Godavari is the largest river in Peninsular India. It rises in the Sahyadris near Triambakeswar in the Nasik district of Maharashtra. It flows for a total length of 1465 km through the States of Maharashtra and Andhra Pradesh before joining the Bay of Bengal. The basin lies between latitudes 16^0 16` N and $23^0$ 43` N longitudes 73^0 26` E and $83^0$ 07`E. The basin extends over an area of 312813 km^2, which is nearly 10 % of the total geographical area of the country. The percentages of the areas of the basin in the States of Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh and Orissa are 48.6, 20.9, 1.4, 23.4, 5.7 respectively (NWDA 1991). Important tributaries of the Godavari are the Pravara, the Purna, the Manjra, the Maner, the Penganga, the Wardha, the Pranhita, the Indravati and the Sabari. Jayakwadi project, Sriramsagar project and Cotton barrage (Dowleswaram) are the important projects existing in the basin. The proposed major projects are Bhopalpatnam, Inchampalli and Polavaram.

The surface water balance studies conducted by NWDA (basin is divided into 12 sub-basins) for the basin indicate surplus of about 15020 Mm^3 at 75 % dependability. The basin map is illustrated at **Fig: 3.2.**

3.2.2 The Krishna Basin

The river Krishna is the second largest river in the Peninsular India. The river rises in the Mahadev range of the Western Ghats near Mahabaleswar in Maharashtra. It flows for a length of 305 km in Maharashtra, 483 km in Karnataka and 612 km in Andhra Pradesh before

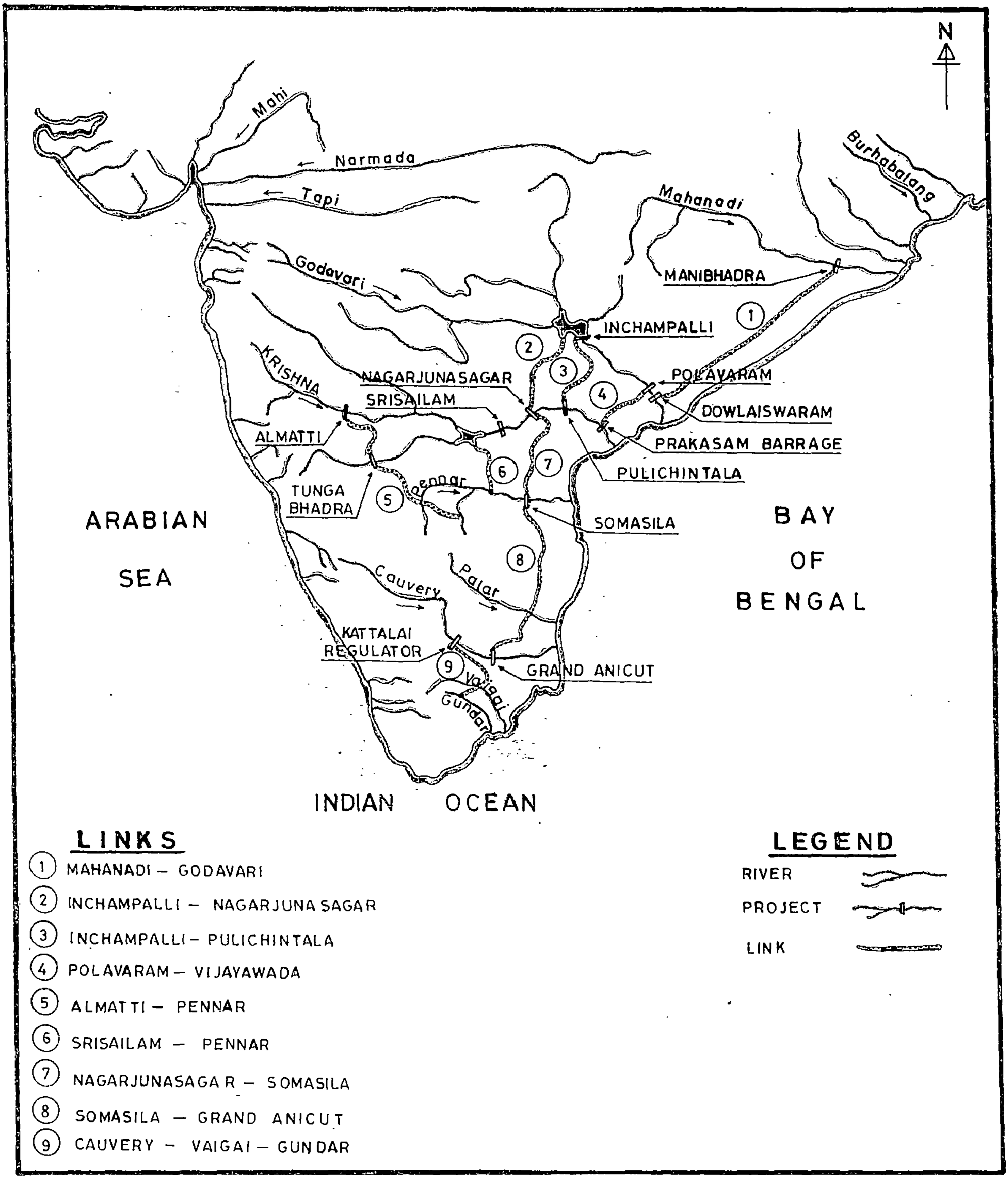


Fig 3.1-INTERLINKING PROPOSALS FOR PENINSULAR RIVERS

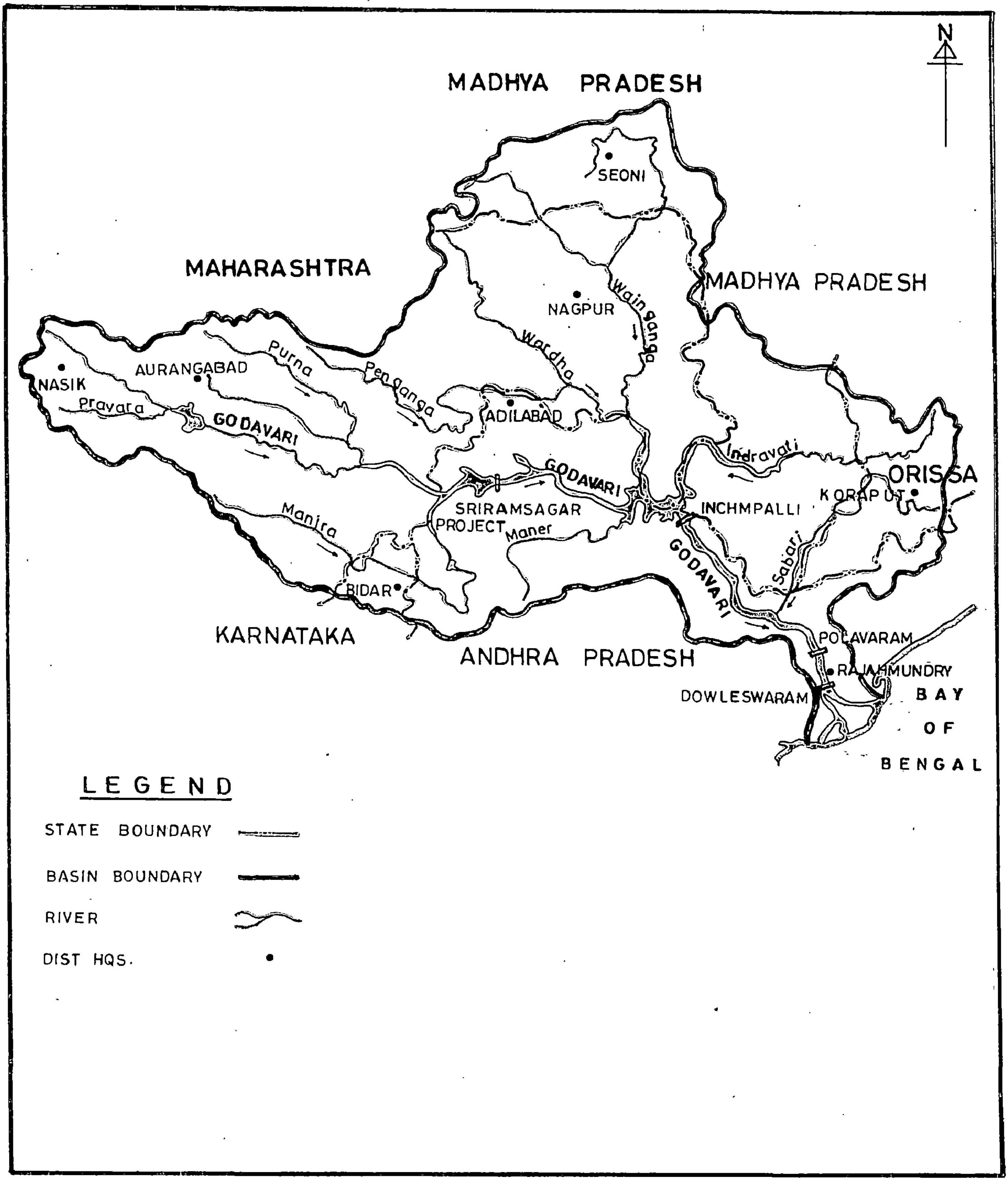


Fig 3.2 - MAP OF GODAVARI BASIN

finally out falling into the Bay of Bengal. The basin lies between latitudes 13^0 07` N and $19^0$ 20` N and longitudes 73^0 22` E and $81^0$ 10`E. The basin extends over an area of 258948 km^2, which is nearly 8 % of total geographical area of the country. The percentages of the area of the basin in the States of Maharashtra, Karnataka, and Andhra Pradesh are 26.8, 43.8, and 29.4 respectively (NWDA 1993). The principal tributaries of the Krishna are the Ghataprabha, the Malaprabha, the Bhima, the Tungabhadra, the Vedavati, the Musi, the Palleru and the Muneru. Tungabhadra, Narayanpur, Srisailam, Nagarjunasagar and Prakasam barrage are the existing major projects in the basin. Jurala and Almatti are the ongoing major projects while Pulichintala is the proposed major project.

The water balance studies by NWDA (basin is divided into 12 sub-basins) have shown that the basin will be water deficit to the tune of 3235 Mm^3 in the ultimate development scenario. The basin map is shown at **Fig: 3.3.**

3.2.3 The Pennar Basin

The Pennar river is one of the major rivers of the Indian peninsula. The river rises in the Chennakesava hills of the Nandidurg range in Kolar district of Karnataka State. The length of the river from the source to its outfall into the sea is 597 km, of which 61 km is in Karnataka and the remaining 536 km in Andhra Pradesh. The basin lies between latitudes 13^0 16` N and $15^0$ 52` N and longitudes 77^0 04` E and $80^0$ 10`E. The total catchment area is 55213 km^2, 6937 km^2 in Karnataka and 48276 km^2 in Andhra Pradesh (NWDA 1994). The principal tributaries of the river are the Jayamangali, the Kunderu, the Sagileru, the Chitravati, the Papagni and the Cheyyeru. Mylavaram and Somasila are the major existing projects in the basin.

The water balance studies of NWDA (basin is divided into 4 sub-basins) show that the basin will be deficit of the order of 3820 Mm^3 to meet its projected requirements. The basin map is illustrated at **Fig: 3.4.**

3.2.4 The Cauvery Basin

The Cauvery river is one of the major peninsular rivers which rises in the Kodagu district of Karnataka. The basin lies between latitudes 10^0 05` N and $13^0$ 30` N and longitudes

75^0 30' E and 79^0 45'E. The total length of the river from source to its out fall into Bay of Bengal is about 800 km of which, 320 km is in Karnataka, 416 km is in Tamilnadu and 64 km fall on the common boundary between these States. The catchment of the river Cauvery is 81155 km^2 spreading in 4 States of Karnataka (42.2%), Kerala (3.5%), Tamilnadu (54.1%) and Pondicherry (0.2%) (NWDA 1996). The principal tributaries of the river are the Kabini, the Suvarnavathi, the Shimsha, the Arkavathi, the Chinnar, the Palar, the Bhavani, the Noyil, the Tirumanimuttar, the Amaravathi and the Ponnanai Ar. Krishnarajasagar, Mettur and Grand Anicut are the existing major projects in the basin.

Water balance studies conducted by NWDA (basin is divided into 16 sub-basins), indicate a deficit of 16118 Mm^3 for the basin in the ultimate scenario. The basin map is given at **Fig: 3.5.**

3.3 THE PROJECTS IN THE SYSTEM

No new major reservoirs have been proposed by NWDA for the peninsular link system from Mahanadi to Vaigai. The link system is proposed in such a way that it integrates the existing, ongoing and proposed major projects by the States as a 'water grid'. In all, thirteen projects have been considered for the present study reach extending from Godavari to Cauvery of the link system. Out of these, three are in Godavari basin, six are in Krishna basin, one in Pennar basin, and the remaining three in Cauvery basin as indicated in **Table 3.1.**

Table: 3.1

PROJECTS IN THE SYSTEM

BASIN	PROJECTS
Godavari	Inchampalli, Polavaram, Dowleswaram
Krishna	Almatti, Narayanpur, Srisailam, Nagarjunasagar, Pulichintala, Prakasam barrage
Pennar	Somasila
Cauvery	Krishnarajasagar, Mettur, Grand Anicut

The line diagram of the system with all these projects is shown at **Fig.3.6**

The salient features of the projects are furnished in **Table 3.2**. Brief description of each of these projects is given as under:

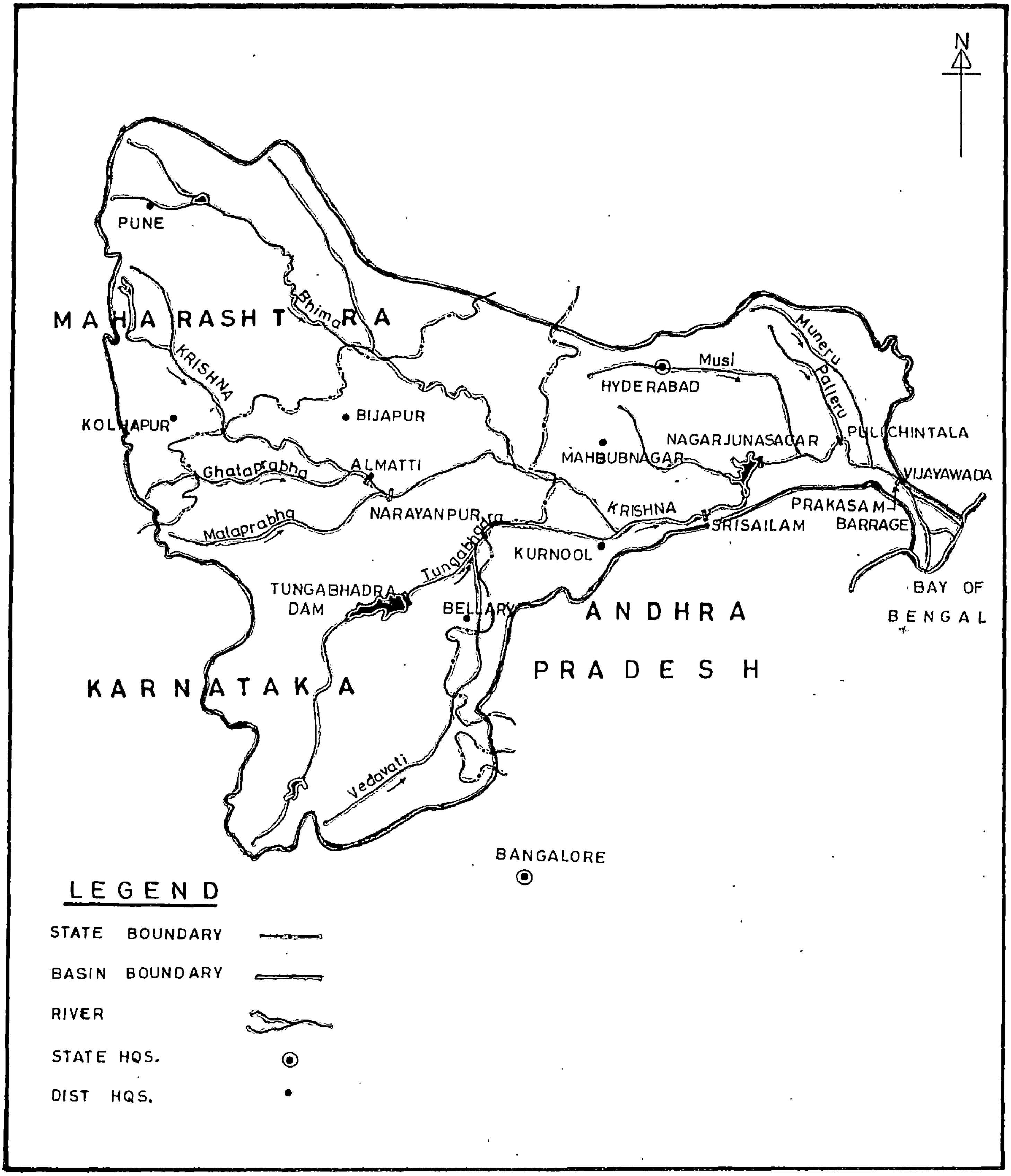


Fig 3.3 - MAP OF KRISHNA BASIN

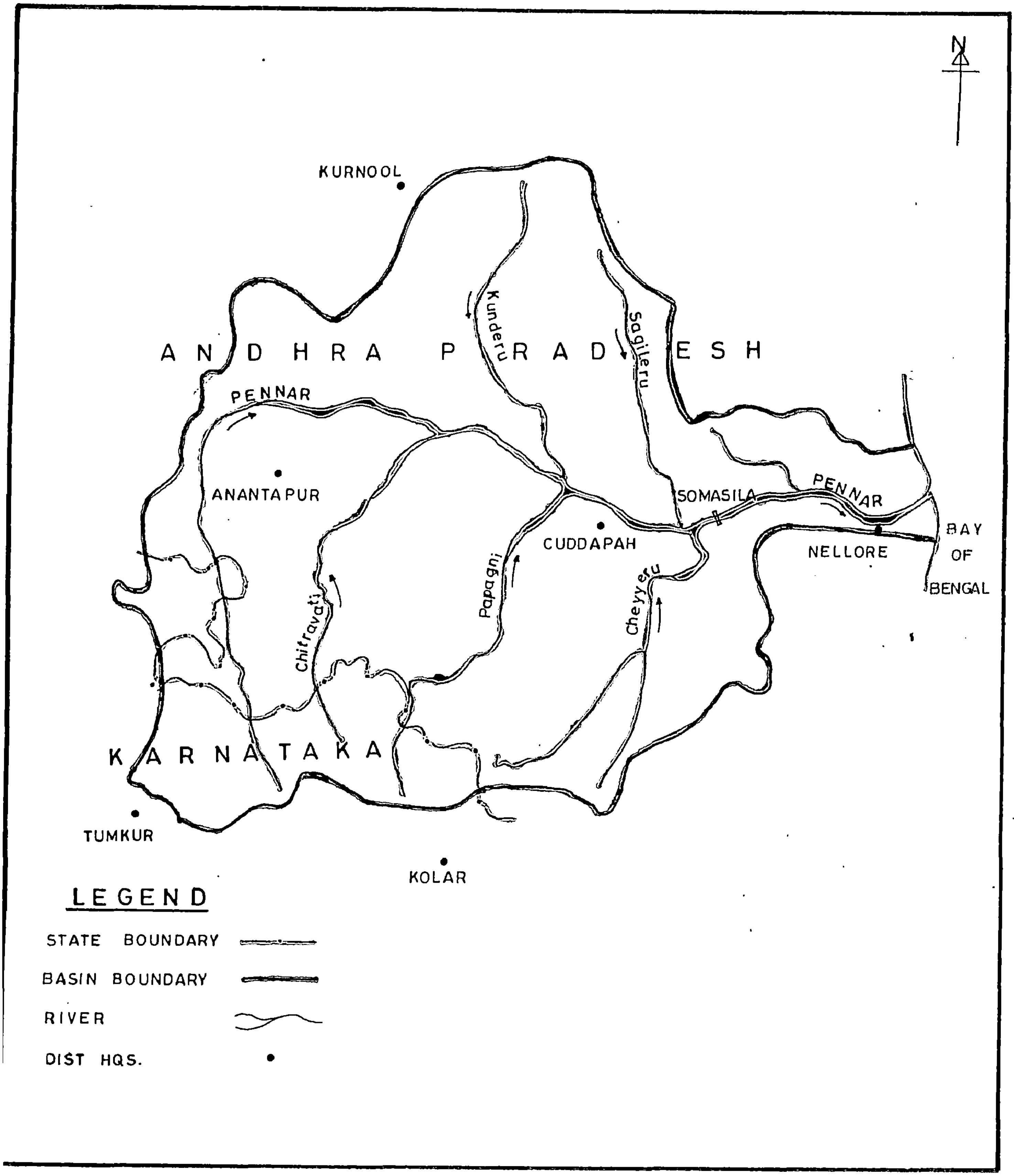


Fig 3.4-MAP OF PENNAR BASIN

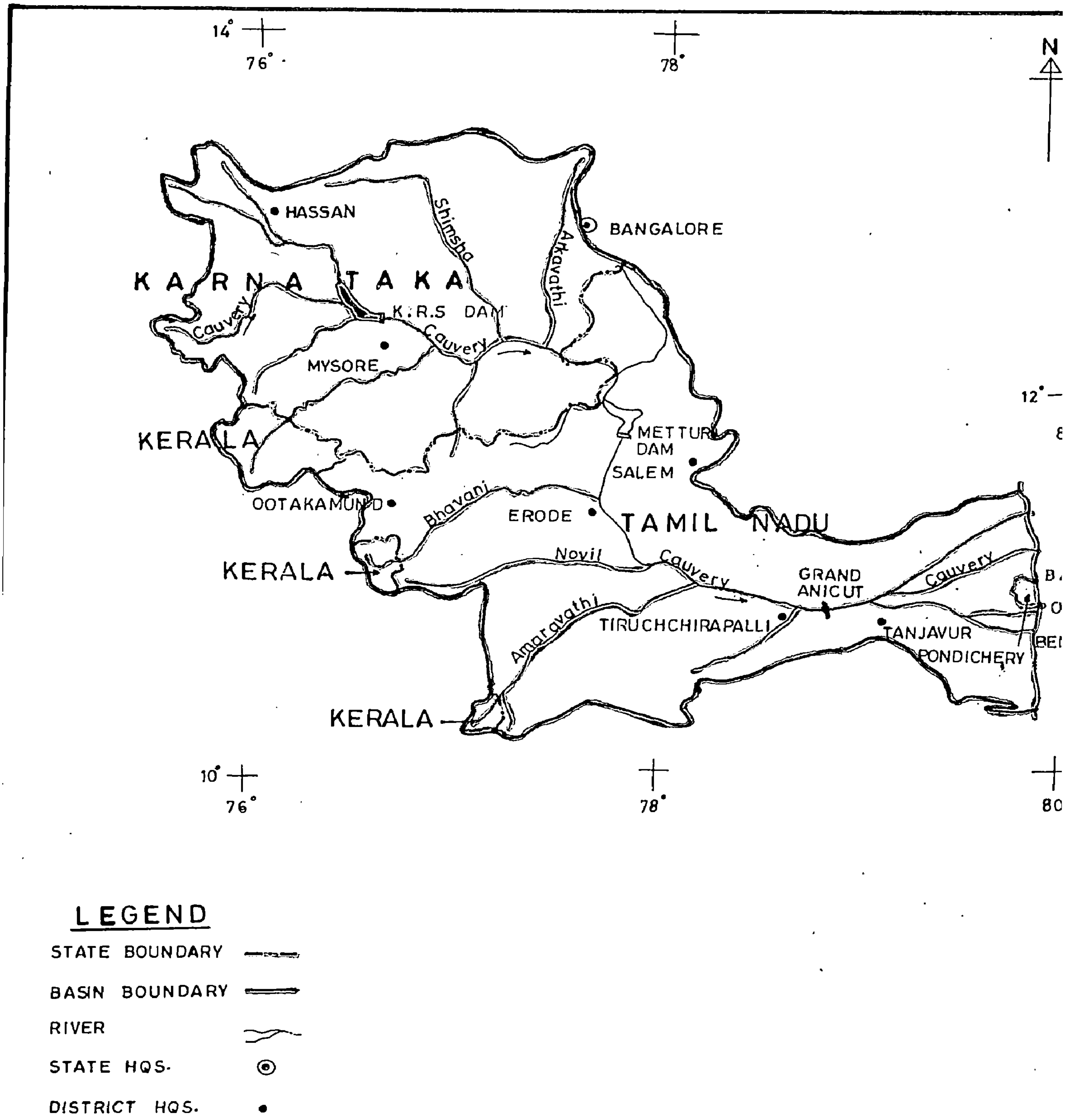


Fig 3.5 - MAP OF CAUVERY BASIN

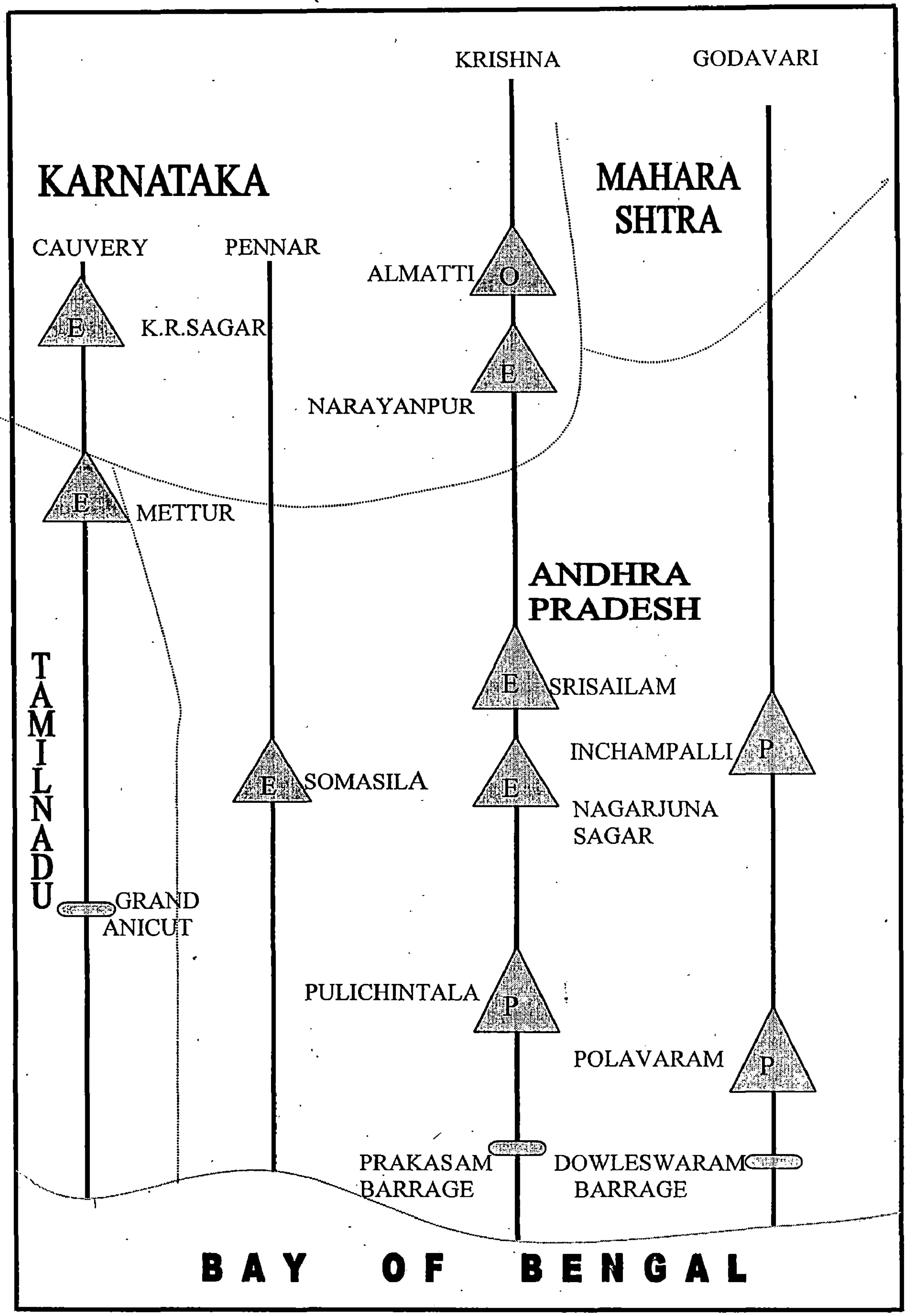


Fig: 3.6 Line diagram of the System

Table 3.2

SALIENT FEATURES OF PROJECTS

Sl.no	Name of Project / Barrage	River	State	Status	Catch-ment area	FRL/ Pond level	MDDL/ DSL	*Gross storage	*Live storage	Annual Irrigation	Annual Utilisation	Power installed capacity	Tail water level
					km^2	m	m	Mm^3	Mm^3	lakh ha	Mm^3	MW	m
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Inchampalli	Godavari	Andhra Pradesh	Proposed	269000	112.77	106.98	8959	4098	0.95	620	975	74.25
2	Polavaram	Godavari	Andhra Pradesh	Proposed	307000	45.72	41.15	4945	2043	4.72	3823	720	13.64
3	Dowleswaram	Godavari	Andhra Pradesh	Existing	312813	13.81	-	10	-	9.80	7774	-	
4	Almatti	Krishna	Karnataka	Ongoing	33375	519.6	504.88	3485	3132	0.41	258	297	492.25
5	Narayanpur	Krishna	Karnataka	Existing	44924	492.25	481.58	1072	869	5.38	4290		
6	Srisailam	Krishna	Andhra Pradesh	Existing	211657	269.75	260.30	8723	4262	3.10	2209	770	180
7	Nagarjunasagar	Krishna	Andhra Pradesh	Existing	220705	179.83	155.45	11560	5733	12.48	7465	810	75
8	Pulichintala	Krishna	Andhra Pradesh	Proposed	240733	53.34	42.67	1155	1016	-		60	22.55
9	Prakasam barrage	Krishna	Andhra Pradesh	Existing	257078	17.4	-	87	-	4.45	5132	-	
10	Somasila	Pennar	Andhra Pradesh	Existing	50493	100.58	82.30	1893	1764	1.68	1375	-	
11	Krishnaraja sagar	Cauvery	Karnataka	Existing	10619	752.49	736.70	1408	1172	0.79	1325	-	719
12	Mettur	Cauvery	Tamil Nadu	Existing	42217	240.79	204.22	2709	2648	0.18	275	240	192
13	Grand Anicut	Cauvery	Tamil Nadu	Existing	70129	59.22	-	10	-	4.92	6938	-	
	Note:	* As considered for simulation											

3.3.1 Projects in Godavari Basin

Inchampalli: The Inchampalli project is proposed on the river Godavari about 12 km downstream of the confluence of Indravati with the Godavari river in Andhra Pradesh. It is a joint project among the States of Maharashtra, Madhya Pradesh and Andhra Pradesh. It is a multi purpose project envisaging irrigation benefit for the upland areas, generation of hydropower, navigation facilities in the river, development of pisciculture and providing recreation benefits besides mitigating flood hazards. Flows in abundance are available at Inchampalli, as it is the threshold for the two major tributaries Pranhita and Indravati of Godavari, which join the river upstream of the site.

Polavaram: The Polavaram project is planned d/s of Inchampalli after the confluence of another major tributary 'the Sabari' with the river Godavari. It is a multi purpose project for irrigation, hydropower and water supply to Vizag city. The project has been planned for utilizing the significant quantum of flows that would be received from Sabari and power releases and spills from Inchampalli for its own uses and also for regulating releases for Godavari delta.

Dowleswaram Barrage (Cotton Barrage): The Dowleswaram Barrage is the terminal project on Godavari, located downstream of Polavaram, catering to the needs of Godavari delta. It is named after Sir Arthur Cotton, who built the barrage in regard to his yeoman services to the upliftment of the people in the area.

3.3.2 Projects in Krishna Basin

Almatti: Almatti dam of Upper Krishna project is located on the river Krishna about 10 km downstream of the confluence of its tributary Ghataprabha. Irrigation and hydropower generation are planned at Almatti apart from ensuring releases for Narayanpur.

Narayanpur: Narayanpur is located d/s of Almatti dam after confluence of the river Malaprabha with the Krishna river. Major part of Upper Krishna command is covered under the Narayanpur canals for which, the main supplementing storage would be at Almatti.

Srisailam: The Srisailam project renamed as ' Neelam Sanjiva Reddy Sagar' in the honour of the former president of India, was originally planned as hydro electric project by the Govt. of Andhra Pradesh. Subsequently, the domestic water supplies to Chennai and irrigation benefits to upland areas have been included. The project is located at the famous shrine 'Srisailam' known as "South Benaras" after the confluence of major rivers Tungabhadra and Bhima with Krishna.

Nagarjunasagar: The Nagarjunasagar project is the largest and highest masonry dam (125 m) in the world (NWDA 1993). It is situated downstream of Srisailam reservoir on the Krishna river in Andhra Pradesh. It is a multi purpose project with irrigation, hydropower and flood control components.

Pulichintala: Pulichintala project was originally investigated as an irrigation project. But due to construction of Nagarjunasagar dam, this project was not taken up as the entire ayacut originally proposed to be irrigated under Pulichintala project was covered by Nagarjunasagar project. The present scheme is only for stabilization of existing ayacut in the Krishna delta for paddy crop. Hydropower generation utilizing the releases for the delta is planned.

Prakasam barrage: This existing barrage is the terminal structure on the river Krishna to meet the delta requirements in Krishna basin. The barrage is located near Vijayawada in Andhra Pradesh.

3.3.3 Project in Pennar Basin

Somasila: This is an existing major project on Pennar river in Andhra Pradesh for stabilizing the irrigation in Pennar delta. It has also been integrated as a component of Telugu Ganga canal project which is proposed to carry water from Srisailam to Chennai city and provide irrigation benefits to the en-route areas.

3.3.4 Projects in Cauvery Basin

Krishnarajasagar: This is an existing major project on Cauvery, which was built under the supervision of eminent engineer- son of India, Dr.M.Visweswaraiah. The project has irrigation as its main component with seasonal power generation from its out flows. The famous Brindavan Garden at Mysore is developed adjacent to this dam site.

Mettur: This project together with Grand Anicut is called Cauvery-Mettur project. The outflows from Krishnarajasagar and flows from Kabini are received in Mettur reservoir to meet major part of the requirement of Cauvery delta. Seasonal power is also generated utilizing releases for Grand Anicut.

Grand Anicut: This is one of the age-old anicuts that have been successfully meeting the requirements of delta area in Tamilnadu. The Grand Anicut is located downstream of Mettur reservoir.

3.4 The Link Projects

NWDA has proposed Mahanadi – Godavari – Krishna – Pennar – Cauvery – Vaigai link system to transfer the surpluses as assessed by it in Mahanadi and Godavari basins to the water short Krishna, Pennar, Cauvery and Vaigai basins. The entire link system from Mahanadi to Vaigai is shown in **Fig 3.1.** The schematic diagram of the link system showing the water availability / surplus / deficit position at each diversion point, proposed diversion through each link project, en-route utilization, net quantum of transfer and transmission losses is illustrated in **Fig 3.7** (NCIWRDP 1999).

The Mahanadi – Vaigai link system is conceived on the basis of "substitution and exchange" to avoid unnecessary lifts. Substitution envisages that the surplus water is delivered at the downstream use points in the water deficit basin substituting for the existing committed releases from the upstream in the deficit basin. In exchange, whole or part quantum of water will be drawn from the upper reservoir to cover the needy upland areas wherever feasible. The individual link projects as proposed by NWDA are described in brief in the following paras:

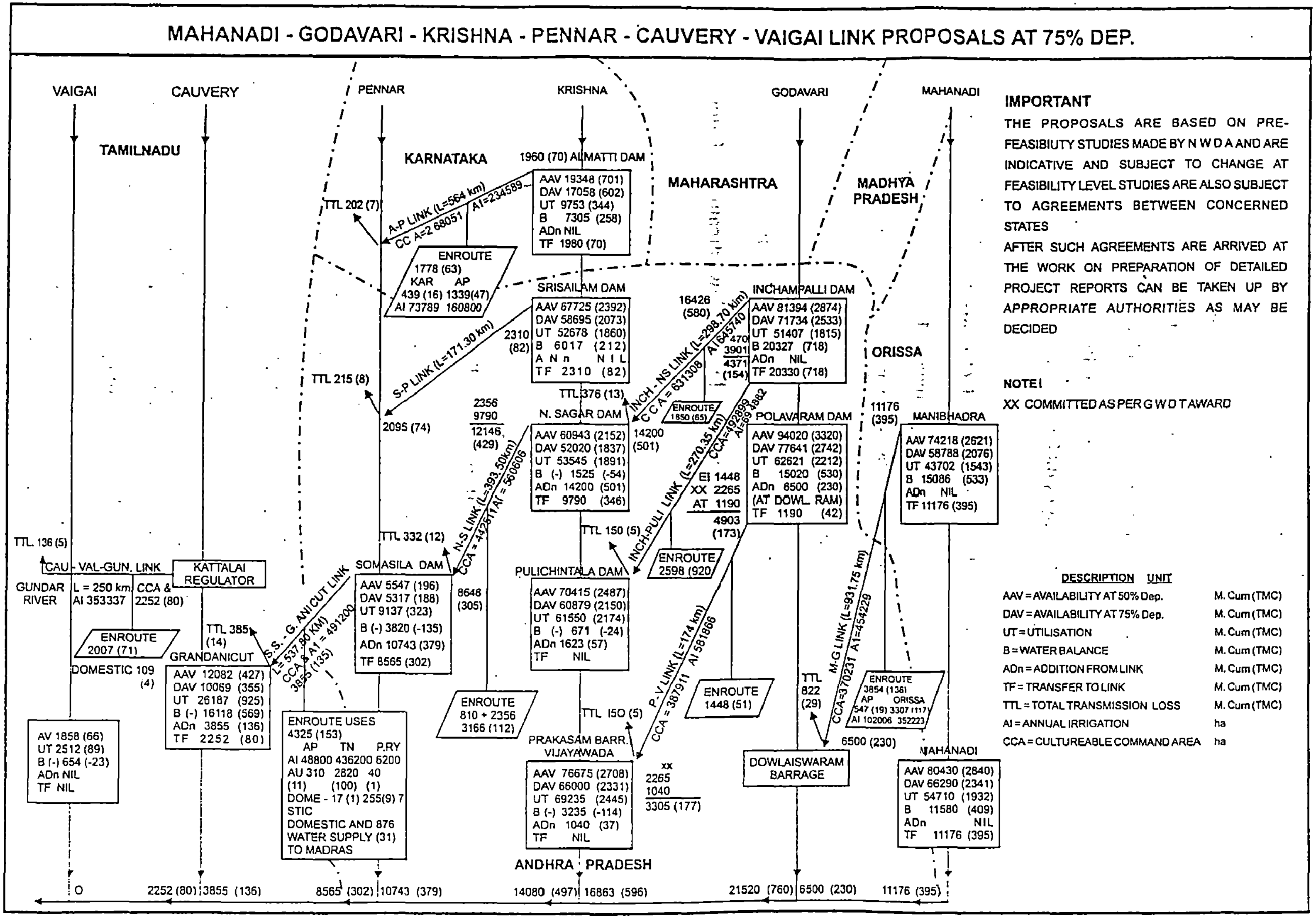


Fig 3.7: Schematic diagram

3.4.1 Mahanadi to Godavari

A quantum of 11176 Mm^3 has been proposed for diversion through Mahanadi – Godavari link taking off at Manibhadra on Mahanadi. The link after providing for en-route irrigation in Orissa and Andhra Pradesh States, proposes to deliver about 6500 Mm^3 of water to Godavari delta.

3.4.2 Godavari to Krishna

The gross surplus available in the Godavari basin considering Mahanadi waters would be 21520 Mm^3 (15020+6500). This is contemplated for diversion to the Krishna through three links viz., (i) 1190 Mm^3 of water through Polavaram - Vijayawada link for supplementation of the Krishna delta requirement (ii) 3901 Mm^3 through Inchampalli – Pulichintala link for taking over part command of Nagarjunasagar LBC and Nagarjunasagar RBC as substitution and (iii) 16426 Mm^3 of water through Inchampalli – Nagarjunasagar link which delivers 14200 Mm^3 into Nagarjunasagar reservoir after accounting for transmission losses and en-route irrigation requirement.

3.4.3 Krishna to Pennar

Out of 14200 Mm^3 received at Nagarjunasagar, 12146 Mm^3 is proposed for diversion through Nagarjunasagar – Somasila link and the balance is utilized for taking over part command of Nagarjunasagar LBC. The quantum of water reaching the Somasila reservoir on Pennar after en-route irrigation is about 8648 Mm^3.

As the entire command of existing Nagarjunasagar Project is proposed to be taken over by the link waters, in part exchange, diversions from upper reaches viz., Srisailam and Almatti have been proposed. About 2310 Mm^3 is proposed to be diverted from Srisailam through Srisailam – Pennar link out of which 2095 Mm^3 would ultimately reach Somasila on Pennar. In addition, about 1980 Mm^3 of water is proposed for diversion from Almatti through Almatti-Pennar link to cater for en-route irrigation in Krishna basin and Upper Pennar sub-basin of Pennar basin.

3.4.4 Pennar to Cauvery

Out of the 10743 Mm^3 of waters received at Somasila on Pennar (8648 Mm^3 through Nagarjunasagar – Somasila and 2095 Mm^3 through Srisailam – Pennar link), 1288 Mm^3 is released for Pennar delta, 890 Mm^3 for irrigation through Telugu Ganga while 8565 Mm^3 is proposed for diversion to Cauvery through Somasila – Grand Anicut link. After accounting for en-route irrigation and domestic and industrial needs of Chennai city, about 3855 Mm^3 of water will reach Cauvery delta.

3.4.5 Cauvery to Gundar

Out of the 3855 Mm^3 water received at Cauvery, 2252 Mm^3 of water is proposed for diversion from upstream in exchange to cover new areas down south up to Gundar river.

The salient features of the 7 link projects pertaining to the study area are given in the **Table 3.3** (NCIWRDP 1999).

Table: 3.3

DETAILS OF PROPOSED LINKS

Sl.No.	Name of the link	Connecting rivers		FSL at		Length	Discharge	Annual Volume of transfer	Enroute Irrigation vol.Mm^3 Area ha.	Losses
		From	To	Head	Tail					
				m	m	km	m^3/sec	Mm^3		Mm^3
1	2	3	4	5	6	7	8	9	10	11
1	Inchampalli Nagarjunasagar	Godavari	Krishna	142	182.77	299	1219	16426 14200	1850 319708	376
2	Inchampalli-Pulichintala	Godavari	Krishna	106.68	69.68	270	263	4371	4221 694882	150
3	Polavaram-Vijayawada	Godavari	Krishna	40.23	27.97	174	361	4903 3305	1448 148418	150
4	Almatti-Pennar	Krishna	Pennar	510	434.4	564	208.12	1980	1778 234589	202
5	Srisailam-Pennar	Krishna	Pennar	268.15	156.51	203.6	186	2310 2095	- -	215
6	Nagarjunasagar-Somasila	Krishna	Pennar	151.67	102.63	394	555	12146 8648	3166 560606	332
7	Somasila - Grand Anicut	Pennar	Cauvery	91.96	59.7	538	616	8565 3855	3170 491200	385

Note: In col.9, the upper figure indicates the gross diversion while the lower one gives the quantity reaching the tail end. The difference is accounted for enroute utilisation and losses.

STUDY APPROACH

4.1 GENERAL

The Godavari – Cauvery link system is a complex system with a large number of reservoirs and barrages serving multiple purposes. Therefore, for the purpose this study, link system has been divided basin wise into four sub-systems viz., Godavari, Krishna, Pennar and Cauvery multi-reservoir sub-systems.

The study is designed to be carried out in four stages.

Stage I: The performance of each sub-system is studied in the ultimate water development scenario, roughly corresponding to year 2050 AD by carrying out multi-reservoir simulation. This case will, prima facie, indicate how much deficient / surplus each sub-system is, in meeting its requirements at desired operational reliabilities without a link to / from a sub-system.

Stage II: It is proposed to optimize the performance of each sub-system through simulation considering different priorities and release patterns from the reservoirs. Stage II study will help the decision-maker with a number of alternatives to choose from, depending upon the desired objective for each reservoir. The firm power generation at the storage type hydro power plants has also been fixed. Further, the surplus / deficit position in each sub-system has also been ascertained.

Stage III: The water balance position obtained in stage II considering only surface water is further improved in **stage III**, by planning conjunctive use of surface and groundwater for irrigation in the project commands. Further, the groundwater resources in each sub- basin of the water deficit basins have been estimated. The surface and groundwater together are considered as a single resource and the net deficit has been assessed for consideration of supplementation through inter-basin water transfer.

Stage IV : The link diversions, wherever found necessary are planned and the effect of these water transfers on the performance of the reservoirs in each basin has been studied.

4.2 THE SUB-SYSTEMS

The link system is visualized in terms of four sub-systems.

1. The Godavari multi-reservoir sub-system comprising Inchampalli and Polavaram reservoirs and Dowleswaram barrage in Andhra Pradesh.

2. The Krishna multi-reservoir sub-system consisting of Almatti and Narayanpur reservoirs in Karnataka and Srisailam, Nagarjunasagar and Pulichintala reservoirs and Prakasam barrage in Andhra Pradesh.

3. The Pennar sub-system consisting of Somasila reservoir in Andhra Pradesh.

4. The Cauvery multi-reservoir sub-system with Krishnarajasagar reservoir in Karnataka, Mettur reservoir and Grand Anicut in Tamilnadu.

4.3 SIMULATION WITH OUT INTER-BASIN TRANSFER (STAGE I)

It is desirable to know how far each basin will successfully sustain the expected further development from its own resources and storages prior to considering supplementation from else where. To determine this, multi-reservoir simulation has been carried out in each sub-system, which are integrated in the link system to find the operational reliabilities. The desired time reliability for power is 90% while the annual reliability for irrigation is 75%. The desired reliability for domestic supply is 100%.

The broad approach adopted is that

(i) The within basin surface water resources only are considered to meet the demands.

(ii) The utilization of existing and ongoing projects and their committed requirements have been duly considered and that of proposed projects have been taken as estimated by NWDA.

(iii) The possible firm power generation has been assessed by Central Electricity Authority (CEA) for one reservoir project. Also, the firm power as planned by the project authorities in respect of two future projects is considered. In other cases, however, the annual energy generation has been computed.

Multi-reservoir simulation is carried out for a common period of 30 years (1951-52 to 1980-81). The basic input data for reservoir simulation study are inflows, demands for different purposes, elevation – area – capacity tables, evaporation depths etc.

Since the present study is for a future scenario, the inflow data used are not the observed inflows at a reservoir but are estimated inflows after considering full upstream development. The inflows, if available, for the common period, in the link reports of NWDA are considered. For other reservoirs the inflows have been worked out from the sub-basin wise water balance studies carried out by NWDA. These water balance studies consider the overall availability in the basin / sub-basin less total projected water requirement for all uses (domestic, industrial irrigation etc.) and export to other basin / sub- basins plus regeneration from the uses in order to arrive at the water balance in the basin / sub-basin. While working out the inflows at a project / reservoir in some deficit years, the situation is such that the water available in an upstream sub-basin may not be enough to meet its own projected requirements. The net annual inflows from that sub-basin into the reservoir in such years are considered to be 'nil'. These annual inflows have been distributed into monthly inflows on an average proportion based on the available observed discharge data at the project site / nearest G&D site.

The elevation – area – capacity tables, evaporation depths and demands have been collected from the pre-feasibility / feasibility reports of NWDA, IMD publications, State project reports / documents.

For the present study, a time step of one month has been chosen. In principle, other time steps may be used as long as the length of time step exceeds the travel time of the water from one end of the basin to another. June is the initial month for simulation and each reservoir is considered to be at its minimum storage at the beginning.

Apart from the above general considerations, specific criteria applicable for each reservoir are described hereunder:

4.3.1 Project Demands in Godavari basin

Inchampalli project: The firm power of 117 MW as planned by Govt. of Andhra Pradesh has been considered in simulation. The irrigation demands of LBC (150 Mm^3) and RBC (470 Mm^3) as considered by NWDA in its reports (NWDA 1991) have been taken in to account.

Polavaram project: The firm power of 60 MW as planned by the State for the project has been considered. The project utilization for Left Main Canal (1881 Mm^3) and Right Main Canal (1402Mm^3) as considered by NWDA are taken. The water supply component to Vizag city (664 Mm^3) through Left Main Canal and domestic & industrial needs of en-route command of Right Main Canal as assessed by NWDA (162 Mm^3) have also been considered in the study (NWDA 1999). It is proposed to provide almost full requirement of Dowleswaram barrage (7423 Mm^3) from Polavaram.

Dowleswaram barrage: The barrage has been simulated for meeting the requirement of Godavari delta (7774 Mm^3) with the marginal flows from local catchment and releases and spills from Polavaram.

4.3.2 Project Demands in Krishna Basin:

Almatti Project: The irrigation demand of Almatti for LBC and RBC as considered by NWDA (258 Mm^3) has been taken for simulation. The monthly factors for average supplementation of 1904 Mm^3 for Narayanpur have been considered in the study based on the 10-year simulation (1974-83) of Almatti reservoir carried out by NWDA (NWDA 1994). In the absence of details, no firm power has been considered but the annual energy generation from the releases to Narayanpur and spills has been computed.

Narayanpur: The full irrigation demands for this project LBC and RBC (4290 Mm^3) have been considered in the study. The spills from Narayanpur will flow to Srisailam.

Srisailam: The possible firm and seasonal power generation from Srisailam project has been assessed by Central Electricity Authority (CEA). According to these studies, the firm power generation at Srisailam by 2006-07 and beyond will be 60 MW (NWDA 2000). Accordingly, firm power demand of 60 MW has been considered in the study. The irrigation demand of 850 Mm^3, 538 Mm^3, and 821 Mm^3 under LBC, RBC and Telugu Ganga respectively have been considered with a middle rule level of 266.70 m during the period from August to October as proposed by the Government of Andhra Pradesh. Further, as per the agreement between the riparian States of Krishna basin, 425 Mm^3 of water has to be diverted from Srisailam through Telugu Ganga to meet domestic needs of Chennai city (ECURWAP 1985). This component proposed during the period from July to October has been considered in the study. Further, Srisailam has to deliver its committed releases for Nagarjunasagar and Prakasam barrage. The committed requirement of Nagarjunasagar (6952 Mm^3) has been considered in the form of monthly downstream release factors while that of Prakasam barrage (2265Mm^3) has been considered under minimum flow.

Nagarjunasagar: The Nagarjunasagar project receives committed releases and spills from Srisailam. Its inflows from the local catchment are marginal. The irrigation demand of 7465 Mm^3 and release for Prakasam barrage (2265 Mm^3) has been considered from the reservoir. In view of lack of information on the power generation that would be possible in future, no firm power demand has been considered. Only power generation possible from the releases for Prakasam barrage and spills has been assessed. In fact, the Government of Andhra Pradesh has a proposal to augment Krishna waters at Prakasam barrage through diversion of 2265 Mm^3 from Polavaram on Godavari. In that case, no committed releases for Prakasam barrage will be needed from Nagarjunasagar and the power generation will be through a pumped storage plant. However, the objective of **Stage I** is to assess the performance of each sub-system to meet the demands from its own resources. Hence, the supplementation for the barrage from Nagarjunasagar only is being considered.

Pulichintala: This project has a single purpose of stabilizing the requirements of Prakasam barrage. The Government of Andhra Pradesh has estimated the yield in the catchment below Nagarjunasagar and up to Prakasam barrage to be 2867 Mm^3 (101 TMC). They have proposed the remaining 2265 Mm^3 (80 TMC) as release from Nagarjunasagar in proportion to the monthly demands at Prakasam barrage. Therefore, sum of the monthly releases from Nagarjunasagar and the average monthly flow from the local catchment between Nagarjunasagar and Pulichintala were considered as the monthly releases from Pulichintala for the barrage.

Prakasam barrage: The operation of this barrage has been simulated to meet its needs (5132 Mm^3) from the releases and spills received from Pulichintala in addition to local inflows.

4.3.3 Project Demands in Pennar Basin:

Somasila: This project has to cater to a total demand of 1453 Mm^3 for its canals and Pennar delta requirement. The Telugu Ganga canal will carry the domestic supplies of 425 Mm^3 from Srisailam meant for Chennai city to Somasila. Somasila reservoir releases them into Kandaleru reservoir through Telugu Ganga from where the waters will be further diverted to Poondi reservoir in Tamil Nadu. Irrigation from Pennar floodwaters (890 Mm^3) in the Telugu Ganga

Canal has been considered as proposed by the State of Andhra Pradesh (NWDA 1996). The rule level for floodwater diversion has initially been considered at FRL.

4.3.4 Project Demands in Cauvery Basin:

Krishnarajasagar: This project has been simulated to meet its irrigation demands of 1325 Mm^3. Seasonal power generation with a maximum draft of 170 Mm^3 (6 TMC) as indicated by Government of Karnataka in their Master Plan (WRDO 1976)has been considered.

Mettur: The Mettur project is to take care of Cauvery delta requirement which have been considered as downstream factors from Mettur. The irrigation demand of 275 Mm^3 under Mettur canals has also been taken in to account. Seasonal power generation utilizing the releases for the Cauvery delta has only been planned by the State of Karnataka at the project (WRDO 1976).

Grand Anicut: The Grand Anicut is simulated for meeting the net requirement in Cauvery delta below (9670 Mm^3) with the releases from the Mettur and local flows.

The output of reservoir simulations for each sub-system provided the primary information as to where the deficit / surplus will be. The Godavari sub-system is comfortable in meeting its requirements while, the Krishna, the Pennar and the Cauvery sub-systems are stressed with water shortage in their performance up to the desired reliability. The detailed analysis and results are presented in **Chapter 5.**

4.4 OPTIMIZATION THROUGH SIMULATION WITHOUT INTER-BASIN TRANSFER (STAGE II)

Having ascertained surplus / deficit in meeting demands at each reservoir in each basin, the optimization of their performance considering different priorities and release patterns has been undertaken in **stage II**. The optimization has been done through simulation in a cascading type of analysis proceeding from upper most reservoir to the down most reservoir in each of the basins.

The broad criteria adopted in the optimization are:

- In case of multi-purpose projects, simulation runs are taken for two cases, viz., irrigation priority and hydropower priority. In both the cases, firm power demand has been varied and the reliabilities are observed. The option, which yields the best performance, has been chosen.

- In case of projects which cater to the requirements of a downstream project, the releases have been enhanced to improve the performance of the downstream reservoir, while ensuring desired reliabilities for its own needs.

- In case of prime hydropower project with secondary irrigation benefits the estimated / planned firm power is restored by curtailing / adjusting the release pattern for other uses to the minimum possible extent.

- In case of diversion projects, the option of net demand has been introduced. If this option is chosen, the net requirement at the barrage in excess of its local inflows will only be drawn from the immediate upstream reservoir. This will not only ensure drawl of water when necessary but also minimize wastage of water at the barrage, if the water would have been released from the upstream reservoir in a fixed released pattern.

- If there are two types of irrigation needs contemplated, one from dependable waters and other from flood waters, simulation runs were taken for rule level optimization for the less priority irrigation demand so as to improve supplies to it while reliability for the higher priority irrigation demand is safe guarded.

- In the event of downstream releases affecting a project's own requirements, the rule levels for downstream releases have been imposed and optimized to enhance the performance of the project to the desired level in meeting its own requirements.

The detailed analysis along with optimized firm power and release pattern for the reservoirs and water balance position in each sub-system are discussed in **Chapter 5.**

4.5 INTEGRATION OF GROUNDWATER IN SYSTEM PLANNING (STAGE III)

The water balances based on surface water planning at 75 % dependability would be extremely conservative. In the context of inter-basin water transfer, the deficit basins should first aim at efficient utilization of all in-basin resources, before seeking the supplementation from surplus basins. Therefore, groundwater has been considered in the planning in the water short basins in two phases and the need and extent of diversion from other basins is assessed.

4.5.1 Phase I- Conjunctive Use in Project Commands

Conjunctive planning would reduce the ill effects of water logging and also help in optimum utilization of both surface and groundwater resources. In the project commands where desired reliability could not be achieved due to shortage of surface water, the conjunctive use planning is proposed. For this purpose, the groundwater recharge in the command from natural rainfall as well as surface water irrigation has been estimated. The Central Groundwater Board (CGWB 1995) has brought out certain norms for the groundwater recharge, for alluvial and hard rock areas. Basically, the peninsular river basins are hard rock areas for which the groundwater recharge varies from 5 % – 15 % of normal rainfall. The recharge for deltaic alluvium ranges from 10 % to 25% Based on these norms, an average 12 % of recharge from rainfall has been considered in the study. The normal rainfall figures are taken from India Meteorological Department (IMD) publication.

The CGWB has also prescribed norms for recharge due to seepage from canals, based on the wetted area. In the absence of details on the cross section of project canals, recharge at 30% of surface irrigation releases at head is assumed in the study. This assumption is reasonable considering the fact that the efficiency in an irrigation system ranges from 30 to 50%. The Central Water Commission (CWC 1995) has brought out certain guidelines for planning conjunctive use according to which seepage loss could be around 50% of the deliveries at the head for unlined canal in a major project. Further, seepage from field channels could be 10-30% of the deliveries at the outlet depending on the site conditions. In addition, deep percolation loss will be about 10-15% of the water supplied to the field. As per these guidelines, about 70% of the canal losses can be taken as entering to the groundwater. NWDA has also considered an efficiency of 55% in respect of future major and medium projects presuming that the canal systems would be lined by then and management practices would improve. In light of all these norms, a realistic assumption at 30% of deliveries at head of the project has been made. Out of the total groundwater recharge from normal rainfall and canal recharge, 15 % is earmarked for drinking and industrial purposes, committed base flow and to account for the unrecoverable losses. The available groundwater potential for irrigation has been reduced to 90% level and considered as utilizable irrigation potential for development as per CGWB, in view of the following.

i) To ensure sustainable development, the level of groundwater extraction has to be kept at a level reasonably lower than the absolute maximum.

ii) To maintain river ecology, minimum flows have to be ensured by limiting extraction of groundwater, which contributes to the lean season flow in the river.

iii) 90% level of extraction is considered reasonable from the above consideration.

The level of groundwater development in an area is the ratio of the net yearly draft to the available groundwater resource for irrigation. Based on the level of development, areas have been categorized as white (<65%), grey (>65% but <85%), dark (>85% but <100%) and over exploited (>100%). The net draft corresponds to 70 % of gross extraction as 30 % is presumed to go as return seepage to groundwater regime. With 90% level of extraction, the level of groundwater development will be just 63% (0.7*90) and therefore will not lead to mining of groundwater but towards its sustainable development.

Different cases considering the groundwater supplementation in percentage ranging from 10% to 90% of groundwater recharge with a time lag of one month during the entire cropping period and also in certain critical months as per the water balance scenario (obtained from stage II) for conjunctive use have been analyzed.

It is seen that some project commands will be able to meet their full demands with little supplementation from groundwater. Some other projects will not be successful in fulfilling their requirements even after taking entire utilizable groundwater resource into account. The detailed analysis is presented in **Chapter 6.**

4.5.2 Phase II : Groundwater Planning in Sub-basins

While computing inflows for multi-reservoir simulation, it is seen that certain sub-basins in deficit basins do not contribute flow in a number of years of the simulation period. These are deficit sub-basins as per the surface water balance studies of NWDA. The groundwater potential in these sub-basins has been estimated for integrated planning from State wise / District wise groundwater particulars given by CGWB. The district wise areas in each sub basin are taken from the reports of NWDA.

The balance utilizable groundwater potential for irrigation after provision for domestic & industrial uses and present draft has been considered as the additional resource for planning. In the water balance reports of NWDA, additional irrigation to cover at least 30% of culturable area has been proposed in deficit sub-basins. In the present study, since both surface and groundwater resources together are considered in the planning, the present utilization from groundwater is considered as part of this additional irrigation.

After all this extensive study, through stages I to III, it is seen that one basin sub-system will need no supplementation from outside while only few sub-basins of other sub-systems will require it. The details are given in **Chapter 6.**

4.6 SIMULATION CONSIDERING INTER-BASIN WATER TRANSFER (STAGE IV)

Having identified the critical areas and the extent of deficit, inter-basin water transfer links have been proposed based on the following broad approach.

i) The links are proposed on the principle of substitution and exchange.

ii) The links have been considered in three phases.
-To meet the deficit at 75% dependability of adjacent basin.
-To provide water to the area originally planned from flood waters in the adjacent basin.
-To provide water to the distant basin to meet its possible requirements.

iii) In simulation, link diversion has been accorded the least priority against the project demands.

iv) Monthly demands have been worked out for new area under the link based on the cropping pattern proposed by NWDA for this area with 100% cropping intensity. Enroute domestic and industrial needs in the command have also been assessed for the projected population (2050 AD) on the basis of the growth rates suggested by United Nations (UN 1994).

Though the water supply and irrigation demands of a project do not get affected due to the link diversion from it, the power generation may not be possible to the same extent. This may be justified as the water is proposed for transfer to the needy areas deprived of any other source and irrigation use has higher priority over power generation as per the National Water Policy. The effect of the proposed link projects on the performance of the whole system has been analyzed in detail in **Chapter 6**.

SIMULATION STUDY OF SURFACE WATER USE WITHOUT INTER-BASIN TRANSFER

5.1 GENERAL

The study has been carried out in four stages. Scope of each stage study has been explained in **Chapter 4: Study Approach.** This chapter deals with analysis and discussion of results pertaining to first two stages viz., (i) multi-reservoir simulation study of Godavari, Krishna, Pennar and Cauvery basins without inter-basin water transfer and (ii) optimization of performance of reservoirs through multi-reservoir simulation study without inter-basin water transfer.

5.2 SIMULATION WITHOUT INTER-BASIN TRANSFER (STAGE I)

In this part of analysis, multi – reservoir simulation for all the projects in the system is carried out without considering any transfer from one basin to another. This step will indicate the primary information as to how the system will perform with the expected development taking place upstream resulting in reduced inflows at the project sites on main rivers.

All the data required have been collected compiled and the input data files for each reservoir/barrage of sub-systems have been prepared in the prescribed format for the model. The reservoir levels, storage, installed capacities and tail water levels considered in the study have already been presented as a part of salient features in **Table 3.2.** The annual inflow data for each reservoir for the period of simulation, their monthly distribution factors, monthly demands for various purposes, factors for meeting the downstream requirements, evaporation depths, elevation – area – capacity tables are presented in **Appendix – B.**

The sub-system wise analysis is done using multi-reservoir simulation model to visualize the likely future scenario.

5.2.1 The Godavari Multi-reservoir Sub-system

Inchampalli: Long term simulation of the operation of this project shows that it can generate its planned firm power of 117 MW with 92.5 % reliability. Besides, it can meet its irrigation demands in full (620 Mm^3) in 80 % of the years providing 99.4 % of the volumetric requirement.

Polavaram: The project can comfortably meet its irrigation requirement of 3283 Mm^3 with 80 % annual reliability and 99.5% volume reliability. Besides, it can also generate its planned firm power of 60 MW at 98.1 % time reliability.

Dowleswaram barrage: There will be full supplies to the Godavari delta (7774 Mm^3) through the barrage in 25 years (86.7%) providing 99.6 % of the requirement. Also, there are spills in every year, in the range of 2200 Mm^3 to 71900 Mm^3.

5.2.2 The Krishna Multi-reservoir Sub-system

Almatti and Narayanpur: The Almatti project has abundant flows to meet its irrigation requirements of 258 Mm^3 in all the years. The bulk of irrigation demand of 4290 Mm^3 under the project is, however, at Narayanpur. The Narayanpur reservoir will be successful in meeting this demand only in 20 years (66.7 %). This is due to consideration of average supplementation of only 1904 Mm^3 from Almatti. Since abundant flows are available at Almatti as seen from simulation, the releases can be enhanced to ensure the desired reliability at Narayanpur which inter-alia, will also improve power generation at Almatti.

Srisailam: The project is stressed with water shortage for meeting both its irrigation and power needs. The annual reliability for irrigation (2209 Mm^3) is 70 % while time reliability for firm power generation of 60 MW is only 71.1 %. Power generation at this dam is required to be improved on priority as irrigation planned is mainly from Krishna floodwaters.

Nagarjunasagar: This reservoir, which depends on the flows from Srisailam, obviously indicates shortage of water to meet its irrigation requirement of 7465 Mm^3. The annual reliability obtained from simulation study is 70 %. The volume reliability however, is 91.8 %. The annual irrigation reliability will improve if firm power releases are ensured at Srisailam.

Pulichintala and Prakasam Barrage: The annual reliability for irrigation is seen to be zero but its volume reliability is as high as 82.6 %. The situation can be inferred to as the mismatch between the releases from Pulichintala and demands at Prakasam barrage. Currently, the release pattern is as per available monthly flow at Pulichintala. There is a need for change in the release pattern in tune with the demands at Prakasam barrage, which is taken up under stage II.

5.2.3 The Pennar Sub-system

Somasila: The project has to cater to its irrigation demands and Pennar delta requirements (1453 Mm^3). Additional irrigation under Telugu Ganga Canal (890 Mm^3) has been proposed from Pennar flood flows available at Somasila. Pennar sub-system is water short as the performance of Somasila reservoir indicates an annual reliability of only 53.3 % for delta irrigation and no reliability for Telugu Ganga irrigation. The rule level for the flood water irrigation is considered at FRL. If the rule level is lowered, more floodwaters can be effectively diverted to Telugu Ganga command.

5.2.4 The Cauvery Multi-reservoir Sub-system

The Cauvery is more prone to water shortage than other basins. The water shortage is felt in number of sub-basins of the basin. The simulation results of the important projects are as follows:

Krishnarajasagar: The reservoir will be successful in meeting its irrigation requirements only in 20 years (66.7 %)

Mettur: The reservoir can meet its demands with a reliability of only 30 %. Obviously, it will not be able to ensure enough releases for Grand Anicut.

Grand Anicut: It will not be successful in meeting its demands even in a single year. The volume reliability of utilization is also poor at 28 %.

The results of stage I are tabulated in **Table 5.1.** The annual irrigation reliability and the time reliability for power in respect of the above reservoirs are shown in graphical form in **Fig: 5.1.**

5.3 OPTIMIZATION THROUGH SIMULATION (STAGE II)

Optimization of the likely performance of reservoirs in the sub-system has been undertaken through systematic runs of the simulation model. The deficit sub-systems are optimized first to explore the possibility of improvement and assessing the ultimate deficit prior to contemplating inter-basin water transfer.

5.3.1 The Krishna Multi-reservoir Sub-system

Almatti and Narayanpur: Almatti and Narayanpur dams are the important components of Upper Krishna project. In the optimization, the objective was to improve the reliability of Narayanpur which is only 66.7 % as per the stage I, by increasing releases from Almatti.

Four cases have been studied for optimization at Almatti and Narayanpur:

i) With downstream factors for Narayanpur (irrigation priority),
ii) With downstream factors for Narayanpur (power priority),
iii) Without downstream factors for Narayanpur (irrigation priority) and
iv) Without downstream factors for Narayanpur (power priority).

A detailed discussion follows.

(I) With downstream factors for Narayanpur (irrigation priority):

First of all, the downstream releases from Almatti for demands of Narayanpur are gradually enhanced observing the failure months in successive runs. Finally, with annual supplementation of 2331 Mm^3 from Almatti, it is seen that Narayanpur can meet its requirements in all the years. At the same time, Almatti's irrigation reliability of 100 % is not affected. This is possible, as the power

Table 5.1 : SUMMARY OF THE RESULTS (STAGE 1) Units: Power -MW ; WS & Irrigation-Mm3

Reservoir	Priority	Power		Irrigation Reliabilities				Water supply		Remarks
		Dem.	Relia-bility	Dem.	Time rel.	Vol rel.	Ann rel.	Dem.	Relia-bility	
Godavari Sub-system										
Inchampalli	Irrigation	117	0.925	620	0.967	0.994	0.8	N.A	N.A	Firm Power of 117 MW as per Project Authorities
Polavaram	Power	60	0.981	3283	0.978	0.995	0.8	826	0.997	Firm Power of 60 MW &Domestic supply to Vizag
										d/s releases of 7423 Mm3 to Dowlaiswaram
Dowleswaram	N. A	N.A	N.A	7774	0.981	0.996	0.867	N. A	N. A	Only Irrigation
Krishna Sub-system										
Almatti	Irrigation	0	N.A	258	1	1	1	N. A	N. A	d/s release of 1904 Mm3 for Narayanpur
Narayanpur	N. A	N.A	N.A	4290	0.923	0.991	0.667	N. A	N. A	Only Irrigation
Srisailam	Power	60	0.711	2209	0.778	0.8	0.7	425	0.983	d/s release of 9217 Mm3 for N.sagar&Prakasam barrage
										firm power as studied by Central Electricity Authority
Nagarjunasagar	d/s rel / power	0	N.A	7465	0.85	0.918	0.7	N. A	N. A	d/s release of 2265 Mm3 for Prakasam Barrage
Pulichintala	N.A	0	N.A	0	N.A	N.A	N.A	N.A	N.A	d/s release of 3363 Mm3 for Prakasam Barrage based
										on available average flow at Pulichintala.
Prakasam barrage	N. A	N.A	N.A	5132	0.453	0.826	0	N.A	N.A	Only Irrigation
Pennar Sub-system										
Somasila	N. A	N.A	N.A	1453	0.767	0.828	0.533	409	0.917	domestic supply to Chennai city
				890	0.158	0.183	0			Proposed irrigation from flood water
Cauvery Sub-system										
Krishnarajasagar	N. A	N.A	N.A	1325	0.808	0.866	0.667	N.A	N.A	Only irrigation and as available energy
Mettur	N. A	N.A	N.A	275	0.678	0.82	0.3	N.A	N.A	Only irrigation and as available energy
Grand Anicut	N. A	N.A	N.A	9670	0.077	0.28	0	N.A	N.A	Only Irrigation

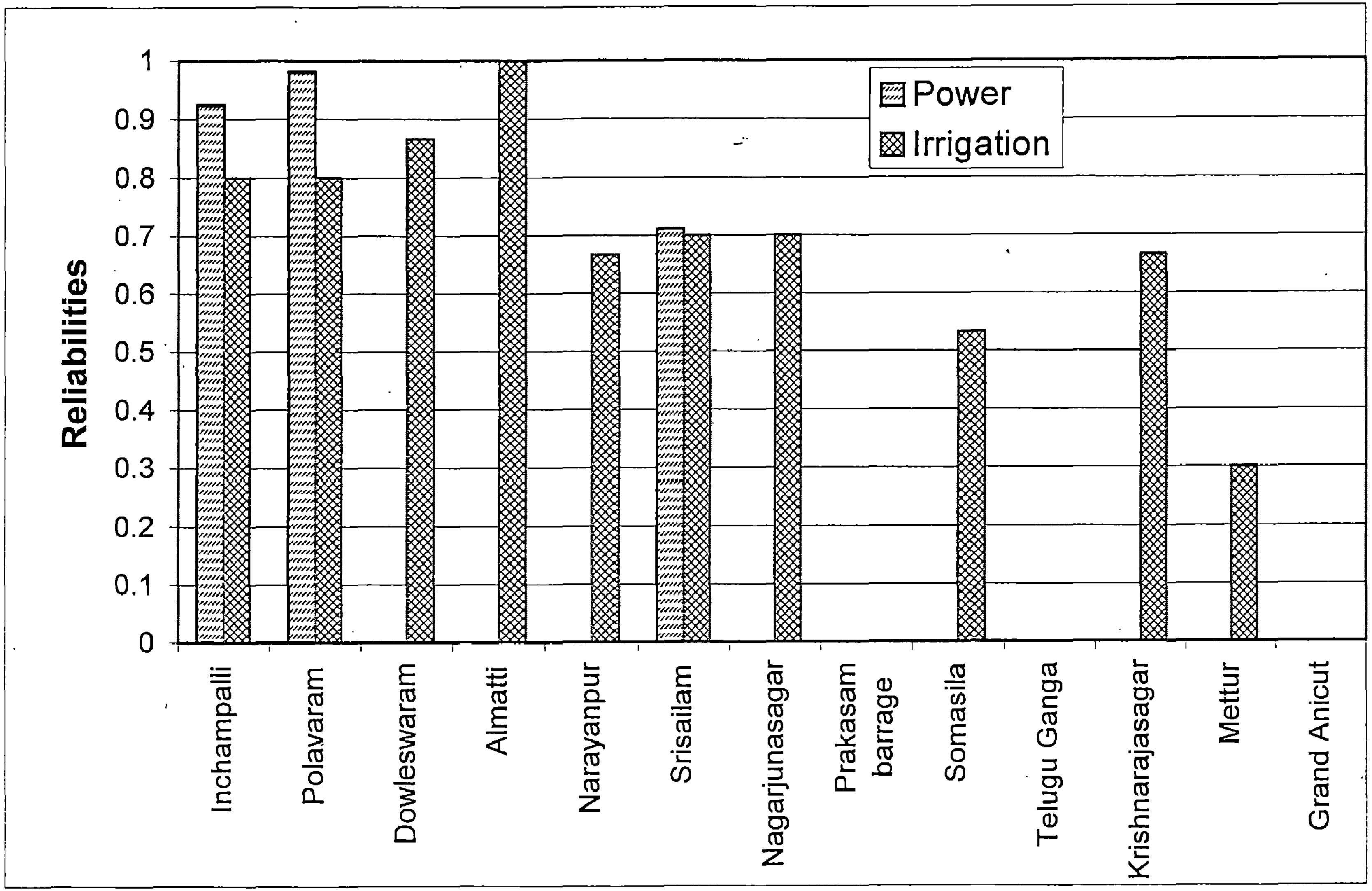


Fig: 5.1 Power and Annual Irrigation reliability of Projects (Stage I)

generation at Almatti and irrigation at Narayanpur are complementary to each other. The supplementation and corresponding reliabilities are presented in **Table 5.2** and **Fig 5.2.**

Table 5.2: Enhanced supplementation from Almatti and corresponding reliabilities at Narayanpur

Supp.from Almatti (Mcum)	Time Reliability	Volume Reliability	Annual Reliability	supp.from Almatti (Mcum)	Time Reliability	Volume Reliability	Annual Reliability
1904	0.936	0.9913	0.67	1965	0.964	0.9934	0.87
1912	0.939	0.9916	0.7	2052	0.972	0.9961	0.9
1919	0.944	0.9919	0.73	2188	0.994	0.9983	0.93
1933	0.956	0.9924	0.77	2267	0.997	0.9995	0.97
1937	0.958	0.9926	0.8	**2331**	**1**	**1**	**1**
1952	0.961	0.9931	0.83				

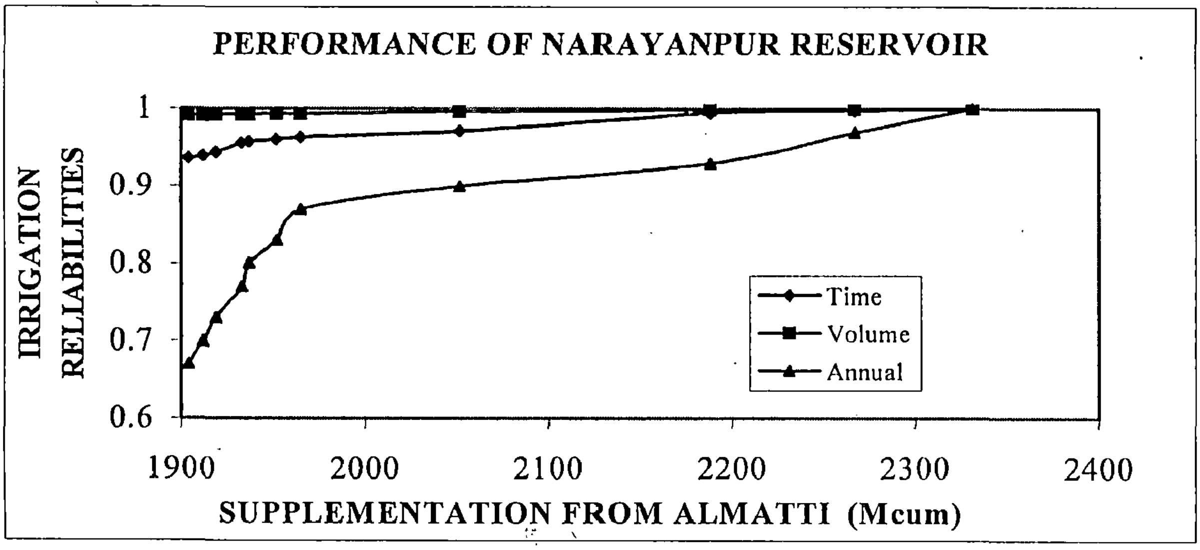


Fig 5.2 : Performance of Narayanpur Reservoir with Supplementation from Almatti

Next, Power demand has been introduced at Almatti to fix up the possible firm power keeping the achieved irrigation reliabilities intact. The simulation runs are taken for different power demands with priority for Almatti irrigation. It is seen that 28.75 MW of firm power can be generated at Almatti with 90 % time reliability. The respective monthly firm power demands have also been fixed up which vary from 11.4 MW in May to 297.0 MW (installed capacity) in August. The annual firm power optimization is shown in **Table 5.3** and **Fig: 5.3** while monthly firm power are given in **Table 5.4.**

Table 5.3 : Annual firm power optimization at Almatti (case I)

Power Demand (MW)	Energy demand (MU)	Time reliability	Power Demand (MW)	Energy demand (MU)	Time reliability
21	15.1	1.000	27	19.4	0.931
22	15.8	0.997	28	20.2	0.903
23	16.6	0.994	28.5	20.5	0.903
24	17.3	0.992	**28.75**	**20.7**	**0.900**
25	18	0.986	29	20.9	0.897
26	18.7	0.972	30	21.6	0.894
30	21.6	0.894			

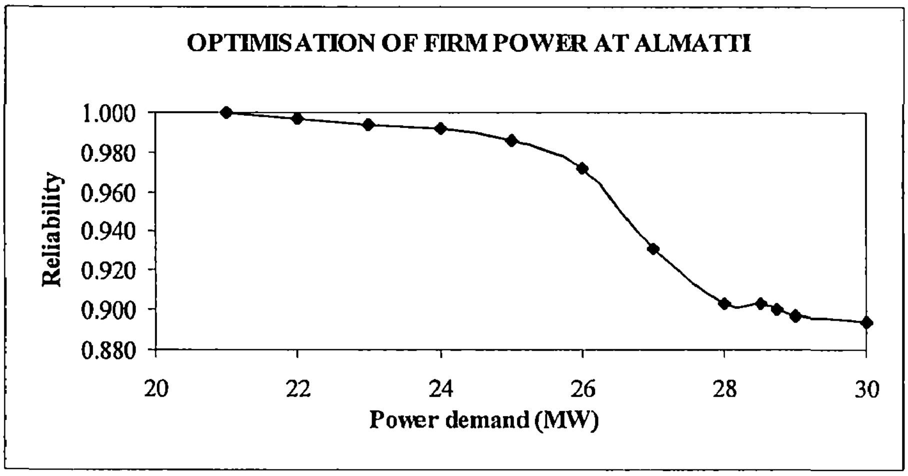


FIG 5.3 : Annual firm power optimization at Almatti (case I)

Table 5.4 : Monthly firm power at Almatti (case I)

Month	Firm Power (MW)	Firm Power (MU)	Month	Firm Power (MW)	Firm Power (MU)
June	26.25	18.9	December	33.2	23.9
July	42.20	30.4	January	46.3	33.3
August	297.00	213.8	February	28.75	20.7
September	112.9	81.3	March	28.75	20.7
October	28.75	20.7	April	28.75	20.7
November	28.75	20.7	May	11.4	8.2

The power demand has been further increased to analyze the trade - off between irrigation and power at Almatti. It is seen that 40 MW of firm power can be generated with 100 % reliability for irrigation. Further increase in firm power will reduce the irrigation reliability. 50.8 MW of power with a reliability of 66.4 % can be generated limiting the irrigation reliability to desired minimum of 76.7 %. Beyond this, increase in firm power will decline the irrigation reliability below the desired level. The tradeoff is given in **Table 5.5** and **Fig 5.4.**

Table 5.5 : Trade off between Power demand and Irrigation reliabilities at Almatti (case I)

Power demand (MW)	Energy demand (MU)	Power reliability	Effect on Irrigation Reliabilities		
			Time	Volume	Annual
21	15.1	1.000	1.000	1.000	1.000
25	18.0	0.986	1.000	1.000	1.000
30	21.6	0.894	1.000	1.000	1.000
35	25.2	0.819	1.000	1.000	1.000
40	28.8	0.783	1.000	1.000	1.000
45	32.4	0.694	0.990	0.998	0.900
50	36.0	0.675	0.977	0.994	0.800
50.8	36.6	0.664	0.973	0.993	0.767
51	36.7	0.661	0.970	0.992	0.733
55	39.6	0.631	0.947	0.986	0.533

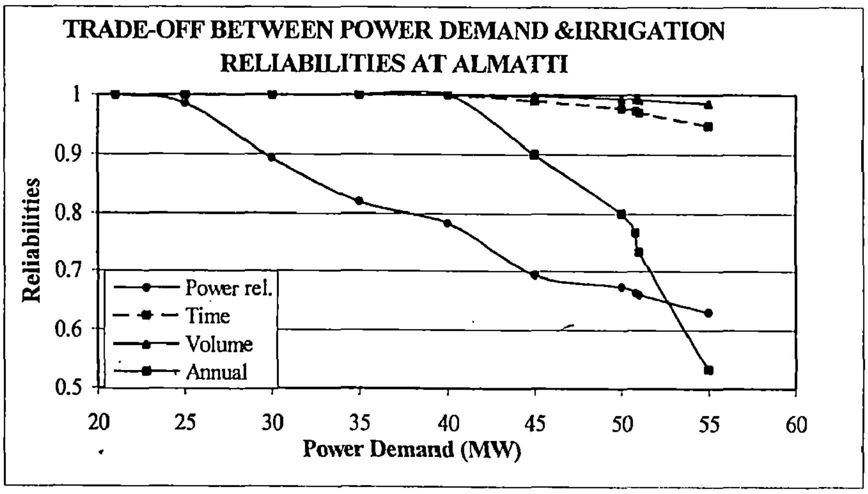


Fig 5.4 : Trade off between power and Irrigation reliabilities at Almatti (case I)

(II) With downstream factors for Narayanpur (power priority)

In the second case, simulation runs were taken for varying power demands, with power priority option. In this case, 29.25 MW of firm power can be generated with an irrigation reliability of 80%. The details are given in **Table 5.6** and **Fig: 5.5.**

Table 5.6: Annual firm power optimization at Almatti (case II)

Power demand (MW)	Energy demand (MU)	Time Reliability	Irrigation reliabilities		
			Time	Volume	Annual
0	0	1.000	1.000	1.000	1.000
10	7.2	1.000	1.000	1.000	1.000
20	14.4	1.000	1.000	1.000	1.000
25	18	0.986	0.993	0.996	0.933
29	20.88	0.900	0.980	0.988	0.800
29.25	**21.06**	**0.900**	0.977	0.987	0.800
29.5	21.24	0.897	0.977	0.986	0.767
30.0	21.6	0.894	0.977	0.985	0.767

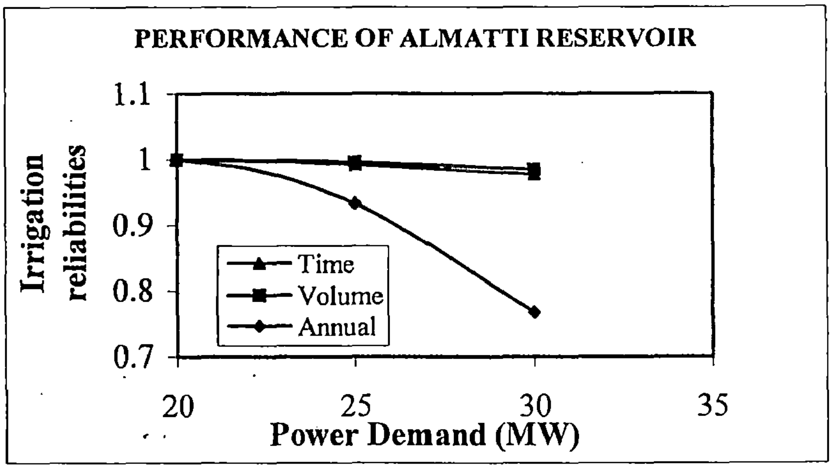


Fig 5.5: Annual firm power optimization at Almatti (case II)

The corresponding monthly firm power are given in **Table 5.7,** which ranges from 9.17 MW in May to 297.0 MW in August.

Table 5.7 : Monthly firm power at Almatti (case II)

Month	Firm Power		Month	Firm Power	
	(MW)	(MU)		(MW)	(MU)
June	26.94	19.4	December	33.06	23.8
July	42.22	30.4	January	46.11	33.2
August	297.00	213.8	February	29.25	21.1
September	112.92	81.3	March	29.25	21.1
October	29.25	21.1	April	29.25	21.1
November	29.25	21.1	May	9.17	6.6

(III) Without downstream factors for Narayanpur (irrigation priority):

While carrying out analyses as above in cases I and II, it is observed that due to the downstream releases for Narayanpur, the firm power generation at Almatti, particularly in May and June, was not possible to the desired extent. Therefore, an alternative study (case III) considering only firm power releases from Almatti (without fixed release pattern for Narayanpur as in cases I & II) was conducted with irrigation priority at Almatti. In this case, 31.5 MW of firm power can be generated at Almatti, at the same time ensuring 100% reliability for irrigation both at Almatti and Narayanpur. The simulation details are presented in **Table 5.8** and **Fig 5.6** and **5.7.**

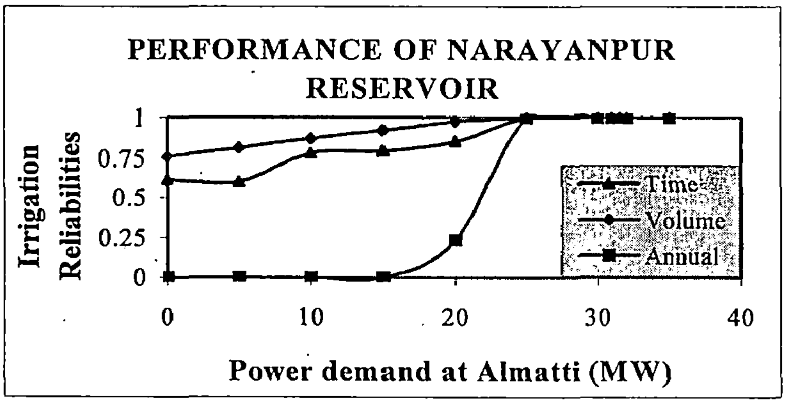


Fig 5.6: Power demand at Almatti vs Irrigation reliabilities at Narayanpur (case III)

Table 5.8: Annual firm power optimization at Almatti (case III)

ALMATTI RESERVOIR			NARAYANPUR RESERVOIR		
Power demand	Energy demand	Power	Irrigation Reliabilities		
(MW)	(MU)	Reliability	Time	Volume	Annual
0	0	1.000	0.617	0.76	0
5	3.6	1.000	0.603	0.816	0
10	7.2	1.000	0.783	0.874	0
15	10.8	1.000	0.797	0.925	0
20	14.4	1.000	0.857	0.979	0.233
25	18.0	1.000	1	1	1
30	21.6	0.958	1	1	1
31	22.32	0.917	1	1	1
31.5	22.68	0.900	1	1	1
32	23.04	0.894	1	1	1
35	25.20	0.875	1	1	1

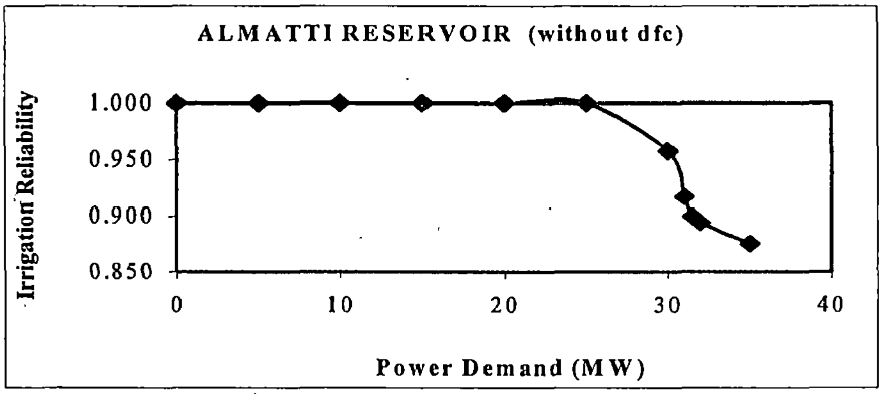


Fig 5.7 Power demand vs Power reliability (case III)

The corresponding monthly firm power is given in **Table 5.9**.

Table 5.9 : Monthly firm power at Almatti (case III)

Month	Power (MW)	Energy (MU)	Month	Power (MW)	Energy (MU)	Month	Firm (MW)	Power (MU)
June	26.25	18.9	October	31.5	22.7	February	31.5	22.7
July	31.50	22.7	November	31.5	22.7	March	31.5	22.7
August	297.0	213.8	December	31.5	22.7	April	31.5	22.7
September	112.9	81.3	January	31.5	22.7	May	13.3	9.6

(IV) Without downstream factors for Narayanpur (power priority):

Simulation runs are also taken with power priority (case IV) for varying power demands. In this case also, 31.5 MW of firm power is possible with 100 % reliability for irrigation at Narayanpur. But the irrigation demands at Almatti can be met with reliability of only 76.7 %. The details are given in **Table 5.10** and **Fig 5.8.** The monthly firm power is identical with that of case III.

Table 5.10: Annual firm power optimization at Almatti (case IV)

ALMATTI RESERVOIR						NARAYANPUR RESERVOIR		
Power demand (MW)	Energy demand (MU)	Reliability	Irrigation Reliabilities			Irrigation Reliabilities		
			Time	Volume	Annual	Time	Volume	Annual
0	0	1.000	1.000	1.000	1.000	0.617	0.760	0.000
5	3.6	1.000	1.000	1.000	1.000	0.603	0.816	0.000
10	7.2	1.000	1.000	1.000	1.000	0.783	0.874	0.000
15	10.8	1.000	1.000	1.000	1.000	0.797	0.925	0.000
20	14.4	1.000	1.000	1.000	1.000	0.857	0.979	0.233
25	18	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30	21.6	0.958	0.983	0.989	0.833	1.000	1.000	1.000
31	22.32	0.917	0.977	0.985	0.767	1.000	1.000	1.000
31.5	**22.68**	**0.900**	**0.977**	**0.985**	**0.767**	**1.000**	**1.000**	**1.000**
32	23.04	0.894	0.977	0.985	0.767	1.000	1.000	1.000
33	23.76	0.892	0.973	0.982	0.733	1.000	1.000	1.000
35	25.2	0.875	0.970	0.980	0.667	1.000	1.000	1.000

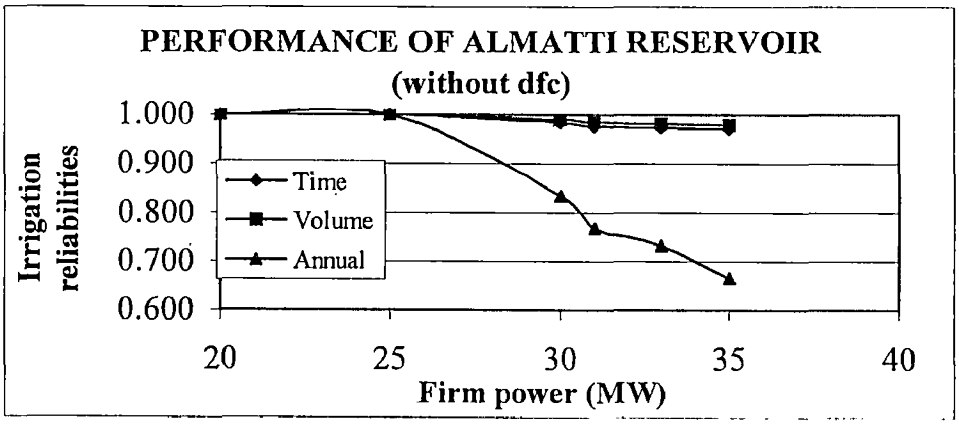


Fig 5.8 Power demand vs Irrigation reliability at Almatti (case IV)

The results of above four cases of analyses are summarized in **Table 5.11** .

Table 5.11 Different cases of optimization at Almatti

CASE	Criterion	Firm Power		Irrigation Reliabilities			
		(MW)	Pow rel.	Demand (Mm^3)	Time rel.	Vol rel.	Ann rel.
I	Dfc / Irr	28.75	0.900	258	1.000	1.000	1.000
II	Dfc / Pow	29.25	0.900	258	0.977	0.987	0.800
III	No dfc / Irr	**31.5**	**0.903**	**258**	**1.000**	**1.000**	**1.000**
IV	No dfc / Pow	31.5	0.903	258	0.977	0.985	0.767

Out of these, case III, i.e., with out downstream factors and with irrigation priority is chosen as the best option with higher firm power and 100 % reliability for irrigation at both the projects. Monthly firm power and month wise percentage of time, annual firm power generation is possible for this case has been presented in **Fig 5.9** and **5.10**.

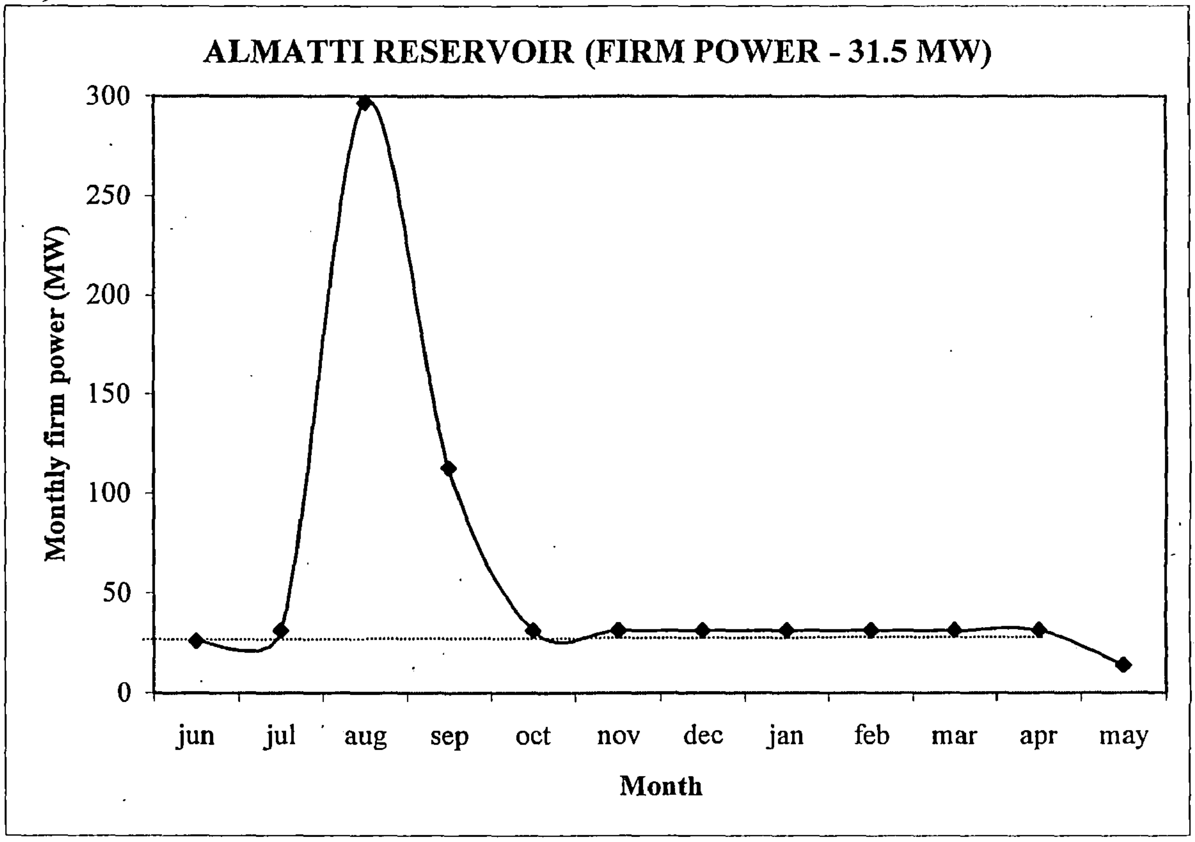


Fig 5.9 : Monthly optimized firm power at Almatti

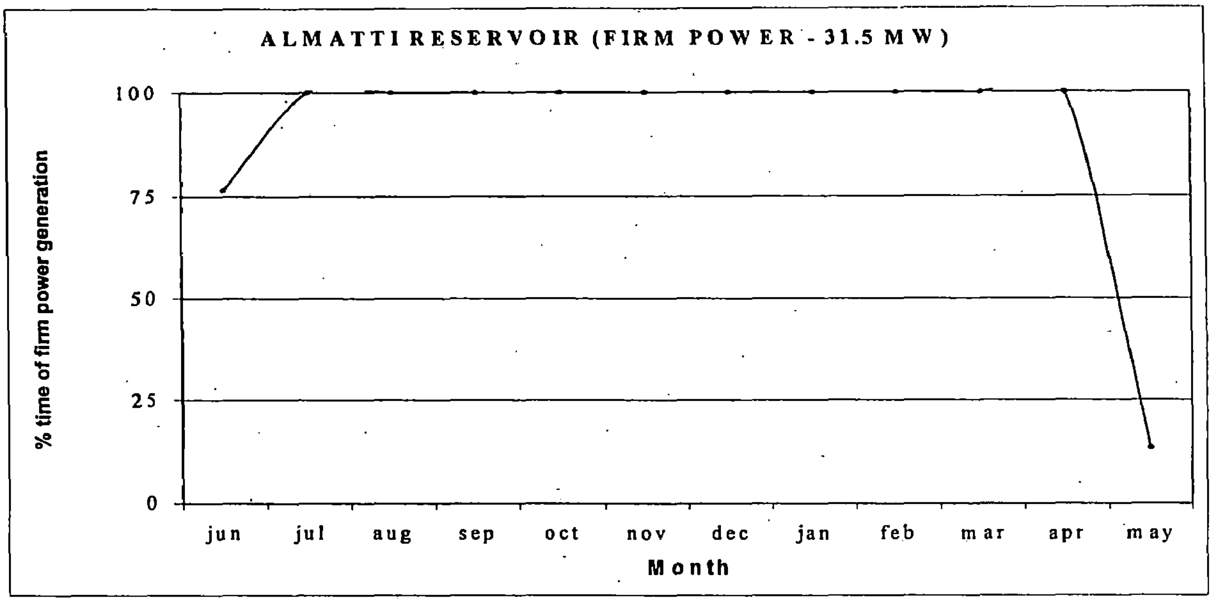


Fig 5.10: Monthly percentage of time of firm power generation at Almatti

The average annual energy generation and spills from Almatti after optimization in relation to that before optimization (stage I) are illustrated in **Fig 5.11** and **5.12.** Also, the irrigation releases at Narayanpur in both before and after optimization conditions are presented in **Fig:5.13**

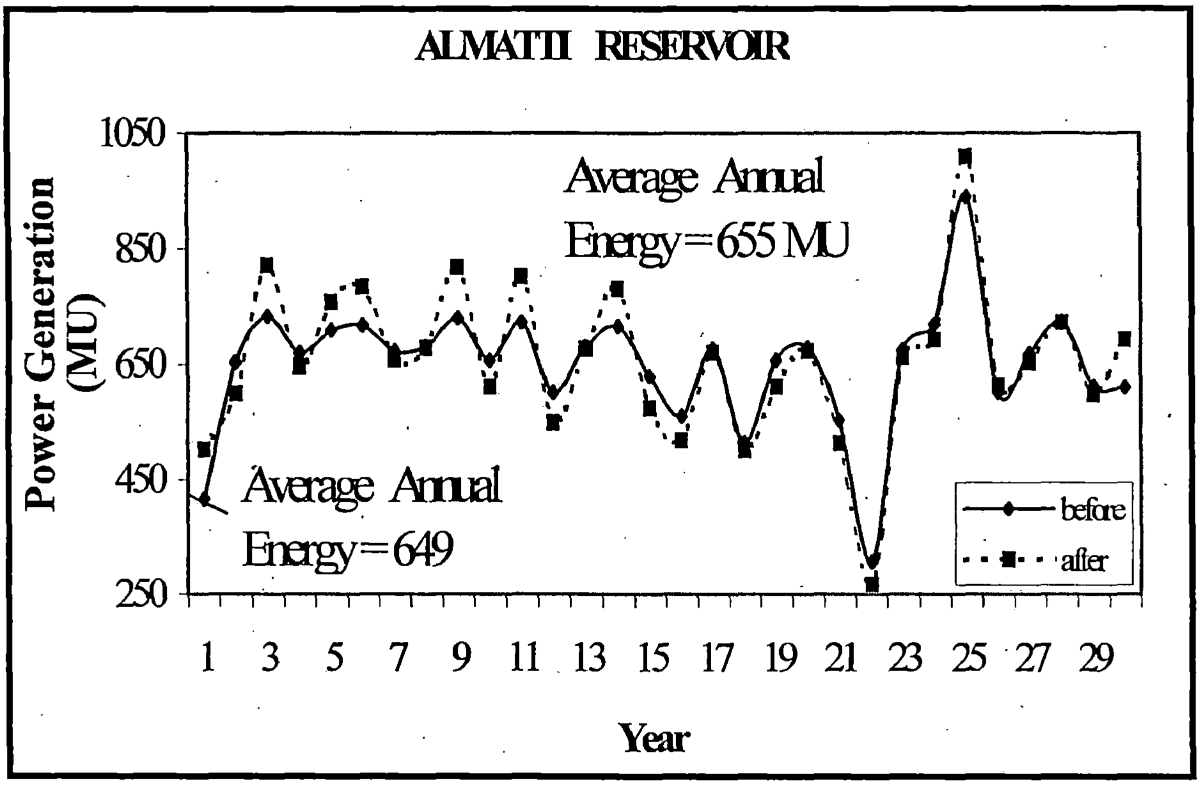


Fig 5.11: Energy generation at Almatti (before and after optimization)

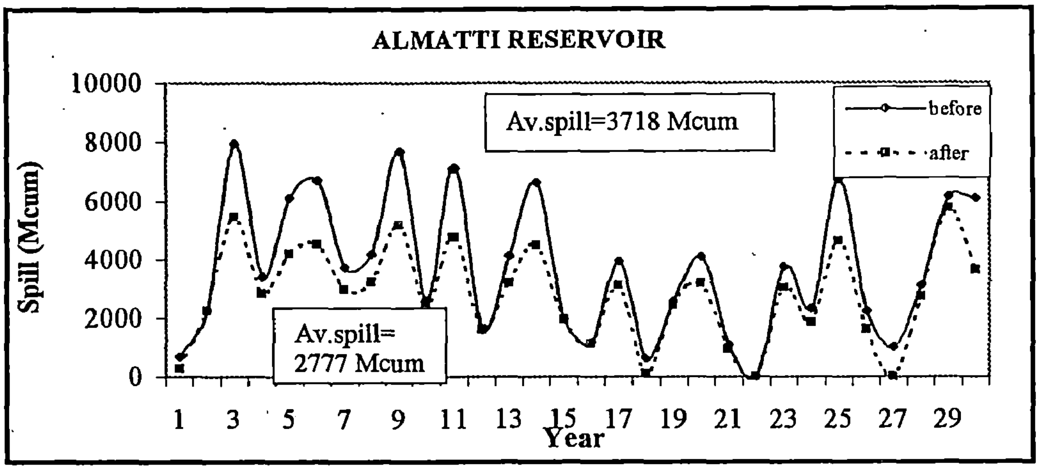


Fig 5.12: Spills at Almatti (before and after optimization)

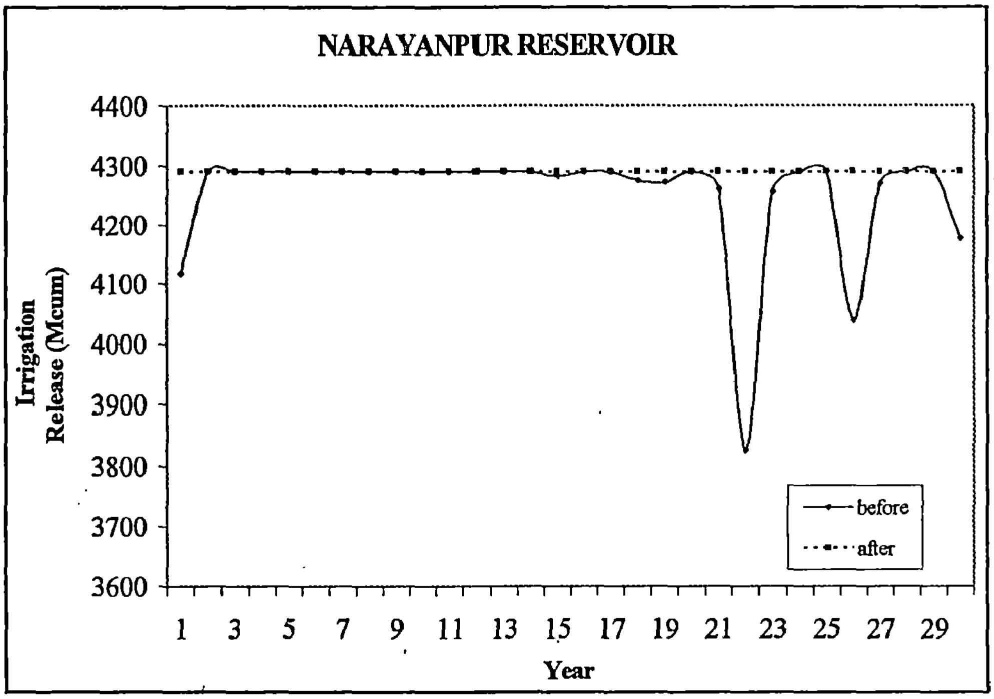


Fig 5.13: Irrigation releases at Narayanpur (before and after optimization)

Srisailam reservoir: The power generation at Srisailam is of utmost importance. However the reliability for 60 MW of firm power generation is obtained at 88.3%. The corresponding reliabilities for irrigation are 74.4 % (time), 76.6 % (volume) and 70 % (annual) respectively. Power demand has been reduced to reassess the possible firm power without disturbing the irrigation demand (2209 Mm^3) and downstream releases (6952 Mm^3 for Nagarjunasagar and 2265 Mm^3 for Prakasam barrage). Only 23 MW of firm power can be generated as given in **Table 5.12** and **Fig: 5.14**, which is quite small.

Table 5.12 : Power demand vs Power reliability at Srisailam

Power / Energy Demand (MW)	(MU)	Power rel.
60	43.2	0.883
50	36	0.883
40	28.8	0.892
30	21.6	0.897
25	18	0.897
23	16.56	0.9
20	14.4	0.903

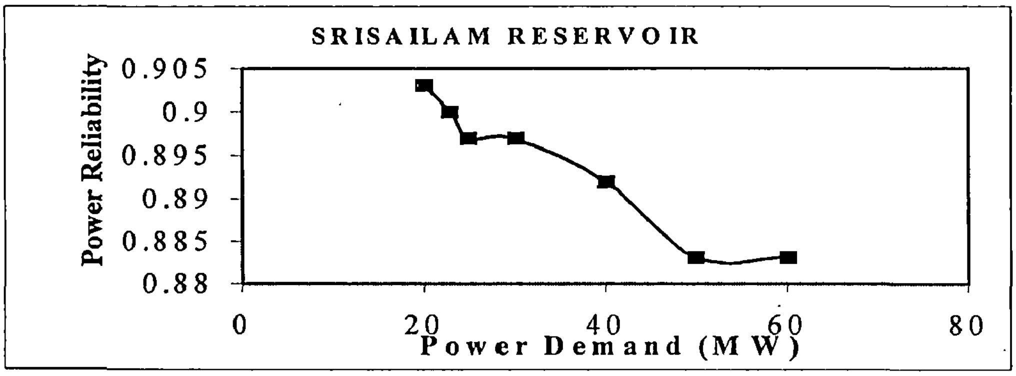


Fig 5.14 Power demand vs Power reliability

If higher firm power is to be generated, the demands for irrigation from floodwater could be reduced or restrictions imposed over their use to improve firm power. Alternatively, downstream committed releases can be reduced / redistributed to be in tune with firm power demand. Therefore, four cases of analyses were examined to ensure power reliability of 90 %.

Case I : Reduction of irrigation demands,

Case II : Raising of rule level for irrigation,

Case III: Uniform reduction of downstream demands and

Case IV: Reduction of downstream demands in critical months.

Case I : Reduction of irrigation demands: The irrigation demands were gradually reduced in steps of 10 % and the power reliability were observed. It was seen that the irrigation needs are to be reduced from 2209 Mm^3 to 772 Mm^3 to ensure power reliability of 90 % for firm power generation of 60 MW. This may be due to the fact that the irrigation releases are proposed at a higher rule level of 226.70 m from Krishna floodwaters and shortage of water for power is felt mainly in non-monsoon months. Thus, power generation is less sensitive to the flood water diversion for irrigation in monsoon months from August to October, which will other wise spill. The simulation details are given in **Table 5.13**.

Table 5.13 : irrigation demand vs Power reliability at Srisailam (case I)

Sl.no	Irr. demand (Mcum)	Irrigation Reliabilities			Power rel.
		Time	Volume	Annual	
1	2209	0.744	0.776	0.700	0.883
2	2099	0.744	0.778	0.700	0.883
3	1988	0.756	0.779	0.700	0.883
4	1878	0.756	0.781	0.700	0.883
5	1767	0.778	0.782	0.733	0.886
6	1657	0.778	0.784	0.733	0.886
7	1547	0.778	0.785	0.733	0.886
8	1436	0.778	0.787	0.733	0.892
9	1326	0.778	0.789	0.733	0.892
10	1215	0.778	0.790	0.733	0.892
11	1105	0.789	0.792	0.733	0.892
12	994	0.789	0.793	0.733	0.892
13	883	0.789	0.795	0.733	0.897
14	**772**	**0.789**	**0.797**	**0.733**	**0.900**

Case II : Raising of rule level for irrigation: Alternatively study has been carried out by raising the rule level from 266.70 m for irrigation, considering the full demand of 2209 Mm^3. The firm power generation of 60 MW will be sustainable at an irrigation rule level of 268.02 m with the corresponding annual irrigation reliability of 60 %. The details of simulation are given in **Table 5.14.**

Table 5.14 Rule level for irrigation vs Power reliability at Srisailam (case II)

Rule level (m)	Power reliability	Irrigation reliabilities		
		Time	Volume	Annual
266.70	0.883	0.744	0.776	0.700
267.00	0.886	0.744	0.771	0.700
267.30	0.892	0.744	0.767	0.700
267.60	0.892	0.733	0.762	0.700
267.90	0.894	0.700	0.757	0.633
268.00	0.894	0.689	0.751	0.600
268.01	0.897	0.689	0.745	0.600
268.02	**0.900**	**0.689**	**0.739**	**0.600**
268.05	0.900	0.678	0.739	0.567

From above two cases, it can be concluded that for achieving slight improvement in performance of the reservoir for power generation, much restrictions on irrigation use need to be imposed.

Case III : Uniform reduction of downstream demands: In case III, the release meant for Prakasam barrage has been reduced uniformly to study its effect on the improvement of firm power generation. This is exactly not reduction but mostly redistribution of downstream release, as the releases reduced in certain months will help improve power generation in subsequent failure months and thus higher power releases would be made in these months. Since the downstream reservoir at Nagarjunasagar has adequate capacity of over 10000 Mm^3, it is expected that it will adjust to this redistribution in meeting not only its own irrigation demands but also that of Prakasam barrage downstream to it. In a number of years the power releases and spills from Srisailam are seen to be more than the committed requirement. From the analysis, it is seen that 40 % (906 Mm^3) of downstream release for Prakasam barrage has to be reduced to achieve the desired power reliability. The details are given in **Table 5.15.**

Table 5.15 Uniform decrease in d/s release vs Power reliability at Srisailam (case III)

%of d/s release	Uniform d/s release (Mcum)	SRISAILAM RESERVOIR			
		Power reliability	Irrigation Reliabilities		
			Time	Volume	Annual
100	2265	0.883	0.744	0.776	0.7
95	2153	0.883	0.744	0.778	0.7
90	2041	0.883	0.744	0.781	0.7
85	1925	0.886	0.744	0.783	0.7
80	1812	0.886	0.767	0.785	0.7
75	1699	0.892	0.767	0.788	0.7
70	1586	0.892	0.767	0.790	0.7
65	1472	0.894	0.767	0.793	0.7
60	**1359**	**0.903**	**0.767**	**0.796**	**0.7**

Case IV : Reduction of downstream demands in critical months: While carrying out analysis as in case III, it is observed that downstream releases in certain non-monsoon months only are critical for power generation. In other months, the curtailment in the downstream release will mostly effect in subsequent spills. Therefore in case IV, reduction of downstream release during only these months is effected by trail and error. It is seen that reduction only in October (100 %) and November (55 %) months amounting to a total of 427 Mm^3 will help in ensuring desired power reliability. The downstream release for Prakasam will be 1836 Mm^3. The details of simulation are presented in **Table 5.16.**

Table 5.16: Non uniform decrease in d/s release vs Power reliability

Non-Uniform d/s release (Mcum)	SRISAILAM RESERVOIR				Remarks
	Power Reliability	Irrigation Reliabilities			(No d/s release for Prakasam Barrage in)
		Time	Volume	Annual	
2201	0.883	0.744	0.778	0.700	April & May
2150	0.883	0.744	0.778	0.700	March to May
2105	0.883	0.744	0.779	0.700	February to May
2050	0.883	0.744	0.779	0.700	January to May
1955	0.889	0.744	0.780	0.700	December to May
1751	0.894	0.756	0.780	0.700	November to May
1434	0.911	0.767	0.784	0.733	October to May
1498	0.911	0.767	0.784	0.733	October to March
1549	0.908	0.767	0.784	0.733	October to February
1594	0.908	0.767	0.784	0.733	October to January
1649	0.906	0.756	0.784	0.733	October to December
1744	0.903	0.756	0.783	0.733	October &November
1836	0.9	0.756	0.782	0.733	October & reduction in Nov.(55%)

Out of the 4 cases, case I is not a good option, as it will entail reduction of 1437 Mm^3 in irrigation demands (65 %) planned for irrigating drought prone areas for which the source is only Srisailam floods waters. Of the remaining three cases, case IV with non uniform reduction in downstream release will give a higher annual reliability of 73.3 % for irrigation while case III operation criteria will yield higher time (76.7 %) and volume (79.6 %) reliabilities. However, in terms of reductions in the demand, either in project irrigation or downstream releases, case IV is the best option as it satisfies both the purposes of irrigation and power with minimum reduction. The analysis is presented in **Table 5.17** and **5.18** and **Fig: 5.15.**

Table 5.17: Cases of Analysis for Optimization at Srisailam

CASE	Criterion		Irrigation reliabilities			Reduction in demand
			Time	Volume	Annual	
I	Irr. demand	772 Mcum	0.789	0.797	0.733	1437
II	MRL	268.02 m	0.689	0.739	0.600	
III	d/s rel(UR)	1359Mcum	0.767	0.796	0.700	906
IV	d/s rel(NUR)	1836Mcum	0.756	0.782	0.733	429

Table 5.18: Reduction in Irrigation demand or d/s release vs Power reliability at Srisailam

CASE I(Irr dem)		CASE III(UR)		CASE IV(NUR)	
Reduction .in Irr. Demand (Mcum)	Power reliability	Red. in d/s Rel (Mcum)	Power reliability	Red. in d/s rel (Mcum)	Power reliability
0	0.883	0	0.883	0	0.883
110	0.883	112	0.883	64	0.883
221	0.883	224	0.883	115	0.883
331	0.883	340	0.886	160	0.883
442	0.886	453	0.886	215	0.883
552	0.886	566	0.892	310	0.889
662	0.886	679	0.892	**429**	**0.900**
773	0.892	793	0.894	521	0.903
883	0.892	**906**	**0.903**	616	0.906
994	0.892			671	0.908
1104	0.892			767	0.911
1215	0.892				
1326	0.897				
1437	**0.9**				

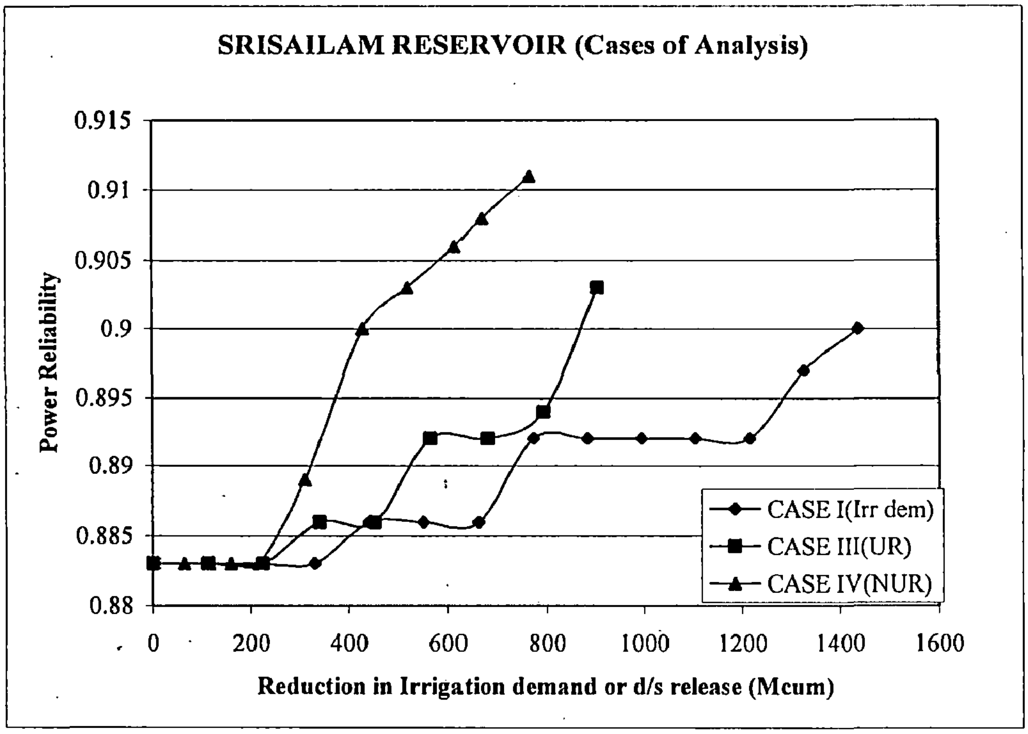


Fig 5.15: Cases of Analysis for Optimization at Srisailam

The irrigation and power releases before (with 9217 Mm^3 of total downstream release) and after (with 8788 Mm^3 of total downstream release) optimization are presented in **Fig: 5.16**and **5.17.**

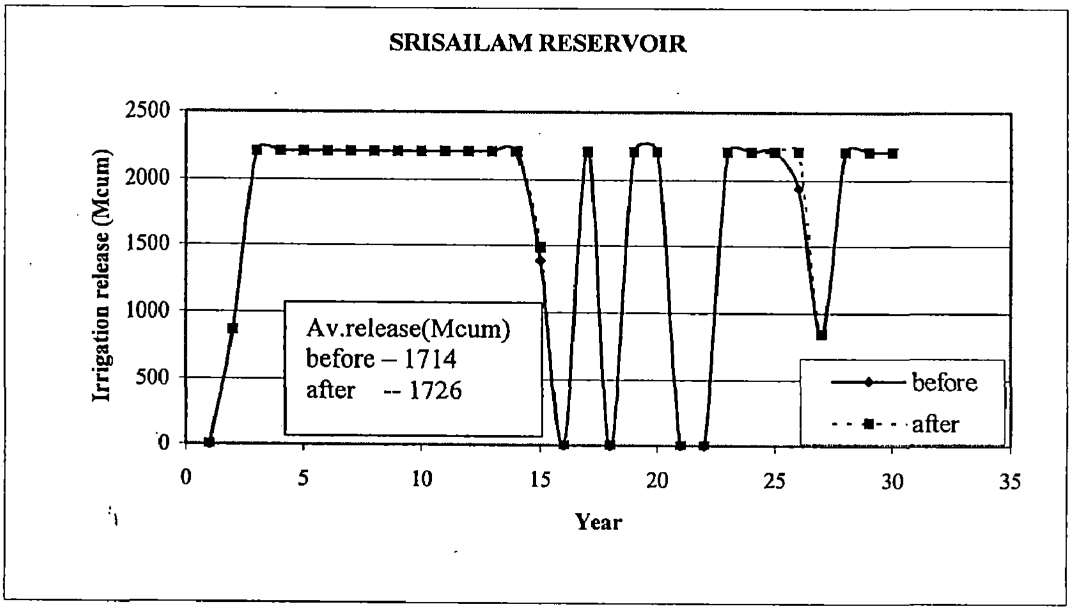


Fig 5.16: Irrigation releases at Srisailam (before and after Optimization)

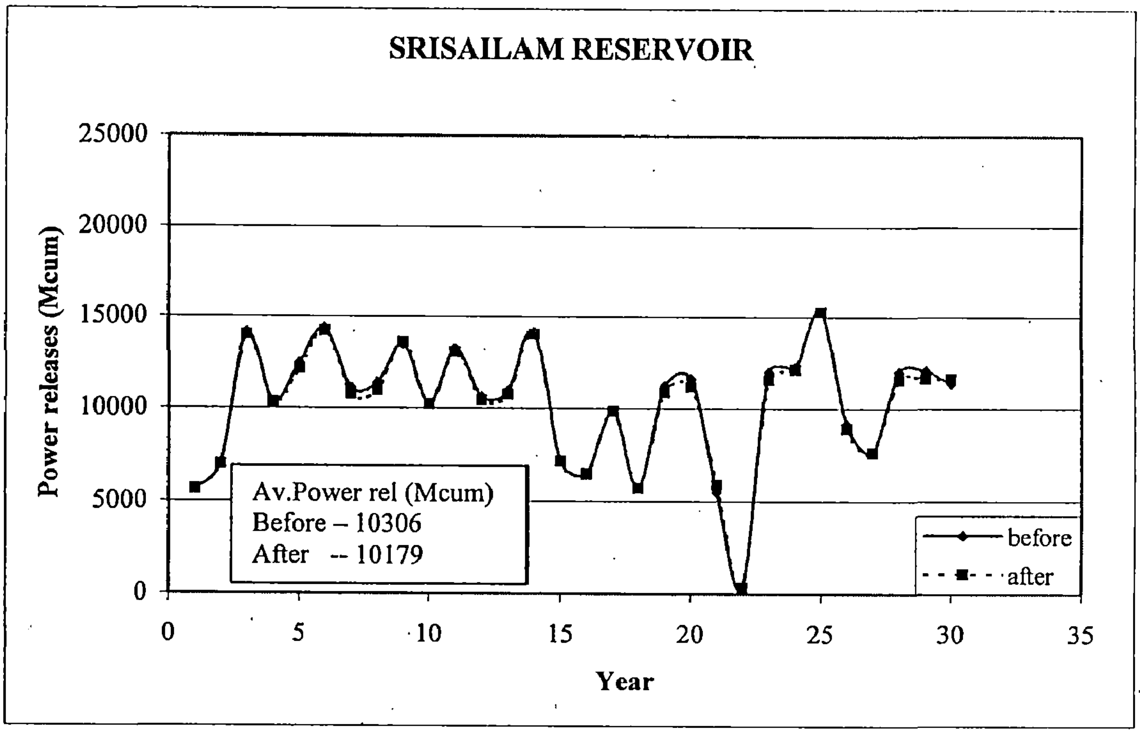


Fig 5.17: Power releases at Srisailam (before and after Optimization)

It is seen that the difference in average annual power release is only 127 Mm^3 as against reduction of 427 Mm^3 in downstream release, the rest being just redistribution. The possible monthly firm power generation in both the cases is given in **Fig: 5.18**.

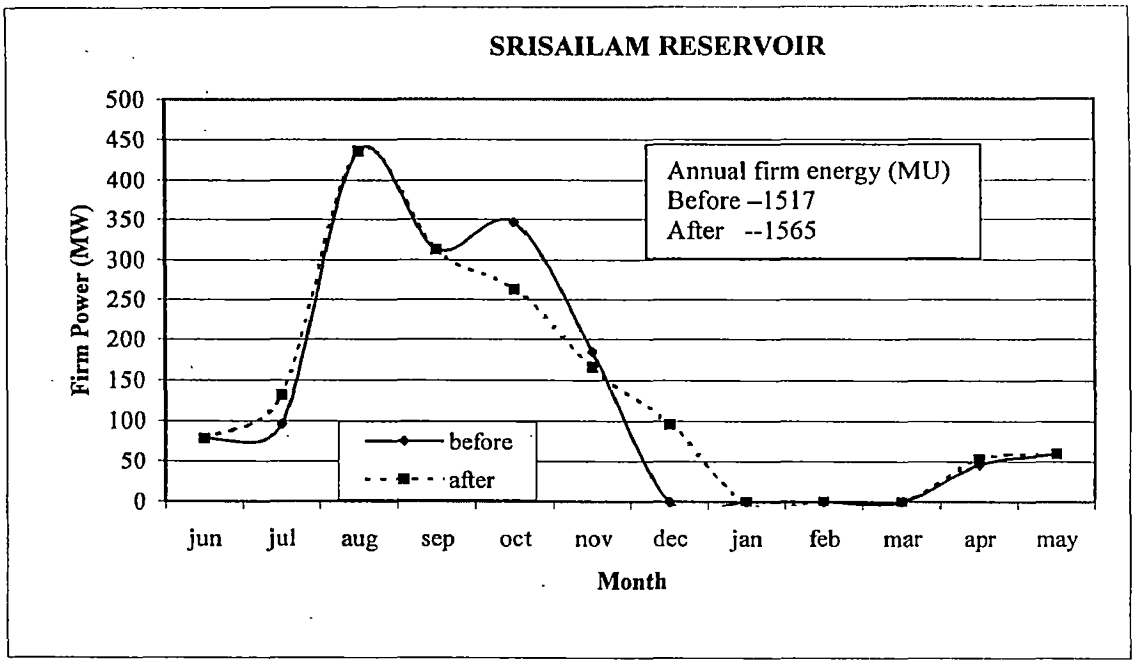


Fig 5.18: Monthly firm power (before and after optimization)

Due to some bad years with negligible inflows, firm power generation appears to be nil in January, February and March. However annual firm power generation of 60 MW is possible in these 3 months to the extent of 73 % to 87 % of time periods as illustrated in **Fig: 5.19**.

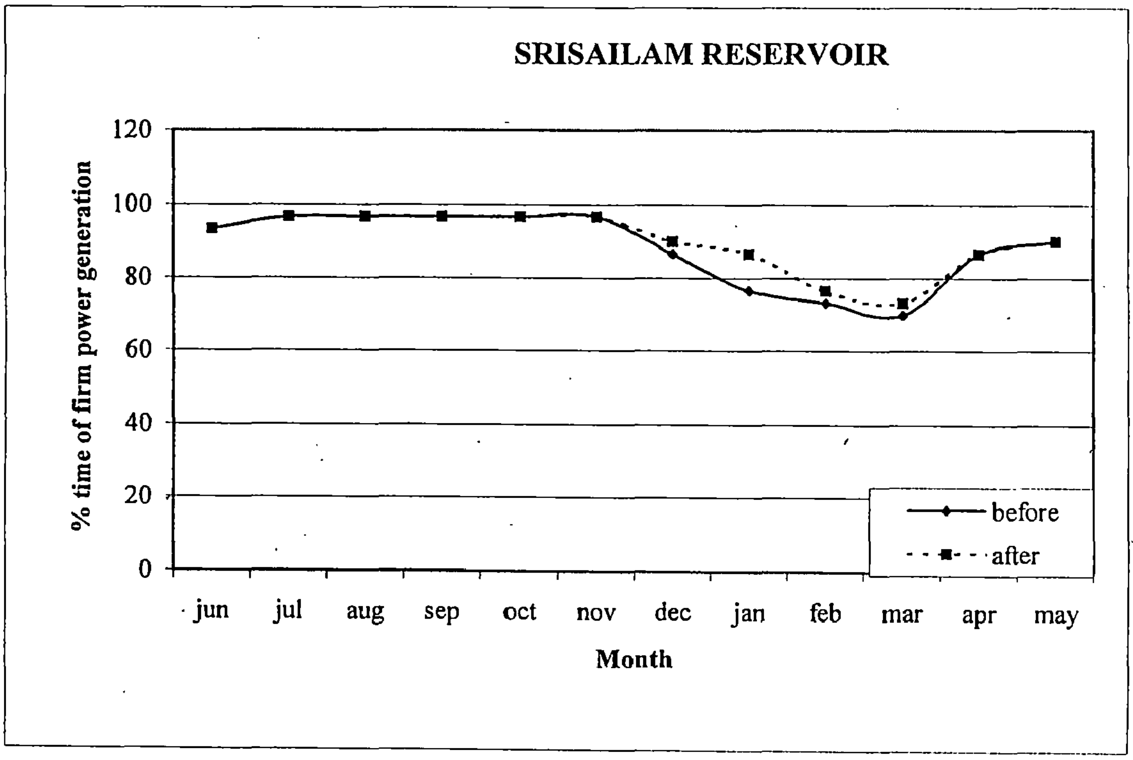


Fig 5.19: Monthly percentage of time of firm power generation (before and after Optimization)

The average annual power generation will be 2028 MU with power release at 10179 Mm^3 as against 2834 MU that has been generated during the period 1987-1992 with a power draft of 15839 Mm^3.

Nagarjunasagar reservoir: Nagarjunasagar reservoir has to meet its irrigation requirement of 7465 Mm^3 apart from ensuring releases for Prakasam barrage (2265 Mm^3). After optimization at Srisailam, Nagarjunasagar will have irrigation reliabilities of 88.1 % (time), 92.3 % (volume) and 80 % (annual). The possible firm power generation in the full upstream development scenario could not be ascertained from Project authorities. Simulation is, however, carried out for optimizing firm power in both the cases with irrigation as well as power (downstream release) priority.

Case I: Irrigation priority: It is seen from the number of simulation runs taken that the reservoir will be able to generate 32 MW as firm power with corresponding annual reliability of 83.3 % for irrigation. The power generation can go up to 68 MW at 81.9 % time reliability while ensuring the minimum desired annual reliability of 76.7 % for irrigation. The details of simulation are given in **Table 5.19** and **Fig: 5.20.**

Table 5.19: Performance of Nagarjunasagar reservoir (Irrigation priority)

Power / Energy Demand		Power Reliability	Irrigation Reliabilities		
(MW)	(MU)		Time	Volume	Annual
0	0	1	0.917	0.937	0.833
5	3.6	0.917	0.917	0.937	0.833
10	7.2	0.914	0.917	0.936	0.833
15	10.8	0.914	0.917	0.936	0.833
20	14.4	0.900	0.914	0.936	0.833
25	18	0.900	0.914	0.934	0.833
30	21.6	0.900	0.914	0.932	0.833
32	**23.04**	**0.900**	**0.914**	**0.932**	**0.833**
35	25.2	0.892	0.914	0.931	0.833
40	28.8	0.881	0.911	0.930	0.833
45	32.4	0.872	0.908	0.928	0.833
50	36	0.858	0.906	0.928	0.800
55	39.6	0.850	0.903	0.927	0.800
60	43.2	0.847	0.900	0.926	0.767
61	43.92	0.842	0.900	0.926	0.767
65	46.8	0.819	0.900	0.925	0.767
68	**48.96**	**0.819**	**0.897**	**0.925**	**0.767**
70	50.4	0.819	0.894	0.924	0.733

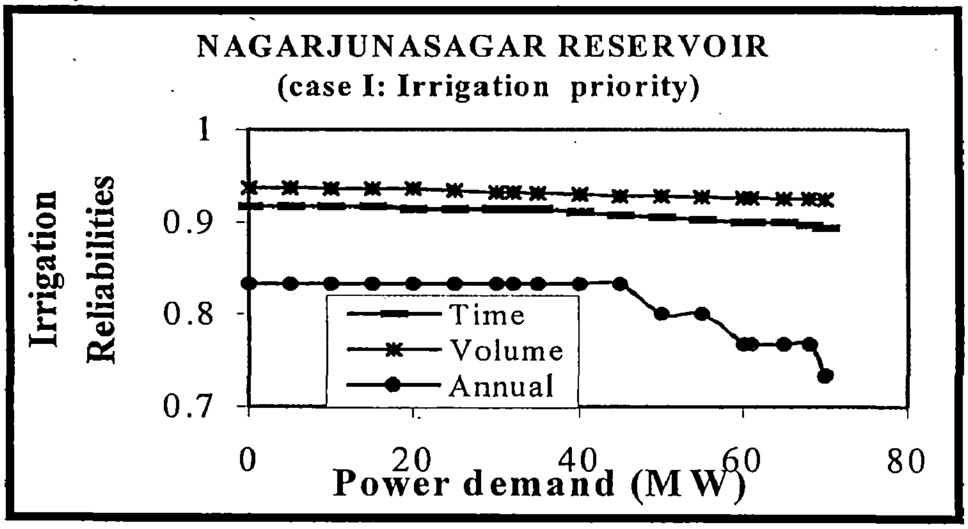


Fig 5.20 Power demand vs Irrigation reliabilities

Case II: Power priority: Simulation studies carried out for the case II indicate a firm power of 61 MW while the reliability for irrigation will be 60 %. However, the deficit in irrigation in 6 years is marginal (less than 1 % of demand). This situation is after considering the committed release of Prakasam barrage in full (2265 Mm^3). The details of simulation are shown in **Table 5.20** and **Fig: 5.21.**

Table 5.20: Performance of Nagarjunasagar reservoir (Power priority)

Power / Energy Demand		Power Reliability	Irrigation Reliabilities		
(MW)	(MU)		Time	Volume	Annual
0	0	1	0.881	0.923	0.800
5	3.6	0.953	0.881	0.922	0.800
10	7.2	0.953	0.878	0.922	0.800
15	10.8	0.950	0.875	0.921	0.767
20	14.4	0.947	0.869	0.919	0.733
25	18	0.942	0.861	0.916	0.733
30	21.6	0.939	0.856	0.914	0.700
35	25.2	0.936	0.853	0.912	0.700
40	28.8	0.931	0.839	0.909	0.700
45	32.4	0.925	0.831	0.908	0.667
50	36	0.908	0.822	0.905	0.667
55	39.6	0.903	0.817	0.902	0.667
60	43.2	0.903	0.811	0.899	0.633
61	**43.92**	**0.900**	**0.808**	**0.899**	**0.600**
65	46.8	0.897	0.803	0.896	0.600

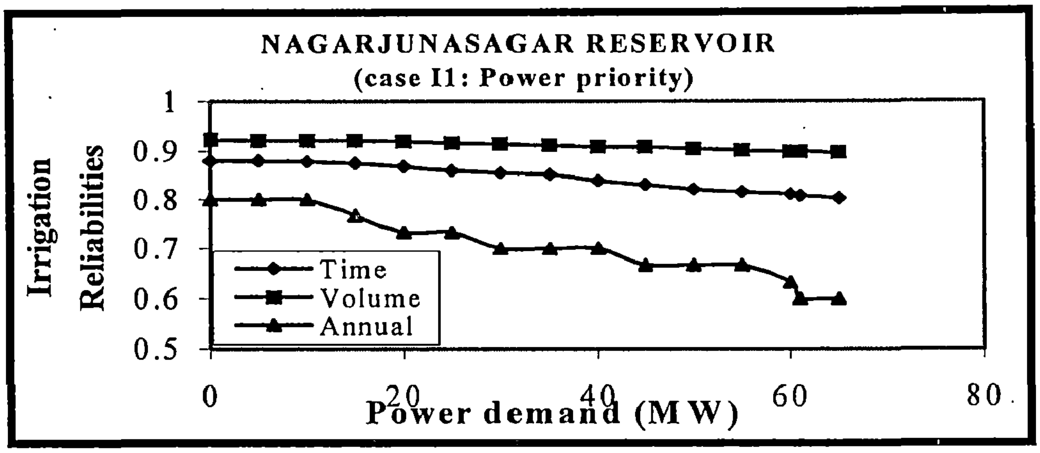


Fig 5.21 Power demand vs Irrigation reliabilities

Case III : Power priority (with redistributed downstream release): In view of the results of case II, further optimization was carried out reducing the downstream release in excess of the firm power demand in certain months to improve releases for irrigation in these years. The critical months were seen to be June and July and releases in these months were gradually reduced in successive runs observing the reservoir performance. With the reduction of 46 Mm^3 in June (from 284 Mm^3 to 238 Mm^3) and 31 Mm^3 in July (from 434 to 403 Mm^3), the irrigation reliability can be enhanced to 73.3 %. Thereafter, the downstream release pattern is not seem to be further critical for irrigation. Also, there is a deficit of only 22 Mm^3 (0.3 %) in June in one year. Instead of further reducing the power demand for making up this negligible deficit, it may be prudent to go for 61 MW of firm power as the time and volume reliabilities for irrigation are as high as 83.6 % and 90.1 % respectively. The details of simulation are given in **Table 5.21** and **Fig: 5.22.**

Table 5.21: Further optimization at Nagarjunasagar (Power –61 MW & rel. --90%)

D/s release	Monthly	Irrigation reliabilities			Remarks
Annual	(quantity)Mm^3	Time	Volume	Annual	
2265	jun(284)	0.808	0.899	0.600	As per the state govt.
2229	jun(248)	0.814	0.900	0.667	
2225	jun(244)	0.817	0.900	0.700	
2188	**Jun (238)**	**0.836**	**0.901**	**0.733**	Release in July reduced
	july(403)				from 484 Mm^3 to 403 Mm^3
Note :1.Failure year 1973-74 7443 Mcum (0.3%)					

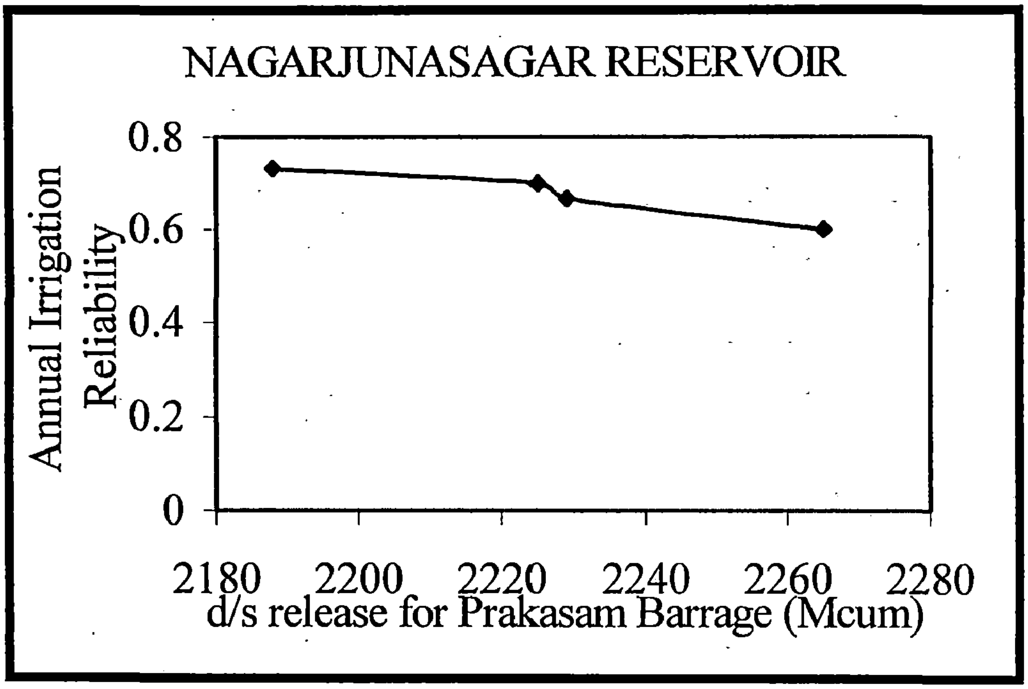


Fig 5.22: d/s release vs irrigation reliability

Out of the above 3 cases, case III operation seems to serve both irrigation and power at desired reliabilities. For a firm power demand of 61 MW, the irrigation reliabilities vs power reliabilities in all these cases are indicated in **Table 5.22.**

Table 5.22: Cases of Analysis at Nagarjunasagar

CASE	Reliabilities	
	Ann.Irr	Power
I	0.767	0.842
II	0.6	0.9
III	0.733	0.903

The performance of the reservoir before (with no firm power demand) and after optimization (with 61 MW of firm power as studied in case III) is compared in **Fig: 5.23 & 5.24.**

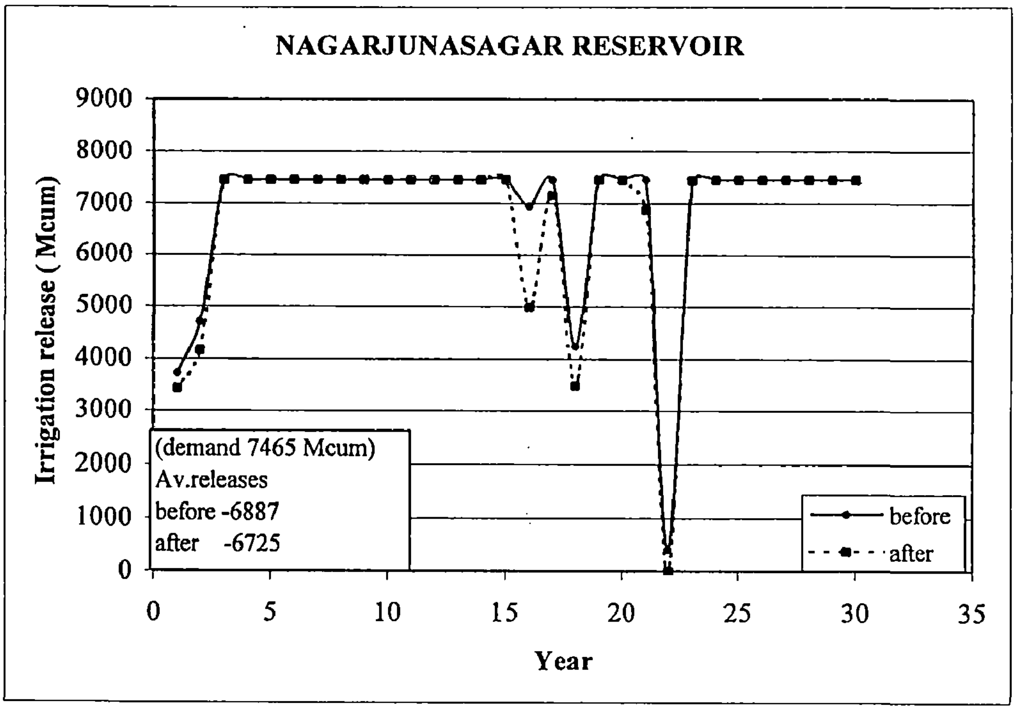


Fig 5.23 Irrigation releases from Nagarjunasagar (before & after optimization)

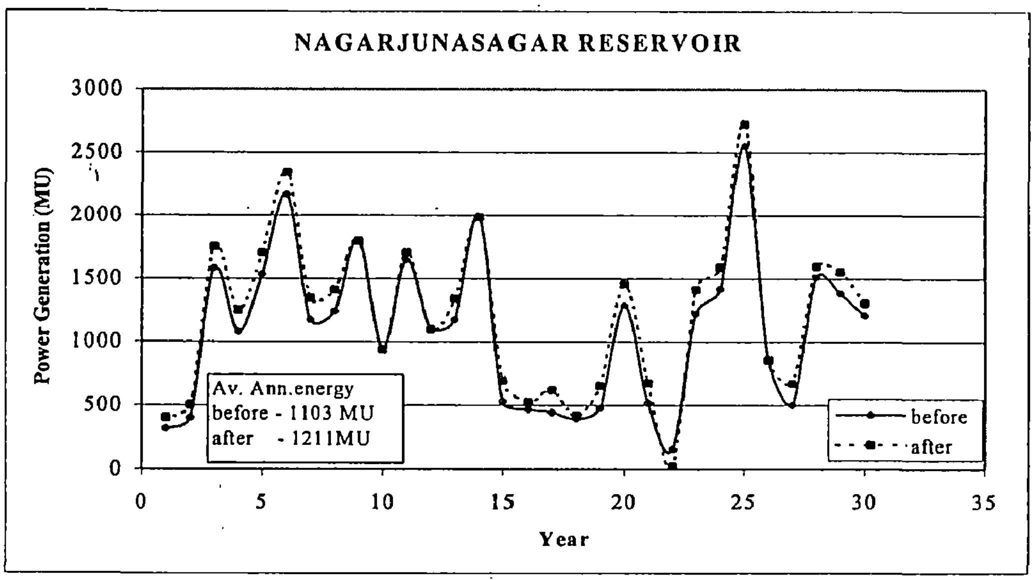


Fig 5.24 Annual energy generation at Nagarjunasagar (before & after optimization)

Due to the power optimization, the average annual irrigation releases are reduced from 6887 Mm^3 to 6725 Mm^3 while higher power release 5274 Mm^3 as against 4739 Mm^3 are effected.

This has led to an increase in average annual power generation of the order of 108 MW (from 1103 MW to 1211 MW). Also, as regulated power releases are made for 61 MW, spills have reduced from 3171 Mm^3 to 2842 Mm^3. Thus, the reservoir in case III of operation will be able to look after both its irrigation as well as power demand reasonably well. Further, it will also help the downstream reservoir with regulated releases and reduced spills in meeting their requirements. The monthly possible firm power and also the percentage of time each month will be able to generate the annual firm power of 61 MW are indicated in **Fig: 5.25** and **5.26.**

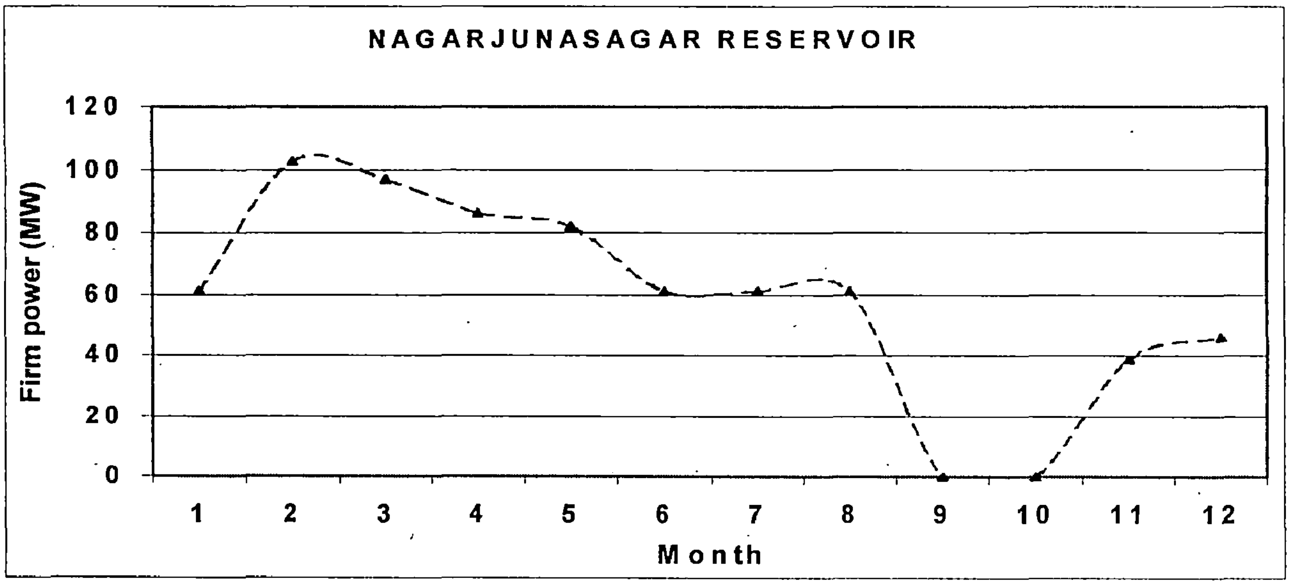


Fig 5.25: Monthly firm power at Nagarjunasagar

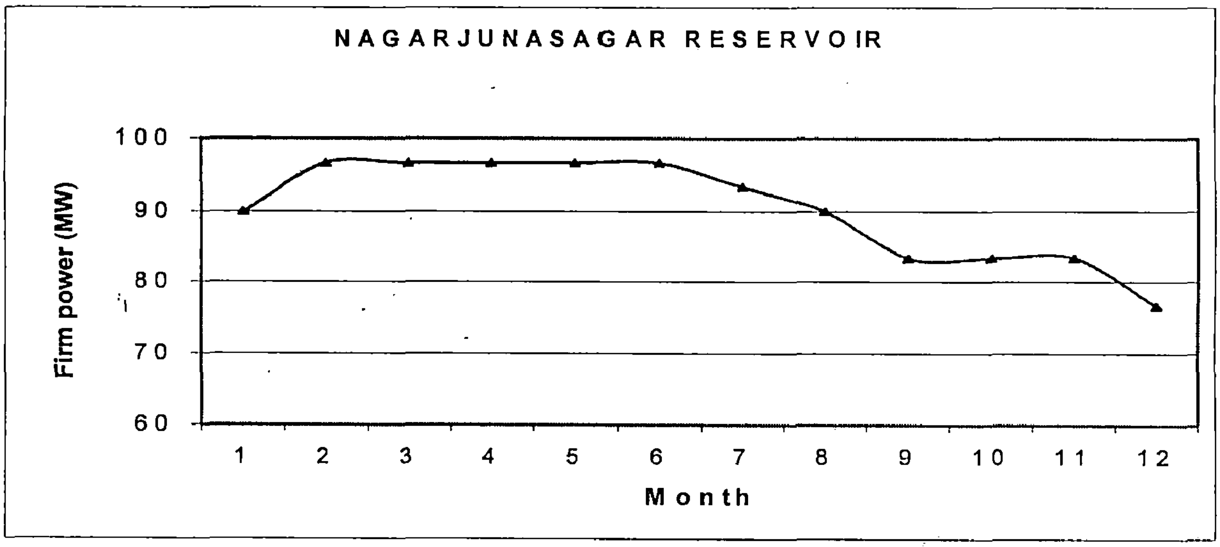


Fig 5.26: Percentage of time of annual firm power generation (61 MW)

Pulichintala reservoir and Prakasam Barrage: Under stage I, the releases from Pulichintala for Prakasam Barrage were considered as sum of committed releases from Nagarjunasagar and the average flow in the local catchment between Nagarjunasagar and Pulichintala. The reliabilities at Prakasam Barrage were 60.3 % (time), 86.3 % (volume), and 0 %(annual). The performance of reservoir was optimized to obtain high reliability at the barrage. In total, five cases of operation were considered for optimization including the case I considered in **Stage I.**

Case I : Release pattern based on average flows in the local catchment and releases from Nagarjunasagar.

Case II : Release pattern as per demand at barrage less average flow from local catchment below Pulichintala.

Case III : Enhanced releases to meet annual deficits at barrage.

Case IV : Upper rule level optimization to improve time reliability.

Case V : Release pattern as per the net demand at Prakasam.

Case II: In this case, the downstream factors have been specified as per the demand at barrage less the average flow below Pulichintala. This case will be effective as the storage at the Pulichintala is utilized to accommodate the fluctuations in inflow and release the same in the pattern required by the barrage. The annual supplementation in this case is 2787 Mm^3 against 3363 Mm^3 considered in **Case I.** The reliabilities have improved considerably: 75 % (time), 89.6 % (volume), 56.7 % (annual).

Case III: Under this case, additional supplementation is considered to further improve the annual reliability at the barrage by observing the deficits in successive runs. This additional supplementation is required to take care of the fluctuations in the local flows at the barrage. The details of additional supplementation along with the corresponding reliabilities are given **Table 5.23.** The supplementation can be raised to 2909 Mm^3 so as to achieve the reliabilities of 81.1 % (time), 90 %(volume) and 63.3 % (annual).

Table 5.23:Additional supplementation from Pulichintala to Prakasam barrage

Release to Barrage (Mcum)	PULICHINTALA Release reliabilities			PRAKASAM BARRAGE Irrigation reliabilities			Release in each month (Mm^3) Criteria
	Time	Volume	Annual	Time	Volume	Annual	
2787	0.955	0.965	0.867	0.75	0.896	0.567	Demand at Barrage less Average local flow
2791	0.955	0.965	0.867	0.753	0.897	0.600	July – 685 ;
2853	0.955	0.964	0.833	0.775	0.898	0.633	July-718 ;Dec - 188 ;Jan -101;
2863	0.956	0.963	0.833	0.778	0.899	0.633	Nov-357 ;
2867	0.956	0.963	0.833	0.781	0.899	0.633	Dec-192 ;
2879	0.956	0.963	0.833	0.783	0.899	0.633	Dec –204 ;
2881	0.956	0.963	0.833	0.789	0.899	0.633	Dec –206 ;
2882	0.956	0.963	0.833	0.792	0.899	0.633	Dec –207 ;
2888	0.956	0.963	0.833	0.794	0.899	0.633	Dec –213 ;
2890	0.956	0.963	0.833	0.797	0.900	0.633	Dec –215 ;
2893	0.956	0.963	0.833	0.800	0.900	0.633	Jan –104 ;
2896	0.956	0.963	0.833	0.806	0.900	0.633	Jan –107 ;
2899	0.956	0.963	0.833	0.808	0.900	0.633	Jan –110 ;
2909	**0.956**	**0.962**	**0.833**	**0.811**	**0.900**	**0.633**	May – 11;

Case IV: From analysis of case III, it is seen that performance in some periods can be still improved with adjustments in upper rule level. The upper rule levels were varied at Pulichintala in each month and the effect in further improving the time reliability at Prakasam Barrage was observed. The optimized upper rule levels in July, January and February which, lead to improvement in the reliability are 46.48 m, 51.62 m and 50.29 m respectively. In other months, the upper rule level was kept at FRL. The upper rule level optimization is shown in **Table 5.24 (a to c)** and **Fig: 5.27(a to b).** The time reliability could be further improved to 82.2 % while the volume reliability has shown a slight decline to 89.8 %.

Table 5.24(a) : Upper rule level Optimization (July)

URL (m) at	Reliabilities at barrage	
Pulichintala	Time	Annual
53.34	0.811	0.633
51.82	0.811	0.633
50.29	0.811	0.633
48.77	0.811	0.633
47.24	0.811	0.633
45.72	0.817	0.600
46.02	0.814	0.600
46.33	0.817	0.600
46.63	0.811	0.633
46.53	0.814	0.633
46.43	0.817	0.600
46.48	**0.814**	**0.633**
46.45	0.817	0.600

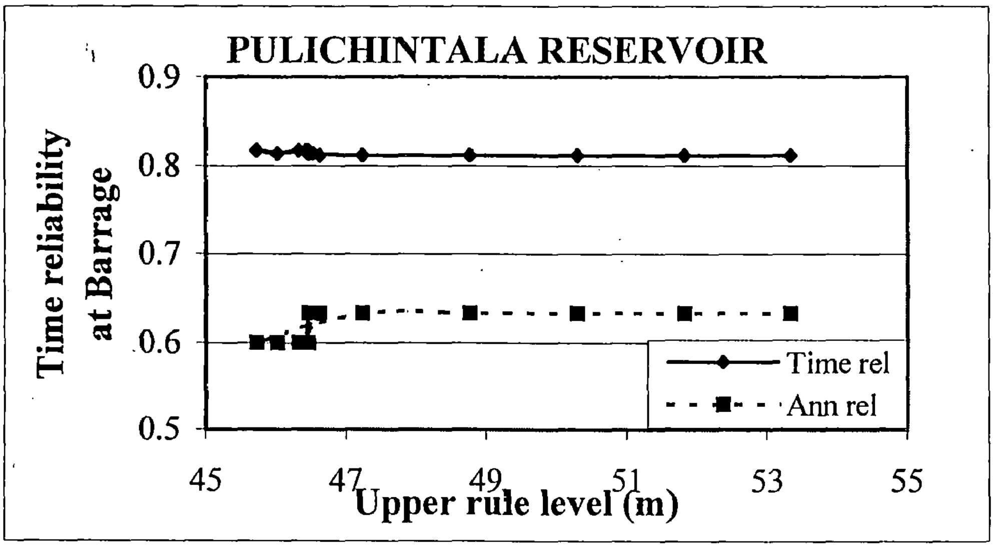


Fig.5.27 (a): Upper rule level optimization (July)

Table 5.24(b) : Upper rule level Optimization (January)

URL (m) at	Reliabilities at barrage	
Pulichintala	Time	Annual
53.34	0.814	0.633
51.82	0.817	0.633
50.29	0.825	0.600
51.52	0.819	0.633
51.72	0.817	0.633
51.62	**0.819**	**0.633**

Table 5.24(c) : Upper rule level Optimization (February)

URL (m) at Pulichintala	Reliabilities at barrage	
	Time	Annual
53.34	0.819	0.633
51.82	0.819	0.633
51.52	0.819	0.633
51.21	0.819	0.633
50.90	0.819	0.633
50.60	0.819	0.633
50.29	**0.822**	**0.633**
49.98	0.819	0.600
48.77	0.836	0.600

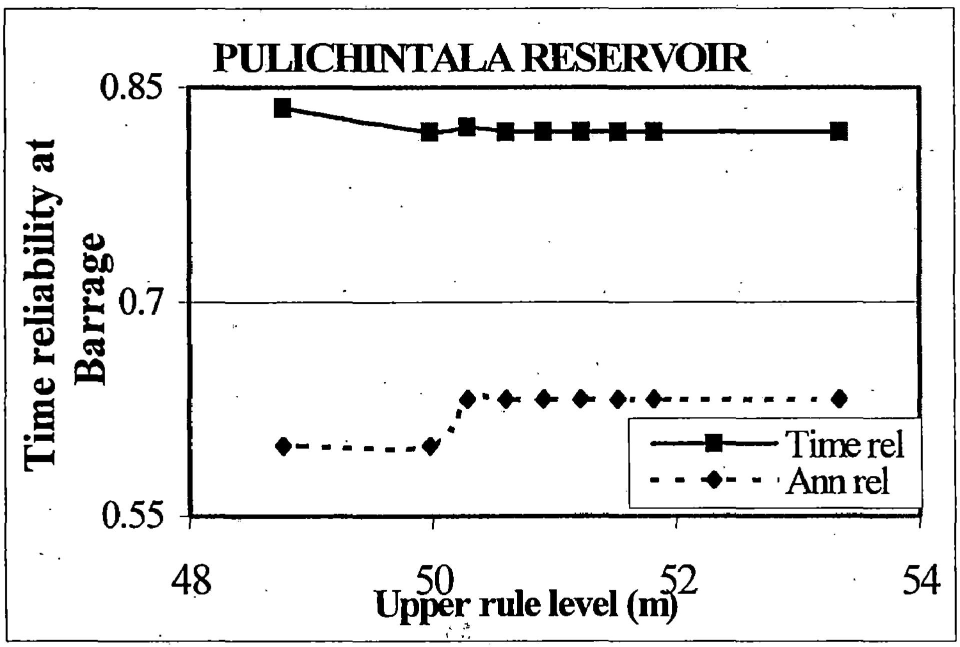


Fig.5.27 (b): Upper rule level optimization (February)

Case V: After carrying out the analysis in the above four cases, it is felt that the method of downstream factors will be more effective in case of a storage reservoir. The barrage can not store any excess flows from the local catchment while the upstream reservoir (Pulichintala) continue to release as per the specified pattern. This situation will lead to spill over the barrage in such periods and in subsequent periods it may fail due to inability of the upstream reservoir to release water.

Therefore, an additional option of "net demand" has been incorporated in the model in case the downstream node is a barrage. The net requirement in excess of local flows at barrage will only be drawn from the upstream reservoir. This concept has helped in improving the performance by avoiding the wastage at barrage and storing the same in the reservoir for use in times of need. The reliabilities obtained in this case are 86.1 % (time), 91.9 % (volume) and 60 % (annual). The five cases of analysis and their reliabilities are presented in **Table 5.25** and **Fig: 5.28**

Table 5.25: Cases of analysis at Pulichintala and Prakasam barrage

Case	Release from Pulichintala (Mcum)	Prakasam barrage			REMARKS
		Irrigation reliabilities			
		Time	Volume	Annual	
I	3363	0.603	0.863	0	average flow from N.sagar to Pulichintala + releases
II	2787	0.750	0.896	0.567	demand at barrage less average flow below Pulichintala
III	2909	0.811	0.900	0.633	increase in release to meet the annual deficits at barrage
IV	2909	0.822	0.898	0.633	URL optimization to further increase time reliability
V	Net demand	0.861	0.919	0.600	release as per net demand at Prakasam Barrage

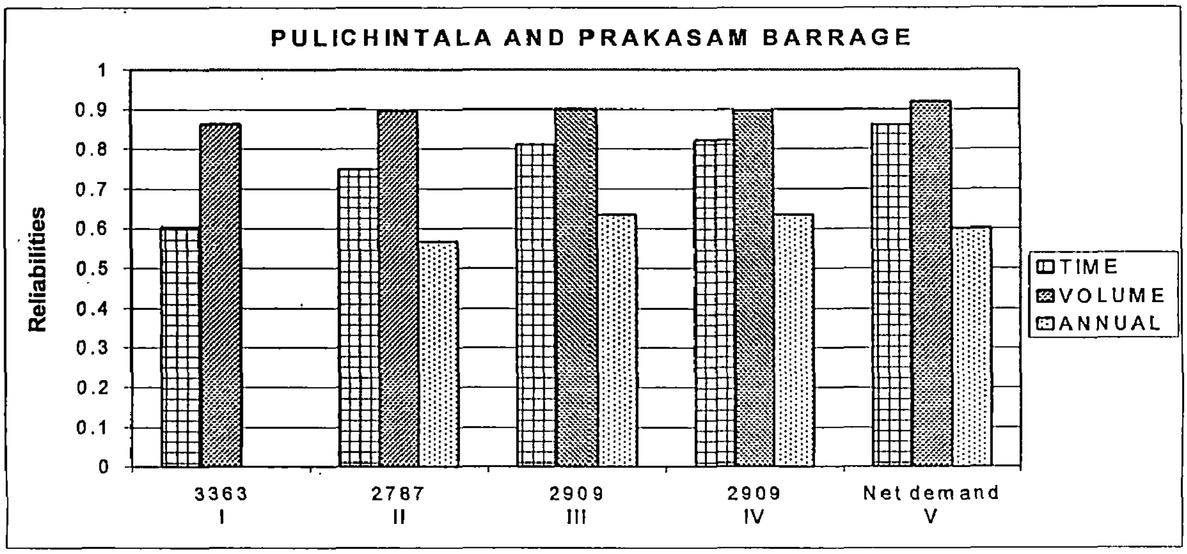


Fig 5.28: Irrigation Performance Optimization in different cases at Pulichintala & Prakasam barrage

After optimizing the performance at Prakasam barrage, power optimization at Pulichintala is taken up. Cases I and II are not considered, as the other cases are improvements over these. In each case (III to V) simulation runs are taken for different power demands to ascertain the firm power generation that can be possible at Pulichintala without affecting the irrigation reliability optimized at Prakasam barrage. Firm power of 6 MW and 5 MW can be generated in Cases III and IV respectively. Under Case V, (i) 7 MW can be generated keeping the reliabilities in tact at Prakasam Barrage while (ii) 10 MW can be generated with slight reduction in time (85.6 %) and volume (91.4 %) reliabilities respectively. This loss is negligible as compared to the gain in power. The difference in annual irrigation release at Prakasam Barrage with 75 % reliability in case V (i) and V(ii) is just 25 Mm^3. The four cases of analysis are presented in **Table 5.26** and **Fig: 5.29.**

Table 5.26: Cases of Analysis for power optimization at Pulichintala

Case	Pulichintala firm power	Prakasam barrage Diversion (Mcum)	Prakasam barrage Deficit (Mcum)
III	6 MW	4397	735
IV	5 MW	4307	825
V (i)	7 MW	4552	580
V (ii)	10 MW	4527	605

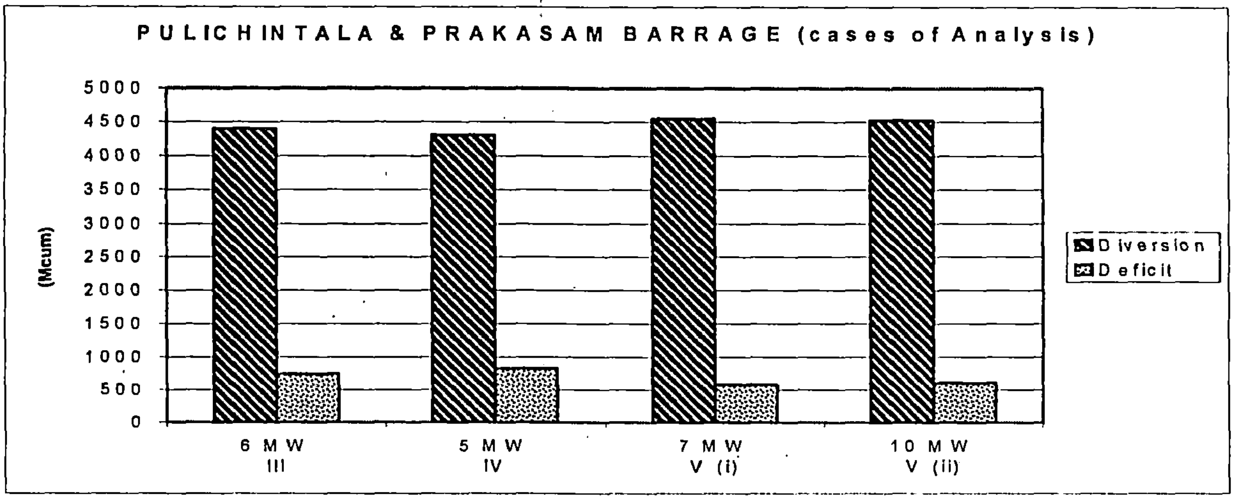


Fig 5.29: Power optimization at Pulichintala in different cases

In view of the optimum water utilization for irrigation and higher firm power generation at Pulichintala, Case V (ii) with a firm power 10 MW is opted to be the best. The performance of the reservoir and the barrage before (Case I) and after (Case V. (ii)) optimization are shown in **Fig: 5.30** to **5.33** respectively.

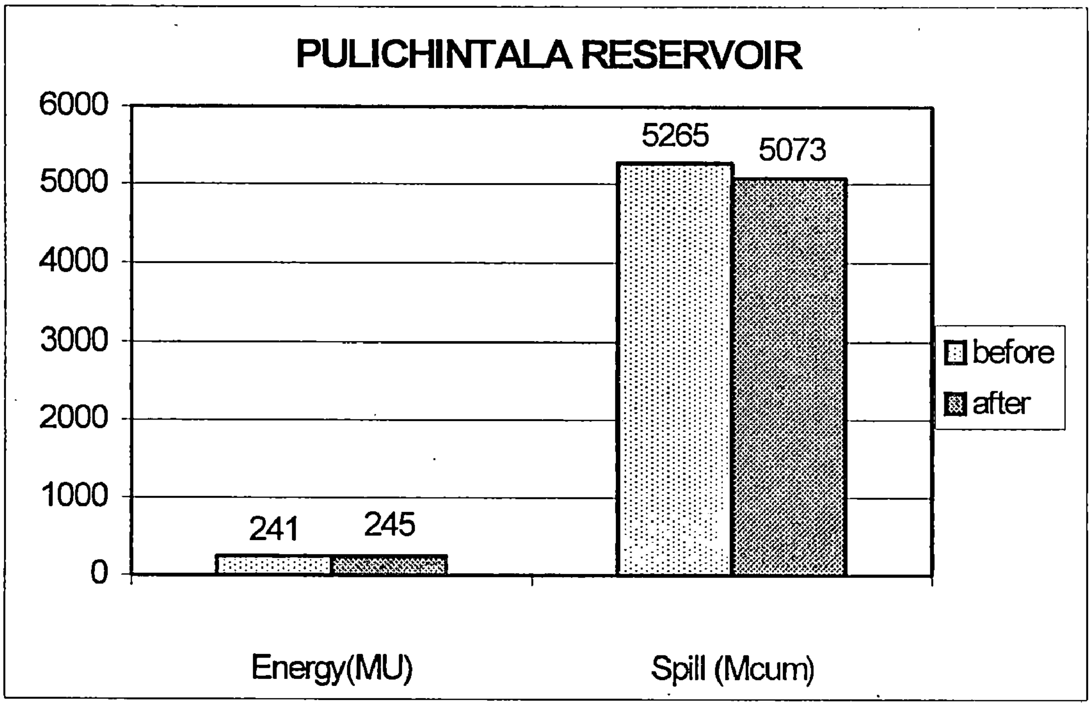


Fig 5.30: Performance of Pulichintala reservoir (before and after optimization)

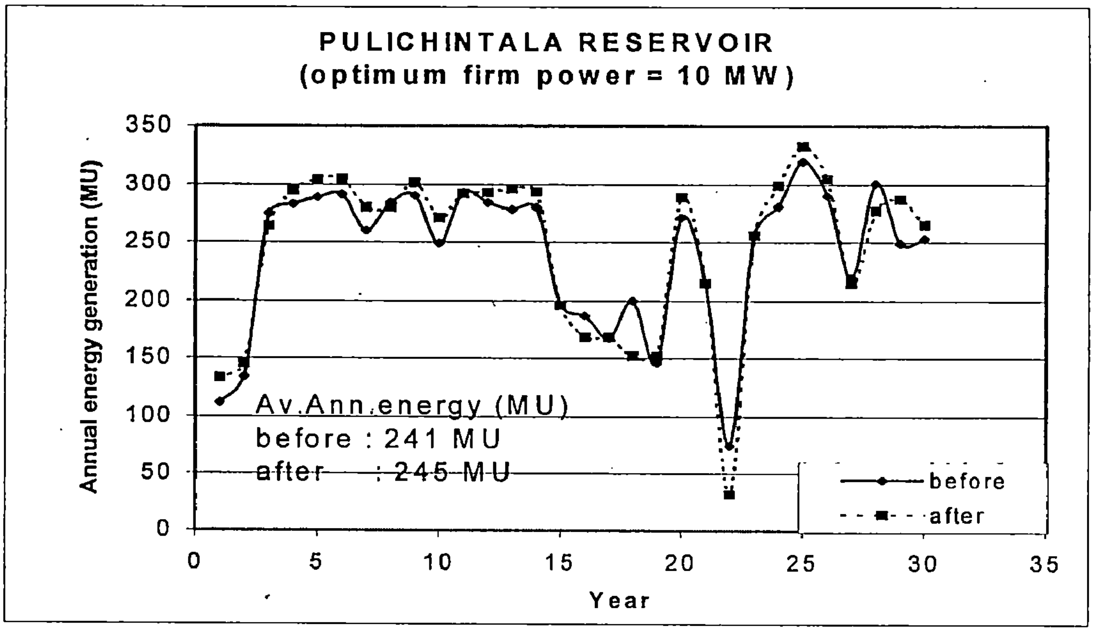


Fig 5.31:Annual energy generation at Pulichintala (before & after optimization)

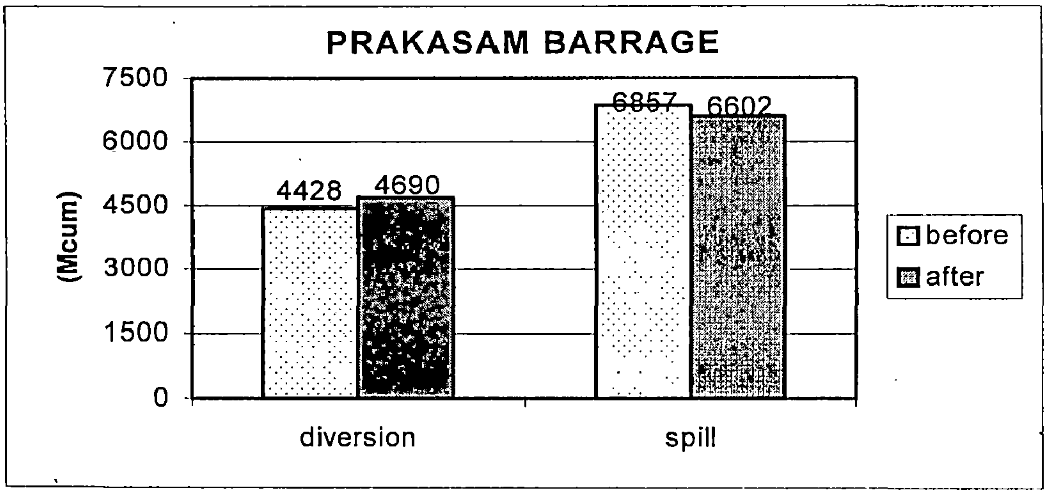


Fig 5.32 Performance of Prakasam barrage (before and after optimization)

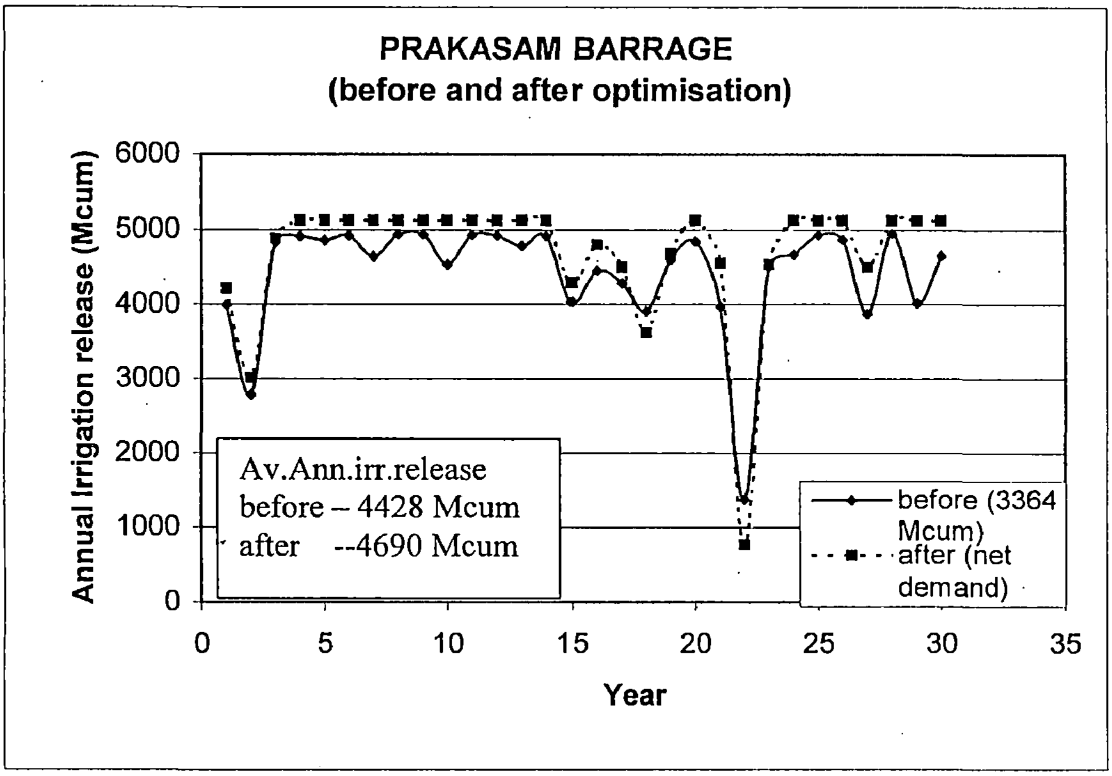


Fig 5.33 : Annual Irrigation releases at Prakasam barrage

(before & after Optimization)

The monthly possible firm power at Pulichintala and percentage of time annual firm power of 10 MW can be generated in each month is shown in **Fig: 5.34** and **5.35** respectively.

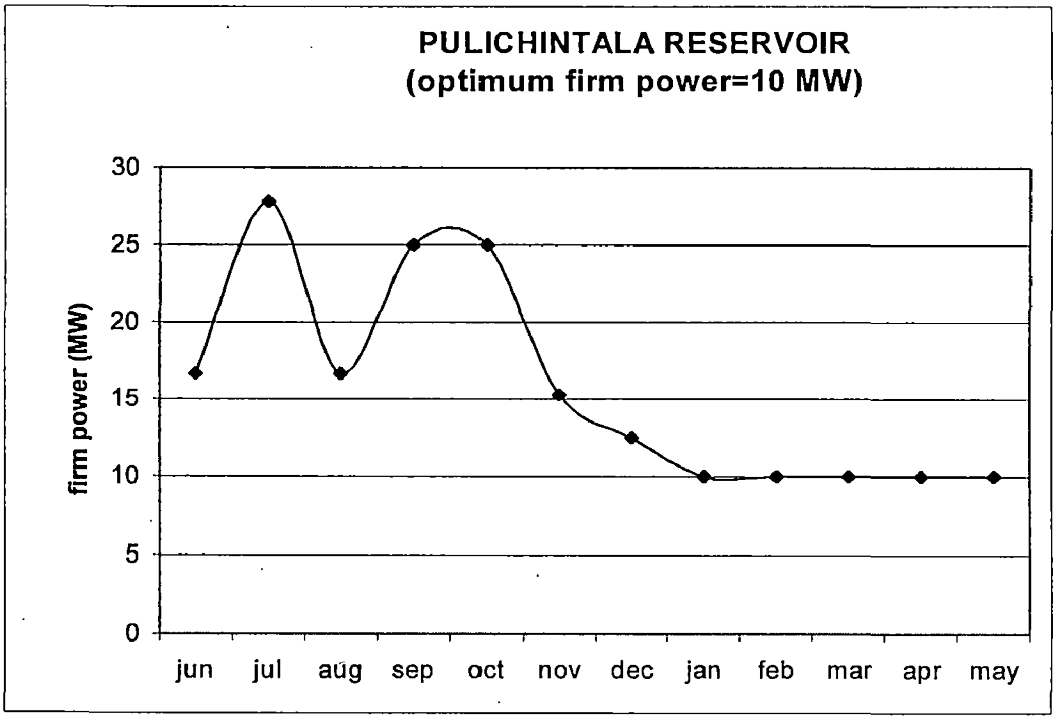


Fig 5.34: Monthly firm power at Pulichintala

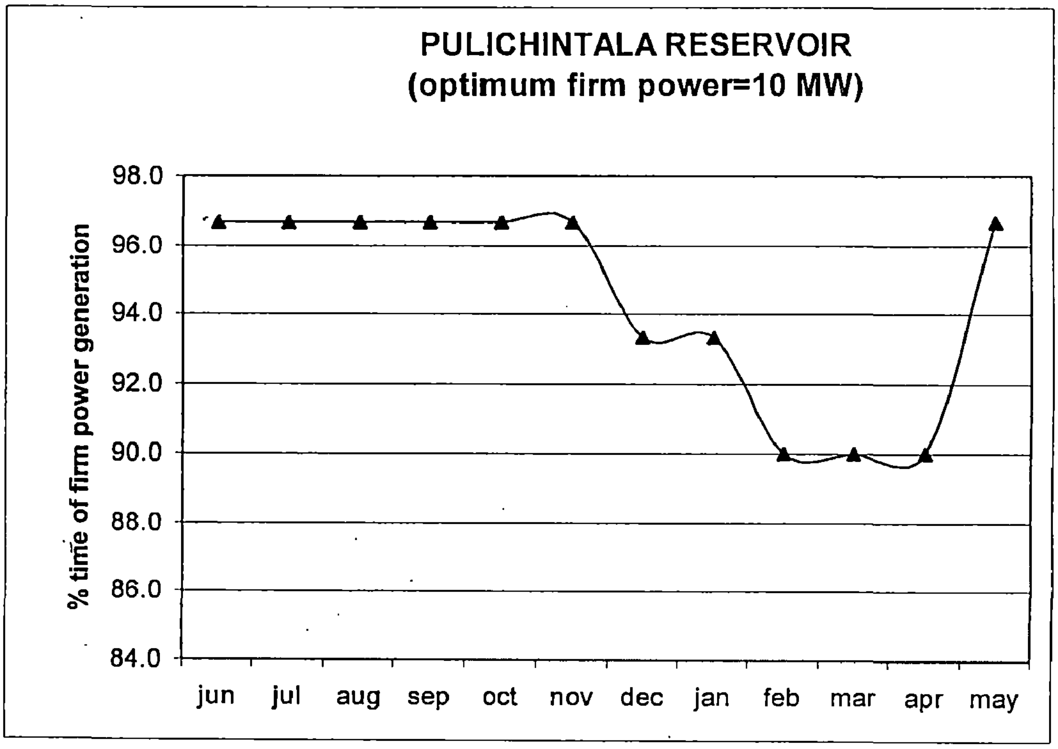


Fig 5.35: Percentage of time of annual firm power generation

5.3.2 The Pennar Sub-system

Somasila reservoir: The Somasila reservoir has to meet its irrigation commitments in Pennar delta in addition to its own demands. Further, irrigation in new areas under Telugu Ganga Canal has been proposed from Pennar floodwaters. Middle rule level optimization has been done to distribute fair amount of release for new area while preserving the releases for delta requirements to the possible extent.

Initially, under Step I, rule level was set at FRL and the corresponding annual reliability for delta was 53.3 % while that of Telugu Ganga was nil. Rule level for Telugu Ganga has been gradually lowered and the reliabilities for both the irrigation demands are observed. RL 98.50 m is seen to be the most optimum level at which Telugu Ganga will have a reliability of 16.7 % while that of delta remained at 53.3 %. The details of simulation are given in **Table 5.27** and **Fig: 5.36.**

Table 5.27 Middle Rule level Optimization at Somasila

Middle rule level*	Annual Reliability		Water Supply to Chennai city
	delta command	Telugu Ganga command	Time reliability
97.50	0.500	0.167	0.917
98.00	0.500	0.167	0.917
98.40	0.500	0.167	0.917
98.50	**0.533**	**0.167**	**0.917**
99.00	0.533	0.167	0.917
99.50	0.533	0.100	0.917
100.00	0.533	0.067	0.917
100.50	0.533	0.033	0.917
100.58	0.533	0	0.917

Note* : The middle rule level is for Telugu Ganga

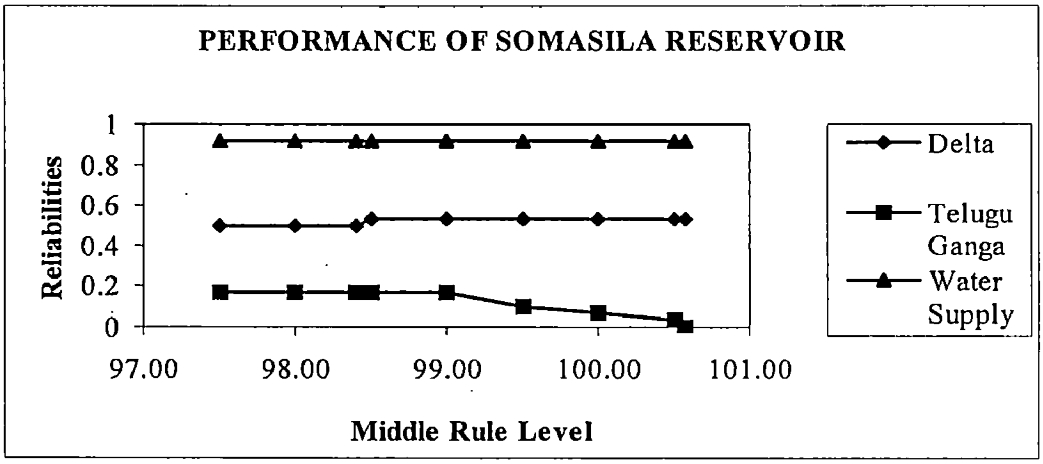


Fig: 5.36 Middle Rule level Optimization at Somasila

The performance of the reservoir before and after rule optimization is given in **Fig:5.37** to **5.39.**

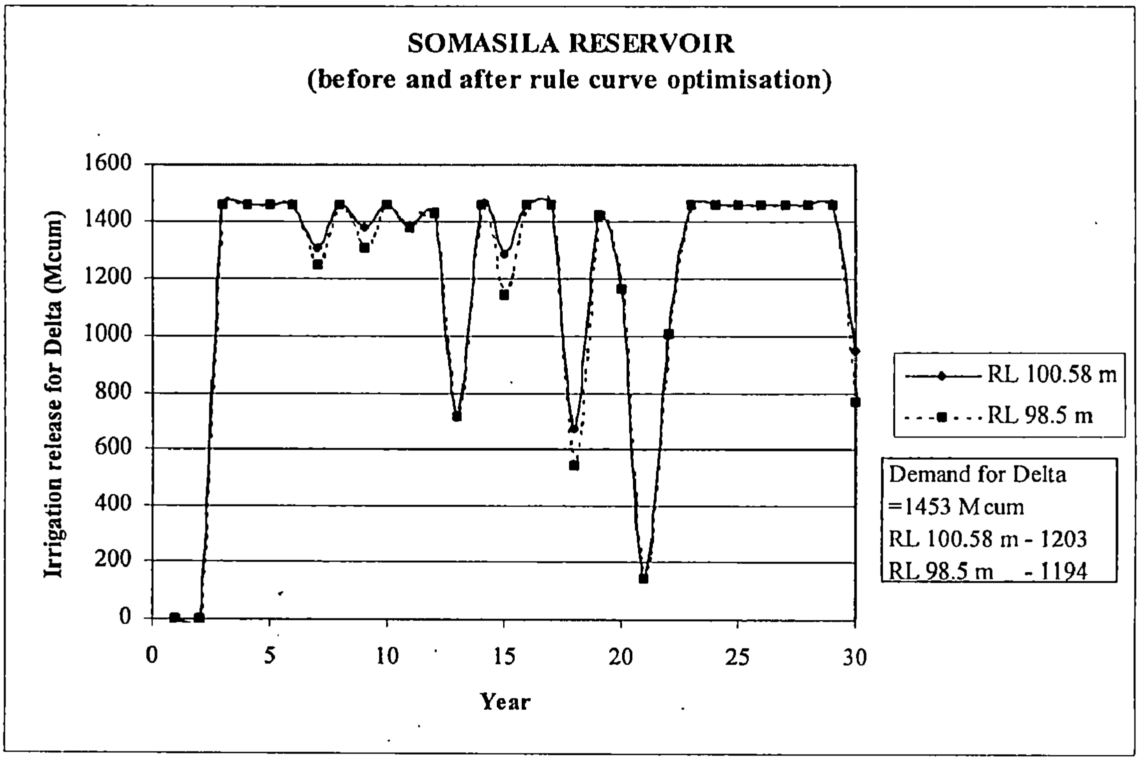


Fig :5.37 Annual Irrigation releases for Delta from Somasila

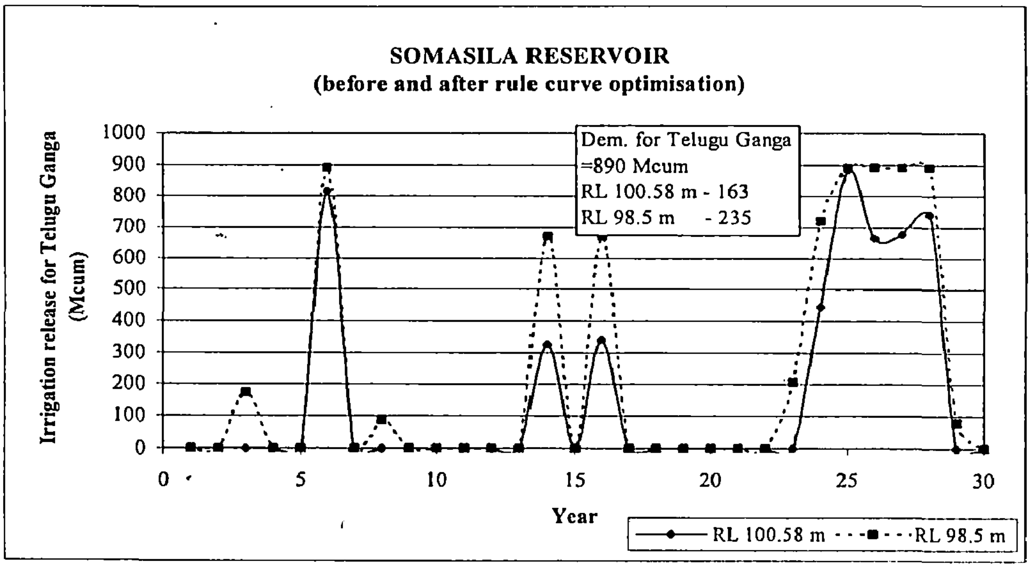


Fig :5.38 Annual Irrigation releases for Telugu Ganga from Somasila

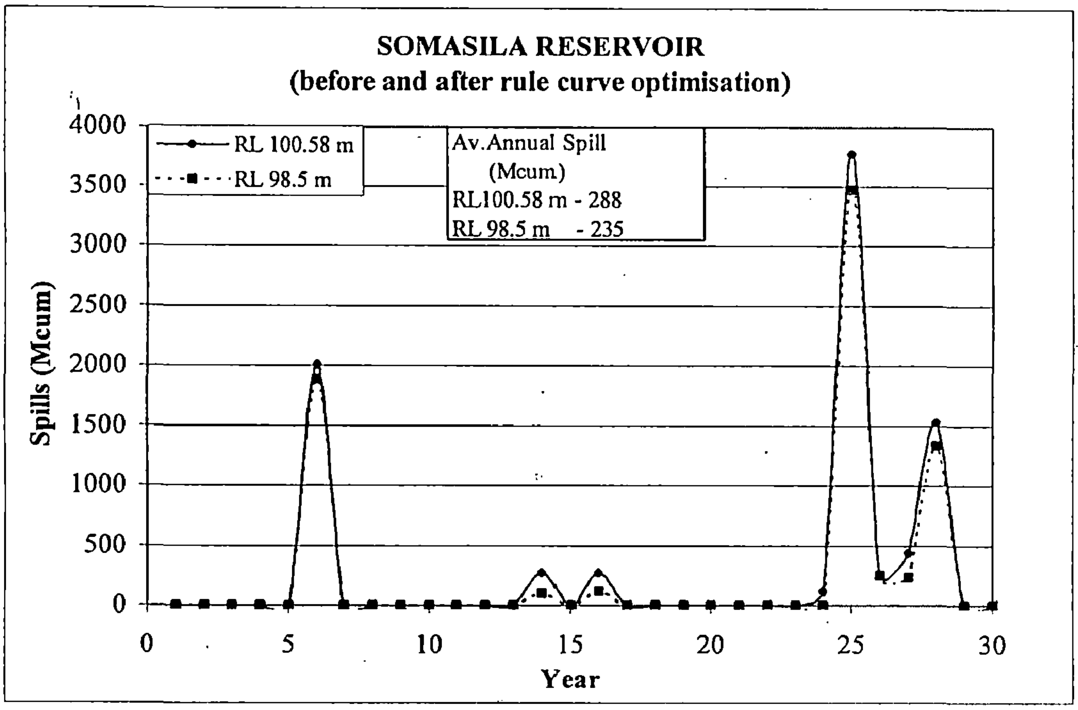


Fig: 5.39 Annual spills at Somasila

There was a slight reduction of 9 Mm^3 in the releases for the Delta against a gain of 72 Mm^3 in the releases for Telugu Ganga. Clearly, the spills have been fruitfully diverted to Telugu Ganga at the optimized rule level.

5.3.3 The Cauvery Multi-reservoir Sub-system

Krishnarajasagar Reservoir: No optimization study for this irrigation reservoir (single purpose) has been done. The reliabilities for irrigation are 80.8 % (time), 86.6 % (volume) and 66.7 % (annual). 'As available energy' from spills with maximum power draft of 6 TMC has been computed.

Mettur Reservoir: Mettur reservoir has to release waters for the Cauvery delta requirements. As per the simulation in Stage I, Mettur has low reliabilities even for its own project demand, the reliabilities being 67.8 % (time) 82% (volume) and only 30 % (annual). It can not, therefore, release sufficient water for Grand Anicut even in a single year. This analysis was done for a committed release of 9311 Mm^3 using 'downstream demand factors' for Grand Anicut. Middle rule level optimization at Mettur for downstream releases using 'net demand' option at Grand Anicut has been done. The rule level in each month was fixed in such a way that the storage at the rule level will be able to meet the Mettur project demand in subsequent months in that year. This way, the Mettur reliabilities have been improved to 83.3 % (time) 86.9 % (volume) and 76.7 % (annual). The rule level optimization is given in **Table 5.28.**

Table 5.28 Rule level (for d/s releases) Optimization at Mettur reservoir

Mettur reservoir			Grand Anicut			Remarks
Irrigation reliabilities			Irrigation reliabilities			Monthly rule level and corresponding storage
Time	Volume	Annual	Time	Volume	Annual	
0.678	0.820	0.300	0.107	0.281	0	Rule level at MDDL for all months
0.678	0.820	0.300	0.107	0.281	0	March R.L 204.31 m (67.8 Mm^3)
0.678	0.820	0.300	0.107	0.281	0	February R.L 204.41 m (74.7Mm^3)
0.678	0.820	0.300	0.107	0.281	0	January R.L 204.89 m (109.4 Mm^3)
0.748	0.837	0.600	0.103	0.280	0	December R.L 205.49 m (153.2 Mm^3)
0.770	0.844	0.667	0.103	0.280	0	November R.L 206.16 m (201.8 Mm^3)
0.807	0.858	0.733	0.103	0.280	0	October R.L 206.88 m (253.9 Mm^3)
0.811	0.860	0.733	0.103	0.279	0	September R.L 207.62 m (307.40 Mm^3)
0.833	**0.869**	**0.767**	0.103	0.279	0	August R.L 204.51 m (82.0 Mm^3)

Secondary power from the releases for the Grand Anicut was also computed. The performance of the reservoir before (with downstream factors) and after (with net demand and rule level) optimization is given in **Fig: 5.40.** The average annual power generation has improved from 111 MW to 115 MW after optimization.

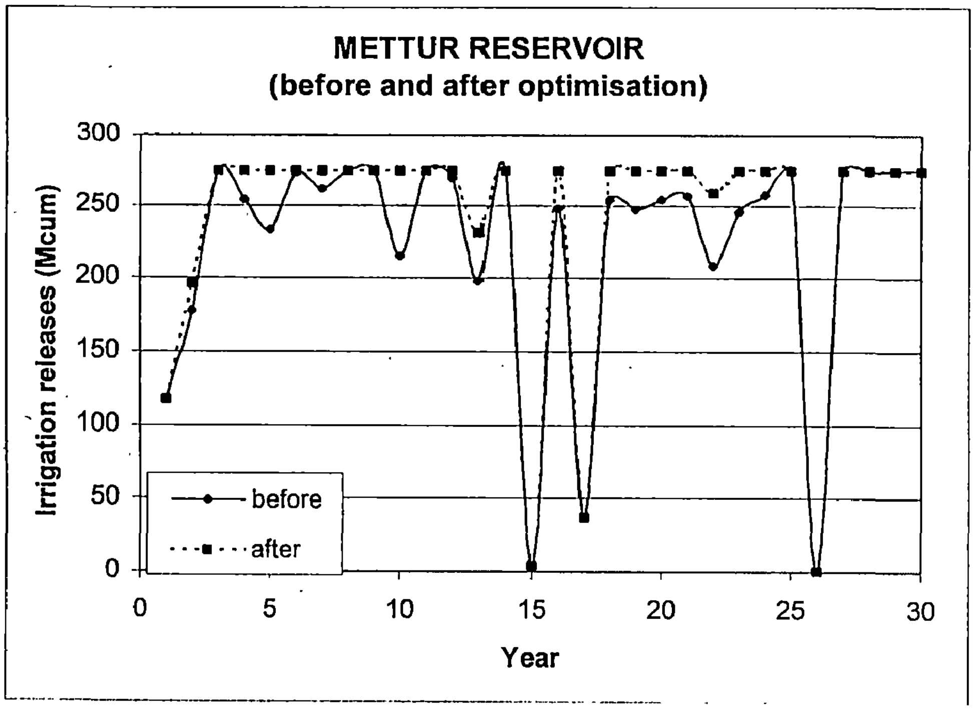


Fig: 5.40 Annual irrigation releases at Mettur

Grand Anicut: The demand at Grand Anicut is so large that the variation in the limited releases from Mettur does not make any difference in its performance. This is due to the expected ultimate development upstream resulting in meagre inflows from Mettur as well as local catchment at the Anicut. The performance of the Grand Anicut is shown in Table: **5.29.** The reliabilities at Grand Anicut after rule level optimization at Mettur, are just 10.3 % (time), 27.9 % (volume) and nil (annual).

Table 5.29 Performance of Grand Anicut

Case	Irrigation reliabilities			Middle Rule level at Mettur for releases to Grand Anicut
	Time	Volume	Annual	
With dfc	0.1	0.280	0	at MDDL
no dfc	0.1	0.281	0	at MDDL
no dfc (opt)	0.1	0.279	0	at optimized levels

After optimizing the performance of the projects in the deficit basin, the projects in the surplus Godavari basin were taken up for similar exercise.

5.3.4 The Godavari Multi-reservoir Sub-system

Inchampalli Reservoir: Two cases have been considered for optimization, one with irrigation priority and other with power priority. In both the cases the performance of the reservoir has been analyzed.

Case I: Irrigation Priority: A number of simulation runs were taken with varying firm power demands. 58 MW of firm power can be generated with100 % irrigation reliability while the planned firm power of 117 MW by the project authorities is possible with 92.5 % reliability and corresponding annual irrigation reliability of 80 %. On further optimization, firm power corresponding to 90 % time reliability is found to be 127 MW with comfortable annual reliability of 80 % for irrigation. Also, even if the power demand is increased up to installed capacity (975 MW), the minimum desired reliability of 76.7 % for irrigation is maintained. The range of power demand with power reliability at different irrigation reliabilities is indicated in **Fig: 5.41 (a to e).**

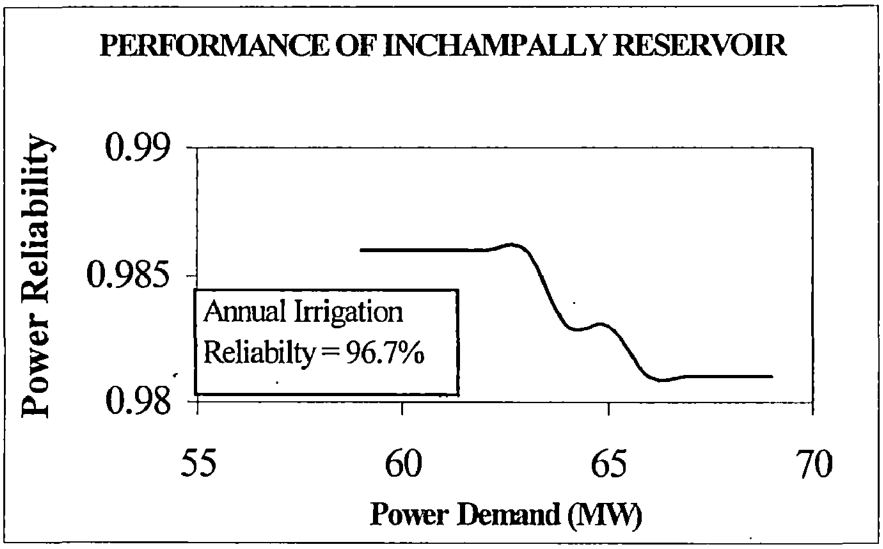


Fig: 5.41 (a) Power demand vs Power reliability

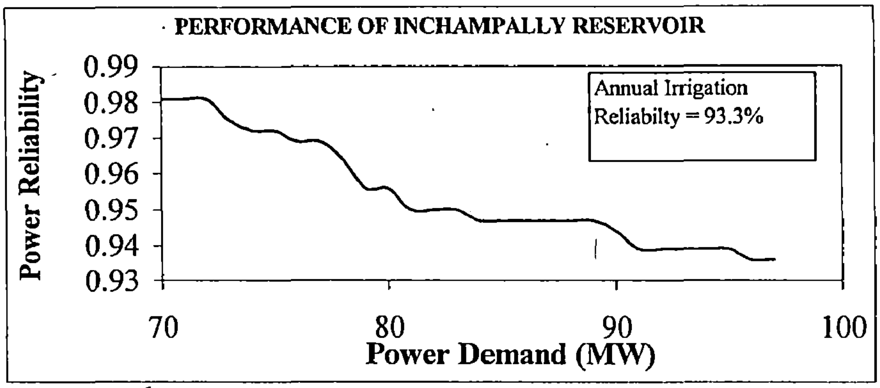


Fig: 5.41 (b) Power demand vs Power reliability

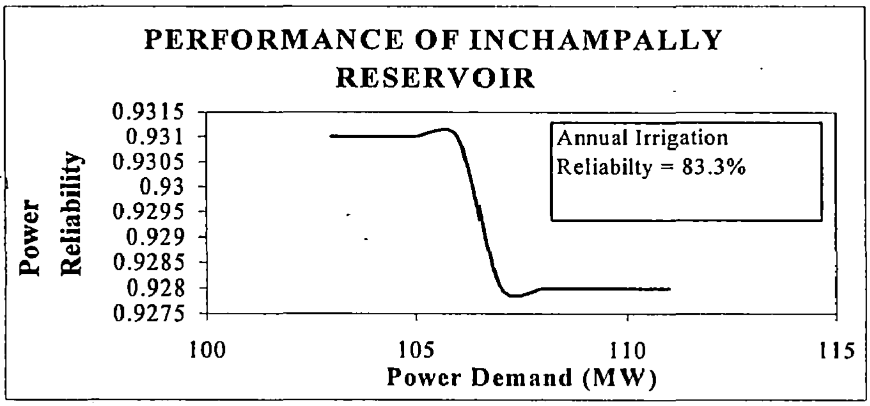


Fig: 5.41 (c) Power demand vs Power reliability

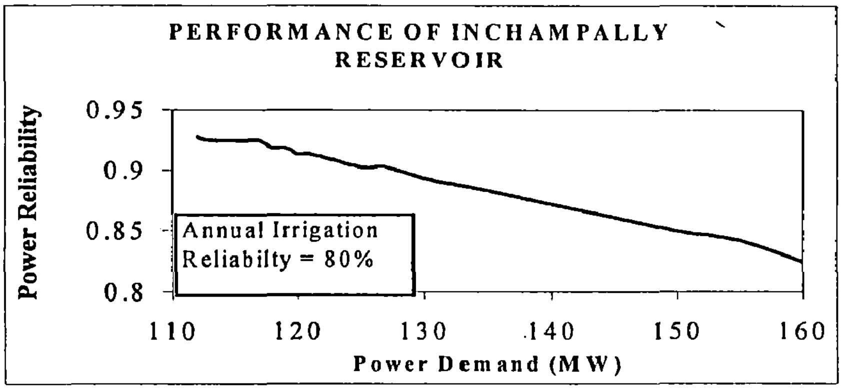


Fig: 5.41 (d) Power demand vs Power reliability

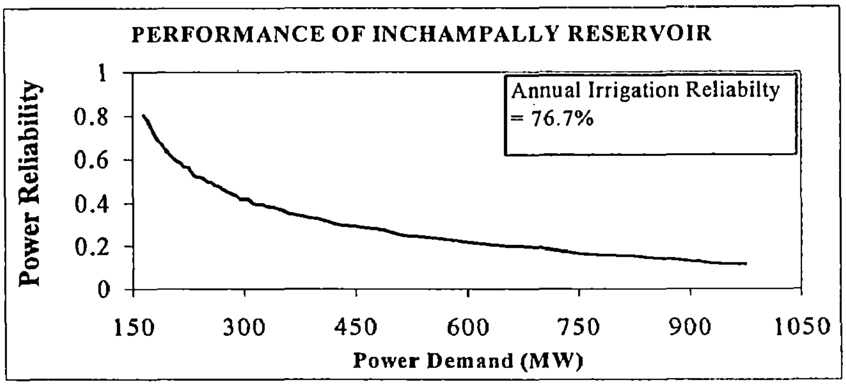


Fig: 5.41 (e) Power demand vs Power reliability

Case II: Power Priority: In this case also, it is seen that a firm power of 127 MW can be generated but with annual irrigation reliability of only 63.3 %. The deficit range for irrigation is 16 Mm^3 to 44 Mm^3 in 9 years. The details of simulation are given in **Table 5.30.**

Table 5.30 Performance of Inchampalli reservoir (Power priority)

Power demand		Power	Irrigation reliabilities		
MW	MU	reliability	Time	Volume	Annual
0	0	1	1	1	1
10	7.2	1	1	1	1
20	14.4	1	1	1	1
30	21.6	0.997	0.997	0.999	0.967
40	28.8	0.997	0.997	0.999	0.967
50	36	0.997	0.997	0.999	0.967
60	43.2	0.986	0.986	0.997	0.867
70	50.4	0.981	0.981	0.996	0.867
80	57.6	0.969	0.956	0.983	0.800
90	64.8	0.950	0.947	0.966	0.733
100	72	0.936	0.936	0.96	0.667
110	79.2	0.928	0.928	0.958	0.667
117	84.24	0.925	0.925	0.958	0.667
120	86.4	0.914	0.914	0.955	0.633
127	**91.44**	**0.903**	**0.903**	**0.946**	**0.633**
130	**93.6**	**0.894**	**0.894**	**0.939**	**0.633**

Since the firm power generation is the same in both cases, Case I has been chosen as it provides higher irrigation reliability. The monthly firm power before (117 MW) and after (127 MW) optimization and percentage of time the annual firm power could be generated in each month are shown in **Fig 5.42** and **5.43.**

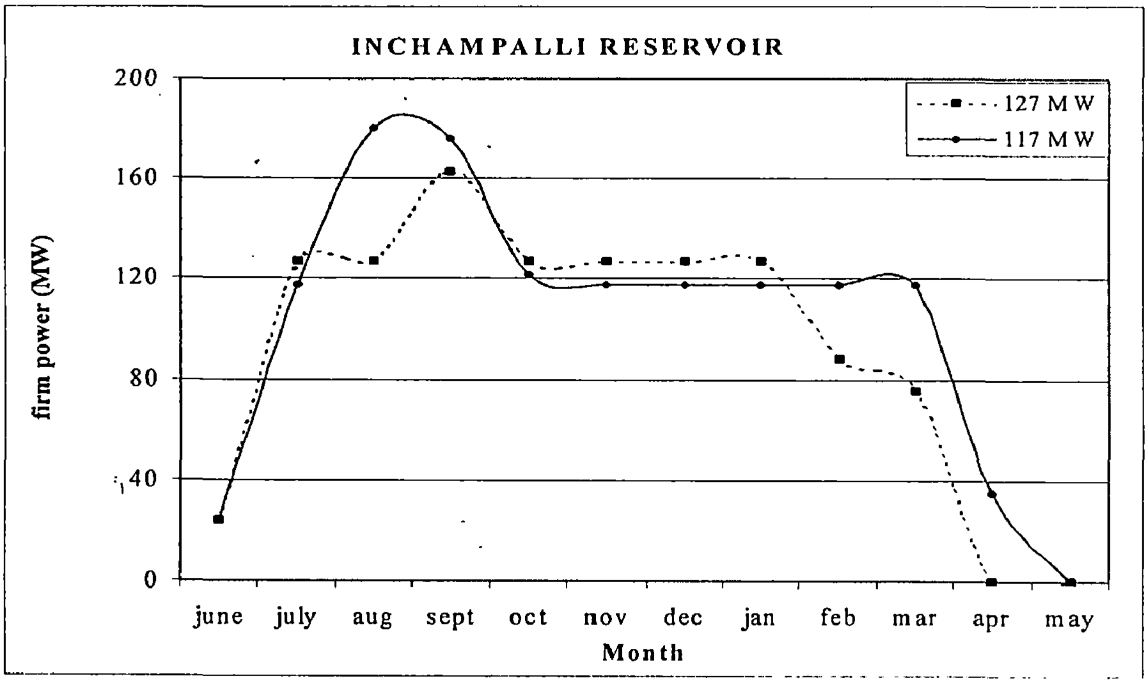


Fig: 5.42 Monthly firm power at Inchampalli

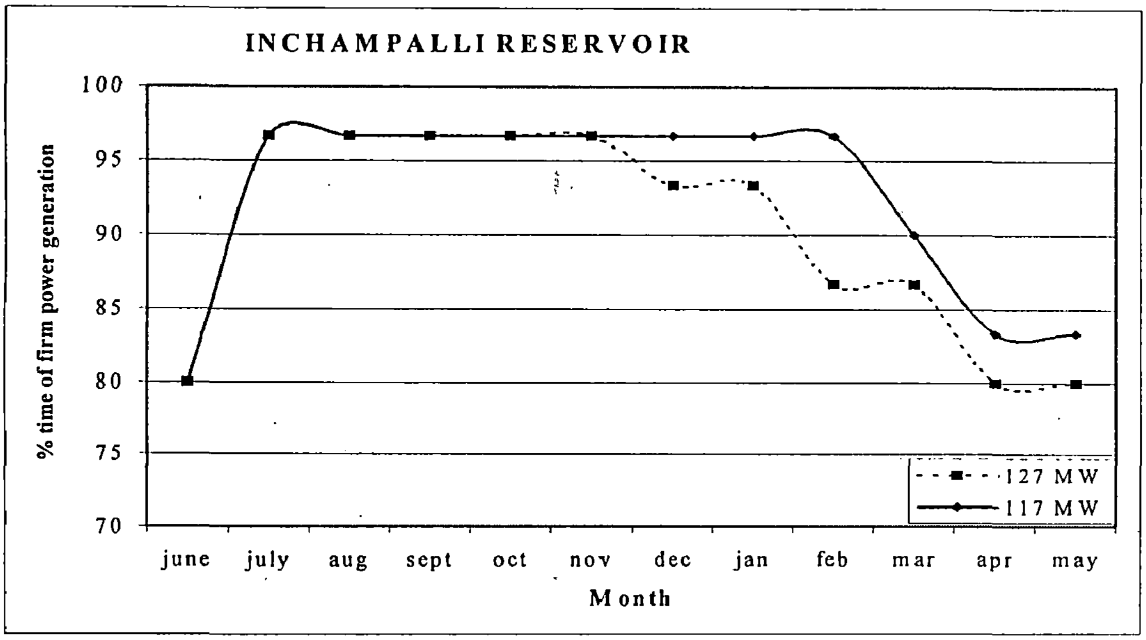


Fig: 5.43 Percentage of time of annual firm power generation at Inchampalli

Polavaram reservoir: Initially in Stage I, reservoir simulation with 60MW of firm power as planned by the authorities was done. Now under optimization two cases corresponding to power generation of 117 MW and 127 MW at Inchampalli have been taken up. In each case, irrigation and power priorities are specified for simulation and performance of the reservoir is studied.

Case I Inchampalli firm power (117 MW): This case has been taken up to ascertain how much firm power is possible at Polavaram beyond 60 MW in the case it receives power releases from Inchampalli with firm power generation of 117 MW.

Irrigation priority: A firm power of 105 MW can be generated at Polavaram while ensuring the irrigation reliability of 76.7 % for its irrigation. The simulation abstract is given in **Table 5.31.**

Table 5.31 : Performance of Polavaram reservoir (Irrigation priority)

POLAVARAM RESERVOIR							DOWLESWARAM BARRAGE		
Power Demand (MW)	Energy Demand (MU)	Power Reliability	Water sup reliability	Irrigation reliabilities			Irrigation reliabilities		
				Time	Volume	Annual	Time	Volume	Annual
50	36.00	0.983	0.997	0.997	0.999	0.967	0.978	0.996	0.867
60	43.20	0.981	0.997	0.997	0.999	0.967	0.981	0.994	0.867
70	50.40	0.978	0.994	0.994	0.999	0.967	0.975	0.992	0.833
80	57.60	0.967	0.992	0.992	0.999	0.933	0.967	0.989	0.800
90	64.80	0.956	0.986	0.983	0.997	0.900	0.956	0.985	0.733
100	72.00	0.947	0.978	0.972	0.995	0.800	0.953	0.983	0.667
105	**75.60**	**0.900**	**0.975**	**0.967**	**0.995**	**0.767**	**0.958**	**0.982**	**0.700**
106	76.32	0.878	0.975	0.967	0.994	0.767	0.958	0.982	0.700
110	79.20	0.825	0.975	0.967	0.994	0.767	0.956	0.982	0.700

Power priority: A firm power of 77 MW is possible at 97.2 % of time reliability. Further increase in power demand will affect the irrigation reliability to below 76.7 %. The simulation details are given in **Table 5.32.** Therefore under case I, irrigation priority will be the better option in view of higher firm power along with desired irrigation reliability.

Table 5.32 Performance of Polavaram reservoir (Power priority)

POLAVARAM RESERVOIR							DOWLESWARAM BARRAGE		
Power Demand (MW)	Energy Demand (MU)	Power relia-bility	Water sup reliability	Irrigation reliabilities			Irrigation reliabilities		
				Time	Volume	Annual	Time	Volume	Annual
0	0	1.000	1.000	0.992	0.998	0.900	0.956	0.998	0.733
5	3.60	1.000	1.000	0.992	0.998	0.900	0.956	0.998	0.733
10	7.20	0.997	1.000	0.992	0.998	0.900	0.956	0.998	0.733
15	10.80	0.997	1.000	0.992	0.998	0.900	0.967	0.998	0.833
20	14.40	0.997	1.000	0.992	0.998	0.900	0.967	0.998	0.833
25	18.00	0.994	1.000	0.992	0.998	0.900	0.967	0.998	0.833
30	21.60	0.994	1.000	0.992	0.998	0.900	0.967	0.998	0.833
35	25.20	0.994	1.000	0.992	0.998	0.900	0.969	0.998	0.867
40	28.80	0.992	1.000	0.992	0.998	0.900	0.972	0.998	0.900
45	32.40	0.992	0.997	0.989	0.997	0.867	0.978	0.998	0.867
50	36.00	0.983	0.997	0.983	0.996	0.833	0.978	0.997	0.867
55	39.60	0.983	0.997	0.983	0.996	0.833	0.978	0.996	0.867
60	43.20	0.981	0.997	0.978	0.995	0.800	0.981	0.996	0.867
65	46.80	0.975	0.997	0.975	0.994	0.800	0.981	0.995	0.867
70	50.40	0.978	0.994	0.975	0.993	0.800	0.978	0.994	0.833
75	54.00	0.975	0.992	0.969	0.992	0.767	0.975	0.994	0.833
76	54.72	0.972	0.992	0.967	0.991	0.767	0.975	0.994	0.833
77	**55.44**	**0.972**	**0.992**	**0.967**	**0.991**	**0.767**	**0.975**	**0.993**	**0.833**
78	56.16	0.972	0.992	0.964	0.991	0.733	0.975	0.993	0.833
80	57.60	0.969	0.992	0.964	0.99	0.733	0.969	0.992	0.800

Case II Inchampalli firm power (127 MW):

In this case, the improvement in firm power generation at Polavaram in the optimized case of firm power generation of 127 MW at Inchampalli is studied.

1. **Irrigation priority:** It is seen that firm power generation can be enhanced to 112 MW while maintaining the irrigation reliability at 76.7 %. The details of simulation are given **Table 5.33.**

Table 5.33 Performance of Polavaram reservoir (Irrigation priority)

POLAVARAM RESERVOIR							DOWLESWARAM BARRAGE		
Power Demand	Energy Demand	Power reliability	Water sup reliability	Irrigation reliabilities			Irrigation reliabilities		
(MW)	(MU)			Time	Volume	Annual	Time	Volume	Annual
95	**68.40**	**0.950**	**0.981**	**0.972**	**0.996**	**0.883**	**0.956**	**0.983**	**0.767**
96	69.12	0.950	0.981	0.972	0.996	0.883	0.953	0.983	0.733
97	69.84	0.947	0.981	0.972	0.996	0.883	0.95	0.982	0.733
98	70.56	0.947	0.981	0.972	0.996	0.883	0.950	0.982	0.700
99	71.28	0.947	0.981	0.972	0.996	0.883	0.947	0.982	0.700
100	72.00	0.944	0.981	0.972	0.996	0.833	0.950	0.982	0.700
102	73.44	0.944	0.975	0.967	0.994	0.767	0.947	0.981	0.667
104	74.88	0.939	0.975	0.967	0.994	0.767	0.956	0.981	0.700
106	76.32	0.939	0.975	0.967	0.994	0.767	0.956	0.98	0.700
108	77.76	0.936	0.975	0.967	0.994	0.767	0.953	0.98	0.700
110	79.20	0.917	0.975	0.967	0.994	0.767	0.953	0.979	0.700
112	**80.64**	**0.908**	**0.975**	**0.964**	**0.994**	**0.767**	**0.950**	**0.979**	**0.700**
113	81.36	0.889	0.972	0.964	0.994	0.767	0.950	0.978	0.700

Power priority: Only 69 MW of firm power demand can be given as further increase will reduce the irrigation reliability to 73.3 %. The power reliability, is however, as high as 97.5 %. The abstract of simulation is given in **Table 5.34.** On comparison of the both the cases, Case II with irrigation priority was found as the better option as it yields high firm power and high reliability for irrigation. The average annual power generation has improved from 2029 MU to 2039 MU after optimization.

Table 5.34 Performance of Polavaram reservoir (Power priority)

POLAVARAM RESERVOIR							DOWLESWARAM BARRAGE		
Power Demand	Energy Demand	Power reliability	Water sup reliability	Irrigation reliabilities			Irrigation reliabilities		
(MW)	(MU)			Time	Volume	Annual	Time	Volume	Annual
40	28.80	0.989	1	0.989	0.996	0.867	0.958	0.996	0.833
50	36.00	0.981	0.997	0.981	0.993	0.800	0.967	0.996	0.833
60	43.20	0.978	0.997	0.978	0.992	0.800	0.972	0.995	0.833
65	46.80	0.975	0.994	0.972	0.991	0.800	0.972	0.993	0.800
69	**49.68**	**0.975**	**0.989**	**0.972**	**0.991**	**0.800**	**0.972**	**0.992**	**0.800**
70	50.40	0.975	0.989	0.964	0.991	0.733	0.972	0.992	0.800

The Irrigation releases in both before and after optimization conditions are presented in **Fig: 5.44.** The average annual irrigation releases have reduced slightly from 3266 Mm^3 to 3262 Mm^3.

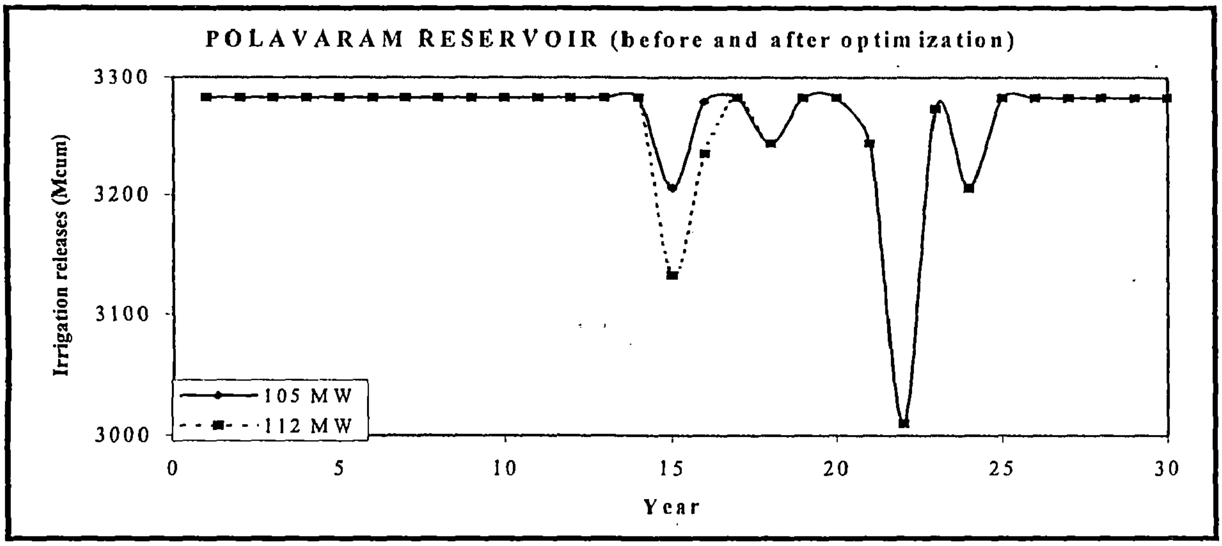


Fig : 5.44 Irrigation releases at Polavaram

The monthly firm power and monthly percentage of time annual firm power generation is possible in each month before and after optimization are given in **Fig: 5.45 & 5.46.**

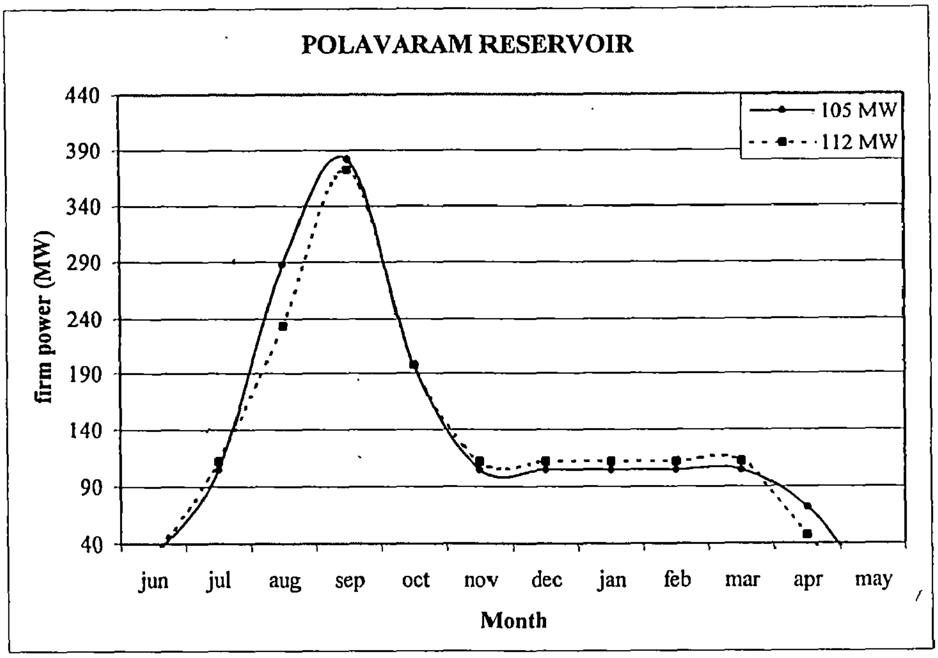


Fig: 5.45 Monthly firm power at Polavaram

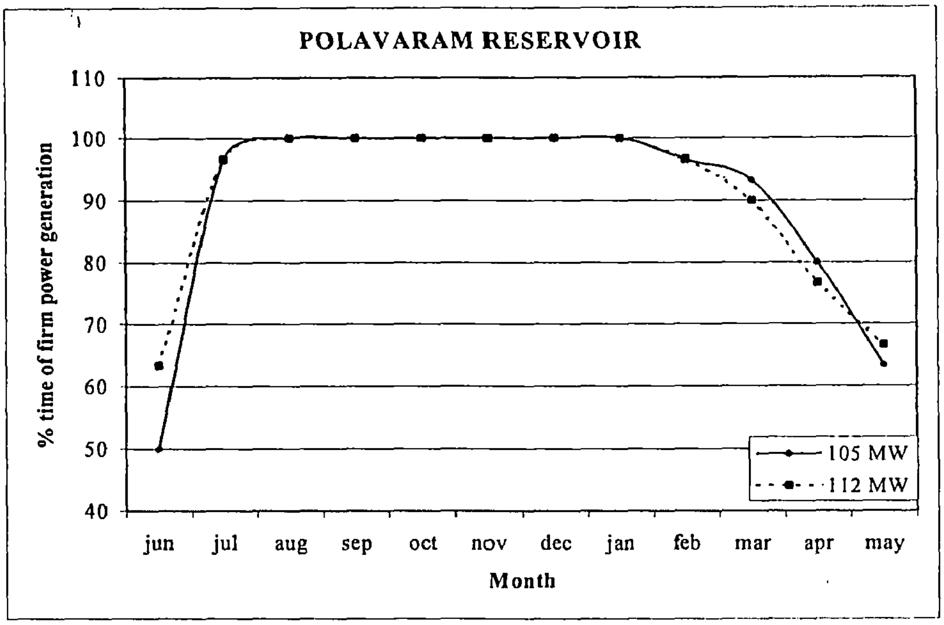


Fig: 5.46 Monthly Percentage of time of annual firm power generation at Polavaram

Dowleswaram barrage: Dowleswaram will have an annual irrigation reliability of 70 % in both the cases. This situation is not due to the deficiency of water at Polavaram, as the time (95 %) and volume (97.5 %) reliabilities indicate. Since Polavaram is optimized for maximum power generation, the power releases and the irrigation needs are mismatching. It is, however, seen that the average annual irrigation release is 7608 Mm^3 against the target demand of 7774 Mm^3 and the deficits in two years are very marginal (1.5%), which can be made up by reducing the power releases in other periods in such years during real time reservoir operation. It may not be appropriate in the planning stage to reduce firm power at Polavaram considerably (to 95 MW) to obtain 76.7% reliability for irrigation needs at Dowleswaram.

The final performance indices for each of the reservoirs / barrages after optimization is presented in **Table 5.35.**

TABLE 5.35 FINAL PERFORMANCE INDICES OF RESERVOIRS AND BARRAGES AFTER OPTIMIZATION

Units : Power - MW; Irrigation - Mcum;

Sl.	Reservoir	Criteria/	Power		Irrigation Reliabilities				Water supply	
no		Priority	Demand	Rel.	Demand	Time	Vol	Ann	Demand	Rel.
I	Whole Krishna System									
1	Almatti	No dfc/Irr	31.5	0.903	258	1	1	1	N. A	N. A
2	Narayanpur	N. A	N.A	N.A	4290	1	1	1	N. A	N. A
3	Srisailam	Power	60	0.883	2209	0.744	0.776	0.7	425	0.967
		Pow vs d/s rel	60	0.9	2209	0.756	0.782	0.733	425	0.967
4	Nagarjunasagar	Pow / d/s rel	61	0.9	7465	0.836	0.901	0.733	N.A	N.A
5	Pulichintala	Pow/d/s rel	10	0.9	N.A	N.A	N.A	N.A	N.A	N.A
6	Prakasam barrage	N. A	N.A	N.A	5132	0.861	0.919	0.6	N. A	N. A
II	Pennar System									
1	Somasila	Rule level-98.5m	N.A	N.A	1453/890*			0.533 / 0.167	409	0.917
III	Cauvery system									
1	Krishnarajasagar	N. A	N.A	N.A	1325	0.808	0.866	0.667	N.A	N.A
2	Mettur	Irrigation	N.A	N.A	275	0.833	0.869	0.767	N.A	N.A
3	Grand Anicut	N. A	N.A	N.A	9670	0.103	0.279	0	N.A	N.A
IV	Godavari System									
1	Inchampalli	Irrigation	127	0.9	620	0.961	0.993	0.8	N.A	N.A
2	Polavaram	Irrigation	112	0.908	3283	0.964	0.994	0.767	826	0.975
3	Dowleswaram	N. A	N.A	N.A	7774	0.95	0.979	0.7	N.A	N.A

* Telugu Ganga canal requirement N.A- Not Applicable.

5.4 SURFACE WATER BALANCE

After optimization, the surface water balance position at the terminal project in each basin has been assessed from the model studies. Reliability concept has been adopted to assess the surplus / deficit in each basin at 76.7% reliability. This concept will provide the annual and monthly pattern of supplementation required in a deficit basin to bring it to the desired reliability as indicated in Table **5.36.**

Table 5.36 SURPLUS/ DEFICIT POSITION IN DIFFERENT BASINS (at 75% reliability)

Basin	Position	Year	Diversion	Surplus/ Deficit	Month	Surplus/ Deficit	Remarks
			(Mcum)	(Mcum)		(Mcum)	
Godavari	Surplus	1951-52		19354*	July	205	***From spills at**
					August	6243	**Dowleswaram**
					September	5660	
					October	2256	
					November	555	
					December	557	
					January	529	
					February	645	
					March	737	
					April	841	
					May	1126	
					Total	**19354**	
Krishna	Deficit	1973-74	4527	606*	June	407	***Deficit at Prakasam**
					July	199	**Barrage**
					Total	**606**	Designed demand =5132 Mm^3
Pennar	Deficit	1965-66	1142	311*	February	22	***Deficit at Somasila**
					March	134	Designed demand =1453 Mm^3
					April	130	
					May	25	
					Total	**311**	
	Addl. Deficit due to Telugu Ganga Demand				September	219	Total deficit including Telugu Ganga is 1201 Mm^3
					October	226	(311+890)
					November	219	
					December	226	
					Total	**890**	
Cauvery	Deficit	1970-71	1076	249*	February	46	***Deficit at K.R. Sagar**
					March	82	
					April	78	Designed demand =
					May	43	1325 Mcum;
					Total	**249**	
	Deficit	1968-69	727	8943*	June	121	***Deficit at Grand Anicut**
					July	883	
					August	1884	Designed demand =9670
					September	1825	
					October	1412	* Diversion at 75% rel.
					November	805	
					December	722	
					January	875	
					February	325	
					March	91	
					Total	**8943**	

In addition, the independent streams / rivers, which are water short, in the deficit basins have also been identified. These rivers are unable to contribute flow to the projects considered in the reservoir simulation in a number of years because their surface water resources are inadequate to meet their own needs. The rivers, which indicate shortage in more than 7 years (out of the study period of 30 years i.e. more than 25% of time), have been considered in the study. The basin wise surplus / deficit situation is discussed as under.

The Godavari Basin: The spills at Dowleswaram have been arranged in descending order from which the Godavari basin is found to contain about 19354 Mm^3 of surplus at 76.7% reliability.

The Krishna Basin: The annual release at 76.7% reliability at Prakasam Barrage was found out. The difference between Target demand and the release indicates the deficit (606 Mm^3) in the basin. In addition, two tributary rivers viz. Tungabhadra and Vedavathi were found to be water short.

The Pennar Basin: Similarly, the deficit at Somasila for delta requirement has been found out to be 311 Mm^3. With additional requirement of 890 Mm^3 for Telugu Ganga command, the deficit would be 1201 Mm^3. Apart from this, Upper Pennar and Lower Pennar are seen to be deficient.

The Cauvery Basin: The deficit in Cauvery at Grand Anicut is found to be 8943 Mm^3. Also, the deficit at Krishnarajasagar is assessed as 249 Mm^3. Besides, the streams of Kabini, Suvarnavathi, Arkavathi, Chinnar, Palar, Bhavani, Noyil, Tirumanimuttar and Amaravathi are found to be water short.

SIMULATION STUDY CONSIDERING GROUNDWATER AND INTER-BASIN WATER TRANSFER

6.1 GENERAL

This chapter deals with the analysis and discussion of results for the last two stage viz. (i) multi reservoir simulation of Krishna, Pennar and Cauvery basins considering groundwater supplementation in deficit project commands and working out net deficit in upper tributary sub-basins in the above three basins and (ii) multi reservoir simulation of the concerned basins with the proposed inter-basin water transfers to study their effect on the performance of the reservoirs and diversion points in the basins.

6.2 INTEGRATION OF GROUNDWATER IN PLANNING (STAGE III)

In this part of the analysis, the effect of groundwater supplementation in deficit project commands and in water short tributary sub-basins has been studied and net deficit in each basin is worked out.

For sustainable development in a basin it is reasonable that both surface and groundwater are planned as one integrated resource. In the context of inter-basin water transfer, it is reasonable that the deficit basins should first explore the full exploitation of within the basin surface and groundwater resources prior to seeking for supplementation from outside. In line with this thinking, groundwater planning has been considered in the present study in two phases (i) conjunctive use in the project commands and (ii) groundwater planning in tributary deficit sub-basins.

6.2.1 Conjunctive Use Planning in Project Commands

Conjunctive use planning is proposed on priority basis in the project commands of Prakasam Barrage, Pennar delta, Telugu Ganga , Cauvery delta and Krishnarajasagar. The groundwater recharge at 12 % from normal rainfall and 30% from canal releases has been estimated. For this purpose, normal rainfall of IMD stations in the vicinity have been considered and average canal releases from simulation study of the respective projects have been considered. Out of the groundwater recharge so estimated, provision @ 15% is made for domestic and industrial requirements as per the prevalent norms. Out of the balance available water for irrigation, 90% is considered to be utilizable and accordingly considered in the planning. The Central Groundwater Board (CGWB 1995) has reported that the contribution from canal irrigation system to the annual groundwater recharge in the state of Andhra Pradesh is above 43% and that in Tamil Nadu is 28%. With abundant caution, only 30% has been considered uniformly in all the project commands in the present study, being well aware that salinity hazards would be there in some of these commands (deltas). Further, while estimating recharge from normal rainfall, an average value of 12% as applicable for hard weathered rocks has been chosen whereas for delta alluviums the recharge varies from 10 to 25%. 90% level of gross extraction is reasonable in view of conservative estimation of groundwater recharge as above. Also, the net extraction will be only 63% with about 30% of groundwater use again is expected to reach groundwater regime. Moreover, 90% level of extraction is not required in all the years when there are adequate supplies through canal.

The effect of conjunctive use on the performance of each of these projects is analyzed as under:

Prakasam Barrage: The Central Groundwater Board has reported that conjunctive utilization of surface and groundwater resources is needed in Andhra Pradesh. The utilizable groundwater recharge in the command of Prakasam barrage is estimated to be 1403 Mm^3 as shown in **Table 6.1.**

Table 6.1: Estimation of Groundwater Potential in the command of Prakasam barrage

Month	Normal rainfall	Canal release	Natural Recharge	Rech.from Canal Irrigation	Total recharge	GW Availability	Prov.for Dom& Ind	GW for Irrigation	Utilisable GW for Irrigation
	(mm)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)
(1)	**(2)**	**(3)**	**(4)**	**(5)= 0.3*(3)**	**(6)= (4)+(5)**	**(7)**	**(8)= 0.15*(7)**	**(9)= (7)-(8)**	**(10)= 0.9*(9)**
Jun	90.6	588	55	176	231	27	4	23	21
Jul	124.3	898	75	269	345	231	35	197	177
Aug	120.5	788	73	236	310	345	52	293	264
Sept	150.3	696	91	209	300	310	46	263	237
Oct	104.4	657	63	197	260	300	45	255	230
Nov	32.1	422	19	127	146	260	39	221	199
Dec	8.1	196	5	59	64	146	22	124	112
Jan	0.4	114	0	34	34	64	10	54	49

1	2	3	4	5	6	7	8	9	10
Feb	7.6	93	5	28	33	34	5	29	26
Mar	6.9	106	4	32	36	33	5	28	25
Apr	19.0	122	12	37	48	36	5	31	28
May	39.7	10	24	3	27	48	7	41	37
Annual	703.9	4690	427	1407	1834	1834	275	1559	**1403**

Two cases of conjunctive use planning (i) with groundwater supplementation through out the cropping period and (ii) in only certain critical months have been studied. In the first case, different percentages of groundwater recharge are considered and the surface water demands in each month have been reduced to that extent. Simulation runs have been taken for all these cases and it is seen that with supplementation at 67% (1045 Mm^3) of available groundwater recharge for irrigation, Prakasam barrage will be able to improve its performance to the desired level of 76.7%. The details of simulation are given in **Table 6.2 (i)**

Table 6.2(i): Performance of Prakasam barrage with groundwater supplementation for entire crop period.

Surface Water	Ground Water	% of Recharge	Irrigation reliabilities(Pul -10 MW)		
			Time	Volume	Annual
(Mcum)	(Mcum)				
5132	0	0	0.856	0.914	0.6
4978	154	10	0.861	0.92	0.6
4819	313	20	0.873	0.927	0.6
4666	466	30	0.873	0.934	0.6
4508	624	40	0.891	0.942	0.633
4087	**1045**	**67**	**0.930**	**0.956**	**0.767**
4040	1092	70	0.930	0.957	0.767
3886	1246	80	0.936	0.960	0.800
3728	1404	90	0.936	0.964	0.800

In the second case, groundwater supplementation is considered only in June and July, which are critical months as identified from simulation. This way, only 39% (606 Mm^3) of groundwater recharge is required to improve the performance of the barrage to the required reliability. The surface water supply constitutes to 88% of the demand while, the remaining 12% is contributed from groundwater. The details of simulation are given in **Table 6.2 (ii).**

Table 6.2(ii): Performance of Prakasam barrage with groundwater supplementation in only critical months.

Month/ (demand)	Water Supply		(Irrigation reliabilities)		
	SW	GW	Time	Volume	Annual
June	643	0	0.856	0.914	0.600
(643 Mm^3)	350	293	0.881	0.932	0.633
	300	343	0.886	0.935	0.667
	235	**408**	**0.894**	**0.939**	**0.667**
July					
(983 Mm^3)	900	83	0.906	0.944	0.700
	850	133	0.908	0.947	0.733
	785	**198**	**0.914**	**0.951**	**0.767**

Pennar delta: The utilizable groundwater recharge for irrigation in the command is estimated to be 414 Mm^3 as given in **Table 6.3.**

Table 6.3: Estimation of Groundwater Potential in Pennar delta

Month	Normal rainfall	Canal Release	Natural Recharge	Rech.from Canal irrigation	Total Recharge	GW Availability	Prov.for Dom& Ind	GW for Irrigation	Utilisable GW for irrigatipon
	(mm)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)
(1)	(2)	(3)	(4)	(5)= 0.3*(3)	(6)= (4)+(5)	(7)	(8)= 0.15*(7)	(9)= (7)-(8)	(10)= 0.9*(9)
Jun	54.0	0	11	0	11	17	3	14	13
Jul	85.9	84	17	25	42	11	2	9	8
Aug	91.3	169	18	51	69	42	6	36	32
Sep	112.9	161	22	48	71	69	10	58	53
Oct	217.8	149	43	45	88	71	11	60	54
Nov	227.7	99	45	30	75	88	13	74	67
Dec	68.4	108	13	32	46	75	11	63	57
Jan	6.6	77	1	23	24	46	7	39	35
Feb	3.6	101	1	30	31	24	4	21	19
Mar	5.9	109	1	33	34	31	5	26	24
April	15.4	106	3	32	35	34	5	29	26
May	53.2	21	10	6	17	35	5	30	27
Annual	942.7	1184	186	355	541	541	81	460	**414**

Groundwater supplementation is considered only in 4 critical months viz. July and March to May. The simulation studies indicate that Somasila will be able to perform to the desired reliability with the help of 43% (198 Mm^3) of available groundwater recharge for irrigation. This will also improve the annual irrigation reliability for Telugu Ganga from 16.7% to 20%. The surface water contribution will be 86% of the demand while the balance 14% is drawn from groundwater. The details are given in **Table 6.4**.

Table 6.4: Performance of Somasila reservoir with groundwater supplementation in only critical months in Pennar delta

Demand/Supply distribution			Water Supply reliability	Irrigatrion (Ann.Irr.rel.)	
month/ (demand)	Water Supply				
	SW	GW		delta	TG canal
July (103 Mm^3)	103	0	0.917	0.533	0.167
	67	**36**	**0.917**	**0.6**	**0.167**
March (134 Mm^3)	109	25	0.917	0.633	0.167
	59	**75**	**0.917**	**0.667**	**0.167**
April (130 Mm^3)	105	25	0.917	0.667	0.167
	80	50	0.917	0.7	0.167
	55	**75**	**0.925**	**0.733**	**0.2**
May (25 Mm^3)	**13**	**12**	**0.925**	**0.767**	**0.2**

Telugu Ganga: The utilizable groundwater recharge in the command is assessed to be 166 Mm^3 as given in **Table 6.5.** This command can not perform to the desired level of reliability even after considering supplementation of all utilizable groundwater recharge.

Table 6.5: Estimation of Groundwater Potential in Telugu Ganga command

Month	Normal Rainfall	Canal Release	Natural recharge	Rech.from canal irri.	Total Recharge	GW availability	Prov.for Dom& Ind	GW for Irrigation	Utilisable GW for irrigation
	(mm)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)
(1)	(2)	(3)	(4)	(5)= 0.3*(3)	(6)= (4)+(5)	(7)	(8)= 0.15*(7)	(9)= (7)-(8)	(10)= 0.9*(9)
Jun	54.0		8	0	8	8	1	7	6
Jul	85.9		13	0	13	8	1	7	6
Aug	91.3		14	0	14	13	2	11	10
Sep	112.9	44	17	13	30	14	2	11	10
Oct	217.8	61	32	18	51	30	4	25	23
Nov	227.7	86	34	26	60	51	8	43	39
Dec	68.4	66	10	20	30	60	9	51	46
Jan	6.6		1	0	1	30	4	25	23
Feb	3.6		1	0	1	1	0	1	1
Mar	5.9		1	0	1	1	0	0	0
Apr	15.4		2	0	2	1	0	1	1
May	53.2		8	0	8	2	0	2	2
Annual	942.7	257	140	77	217	217	33	184	**166**

Krishnarajasagar: About 324 Mm^3 of groundwater is estimated to be available for irrigation in the command as shown in **Table 6.6.**

Table 6.6: Estimation of Groundwater Potential in the command of Krishnarajasagar

Month	Normal Rainfall (mm)	Canal release (Mcum)	Natural Recharge (Mcum)	Rech.from canal irri. (Mcum)	Total recharge (Mcum)	GW availability (Mcum)	Prov.for Dom& Ind (Mcum)	GW for Irrigation (Mcum)	Utilisable GW for Irri.(Mcum)
(1)	(2)	(3)	(4)	(5)= 0.3*(3)	(6)= (4)+(5)	(7)	(8)= 0.15*(7)	(9)=(7)-(8)	(10)= 0.9*(9)
Jun	60.5	51.1	6	15	21	26	4	22	20
Jul	71.9	111.9	7	34	40	21	3	18	16
Aug	80.1	164.4	8	49	57	40	6	34	31
Sep	116.3	142.4	11	43	54	57	9	48	44
Oct	179.9	127.0	17	38	55	54	8	46	41
Nov	66.6	149.8	6	45	51	55	8	47	42
Dec	14.7	101.7	1	31	32	51	8	44	39
Jan	2.8	66.5	0	20	20	32	5	27	24
Feb	5.5	57.5	1	17	18	20	3	17	15
Mar	12.0	70.7	1	21	22	18	3	15	14
Apr	67.6	67.2	6	20	27	22	3	19	17
May	156.9	37.6	15	11	26	27	4	23	20
Annual	834.8	1148.0	79	344	424	424	64	360	**324**

Its supplementation in four critical months viz. February to April and June has been considered in simulation. With groundwater supply of 129 Mm^3 (35.8% of recharge) , the project will be successful in fulfilling its demands at desired reliability. 90% of the project demand is met from surface water while the remaining 10% will be taken care of by groundwater. Details of simulation are given in **Table 6.7.**

Table 6.7: Performance of Krishnarajasagar reservoir with groundwater supplementation in only critical months

Demand / Supply distribution					
month/ (demand)	Water Supply		(Irrigationreliabilities)		
	SW	GW	Time	Volume	Annual
February (66.4 Mm^3)	66.4	0	0.808	0.866	0.667
	20	**46**	**0.819**	**0.879**	**0.667**
March (81.6 Mm^3)	56.6	25	0.831	0.886	0.700
	31.6	**50**	**0.836**	**0.893**	**0.700**
April (77.6 Mm^3)	**52.6**	**25**	**0.844**	**0.899**	**0.733**
June (59.0 Mm^3)	**51**	**8**	**0.847**	**0.901**	**0.767**

Cauvery delta: The utilizable groundwater recharge is estimated to be 1403 Mm^3 as shown in **Table 6.8**.

Table 6.8: Estimation of Groundwater Potential in Cauvery delta

Month	Normal rainfall	Canal Release	Natural Recharge	Rech.from canal irri.	Total Recharge	GW availability	Prov.for Dom& Ind	GW for Irrigation	Utilisable GW for Irrigation
	(mm)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)	(Mcum)
(1)	(2)	(3)	(4)	(5)= 0.3*(3)	(6)= (4)+(5)	(7)	(8)= 0.15*(7)	(9)=(7)-(8)	(10)= 0.9*(9)
Jun	28.8	45	22	14	36	43	6	36	33
Jul	47.7	297	37	89	126	36	5	30	27
Aug	62.0	570	48	171	219	126	19	107	96
Sep	61.8	510	47	153	200	219	33	186	167
Oct	224.0	421	172	126	298	200	30	170	153
Nov	458.2	254	351	76	427	298	45	253	228
Dec	239.0	224	183	67	250	427	64	363	327
Jan	57.2	251	44	75	119	250	38	213	192
Feb	25.2	99	19	30	49	119	18	101	91
Mar	21.5	27	16	8	25	49	7	42	38
Apr	55.1	0	42	0	42	25	4	21	19
May	56.0	0	43	0	43	42	6	36	32
Annual	1336.5	2699	1025	810	1834	1834	275	1559	**1403**

In the Master Plan of Karnataka (WRDO 1976), it was reported that according to the UNDP investigations conducted in the Cauvery delta sub-basin (C-16), the total quantity of replenishable groundwater that can be eventually extracted in the Cauvery delta amounts to about 3650 Mm^3 per year. This groundwater is stated to be of good or acceptable quality. For comparison, the utilizable groundwater recharge for irrigation is estimated considering full supplies from Grand Anicut (9670 Mm^3), which is of the order of 3003 Mm^3. This finding also provides ground to the broad assumptions made in the estimation of groundwater recharge and level of its extraction in the present study.

The deficit at Grand Anicut is much more than the utilizable groundwater in the command. Three cases of groundwater supplementation have been studied (i) with supplementation through out the cropping period (ii) supplementation from September to March and (iii) supplementation from January to March. While case I yields an annual reliability of meagre 3.3%, the other cases improve it to 6.7%. Case III of operation, which provides marginally more releases than the other cases is considered for further study.

6.2.2 Groundwater Planning in the Sub-basins.

The Central Groundwater Board has published the State wise / District wise groundwater resource (CGWB 1995) in the country. The Groundwater potential, present draft and the balance available for future utilization in each sub-basin of the deficit basins has been computed from this publication using district wise areas as considered in the water balance studies of NWDA and Govt of India Publications (MOIB 2001 & CSO 1990). The groundwater resources assessment in respect of deficit sub basins is given in **Table 6.9** to **6.11.**

The utilizable groundwater less the present draft has been considered as additional resource in each identified deficit sub basin. The sub basins, which have more than seven failure years (out of 30 years) even after considering both surface and groundwater are termed as deficit and are considered for further study. The basin wise situation considering groundwater integration is described as under:

Krishna basin: Only Vedavathi sub-basin is found to be water short to meet its ultimate requirement in 12 out of 30 years, the net deficit being 348 Mm^3. However this deficit is mainly due to the additional irrigation proposed (1336 Mm^3) to bring annual irrigation to the level of 30 % of culturable area in the sub basin by NWDA. Since both surface and groundwater are considered as one integrated resource in the present study, the present draft for irrigation from groundwater (524 Mm^3) is considered as part of this additional irrigation. Thus, the sub basin will be able to achieve 30 % level of irrigation development from its own resources.

Pennar basin: Only the Upper Pennar sub basin is found to be critically water short in all the 30 years. The net deficit works out to 2295 Mm^3. In this sub basin also, additional irrigation (2630 Mm^3) has been proposed by NWDA to make it to 30 % of culturable area. The present draft from groundwater is 538 Mm^3. Thus the net deficit in the sub- basin considering groundwater draft works out to 1757 Mm^3.

Cauvery basin: Out of 16 sub basins, nine sub basins are found to be water short in Cauvery even after considering integrated resources planning. Out of these, no additional irrigation is proposed in two sub basins viz., Kabini and Suvarnavathi whose deficits are 214 Mm^3 and 34 Mm^3 respectively. In the remaining seven sub basins viz., Arkavathi, Chinnar, Palar, Bhavani, Noyil, Tirumanimuttar and Amaravathi, additional irrigation has been proposed. After accounting for respective present groundwater draft in these sub basins, three sub basins viz., Arkavathi, Bhavani and Amaravathi will still remain water short to the extent of 534 Mm^3, 207 Mm^3 and 19 Mm^3 respectively.

Table 6.9 Estimation of Ground water potential in the deficit sub-basins of Krishna Basin

State / District	Geographical area Whole District	within the sub-basin	factor (%)	GROUND WATER: WHOLE DISTRICT: Total replenishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	WITHIN SUB-BASIN: Total replenishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	Balance for future use
1	2	3	4	5	6	7	8	9	10	11	12	13
Tungabhadra Sub-basin (K-8)												
Karnataka												
Bellary	9885	6589	66.66	701.2	105.2	596.0	145.0	467.4	70.1	397.3	96.7	300.6
Chikmagalur	7201	4011	55.70	590.5	88.6	501.9	31.0	328.9	49.3	279.6	17.3	262.3
Chitradurga	10852	3075	28.34	748.2	112.2	636.0	277.0	212.0	31.8	180.2	78.5	101.7
Dharwar	13738	6826	49.69	1038.9	155.8	883.1	177.0	516.2	77.4	438.8	87.9	350.8
Karwar (U.K)	10291	524	5.09	783.5	117.5	666.0	109.0	39.9	6.0	33.9	5.6	28.4
Raichur	14336	10031	69.97	1071.7	160.8	910.9	133.0	749.9	112.5	637.4	93.1	544.3
Shimoga	10553	7734	73.29	1498.8	224.8	1274.0	261.0	1098.4	164.8	933.7	191.3	742.4
Andhra Pradesh												
Kurnool	17658	7481	42.37	1153.5	173.0	980.5	172.0	488.7	73.3	415.4	72.9	342.5
Mahaboobnagar	18472	1556	8.42	1450.1	217.5	1232.6	410.5	122.2	18.3	103.8	34.6	69.2
Sub-total		**47827**						**4023.6**	**603.5**	**3420.0**	**677.7**	**2742.3**
Vedavati Sub-basin (K-9)												
Karnataka												
Bellary	9885	2974	30.09	701.2	105.2	596.0	145.0	211.0	31.6	179.3	43.6	135.7
Chitradurg	10852	7080	65.24	748.2	112.2	636.0	277.0	488.1	73.2	414.9	180.7	234.2
Chikmagalur	7201	2258	31.36	590.5	88.6	501.9	31.0	185.2	27.8	157.4	9.7	147.7
Hassan	6814	1591	23.35	504.7	75.7	429.0	47.0	117.8	17.7	100.2	11.0	89.2
Tumkur	10598	4316	40.72	895.3	134.3	761.0	438.0	364.6	54.7	309.9	178.4	131.5
Andhra pradesh												
Anantapur	19130	4541	23.74	1249.0	187.4	1061.7	391.2	296.5	44.5	252.0	92.9	159.1
Kurnool	17658	830	4.70	1153.5	173.0	980.5	172.0	54.2	8.1	46.1	8.1	38.0
Sub-total		**23590**						**1717.4**	**257.6**	**1459.8**	**524.4**	**935.4**

Table 6.10 Estimation of Ground water potential in deficit sub-basins of Pennar basin

State/ District	Geographical area Whole District	within the sub-basin	factor (%)	GROUND WATER WHOLE DISTRICT Total replenishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	WITHIN SUB-BASIN Total replenishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	Balance for future use
1	2	3	4	5	6	7	8	9	10	11	12	13
Upper Pennar Sub-basin (P-1)												
Karnataka												
Bangalore	8005	407	5.08	763.5	114.5	649.0	475.0	38.8	5.8	33.0	24.2	8.8
Kolar	8223	1937	23.56	803.6	120.5	683.1	471.0	189.3	28.4	160.9	110.9	50.0
Tumkur	10598	2690	25.38	895.3	134.3	761.0	438.0	227.2	34.1	193.2	111.2	82.0
Andhra Pradesh												
Anantapur	19130	13482	70.48	1249.0	187.4	1061.7	391.2	880.2	132.0	748.2	275.7	472.5
Cuddapah	15359	441	2.87	1057.2	158.6	898.6	314.8	30.4	4.6	25.8	9.0	16.8
Kurnool	17658	743	4.21	1153.5	173.0	980.5	172.0	48.5	7.3	41.3	7.2	34.0
Sub-total		**19700**						**1414.5**	**212.2**	**1202.3**	**538.2**	**664.1**
Lower Pennar Sub-basin (P-3)												
Karnataka												
Kolar	8223	26	0.32	803.6	120.5	683.1	471.0	2.5	0.4	2.2	1.5	0.7
Andhra Pradesh												
Chittoor	15152	3332	21.99	1581.4	237.2	1344.2	453.5	347.8	52.2	295.6	99.7	195.9
Cuddapah	15359	8954	58.30	1057.2	158.6	898.6	314.8	616.3	92.4	523.9	183.5	340.4
Prakasam	17626	968	5.49	1830.8	274.6	1556.2	211.3	100.5	15.1	85.5	11.6	73.9
Sub-total		**13280**						**1067.2**	**160.1**	**907.1**	**296.3**	**610.8**

Table 6.11 Estimation of Groundwater Potential in deficit sub-basins of Cauvery basin

State/	Geographical area		factor	GROUND WATER								
District	Whole	within the	(%)	WHOLE DISTRICT				WITHIN SUB-BASIN				
	District	sub-basin		Total repl-enishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	Total repl-enishable Resource	Provision for Dom& Ind.use	Available resource for Irri.	Net draft	Balance for future use
1	2	3	4	5	6	7	8	9	10	11	12	13
Kabini Sub-basin (C-3)												
Karnataka												
Kodagu	4102	151	3.68	165.9	24.9	141.0	11.0	6.1	0.9	5.2	0.4	4.8
Mysore	11954	4757	39.79	812.9	121.9	691.0	158.0	323.5	48.5	275.0	62.9	212.1
Kerala												
Cannanore	4958	18	0.36	733.1	110.0	623.1	90.7	2.7	0.4	2.3	0.3	1.9
Kozhikode	2345	29	1.24	423.1	63.5	359.6	118.3	5.2	0.8	4.4	1.5	3.0
Wyanad	2132	1873	87.85	424.6	63.7	360.9	178.0	373.0	56.0	317.1	156.4	160.7
Tamilnadu												
Nilgiris	2549	212	8.32	58.0	8.7	49.3	1.6	4.8	0.7	4.1	0.1	4.0
Sub-total		**7040**						**715.3**	**107.3**	**608.0**	**221.6**	**386.4**
Suvarnavathi Sub-basin (C-4)												
Karnataka												
Mysore	11954	1207	10.10	812.9	121.9	691.0	158.0	82.1	12.3	69.8	16.0	53.8
Tamilnadu												
Periyar	8209	580	7.07	1232.8	184.9	1047.9	904.5	87.1	13.1	74.0	63.9	10.1
Sub-total		**1787**						**169.2**	**25.4**	**143.8**	**79.9**	**63.9**
Arkavathi Sub-basin (C-6)												
Karnataka												
Bangalore	8005	4109	51.33	763.5	114.5	649.0	475.0	391.9	58.8	333.1	243.8	89.3
Kolar	8223	6	0.07	803.6	120.5	683.1	471.0	0.6	0.1	0.5	0.3	0.2
Mandya	4961	69	1.39	790.6	118.6	672.0	78.0	11.0	1.6	9.3	1.1	8.3
Tamilnadu												
Dharmapuri	9622	167	1.74	1154.7	173.2	981.5	648.5	20.0	3.0	17.0	11.3	5.8
Sub-total		**4351**						**423.5**	**63.5**	**360.0**	**256.5**	**103.5**

State/ District	Geographical area Whole District	within the sub-basin	factor (%)	GROUND WATER WHOLE DISTRICT Total repl-enishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	WITHIN SUB-BASIN Total repl-enishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	Balance for future use
1	2	3	4	5	6	7	8	9	10	11	12	13
Chinnar Sub-basin (C-7)												
Karnataka												
Bangalore	8005	100	1.25	763.5	114.5	649.0	475.0	9.5	1.4	8.1	5.9	2.2
Tamilnadu												
Dharmapuri	9622	3630	37.73	1154.7	173.2	981.5	648.5	435.6	65.3	370.3	244.7	125.6
Salem	8650	331	3.83	1736.7	260.5	1476.2	176.0	66.5	10.0	56.5	6.7	49.8
Sub-total		**4061**						**511.6**	**76.7**	**434.9**	**257.3**	**177.6**
Palar Sub-basin (C-8)												
Karnataka												
Mysore	11954	1870	15.64	812.9	121.9	691.0	158.0	127.2	19.1	108.1	24.7	83.4
Tamilnadu												
Periyar	8209	1097	13.36	1232.8	184.9	1047.9	904.5	164.7	24.7	140.0	120.9	19.2
Salem	8650	247	2.86	1736.7	260.5	1476.2	176.0	49.6	7.4	42.2	5.0	37.1
Sub-total		**3214**						**341.5**	**51.2**	**290.3**	**150.6**	**139.7**
Bhavani Sub-basin (C-9)												
Kerala												
Palghat	4480	562	12.54	885.6	132.8	752.8	78.6	111.1	16.7	94.4	9.9	84.6
Tamilnadu												
Coimbattore	7469	1002	13.42	941.5	141.2	800.3	695.1	126.3	18.9	107.4	93.3	14.1
Nilgiris	2549	1881	73.79	58.0	8.7	49.3	1.6	42.8	6.4	36.4	1.2	35.2
Periyar	8209	2469	30.08	1232.8	184.9	1047.9	904.5	370.8	55.6	315.2	272.0	43.1
Sub-total		**6154**						**667.3**	**100.1**	**567.2**	**379.5**	**187.7**

State/ District	Geographical area Whole District	within the sub-basin	factor (%)	GROUND WATER WHOLE DISTRICT Total repl-enishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	WITHIN SUB-BASIN Total repl-enishable Resource	Provision for Dom& Ind.use	Available resource for Irrigation	Net draft	Balance for future use
1	2	3	4	5	6	7	8	9	10	11	12	13
Noyil Sub-basin (C-10)												
Tamilnadu												
Coimbattore	7469	2117	28.34	941.5	141.2	800.3	695.1	266.9	40.0	226.8	197.0	29.8
Periyar	8209	742	9.04	1232.8	184.9	1047.9	904.5	111.4	16.7	94.7	81.8	13.0
Tiruchirapalli	11095	140	1.26	2228.0	334.2	1893.8	984.6	28.1	4.2	23.9	12.4	11.5
Sub-total		**2999**						**406.4**	**61.0**	**345.4**	**291.2**	**54.2**
Tirumanimuttar Sub-basin (C-11)												
Tamilnadu												
Dindigal Anna	6051	165	2.73	927.8	139.2	788.6	479.2	25.3	3.8	21.5	13.1	8.4
Periyar	8209	976	11.89	1232.8	184.9	1047.9	904.5	146.6	22.0	124.6	107.5	17.0
Salem	8650	5042	58.29	1736.7	260.5	1476.2	1235.1	1012.3	151.8	860.5	719.9	140.5
Tiruchirapalli	11095	2246	20.24	2228.0	334.2	1893.8	984.6	451.0	67.7	383.4	199.3	184.1
Sub-total		**8429**						**1635.2**	**245.3**	**1389.9**	**1039.8**	**350.1**
Amaravathi Sub-basin (C-12)												
Kerala												
Idukki	5061	384	7.59	458.0	68.7	389.3	19.2	34.8	5.2	29.5	1.5	28.1
Tamilnadu												
Coimbattore	7469	1515	20.28	941.5	141.2	800.3	695.1	191.0	28.6	162.3	141.0	21.3
Madurai	12624	3888	30.80	1320.0	198.0	1122.0	597.4	406.5	61.0	345.6	184.0	161.6
Periyar	8209	1663	20.26	1232.8	184.9	1047.9	904.5	249.7	37.5	212.3	183.2	29.0
Tiruchirapalli	11095	830	7.48	2228.0	334.2	1893.8	984.6	166.7	25.0	141.7	73.7	68.0
Sub-total		**8280**						**1048.7**	**157.3**	**891.4**	**583.3**	**308.0**

The abstract of deficits in various tributaries / rivers are presented in **Table 6.12.**

Table 6.12 Deficits in Tributary Sub-basins

Basin / Sub-basin	Net deficit (at 75% dep.) (Mm^3)	Net present draft from GW (Mm^3)	Addl Irri.as per NWDA		Net deficit with present draft (Mm^3)
			Area (Mm^3)	Utilisation (Mm^3)	
1	2	3	4	5	6
KRISHNA BASIN					
Vedavathi	348	524	163964	1336	**0**
PENNAR BASIN					
Upper Pennar	2295	538	284298	2630	**1757**
CAUVERY BASIN					
Kabini	214	222	-	-	**214**
Suvarnavathi	34	80	-	-	**34**
Arkavathi	729	256	38989	195	**534**
Chinnar	252	257	49756	512	**0**
Palar	76	150	15310	154	**0**
Bhavani	335	379	13448	128	**207**
Noyil	66	291	15827	117	**0**
Tirumanimuttar	19	1040	36528	384	**0**
Amaravathi	530	583	43302	511	**19**
Sub-total	**2255**	**3258**	**213160**	**2001**	**1008**

Thus, it is found that while Krishna basin will be self sufficient, Upper Pennar of Pennar basin, Telugu Ganga command, Kabini, Suvarnavathi, Arkavathi, Bhavani and Amaravathi sub basins of Cauvery basin and Cauvery delta will require supplementation from other basins to meet their projected needs.

6.3 PLANNING OF INTER-BASIN WATER TRANSFER (STAGE IV)

Having identified the most vulnerable sub-basins / commands, inter-basin water transfer proposals to augment supplies to these areas have been planned in three phases.

Phase I : Link projects to benefit Upper Pennar

Phase II : Link projects to benefit Telugu Ganga command

Phase III : Link projects to augment supplies to Cauvery.

In all these proposals en-route irrigation in new areas is considered only if these sub basins are found to be water short even after the integrated resource planning. Since it is not practicable to transfer the water through a canal without benefiting en route areas, irrigation in new areas along the canal as required from practical considerations should be provided. Under the proposed Godavari - Cauvery link system, the delivery of water in Cauvery will be possible at Grand Anicut only and its five upper deficit sub basins can not be covered. Since water is proposed for diversion through links, minimum flows at 1 % of average annual flows has been considered downstream of all the reservoirs from environmental considerations.

6.3.1 Link Projects to benefit Upper Pennar (Phase I)

Two link projects are studied under phase I. One link takes off from Almatti on Krishna to Upper Pennar while another link supplements the shortage at Prakasam barrage arising due to the first link from Polavaram on Godavari.

1. **Krishna (Almatti) - Upper Pennar Link Project:** The link takes off at Almatti on the Krishna river to benefit upland areas in Upper Pennar sub-basin. It crosses the Pennar river at Kalvapalli and extends up to Maddileru stream of Pennar river. The monthly demands for utilization of 1757 Mm^3 in the Upper Pennar sub-basin with 100 % intensity of irrigation have been computed based on the proposed cropping pattern by NWDA. Out of this, 600 Mm^3 will be diverted in Pennar river while the balance gets utilized in the en route command directly from the link. The domestic and industrial requirements in the en route command of the link have been estimated by projecting the population to 2050 AD (COI 1991). The monthly transmission losses have been computed to be 301 Mm^3 @ 0.6 cumec per million sq. m of wetted area based on a typical canal design for the link. An annual diversion of 2058 Mm^3 including transmission losses has been proposed from Almatti in all the months. Two balancing reservoirs viz., Kalvapalli and Bukkapatnam tank are integrated in the link project.

The effect due to the link diversion on the performance of the reservoirs in the Krishna basin is studied by simulation as under.

Almatti and Narayanpur reservoirs: The Almatti and Narayanpur can sustain irrigation development comfortably but the firm power (31.5 MW) reliability at Almatti is affected from 90 % to 77.2 %. Though the time and volume reliabilities are considerable, the link diversion also fails every year. Four cases of analysis, therefore, are studied to improve the situation at these reservoirs.

Case I: March to May are seen to be the critical failure months for link diversion and also for firm power generation at Almatti. It is also observed that the capacity of balancing reservoirs is enough to take care of link demands during these months, if filled earlier.

Therefore, under case I link diversion is proposed only during the period from June to February. Transmission losses have been re-assessed and annual diversion from Almatti is proposed at 2040 Mm^3. In this case, the link diversion reliability has improved to 66.7 % but the power reliability at Almatti has not at all improved.

Case II: In this case rule levels have been imposed for link diversion to study the possible improvement in the power performance at Almatti. It is seen that power reliability can be improved to 90 % with rule level imposition in the months from November to February for the link. But the link diversion will suffer drastically to 50 % of the demand with not even a single year of success.

Case III: Narayanpur reservoir has no irrigation demands in April and May and only 86 Mm^3 in March. Therefore under this case, firm power generation at Almatti is proposed only from June to February and energy as available is generated from the release for Narayanpur in March. It is seen that 33.5 MW of firm power can be generated with 97.4% time reliability during this period at Almatti and at the same time link diversion can also be effected with 76.7 % of annual reliability.

Case IV: As an alternative to case III, instead of restricting the period of firm power generation, firm power demand has been reassessed proposing it in all months. It is seen that 23 MW of firm power can be generated annually.

Obviously case III and case IV are better options over the other two. Case III of operation has been chosen in view of the following:

- The annual firm energy in case III (211 MU) is more than that in case IV (179 MU).
- Instead of releasing water for power during March to May when there is no irrigation demand at Narayanpur, it may be in the interest of the whole project to preserve these waters in Almatti reservoir and release them from June to February to serve both the purposes.

Details of simulation in all four cases are given in **Table 6.13.**

Srisailam reservoir: Due to the link diversion from Almatti to Upper Pennar, the project power reliability has reduced to 75.6 % and irrigation reliability declined to 70 %. In order to restore the reliability, no committed releases for Prakasam barrage have been proposed in the non-monsoon months. This has helped the power reliability to improve to 78.6 %. Further the committed releases for Nagarjunasagar are limited to power demand (235 Mm^3) during the

Table 6.13 Performance of reservoirs pertaining to the Krishna (Almtti) – Pennar Link Project

	Almatti Reservoir				Link Project		Narayanpur Reservoir			Kalvapalli Reservoir			Bukkapatnam Tank			Remarks
Criterion	Time	Vol.	Ann.	Pow	Time	Vol.	Time	Vol.	Ann.	Time	Vol.	Ann.	Time	Vol.	Ann.	
Diversion (2058 Mcum) & firm power(31.5 MW)					**in all months**											
	0.99	0.998	0.9	0.772	0.728	0.904	0.997	0.999	0.967	0.736	0.923	0	0.292	0.826	0	T/L :301 Mm^3
Case I																
Diversion from June to		**February (2040 Mcum) but firm power(31.5 MW)**							**in all months**							
	0.99	0.998	0.9	0.769	0.969	0.982	0.993	0.998	0.967	0.933	0.985	0.667	0.933	0.983	0.667	T/L :257 Mm^3
Case II																
Diversion (2040 Mcum)&firm power from June to						**February**										
31.5 MW	0.99	0.998	0.9	0.978	0.983	0.988	0.993	0.998	0.967	0.961	0.989	0.833	0.964	0.99	0.833	
33.5 MW	**0.98**	**0.994**	**0.833**	**0.974**	**0.972**	**0.982**	**0.997**	**0.999**	**0.967**	**0.944**	**0.985**	**0.767**	**0.944**	**0.981**	**0.767**	
40 MW	0.977	0.986	0.9	0.9	0.881	0.931	0.993	0.999	0.967	0.786	0.939	0.233	0.75	0.918	0.233	Feb:505.3 m
Case III																
Diversion from June to		**February (2040 Mcum) but firm power(31.5 MW)**							**in all months**							
Raising Rule levels for Link Diversion to ensure 90% Power reliability																
June: 507 m;July to October:519.6 m(FRL);November:519.25 m;Decemeber:518.5 m;January:517.2 m;February:515.8 m;																
	1	1	1	0.9	0.572	0.53	0.997	0.999	0.967	0.392	0.544	0	0.369	0.492	0	
Case IV																
Reducing the Power Demand to reassess the firm power																
22.85 MW	1	1	1	0.9	0.992	0.998	0.963	0.993	0.833	0.989	0.998	0.933	0.997	0.999	0.967	
23 MW	1	1	1	0.9	0.975	0.987	0.967	0.993	0.867	0.953	0.989	0.767	0.958	0.987	0.8	Feb:512.5 m

months from November to April. In October, the committed demand has been reduced to 719 Mm^3. This could help in restoring the required power reliability (90 %) and irrigation reliability (73.3%). The details are shown in **Table6.14.**

Table 6.14 Performance optimization at Srisailam reservoir with link diversion (Phase I)

DOWNSTREAM RELEASE	RELIABILITIES					REMARKS
(Mcum)	WS	POW	IRRIGATION			(Downstream release in Mcum)
			Time	Volume	Annual	
8788	0.95	0.756	0.722	0.746	0.7	as planned prior to considering the link
8729	0.95	0.758	0.722	0.746	0.7	No com. rel.(59) for barrage in April
8678	0.95	0.761	0.722	0.746	0.7	No com. rel.(51) for barrage in March
8633	0.95	0.761	0.722	0.746	0.7	No com. rel.(45) for Barrage in Feb.
8578	0.95	0.769	0.722	0.746	0.7	No com. rel.(55) for Barrage in Jan.
8519	0.95	0.778	0.722	0.746	0.7	No com. rel.(59) for Barrage in Dec.
8427	0.95	0.786	0.722	0.746	0.7	No com. rel.(92) for Barrage in Nov.
8077	0.95	0.808	0.722	0.751	0.7	d/s rel.limit to Pow.dem in April (235)
7493	0.958	0.831	0.733	0.757	0.7	d/s rel.limit to Pow.dem in March (235)
7272	0.958	0.836	0.733	0.761	0.7	d/s rel.limit to Pow.dem in Feb.(235)
7164	0.958	0.836	0.733	0.763	0.7	d/s rel.limit to Pow.dem in Jan.(235)
6815	0.967	0.85	0.733	0.767	0.7	d/s rel.limit to Pow.dem in Dec.(235)
6512	0.967	0.872	0.744	0.77	0.7	d/s rel.limit to Pow.dem inNov.(235)
6250	**0.967**	**0.9**	**0.756**	**0.774**	**0.733**	**d/s rel.limit to 719 in October**

Nagarjunasagar reservoir: The reservoir can meet its irrigation demands at 76.7 % reliability but its firm power cuts down to just 5 MW. No committed releases for Prakasam barrage can be considered, as it would affect the project irrigation. Both the priority options are considered in the analysis, which is presented in **Table 6.15.**

Table 6.15 Performance optimization at Nagarjunasagar with link diversion (Phase I)

CRITERION	RELIABILITIES				REMARKS
	POW	IRRIGATION			
		Time	Volume	Annual	
IRRIGATION PRIORITY					
61 MW	0.764	0.794	0.872	0.633	d/s release for barrage - 2178 Mcum.
0 MW		0.822	0.888	0.633	d/s release for barrage - 2178 Mcum.
0 MW		0.894	0.932	0.767	no committed d/s release for barrage.
4 MW	0.894	0.894	0.932	0.767	no committed d/s release for barrage.
3 MW	0.936	0.894	0.932	0.767	no committed d/s release for barrage.
POWER PRIORITY					
61 MW	0.803	0.739	0.829	0.6	d/s release for barrage - 2178 Mcum.
0 MW		0.894	0.932	0.767	no committed d/s release for barrage.
5 MW	**0.936**	**0.894**	**0.93**	**0.767**	**no committed d/s release for barrage.**
6 MW	0.936	0.892	0.929	0.733	no committed d/s release for barrage.

The low value of firm power can not entirely be attributed to the link diversion from Almatti but also due to certain bad years with low flows. In about 28 periods (7.8%), the optimized firm power of 61 MW can not be generated due to the link diversion.

Pulichintala and Prakasam barrage: The firm power of 10 MW at Pulichintala can be generated with only 61.9 % reliability. The corresponding irrigation reliability at Prakasam barrage is just 16.7 %. Since the irrigation at the barrage is of prime importance, simulation has been done with out firm power at Pulichintala which improved the irrigation reliability to 30 %. Then, groundwater potential in the command has been reassessed with reduced canal releases and entire utilizable groundwater resource of 1147 Mm^3 is proposed for conjunctive use. This resulted in the reliability improvement to 53.3 %. Still, the net deficit at 75 % reliability is found to be 1629 Mm^3. The details of simulation are given in **Table 6.16**

Table 6.16 Performance optimization at Pulichintala & Prakasam barrage with link diversion (Phase I)

	RELIABILITIES				REMARKS
CRITERION	POW	IRRIGATION			
		Time	Volume	Annual	
10 MW	0.619	0.608	0.750	0.167	Groundwater supplementation :606 Mcum
0 MW		0.628	0.763	0.300	
0 MW		0.689	0.799	0.533	Groundwater supplementation :1147Mcum

2. **Godavari (Polavaram) - Krishna (Prakasam barrage) Link Project:** The net deficit at Prakasam barrage is proposed to be made good by supplementation from Polavaram. The link diversion including transmission losses will be 1730 Mm^3. The effect on Polavaram due to this diversion is that its firm power will reduce to 86 MW (still more than 60 MW as planned by Project authorities) while its irrigation performance is preserved. In fact the minimum desired reliability of 76.7 % for irrigation at Dowleswaram has been safeguarded by imposing the rule levels for link diversion in March and April. With the supplementation from Polavaram through the link , Prakasam barrage will be able to meet its demands with 76.7 % reliability. The details of simulation are tabulated in **Table 6.17.** The Phase I link system is shown in **Fig 6.1.**

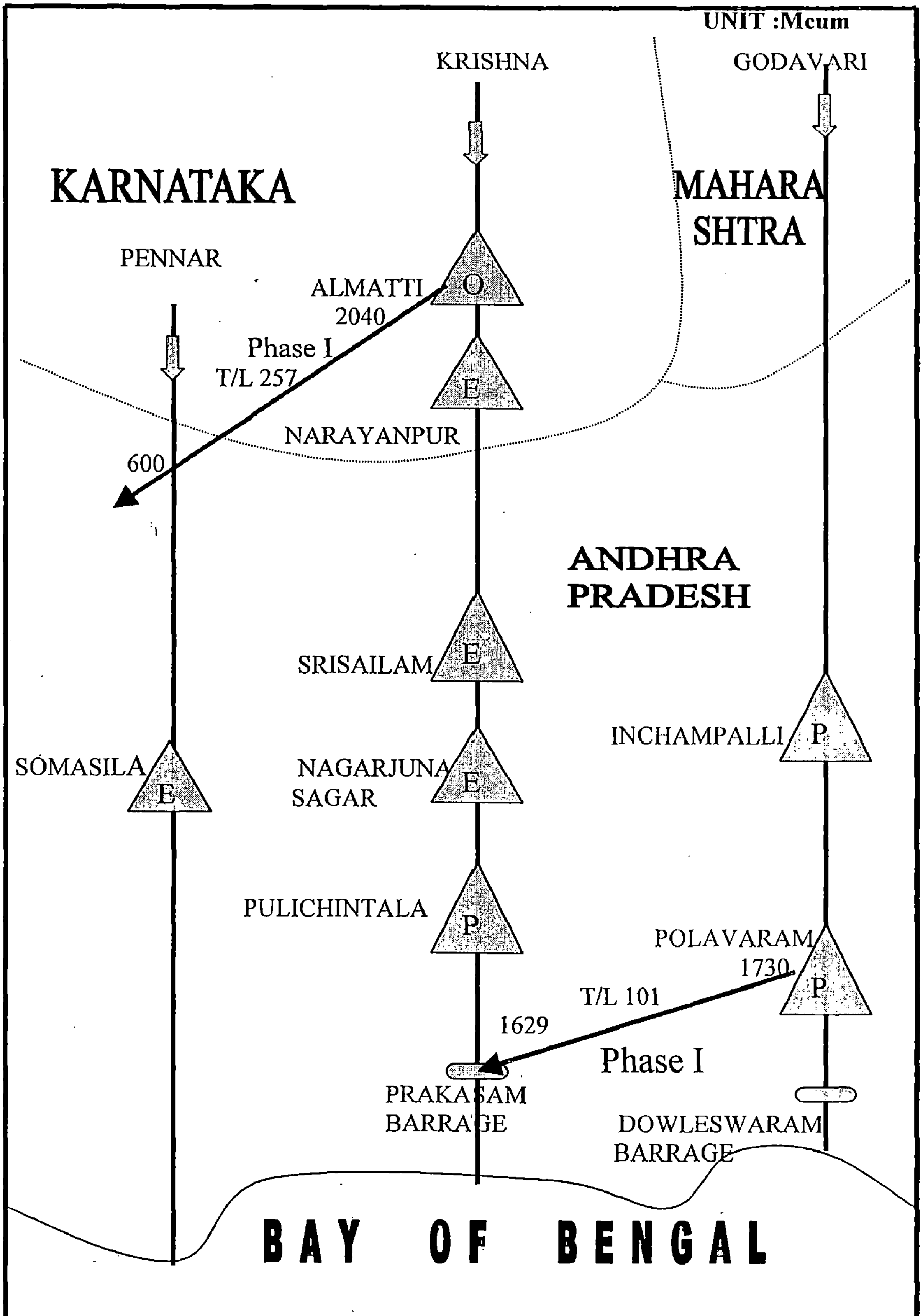


Fig:6.1 INTER BASIN WATER TRANSFER PROPOSALS (PHASE I)

Table 6.17 Performance optimization of reservoirs pertaining to Godavari (Polavaram) –Krishna (Prakasam barrage) Link Project (Phase I)

	Polavaram Reservoir					Link Project		Dowleswaram Barrage			Prakasam Barrage		
MW	WS	Time	Vol.	Ann.	Pow	Time	Vol.	Time	Vol.	Ann.	Time	Vol.	Ann.
112	0.961	0.956	0.991	0.767	0.767	0.867	0.946	0.944	0.973	0.700	0.817	0.936	0.733
60	0.989	0.983	0.998	0.833	0.972	0.987	0.992	0.969	0.990	0.800	0.819	0.946	0.767
84	0.981	0.972	0.994	0.833	0.947	0.973	0.987	0.961	0.984	0.767	0.819	0.944	0.767
85*	0.981	0.972	0.994	0.833	0.947	0.970	0.986	0.958	0.983	0.767	0.819	0.944	0.767
86**	**0.981**	**0.972**	**0.994**	**0.833**	**0.947**	**0.960**	**0.983**	**0.958**	**0.983**	**0.767**	**0.819**	**0.944**	**0.767**
87***	0.981	0.972	0.994	0.833	0.947	0.827	0.937	0.958	0.983	0.767	0.814	0.936	0.733

Note: * Rule level : April: 41.65 m **Rule level: March : 44.0m and April 41.65 m

*** Rule level: February : 44.0m , March and April : 44.50m

6.3.2 Link projects to benefit Telugu Ganga command (Phase II)

One additional link has been proposed from Srisailam on Krishna under this phase to benefit Telugu Ganga command. Additional diversion as required at Prakasam barrage has been proposed from Polavaram due to the diversion to Telugu Ganga.

1. **Krishna (Srisailam) - Pennar (Somasila) Link Project:** The net deficit in Telugu Ganga command (724 Mm^3) after groundwater supplementation is proposed to be supplied from Srisailam through natural streams in the months of August and September. The link diversion of 796 Mm^3 (including transmission losses) is proposed at a rule level of 266.7 m to utilize the floodwaters of Krishna at Srisailam for the Telugu Ganga command. The effect of this link diversion on the performance of the reservoirs in Krishna and Pennar basins is analyzed as under:

Srisailam reservoir: The power reliability at Srisailam has reduced slightly to 89.4 % while irrigation reliability came down to 70 %. Therefore the rule level for link diversion in September which was affecting the releases for irrigation in October has been raised to 268.4 m to restore the project irrigation reliability to 73.3 %. Further, the downstream release in October has been marginally reduced from 719 Mm^3 to 663 Mm^3 to achieve desired firm power reliability of 90 %. The abstract of simulation is given in **Table 6.18.**

Table 6.18 Performance of optimization of reservoirs pertaining to Krishna (Srisailam) – Pennar (Somasila) Link Project

CRITERION	SRISAILAM PROJECT					LINK PROJECT		SOMASILA PROJECT		
AT SRISAILAM	WS rel.	POW rel.	IRRIGATION reliabilities			(796 Mm^3)		WS rel.	IRRIGATION Annual reliability	
Rule level (m) for link		(60 MW)	(2209 Mm^3)			Reliabilities		(409 Mm^3)	Delta	TG canal
diversion in September			Time	Vol.	Ann.	Time	Vol.		(1255 Mm^3)	(724 Mm^3)
266.7	0.967	0.894	0.733	0.766	0.700	0.750	0.750	0.925	0.833	0.367
267.7	0.967	0.894	0.733	0.766	0.700	0.750	0.750	0.925	0.833	0.367
268.0	0.967	0.894	0.733	0.768	0.700	0.733	0.744	0.925	0.833	0.367
268.3	0.967	0.894	0.733	0.770	0.700	0.733	0.737	0.925	0.833	0.367
268.4	0.967	0.894	0.744	0.771	0.733	0.733	0.735	0.925	0.833	0.367
d/s rel.Oct (663 Mm^3)	**0.967**	**0.900**	**0.744**	**0.772**	**0.733**	**0.733**	**0.735**	0.925	0.833	0.367

Nagarjunasagar reservoir: The effect of diversion on Nagarjunasagar is negligible with its irrigation reliability at 73.3 %. There is just one failure year with 15 Mm^3 of deficit in June. Adjusting the power release during the real time reservoir operation can easily make this up. The details are given in **Table 6.19.**

Table 6.19 Performance optimization of Nagarjunasagar reservoir with link diversion (Phase II)

CRITERION	IRRIGATION (7465 Mm^3)			POWER
				(5 MW)
	Time	Vol.	Ann.	
POWER Priority	**0.883**	**0.926**	**0.733**	**0.931**
IRRIGATION Priority	0.886	0.926	0.733	0.883
Failure year	Release	Deficit		
	(Mm^3)	(Mm^3)	(%)	
1969-70	7450	15	0.2	

Pulichintala and Prakasam barrage: Here also, the effect is marginal with irrigation reliability at 73.3 %. The deficit in one failure year is only 14 Mm^3 in April, which the command may be able to adjust to. Since there is already a link proposal from Polavaram to Prakasam barrage under Phase I, additional water can be drawn through it. The simulation details are furnished in **Table 6.20.**

Table 6.20: Performance optimization of Pulichintala & Prakasam barrage with link diversion (Phase II)

Criterion for Supply	IRRIGATION (3985 Mm^3)		
Surface water :3985 Mm^3			
Groundwater:1147Mm^3	Time	Vol.	Ann.
	0.817	**0.943**	**0.733**
Failure year	Release	Deficit	
	(Mm^3)	(Mm^3)	(%)
1966-67	3971	14	0.35

Somasila reservoir: With the additional inflows from Srisailam, simulation has been carried to observe the improvement in the performance of Somasila reservoir in meeting the demands of both delta and Telugu Ganga. Rule level for Telugu Ganga has been gradually relaxed up to 88.5 m in decrements of 0.5 m. It is seen that a rule level of 89 m will improve the reliability for Telugu Ganga to 70 % while safe guarding the irrigation reliability of 76.7 % for Pennar delta. The abstract of simulation is given in **Table 6.21.**

Table 6.21: Performance optimization of Somasila reservoir with link diversion (Phase II)

Criterion	SOMASILA PROJECT		
	Water Sup	IRRIGATION (Ann)	
Rule level (m) for Telugu Ganga canal	(409 Mm^3)	delta (1255 Mm^3)	TG canal (724 Mm^3)
98.0	0.925	0.833	0.500
97.5	0.925	0.833	0.500
97.0	0.925	0.833	0.533
96.5	0.925	0.833	0.567
96.0	0.925	0.833	0.567
95.5	0.925	0.833	0.567
95.0	0.925	0.833	0.567
94.5	0.925	0.833	0.600
94.0	0.925	0.833	0.600
93.5	0.925	0.833	0.600
93.0	0.925	0.833	0.633
92.5	0.925	0.833	0.667
92.0	0.925	0.800	0.667
91.5	0.925	0.800	0.667
91.0	0.925	0.800	0.700
90.5	0.925	0.800	0.700
90.0	0.925	0.767	0.700
89.5	0.925	0.767	0.700
89.0	**0.925**	**0.767**	**0.700**
88.5	0.917	0.733	0.733

2. **Godavari (Polavaram) - Krishna (Prakasam barrage) Link Project:** Additional diversion of 15 Mm^3 (Total diversion of 1745 Mm^3) is proposed from Polavaram to make up deficit in April at Prakasam barrage, which can be effected with out any stress on the performance of Polavaram. The abstract of simulation is given in **Table 6.22.** The Phase II link system is shown in **Fig 6.2**

Table 6.22 Performance optimization of reservoirs pertaining to Godavari (Polavaram) –Krishna (Prakasam barrage) Link Project (Phase II)

POALAVARAM PROJECT					LINK PROJECT		DOWLESWARAM			PRAKASAM BARRAGE		
WS	POW	IRRIGATION (3283 Mm^3)			(1745 Mm^3)		IRRIGATION (7774 Mm^3)			IRRIGATION (3985 Mm^3)		
(664 Mm3)	(86 MW)						Time	Vol.	Ann.	Time	Vol.	Ann.
0.981	0.947	0.972	0.994	0.833	0.96	0.982	0.958	0.983	0.767	0.822	0.944	0.767

6.3.3 Link Projects to augment supplies to Cauvery

The following three link projects are studied under Phase III.

1. Pennar (Somasila) - Cauvery (Grand Anicut) link project
2. Krishna (Nagarjunasagar) - Pennar (Somasila) link project
3. Godavari (Inchampalli) - Krishna (Nagarjunasagar) link project.

1. **Pennar (Somasila) - Cauvery (Grand Anicut) Link Project:** The Cauvery delta is short of 7540 Mm^3 to meet its irrigation demands at 75% reliability. Its time, volume and annual reliabilities were 13.7 %, 32.7% and 6.7 % respectively. Further the surplus / deficit in three small basins between Pennar and Cauvery viz., the basin covering streams between Pennar and Palar, Palar basin and Basin covering Streams Palar and Cauvery have been worked out considering surface and groundwater resources in these basins. Out of these, Palar basin is found to be water deficit to the tune of 440 Mm^3 and is therefore proposed to be supplemented through link project. The transmission losses have been computed to be 748 Mm^3 for the typical canal section designed in the pre-feasibility report of Somasila – Grand Anicut link of NWDA. Thus the total diversion from the link works out to 8728 Mm^3. Since Pennar basin is itself a water short basin , link diversion is proposed from Somasila with a rule level at 100.58 m (FRL) so as not to affect the irrigation releases Somasila project. The time and volume reliabilities at Grand Anicut have slightly improved to 16.7 % and 37.6% respectively.

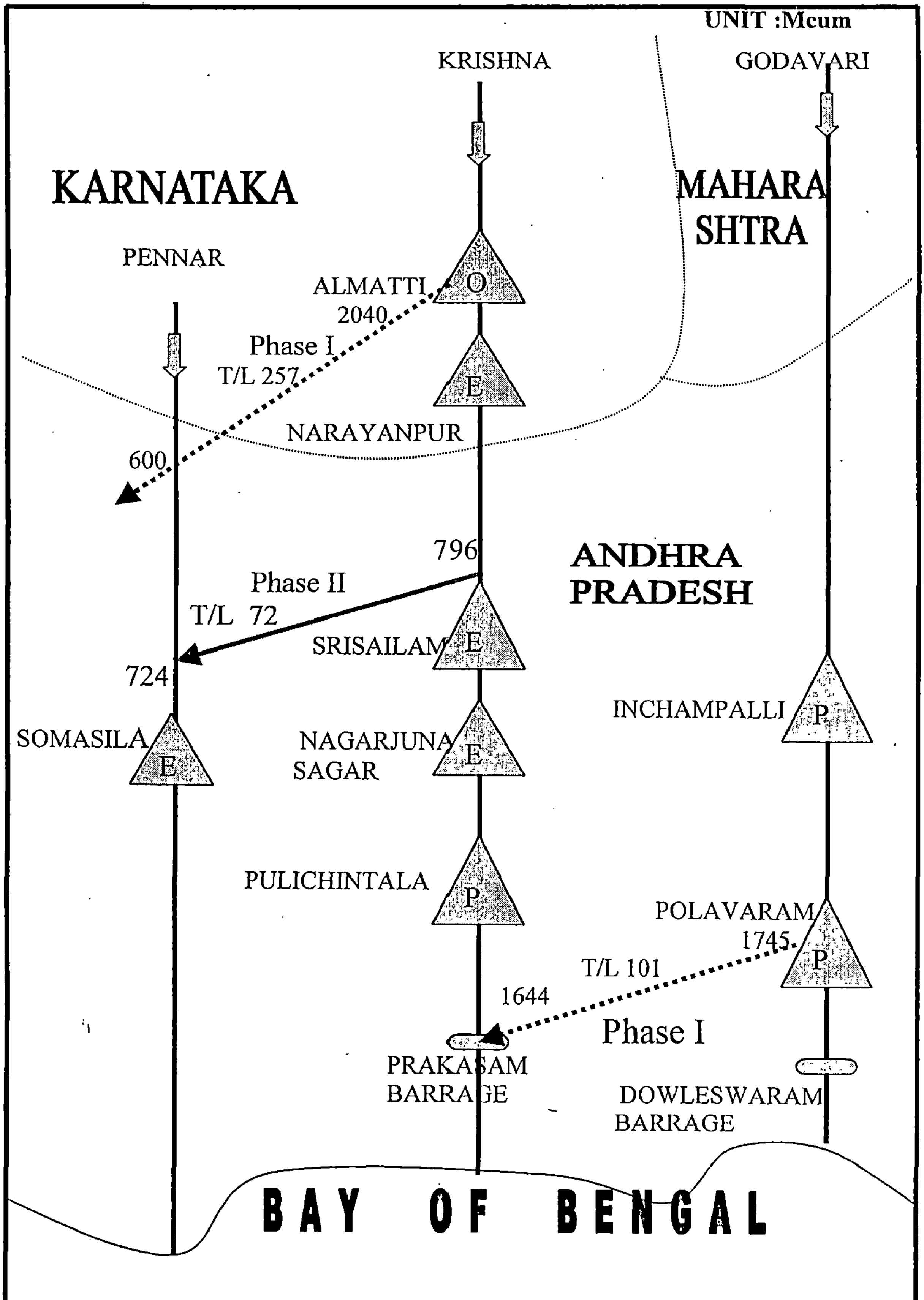


Fig:6.2 INTER BASIN WATER TRANSFER PROPOSALS (PHASE II)

2. Krishna (Nagarjunasagar) - Pennar (Somasila) Link Project: Then the Krishna flood waters are proposed for diversion from Nagarjunasagar to Pennar basin at Somasila with a rule level of 179.83 m(FRL). There are three small basins between Krishna and Pennar viz., basin covering streams between Krishna and Gundlakamma, Gundlakamma basin and basin covering streams between Gundlakamma and Pennar. Theses basins are found to be not water short considering respective with in basin surface and groundwater resources and projected needs. The proposed diversion from Nagarjunasagar including transmission losses of 332 Mm^3 (as considered in the pre-feasibility report of Nagarjunasagar – Somasila link of NWDA) is 9060 Mm^3. From simulation it is seen that the time, volume and annual reliabilities at Grand Anicut have further improved to 33.7 %, 53.3 % and 13.3 % respectively.

3. Godavari (Inchampalli) - Krishna (Nagarjunasagar) Link Project: About 9300 Mm^3 of water (including 240 Mm^3 of transmission losses is proposed to be diverted from Inchampalli on Godavari river to Nagarjunasagar on Krishna river. The irrigation reliabilities at the Grand Anicut have significantly improved to 55.3 % (time), 75.4 % (volume) and 36.7 % (annual). Now that the water for Cauvery basin are proposed to be drawn from surplus Godavari basin, the rule level at Somasila and Nagarjunasagar have been relaxed to improve the reliability for the link diversion. The irrigation performance at Grand Anicut under various stages and operation policies of link diversion as explained above is summarized in **Table 6.23.**

Table 6.23: Performance of Grand Anicut under various stages of supplementation through link

Irrigation reliabilities			Remarks
Time	Volume	Annual	
0.137	0.327	0.067	Without a link diversion
0.167	0.376	0.067	Diversion of spills from Somasila
0.327	0.531	0.133	Diversion of spills from Nagarjunasagar to Somasila
0.553	0.754	0.367	Diversion of waters from Inchampalli
0.597	0.783	0.367	Rule level for link diversion from Somasila at 89 m from Sept to Dec.
0.690	0.872	0.567	Rule level at 155.45 m (MDDL) at Nagarjunasagar for link diversion
0.770	0.889	0.633	Rule level for diversion from Somasila at 89 m in all months.

The effect of the link diversion on the performance of the reservoirs in Godavari basin is studied by simulation as under.

Inchampalli Reservoir: The Inchampalli reservoir will be able to meet its irrigation demands (620 Mm^3) with 73.3 % annual reliability. But, its reliability for power generation of 127 MW has reduced to 79.2 %. Therefore the possible firm power generation at Inchampalli with proposed link diversion has been reassessed to be 76 MW from simulation runs. Its corresponding annual irrigation reliability will be 76.7 %. The details of simulation are given in **Table 6.24.**

Table 6.24: Firm power reassessment at Inchampalli

Power (MW)		Irrigation reliabilities			**Remarks**
Demand	reliability	Time	Volume	Annual	
127	0.729	0.928	0.975	.0733	*The irrigation reliabilities at Grand Anicut corresponding to the reservoir operation at Inchampalli with firm power of 76 MW will be 79.3 % (time) 92.4 % (volume) and 70 % (annual).
117	0.811	0.928	0.975	.0733	
115	0.814	0.928	0.975	.0733	
110	0.822	0.928	0.975	.0733	
100	0.839	0.928	0.975	.0733	
90	0.856	0.931	0.975	0.767	
80	0.881	0.933	0.978	0.767	
76*	**0.900**	**0.939**	**0.982**	**0.767**	

Polavaram reservoir: The Polavaram reservoir will be able to meet its irrigation demands (3283 Mm^3) with 76.7 % annual reliability. However, its power reliability for generation of 86 MW will be only 68.1 %. From simulation the firm power has been reassessed at 62 MW, the details of which are given in **Table 6.25.**

Table 6.25: Firm power reassessment at Polavaram

Power (MW)		Irrigation reliabilities		
Demand	reliability	Time	Volume	Annual
86	0.681	0.939	0.982	0.767
80	0.722	0.942	0.984	0.767
70	0.836	0.944	0.988	0.767
62	**0.903**	**0.953**	**0.990**	**0.767**

Dowleswaram barrage: The corresponding reliabilities for meeting the irrigation demand (7774 Mm^3) at the barrage with reassessed firm power generation of 62 MW at Polavaram will be 92.8 % (time), 96.7 % (volume) and 70.% (annual). The deficits in two failure years are however marginal at 2.3 % and 6.1 % of the demand respectively.

The effect of the link diversion on the performance of the projects in Krishna basin will be as under.

Nagarjunasagar reservoir: The reservoir will be able to meet its irrigation demand (7465 Mm^3) with reliabilities of 86.7 % (time), 91.8 % (volume) and 70 % (annual). Here also the deficits in two failure years are negligible at 0.3 % and 2 % of the demand respectively.

Prakasam barrage: The performance indices of Prakasam barrage in meeting its irrigation requirements of 3985 Mm^3 will be 80.8 % (time), 93.6 % (volume) and 70.3 % (annual). The deficit in one failure year is 3.2 % of the demand, which is not significant.

Effect of link diversion on the performance of Somasila Project is as detailed below.

Somasila reservoir: The annual reliability of Somasila reservoir in meeting its delta requirements will improve to 83.3 % and that of Telugu Ganga command to 76.7 %. The improvement in reliabilities is mainly due to the imposition of rule level at 89 m for link diversion as applicable for releases to Telugu Ganga.

The phase III link system is shown in **Fig: 6.3**

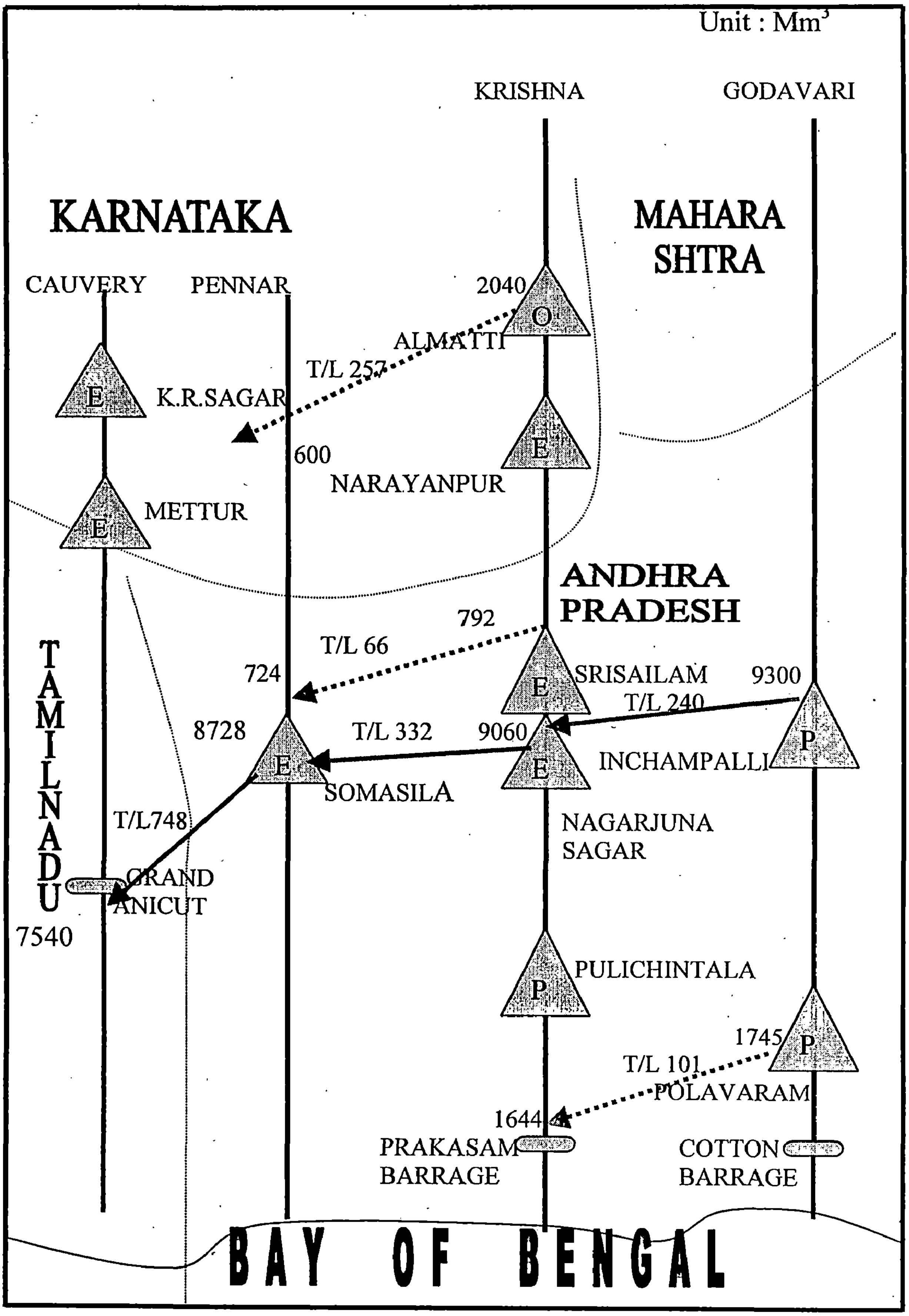


Fig 6.3: INTER-BASIN WATER TRANSFER PROPOSALS (PHASE III)

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Based on the present system study, the following conclusions could be drawn.

1. The multi reservoir simulation model is an effective tool for analysis of complex inter-basin water transfer link systems as demonstrated by this study. The model can be used to optimize the reservoir performance through simulation. Reservoirs in the link system are operated according to specified policy for meeting target demands (irrigation, municipal supply, firm power generation, committed downstream release etc.). Trade–off studies between irrigation and hydropower at different reliabilities have been carried out for each of the reservoirs in the link system. Such trade-off studies enable a decision-maker to analyze many options for development of multi-purpose reservoir projects. The multi-reservoir simulation model also helps in intelligent co-ordination of reservoirs in different basins integrated through link projects.

2. The within year and carry over storage capacities of the reservoir and their impact in storing the excess water when available and releasing it in times of need has been considered in the present study. The storage impact coupled with appropriate operation policies for power generation not only ensures supplies for project utilization at desired reliability but also helps in making downstream releases in accordance with the optimized firm power demand / committed down stream requirement. Thus, supplies more than those estimated in conventional water balance studies would be available at the subsequent sites for utilization.

3. A comparison of the water balance situation in each basin as per the present study with that assessed in the water balance studies of NWDA is presented in **Table 7.1.** Water balance situation arrived at by the system study is considered to be more realistic as (i) it is based on long term simulation. (ii) inflows at reservoir sites take in to account only the surplus yields from tributaries and (iii) deficit / surplus tributary sub basins have been identified.

Table 7.1 Water balance as per the Present Study and NWDA studies

Basin / Project	Water Balance (Mm^3) as per the		Remarks
	Present Study	NWDA Studies	
Godavari at Polavaram	(+) 19354	(+) 15020*	* considering proposed transfer of 2265 Mm^3 from Godavari to Krishna
Krishna at Prakasam Barrage	(-) 606	(-) 3235*	
Pennar at Somasila	(-) 311	(-) 3820	
	(-) 1201 @		@ including Telugu Ganga requirement of 890 Mm^3. NWDA has considered this demand from 50 % dependable waters in the water balance study.
Cauvery at Krishnarajasagar	(-) 249	Not studied	
Cauvery at Grand Anicut	(-) 8945	(-) 16118	

4. With integration of surface water and groundwater in project commands and in the upstream deficit tributary sub-basins, the situation in deficit basins will improve as indicated in **Table 7.2.**

Table 7.2 Water balance after Groundwater integration in the Planning

Basin	Water balance (Mm^3)	Remarks
Krishna	No deficit	
Pennar	(-) 1757	In Upper Pennar sub-basin
	(-) 724	In Telugu Ganga Command
Cauvery	(-) 7540	At Grand Anicut
	(-) 1008	In five upstream sub- basins of Kabini, Suvarnavathi, Bhavani Arkavathi and Amaravathi

5. Based on the simulation study, the link system from Godavari to Cauvery can be planned in three Phases:

Under Phase I, the Upper Pennar sub-basin is provided with 1757 Mm^3 of water from Almatti reservoir on Krishna river to develop irrigation in a new area of 2.00 lakh ha. As a supplementary link, 1730 Mm^3 of water are to be provided from Polavaram on Godavari to Prakasam barrage on Krishna **(Fig. 6.1).**

Under Phase II, the Telugu Ganga command of 1.24 lakh ha. is proposed to be benefited from Srisailam on Krishna , which was originally planned with Pennar flood waters. **(Fig. 6.2)**

Under Phase III, the Cauvery basin is proposed to be benefited with augmentation of 7540 Mm^3 to Grand Anicut. This would benefit the upper areas of Cauvery with proposed development. The link system, inter alia, will provide relief to the water short Palar basin en route. **(Fig. 6.3)**

6. The additional benefits of this multi-reservoir simulation study over the conventional water balance and link studies are that (i) the link proposals are small in size as ground water resource is also considered in deficit commands and tributary sub-basins prior to quantifying inter-basin water transfers to these areas and (ii) firm power fixation for six projects in Godavari and Krishna basins in both without and with link scenario has been done, as given in **Table 7.3.**

Table 7.3 Firm power of the projects in the link system

Basin	Project	Firm Power (MW)		Remarks
		Without link diversion	With link diversion	
Godavari	Inchampalli	127	76	* Power demand is only in nine months from June to February.
	Polavaram	112	62	
Krishna	Almatti	31.5	33.5*	
	Srisailam	60	60	
	Nagarjunasagar	61	5	
	Pulichintala	10	0	

7. Inter-basin water transfer projects are mega and complex systems. The associated economic and environmental problems with such projects are (i) they require large-scale storages cum diversion works and large and long links in between. This would involve reservoir submergence and rehabilitation problems and (ii) construction of inter-basin links would involve construction of a number of major cross drainage works. Socio economic and environmental feasibility of the proposals will have to be critically examined.

8. The major gains from inter-basin water transfer projects are (i) Temporal and spatial imbalance in the availability of water vis-à-vis demands on regional scale will be overcome; (ii) They cause social cohesion and national integration; and (iii) Balanced development of all the affected regions can be achieved through increased agricultural activity in water scarce regions, reduction in drought prone areas and protection of flood prone areas in water abundant regions.

7.2 RECOMMENDATIONS

1. This study has considered only those projects in each of the river basins which are pertaining to the inter basin link system. A long-term water balance simulation study of each of the basins should be carried out so as to identify intra basin transfer links to overcome temporal and spatial imbalance within the basin itself.

2. Appropriate guidelines and criteria for environmental feasibility (such as minimum flows, maximum / minimum reservoir levels in each time period) need to be standardized so that these could be incorporated in simulation models to the extent possible.

Tail Spark

The conservation of water right from **'WASH BASIN'** in home to the **'RIVER BASIN'** should be the guiding motto for the future generation. The Godavari – Cauvery link project is has inter state character and its implementation would depend on inter state cooperation. Some of the components of link system are being planned by States themselves in a similar or different form within their administrative jurisdiction.. The Polavaram – Prakasam barrage link has already been planned by Andhra Pradesh as the project lies within the jurisdiction of the State. Andhra Pradesh State also proposed a number of lift schemes from

Srisailam in Krishna basin to upper areas in Pennar basin entirely within the State. The Almatti - Pennar link of the link system proposed by NWDA will cover some of these areas in Pennar by gravity. Like wise, Andhra Pradesh State has its own plans to take care of irrigation demand in the command of Somasila project (Pennar) from Srisailam reservoir (Krishna) in the years of distress. However, the link system (NWDA) will benefit all the concerned States and deprive none. The Karnataka State will derive benefits by way of additional irrigation development in Krishna and Cauvery basins and also through en-route irrigation along Almatti – Pennar link. Andhra Pradesh will have its drought prone areas in Upper Pennar and Telugu Ganga command benefited with assured waters. Besides, it can have en-route irrigation in new areas along all the links right up to its boundary.

Water is a State subject as per the constitution of India. The concept of inter-basin water transfer can form and take concrete shape only with mutual cooperation of the States in the interest of the Nation. The spirit of cooperation shown by the States of Andhra Pradesh and Karnataka in case of 'Tungabhadra inter-state project' is required to be displayed by concerned States in case of link system also. One State may perhaps have to bear part of the cost of the link system or share its resources in exchange. Telugu Ganga inter-basin water transfer scheme for supply of water to Chennai city from Srisailam reservoir (A.P) is a good example of inter-state cooperation and harmony. It is hoped that the inter-basin water transfer links will become the real **'LINKS OF HEARTS'** of people of India and shall not remain just ' **INK PROJECTS ON PAPER'**.

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Annexure I

Input Data format and Description

Line	Variable name	Format	Description
1	TITL	A	Title of the problem
2	NLOC	Free	Total number of controlling locations in the system
	IMON (1)	Free	Initial month of operation
	IYR (1)	Free	Initial year of operation
	NMON	Free	Number of months of operation
	IFMON	Free	A factor for specifying length of a period=1 for monthly operation, =3 for ten daily operation
3	-	-	Blank line
4	NAME (I)	A	Name of location in alphanumeric
5	ICP(I)	Free	Node number of the control point
	ICP1(I)	Free	Number of the control points immediately u/s of the present control
	ICON(I)	Free	A flag to specify the way of supply of water through the power plants =0---no power plants, =1---All release pass through plant, =2---Irri. release bypasses the plant =3---WS release bypasses the plant =4---All releases bypass the plant
	FIR (I)	Free	A factor for reducing demands of irrigation in case of insufficient water
	FPOW(I)	Free	A factor for reducing demands of hydropower in case of insufficient water(if icon(i)=0, then 0)
	FCRI(I)	Free	A factor for defining critical conditions(release less than a specified % of total demands)
	ICP2(I)	Free	Node number of ICPI control points u/s of the present control point.

If ICON(I) is greater than 0, then			
6	PINST(I) ETAIL(I) PLMIN(I) EFF(I)	Free Free Free Free	Installed capacity of the power plants in MW Tail water elevation (m) Minimum level for power production in metre. Efficiency of the power plants.
7	IPRIO(I,J)	Free	Priority index for irrigation & Power =0 if irrigation has higher priority =1 if power has higher priority
8	POW(I,J)	Free	Monthly/ ten daily hydropower demand in M Kwh
Endif			
9	SMAX(I) SMIN(I) STOR(I,1) NN(I) IDP(I)	Free Free Free Free Free	Gross capacity up to FRL (m^3) Gross capacity up to intake of WS outlet (m^3) Initial reservoir storage (m^3) Number of points in Elevation-area-capacity table. NN=0 for non-reservoir locations like weirs & barrage. A flag controlling simulation table printing: =1 for annual summary of simulation. =2 for detailed simulation table in output file =0 for no simulation table.(only performance indices)
10 on wards Next line	ELEV(I,J) AREA (I,J) CAP(I,J) INFL FAC(I)	Free Free Free Free Free	Elevation in the Elevation – Area – Capacity table (m) Corresponding area in Million sq.m. Corresponding Capacity in Million cu.m. A flag for reading / calculating local inflows. =1 If inflow data of present location is to be read. =2 If inflow data of present location is to be computed from the inflow data of some other location. Multiplication factor to convert inflow values in cu.m.

	IDDP(I)	Free	Node number of the downstream location whose partial demands are to be satisfied by the present location
	RTEF(I)	Free	Return flow expressed as fraction of the irrigation releases from the present location that will join the downstream location.
	ILIN(I)	Free	A factor for specifying link diversion from the control point =1 in case of link diversion from the node =0 in case no link from the node
	IGET(I)	Free	node number from where link water is received in the current node. = 0 in case no link to this node
	CL(I)	Free	% of link diversion that reaches the receiving node from the current node.
Next line	DFC(I,J)	Free	% of the downstream location demands to be satisfied
Next line	RDMD1 (I,J)	Free	Irrigation demand from a canal (LBC or RBC) which passes through the power house (if applicable) in M cum (either monthly or ten daily) starting from January. If there is no power house or all irrigation demand (LBC+RBC) passes through powerhouse, then this represents total irrigation demand (LBC+RBC).
Next line	RDMD2 (I,J)	Free	Irrigation demand from a canal which does not pass through the power house (if applicable) in M cum (either monthly or ten daily) starting from January. If there is no power house or all irrigation demand (LBC+RBC) passes through powerhouse, then this represents zero (0) irrigation demand.
Next line	WDMD (I,J)	Free	Total domestic and industrial water supply demand in Million cu.m (either monthly or ten daily) starting from January.
Next line	AMFLO (I,J)	Free	Minimum flow demand in the downstream channel in M.cu.m .
Next line	RULE(I,J)	Free	Upper rule levels in metre (either monthly or ten daily) starting from January.

	AIL(I,J)	Free	First middle rule level critical for irrigation or hydropower demands (depending on priority) in metre (either monthly or ten daily) starting from January.
If both irrigation and hydro power are to be served, then			
Next line	POL(I,J)	Free	Second middle rule level critical for irrigation or hydropower demands (depending on priority) in metre (either monthly or ten daily) starting from January.
Endif			
Next line	WPL(I,J)	Free	Lower rule levels critical for water supply and minimum flow demands in metre (either monthly or ten daily) starting from January.
Next line	EVPD(I,J)	Free	Evaporation depth in metre (either monthly or ten daily) starting from January.
Next line	DDM(I,J) (if link diversion is there)	Free	Monthly / Ten daily link demands starting from January.
Next line	DLEV(I,J)	Free	Levels in metre critical for link diversion starting from January.
Next line on wards	FLOW(I,J)		Inflow values at the location in Million cu.m for all the periods of record (either monthly or ten daily). If INFL ≠1, then node number of the location whose Inflow data is to be used for calculating the inflows at the present node must be specified here.

NOTE:

a) Data for each structure is read one by one. First, entire data of a location point is entered and then input for next location is taken up.

b) Before entering the name of a subsequent structure, a blank line is a must

c) For each variable, except for FLOW (I, J), ELEV (I, J), AREA (I,J), and CAP(I,J), the index (I) refers to the structure while the index (J) refers to the period of operation of a water year. For variable FLOW (I, J), (I) represents the same as above but the index (J) refers to the total period of operation and is equal to NMON*IFMON. Similarly for variables ELEV(I,J), AREA(I,J) and CAP(I,J), J is equal to NN(I)

SAMPLE INPUT DATA FILE

```
Monthly Reservoir Simulation of Krishna Basin System
6  6  1951  360  1
Almatti Reservoir 1

1  0  4  1.00  1.00  0.75  0
297.0  492.25   504.88   0.85
0  0  0  0  0  0  0  0  0  0  0  0
24.12  24.12  0  0  0  24.12  24.12  24.12  24.12  24.12  24.12  24.12

3485.0E+06   352.840E+06  352.840E+06   51   2
  504.575    57.820      334.72
  504.880    61.156      352.84
  ...Intermediate Data Deleted......
  519.510    488.096    3438.50

  519.600    493.510    3485.00

1  1000000   2   0  1  0  0.91
0  0  0.81  0  0  0  0  0  0  0  0  0

36.000  19.000  5.000  0.00  0.00  17.000  47.000  35.000  21.000  14.000
24.000  40.000  Alm_DEMAND
0.00    0.00    0.00   0.00   0.00   0.00    0.00   0.00   0.00   0.00
0.00    0.00    RDMD2_DEMAND
0.00    0.00    0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00    0.00    WS_DEMAND
12.7    12.7    12.7   12.7   12.7   12.7   12.7   12.7   12.7   12.7
12.7    12.7    MIN_FLOW

519.60  519.60  519.60  519.60  519.60  519.60  519.60  519.60  519.60  519.60
519.60  519.60  UPPER RULE CURVE
504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88
504.88  504.88  First Middle RULE CURVE
504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88
504.88  504.88  Second Middle RULE CURVE
504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88
504.88  504.88  Lower RULE CURVE

0.1087  0.1229  0.1654  0.1803  0.1974  0.1565  0.1374  0.1346  0.1244  0.1231
0.1023  0.0965  EVAP_DEPTH

223.00  172.00  0.00  0.00   0.00   73.00   297.00  297.00  297.00  279.00
163.00  239.00  LINK_DEMAND from Almatti
504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88  504.88
504.88  504.88  LINK RULE CURVE

                                   679.0  3312.0  4234.0  1271.0  467.0  125.0  25.0
4.0    2.0    3.0    5.0    5.0    925.0  4512.0  5768.0  1731.0  636.0  170.0  35.0
.............................. Intermediate Data Deleted..............................
0.0    0.0    0.0    0.0    0.0   1317.0  6477.0  7128.0  1554.0  220.0   61.0   0.0
0.0    0.0    0.0    0.0    0.0
```

SAMPLE OUTPUT FILE
(i) ANNUAL ABSTRACT OF SIMULATION

```
          RESULTS FOR LOCATION NO.  1 -   Almatti Reservoir
 At this node, Flow for no demand goes through the power plant
 A link diverts water from this node
□
 Water supply demands at this node (m m3)
    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 Link demands at this node (m m3)
 223.00 172.00    .00    .00    .00  73.00 297.00 297.00 297.00 279.00 163.00 239.00
```

YYYY	Loc_Flo	Evapr	Tir_Dem	Pw_Dem	Tds_Dem	Ir_Rel	Ws_Rel	Tot_Rel	Pw_Gen	PW-Rel	Lin_Dv	Spill
	m m3	m m3	m m3	m m3	m m3	m m3	m m3	m m3	Mkwh	m m3	m m3	m m3
1952	10132.	372.	258.0	4491.	222.	258.0	0.	7805.	409.	7547.	1967.	0.
1953	13803.	425.	258.0	4319.	222.	258.0	0.	9147.	493.	8889.	2035.	1962.
1954	20706.	479.	258.0	3935.	222.	258.0	0.	12841.	730.	12583.	2040.	5090.
1955	15142.	462.	258.0	3952.	222.	258.0	0.	10272.	579.	10014.	2040.	2521.
1956	18457.	475.	258.0	3934.	222.	258.0	0.	11923.	676.	11665.	2040.	3906.
Intermediate Data Deleted												
1979	15459.	422.	258.0	4058.	222.	253.0	0.	11107.	637.	10854.	1950.	2426.
1980	17062.	443.	258.0	4293.	222.	258.0	0.	9331.	507.	9073.	2040.	4743.
1981	16757.	391.	258.0	4218.	222.	253.0	0.	11409.	637.	11156.	1868.	3596.

```
Number of Failures for Irr.  =   6, Time and Vol. Reliability =   .980   .994

Number of Critical (Release <  .75 * Demand) Irrigation Failures =   6
Annual Irrigation Reliability    =   .833

Number of Failures for Pow.  =   7, Time and Vol. Reliability =   .974   .976

Link time and vol. reliabilities =    .972    .982

Resi. for WS, Irr, Pow:   .000   .833  1.000
Vul.  for WS, Irr, Pow:   .000   .992   .434
```

Annexure II(contd)

(ii) DETAILED MONTHLY SIMULATION TABLE

RESULTS FOR LOCATION NO. 1 - Almatti Reservoir

□

At this node, Flow for no demand goes through the power plant

□

A link diverts water from this node

□

Water supply demands at this node (m m3)

□

.00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00

Link demands at this node (m m3)

223.00 172.00 .00 .00 .00 73.00 297.00 297.00 297.00 279.00 163.00 239.00

YYYY-Mn-D	Ini_Sto m m3	Loc_Flo m m3	Evapr m m3	Tir_Dem m m3	Pw_Dem m m3	Tds_Dem m m3	Ir_Rel m m3	Ws_Rel m m3	Tot_Rel m m3	Pw_Gen MKwh	PW-Rel m m3	Lin_Dv m m3	Spill m m3	End_Lev m	Mdl_Rul m	Upr_Rul m
1951-06-0	352.8	679.0	9.6	17.0	832.2	12.7	17.0	.0	669.4	18.9P	652.4	.0L	0.	504.88	504.88	519.60
1951-07-0	352.8	3312.0	31.6	47.0	548.7	12.7	47.0	.0	595.7	24.1	548.7	297.0	0.	517.93	504.88	519.60
1951-08-0	2740.6	4234.0	60.0	35.0	396.4	12.7	35.0	.0	3132.6	188.5	3097.6	297.0	0.	519.60	504.88	519.60
1951-09-0	3485.0	1271.0	61.4	21.0	384.3	12.7	21.0	.0	912.6	56.0	891.6	297.0	0.	519.60	504.88	519.60
1951-10-0	3485.0	467.0	58.7	14.0	388.4	12.7	14.0	.0	402.4	24.1	388.4	279.0	0.	519.03	504.88	519.60
1951-11-0	3212.0	125.0	43.6	24.0	401.4	12.7	24.0	.0	425.4	24.1	401.4	163.0	0.	517.84	504.88	519.60
1951-12-0	2705.0	25.0	33.0	40.0	428.3	12.7	40.0	.0	468.3	24.1	428.3	239.0	0.	515.74	504.88	519.60
1952-01-0	1989.7	4.0	25.7	36.0	481.9	12.7	36.0	.0	517.9	24.1	481.9	223.0	0.	512.38	504.88	519.60
1952-02-0	1227.0	2.0	15.5	19.0	629.8	12.7	19.0	.0	648.8	24.1	629.8	172.0	0.	505.50	504.88	519.60
1952-03-0	392.8	3.0	10.7	5.0	.0	82.4	5.0	.0	32.2C	.8	27.2	.0	0.	504.88	504.88	519.60
1952-04-0	352.8	5.0	10.9	.0	.0	12.7	.0	.0	.0C	.0	.0	.0	0.	504.78	504.88	519.60
1952-05-0	346.9	5.0	11.7	.0	.0	12.7	.0	.0	.0C	.0	.0	.0	0.	504.67	504.88	519.60
1952		10132.	372.	258.0	4491.	222.	258.0	0.	7805.	409.	7547.	1967.	0.			

```
C        Simulation of a Multipurpose Multireservoir System For Conservation
C        *******************************************************************
      include 'fgraph.fi'
      include 'fgraph.fd'

      CHARACTER*20 Infile, outfile
      character name*20, Titl*60
      parameter(l1=15,l2=400)

      common/conf/icp(l1), icp1(l1), icp2(l1,l1), name(l1), icon(l1),
     1   iprio(l1,36), trelir, tpgen, fir(l1)

      common/res/smax(l1), smin(l1), nn(l1), elev(l1,150), retf(l1),
     1  area(l1,150), cap(l1,150), fac(l1),iddp(l1),dfc(l1,l2),trel(l1),
     2  plmin(l1), etail(l1), eff(l1), pinst(l1), ifail(l1),
     3  ifaiw(l1), ifaic(l1), amf(l1,36), fpow(l1), fcri(l1),
     4  tri(l1), trw(l1), trp(l1), tdi(l1), tdw(l1), tdp(l1)

      common/op1/rule(l1,36), evpd(l1,36), rdmd1(l1,36), ail(l1,36),
     1   wpl(l1,36), wdmd(l1,36), pow(l1,36), tddm(l1,36), pol(l1,36)

      common/op2/flow(l1,l2), stor(l1,l2), rel(l1,l2), elos(l1,l2),
     1   rflo(l1,l2), spil(l1,l2), pgen(l1,l2), tdem(l1,l2),endl(l1,l2),
     2   relir(l1,l2),rspil(l1,l2), relws(l1,l2), rdmd2(l1,36),pf(l1,l2)
     3   , pdm(l1,l2)
      common/li/dive(l1,l2), ddm(l1,36),dlev(l1,36), ilin(l1),iget(l1)
     1   , lfa(l1), vli(l1), tld(l1), cl(l1)
      common/pri/iyr(0:l2), imon(0:l2), iday(0:l2), idp(l1), nloc,
     1   nmon, ifmon

      call getarg(1, INFILE, stat)
      call getarg(2, OUTFILE, stat)

      OPEN(1,FILE=Infile,STATUS='OLD')
      OPEN(2,FILE=Outfile)

      read(1,1) Titl
      write(2,1) Titl
      read(1,*) nloc, imon(1), iyr(1), nmon, ifmon
      i12 = 12
      iday(1) = 1
      if(ifmon.eq.3) then
        nmon = nmon * 3
        i12 = 36
      endif

c***     Data related to Configuration
      do 17 i = 1, nloc
       read(1,2) name(i)
2        format(/a)
       read(1,*) icp(i), icp1(i), icon(i), fir(i), fpow(i), fcri(i),
     1      (icp2(i,j),j=1,icp1(i))
       if(icon(i).eq.0) then
         do j = 1, i12
           iprio(i,j) = 0
         enddo
       endif
       write(*,3) icp(i), name(i)
3        format(/' Location No.'i3', ',a)
```

```
      write(2,3) icp(i), name(i)
      if(icp1(i).gt.0) Write(2,5)  (icp2(i,j),j=1,icp1(i))
5       format(' Just Upstream Location Number(s) ='10i4)

c***     Data related to Hydropower plant
      if(icon(i).gt.0) then
        read(1,*)  pinst(i), etail(i), plmin(i), eff(i)
        pinst(i) = pinst(i) * 1000000
        read(1,*) (iprio(i,j), j = 1, i12)
        read(1,*) (pow(i,j), j = 1, i12)
        do j = 1, i12
          pow(i,j) = pow(i,j) * 1000000    ! Power converted in Kwh
        enddo
      endif

c***     Storage details of the structure
      read(1,*) smax(i), smin(i), stor(i,1), nn(i), idp(i)
      write(*,'(''   Stor OK   '',$)')
      write(2,7) smax(i), smin(i), stor(i,1)
7       format(' Max. Storage    ='e10.3' Cubic m,'/' Dead Storage
     1    '='E10.3' Cubic m,'/' Initial Storage ='e10.3' Cubic m')
      if(nn(i).gt.0) then
       do j = 1, nn(i)
          read(1,*) elev(i,j), area(i,j), cap(i,j)
        area(i,j) = area(i,j) * 10**6
        cap(i,j)  = cap(i,j) * 10**6
       enddo
       write(*,'('' EAC-Table  OK   '',$)')
      endif

      read(1,*) infl, fac(i), iddp(i), retf(i), ilin(i),iget(i),cl(i)
      read(1,*) (dfc(i,j),j=1,12)
      if(nn(i).gt.0.and.icon(i).gt.0) write(2,14) pinst(i)/1000000
14      format(' Installed Capacity of Power Plant = 'f7.1' MW')
      if(infl.eq.1) write(2,13) fac(i)
13      format(' Multiplication factor for inflows ='E9.3)
      read(1,*) (rdmd1(i,j),j=1,i12)
      read(1,*) (rdmd2(i,j),j=1,i12)
      write(*,'(''  Irr Demd OK   '',$)')
      if(nn(i).gt.0) then
       read(1,*) (wdmd(i,j),j=1,i12)
       read(1,*) (amf(i,j),j=1,i12)
       read(1,*) (rule(i,j),j=1,i12)
       read(1,*) ( ail(i,j),j=1,i12)
       if(icon(i).gt.0) read(1,*) (pol (i,j),j=1,i12)
       read(1,*) ( Wpl(i,j),j=1,i12)
       read(1,*) (evpd(i,j),j=1,i12)
       write(*,'('' Evpd  OK   '',$)')
       write(2,*) ' Evaporation depths (m/month) at node ', i
       write(2,29) (evpd(i,j),j=1,i12)
      endif
29    format(12f6.3)

     if(ilin(i).eq.1) then
      read(1,*) (ddm (i,j),j=1,i12)
      read(1,*) (dlev(i,j),j=1,i12)
     endif

      do j = 1, i12
```

```
        rdmd1(i,j) = rdmd1(i,j) * 1000000
        rdmd2(i,j) = rdmd2(i,j) * 1000000
        wdmd(i,j)  = wdmd(i,j) * 1000000
        amf(i,j)   = amf(i,j) * 1000000
        ddm(i,j)   = ddm(i,j) * 1000000
       enddo

       if(infl.eq.1) then
         read(1,*) (flow(i,j), j = 1, nmon)
         do j = 1, nmon
          flow(i,j) = flow(i,j) * fac(i)
         enddo
        else
         read(1,*) inod
         write(2,15) inod, fac(i)
15         format(' Flow at this node = Flow at node'i3' * 'f5.2)
         do j = 1, nmon
          flow(i,j) = flow(inod,j) * fac(i)
         enddo
       endif
       if(iddp(i).gt.0) write(2,11) dfc(i,1)*100, iddp(i)
11       format(' This node is also operated to meet ',f5.2'... '
     1    '% demand of location'i3)
       write(*,'(''  Flow  OK '')')
17      continue

c***    Simulate the system operation
      write(*,19)
19      format(/' SIMULATION BEGINS ***'/)

c***    Calculation of Year, Month and period of operation
      imon(0) = imon(1) - 1
      iyr(0) = iyr(1)
      iday(0) = iday(1) - 1
      if(ifmon.eq.3) imon(0) = imon(1)
      do 21 j = 1, nmon
       if(ifmon.eq.3) then
         iday(j) = iday(j-1) + 1
         imon(j) = imon(j-1)
         iyr(j) = iyr(j-1)
         if(iday(j).gt.3) then
           imon(j) = imon(j) + 1
           iday(j) = 1
         endif
         if(imon(j).gt.12) then
           iyr(j) = iyr(j)+1
           imon(j) = 1
         endif
        else
         imon(j) = imon(j-1) + 1
         iyr (j) = iyr(j-1)
         if(imon(j).gt.12) then
           iyr(j) = iyr(j) + 1
           imon(j) = 1
         endif
       endif
c      write(*,'(''+   Simulating for''i5,i7,i5)') j, iyr(j), imon(j)

c***    Simulate location i for period j
```

```
      do 21 i = 1, nloc
       call oper(i,j)
21     continue

C****   Output of results
      call result
      endif
      end

      subroutine oper(i,jm)
      character name*20
      parameter(l1=15,l2=400)

      common/conf/icp(l1), icp1(l1), icp2(l1,l1), name(l1), icon(l1),
     1   iprio(l1,36), trelir, tpgen, fir(l1)

      common/res/smax(l1), smin(l1), nn(l1), elev(l1,150), retf(l1),
     1  area(l1,150), cap(l1,150), fac(l1),iddp(l1),dfc(l1,12),trel(l1),
     2  plmin(l1), etail(l1), eff(l1), pinst(l1), ifail(l1),
     3  ifaiw(l1), ifaic(l1), amf(l1,36), fpow(l1), fcri(l1),
     4  tri(l1), trw(l1), trp(l1), tdi(l1), tdw(l1), tdp(l1)

      common/op1/rule(l1,36), evpd(l1,36), rdmd1(l1,36), ail(l1,36),
     1   wpl(l1,36), wdmd(l1,36), pow(l1,36), tddm(l1,36), pol(l1,36)

      common/op2/flow(l1,l2), stor(l1,l2), rel(l1,l2), elos(l1,l2),
     1   rflo(l1,l2), spil(l1,l2), pgen(l1,l2), tdem(l1,l2),endl(l1,l2),
     2   relir(l1,l2),rspil(l1,l2), relws(l1,l2), rdmd2(l1,36),pf(l1,l2)
     3   , pdm(l1,l2)

      common/li/dive(l1,l2), ddm(l1,36),dlev(l1,36), ilin(l1),iget(l1)
     1   , lfa(l1), vli(l1), tld(l1), cl(l1)

      common/pri/iyr(0:12), imon(0:12), iday(0:12), idp(l1), nloc,
     1   nmon, ifmon

      jc=imon(jm)
      if(ifmon.eq.3) jc = (imon(jm)-1) * 3 + iday(jm)
      rdmd = rdmd1(i,jc) + rdmd2(i,jc)     ! Lft bank & Rt bank canals

      if(icp1(i).eq.0) then
        rflo(i,jm) = 0
       else
        do k = 1, icp1(i)
         ii = icp2(i,k)
         dsf = 0
         dsf = rel(ii,jm) -relir(ii,jm)-relws(ii,jm)
         rflo(i,jm) = rflo(i,jm) + dsf
     1     + retf(ii) * relir(ii,jm) + spil(ii,jm)
        enddo
      endif
      if(iget(i).gt.0) rflo(i,jm) = rflo(i,jm) + dive(iget(i),jm)
     1   *cl(iget(i))

      if(nn(i).eq.0) then
        tdem(i,jm) = rdmd
        tavfl = flow(i,jm) + rflo(i,jm) + stor(i,jm)
        rel(i,jm) = amin1(tavfl, rdmd)
        def = rdmd - rel(i,jm)
```

```fortran
        if(dfc(i,jc).eq.100.and.def.gt.0) then
         ii = icp2(i,1)
         sirl = fint(elev,cap,ail(ii,jc),nn(ii),ii)
         if(stor(ii,jm+1).gt.sirl) then
          def = amin1(def, stor(ii,jm+1) - sirl)
          stor(ii,jm+1) = stor(ii,jm+1) - def
          endl(ii,jm) = fint(cap,elev,stor(ii,jm+1),nn(ii),ii)
          bll = fint(cap,elev,stor(ii,jm),nn(ii),ii)
          rel(ii,jm) = rel(ii,jm) + def
          rel (i,jm) = rel( i,jm) + def
          rflo(i,jm) = rflo(i,jm) + def
          tavfl = tavfl + def
          effh = ((endl(ii,jm) + bll)/2. - etail(ii)) * 0.99
          pfl = 0
          if(icon(ii).eq.1) pfl = rel(ii,jm)
          if(icon(ii).eq.3) pfl = rel(ii,jm) - relws(ii,jm)
          if(icon(ii).eq.2) pfl = rel(ii,jm) - relir(ii,jm)
          if(icon(ii).eq.4) pfl = rel(ii,jm)-relir(ii,jm)-relws(ii,jm)
          if(pfl.lt.0) pfl = 0.
          pgen(ii,jm) = 9.817*effh*pfl*eff(ii)/3600*ifmon
          if(pgen(ii,jm).ge.pinst(ii)*0.72/ifmon) then
            pgen(ii,jm) = pinst(ii) * 0.72/ifmon
            pfl = pgen(ii,jm)*3600*ifmon/(9.817*effh*eff(ii))
          endif
          pf(ii,jm) = pfl
         endif
        endif
        reli = rel(i,jm)
        relw = 0.0
        stor(i,jm+1) = amin1(smax(i), (tavfl - rel(i,jm)))
        spil(i,jm) = amax1((tavfl-rel(i,jm)-smax(i)),0.0)
        go to 103
      endif

c***    Operation for Storage Structure
      it = 0
      supl = fint(elev,cap,rule(i,jc),nn(i),i)
      if(supl.gt.smax(i)) supl = smax(i)
      sirl = fint(elev,cap,ail(i,jc),nn(i),i)
      if(icon(i).gt.0) spwl = fint(elev,cap,pol(i,jc),nn(i),i)
      swsl = fint(elev,cap,wpl(i,jc),nn(i),i)
      ari = fint(cap,area,stor(i,jm),nn(i),i)
      eli = fint(cap,elev,stor(i,jm),nn(i),i)
      arf = ari
      elf = eli
      stf = stor(i,jm)
      amean = (ari+arf)/2.0
      elos(i,jm) = amean * evpd(i,jc)/ifmon
      stinf = stor(i,jm) + flow(i,jm) + rflo(i,jm)
      if(iprio(i,jc).eq.0) apl = ail(i,jc)
      if(iprio(i,jc).eq.1) apl = pol(i,jc)

      tddm(i,jc) = amf(i,jc)
      if(iddp(i).gt.0) tddm(i,jc) = (rdmd1(iddp(i),jc) +
     1   rdmd2(iddp(i),jc) + Wdmd(iddp(i),jc)) * dfc(i,jc) + amf(i,jc)

101     it = it + 1
      avl = (eli + elf)/2
      if(icon(i).eq.0) then
```

```
      tdem(i,jm) = rdmd + wdmd(i,jc) + tddm(i,jc)
      pdmd = 0.0
     else
      effh = ( avl - etail(i)) * 0.99
      pdmd = (pow(i,jc)/(9.817*effh*eff(i))) * 3600/ifmon
      pdm(i,jm) = pdmd
      if( pdmd.lt.tddm(i,jc) )      pdmd = tddm(i,jc)

      if(icon(i).eq.1) tdem(i,jm) =                  !All rel thru plant
   1        amax1(pdmd, rdmd + Wdmd(i,jc) + tddm(i,jc) )

      if(icon(i).eq.2) then                          !Ws+Min flow thru pt
        if(pdmd.gt.(tddm(i,jc)+wdmd(i,jc))) then
          tdem(i,jm) = pdmd + rdmd
         else
          tdem(i,jm) = tddm(i,jc) + rdmd + Wdmd(i,jc)
        endif
      endif

      if(icon(i).eq.3) then
        if(pdmd.gt.(tddm(i,jc) + rdmd )) then
          tdem(i,jm) = pdmd + wdmd(i,jc)
         else
          tdem(i,jm) = tddm(i,jc) + rdmd + Wdmd(i,jc)
        endif
      endif

      if(icon(i).eq.4) then                          !only min thru pt
        if(pdmd.ge.tddm(i,jc)) then
            tdem(i,jm) = pdmd + rdmd + Wdmd(i,jc)
         else
          tdem(i,jm) = tddm(i,jc) + rdmd + wdmd(i,jc)
        endif
      endif
    endif

    if(avl.ge.apl) then
     rel(i,jm) = tdem(i,jm)
     stor(i,jm+1) = stinf - rel(i,jm) - elos(i,jm)
    endif

    if(iprio(i,jc).eq.0.and.avl.lt.ail(i,jc)) then ! Irr. Higher Prio.
     rel1 = stinf - elos(i,jm) - sirl
     if(rel1.lt.0) rel1 = 0
     if(icon(i).eq.0) rel2 = (rdmd+tddm(i,jc)-amf(i,jc))*fir(i)
   1    +amf(i,jc)+wdmd(i,jc)
       if(icon(i).eq.1) then
        if(pdmd.gt.(rdmd +wdmd(i,jc)+tddm(i,jc))) then
          rel2 = Amin1(rdmd+wdmd(i,jc)+tddm(i,jc),pdmd * fpow(i))
        else
         rel2 = wdmd(i,jc) + (tddm(i,jc) + rdmd) *fir(i)
        endif
      endif
      if(icon(i).eq.2) then
        if(pdmd.gt.(wdmd(i,jc)+tddm(i,jc))) then
            rel2 = pdmd * fpow(i) + rdmd
        else
            rel2 = wdmd(i,jc) + (tddm(i,jc) + rdmd)* fir(i)
        endif
```

```
      endif
      if(icon(i).eq.3) then
        if(pdmd.gt.(rdmd + tddm(i,jc))) then
          rel2 = pdmd * fpow(i) + wdmd(i,jc) + rdmd2(i,jc)
        else
          rel2 = amax1((pdmd*fpow(i)+wdmd(i,jc)),(rdmd*fir(i) +
     1          wdmd(i,jc) + tddm(i,jc)))
        endif
      endif
      if(icon(i).eq.4) then
        if(pdmd.gt.tddm(i,jc)) then
          rel2 = pdmd * fpow(i) + wdmd(i,jc) + rdmd*fir(i)
        else
          rel2 = tddm(i,jc) + wdmd(i,jc) + rdmd*fir(i)
        endif
      endif
      rel(i,jm) = amin1(rel1, rel2)
      stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
      elf = fint(cap,elev,stor(i,jm+1),nn(i),i)
      if(stor(i,jm+1).gt.swsl.and.rel(i,jm).lt.wdmd(i,jc)) then
       rel1 = stinf - elos(i,jm) - swsl
       relw = amin1(wdmd(i,jc),rel1)
       rel(i,jm) = amax1(relw, rel(i,jm))
       stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
      endif
     endif

    if(iprio(i,jc).eq.1.and.avl.lt.pol(i,jc)) then
      rel1 = (stinf - elos(i,jm) - spwl)*0.999999
      if(rel1.lt.0) rel1 = 0

      if(icon(i).eq.1) then
        if(wdmd(i,jc)+tddm(i,jc)+rdmd.ge.pdmd) then
          rel2 = amax1(pdmd, wdmd(i,jc) + tddm(i,jc))
        else
          rel2 = amax1(pdmd*fpow(i), wdmd(i,jc)+amf(i,jc))
        endif
      endif
      if(icon(i).eq.2) then
        if(wdmd(i,jc)+tddm(i,jc).ge.pdmd) then
          rel2 = pdmd ! wdmd(i,jc) + tddm(i,jc)
        else
          rel2 = amax1(pdmd*fpow(i), wdmd(i,jc) + amf(i,jc))
        endif
      endif
      if(icon(i).eq.3) then
        if(rdmd+tddm(i,jc).ge.pdmd) then
          rel2 = pdmd  !amax1(pdmd, wdmd(i,jc) + amf(i,jc))
        else
          rel2 = amax1(pdmd*fpow(i), tddm(i,jc) + rdmd*fir(i))
        endif
      endif
      if(icon(i).eq.4) then
        if(tddm(i,jc).ge.pdmd) then
          rel2 = amin1(pdmd*fpow(i), wdmd(i,jc) + tddm(i,jc))
        else
          rel2 = amax1(pdmd*fpow(i), wdmd(i,jc) + tddm(i,jc))
        endif
      endif
```

```
    rel(i,jm) = amin1(rel1, rel2)
    relw = amin1(wdmd(i,jc), rel(i,jm))
    stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
    reli = amax1( rel(i,jm) - amf(i,jc) -relw - pdmd*fpow(i), 0. )
   endif

   if(iprio(i,jc).eq.1.and.avl.lt.ail(i,jc)) then
     if(icon(i).eq.2)
1            reli = amax1(rel(i,jm) - amf(i,jc) - wdmd(i,jc)-
1          (pdmd-amf(i,jc) - wdmd(i,jc))*fpow(i), 0.)
     if(icon(i).eq.4)
1            reli = amax1(rel(i,jm) - amf(i,jc) - wdmd(i,jc) -
1         (pdmd-amf(i,jc))*fpow(i), 0.)
       rel1 = amin1(rdmd*fir(i), reli)
       if(reli-rel1.gt.0) rel(i,jm) = rel(i,jm) -(reli - rel1)
       reli = rel1
       stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
       if(stor(i,jm+1).gt.sirl.and.rdmd.gt.0.and.reli.lt.rdmd)then
        dr = stor(i,jm+1) - sirl !ending higher, can make more rel
        rel1 = reli + dr
        if(rel1.gt.rdmd) rel1 = rdmd
        rel(i,jm) = rel(i,jm) + rel1 - reli
        reli = rel1
        stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
       endif
   endif

   if(iprio(i,jc).eq.1.and.stor(i,jm+1).lt.sirl.and.rdmd.gt.0)then
     rel1 = sirl - stor(i,jm+1)
     rel2 = amin1(rel1, rdmd)  !wdmd(i,jc)+amf(i,jc))
     rel(i,jm) = rel(i,jm) - rel2
     if(rel(i,jm).lt.0) rel(i,jm) = 0
     stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
   endif

   if(iprio(i,jc).eq.0.and.stor(i,jm+1).lt.sirl.and.rdmd.gt.0
1       .and.rel(i,jm).gt.0) then
    rel1 = (stinf - elos(i,jm) - sirl)
    if(rel1.lt.0) rel1 = 0
    rel2 = amin1(rdmd*fir(i), rel1)
    reli = amax1(rel(i,jm) - wdmd(i,jc) - amf(i,jc), 0.)
    dr = amax1(reli -rel2,0.)
    if(dr.lt.0) dr = 0
    rel(i,jm) = rel(i,jm) - dr
    stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
    if(stor(i,jm+1).gt.sirl.and.rel(i,jm).lt.tdem(i,jm)) then
     dr = amin1(stor(i,jm+1) - sirl, tdem(i,jm) - rel(i,jm))
     rel(i,jm) = rel(i,jm) + dr
    endif
   endif

  if(avl.lt.wpl(i,jc).and.wdmd(i,jc).gt.0.and.rel(i,jm).lt.
1     wdmd(i,jc)) then
    rel(i,jm) = wdmd(i,jc) + amf(i,jc)
    reli = 0.0
    relw = wdmd(i,jc)
    if(wdmd(i,jc).eq.0) rel(i,jm) = amf(i,jc)
    stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
    if(avl.gt.wpl(i,jc)) then
```

```
          if(iprio(i,jc).eq.0) edem = rdmd + wdmd(i,jc) + amf(i,jc)
          if(iprio(i,jc).eq.1) edem = pdmd + wdmd(i,jc) + amf(i,jc)
          rel(i,jm) = amin1(edem, stinf - elos(i,jm) - swsl)
          relw = wdmd(i,jc)
          stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)
          if(iprio(i,jc).eq.0) reli = rel(i,jm) - relw - amf(i,jc)
          if(reli.lt.0) reli = 0
          if(iprio(i,jc).eq.1) pfl = rel(i,jm) - relw
          if(pfl.lt.0) pfl = 0
         endif
      endif
      stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm)

      dst = fint(elev,cap,dlev(i,jc),nn(i),i)
      if(ilin(i).gt.0.and.stor(i,jm+1).gt.dst) then
       d1 = 0
       if(rel(i,jm).gt.tdem(i,jm)) then
        d1 = amin1(rel(i,jm) - tdem(i,jm), ddm(i,jc))
        rel(i,jm) = rel(i,jm) - d1
       endif
       if(d1.lt.ddm(i,jc).and.stor(i,jm+1).gt.dst) then
        dr = amin1(stor(i,jm+1)-dst,ddm(i,jc)-d1) !dive(i,jm))
        d1 = d1 + dr
        stor(i,jm+1) = stor(i,jm+1) - dr
       endif
       dive(i,jm) = d1
c      stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm) - dive(i,jm)
       if(stor(i,jm+1).lt.smin(i).and.dive(i,jm).gt.0) then
        dr1 = stinf - smin(i) - rel(i,jm) - elos(i,jm)
        if(dr1.lt.0) dr1 = 0
        stor(i,jm+1) = smin(i)
        dive(i,jm) = dive(i,jm) - dr1
       endif
      endif

      if(stor(i,jm+1).lt.smin(i).and.rel(i,jm).gt.0) then
        stor(i,jm+1) = smin(i)
        if(elos(i,jm).ge.stinf) then
          elos(i,jm) = stinf
          stor(i,jm+1) = 0.0
        endif
        rel2 = stinf - elos(i,jm) - stor(i,jm+1)
        if(rel2.lt.0) then
         rel2 = 0.0
         dive(i,jm) = 0
        endif
        rel(i,jm) = rel2
      endif

      if(stor(i,jm+1).gt.supl) then
        stor(i,jm+1) = supl
        rel(i,jm) = stinf - elos(i,jm) - stor(i,jm+1) - dive(i,jm)
      endif

      arf = fint(elev,area,elf,nn(i),i)
      elos(i,jm) = (ari+arf)/2.0 * evpd(i,jc)/ifmon
      stor(i,jm+1) = stinf - elos(i,jm) - rel(i,jm) - dive(i,jm)
      endl(i,jm) = fint(cap,elev,stor(i,jm+1),nn(i),i)
      if(abs(stf - stor(i,jm+1)).lt.1.0.or.it.gt.80) go to 103
```

```
      if(endl(i,jm).gt.elf) elf = elf + abs(endl(i,jm) - elf)*0.15
      if(endl(i,jm).lt.elf) elf = elf - abs(endl(i,jm) - elf)*0.15
      stf = stor(i,jm+1)
      go to 101
103   elf = endl(i,jm)
      avl = (eli + elf)/2.

      reli = 0
      wata = rel(i,jm)
      relw = amin1(wata, wdmd(i,jc))
      wata = wata - relw
      if(wata.gt.0) then
       am = amin1(wata, amf(i,jc))
       wata = wata - am
      endif
      if(wata.gt.0.and.iprio(i,jc).eq.0) then
        if(avl.ge.ail(i,jc)) reli = amin1(wata, rdmd)
        if(avl.lt.ail(i,jc)) reli = amin1(wata, rdmd*fir(i))
        wata = wata - reli
      endif

      if(wata.gt.0.and.iprio(i,jc).eq.1) then
        if(avl.ge.pol(i,jc)) pfl = amin1(wata, amax1(pdmd-am,0.))
        if(avl.lt.pol(i,jc)) pfl = amin1(wata, amax1(pdmd*fpow(i)
     1      -am,0.))
        wata = wata - pfl
        if(wata.gt.0) then
         if(avl.ge.ail(i,jc)) reli = amin1(wata,rdmd)
         if(avl.lt.ail(i,jc)) reli = amin1(wata,rdmd*fir(i))
         if(elf.gt.ail(i,jc)-0.002) reli = amin1(wata,rdmd)
        endif
      endif

      pfl = 0
      if(icon(i).gt.0.and.nn(i).gt.0) then
        effh = ((eli + elf)/2. - etail(i)) * 0.99
        if(icon(i).eq.1) pfl = rel(i,jm)
        if(icon(i).eq.3) pfl = rel(i,jm) - relw
        if(icon(i).eq.2) pfl = rel(i,jm) - reli
        if(icon(i).eq.4) pfl = rel(i,jm) - reli - relw
        if(pfl.lt.0) pfl = 0.
        pgen(i,jm) = 9.817*effh*pfl*eff(i)/3600*ifmon
        if(pgen(i,jm).ge.pinst(i)*0.72/ifmon) then
          pgen(i,jm) = pinst(i) * 0.72/ifmon
          pfl = pgen(i,jm)*3600*ifmon/(9.817*effh*eff(i))
        endif
        pf(i,jm) = pfl
      endif

c****   Calculation of Release and Spill
      if(nn(i).gt.0) then
        rspil(i,jm) = 0
        spil(i,jm) = 0
        if(rel(i,jm).gt.tdem(i,jm)) then
          if(icon(i).eq.0) spil(i,jm) = rel(i,jm) - tdem(i,jm)
          if(icon(i).eq.1) spil(i,jm) = rel(i,jm) - pfl
          if(icon(i).eq.2) spil(i,jm) = rel(i,jm) - pfl - reli
          if(icon(i).eq.3) spil(i,jm) = rel(i,jm) - pfl - relw
          if(icon(i).eq.4) spil(i,jm) = rel(i,jm) - pfl - reli - relw
```

```
    if(spil(i,jm).lt.0) spil(i,jm) =  0
    rel(i,jm) = rel(i,jm) - spil(i,jm)
  endif
endif

if(reli.lt.rdmd*0.9999) ifail(i) = ifail(i) + 1
if(rel(i,jm).lt.wdmd(i,jc)*0.999) ifaiw(i) = ifaiw(i) + 1
if(reli.lt.fcri(i)*rdmd*0.999.and.rdmd.gt.0) ifaic(i)=ifaic(i)+1

if(ilin(i).gt.0) then
 vli(i) = vli(i) + dive(i,jm)
 tld(i) = tld(i) + ddm(i,jc)
endif
Tri(i) = Tri(i) + reli
trw(i) = trw(i) + relw
trp(i) = trp(i) + amin1(pfl, pdmd)
Tdi(i) = Tdi(i) + rdmd
tdw(i) = tdw(i) + wdmd(i,jc)
tdp(i) = tdp(i) + pdmd
relir(i,jm) = reli
relws(i,jm) = relw
return
end
```

Input Data Presentation **Appendix B**

A. Inflows at nodes unit Mcun

	Godavari			Krishna						Pennar	Cauvery		
Year	**Incham palli**	**Pola varam**	**Dowle swaram**	**Almatti**	**Narayana pur**	**Srisai lam**	**Nagarju nasagar**	**Pulichin tala**	**Prakasam Barrage**	**Soma sila**	**K R sagar**	**Mettur**	**Grand Anicut**
1951-52	22284	13802	455	10132	684	2046	303	535	2165	409	1	158	6
1952-53	11712	14236	137	13803	443	1	285	228	4	409	737	268	1
1953-54	47671	18316	632	20706	1608	13599	740	1613	3346	3137	5061	2406	381
1954-55	37380	13122	391	15142	572	4663	394	1423	3115	1848	2546	1044	13
1955-56	68490	17674	395	18457	1361	10100	895	1792	2780	1738	94	507	225
1956-57	48641	18613	227	19193	1705.00	16700	969	1758	3254	5776	3741	2034	148
1957-58	32525	14317	111	15544	1186	5826	315	526	1924	569	1509	1415	882
1958-59	47742	14091	309	16123	1024	6688	513	1461	4981	3033	4115	2237	1
1959-60	76599	23629	1092	20382	926	11188	415	1617	5023	959	7501	3355	573
1960-61	25244	10429	147	14147	693	4353	330	580	1477	2735	1841	409	43
1961-62	64384	6565	682	19698	1313	11141	880	2106	4495	1220	8251	3697	271
1962-63	32484	8390	521	12304	709	6670	468	1470	3459	2104	4040	1876	947
1963-64	44917	15008	475	16051	366	6416	370	1204	2245	1032	773	325	28
1964-65	38406	12251	427	19112	1538	14892	759	580	2990	3934	4666	3488	947
1965-66	8114	7083	1	13086	77	755	399	146	622	593	1	1	63
1966-67	24583	14143	414	11232	865	684	535	406	1831	3955	970	792	596
1967-68	27152	14996	364	15829	157	3228	289	626	1311	1383	1556	48	84
1968-69	12145	8764	1	9942	247	1707	342	602	533	615	1314	1067	6
1969-70	35921	17668	430	14166	512	8072	442	681	2487	2221	1198	724	299
1970-71	53464	15244	360	15996	566	8707	454	1126	3026	1398	1127	1068	67
1971-72	9845	11068	63	10989	97	554	310	529	524	585	1001	1148	425
1972-73	6870	7823	38	5944	1	1	153	214	23	1454	1291	379	1768
1973-74	47642	10473	313	15617	433	11628	671	1350	1684	3148	2781	711	134
1974-75	9877	7896	163	14999	1224	9125	384	974	1716	2817	1375	1242	1
1975-76	56279	22824	605	22784	1337	25128	1219	4020	4500	6963	4220	2794	484
1976-77	34165	17090	584	12715	1	3504	458	1710.	2853	2942	1	1	28
1977-78	32267	12973	79	13018	472	2080	475	555	431	3283	3946	2216	972
1978-79	43694	23261	749	15459	574	11584	1155	2744	5957	4467	3190	2118	462
1979-80	17138	8437	1	17062	1650	7203	295	101	102	1848	4172	2685	1064
1980-81	29594	18215	381	16757	508	8368	274	229	1987	472	4108	2225	1

Input Data Presentation

B. Monthly requirements (Mcum), distribution factors of inflows and evaporation depths (m)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Godavari basin													
Inchampalli													
Inflow fact.	0.0082	0.0077	0.0051	0.0019	0.0015	0.0173	0.1503	0.4225	0.2280	0.1093	0.0360	0.0122	**1.0000**
Irri.demand	65	20	8	8	8	16	109	97	90	61	58	80	**620**
evap.depth	0.1000	0.0943	0.2302	0.2926	0.2840	0.2240	0.1592	0.1363	0.1483	0.1534	0.1060	0.1013	
Polavaram													
Inflow fact.	0.0099	0.0076	0.0063	0.0048	0.0050	0.0248	0.1733	0.3640	0.2568	0.1019	0.0296	0.0160	**1.0000**
Irri.demand	293	162	74	38	39	130	834	615	383	149	188	378	**3283**
WS demand	70	62	70	126	14	68	70	70	68	70	68	70	**826**
d/s factor	0.9838	0.9838	0.9808	0.9791	0.9354	0.9705	0.9442	0.9051	0.9179	0.9647	0.9767	0.9790	
evap.depth	0.0956	0.0964	0.2219	0.2943	0.2974	0.2097	0.1391	0.1413	0.1503	0.1484	0.0997	0.0974	
Dowleswaram													
Inflow fact.	0.0321	0.0275	0.0284	0.0256	0.0266	0.044	0.1648	0.2692	0.196	0.1016	0.0467	0.0375	**1.0000**
Irri.demand	621	527	456	383	131	518	1067	1050	909	891	652	569	**7774**
Krishna basin													
Almatti													
Inflow fact.	0.0004	0.0002	0.0003	0.0005	0.0005	0.0670	0.3269	0.4179	0.1254	0.0461	0.0123	0.0025	**1.0000**
Irri.demand	36	19	5	0	0	17	47	35	21	14	24	40	**258**
d/s factor	0.9200	0.9500	0.9600	0.0000	0.0000	0.8600	0.6800	0.0000	0.0000	0.0000	0.0000	0.3100	
evap.depth	0.1087	0.1229	0.1654	0.1803	0.1974	0.1565	0.1374	0.1346	0.1244	0.1231	0.1023	0.0965	
Narayanpur													
Inflow fact.	0.0299	0.0247	0.0119	0.0076	0.0257	0.0721	0.1151	0.1845	0.2498	0.1661	0.0684	0.0442	**1.0000**
Irri.demand	587	314	86	0	0	281	780	592	339	228	401	682	**4290**
evap.depth	0.1087	0.1229	0.1654	0.1803	0.1974	0.1565	0.1374	0.1346	0.1244	0.1231	0.1023	0.0965	

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Srisailam													
Inflow fact.	0.0003	0.0000	0.0000	0.0000	0.0000	0.0296	0.2592	0.4071	0.1874	0.1029	0.0114	0.0021	**1.0000**
Irri.demand	0	0	0	0	0	0	0	841	841	527	0	0	**2209**
WS demand	0	0	0	0	0	0	107	104	107	107	0	0	**425**
d/s factor	0.9999	1.0000	1.0000	1.0000	1.0000	0.7727	0.9267	0.9387	0.7607	0.8992	0.9800	0.9910	
Min flow	55	45	51	59	5	284	434	380	336	317	204	95	**2265**
evap.depth	0.1113	0.1448	0.2178	0.2393	0.2649	0.2070	0.1406	0.1237	0.1173	0.1016	0.1018	0.0900	
Nagarjunasagar													
Inflow fact.			Inflows are taken from pre-feasibility report of Nagarjunasagar -Somasila link project										
Irri.demand	343	456	819	585	37	22	587	1353	1070	1091	549	553	**7465**
Min flow	55	45	51	59	5	284	434	380	336	317	204	95	**2265**
evap.depth	0.1016	0.1016	0.2286	0.3048	0.3048	0.2286	0.1524	0.1524	0.1524	0.1524	0.1016	0.1016	
Pulichintala													
Inflow fact.	0.0185	0.0150	0.0150	0.0118	0.0070	0.0168	0.1309	0.3136	0.2142	0.191	0.0478	0.0184	**1.0000**
evap.depth	0.1016	0.1016	0.2286	0.3048	0.3048	0.2286	0.1524	0.1524	0.1524	0.1524	0.1016	0.1016	
Prakasam barrage													
Inflow fact.	0.0164	0.0124	0.0129	0.0107	0.0114	0.0127	0.1277	0.3401	0.206	0.1836	0.0486	0.0175	**1.0000**
Irri.demand	125	102	116	133	11	643	983	861	762	719	462	215	**5132**
Pennar Basin													
Somasila													
Inflow fact.			from PFR of Somasila - Grand Anicut link report of NWDA										
Irri.demand	95	124	134	130	25	0	103	207	197	183	122	133	**1453**
TG canal	0	0	0	0	0	0	0	0	219	226	219	226	**890**
WS demand	0	0	0	0	0	0	103	103	100	103	0	0	**409**
evap.depth	0.1008	0.1008	0.1773	0.2294	0.2607	0.183	0.1507	0.1512	0.1512	0.1288	0.1008	0.1008	

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Cauvery Basin													
K.R. Sagar													
Inflow fact.			in the ratio of monthly observed flows for the period from 1951-1980										
Irri.demand	76.8	66.4	81.6	77.6	43.4	59	129.2	189.7	164.4	146.6	172.9	117.4	**1325**
evap.depth	0.1284	0.1335	0.1659	0.1542	0.1476	0.1235	0.1155	0.1172	0.1169	0.1105	0.1060	0.1143	
Mettur													
Inflow fact.	0.0161	0.0041	0.0036	0.0087	0.0417	0.0393	0.1733	0.2034	0.1534	0.1908	0.0948	0.0708	**1.0000**
Irri.demand	34.2	6.4	4	0	0	0	3.9	37.7	49.7	48.6	47.4	43	**275**
d/s factor	0.9705	0.9602	0.9622	0.0000	0.0000	0.9657	0.9443	0.9624	0.9660	0.9721	0.9623	0.9570	
evap.depth	0.1389	0.1517	0.1895	0.1749	0.1708	0.1472	0.1351	0.1348	0.1331	0.1200	0.1115	0.1202	
Grand Anicut													
Inflow fact.	0.0729	0.0389	0.0102	0.0046	0.0083	0.0154	0.1629	0.2110	0.1708	0.1156	0.0944	0.0950	**1.0000**
Irri.demand	900	356	98	0	0	163	1064	2042	1826	1508	910	803	**9670**

Input Data Presentation — **Appendix - B**

C. Elevation-Area- Capacity tables of reservoirs

Inchampalli Reservoir		
Elevation	**Area**	**Capacity**
(m)	(Mm^2)	(Mm^3)
104.000	402	3480
105.000	434	3898
106.000	475	4340
106.980	530	4861
107.000	535	4870
108.000	587	5403
109.000	632	6012
110.000	711	6702
111.000	773	7444
112.000	854	8266
112.770	926	8959

Polavaram Reservoir		
Elevation	**Area**	**Capacity**
(m)	(Mm^2)	(Mm^3)
40.00	308	2500
41.00	338	2860
41.15	343	2902
42.00	374	3300
43.00	414	3640
44.00	450	4120
45.00	492	4620
45.72	541	4945
46.00	560	5100

Somasila Reservoir		
Elevation	**Area**	**Capacity**
(m)	(Mm^2)	(Mm^3)
79.250	21.6	57.483
80.770	23.4	85.715
82.300	32.9	128.756
83.820	46.0	194.423
85.340	48.9	262.553
86.870	57.4	345.748
88.390	69.5	440.241
89.920	76.7	555.377
91.440	90.7	683.766
92.960	105.9	834.496
94.490	111.5	999.017
96.010	128.0	1178.234
97.540	148.0	1392.705
99.060	166.2	1628.443
100.580	178.6	1893.488

Mettur Reservoir*		
Elevation	**Area**	**Capacity**
(m)	(Mm^2)	(Mm^3)
204.220	3.47	61.2
205.000	6.66	117.6
207.000	14.86	262.4
209.000	23.07	407.2
211.000	31.27	552
213.000	39.47	696.8
215.000	47.68	841.6
217.000	55.88	986.4
219.000	64.08	1131.2
221.000	72.29	1276
223.000	80.49	1420.8
225.000	88.69	1565.6
227.000	96.90	1710.3
229.000	105.10	1855.1
231.000	113.30	1999.9
233.000	121.50	2144.7
235.000	129.71	2289.5
237.000	137.91	2434.3
239.000	146.11	2579.1
240.790	153.46	2708.8

Krishnarajasagar*		
Elevation	**Area**	**Capacity**
(m)	(Mm^2)	(Mm^3)
736.700	22.730	236
737.000	24.880	258
738.000	32.030	332
739.000	39.190	407
740.000	46.340	481
741.000	53.500	555
742.000	60.650	629
743.000	67.810	703
744.000	74.960	778
745.000	82.120	852
746.000	89.270	926
747.000	96.430	1000
748.000	103.580	1075
749.000	110.740	1149
750.000	117.890	1223
751.000	125.050	1297
752.000	132.200	1371
752.490	135.710	1408

Pulichintala Reservoir		
Elevation	**Area**	**Capacity**
(m)	(Mm^2)	(Mm^3)
38.100	10	37
39.620	15	71
41.150	22	100
42.670	30	139
44.200	52	200
45.720	79	300
47.240	93	431
48.770	105	583
50.290	119	754
51.820	131	945
53.340	144	1155

Note: * In the absence of data,Linear interpolation is done.

Elevation (m)	Area (Mm^2)	Capacity (Mm^3)	Elevation (m)	Area (Mm^2)	Capacity (Mm^3)	Elevation (m)	Area (Mm^2)	Capacity (Mm^3)
Almatti Reservoir								
504.575	57.820	334.72	509.760	133.125	814.23	514.945	255.196	1772.00
504.880	61.156	352.84	510.065	138.420	855.59	515.245	267.644	1851.64
505.185	64.658	372.00	510.370	143.809	898.57	515.550	281.208	1935.24
505.490	68.235	392.24	510.675	149.383	943.22	515.855	294.864	2022.98
505.795	71.886	413.58	510.980	155.420	989.64	516.160	308.938	2114.96
506.100	75.667	436.05	511.285	161.274	1037.87	516.465	323.617	2211.30
506.405	79.987	459.75	511.590	167.498	1087.94	516.770	338.574	2312.17
506.710	84.492	484.80	511.895	173.630	1139.89	517.075	353.809	2417.62
507.015	88.960	511.22	512.200	180.597	1193.84	517.380	369.231	2527.75
507.320	93.643	539.03	512.505	185.567	1249.60	517.685	385.024	2642.64
507.625	98.288	568.26	512.810	191.188	1306.98	517.990	401.328	2762.40
507.930	103.026	598.92	513.115	196.762	1366.07	518.290	417.957	2887.19
508.235	107.857	631.04	513.420	202.522	1426.89	518.595	434.864	3017.09
508.540	112.687	664.63	513.725	209.117	1489.60	518.900	452.004	3152.16
508.845	117.610	699.70	514.030	220.080	1554.97	519.205	469.888	3292.59
509.150	122.720	736.30	514.335	231.553	1623.77	519.510	488.096	3438.50
509.455	127.923	774.47	514.640	243.212	1696.08	519.600	493.510	3485.00
Narayanpur Reservoir			**Narayanpur Reservoir**			**Narayanpur Reservoir**		
Elevation	**Area**	**Capacity**	**Elevation**	**Area**	**Capacity**	**Elevation**	**Area**	**Capacity**
(m)	(Mm^2)	(Mm^3)	(m)	(Mm^2)	(Mm^3)	(m)	(Mm^2)	(Mm^3)
481.285	43.710	189.31	484.635	53.66	351.47	489.820	107.140	780.12
481.585	44.640	202.76	485.855	66.96	424.54	490.125	110.860	813.29
481.890	45.200	216.42	486.160	70.22	445.39	490.430	113.460	847.42
482.195	46.120	230.32	486.465	73.94	467.33	490.735	116.720	882.43
482.500	47.150	244.50	486.770	77.66	490.39	491.040	119.970	918.42
482.805	47.900	258.96	487.380	85.10	539.91	491.345	122.760	955.35
483.110	48.860	273.67	487.990	94.67	594.42	491.650	126.020	993.22
483.415	50.030	288.70	488.295	103.97	624.64	491.955	128.340	1031.93
			489.515	105.83	747.72	492.255	132.060	1071.55
Srisailam	**Reservoir**							
Elevation	**Area**	**Capacity**	**Elevation**	**Area**	**Capacity**	**Elevation**	**Area**	**Capacity**
(m)	(Mm^2)	(Mm^3)	(m)	(Mm^2)	(Mm^3)	(m)	(Mm^2)	(Mm^3)
258.780	272.67	4022	262.740	374.96	5297	266.400	493.87	6868
259.080	279.36	4106	263.040	382.67	5413	266.700	506.04	7021
259.380	286.51	4192	263.350	390.38	5531	267.000	516.26	7177
259.690	293.67	4280	263.650	398.00	5652	267.310	526.48	7335
259.990	300.82	4369	263.960	407.57	5774	267.610	536.70	7497
260.300	307.97	4461	264.260	416.95	5900	267.920	546.92	7662
260.600	315.13	4556	264.570	426.52	6029	268.220	557.23	7829
260.910	324.14	4656	264.870	435.90	6160	268.530	568.75	8001
261.210	332.96	4754	265.180	445.38	6295	268.830	580.37	8176
261.520	341.79	4857	265.480	457.55	6432	269.140	591.98	8355
261.820	350.80	4963	265.790	469.62	6574	269.440	603.59	8537
262.130	359.63	5073	266.090	481.61	6719	269.750	615.20	8723
262.430	367.34	5184						

Elevation (m)	Area (Mm²)	Capacity (Mm³)	Elevation (m)	Area (Mm²)	Capacity (Mm³)	Elevation (m)	Area (Mm²)	Capacity (Mm³)
Nagarjunasagar Reservoir								
153.000	176.79	5388	162.200	208.85	7150	171.000	249.16	9162
154.200	181.40	5607	163.100	212.17	7344	172.200	254.72	9472
155.100	184.86	5772	164.000	215.49	7538	173.100	258.89	9705
155.450	186.02	5827	165.200	220.70	7804	174.000	263.48	9942
156.100	188.00	5943	166.100	225.19	8010	175.000	268.92	10190
157.000	190.98	6117	167.000	229.68	8216	176.200	276.18	10519
158.200	194.95	6350	168.200	235.70	8499	177.100	281.38	10772
159.100	198.08	6531	169.200	240.23	8719	178.000	286.09	11034
160.000	201.29	6715	170.100	244.75	8938	179.200	292.37	11385
161.200	205.57	6960				179.830	295.51	11560