OPTIMALLARGE SCALE WATER TRANSFERS IN SPACE AND TIME

Ph.D. THESIS

by

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A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree
of
DOCTOR OF PHILOSOPHY
in
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ROORKEE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **OPTIMAL LARGE SCALE WATER TRANSFERS IN SPACE AND TIME** in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy and submitted in the **Department of Hydrology, Indian Institute of Technology Roorkee, Roorkee**, is an authentic record of my own work carried out during a period from January, 2006 to October, 2015 under the supervision of **Dr. D. K. Srivastava,** Professor, Department of Hydrology, Indian Institute of Technology Roorkee, Roorkee.

The thesis has been modified as per suggestions of the examiners.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

(Chandra SekharPadhi)

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

(D. K. Srivastava)
Supervisor

Dated: October, 2015

The Ph. D. Viva-Voce Examination of **Mr. Chandra SekharPadhi**, Research Scholar has been held on ……………………

Supervisor **Chairman SRC** **External Examiner**

Head of the Deptt./ Chairman ODC

ABSTRACT

In the domain of planning for optimal development, supply management is a crucial issue. Given the uncertainties and vagaries associated with monsoon precipitation in space and time, and given the ever increasing demands from consumptive and non-consumptive uses of water, the mismatch between the supply and demands is increasing day by day. From the perspective of supply management, inter basin transfer has been considered as one of the options. While planning for transfer of water, it becomes imperative to know beforehand the expected behaviour on the water availability at export points planned for above. Systemsanalysis provides the answer as an approach to estimate the yield at the export point.

Inter-basin transfer of water is a gigantic exercise encompassing wide spectrum of fields and is highly complex. The evaluation of such an exercise can best be accomplished with the help of systems analysis. There are a number of techniques employed in systems analysis. By far, the most important of all is optimization by linear programming where the objective function and constraints are linear functions of decision variables. Among different L.P. models, Reservoir Yield Model has many distinct advantages. It has the advantage of dealing with very large size of problem efficiently. As compared to the complete model, there is a substantial reduction in the problem size with reasonable estimates of over-year and within-year reservoir capacity requirements. Further the model has advantages of taking into account the critical year flows and allowable deficit in a dry year.

The available yield model has been modified to take into account the transfer criteria from different states, basinsand reservoir and is coined as the Generalised Reservoir yield Model (GRYM). The model takes into account the transfer from a point to another by has the capability to analyse at the level state (province in India), basin level and reservoir level.

The improved model, GRYM is applied to the study area, which comprises the first part of the peninsular component of the National Perspective Plan, 1980 of Government of India. The area almost covers the entire basins of major peninsular rivers of India, namely, the Mahanadi, the Godavari, the Krishna, the Pennar and the Cauvery. The combined area of thesebasin is in excess of 8 lakh sq. km and covers more than 25% of the area of India. There are about 200 major, 900 medium and a large number of minor

irrigation projects. Due to the large size of the problem, only major reservoir projects have been considered in the study. The contributions of the medium and minor irrigation projects have been lumped together for their contributions to the inflow, utilisations and demand scenario.

For the inflow data, the period chosen for analysis is 28 years i.e., from 1972-73 to 1999-2000. Within year analysis has been made for 12 within-year time periods for the critical year.The water year in India starts in the month of Juneand ends in May. Annual reliabilities for the firm and secondary yields considered are 97 percent and 76 percent based on weibull plotting position for a data series of 28 years, respectively. The net inflow series at each project are calculated by the basin water balance method from the discharge data available at nearby river gauging site. In order to process voluminous data available and received from different organisations in different formats and to place them on uniform platform, different FORTRAN programs are written and utilised. Failure years at each project are identified from the respective net inflow series. The inflow fractions in within-year time periods are calculated for each reservoir considering inflow of the driest year. Storage area curves (linearized over dead storage) are used for computation of evaporation parameters.

Demands from different sectors have been considered for a time horizon of 2050 AD. The reason for adopting the planning horizon is due to the fact that the population in India is expected to stabilise in 2050 AD and consequently the demand patterns will also be realistic. The gross irrigation water requirements at each within-year time period of the proposed crop plan under each project is estimated by using FAO-56. Population of the basin in year 2001 is calculated from the district census data and then projected for year 2050. Population of a sub-basin is distributed proportionately among all the projects in proportion of their respective culturable/cultivable command area (CCA). Municipal and industrial water demand at each project is calculated for projected populationx Site-specific values of allowable percentage yield (failure fraction) for satisfying the project specific demands as far as possible in successful years have been considered in the study. Protein and calorie requirements of the total as well as of the agricultural population have been computed.

After the flow parameters or the supply parameters, demand parameters and the parameters pertaining to the physical parameters are known, they are put to the model. In order to write the large number of equations into the solver, again FORTRAN programmes are used. The matrix so generated is solved by using LINDO software.Thestudy is limited to the surface water resources and also for major projects only.

The model was successfully applied on the study area comprising of five major river basins of peninsular India. The outcomes of the results have been analysed and put in Chapter 6 and Chapter 7. On the basis of the results the following conclusions were drawn. In the matter of satisfying the export demand, it is seen that in only 3 nos of link canal, viz., Link Canal 1, 5 and 9, the export demands at the exporting points are fully met, whereas in case of Link Canal 8, the achievement is 94.59%. In respect of other Link Canals, the demands met are 6.7% for Link Canal No 2& 3; 41.53% for Link Canal 4; 16.9% for Link Canal No 6; 25.69% for Link Canal 7. Further basinwise, Mahanadi, Krishna and Cauvery fully met the demands where as Godavari fell short of it.

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I would like to express my highest appreciation for the strong moral and emotional support, and deep understanding shown by my wife Aparna and son Uditanshu during my endeavour to complete this research work.

Date: **(CHANDRA SEKHAR PADHI)**

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NOTATIONS

A_a = water surface area per unit active storage volume above dead storage level;

A_0 = water surface area at dead storage level;

$Ac_{SN_s,BN_{s,b},RN_{s,b,i}}$ = cultivable command area (CCA) of i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

C_f = conversion factor for computation of hydroelectric energy;

Cl_{Cn_r} = calorie content of r^{th} cropper unit weight of yield produced;

$E^{AT}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = annual energy target at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$EV^{o}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = average annual fixed evaporation volume losses at the level of dead storage of i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$EV^{a}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = average annual evaporation loss rate per unit of the active storage volume from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$EV_{SN_s,BN_{s,b},RN_{s,b,i},j}$ = annual evaporation volume loss in j^{th} year from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Ev_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = within-year evaporation in t^{th} within-year time period at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$E_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = firm energy generations in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$E^{AT}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = the annual firm energy target from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\bar{E}^{AT}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = the annual secondary energy target from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\bar{E}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = secondary energy generations in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$h_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = number of hours of generation of power in t^{th} within-year time period from plant at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$H_{SN_s,BN_{s,b},RN_{s,b,i}}$ = hydro plant capacity at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Ha_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = effective head at t^{th} within-year time period for generation of power from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$I_{SN_s,BN_{s,b},RN_{s,b,i},j}$ = annual inflow in j^{th} year at site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$LBAc_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r}$ = lower bound on (in fraction of CCA) for r^{th} cropped area for i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$NCT_{s,b,i}$ = number of cropsat i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$OAT^{m}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = annual mandatory release target from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$OE^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = export/transfer of water out of firm yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state under consideration;

$OE^{sp2;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = export/transfer of water out of secondary yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state under consideration;

$OI^{fp;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = import of water out of firm yield in t^{th} within-year time period from k^{th} site/reservoir in z^{th} sub-basin of isn^{th} state to meet the demands (irrigation or otherwise) in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$OI^{sp2;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = import of water out of secondary yield in t^{th} within-year time period from k^{th} site/reservoir in z^{th} sub-basin of isn^{th} state to meet the demands (irrigation or otherwise) in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$Os^{m}_{USN_l,UBN_{l,y},URN_{l,y,x},t}$ = mandatory release in t^{th} within-year time period from x^{th} site/reservoir in y^{th} sub-basin of upstream l^{th} state(the upstream l^{th} stateis in reference to the downstream s^{th} under consideration);

$OE^{fp;ISNU_{nis},IBNU_{nis,d},IRNU_{nis,d,c}}_{USN_l,UBN_{l,y},URN_{l,y,x},t}$ = export/transfer of water out of firm yield in t^{th} within-year time period from x^{th} site/reservoir in y^{th} sub-basin of upstream l^{th} state (the upstream l^{th} stateis in reference to the downstream s^{th} under consideration) to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state;

$OE^{sp2;ISNU_{nis},IBNU_{nis,d},IRNU_{nis,d,c}}_{USN_l,UBN_{l,y},URN_{l,y,x},t}$ = export/transfer of water out of secondary yield in t^{th} within-year time period from x^{th} site/reservoir in y^{th} sub-basin of upstream l^{th} state (the upstream l^{th} stateis in reference to the downstream s^{th} under consideration) to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state;

$OE^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{ESN_s,EBN_{s,p},ERN_{s,p,q},t}$ = export/transfer of water out of firm yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state under consideration;

$OE^{sp2;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{ESN_s,EBN_{s,p},ERN_{s,p,q},t}$ = export/transfer of water out of secondary yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state under consideration;

$OI^{fp;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{NIS_s,NIB_{s,u},NIR_{s,u,v},t}$ = import of water out of firm yield in t^{th} within-year time period from k^{th} site/reservoir in z^{th} sub-basin of isn^{th} state to meet the demands (irrigation or otherwise) in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$OI^{sp2;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{NIS_s,NIB_{s,u},NIR_{s,u,v},t}$ = import of water out of secondary yield in t^{th} within-year time period from k^{th} site/reservoir in z^{th} sub-basin of isn^{th} state to meet the demands (irrigation or otherwise) in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$OEn^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$

$OEn^{sp2;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$

$OR^{ISN_{nis}}_{ESN_s,t}$ = minimum total export/transfer to the nis^{th} state from the s^{th} state under consideration;

$O^{m}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = minimum mandatory release in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Os^{m}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = mandatory release in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Oy^{fp}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = annual firm yield of reliability p from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Oy^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = annual secondary yield of reliability p2 (less than p) from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Ow^{fp}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = firm within-year reservoir yield in t^{th} within-yeartime period with annual reliability *p* from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Ow^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = secondary within-year reservoir yield in t^{th} within-yeartime period with annual reliability *p2* from i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\Pr_{Cn_r}$ = protein content of r^{th} cropper unit weight of yield produced;

$S^{o}_{SN_s,BN_{s,b},RN_{s,b,i},j}$ = final over-year storagein j^{th} year at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$S^{o}_{SN_s,BN_{s,b},RN_{s,b,i},j-1}$ = initial over-year storagein j^{th} year at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$S^{o}_{SN_s,BN_{s,b},RN_{s,b,i},cr}$ = initial over-year storage volume critical year (cr) of i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$S^{w}_{SN_s,BN_{s,b},RN_{s,b,i},t-1}$ = initial within-year storage in t^{th} within-yeartime period at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$S^{w}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = final within-year storage in t^{th} within-yeartime period at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Sp_{USN_l,UBN_{l,y},URN_{l,y,x},j}$ = spill in j^{th} year from upstream x^{th} site/reservoir in y^{th} sub-basin of l^{th} sub-basin contributing to i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$TPR_{SN_s,BN_{s,b},RN_{s,b,i}}$ = total protein demand to be met i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$TCR_{SN_s,BN_{s,b},RN_{s,b,i}}$ = total calorie demand to be met i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$UBAc_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r}$ = upper bound on (in fraction of CCA) for r^{th} cropped area for i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Y^{o}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = over-year storage capacity of i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Ya_{SN_s,BN_{s,b},RN_{s,b,i}}$ = the total active storage capacity of i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$Y^{w}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = within-year storage capacity of i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\alpha_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = plant factor of power (hydro) installation in t^{th} period of the critical year of the record to the total annual inflow to at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\beta_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = ratio of the inflow in t^{th} period of the critical year of the record to the total annual inflow to at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\gamma_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = fraction of annual evaporation volume loss from reservoir at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$e_{SN_s,BN_{s,b},RN_{s,b,i}}$ = efficiency of the turbine at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\theta^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = factor to identify a successful or a failure year for incremental secondary yield at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration (in case of a multiple yield model its value is either 0 for a failure year or 1for a successful year);

$\nabla_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r,t}$ = gross irrigation requirement (GIR) [measured in terms of depth of water] for r^{th} crop in t^{th} within-year time for i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\delta^{f}_{USN_l,UBN_{l,y}}$ = fraction of return flow from upstream firm water use of contributing (upstream) y^{th} sub-basin of l^{th} sub-basin to i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\delta^{s}_{USN_l,UBN_{l,y}}$ = fraction of return flow from upstream secondary water use of contributing (upstream) y^{th} sub-basin of l^{th} sub-basin to i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\delta^{m}_{USN_l,UBN_{l,y}}$ = fraction of return flow from upstream mandatory water use of contributing (upstream) y^{th} sub-basin of l^{th} sub-basin to i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\phi_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r}$ = fractions of the CCA under cultivation/occupation of r^{th} crop in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\rho^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = fraction of total annual yield desired to be released in the failure yearsat i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\alpha_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = load factor (or hydropower plant factor) at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\varphi_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r}$ = yield of r^{th} crop per unit area of CCA in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

$\omega_{SN_s,BN_{s,b},RN_{s,b,i}}$ = annual irrigation intensity at i^{th} site/reservoir in b^{th} sub-basin of s^{th} stateunder consideration;

SUBSCRIPTS AND SUPERSCRIPTS

j = index to refer year, j = 1, 2, 3…;

t = index to refer within-year time period, t = 1, 2, 3… 12;

s = index to refer either (i) the state in general under consideration, or (ii) the exporting state under consideration, or (iii) the importing-state under consideration, or (iv) the downstream-state under consideration receiving regenerated flows (return flows) from irrigation etc from the upstream state;

b = index to refer either (i) the sub-basin of the state s in general under consideration or (ii) the downstream-state s under consideration;

i = index to refereither (i) the site/reservoir inthe sub-basin b of the state s in general under consideration or (ii) the site/reservoir inthe sub-basin b of the downstream-state s under consideration;

l = index to refer the upstream statecontributing regenerated flows (return flows) from irrigation etc. to the site/reservoir i in the sub-basin b of the downstream-state s under consideration;

y = index to refer the sub-basin of the upstreamstate l, contributing regenerated flows (return flows) from irrigation etc. to the site/reservoir i in the sub-basin b of the downstream-state s under consideration;

x = index to refer the site/reservoir in the sub-basin y of the upstreamstate l, contributing regenerated flows (return flows) from irrigation etc. to the site/reservoir i in the sub-basin b of the downstream-state s under consideration;

p = index to refer the sub-basin of the exporting state s under consideration;

q = index to refer the site/reservoir in the sub-basin p of the exporting state s under consideration;

nis = index to refer the state,to which the water is being exported by the site/reservoir q in the sub-basin p of the s exporting state under consideration;

d = index to refer the sub-basin of the nis state, to which the water is being exported by the site/reservoir q in the sub-basin p of the exporting s state under consideration;

c = index to refer the site/reservoir in the sub-basin d of the nis state, to which the water is being exported by the site/reservoir q in the sub-basin p of the exporting state s under consideration;

u = index to refer the sub-basin of the importing state s under consideration;

v = index to refer the site/reservoir of the sub-basin v of the importing state s under consideration;

$\sin$ = index to refer the state from which the water is being importedby the site/reservoir v in the sub-basin u of the importing state s under consideration;

z = index to refer the sub-basin of the $\sin$ statefrom which the water is being importedby the site/reservoir v in the sub-basin u of the importing state s under consideration;

k = index to refer the site/reservoir in the sub-basin z of the $\sin$ statefrom which the water is being importedby the site/reservoir v in the sub-basin u of the importing state s underconsideration.

ABBREVIATIONS

Ha	Hectare
GWh	Giga watt hours
IBWT	Inter basin water transfer
MCM	Million cubic meters
mm	Millimeters
MW	Megawatts
TMC	Thousand million cubic feet
Lakh	HundredThousand

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

All living beings in planet earth owe their existence to water. The importance of water as one of the most vital inputs to life has been recognized since time immemorial. Its availability in plenty has largely been responsible for development of civilizations along river courses. Rivers are the principal source of fresh water in India. Therefore, their place in the civilization is unique. Not surprisingly, they have been deified and worshipped in India in the form of mother goddess.

In the Indian context, rivers are fed mostly by precipitation in the form of rainfall; the Himalayan Rivers being additionally fed by snow melt of glaciers. The rainfall in India is highly uneven in space and time. The water resources once considered abundant and inexhaustible, have now been rendered scarce due to ever increasing demands from various sectors like agriculture for food and fiber, industrial uses, municipal uses for human and cattle population and environmental uses. Needless to say, there is an ever increasing pressure on available water resources. It is therefore required toput the demand and supply management on high priority and resort to innovations at a greater scale to meet the challenge of demand-supply mismatch, which threatens to aggravate in the future. Of the various innovations that are possible, interlinking of rivers in India is a prominent one, highly promising but at the same time immensely complex one. The proposals not only entail stupendous engineering and economic activity, but also associated with unparalleled environmental impacts and myriad legal and institutional battles.

1.2 IMPORTANCE OF THE STUDY

In India, the concept of inter-basin transfer of water finds mention in the National Water Policy, 2012. The widening demand-supply gap due to expanding economic activities has been sought to be narrowed with the help of different innovative measures in supply and demand management. The concept of inter-basin transfer of water is considered a key component in the realm of supply management. The Policy recognizes the importance of basins as hydrological units for the purpose of planning and management. Since the basin boundaries do not obey political boundaries, the overlay of political boundary over the basin boundary is apprehended to result in clash of interests.

Recognizing the difficultyin resolving the clash of interests among co-basin states, the Policy has taken care in declaring water as a national asset and ordaining the water resources to be treated as of national interest. The planning and development, therefore, must conform to the national interest. The Policy further recommended for review and modification in the Inter-State Water Disputes Act of 1956 for resolution of water disputes referred to the Tribunals.

The Constitution of India does not explicitly deal with the issue of inter-basin water transfer. However, it draws its strength from Article 262, which deals with the adjudication of disputes relating to waters of interstate rivers or river valleys. Since the matter comes under the purview of both the states and the union vide Entry 17 of List II and Entry 56 of List I of Seventh schedule, a lot of consensual effort is required for conflict of resolution.

Though the issue ofinter basin transfer of water has many ramifications from the social, economic, political, legal and environment viewpoint, the foremost question that comes to the mind of water resources planner and manager is the question of availability and reliability of the transfer at the export points. When the question of acceptance of the figures by the donor states arises, there is always an associated skepticism about their correctness. Further there is always an apprehension about the future. It is therefore important to know about the implications to the water availability scenario not only at the point of transfer, but also in the entire system. Here, system analysis comes handy.

1.3 STUDY AREA

The Mahanadi-Godavari-Krishna-Pennar-Cauvery-Vaigai-Gundar inter-basin water transfer link comprises the first part of the peninsular river development component (National Commission for Integrated Water Resources Development Plan 1999). It contemplates flow of surplus water from the Mahanadi basin to the Godavari system and thereafter to water deficit basins of Krishna, Pennar, Cauvery and Vaigai. This would benefit the drought prone areas of Odisha, Maharastra, undivided Andhra Pradesh, Karnataka, and Tamilnadu.

As per the study carried out so far, the scheme consists of setting aside a flow of 12165 MCM of water on annual basis from Mahanadi system through Link Canal-1, i.e., Mahanadi-Godavari link canal. From Godavari system, there is a proposal to make available a quantity of 26122 MCM of water including the water received from

Mahanadi-Godavari link to Krishna system. Out of the water so received from Godavari, a quantity of 14080 MCM of water is to be diverted to Pennar. A quantity of 8343 MCM of water is proposed to be diverted to the Cauvery basin from Pennar system. Further down, a quantity of 2252 MCM of water is proposed to be diverted to meet the demands of Vaigai and Gundar basins. An index map of the different links is provided in Fig. 1.1 showing the different linkages

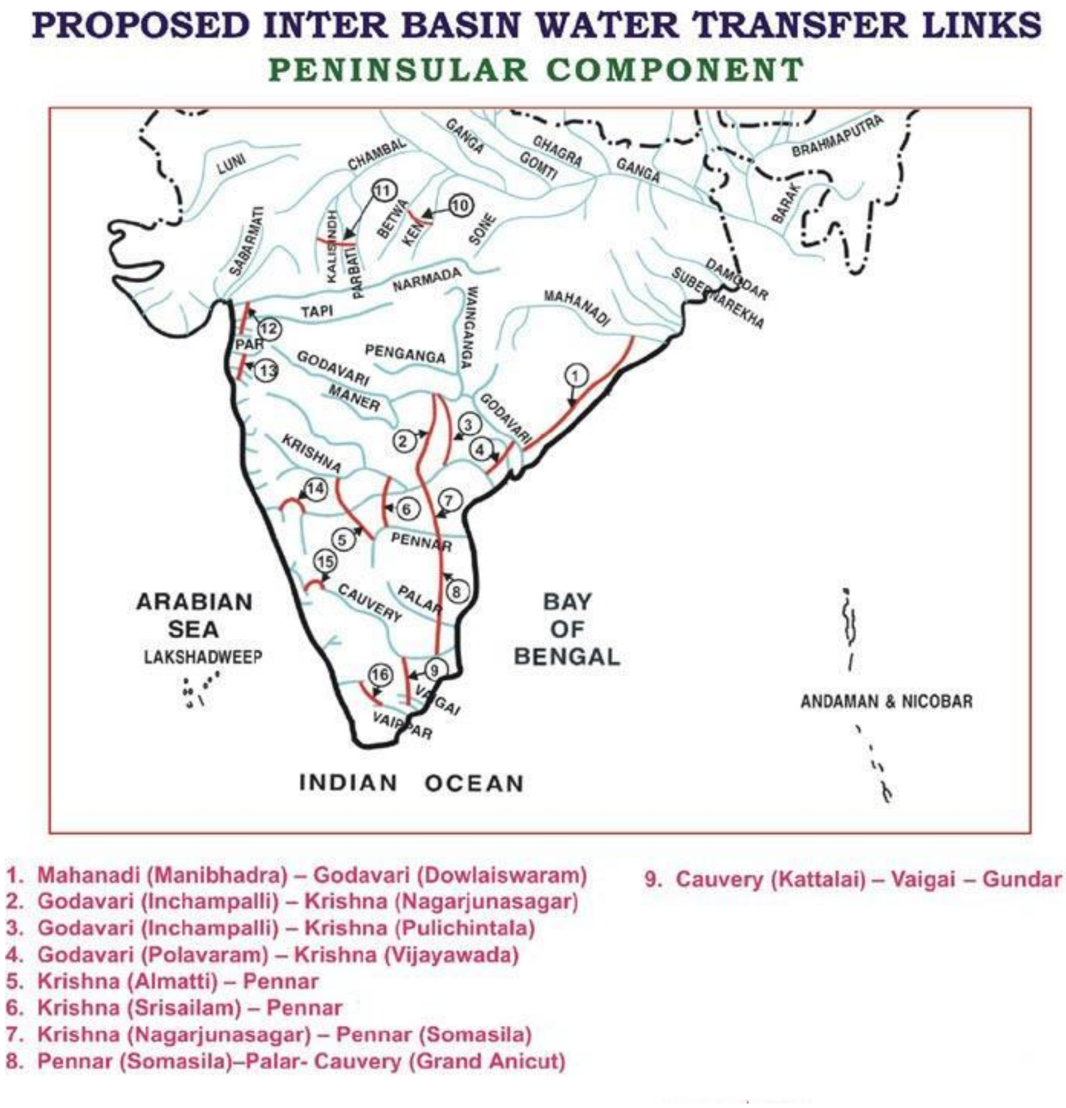

Fig. 1.1 Mahanadi-Godavari-Krishna-Pennar-Cauvery-Gundar link (www.nwda.gov.in)

The diversion of water is proposed to be accomplished through construction of 9(nine) numbers of link canals. The other links from 10 to 16 do not relate to the study area. The related links are described hereinafter.

Link Canal-1: Mahanadi (Manibhadra) to Godavari (Dowlaiswaram)

This link canal is contemplated to startat Manibhadra (exporting reservoir) in Mahanadi basin (exporting basin) to be connected to Dowlaiswaram barrage (importing point), in Godavari basin (importing basin). The Mahanadi basin is divided into 10(ten) sub-basins. The export point, i.e., Manibhadra is situated in the Lower Mahanadi sub-basin which happens to be at the tail end. Therefore, the catchment areas of all the remaining 9 upstream sub-basins in Mahanadi along with the portion of Lower Mahanadi sub-basin up to Manibhadra are contributing to the inflow at the export point.

Link Canal-2: Godavari (Inchampalli) to Krishna (Nagarjunasagar)

This link canal is proposed to take off from Inchampalli (exporting reservoir) in Godavari basin (exporting basin) to be connected to Nagarjunasagar (importing reservoir) in Krishna basin (importing basin). The Godavari basin is divided into 12(twelve) sub-basins.The export point, i.e., Inchampalli is situated in the Lower Godavari sub-basin just after the confluence of Indravati river (the 10th sub-basin). All the 10(ten) upstream sub-basins in Godavari along with the portion of Lower Godavari sub-basin up to Inchampalli are contributing to the inflow at the export point.

Link Canal-3: Godavari (Inchampalli) to Krishna (Pulichintala)

This link canal is planned to origin at Inchampalli (exporting reservoir) in Godavari basin (exporting basin) to be connected to Pulichintala (importing reservoir) in Krishna basin(importing basin).The position of the export point, i.e., Inchampalli, has earlier been explained**.**

Link Canal-4: Godavari (Polavaram) to Krishna (Vijayawada)

It is proposed to take off from Polavaram (exporting reservoir) in Godavari basin(exporting basin) to be connected to Prakasam barrage (importing point) at Vijayawada in Krishna basin(importing basin).The export point, i.e., Polavaram is situated in the Lower Godavari sub-basin. The contributing catchment areas consist of 11(eleven) sub-basins in Godavarialong with a portion of Lower Godavari sub-basin up to Polavaram would be contributing to the inflow at the export point.

Link Canal-5: Krishna (Almatti) to Pennar

It is proposed to take off from Almatti (exporting reservoir) in Krishna basin (exporting basin) to be connected to Maddilleru river (importing point)in Pennar basin (importing basin). The export point is situated in the Middle Krishna sub-basin. The Krishna basin consists of 12(twelve) sub-basins.The catchment areas of Upper Krishna and Ghataprabha sub-basins along with portion of Middle Krishna sub-basin up to Almatti are contributing to the inflow at the export point.

Link Canal-6: Krishna (Srisailam) to Pennar

This link canal has been planned for taking off from Srisailam (exporting reservoir) in Krishna basin (exporting basin) to be connected to Nippulavagu River (importing point) in Pennar basin (importing basin) through natural drainages. The export point is situated in the Lower Krishnasub-basin (the 9th sub-basin). All the upstream 8 sub-basins in Krishna along with the portion of Lower Krishna sub-basin up to Srisailam would be contributing to the inflow at the export point.

Link Canal-7: Krishna (Nagarjunasagara) to Pennar (Somasila)

This link canal is proposed to take off from Nagarjunasagara (exporting reservoir) in Krishna basin (exporting basin) to be connected to Somasila (importing reservoir) in Pennar basin (importing basin).

Link Canal-8: Pennar (Somasila) to Cauvery (Grand Anicut)

It is proposed to take off from Somasila (exporting reservoir) in Pennar basin (exporting basin) to be connected to Grand Anicut (importing point) in Cauvery basin (importing basin).The Pennar basin is divided into 4(four) sub-basins.The export point, i.e., Somasila is situated in the Pennar Delta sub-basin. The catchment areas of upstream 3 sub-basins along with the portion of Pennar Delta sub-basin up to Somasila are contributing to the inflow at the export point.

Link Canal-9: Kattalai (Cauvery) - Vaigai-Gundar

This link canal is considered to take off from Kattalai bed regulator (exporting point) in Cauvery basin (exporting basin) to be connected to Vaigai and Gundar rivers (importing basins). The Cauvery basin is divided into 16(sixteen) sub-basins. The export point, i.e., Kattalai bed regulator is situated in the Tirumanimuttar sub-basin (12th sub-basin). All the 11 upstream sub-basins in Cauvery along with the portion of

Tirumanimuttar sub-basin up to Kattalai bed regulator would be contributing to the inflow at the export point

1.4 PROBLEM IDENTIFICATION

Interbasin transfer of water as envisaged in the Study Area is a gigantic exercise. The question of inter-basin transfer of water as embodied in the National Perspective Plan,1980 involves five major river basins covering more than 25% of the geographical area of India and having around 200 major, 900 medium and a very large number of minor irrigation schemes.

The question of determination of sub-basin/basin wise water availability to establish surplus/shortage in a basin is of paramount importance. The studies on water balance carried out so far in respect of annual water availability of a sub-basin normally tend to take into account only observed yield at the terminal gauge and discharge (G&D) site and compute the virgin basin yield. Furthermore, the computation of the annual yields is generally arrived at for the water year of a given dependability only. However, ideally the water balance should take into consideration the regulation effect of storages of the existing, ongoing and contemplated projects in the basins. The spatial and temporal distribution in parameters is also significant and useful in assessing the water availability more realistically. Furthermore, there is a need for determining optimal multi-yields from every reservoir in order to ascertain the excess/shortage in water availability in a basin as a whole. Studies carried out so far lack consideration of spatial distribution of water availability and demand. These considerations will enable different projects situated in the concerned sub-basins to be evaluated in an integrated manner.

The matter of adoption of systems approach on the issues involving transfer of waters has been recommended by the working group on inter-linking of rivers (National Commission for Integrated Water Resources Development Plan 1999). No systems analysis studies so far have been attempted for the optimal evaluation of the water export potential in space and time on such a large scale.

The matter of application of system engineering techniques to water resources development problems has been in vogue for a quite some time and is widely accepted, since it considers complex issues in their totality. Apart from dealing with the vexed engineering issues, these techniques also cater to soft issues like environmental, displacement, rehabilitation and other social issues.

Similarly, Mathematical models are also indispensable tools for carrying out system engineering studies. Advantages of screening models for planning and management of large complex water resources systems are well acknowledged. However, selection of a particular model out of so many families of screening models available after their development since 1962 is a tedious task. Presence of a large number of single-purpose and multi-purpose reservoirs further introduces complexities in the system as the number of system constraints and variables are very high. In such cases, it becomes very difficult to model the system to obtainan optimal solution. Whenthe number of decision variables and constraints are large for the system, a linear programming (LP) based model is very often found suitable.

Yield from a multi- reservoir system can be explained as the maximum quantity of water that is possible for end useat a specified reliability for each time step in the configuration. Determination of yield is consideredto be one of complicated nature for a system because ofthe influence of different factors. The physical configuration of the system emanating from arrangement of the components; actual site conditions represented through specific characteristics of the individual project; historical distribution of flow data; consideration of reservoir specific active storage capacities and reservoir operating policy play a crucial role in determination of yield.

Techniques are available to quantify the yield from a multiple reservoir system. They include optimization, simulation and techniques that combine the use of both optimization and simulation. During early stage of planning, it is convenient to use screening models based on optimization techniques for finding out system yields. But in this case, major difficulty is encountered due to the size of the optimization model owing to long period of historical river flows. It may be worthwhile to mention that data of long duration are extremely useful to pin point the characteristics of the critical period of flows.

Loucks et al. (1981) formulated the yield model to precisely overcome the limitations posed by huge data size. The yield model can be described as an approximation of full optimization model based on Linear Programming (LP). The model explained the concept of the over-year and within-year reservoir capacity in a system. The model, it was demonstrated, has the capability to estimatethem to meet the specified release reliability targets. Stedinger et al. (1983) studied and compared different methods like deterministic, explicitly stochastic and implicitly stochastic reservoir models. On the basis of the results obtained from the studies, it was demonstrated that the implicitly stochastic yield model of Loucks et al. (1981) delivered reasonable reservoir designs with release reliabilities near targets. Dandy et al. (1997) also contributed to the concept by comparing different optimization techniques like yield model, full optimization model, simulation and net-work LP for determining safe yield of Canberra water supply system.

Study carried out by Dahe and Srivastava (2002) is a major achievement in this field. Their study was aimed at achievingpre-specified reliabilities for irrigation and energy generation and also in particular to incorporate an allowable deficit in the annual irrigation target.The same was accomplished through application of a multi-yield model for a multi-reservoir system comprising single-purpose and multi-purpose reservoirs numbering eight in Narmada basin in India. Panigrahi and Srivastava (2005) considered independent failure years at each reservoir site depending upon its own catchment inflow characteristics and assessed the optimal annual yields by optimizing the cropping pattern for each project simultaneously, satisfying the project specific demands to the maximum possible extent during the successful years. Also, due consideration was given to meet the mandatory water demands completely in each within-year time periods for achieving maximum reliability at each site. In a system comprising of reservoirs and barrages, a combined optimization-simulation model was recommended and applied it to the Ong sub-basin of Mahanadi basin in India.

On examination of the aforesaid yield models developed by Loucks et al. (1981) and further extended by Dahe (2001), Dahe and Srivastava (2002), Panigrahi and Srivastava (2005), and Panigrahi (2006); it is observed that these models had limitations as a result of which the same could not be applied to cater to the particular problem of water transfer.

1.5 OBJECTIVES OF THE STUDY

The objectives of the current study for the optimal large scale water transfers in space and time comprising the first part of the peninsular river development component of National Perspective Plan, 1980 are to:

1. To assess the surface water potential in the basins involved in the water transfer links.
2. To estimate water demands of different sectors by the end of the planning horizon, i.e., 2050 A.D.

3. Improve and modify the available reservoir yield model to particularly incorporate the peculiarities and complexities involved in inter-basin transfer of water wthin the river basin (i.e., particularly to take care of the right of the exporting basin to realise full potential before export is allowed).
4. To apply the improved LP based implicit stochastic reservoir yield model, i.e., Generalised Reservoir Yield Model (GRYM) to estimate the annual and within year water yields (firm and secondary) and reservoir storages and their behavioral statistics at individual major reservoirs, sub-basins and basin levels.
5. To apply the model and evaluate the water availability scenarios and corresponding water export potential at the export points in the nine links for water transfers.
6. To evaluate the optimal cropping pattern and their statistics in the irrigated areas served by reservoir at each reservoir sites.

1.6 THE APPROACH AND METHODOLOGY

Most of the studies conducted so far on the subject involved only conventional approach. The river flows considered in these studies were deterministic whereas in real life process, the flows are stochastic. The Yield Model, however, is an implicit stochastic model represents the real life processes more faithfully than the deterministic model. Therefore the Yield Model has been improved, modified and generalized into Generalised Reservoir Yield Model (GRYM) to represent the real life process even more accurately. The model takes care of the export scenario in the peninsular river interlinking projects.

Various virgin water year dependable flows at each sub-basin level and at each reservoir site have been obtained from available discharge data at discharge sites and upstream utilizations by using available FORTRAN programmes. Details of import/export from identified projects in the sub-basin have been studied. The various water needs in the basin that are to be met while planning for water resources development are calculated for the year 2050 AD. The reasons for taking the year 2050 AD basically emanates from the fact that population of India is expected to stabilize at 2050 AD and therefore the estimate of future water demands will be more stable.

In order to generate the matrix for the L.P. solver, the existing program for matrix generation has been improved and used. The program has been used in tandem with the L.P. solver to obtain the desired results. The LINDO 6.1 as the L.P solver has been used, which can accommodate very large problems. The solver can take care of 64000 constraints and 200,000 variables.

Since the scope of the study is very large (there are total 5 basins and 54 numbers of sub-basins in the study area as per classifications by N.W.D.A), only the major projects have been considered individually for their contributions to the system. The medium and minor irrigation projects are lumped and their contribution is evaluated accordingly.

1.7 OUTCOMES OF THE STUDY

The model was successfully applied on the study area comprising of five major river basins of peninsular India. The outcome of the results have been analysed and are reported in Chapter 6 and Chapter 7. On the basis of the results, the following conclusions were drawn. In the matter of satisfying the export demand, it is seen that the export demands at the exporting points are fully met in only 3 link canals, viz., Link Canal 1, 5 and 9, whereas in case of Link Canal 8, the achievement is 94.59%. In respect of other Link Canals, the demands met are 6.7% for Link Canal No 2& 3; 41.53% for Link Canal 4; 16.9% for Link Canal No 6; 25.69% for Link Canal 7. Further basin wise, export demands in Mahanadi, Krishna and Cauvery are fully met where as in case ofGodavari it was not fully met.

1.8 COMPOSITION OF THESIS

Composition of the thesis is accomplished through seven chapters. Brief description of each chapter is as follows:

Chapter 2

A review of literature relevant to the study is presented in this chapter. Brief description of the said review is arranged for inter basin water transfers and different conventional/traditional as well as latest modeling approaches used for water resources systems analysis.

Chapter 3

This chapter presents a brief description of study area. An exhaustive account of the different inter-basin water transfer links are discussed in brief.

Chapter 4

This chapter presents the basic concepts of yield model and its improvements in a chronological order. Limitations of the latest form of yield model available in literature are briefly given. The development of Generalised Reservoir Yield Model (GRYM) developed and employed for the links is presented.

Chapter 5

This chapter deals with the estimation of parameters related to the model. The parameters pertain to the physical configurations of the system, the supply parameters impinging on the physical system and the demand parameters drawing on the physical systems are explained in details.

Chapter 6

This chapter provides the details of the computations and the procedures adopted to get the results.

Chapter 7

This chapter provides the analyses of results.

Chapter 8

This chapter provides the summary, conclusions, major contributions from the.study and the limitations involved.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

Literature review is conducted in order to have an impression of different works done in the past on the wider subject and at the same time relevant to the concerned topic. These works by different scholars provide valuable inputs for further possible research directions.They also point to the possible approach and methodology to be chosen for the work at hand by offering comparative studies.

2.2 LARGE SCALE WATER TRANSFERS

Water, along with fresh air and land, is one of the foremost resource materials for survival of mankind and has therefore engaged the attention of intellectuals since pre-historic time. The need and use of water find extensive mention in the literature starting from Vedas in ancient India. The incidence of flow of water under natural gravity and manual lifting for the purpose of specified end uses on a limited scale is as old the story of water itself. The phenomena got accentuated as civilization progressed, from manual lifting to pumping. Different barriers were constructed to raise the water level to be further led through gravity for cultivation in the fields. Everything literally constituted diversion of water from its natural and unobstructed flow.

Similarly, the subject of diversion of water in a substantive manner for the well-being of mankind finds extensive references, the most ancient being the mythological tale of the holy river Ganga, descending from the heaven to the earth due to the endeavor of king Bhagirath. The matter of intra-basin and inter-basin transfer of water as means of overcoming the water scarcity in a particular region has resulted in many projects being constructed in India and abroad. Many of these projects are well documented for meaningful understanding.

Large scale water transfers are essentially deliberate rearrangement of natural hydrologic patterns accomplished through man made interventions like reservoirs, link canals, tunnels, pumping stations etc. to transfer water across natural obstacles to fulfill human needs. The natural obstaclescan be of varying size and can be classified as small, medium and largedrainage divides or the watersheds. However, these terms are only relative. The water transfer between two small basins is considered as a inter basin transfer, but from the viewpoint of a larger basin, in which both the small basins are part, it is only an intra-basin transfer. Therefore, in order to overcome this fractal dilemma, an assumption has been made and large scale water transfers have been synonymously used as transfers of water between two large basins by area, who have independent outlets to the sea.

2.2.1 Raison D' etre

Water resources were once considered to be abundant and inexhaustible in the planet. However, with increasing population and incident growth and development in the areas of agriculture, industry, municipal use and other allied activities, the hitherto abundance of water has now been relegated to a scarce resource. The supply situation is also not favourable as the availability of water resource varies widely in space and time. Thus there exists a wide gap and mismatch between demand and supply. In order to fill up the gap, from the supply side, interlinking of rivers offers a prominent potential solution to transfer water from water surplus basins to water deficient basins.

2.2.2 Examples of Inter-basin Water Transfers Outside India

There are numerous examples of inter-basin transfer of water in developed countries (National Commission for Integrated Water Resources Development Plan 1999, IWRS 1996). In the United States, California State Water Project regulates the seasonal flow in Sacramento river by storage reservoirs on its major tributary, the Feather, along with transfer of water from the delta of the San Joaquin and Sacramento rivers southwards and transfers it to meet domestic, industrial and irrigation demands (Miklin, 1985). Similarly there are major plans for transfer of water from Missouri-Mississippi system to the high plains region in Colorado, Kansass, New Mexico, Oklahoma and Texas states. However, the most ambitious of all is North America Water and Power Alliance (NAWAPA) to link water rich Alaska and North Western Canada to transfer water to central and western USA and finally to Mexico. It envisages construction of 240 reservoirs, 112 irrigation systems and 17 navigation channels. The enormity of the scale of the scheme can be comprehended from the fact that one of the dams, Chitina dam on Cooper River will be 543 m high and more than one and half times the height of Nurek Dam, reportedly the highest dam in the world. The Rocky Mountain Trench Reservoir, when created will impound 693 BCM of water, more than 50 times the size created by Grand Coulee Dam. The initial diversion would be 18.5 billion cubic meters/year (BCM/year) and the design capacity for transfer will be 136 BCM/year. The scheme will benefit as many as 33 states of the USA, 7 provinces of Canada and 8 northern states of Mexico (Sewell, 1985).

Examples from erstwhile USSR include transfer of water from north flowing rivers to Volga basin and large scale diversion of Siberian river waters to Kazakhastan and Central Asian Republics. The water resources transfer to the Volga basin is to compensate for the growth of water consumption in the Caspian Sea basin and thus stabilize the hydrological regime of the basin’s aquatic system. This will help develop irrigation and thereby improve industrial, municipal and agricultural water availability in the concerned basins. In the case of the planned Siberian rivers diversion project to the erstwhile Soviet Central Asia and Kazakhstan to supply water to the region’s economy primarily for agriculture. Water resources of the Siberian rivers will be utilized to irrigate 4.5 million hectares (Ha). Towards this end, about 25-27 BCM of water will be diverted annually from OB riverand from lower reaches of the Irtish (Voropaev and Velikanov, 1985).

Similarly, in China, there are schemes existing from ancient times and are sought to be supplemented by modern construction to transfer water from south to north through canal close to eastern coast. The East Route canal which is under construction has been inviting international attention for many reasons particularly regarding the methods used for eviction of people to be displaced by the project. However, the project is considered gigantic and is being carried out by transferring water from rich southern region to water starved northern region. The transfer is sought to be accomplished both through gravity canals and pumping stations to cross intermediate ridges. The annual average water diversion will be to the tune of 14 BCM and will irrigate 4.3 MHa besides providing 2.7 BCM for industrial, mining and municipal uses (Changming, Dakang and Yuexian, 1985).

There are similar examples of large scale water transfers throughout the globe. The Nile basin in Egypt, the Mahaveli-Ganga project of Sri Lanka include several inter basin transfer links that can be cited as examples of interbasin water transfer (Rao et al. 2005).

Although there have been examples of the water transfer schemes existing in different countries from pretty old time, their scale was not large enough to classify them as large scale water transfers. This has been due, partly to low scale water demand due to less population and lower level of industrial development and to the absence of big nation states to warrant a basin scale vision. Absence of adequate technical knowledge along with financial and other resources to implement projects of large size was also another factor for that. This is primarily the reason, water resources development looked up after Second World War and some of the large scale water resources projects have been executed since then.

2.2.3 The Indian Experience on Water Transfer

There have been quite number of examples, though as isolated cases, in India too dating back to British time to the present (National Commission for Integrated Water Resources Development Plan 1999). The notable among those are Periyar project, Parambikulam Aliyar project, Kurnool Cudappah canal, Telugu Ganga project, Ravi-Beas-Sutlej- Indira Gandhi Nahar project**,** Indravati-Hati basin transfers. A preferred re-distribution of resources has been the prime mover for these cases of interlinking of basins. The benefits that are expected from the projects are increase in yields due to irrigation, flood control, drought mitigation, development of hydropower, pisciculture, recreation and environmental improvement in addition to the one of the major objectives of ameliorating regional disparity.

2.2.4 Reference in Indian Constitution

Article 262 of the Constitution of India expressly deals with the adjudication of disputes relating to waters of interstate rivers or river valleys but fails to mention aboutinter-basin water transfer. Entry 56 of List I and Entry 17 of List II of Seventh schedule deal with items that fall within the purview of theParliamentand state legislation respectively.

2.2.5 Judicial Interventions

Supreme Court of India, in response to writ petition no. 724/1994 filed in September, 2002 regarding the need for networking of rivers (can be accessed at current date in the link http://www.nwda.gov.in/index2.asp?slid=58&sublinkid=52&langid=1), directed the Union of India to take expeditious steps for implementation of the scheme. In pursuance to the directives of the Hon’ble court a high powered task committee was formed in December, 2002, and decided that the interlinking of the peninsular rivers be completed by the end of 2016. The intervention by the Hon’ble court is this matter is regarded as the mark of imperativeness of the plan and the urgent state of affairs.

2.2.6 Provisions in National Water Policy, 2012

The National Water Policy, 2012 recognizes the importance of basins as hydrological units for the purpose of planning and management. Since the basin boundaries do not obey the political boundaries, the overlay of political boundary over the basin boundary often result in clash of interests. Recognizing the difficulties of resolving the clash of interests among co-basin states, the policy has taken care in declaring water as a national asset and ordaining that the water resources be planned, developed and managed in a way to best serve the national interest. The policy has also recommended that the Inter-State Water Disputes Act of 1956 be suitably reviewed and amended for timely adjudication of water disputes referred to the Tribunals. Thus the Policy takes care of the inter-basin water transfers in this perspective for overall development of the nation.

2.2.7 National Perspective Plan, 1980

The matter of wide variability of water resources in India in terms of space and time made people to sit up and think about ways to utilize surplus resources in deficit areas. Different approach to this problem gave rise to different proposals. However, almost all proposals envisaged construction of links from surplus basins to deficit basins. Notably, proposals for large scale inter basin transfer of water in India came from Dr K.L.Rao and Capt. Dastur in the seventies of the last century, who put forward their plans of interlinking almost all major rivers in India. However, these projects were not found to be techno-economically viable (National Commission for Integrated Water Resources Development Plan 1999). Some other recent proposals for inter-linking of rivers have also been come up from different persons and organizations. But these proposals have not been given importance from techno-economic considerations.

Later the erstwhile Ministry of Irrigation (now Ministry of Water Resources) and Central Water Commission came out with a novel plan called National Perspective Plan (NPP) for water resources development in August, 1980, envisioning inter basin transfer of water from surplus basins to deficit ones with a sightforoptimal utilization of the available water resources and minimization of the regional disparities.

The NPP comprises of two components (National Commission for Integrated Water Resources Development Plan 1999), viz., Himalayan rivers development and peninsular rivers development. The details of the proposals are enumerated below. First, the Himalayanrivers development componentenvisages taking up of storage reservoirs on the principal tributaries of Ganga and Brahmaputra rivers in India, Bhutan and Nepal.The storage reservoirs will be interlinked to transfer surplus water of the eastern tributaries of the river Ganga to the west. It further envisages to linkBrahmaputra and its tributaries with Ganga and further Ganga with the river Mahanadi.

Second is the peninsular rivers development component.It is divided into four major parts (National Commission for Integrated Water Resources Development Plan 1999). Interlinking of Mahanadi-Godavari-Krishna-Pennar-Cauvery Rivers and building storages at potential sites in these basins is the first and largest part of the peninsular component.The other three more proposals of water transfer are (i) to divert a part of the waters of the west flowing rivers of Kerala to the arid east to meet the needs of the drought areas of Tamil Nadu; (ii) to transfer water from the west flowing rivers north of Bombay and south of Tapi to cater to irrigation requirements in areas of Saurashtra, Kachchh and coastal Maharashtra while augmentingwater supplies to Mumbai and (iii) to interlink the southern tributaries of the Yamuna to provide irrigation facilities in parts of Madhya Pradesh and Rajasthan.

The benefits from this scheme has been estimated at 25 million hectares of irrigation from surface waters, 10 million hectares by increased use of ground water, totaling to 35million hectares and 34,000 MW of hydro-power capacity. There will be additional benefits of mitigation of droughts, inland navigation, flood mitigation, domestic and industrial water supply, employment generation, fisheries, salinity control, pollution control, recreation facilities, infrastructure facilities and environmental enhancement and overall socio-economic development arising out of the links.

2.2.8 National Commission for Integrated Water Resources Development Plan, 1999

The Government of India in the Ministry of Water Resources started recognizing river basin as a unit of development in mid-nineties. It was thought, in the fitness of things, to develop the availability of utilizable water in a basin to the maximum extent so as to pass on benefit of water resources development in a basin. Further, it was also expected to involve transfer of water from surplus basin to water deficient basin in national interest. It also further recognized the need to integrate the development of water resources concerning both surface and ground water and thereupon reap the benefits accruing from such arrangements. The Government of India, for this purpose, set up a National

Commission for Integrated Water Resources Development Plan under the Chairmanship of Dr. S.R. Hashim, the then member, Planning Commission and comprising eminent persons in water resources sector to look into issues discussed aforesaid.

One of the objectives of the Commission was to suggest modalities for transfer of surplus water to water deficit basins by inter-linking of rivers for achieving the objectives of equitable growth. For this purpose a Working Group was formed to look after the aspects of Inter-basin Transfer of Water. One of the main recommendations of the Commission pertaining to inter basin transfer of water was to aim at optimal utilisation of land and water in basins having surplus before considering inter basin transfers (intra basin transfer to be given first priority).

The impetus was thus given to determining the quantum of surplus and deficit in the potential exporting and importing basins before working on the modality of water transfer. The supply parameters represented through the water resource potential, the demand parameters in the shape of sectoral demands like agriculture, drinking water, municipal & industrial water, aquatic life considerations etc. along with the human interventions in the shape of storage and regulation structures make the whole exercise enormous and complex. This requires a definitive approach to find out acceptable solutions.

Subhash Chander (2003) defines the framework for evaluating inter-basin water transfer projects and suggested some criteria and also identifies the database required for each criterion. The criteria included i) That, the donor basin should experience high flows when recipient basin experiences drought; ii) That, the scope for future development of the donor basin must not be constrained by the inter-basin water transfer; iii) That, the recipient must experience substantial deficit at present or future after utilizing present resources in a most optimal manner and after considering all alternative water sources; iv) That, comprehensive environmental and v) Socio-economic assessment studies in both donor and recipient basins to be carried out.

Rao et al (2005) demonstrated the usefulness of LP in solving the network problem in the context of inter basin water transfer.

Sarma (2007) studied the aspect of inter basin water transfer in the Parbati-Kalisindh-Chambal link in central India to find out the optimal yield for transfer in the link by successfully applying LP and dynamic programming (DP) techniques.

The Brazilian experience has been examined by JGP de Andrade et al. (2011) dealing with trans-basin water diversion between river basins, with a comparative review of other similar projects around the world.

2.3 ANALYSIS OF COMPLEX WATER RESOURCES SYSTEM

Large scale transfer of water, as already stated, is an enormous exercise and is highly complex. The evaluation of such an exercise can best be accomplished with the help of systems analysis. Systems analysis can be defined as an analytical study which helps a decision maker to properly identify and select a preferred course of action from among several feasible alternatives. It is a logical and systematic approach wherein the assumptions, goals and criteria are clearly delineated and specified. It can significantly help a decision maker to take better decisions by broad basingthe data set. This also provides a better understanding of the system and inter-relationships of the various sub-systems, by forecasting the consequences arising out of several alternatives or by selecting the most suitable course that will accomplish a prescribed result (Biswas 1976).

2.4 SYSTEM AND MODELS

A system is one having a physical or conceptual boundary within which the components are basically interlinked though a set of defined relationship. A change induced through external stimuli thus gets reflected in not only the component on which it may act but also on other interdependent components. The interaction between components in a system can be physical, economic or social.

Model, on the other hand, is a conceptualization of a system, which reflects the essential characteristics of the system and is used for a particular purpose. A model does have a set of specified rules intended to expressly describe the essential functioning and interrelationship thereof. A model can be a physical model or a mathematical model. A physical model is a scaled version of the real life entity where external stimuli arephysically applied to get response. Mathematical models on the other hand are abstract idealization of the physical system and can represent the important interactions among the various components in an orderly and fairly structured manner. In this type of model the system characteristics are represented by cardinal numerical measures and corresponding arithmetic relationship. Mathematical models have distinct advantages over the physical model for quickness, amenabity to mathematical treatment and cost-effectiveness. This is the reason why mathematical models have to a large extent taken over as a preferred model than physical models in recent times.

Broadly, mathematical models can be grouped into two distinct classes. One group of models is known as descriptive model or the cause and effect model, and the other prescriptive model. System simulation model comes under the former group and used to answer descriptive “What if?” questions. In contrast to descriptive models, prescriptive models are used for finding “best” planning, design, and management of operational alternatives without having to consider all possible alternatives or use trial and error. As such, prescriptive models are often termed as “screening models” or alternative evaluation model. Large varieties of optimization models such as, those solved by linear programming (LP), non-linear programming (NLP), and dynamic programming (DP) methods are examples of prescriptive models. Although optimization and simulation are two alternative modeling approaches with different characteristics, the distinction is somewhat blurred by the fact that most models, to different extent, contain elements of both approaches. All optimization models also “simulate” the system. An optimization model is a model whose purpose is the accomplishment of the optimization of the system. Obviously, one cannot have an optimization model, which does not include an accurate system simulation model.

2.5 DETERMINISTIC AND STOCHASTIC MODELS

In the deterministic model, the behavior of the physical system is more or less explicitly explained and thereby the physical interrelationship is ostensibly ingrained into it. However, it fails to take care of the uncertainty aspect in the physical phenomenon, particularly in the case of the sequence of inflows entering into a reservoir. The assumption is that the past flow records are sufficient to reflect the general hydrologic conditions for the corresponding water resources system.

The stochastic models, on the other hand take care of the uncertainty aspect in physical phenomena. They commonly use a representation of stream flows in terms of a probability distribution or a stochastic process that captures the probabilistic characteristics of the historical data. There are two types of stochastic models generally in use in water resources system analysis technique. These are implicit stochastic, also referred to as Monte Carlo optimization and explicit stochastic models. In implicit stochastic models, the system and the stochastic nature of the inputs are represented appropriately by mathematical formulations to generate a time series of inputs over the planning horizon. However in the explicit stochastic models, either the Markov assumption or chance constraints are included as basic components to account for hydrological uncertainties. In these cases, inflows in each period are represented by a number of discrete values, q_t, each having a distinct probability, Pq_t, instead of representing the entire range by its expected value (Thomas and Watermeyer 1962)

Hall et al. (1969) as well as Askew et al. (1971) used a deterministic model and examined the flow record of 26 river basins throughout USA. Large numbers of equally likely hydrographs of the same length as the historical data were used to obtain the yields from the river basins and compared to those of the observed records.

Young (1967) applied implicit stochastic optimization model using dynamic programming to a single reservoir operational problem. One of the earliest models, based on explicit stochastic approach to a multi reservoir system, with explicit consideration given to the dependencies of stream flows is of Schweig and Cole (1968). Expected values of the net benefits from two linked reservoirs are maximized. Serial correlation of inflows as well as cross correlation between the inflows to each reservoir is incorporated into the model with the assumption of very simple stream flow interdependence.

2.6 OPTIMIZATION TECHNIQUES

In system analysis**,** the main role of optimization models is to search through a large number of possible combinations of the decision variables to work out the decision policy to optimize a given objective function. However, the representation of the objectives and performance criteria in the required format, is considered a difficult aspect of modeling process which limits the application of the techniques. There are a number of techniques employed in systems analysis. Some of them are mathematical programming (linear, non-linear and dynamic), control theory, calculus of variations, benefit-cost analysis, input-output analysis, optimal search theory, inventory analysis, Langrangian analysis, multivariate analysis, regression theory, factor analysis, principal component analysis, sampling theory, PERT/CPM, simulation, queuing theory, information theory (Meta Systems Inc. 1975).

Extensive review of literature on the subject of reservoir operation and management reveals that choice of method depends on the characteristics of the system being considered, data availability and the nature of the objective function and constraint specified (Yeh 1985).

2.6.1 Linear Programming (LP)

Linear programming (LP) has been in use for quite a time as a systems analysis technique to solve problems in water resources system problems. The name linear programming derives from the fact that the non-linear relationship among various components and parameters are normalized into a linear relationship. This makes the mathematical treatment of analyses simpler. Due to development of high computing ability of modern computers, linear programming algorithms are widely used. The ostensible advantages of treatment of linear programming are manifold. They are (i) the ability to accommodate very large problems associated with the water resources systems (ii) the solution in one level as compared to multi-level problems (iii) near achievement of global optimal solution (iv) amenability for sensitivity analyses.

Strictly speaking, no real life problem, let alone the water resources system problem, is linear. Therefore it always becomes a challenge to make the inter-relationship of parameters in the system linear. The process of devising a linear relationship out of a non-linear relationship is called as the process of linearization.

Indian Scenario:

Maya and Rama Prasad (1989) investigated interrelationship between water availability with resources parameters of animal power, labour and nutritional requirements to optimize net profit and thereby formulating the optimal cropping pattern.

Mohan and Raipure (1992) derived the optimal releases from a large-scale multi-reservoir system of five reservoirs in India by formulating a linear multi-objective programming model to maximize the irrigation releases and maximize the hydropower production

A linear programming model (Sunita Devi 1997) for optimal water allocation in a large river basin system is described by Sunita Devi et al. (2005). The model has been applied to Subarnarekha river in India, having two mainstream reservoirs, two barrages and three small command area reservoirs. The main objective was to optimize the annual benefits accruing from irrigation and hydropower while being constrained by different criteria, TPA (tripartite agreement) being the foremost. The water sharing among riparian states (i.e., undivided Bihar, Odisha, and West Bengal) at individual dams and barrages are thus considered.

Vedula et al. (2005) carried out studies in an existing reservoir command area in Chitradurga district, Karnataka State, India to demonstrate optimal conjunctive use planning in multicrop irrigation area to maximize the sum of annual relative yields of crops in a normal year.

Sethi and Srivastava (2006) formulated a LP model for maximization of the cropped areas at projects sites in Upper Krishna sub-basin taking different constraints relating to reservoir parameters, ground water parameters and command area parameters.

Khare et al. (2007) proposed a conjunctive LP for proposed Krishna (Nagarjunasagar)–Pennar (Somasila) canal, under National Perspective Plan, 1980 with various hydrological and management constraints to arrive at an optimal cropping pattern.

Works outside India

Windsor (1973) analyzed multiple-reservoir flood control operations wherein release schedules were determined minimizing the total damage cost at pertinent locations for a design storm. Reservoir and channel routing equations have been taken into account.

Nayak and Arora (1973) developed a model to solve the problem of finding the best sites for constructing a system of reservoir that will optimally meet the various water demands. The solution involved piece-wise linearization of non-linear relationships. The model was applied to the Minnesota river basin.

Mejia et al. (1974) formulated different decision rules for operation of a multi-reservoir system in the North River located near Montreal. The rules considered range from the standard operating policy to a policy incorporating multiple-period flow forecasting and sequential linear programming for determining the optimal allocation of the available water in space and time.

Yazicigil et al. (1983) formulated an optimization model using LP for a system of four flood control reservoirs in the Green river basin, Kentucky, for use in real-time as well as long-term operations. Recreation and low flow augmentation were considered as secondary objectives.

Martin (1983) applied successive linear approximation technique to solve a deterministic nonlinear optimization problem in a large-scale system consisting of 27 reservoirs on the Arkansa, White, and Red rivers. The optimal long-term operation of the system to meet the target of water supply, stream flow maintenance, and hydroelectric power generation was determined.

Turgeon (1987) sought to solve the problem of optimal site selection along with sizing of reservoir for different components. He compared the solutions obtained from parametric mixed integer linear programming employing the branch and bound algorithm and LP parametric analysis applied at the point of solution.

Lele (1987) dealt with the problem of sizing of reservoir by finding solutions by adopting two algorithms and compared them with the solution obtained from LP formulations. The first algorithm improved on the sequent peak procedure by incorporating storage dependent losses whereas the second one extended it further by incorporating less than maximum reliability.

Afzal et al. (1992) used a LP model to optimize the use of different quality water by alternative irrigation. The model provides for a method of allocating land and water to different crops wherever scarcity occurs in the supply parameters.

Crawley and Dandy (1993) developed a LP model for identification of optimum monthly operation policies for the Adelaide headwork's system in Australia. They developed model with the objective function to minimize the pumping costs while ensuring system reliability by maintaining minimum-target levels in the reservoirs.

2.6.1.1 Explicit stochastic linear programming

Due to the inherent uncertainties in the prediction of behavior of different parameters in a water resources system, the deterministic planning models are often considered inadequate for effective analysis culminating in an acceptable solution. Thus in order to emulate the real life situation, an element of probabilistic treatment to the objective function and constraints are considered.

Works outside India

Markov process was used for the treatment of stream inflows as random variables by Manne (1962) for evaluation of the values of flood control storage for hydroelectric and water supply purpose.

Loucks (1968) also similarly used Markov process to prepare a stochastic model and used stream flow data to Fibger lakes within the Osevego river basin. It was pointed out that the dimensionality problem is associated with this type of model in real situations, which can easily exceed several thousand of constraints.

Houck and Cohon (1978) again followed the Markov process for adding randomness to the streamflow. They devised an algorithm called SESLP (sequential explicitly stochastic linear programming) model for a hypothetical two-site, dual-purpose planning problem. The solution however entailed huge computational requirement to handle heavy data set.

2.6.1.2 Chance-constrained linear programming

Chance-constrained Linear Programming models are another kind of Stochastic LP wherein the constraints are put on a probabilistic guard. The advantages of the model are that they are small and they define explicit operating policies. Another advantage is that they can be converted to their deterministic equivalents with the knowledge of the distribution function.

Indian Scenario

Sethi et al. (2006) worked on DLP and (CCLP) to allocate available resources optimally to maximize revenue in the study area by using QSB package. The net irrigation requirement for crops in this case was considered to be a stochastic process.

Mahootchi et al. (2013) used a stochastic programming technique which includes reliability constraints to solve the optimization problem relating to operations the Parambikulam-Aliyar project (PAP), a multireservoir system in India. The use of reliability constraints as chance constraints in reservoir operations optimization have been used by many authors. However, it has not been popular due to non-applicability to problems with more than one or two reservoirs when such techniques depend on discretization. The new implementation of chance constraints based on a previous model extended to multireservoir systems provides better results than so far known. This work is easy to apply because it requires only a standard nonlinear programming solver.

Works outside India

ReVelle et al. (1969) applied chance-constrained LP to reservoir system optimization. He proposed the linear decision rules (LDR) that relate release to storage and decision parameters.

Further ReVelle and Gundelach (1975) adopted Linear Decision Rule as a way to incorporate the stochastic nature of inflows. A prior knowledge of current inflow is required when using this rule. The reservoir capacity required was slightly larger when compared to original LDR.

Houck (1979) and Houck et al. (1980) also applied the LDRs with different conditions like multi LDR etc. They demonstrated that LDRs generally result in very large models but within the computational feasibility.

2.6.1.3 Implicit stochastic approach based on the yield model

In the implicit stochastic approach, the temporal characteristics of inflows are considered to be included implicitly in the model itself and therefore deterministic methods can directly be considered for application.

Indian Scenario

Sinha et al. (1999b) prepared a linked simulation-optimization formulation, wherein mass equations and the decision variables, like release and storage, are not explicitly considered but are satisfied implicitly through the simulation. Sequent trough algorithm is used for sizing reservoirs. The sizing of reservoirs and hydro-plants, evaluation of objective function and constraints and their derivatives are done as a part of simulation. The model was applied in Purna sub basin of the Godavari basin.

Dahe and Srivastava (2002) made elaborate studies on the basic yield model and further made improvements for application to a system of eight reservoirs in the upper Narmada basin in India. A multiple yield model for multiple reservoir system consisting of single purpose and multipurpose reservoirs with an objective to achieve pre-specified reliabilities for irrigation and energy generation was developed and presented. The model also successfully incorporated a new concept called allowable deficit in annual irrigation target and applied in the study area.

Panigrahi and Srivastava (2005) presented an integrated yield model (IYM) for development problem of Ong sub-basin in Mahanadi basin in the state of Odisha. In the model formulation, the optimal annual yields from reservoirs are assessed based on pre-specified annual release reliabilities with site specific yield failure years and failure fraction factors while simultaneously optimizing the cropping pattern at each site. Results showed that IYM closely reproduce the behaviour of the system and results reasonably match with simulation.

Panigrahi (2006) further improved the yield model and devised IRYM (Integrated River Yield Model) and successfully applied the same to 54 reservoirs in Mahanadi basin lying in Odisha state.

Thube (2007) further improved the model to incorporate particular peculiarities involved in the cases of barrages and hydropower and made a study in Krishna having storages in Maharashtra, Undivided Andhra Pradesh and Karnataka.

Sethi (2008) went further to extend the model for groundwater usage in Cauvery basin by incorporating the tribunal awards as constraints in the model.

Srivastava D. K. and Awchi Taymoor A. (2009) compared results obtained by adopting different methods of optimization, viz., linear programming, dynamic programming, artificial neural networks and hedging rules. Simulation was also done to evaluate the methods adopted. The models were applied to an existing reservoir Mula in India to evaluate the storage, water yield and the operational performance of the multipurpose project. On the basis of the results obtained, reevaluation of the project to cater to the needs of water supply and irrigation was recommended.

Works outside India

Loucks et al. (1981) devised and developed the yield model which has altogether opened up new vistas in the arena of stochastic modelling. The model developed is a general purpose implicitly stochastic LP model that aimed at curtailing the size of constraints usually associated with the explicit stochastic models. In order to achieve this end, he proposed ways to approximate to reduce problem size that are usually very large in case of a complex reservoir system.

Stedinger et al. (1983) compared deterministic, explicitly stochastic and implicitly stochastic reservoir screening models to find out the most desirable model to be adopted in a particular situation. In case of a water resources system, it was found that the implicitly stochastic model provided better solution set. The screening models based on implicitly stochastic model scored over other models due to the following reasons.

i. The screening models that can identify potentially efficient system designs are extremely desirable.

ii. Purely deterministic screening models based on historical mean monthly flows do not provide sufficient reservoir capacity to achieve target reliabilities.

iii. Use of most critical flows in a record leads to larger reservoir capacities and higher system reliabilities

iv. The explicitly storage models, linear decision rule, chance-constrained formulations of ReVelle et al. (1969) and Loucks (1970) overestimated reservoir capacity and generated operating policies that failed to utilize available water and storage space efficiently.

v. The yield model of Loucks et al. (1981) produced reasonable reservoir designs with release reliabilities near targets.

Lall and Miller (1988) provided an optimization model based on the yield model for sizing of potential reservoirs on a river basin. The problem was divided into two parts. In the first part, the reservoir capacities are determined using a modified sequent peak algorithm. Simulation is also done in the second part and used for optimizing the sizing of hydropower generations at the site.

Lall (1995) used the yield model for resolving between surface water reservoirs and ground water development. A hybrid simulation-optimization strategy is used to consider monthly operation of the reservoir and aquifer system. A modified sequent peak algorithm is used for reservoir sizing, and a unit response matrix approach is used to model the ground-water subsystem. The model was applied to Jordan river basin in Utah successfully.

Dandy et al. (1997) also compared the results obtained from simulation, network linear programming, full optimization LP model and the LP yield model for calculating yield from a system containing four reservoirs. On the basis of the studies conducted by them, it was concluded that the optimization model provides for the maximum yield in a given scenario which may be missed in a simulation procedure. However, once optimistion has provided a solution, the accurate evaluation can only be accomplished by the simulation only.

2.6.1.4 Linear programming application in crop planning

L.P models with cropping pattern as constraints for an existing system can be used for evaluation of an existing system as well as crop planning for contemplated projects. The planning and evaluation with respect to the area under command, the crop water requirement for the existing and proposed system along with further derivatives like nutritional and calorie requirement of the population to be served is possible in LP models. Review of available literature reveals the following examples in Indian scenario as well as in countries outside India.

Indian Scenario

Chaturvedi and Chaube (1985) used linear programming model to study the Indo-Nepal region of the Ganga basin. The objective function was to maximize the sum of irrigated areas subject to surface and ground water availabilities.

Maya and Prasad (1989) delved into the issues that involve developing a linear programming model to optimize the net benefit from the system and to determine the optimal cropping pattern under the influence of various parameters, e.g., animal power, labour, fodder production, the resources of farmers, and the nutritional energy requirement of the system. The solution reveals the effectiveness of prevailing agricultural practices consistent with the availability of water resources in the initial crop season.

Paudyal and Gupta (1990) found out the optimal design capacities of irrigation facilities including both the surface and ground water resources and optimal water allocation policies for the conjunctive use by adopting a multilevel optimization approach to a LP model.

Raman et al. (1992) developed a linear programming model to generate optimal cropping patterns from synthetic drought occurrences. From this an expert system was developed for drought management.

Sunita Devi et al. (2005) developed a LP model for optimal water allocation in a trans-boundary system of Subernarekha River involving the states of Odisha, Jharkhand and West Bengal.

Works outside India

Chávez-Morales et al. (1987) presented a linear optimization model for planning the management of irrigation district in the state of Sonora, Mexico. The model considered both the surface and ground water requirements of crops and yielded the cropping pattern and monthly schedule of reservoir releases and aquifer withdrawals that maximize the annual profit in irrigation district

El-Awar et al. (2001) developed a linear programming mathematical model to determine optimum water allocation with the objective to choose the optimal cropping pattern that satisfies the existing climatic, agronomic, economic, land and water availability constraints for a selected pilot study area in Ghazzah, in the South Bekka region of Lebanon.

Moradi-Jalal et al. (2007) also used an LP model to carry out optimal crop planning associated with proper reservoir operation and irrigation scheduling to maximize annual benefits derived from crops and fruits in a mixed cropped area.

2.6.1.5 Mixed integer linear programming (MILP)

The Mixed Integer Linear programming is a type of LP model with restrictions on some components of variables taking integer values. Windsor and Chow (1972) made a study, wherein mixed integer programming is coupled with historical, or stochastically generated, stream flow sequences to derive the optimal design for a complex river basin development. In formulating the model, emphasis is placed on the interrelationships which exist between the various components of the system and the coordination and integration of these components into a single economic unit. The model is designed to determine simultaneously the optimal set and sizes of reservoirs in the system, the optimal target outputs for the tangible water uses, power and irrigation, and the optimal operating procedure for attaining these outputs subject to the technological constraints.

Indian Scenario

Srinivasan et al. (1999) presented a mixed-integer linear programming model for reservoir performance optimization. They improved the mixed-integer formulation of Moy et al. (1986) for a more complete representation of the resiliency criteria. A set of constraints involving zero-one integer variables for spill indication introduced by Shih and ReVelle (1994, 1995) is used in their formulation The improvements achieved with the modified model is demonstrated using the same example as presented with the original model.

Works outside India

Windsor (1975) further presented a methodology for determining the optimal size, number and location of flood control reservoirs in a river basin development. Temporal and spatial flood variability is accounted for in the analysis by using representative sets of recorded or synthetically derived flood hydrographs for each sub-area in the basin. The model is formulated to use LP or mixed integer programming as the optimization tool.

Needham et al. (2000) conducted a study based on the mixed-integer linear programming to address questions related to flood-control operating procedures to be followed by the US Army Corps of Engineers, Rock Island District. The analysis of three projects on the Iowa and Des Moines river was done using the approach.

Wei and Hsu (2007) proposed a procedure involving two models, viz., a hydrological forecasting model and a reservoir operation model for determining the reservoir releases at each time step during a flood. In the reservoir operation model, they compared two flood-control operation strategies formulated as mixed-integer linear programming (MILP) problems for a multipurpose multi-reservoir system.

2.6.2 Dynamic Programming

Dynamic programming (DP) was developed from the study of multistage or sequential decision problems especially the stochastic decision problems. The stage or sequential characteristics of the problem are often time periods. However, the stages are sometimes space or physical entities like reservoir sites. The main advantaged of DP lies in its flexibility and simplicity. However, its disadvantages stem particularly from its inability to address to problems with more than three state variables at each stage. This method was first introduced by Bellman (1957) and has since been recognized as a powerful approach in the analysis of water resources system. Hall and Buras (1961) was first to propose the application of DP to determine optimal returns from reservoir systems. Extensive review of DP applications to reservoir systems can be found in Yakowitz (1982) and Yeh (1985).There are two approaches in the DP which are known as Deterministic DP and Stochastic DP.

Indian Scenario

Vedula and Mujumdar (1992) used a stochastic dynamic programming model to find out the optimal operating policy of a reservoir for irrigation under a multiple crops scenario. An optimal allocation process is incorporated in the model to determine the allocation to individual crops when a competition for water exists among them. The model also serves as an irrigation scheduling model in that at any given intra-season period it specifies whether irrigation is needed and, if it is, the amount of irrigation to be applied to each crop.

Ponnambalam and Adams (1996) used stochastic optimization model to determine optimal operational policies for five of the major reservoirs of the Parambikulam-Aliyar irrigation and power project in India. A closed-loop suboptimal policy was determined for the stochastic supply parameters and deterministic demand problem. Optimal rule curves for the major reservoirs were devised.

Nagesh Kumar and Baliarsingh (2003) developed Folded DP for optimal operation of multi reservoirs, which is an iterative process without the requirement of initial values. The developed algorithm is successfully applied to a hypothetical four reservoir system of Larson (1968a, 1968b).

Works outside India

Bellman and Dreyfus (1962) developed Discrete Dynamic Programming (DDP) based on the use of Lagrangian Multipliers and successive approximations. The main disadvantage of the DDP is dimensionality problem associated. The trade-off between the accuracy and ease of solution in various methods to overcome the problem associated were considered by Baliarsingh and Nagesh Kumar (2002). Workers in Hydrology and elsewhere concede that the limit to the domain of computational applicability of DDP is restricted to problems having at most four or five states and control variables (Yakowitz 1982).

Buras (1963) is considered as one among those who attempted to solve optimization problem using stochastic DP. Both correlation and reliability issues are omitted in the formulated model that seeks to maximize expected return from conjunctive operation of a surface water reservoir and an aquifer supplying water for irrigation.

Larson (1968a, 1968b) developed a technique called incremental successive approximation DP (IDPSA) with a variable time interval and used this approach to solve the four reservoir system problem. However Hall et al. (1969) proposed another version of IDPSA with fixed interval to solve the optimization problem.

Butcher (1971) formulated discrete stochastic dynamic programming and applied it to find the optimal stationary strategy for operating the Wataheamu Dam on the California-Nevada border. He derived the operating policy on a monthly basis. The operating policy was stated in terms of the state of the reservoir indicated by the storage volume and the inflow in the preceding month using conditional probability and inflows as input to the SDP model.

Heidari et al. (1971) considered a four-reservoir problem and proposed a computational scheme called discrete differential dynamic programming. They modified the Larson's incremental dynamic programming to incorporate fixed time steps in the algorithm and named it as DDDP. They solved the same problem as that of Larson (1968a, 1968b). Since then, DDDP has become a popular technique for reservoir operation problem (Chow and Cortes_Rivera 1974, and Chow et al. 1975).

Trott and Yeh (1973) used IDPSA method and applied to a six reservoir problem. The same technique was applied by Giles and Wunderlich (1981) to a reservoir system.

Murray and Yakovitz (1979) used the four-reservoir configuration of Heidari et al. (1971). To illustrate their constrained differential dynamic programming algorithm, they also enlarged the problem to a ten-reservoir case and computed the optimal policy.

Gal (1979) and Turgeon (1981b) describe an approach to derive optimal operating policies for a multiple reservoir system. The proposed approach used a parametric stochastic DP, aggregation-decomposition and aggregation stochastic DP algorithm based on a choice of a parameter vectors that approximate a quadratic return function over a substantial portion of the state space and chooses the set of controls that minimize the returns.

Turgeon (1980, 1981b) developed stochastic DP models for the optimization of weekly operating policies of multi-reservoir hydroelectric power systems. The concept of successive approximations was used to alleviate the problem of dimensionality. Turgeon (1981a) used the progressive optimality algorithm to handle large-scale systems.

Esmaeil-Beik and Yu (1984) used stochastic DP to develop weekly optimal policies for operating the multipurpose pool of Elk City Lake in Kansas. The inflows to the lake were considered serially correlated and it was treated as a periodic Markov decision process with finite states and discrete time.

Marino and Loaiciga (1985b) presented a methodology using a sequential dynamic decomposition algorithm to obtain optimal reservoir operating policies for a large-scale system of the Central Valley Project.

Buras (1985) presented a SDP model for seasonal operation of Sardar Sarovar Project in Narmada river system of Central India. The seasonal inflows were considered to be serially correlated and Markovian decision problem was formulated for discrete state space. Further, he derived the steady state probabilities of initial storages, inflows, and final storages. Finally reservoir releases were estimated corresponding to 75%, 80% and 90% reliability levels.

Karamouz and Houck (1987) concluded that the stochastic DP model performed better than the deterministic DP model for small reservoirs in developing single reservoir operating rules. However, for large reservoirs the deterministic DP model performed better. The authors concluded that the stochastic DP model behavior is highly related to the number of state variables (inflow intervals and characteristic storage) and as these numbers increase, the computational efforts required to solve the model increase drastically.

Braga et al. (1991) developed a stochastic DP model for the optimization of hydropower production of a multiple storage reservoir system. They proposed an offline analysis to establish the value of stored water in terms of future generation of power and used it in an outline SDP analysis.

Liang et al. (1996) demonstrated the use of a methodology of autoregressive decision rule for an aggregated reservoir operation as surrogate of a multi-reservoir system of the Upper Colorado River Basin. The method incorporated a lag-1 correlation for the releases between consecutive periods with the optimal operating policy solved by a stochastic dynamic program. The decision rules with and without incorporation of the autoregressive correlation for the releases were then used in simulated operation of the reservoir with historical inflow records to evaluate their effectiveness. The results showed that the autoregressive decision rule yields more stable and higher reliability of annual water supply for the aggregated reservoir operations.

Zhao et al. (2012) developed an algorithm to improve the computational efficiency of both stochastic dynamic programming (SDP) and deterministic dynamic programming (DP) for reservoir operation with concave objective functions. The results from a real-world case study show that the improved SDP and DP exhibit higher computational efficiency than conventional ones.

Davidsen et al. (2014) applied the water value method, a variant of stochastic dynamic programming, to optimize water resources management in the Ziya River basin. This model was used to assess the economic impacts of ecosystem minimum flow constraints, limited groundwater pumping, and the middle route of the South–North Water Transfer Project (SNWTP).

Pereira-Cardenal et al. (2014) developed an application of SDP, known as the water value method. They used it to maximize irrigation benefits while minimizing the costs of power generation within a power market. The method yields optimal operation rules that maximize current and expected future benefits as a function of reservoir level, week of the year, and inflow state. The method was tested on the Iberian Peninsula and performed better than traditional approaches that use exogenous prices.

2.6.3 Non Linear Programming (NLP)

In Non Linear Programming (NLP), the objective function and the constraints are characterized by nonlinear relationship. As compared to the LP models, the NLPs are more realistic in the sense that they capture the real life phenomena more faithfully. However, the use of nonlinear programming models in water resources systemsare limited due to the computational difficulties.The degrees of difficulties encountered in the NLP are usually a function of the level of nonlinearity and non-convexity of the associated problems. Furthermore, unlike DP, it cannot handle stochastic nature of inflow into the system. In the case of nonlinear model search methods such as that steepest ascent (descent) method or solution techniques for special type of problems such as quadratic programming problem, separable programming problem are used. As such, NLP formulation requires continuity and differentiability in its search procedure. NLP requires large amount of storage and execution time when compared to other methods limiting its applicability to large systems (Yeh 1985). The NLP technique has seen relatively limited applications, as compared to LP and DP to problems of optimizing reservoir operations (Wurbs 1995).

Indian Scenario

Sinha et al. (1999a) improved upon the works of Lall and Miller (1988) and Lall (1995) by replacing the modified sequent peak algorithm for sizing reservoirs with a behavior analysis algorithm that allows operation of the reservoir system with realistic operating policies. They used a nonlinear optimization model for selecting and sizing potential reservoir sites on Par, Auranga, Ambica and Purna river basins in India.

Devamane et al (2006) compared the results obtained from a NLP model and LP model when applied to a multipurpose multireservoir system in the upper reaches of Krishna river basin in Karnataka, India. He analysed the system performances such as the irrigation deficit, frequency of irrigation deficit and power production in the system.

Works outside India

Roefs and Bodin (1970) worked on Dantzig-Wolfe decompositions, which are shown to be reasonably accurate representations of a nonlinear multi-reservoir deterministic optimization problem. The idea is to define a master problem, which can be seen as a coordinating agency and the sub-problems as single reservoir managers. However, substantial difficulties were encountered when it was applied to a three reservoir problem.

Philbrick and Kitanidis (1999) applied deterministic feedback control (DFC) and stochastic dynamic programming (SDP) to a range of hypothetical small-scale reservoir models to illustrate the impact of an increasing departure from the condition of certainty equivalent. Both DFC and SDP incorporate the nonlinear programming package NPSOL as a search engine.

Mendes, L**.**et al**.** (2015) evaluated the impacts of multiple water uses on the operation of a system of existing reservoirs that originally were designed for hydropower generation. The research reported in this paper utilizes a nonlinear optimization model, developed to optimize hydropower production for a system of interconnected reservoirs.

2.7 SIMULATION

Simulation is known as a descriptive technique. A simulation model incorporates the quantifiable relationships among decision variables and describes the outcome of operating a system under a given set of inputs and desired operationpolicy. Most simulation models are not equipped with provisions for optimization.

Often a simulation model is run many times with various inputs and parametric data. The output of these runs describes the response of the system to the variations inputs and parameters. Thus mostly the simulation models are also called 'what if' models and as discussed are most useful in sensitivity analyses.

Indian Scenario

Rangarajan et al. (1999) incorporated a four-step simulation algorithm to derive the loss function in the parlance of reliability programming model, in which a relationship between the reliability and its associated economic losses is established.

Works outside India

Concept of simulation had a head start with U.S. Army Corps of Engineers doing simulation of Missouri River (Manzer and Barnett 1966). The famous Harvard water program applied simulation techniques to the economic design of water resources (Maass et al. 1962).

Wurbs and Karama (1995) used asimulation model called RESSALT and applied it in the evaluation of the water-supply capabilities of a system of 12 reservoirs in the Brazos River Basin in the context of salinity and water supply reliability.

There are several computer programs for reservoir system simulation. The earliest simulation packages of HEC series have been introduced by the USACE Hydrologic Engineering Center (HEC), which was established in 1964. A list of currently available major HEC software packages are listed in Wurbs (1996).

Wurbs (2005) verified the efficacy of a simulation model by incorporating the peculiarities involved in the practice of allocation of water to different stake holders and thereafter verified the availability and reliability of water resources in a water resources system.On the basis of the exercise done and results obtained, he made conclusions about the generalized modeling system and described the lessons learnt in its implementation in the system.

2.8 COMBINED USE OF MODELS

Indian Scenario

Chaturvedi and Srivastava (1981) adopted a sequential iterative modeling process to obtain optimal design alternatives in a system of six major projects namely Bargi, Tawa, Narmada Sagar, Harinphal, Jalsindhi, and Navagam (Sardar Sarovar) in the Narmada river basin in India. They used the simulation model to do the screening on the basis of information obtained from LP models to find near optimal solutions. This study reports the investigations on the alternative combinations, capacities, and operating policies of. The study was aimed at the determination of optimum height of Sardar Sarovar, the terminal storage dam. Deterministic linear programming models [linear programming deterministic continuous (LPDC) and linear programming deterministic discontinuous (LPDD)] were employed for screening, followed by simulation to decide the alternative combinations and capacities of these six major projects. The LPDC model regulated the mean monthly flows whereas the LPDD model used wet and dry years in order to deviate from regulating mean monthly flows.

Srivastava and Patel (1992) used optimization (LP and DP)-simulation models for systems analysis of the Karjan irrigation reservoir project in India. They reported that, the linear programming model is most suitable for finding reservoir capacity. Dynamic programming may be used for further refining the output targets and finding the possible reservoir carry-over capacity. The simulation should then be used to obtain the near optimum values of the design variables.

Vedula and Nagesh Kumar (1996) made a two module presentation pertaining to a system. The first module was an intra-seasonal allocation model to maximize the sum of relative yields of all crops for a given state of the system using LP. The second module used a stochastic dynamic programming (SDP) to derive the steady state reservoir operating policy. The objective of the SDP was to maximize the expected sum of relative yields of all crops in a year.

Works outside India

Hall and Shephard (1967) used DP for optimizing individual reservoirs and LP for combining the reservoirs for determining the optimal operating policies for reservoirs of CVP.

Hall et al. (1969) used DP-LP technique to find the optimal release for firm, dump, peak and off-peak power generation. The objective function was to maximize the benefits from the system while considering other uses of water as constraints.

Windsor and Chow (1971) demonstrated the use of combined optimization model for a farm irrigation system. At the first level of optimization dynamic programming model was used to estimate the expected yield data and expected irrigation labour and water requirements for each crop. Linear programming model was used for second level optimization for optimal land and water allocation.

Viessman et al. (1975) combined both the optimization and simulation models to select the most efficient arrangement of components for regional water resources development and management policy. The technique was applied to the Elkhorn river basin in Nebraska. The model is also used as a preliminary screening tool.

Wurbs et al. (1985) also reported that during the past many years, a major thrust of research and the resulting literature related to reservoir operation has been to supplement simulation models with optimization techniques such as linear programming, dynamic programming and various nonlinear programming algorithms. Simulation models may also be embedded within an optimization model. Likewise, one or more optimization models may be embedded within a complex simulation model. Simulation and optimization model may be either deterministic or stochastic. Some of simulation-optimization work has already been presented in the optimization section.

Ponnambalam and Adams (1987) used stochastic dynamic programming (SDP) and carried out optimizationof the reservoir level to provide a closed-loop type of policy. A modified SDP model was proposed for the farm level optimization. A deterministic coordination between the reservoir and farm level is accomplished by a Dantzig-Wolfe type linear programming algorithm for determining the optimal irrigation water allocation in a canal system in India to maximize the net benefits of agricultural production.

Wurbs (1995) reviewed the simulation models, which according to him, provide a broad range of modeling capabilities in the context of reservoir/river system operation models. In order to select the best decision, simulation models have to be used in conjunction with optimization models. The most effective strategy for analyzing multi reservoir operation problems will involve a combination of both optimization and simulation.

Q. Goor et al. (2011) made a presentation on stochastic dual dynamic programming (SDDP) that can be proposed to be used to solve complex operation problems in a stochastic environment. This algorithm requires that the one-stage optimization problem be a convex program so that the efficient Benders decomposition scheme can be implemented to handle the large state-space that characterizes multireservoir operation problems. Recent developments improve the representation of the nonlinear hydropower function through a convex hull approximation of the true hydropower function. A network of hydropower plants and irrigated areas in the Nile Basin is used to illustrate the difference between the two SDDP formulations on the energy generation and the allocation decisions.

Bozorg-Haddad et al. (2014) developed metaheuristic algorithms for optimum reservoir system operation as an alternative to traditional operations research algorithms such as linear programming (LP), nonlinear programming (NLP), and dynamic programming (DP). They used the metaheuristic bat algorithm (BA) and its application to the optimal operation of the Karoun-4 reservoir system in Iran and to a hypothetical four-reservoir system. The merits of the performance of the BA in the optimization of reservoir operation are demonstrated by comparison to those of LP, NLP, and genetic algorithm (GA) in terms of the convergence to global optima and of the variance of results about global optima for reservoir optimization problems.

Steinschneider et al. (2015) presented a decision-scaling based framework to determine whether one or more preselected planning alternatives for a multiobjective water-resources system are robust to a variety of non-stationaryhydro climatic conditions and modeling uncertainties. The decision-scaling methodology is advanced beyond previous applications with an efficient procedure to select realizations of climate variability and Bayesian methods to assess the effects of hydrologic uncertainty.

2.9 SOME MORE APPLICATIONS OF SYSTEM ANALYSIS TECHNIQUES TO THE FIELD OF WATER RESOURCES SYSTEMS

There have been recent developments of applications of system analysis in water resources development. Different applications like artificial neural network, hedging rules, reliability programming, experts system technology, fuzzy inference system, game theory, queuing theory, Markov chain, artificial intelligence, genetic algorithms, fuzzy based logic system etc. been more popular in the domain of system studies.

It will not be out of place to mention here that different authors in the last half century have contributed variously in the field of system studies in Water Resources Development. They are Maass et al. (1962), Hufschmidt and Fiering (1966), Hall and Dracup (1970), Ladson (1970), James and Lee (1971), Biswas (1976), Haimes (1977), Major (1977), Cohon (1978), Major and Lenton (1979), Loucks et al. (1981), Goodman (1984), Helweg (1985), Chaturvedi and Rogers (1985), Jewell (1986), Chaturvedi (1987), Labadie and Fontane (1989), Karamouz (1990), Datta (1993), Hiller and Lieberman (1995), Wurbs (1996), Biswas (1997), ReVelle (1999), and Wurbs and James (2002). Application of the system analysis techniques to real life problems related to some river basins in India are reported in doctoral works carried out by Srivastava (1976), Ranvir Singh (1981), Chaube (1983), Bhatia (1984), Singh (1991), Kohistani (1995), Khosa (1997), Sunita Devi (1997), Mishra (1998), Waikar (1998), Talukdar (1999), Kothari (1999), Dahe (2001), Al-Mohaseen (2003), Chaudhury (2003), Jena (2004), Patil (2004), Awachi (2004), Deepti Rani (2004), Ahmed (2004), Sara (2004), and Panigrahi (2006).

Indian Scenario

Mohan and Rangacharya (1991) adopted a methodology to identify the parameters in identifying drought, which include onset, termination and severity, from the available historic data on stream flow and rainfall having seasonal pattern.

Mohan and Arumugam (1994) developed a rule-based expert system for crop selection in India. The development of a PC based expert system (CROPES) for selecting crops in a region in Tamilnadu, India is presented that uses all available information to select the best suitable crops.

Kumar et al. (1996) used the box complex nonlinear programming algorithm for the optimization. In this model a system-dependent simulation model is developed incorporating the concept of reservoir zoning to facilitate releases and transfers. The simulation model generates a large number of solutions, which are then screened by the optimization model.

Arumugam and Mohan (1997) developed an integrated decision support system (DSS) to help in operating a tank irrigation system in south India. The DSS was evaluated to assess its decision-making capability using five years data. Shortages in irrigation water supply simulated from the DS were less than those occurring in the actual operation practiced by water authorities.

Lohani and Loganathan (1997) studied on the stochastic behavior of extreme drought events. They utilized the Palmer Drought Severity Index (PDSI), which provides a numerical value for drought severity classes with the highest class being the extreme drought. They utilized this class assignment to formulate a non-homogenous Markov chain model to characterize the stochastic behavior of the index. The computed probabilities are then used to develop a decision tree for drought management. The main advantage of the proposed technique is the enumeration of all possible sequences of drought occurrences.

Ravi Kumar and Venugopal (1998) worked on Krishnagiri Reservoir Project in southern India and devised a three stage treatment in the model. Simulation-SDP-Simulation represented sequential steps based on the model. While the first stage simulated the command area of the reservoir, the second one adopted a SDP model to obtain an optimal release policy. This SDP model considers both demand and inflows as stochastic and both are assumed to follow first-order Markov chain model. Third stage is simulation using the optimal release policy from the SDP model.

Ravi Kumar and Khosa (2005) adopted a sequentially implemented multi-criteria approach to the problem of allocating Cauvery water among the co-basin states of Karnataka, Tamilnadu and Kerala.

Works outside India

Hashimoto et al. (1982) contributed to the understanding of three concepts like reliability, resiliency and vulnerability and their importance in evaluating and selecting alternative design and operating policies.They demonstated it with application to a water supply reservoir.

Simonovic and Marino (1982) extended the approach of Hashimoto et al. (1982) for a system of multipurpose reservoirs. The reliability programming model they adopted was nonlinear. They split it into two models: search model and special linear programming model. A two-level solution algorithm was proposed. The procedure was illustrated using a portion of Red river system in Oklahoma and Texas, which is a system of three reservoirs.

Wurbs and Bergman (1990) postulated an evaluation of key practical aspects of analyzing reservoir system yield from the perspective of a case study. They stated that estimates of yield versus reliability relationships and firm yield are fundamental to water supply planning and management and therefore must be given due importance.

Loucks (1992) observed that the major challenges facing water resources system planners and managers, the information they need to meet these challenges, and the role analysis have in helping to provide this information, have been discussed. The author has reviewed some criteria for evaluating the success of any molding activity designed to help planners or managers to solve real life problems.

Wurbs and Yerramreddy (1994) used conventional simulation models and network flow programming for a case study of the Water Rights Analysis program (TAMUWARP). A comparative evaluation of the alternative modeling approaches is provided. They found that, in general, the characteristics of the alternative modeling approaches result in each being most appropriate in certain situations. The different models can also be used in combination.

Loucks (1995) reviewed another new area called decision support system (DSS). He emphasized on the information needs of the decision making process that motivate the development of DSSs. The focus of the paper is on the process of the successful DSS development and implementation. The paper concludes by identifying some research needs and opportunities affecting DSS development and its effective use.

Wurbs (1996) dealt with an optimisation problem on minimization of cost of a flood reduction plan which included both structural and non-structural components.He made economic analyseson the annual cost and annual benefits to be derived from the plan. A hydrologic and economic simulation model is combined with a search algorithm. The simulation model incorporates procedures for determining the total economic cost for a specified plan. The optimization algorithm iteratively executes the simulation model in an automated search for the optimum plan.

Wurbs (1997) considered water quality, return flows, hydrologic data compilation, and reliability assessment in a simulation study of the Brazos River Basin and identified issues and concerns that illustrate the practical complexities of administering and modeling a water allocation system. He states that the issues affecting evaluation of water availability within the Texas water rights system are representative of other states as well. The study is useful in highlighting the major concerns, issues and constraints, which are to be handled while managing such systems

Jacobs and Vogel (1998) utilized a graphical tool for allocating and permitting water withdrawals in a river basin by using simple spreadsheets to facilitate easy understanding. A mathematical programming methodology facilities optimal stream flow allocation while maintaining desired levels of in stream flow.

Vogel et al. (1999 experimented on the behavior of individual storage reservoirs across the United States. Statistical treatment on the inflow records were made to variously organize the data set. The resilience and vulnerability of the parameters were derived for reservoirs fed by correlated lognormal inflows. They compared the resilience, reliability, yield, and vulnerability of individual reservoirs under existing scenarios and one possible future climate scenario.

de Azevedo et al. (2000)made a study on river basin planning of the Piracicaba river basin in the State of Sao Paulo Brazil with the integration of surface water quantity and quality objectives within the framework of a decision-support tool. Emphasis is given to simulation-based assessment of strategic planning alternatives through the combined use of water allocation (MODSIM) and water quality routing (QUAL2E-UNCAS) models. Uncertainty from temporal and spatial variability and inadequate data associated with model parameters is addressed.

Lund (2000) made studies on reservoirs in parallel, in series and single reservoir cases where reservoirs typically refill before they empty and for parallel reservoirs when reservoirs are expected to drawdown to empty. He derived and discussed theoretical hydropower operation rules for them.

Jenkins and Lund (2000) evolved an economic-engineering modeling approach for integrating urban water supply reliability analysis with storage management options such as dry year option and spot market water transfers, water reuse and long-and short-term water conservation. The integrated model uses a probability plotting position formula to link supply side yield simulation to probabilistic storage management optimization.

Peng and Buras (2000) estimated the inflows into a multiple reservoir system where storage levels and gauged releases are available at regular intervals. The inflows were estimated by water budget computations.

Zhao et al. (2014)developed optimal hedging rules for reservoir flood control operation under hydrological uncertainty using hydro economic and mathematical analysis. The capacity to convey flood flows is sometimes a scarce resource. Hedging for flood operations uses reservoir storage to allocate the expected flood-safety margin (EFSM, i.e., the gap between expected flood volume and flood-conveyance capacity) optimally between present and future periods. Optimal flood-operation hedging falls into three cases, namely, (1) for large expected floods, all flood storage and almost all channel-conveyance capacity are used in the current period to cope with the current, more certain, and urgent flood risk; (2) for medium expected floods, the available EFSM is balanced between the current and future periods, but a larger portion of the total EFSM remains allocated to the current stage; and (3) for small expected floods, the future stage receives greater EFSM allocation by keeping reservoir space empty in the current period. Optimal hedging for flood operation is illustrated by a curve similar to that of hedging for water supply. The physical implications of hedging highlight the economic significance of this practice for balancing the marginal value of scarce flood-management resources under uncertainty.

Berguland (2015) developed agent-based models and multiagent systems to simulate the emergence of system-level properties based on the actions of adaptive agents that interact with other agents, react to environmental signals, and optimize decisions to achieve individual goals. In water resources planning and management, agent-based modeling has been applied to explore, simulate, and predict the performance of infrastructure design and policy decisions as they are influenced by human decision making, behaviors and adaptations.

2.10 LATEST SOLUTION TECHNIQUES

Keeping with the development of technology and greater understanding of the underlying processes in physical phenomena, new models and solution techniques have come into play. Though they are at different stages of development and rigour of further scientific scrutiny will be required for further acceptability by the scientific community, their contribution to the understanding of nature has been phenomenal.

Thenew techniques used in water resources system analysis, that are competing with the established techniques can be described as evolutionary algorithm (EA), computational intelligence (CI) or artificial intelligence (AI) (Heitkoetter and Beasley 1995). Computational intelligence incorporates EA, Fuzzy Logic Systems (FLS), Artificial Neural Network (ANN), and Simulated Annealing (SA). EA may currently be characterized by the followings pathways: Genetic Algorithms (GA), Evolutionary Programming (EP), Evolutionary Strategy (ES), Genetic Programming (GP) and several other problem solving strategies that are based upon biological observations dating back to 19^{th} Century (Charles Darwin and his theory of evolution).

Indian Scenario

Srinivasa Raju and Nagesh Kumar (2004) demonstrated the efficacy of adopting Genetic Algorithms (GA) for irrigation planning. They compared the results obtained from GA with that from LP and found that the results compared well.

Ahmed and Sarma (2005) carried out studies on optimal operating policy of a multi-purpose reservoir, located on the river Pagladia in India with the help of a GA model. The operating policy derived from a synthetic monthly stream flow series of 100 years was compared with that of the SDP model. The results obtained in GA model compared well.

Mishra and Kothari (1989) developed a multiobjective (fuzzy set) approach to decision making in irrigation planning and demonstrated it within the framework of linear programming by means of a case study. An optimal land allocation plan is obtained with several non-commensurate and conflicting objectives.

Vasan and Srinivasa Raju (2007) presented Differential Evolution (DE) to a case study of Mahi Bajaj Sagar Project (MBSP), India and compared with the results obtained from LP model. Comparison of results for the given parameters indicated that both the results are comparable even for high dimensional problems.

Dattatray G. Regulwar and Jyotiba B. Gurav (2011) discussed the Multi Objective Fuzzy Linear Programming (MOFLP) irrigation planning model formulated for deriving the optimal cropping pattern plan for the case study of Jayakwadi project in the Godavari river sub basin in Maharashtra State, India considering four conflicting objectives.

Works outside India

Fahmy et al. (1994), Oliveira and Loucks (1997), Wardlaw and Sharif (1999) and Sarma and Ahmed (2004) applied GA to different reservoir operation problems. Every author agreed on the point that GA has a distinct advantage over standard DP techniques in terms of computational requirements and it has potential as an alternative to SDP.

Another new addition in the area of water resources system is Fuzzy rule based modeling (Zadeh 1965). Fuzzy logic based approach is an approximate reasoning method and is useful for coping with uncertainties in modeling situations. It is also more flexible than regression and allows the modeler to incorporate expert opinion (Ross 1995).

Murat Kilic · Suer Anac (2010) developed a multi-objective planning model and applied on the Menemen Left Bank Irrigation System of the Lower Gediz Basin in Turkey. The aims of the model were to increase the benefit from production, to increase the size of the total area irrigated, and to reduce the water losses.

Mehmet Kucukmehmetoglu and Jean-Michel Guldmann (2010) presented the formulation and application of a multiobjective linear programming model, where each objective represents the benefits for a country from using water for agriculture, urban consumption, and energy production, net of conveyance costs. This model is applied to the Euphrates and Tigris River basin and its three riparian countries-Turkey, Syria, and Iraq.

Li et al. (2015) developed a two-level linear fractional water management (TLFWM) model based on interactive fuzzy programming. The model can solve multi-objective problems quantitatively, particularly for the ratio multi-objective problems (e.g., benefit per unit of water in water resources management system).

2.11 SUMMARY

A detailed discussion made in chapter reveals a number of things about the comparative advantages and disadvantages of adopting different models. Each of these models has its own set of advantages and disadvantages to deal with. Therefore it is not only important to have a right model but also to have a relevant model which can answer the problems at hand more satisfactorily than others.

Of the different optimization models, the deterministic approach is the simplest, easy and versatile one. However, this results in less faithful description of the underlying process which is not deterministic. As a result adopting deterministic reservoir screening models, the reservoir capacity either gets underestimated or overestimated impacting on the reliability to be achieved in a water resources system. These findings were made from studies made by Stedinger et al. (1983). Similar observations were also made by Yeh (1985). (Chaturvedi and Srivastava 1981) also, on the basis of their studies, concluded that in the foregoing cases a further refinement would be required of the results obtained from the deterministic analysis.

However, the stochastic models, which represent the real life situation, are not easy to adopt. The most important drawback of using it stems from the curse of dimensionality. Thus there is a dimensionality problem associated with stochastic models in real situations, which can easily exceed several thousand constraints (Loucks 1968). Similar conclusions are also put on record by Jacoby and Loucks (1972), and Houck and Cohon (1978).

ReVelle et al. (1969) considered chance-constrained programming using linear decision rule (LDR), initiated its application to reservoir system optimization. There are two basic limitation of LDR. First, it yields conservative results, i.e., overly large reservoir capacities, and second, the solution from an LDR model is not guaranteed to be optimal as it reduces the number of possible operating policies and each flow in each period is considered critical (Loucks and Dorfman 1975). Stedinger et al. (1983) reported a comparative study of deterministic, implicitly stochastic and explicitly stochastic reservoir screening models with an evaluation by simulation using the space rule. In this study, it was found that the chance-constrained model using the LDR proposed by ReVelle et al. (1969) substantially overestimated the reservoir capacity requirements.

Dynamic programming (DP) and in particular discrete dynamic programming (DDP) have a distinct disadvantage over the dimensionality problem that occur when the problem size reaches the threshold value. Attempts at improving the model to address the problem of dimensionality have not yielded the desired results.

Nonlinear programming algorithms are considered to be truthful to the nature of physical phenomena as no relation between components or parameters in a system is linear. Different programming techniques employed are i) Successive (or sequential) Linear Programming (SLP); ii) Successive (or sequential) Quadratic Programming (SQP) (or projected Lagrangian method); iii) Augmented Lagrangian method [or method of multipliers (MOM)]; and iv) Generalized Reduced Gradient method (GRG) (Labadie 2004). However, the disadvantages of the method lie in the difficulty and reliability in solving due to non-linear nature of the problem. Hiew (1987) compared the SLP, GRG and a feasible direction form of SQP for hydropower systems of up to seven reservoirs and concluded that the SLP method was by far the most efficient among the various nonlinear programming algorithms. Grygier and Stedinger (1985) also concluded that SLP was the most efficient of the mathematical programming algorithms evaluated. Arnold et al. (1994) compared SQP with method of multipliers. Results show that MOM converged more rapidly than SQP, but to a somewhat less accurate solution (Labadie 2004).

Simulation is a descriptive technique employed to assess the behaviour of the system catering to a set of operation rules. However, it fails to locate the best or optimal policy that can be adopted in a particularly constraining environment. To put it in another way, in order to find the optimal policy, a large number of simulation runs are to be made catering to different operating rules and thereafter selecting the best one. Thus, if there is no prior knowledge of what the maximum possible annual yield may be, the process of yield estimation may be long and tiresome (Dandy et al. 1997). They are ill suited for prescribing the best or optimum strategies when flexibility exists in coordinated system operations.

2.12 SYSTEM ANALYSIS TECHNIQUE ADOPTED IN THIS STUDY

The study in hand is about the application of systems analysis to large scale water transfers in peninsular India, which is complex in nature. The optimization of the of system of reservoirs encompassing 194 reservoirs spanning over 54 sub-basins in 5 major river basins in India encompassing about a million square km (8,49,718 sq. km) and covering 25% of the geographic area of India requires considerable computing effort.

Keeping in view the literature review conducted on the various systems analysis techniques. The comparative advantages and disadvantages of the various models and techniques have been discussed in details. The non-linear forms of optimization can give satisfactory solution for small problems, but in case of a large problem like one at hand, the process becomes very cumbersome due to dimensionality problem.

The implicit stochastic optimization model overcomes the difficulties faced in analysing a large river basin's water resources developmental modelling for its optimal planning of resources, as the modelled system has thousands of design variables. While maximizing the system's water yields, the objective function in the model remains linear. Except a few, most of the system's constraints in the model are also linear. The non-linear system constraints (the hydropower generation constraints) in the model can be easily converted into a linear form for the model solution. Other models may not be able to handle such a large problem in practice.

Thus from the discussion held, it is clear that the deterministic LP model does not faithfully represent the processes underlying the hydrological processes. This leaves only the stochastic LP model to look for. The explicit stochastic model is also not suitable due to problem of handling large data. Thus it is seen that the foregoing models do not have the capability to handle a complex large river basin system where the basic issue is of optimal transfer of water resources from one large basin to another and where the number of decision variables and constraints are large.

Thus the implicit stochastic approach based ***yield model*** is found to be most appropriate. It can consider a longer period of flow record and incorporate the reliability of releases, keeping the size of problem computationally manageable. It can incorporate an allowable deficit criterion for the annual reservoir yield, thus assuring a certain proportion of the annual yield to be made available during failure years and thereby reducing the vulnerability of the system and also gives optimal crop plans simultaneously as has been discussed in the literature review.

2.12.1 The Present Study and Literature Enhancement

For integrated water resources development and planning in a river basin system in a multi stakeholder water user's domain: beforehand it is essential to analyze which water (the river basin under consideration), what water (the water potential in the basin), and why do we need water (the purposes of water uses), i.e., are we talking about. Then, there would be a large number of well known problems related to the expected behavioural aspects of the integrated multi-reservoir system in the concerned river basin. Detailed in-depth answers for many such intricate aspects/problems/questions are required to be derived. These answers cannot be derived from the available conventional methods of water resources analysis. The application of the systems analysis technique for integrated trans-boundary river basin water resources developments with multi-reservoir system, using linear programming (LP) optimization based approximate reservoir yield model is a new methodology, which works as a preliminary screening model. Enormous information could be derived from these model's solutions (Srivastava 2013). Such answers relate to whose' waters and its supply availability in space and time, i.e., from where and when and but then for whom, are essentially established and ascertained.

Therefore, during a normal water year, this enormous information is basically about the values of the expected physical behaviour of each and every reservoir in the river system. These are (a) the reservoir's optimal annual quantum of yields with within-the year distributions (firm and secondary, and water shares for the co-basin states involved) and within-the year distributions of storages, and reservoir's behavioural statistical properties; and (b) the expected optimal crop plans under various resource bounds and their statistics at each reservoir. Also, the preliminary screening models give a lot of impetus to simulation's success in further analysis and refinement towards solution of the problem.

Therefore, the research work in this present thesis on integrated systems optimization studies, using generalized reservoir yield model (GRYM), enhance the knowledge and literature in the field of systems analysis modelling and its application to large scale water resources river basin developments including water transfers in space and time. The study also contributes in achieving and providing optimally the answers to the intricate behavioural aspects of any trans-boundary river system, and which previously would have remained out of reach or were left unanswered.

CHAPTER 3

THE STUDY AREA

3.1 INTRODUCTION

The proposed Mahanadi-Godavari-Krishna-Pennar-Cauvery-Vaigai-Gundarinter-basin water transfer link comprising the first part of the peninsular river development component of National Perspective Plan, 1980 of Ministry of water Resources, Government of India is the study area.It covers all the major river basins of peninsular India with an area of 849,718 sq. km. and about 25.85% of the geographical area of India. If the intervening small basins in between these large basins are added, the figure will be even more. The details of the basins covered are in Table 3.1

Table 3.1 The geographical area of different basins in the study area

Sl. No.	Basin	Geographical Area (sq. km)	Geographical area as percentage of geographical area of India (%)
(1)	(2)	(3)	(4)
1	Mahanadi	141,589	4.30
2	Godavari	312,813	9.51
3	Krishna	258,948	7.87
4	Pennar	55,213	1.68
5	Cauvery	81,155	2.59
	Total	**8,49,718**	**25.95**

The proposals envisage diversion of surplus flows of the Mahanadi to the Godavari system and thereafter to water deficit basins of Krishna, Pennar, Cauvery and Vaigai. This would benefit the drought prone areas of Odisha, undivided Andhra Pradesh, Karnataka, Maharastra and Tamilnadu. As per the study carried out so far, the scheme consists of diverting 12165 MCM of water annually from Mahanadi through Mahanadi-Godavari link canal. From Godavari, a quantity of 26122 MCM of water including the water received from Mahanadi-Godavari link is proposed to be diverted to Krishna. Out of the water so received from Godavari, a quantity of 14080 MCM of water is to be diverted to Pennar. From Pennar, a quantity of 8343 MCM of water is proposed to be diverted to the Cauvery basin. Further down, a quantity of 2252 MCM of water is proposed to be diverted to meet the demands of Vaigai and Gundar basins. The diversion of water is proposed to be accomplished through construction of 9(nine) numbers of link canals. A line diagram showing the inter linkages of the link canals are shown in Fig.3.1

3.2 LINK CANAL 1: MAHANADI (MANIBHADRA) – GODAVARI (DOWLAISWARAM)

The Mahanadi (Manibhadra) - Godavari (Dowlaiswaram) link canal takes off at Manibhadraand traverses a total distance of 827 km in Odisha and united Andhra Pradesh States. The canal mostly completes its path as a contour canal and joinsDowlaiswaram barrage which happens to be the terminal structure on river Godavari.

The link canal has been proposed to run through the states of Odisha benefitting the districts of Khurda, Nayagarh, Ganjam and Gajapatidistricts.Similarly benefits will accrue to the districts of Srikakulam, Vizianagaram, Visakhapatnam and East Godavari in undividedAndhra Pradesh. The distance covered by the canal is 302 km in the state of Odisha, the rest being in Andhra Pradesh.The link canal runs mostly parallel to the East coast, and close to NH 5 and Chennai - Kolkata railway main line.

The proposed link canal is designed to discharge 801.98 cumec at head, 352.79 cumec at the tail end. The command area proposed enroute of the link canal lies in Nayagarh, Khurda, Puri, Cuttack, Ganjam and Gajapati districts of Odisha State and Srikakulam, Vizianagaram and Visakhapatnam districts of Andhra Pradesh State.

3.2.1 Mahanadi River Basin

The Mahanadi, one of the largest peninsular trans boundary river system and the 6th biggest river of India, is an east flowing interstate river (Chaturvedi, 1985). It is bounded on the north by Central India Hills, on the south and east by Eastern Ghats and on the west by Maikela range, lying on the north east of Deccan Plateau. The basin extends over an area of 1, 41,589sq. km is encompassed within the geographical co-ordinate of east longitude $80^0 30^{'} 00^{''}$ and $86^0 48^{'} 56^{''}$ and north latitude $19^0 20^{'} 00^{''}$ to $23^0 35^{'} 00^{''}$. Seven principal tributaries of Mahanadi are Sheonath, Jonk, Hasdeo, Mand, Ib, Ong, and Tel.

Besides these principal tributaries, all other minor tributaries which are directly draining to main river are clubbed to form three sub-basins namely, Upper Mahanadi, Middle Mahanadi, and Lower Mahanadi. Taking these three into consideration, the Mahanadi river basin has 10 number of sub-basins. The annual rainfall varies from 1143 mm to 2032 mm over the entire basin and more than 90 percent of the annual rainfall

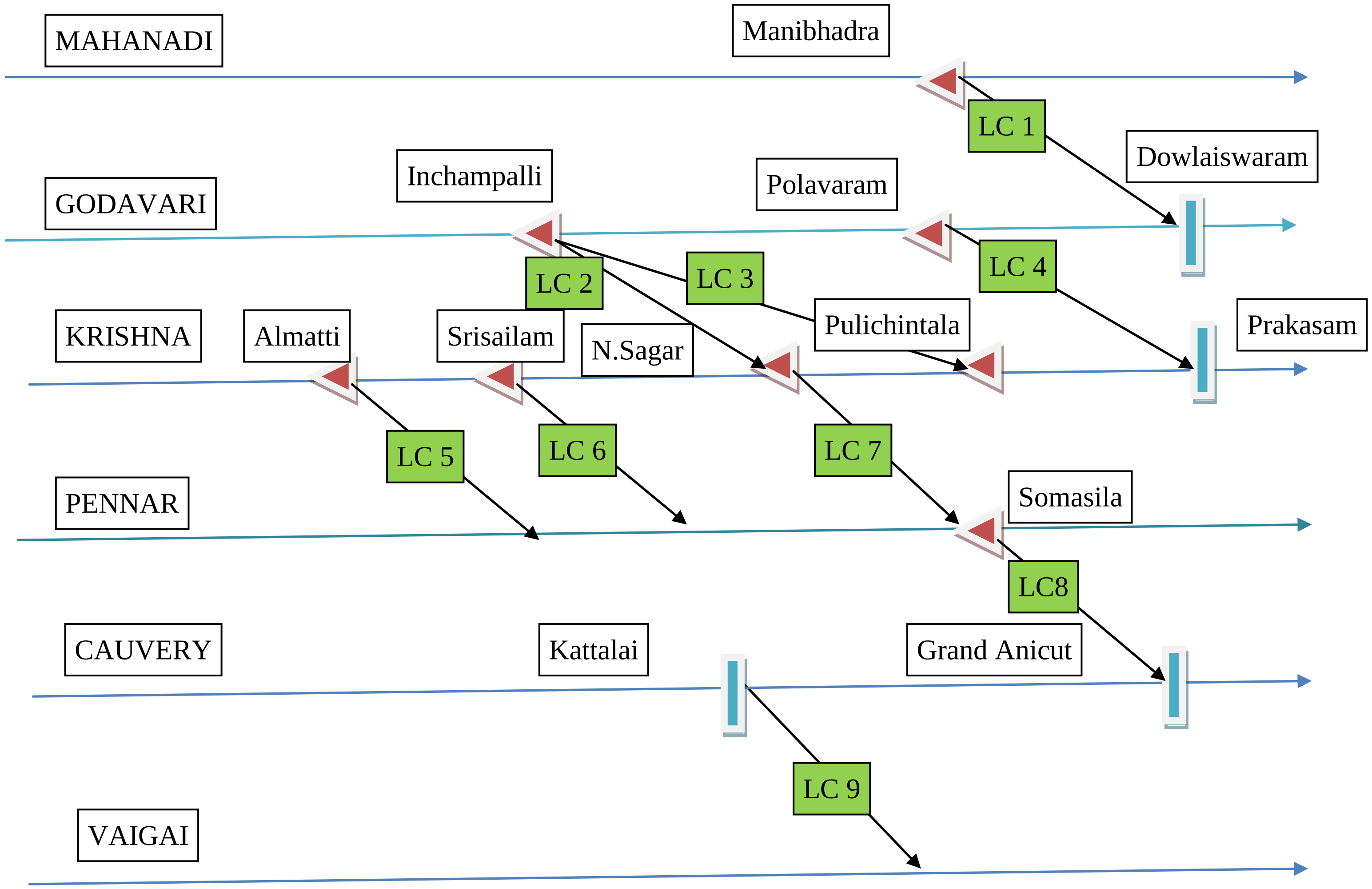

Fig. 3.1 Line diagram showing the configuration of Mahanadi-Godavari-Krishna-Pennar-Cauvery link in peninsular India

occurs during monsoon season spread over from June to October. Sub-basin wise break up of Mahanadi river basin lying in different states is presented in Table 3.2.

Table 3.2 Sub-basin wise break up of Mahanadi river basin lying in different states

Name of the sub-basin	Catchment area (sq km)				Total (sq. km)
	Maharastra	Jharkhand	Chhattisgarh	Odisha	
(1)	(2)	(3)	(4)	(5)	(6)
Sheonath	238		30523		30761
Jonk			2495	989	3484
Hasdeo			9856		9856
Mand			5200		5200
Ib		126	4579	7742	12447
Upper Mahanadi			20107	1545	21652
Ong			1039	4089	5128
Tel			1385	21433	22818
Middle Mahanadi			152	12502	12654
Lower Mahanadi				17589	17589
Total	**238**	**126**	**75336**	**65889**	**141589**

3.2.2 Godavari River Basin

The Godavari basin is the largest river basin in the southern part of India. The river drains an area of more than 1.4 lakh sq. km. and has in its catchment the states of undivided Andhra Pradesh, Maharashtra, Madhya Pradesh, Chhattisgarh, Karnataka and Odisha. The Godavari basin is bounded on the west by the Western Ghats on the south by the Ajanta Range and the MahadeoHills, on north by the Satmala Hills, and on the east by the Eastern Ghats.

The river Godavari happens to be the second largest in India. It covers about 10% of the geographical area of the country. It rises in the Sahyadri hills at an altitude of about 1067 m near Triambakeswar in the Nasik district of Maharashtra State.It traverses a distance of 1465 km in a general south-eastern direction before having its outfall in Bay of Bengal.The states of Maharashtra and undivided Andhra Pradeshare the riparian states for the basin.

Godavari has 10 tributaries joining it before its outfall in Bay of Bengal. They are (i) Pravara, (ii) Purna, (iii) Manjra, (iv) Maner, (v) Pranhita, (vi) Penganga, (vii) Wardha, (viii) Wainganga, (ix) Indravati and (x) Sabari. Out of the total basin area of 312813 km^2, Maharashtra, Karnataka, undivided Andhra Pradesh, Madhya Pradesh, Chhattisgarh and Odishahave their share of areas as 152199 km^2, 4406 km^2,73201 km^2, 26168 km^2,39087 km^2and17752 km^2respectively.Sub-basin wise break up of Godavari river basin lying in different states is presented in Table 3.3

Table 3.3 Sub-basin wise break up of Godavari river basin lying in different states

Name of the sub-basin	Catchment area (sq. km)						Total (sq. km)
	Maharastra	undivided Andhra Pradesh	Karnataka	Madhya Pradesh	Chhattisgarh	Odisha	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
U.Godavari	33502						33502
Pravara	6537						6537
Purna	15579						15579
Manjra	15665	10773	4406				30844
M.Godavari	1122	16083					17205
Maner		13106					13106
Penganga	22344	1554					23898
Wardha	22130	355		1602			24087
Pranhita	30100	6157		24566	271		61094
L.Godavari	269	20292			4308		24869
Indravati	4951				29279	7435	41665
Sabari		4881			5229	10317	20427
Total	**152199**	**73201**	**4406**	**26168**	**39087**	**17752**	**312813**

3.2.3 Basin covering the streams between Mahanadi and Godavari

There are three major rivers flowing between the river Mahanadi and Godavari. They are Rushikulya, Vamsadhara and Nagavali.The link canal traverses through the basins.

3.2.3.1 Rushikulya basin

The basin comprises an area which is undulating and sloping flat plains.The catchment area of the basin is 1320 km^2 and roughly fan shaped. The basin lies in Odisha State in two districts viz., Puri (951 km^2) and Ganjam (369 km^2).

3.2.3.2 Basin covering the streams between Rushikulya and Vamsadhara

There are a few important streams like Bahuda,Poichendia,Kontiajore,Bogi and MahendraTanayaflowing east between the river Rushikulya and Vamsadharaand independently joiningthe Bay of Bengal.The catchment area of these streams is 3790 km^2. They cover Ganjam district of Odisha and Srikakulam district of Andhra Pradesh.

3.2.3.3 Vamsadhara basin

Vamsadhara is an important east flowing river between Mahanadi and Godavari.Ithas its catchment in Odisha and Andhra Pradeshstates. It is surroundedby the Mahanadi basin, Rushikulya basinand Nagavali basin.The catchment area comprises of hilly terrain. The river rises inPhulbani district of Odishaand traverses a length of 221 km before joining the Bay of Bengal. The catchment area of the Vamsadhara River is 10830 km^2 of which 8926 km^2 lies in Odisha and 1904 km^2 lies in Andhra Pradesh.

3.2.3.4 Nagavali basin

Nagavali basin lies in Odisha and Andhra Pradesh States. It is bounded on the north by Mahanadi and Vamsadhara basins, on the west by Godavari basin and on the south by Champavati and Peddagedda basins. The basin area in Odisha forms undulating hills and valleys whereas the lower portions form gentle to undulating plains.

3.2.3.5 Basin covering the streams between Nagavali and Godavari

This basin covers about 10 major streams viz., Kandivalasagedda, Champavati, Gosthani, Borammagedda, Naravagedda, Sarada, Varaha, Tandava, Pampa and Gorrekhandi (Eleru) and are draining into the Bayof Bengal. The basin consists of hill ranges, which are well terrestrial and slope gently towards the Bay of Bengal.The catchment area of the basin is 15058 km^2, which lies entirely in Andhra Pradesh.

3.3 LINK CANAL 2: GODAVARI (INCHAMPALLI) – KRISHNA (NAGARJUNASAGARA)

The Godavari (Inchampalli) - Krishna (Nagarjunasagar) link canal is contemplated to origin from Inchampalli reservoir proposed on the main Godavari river and links Krishna at Nagarjunasagar dam. It traverses a total length of 299.256 kmtill it reaches Nagarjunasagardam. The crossing of major ridge between Godavari and Krishana basins is accomplished through a tunnel of 9.150 km length.The canal travels through Karimnagar, Warangaland Nalgonda districts of Telengana.

3.3.1 Godavari River Basin

The basin description of Godavaribasin has already been provided at 3.2.2

3.3.2 Krishna River Basin

The Krishna, the second largest peninsular river system and the fourth biggest river of India is an east flowing interstate river (Chaturvedi, 1985). The river rises in the Mahadev range of the Western Ghats and flows from west to east through the States of Maharashtra, Karnataka and undivided Andhra Pradesh to join the Bay of Bengal. The Krishna basin lies between east longitudes $73^0 21' 00''$ to $81^0 09' 00''$ and north latitudes $13^0 07' 00''$ to $19^0 25' 00''$. The Basin extends over an area of 258948 sq. km, which is nearly

8 percent of the total geographical area of the country. The percentages of the area of the basin in the states of undivided Andhra Pradesh, Karnataka and Maharashtra are 29.4, 43.8 and 26.8, respectively.

The Krishna basin is bounded on the north by the common ridge separating it from Godavari basin, on the south and east by the Eastern Ghats and on the west by Western Ghats. The total length of the river from the source to its outfall into the sea is about 1400 km, of which 306 km are in Maharashtra, 483 km in Karnataka and 612 km in undivided Andhra Pradesh, and outfalls into the Bay of Bengal.

The principal tributaries joining Krishna in the order of their coverage are Ghataprabha (right), Malaprabha (right), Bhima (left), Tungabhadra (right), Musi (left), Palleru (left) and Muneru (left). The entire Krishna basin has been divided into 12 sub-basins namely Upper Krishna, Middle Krishna, Ghataprabha, Malaprabha, Upper Bhima, Lower Bhima, Lower Krishna, Tungabhadra, Vedavathi (Vedvathi river is the principal tributary of Tungabhadra river) , Musi, Palleru and Muneru. Sub-basin wise break up of Krishna river basin lying in different states is as shown in Table 3.4.

Table 3.4 Sub-basin wise break up of Krishna river basin lying in different states

Sl. No.	Name of the sub-basin	Catchment area (sq. km)			Total sq. km
		Maharashtra	Karnataka	undivided Andhra Pradesh	
(1)	(2)	(3)	(4)	(5)	(6)
2	Middle Krishna	1388	16170	0	17558
3	Ghataprabha	2010	6819	0	8829
4	Malaprabha	0	11549	0	11549
5	Upper Bhima	45335	731	0	46066
6	Lower Bhima	3564	18467	2517	24548
7	Lower Krishna	0	1683	34442	36125
8	Tungabhadra	0	38790	9037	47827
9	Vedavathi	0	18219	5371	23590
10	Musi	0	0	11212	11212
11	Palleru	0	0	3263	3263
12	Muneru	0	0	10409	10409
	Total	**69425**	**113272**	**76251**	**258948**

3.3.3 Basin covering the streams between Godavari and Krishna

There is no intervening basin in between Godavari and Krishna basins along the link canal.

3.4 LINK CANAL 3: GODAVARI (INCHAMPALLI) – KRISHNA (PULICHINTALA)

The Godavari (Inchampalli) - Krishna (Pulichintala) link canal is the third in series and has been planned to takes-off from the same place as in the case of Link Canal 2, i.e., Inchampalli.The canal passes through dense forests andagricultural lands. It runs in southwest direction from Inchampalli reservoir to Nagarjunasagar reservoir. The ridge between the Godavari and the Krishna basins is proposed to be negotiated through a tunnel of 9.150 km length. Total length of the link canal from Inchamapalli to its outfall at Nagarjunasagar is 299.256 km. The canal passes through Karimnagar, Warangal and Nalgonda district of Telengana.

3.4.1 Godavari River Basin

The basin description of Godavaribasin has already been provided at 3.2.2

3.4.2 Krishna River Basin

The basin description of Krishnabasin has already been provided at 3.3.2

3.4.3 Basin covering the streams between Godavari and Krishna

There is no intervening basin in between Godavari and Krishna.

3.5 LINK CANAL 4: GODAVARI (POLAVARAM) – KRISHNA (VIJAYAWADA)

The Polavaram - Vijayawada link canal takes-off from the head works acrossGodavari river near Polavaram. The canal runs between Godavari and Krishna riversroughly in east towestward direction. The canal passes through West Godavari and the Krishna district

3.5.1 Godavari River Basin

The basin description of Godavari basin has already been provided at 3.2.2

3.5.2 Krishna River Basin

The basin description of Krishna basin has already been provided at 3.3.2

3.5.3 Basin covering the streams between Godavari and Krishna

There is no intervening basin in between Godavari and Krishna basins along the link canal.

3.6 LINK CANAL 5: KRISHNA (ALMATTI) - PENNAR

Krishna (Almatti) – Pennar link canal is contemplated to take off from Almatti dam and traverse 587.175 km to deliver 1980 MCM of water form Krishna for enroute irrigation of 258334 Ha.in Krishna and Pennar basins. The transfer of water through this link is against the surplus water received from river Godavari. The project comprises of the following components: i) the existing dam at Almatti across the river Krishna with gross storage capacity of 3439.70 Mm3 and live storage capacity of 3104.70 Mm3 at FRL 519. 6 m. ii) A 587.175 km long link canal, which off takes from the right bank of Almatti dam with full supply level of 510m. This canal finally outfalls into Maddileru River, a tributary of Pennar River. iii) A reservoir across river Pennar near Kalvapalli to serve as a balancing reservoir for the link canal situated in Anantapur district of undivided Andhra Pradesh. This reservoir is proposed at RD 386.4 km of the link canal. iv) The existing Bukkapatnam tank across the river Chitravati with a live storage capacity of 15.30 Mm3 at FRL 448.07 m. It is situated near Bukkapatnam village of Anantapur district in undivided Andhra Pradesh.

3.6.1 Krishna River Basin

The basin description of Krishna basin has already been provided at 3.3.2

3.6.2 Pennar River Basin

The Pennar river is one of the major rivers of the Indian peninsula flowing eastwards and draining into the Bay of Bengal. The river has its originin Chennakesava hills of the Nandidurg range in Kolar district of Karnataka state. The total length of the river from the source to its out fall into the sea is 597 km, of which about 61 km is in Karnataka and the remaining 536 km is in undivided Andhra Pradesh. The important tributaries of the Pennar river are the Jayamangala, Chitravati, Kunderu, Papagni, Sagileru, Cheyyeru and Boggeru. Sub-basin wisebreakup of the basin is shown in Table 3.5.

The Pennar basin happens to be a fan shaped basin. It has Erramala hills on the north,Nallamala and Velikonda hills of Eastern Ghatson the east, Nandidurg hills on the south and a narrow ridge on the west separating it from Vedavathivalley of the Krishna basin.

Table 3.5 Sub-basin wise break up of Pennar river basin lying in different states

Name of the sub-basin	Catchment area (sq km)		Total(sq. km)
	Karnataka	undivided Andhra Pradesh	
(1)	(2)	(3)	(4)
Upper Pennar	5034	14666	19700
Middle Pennar	1877	15076	16953
Lower Pennar	26	13254	13280
Pennar Delta		5280	5280
Total	**6937**	**48276**	**55213**

3.6.3 Basin covering the streams between Krishna and Pennar

There is no intervening basin in between Krishna and Pennar basins along the link canal.

3.7 LINK CANAL 6 : KRISHNA (SRISAILAM) - PENNAR

The Krishna (Srisailam) - Pennar link is designed to transfer a part of the additional water available at Srisailamagainst the surplus water received from Godavari river.The diversion of the water is proposed by utilising the existing Srisailam reservoir and Srisailam Right Main Canal (SRMC). The water will be drawn into SRMC through Pothireddipadu head regulator and is proposed to be let-off into Nippulavagu stream through the existing Banakacherla cross regulator and the escape channel. Thereafter, the water will reach the Pennarriver through the natural streams of Nippulavagu, Galeru and Kunderu. The total length of the link canal is about 204 km out of which 180 km is through natural streams. No irrigation is proposed enroute of this link, as the area in the vicinity of the conveyance system is already being served/proposed to be served by the existing Kurnool-Cuddapah canal, ongoing Srisailam Right Branch Canal, Telugu Ganga and Mylavaram north canals.

3.7.1 Krishna River Basin

The basin description of Krishna basin has already been provided at 3.3.2

3.7.2 Pennar River Basin

The basin description of Pennar basin has already been provided at 3.6.2

3.7.3 Basin covering the streams between Krishna and Pennar

There is no intervening basin in between Krishna and Pennar basins along the link canal.

3.8 LINK CANAL 7: KRISHNA (NAGARJUNASAGAR) – PENNAR (SOMASILA)

Nagarjunasagar - Somasila link canal is contemplated to originate from the existing Nagarjunasagar reservoir and run as parallel canal of Nagarjunasagar Right Branch Canal (NSRBC) to its right side up to the point of their merger at RD 202.75 km. After travelling for some distance, it out-falls in Somasilareservoir. The canal passes throughGuntur, Prakasam and Nellore districts of Andhra Pradesh till its outfall.

3.8.1 Krishna River Basin

The basin description of Krishna basin has already been provided at 3.3.2

3.8.2 Pennar River Basin

The basin description of Pennar basin has already been provided at 3.6.2

3.8.3 Basin Covering the Streams Between Krishna and Pennar

Gundlakamma basin along with few small streams comes in between Krishna and Pennar basins along the link canal.

3.9 LINK CANAL 8: PENNAR (SOMASILA) – CAUVERY (GRAND ANICUT)

The Pennar (Somasila) - Palar - Cauvery (Grand Anicut) Link Project is proposed as a contour canal running for a total length of 529.190 km from Somasila dam to Grand Anicut. The canal is the eighth in the series pertaining to the 1st part of peninsular component of NPP, 1980. The link canal is planned to pass through Nellore andChittoor districts of undividedAndhra Pradesh; Tiruvallur district and Vellore,Tiruvannamalai,Villupuram,Cuddalore,Perambalur and Tiruchchirappalli districts of Tamil Nadu.

3.9.1 Pennar River Basin

The basin description of Pennar basin has already been provided at 3.6.2

3.9.2 The Cauvery River Basin

The Cauvery river has its origin at Talacauvery near Madikeri in Coorg district in thestate of Karnataka on the Western Ghats. It travels for a length of 800 km through the states of Karnataka, Tamil Naduand the Union Territory of Puducherry and falls into the Bay of Bengal.

It has a catchment area of 81,155 sq.km between 75^0 30’ E and 79^0 45’E longitude and between 10^0 5’N and 13^0 30’N latitude. It comprises 2.49% of the geographical area of the country. The sub-basin wise break up of area is shown in Table 3.6.

Table 3.6 Sub-basin wise break up of Cauvery river basin lying in different states

Name of the sub-basin	Catchment area (sq. km)				Total(sq. km)
	Kerala	Karnataka	Tamilnadu	Puducherry	
(1)	(2)	(3)	(4)	(5)	(6)
Upper Cauvery		10619			10619
Kabini	1920	4908	212		7040
Suvarnavathi		1207	580		1787
Shimsha		8469			8469
Arkavathi		4184	167		4351
Middle Cauvery		2676			2676
Palar		1870	1344		3214
Chinar		100	3961		4061
Bhavani	562	240	5352		6154
Noyil			2999		2999
Amaravathi	384		7896		8280
Tirumanimuttar			8429		8429
PonnanaiAr			2050		2050
Upper Coleroon			3082		3082
Lower Coleroon			1378		1378
Cauvery Delta			6417	149	6566
Total	**2866**	**34373**	**43867**	**149**	**81155**

3.9.3 Basin Covering the Streams betweenPennarand Cauvery

Palar basin along with few small streams comes in between Pennar and Cauvery basins along the link canal.

3.10 LINK CANAL 9: CAUVERY (KATTALAI) – VAIGAI - GUNDAR

The Cauvery (Kattalai) - Vaigai - Gundar link canal is proposed as a contour canal running for a total length of 255.60 km till it joins with Gundar river. The link canal is aligned through Karur, Tiruchchirappalli,Pudukkottai,Sivaganga,Tiruvadanai, Ramanathapuram,Virudhunagar districts of Tamilnadu.

3.10.1 Cauvery River Basin

The basin description of Cauvery basin has already been provided at 3.9.2

3.10.2 Vaigai River Basin

The Vaigai basin is bounded on the west by the Western Ghats, on the east by the Bay of Bengal, on the north by a group of hills separating it from the Cauvery and other small streams and on the south by the Gundar and Vaippar basins.

CHAPTER 4

GENERALISED RESERVOIR YIELD MODEL

4.1 INTRODUCTION

Natural Rivers are the lifeline of the mankind, from which we receive water for our use and sustenance. Reservoirs on rivers are meant for supplying stored water for meeting different multipurpose water needs through releases made during inadequate reservoir inflows. Comprehensive integrated water resource planning and analysis of a river basin is required for its efficient water use in an optimal manner. Thus, the resource planning problems are of multi-objective nature; fitting very well to the current scenario and status of our water resources. It involves; (a) project planning, (b) hydrological analysis, (c) data processing, and (d) integrated systems analysis of various trans-boundary river basins for their sustainable water resources development.

Optimization models which determine various reservoir yields from a known reservoir capacity during project planning stages are called the reservoir yield models and are based mostly on the linear programming (LP) technique. These models are widely used for eliminating non-optimal design alternatives during project planning and are termed as the initial screening models. With efficient computer software available these days considerable large size problems are being solved.

4.2 ANNUAL RESERVOIR YIELDS AND THEIR RELIABILITY

Determination of reservoir capacity of a reservoir project during planning stages, to meet given annual water demand from reservoir releases (or annual reservoir yield) is usually associated with historic inflows. A percent annual probability is initially assigned to the annual yield that can be achieved in future (or expected during its operation during the life of the reservoir) by a given size of reservoir with a particular operating policy. These probabilities are usually estimated initially from the unregulated historical river flows (Stedinger et al. 1983).

Therefore, the reliability of any annual yield is the probability that the stream flow in any year is greater than or equal to the value of that yield. This project dependability is further ascertained after sizing of the reservoir. This is done by simulation (a trial and error approach), by preparing detailed water balance (working tables) of the reservoir using standard operating policy (SOP) of reservoir. The approach takes care of the uneven distributions between the within-year river flows and the water requirements, or tries to make both of them compatible with each other during the life of the reservoir.

4.2.1 Estimation of Probabilities

There are various methods employed to estimate the probability that any given stream flow will be equalled or exceeded. The Weibull plotting position method is commonly employed using unregulated stream flows, which involves the prediction of the mean number of random events that can occur in future. The probability estimated is termed as the mean probability. This estimate of the mean probability of a given unregulated stream flow makes it possible to define the mean probability of any particular reservoir yield.

4.2.2 Estimation of Reservoir Yields

The linear programming (LP) technique based optimization models which determine various reservoir yields are called the reservoir yield models. These models, used for eliminating non-optimal design alternatives during project planning stages are termed as the initial screening models; and are currently widely used for planning large trans-boundary river basin water resources developments. With efficient computer software available these days large size problems are being solved.

4.2.3 Types and Definition of Reservoir Yields

A reservoir with a certain reservoir capacity, can provide (or release) various types of annual reservoir yields. These annual reservoir yields are associated with different probabilities (reliabilities). Loucks et al. (1981) define these annual reservoir yields, for various reservoir yield models which are in use these days. These yields are described below:

4.2.3.1 A single-yield reservoir yield model

A single annual reservoir yield would be either of the following:

(i) An annual yield with the maximum possible probability (reliability) of exceedence *p* is defined as the *safe* or *firm annual reservoir yield* and is denoted as Oy^{fp}, and

(ii) An annual yield with reliability p1 less than the maximum reliability p will be denoted as Oy^{fp1}.

4.2.3.2 A multi-yield reservoir yield model

On the other hand, for a multi-yield reservoir yield model all other annual yields with reliability less than *p* are *incremental annual reservoir yields*. In this multi-yield reservoir yield model,

(i) The annual reservoir yield with the maximum possible reliability *p* is again Oy^{fp} and is called as the *firm annual yield, and*

(ii) The incremental annual reservoir yield with a probability of exceedance*p2*, which is less than *p* is denoted by Oy^{sp2} and is termed as the *secondary annual yield*.

The summation of the firm and secondary annual yields is the *total annual reservoir yield*.

4.2.4 The Firm or Safe Yield

The firm or safe yield (or release) from a reservoir means that, the annual water demand which can be met without the reservoir falling to its dead storage level at any point of time, or it is the guaranteed yield from the reservoir with focus on the system reliability. The reservoir's firm yield mainly depends on its active storage capacity, the distribution of inflows, and the reservoir operating policy; released/made available from a reservoir for some specific use(s). This guaranteed yield is called as the 'reservoir firm yield'.

4.3 ISSUES IN INTEGRATED TRANS-BOUNDARY RIVER BASIN WATER RESOURCES DEVELOPMENTS

Comprehensive integrated water resource planning and analysis of trans-boundary river basins in an optimal manner is required for their efficient water use. For such analyses, the following issues are very essential and should be discussed while modelling and need great emphasis (Srivastava 2013).

4.3.1 Issue of Water Availability and River Basin Water Balance

In assessing the water availability more realistically of a river basin, the importance of spatial and temporal distributions in water availability and demand (utilization) within the basin is very significant and useful. The following observations are important,

(a) Observed stream flow data are generally not available at many project sites in a large river basin. This puts a major drawback in assessing water availability in space and time. The estimation of long-term monthly inflow data series at each and every reservoir site in a multi-reservoir system is not easy task and requires other hydrological data mainly rainfall. Catchment area rainfall ratio method is usually used for this purpose.

(b) The river water balance method should be used instead. The water balance of a river basin ideally should take into consideration the regulation effect of storages of the existing, ongoing and contemplated reservoir projects in the basin. For this, (i) different reservoir projects situated in the concerned basins/sub-basins should be evaluated in an integrated manner, and (ii) furthermore, there is a need for determining optimal integrated multi-reservoir yields from the system.

(c) The considerations of the regulation effect could enable and ascertain (i) a better water availability and its utilization within the concerned basin, and (ii) also the excess/shortage in water availability in the basin for a possible export/import.

(d) Generally, it is found that studies on river basin water balance usually lacked consideration of the above facts.

4.3.2 Issue of Water Disputes and Tribunal Awards in Interstate Trans-Boundary Rivers

There are several trans-boundary interstate water disputes (conflicts) in India, regarding the share of water amongst their concerned riparian co-basin states involved. Tribunal awards towards resolving such disputes exist. In this regard the following points are important,

(a) The tribunal awards in general, usually provide the annual quantum of the total part of the disputed shares of trans-boundary river waters as transfers (imports to) from a co-basin state to other concerned co-basin state or states. This is because, for these awards the availability of water is usually derived only based on a specified water-year. For this purpose conventional method of water balance of rivers at a specified point is carried out and which is generally based on the 75% water-year dependability criteria.

(b) At times the above mentioned water shares are to be made available at a given point (generally at a specified reservoir through releases) as an import of water to a downstream state, which is (the shares) to be released as a water export from a set of specified multi-reservoirs located in an upstream state.

(c) Up to a large extent, on the other hand, these awards do not always provide guidelines regarding the important aspect of the quantum of releases along with their within-year time distributions to be made from each of these individual specified multi-reservoirs.

(d) Due considerations, therefore, should be given to the various awards of the Tribunal in various studies involved on basin water availability and its utilization in space and time in an optimal and integrated manner.

4.3.3 Issue of Real Time Operations of Multi-Reservoirs and Managing Water Exports

At a water export point in a trans-boundary river, a certain amount of pre quantified total share annual amount of water is to be diverted for use at its downstream. The following points are important to note,

(a) The above mentioned total annual quantum of export water, are usually shared by contributions from releases made by a large number of pre specified multi-reservoir projects, lying in its upstream catchment/river reaches.

(b) The total annual quantum of water being diverted is usually time dependent. During a year/water-year it is governed by its within-year quantum distributions from each upstream contributing multi-reservoir.

(c) It is not directly possible to quantify or specify its distribution or share for water diversions among the upstream contributing multi-reservoirs. Their space and within-year time wise water share distributions are either not directly defined, or are not possibly could be estimated during planning/operation stages.

(d) Quantifying these multi-reservoir contribution releases for diversion at the water export point during the within-year time periods in space and time is a huge task. Under such conditions, real time operations practically would become unmanageable and cumbersome.

(e) The multi-reservoir's contribution quantification again, needs optimal integrated approach towards trans-boundary river basin planning.

4.4 IMPORTANCE OF SYSTEMS ANALYSIS APPROACH AND ITS APPLICATION TO REAL LIFE PROBLEMS

A basin's available water resources should be utilized to its maximum possible extent as emphasized by the National Water Policy of Ministry of Water Resources, Government of India. For water, it becomes essential that, the resource planning in trans-boundary river basins, should be carried out starting from a hydrological unit; such as starting at each reservoir level (water use delivery points), to at each sub-basin level, and to the basin as a whole. For achieving this, all the major and medium individual developmental water resources projects (reservoir etc.) formulated within the river basin should be considered. The developmental aspects should be analysed within the frame work of an overall plan for a basin or sub-basin, which benefits all its stakeholders. This would provide the best possible combination of options of water uses within the basin/basins. The matter of application of systems analysis approach, on issues involving best possible water utilizations of rivers would provide the solutions.

4.4.1 Scientific Assessment of a River Basin's Water Resources: Need and Importance

Under the current worsened scenario of the water resources in India and elsewhere, it has become most essential to opt for appraisal of water resources system in a river basin. This certainly, would determine the extent of the capability of water sources to deliver, their extent and dependability of supplies of water on which an evaluation of their control and utilization is to be made. In this, the delivered resource's, quantity and quality and their reliabilities are the important considerations. Reservoirs in a river system should be able to provide reliable supplies in space and time to its stakeholders when they need, during the period of water distress. For this, assessment in spatial and temporal variations of water availability and demand (utilizations) is a must. Systematic optimal integrated river basin planning approach essentially would provide the answer.

The integrated system modelling is often a quite complex problem, because it depends on various factors, such as, physical configuration of the system; site specific characteristics of the reservoir projects; active reservoir storage capacities; distribution of natural stream flows entering into the reservoirs; and multi-reservoir operating policy, etc.

In India, very few integrated systems studies on a large scale, so far were earlier attempted or are found in literature, for the optimal evaluation of water utilizations and water export potentials of interstate trans-boundary rivers in space and time. Various river water disputes tribunal awards also put constraints on rivers water utilization. Studies also lack consideration of these tribunal awards, which need to be incorporated. This of course is a herculean and tedious task requiring a lot of expertise in the field of systems analysis. Such trans-boundary river basin water resources developmental problems remain large scale in size, with large alternatives options in numbers. Therefore, to choose some better alternative options of development, preliminary screening of alternative development plans becomes mandatory. Reservoir yield models, which use linear programming optimization technique for preliminary screening, are recent developments in this category.

For the integrated river basin water resources systems analysis, the use of Screening-simulation models is recommended and should be made mandatory; that is combined use of optimization and simulation modelling approach, i.e., firstly, the linear programming based models, i.e., reservoir yield models, do preliminary screening, and secondly, followed by simulation model for further finer screening) etc. Such studies should provide detailed answers (capabilities of reservoirs to deliver) and statistics of systems' behaviour in an integrated manner, to intricate inaccessible untold solutions in space and time.

4.5 THE RESERVOIR YIELD MODELS AND MODELLING APPROACH

Use of linear programming (LP) based preliminary screening optimization models for planning and management of large complex water resources systems is already well established and acknowledged (Loucks et al., 1981; Chaturvedi and Srivastava, 1981; Srivastava 1976, and Sunita Devi et al. 2005). In rivers, where a large number of single-purpose and multi-purpose reservoirs exist in the system, the system constraints and variables become very high in numbers. Then the task of modelling and solving the large integrated system for its solution becomes very difficult. This restricts many in attempting such problems.

Two types of reservoir yield models, using the linear programming technique, for preliminary screening purposes are well known in the literature. The first category models are called the *"complete reservoir yield models"*. The second type of reservoir yield models (the *"approximate reservoir yield models"*) are recent developments in this category, and are used for the purpose of preliminary screening to directly screen out a large number of non-optimal developmental alternative solution strategies, and thereby retaining other better prospective alternatives near to the expected optimal developmental solution which would produce a reliable and sustainable water resources system. On the other hand, the well-known simulation technique is very realistic in model presentation in comparison to any optimization model. But, the simulation is not directly capable to serve the required purpose of screening up to the same extent as that provided directly by the optimization.

For this reason, earlier the importance of using the well-known screening-simulation modelling technique was emphasized. Thus, for the integrated river basin water resources systems analysis, the use of Screening-simulation models became mandatory; that is combined use of optimization and simulation modelling approach, i.e., firstly, the linear programming based models, i.e., reservoir yield models, do preliminary screening, and produce a solid initial base for other efficient search techniques to begin their trial and error search for an early solution near to optimal (Wurbs 2005); and secondly, followed by simulation model for further finer screening) etc. Such studies should provide detailed answers (capabilities of reservoirs to deliver) and statistics of systems' behavior in an integrated manner, to intricate inaccessible untold solutions in space and time (Loucks et al., 1981; Chaturvedi and Srivastava, 1981; and Srivastava, 1976). This is likely to produce efficient and reliable developmental outcomes from the system which could be implemented later.

A detailed evaluation of basin wise impacts of water management decisions, the prior appropriation water rights and other institutional mechanisms for allocating stream flow and reservoir storage resources among numerous water users need consideration. Therefore, in this thesis, basically in modelling, emphases given on the use of LP based screening models for analyzing large size interstate trans-boundary river basin systems in an integrated manner in space and time and provide answers for the solutions of many intricate problems involved in integrated water transfers.

4.5.1 Expected Model Deliveries

In the era of water scarcity, extensive and intensive uses of water cause a great concern. There are diversified water requirements, which need varied quantities of water, and meeting these demands has become essential. Therefore, comprehensive models, for planning integrated multi-purpose multi-reservoir system should be developed. These must have various provisions available, which analyze and are capable of providing and delivering in space and time for each reservoir during a normal water-year, the following:

(i) Annual multi-yields (both firm and secondary yields with within-year distributions) from a reservoir,

(ii) Over year carry over storage capacity in a reservoir,

(iii) Storages in a reservoir (with within-year variations) for developing operation policy,

(iv) Provide proper consideration for crop planning at a site/reservoir which

(a) Should take care for the food habits of the population in the region,

(b) Should take care for the minimum food requirements of the farmers in the region for their survival during recurring droughts, further this should be based on age groups and

(c) Should take care to improve health (i.e., food nutritional values) of the people in the region.

(v) Able to mitigate the deteriorating environmental conditions at a site/reservoir in the river,

(vi)Includes system constraints pertaining to river water disputes, constrained by Tribunal Awards at a site/reservoir,

(vii) Provision to allow for inter-basin water transfers (with within-year contributions from all contributing reservoirs) at export points,

(viii) Possible to incorporate model system constraints pertaining to conjunctive water use development at a site/reservoir,

(ix) Allows for multi-objective planning at a site/reservoir,

(x) Lastly, contribution in integrated reservoir operation policy, in terms of water releases for various uses and to different stake holders at different within-year times.

4.5.2 System Constraints Derived Based on Various River Water Disputes Tribunal Awards

In the light of various existing inter-basin trans-boundary river basin water disputes, especially in India, apart from system's basic model constraints, a number of additional system constraints are required to be incorporated in these models based on these tribunal awards and specified water exports (Thube, 2007; Sethi, 2009; and Srivastava, 2013). These would help to answer the above expected deliveries up to a large extent during a normal water-year. These constraints may be categorized for modelling purposes as follows:

4.5.2.1 Constraints for water share allocations among riparian co-basin states during a water-year

Constraints which are mandatory in nature:

(i) Site specific water shares of river flows (up to and/or below a reservoir or a given location in the river)

(a) Restricted water use shares, which are essentially to be met

(b) Free use of water shares, excess water available over and above as in (a)

(ii) Specified reservoir and/or multi-reservoirs wise water shares for each co-basin states

(iii) Exclusive individual sub-basin wise water shares

(iv) Water share between two or among more states

(v) Total water shares for each individual state

4.5.2.2 Constraints for water release/storage (water-year and/or within-year) allocations

Constraints which are mandatory in nature:

(i) Scheduled releases/storage provisions including exports from specified reservoirs

(a) From a single specified reservoir

(b) From a set of specified multi-reservoirs (these may include from one or more co-basin states)

(ii) Scheduled sub-basin wise releases/storage provisions

(iii) Ensured releases/storage provisions for downstream environmental needs including environmental exports

Constraints which are recommendatory in nature:

(i) Provision of storage reservation in specified multi-reservoirs and/or a reservoir

(ii) Increase reservoir yields by

(a) Provision of over-year storage capacity in reservoirs to improve water availability

(b) Maintaining monsoon end storage in reservoirs to guarantee ordered releases during the following non-monsoon season/or otherwise.

Constraints based on public demand:

(i) **T**his stipulatesannual quantum of water to be ensured by specified state/states for safety of the crops in a given region and are based on various public demands.

4.5.2.3 Constraints for crops

Contractual constraints:

(i) Limitations put on cropping areas of individual crops/a set of multi-crops

(a) Site specific limitations on crops (up to and/or below a reservoir or a given location)

(b) Reservoir wise limitations on crop/crops

(c) State wise limitations on crop/crops

4.5.2.4 Other technical constraints

(i) At each reservoir proportioning of firm and secondary reservoir yields including exports (so as to guarantee the mandatory water needs, which includes water for environmental use, irrigation requirements for meeting minimum food needs, and tribunal awarded exports)

(ii) Meeting each reservoir wise annual design target demands.

4.6 THE MODELS

4.6.1 Complete Yield Model for a Single Reservoir

One of the most widely used first category optimization model, in the field of water resources for planning and operation of reservoir system is called the *complete reservoir yield model* (Loucks et al. 1981; Chaturvedi and Srivastava 1981). The main features of this model for a single reservoir are described below:

Let active over-year reservoir capacity Y^{O} is required to regulate and deliver a safe or firm annual yield Oy^{fp}, when the same firm yield differs from the annual inflows I_j to the reservoir. However, a desired within-year distribution Oy_t^{fp} of the annual yield that does not coincide with the within-year distribution of the stream flows may require additional active reservoir storage capacity Ya^{w}.

Both the storage capacity requirements can be obtained by minimizing the total active storage capacity, $Ya = Y^{O} + Ya^{w}$, subject to the continuity, capacity and constraints for every within-year period of each year. This model for a reservoir system is defined by equations 4.1 through 4.4 for each period *t* in each year *j*, i.e.,

Minimize $\quad Ya \qquad (4.1)$

Subject to

$$S_{j,t-1} + I_{jt} - Oy_t^{fp} - Sp_{jt} = S_{jt} \qquad \forall_{jt} \qquad (4.2)$$

$$S_{j,t-1} \le Ya \qquad \forall_{jt} \qquad (4.3)$$

$$Oy_t^{fp} = K_t\left(Ir\right) \qquad \forall_{t} \qquad (4.4)$$

where $S_{j,t-1}$ = initial storage at the beginning of period *t* inyear *j;* S_{jt} = final storage at the end of period *t* in year *j*; Sp_{jt} = excess release (spill) during period *t* in year *j*; Oy_t^{fp} = reservoir yield during period *t*; *Ir* is the annual irrigation target and K_t is the known percent of annual irrigation required in time t.

The equation (4.2) is presentation of the continuous long term water balance or behaviour of the reservoir over a period of water-years during its planning period or its life, carried out for each and every within-year (usually monthly) time period. The model described above is termed as the "*complete reservoir yield model"*.

4.6.2 Approximate Yield Model for River Basin Water Resources Developments

The second category optimization models are called the "*approximate reservoir yield models",* for river basin water resources development, which now have wider applications in real life problems, due to their being comprehensiveness, utility and are more informative.

4.6.2.1 Approximate yield model for a single reservoir (YM)

The "*approximate reservoir yield model"* for a single reservoiris described below:

In this reservoir yield model, a single annual reservoir yield, i.e., firm or safe yield is defined with a given maximum reliability *p*. Another annual reservoir yield, an incremental secondary (or secondary) annual reservoir yield was defined with a reliability *p1* less than the firm annual yield. A third annual reservoir yield, now alternatively referred to as the secondary annual yield instead of incremental secondary annual yield having a reliability *p2* less than the firm annual yield was also incorporated in the model. For example, let us assume that two annual reservoir yields are desired from 99 years of historical stream flow record, one with 99% reliability [*p* = 99 / (99 + 1)] and the other with 75% reliability [*p2* = 75 / (99 + 1)]. Let, Oy^{fp} and Oy^{sp2} represent these annual yields having reliabilities of 0.99 and 0.75, respectively. The secondary annual yield Oy^{sp2} represents the amount in addition to Oy^{fp} and is only 75% reliable. Aforesaid statement implies that, no failure year is allowed in firm annual yield whereas 24 failure years are allowed in case of secondary annual yield. In case of the 75% reliable secondary yield, the factor θ_j^{p2} shall be 1 for seventy five successful years and zero for 24 selected failure years.

The YM, to determine single yield and multi-yields from a single reservoir (Dahe and Srivastava, 2002; and Srivastava and Awchi, 2009), the model is as follows:

The objectives were to maximize the within-the-year firm and secondary reservoir yields, i.e,

Objective for a single yield: Max $\sum_t Oy_t^{fp}$ (4.5a);

Objective for multi-yields: Max $\sum_{t}(Oy_t^{fp} + Oy_t^{sp2})$ (4.5b)

Where Oy_t^{fp} and Oy_t^{sp2} = the firm and secondary within-the-year reservoir yields in time t with a given predefined reliabilities of *p* and *p2*, respectively; and t is the within-the-year time period during the modelled critical year.

The objective function is subjected to the following constraints:

1. Equations for over-the-year storage continuity

The equation of continuity for over-the year reservoir storage at the end of year j, S_j^o, is the sum of (i) the initial over-the year reservoir storage at the beginning of year j and (ii) the inflow to the reservoir in year j; minus the sum of (i) the reservoir releases (yields from the reservoir; which may include firm yield or both firm and secondary yields, depending on the model of single yield or multi-yields of given annual reliabilities, respectively) in year j, (ii) the evaporation from the reservoir in year j and (iii) the reservoir spill in year j from the reservoir. Then,

(a) The over-the year reservoir continuity equation for a reservoir with single yield is written as follows:

For single yield: $S_{j-1}^o + I_j - \theta_j^{p2} Oy^{fp} - EV_j - Sp_j = S_j^o \qquad \forall j$ (4.6a)

The distribution of annual stream flows and the annual yield to be provided govern the over-the-year reservoir capacity. The maximum of all over-the-year storage volumes is the over-the-year storage capacity. A failure fraction is specified to define the allowable deficit in annual reservoir yield during the failure years in a single-yield problem. In the above equation Oy^{fp} = the safe (firm) annual reservoir yield with reliability *p*; S_{j-1}^o and S_j^o = the initial and final over-the-year active storages in year j, respectively; I_j is flow in year j; θ_j^{p2} = the failure fraction defining proportion of annual reservoir yield to be made available during failure years to safeguard against the risk of extreme water shortage during critical dry periods θ_j^{p2} lies between 0 and 1, i.e., for a complete failure year θ_j^{p2} = 0, for a partial failure year 0 < θ_j^{p2} <1, and for a successful year θ_j^{p2} = 1, Sp_j = the excess release (spills) in year j; and EV_j = the evaporation loss in year j.

(b) The over-the year reservoir continuity equation for a reservoir with multi-yields is written as follows:

For multi-yields: $S_{j-1}^{o} + I_j - Oy^{fp} - \theta_j^{p2} Oy^{sp2} - EV_j - Sp_j = S_j^{o} \ \forall j$ (4.6b)

For multi-yields, one firm (safe) and one secondary yield with lower reliability can be defined. However, in such a case, it is not possible to define a failure fraction to be greater than zero for the secondary yield as the firm yield is essentially increased by an amount equal to the failure fraction times the secondary yield (Loucks et al. 1981). In the above equation Oy^{sp2} = the secondary annual reservoir yield in year i with reliability *p2*; and θ_j^{p2} is equal to 0 for failure years and 1.0 for successful years.

2. Equation for within-the-year continuity

The equation of continuity for within-the year reservoir storage at the end of within-the year time period t, S_t^w, is the sum of (i) the initial within-the year reservoir storage at the beginning of time period t and (ii) the within-the year inflow to the reservoir in time period t; minus the sum of (i) the within-the year reservoir releases (yields from the reservoir; which may include within-the year firm yield or both within-the year firm and secondary yields, depending on the model of single yield or multi-yields of given annual reliabilities, respectively) in time period t, and (ii) the within-the year evaporation from the reservoir in time period t. Then,

For the within-the year time period t, the general reservoir continuity equation for a reservoir during the modelled critical year is written as follows:

$$S_{t-1}^{w} + \beta_t \left[(Oy^{fp} + Oy^{sp2}) + \sum_t Ev_t \right] - (Oy_t^{fp} + Oy_t^{sp2}) - Ev_t = S_t^{w} \qquad \forall t \qquad (4.7)$$

Any distribution of within-the-year yields that differs from the distribution of within-the-year inflows may require additional active reservoir capacity. The maximum of all within-the-year storage volumes is the within-the-year storage capacity. In the above equation S_{t-1}^{w} and S_t^{w} = the initial and final within-the-year active storages at time t; β_t = the ratio of inflow in time t of the modelled critical year of record to total inflow in that year; and Ev_t = the within-the-year evaporation losses. In the above equation for the single yield model the terms related to the secondary yields are to be excluded from the model.

In Eq. (4.7), that reservoir neither fills nor empties during the modelled critical year, the inflows and required releases are just in balance. However, good results are generally obtained by letting some appropriate fraction $_t$ of total annual reservoir yield given within the brackets, [ ], to be the inflow in each period t within-the-critical year (Loucks et al. 1981).

3. Equations for proportioning of yields in within-the-year periods

The fractions for within-the-year distributions of the annual firm and secondary annual reservoir yields, would depend on the factors of the within-the year distributions of water requirements of environmental, M & I, and crop requirements etc. For these fractions; for the firm yields, the first two water needs are important, and for the secondary yield the crop waters are important. Thus, the equations would be as follows:

$$Oy_t^{fp} = \zeta_t^{fp} Oy^{fp} \qquad \forall t \text{ (4.8a)}; \qquad Oy_t^{sp2} = \zeta_t^{sp2} Oy^{sp2} \qquad \forall t \qquad (4.8)$$

where ζ_t^{fp} and ζ_t^{sp2} = the fractions for within-the-year distributions of firm and secondary annual reservoir yields, respectively.

4. Equations for reservoir evaporation

Two constraints were related to: (i) estimated annual reservoir evaporation losses, EV_j, (ii) estimated within-the-year reservoir evaporation losses, Ev_t, as follows:

Now, define approximate expected storage volume in any period *t* in year *j* as the initial over year volume, plus the estimated average within-year volume, i.e,

$$\text{Approximate expected storage volume} = S_{j-1}^{o} + \frac{S_{t-1}^{w} + S_{t}^{w}}{2}$$

Then, the annual evaporation loss, EV_j, in year *j* equals the average annual fixed loss from the dead storage, plus the sum of each period's volume loss per unit of active storage volume times the expected storage volume in the period, i.e.,

$$EV_j = \sum_t \left[\gamma_t EV^0 + \left(S^o_{j-1} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t EV^a \right] \qquad \forall j \qquad (4.9)$$

where γ_t = the fraction of the annual evaporation loss that occurs in period *t*.

As the sum of all fractions γ_t equals 1.0, equation 4.9 can be rewritten as

$$EV_j = EV^0 + \left[S^o_{j-1} + \sum_t \left(\frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t \right] EV^a \qquad \forall j \qquad (4.10)$$

Now, the within-year evaporation loss, Ev_t, in each period t of the critical year is approximately

$$Ev_t = \gamma_t EV^0 + \left(S^o_{cr} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t EV^a \qquad \forall t \qquad (4.11)$$

where

$EV^a =$ average annual evaporation volume loss rate per unit of active storage volume

where, A_a = water surface area per unit active storage volume above dead storage level,

EV^0 = average annual fixed evaporation volume loss from the dead storage;

$= A_0 \times$ average annual depth of evaporation

A_0 = water surface area at dead storage level

The within-year evaporation loss in each period t of the critical year is approximately

$$Ev_t = \gamma_t EV^0 + \left(S^o_{cr} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t EV^a \qquad \forall t \qquad (4.12)$$

where S^o_{cr} = initial over-year storage volume in the critical year.

5. Equations for reservoir storage bounds

(a) The over-the year active storage, S_{j-1}^{o} limited by the over-the-year active storage capacity, Y^{o}, i.e.,

$$S_{j-1}^{o} \leq Y^{o} \qquad \forall j \qquad (4.13)$$

(b) The within-the year active storage, S_{t-1}^{w}, limited by the total active storage capacity, Ya (which is simply the sum of the over-the-year and within-the-year storage capacities), i.e.,

$$Y^{o} \leq S_{t-1}^{w} \leq Ya, \qquad \forall t \qquad (4.14)$$

6. Equations based on specific project planning practices in India

Depending upon some project planning practices followed in India, two additional within-the-year constraints based on certain water use ratios could be added (Awchi 2004): (i) the ratio of annual water utilization from the reservoir and annual inflow to the reservoir should be at least equal to 0.8 and (ii) the ratio of the maximum reservoir submergence area and the cultivable command area should not exceed 0.2.

4.6.2.2 Multiple yield models for multi reservoir system

The Improvements from the Earlier Models:

(a) The single reservoir multiple yield models discussed above; was further improved for multiple, multipurpose reservoir river basin system, which had single purpose and multipurpose reservoirs in the system, with suitable constraints pertaining to irrigation and hydropower facilities. They proposed two reservoir yields (the annual, firm and secondary) formulation. Each yield having the same reliability at all the reservoirs in the system, irrespective of a reservoir being single or multipurpose (Dahe 2001, and Dahe and Srivastava 2002).

(b) The above consideration facilitated many provisions in the model. Firstly, these two yields served two purposes for irrigation, by (i) the annual irrigation target summed up by the firm and secondary annual reservoir yields and (ii) the incorporation of desired, annual reliability criteria by the use of the firm yields as well as an allowable deficit criterion (failure fraction) by the use of secondary yield. Secondly, a single purpose hydropower reservoir was represented by, using the firm and secondary reservoir yields for the firm and secondary annual energy generations, respectively. Thirdly, for a multipurpose reservoir with irrigation and hydropower; these two annual reservoir yields (i) were available for the firm and secondary annual energy generations, respectively and (ii) served both the purposes, in the same way for irrigation, as explained earlier. With the benefit, that the hydropower being the non-consumptive water uses; both the yields serve for power generation and irrigation, in that sequence. Fourthly, an additional constraint for irrigation use was incorporated, for monitoring the desired allowable proportions of firm and secondary annual reservoir yields.

(c) The model was successfully applied by Dahe and Srivastava (2002) to 8 reservoirs in the upper basin of Narmada river in India. Dahe (2001) later applied the model to all the 30 reservoirs in Narmada basin. For analysis 22 years flows were used in the study. The objective of the model in both the study was to maximize the returns from energy generations.

Some Drawbacks and Limitations of the Multiple Yield Model for Multi Reservoir System:

However, the above model had some limitations to handle some real world problems (Panigrahi and Srivastava 2005, Panigrahi 2006).

Firstly, the model did not consider directly, the municipal and industrial (M & I) water supply demand, which is mandatory. The required quantities for the same were deducted beforehand from the inflows prior to applying the model. Secondly, the model uses a common value of the failure fraction, which is not desirable and admissible at all the reservoirs in the entire river basin. This assumption of a common value for the failure fraction (which allows to meet the minimum food needs of agricultural population during failure years) at each reservoir, is either likely to under estimate or overestimate the reservoir yields. Thirdly, the firm reservoir yield is used for firm irrigation as well as for firm energy generation. The within-year time periods’ firm water needs for irrigation and hydropower differ largely from each other. For this rigid constraint, therefore, for a multipurpose project, the model is likely to become infeasible. Lastly, after some model results investigations, Dahe and Srivastava (2002) reveals that, (i) it gives the desired proportions of firm and incremental secondary yields on annual basis, (ii) the within-year distribution of yields do not follow their assigned proportionality, and (iii) even during some within-year time periods there is no firm yields found, means failing to deliver water in some within-year periods during critical water years.

4.6.2.3 Integrated reservoir yield model

The Improvements from the Earlier Models:

(a) The multi-reservoir multipurpose reservoir yield model's limitations in Dahe and Srivastava (2002) were overcome by Panigrahi and Srivastava (2005) and Panigrahi (2006). The latter authors' improved reservoir yield model was termed as the "I*ntegrated Reservoir Yield Model* (IRYM)". Their improvements were as follows.

Firstly, in the model they included mandatory water demands as well in a multipurpose project. The water requirements towards municipal and industrial, environmental, ecological, and other downstream water riparian rights were exclusively clubbed under the mandatory water demands. Secondly, for each project two types of annual yields, one the firm yield (a part of this yield, essentially meets all the mandatory water demands, even during a failure year) with a maximum possible annual reliability p and the other secondary yield with a desired annual reliability $p2$ less than p, depending on the purpose of use (irrigation and/or hydropower). Thirdly, the irrigation demands would be met from both the yields, whereas, the hydropower generations would follow the within-year distributions as that of irrigation demand. Fourthly, the model could select site specific failure years (maintaining hydrological diversity within a river basin) and allowable percentage yields during failure years at each reservoir. Fifthly, optimal crop plans were derived simultaneously at each reservoir. Sixthly, separate regeneration contributions from different water uses are considered. Lastly, a river system when comprised both of reservoirs and barrages, their model solution was dealt with an optimization-simulation approach.

(b) The applications of the IRYM were by (i) Panigrahi and Srivastava (2005) on Ong Sub-basin of Mahanadi River in Orissa, India, and (ii) Panigrahi (2006) on the lower part of the Mahanadi river basin system lying in Orissa, which consisted of 24 major and 32 medium projects. The model had an objective function to maximize the annual system yields.

Some Drawbacks and Limitations of the Integrated Reservoir Yield Model (IRYM):

The IRYM (Panigrahi and Srivastava 2005, Panigrahi 2006), the multiple yield model for multireservoir system of Dahe and Srivastava (2002) and the yield model of Loucks et al. (1981) did well in their applications to the real life problems. But, the following limitationspropped up, to handle some important planning issues. One was that, as said earlier that, these models faced certain computational difficulties with the presence of barrages in the river system. Optimization-simulation model then came to rescue for the models' computational and solution difficulties (Panigrahi and Srivastava 2005, Panigrahi 2006). However, other following limitations remained or unanswered.

Firstly, a reservoir on a river receives natural flow from its contributing/intervening catchment; in addition, depending upon its location in the catchment it may also receive flow generated by the regenerations made from water uses from the projects located on its upstream. Both the flows summed up to make the reservoir's total inflows. So, the following two deficiencies were observed in the model's results and findings: that; (I) When the total inflow to a reservoir is: (a) substantial but is less than its within-the year water demands and (b) greater in comparison to the active storage of the reservoir; then the modelled annual firm and secondary yields, both result into either equal to zero or a very small values in comparison to the total in coming flow received by the reservoir, and (II) When the total inflow to a reservoir is: (a) greater than its timely water demands and (b) greater in comparison to the active storage of the reservoir; then the model becomes infeasible, due to the constraints put on the within year continuity and water availability/requirement for certain time periods. This may be due to two reasons; one that the within-year storage capacity being very small or even zero and second that the water requirements are less than the water available. Secondly, the models give smaller annual system yields, for a reservoir having inadequate live storage capacity. Thirdly, the firm and secondary reservoir yields, both serve irrigation needs as well as firm and secondary energy generations. Therefore, in case of a reservoir with small hydropower plant capacity, and with larger irrigation, then under such circumstances, the model is likely to be infeasible. This is due the presence of the rigid power constraints; and for the irrigation water released being larger finds the turbine capacity small. Lastly, the releases towards various mandatory water demands are clubbed together. Since, the regeneration contribution factors as well as the gross benefits for municipal and industrial (M&I) water demands differ largely from others, this need to be considered separately.

4.6.2.4 Multiobjective modified integrated yield model (MOIYM)

In order to overcome the limitations of the IRYM (Panigrahi 2006, Panigrahi and Srivastava 2005), as discussed above, and for improving the yield model, Thube (2007) formulated MOIYM based on the following considerations.

(i) An improvement is made by introducing necessary variables so that the model will be used for the river basin comprising of reservoirs as well as barrages to assess the various optimal integrated annual system yields by simultaneously optimizing the cropping pattern for each project at the same time after the mandatory demands in each within-year time periods are fully met out of the within-year firm yields.

(ii) Within-year storage continuity constraint and continuity of annual yields at each reservoir have been modified by introducing new variables and this will overcome the limitations (i) to (iv) as discussed in IRYM.

(iii) Firm power will be generated by the firm yield with within-year distributions as that of irrigation because it is the main purpose of most of the projects. In case of hydropower projects annual firm energy is considered to be distributed in within-year time periods as per its within-year average release from past records, if available. Secondary power will be generated by the secondary yield, whereas irrigation demand will be met from both the yields. Energy constraints are modified suitably and additional discharge capacity constraint is included so that model becomes feasible. This will overcome the limitation (v) as discussed under section IRYM.

(iv) For modeling purpose, maximum four types of water uses are considered for a multipurpose project, viz., municipal demand, industrial demand, irrigation and hydropower generation. Releases towards municipal and industrial demands are considered as mandatory demands.

(v) Fixed quantity towards mandatory demands in each within-year period has to be released under all circumstances, even during the failure years with an intention to achieve the maximum possible annual yield reliability *p* and simultaneously satisfying its within-year distribution.

(vi) Separate contributions from regeneration from different water use, i.e., irrigation, municipal and industrial are considered in the model.

(vii) The two objectives explicitly considered are either to maximize the annual yield or maximize gross benefit from different water uses such as, crop production, energy generation and quantity of water released for municipal and industrial purposes for known reservoir capacities.

(viii) The model can also be used to find out the required active reservoir capacity for desired demands. Additionally, the power plant capacity of a proposed power plant can also be assessed.

The model by Thube (2007) and Panigrahi (2006) are the latest form of yield model using linear programming available in literature. However, the following paragraphs enunciate some of its limitations and capability to handle the real world problems:

The major limitation of MOIYM (Thube, 2007) , IRYM (Panigrahi 2006), multiple yield model for multireservoir system (Dahe and Srivastava 2002) and yield model (Loucks et al. 1981) is that these models do not take into account the transfer of water between sub-basins, basins and states. Ignoring of the water transfers will result in poor estimate of water resources and resultant optimality in the model.

4.7 FORMULATION OF THE GENERALISED RESERVOIR YIELD MODEL (GRYM)

4.7.1 Improvements over Earlier Yield Models

In order to overcome the limitations as discussed earlier and for improving the present form of the available latest yield models, i.e., Panigrahi (2006) and Thube (2007); the approach followed in the present study is as discussed below:

(i) Major improvement is made by introducing necessary variables for transfer of water so that the model will be used for the river basin comprising of reservoirs in co-basin as well as inter basin states to assess the various optimal integrated annual system yields by simultaneously optimizing the export from and export to basins and sub-basins in different states along with cropping pattern and mandatory demands in each within-year time periods to be fully met out of the within-year firm yields.

(ii) Flow to downstream co-basin states to meet special requirement like saving of standing crops and ordered releases from statutory authorities have been taken care of in the model.

(iii) Allowable deficit criterion by (Dahe and Srivastava 2002) is applicable for self-utilisation. The same has now been introduced for water transfers also.

(iv) Proportioning of water transfer out of firm and secondary reservoir yield has been made to maintain structural compatibility.

4.7.2 Generalised Reservoir Yield Model (GRYM)

Objective functions:

Maximize the annual system yield, i.e.,

Max

$$\sum_{s}^{SNs}\sum_{b}^{TNBs}\sum_{i}^{TNRs}\sum_{t}^{Tw} \left(Ow^{fp}_{SN_s,BN_{s,b},RN_{s,b,i},t} + Ow^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i},t}\right) \tag{4.15}$$

Subject to:

1. Over-year storage continuity equation

The over-year continuity is based on the principle of water balance at a site/reservoir for each water-year taken as a single period. Now the constraint for the over-year continuity at a site/reservoir can be given by the following equation,

$$S^{o}_{SN_s,BN_{s,b},RN_{s,b,i},j-1} + \sum_{l=1}^{NTUS_s}\sum_{y=1}^{NTUB_{s,l}}\sum_{x=1}^{NTUR_{s,l,y}}\sum_{j=1}^{T_{Yr}}\left[Sp_{USN_l,UBN_{l,y},URN_{l,y,x},j}\right] + I_{SN_s,BN_{s,b},RN_{s,b,i},j}$$

$$-Oy^{fp}_{SN_s,BN_{s,b},RN_{s,b,i}} - \theta^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}} * Oy^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i}}$$

$$-EV_{SN_s,BN_{s,b},RN_{s,b,i},j} - Sp_{SN_s,BN_{s,b},RN_{s,b,i},j} = S^{o}_{SN_s,BN_{s,b},RN_{s,b,i},j} \qquad \forall_{s,b,i,j} \tag{4.16}$$

where;

$S^{o}_{SN_s,BN_{s,b},RN_{s,b,i},j-1}$ = initial over-year storage in j^{th} year at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$NTUS_s$ = the total number of upstream states, contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

$NTUB_{s,l}$ = the total number of sub-basin in the l^{th} upstream state, contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

$NTUR_{s,l,y}$ = the total number of reservoirs in the y^{th} sub-basin of the l^{th} upstream state, contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

$Sp_{USN_l, UBN_{l,y}, URN_{l,y,x}, j}$ = spill in j^{th} year from upstream x^{th} site/reservoir in y^{th} sub-basin of l^{th} sub-basin contributing to i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$I_{SN_s, BN_{s,b}, RN_{s,b,i}, j}$ = annual inflow in j^{th} year at site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$Oy^{fp}_{SN_s, BN_{s,b}, RN_{s,b,i}}$ = annual firm yield of reliability p from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\theta^{p2}_{SN_s, BN_{s,b}, RN_{s,b,i}}$ = factor to identify a successful or a failure year for incremental secondary yield at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration (in case of a multiple yield model its value is either 0 for a failure year or 1 for a successful year);

$Oy^{sp2}_{SN_s, BN_{s,b}, RN_{s,b,i}}$ = annual secondary yield of reliability p2 (less than p) from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$EV_{SN_s, BN_{s,b}, RN_{s,b,i}, j}$ = annual evaporation volume loss in j^{th} year from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$Sp_{USN_l,UBN_{l,y},URN_{l,y,x},j}$ = spill in j^{th} year from upstream x^{th} site/reservoir in y^{th} sub-basin of l^{th} sub-basin contributing to i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$S^o_{SN_s,BN_{s,b},RN_{s,b,i},j}$ = final over-year storage in j^{th} year at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

(2) Over-year active storage volume capacity at a site/reservoir

This is based on the consideration that initial storage of a reservoir in a year should be less than its active storage capacity. Symbolically, it can be expressed as follows:

$$S^o_{SN_s,BN_{s,b},RN_{s,b,i},j-1} \le Y^o_{SN_s,BN_{s,b},RN_{s,b,i}} \qquad \forall_{s,b,i,j} \qquad (4.17)$$

where;

$Y^o_{SN_s,BN_{s,b},RN_{s,b,i}}$ = over-year storage capacity of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(3) Within-year Continuity Equation at a site/reservoir

The within-year continuity is based on the principle of water balance at a site/reservoir for different within-year time periods of a critical water-year. Therefore the constraint for the within-year continuity at a site/reservoir can be given by the following equation,

$$S^w_{SN_s,BN_{s,b},RN_{s,b,i},t} = S^w_{SN_s,BN_{s,b},RN_{s,b,i},t-1}$$

$$+\beta_{SN_s,BN_{s,b},RN_{s,b,i},t} * \left[\left(Oy^{fp}_{SN_s,BN_{s,b},RN_{s,b,i}} + Oy^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i}}\right) + \sum_{t=1}^{T_w} Ev_{SN_s,BN_{s,b},RN_{s,b,i},t}\right]$$

$$+ \sum_{l=1}^{NTUS_s} \sum_{y=1}^{NTUB_{s,l}} \sum_{x=1}^{NTUR_{s,l,y}} \sum_{t=1}^{T_w} \left[\delta^f_{USN_l,UBN_{l,y}} * \left(Ow^{fp}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right)\right.$$

$$+\left(\delta^{m}_{USN_l,UBN_{l,y}}-\delta^{f}_{USN_l,UBN_{l,y}}\right)*Os^{m}_{USN_l,UBN_{l,y},URN_{l,y,x},t}+\delta^{s}_{USN_l,UBN_{l,y}}*\left(Ow^{sp2}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right)\Bigg]$$

$$-\left[\sum_{l=1}^{NTUS_s}\sum_{y=1}^{NTUB_{s,l}}\sum_{x=1}^{NTUR_{s,l,y}}\sum_{t=1}^{T_w}\delta^{f}_{USN_l,UBN_{l,y}}*\left(OE^{fp;ISNU_{nis},IBNU_{nis,d},IRNU_{nis,d,c}}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right.\right.$$

$$\left.\left.+OE^{sp2;ISNU_{nis},IBNU_{nis,d},IRNU_{nis,d,c}}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right)\right]-Ev_{SN_s,BN_{s,b},RN_{s,b,i},t}$$

$$-\left[\left(Ow^{fp}_{SN_s,BN_{s,b},RN_{s,b,i},t}+Ow^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i},t}\right)\right]\qquad\forall_{s,b,i,t}\qquad(4.18)$$

where;

$S^{w}_{SN_s,BN_{s,b},RN_{s,b,i},t-1}$ = initial within-year storage in t^{th} within-year time period at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$S^{w}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = final within-year storage in t^{th} within-year time period at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\beta_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = ratio of the inflow in t^{th} period of the critical year of the record to the total annual inflow to at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$Ev_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = within-year evaporation in t^{th} within-year time period at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$Ow^{fp}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = firm within-year reservoir yield in t^{th} within-year time period with annual reliability p from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$Ow^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = secondary within-year reservoir yield in t^{th} within-year time period with annual reliability $p2$ from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

$\delta^{f}_{USN_l,UBN_{l,y}}$ = fraction of return flow from upstream firm water use of contributing (upstream) y^{th} sub-basin of l^{th} state to i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\delta^{s}_{USN_l,UBN_{l,y}}$ = fraction of return flow from upstream secondary water use of contributing (upstream) y^{th} sub-basin of l^{th} state to i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\delta^{m}_{USN_l,UBN_{l,y}}$ = fraction of return flow from upstream mandatory water use of contributing (upstream) y^{th} sub-basin of l^{th} state to i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$Os^{m}_{USN_l,UBN_{l,y},URN_{l,y,x},t}$ = mandatory release in t^{th} within-year time period from x^{th} site/reservoir in y^{th} sub-basin of upstream l^{th} state (the upstream l^{th} state is in reference to the downstream s^{th} under consideration);

$OE^{fp;ISNU_{nis},IBNU_{nis,d},IRNU_{nis,d,c}}_{USN_l,UBN_{l,y},URN_{l,y,x},t}$ = export/transfer of water out of firm yield in t^{th} within-year time period from x^{th} site/reservoir in y^{th} sub-basin of upstream l^{th} state (the upstream l^{th} state is in reference to the downstream s^{th} under consideration) to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state;

$OE^{sp2;ISNU_{nis},IBNU_{nis,d},IRNU_{nis,d,c}}_{USN_l,UBN_{l,y},URN_{l,y,x},t}$ = export/transfer of water out of secondary yield in t^{th} within-year time period from x^{th} site/reservoir in y^{th} sub-basin of upstream l^{th} state (the upstream l^{th} state is in reference to the downstream s^{th} under consideration) to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state.

(4) Total active storage capacity constraint at a site/reservoir

The sum of the within-the-year storage and the over-year-storage cannot exceed the total active storage capacity. Symbolically, it can be expressed as follows:

$$Y^{o}_{SN_s,BN_{s,b},RN_{s,b,i}} + S^{w}_{SN_s,BN_{s,b},RN_{s,b,i},t-1} \le Ya_{SN_s,BN_{s,b},RN_{s,b,i}} \qquad \forall_{s,b,i,t} \qquad (4.19)$$

where $Ya_{SN_s,BN_{s,b},RN_{s,b,i}}$ = the total active storage capacity of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(5) Constraint to account for annual evaporation at a site/reservoir

The total loss of water due to evaporation in a year from a site/reservoir is equal to the sum of the evaporation losses at dead storage level plus sum of the within-the-year time period evaporation losses above the level of dead storage in that reservoir. It is as follows:

$$EV_{SN_s,BN_{s,b},RN_{s,b,i},j} = EV^o_{SN_s,BN_{s,b},RN_{s,b,i}} + \left\langle S^o_{SN_s,BN_{s,b},RN_{s,b,i},j-1} + \sum_{t=1}^{T_w}\left\{\left[\left(S^w_{SN_s,BN_{s,b},RN_{s,b,i},t-1} + S^w_{SN_s,BN_{s,b},RN_{s,b,i},t}\right)/0.5\right] * \gamma_{SN_s,BN_{s,b},RN_{s,b,i},t}\right\}\right\rangle * EV^a_{SN_s,BN_{s,b},RN_{s,b,i}} \quad \forall_{s,b,i,j} \qquad (4.20)$$

where

$EV^o_{SN_s,BN_{s,b},RN_{s,b,i}}$ = average annual fixed evaporation volume losses at the level of dead storage of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration; $EV_{SN_s,BN_{s,b},RN_{s,b,i},j}$ = annual evaporation volume loss in j^{th} year from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$EV^a_{SN_s,BN_{s,b},RN_{s,b,i}}$ = average annual evaporation loss rate per unit of the active storage volume from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration; and

$\gamma_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = fraction of annual evaporation volume loss from reservoir at i^{th} site/ reservoir in b^{th} sub-basin of s^{th} state under consideration.

(6) Constraint for time period wise evaporation losses

This is represented for the critical water-year sub-periods as follows:

$$Ev_{SN_s,BN_{s,b},RN_{s,b,i},t} = \gamma_{SN_s,BN_{s,b},RN_{s,b,i},t} * EV^o_{SN_s,BN_{s,b},RN_{s,b,i}} + \left(S^o_{SN_s,BN_{s,b},RN_{s,b,i},cr} + \left(S^w_{SN_s,BN_{s,b},RN_{s,b,i},t-1} + S^w_{SN_s,BN_{s,b},RN_{s,b,i},t}\right)/2.0\right) * \gamma_{SN_s,BN_{s,b},RN_{s,b,i},t} * EV^a_{SN_s,BN_{s,b},RN_{s,b,i}} \quad \forall_{s,b,i,t} \qquad (4.21)$$

where,

$S^{o}_{SN_s,BN_{s,b},RN_{s,b,i},cr}$ = initial over-year storage volume critical year (cr) of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(7) Constraint for continuity of annual yields at a site/reservoir

(a) For firm yield

The annual firm release is the sum of the time-period wise firm releases from a reservoir. It takes into account the regenerated flows of the upstream reservoir firm releases.

$$\sum_{t=1}^{T_w} Ow^{fp}_{SN_s,BN_{s,b},RN_{s,b,i},t} = Oy^{fp}_{SN_s,BN_{s,b},RN_{s,b,i}} + \left[\sum_{l=1}^{NTUS_s}\sum_{y=1}^{NTUB_{s,l}}\sum_{x=1}^{NTUR_{s,l,y}}\sum_{t=1}^{T_w}\delta^{f}_{USN_l,UBN_{l,y}} * \left[\left(Ow^{fp}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right)\right.\right.$$

$$\left.\left. + \left(\delta^{m}_{USN_l,UBN_{l,y}} - \delta^{f}_{l,UBN_{l,y}}\right) * Os^{m}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right]\right.$$

$$\left. - \sum_{l=1}^{NTUS_s}\sum_{y=1}^{NTUB_{s,l}}\sum_{x=1}^{NTUR_{s,l,y}}\sum_{t=1}^{T_w}\delta^{f}_{USN_l,UBN_{l,y}} * \left(OE^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right)\right] \qquad \forall_{s,b,i} \qquad (4.22a)$$

(b) For secondary yield at a site/reservoir

This is based on the same principle as stated above but the yield is secondary.

$$\sum_{t=1}^{T_w} Ow^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i},t} = Oy^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i}}$$

$$+ \left[\sum_{l=1}^{NTUS_s}\sum_{y=1}^{NTUB_{s,l}}\sum_{x=1}^{NTUR_{s,l,y}}\sum_{t=1}^{T_w}\delta^{f}_{USN_l,UBN_{l,y}} * \left[\left(Ow^{sp2}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right)\right]\right]$$

$$- \sum_{l=1}^{NTUS_s}\sum_{y=1}^{NTUB_{s,l}}\sum_{x=1}^{NTUR_{s,l,y}}\sum_{t=1}^{T_w}\delta^{s}_{USN_l,UBN_{l,y}} * \left(OE^{sp2;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{USN_l,UBN_{l,y},URN_{l,y,x},t}\right)\Bigg] \qquad \forall_{s,b,i} \qquad (4.22b)$$

(8) Constraint for allowable annual deficit criterion at a site/reservoir

The annual firm yield is made equal to the failure fraction times the sum of the annual firm and secondary yields to incorporate deficit criterion in the model. On rearranging the terms of the above statement, it can be expressed symbolically as follows:

$$\left[\rho^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}} / \left(1 - \rho^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}}\right)\right]\left(\sum_{t=1}^{T_w} Ow^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i},t}\right)$$

$$\leq \sum_{t=1}^{T_w} Ow^{fp}_{SN_s,BN_{s,b},RN_{s,b,i},t} \quad \text{for } 0 \leq \rho^{p2}_{s,b,i} < 1 \qquad \forall_{s,b,i} \qquad (4.23)$$

where $\rho^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = fraction of total annual yield desired to be released in the failure years at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(9) Constraint for firm energy generation at a site/reservoir

This is based on production of energy from the firm releases:

$$E_{SN_s,BN_{s,b},RN_{s,b,i},t} = C_f * e_{SN_s,BN_{s,b},RN_{s,b,i}} * Ha_{SN_s,BN_{s,b},RN_{s,b,i},t} * Ow^{fp}_{SN_s,BN_{s,b},RN_{s,b,i},t} \quad \forall_{s,b,i,t} \quad (4.24)$$

where $E_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = firm energy generations in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

C_f = conversion factor for computation of hydroelectric energy;

$e_{SN_s,BN_{s,b},RN_{s,b,i}}$ = efficiency of the turbine at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration; and

$Ha_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = effective head at t^{th} within-year time period for generation of power from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(10) Constraint for secondary energy generation at a site/reservoir

This is energy production from secondary releases of the reservoir.

$$\bar{E}_{SN_s,BN_{s,b},RN_{s,b,i},t} = C_f * e_{SN_s,BN_{s,b},RN_{s,b,i}} * Ha_{SN_s,BN_{s,b},RN_{s,b,i},t} * Ow^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i},t} \quad \forall_{s,b,i,t} \quad (4.25)$$

where $\bar{E}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = secondary energy generations in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(11) Plant capacity constraint at a site/reservoir

This is a constraint arising out of the fact that the total generation at any instant of time from a site cannot exceed the installed capacity in case of an existing one or proposed capacity to be installed, if it is a new one. Symbolically, it can be expressed as follows:

$$E_{SN_s,BN_{s,b},RN_{s,b,i},t} + \bar{E}_{SN_s,BN_{s,b},RN_{s,b,i},t}$$

$$\leq \alpha_{SN_s,BN_{s,b},RN_{s,b,i},t} * h_{SN_s,BN_{s,b},RN_{s,b,i},t} * H_{SN_s,BN_{s,b},RN_{s,b,i}} \quad \forall_{s,b,i,t} \quad (4.26)$$

Where $\alpha_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = load factor (or hydropower plant factor) at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$h_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = number of hours of generation of power in t^{th} within-year time period from plant at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration; and

$H_{SN_s,BN_{s,b},RN_{s,b,i}}$ = hydro plant capacity at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(12) Constraint for annual firm energy generation at a site/reservoir

This is a constraint based on the concept that subject to availability [of water and installed capacity (if it is an existing plant)] the sum total of the firm power proposed to be generated from a site i over a period of one year should meet the annual firm energy target from that site. Symbolically, it can be expressed as follows:

$$\sum_{t=1}^{T_w} E_{SN_s,BN_{s,b},RN_{s,b,i},t} = E^{AT}_{SN_s,BN_{s,b},RN_{s,b,i}} \qquad \forall_{s,b,i} \qquad (4.27)$$

where $E^{AT}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = the annual firm energy target from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(13) Constraint for secondary generation at a site/reservoir

This is based on the same consideration/condition as explained in the above section except that the considered generation is secondary in nature.

$$\sum_{t=1}^{T_w} \overline{E}_{SN_s,BN_{s,b},RN_{s,b,i},t} = \overline{E}^{AT}_{SN_s,BN_{s,b},RN_{s,b,i}} \qquad \forall_{s,b,i} \qquad (4.28)$$

where $\overline{E}^{AT}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = the annual secondary energy target from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(14) Constraint for water availability at a site/reservoir

Definitions of various nomenclatures:

Before the equation is derived, it is necessary to give some definitions of various nomenclatures used:

a) For the s^{th} exporting state under consideration which is exporting state water to the nis^{th} state, the nomenclature used for numbering the nis^{th} state and for numbering their respective sub-basins and reservoirs are defined here, i.e.,

ISN_{nis} = the number of the nis^{th} state, to which the water is being exported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} exporting state under consideration;

$IBN_{nis,d}$ = the number of the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} exporting state under consideration; and

$IRN_{nis,d,c}$ = the number of the c^{th} reservoir in the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} exporting state under consideration.

b) For the s^{th} importing state under consideration which is importing water from the isn^{th} state, the nomenclature used for numbering the isn^{th} state and for numbering their respective sub-basins and reservoirs are defined here, i.e.,

NES_{isn} = the number of the isn^{th} state from which water is being imported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} importing state under consideration;

$NEB_{isn,z}$ = the number of the z^{th} sub-basin of the isn^{th} state from which water is being imported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} importing state under consideration; and

$NER_{isn,z,k}$ = the number of the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state from which water is being imported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} importing state under consideration.

Water availability constraint at a site/reservoir

This is a condition to plan schedule of water withdrawal from a site/reservoir according to availability of surface water. Symbolically, this can be expressed as follows:

$$\sum_{r=1}^{NCT_{s,b,i}} \left[Ac_{SN_s, BN_{s,b}, RN_{s,b,i}} * \phi_{SN_s, BN_{s,b}, RN_{s,b,i}, Cn_r} * \nabla_{SN_s, BN_{s,b}, RN_{s,b,i}, Cn_r, t} \right] + Os^{m}_{SN_s, BN_{s,b}, RN_{s,b,i}, t}$$
$$+ \left[\sum_{nis=1}^{TIS_s} \sum_{d=1}^{NTIB^{s,nis}} \sum_{c=1}^{NTIR^{s,nis,d}} \sum_{t=1}^{T_w} \left(OE^{fp;ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}}_{SN_s, BN_{s,b}, RN_{s,b,i}, t} + OE^{sp2;ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}}_{SN_s, BN_{s,b}, RN_{s,b,i}, t} \right) \right]$$

$$= Ow^{fp}_{SN_s,BN_{s,b},RN_{s,b,i},t} + Ow^{sp2}_{SN,BN_{s,b},RN_{s,b,i},t}$$

$$+\left[\sum_{isn=1}^{TES_s}\sum_{z=1}^{EBTN^{s,isn}}\sum_{k=1}^{ERTN^{s,isn,z}}\sum_{t=1}^{T_w}\left(OI^{fp;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{SN_s,BN_{s,b},RN_{s,b,i},t} + OI^{sp2;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{SN_s,BN_{s,b},RN_{s,b,i},t}\right)\right] \quad \forall_{s,b,i,t} \tag{4.29}$$

Where,

$Ac_{SN_s,BN_{s,b},RN_{s,b,i}}$ = cultivable command area (CCA) of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\nabla_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r,t}$ = gross irrigation requirement (GIR) [measured in terms of depth of water] for r^{th} crop in t^{th} within-year time for i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$\phi_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r}$ = fractions of the CCA under cultivation/occupation of r^{th} crop in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration; $Os^{m}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = mandatory release in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$OE^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = export/transfer of water out of firm yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state under consideration;

$OE^{sp2;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = export/transfer of water out of secondary yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state under consideration;

$OI^{fp;NSB_{isn},NEB_{isn,z},NER_{isn,z,k}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = import of water out of firm yield in t^{th} within-year time period from k^{th} site/reservoir in z^{th} sub-basin of isn^{th} state to meet the demands (irrigation or otherwise) in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$OI^{sp2;NSB_{isn},NEB_{isn,z},NER_{isn,z,k}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = import of water out of secondary yield in t^{th} within-year time period from k^{th} site/reservoir in z^{th} sub-basin of isn^{th} state to meet the demands (irrigation or otherwise) in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(15) Constraint for annual M&I release requirement at a site/reservoir

The sum of time period wise municipal and industrial releases is equal to that of the annual target/requirement. Symbolically, it can be expressed as follows:

$$\sum_{t=1}^{T_w} Os^m_{SN_s,BN_{s,b},RN_{s,b,i},t} = OAT^m_{SN_s,BN_{s,b},RN_{s,b,i}} \qquad \forall_{s,b,i} \qquad (4.30)$$

Where,

$OAT^m_{SN_s,BN_{s,b},RN_{s,b,i}}$ = annual mandatory release target from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(16) Constraint to meet the maximum reliability for M&I releases at a site/reservoir

This is a condition set to have greater reliance in M&I releases by the fact that the firm yield from a reservoir over a period of time should be equal to or greater than the M&I release/requirement during that period to safeguard either the contractual obligations arising out of an agreed upon export scenario or to meet the most essential demands like the domestic water demand. Symbolically, this can be expressed as follows:

$$Os^m_{SN_s,BN_{s,b},RN_{s,b,i},t} \geq O^m_{SN_s,BN_{s,b},RN_{s,b,i},t} \qquad \forall_{s,b,i,t} \qquad (4.31)$$

where

$O^m_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = minimum mandatory release in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(17) Irrigation intensity limitation at a site/reservoir

From the point of view of better soil management for sustainable use, a constraint can be put in the modeling stage such that over utilization of land resource is capped during planning. It can be expressed as:

$$\sum_{r=1}^{NCT_{s,b,i}} \phi_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r} \le \omega_{SN_s,BN_{s,b},RN_{s,b,i}} \qquad \forall_{s,b,i} \qquad (4.32)$$

where,

$\phi_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r}$ = fractions of the CCA under cultivation/occupation of r^{th} crop in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration; $\omega_{SN_s,BN_{s,b},RN_{s,b,i}}$ = annual irrigation intensity at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration; and

$NCT_{s,b,i}$ = number of crops at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(18) Minimum area constraint under each crop at a site/reservoir

This constraint has been framed to maintain minimum nutritional requirement. It can also take care of preferential agricultural practices as is prevalent especially in tribal pockets. Symbolically, this can be expressed as below:

$$LBAc^{min}_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r} \le \phi_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r} \le UBAc^{\max}_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r} \qquad \forall_{s,b,i,r} \qquad (4.33)$$

where $LBAc_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r}$ = lower bound on (in fraction of CCA) for r^{th} cropped area for i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration; and $UBAc_{SN_s,BN_{s,b},RN_{s,b,i},Cn_r}$ = upper bound on (in fraction of CCA) for r^{th} cropped area for i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(19) Constraint for meeting minimum protein requirement at a site/reservoir

This a condition imposed on the model such that crop planning should be done in such a fashion that a balanced diet is safeguarded for the basin/sub-basin population to meet the minimum protein requirement. Symbolically, it can be expressed as follows:

$$\sum_{r=1}^{NCT_{s,b,i}} Ac_{SN_s,BN_{s,b},RN_{s,b,i}} * \phi_{SN_s,BN_{s,b},RN_{s,b,i},r} * \varphi_{SN_s,BN_{s,b},RN_{s,b,i},r} * \Pr_{Cn_r} \ge TPR_{SN_s,BN_{s,b},RN_{s,b,i}}$$

$$\forall_{s,b,i} \qquad (4.34)$$

where $\Pr_{Cn_r}$ = protein content of r^{th} cropper unit weight of yield produced; and $TPR_{SN_s,BN_{s,b},RN_{s,b,i}}$ = total protein demand to be met i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(20) Constraint for meeting minimum calorie requirement at a site/reservoir

This is a constraint put into the model to safeguard the minimum calorie requirement of the population inhabiting the area to be met from site i in sub-basin b. This can be expressed as:

$$\sum_{r=1}^{NCT_{s,b,i}} A_{SN_s,BN_{s,b},RN_{s,b,i}} * \phi_{SN_s,BN_{s,b},RN_{s,b,i},r} * \varphi_{SN_s,BN_{s,b},RN_{s,b,i},r} * Cl_{Cn_r} \geq TCR_{SN_s,BN_{s,b},RN_{s,b,i}}$$

$$\forall_{s,b,i} \qquad (4.35)$$

where,

Cl_{Cn_r} = calorie content of r^{th} cropper unit weight of yield produced; and $TCR_{SN_s,BN_{s,b},RN_{s,b,i}}$ = total calorie demand to be met i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(21) Consideration for Monsoon End Storage to Guarantee Ordered Releases

To ensure pre specified monthly releases from specified reservoirs, the storages at the end of the monsoon period, i.e., at the end of October should be at least equal to the pre specified value. In addition to the release requirements during the non-monsoon months (November to May), a part of the storage will be lost through evaporation. Therefore, the monsoon-end storage should be more than or equal to sum of the monthly pre specified release requirements and the evaporation losses in the non-monsoon months. Mathematically, this can be stated as given below:

$$\sum_{b=1}^{TNBS_s} \sum_{i=1}^{TNRS_{s,b}} S^w_{SN_s,BN_{s,b},RN_{s,b,i},t} \geq LOB\_STOT^w_s \qquad \forall_{s,t=5} \qquad (4.36)$$

Where, $LOB\_STOT^w_s$ = lower bound on the total storage to be made available at the end of the monsoon (at the end of October month, i.e., t = 5) from all the reservoirs in the s^{th} state under consideration.

(22) Over-Year Carry-Over Storage

Provisioning for a minimum amount of over year end of year storage for a reservoir is always advisable. This is essential to take care of initial water needs for a crop, which are basically small but important as they hedge against any delay in onset of the rainy season. The mathematical statement for formulation is: the sum of the over-year carry-over storages of the specified/designated reservoirs for the purpose at the end a water-year (i.e., storage at the beginning of the following water year) should be equal to or more that the predefined value. Symbolically, it is as given below:

$$\sum_{b=1}^{TNB_s} \sum_{i=1}^{TNR_{s,b}} S^{o}_{SN_s, BN_{s,b}, RN_{s,b,i}, j-1} \geq OYRCRO\_STO_{SN_s, BN_{s,b}, RN_{s,b,i}} \qquad \forall_{s,j} \qquad (4.37)$$

Where,

$OYRCRO\_STO_{SN_s, BN_{s,b}, RN_{s,b,i}}$ = the over-year carry-over storage need to be maintained at the i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(23) Annual Target Demand for Self-Utilization

This is a consideration for analysis of a water resources system enunciating the option for water transfer from the site/reservoir under consideration after meeting its own demand. It has been composed for a case where water transfer is optional. This constraint may not be used in case of mandated nature of water transfer involved. The mathematical formulation for the said statement is as follows:

$$(Oy^{fp}_{SN_s, BN_{s,b}, RN_{s,b,i}} + Oy^{sp2}_{SN_s, BN_{s,b}, RN_{s,b,i}}) - \left[\sum_{nis=1}^{TIS_s} \sum_{d=1}^{NTIB^{nis}} \sum_{c=1}^{NTIR^{nis,d}} \sum_{t=1}^{T_w} \left(OE^{fp;ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}}_{SN_s, BN_{s,b}, RN_{s,b,i}, t} + OE^{sp2;ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}}_{SN_s, BN_{s,b}, RN_{s,b,i}, t} \right) \right] \leq ATD_{SN_s, BN_{s,b}, RN_{s,b,i}} \qquad \forall_{s,b,i} \qquad (4.38)$$

where,

$ATD_{SN_s, BN_{s,b}, RN_{s,b,i}}$ = the targeted water-year demand at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(24) Consideration for crop area limitation for given set of reservoirs

Stipulations may put limits or bounds on cropped area of a particular crop receiving irrigation water by means of reservoirs in a riparian co-basin state of a trans-boundary river and its tributaries. Mathematically, this can be stated as given below:

$$LBCROP\_A_s \leq \sum_{b=1}^{TCNB_s} \sum_{i=1}^{TCNR_{s,b}} \phi_{SN_s, BN_{s,b}, RN_{s,b,i}, Cn_r} * Ac_{SN_s, BN_{s,b}, RN_{s,b,i}} \leq UBCROP\_A_s \quad \forall_{s,r} \quad (4.39)$$

Where,

$TCNB_s$ = total number of given set of basins of the s^{th} state under consideration for crop area limitation;

$TCNR_{s,b}$ = total number of given set of reservoirs in the b^{th} basin of the s^{th} state under consideration for crop area limitation;

$UBCROP\_A_s$ = upper bound on the total cropped area of the s^{th} state under consideration; and

$LBCROP\_A_s$ = lower bound on the total cropped area of the s^{th} state under consideration.

(25) Final-Monthly Releases from Reservoirs to other states

In a trans-boundary River, as governed by its Tribunal Award a riparian co-basin state may have to ensure water exports from release of scheduled monthly quantum from its specified reservoirs to another riparian co-basin state. Mathematically, it can be as follows:

$$\sum_{p=1}^{NTEB_s} \sum_{q=1}^{NTER_{s,p}} \sum_{nis=1}^{TIS_s} \sum_{d=1}^{NTIB^{nis}} \sum_{c=1}^{NTIR^{nis,d}} \left(OE_{ESN_s, EBN_{s,p}, ERN_{s,p,q}, t}^{fp; ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}} + OE_{ESN_s, EBN_{s,p}, ERN_{s,p,q}, t}^{sp2; ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}} \right) \geq OR_{ESN_s, t}^{ISN_{nis}}$$

$$\forall_{s,nis,t} \quad (4.40)$$

Where,

$OR_{ESN_s, t}^{ISN_{nis}}$ = minimum total export/transfer to the nis^{th} state from the s^{th} state under consideration.

(26) Constraint for Environmental consideration

In a trans-boundary River, as governed by its Tribunal Award a riparian co-basin state may have to ensure a total environmental water requirement to be made available from the operation of its specified reservoirs in the months from t_1 to t_2 as an export to its another riparian co-basin state.

$$\sum_{nis=1}^{TIS_s} \sum_{d=1}^{NTIB^{nis}} \sum_{c=1}^{NTIR^{nis,d}} \sum_{t=1}^{T_w} \left(OEn_{SN_s, BN_{s,b}, RN_{s,b,i}, t}^{fp; ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}} \right) \geq q_1 \qquad \forall_{t = t_1 to t_2} \qquad (4.41)$$

Where,

$OEn^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}$ = export/transfer of water to meet the demands for environmental purposes of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state, made out of the firm yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(27) Proportioning of the Reservoir Yields in respect of Water Transfer

Due to incorporation of deficit criterion (Dahe and Srivastava, 2002) in the original yield model (Loucks et. al, 1981), the system reliability for self-utilization was structured in the model. But no such concept is found for water transfer. Due to incorporation of water transfers in the modified reservoir yield model improved and employed in this study, it is also felt necessary that some proportioning of the water transfer out of the firm and secondary reservoir yields should be done in order to maintain structural compatibility of water transfer in the model such that like self-utilization, the water transfer aspect is also dealt with similar fashion, which beyond doubt may be mandatory or obligatory out of contractual provisions otherwise, if any. This can be achieved by taking water transfer out of the firm yield equal to the failure fraction times the total water transfer – mandated or obligatory. This is similar with the aspect of self-utilization of water. The mathematical formulation of the said statement, after rearrangement, is as follows:

$$\left[\sum_{nis=1}^{TIS_s}\sum_{d=1}^{NTIB^{nis}}\sum_{c=1}^{NTIR^{nis,d}}\sum_{t=1}^{T_w}\left(OE^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}\right)\right] \geq \left[\rho^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}} \Big/ \left(1-\rho^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}}\right)\right]$$

$$*\left[\sum_{nis=1}^{TIS_s}\sum_{d=1}^{NTIB^{nis}}\sum_{c=1}^{NTIR^{nis,d}}\sum_{t=1}^{T_w}\left(OE^{sp2;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{SN_s,BN_{s,b},RN_{s,b,i},t}\right)\right]$$

Where $0 \leq \rho^{p2}_{s,b,i} < 1 \qquad \forall_{s,b,i}$ (4.42)

Where

$\rho^{p2}_{SN_s,BN_{s,b},RN_{s,b,i}}$ = fraction of total annual yield desired to be released in the failure years at i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

(28) Flow to co-basin downstream states to meet special requirements

Sometimes due to impact of various pressure groups within the co-basin states of a trans-boundary river, it may be required to ensure annually release of some specific amount of water by one co-basin state and made available to it's another co-basin state for supply of water of the crops and other special requirements. Mathematical formulation of the scenario of the said claim is presented and is given below:

$$LOB\_REL_s^{nis} \le \left[\sum_{p=1}^{NTEB_s} \sum_{q=1}^{NTER_{s,p}} \sum_{nis=1}^{TIS_s} \sum_{d=1}^{NTIB^{nis}} \sum_{c=1}^{NTIR^{nis,d}} \sum_{t=1}^{T_w} \left(OE_{ESN_s, EBN_{s,p}, ERN_{s,p,q}, t}^{fp; ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}} \right.\right.$$

$$\left.\left. + OE_{ESN_s, EBN_{s,p}, ERN_{s,p,q}, t}^{sp2; ISN_{nis}, IBN_{nis,d}, IRN_{nis,d,c}} \right) \right] \le UPB\_REL_s^{nis} \qquad \forall s \qquad (4.43)$$

where,

$LOB\_REL_s^{nis}$ = lower bound on the export/transfer of water in a water-year from s^{th} state under consideration to meet the demands (irrigation or otherwise) in the nis^{th} state; and

$UPB\_REL_s^{nis}$ = lower bound on the export/transfer of water in a water-year from s^{th} state under consideration to meet the demands (irrigation or otherwise) in the nis^{th} state.

(29) Constraint for state wise sharing of waters by its riparian co-basin states

Definitions of various nomenclatures:

Before the constraint for state wise sharing of waters by its riparian co-basin states is derived, it is necessary to give some definitions of various nomenclatures used:

a) The nomenclature used for the total numbers, of the reservoirs and their respective sub-basins of the s^{th} exporting state under consideration and for the respective sub-basins and reservoirs of the nis^{th} state to which the water is being exported are,

$NTEB_s$ = the total number of sub-basins of the s^{th} exportingstate under consideration;

$NTER_{s,p}$ = the total number of reservoirs in the p^{th} sub-basin of the s^{th} exporting state under consideration;

TIS_s = the total number of states, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration;

$NTIB^{nis}$ = the total number of sub-basins of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration; and

$NTIR^{nis,d}$ = the total number of reservoirs in the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration.

b) The nomenclature used for the total numbers, of the reservoirs and their respective sub-basins of the s^{th} importing state under consideration and for the respective sub-basins and reservoirs of the isn^{th} state from which the water is being imported are,

$IBTN_s$ = the total number of sub-basins of the s^{th} importing state under consideration;

$IRTN_{s,u}$ = the total number of reservoirs in the u^{th} sub-basin of the s^{th} importing state under consideration;

TES_s = the total number of states, importing water from the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state;

$EBTN^{sin}$ = the total number of sub-basins of the s^{th} importing state under consideration, importing water from the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state; and

$ERTN^{sin,z}$ = the total number of reservoirs in the u^{th} sub-basin of the s^{th} importing state under consideration, importing water from the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state.

c) The nomenclature used, for numbering of the s^{th} exporting state under consideration and for its respective sub-basins and reservoirs which are exporting water to the nis^{th} state and for its respective sub-basins and reservoirs are,

ESN_s = the number of the s^{th} exporting state under consideration;

$EBN_{s,p}$ = the number of the p^{th} sub-basin of the s^{th} exporting state under consideration;

$ERN_{s,p,q}$ = the number of the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration;

ISN_{nis} = the number of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration;

$IBN_{nis,d}$ = the number of the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration; and

$IRN_{nis,d,c}$ = the number of the c^{th} reservoir in the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration.

d) Further the nomenclature used, for numbering of the s^{th} importing state under consideration and for its respective sub-basins and reservoirs which are importing water from the isn^{th} state and for its respective sub-basins and reservoirs are,

NIS_s = the number of the s^{th} importing state under consideration;

$NIB_{s,u}$ = the number of the u^{th} sub-basin of the s^{th} importing state under consideration;

$NIR_{s,u,v}$ = the number of the v^{th} reservoir in the u^{th} sub-basin of the s^{th} importing state under consideration;

NES_{isn} = the number of the isn^{th} state from which water is being imported by the v^{th} reservoir in the u^{th} sub-basin of the s^{th} importing state under consideration;

$NEB_{isn,z}$ = the number of the z^{th} sub-basin of the isn^{th} state from which water is being imported by the v^{th} reservoir in the u^{th} sub-basin of the s^{th} importing state under consideration; and

$NER_{isn,z,k}$ = the number of the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state from which water is being imported by the v^{th} reservoir in the u^{th} sub-basin of the s^{th} importing state under consideration.

State wise sharing of waters by its riparian co-basin states

At any stage of development of a trans-boundary River its waters are generally shared amongst its co-basin riparian states. These water shares (allocated quantum of water) in a trans-boundary River out of its waters at times are governed by Tribunal Awards arising out of water disputes among the co-basin states involved. These shares for any riparian co-basin state at that stage of development should not exceed this allocated quantum and may include: (i) the sum of the water uses from the releases of its reservoirs, (ii) minus the sum of the exports to other riparian co-basin states (this export forms a part the water shared by the riparian co-basin state to which the water is being exported) out of the releases of these reservoirs and (iii) plus the uses from other non-storage schemes out of the river waters, viz., the river channel schemes and the minor irrigation schemes.

Now the constraint for the water shared by a riparian co-basin state of a trans-boundary River can be given by the following equation,

$$\left\{\left[\sum_{b=1}^{TNBS_s}\sum_{i=1}^{TNRS_{s,b}}\left(Oy^{fp}_{SN_s,BN_{s,b},RN_{s,b,i}}+Oy^{sp2}_{SN_s,BN_{s,b},RN_{s,b,i}}\right)\right]\right.$$
$$\left.-\left[\sum_{p=1}^{NTEB_s}\sum_{q=1}^{NTER_{s,p}}\sum_{nis=1}^{TIS_s}\sum_{d=1}^{NTIB^{nis}}\sum_{c=1}^{NTIR^{nis,d}}\sum_{t=1}^{T_w}\left(OE^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{ESN_s,EBN_{s,p},ERN_{s,p,q},t}+OE^{sp2;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{ESN_s,EBN_{s,p},ERN_{s,p,q},t}\right)\right]\right\}$$
$$+\left\{\sum_{u=1}^{IBTN_s}\sum_{v=1}^{IRTN_{s,u}}\sum_{isn=1}^{TES_s}\sum_{z=1}^{EBTN^{isn}}\sum_{k=1}^{ERTN^{isn,z}}\sum_{t=1}^{T_w}\left(OI^{fp;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{NIS_s,NIB_{s,u},NIR_{s,u,v},t}+OI^{sp2;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{NIS_s,NIB_{s,u},NIR_{s,u,v},t}\right)\right\}\le q_2$$

$$\forall_s \qquad (4.44)$$

where,

$OE^{fp;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{ESN_s,EBN_{s,p},ERN_{s,p,q},t}$ = export/transfer of water out of firm yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state under consideration;

$OE^{sp2;ISN_{nis},IBN_{nis,d},IRN_{nis,d,c}}_{ESN_s,EBN_{s,p},ERN_{s,p,q},t}$ = export/transfer of water out of secondary yield in t^{th} within-year time period from i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration to meet the demands (irrigation or otherwise) in the command area of c^{th} site/reservoir in d^{th} sub-basin of nis^{th} state under consideration;

$OI^{fp;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{NIS_s,NIB_{s,u},NIR_{s,u,v},t}$ = import of water out of firm yield in t^{th} within-year time period from k^{th} site/reservoir in z^{th} sub-basin of isn^{th} state to meet the demands (irrigation or otherwise) in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration;

$OI^{sp2;NES_{isn},NEB_{isn,z},NER_{isn,z,k}}_{NIS_s,NIB_{s,u},NIR_{s,u,v},t}$ = import of water out of secondary yield in t^{th} within-year time period from k^{th} site/reservoir in z^{th} sub-basin of isn^{th} state to meet the demands (irrigation or otherwise) in the command area of i^{th} site/reservoir in b^{th} sub-basin of s^{th} state under consideration.

CHAPTER 5

ESTIMATION OF THE MODELPARAMETERS

5.1 COMPILATION AND PROCESSING OF DATA

Compilation and processing of data and parameters required for planning and managing water resources of a river basin is the very first step. These serve the purpose of providing basic input data to the planning. The amounts of required data/parameter are exclusively very large, and handling their compilation and processing is a complex problem. There are several parameters which are important and play major roles in planning and managing water resources of a river basin. They play roles in two ways; individually and collectively at different times/stages during the entire process. These data/parameters are usually are to be processed to be made suitable for planning and model applications and user friendly.

The main aim of developing water resources of a river basin is to meet the water needs of the people living within it. Many a times such water resources developments are trans-boundary in nature, and excess water from a basin can also be transferred to a water deficit basin. Therefore, two main features of any water planning process are; the water resource supply and water demand. The resource supply is its availability (in terms of the system's inputs and the resulting outputs) and thereof the demands to be fulfilled from these resources; both play a major role in planning a river basin's water resources development. It is therefore, (a) First essential, to compile and estimate the supply parameters in useful formats. These includes; (i) inflow data, upstream abstractions in medium and minor irrigation projects, imports and exports within the basin, (ii) identification of failure years for individual projects, consideration of independent failure years instead of a common set of failure years, allowable percentage yield during failure years, criteria for deciding the percentage of annual yield to be made available during failure years, and reliability of different yields and water uses, and (iii) selection of criterion for estimation of the values of parameter β_t, and (b) Similarly, the estimation of the demand parameters in the sequence includes; planning horizon, and thereof based on this, the calculation of population forecast, which is needed to estimate agriculture demand in the river basin. Once we know the agricultural demand it would be required to know and estimate the crop water requirements, nutritional requirement of the population, and the nutritional demand to be met by each project. Further, municipal and drinking water demands' estimates are required to be determined.

Next, there are some more factors or aspects (parameters) which deal with water resources planning, apart from water resource availability and its demand within the river basin system. These parameters are river water disputes and agreements arising due to national and international boundaries of trans-boundary river basins. Many a times, these put hindrance in water planning process and their implementation. The water disputes are controlled by their respective water tribunal awards for share and use of the river's waters by the co-basin states/stakeholders. The water use agreements are the prior mutual agreements among various stakeholders for share of the river's waters. Then, the upstream submergence coming up due construction of dams, arising rehabilitation and resettlement of the displaced persons are other constraints and need special consideration in water resources planning. These are jurisdictional interventions, which require attention of national and international laws.

Lastly, the water supplies to various stakeholders/water users are managed through water distribution systems. To this effect; we require storing, regulating, and managing our waters before distribution. Therefore, physical structures (hydraulic structures); like storage reservoirs, hydropower plants, diversions, and canals for conveying irrigation water and water from water surplus areas to water deficit areas, etc. are another set of parameters and play an important role.

5.2 SYSTEM'S PHYSICAL PARAMETERS

5.2.1 System and Its Configuration

The model (GRYM) is applied in the study area encompassing the nine link canals in peninsular India proposed by N.W.D.A in peninsular India for transfer of water from water surplus Mahanadi and Godavari basin to water deficient Krishna, Pennar and Cauvery basins. They are LC1: Mahanadi (Manibhadra) to Godavari (Dowlaiswaram); LC2: Godavari (Inchampalli) to Krishna (Nagarjunasagar); LC3: Godavari (Inchampalli) to Krishna (Pulichintala); LC4: Godavari (Polavaram) to Krishna (Vijayawada) LC5: Krishna (Almatti) to Pennar LC6: Krishna (Srisailam) to Pennar LC7: Krishna (Nagarjunasagara) to Pennar (Somasila) LC8: Pennar (Somasila) to Cauvery (Grand Anicut) LC9: Kattalai (Cauvery Vaigai-Gundar.

The basins involved in the link canals, i.e., Mahanadi, Godavari, Krishna, Cauvery and Pennar are trans-boundary in nature. The planning, development and utilization in the basins have largely been done by the co-basin states basing on their own requirement, perception and vision of utilizing the water resources potential in the best interests of their respective states. The category and status of the projects that have come up, have been taken up and envisaged in the involved basins are given in Table 5.1.

Table 5.1 Major projects basin wise

River Basin	Total projects in the basin			
	Existing	Ongoing	Proposed	Total
(1)	(2)	(3)	(4)	(5)
Mahanadi	17	5	31	53
Godavari	34	20	30	84
Krishna	20	23	1	44
Pennar	1	0	0	1
Cauvery	11	1	3	15
Total	**83**	**49**	**65**	**197**

The number and status of projects that have come up, have been taken up and envisaged on the upstream of the export and import points of the link canals are given in Table 5.2. The sample details for the first link giving the details of the projects are given in Table 5.3(a) and 5.3(b).

Table 5.2 Status of projects involved in the link canals

Link	Name of the link	Location	Import/ export	Basin	Major projects			Total
					Existing	Ongoing	Proposed	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LC1	Manibhadra Dowlaiswaram	Manibhadra	Export	Mahanadi	15	5	31	51
		Dowlaiswaram	Import	Godavari	34	20	30	84
LC2	Inchampalli Nagarjunasagara	Inchampalli	Export	Godavari	30	19	24	73
		Nagarjunasagara	Import	Krishna	18	22	1	41
LC3	Inchampalli Pulichintala	Inchampalli	Export	Godavari	30	19	24	73
		Pulichintala	Import	Krishna	19	22	2	43
LC4	Polavaram Vijayawada	Polavaram	Export	Godavari	33	19	30	82
		Vijayawada	Import	Krishna	20	23	1	44
LC5	Almatti Kalvapalli	Almatti	Export	Krishna	8	5	0	13
		Kalvapalli	Import	Pennar	0	0	0	0
LC6	Srisailam Pennar	Srisailam	Export	Krishna	17	22	1	40
		Pennar	Import	Pennar	0	0	0	0
LC7	Nagarjunasagara Somasila	Nagarjunasagara	Export	Krishna	18	22	1	41
		Somasila	Import	Pennar	1	0	0	1
LC8	Somasila Grand anicut	Somasila	Export	Pennar	1	0	0	1
		Grand anicut	Import	Cauvery	11	1	3	15
LC9	Kattalai Vaigai Gundar	Kattalai	Export	Cauvery	10	1	3	14
		Vaigai	Import	Vaigai	0	0	0	0

Table 5.3 (a) Status of projects upstream of export point Manibhadra in LC1 Manibhadra- Dowlaiswaram link

Basin	Sub-Basin		Name of the project	code	Status of the project
(1)	(2)	(3)	(4)	(5)	(6)
Mahanadi	Upper Mahanadi	1	Dudhawa	MUDH	Existing
		2	Sondur	MUSN	Existing
		3	Sikasar	MUSK	Existing
		4	Pairi	MUPR	Contemplated
		5	Murram Silli	MUMS	Existing
		6	Ravi Shankar	MURS	Existing
		7	Kodar	MUKD	Contemplated
		8	Lath	MULT	Contemplated
		9	Kelo	MUKL	Contemplated
	Sheonath	10	Bhivkurd	MSBK	Contemplated
		11	Sukhanallah	MSSN	Contemplated
		12	Kharkhara	MSKH	Existing
		13	Tandula	MSTN	Existing
		14	Jhenjori	MSJH	Contemplated
		15	Deokar	MSDK	Contemplated
		16	Saroda	MSSR	Existing
		17	Kachanari	MSKN	Contemplated
		18	Simga	MSSG	Contemplated
		19	Hamp	MSHP	Contemplated
		20	Maniyari	MSMN	Existing
		21	Kharang	MSKR	Existing
		22	Arpa	MSAR	Ongoing
	Jonk	23	Joint Jonk	MJJJ	Contemplated
		24	Jonk Diversion	MJJD	Contemplated
	Hasdeo	25	Hasdeo Bango	MHHB	Ongoing
	Mand	26	Mand	MDMD	Contemplated
		27	Kuruket	MDKU	Contemplated
	Ib	28	Ib Diversion	MIID	Existing
		29	Haldi Munda	MIHM	Ongoing
		30	Ib Dam	MIIB	Contemplated
		31	Upper Bheden Dam	MIUB	Contemplated
		32	Lower Bheden Dam	MILB	Contemplated
		33	Lamdora Dam	MILM	Contemplated
	Ong	34	Ong Dam	MOOD	Contemplated
		35	Ong Barrage	MOOB	Existing

(1)	(2)	(3)	(4)	(5)	(6)
	Tel	36	Upper Tel Dam	MTUT	Contemplated
		37	Hati Barrage	MTHB	Existing
		38	Sagada Dam	MTSD	Contemplated
		39	Upper Udanti Dam	MTUU	Contemplated
		40	Lower Udanti Dam	MTLU	Contemplated
		41	Lower Indra Dam	MTLI	Ongoing
		42	Uttei Raul Dam	MTUR	Contemplated
		43	Lower Lanth dam	MTLL	Contemplated
		44	Khadago Dam	MTKH	Contemplated
		45	Lower Tel Barrage	MTTB	Contemplated
		46	Lower Suktel Dam	MTLS	Ongoing
	Middle Mahanadi	47	Hirakud Dam	MMHD	Existing
		48	Surubalijore	MMSB	Contemplated
		49	Salki Barrage	MMSL	Existing
	Lower Mahanadi	50	Brutanga Dam	MLBR	Contemplated
		51	Manibhadra Dam	MLMB	Contemplated

Table 5.3 (b) Status of projects upstream of import point Dowlaiswaram in LC 1 Manibhadra- Dowlaiswaram link

Basin	Sub-Basin		Name of the project	code	Status of the project
(1)	(2)	(3)	(4)	(5)	(6)
Godavari	Upper Godavari	1	Palkhed	GUPK	Existing
		2	Ozarkhed	GUOK	Existing
		3	N. Madyameswar	GUNM	Existing
		4	Karwa	GUKR	Ongoing
		5	Gangapur	GUGP	Existing
		6	Jayakwadi Stage-I	GUJK	Existing
		7	Jayakwadi Stage-II	GUJW	Ongoing
		8	Vishnupuri	GUVP	Ongoing
	Pravara	9	Bhandaradara	GPBD	Existing
		10	Upper Pravara	GPUP	Ongoing
		11	Mula	GPML	Existing
	Purna	12	Khadak Purna	GRPU	Ongoing
		13	Yeldhari	GRYD	Existing
		14	Purna Sidheswar	GRPS	Existing
		15	Lower Dudhana	GRLD	Ongoing
	Manjira	16	Manjra	GJMA	Existing

(1)	(2)	(3)	(4)	(5)	(6)
		17	Lower Terna	GJLT	Existing
		18	Karanja	GJKR	Existing
		19	Singur	GJSG	Contemplated
		20	Nizamsagar	GJNS	Existing
		21	Lendi	GJLN	Existing
		22	Manar	GJMN	Existing
	Middle Godavari	23	Sriramsagar	GMSS	Existing
		24	Kaddam	GMKD	Existing
	Maner	25	Lower Maner Dam	GNLM	Existing
	Penganga	26	Pentakali	GGPK	Ongoing
		27	Isapur		Ongoing
		28	Upper Pus	GGUP	Existing
		29	Arunavati	GGAV	Ongoing
		30	Adan	GGAD	Ongoing
		31	Lower Penganga	GGLG	Contemplated
	Wardha	32	Upper Wardha	GWUW	Ongoing
		33	Bembla	GWBM	Contemplated
		34	Lower Wardha	GWLW	Ongoing
		35	Lower Wunna	GWLN	Ongoing
		36	Bor	GWBR	Existing
		37	Dham	GWDH	Existing
	Pranhita	38	Upper Wainganga	GHUW	Ongoing
		39	Thanwar	GHTW	Ongoing
		40	Hirri	GHHR	Contemplated
		41	Dhuti Weir	GHDH	Existing
		42	Nahara Diversion	GHND	Contemplated
		43	Bagh	GHBG	Existing
		44	Son Diversion	GHSD	Contemplated
		45	Deo Diversion	GHDD	Contemplated
		46	Khairbandha	GHKB	Existing
		47	Bhawanthadi	GHBT	Ongoing
		48	Dhapewada	GHDW	Contemplated
		49	Chorkamra	GHCK	Existing
		50	Kanhan Diversion	GHKD	Contemplated

(1)	(2)	(3)	(4)	(5)	(6)
		51	Pench Diversion	GHPD	Contemplated
		52	Gosikurd	GHGK	Contemplated
		53	Itihado	GHIH	Existing
		54	Tultuli	GHTT	Ongoing
		55	Sathi	GHST	Contemplated
		56	Lower Kathani	GHLK	Contemplated
		57	Bhimkund	GHBK	Contemplated
		58	Dina	GHDN	Existing
		59	Human	GHHN	Ongoing
		60	Ghorazhari	GHGZ	Existing
		61	Asolmandha	GHAM	Existing
		62	Pranhita	GHPR	Contemplated
		63	Vattivagu	GHVV	Ongoing
	Indravati	64	Upper Indravati	GIUI	Existing
		65	Lower Indravati	GILI	Contemplated
		66	Markandi	GIKT	Contemplated
		67	Dantewada	GIDW	Contemplated
		68	Sankini	GISK	Contemplated
		69	Kutru-II	GIKU	Contemplated
		70	Berudi	GIBR	Contemplated
		71	Kindrunj	GIKR	Contemplated
		72	Bhopalpatnam-II	GIBP	Contemplated
	Sabari	73	Upper Kolab	GSUK	Existing
		74	Govindpali	GSGP	Contemplated
		75	Baru	GSBR	Contemplated
		76	Sileru Vagu	GSSV	Contemplated
		77	Potteru	GSPT	Existing
		78	Satiguda	GSSG	Existing
		79	Janavagu	GSJV	Contemplated
	Lower Godavari	80	Inchampalli	GLIP	Contemplated
		81	Talperu	GLTP	Ongoing
		82	Polavaram	GLPV	Contemplated
		83	Buradakalva	GLBK	Contemplated
		84	Cotton Barrage	GLCB	Existing

The export and import points in the proposed links have their own configurations with respect to the upstream development. There are in total 197 numbers of major projects in the basins involved in the implementation of the first part of the peninsular component of the National Perspective Plan, 1980 of Ministry of Water Resources, Government of India. The basin wise line diagrams of the existing, ongoing and proposed projects are shown in Figures 5.1 to 5.5. Due to the large size of the study area, only major projects have been considered in the study.

The export points of the link canals are situated in the main rivers. Manibhadra Project, the export point of LC1 is contemplated on the Mahanadi. Inchampalli project is the export point of both LC2 and LC3 and is contemplated on the Godavari. Polavaram, the export point of LC4 is also contemplated on Godavari. Dowlaiswaram, the import point of LC1 is located on the Godavari. Nagarjunasagara project, located on Krishna happens to be the import point of LC2 as well as the export point for LC7. Almatti, an ongoing project on main river Krishna is the export point for LC5. While Srisailam project located on the Krishna serves as the export point of LC6, Pulichintala, another project contemplated on the river Krishna, serves as the import point of LC3. Prakasam barrage, in the deltaic area of Krishna is the import point for LC4.Somasila project located on the Pennar serves as the import point for LC7 and export point for LC8. The import points of LC5 and LC6 are tributaries in Pennar river system which is picked up by downstream projects for utilization of the transferred water. Kattalai bed regulator on the Cauvery is proposed to be strengthened to serve as the export point of LC9. Grand Anicut on the Cauvery in the deltaic region is the import point for LC8.

The above system accomplishes transfer of surplus flows of the Mahanadi to the Godavari system and thereafter to water deficit basins of Krishna, Pennar, Cauvery and Vaigai. This would benefit the drought prone areas of Odisha, Andhra Pradesh, Karnataka, Maharastra and Tamilnadu. As per the study carried out by NWDA, the scheme contemplates transfer of 12165 MCM of water annually from Mahanadi through

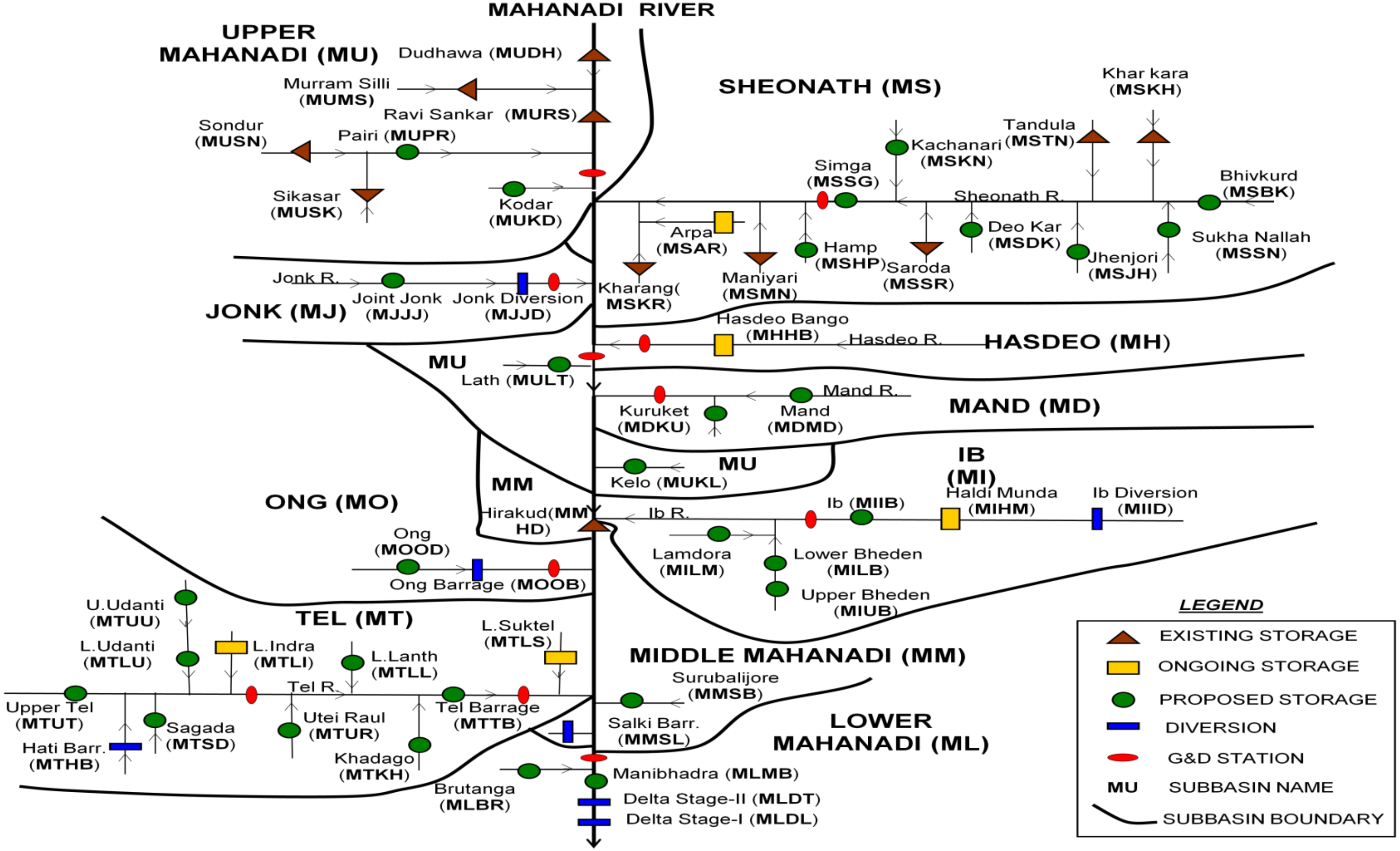

Fig. 5.1 Mahanadi River Basin System

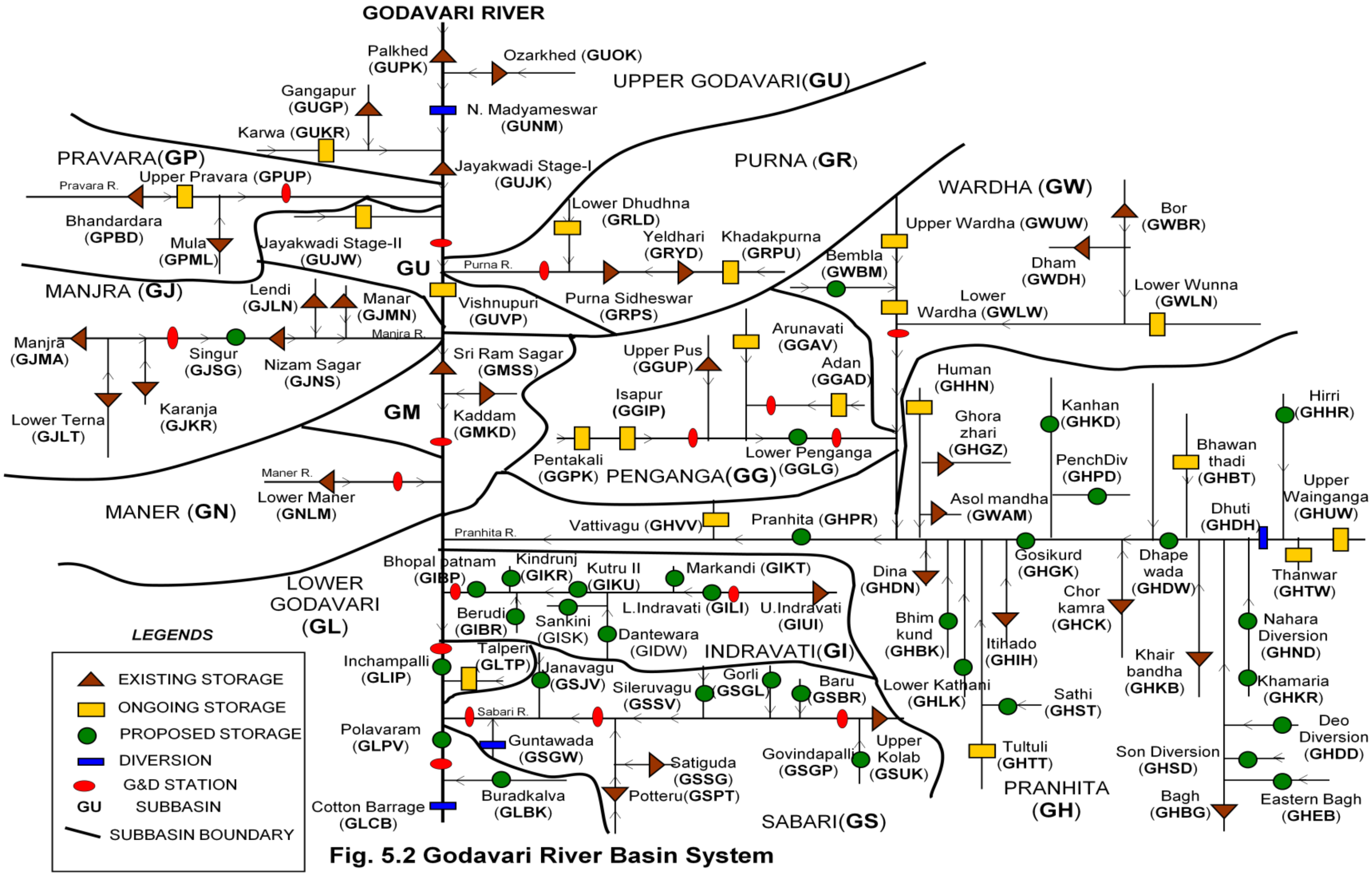

Fig. 5.2 Godavari River Basin System

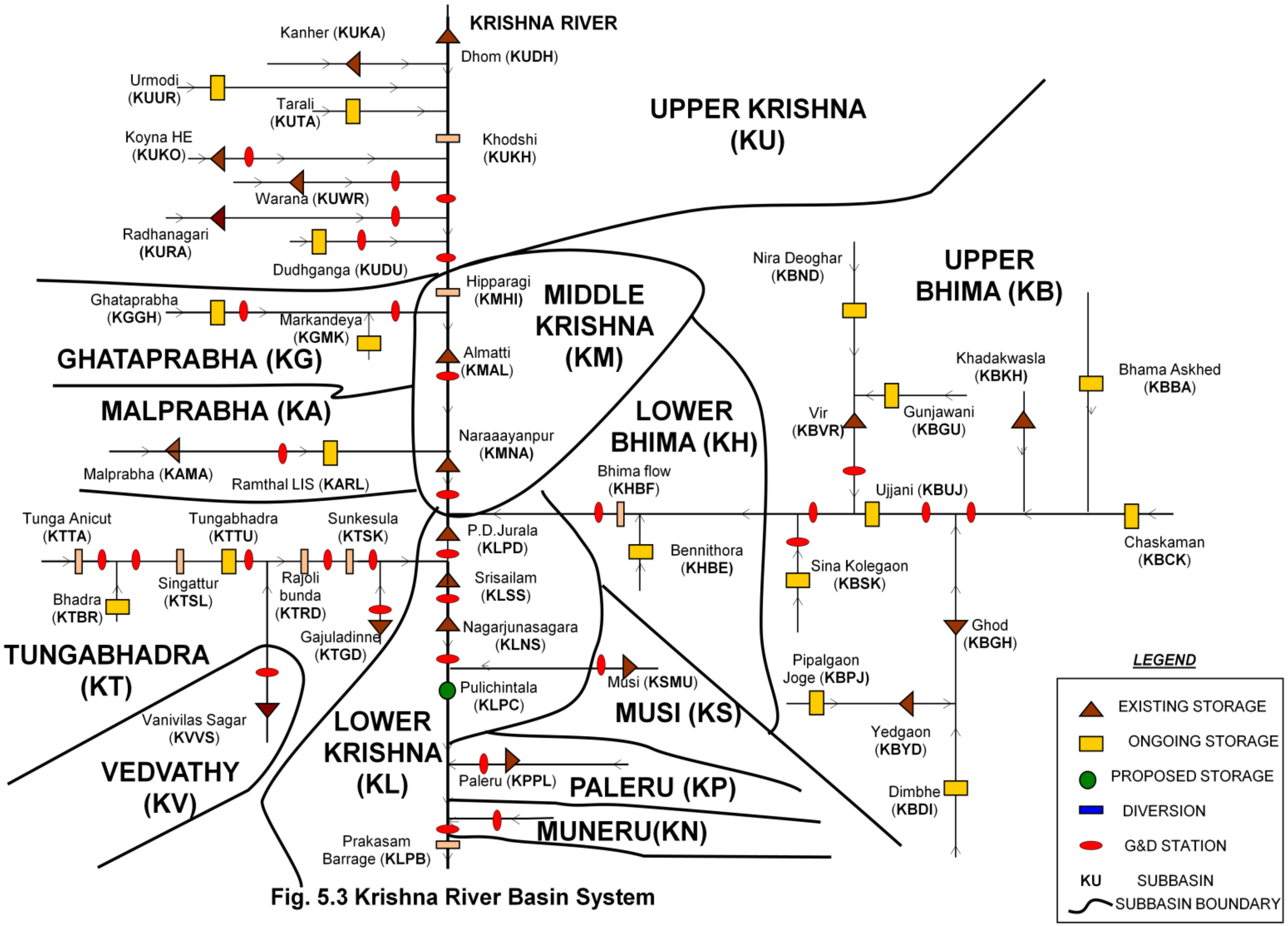

Fig. 5.3 Krishna River Basin System

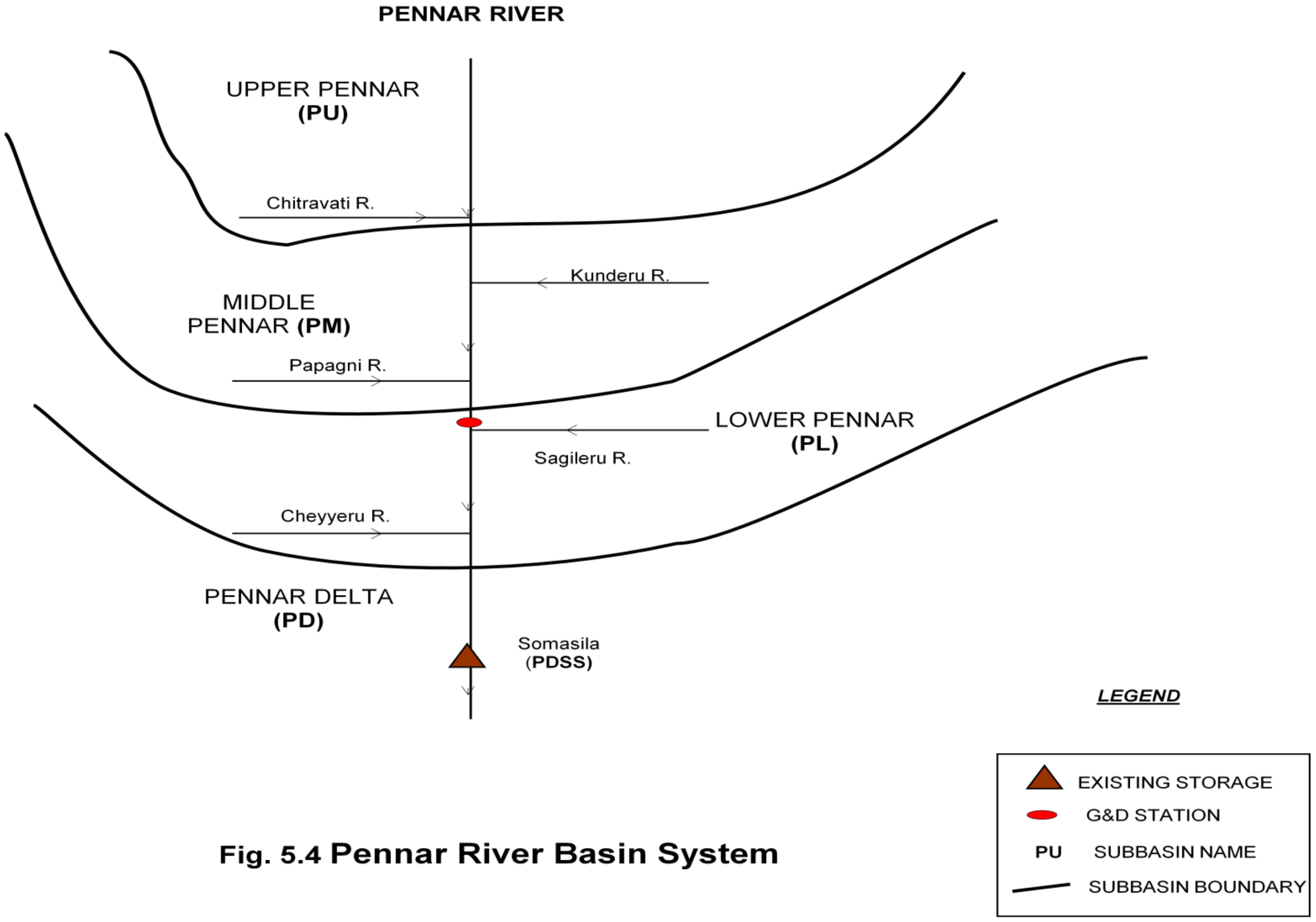

Fig. 5.4 Pennar River Basin System

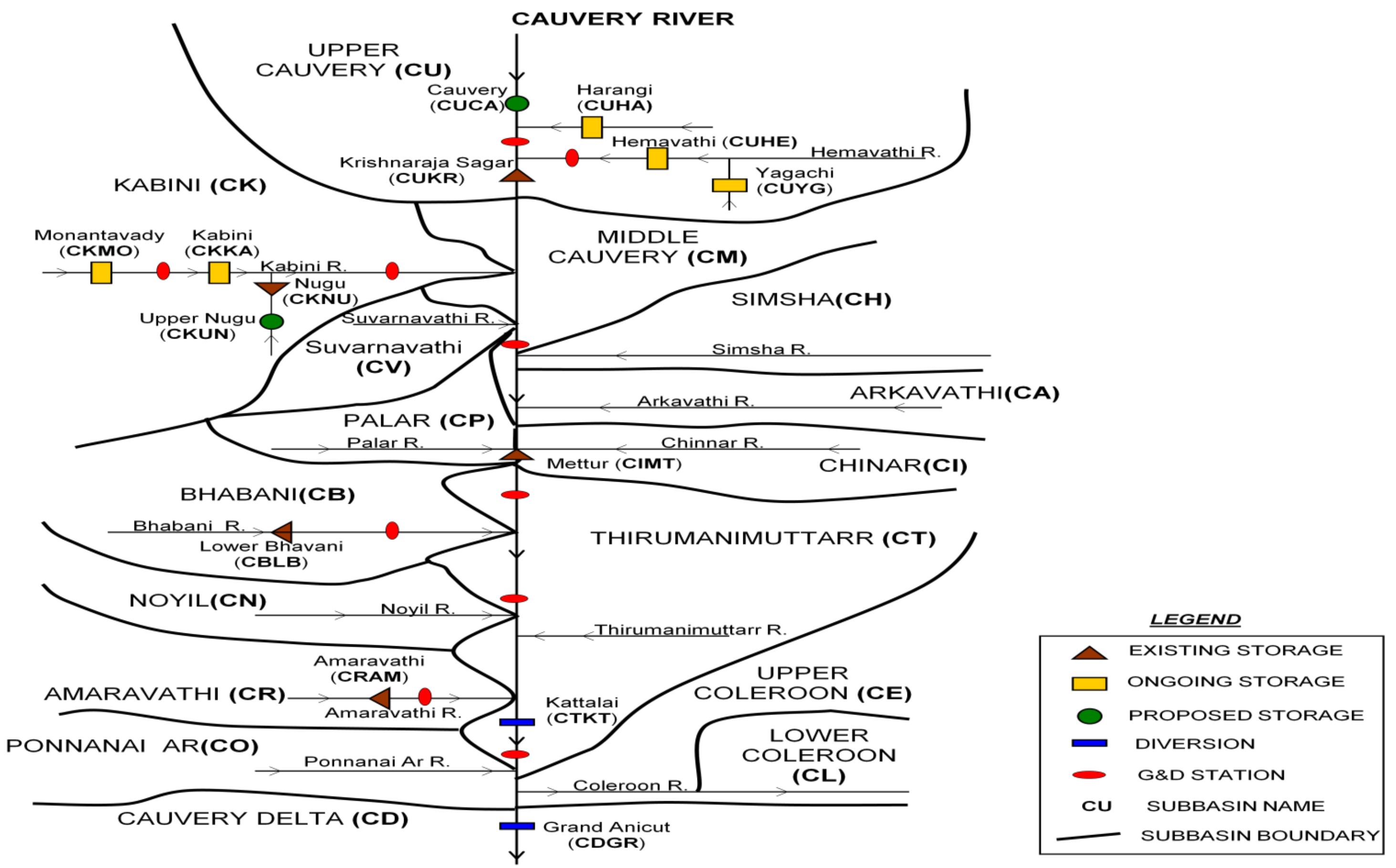

Fig. 5.5 Cauvery River Basin System

LC1, i.e., Mahanadi-Godavari link canal. From Godavari, a quantity of 26122 MCM of water including the water so received through LC1 is proposed to be diverted to Krishna through LC2, LC3 and LC4. Out of the water so received from Godavari, a quantity of 14080 MCM of water is to be diverted to Pennar from Krishna through LC5, LC6 and LC7. From Pennar, a quantity of 8343 MCM of water is proposed to be diverted to the Cauvery basin through LC8. Further down, a quantity of 2252 MCM of water is proposed to be diverted to meet the demands of Vaigai and Gundar basins through LC9.

The optimal utilization of the available water resources potential at the export and import points of the Link Canals can be found out only by comprehensive planning of the projects that are located and contemplated in the upstream of the link projects. The evaluation of the utilizable annual flow based on system annual reservoir yield determined from an integrated planning of system of reservoirs will provide a reliable assessment of its utilizable water resources potential.

5.2.2 Projects' Evaporation Parameters

Station wise monthly details of pan evaporation depths were obtained from different reports (GOM 1999, NWDA). Due to the non-availability of evaporation depth for individual projects, a reservoir's evaporation was computed using this data. This was done by multiplying pan evaporation data of its nearby station with a constant pan coefficient of 0.7 used in this study. The coefficient of 0.7 has been adopted in the absence of more region specific values.

For a reservoir the annual evaporation volume loss from its dead storage ($EV^{o}_{SNs,BNs,b,RNs,b,j}$) was obtained by multiplying the average annual evaporation depth and the area at dead storage elevation. For the elevations above the dead storage, a linear fit between the storage-area for each reservoir above the dead storage was derived from the storage area relationship. Using this relationship, the annual evaporation volume loss ($EV^{a}_{SNs,BNs,b,RNs,b,j}$) above dead storage is obtained by multiplying the slope of this curve and the average annual evaporation depth at the reservoir. The parameter γ_t (the fraction of the annual evaporation volume loss that occurs in within-year monthly period t) has been computed by the ratio of the depths of monthly to annual reservoir evaporation losses, wherever available. Otherwise, the values at nearby reservoir/observatory data have been utilised. Sample data for Mahanadi basin is shown in Table 5.4.

Table 5.4 Month wise gamma value of projects in Mahanadi basin

Sl No	Sub-basin	Name of the project	Code	LRC (MCM)	dA/dS	Evo	Month wise gamma value at different projects												
							June	July	August	September	October	November	December	January	February	March	April	May	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
1	Upper Mahanadi	Dudhawa	MUDH	284.0000	0.2209	0.9180	0.1067	0.0806	0.0712	0.0714	0.0756	0.0587	0.0502	0.0548	0.0688	0.1029	0.1201	0.1390	1.0000
2		Sondur	MUSN	179.6100	0.0960	6.8580	0.1067	0.0806	0.0712	0.0714	0.0756	0.0587	0.0502	0.0548	0.0688	0.1029	0.1201	0.1390	1.0000
3		Sikasar	MUSK																
4		Pairi	MUPR	639.0000	0.0737	8.9831	0.1067	0.0806	0.0712	0.0714	0.0756	0.0587	0.0502	0.0548	0.0688	0.1029	0.1201	0.1390	1.0000
5		Murram Silli	MUMS																
6		Ravi Shankar	MURS	930.0000	0.0849	12.3882	0.1067	0.0806	0.0712	0.0714	0.0756	0.0587	0.0502	0.0548	0.0688	0.1029	0.1201	0.1390	1.0000
7		Kodar	MUKD	149.0200	0.0866	0.9783	0.1067	0.0806	0.0712	0.0714	0.0756	0.0587	0.0502	0.0548	0.0688	0.1029	0.1201	0.1390	1.0000
8		Lath	MULT	33.0000	0.0780	7.1300	0.1067	0.0806	0.0712	0.0714	0.0756	0.0587	0.0502	0.0548	0.0688	0.1029	0.1201	0.1390	1.0000
9		Kelo	MUKL	130.0000	0.8970	6.5700	0.1067	0.0806	0.0712	0.0714	0.0756	0.0587	0.0502	0.0548	0.0688	0.1029	0.1201	0.1390	1.0000
10	Sheonath	Bhivkurd	MSBK	472.2600	0.1050	9.9800	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
11		Sukhanallah	MSSN	479.0000	0.0950	9.1000	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
12		Kharkhara	MSKH	141.6000	0.1100	4.9500	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
13		Tandula	MSTN	398.8900	0.1597	2.7932	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
14		Jhenjori	MSJH	358.0780	0.1120	7.8600	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
15		Deokar	MSDK	46.9500	0.0980	6.4700	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
16		Saroda	MSSR	30.1400	0.1300	1.5000	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
17		Kachanari	MSKN	61.33	0.10	14.3600	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
18		Simga	MSSG	803.30		0.0000	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
19		Hamp	MSHP	475.04	0.89	13.2600	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
20		Maniyari	MSMN	147.72	0.89	4.9800	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
21		Kharang	MSKR	192.16	0.11	4.6500	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
22		Arpa	MSAR	338.00	0.16	27.3992	0.1116	0.0710	0.0689	0.0698	0.0779	0.0584	0.0505	0.0554	0.0688	0.1007	0.1215	0.1455	1.0000
23	Jonk	Joint Jonk	MJJJ	340.50	0.20	37.2000	0.1176	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.0460	0.0660	0.1072	0.1423	0.1649	1.0000
24		Jonk Diversion	MJJD	220.77	0.13	31.1831	0.1176	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.0460	0.0660	0.1072	0.1423	0.1649	1.0000
25	Hasdeo	Hasdeo Bango	MHHB	3046.00	0.05	19.7904	0.0745	0.0770	0.0712	0.0723	0.0799	0.0660	0.0537	0.0594	0.0748	0.1048	0.1229	0.1435	1.0000
26	Mand	Mand	MDMD	1948.80	0.10	15.0000	0.1052	0.0713	0.0667	0.0673	0.0765	0.0650	0.0569	0.0621	0.0736	0.1018	0.1179	0.1357	1.0000
27		Kuruket	MDKU	637.22	0.10	7.0000	0.1052	0.0713	0.0667	0.0673	0.0765	0.0650	0.0569	0.0621	0.0736	0.1018	0.1179	0.1357	1.0000
28	Ib	Ib Diversion	MIID	47.79	0.16	6.2778	0.1067	0.0806	0.0712	0.0714	0.0756	0.0587	0.0502	0.0548	0.0688	0.1029	0.1201	0.1390	1.0000
29		Haldi Munda	MIHM	114.17	0.06	31.5194	0.1076	0.0725	0.0706	0.0716	0.0778	0.0601	0.0501	0.0554	0.0683	0.1017	0.1233	0.1410	1.0000
30		Ib	MIIB	1583.05	0.06	55.9000	0.1076	0.0725	0.0706	0.0716	0.0778	0.0601	0.0501	0.0554	0.0683	0.1017	0.1233	0.1410	1.0000
31		Upper Bheden	MIUB	162.80	0.10	6.5300	0.1076	0.0725	0.0706	0.0716	0.0778	0.0601	0.0501	0.0554	0.0683	0.1017	0.1233	0.1410	1.0000
32		Lower Bheden	MILB	359.57	0.14	15.9700	0.1076	0.0725	0.0706	0.0716	0.0778	0.0601	0.0501	0.0554	0.0683	0.1017	0.1233	0.1410	1.0000
33		Lamdora	MILM	49.01	0.10	8.7100	0.1076	0.0725	0.0706	0.0716	0.0778	0.0601	0.0501	0.0554	0.0683	0.1017	0.1233	0.1410	1.0000
34	Ong	Ong	MOOD	189.00	0.21	14.88	0.1176	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.0460	0.0660	0.1072	0.1423	0.1649	1.0000
35		Ong Barrage	MOOB	0.13		0	0.1176	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.0460	0.0660	0.1072	0.1423	0.1649	1.0000
36	Tel	Upper Tel	MTUT	143.80	0.03	6.99	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
37		Hati Barrage	MTHB	0.00	0.04	102.83	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
38		Sagada	MTSD	221.63	0.06	5.73	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
39		Upper Udanti	MTUU	99.50	0.13	4.12	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
40		Lower Udanti	MTLU	399.60	0.09	86.74	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
41		Lower Indra	MTLI	308.40	0.11	17.34	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
42		Uttei Raul	MTUR	505.14	0.05	15.23	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
43		Lower Lanth	MTLL	434.00	0.13	16.12	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
44		Khadago	MTKH	387.40	0.04	14.33	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
45		Lower Tel	MTTB	0.00			0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
46		Lower Suktel	MTLS	439.87	0.14	25.49	0.1098	0.0672	0.0579	0.0603	0.0668	0.0579	0.0554	0.0602	0.0736	0.1071	0.1327	0.1511	1.0000
48		Surubalijore	MMSB	193.99	0.11	7.75	0.1177	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.046	0.066	0.1072	0.1423	0.1647	1.0000
49		Salki Barrage	MMSL	0.00			0.1177	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.046	0.066	0.1072	0.1423	0.1647	1.0000
50	Lower Mahanadi	Brutanga	MLBR	209.40	0.08	4.65	0.1177	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.046	0.066	0.1072	0.1423	0.1647	1.0000
51		Manibhadra	MLMB	4490.00	0.05	470.49	0.1177	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.046	0.066	0.1072	0.1423	0.1647	1.0000
52		Delta stage-I	MLDT	0.00		0	0.1177	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.046	0.066	0.1072	0.1423	0.1647	1.0000
53		Delta stage-I	MLDL	0.00		0	0.1177	0.0633	0.0589	0.0685	0.0722	0.0538	0.0394	0.046	0.066	0.1072	0.1423	0.1647	1.0000

5.3 COMPILATION AND ESTIMATION OF SUPPLY PARAMETERS

The supply parameters are essentially those input components which impinge on the system to produce outputs or results for a particular purpose. In the analysis of a complex water resources system, the most important aspect is the estimation of water resources of the system and to derive parameters as are useful in the process of system analysis.

5.3.1 Inflow Data

Considering that 5 major basins in India and 54 sub-basins thereof are involved in the process of the peninsular inter basin transfer of water, and considering the difficulty in obtaining reliable data, monthly inflow data for 28 years (1972-73 to 1999-2000) has been adopted being the common period. In absence of inflow data available at project sites or for a particular period, inflow series is generated using discharge data at nearby discharge gauging site, water utilizations available at some project sites, storage effect, evaporation losses, catchment area and regeneration from contributing projects upstream of the gauging site. The CWC maintains a large network of gauge-discharge sites in all the basins, which has been adopted as common period for all the basins, viz., Mahanadi, Godavari, Krishna, Pennar and Cauvery river basins.

The virgin flow at any gauged site is calculated (Wurbs 2005, Wurbs 1996) by adding the utilization, evaporation losses, storage effect and export from the upstream projects and deducting the regeneration from water use from the upstream projects (including the imports) to the observed flows. Then the law of proportionality on the catchment areas is applied to find out the virgin flow at ungauged site. (Loucks 1981, Wurbs 1996). As has already been mentioned, logical and rational approximations have been resorted to while computing the virgin inflow at the project sites wherever necessary. In this manner the virgin flow at the project sites are computed.

5.3.1.1 Computation of water availability in space and time

In a large river basins stream flow data are generally not available at many project sites. Various approaches existing along with one proposed have been used to estimate long-term monthly inflow data series at each and every reservoir site in a multi-reservoir system.

Estimation of Stream Flows at Various Sites in the System

The following approaches have been adopted to estimate the stream flows at individual sites in different situations (Sethi, 2009).

(i) Projects where some flow data are missing/not available

Monthly missing data are estimated randomly between the observed maximum and minimum values for the corresponding months.

(ii) Reservoir on tributaries with no upstream regulation, with upstream/downstream gauged data available

(a) the flows have been estimated based on proportionate area basis using the upstream/downstream gauged data, if the difference between the catchment areas at the gauging site and the reservoir locations is not substantial, and (b) if the difference between the catchment areas at the reservoir location and the gauging site is substantial, then the relation between the rainfall and runoff at the gauging site has been determined and this relation has been employed to estimate the stream flows at the reservoir site from the long-term average rainfall of the nearby rain gauge sites.

(iii) No gauging site in the stream across which the projects are situated/ proposed, but gauged data available at nearby site.

In such case, the rainfall-runoff relation of nearby site having topographic and hydrometeorologic similarity with the site(s) under consideration has been employed to estimate the stream flows from the long-term average rainfall of nearby rainfall data of the site under consideration.

(iv) Downstream gauged site in series receiving regulated contributions from just upstream reservoirs, with long term water utilization data available/not available.

In this case, the method of water balance has been adopted. An algorithm – termed as FLOWGEN was developed for this purpose to estimate the stream flows. Fig. 5.6 presents the flowchart of the developed FLOWGEN algorithm. The computational steps involved in this algorithm are as follows:

The computational steps for FLOWGEN algorithm (Fig. 5.6)

(1) Calculate the average rainfall in each intervening catchment.

(2) Make groups of projects having same years of project completion.

(3) Calculate the average rainfall up to the downstream gauged site.

(4) Arrange annual flows at downstream-gauged site.

(5) Identify successful and failure years in calendar years.

(6) Identify successful and failure years in each group.

(7) Calculate upstream and downstream water utilization potentials at each ungauged site.

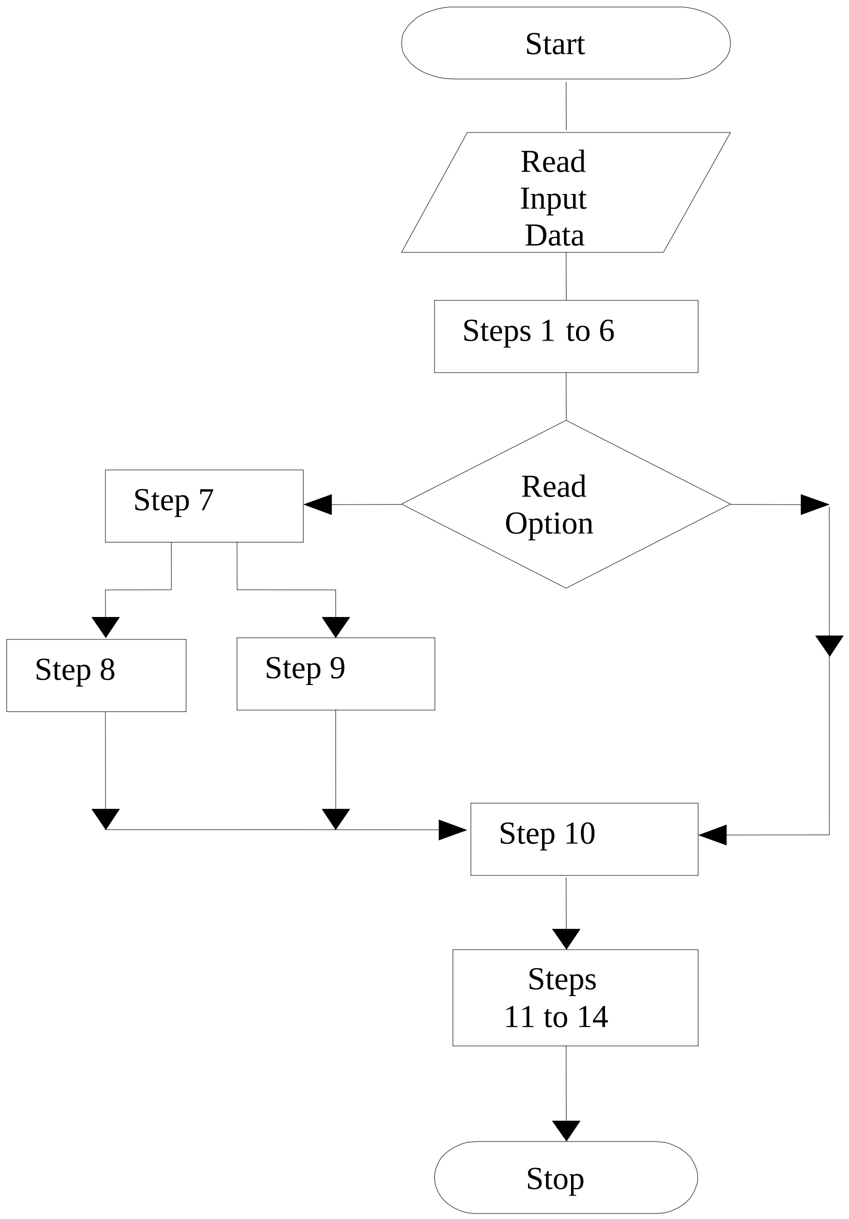

Fig. 5.6 Flowchart for FLOWGEN algorithm

(8) Define water utilization for upstream and downstream requirements during the failure years, based on the option of linear relationship for estimation of annual potential development.

or

(9) Define water utilization for upstream and downstream requirements during the failure years, based on the option of annual rainfall ratios for estimation of annual potential development.

(10) Calculate for the downstream gauged site; the virgin flow when the water utilization is known, and unused flow when the water utilizations are not known.

(11) Estimate virgin flow without storage at the downstream gauged site.

(12) Add storage effect and water export and deduct water import.

(13) Distribute virgin flow including storage effect at all sites.

(14) Arrange annual flows at each site using Weibull plotting position formula. Then the 75% water year dependable flows are selected for use in further analysis.

5.3.1.2 Selection of criterion for estimation of the values of parameter β_t

The parameter β_t serves the purpose of defining the fraction of the annual inflow that reaches a reservoir during the within-year period, t, and which is used in the within-year continuity equation of the yield model (refer section 4.6.2.1) written for the single modelled critical year. This total annual inflow is assumed, equal to the total annual yield that would be released including evaporation losses from the reservoir during the critical year. This equation is governed by the within-year storage capacity required in case the distribution of within-year yields differs from the distribution of within-year inflows. Here, it is assumed that during the modelled critical year (i) there would be no spills from the reservoir, and (ii) the inflows and the required releases would be in balance, so that the reservoir neither fills nor empties. Thus, the parameter β_t reflects the relative proportion of the critical year's inflow that is likely to occur in within-year period *t*.

Various studies on the selection of criterion for estimation of the values of parameter β_t were conducted as described below:

Loucks et al. (1981) conducted studies using optimization and simulation models and concluded that; (i) After using the values of parameter β_t derived from different criterion for the yield model, the driest year's β_t derived values provides a reasonable estimate of the future storage requirements similar to the complete and larger optimization model, and (ii) Simulation with other within-year yield distributions produce similar results except when β_t's representing the inflow distribution closely correspond to the within-year distribution of the yields. Then the yield model tends to underestimate within-year storage requirements, especially if the level of development is low, such situation would not prop up in practice, due to the demands for water generally increase during periods of low natural flows.

For a hypothetical three-reservoir water supply system, Stedinger et al. (1983) tried yield model with different values of β_t and compared the results with simulation. Their findings were; that (i) a conservative choice is to select the within-year flows corresponding to the driest year of record and (ii) simulation can help in selecting/modifying the modelled β_t 's values that could provide system designs more near to meet desired/expected release reliability targets.

Dandy et al. (1997) evaluated the yield model for multiple reservoir system, with β_t values for the driest and the second driest year. They revealed that, the value of system annual reservoir yield obtained by the β_t values of the driest year were closest to that with full (complete) optimization model results. Therefore, β_t's based on inflows of the driest year of record have been considered in this study.

The choice of these within-year flows (the values of parameter β_t) will primarily determine the reliability of the identified designs (Dahe 2001). Thus, proper selection criterion for estimation of the values of the parameter β_t (within-year flows) is very important for the yield model applications, with the following observations:

For a given reservoir capacity; (a) in case the low inflows in periods of high demands occur (i) the within-year storage requirements would be higher and (ii) this will lead to a conservative reservoir design, or a low estimate of annual reservoir yield and (b) if the distribution closely follows the required proportion of yields, the within-year storage requirements shall be low.

5.3.2 Upstream Abstractions in Medium and Minor Irrigation Projects

The water utilizations in the upstream of any project play important role in combination with evaporation loss, storage effect and export data, and which sums up to a considerable amount. For the utilizations upstream of a major project, the data are available. Regarding medium irrigation projects, their locations and utilizations are also fairly known. However, the locations and utilizations of the minor projects in the upstream are mostly not known in details. But, the sub-basin wise utilization data are available in a lumped manner. Therefore, an approximation is made to distribute the minor irrigation projects in the free catchment area of the project proportionally in the ratio of the 75% dependable inflow at the project site to the 75% dependable inflow at the sub-basin level and evaporation @ 20% of the utilizations, the net utilizations of the minor irrigation projects coming in the upstream of a major project is arrived at. Thus, the time wise utilizations are deducted directly from the virgin inflows at the major project heads to arrive at the inflow net of the medium projects utilization.

5.3.3 Regeneration

It is assumed that, regenerations from irrigation is considered as 10 percent of the gross utilization for irrigation, 80 percent of the municipal water supply of drawls and 97.5 percent of the industrial water use.

5.3.4 Import and Export

There is a provision for import and export of water from one sub-basin to another sub-basin within the basins.

5.3.5 Projects' Failure and Success and Water Use Reliabilities

5.3.5.1 Identification of failure years for individual project

When the annual reservoir yield with reliability (*p1* or *p2*) less than the maximum possible reliability (*p*) is to be estimated, a failure is allowed in meeting the target annual demand in some years in accordance with the desired reliability, *p1* or *p2*. The identification of these likely failure years can be done by:

1. Visual inspection of the historical annual flow data at the reservoir site,
2. Simulation of reservoirs, and
3. Making trials with yield model.

The visual inspection is usually sufficient when the length of the historical inflow data is not very long and the trend of annual inflows can clearly indicate the failure years. If the nature of inflows does not easily permit the selection of failure years, a simulation study of the reservoir shall be able to identify the actual failure years. A few trials with MIYM can also confirm the selection of failure years determined by other two approaches.

Apart from the above mentioned approaches, Dahe (2001) suggested some modifications in the yield model to identify the failure years. Awchi (2004) successfully applied this approach to Mula multipurpose project in India. Dahe (2001) reported that, this modification imposes at each reservoir a burden of additional variables, and additional constraints (equal to number of years of flow record). Further, the number of failure years is not exactly equal to the numbers as required for the desired annual reliability due to insufficient length of historical flow data available. Thus it is not possible to incorporate the above modifications in the yield model for multireservoir systems when the desired annual reservoir yield reliabilities are pre-specified, and are to be strictly maintained (Panigrahi, 2006).

5.3.5.2 Consideration of independent failure years instead of a common set of failure years

Loucks et al. (1981) indicated that in a multireservoir problem, maintaining same set of failure years throughout the river basin having multiple gauge sites is difficult. But, this may not be otherwise possible due to difficulty in their identification. Dahe (2001) from a study carried out on Narmada basin in India, gives sufficient account of justification for maintaining the independent failure years at each site, instead of assuming common set of failure years throughout the basin in a multiple reservoir system. It says as follows, that;

(a) In a multireservoir system; (i) Maintaining same failure years at all the sites in a approximate yield model would lead to an incorrect estimation of multireservoir yields, as it would be not in accordance with the hydrological conditions within the system, and (ii) While using the complete reservoir yield models average monthly flows or monthly flows of some predefined annual dependability are adopted.

(b) In a multiple reservoir simulation, the results show that the failure years actually were also not found similar at different reservoir sites, and

(c) Thus, it seems more logical and in accordance with the actual behavior of the system, to explicitly identify different failure years and retain them as per their natural occurrences in a yield model. It shall then have a close resemblance with a simulation results. Also it will lead to maintain the over-year continuity more correctly in the model. In case of a single reservoir it is possible to implicitly identify the set of failure years in a yield model (Dahe 2001, Awchi 2004).

Later, Panigrahi (2006) modified multiple yield models for multireservoir system of Dahe (2001), to include detailed crop planning aspects. He applied it to the system of 42 reservoirs in Mahanadi river basin in Odisha State, India, considering independent failure years for all the reservoirs in the basin. The results obtained were then compared with the simulation results. For this, he used two indices, namely; mean square error (MSE) and Nash-Sutcliffe model efficiency. He then concluded that, adoption of site-specific failure years at all the reservoirs in a large basin is likely to produce better results in comparison to a common set of failure years. It seems more logical and in accordance with the hydrological conditions and actual behaviour of the system, to retain failure years as per their natural occurrences. Weibull's plotting position formula was used to identify independent failure years at each project. The same procedures are also used in the current study under consideration.

5.3.5.3 Allowable percentage yield during failure years

It is established in India that, irrigation projects are planned to provide reservoir yields at 75 percent dependability on an annual basis. The meaning is that, if the life of a project is assumed to be 100 years, it would be able to deliver its goods for 75% of the years during its life without any failures. This assumption may not be totally appropriate, as there are always chances that, due to changing hydrologic scenario and increasing water demands with time, a reservoir would not sustain during successful years as well. Under this context, the consideration of some extent of yield failure during the successful years would play a significant role. Therefore, allowing an extent of failure (deficit) say of about 5% or so in meeting target annual demand during a successful year seems appropriate, indicating a meagre low risk, and that year then can be treated as a successful year.

Saying so does not mean that, a failure year has no water available; but is counted as a failure year, that is meant as a deficit period able to meet the annual target demand partially only. These deficits may vary within a large range in terms of their quantities. Therefore, there is an associated risk involved in severe reservoir yield failures during some of the failure years having low flows. Moreover, as the extent of the yield available from a reservoir during a failure year is uncertain, the agricultural activity during the probable failure years cannot be planned properly.

This understanding can help in improving and justifying the feasibility of an irrigation project during its planning process. Therefore, during planning a provision for some proportion of the planned design annual reservoir yield to be made available during failure years can be defined and allowed. Then, a 'risk aversion' as well as 'preparedness' against a severe yield failure for the agricultural activity can be incorporated. But, this provision shall certainly reduce the planned design annual yield a reservoir is going to deliver. However, it is always better to know the extent of yield failure rather than to face unexpected severe failures.

Hence, it becomes essential that, in planning models, the irrigation planning criteria should include a provision for allowing some proportion of the design annual reservoir yield to be made available during expected failure years. This would certainly result in improved designs and operating policies of a reservoir. This design annual reservoir yield and the proportion of it to be made available (additional reliability criteria) from a reservoir during the failure years, are referred as the “annual reservoir yield” and “allowable percentage yield”.

On the other hand, without the consideration of the allowable percentage yield, can at times lead to very severe failures during very low flow years, making the reservoir system more vulnerable. Hashimoto et al. (1982) provided clear illustrations of the concept of vulnerability. Vulnerability is a measure of the significance (extent) of yield failure, which supplements the more common reliability criteria by providing a more complete picture of risk in reservoir performance. The vulnerability criterion used by Moy et al. (1986) is the magnitude of largest deficit during the period of operation. The allowable percentage yield employed in the reservoir yield model can be one way to represent the vulnerability of a reservoir system. Therefore, some minimum assured annual irrigation supply is necessary to the farmer particularly during failure years.

5.3.5.4 Criteria for deciding the percentage of annual yield to be made available during failure years for irrigation

Earlier, making a provision of some percent of the annual yield to occur during failure years and allowing it to be incorporated in the reservoir yield model was felt necessary. This would result in a reduction in the annual yield from a reservoir during the successful years. This reduction in yield is directly proportional to the allowable percentage yield. Thus, the aversion of risk or preparedness against the probable severe failures shall be at the cost of reduced design annual yield or the target to be achieved from the reservoir. As such assessment of the yield’s reduction needs a careful consideration.

A farmer’s survival is the most important aspect to be discussed during a failure year. This fraction (percentage) derived from criterion of minimum food requirements of the agricultural population seemed to be most appropriate, feasible and practical. Dahe (2001) estimated and adopted this value of allowable percentage yield for all the projects in his study of Narmada River in India. Whereas, Panigrahi (2006) took different values of allowable percentage yield at each project satisfying a project’s specific demands (crop plan) as far as possible in successful years; which seemed practically more near to the reality and is adaptable.

5.3.5.5 Reliability of different yields and water uses

Applying Weibull's plotting position formula, the maximum possible reliability (*p*) of the annual firm yield (without any failure years) considering available 28 years inflow data works out to be 97 percent. Similarly, the reliability (*p2*) of the annual secondary yield (allowing 7 failure years) would be 76 percent.

The priorities of water use as per the National Water Policy of India are: (i) Drinking water, (ii) Irrigation, (iii) Hydropower, and (iv)Industrial and other uses. But, in this study municipal and industrial use are considered as mandatory requirements. The annual reliability of mandatory release and firm power generation considered in this study is 97 percent and for irrigation and secondary power generation is 76 percent. These are assumed in place of the specified target annual reliabilities; of 100 percent, 75 percent and 90 percent for water supply, irrigation, and hydropower generation (firm), respectively. As regards to the reliability of water export, if irrigation as well as municipal and industrial demand of the area will be directly controlled by reservoirs in the study area through export quantity, reliability as applicable for irrigation and mandatory release, i.e., 76 percent and 97 percent are considered.

5.4 ESTIMATION OF DEMAND PARAMETERS

Water resources projects are meant to provide water from the project's yields made available, to meet the needs of people living in the river basin and may be outside the basin as well. There is most of the times during a year, is mismatch between the river's water resource available and the prevailing water demands thereof. A project or reservoir overcomes these imbalances and variations, through the storage built up in the reservoir during high flows in the river, to be used later at the time of low flows.

The demand parameters are the third set of parameters which are important from the model point of view or otherwise for the project's planning. The estimates of the water resources available in the river may be almost assumed to be a fixed quantity. Whereas, the water demands ever may remain increasing with time. It is a well-known fact that, water demands usually prevail over its availability in the current scenario. The demands for water come from water use sectors like agriculture, drinking water and municipal uses, industrial uses, environmental uses. The demands towards evaporation losses from a reservoir’s storage etc. were discussed earlier. Agriculture remains the largest drawer and consumer of water resources in India. The estimates of water requirement for agriculture and other water uses, depends on the populations’ water demands to be met from the water resources of that particular area. As the population is a dynamic entity itself, it is also important to project/forecast future population to a fixed planning horizon. Then estimate various water demands associated with the forecasted populations’ direct and indirect consumption.

5.4.1 Planning Horizon

As per the recommendations of the working group on inter basin transfer of water, the planning horizon has been kept at 2050 AD. This has two reasons for this assumption; (i) firstly, is that during the period by 2050 AD, it is expected that, considerable improvements in present technology of agricultural production would take place, for wide adoption in practice and (ii) secondly, it is expected for the population to more or less get stabilized by the year 2050 AD. Furthermore, extrapolating from the available data, it has been observed/expected that about 40% of the total population would live in urban areas by that time.

5.4.2 Population

In this study, for computing the future populations’ water demands the following process is followed:

(a) Population forecast for drinking water, municipal and industrial water

To arrive at the populations’ projected figure by the 2050 AD, the total and rural populations of the basin/sub-basin have been assessed on proportionate area basis from the district wise census data of the years 1981, 1991 and 2001. The variable growth rates adopted for different block years are 1.51% for the period 2001-2010; 1.1% for the period 2010-2020; 0.92% for the period 2020-2030; 0.72% for the period 2030-2040 and 0.48% for the period 2040-2050.

(b) Population forecast for live stock

The livestock population of the basin/sub-basin is also assessed based on proportionate area basis from district wise livestock census data. Livestock census data is available for year 2003 and is used to calculate projected population by the year 2050 on the basis of the same formula considering an annual compound growth rate of 1 percent.

(c) A river basin's projected population

It is assumed that projected population of a sub-basin is supported by the major, medium, minor projects and import in the sub-basin; and distributed in proportion of their cultivable command area (CCA). Population supported by any reservoir is computed as below:

$$Population\ served\ by\ a\ project = \frac{Projected\ population\ of\ the\ sub\text{-}basin}{Area\ of\ the\ sub\text{-}basin} \times CCA\ of\ the\ project$$

Further, the total population served by a reservoir is considered as summation of population in its command area both inside the sub-basin/basin and in export command areas (if any) in other sub-basins/basins. Population in export command is considered in the same ratio for the export for the sub-basins/basins.

5.4.3 Agriculture Demand

Agriculture in India is the largest consumer of water in the world. Therefore, the water demands of various crops should be known/determined and superimposed on the system to get the best out of it. In this study,

(i) The crop water demands for each project have been calculated as per the original crop plan adopted/specified by the project implementation authorities. Where the data are not available, particularly in the case of contemplated/proposed projects, the crop plan of nearby projects or those proposed by NWDA is adopted;

(ii) For all the projects involved, there are four crop seasons, i.e., kharif, rabi, hot weather and perennial;

(iii) Further, the irrigation intensities (a) for each existing projects are different and are known, and (b) in case of the proposed projects, the NWDA norms are followed, i.e., 1.50 for major and 1.25 for medium projects.

5.4.3.1 Estimation of crop water requirement

Crop water requirements for within-year time periods (monthly) of each crop under each project are required. For this, the required data has been taken from various NWDA reports by assuming the cropping pattern to be same at the sub-basin level. However, whenever required the crop water requirement has been computed by using FAO-56 and data from IMD.

5.4.3.2 Other crop related data

Different reports (Agricultural statistics at a glance 2004, Ghei and Ghei 1973, Thapar 1981, and Panigrahi 2006) made available other required data for different crops at each project; these were related to crop produce (yield), gross income (market price), and protein and calorie contents.

5.4.3.3 Nutritional requirement of the population

For farmers' survival and their good health and in order to maintain its minimum level during distress, it is essential to provide them good and healthy nutrition at all times. So, it becomes necessary that we determine and estimate such nutritional needs of farmers. Protein and calorie are the two main sources of providing nutritional health supplement to the human body. Hence, the basic daily dietary allowances of proteins and calories need to be determined for all ages of people.

This can be partially fulfilled by growing suitable crops, which contain nutritional values, with dependable guaranteed water supplies available to the concerned for carrying out irrigation activities. Therefore, in development planning care should be taken so that at least the minimum nutritional requirements of its population are met. Below is described the methods of estimating the per capita per day nutritional requirements of person/persons:

(i) Nutritional requirements by weighted average method (per capita per day)

The nutritional requirements of a healthy person depend upon its sex and age. The dietary allowances on daily basis of proteins and calories for male and female in various age groups given in Ghei and Ghei (1973) and Thapar (1981) were used. As per them, the daily dietary allowances based on population structure and compositions are shown in Table 5.5.

Table 5.5 Daily dietary allowances

Age group	Requirement of Male		Requirement of Female	
	Proteins (grams)	Calories (calorie units)	Proteins (grams)	Calories (calorie units)
(1)	(2)	(3)	(4)	(5)
0 to 9 years	42	1500	42	1500
10 to 19 years	83.33	2600	73.33	2133
20 to 39 years	65	3000	60	2200
40 to 59 years	65	2800	60	2100
Above 60 years	65	2500	60	2000

The population projection in terms of age group and sex as obtained from the population projection for India, for the period 1981-2001 (Panigrahi 2006) and shown in Table 5.6 is used for the present analysis.

Table 5.6 Population projection in India in terms of age group and sex

Age group	Male (%)	Female (%)
(1)	(2)	(3)
0 to 9 years	21.42	21.44
10 to 19 years	20.23	20.20
20 to 39 years	33.16	32.51
40 to 59 years	17.69	18.48
Above 60 years	07.50	07.37
Total	100.00	100.00

The average per day requirement of proteins and calories for males and females has been worked out separately by using the weighted average method. The projected male female ratio is used to obtain the weighted average of protein and calorie requirement on per capita per day basis. The same are reflected in Table 5.7 and Table 5.8.

Table 5.7. Projected male female ratios in different basins

Sl no	Basin	Male (%)	Female (%)
(1)	(2)	(3)	(4)
1	Mahanadi	50.95	49.05
2	Godavari	50.79	49.21
3	Krishna	50.75	49.25
4	Pennar	50.42	49.58
5	Cauvery	50.39	49.61

Table 5.8 Computation of weighted (age group) per capita nutritional requirement

Age group	Weighted Average Nutritional Requirement			
	Male component		Female component	
	Proteins (grams)	Calories (calorie units)	Proteins (grams)	Calories (calorie units)
(1)	(2)	(3)	(4)	(5)
0 to 9 years	9.00	321.30	9.00	321.60
10 to 19 years	16.86	525.95	14.81	430.87
20 to 39 years	21.55	994.80	19.51	715.22
40 to 59 years	11.50	495.32	11.09	388.08
Above 60 years	4.87	187.50	4.42	147.40
Total	63.78	2524.90	58.83	2003.17

ii) Approach based comprehensive per capita per day nutritional requirement

In this approach, the nutritional level is associated with the local food habits and crop produce in addition to other items like milk and poultry/meat etc. The protein and calorie content of different crops have been taken from from Ghei and Ghei (1973) and Thapar (1981). The same are tabulated in Table 5.9

Table 5.9 Comprehensive nutritional requirement

Sl. No.	Item	Protein Content (grams/kg)	Calorie Content (cal./kg)	Requirement (kg/capita/ day)	Protein (grams/capita/ day)	Calorie (cal./capita/ day)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Paddy	75	3460	0.20	15.0	692.0
2	Wheat	121	3410	0.20	24.2	682.0
3	Jowar	104	3490	0.05	5.2	174.5
4	Pulses	245	3480	0.05	12.25	174.0
5	Groundnut	315	5610	0.05	15.75	280.5
6	Vegetable	40	800	0.25	10.0	200.0
7	Sugar & Gur	0	400	0.03	0.0	12.0
8	Milk	30	1170	0.25	7.5	292.5
9	Egg/Meat	130	1500	0.10	13.0	150.0
	Total				102.9	2657.5

From the two criteria, it is seen that the second one gives the higher values of nutritional requirements, which seems to be logical and reasonable and is considered in estimating the minimum and total requirements in this study. Based on this approach and the distributed total population by 2050 AD at various sites, the total requirement of nutrition by 2050 AD at various sites has been computed in proportion of respective annual irrigation potential of that site.

5.4.3.4 Estimation of nutritional demand to be met by each project

It is envisaged that the total agricultural potential to be created from all sources by the end of the planning horizon, would serve the total nutritional requirements of the entire basin Therefore, the total requirements is distributed proportionately among the projects/schemes as per their respective potentials in terms of annual irrigations. On this basis, the quantities to be met by all the major and medium projects have been worked out to 37.52×10^5 ton of protein and 1033.67×10^{11} calorie unit. The agricultural population within the basin has been worked out as 22.76 percent of the total population of India as per census data of the year 2001, which is used to find out the projected agricultural population of the individual project and their nutritional requirements. The demand to be met by individual project against the said requirements has been calculated both for total as well as for agricultural population.

5.4.4 Municipal and Drinking Water Demand

The total annual municipal water requirements to be met from a project are calculated to cater to the needs of the population projected for the year 2050. As per the norms in India, (i) the full requirement of urban population and 50 percent of rural population will be met from surface water sources and (ii) the requirement of remaining 50 percent of rural population and entire livestock population shall be met from groundwater.

The annual municipal demand to be met by each project is estimated considering per capita daily water requirement for urban and rural populations as 200 litres and 70 litres, respectively and the same demand is distributed equally in all within-year time periods. For livestock population, requirement of 50 litres per capita is taken in the absence of standard norms.

CHAPTER 6

COMPUTATION & RESULTS

6.1 SOLUTION OF LP PROBLEM

6.1.1 Selection of Solver

One of the objectives of thestudy is to apply GRYM in the study area to assess the annual and within year yields (firm and secondary) at the major reservoirs and the export points. For this purpose LINDO solver (Extended LINDO/PC; Release 6.1 of 2002 by LIDO Systems, Inc. of Chicago) has been selected for use. The limitations for maximum model size for this version is 64,000 constraints, 2,00,000 variables, 20,000 integer variables and 20,00,000 nonzeroes. The reason for using this solver over others is its relative ease of operation, ready availability and facility of sensitivity analysis.

6.1.2 Input Matrix for the Solver

Since the number of projects involved in this case of multiple yields and multiple reservoir case, it is not possible to manually write the input matrix into the LINDO solver. Thus an available FORTRAN programme comprehensive river basin analysis (CRBA) has been improved and used as a preprocessor to the solver to write the voluminous input matrix.

6.1.3 Input Data for FORTRAN Programme

The input data basically feature the sequential information to be processed so that the output of the programme becomes the matrix for the solver. For this purpose, values of the estimated model parameters as discussed in Chapter-5 are used. Some of the key input parameters are discussed below.

Most important of all is the inflow data. The annual inflow data and the within year monthly inflow data in critical are required to write the relevant constraints in the solver. In this instant case 28 years of inflow and monthly (12 within year periods) inflow data for critical years are taken. The driest year has been adopted as the critical year since it has been reported to give better and more realistic picture on the water availability scenario. Since project level failures are considered individually for the secondary yield, the success/failure data are fed into the data file. In order to estimate the annual inflow into the reservoir, the procedure has already been laid out at Chapter-5. However, repetition of the same is warranted from the fact that another available computer programme (FLOWGEN) has been extensively used as a pre-processor to CRBA to estimate the inflow at the ungauged sites or where data ate unavailable.

Furthermore, the model is formulated so as to release the fixed quantity towards mandatory demands in each within-year time periods even during the critical years with an intention to achieve the maximum possible annual release reliability of 97 percent (Weibull plotting position for 28 years) before releasing for any other purposes.

The reservoir data including the live capacity, evaporation data, fixed annual evaporation data along with the storage-area relationship also are part of the input data files for CRBA. The crops as a whole adopted in the basin and the reservoir points are also fed in along with the GIR data for the crops concerned. The failure fraction and a host of other variables are built into the data file.

The objective of the model is to find the optimal integrated annual system yield by simultaneously optimizing the cropping pattern for each project at the same time. Apart from this, it also estimates for the optimal crop plan, the quantities of protein and calorie productions.While optimizing crop plans, due consideration is given to achieve crop area for each crop at least equal to what it is being proposed in the original crop plan of each project. Similarly, maximum limit on irrigation intensity is kept 1.5 for all major irrigation projects. Further, constraints were applied such that the optimal crop plans shall meet at least the share of the protein and calorie requirements of the projected population by each project. However, above mentioned criteria were suitably and exclusively relaxed in cases of the projects which fail to meet the demand under basic resource constraints.

6.1.4 Formatting of the System Variables

For use in the LINDO software, large number of variables and different parameters of the model need to be formatted. For this purpose, the nomenclature (notation) of variables consisting of not more than 8 characters including letters and numerals used in objective function and constraints has been done using the following conventions. The first alphabet denotes name of the basin; the second denotes name of the sub-basin; the next two alphabets, i.e., 3^{rd} and 4^{th} denote name of the project and 5^{th} and 6^{th} alphabet denote name of the variable and last two numerals, i.e., at position 7^{th} and 8^{th} represent annual or within-year time periods. However, in the case of crops, the last four alphabets denote the crop code.

The notations used for the names of different projects along with the name of sub-basin under which it comes and notations used for different reservoir variables are shown in Table 6.1and 6.2. Further, notations used for different crops in different basins are shown separately in Table 6.3 to 6.6. Use of such significant notations for variable names can assist a user in easy preparation of input data for the model and interpretation of the results from model solutions when there are a large number of variables involved in the model.

Table 6.1 Notations representing reservoirs

Sl No	Basin Sl no	Basin	Sub-basin	Name of the project	Code
(1)	(2)	(3)	(4)	(5)	(6)
1	1	Mahanadi	Upper Mahanadi	Dudhawa	MUDH
2	2			Sondur	MUSN
3	3			Sikasar	MUSK
4	4			Pairi	MUPR
5	5			MurramSilli	MUMS
6	6			Ravi Shankar	MURS
7	7			Kodar	MUKD
8	8			Lath	MULT
9	9			Kelo	MUKL
10	10		Sheonath	Bhivkurd	MSBK
11	11			Sukhanallah	MSSN
12	12			Kharkhara	MSKH
13	13			Tandula	MSTN
14	14			Jhenjori	MSJH
15	15			Deokar	MSDK
16	16			Saroda	MSSR
17	17			Kachanari	MSKN
18	18			Simga	MSSG
19	19			Hamp	MSHP
20	20			Maniyari	MSMN
21	21			Kharang	MSKR
22	22			Arpa	MSAR
23	23		Jonk	Joint Jonk	MJJJ
24	24			Jonk Diversion	MJJD
25	25		Hasdeo	HasdeoBango	MHHB
26	26		Mand	Mand	MDMD
27	27			Kuruket	MDKU
28	28		Ib	Ib Diversion	MIID

29	29			HaldiMunda	MIHM
30	30			Ib	MIIB
31	31			Upper Bheden	MIUB
32	32			Lower Bheden	MILB
33	33			Lamdora	MILM

(1)	(2)	(3)	(4)	(5)	(6)
34	34		Ong	Ong	MOOD
35	35			Ong Barrage	MOOB
36	36		Tel	Upper Tel	MTUT
37	37			Hati Barrage	MTHB
38	38			Sagada	MTSD
39	39			Upper Udanti	MTUU
40	40			Lower Udanti	MTLU
41	41			Lower Indra	MTLI
42	42			Uttei Raul	MTUR
43	43			Lower Lanth	MTLL
44	44			Khadago	MTKH
45	45			Lower Tel	MTTB
46	46			Lower Suktel	MTLS
47	47		Middle Mahanadi	Hirakud	MMHD
48	48			Surubalijore	MMSB
49	49			Salki Barrage	MMSL
50	50		Lower Mahanadi	Brutanga	MLBR
51	51			Manibhadra	MLMB
52	52			Delta stage-I	MLDT
53	53			Delta stage-II	MLDL
54	1	Godavari	Upper Godavari	Palkhed	GUPK
55	2			Ozarkhed	GUOK
56	3			N. Madyameswar	GUNM
57	4			Karwa	GUKR
58	5			Gangapur	GUGP
59	6			Jayakwadi Stage-I	GUJK
60	7			Jayakwadi Stage-II	GUJW
61	8			Vishnupuri	GUVP
62	9		Pravara	Bhandaradara	GPBD
63	10			Upper Pravara	GPUP
64	11			Mula	GPML
65	12		Purna	KhadakPurna	GRPU
66	13			Yeldhari	GRYD
67	14			PurnaSidheswar	GRPS

68	15			Lower Dudhana	GRLD
69	16		Manjira	Manjra	GJMA
70	17			Lower Terna	GJLT
71	18			Karanja	GJKR
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
72	19			Singur	GJSG
73	20			Nizamsagar	GJNS
74	21			Lendi	GJLN
75	22			Manar	GJMN
76	23		Middle Godavari	Sriramsagar	GMSS
77	24			Kaddam	GMKD
78	25		Maner	Lower Maner Dam	GNLM
79	26		Penganga	Upper Penganga	GGUG
80	27			Pentakali	GGPK
81	28			Isapur	GGIP
82	29			Upper Pus	GGUP
83	30			Arunavati	GGAV
84	31			Adan	GGAD
85	32			Lower Penganga	GGLP
86	33		Wardha	Upper Wardha	GWUW
87	34			Bembla	GWBM
88	35			Lower Wardha	GWLW
89	36			Bor	GWBR
90	37			Dham	GWDH
91	38		Pranhita	Upper Wainganga	GHUW
92	39			Thanwar	GHTW
93	40			Hirri	GHHR
94	41			Dhuti Weir	GHDH
95	42			Nahara Diversion	GHND
96	43			Bagh	GHBG
97	44			Son Diversion	GHSD
98	45			Deo Diversion	GHDD
99	46			Khairbandha	GHKB
100	47			Bhawanthadi	GHBT
101	48			Dhapewada	GHDW
102	49			Chorkamra	GHCK

103	50			Kanhan Diversion	GHKD
104	51			Pench Diversion	GHPD
105	52			Gosikurd	GHGK
106	53			Itihado	GHIH
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
107	54			Tultuli	GHTT
108	55			Sathi	GHST
109	56			Lower Kathani	GHLK
110	57			Bhimkund	GHBK
111	58			Dina	GHDN
112	59			Human	GHHN
113	60			Ghorazhari	GHGZ
114	61			Asolmandha	GHAM
115	62			Pranhita	GHPR
116	63			Vattivagu	GHVV
117	64		Indravati	Upper Indravati	GIUI
118	65			Lower Indravati	GILI
119	66			Markandi	GIKT
120	67			Dantewada	GIDW
121	68			Sankini	GISK
122	69			Kutru-II	GIKU
123	70			Berudi	GIBR
124	71			Kindrunj	GIKR
125	72			Bhopalpatnam-II	GIBP
126	73		Sabari	Upper Kolab	GSUK
127	74			Govindpali	GSGP
128	75			Baru	GSBR
129	76			SileruVagu	GSSV
130	77			Potteru	GSPT
131	78			Satiguda	GSSG
132	79			Janavagu	GSJV
133	80		Lower Godavari	Inchampalli	GLIP
134	81			Talperi	GLTP
135	82			Polavaram	GLPV
136	83			Buradakalva	GLBK
137	84			Cotton Barrage	GLCB

138	1	Krishna	Upper Krishna	Dhom	KUDH
139	2			Kanher	KUKA
140	3			Urmodi	KUUR
141	4			Tarali	KUTA
142	5			Khodsi	KUKH
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
143	6			Koyna	KUKO
144	7			Warna	KUWR
145	8			Radhanagari	KURA
146	9			Dudhganga	KUDU
147	10		Middle Krishna	Hippargi Barrage	KMHI
148	11			Almatti	KMAL
149	12			Narayanpur	KMNA
150	13		Ghataprabha	Ghataprabha	KGGH
151	14			Markandeya Project	KGMK
152	15		Malprabha	Malprabha	KAMA
153	16			Ramthal Lift Irrigation Project	KARL
154	17		Upper Bhima	Chaskaman	KBCK
155	18			BhamaAskhed	KBBA
156	19			Khadakwasla	KBKH
157	20			Dimbhe	KBDI
158	21			PipalgaonJoge	KBPJ
159	22			Yedgaon	KBYD
160	23			Ghod	KBGH
161	24			Ujjani	KBUJ
162	25			NiraDeoghar	KBND
163	26			Vir	KBVR
164	27			Gunjwani	KBGU
165	28			SinaKolegaon	KBSK
166	29		Lower Bhima	Benithora Project	KHBE
167	30			Bhima Flow Irrigation Project	KHBF
168	31		Tungabhadra	TungaAnicut	KTTA
169	32			Bhadra Reservoir Project	KTBR
170	33			Singattur LIS	KTSL
171	34			Tungabhadra Project	KTTU
172	35			Rajolibandra diversion scheme	KTRD
173	36			Gajuladine	KTGD
174	37		Vedvathy	VanivilasSagar	KVVS
175	38		Lower Krishna	P.D.Jurala	KLPU
176	39			Srisailam	KLSS
177	40			NagarjunaSagara	KLNS

178	41			Pulichintala	KLPC
179	42			Prakasambaarage	KLPB
180	43		Musi	Musi	KSMU
181	44		Paleru	Paleru	KPPL
182	1	Pennar	Pennar Delta	Somasila	PDSS
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
183	1	Cauvery	Upper Cauvery	Hardu	CUHD
184	2			Hospatna	CUHP
185	3			Harangi	CUHG
186	4			Yagachi	CUYG
187	5			Hemavathy	CUHV
188	6			KrishnarajSagar	CUKR
189	7		Kabini	Monantavady	CKMV
190	8			Kabini	CKKB
191	9			Upper Nugu	CKUN
192	10			Nugu	CKNU
193	11		Chinar	Metur	CCMT
194	12		Bhabani	Lower Bhabani	CBLB
195	13		Thirumanimuttar	Kattalai	CTKL
196	14		Amaravathy	Amaravathy	CRAV
197	15		Delta	Grand Anicut	CDGA

Table 6.2 Sample notations representing reservoir variables

Sl No	Name of the project	Code
(1)	(2)	(3)
1	$S^{o}_{SN_s, BN_{s,b}, RN_{s,b,i}, j-1}$	SO
2	$Sp_{USN_l, UBN_{l,y}, URN_{l,y,x}, j}$	SL
3	$Oy^{fp}_{SN_s, BN_{s,b}, RN_{s,b,i}}$	FP
4	$Oy^{sp2}_{SN_s, BN_{s,b}, RN_{s,b,i}}$	SP
5	$EV_{SN_s, BN_{s,b}, RN_{s,b,i}, j}$	EA
6	$Y^{o}_{SN_s, BN_{s,b}, RN_{s,b,i}}$	YA
7	$OE^{fp; ISNU_{nis}, IBNU_{nis,d}, IRNU_{nis,d,c}}_{USN_l, UBN_{l,y}, URN_{l,y,x}, t}$	OE

Table 6.3 crop notations in Mahanadi Basin

Sl No	Name of the crop	Code
(1)	(2)	(3)
	Kharif crops	
1	Early Paddy	EPDK
2	Medium Paddy	MPDK
3	Late Paddy	LPDK
4	Ragi	RAGK
5	Groundnut	GNTK
6	Maize	MAZK
7	Vegetable	VEGK
8	Jute	JUTK
9	Pulses	PULK
10	Millet	MILK
11	Fodder	FODK

12	Soyabeans	SOYK
	Rabi crops	
13	Wheat	WHTR
14	Paddy	PADR
15	Pulses	PULR
16	Groundnut	GNTR
17	Vegetable	VEGR
18	Potatoes	POTR
19	Mustard	MSTR
20	Til	TILR
21	Arhar	ARHR
22	Cotton	COTR
23	Oilseeds	OILR
24	Linseed	LINR
25	Grams	GRMR
	Perennial	
26	Sugar	SUGP

Table 6.4 crop notations in Godavari Basin

Sl No	Name of the crop	Code
(1)	(2)	(3)
	Kharif crops	
1	Paddy	PADK
2	Bajra	BAJK
3	Maize	MAZK
4	Jowar	JOWK
5	Groundnut	GNTK
6	Cotton	COTK
7	Chillies	CHLK
8	Pulses	PULK
9	Gram	GRMK
10	Sunflower	SUNK
11	Vegetable	VEGK
12	Soyabeans	SOYK
13	Turmeric	TURK
14	Fodder	FODK
	Rabi crops	
15	Paddy	PADR
16	Groundnut	GNTR
17	Maize	MAZR

18	Jowar	JOWR
19	Pulses	PULR
20	Wheat	WHTR
21	Vegetable	VEGR
22	Sunflower	SUNR
23	Gram	GRMR
24	Mustard	MUSR
25	Chillies	CHLR
26	Cotton	COTR
27	Potatoes	POTR
28	Fodder	FODR
	Hot weather	
29	Groundnut	GNTH
30	Vegetable	VEGH
31	Jowar	JOWH
32	Pulses	PULH
33	Gram	GRMH
34	Bajra	BAJH
35	Cotton	COTH
36	Maize	MAZH
37	Fodder	FODH
	Perennial	
38	Sugar	SUGP

Table 6.5 crop notations in Krishna and Pennar Basins

Sl No	**Name of the crop**	**Code**
(1)	**(2)**	**(3)**
	Kharif crops	
1	Paddy	PADK
2	Vegetable	VEGK
3	Pulses	PULK
4	Groundnut	GNTK
5	Fodder	FODK
6	Jowar	JOWK
7	Bajra	BAJK
8	Hybrid Bajra	HYBK
9	Cotton	COTN
10	Maize	MAZK
11	Chillies	CHIL
12	Sunflower	SUNK

13	Ragi	RAGK
14	Turmeric	TURM
	Rabi crops	
15	Grams	GRMR
16	Fodder	FODR
17	Vegetable	VEGR
18	Wheat	WHTR
19	Jowar	JOWR
20	Pulses	PULR
21	Maize	MAZR
22	Safflower	SAFR
23	Sunflower	SUNR
24	Potato	POTR
25	Oilseeds	OILR
26	Paddy	PADR
	Hot weather	
27	Groundnut	GNTH
28	Vegetable	VEGH
29	Fodder	FODH
	Perennial	
30	Sugar	SUGP

Table 6.6 crop notations in Cauvery Basins

Sl No	Name of the crop	Code
1	**2**	**3**
	Kharif crops	
1	Paddy	PADK
2	Jowar	JOWK
3	Ragi	RAGK
4	Fodder	FODK
5	Groundnut	GNTS
6	Tobacco	TOBK
7	Cotton	COTK
8	Pulses	PULK
9	Maize	MAZK
10	Groundnut	GNTK
11	Chillies	CHLK
12	Paddy(Samba)	SAMB
	Rabi crops	
13	Pulses	PULR

14	Vegetable	VEGR
15	Paddy	PADR
16	Oilseeds	OILR
17	Maize	MAZR
18	Groundnut	GNTR
19	Jowar	JOWR
20	Paddy(Nava)	NAVA
21	Chillies	CHLR
	Hot weather	
22	Ragi	RAGS
23	Fodder	FODS
24	Bajra	BAJS
25	Cotton	COTS
26	Paddy	PADS
27	Jowar	JOWS
	Perennial	
28	Sugar	SUGA
29	Coconut	COCO

6.1.5 Model Runs

The model runs were done for all the basins involved and at the export points of the nine links. The strategy was to run the model individually and then in an integrated manner. The sequence of grouping the reservoir progressed from the uppermost reservoir to the downstream reservoirs as the contributions of the upstream reservoirs play a significant role in making the downstream project feasible by way of contribution of regeneration from water uses as well as spill.

6.1.5.1 Addressing infeasibility in the model runs

Whenever running of the model resulted in infeasibility, the help of debugging command inbuilt in the software was used to isolate the sources of infeasibility. The software provides information in two categories like sufficient conditions and necessary conditions. In the category of sufficient conditions, it indicates the source as either a single variable or a group of variables. When it is a single variable, it is easy to address the infeasibility. However, when it is a combination of variables, it becomes difficult to pin point the source the infeasibility. Further, if no sufficient condition is given and only necessary conditions are provided, then it becomes difficult to isolate the source of infeasibility. Therefore, in order to address the issue and to make a uniform procedure, first of all the crops were made free in the matrix generated for LINDO software with no upper or lower bounds. Then gradually, the crops ware assigned upper, lower or equality bounds based on the result got from the model run. The process is repeated till feasible crop plan is assigned the bounds with the help of LINDO runs. In most of the cases this procedure worked.

6.2 COMPILATION OF RESULTS

The results obtained from the LINDO are lengthy and are cumbersome to compile. Since the model runs comprised of large number of reservoir at a time, the variables given as input and output generated are also very large. For example, in the largest run by LINDO the variable used were 9005. Therefore to compile and analyse the output data is a challenge of high order and is time consuming. In order to simplify the matter and to make the output data amenable to compilation and further mathematical treatment, a FORTRAN programme is used as a post processor to the LINDO results. The programme uses the result from the software as the input file and makes analysis on the basis of the algorithm in it.

6.3 ANALYSIS OF RESULTS

The compilation of the results and the analyses thereof are provided in Chapter-7. Therefore the results are not provided here in order to avoid duplicity. However, token results have been placed in Table 6.7 in respect of yield scenario in Mahanadi basin.

TABLE 6.7 Results in respect of major projects in Mahanadi Basin

Projects upstream of export point (Manibhadra)							SINGLE PROJECT			SUBBASIN LEVEL INTEGRATION			BASIN LEVEL INTEGRATION		
Basin	Sub-Basin		Name of the project	Code	Status of the project	75% dependable yield (Annual)	Firm Yield	Secondary Yield	TOTAL	Firm Yield	Secondary Yield	TOTAL	Firm Yield	Secondary Yield	TOTAL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Mahanadi	**Upper Mahanadi**	1	Dudhawa	**MUDH**	Existing	215.98	25.84	23.67	**49.51**	66.13	45.34	**111.47**	22.03	252.18	**274.21**
		2	Sondur	**MUSN**	Existing	178.07	55.69	69.45	**125.14**	61.76	107.18	**168.94**	104.82	90.68	**195.50**
		3	Pairi	**MUPR**	Contemplated	735.18	211.32	229.02	**440.34**	573.59	716.11	**1289.69**	463.28	616.89	**1080.17**
		4	Ravi Shankar	**MURS**	Existing	1060.43	632.91	284.61	**917.52**	580.31	1085.43	**1665.74**	732.11	689.71	**1421.82**
		5	Kodar	**MUKD**	Contemplated	125.59	74.45	92.85	**167.29**	74.45	92.85	**167.29**	70.75	97.64	**168.39**
		6	Lath	**MULT**	Contemplated	249.04	37.54	46.82	**84.35**	37.54	46.82	**84.35**	37.54	219.83	**257.36**
		7	Kelo	**MUKL**	Contemplated	363.76	141.86	176.92	**318.78**	141.86	176.92	**318.78**	141.86	240.79	**382.65**
	Sheonath	8	Bhivkurd	**MSBK**	Contemplated	112.32	110.29	137.55	**247.84**	98.58	122.94	**221.52**	98.58	144.20	**242.78**
		9	Sukhanallah	**MSSN**	Contemplated	99.40	76.63	95.57	**172.21**	76.44	95.33	**171.77**	76.44	95.33	**171.77**
		10	Kharkhara	**MSKH**	Existing	61.94	36.29	45.26	**81.54**	36.29	92.85	**129.14**	60.88	61.62	**122.49**
		11	Tandula	**MSTN**	Existing	165.73	139.70	174.24	**313.94**	32.95	322.64	**355.58**	32.95	193.36	**226.30**
		12	Jhenjori	**MSJH**	Contemplated	118.80	90.27	112.58	**202.85**	10.78	1.41	**12.19**	10.78	198.85	**209.63**
		13	Deokar	**MSDK**	Contemplated	182.98	52.00	64.86	**116.86**	52.00	146.31	**198.32**	52.00	146.31	**198.32**
		14	Saroda	**MSSR**	Existing	14.81	10.04	12.52	**22.55**	5.12	20.09	**25.21**	5.12	15.32	**20.44**
		15	Kachanari	**MSKN**	Contemplated	220.95	93.14	32.22	**125.37**	55.79	190.63	**246.42**	55.79	190.63	**246.42**
		16	Simga	**MSSG**	Contemplated	2215.46			**0.00**	1202.72	2210.46	**3413.18**	767.72	3458.69	**4226.41**
		17	Hamp	**MSHP**	Contemplated	119.77	94.57	117.95	**212.53**	22.23	212.73	**234.96**	22.23	200.16	**222.39**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
		18	Maniyari	**MSMN**	Existing	164.94	121.82	105.94	**227.77**	125.31	105.94	**231.26**	88.25	142.90	**231.15**
		19	Kharang	**MSKR**	Existing	144.23	84.05	104.83	**188.88**	62.18	132.76	**194.94**	59.99	134.90	**194.89**
		20	Arpa	**MSAR**	Ongoing	344.08	230.73	287.76	**518.49**	215.22	371.15	**586.36**	215.22	371.15	**586.36**
	Jonk	21	Joint Jonk	**MJJJ**	Contemplated	446.56	114.48	343.44	**457.91**	114.48	343.44	**457.91**	113.73	350.34	**464.08**
		22	Jonk Diversion	**MJJD**	Contemplated	374.27	78.75	236.24	**314.98**	106.55	153.41	**259.97**	58.15	388.45	**446.60**
	Hasdeo	23	HasdeoBango	**MHHB**	Ongoing	2257.08	1477.62	1842.88	**3320.51**	1477.62	1842.88	**3320.51**	1463.76	1876.23	**3339.99**
	Mand	24	Mand	**MDMD**	Contemplated	588.44	69.76	87.00	**156.76**	69.76	87.00	**156.76**	69.76	752.34	**822.10**
		25	Kuruket	**MDKU**	Contemplated	202.91	33.15	41.35	**74.50**	33.15	41.35	**74.50**	33.15	245.67	**278.82**
	Ib	26	Ib Diversion	**MIID**	Existing	186.48	78.11	0.00	**78.11**	78.11	0.00	**78.11**	126.73	57.54	**184.27**
		27	HaldiMunda	**MIHM**	Ongoing	936.31	69.06	86.13	**155.19**	60.42	91.28	**151.70**	487.96	441.10	**929.06**
		28	Ib Dam	**MIIB**	Contemplated	420.56	778.59	141.95	**920.53**	1191.30	98.48	**1289.79**	183.62	1359.27	**1542.89**
		29	Upper Bheden Dam	**MIUB**	Contemplated	567.20	153.27	0.55	**153.82**	125.06	0.45	**125.51**	112.02	75.45	**187.47**
		30	Lower Bheden Dam	**MILB**	Contemplated	453.24	137.20	58.80	**196.00**	170.28	78.53	**248.81**	123.54	111.04	**234.58**
		31	Lamdora Dam	**MILM**	Contemplated	448.94	72.03	12.66	**84.69**	56.73	42.74	**99.47**	18.24	120.24	**138.48**
	Ong	32	Ong Dam	**MOOD**	Contemplated	381.85	200.93	218.06	**418.98**	174.11	224.08	**398.19**	113.89	284.30	**398.19**
		33	Ong Barrage	**MOOB**	Existing		38.77	116.30	**155.07**	0.00	124.96	**124.96**	0.00	124.96	**124.96**
	Tel	34	Upper Tel Dam	**MTUT**	Contemplated	379.98	88.31	64.68	**152.99**	88.31	64.68	**152.99**	78.29	151.32	**229.61**
		35	Hati Barrage	**MTHB**	Existing	450.05	1853.90	0.00	**1853.90**	1853.90	0.00	**1853.90**	1140.65	884.27	**2024.93**
		36	Sagada Dam	**MTSD**	Contemplated	383.89	91.55	111.76	**203.31**	91.55	111.76	**203.31**	78.95	132.77	**211.72**
		37	Upper Udanti Dam	**MTUU**	Contemplated	319.39	68.35	67.53	**135.88**	68.35	67.53	**135.88**	89.20	150.79	**239.99**
		38	Lower Udanti Dam	**MTLU**	Contemplated	268.22	112.21	0.00	**112.21**	112.21	0.00	**112.21**	27.72	259.21	**286.94**
		39	Lower Indra Dam	**MTLI**	Ongoing	354.52	177.08	154.64	**331.72**	177.08	154.64	**331.72**	132.20	207.13	**339.34**
		40	Uttei Raul Dam	**MTUR**	Contemplated	471.63	333.84	2.08	**335.92**	333.84	2.08	**335.92**	281.21	511.35	**792.56**
		41	Lower Lanth dam	**MTLL**	Contemplated	230.12	156.61	193.91	**350.52**	156.61	193.91	**350.52**	126.60	243.03	**369.63**
		42	Khadago Dam	**MTKH**	Contemplated	409.63	276.39	273.64	**550.03**	276.39	273.64	**550.03**	239.11	541.57	**780.68**

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
		43	Lower Tel Barrage	**MTTB**	Contemplated	383.30	689.89	0.00	**689.89**	80.33	25.37	**105.70**	216.10	1413.26	**1629.37**
		44	Lower Suktel Dam	**MTLS**	Ongoing	383.14	209.11	112.75	**321.86**	209.11	112.75	**321.86**	169.04	257.58	**426.62**
	Middle Mahanadi	45	Hirakud Dam	**MMHD**	Existing	11393.06	3227.24	1008.54	**4235.78**	3227.24	1008.54	**4235.78**	3227.24	1008.54	**4235.78**
		46	Surubalijore	**MMSB**	Contemplated	470.37	97.16	87.91	**185.08**	97.16	87.91	**185.08**	87.14	103.84	**190.99**
		47	Salki Barrage	**MMSL**	Existing	325.22	89.99	436.24	**526.23**	89.99	436.24	**526.23**	7.32	1050.52	**1057.84**
	Lower Mahanadi	48	Brutanga Dam	**MLBR**	Contemplated	344.18	110.09	171.04	**281.12**	110.09	171.04	**281.12**	87.08	209.83	**296.92**
		49	Manibhadra Dam	**MLMB**	Contemplated	359.52	1770.37	948.26	**2718.62**	1770.37	948.26	**2718.62**	1770.37	948.26	**2718.62**
						31083.56	**14972.93**	**9032.96**	**24005.88**	**15931.34**	**13082.86**	**29014.20**	**13781.10**	**21821.36**	**35602.46**

CHAPTER 7

ANALYSIS OF RESULTS

7.1 PREMISES OF ANALYSIS

A study was undertaken for integrated river basin development for their water resources utilizations for large rivers in Indian. The specific emphasis was on transferring surplus waters from water surplus basins to water deficit basins. The problem is multi-dimensional in space and time. This is only possible through inter linking of rivers. The national perspective plan of the Government of India envisages transfer of river basin waters. The National Water Development Agency in India has already carried out many studies on the problem. These studies are based on conventional methods and provide very useful information, and which has come up in very exhaustive reports. Optimal water utilization is the need of today due to increasing water demands, the reason being the availability of water which is not uniformly distributed in space and time, and has also become scares. Therefore the aim of the study was to apply systems analysis method to solve such problem. The study area is the peninsular river basins in India which consists of five large river basins, namely the Mahanadi, Godavari, the Krishna, the Pennar and the Cauvery. These river basins have huge water resources, but some of them face water shortages at different times during years, especially in the non-monsoon seasons. Also these river basins are still under development stage as far as their water resources are concerned.

The objectives of the problem are defined in the Chapter-1. The salient features of the river systems are described in Chapter-3.There are five major river basins involved in this study from which water is to be exported from altogether eight export points. The models used for the study are described in the Chapter-4. In the study the linear programming (LP) technique was employed as an optimization tool, the reason being its applicability to handle large size optimization problems for their solution. Another reason was that very standard software is available for the technique in the market. The model is based on the reservoir yield model approach, earlier used by various researchers, which is being presented in a generalized form now. The model considers over the year and within the year reservoir storages separately, and provides as well the within the year firm and secondary reservoir releases. The firm reservoir release also takes care of the minimum food requirements of the people in the concerned region, especially the farmers. The release of water towards meeting of the downstream environmental is made mandatory. The project dependability (reliability) is pre-assigned by defining project's success and failure in terms of successful and failure years. In this study the water-year project dependability taken is 75%. This means let out of 40 years life of a project, there would be 30 successful years and 10 failure years. A provision of export of water is also being made in the model. In order to derive various parameters to be used in the LP model, the assessment of the water resources of these river basins is presented in the Chapter-5. The Chapter-6 deals with the computations carried out for solving the problem at hand.The LINDO software was used for this purpose. Only limited results obtained from the LP model were presented in the chapter on computation.

The analysis is carried out in this chapter based on the above information. As said earlier the most of the results obtained during the computations are presented in this chapter but not in the Chapter-6 side by side along with the analysis being made, because of the ease in understanding the results and analyzing them. The analysis is described in this chapter in the manner given below.

Firstly, the analysis is carried out at each basin level for crops, with various sub-levels, aspects such as for each reservoir, for each sub-basin, andfor each crop. Secondly, (a) for the within the year reservoir storages the analysis is made at each basin level and (b) for the within the year reservoir firm and secondary reservoir yields again the analysis is made at each basin level. Thirdly, the analysis is carried out for each of the water exporting points.

7.2 ANALYSIS OF CROPS AT EACH BASIN LEVEL

Water transfers from water surplus river basins to water deficit river basins, which may be of small or large in sizes and may be of short or long distances are due to the large water needs at the importing basins. Irrigation is the maximum consumer of water amongst the consumptive water uses. Most of the water received by an importing basin is used for the irrigation purposes. Therefore, it becomes necessary to analyze for the crops grown in the basins in detail.

The results of the crops involved are assessed and analyzed at the reservoir project levels, at the sub-basin levels and at the crop levels for each of the basins. At the reservoir project level the assessment is based on the modeled total cropped intensities. At the sub-basin level this is done on the basis of the modeled average cropped intensities. The later criterion is also followed while analyzing at the cropped level. At places the expected probability of exceedance of some of the items are presented for the maximum and the minimum values achieved.

7.2.M Analysis for Crops at Mahanadi Basin Level

7.2.M.1 Crop intensities achieved at the reservoir levels in Mahanadi

The total cropped intensity achieved at each reservoir in **Mahanadi** basin is summarized in Table-**7**.2.M.1. and their percentexceedances are given in Table-7.2.M.1.(a). It is found that many reservoirs; i.e., (i) **DH, SN, PR, LT and KL** in sub-basin **U**, (ii) **KH, DK, KN and SG** in sub-basin **S**, (iii) **JD** in sub-basin **J**, (iv) **MD** and **KU** in sub-basin **D** and (v) **MB** in sub-basin **L** are with a total cropped intensity of **1.5** and have the lowest percent exceedance of **26** and the reservoir **TN** with total cropped intensity of **0.023** of the sub-basin **S** has the highest percent exceedance of **98**.

7.2.M.2 Sub-basin crop intensity achieved for crops in sub-basins of Mahanadi

The total and average cropped intensities achieved at each sub-basin in **Mahanadi** basin is summarized in Table-7.2.M.2 along with their percent exceedances. The sub-basin **T** has the lowest percent exceedance of **9** with a total cropped intensity of **13.275**, whereas the sub-basin **H**has the highest percent exceedance of **90** and a total cropped intensity of **1.028**. In case of the average cropped intensity the sub-basin **D** has the lowest percent exceedance of **9** with an average cropped intensity of **0.190**, whereas the sub-basin **S** has the highest percent exceedance of **90** with an average cropped intensity of **0.065**.

7.2.M.3 Crop intensities achieved for each crop inMahanadi

The total cropped intensity achieved for each crop in **Mahanadi** basin are summarized in Table-7.2.M.3 and their percentexeedances for average cropped intensities are given in Table-7.2.M.3(a). It is found that in **Mahanadi** basin the crop **MPDK** has a total cropped intensity of **13.094** and the crop **MILK** with a minimum total cropped intensity of **0.100**. The crop **MPDK** with an average cropped intensity of **0.267**has the lowest percent exceedance of **3** and the crop **SUGP** with cropped intensity of **0.010**has the highest percent exceedance of **96**.

7.2.G Analysis for Crops at Godavari Basin Level

7.2.G.1 Crop intensities achieved at the reservoir levels in Godavari

The total cropped intensity achieved at each reservoir in **Godavari** basin is summarized in Table-**7**.2.G.1 and their percentexceedances are given in Table-**7**.2.G.1 (a). It is found that the reservoir **DN** with a cropped intensity of **1.414** of the sub-basin **H** has the lowest percent exceedance of **1** and the reservoir **JW** with cropped intensity of **0.242** of the sub-basin **U** has the highest percent exceedance of **98**. The reservoirs **KD, IH, TT, ST, LK, BK and AM** all in sub-basin H have a total cropped intensity **1.400**.

7.2.G.2 Sub-basin crop intensity achieved for crops in sub-basins of Godavari

The total and average cropped intensities achieved at each sub-basin in **Godavari** basin is summarized in Table-7.2.G.2 along with their percent exceedances. The sub-basin **H** has the lowest percent exceedance of **10** with a total cropped intensity of **33.243**, whereas the sub-basin N has the highest percent exceedance of **90** and a total cropped intensity of **1.000**. In case of the average cropped intensity the sub-basin **J** has the lowest percent exceedance of **10** with an average cropped intensity of **0.152**, whereas the sub-basin **R** has the highest percent exceedance of **90** with an average cropped intensity of **1.000**.

7.2.G.3 Crop intensities achieved for each crop in Godavari

The total cropped intensity achieved for each crop in **Godavari** basin are summarized in Table-7.2.G.3 and their percentexeedances for average cropped intensities are given in Table-7.2.G.3(a). It is found that in **Godavari** basin the crop **PADK** has a total cropped intensity of **14.100** and the crop **COTH** with a minimum total cropped intensity of **0.060**. The crop **PADK** with an average cropped intensity of **0.243**has the lowest percent exceedance of **3** and the crop **FODK** with cropped intensity of **0.037**has the highest percent exceedance of **96**.

7.2.K Analysis for Crops at Krishna Basin Level

7.2.K.1 Crop intensities achieved at the reservoir levels in Krishna

The total cropped intensity achieved at each reservoir in **Krishna** basin is summarized in Table-7.2.K.1 and their percentexceedances are given in Table-7.2.K.1. (a). It is found that the reservoir **PD** with a cropped intensity of **1.998** of the sub-basin **L** has the lowest percent exceedance of **2** and the reservoir **PJ** with cropped intensity of **0.003** of the sub-basin **B** has the highest percent exceedance of **97**.

7.2.K.2 Sub-basin crop intensity achieved for crops in sub-basins of Krishna

The total and average cropped intensities achieved at each sub-basin in **Krishna** basin is summarized in Table-7.2.K.2 along with their percent exceedances. The sub-basin **U** has the lowest percent exceedance of **10** with a total cropped intensity of **9.081**, whereas the sub-basin **V**has the highest percent exceedance of **90** and a total cropped intensity of **1.599**. In case of the average cropped intensity the sub-basin **L** has the lowest percent exceedance of **10** with an average cropped intensity of **0.208**, whereas the sub-basin B has the highest percent exceedance of **90** with an average cropped intensity of **0.053**.

7.2.K.3 Crop intensities achieved for each crop in Krishna

The total cropped intensity achieved for each crop in **Krishna** basin are summarized in Table-7.2.K.3 and their percentexeedances for average cropped intensities are given in Table-7.2.K.3(a). It is found that in **Krishna** basin the crop **JOWK** has a total cropped intensity of **4.613** and the crop **SUNK** with a minimum total cropped intensity of **0.028**. The crop **JOWK** with an average cropped intensity of **0.121**has the lowest percent exceedance of **3** and the crop **SAFR** with cropped intensity of **0.022**has the highest percent exceedance of **96**.

7.2.P Analysis for Crops at Pennar Basin Level

7.2.P.1 Crop intensities achieved at the reservoir levels in Pennar

The total cropped intensity achieved at each reservoir in **Pennar** basin is summarized in Table-7.2.P.1. It is found that the reservoir SS has a total cropped intensity of **1.000** of the sub-basin.

7.2.P.2 Crop intensities achieved for each crop in **Pennar**

The total cropped intensity achieved for each crop in **Pennar** basin are summarized in Table-7.2.P.2. It is found that in **Cauvery** basin the crop **PADK** has a maximum total cropped intensity of **0.19** and the crop CHIL with a minimum total cropped intensity of**0.040**.

7.2.C Analysis for Crops at Cauvery Basin Level

7.2.C.1 Crop intensities achieved at the reservoir levels in Cauvery

The total cropped intensity achieved at each reservoir in **Cauvery** basin is summarized in Table-7.2.C.1 and their percentexceedances are given in Table-7.2.C.1 (a). It is found that the reservoir LB with a cropped intensity of **2.300** of the sub-basin B has the lowest percent exceedance of **7** and the reservoir **HE** with cropped intensity of **0.647** of the sub-basin **U** has the highest percent exceedance of **92**.

7.2.C.2 Sub-basin crop intensity achieved for crops in sub-basins of Cauvery

The total and average cropped intensities achieved at each sub-basin in **Cauvery** basin is summarized in Table-7.2.C.2 along with their percent exceedances. The sub-basin **U** has the lowest percent exceedance of **20** with a total cropped intensity of **5.608**, whereas the sub-basin **I**has the highest percent exceedance of **80** and a total cropped intensity of **1.600**. In case of the average cropped intensity again the sub-basin **U** has the lowest percent exceedance of **20** with an average cropped intensity of **0.104**, whereas again the sub-basin I has the highest percent exceedance of **80** with an average cropped intensity of **0.084**.

7.2.C.3 Crop intensities achieved for each crop in Cauvery

The total cropped intensity achieved for each crop in **Cauvery** basin are summarized in Table-7.2.C.3 and their percentexeedances for average cropped intensities are given in Table-7.2.C.3(a). It is found that in **Cauvery** basin the crop **PADK** has a total cropped intensity of **3.331** and the crop **JOWS** with a minimum total cropped intensity of **0.150**. The crop **COTS** with an average cropped intensity of **0.350**has the lowest percent exceedance of **5** and the crop **TOBK** with cropped intensity of **0.040**has the highest percent exceedance of **95**.

7.3 ANALYSIS OF STORAGES, FIRM YIELD AND SECONDARY YIELDS FOR WITHIN YEAR PERIODS AT EACH BASIN LEVEL

Knowing the expected total storage available from all the reservoirs in a river basin, at the beginning of each month during a normal water year generally helps in developing various reservoir release policiesbeforehand. Therefore, it is essential to know the state of reservoir storages in a basin to decide about a broad tentative reservoir release schedule to be adopted. Also, information about the availability of the various expected total within year yields from all the reservoirs is necessary. This would help in organizing of (i) releases to be made from reservoir for irrigation, (ii) sharing of trans-boundary inter-state river waters among its co-basin statesand (iii) transfer of river waters from water surplus basins to water deficit basins.

The above information for each basin was therefore estimated from the model resultsby totalingthe respective required values obtained for each reservoir:

(i) The expected total within year storage available from all the reservoirs in the basin for finalizing broad tentative reservoir release schedule.

(ii) The expected total within year firm releases available from all the reservoirs in the basin, which could be released from reservoirs to meet essential water needs, i.e., (i) the mandatory water needs at the downstream and (ii) water needed for irrigation purposes to meet the minimum food requirements.

(iii) The expected total within year secondary yields. This would help in knowing the additional water available to meet the water requirements over and above the essential needs.

The results for the within-year reservoir storages are assessed and analyzed at the basin level. The reservoir storages considered for this purpose are the expected total reservoir storage available in the entire basin system for each of the within-year periods.

The results for the within-year reservoir firm and secondary yields are again assessed and analyzed at the basin level. The criteria used were same as that in case of the within-year reservoir storages. Therefore the reservoir firm and secondary yields considered for this purpose are the expected total yields available in the entire basin system for each of the within-year periods.

7.3.M Analysis at Mahanadi Basin Level

In Mahanadi basin the following is achievedduring a normal water year:

(a) The expected total within-year storages that are likely to be available are presented in Table-7.3.M. (a)and Fig.7.3.M (a).It is found that the expected maximum total within year storages of 6062.90MCM from all the reservoirs would be available in the month of December. On the other hand the expected minimum total within year storages of 297.24MCM from all the reservoirs would be available in the month of June.

(b) Similarly, the expected total within-year firm yields that are likely to be available in this basin are presented in Table 7.3.M(b) and Fig.7.3.M (b). It is found that the expected maximum total within year firm yield of 5488.98 MCM from all the reservoirs would be available in the month of July. On the other hand the expected minimum total within year firm yield of 56MCM from all the reservoirs would be available in the month of May.

(c) Similarly, the expected total within-year secondary yields that are likely to be available in this basin are presented in Table 7.3.M. (c) and Fig.7.3.M(c). It is found that the expected maximum total within year secondary yield of 1435.72MCM from all the reservoirs would be available in the month of August. On the other hand the expected minimum total within year secondary yield of 33.6MCM from all the reservoirs would be available in the month of November.

The percent exceedances of the above maximum and the minimum values would be 92% and 7%, respectively.

7.3.G Analysis at Godavari Basin Level

In Godavari basin the following is achievedduring a normal water year:

(a) The expected total within-year storages that are likely to be available are presented in Table-7.3.G (a) and Fig.7.3.G (a). The expected maximum total within year storages of 7246.50 MCM from all the reservoirs would be available in the beginning of month of November. On the other hand the expected minimum total within year storages of 1928.89MCM from all the reservoirs would be available in the beginning of month of June.

(b) Similarly, the expected total withinyear firm yields that are likely to be available in this basin are given in Table 7.3.G. (b) and Fig.7.3.G (b).The expected maximum total within year firm yields of 1908.87 MCM from all the reservoirs would be available in the month of July. On the other hand the expected minimum total within year firm yields of 312.17MCM from all the reservoirs would be available in the month of April.

(c) Similarly, the expected total within year secondary yields that are likely to be available in this basin are shown in Table 7.3.G(c) and Fig.7.3.G(c). The expected maximum total within year secondary yields of 1806.66 MCM from all the reservoirs would be available in the month of July. On the other hand the expected minimum total within year secondary yields of 246.26MCM from all the reservoirs would be available in the month of March.

The percent exceedances of the above maximum and the minimum values would be 92% and 7%, respectively.

7.3.K Analysis at Krishna Basin Level

In Krishna basin the following is achievedduring a normal water year:

(a) The expected total within-year storages that are likely to be available are given in Table-7.3.K(a) and Fig.7.3.K(a). The expected maximum total within year storages of 6841.60 MCM from all the reservoirs would be available in the beginning of month of November. On the other hand the expected minimum total within year storages of 292.79MCM from all the reservoirs would be available in the beginning of month of July.

(b) Similarly, the expected total withinyear firm yields that are likely to be available in this basin are given in Table 7.3.K (b) and Fig.7.3.K (b).The expected maximum total within year firm yields of 2799.69 MCM from all the reservoirs would be available in the month of August. On the other hand the expected minimum total within year firm yields of 554.54MCM from all the reservoirs would be available in the month of May.

(c) Similarly, the expected total within year secondary yields that are likely to be available in this basin are presented in Tables 7.3.K(c) and Fig 7.3.K(c). The expected maximum total within year secondary yields of 1194.68 MCM from all the reservoirs would be available in the month of July. On the other hand the expected minimum total within year secondary yields of 164.08MCM from all the reservoirs would be available in the month of February.

The percent exceedances of the above maximum and the minimum values would be 92% and 7%, respectively.

7.3.C Analysis at Cauvery Basin Level

In Cauvery basin the following is achievedduring a normal water year:

(a) The expected total within-year storages that are likely to be available are presented in Table-7.3.C (a) and Fig.7.3.C (a). The expected maximum total within year storages of 1722.33 MCM from all the reservoirs would be available in the beginning of month of December. On the other hand the expected minimum total within year storages of 390.38MCM from all the reservoirs would be available in the beginning of month of June.

(b) Similarly, the expected total withinyear firm yields that are likely to be available in this basin are shown in Table 7.3.C (b) and Fig.7.3.C (b).The expected maximum total within year firm yields of 220.79 MCM from all the reservoirs would be available in the month of October. On the other hand the expected minimum total within year firm yields of 30.33MCM from all the reservoirs would be available in the month of December.

(c) Similarly, the expected total within year secondary yields that are likely to be available in this basin are shown in Tables 7.3.C(c) and Fig.7.3.C(c). The expected maximum total within year secondary yields of 793.38 MCM from all the reservoirs would be available in the month of August. On the other hand the expected minimum total within year secondary yields of 95.13MCM from all the reservoirs would be available in the month of November.

The percent exceedances of the above maximum and the minimum values would be 92% and 7%, respectively.

7.4 ANALYSIS AT THE WATER EXPORT POINTS

For reservoir operation, storages available in reservoir at any time period play an important role for deciding reservoir operation policies. Therefore, the expected storages available in a reservoir at any time and obtained from the model results can serve as the initial guidelines for its operation, or which can serve as a rule curve for its operation. Therefore, the values of the initial storages obtained from the model results and available at any time in a reservoir at a water transfer point actually would serve as an initial rule curve values for reservoir operation. These initial rule curve values can be further refined through reservoir simulation.

The monthly optimal values of water transfers were also obtained from the model results, which generally cannot be obtained easily from any conventional approach used in planning studies.

The expected within-year storages that are likely to be available at the various water Export Points are presentedin this section.Also the expected within-year reservoir firm yields that are likely to be available at the various water Export Pointsfor use other than what is required for export purposes (i.e., for mandatory water needs and irrigation) are presented.Similarly, the expected within-year reservoir secondary yields that are likely to be available at the various water Export Pointsfor use other than what is required for export purposes (i.e., for irrigation) are also presented.

Further the expected within-year values of the water that would possiblybe availableat the various water Export Points,out of which therequired exports could be made ispresented.

7.4.M Water Export Point-1 at Manibhadra in Mahanadi

7.4. M.1 (a) About within year reservoir storagesat Manibhadra

At the water Export Point-1 at Manibhadra the expected maximum within year storage of 134.06 MCM in the reservoir, Table-7.4.M.1 (a) and Fig. -7.4.M.1 (a), would be available in the beginning of month of October. On the other hand the expected minimum within year storage of 0.19MCM in the reservoir would be available in the beginning of month of August.

7.4. M.1 (b) About within year reservoir firm yields at Manibhadra

As seen from the Table-7.4.M.1 (b) andFi*g*7.4.M.1 (b) at the water Export Point-1 at Manibhadra the expected maximum within year reservoir firm yield of 335.15 MCM in the reservoir would be available in the month of September. On the other hand the expected minimum within year reservoir firm yield of 0.48 MCM in the reservoir would be available in the months of April to June.

7.4. M.1(c) About within year reservoir secondary yields at Manibhadra

The Table-7.4.M.1(c) and Fig. - 7.4.M.1(c) shows that at the water Export Point-1 at Manibhadra the expected maximum within year reservoir secondary yield of 325.97 MCM in the reservoir would be available in the month of July. Whereas the other hand the expected minimum within year reservoir secondary yield of 6.57 MCM in the reservoir would be available in the month of March.

7.4. M.1 (d) About within year exportsat Manibhadra

The expected within-year values of the water that is possibly available at the water Export Point-1 atManibhadra, out of which the exports could be made is presented in Table-7.4.M.1 (d) and Fig. -7.4.M.1 (d). The available annual amount of 21713 MCM water is more than the actual amount of water that is envisaged to be diverted as an export. The annual amount of the export water target is equal to 12165 MCM, i.e., 100% of the annual export target is fulfilled.

7.4. G Water Export Points-2 and 3 at Inchampalli and Export Point-4 at Polavaram in Godavari

7.4. G.1(a) About within year reservoir storages at Inchampalli

At the water Export Points-2 and 3 at Inchampalli the expected maximum within year storage of 75.81 MCM in the reservoir, 7.4.G.1 (a),Fig.7.4.G.1 (a) would be available in the beginning of month of September. On the other hand the expected minimum within year storage of 2.27 MCM in the reservoir would be available in the beginning of month of February.

7.4. G.1 (b) About within year reservoir firm yields at Inchampalli.

As seen from the Table-7.4.G.1 (b), Fig7.4.G.1 (b) at the water Export Points-2 and 3 at Inchampallithe expected maximum within year reservoir firm yield of 70.02 MCM in the reservoir would be available in the month of November. But the expected minimum within year reservoir firm yield of 2.84 MCM in the reservoir would be available except in the months of July, November and May.

7.4. G.1(c) About within year reservoir secondary yields at Inchampalli

The Table-7.4.G.1(c), Fig7.4.G.1(c) shows that at the water Export Points-2 and 3 at Inchampallithe expected maximum within year reservoir secondary yield of 58.18 MCM in the reservoir would be available in the month of December. Whereas the other hand the expected minimum within year reservoir secondary yield of 3.68MCM in the reservoir would be available in the month of March. There is no storage is available in the months of March, July and November.

7.4. G.1 (d) About within year exportsat Inchampalli

The expected within-year values of the water that is possibly availableat the water Export Points-2 and 3 at Inchampalliout of which the exports could be made is presented in Table-7.4.G.1(d))& Fig. 7.4.G.1(d). The available annual amount of 1393 MCMwater is less than the actual amount of water that is envisaged to be diverted as an export. The annual amount of the export water target is equal to 20796 MCM, i.e., only 6.70% of the annual export target is fulfilled.

7.4. G.2 (a) About within year reservoir storagesat Polavaram

At the water Export Point-4 at Polavaram the expected maximum within year storage of 106.07 MCM in the reservoir, as shown in Table-7.4.G.2 (a) & Fig. 7.4.G.2 (a)would be available in the beginning of month of September. On the other hand the expected minimum within year storage of 2.1 MCM in the reservoir would be available in the beginning of month of August. The month of February has zero storage.

7.4. G.2 (b) About within year reservoir firm yields at Polavaram.

As seen from the Table-7.4.G.2 (b) & Fig. 7.4.G.2 (b) at the water Export Point-4 at Polavaramthe expected maximum within year reservoir firm yield of 86.02 MCM in the reservoir would be available in the month of December. But the expected minimum within year reservoir firm yield of 4.34 MCM in the reservoir would be available in the months June, August, October, November, January, February, March and May.

7.4. G.2(c) About within year reservoir secondary yields at Polavaram

The Table-7.4.G.2(c) & Fig. 7.4.G.2(c) show that at the water Export Point-4 at Polavaramthe expected maximum within year reservoir secondary yield of 94.32 MCM in the reservoir would be available in the month of November. Whereas the other hand the expected minimum within year reservoir secondary yield of 5.17 MCMin the reservoir would be available in the month of March. In the monthsof April, September and December it will be zero.

7.4. G.2 (d) About within year exports at Polavaram

The expected within-year values of the water that is possibly available at the water Export Point-4 at Polavaram, out of which the exports could be made is presented in Table-7.4.G.2 (d) & Fig. 7.4.G.2 (d). The available annual amount of 2211 MCM water is less than the actual amount of water that is envisaged to be diverted as an export. The annual amount of the export water target is equal to 5325 MCM, i.e., only 41.53% of the annual export target is fulfilled.

7.4. K. Water Transfer Point-5 (Almatti), Transfer Point-6 (Srisailam) and Transfer Point-7 (Nagarjunasagara) in Krishna

7.4. K.1 (a) About within year reservoir storages at Almatti

At the water Export Point-5 at Almatti the expected maximum within year storage of 1354 MCM in the reservoir, as shown in Table-7.4.K.1 (a) & Fig.7.4.K.1 (a), would be available in the beginning of month of November. On the other hand the expected minimum within year storage of 16.08 MCM in the reservoir would be available in the beginning of month of May.

7.4. K.1 (b) About within year reservoir firm yieldsat Almatti

As seen from the Table-7.4.K.1 (b) & Fig. 7.4.K.1 (b), at the water Export Point-5 at Almattithe expected maximum within year reservoir firm yield of 35.18 MCM in the reservoir would be available in the month of August. But the expected minimum within year reservoir firm yield of 0.8 MCM in the reservoir would be available in the month of January, March, June and July.

7.4. K.1(c) About within year reservoir secondary yieldsat Almatti

The Table-7.4.K.1(c) & Fig.7.4.K.1(c) show that at the water Export Point-5 at Almattithe expected maximum within year reservoir secondary yield of 40.78 MCM in the reservoir would be available in the month of July. Whereas the other hand the expected minimum within year reservoir secondary yield of 1.2 MCM in the reservoir would be available in the month of August.

7.4. K.1 (d) About within year exports at Almatti

The expected within-year values of the water that is possibly available at the water Export Point-5 at Almatti,out of which the exports could be made is presented in Table-7.4.K.1 (d) & Fig. 7.4.K.1 (d). The available annual amount of 14163 MCM water is more than the actual amount of water that is envisaged to be diverted as an export. The annual amount of the export water target is equal to 1980 MCM, i.e., **100%** of the annual export target is fulfilled.

7.4. K.2 (a) About within year reservoir storages at Srisailam

At the water Export Point-6 at Srisailam the expected maximum within year storage of 260.9 MCM in the reservoir, Table-7.4.K.2 (a)& Fig.7.4.K.2 (a), would be available in the beginning of month of October. On the other hand the expected minimum within year storage of 20.92 MCM in the reservoir would be available in the beginning of month of June. The month July does not need any storage.

7.4. K.2 (b) About within year reservoir firm yields at Srisailam

As seen from the Table-7.4.K.2 (b) & Fig. -7.4.K.2(b) at the water Export Point-6 at Srisailamthe expected maximum within year reservoir firm yield of 754.15 MCM in the reservoir would be available in the month of July-. But the expected minimum within year reservoir firm yield of 96.82MCM in the reservoir would be available in the month of February.

7.4. K.2(c) About within year reservoir secondary yields at Srisailam

The Table-7.4.K.2(c) & Fig. 7.4.K.2(c) shows that at the water Export Point-6 at Srisailamthe expected maximum within year reservoir secondary yield of 249.86 MCM in the reservoir would be available in the month of July. Whereas the other hand the expected minimum within year reservoir secondary yield of 4 MCM in the reservoir would be available in the month of August.

7.4. K.2(d) About within year exports at Srisailam

The expected within-year values of the water that is possibly available at the water Export Point-6 at Srisailam,out of which the exports could be made is presented in Table-7.4.K.2(d) & Fig. 7.4.K.2(d). The available annual amount of 390 MCM water is less than the actual amount of water that is envisaged to be diverted as an export. The annualamount of the export water target is equal to 2310 MCM, i.e., only **16.90%** of the annual export target is fulfilled.

7.4. K.3 (a) About within year reservoir storages at Nagarjunasagara

At the water Export Point-7 at Nagarjunasagara the expected maximum within year storage of 2967.16 MCM in the reservoir, Table-7.4.K.3 (a) & Fig.7.4.K.3 (a),would be available in the beginning of month of November. On the other hand the expected minimum within year storage of 237.18 MCM in the reservoir would be available in the beginning of month of June. The month July does not need any storage.

7.4. K.3 (b) About within year reservoir firm yields at Nagarjunasagara

As seen from the Table-7.4.K.3 (b) & Fig. 7.4.K.3 (b), at the water Export Point-7 at Nagarjunasagarathe expected maximum within year reservoir firm yield of 3016.60 MCM in the reservoir would be available in the month of July. But the expected minimum within year reservoir firm yield of 387.28 MCM in the reservoir would be available in the month of February.

7.4. K.3(c) About within year reservoir secondary yields at Nagarjunasagara

The Table-7.4.K.3(c) & Fig.7.4.K.3(c) show that at the water Export Point-7 at Nagarjunasagarathe expected maximum within year reservoir secondary yield of 345 MCM in the reservoir would be available in the month of July. Whereas the other hand the expected minimum within year reservoir secondary yield of 3.4 MCM in the reservoir would be available in the month of January. The yield would be zero in the months of October, November & December.

7.4. K.3 (d) About within year exports at Nagarjunasagara

The expected within-year values of the water that is possibly available at the water Export Point-7 at Nagarjunasagara,out of which the exports could be made is presented in Table-7.4.K.3 (d) & Fig.7.4.K.3 (d). The available annual amount of 3120 MCM water is more/less than the actual amount of water that is envisaged to be diverted as an export. The annual amount of the export water target is equal to 12146 MCM, i.e., only **25.69%** of the annual export target is fulfilled.

7.4. P Water Export Point-8 at Somasila in Pennar

7.4. P.1 (a) About within year reservoir storages at Somasila

At the water Export Point-8 at Somasila the expected maximum within year storage of 1809.63 MCM in the reservoir, Table-7.4.P.1 (a) and Fig.7.4.P.1 (a), would be available in the beginning of month of October. On the other hand the expected minimum within year storage of 378.31 MCM in the reservoir would be available in the beginning of month of June. The month of July does not need any storage.

7.4. P.1 (b) About within year reservoir firm yields at Somasila

As seen from the Table-7.4.P.1 (b) and Fig. 7.4.P.1 (b),at the water Export Point-8 at Somasilathe expected maximum within year reservoir firm yield of 599.11 MCM in the reservoir would be available in the month of September. But the expected minimum within year reservoir firm yield of 35.41 MCM in the reservoir would be available in the months of February to May.

7.4. P.1(c) About within year reservoir secondary yields at Somasila

The Table-7.4.P.1(c) & Fig. 7.4.P.1(c) show that at the water Export Point-8 at Somasilathe expected maximum within year reservoir secondary yield of 284.36 MCM in the reservoir would be available in the month of April. Whereas the other hand the expected minimum within year reservoir secondary yield of 102.81 MCM in the reservoir would be available in the month of February. The secondary yield in the months from June to January is zero.

7.4. P.1 (d) About within year exports at Somasila

The expected within-year values of the water that is possibly available at the water Export Point-8 at Somasila,out of which the exports could be made is presented in Table-7.4.P.1 (d) and Fig. 7.4.P.1 (d). The available annual amount of 8101 MCM water is less than the actual amount of water that is envisaged to be diverted as an export. The annual amount of the export water target is equal to 8565 MCM, i.e., only **94.59%** of the annual export target is fulfilled.

7.4. C Water Export Point-9 at Kattalai in Cauvery

7.4. C.1 (a) About within year reservoir storages at Kattalai

At the water Export Point-9 at Kattalai the expected maximum within year storage of 113.7 MCM in the reservoir, Table-7.4.C.1 (a) & Fig.7.4.C.1 (a), would be available in the beginning of month of March. On the other hand the expected minimum within year storage of 4.32 MCM in the reservoir would be available in the beginning of month of November. In the month of October it would be zero.

7.4. C.1 (b) About within year reservoir firm yields at Kattalai

As seen from the Table-7.4.C.1(b)) & Fig. 7.4.C.1(b), at the water Export Point-9 at Kattalaithe expected maximum within year reservoir firm yield of 29.43 MCM in the reservoir would be available in the month of July. But the expected minimum within year reservoir firm yield of 1.1 MCM in the reservoir would be available in the month of November.

7.4. C.1(c) About within year reservoir secondary yields at Kattalai

The Table-7.4.C.1(c) & Fig. 7.4.C.1(c) shows that at the water Export Point-9 at Kattalaithe expected maximum within year reservoir secondary yield of 11.74 MCM in the reservoir would be available in the month of June. Whereas on the other hand the expected minimum within year reservoir secondary yield of 0.44 MCM in the reservoir would be available in the months of November. There will not be any secondary yield in the month of May.

7.4. C.1 (d) About within year exports at Kattalai

The expected within-year values of the water that is possibly available at the water Export Point-9 at Kattalai,out of which the exports could be made is presented in Table-7.4.C.1 (d) and Fig. 7.4.C.1 (d). The available annual amount of 4910 MCM water is more/less than the actual amount of water that is envisaged to be diverted as an export. The annual amount of the export water target is equal to 2252 MCM, i.e., **100%** of the annual export target is fulfilled.

7.5 INITIAL RULE CURVES AT EXPORT POINTS

The dimensionless rule curves at export points are provided in Fig. 7.5.1 to 7.5.8 to facilitate framing of further policy on them.

Table- 7.2.M.1 Total cropped intensity achieved at each reservoir in Mahanadi basin

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	M	1	U	1	DH	1.500
				2	SN	1.500
				3	PR	1.500
				4	RS	1.272
				5	KD	1.104
				6	LT	1.500
				7	KL	1.500
						9.876
		2	S	1	BK	1.200
				2	SN	1.200
				3	KH	1.500
				4	TN	0.023
				5	JH	0.060
				6	DK	1.500
				7	SR	0.303

				8	KN	1.500
				9	SG	1.500
				10	HP	0.060
				11	MN	0.440
				12	KR	0.550
				13	AR	1.085
						10.921
		3	J	1	JJ	1.450
				2	JD	1.500
		4	H	1	HB	1.028
						1.028
1	M	5	D	1	MD	1.500
				2	KU	1.500
						3.000
		6	I	1	ID	0.900
				2	HM	1.363
				3	IB	1.051
				4	UB	1.280
				5	LB	1.280
				6	LM	0.800
						6.674
		7	M	1	HD	1.450
				2	SB	1.350
				3	SL	0.980
						3.780
		8	O	1	OD	1.254
				2	OB	1.050
						2.304
		9	T	1	UT	1.200
				2	HB	1.210
				3	SD	1.300
				4	UU	0.890
				5	LU	0.900
				6	LI	1.355
				7	UR	1.330
				8	LL	1.200
				9	KH	1.420
				10	TB	1.200
				11	LS	1.270
						13.275
		10	L	1	BR	1.120
				2	MB	1.500
						2.620
						56.429

Table- 7.2.M.1 (a) Total cropped intensity achieved and its percent exceedance at each reservoir in Mahanadi basin

Sl. No.	% Exceedance	Total Cropped Intensity	ReservoirName	Sl. No.	% Exceedance	Total Cropped Intensity	ReservoirName
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	2	1.500	MD	26	52	1.254	OD
2	4	1.500	KU	27	54	1.210	HB
3	6	1.500	MB	28	56	1.200	BK
4	8	1.500	DH	29	58	1.200	SN
5	10	1.500	SN	30	60	1.200	LL
6	12	1.500	PR	31	62	1.200	TB
7	14	1.500	LT	32	64	1.200	UT
8	16	1.500	KL	33	66	1.120	BR
9	18	1.500	KH	34	68	1.104	KD
10	20	1.500	DK	35	70	1.085	AR
11	22	1.500	KN	36	72	1.051	IB
12	24	1.500	SG	37	74	1.050	OB
13	26	1.500	JD	38	76	1.028	HB
14	28	1.450	HD	39	78	0.980	SL
15	30	1.450	JJ	40	80	0.900	ID
16	32	1.420	KH	41	82	0.900	LU
17	34	1.363	HM	42	84	0.890	UU
18	36	1.355	LI	43	86	0.800	LM
19	38	1.350	SB	44	88	0.550	KR
20	40	1.330	UR	45	90	0.440	MN
21	42	1.300	SD	46	92	0.303	SR
22	44	1.280	LB	47	94	0.060	HP
23	46	1.280	UB	48	96	0.060	JH
24	48	1.272	RS	49	98	0.023	TN
25	50	1.270	LS				

Table- 7.2.M.2 Total cropped intensity and average crop intensity and their percent exceedances in each Sub-basin of Mahanadi basin

Sl. No.	Sub-Basin Name	% Exceedance Of Total Cropped Intensity	Total Cropped Intensity in Sub-Basin	Sub-Basin Name	% Exceedance Of Average Cropped Area	Average Cropped Intensity in Sub-Basin
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	T	9	13.275	D	9	0.190
2	S	18	10.921	H	18	0.147
3	U	27	9.876	L	27	0.146
4	I	36	6.674	T	36	0.125
5	M	45	3.780	I	45	0.124
6	D	54	3.000	M	54	0.118
7	J	63	2.950	U	63	0.117
8	L	72	2.620	J	72	0.106
9	O	81	2.304	O	81	0.105
10	H	90	1.028	S	90	0.065

Table- 7.2.M.3 Total cropped intensity achieved for each crop in Mahanadi basin

Sl. No.	Crop Name	Total Cropped Intensity	Sl. No.	Crop Name	Total Cropped Intensity
(1)	(2)	(3)	(4)	(5)	(6)
1	EPDK	11.592	14	VEGR	2.725
2	MPDK	13.094	15	VEGK	3.884
3	LPDK	2.808	16	MSTR	1.606
4	RAGK	1.150	17	GNTR	2.648
5	GNTK	3.024	18	JUTK	0.268
6	MAZK	1.419	19	MAZK	2.351
7	VEGK	2.173	20	OILR	0.210
8	JUTK	0.206	21	POTR	0.110
9	PULK	0.583	22	PULK	0.987
10	MILK	0.100	23	COTR	0.160
11	FODK	1.703	24	TILR	0.240
12	SOYK	0.160	25	SUGP	0.020
13	WHTR	3.209			

Table- 7.2.M.3 (a) Average cropped intensity achieved for each crop and its percent exceedance in Mahanadi basin

Sl. No.	% Exceedance	Average Cropped Intensity	Crop	Sl. No.	% Exceedance	Average Cropped Intensity	Crop
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	3	0.267	MPDK	14	53	0.071	VEGR
2	7	0.237	EPDK	15	57	0.068	VEGK
3	11	0.134	LPDK	16	61	0.063	MSTR
4	15	0.120	GRMR	17	65	0.062	GNTR
5	19	0.100	MILK	18	69	0.052	JUTK
6	23	0.090	PULR	19	73	0.049	MAZK
7	26	0.085	FODK	20	76	0.046	OILR
8	30	0.082	RAGK	21	80	0.045	POTR
9	34	0.080	PADR	22	84	0.042	PULK
10	38	0.080	SOYK	23	88	0.037	COTR
11	42	0.080	LINR	24	92	0.030	TILR
12	46	0.080	GNTK	25	96	0.010	SUGP
13	50	0.078	WHTR				

Table- 7.2.G.1 Total cropped intensity achieved at each reservoir in Godavari basin

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	G	1	U	1	PK	0.424
				2	OK	0.897
				3	NM	0.436
				4	KR	0.920
				5	GP	1.403
				6	JK	1.000
				7	JW	0.242
						5.323
		2	P	1	BD	1.000
				2	UP	1.000
				3	ML	1.050
						3.050
		3	R	1	PU	0.970
				2	YD	1.000
				3	PS	0.652
				4	LD	1.335
						3.957
		4	J	1	MA	1.361
				2	LT	0.900
				3	KR	0.920
				4	SG	1.000
				5	NS	1.200
				6	LN	1.203
				7	MN	1.010
						7.594
		5	M	1	SS	1.000
				2	KD	1.000
						2.000
		6	N	1	LM	1.000
						1.000

Table-**7**.2.G.1 Continued

Table-**7**.2.G.1 Continued

Basin No.	**Basin Name**	**Sub-Basin No.**	**Sub-Basin Name**	**Reservoir No.**	**Reservoir Name**	**Total Cropped Area**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
1	G	7	G	1	PK	1.190
				2	IP	1.070
				3	UP	1.000
				4	AV	1.274
				5	AD	1.274
				6	LP	1.070
						6.878
		8	W	1	UW	1.166
				2	LW	1.203
				3	BM	1.240
				4	DH	1.240
				5	BR	0.634
				6	LN	1.240
						6.726
		9	H	1	UW	1.270
				2	TW	1.350
				3	HR	1.318
				4	DH	1.340
				5	ND	1.318
				6	BG	1.048
				7	SD	1.318
				8	DD	1.340
				9	KB	1.285
				10	BT	1.302
				11	DW	1.318
				12	CK	1.318
				13	KD	1.400
				14	PD	1.148
				15	GK	1.277
				16	IH	1.400
				17	TT	1.400
				18	ST	1.400
				19	LK	1.400
				20	BK	1.400
				21	DN	1.414
				22	HN	1.300
				23	GZ	1.323
				24	AM	1.400
				25	VV	1.6
						33.243
						69.771

Table-7.2.G.1 (a) Total cropped intensity achieved and its percent exceedance at each reservoir in Godavari basin

Sl. No.	% Exceedance	Total Cropped Intensity	Reservoir Name	Sl. No.	% Exceedance	Total Cropped Intensity	Reservoir Name
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	1	1.414	DN	32	51	1.203	LW
2	3	1.403	GP	33	53	1.203	LN
3	4	1.400	DH	34	54	1.200	NS
4	6	1.400	DD	35	56	1.190	PK
5	8	1.400	KD	36	58	1.166	UW
6	9	1.400	IH	37	59	1.148	PD
7	11	1.400	TT	38	61	1.070	IP
8	12	1.400	ST	39	62	1.070	LP
9	14	1.400	LK	40	64	1.050	ML
10	16	1.400	BK	41	66	1.048	BG
11	17	1.400	AM	42	67	1.010	MN
12	19	1.360	MA	43	69	1.000	JK
13	20	1.350	TW	44	70	1.000	BD
14	22	1.336	VV	45	72	1.000	UP
15	24	1.335	LD	46	74	1.000	YD
16	25	1.323	GZ	47	75	1.000	SG
17	27	1.318	HR	48	77	1.000	SS
18	29	1.318	ND	49	79	1.000	KD
19	30	1.318	SD	50	80	1.000	LM
20	32	1.318	DW	51	82	0.000	UP
21	33	1.318	CK	52	83	0.970	PU
22	35	1.302	BT	53	85	0.920	KR
23	37	1.300	HN	54	87	0.920	KR
24	38	1.285	KB	55	88	0.900	LT
25	40	1.277	GK	56	90	0.897	OK
26	41	1.274	AV	57	91	0.652	PS
27	43	1.274	AD	58	93	0.636	BR
28	45	1.270	UW	59	95	0.436	NM
29	46	1.240	BM	60	96	0.424	PK
30	48	1.240	DH	61	98	0.242	JW
31	50	1.240	LN				

Table-7.2.G.2 Total cropped intensity and average crop intensity and their percent exceedances in each Sub-basin of Godavari basin

Sl. No.	Sub-Basin Name	% Exceedance Of Total Cropped Intensity	Total Cropped Intensity in Sub-Basin	Sub-Basin Name	% Exceedance Of Average Cropped Area	Average Cropped Intensity in Sub-Basin
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	H	10	33.243	J	10	0.152
2	J	20	7.594	G	20	0.132
3	G	30	6.878	H	30	0.109
4	W	40	6.726	U	40	0.097
5	U	50	5.323	W	50	0.096
6	R	60	3.957	P	60	0.092
7	P	70	3.050	N	70	0.083
8	M	80	2.000	M	80	0.083
9	N	90	1.000	R	90	0.0824

Table-7.2.G.3 Total cropped intensity achieved for each crop in Godavari basin

Sl. No.	Crop Name	Total Cropped Intensity	Sl. No.	Crop Name	Total Cropped Intensity
(1)	(2)	(3)	(1)	(2)	(3)
1	PADK	14.100	16	JOWR	5.282
2	BAJK	0.395	17	PULR	0.340
3	MAZK	2.115	18	WHTR	9.959
4	JOWK	6.335	19	VEGR	1.740
5	GNTK	3.435	20	SUNR	0.200
6	COTK	5.688	21	GRMR	4.153
7	CHLK	2.190	22	CHLR	0.080
8	PULK	1.780	23	COTR	1.120
9	SUNK	0.190	24	FODR	0.426
10	VEGK	1.581	25	GNTH	0.740
11	TURK	0.240	26	VEGH	0.100
12	FODK	0.931	27	JOWH	0.080
13	PADR	1.010	28	COTH	0.060
14	GNTR	0.700	29	FODH	0.200
15	MAZR	1.305	30	SUGP	3.296

Table-7.2.G.3 (a) Average cropped intensity achieved for each crop and its percent exceedance in Godavari basin

Sl. No.	% Exceedance	Average Cropped Intensity	Crop	Sl. No.	% Exceedance	Average Cropped Intensity	Crop
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	3	0.243	PADK	16	51	0.075	VEGK
2	6	0.200	SUNR	17	54	0.074	PULK
3	9	0.190	SUNK	18	58	0.068	PULR
4	12	0.181	WHTR	19	61	0.067	FODH
5	16	0.140	GNTR	20	64	0.066	MAZK
6	19	0.140	COTR	21	67	0.063	SUGP
7	22	0.132	COTK	22	70	0.0617	GNTH
8	25	0.132	JOWK	23	74	0.061	FODR
9	29	0.112	PADR	24	77	0.060	COTH
10	32	0.102	JOWR	25	80	0.056	BAJK
11	35	0.097	GRMR	26	83	0.056	CHLK
12	38	0.093	MAZR	27	87	0.051	VEGR
13	41	0.086	GNTK	28	90	0.050	VEGH
14	45	0.080	CHLR	29	93	0.048	TURK
15	48	0.080	JOWH	30	96	0.037	FODK

Table-7.2.K.1 Total cropped intensity achieved at each reservoir in Krishna basin

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	K	1	U	1	DH	1.410
				2	KA	1.238
				3	UR	1.581
				4	TA	1.499
				5	KH	0.899
				6	KO	0.999
				7	WR	0.899
				8	RA	0.556
						9.081
		2	M	1	HI	1.700
				2	HI	1.700
				3	AL	1.080
				4	NA	1.335
						5.815
		3	G	1	GH	1.000
				2	MK	1.000
						2.000
		4	A	1	MA	0.910
				2	RL	1.000
						1.910
		5	B	1	CK	0.837
				2	BA	0.822
				3	KH	0.938
				4	DI	0.694
				5	PJ	0.003
				6	YD	0.567
				7	GH	0.402
				8	UJ	0.679
				9	ND	1.153
				10	GU	1.050
				11	SK	1.001
						8.146

Table-7.2.K.1 Contd.

Table- 7.2.K.1 Contd.

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
1	K	6	H	1	BE	1.000
				2	BF	0.737
						1.737
		7	L	1	PD	1.998
				2	SS	0.700
						2.698
		8	T	1	TA	0.504
				2	BR	0.999
				3	SL	1.540
				4	TU	0.804
				5	RD	1.000
				6	SK	0.244
				7	GD	1.000
						6.091
		9	V	1	VS	1.599
						1.599
						39.076

Table-7.2.K.1 (a) Total cropped intensity achieved and its percent exceedance at each reservoir in Krishna basin

Sl. No.	% Exceedance	Total Cropped Intensity	Reservoir Name	Sl. No.	% Exceedance	Total Cropped Intensity	Reservoir Name
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	2	1.998	PD	21	52	0.999	KO
2	5	1.700	HI	22	55	0.999	BR
3	7	1.700	HI	23	57	0.938	KH
4	10	1.599	VS	24	60	0.910	MA
5	12	1.581	UR	25	62	0.899	WR
6	15	1.540	SL	26	65	0.899	KH
7	17	1.499	TA	27	67	0.837	CK
8	20	1.410	DH	28	70	0.822	BA
9	22	1.335	NA	29	72	0.804	TU
10	25	1.238	KA	30	75	0.737	BF
11	27	1.153	ND	31	77	0.700	SS
12	30	1.080	AL	32	80	0.694	DI
13	32	1.050	GU	33	82	0.679	UJ
14	35	1.001	SK	34	85	0.567	YD
15	37	1.000	GH	35	87	0.556	RA
16	40	1.000	MK	36	90	0.504	TA
17	42	1.000	RL	37	92	0.402	GH
18	45	1.000	BE	38	95	0.244	SK
19	47	1.000	RD	39	97	0.003	PJ
20	50	1.000	GD				

Table- 7.2.K.2 Total cropped intensity and average crop intensity and their percent exceedances in each Sub-basin of Krishna basin

Sl. No.	Sub-Basin Name	% Exceedance Of Total Cropped Intensity	Total Cropped Intensity in Sub-Basin	Sub-Basin Name	% Exceedance Of Average Cropped Area	Average Cropped Intensity in Sub-Basin
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	U	10	9.081	L	10	0.208
2	B	20	8.146	V	20	0.123
3	T	30	6.091	U	30	0.096
4	M	40	5.815	M	40	0.088
5	L	50	2.698	G	50	0.087
6	G	60	2.000	A	60	0.076
7	A	70	1.910	T	70	0.073
8	H	80	1.737	H	80	0.072
9	V	90	1.599	B	90	0.053

Table-7.2.K.3 Total cropped intensity achieved for each crop in Krishna basin

Sl. No.	Crop Name	Total Cropped Intensity	Sl. No.	Crop Name	Total Cropped Intensity
(1)	(2)	(3)	(1)	(2)	(3)
1	PADK	4.091	16	FODR	0.669
2	VEGK	0.443	17	VEGR	0.399
3	PULK	1.866	18	WHTR	3.067
4	GNTK	3.648	19	JOWR	4.035
5	FODK	0.471	20	PULR	0.480
6	JOWK	4.613	21	MAZR	0.419
7	BAJK	1.733	22	SAFR	0.174
8	HYBK	0.073	23	SUNR	0.073
9	COTN	2.708	24	POTR	0.185
10	MAZK	1.488	25	OILR	0.255
11	CHIL	1.323	26	PADR	0.492
12	SUNK	0.028	27	GNTH	1.626
13	RAGK	0.415	28	VEGH	0.132
14	TURM	0.120	29	FODH	0.056
15	GRMR	0.975	30	SUGP	3.019

Table-7.2.K.3 (a) Average cropped intensity achieved for each crop and its percent exceedance in Krishna basin

Sl. No.	% Exceedance	Average Cropped Intensity	Crop	Sl. No.	% Exceedance	Average Cropped Intensity	Crop
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	3	0.121	JOWK	16	51	0.056	FODR
2	6	0.117	PADK	17	54	0.047	FODK
3	9	0.109	JOWR	18	58	0.046	CHIL
4	12	0.104	PULK	19	61	0.041	GRMR
5	16	0.100	COTN	20	64	0.040	TURM
6	19	0.099	GNTK	21	67	0.037	HYBK
7	22	0.098	PADR	22	70	0.036	OILR
8	25	0.097	SUGP	23	74	0.032	MAZR
9	29	0.093	MAZK	24	77	0.032	VEGK
10	32	0.091	BAJK	25	80	0.0280	SUNK
11	35	0.083	WHTR	26	83	0.0264	VEGH
12	38	0.069	PULR	27	87	0.025	VEGR
13	41	0.063	GNTH	28	90	0.024	SUNR
14	45	0.059	RAGK	29	93	0.023	POTR
15	48	0.056	FODH	30	96	0.022	SAFR

Table-7.2.P.1Total cropped intensity achieved at each reservoir in Pennar basin

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
(1)	(2)	(3)	(4)	(5)	(6)	(7)
5	P	1	D	1	SS	1.000
						1.000
						1.000

Table-7.2.P.2 Total cropped intensity achievedfor each crop in Pennar Basin

Sl. No.	Crop Name	Total Cropped Intensity
(1)	(2)	(3)
1	PADK	0.19
2	GNTK	0.09
3	FODK	0.18
4	COTN	0.14
5	CHIL	0.04
6	FODR	0.07
7	JOWR	0.07
8	PULR	0.15
9	GNTH	0.07

Table-7.2.C.1Total cropped intensity achieved at each reservoir in Cauvery basin

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
(1)	(2)	(3)	(4)	(5)	(6)	(7)
4	C	1	U	1	HD	1.000
				2	HP	1.000
				3	HA	1.000
				4	YG	0.961
				5	HE	0.647
				6	KR	1.000
						5.608
		2	K	1	MN	1.404
				2	KB	1.600
				3	UN	0.866
				4	NU	1.040
						4.910
		3	I	1	MT	1.600
						1.600
		4	B	1	LB	2.300
						2.300
						14.348

Table-7.2.C.1 (a) Total cropped intensity achieved and its percent exceedance at each reservoir in Cauvery basin

Sl. No.	% Exceedance	Total Cropped Intensity	Reservoir Name
(1)	(2)	(3)	(4)
1	7	2.300	LB
2	15	1.600	MT
3	23	1.600	KB
4	30	1.404	MN
5	38	1.040	NU
6	46	1.000	HD
7	53	1.000	HP
8	61	1.000	HA
9	69	1.000	KR
10	76	0.961	YG
11	84	0.866	UN
12	92	0.647	HE

Table-7.2.C.2 Total cropped intensities and average crop intensities and their percent exceedances in each Sub-basin of Cauvery basin

Sl. No.	Sub-Basin Name	% Exceedance Of Total Cropped Intensity	Total Cropped Intensity in Sub-Basin	Sub-Basin Name	% Exceedance Of Average Cropped Intensity	Average Cropped Intensity in Sub-Basin
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	U	20	5.608	U	20	0.104
2	K	40	4.909	K	40	0.102
3	B	60	2.230	B	60	0.101
4	I	80	1.600	I	80	0.084

Table-7.2.C.3 Total cropped intensity achieved for each crop in Cauvery basin

Sl. No.	Crop Name	Total Cropped Intensity	Sl. No.	Crop Name	Total Cropped Intensity
(1)	(2)	(3)	(1)	(2)	(3)
1	PADK	3.331	11	PADR	0.434
2	JOWK	0.774	12	COCO	0.344
3	RAGK	1.540	13	PULK	0.200
4	FODK	0.814	14	MAZK	0.100
5	GNTS	1.058	15	GNTR	0.200
6	TOBK	0.480	16	JOWR	0.200
7	PULR	1.716	17	COTS	0.700
8	VEGR	1.128	18	PADS	0.150
9	SUGA	0.694	19	JOWS	0.150
10	COTK	0.334			

Table-7.2.C.3 (a) Average cropped intensity achieved for each crop and its percent exceedance in Cauvery basin

Sl. No.	% Exceedance	Average Cropped Intensity	Crop Name	Sl. No.	% Exceedance	Average Cropped Intensity	Crop Name
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1	5	0.350	COTS	11	55	0.094	VEGR
2	10	0.278	PADK	12	60	0.088	GNTS
3	15	0.150	PADS	13	65	0.072	PADR
4	20	0.150	JOWS	14	70	0.068	FODK
5	25	0.143	PULR	15	75	0.064	JOWK
6	30	0.128	RAGK	16	80	0.058	SUGA
7	35	0.100	PULK	17	85	0.057	COCO
8	40	0.100	MAZK	18	90	0.056	COTK
9	45	0.100	GNTR	19	95	0.040	TOBK
10	50	0.100	JOWR				

Table-7.3.M (a) Expected total within-year storages available in Mahanadi basin in a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Storages In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Storages In Basin	Expected Total Within-Year Reservoir Storages In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	1584.89	1	7	6062.90
2	Jul	741.13	2	15	5894.59
3	Aug	297.24	3	23	5364.81
4	Sep	4195.05	4	30	4620.54
5	Oct	4620.54	5	38	4195.05
6	Nov	5894.59	6	46	3795.61
7	Dec	6062.90	7	53	2683.24
8	Jan	5364.81	8	61	1846.35
9	Feb	3795.61	9	69	1584.89
10	Mar	2683.24	10	76	1358.31
11	Apr	1846.35	11	84	741.13
12	May	1358.31	12	92	297.24

Table-7.3.M (b) Expected total within-year firm yields available in Mahanadi basin in a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Firm Yields In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Firm Yields In Basin	Expected Total Within-Year Reservoir Firm Yields In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	1049.13	1	7	5488.98
2	Jul	5488.98	2	15	3196.76
3	Aug	2392.87	3	23	2702
4	Sep	3196.76	4	30	2392.87
5	Oct	2120.98	5	38	2120.98
6	Nov	913.19	6	46	1979.44
7	Dec	1979.44	7	53	1840.17
8	Jan	2702	8	61	1173.49
9	Feb	1840.17	9	69	1049.13
10	Mar	1173.49	10	76	913.19
11	Apr	803	11	84	803
12	May	56	12	92	56

Table-7.3.M(c) Expected total within-year secondary yields available in Mahanadi basinin a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Secondary Yields In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Secondary Yields In Basin	Expected Total Within-Year Reservoir Secondary Yields In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	346.21	1	7	1435.72
2	Jul	1372.25	2	15	1372.25
3	Aug	1435.72	3	23	1104.10
4	Sep	1054.93	4	30	1054.93
5	Oct	530.25	5	38	675.50
6	Nov	547.91	6	46	653.22
7	Dec	653.22	7	53	547.91
8	Jan	675.50	8	61	530.25
9	Feb	1104.10	9	69	387.25
10	Mar	387.25	10	76	346.21
11	Apr	200.75	11	84	200.75
12	May	33.60	12	92	33.60

Table-7.3.G (a) Expected total within-year storages available in Godavari basin in a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Storages In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Storages In Basin	Expected Total Within-Year Reservoir Storages In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	1928.89	1	7	7246.50
2	Jul	2357.24	2	15	6875.99
3	Aug	3073.47	3	23	6747.91
4	Sep	6875.99	4	30	6365.25
5	Oct	7246.50	5	38	5191.49
6	Nov	6747.91	6	46	3979.26
7	Dec	6365.25	7	53	3407.92
8	Jan	5191.49	8	61	3073.47
9	Feb	3979.26	9	69	3005.67
10	Mar	3407.92	10	76	2565.96
11	Apr	3005.67	11	84	2357.24
12	May	2565.96	12	92	1928.89

Table-7.3.G (b) Expected total within-year firm yields available in Godavari basin in a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Firm Yields In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Firm Yields In Basin	Expected Total Within-Year Reservoir Firm Yields In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	475.65	1	7	1908.87
2	Jul	1908.87	2	15	1857.01
3	Aug	1549.28	3	23	1549.28
4	Sep	1266.22	4	30	1266.22
5	Oct	1857.01	5	38	1103.01
6	Nov	968.38	6	46	968.38
7	Dec	1103.01	7	53	896.36
8	Jan	896.36	8	61	568.57
9	Feb	568.57	9	69	531.23
10	Mar	348.28	10	76	475.65
11	Apr	312.17	11	84	348.28
12	May	531.23	12	92	312.17

Table-7.3.G(c) Expected total within-year secondary yields available in Godavari basinin a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Secondary Yields In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Secondary Yields In Basin	Expected Total Within-Year Reservoir Secondary Yields In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	386.86	1	7	1806.66
2	Jul	1806.66	2	15	1425.69
3	Aug	1332.42	3	23	1414.72
4	Sep	1425.69	4	30	1332.42
5	Oct	1414.72	5	38	1063.50
6	Nov	860.49	6	46	1031.11
7	Dec	1063.50	7	53	860.49
8	Jan	1031.11	8	61	409.05
9	Feb	328.57	9	69	386.86
10	Mar	246.26	10	76	328.57
11	Apr	325.57	11	84	325.57
12	May	409.05	12	92	246.26

Table-7.3.K (a) Expected total within-year storages available in Krishna basin in a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Storages In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Storages In Basin	Expected Total Within-Year Reservoir Storages In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	990.43	1	7	6841.60
2	Jul	292.79	2	15	6595.05
3	Aug	1542.07	3	23	5504.06
4	Sep	4380.05	4	30	5124.53
5	Oct	5504.06	5	38	4380.05
6	Nov	6841.60	6	46	3241.57
7	Dec	6595.05	7	53	2298.97
8	Jan	5124.53	8	61	1542.07
9	Feb	3241.57	9	69	1294.44
10	Mar	2298.97	10	76	990.43
11	Apr	1294.44	11	84	647.88
12	May	647.88	12	92	292.79

Table-7.3.K (b) Expected total within-year firm yields available in Krishna basin in a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Firm Yields In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Firm Yields In Basin	Expected Total Within-Year Reservoir Firm Yields In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	906.55	1	7	2799.69
2	Jul	2505.76	2	15	2505.76
3	Aug	2799.69	3	23	1945.83
4	Sep	1945.83	4	30	1894.23
5	Oct	1149.39	5	38	1639.53
6	Nov	1115.27	6	46	1149.39
7	Dec	1894.23	7	53	1125.46
8	Jan	1639.53	8	61	1115.27
9	Feb	1125.46	9	69	906.55
10	Mar	576.92	10	76	576.92
11	Apr	568.55	11	84	568.55
12	May	554.54	12	92	554.54

Table-7.3.K(c) Expected total within-year secondary yields available in Krishna basinin a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Secondary Yields In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Secondary Yields In Basin	Expected Total Within-Year Reservoir Secondary Yields In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	331.83	1	7	1194.68
2	Jul	1194.68	2	15	862.10
3	Aug	783.46	3	23	840.95
4	Sep	731.87	4	30	783.46
5	Oct	862.10	5	38	740.82
6	Nov	740.82	6	46	731.87
7	Dec	631.32	7	53	633.43
8	Jan	840.95	8	61	631.32
9	Feb	164.08	9	69	485.14
10	Mar	633.43	10	76	343.98
11	Apr	485.14	11	84	331.83
12	May	343.98	12	92	164.08

Table-7.3.C (a) Expected total within-year storages available in Cauvery basin in a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Storages In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Storages In Basin	Expected Total Within-Year Reservoir Storages In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	390.38	1	7	1722.33
2	Jul	752.27	2	15	1621.59
3	Aug	1124.86	3	23	1603.50
4	Sep	1621.59	4	30	1574.14
5	Oct	1603.50	5	38	1544.09
6	Nov	1544.09	6	46	1268.77
7	Dec	1722.33	7	53	1124.86
8	Jan	1574.14	8	61	862.36
9	Feb	1268.77	9	69	752.27
10	Mar	862.36	10	76	481.49
11	Apr	481.49	11	84	420.58
12	May	420.58	12	92	390.38

Table-7.3.C (b) Expected total within-year firm yields available in Cauvery basin in a normal water year

Sl. No.	Month	Expected Total Within-Year Reservoir Firm Yields In Basin (MCM)	Sl. No.	% Exceedance Of Expected Total Within-Year Reservoir Firm Yields In Basin	Expected Total Within-Year Reservoir Firm Yields In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	98.71	1	7	220.79
2	Jul	173.47	2	15	189.76
3	Aug	34.20	3	23	173.47
4	Sep	42.57	4	30	98.71
5	Oct	220.79	5	38	72.63
6	Nov	72.63	6	46	60.54
7	Dec	30.33	7	53	57.39
8	Jan	43.94	8	61	50.31
9	Feb	189.76	9	69	43.94
10	Mar	60.54	10	76	42.57
11	Apr	50.31	11	84	34.20
12	May	57.39	12	92	30.33

Table-7.3.C(c) Expected total within-year secondary yields available in Cauvery basin

Sl. No.	Month	Expected Total Within-Year Reservoir Secondary Yields In Basin (MCM)	Sl. No.	% Exceedance of Expected Total Within-Year Reservoir Secondary Yields In Basin	Expected Total Within-Year Reservoir Secondary Yields In Basin (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	343.24	1	7	793.38
2	Jul	674.95	2	15	674.95
3	Aug	793.38	3	23	667.31
4	Sep	667.31	4	30	515.19
5	Oct	384.68	5	38	441.85
6	Nov	95.13	6	46	401.31
7	Dec	349.81	7	53	384.68
8	Jan	441.85	8	61	349.81
9	Feb	401.31	9	69	343.24
10	Mar	515.19	10	76	163.89
11	Apr	163.89	11	84	121.47
12	May	121.47	12	92	95.13

Table-7.4.M.1(a) Expected within-year storage required at the Transfer Point-1 (Manibhadra)

Sl. No.	Month	Expected Within-Year Storage to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year Reservoir Storage	Expected Within-Year Storage to Meet Water Demands at (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	22.74	1	7	134.06
2	Jul	34.50	2	15	113.34
3	Aug	0.19	3	23	92.00
4	Sep	89.01	4	30	89.01
5	Oct	134.06	5	38	83.08
6	Nov	83.08	6	46	77.25
7	Dec	113.34	7	53	59.20
8	Jan	77.25	8	61	49.33
9	Feb	49.33	9	69	34.50
10	Mar	15.92	10	76	22.74
11	Apr	59.20	11	84	15.92
12	May	92.00	12	92	0.19

Table-7.4.M.1(b) Expected within-year firm yield at the Transfer Point-1 (Manibhadra)

Sl. No.	Month	Expected Within-Year Firm Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	0.48	1	7	335.15
2	Jul	249.15	2	15	283.35
3	Aug	0.48	3	23	249.15
4	Sep	335.15	4	30	222.52
5	Oct	222.52	5	38	207.71
6	Nov	0.48	6	46	193.13
7	Dec	207.71	7	53	123.33
8	Jan	283.35	8	61	0.48
9	Feb	193.13	9	69	0.48
10	Mar	123.33	10	76	0.48
11	Apr	0.48	11	84	0.48
12	May	0.48	12	92	0.48

Table-7.4.M.1 (c) Expected within-year Secondary yield at the Transfer Point-1 (Manibhadra)

Sl. No.	Month	Expected Within-Year Secondary Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year secondary yield	Expected Within-Year secondary yield to Meet Water Demands (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	109.83	1	7	325.97
2	Jul	325.97	2	15	250.51
3	Aug	250.51	3	23	109.83
4	Sep	23.40	4	30	95.6
5	Oct	29.00	5	38	84.07
6	Nov	95.60	6	46	47.8
7	Dec	47.80	7	53	37.83
8	Jan	23.90	8	61	29
9	Feb	11.95	9	69	23.9
10	Mar	6.57	10	76	23.4
11	Apr	84.07	11	84	11.95
12	May	37.83	12	92	6.57

Table-7.4.M.1(d) Expected within-year value of export at the Transfer Point-1 (Manibhadra)

Sl. No.	Month	Expected Within-Year value of export (MCM)	Month	% Exceedance Of Expected Within-Year value of export	Expected Within-Year value of export (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	831.5	1	7	21713.13
2	Jul	10806.34	2	15	10806.34
3	Aug	21713.13	3	23	6236.01
4	Sep	6236.01	4	30	1649.09
5	Oct	1649.09	5	38	831.5
6	Nov	575.42	6	46	575.42
7	Dec	123.89	7	53	323.89
8	Jan	323.89	8	61	123.89
9	Feb	123.89	9	69	123.89
10	Mar	23.89	10	76	47.12
11	Apr	47.12	11	84	0.48
12	May	29.35	12	92	0.48

Table-7.4.G.1(a), Expected within-year storage required at the Transfer Point 2 & 3 (Inchampalli)

Sl. No.	Month	Expected Within-Year Storage to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year Reservoir Storage	Expected Within-Year Storage to Meet Water Demands at (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	8.49	1	7	75.81
2	Jul	13.91	2	15	68.41
3	Aug	4.7	3	23	61.85
4	Sep	75.81	4	30	34.49
5	Oct	61.85	5	38	25.16
6	Nov	68.41	6	46	23.92
7	Dec	25.16	7	53	16.62
8	Jan	16.62	8	61	13.91
9	Feb	2.27	9	69	12.49
10	Mar	12.49	10	76	8.49
11	Apr	34.49	11	84	4.7
12	May	23.92	12	92	2.27

Table7.4.G.1(b)Expected within-year firm yield at the Transfer Point 2 & 3 (Inchampalli)

Sl. No.	Month	Expected Within-Year Firm Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	2.84	1	7	70.02
2	Jul	55.21	2	15	55.21
3	Aug	2.84	3	23	9.34
4	Sep	2.84	4	30	2.84
5	Oct	2.84	5	38	2.84
6	Nov	70.02	6	46	2.84
7	Dec	2.84	7	53	2.84
8	Jan	2.84	8	61	2.84
9	Feb	2.84	9	69	2.84
10	Mar	2.84	10	76	2.84
11	Apr	2.84	11	84	2.84
12	May	9.34	12	92	2.84

Table-7.4.G.1(c) Expected within-year Secondary yield at the Transfer Point 2 & 3 (Inchampalli)

Sl. No.	Month	Expected Within-Year Secondary Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year secondary yield	Expected Within-Year secondary yield to Meet Water Demands (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	7.89	1	7	58.18
2	Jul	0	2	15	46.97
3	Aug	37.22	3	23	44.92
4	Sep	36.1	4	30	37.22
5	Oct	46.97	5	38	36.1
6	Nov	0	6	46	18.09
7	Dec	58.18	7	53	7.89
8	Jan	44.92	8	61	4.04
9	Feb	18.09	9	69	3.68
10	Mar	3.68	10	76	0
11	Apr	4.04	11	84	0
12	May	0	12	92	0

Table-7.4.G.1(d)Expected within-year value of export at the Transfer Point 2 & 3 (Inchampalli)

Sl. No.	Month	Expected Within-Year value of export (MCM)	Month	% Exceedance Of Expected Within-Year value of export	Expected Within-Year value of export (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	28.7	1	7	244.35
2	Jul	190.48	2	15	211.61
3	Aug	135.38	3	23	190.48
4	Sep	131.27	4	30	170.84
5	Oct	170.84	5	38	163.38
6	Nov	244.35	6	46	135.38
7	Dec	211.61	7	53	131.27
8	Jan	163.38	8	61	65.79
9	Feb	65.79	9	69	28.7
10	Mar	13.38	10	76	23.65
11	Apr	14.71	11	84	14.71
12	May	23.65	12	92	13.38

Table-7.4.G.2.(a) Expected within-year storage required at the Transfer Point-4 (Polavaram)

Sl. No.	Month	Expected Within-Year Storage to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year Reservoir Storage	Expected Within-Year Storage to Meet Water Demands at (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	12.67	1	7	106.07
2	Jul	21.69	2	15	94.37
3	Aug	2.10	3	23	86.35
4	Sep	106.07	4	30	45.30
5	Oct	86.35	5	38	33.32
6	Nov	94.37	6	46	32.28
7	Dec	33.32	7	53	21.69
8	Jan	20.43	8	61	20.43
9	Feb	0.00	9	69	14.15
10	Mar	14.15	10	76	12.67
11	Apr	45.30	11	84	2.10
12	May	32.28	12	92	0.00

Table-7.4.G.2(b) Expected within-year firm yield at the Transfer Point-4 (Polavaram)

Sl. No.	Month	Expected Within-Year Firm Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	4.34	1	7	4.34
2	Jul	70.91	2	15	70.91
3	Aug	4.34	3	23	4.34
4	Sep	55.01	4	30	55.01
5	Oct	4.34	5	38	4.34
6	Nov	4.34	6	46	4.34
7	Dec	86.02	7	53	86.02
8	Jan	4.34	8	61	4.34
9	Feb	4.34	9	69	4.34
10	Mar	4.34	10	76	4.34
11	Apr	10.01	11	84	10.01
12	May	4.34	12	92	4.34

Table-7.4.G.2(c) Expected within-year Secondary yield at the Transfer Point-4 (Polavaram)

Sl. No.	Month	Expected Within-Year Secondary Yield to Meet Water Demands (MCM)	Month	% Exceedanceof Expected Within-Year secondary yield	Expected Within-Year secondary yield to Meet Water Demands (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	11.08	1	7	94.32
2	Jul	6.95	2	15	65.95
3	Aug	52.26	3	23	63.07
4	Sep	0.00	4	30	52.26
5	Oct	65.95	5	38	25.40
6	Nov	94.32	6	46	11.08
7	Dec	0.00	7	53	9.13
8	Jan	63.07	8	61	6.95
9	Feb	25.40	9	69	5.17
10	Mar	5.17	10	76	0.00
11	Apr	0.00	11	84	0.00
12	May	9.13	12	92	0.00

Table-7.4.G.2 (d) Expected within-year value of export at the Transfer Point-4 (Polavaram)

Sl. No.	Month	Expected Within-Year value of export (MCM)	Month	% Exceedance Of Expected Within-Year value of export	Expected Within-Year value of export (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	45.54	1	7	387.75
2	Jul	302.26	2	15	335.79
3	Aug	214.83	3	23	302.26
4	Sep	208.32	4	30	271.10
5	Oct	271.10	5	38	259.27
6	Nov	387.75	6	46	214.83
7	Dec	335.79	7	53	208.32
8	Jan	259.27	8	61	104.40
9	Feb	104.40	9	69	45.54
10	Mar	21.23	10	76	37.53
11	Apr	23.34	11	84	23.34
12	May	37.53	12	92	21.23

Table-7.4.K.1(a) Expected within-year storage required at the Transfer Point-5 (Almatti)

Sl. No.	Month	Expected Within-Year Storage to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year Reservoir Storage	Expected Within-Year Storage to Meet Water Demands at (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	25.13	1	7	1354.00
2	Jul	45.90	2	15	1310.00
3	Aug	78.00	3	23	1254.00
4	Sep	1061.00	4	30	1061.00
5	Oct	1254.00	5	38	855.60
6	Nov	1354.00	6	46	274.00
7	Dec	1310.00	7	53	110.99
8	Jan	855.60	8	61	78.00
9	Feb	274.00	9	69	45.90
10	Mar	110.99	10	76	25.13
11	Apr	19.95	11	84	19.95
12	May	16.08	12	92	16.08

Table-7.4.K.1(b) Expected within-year firm yield at the Transfer Point-5 (Almatti)

Sl. No.	Month	Expected Within-Year Firm Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	0.80	1	7	35.18
2	Jul	0.80	2	15	32.87
3	Aug	35.18	3	23	23.98
4	Sep	23.46	4	30	23.46
5	Oct	21.45	5	38	21.45
6	Nov	23.98	6	46	17.83
7	Dec	32.87	7	53	13.04
8	Jan	0.80	8	61	7.51
9	Feb	17.83	9	69	0.80
10	Mar	0.80	10	76	0.80
11	Apr	7.51	11	84	0.80
12	May	13.04	12	92	0.80

Table-7.4.K.1(c) Expected within-year Secondary yield at the Transfer Point-5 (Almatti)

Sl. No.	Month	Expected Within-Year Secondary Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year secondary yield	Expected Within-Year secondary yield to Meet Water Demands (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	22.53	1	7	40.78
2	Jul	40.78	2	15	38.47
3	Aug	1.20	3	23	22.53
4	Sep	21.20	4	30	21.20
5	Oct	2.67	5	38	16.10
6	Nov	4.70	6	46	5.08
7	Dec	2.67	7	53	4.70
8	Jan	38.47	8	61	3.00
9	Feb	2.67	9	69	2.67
10	Mar	16.10	10	76	2.67
11	Apr	5.08	11	84	2.67
12	May	3.00	12	92	1.20

Table-7.4.K.1(d) Expected within-year value of export at the Transfer Point-5 (Almatti)

Sl. No.	Month	Expected Within-Year value of export (MCM)	Month	% Exceedance Of Expected Within-Year value of export	Expected Within-Year value of export (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	422.93	1	7	7837.06
2	Jul	7837.06	2	15	2745.24
3	Aug	2745.24	3	23	728.04
4	Sep	728.04	4	30	638.67
5	Oct	515.20	5	38	539.19
6	Nov	388.99	6	46	515.20
7	Dec	539.19	7	53	422.93
8	Jan	638.67	8	61	388.99
9	Feb	306.03	9	69	306.03
10	Mar	16.12	10	76	16.12
11	Apr	12.61	11	84	13.06
12	May	13.06	12	92	12.61

Table-7.4.K.2(a) Expected within-year storage required at the Transfer Point-6 (Srisailam)

Sl. No.	Month	Expected Within-Year Storage to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year Reservoir Storage	Expected Within-Year Storage to Meet Water Demands at (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	20.92	1	7	260.90
2	Jul	0.00	2	15	243.30
3	Aug	76.89	3	23	153.20
4	Sep	141.10	4	30	141.10
5	Oct	260.90	5	38	79.58
6	Nov	243.30	6	46	76.89
7	Dec	153.20	7	53	61.48
8	Jan	79.58	8	61	55.92
9	Feb	61.48	9	69	46.74
10	Mar	55.92	10	76	36.67
11	Apr	46.74	11	84	20.92
12	May	36.67	12	92	0.00

Table-7.4.K.2(b) Expected within-year firm yield at the Transfer Point-6 (Srisailam)

Sl. No.	Month	Expected Within-Year Firm Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	110.89	1	7	754.15
2	Jul	754.15	2	15	620.54
3	Aug	620.54	3	23	457.79
4	Sep	457.79	4	30	153.65
5	Oct	102.70	5	38	140.83
6	Nov	107.29	6	46	124.81
7	Dec	124.81	7	53	116.30
8	Jan	109.33	8	61	110.89
9	Feb	96.82	9	69	109.33
10	Mar	153.65	10	76	107.29
11	Apr	140.83	11	84	102.70
12	May	116.30	12	92	96.82

7.4.K.2(c) Expected within-year Secondary yield at the Transfer Point-6 (Srisailam)

Sl. No.	Month	Expected Within-Year Secondary Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year secondary yield	Expected Within-Year secondary yield to Meet Water Demands (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	5.74	1	7	249.86
2	Jul	249.86	2	15	176.09
3	Aug	4.00	3	23	136.83
4	Sep	176.09	4	30	88.64
5	Oct	88.64	5	38	80.61
6	Nov	136.83	6	46	43.00
7	Dec	80.61	7	53	34.00
8	Jan	14.87	8	61	28.00
9	Feb	14.87	9	69	14.87
10	Mar	34.00	10	76	14.87
11	Apr	43.00	11	84	5.74
12	May	28.00	12	92	4.00

Table-7.4.K.2(d) Expected within-year value of export at the Transfer Point-6 (Srisailam)

Sl. No.	Month	Expected Within-Year value of export (MCM)	Month	% Exceedance Of Expected Within-Year value of export	Expected Within-Year value of export (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	29.47	1	7	201.00
2	Jul	201.00	2	15	150.00
3	Aug	150.00	3	23	121.00
4	Sep	121.00	4	30	78.00
5	Oct	21.00	5	38	29.47
6	Nov	21.00	6	46	29.00
7	Dec	78.00	7	53	29.00
8	Jan	12.00	8	61	21.00
9	Feb	15.00	9	69	21.00
10	Mar	29.00	10	76	21.00
11	Apr	29.00	11	84	15.00
12	May	21.00	12	92	12.00

Table-7.4.K.3(a) Expected within-year storage required at the Transfer Point-7(Nagarjunasagara)

Sl. No.	Month	Expected Within-Year Storage to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year Reservoir Storage	Expected Within-Year Storage to Meet Water Demands at (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	237.18	1	7	2967.16
2	Jul	0.00	2	15	2963.97
3	Aug	2657.68	3	23	2743.17
4	Sep	2194.08	4	30	2657.68
5	Oct	2743.17	5	38	2576.94
6	Nov	2967.16	6	46	2194.08
7	Dec	2963.97	7	53	2181.92
8	Jan	2576.94	8	61	1824.97
9	Feb	2181.92	9	69	1233.91
10	Mar	1824.97	10	76	697.88
11	Apr	1233.91	11	84	237.18
12	May	697.88	12	92	0.00

Table-7.4.K.3(b) Expected within-year firm yield at the Transfer Point-7 (Nagarjunasagara)

Sl. No.	Month	Expected Within-Year Firm Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	443.56	1	7	3016.60
2	Jul	3016.60	2	15	2482.15
3	Aug	2482.15	3	23	1831.16
4	Sep	1831.16	4	30	614.59
5	Oct	410.79	5	38	563.32
6	Nov	429.14	6	46	499.23
7	Dec	499.23	7	53	465.21
8	Jan	437.32	8	61	443.56
9	Feb	387.28	9	69	437.32
10	Mar	614.59	10	76	429.14
11	Apr	563.32	11	84	410.79
12	May	465.21	12	92	387.28

Table-7.4.K.3(c) Expected within-year Secondary yield at the Transfer Point-7 (Nagarjunasagara)

Sl. No.	Month	Expected Within-Year Secondary Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year secondary yield	Expected Within-Year secondary yield to Meet Water Demands (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	35.00	1	7	345.00
2	Jul	345.00	2	15	56.00
3	Aug	45.00	3	23	45.00
4	Sep	10.00	4	30	35.00
5	Oct	0.00	5	38	19.80
6	Nov	0.00	6	46	10.00
7	Dec	0.00	7	53	8.00
8	Jan	3.40	8	61	6.00
9	Feb	56.00	9	69	3.40
10	Mar	6.00	10	76	0.00
11	Apr	8.00	11	84	0.00
12	May	19.80	12	92	0.00

Table-7.4.K.3(d) Expected within-year value of export at the Transfer Point-7(Nagarjunasagara)

Sl. No.	Month	Expected Within-Year value of export (MCM)	Month	% Exceedance Of Expected Within-Year value of export	Expected Within-Year value of export (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	117.87	1	7	926.54
2	Jul	926.54	2	15	761.36
3	Aug	761.36	3	23	557.01
4	Sep	557.01	4	30	117.87
5	Oct	112.67	5	38	116.06
6	Nov	107.58	6	46	112.67
7	Dec	111.77	7	53	111.77
8	Jan	51.54	8	61	111.17
9	Feb	63.28	9	69	107.58
10	Mar	111.17	10	76	83.45
11	Apr	116.06	11	84	63.28
12	May	83.45	12	92	51.54

Table-7.4.P.1(a) Expected within-year storage required at the Transfer Point-8(Somasilam)

Sl. No.	Month	Expected Within-Year Storage to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year Reservoir Storage	Expected Within-Year Storage to Meet Water Demands at (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	378.31	1	7	1809.63
2	Jul	0.00	2	15	1596.98
3	Aug	1458.67	3	23	1499.14
4	Sep	1596.98	4	30	1485.59
5	Oct	1809.63	5	38	1458.67
6	Nov	1499.14	6	46	1312.47
7	Dec	1485.59	7	53	1222.12
8	Jan	1312.47	8	61	1092.42
9	Feb	1222.12	9	69	866.95
10	Mar	1092.42	10	76	552.70
11	Apr	866.95	11	84	378.31
12	May	552.70	12	92	0.00

Table-7.4.P.1(b) Expected within-year firm yield at the Transfer Point-8(Somasilam)

Sl. No.	Month	Expected Within-Year Firm Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	447.82	1	7	599.11
2	Jul	486.48	2	15	550.24
3	Aug	550.24	3	23	524.30
4	Sep	599.11	4	30	486.48
5	Oct	524.30	5	38	447.82
6	Nov	157.13	6	46	209.10
7	Dec	209.10	7	53	157.13
8	Jan	102.61	8	61	102.61
9	Feb	35.41	9	69	35.41
10	Mar	35.41	10	76	35.41
11	Apr	35.41	11	84	35.41
12	May	35.41	12	92	35.41

Table-7.4.P.1(c) Expected within-year Secondary yield at the Transfer Point-8 (Somasilam)

Sl. No.	Month	Expected Within-Year Secondary Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year secondary yield	Expected Within-Year secondary yield to Meet Water Demands (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	0.00	1	7	284.36
2	Jul	0.00	2	15	194.96
3	Aug	0.00	3	23	136.50
4	Sep	0.00	4	30	102.81
5	Oct	0.00	5	38	0.00
6	Nov	0.00	6	46	0.00
7	Dec	0.00	7	53	0.00
8	Jan	0.00	8	61	0.00
9	Feb	102.81	9	69	0.00
10	Mar	194.96	10	76	0.00
11	Apr	284.36	11	84	0.00
12	May	136.50	12	92	0.00

Table-7.4.P.1(d) Expected within-year value of export at the Transfer Point-8 (Somasilam)

Sl. No.	Month	Expected Within-Year value of export (MCM)	Month	% Exceedance Of Expected Within-Year value of export	Expected Within-Year value of export (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	899.97	1	7	1230.12
2	Jul	984.33	2	15	1123.47
3	Aug	1123.47	3	23	1060.01
4	Sep	1230.12	4	30	984.33
5	Oct	1060.01	5	38	899.97
6	Nov	178.15	6	46	846.91
7	Dec	258.12	7	53	644.11
8	Jan	132.06	8	61	430.80
9	Feb	313.53	9	69	313.53
10	Mar	644.11	10	76	258.12
11	Apr	846.91	11	84	178.15
12	May	430.80	12	92	132.06

Table-7.4.C.1(a) Expected within-year storage required at the Transfer Point-9 (Kattalai)

Sl. No.	Month	Expected Within-Year Storage to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year Reservoir Storage	Expected Within-Year Storage to Meet Water Demands at (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	83.94	1	7	113.70
2	Jul	61.03	2	15	107.16
3	Aug	32.86	3	23	94.15
4	Sep	8.44	4	30	88.32
5	Oct	0.00	5	38	83.94
6	Nov	4.32	6	46	67.46
7	Dec	55.33	7	53	61.03
8	Jan	67.46	8	61	55.33
9	Feb	107.16	9	69	32.86
10	Mar	113.70	10	76	8.44
11	Apr	94.15	11	84	4.32
12	May	88.32	12	92	0.00

Table-7.4.C.1(b) Expected within-year firm yield at the Transfer Point-9 (Kattalai)

Sl. No.	Month	Expected Within-Year Firm Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	23.48	1	7	29.43
2	Jul	29.43	2	15	27.49
3	Aug	27.49	3	23	23.48
4	Sep	11.45	4	30	22.38
5	Oct	1.62	5	38	19.47
6	Nov	1.10	6	46	14.99
7	Dec	3.85	7	53	11.45
8	Jan	14.99	8	61	8.57
9	Feb	19.47	9	69	6.84
10	Mar	22.38	10	76	3.85
11	Apr	8.57	11	84	1.62
12	May	6.84	12	92	1.10

Table-7.4.C.1(c) Expected within-year Secondary yield at the Transfer Point-9 (Kattalai)

Sl. No.	Month	Expected Within-Year Secondary Yield to Meet Water Demands (MCM)	Month	% Exceedance Of Expected Within-Year secondary yield	Expected Within-Year secondary yield to Meet Water Demands (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	11.74	1	7	11.74
2	Jul	8.83	2	15	10.1713
3	Aug	10.17	3	23	8.829
4	Sep	4.58	4	30	8.2806
5	Oct	0.65	5	38	5.841
6	Nov	0.44	6	46	4.58
7	Dec	1.16	7	53	4.497
8	Jan	4.50	8	61	3.428
9	Feb	5.84	9	69	1.155
10	Mar	8.28	10	76	0.648
11	Apr	3.43	11	84	0.44
12	May	0.00	12	92	0

Table-7.4.C.1(d) Expected within-year value of export at the Transfer Point-9 (Kattalai)

Sl. No.	Month	Expected Within-Year value of export (MCM)	Month	% Exceedance Of Expected Within-Year value of export	Expected Within-Year value of export (MCM)
(1)	(2)	(3)	(4)	(5)	(6)
1	Jun	680.06	1	7	854.07
2	Jul	854.07	2	15	797.25
3	Aug	797.25	3	23	680.06
4	Sep	328.31	4	30	647.74
5	Oct	40.66	5	38	562.69
6	Nov	25.39	6	46	431.65
7	Dec	106.00	7	53	328.31
8	Jan	431.65	8	61	243.97
9	Feb	562.69	9	69	193.19
10	Mar	647.74	10	76	106.00
11	Apr	243.97	11	84	40.66
12	May	193.19	12	92	25.39

Table 7.5 Table of reservoir statistics based on the study

		Monsoon Period		Non-monsoon Period	
Export point	Reservoir	Full Storage Period	Minimum Storage Period	Maximum Storage Period	Minimum(Empty) Storage Period
(1)	(2)	(3)	(4)	(5)	(6)
1	Manibhadra	Oct.	Aug.	Dec.	-
2,3	Inchampalli	Sep.	Aug.	Nov.	-
4	Polavaram	Sep.	Aug.	Nov.	Feb.
5	Almatti	Aug.	Jun., Jul.	Dec.	-
6	Srisailam	Oct.	Jul.	Nov.	-
7	Nagarjunasagara	Oct.	Jul.	Nov.	-
8	Somasila	Oct.	Jul.	Nov.	-
9	Kattalai	Jun.	Oct.	Mar.	-

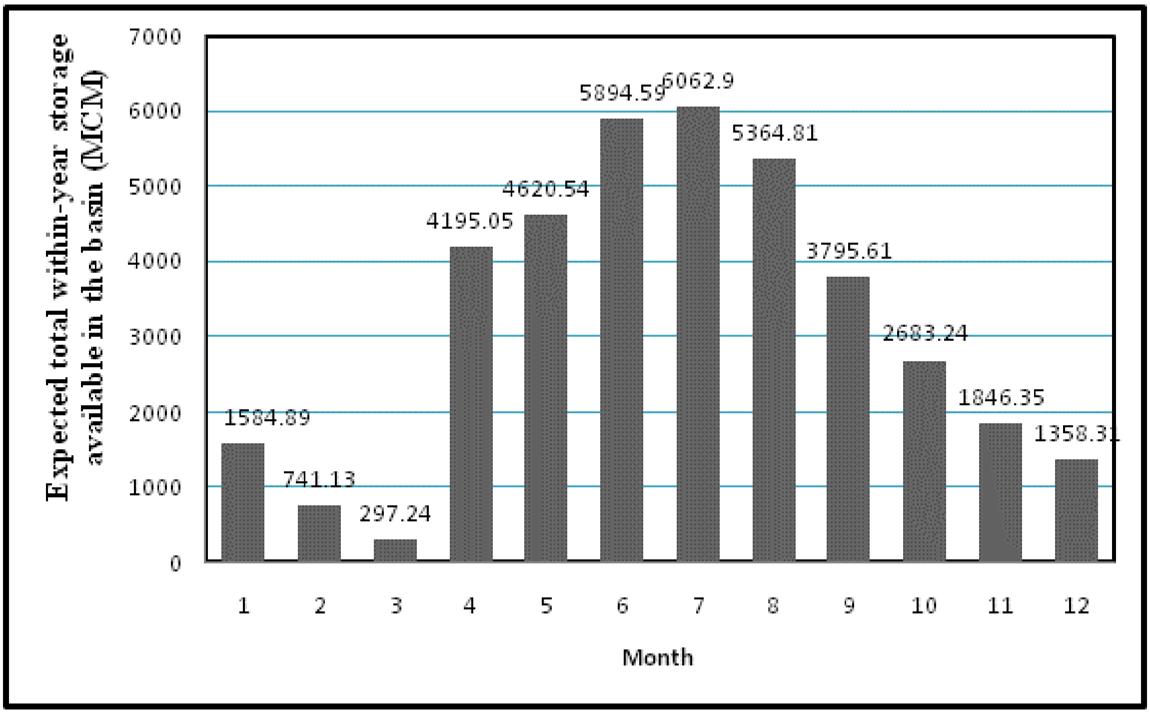

Fig.-7.3.M. (a) Expected total within-year storages available in Mahanadi basin in a normal water year

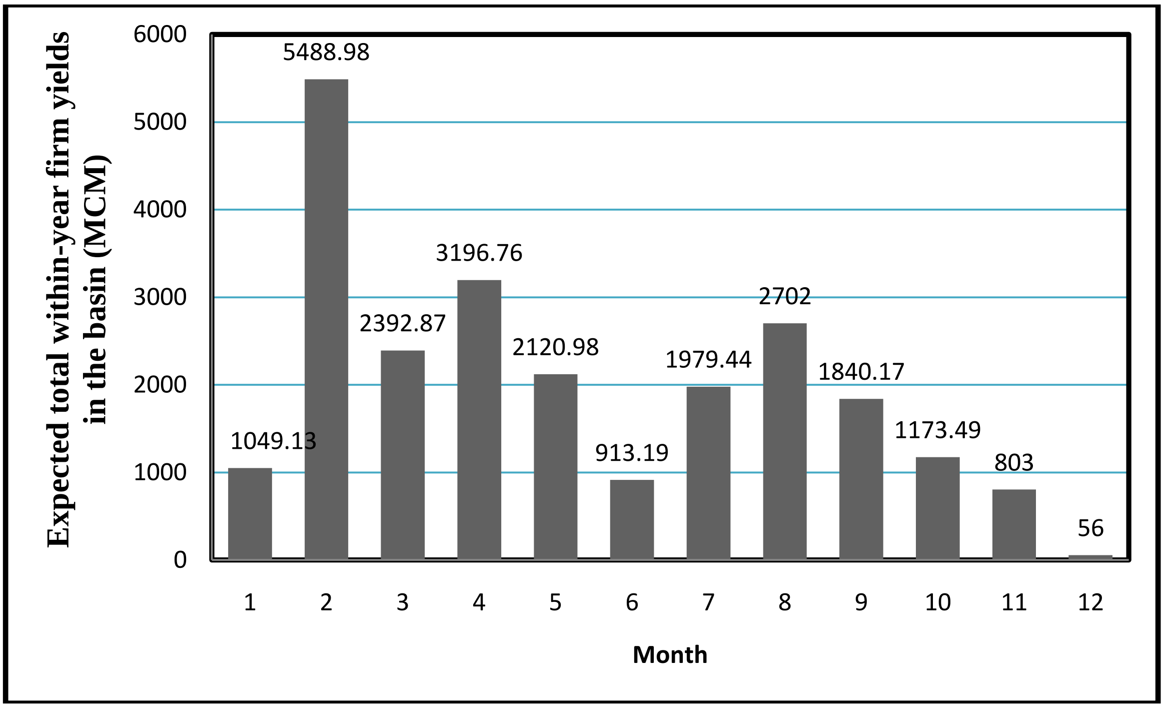

Fig.-7.3.M. (b) Expected total within-year firm yields available in Mahanadi basin in a normal water year

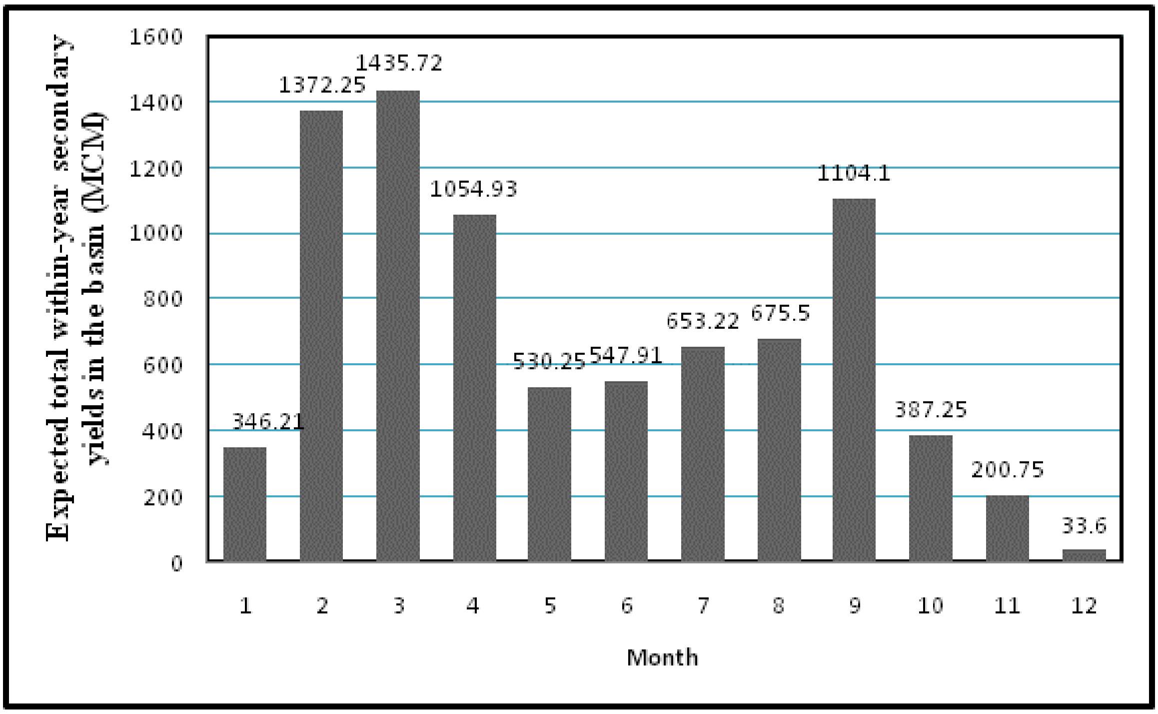

Fig.-7.3.M(c) Expected total within-year secondary yields available in Mahanadi basinin a normal water year

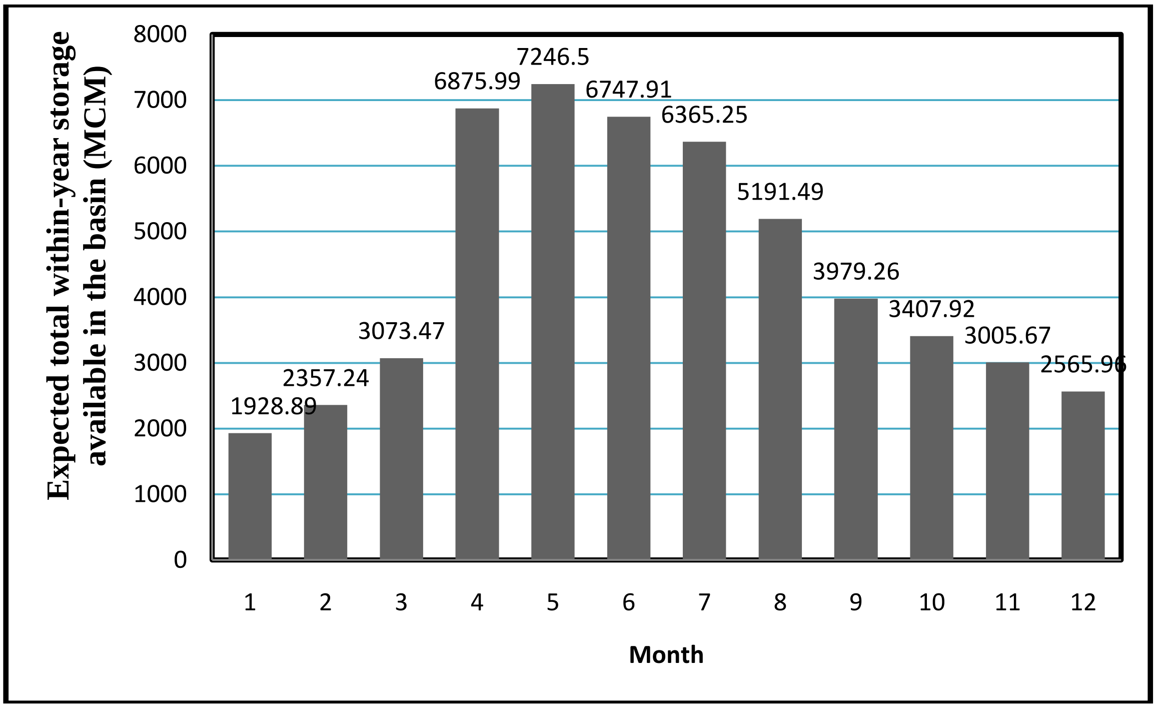

Fig.-7.3.G (a) Expected total within-year storages available in Godavari basin in a normal water year

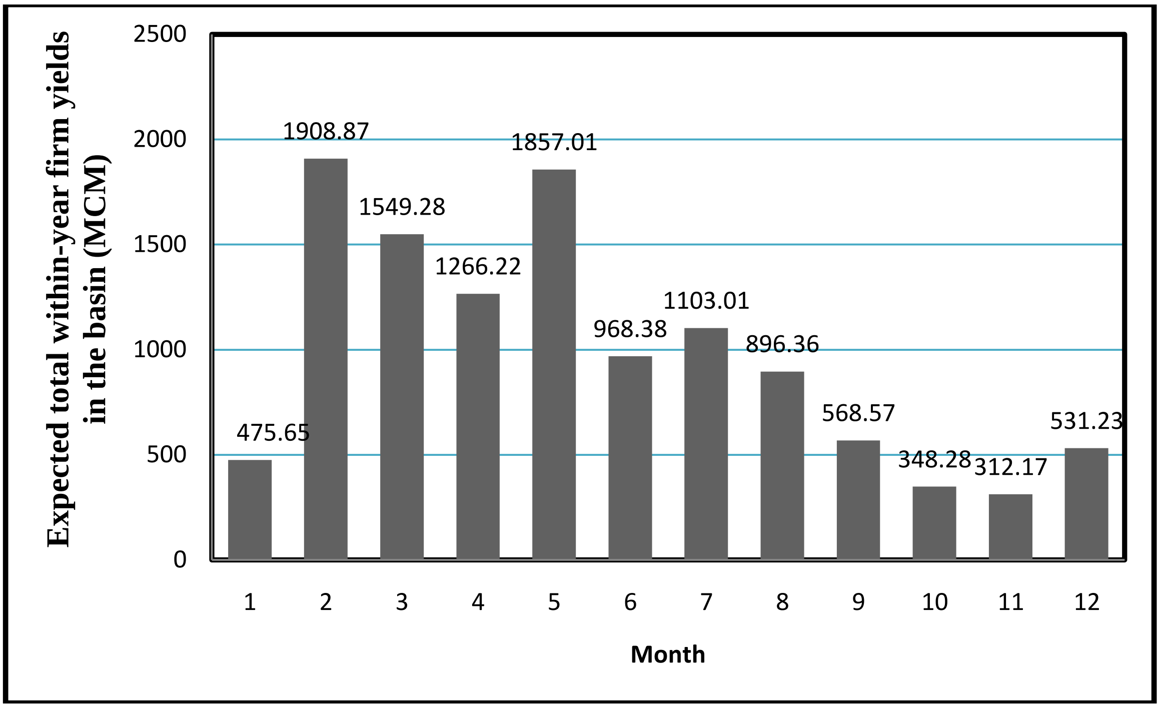

Fig.-7.3.G (b) Expected total within-year firm yields available in Godavari basin in a normal water year

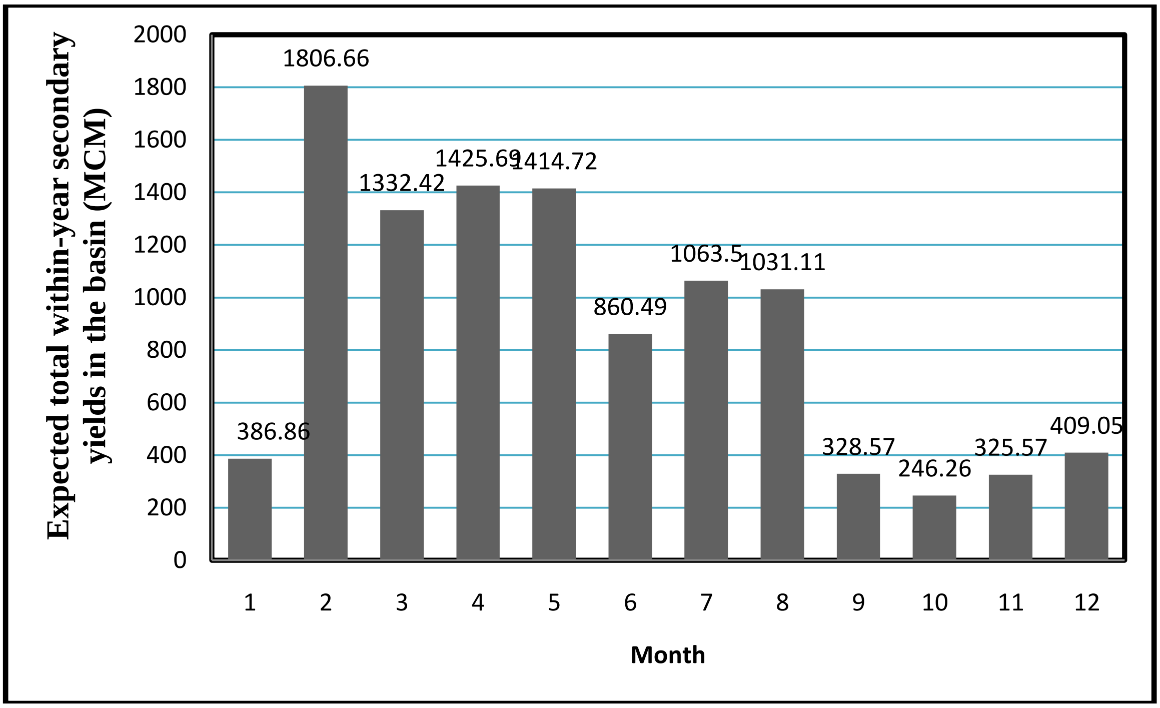

Fig.-7.3.G(c) Expected total within-year secondary yields available in Godavari basinin a normal water year

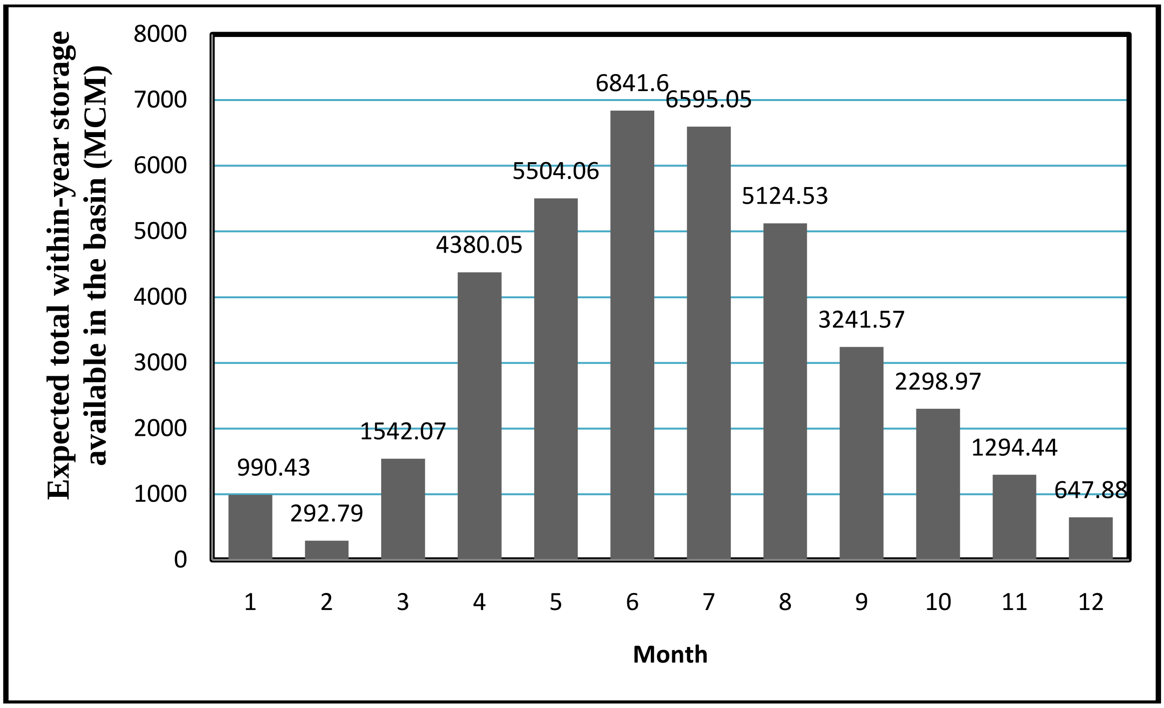

Fig.-7.3.K(a) Expected total within-year storages available in Krishna basin in a normal water year

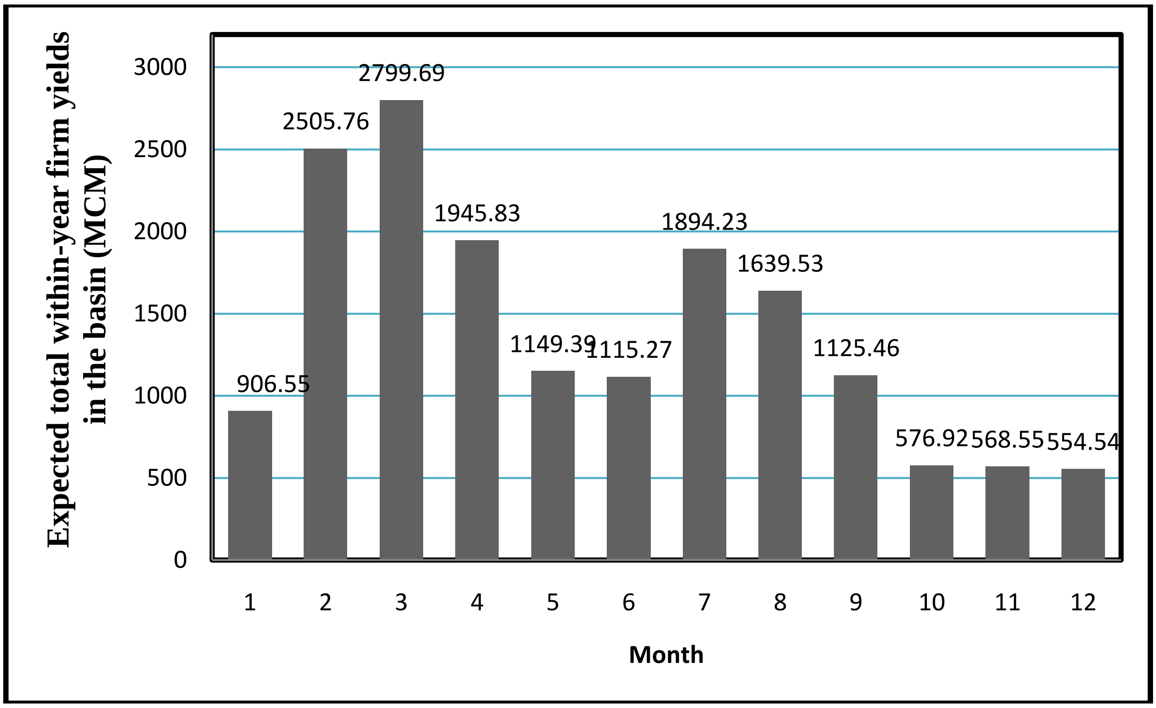

Fig.-7.3.K (b) Expected total within-year firm yields available in Krishna basin in a normal water year

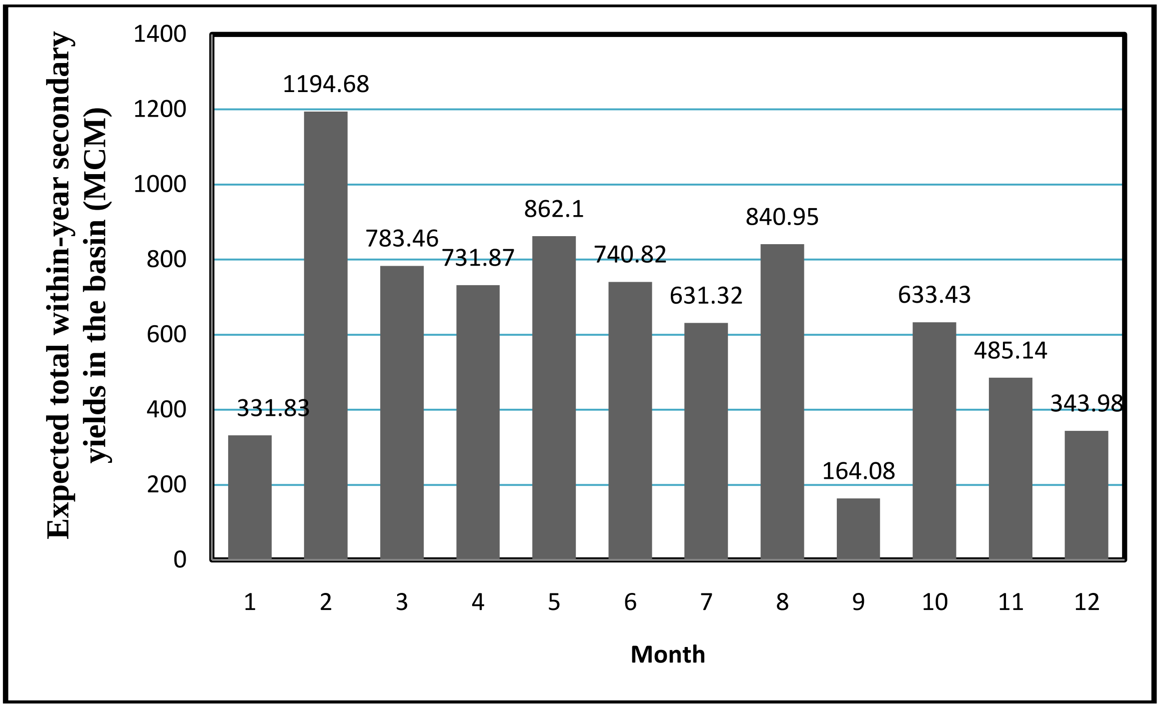

Fig.-7.3.K(c) Expected total within-year secondary yields available in Krishna basin in a normal water year

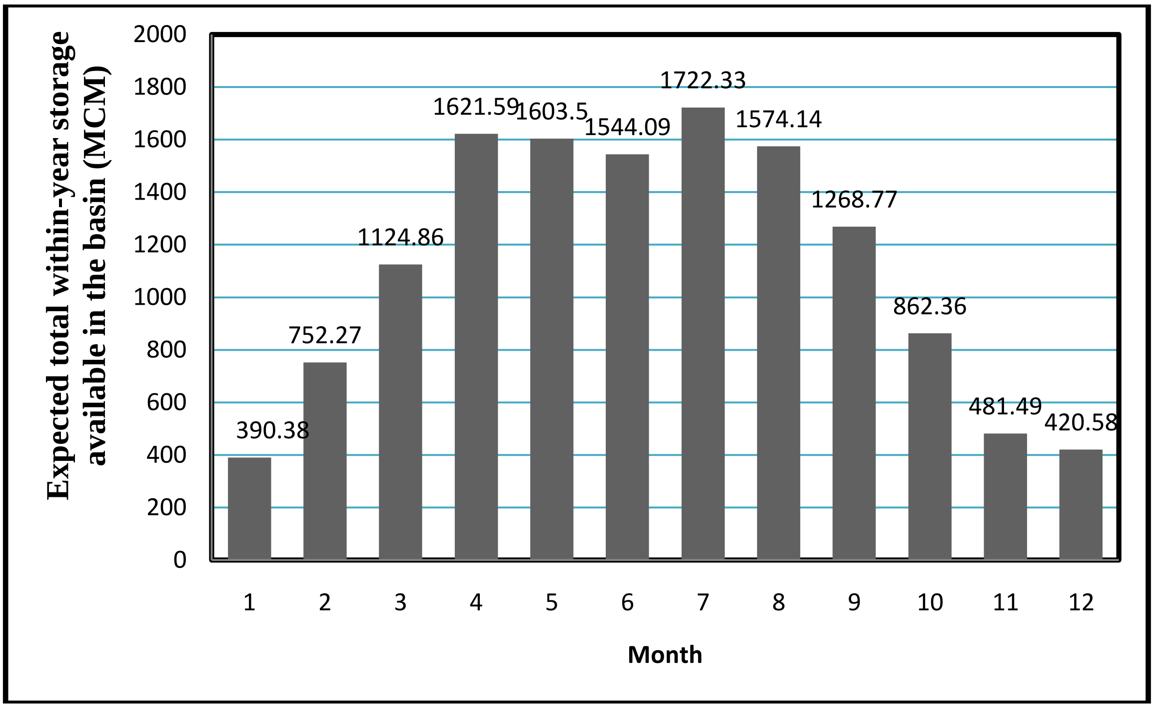

Fig.-7.3.C(a) Expected total within-year storages available in Cauvery basin in a normal water year

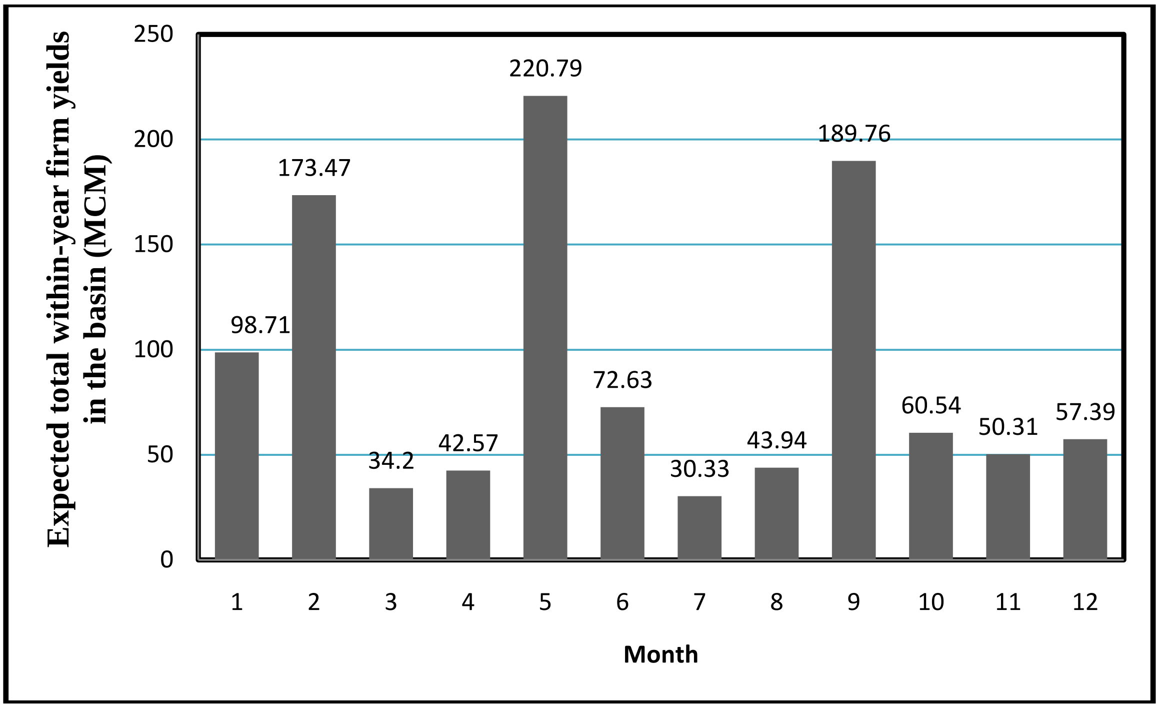

Fig.-7.3.C (b) Expected total within-year firm yields available in Cauvery basin in a normal water year

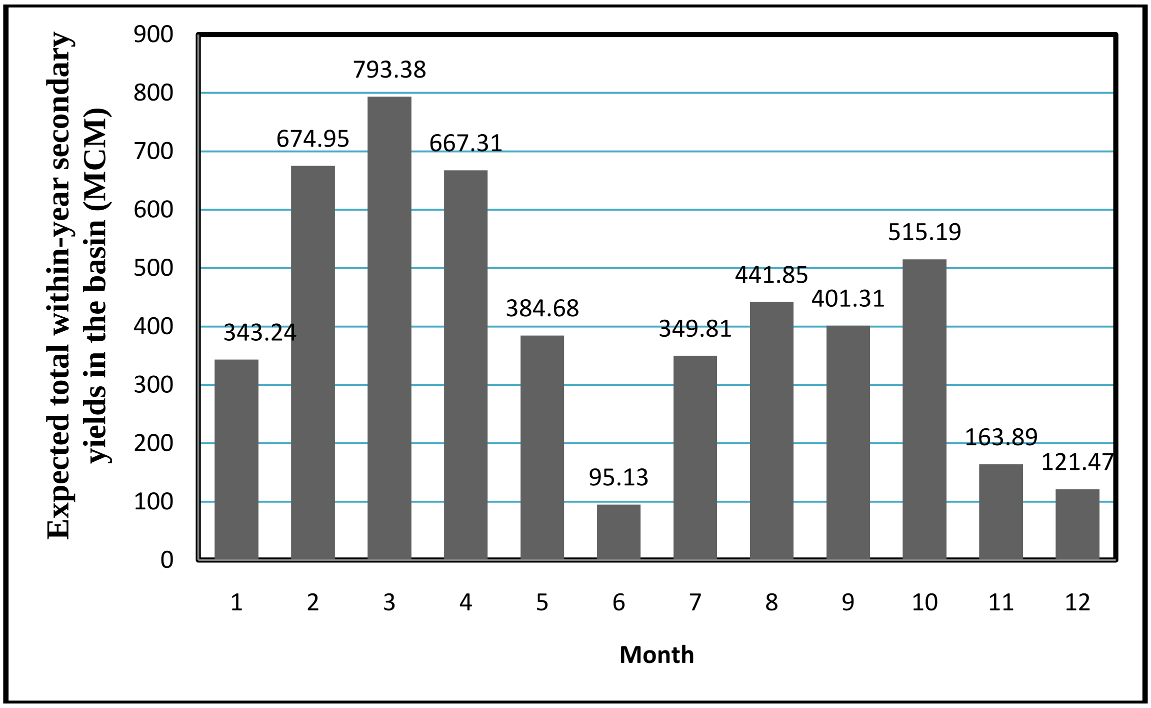

Fig.-7.3.C(c) Expected total within-year secondary yields available in Cauvery basin

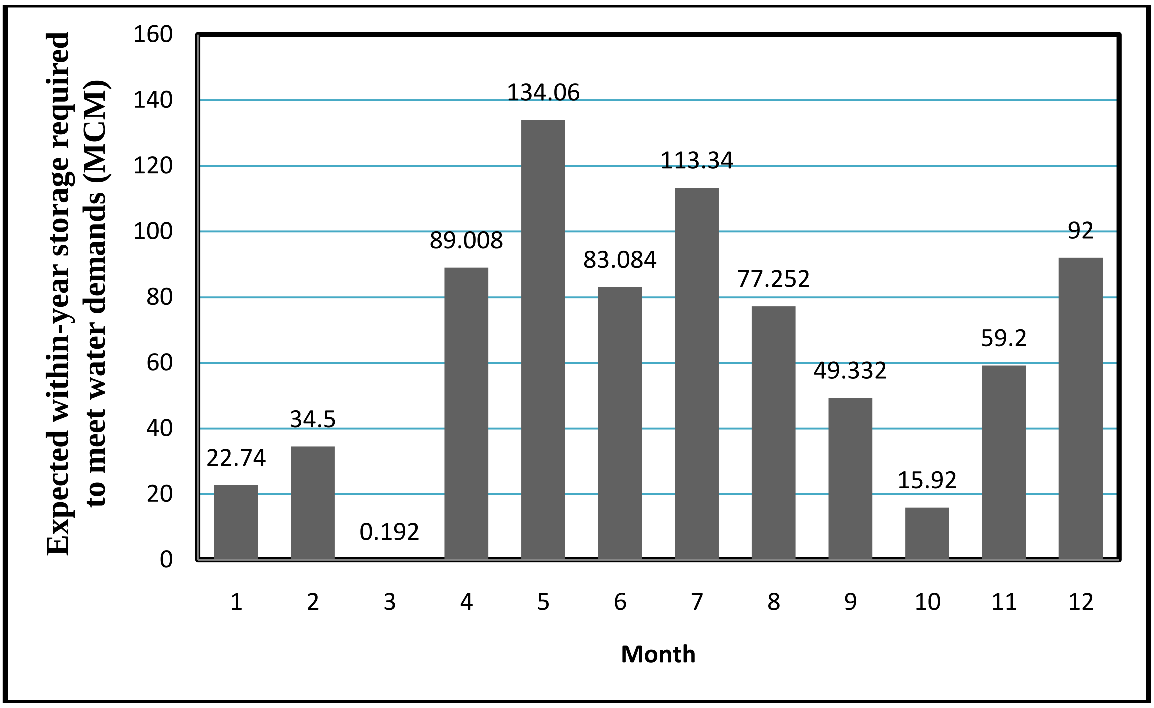

Fig.-7.4.M.1 (a) Expected within-year storage required at the Transfer Point-1 (Manibhadra)

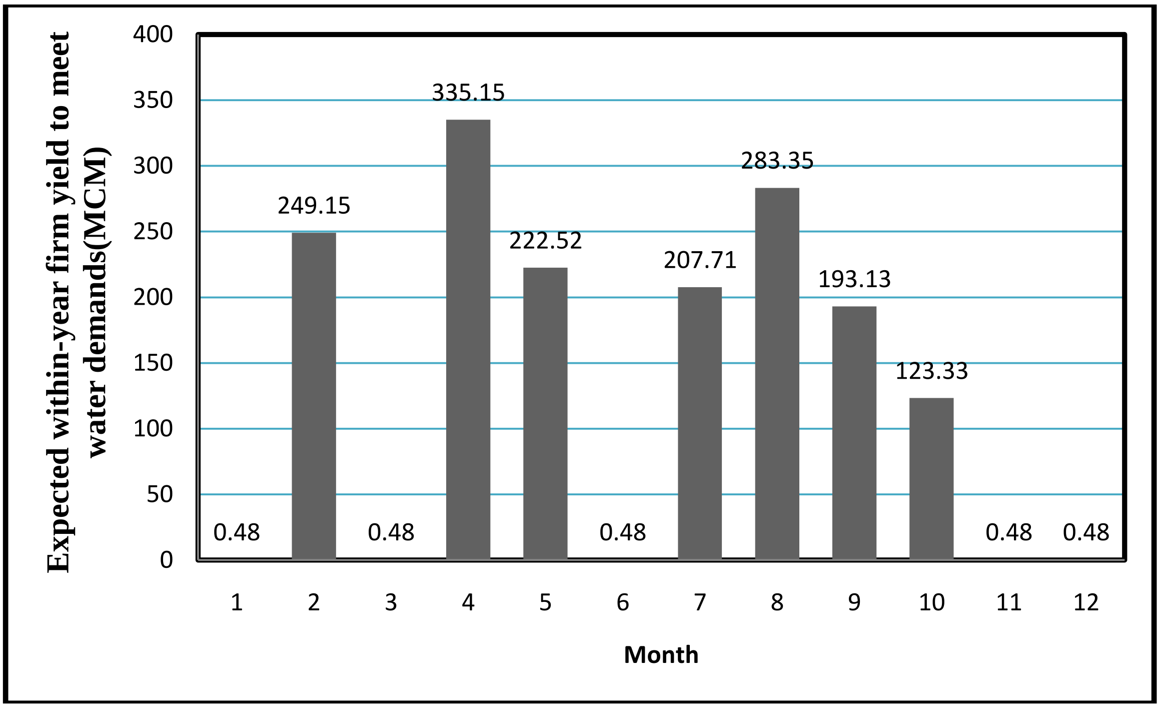

Fig.-7.4.M.1 (b) Expected within-year firm yield at the Transfer Point-1 (Manibhadra)

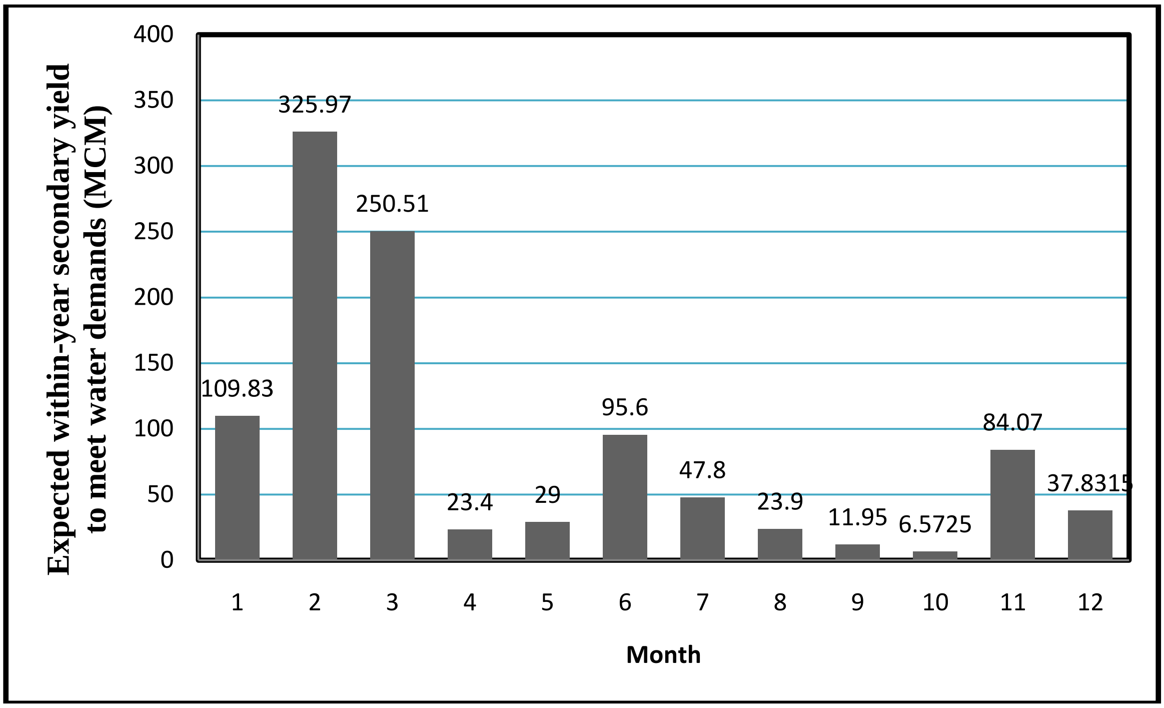

Fig.-7.4.M.1 (c)Expected within-year Secondary yield at the Transfer Point-1 (Manibhadra)

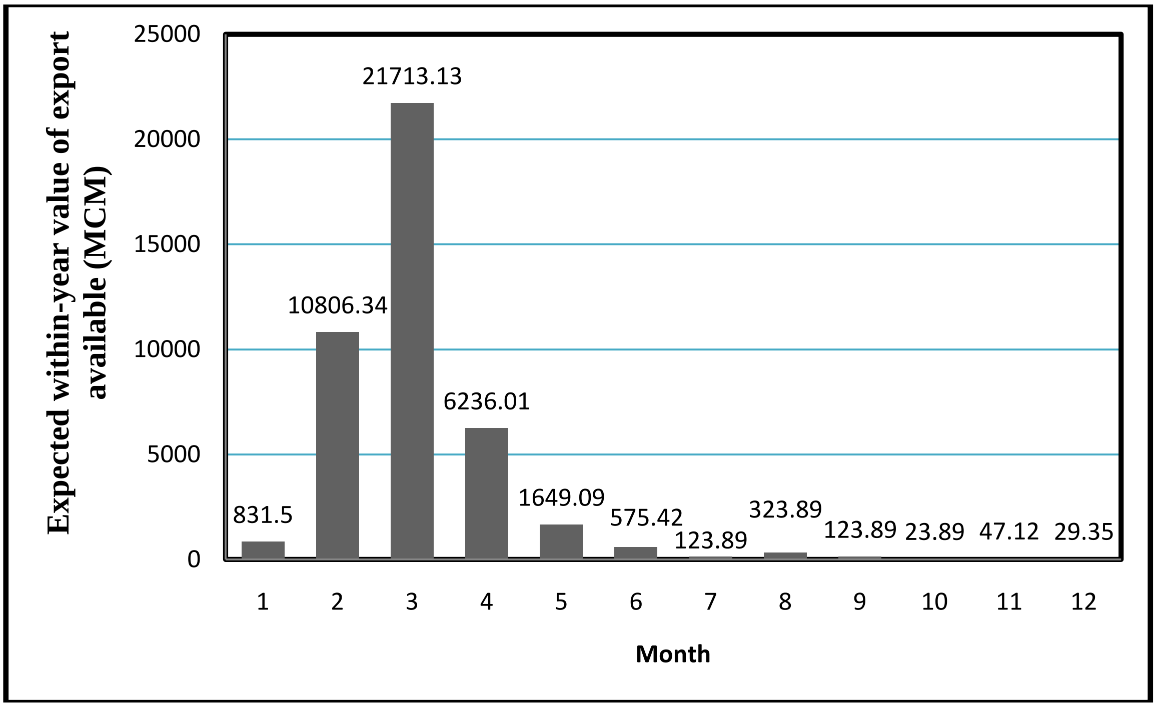

Fig.-7.4.M.1 (d) Expected within-year value of available export at the Transfer Point-1 (Manibhadra)

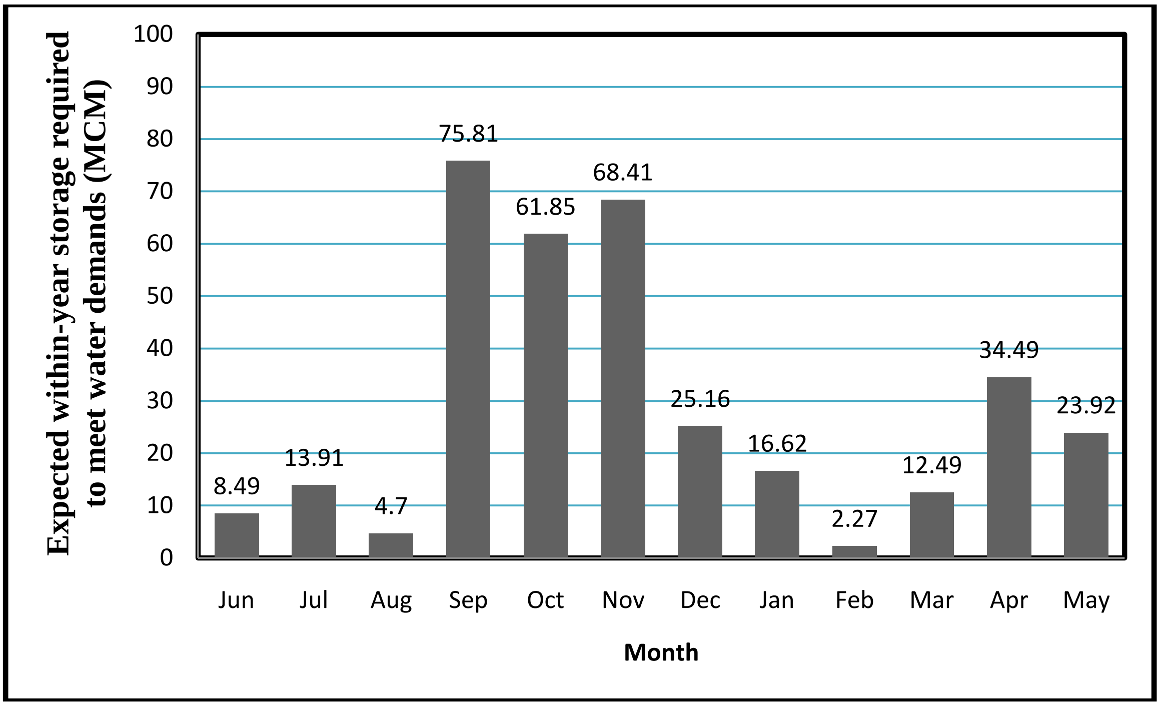

Fig 7.4.G.1 (a),Expected Within-Year Storage to Meet Water Demands at Transfer Point-2& 3 (Inchampalli)

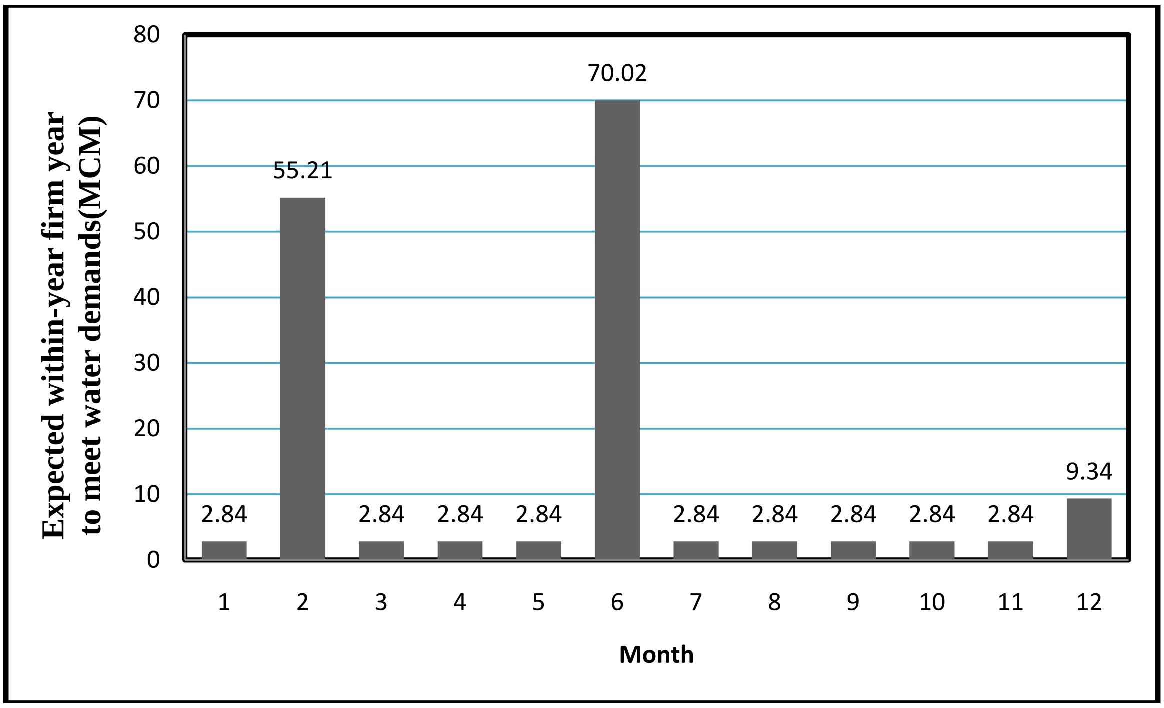

Fig 7.4.G.1 (b),Expected Within-Year Firm Yield to Meet Water Demands at Transfer Point-2& 3 (Inchampalli)

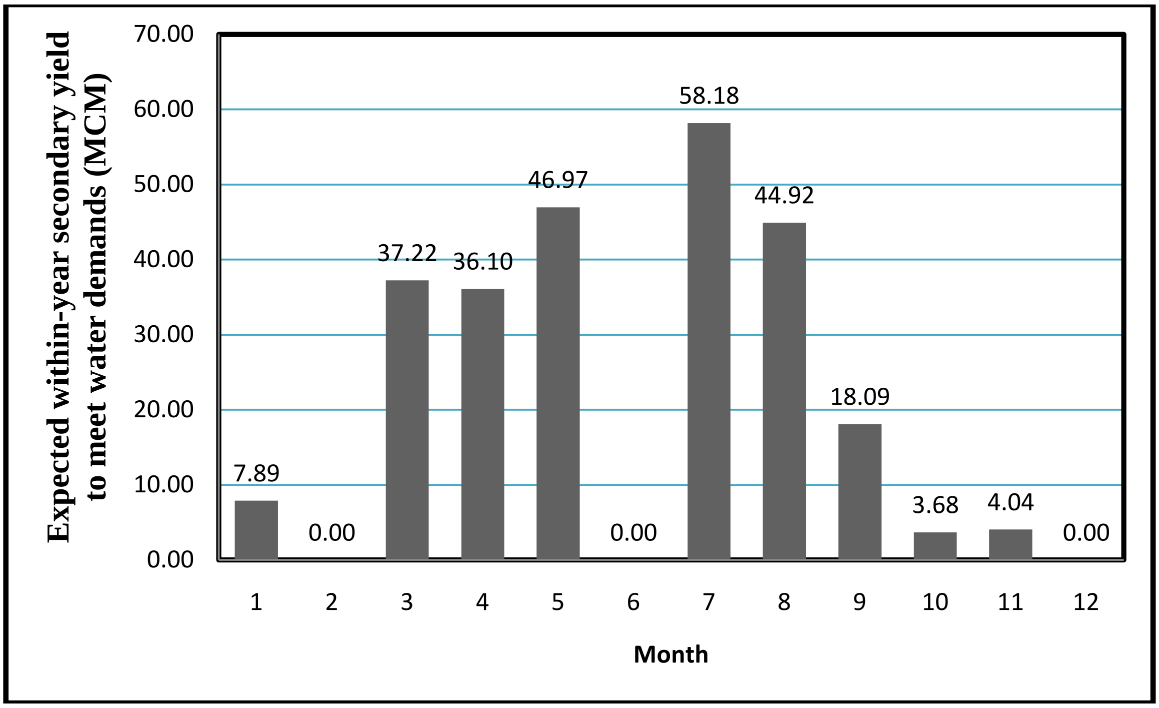

Fig 7.4.G.1(c),Expected within-year Secondary yield at the Transfer Point-2 & 3 (Inchampalli)

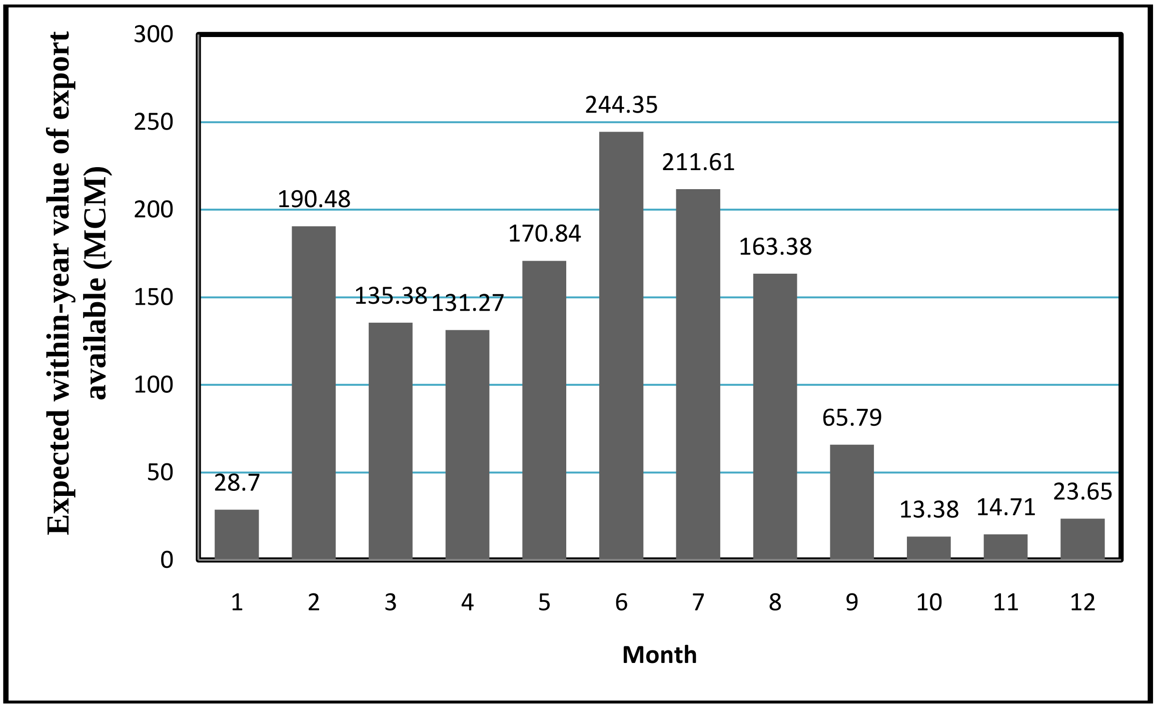

Fig. 7.4.G.1 (d). Expected Within-Year value of available export at the Transfer Point-2 & 3 (Inchampalli)

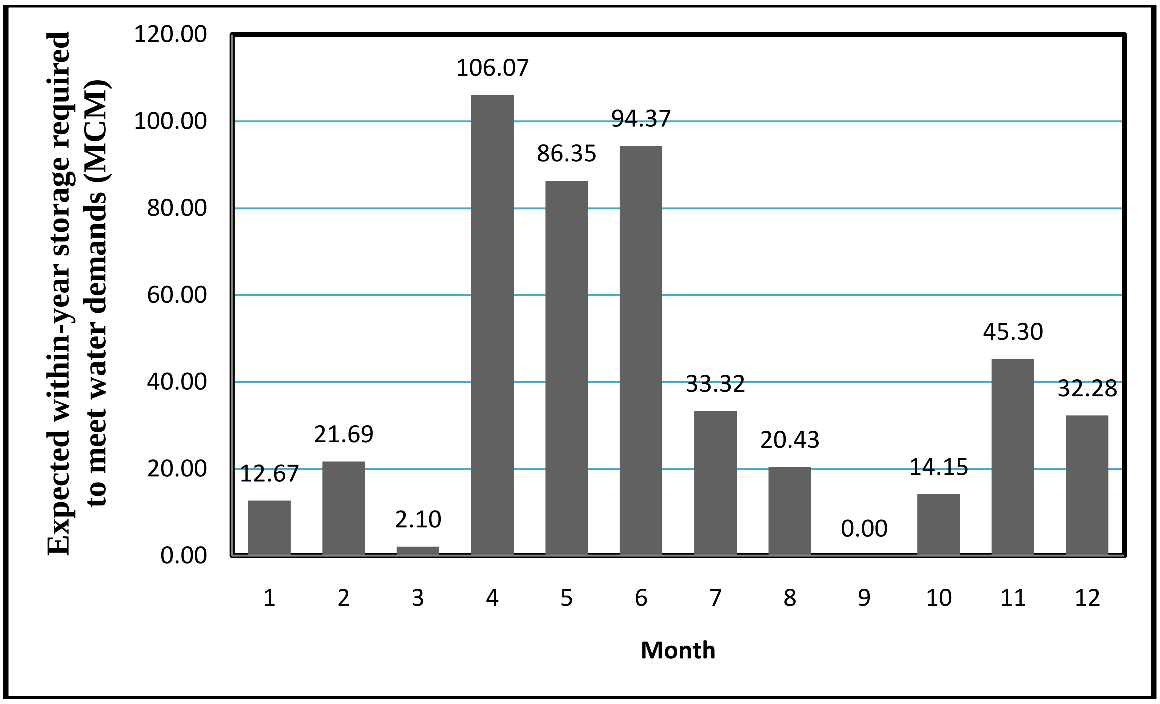

Fig. 7.4.G.2. (a) Expected within-year storage required at the Transfer Point-4 (Polavaram)

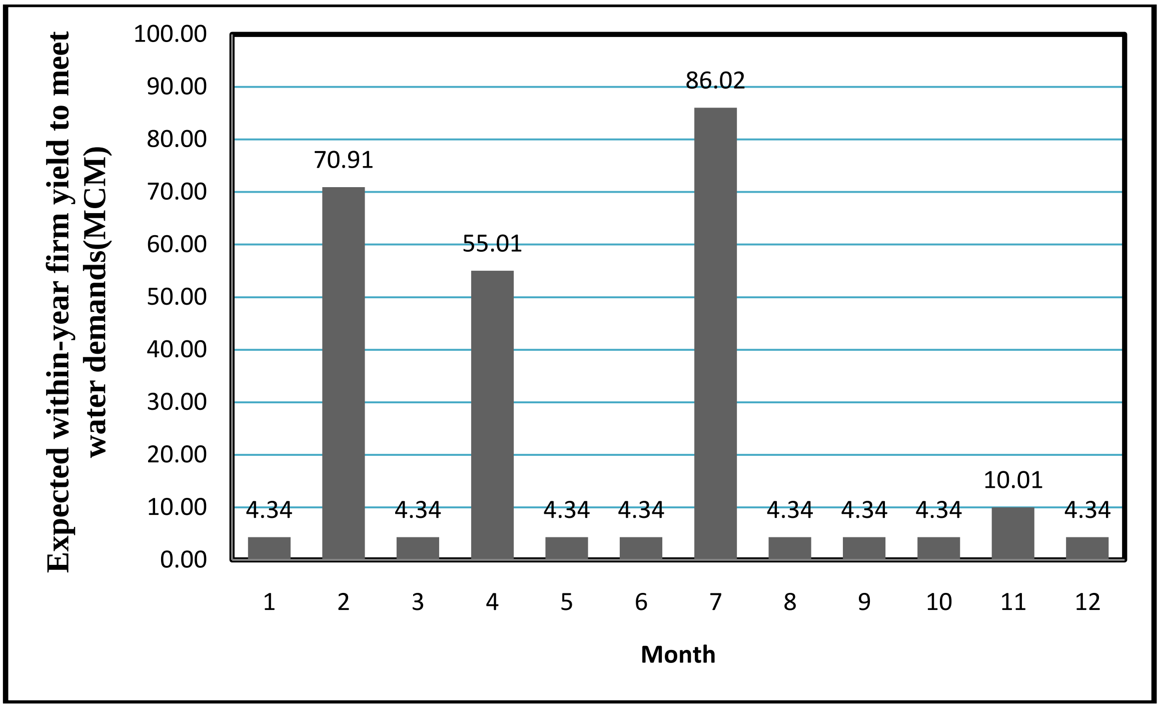

Fig. 7.4.G.2 (b) Expected within-year firm yield at Transfer Point-4 (Polavaram)

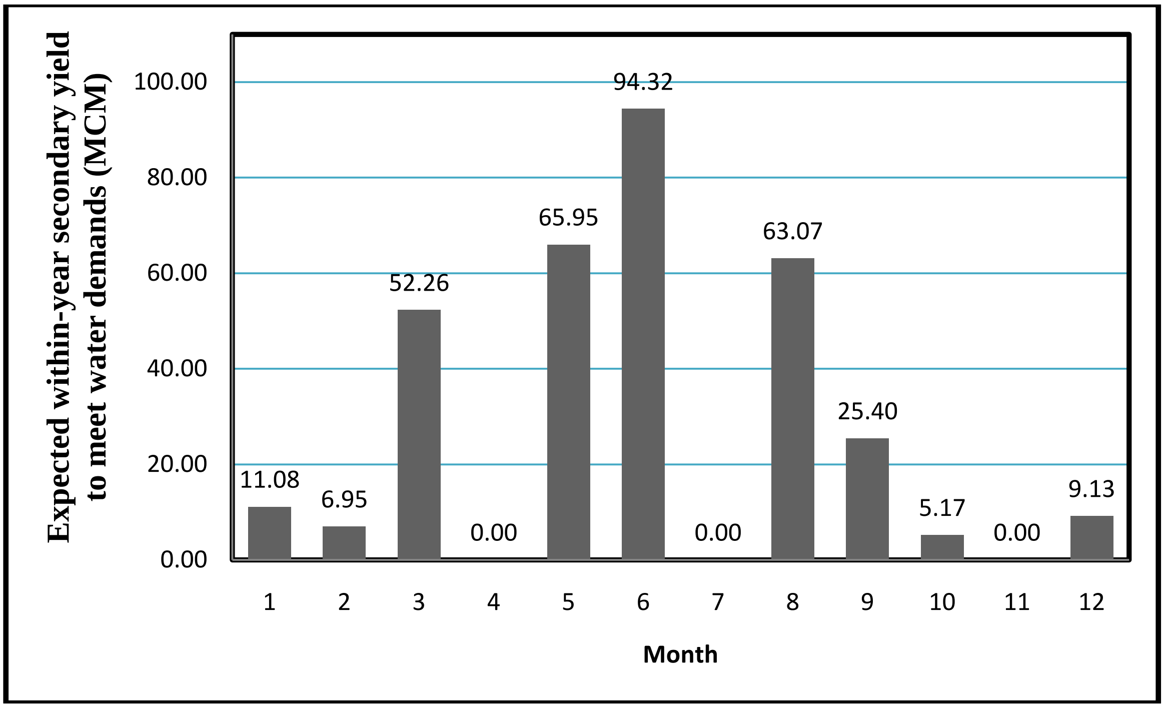

Fig. 7.4.G.2(c) Expected Within-Year Secondary Yield to Meet Water Demands at Polavaram (MCM)

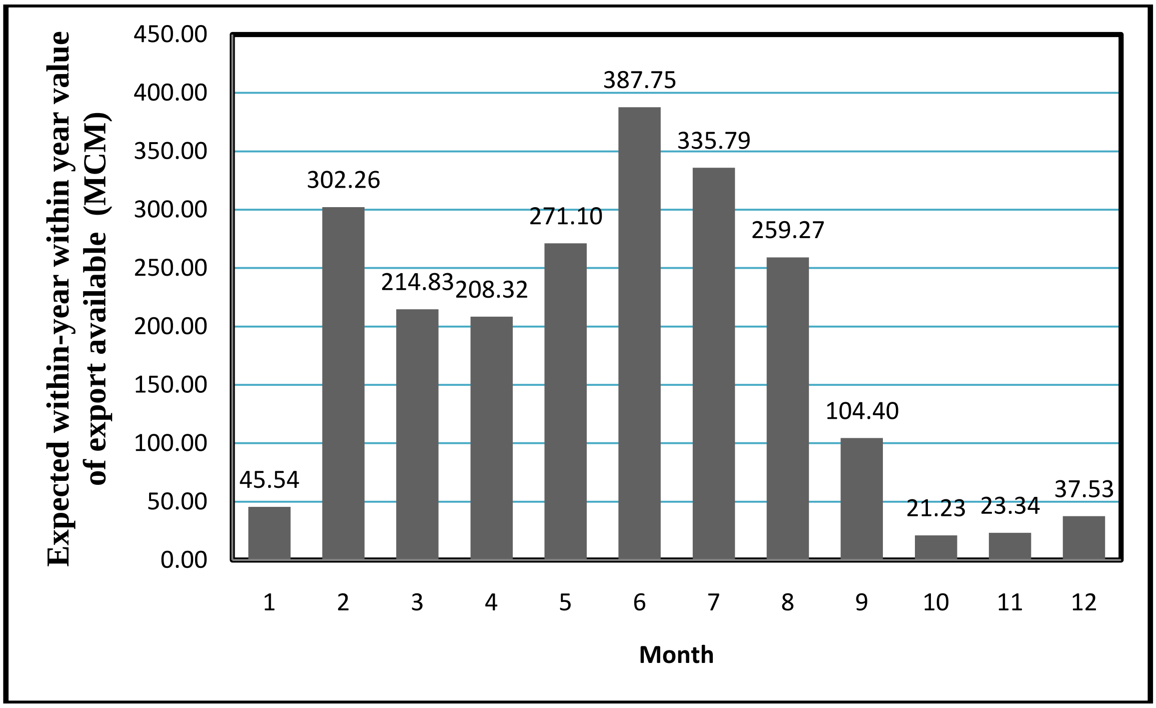

Fig. 7.4.G.2 (d)Expected Within-Year value of available export at Polavaram

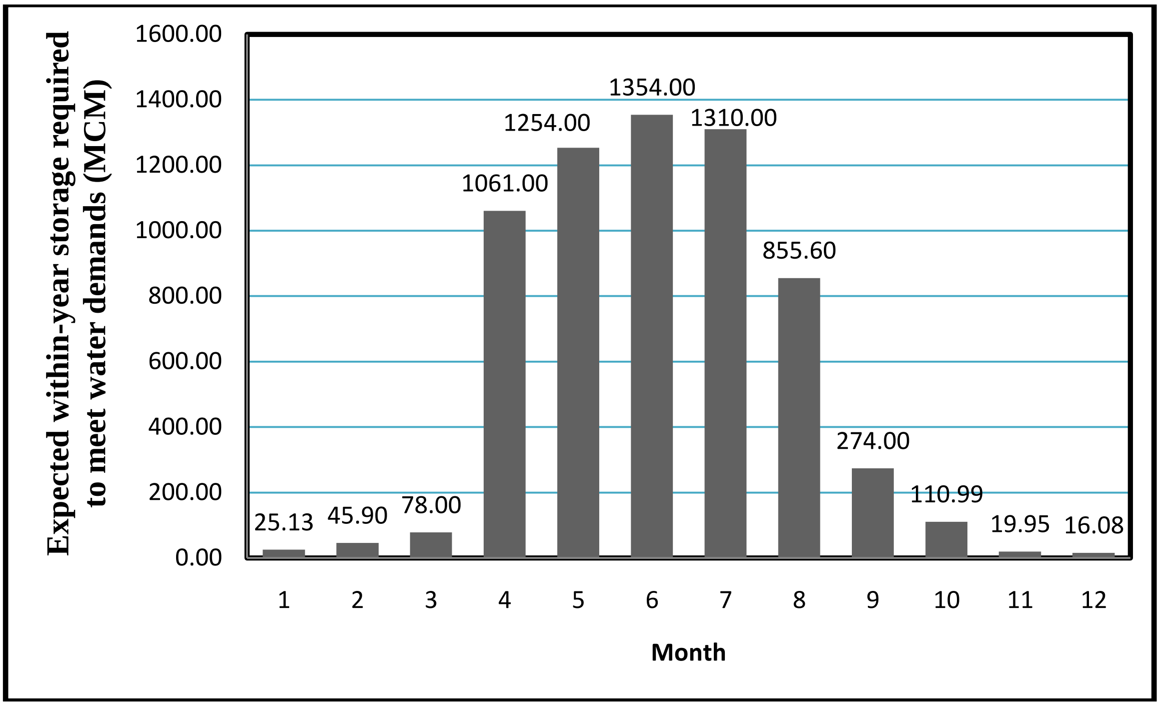

Fig.7.4.K.1 (a)Expectedwithin-year storage required at the Transfer Point-5 (Almatti)

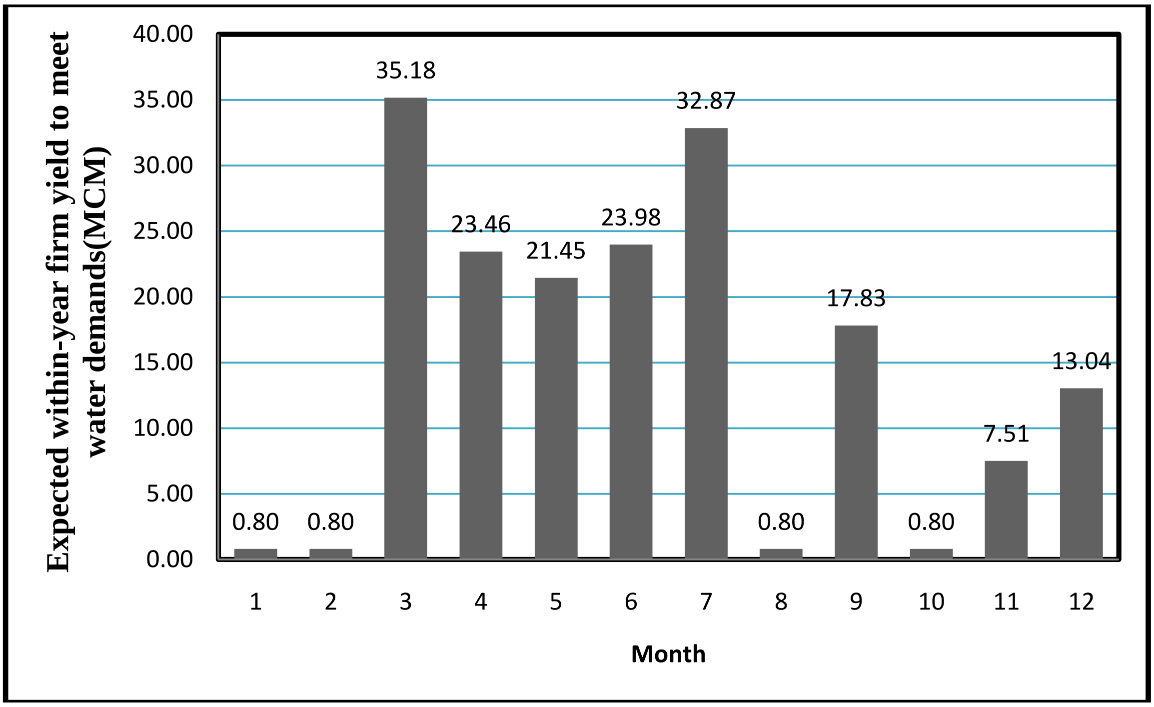

Fig. 7.4.K.1 (b)Expected within-year firm yield at the Transfer Point-5 (Almatti)

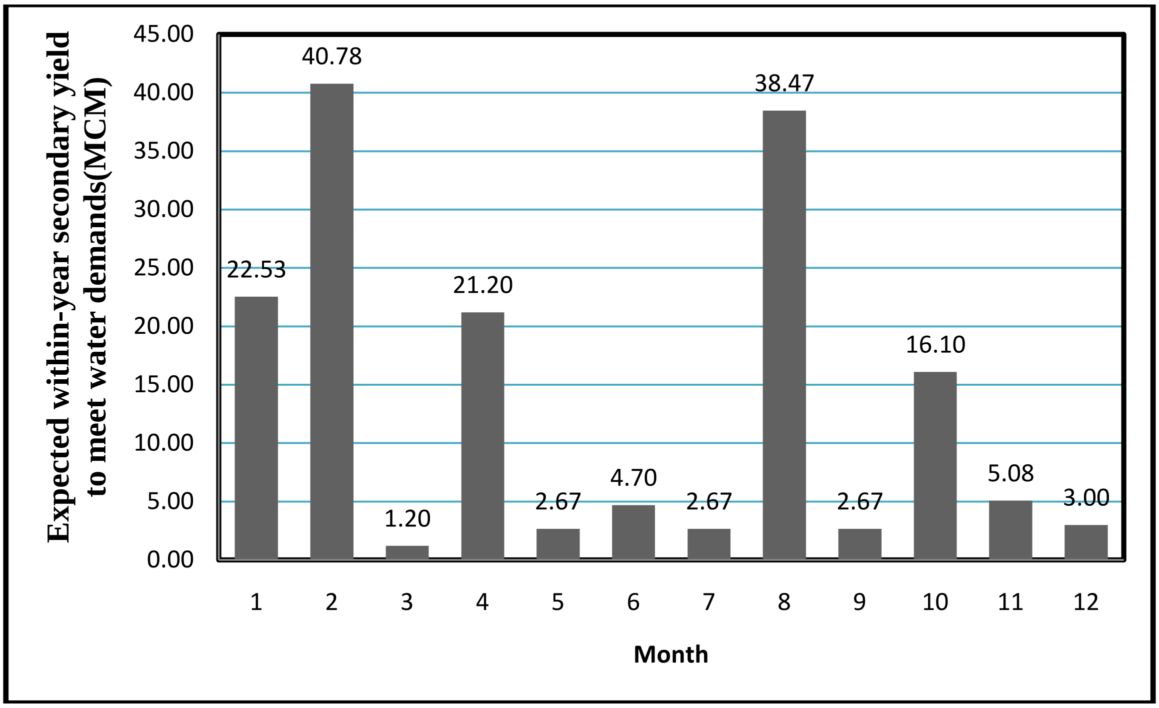

Fig.7.4.K.1(c) Expectedwithin-year Secondary yield at the Transfer Point-5 (Almatti)

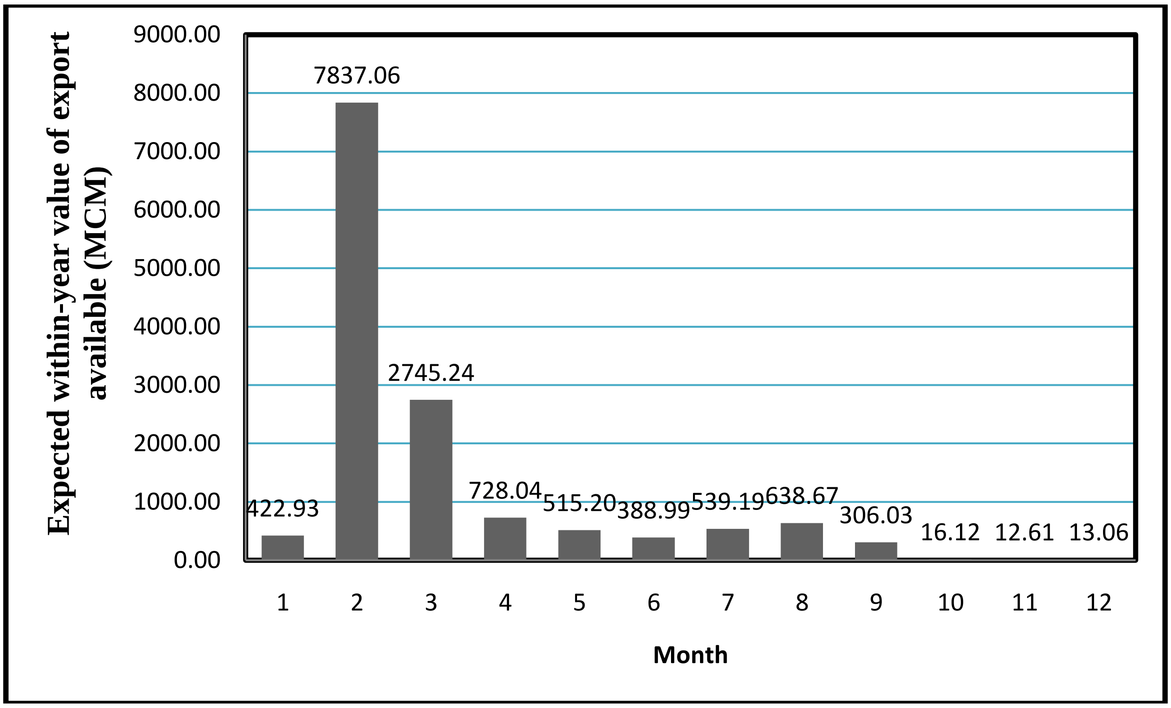

Fig.-7.4.K.1 (d) Expected within-year value of available export at the Transfer Point-5 (Almatti)

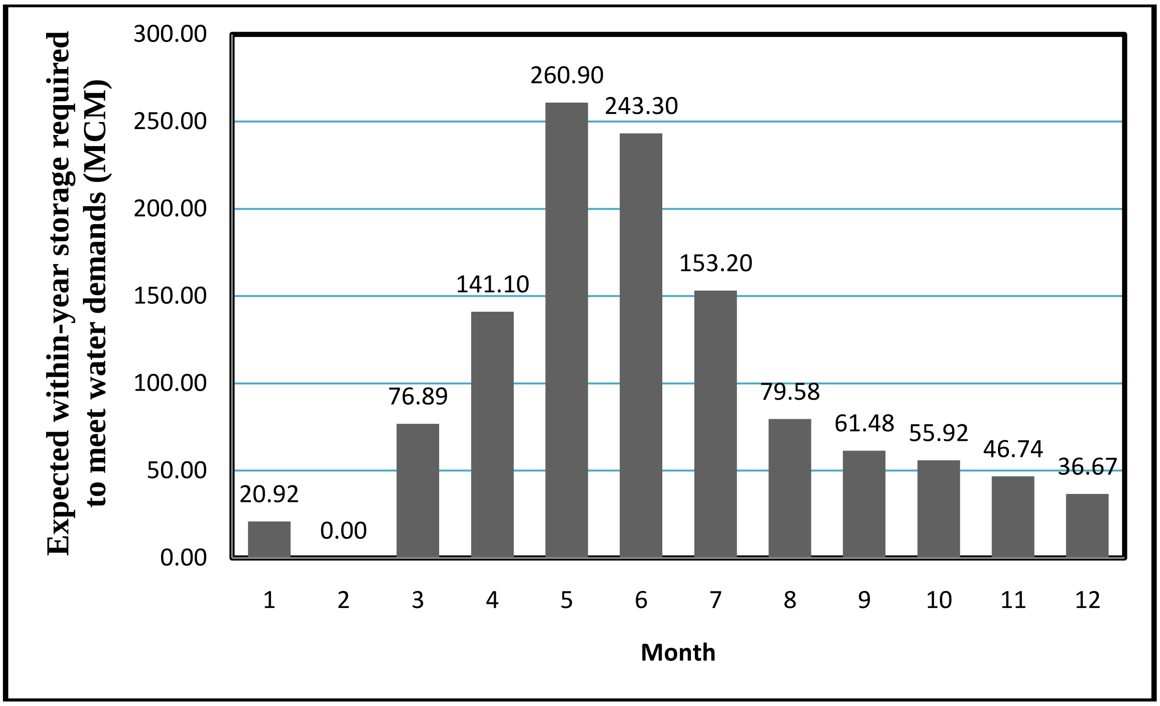

Fig.-7.4.K.2 (a) Expected Within-Year Storage to Meet Water Demands at Transfer Point-6 (Srisailam)

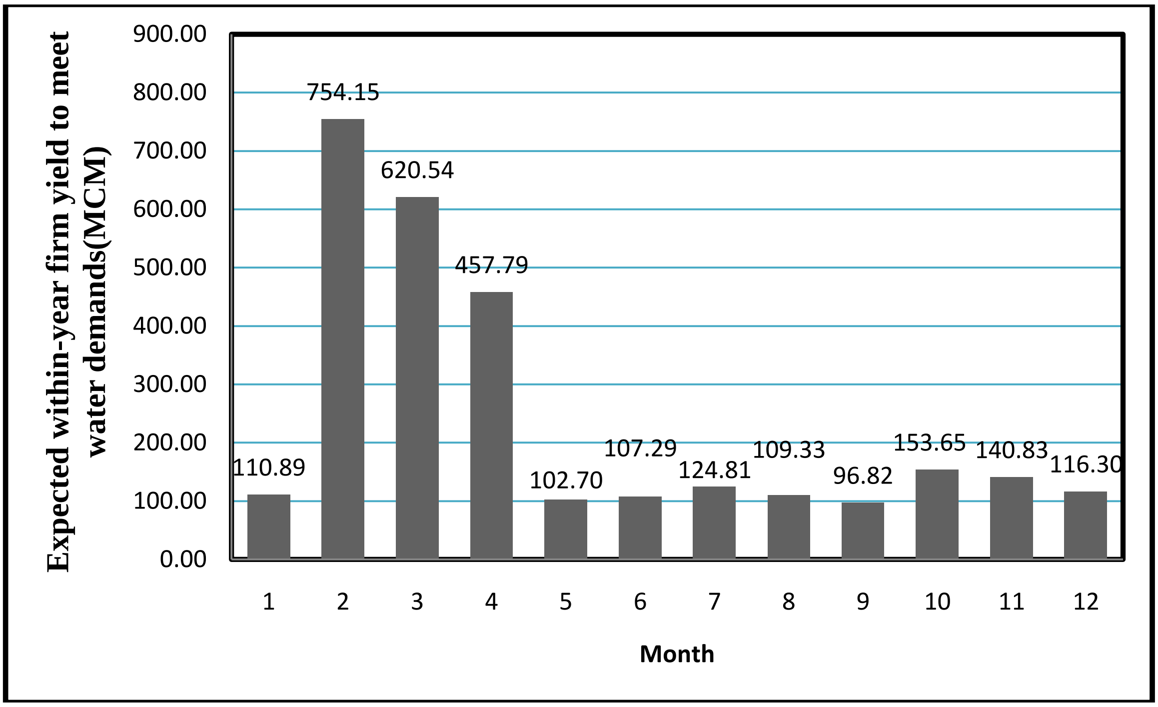

Fig.-7.4.K.2 (b) Expected Within-Year Firm Yield to Meet Water Transfer Point-6 (Srisailam)

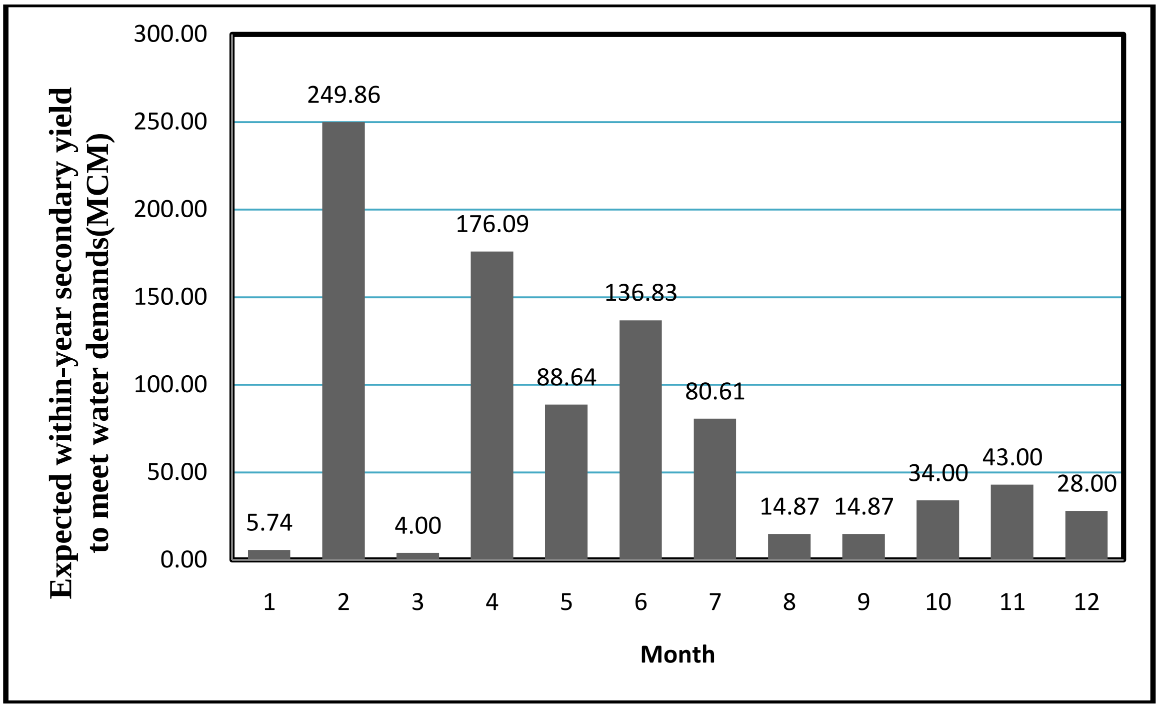

Fig.- 7.4.K.2(c) Expected Within-Year Secondary Yield to Meet Water Demands Transfer Point-6 (Srisailam)

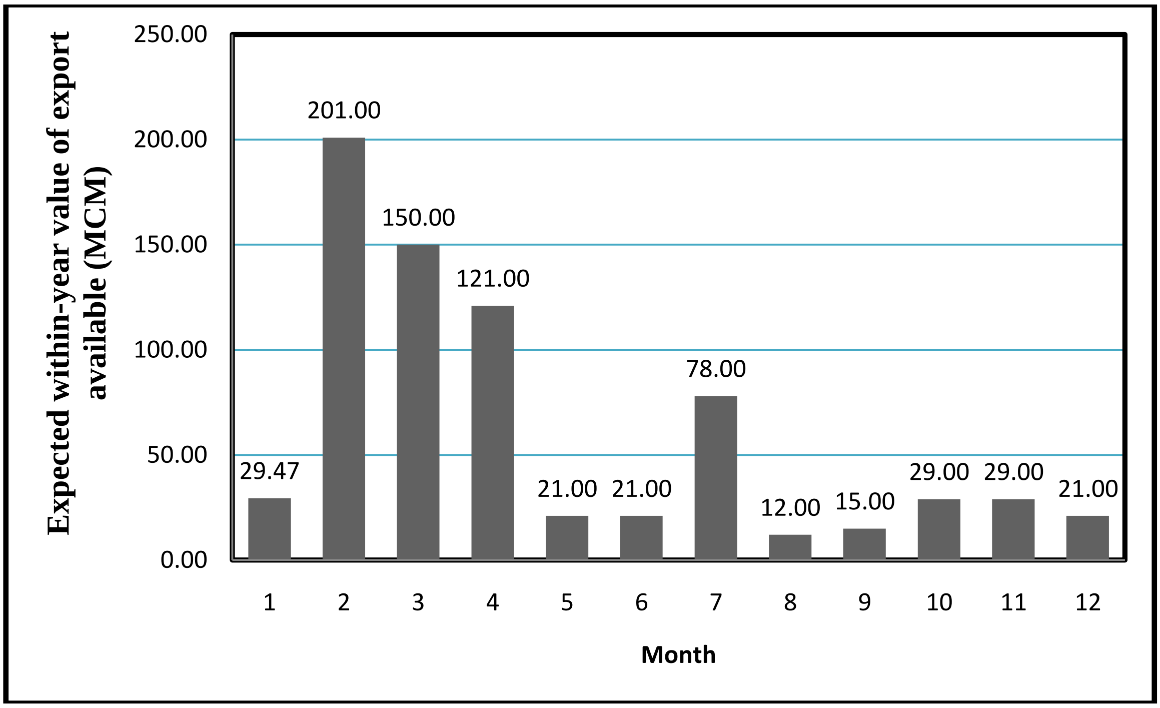

Fig.-7.4.K.2 (d) 1 Expected Within-Year value of available export at atTransfer Point-6 (Srisailam)

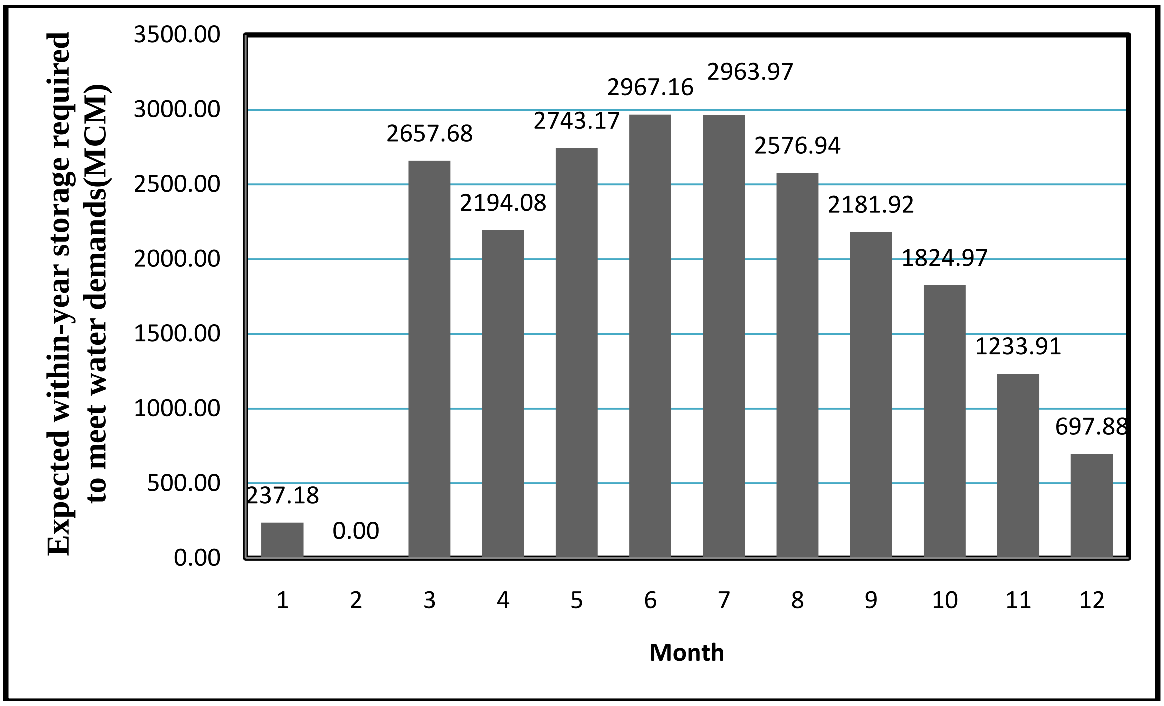

Fig.- 7.4.K.3(a) Expected Within-Year Storage to Meet Water Demands at Transfer Point-7 (Nagarjunasagara)

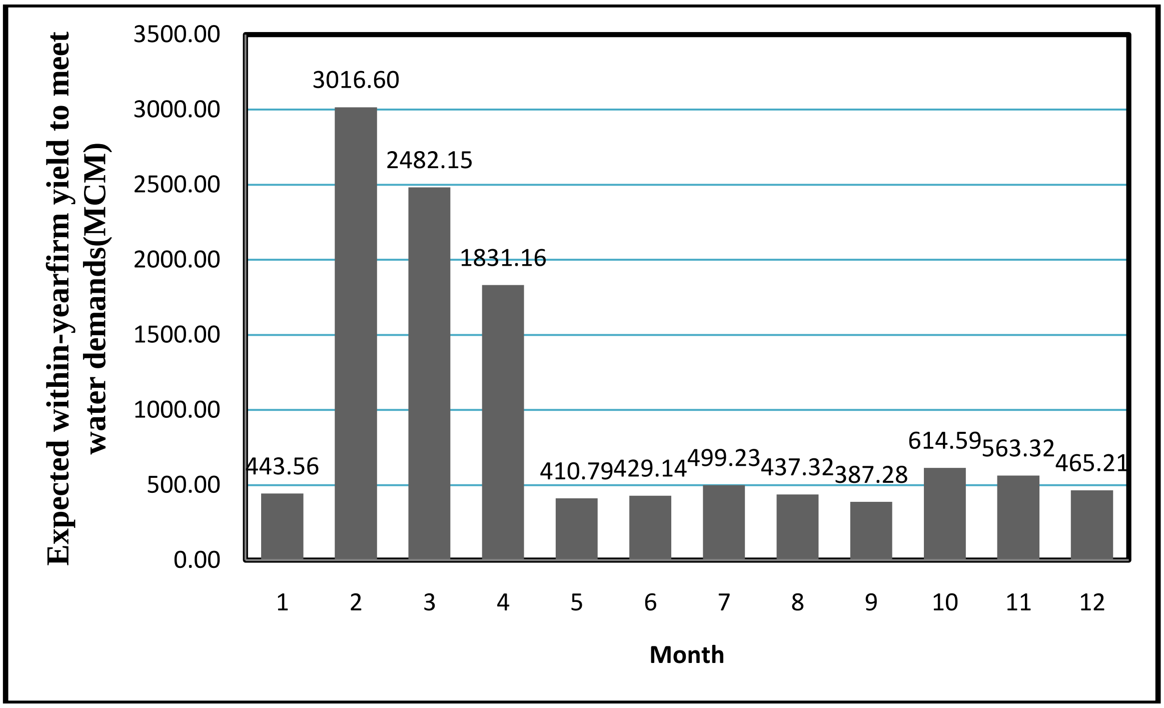

Fig.-7.4.K.3 (b) Expected Within-Year Firm Yield to Meet Water Demands at Transfer Point-7 (Nagarjunasagara)

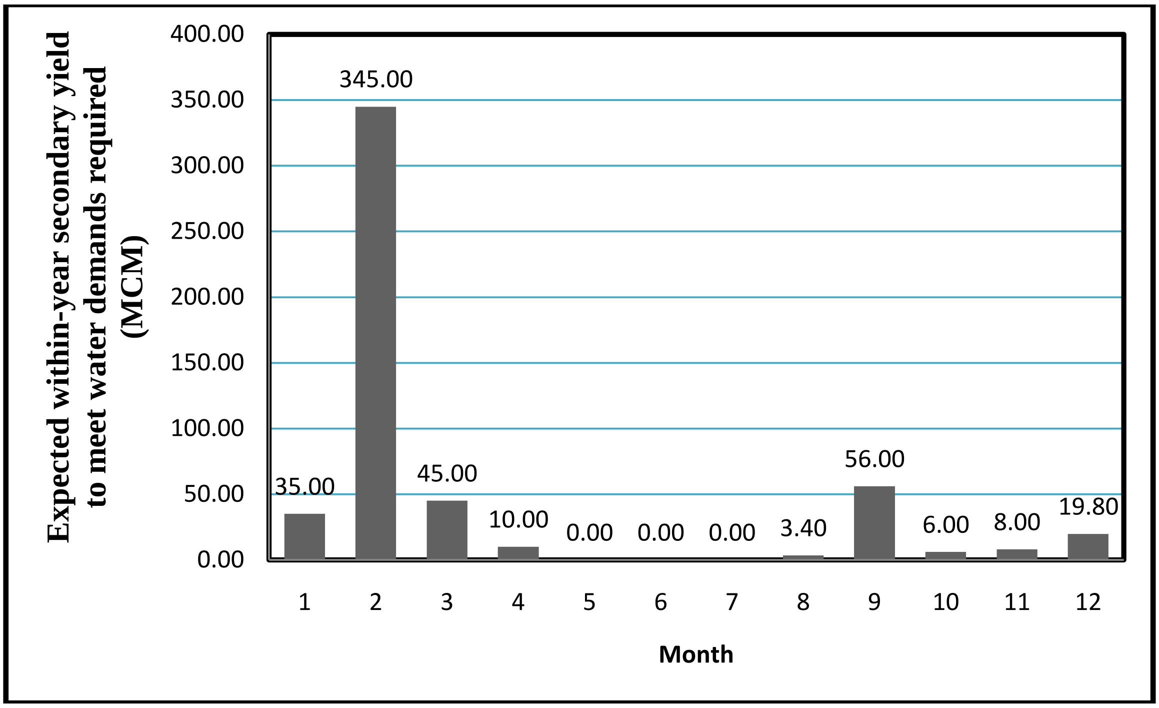

Fig.7.4.K.3(c)Expected Within-Year Secondary Yield to Meet Water Demands at Transfer Point-7 (Nagarjunasagara)

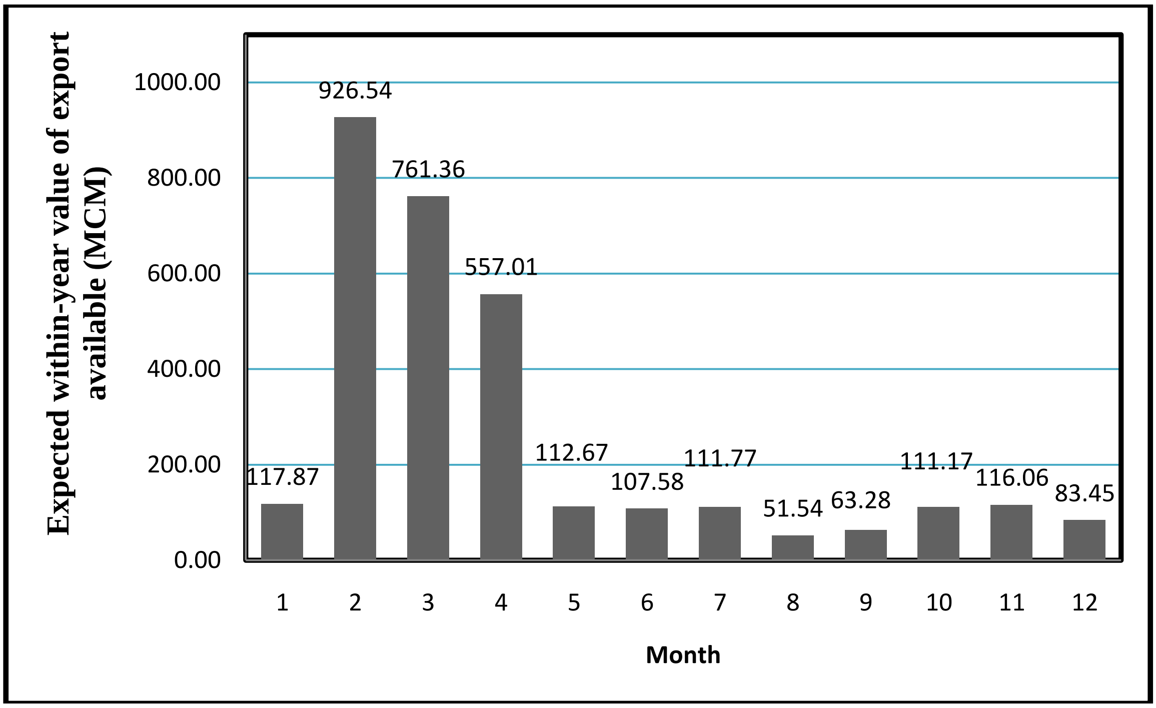

Fig.7.4.K.3 (d). Expected Within-Year value of available export at Transfer Point-7 (Nagarjunasagara)

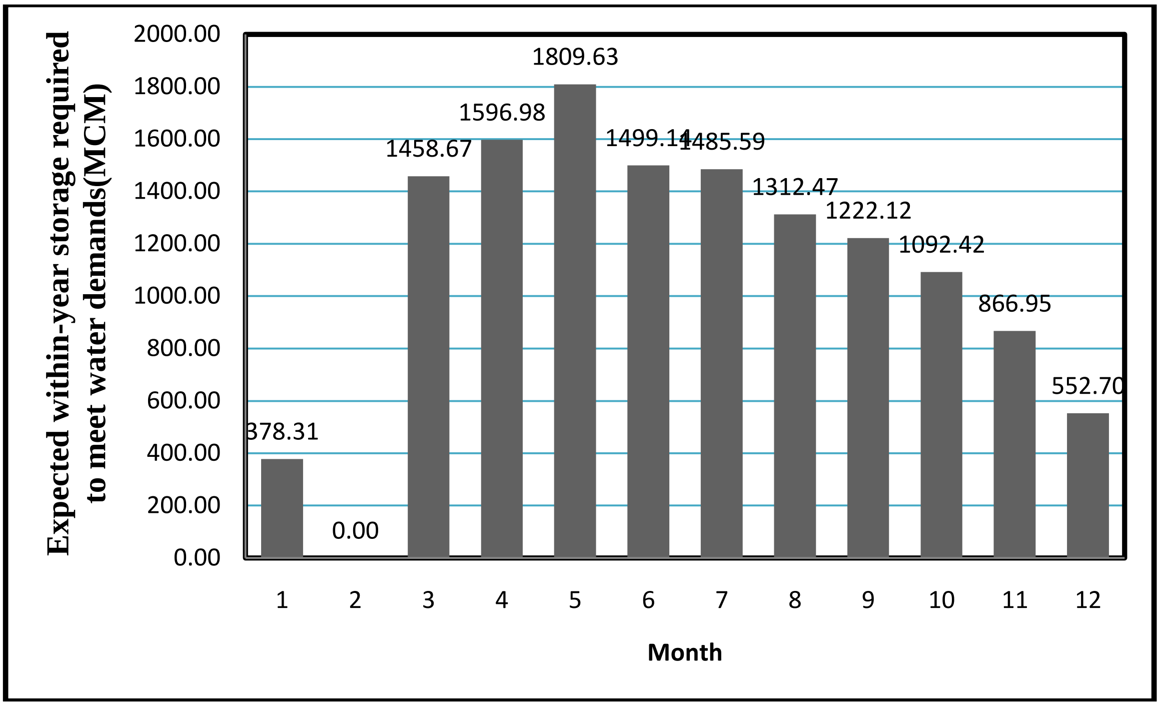

Fig.-7.4.P.1 (a) Expected within-year storage required at the Transfer Point-8 (Somasila)

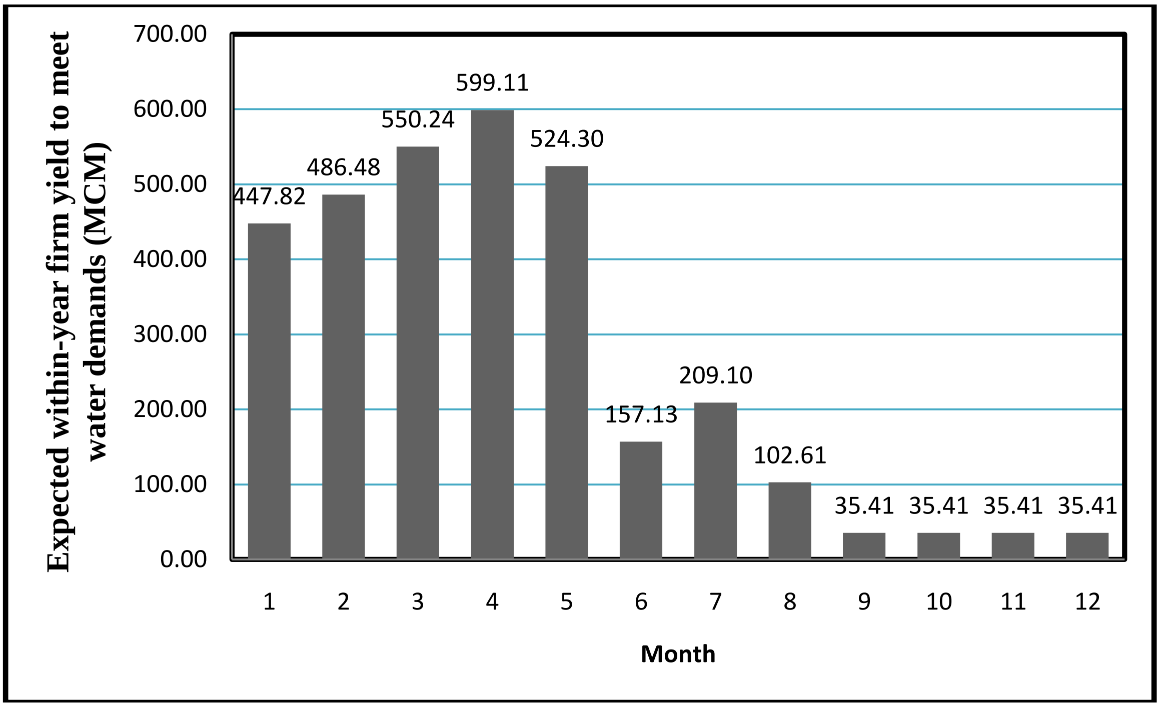

Fig.-7.4.P.1 (b) Expected within-year firm yield at the Transfer Point-8 (Somasila)

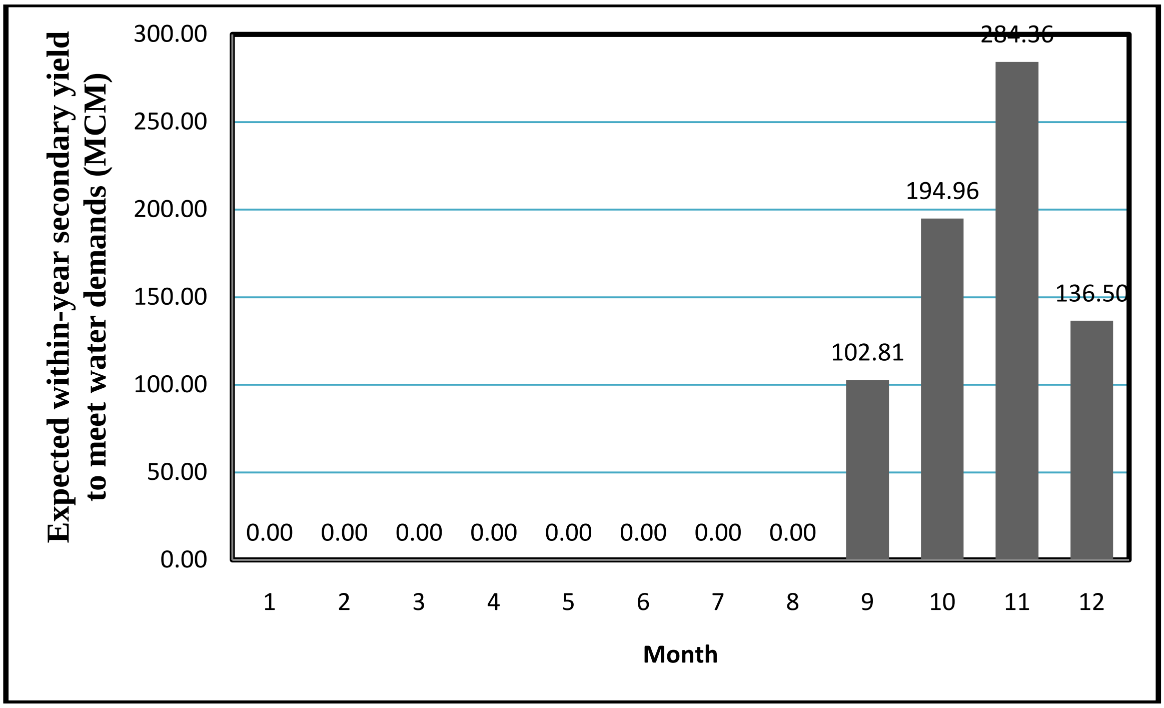

Fig.- 7.4.P.1(c) Expected within-year Secondary yield at the Transfer Point-8 (Somasila)

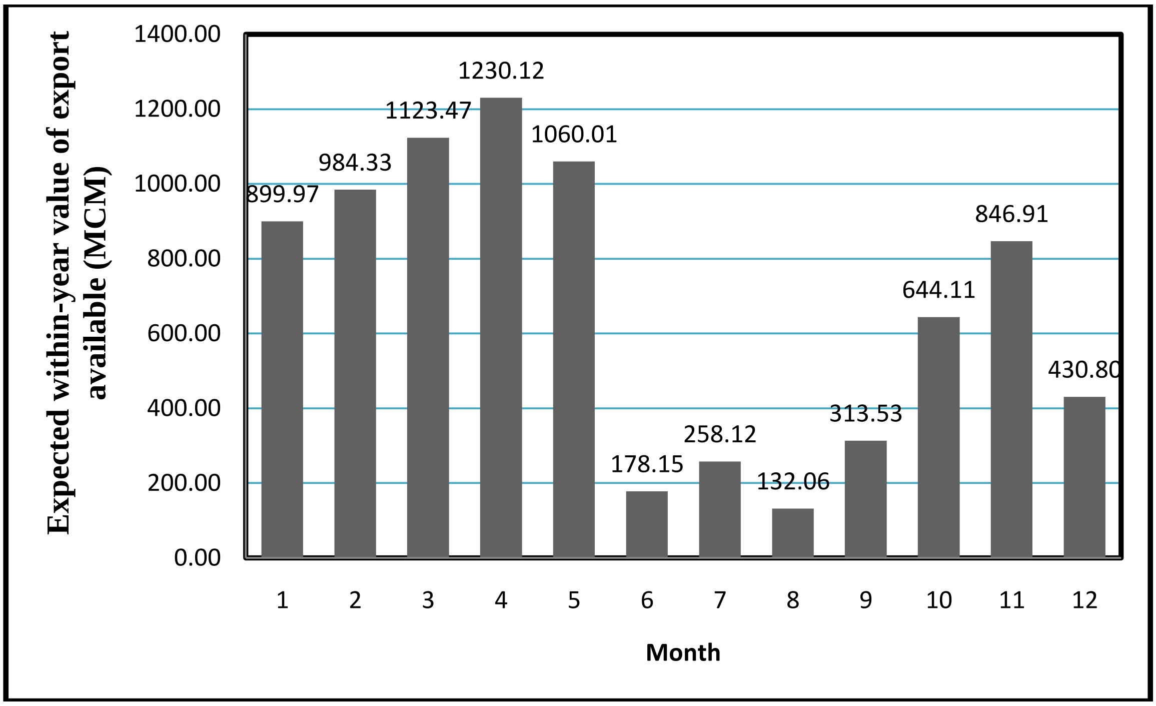

Fig.-7.4.P.1 (d) Expected within-year value of available export at the Transfer Point-8 (Somasila)

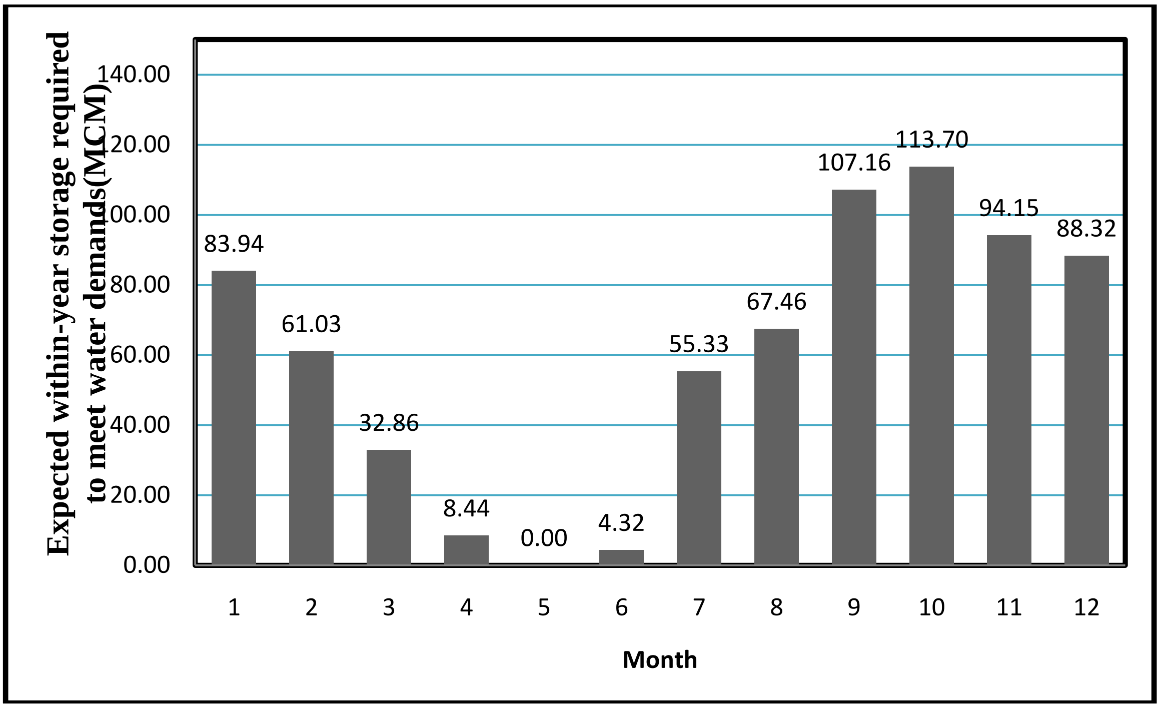

Fig.-7.4.C.1 (a) Expected within-year storage required at the Transfer Point-9(Kattalai)

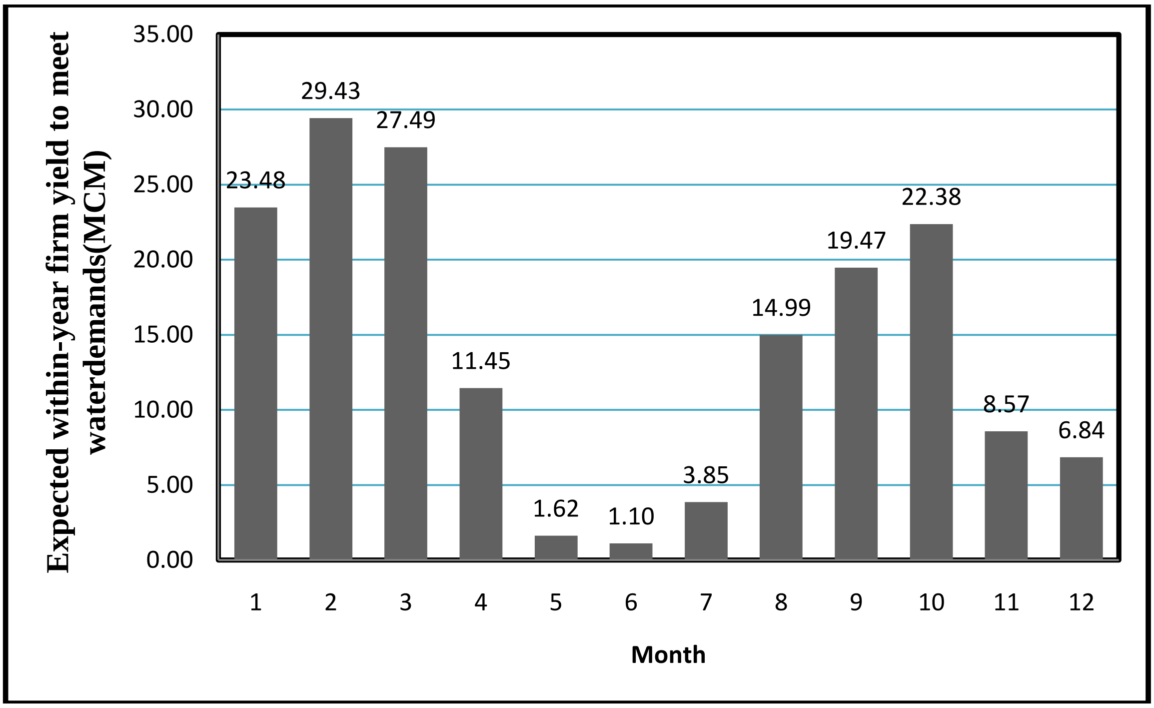

Fig.-7.4.C.1 (b) Expected within-year firm yield at the Transfer Point-9(Kattalai)

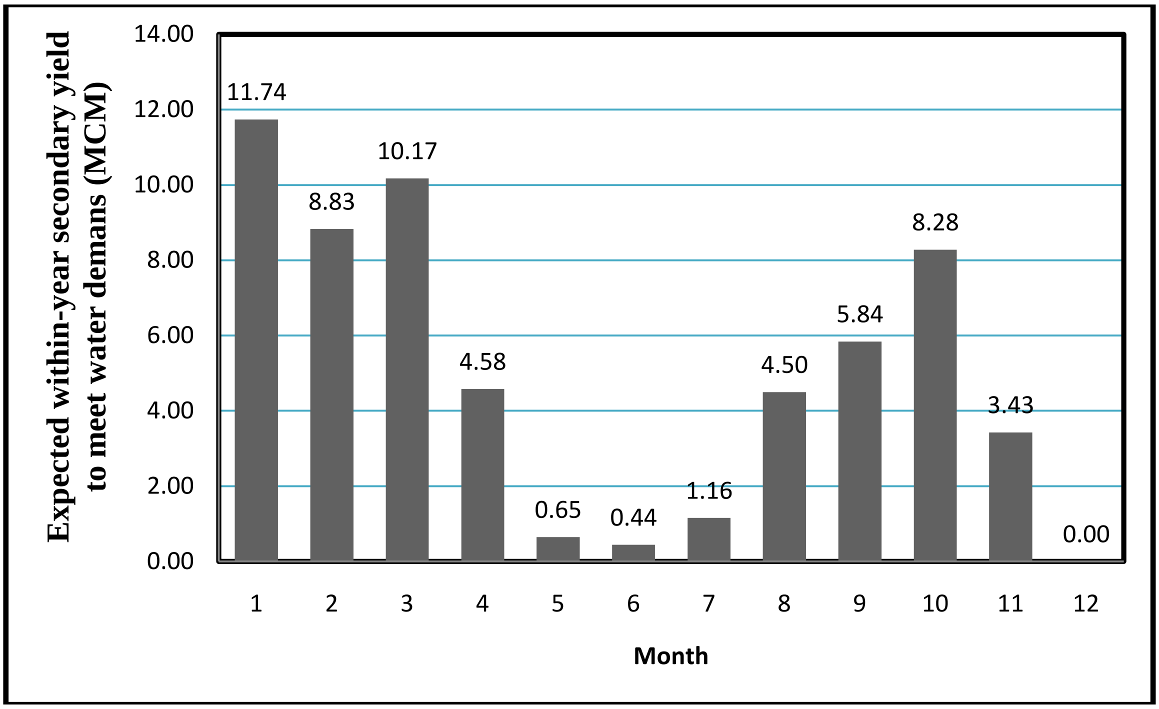

Fig.- 7.4.C.1(c) Expected within-year Secondary yield at the Transfer Point-9 (Kattalai)

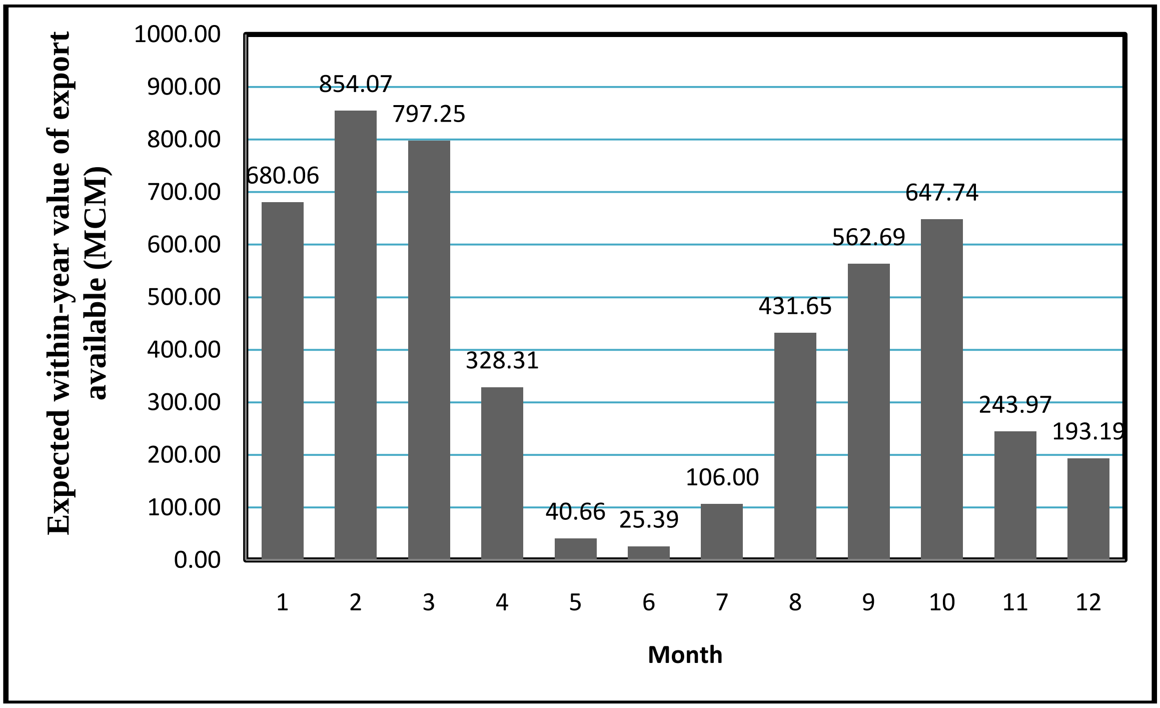

Fig.-7.4.C.1 (d) Expected within-year value of export at the Transfer Point-9 (Kattalai)

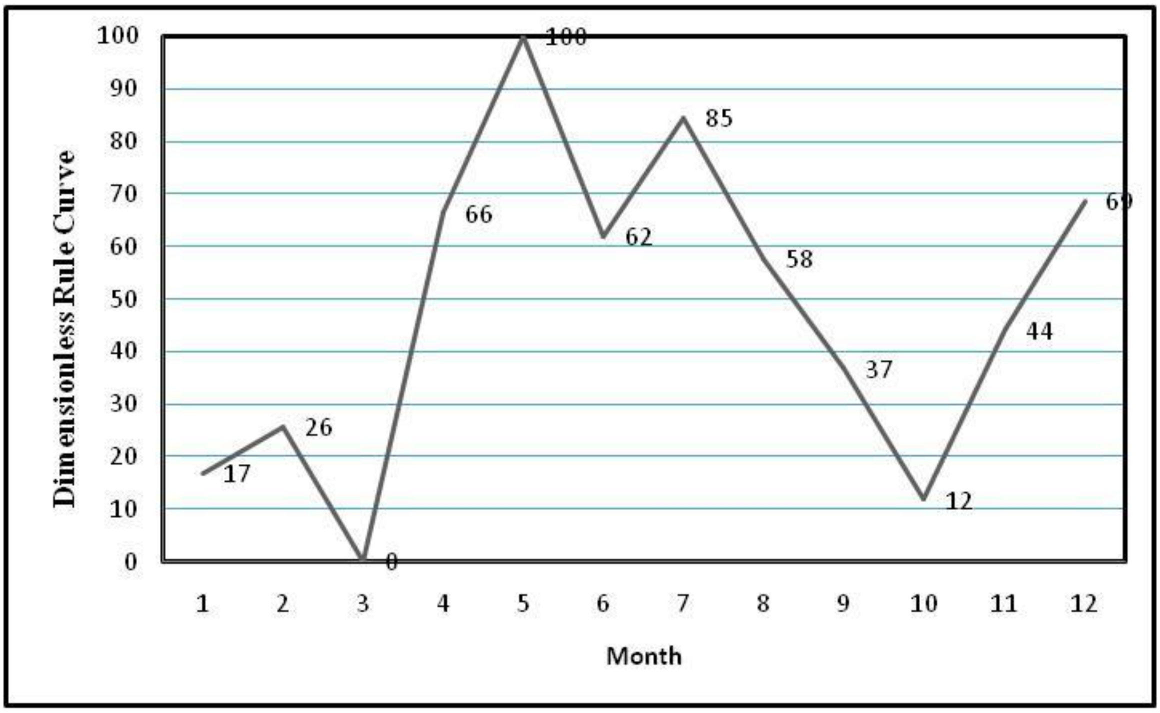

Fig.-7.5.1 Dimensionless rule curve at the Transfer Point-1(Manibhadra)

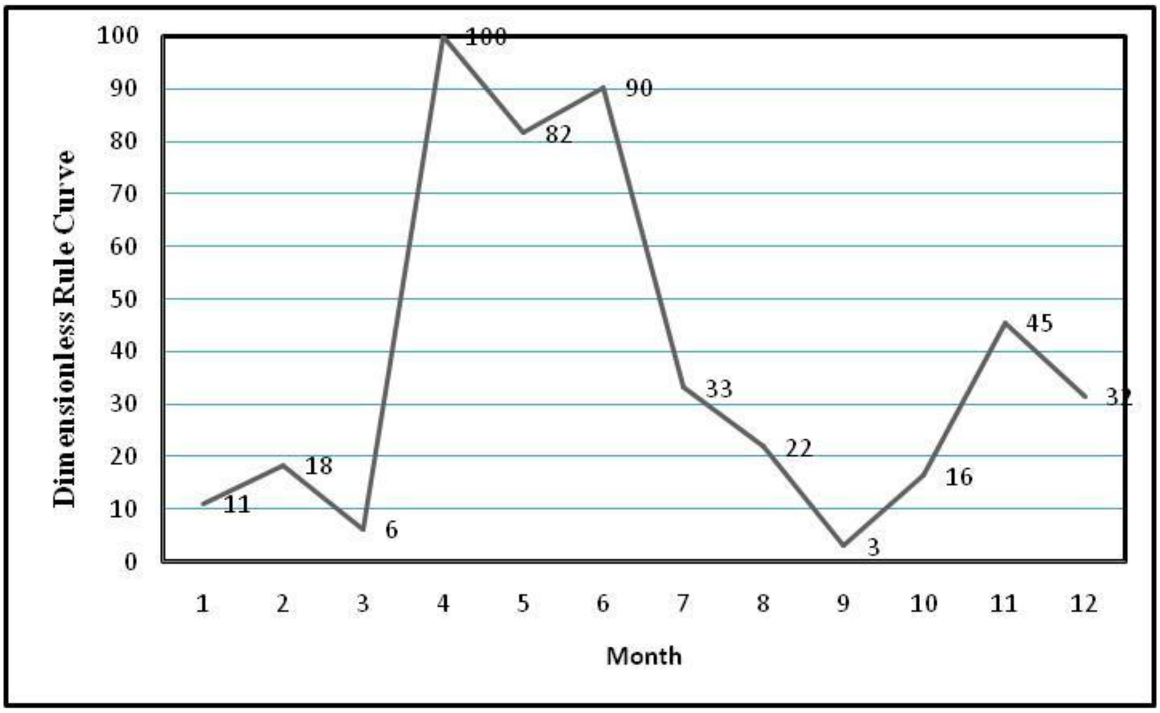

Fig.-7.5.2 Dimensionless rule curve at the Transfer Point-2 & 3(Inchampalli)

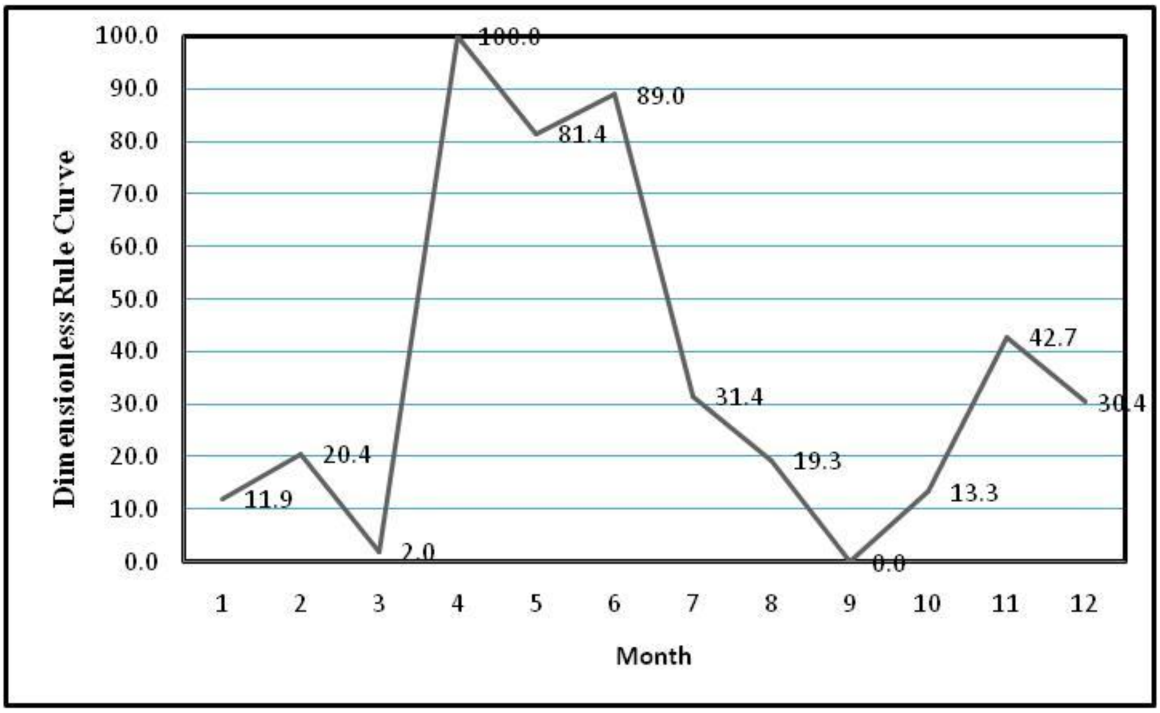

Fig.-7.5.3 Dimensionless rule curve at the Transfer Point-4 (Polavaram)

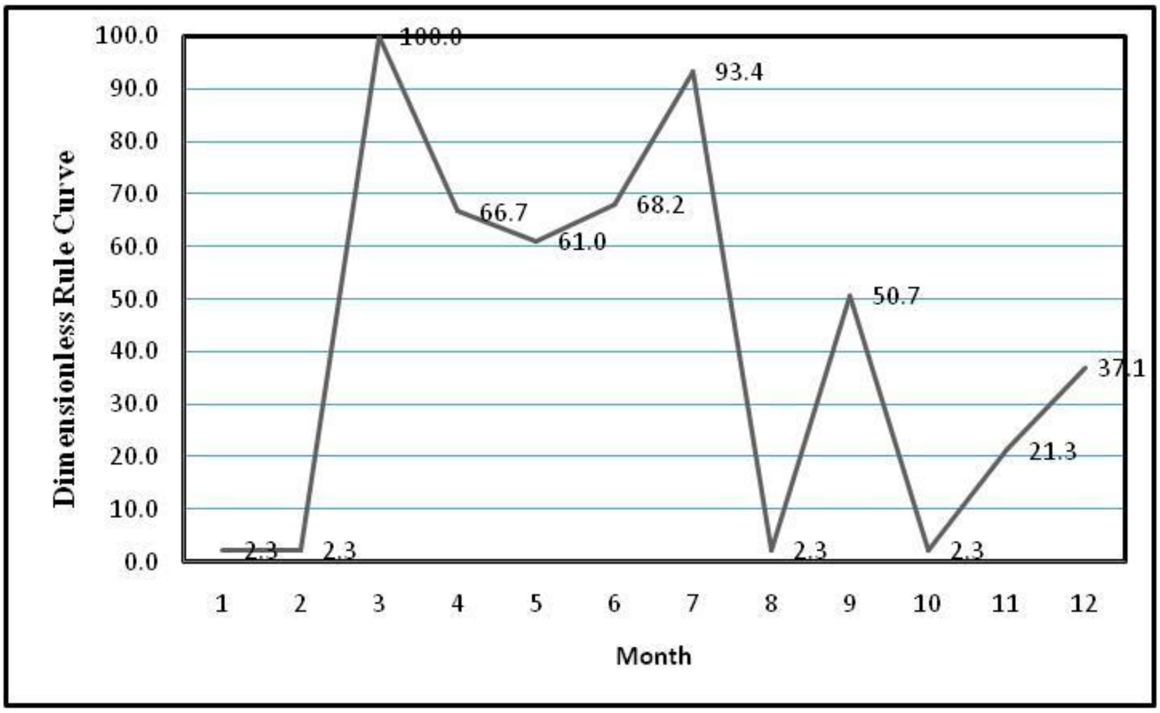

Fig.-7.5.4 Dimensionless rule curve at the Transfer Point-5 (Almatti)

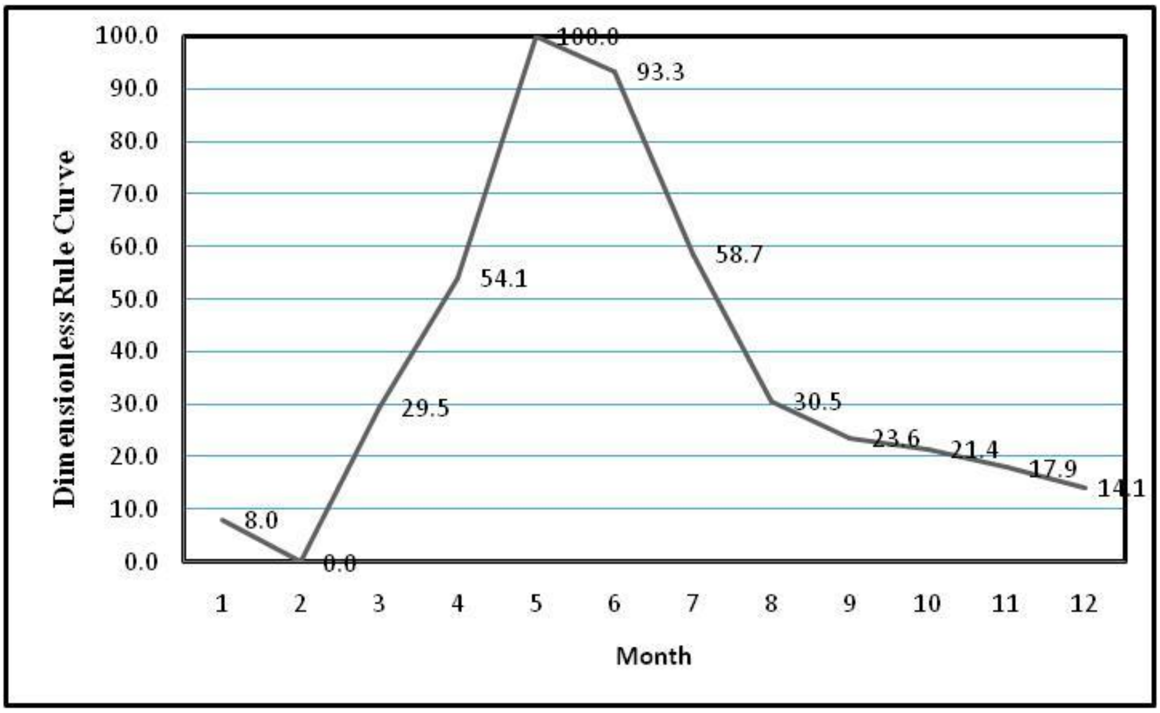

Fig.-7.5.5 Dimensionless rule curve at the Transfer Point-6 (Srisailam)

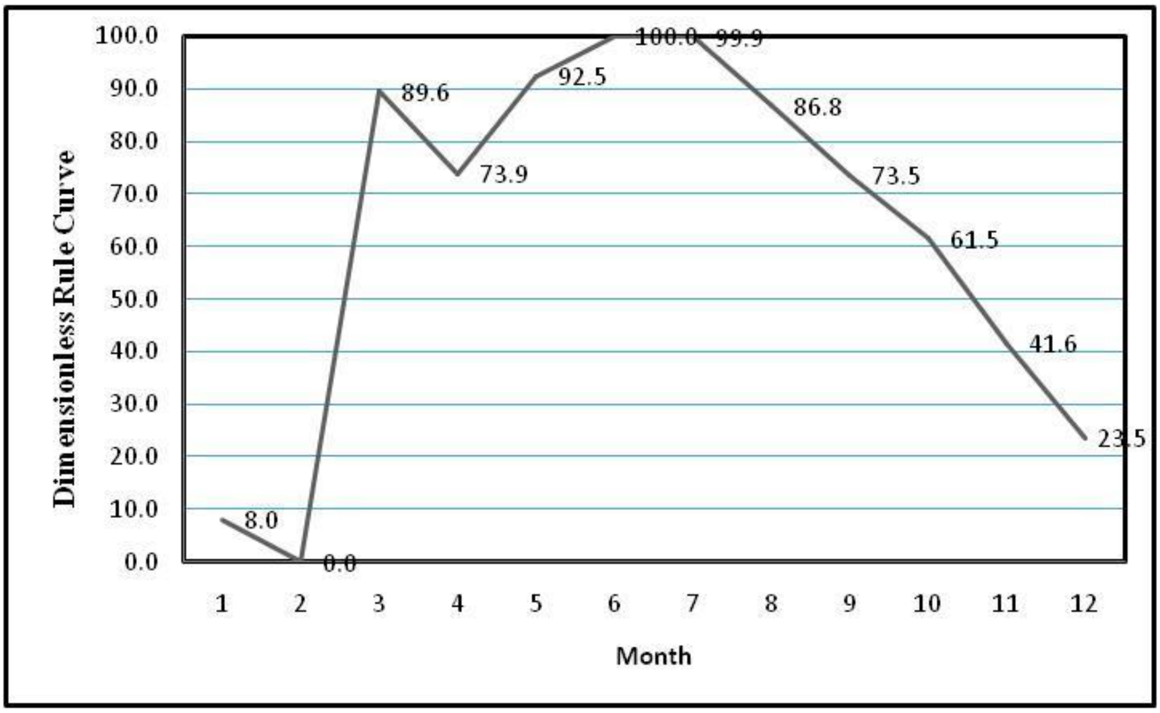

Fig.-7.5.6 Dimensionless rule curve at the Transfer Point-7 (Nagarjunasagara)

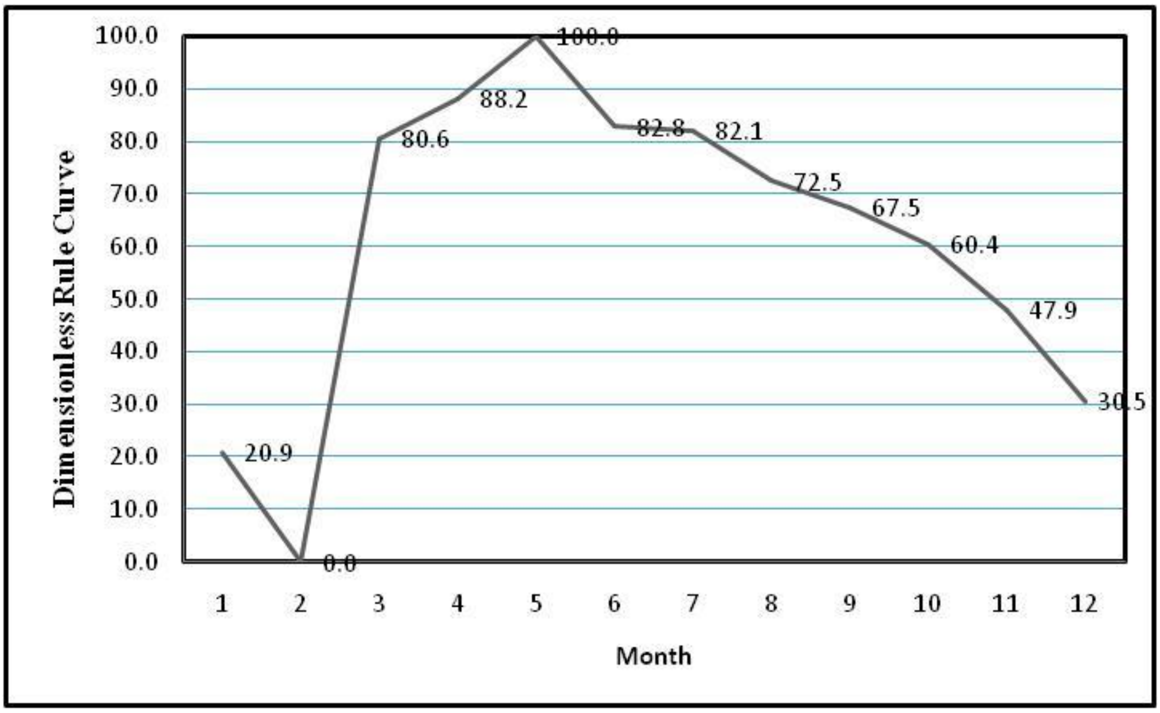

Fig.-7.5.7 Dimensionless rule curve at the Transfer Point-8 (Somasila)

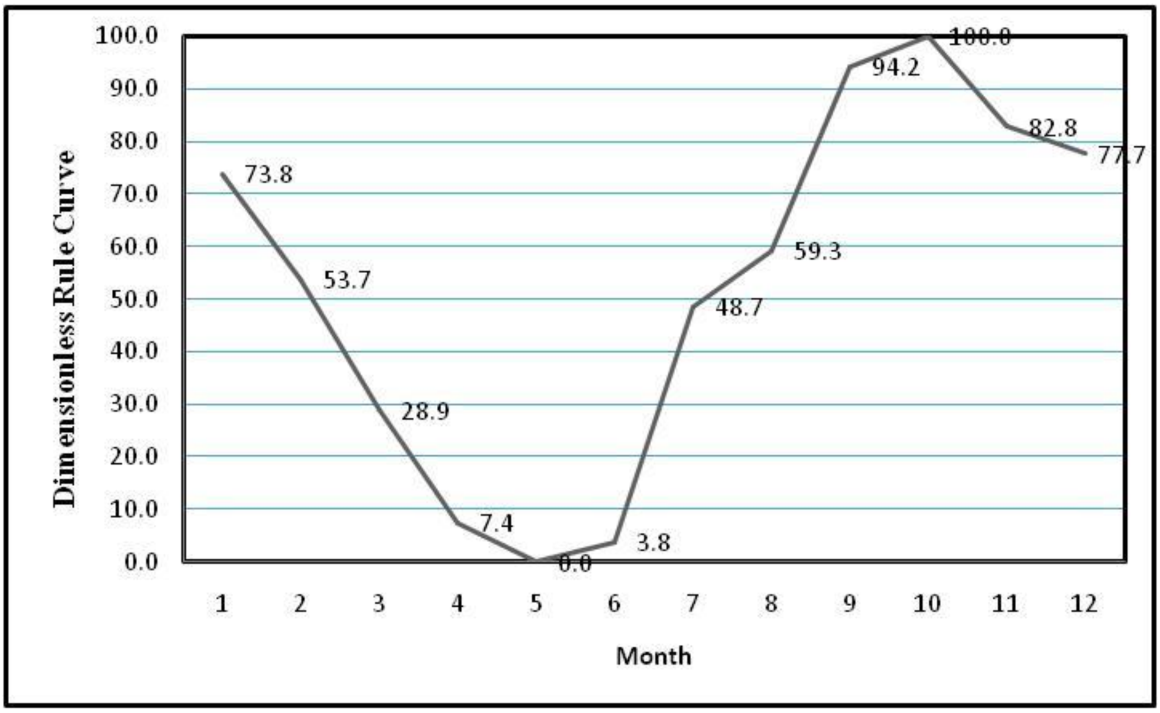

Fig.-7.5.8 Dimensionless rule curve at the Transfer Point-9 (Kattalai)

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 SUMMARY

A study was undertaken on large scale water transfers in space and time. The system under consideration was the peninsular trans-boundary river system in India consisting of five major river basins, i.e., Mahanadi, Godavari, Krishna, Pennar and Cauvery. This chapter discusses the summary of the research work carried out and the conclusions reached thereafter. The discussion is based on the analysis presented in the Chapter-7.

8.1.1 General

Optimal water utilization is the need of today due to increasing water demands, the reason being the availability of water which is not uniformly distributed in space and time, and has also become scarce. Therefore a study was undertaken for integrated river basin development for their water resources utilizations for large rivers in Indian. The specific emphasis was on transferring surplus waters from water surplus basins to water deficit basins.

8.1.2 The Modeling Approach

(1) In planning water transfers from a river basin with surplus waters to a water deficit basin, some of the studies available have used conventional water balance of rivers. The water balance first estimates their water availability or their water potentials, and then establishes the type of basin in terms of being water surplus or deficit. Such water balance is carried out at a specified site, generally at a point from where the water transfer is being proposed. This river basin water balance is between the amount of water available in the basin and the basin's total water requirements up to the specified site under consideration. The criteria is based on annual (or water year) basis for a given annual (or water year) project dependability.

First step is to estimate virgin flow at the specified site. Second step is to estimate the basin's total future water requirements, which include domestic, irrigation, industrial, irrigation and evaporation losses in hydropower project with storage etc. Usual practice then is to select a dependability of 75% for determining the available water yield of the basin to meet these requirements. The 75% water year dependability is chosen because the major portion of the water being diverted is for the use of irrigating purposes. Various exports of water from the basin and the imports from the basin are also are estimated. In all these no consideration is given to the variability in water availability and the water demands in respect of space and time. Basically the procedure adopted is a lumped approach.

Finally the water balance at the specified site is done in the following manner:

Water balance = (The 75% annual water year dependable yield of the catchment + Regeneration + Imports) – (Export + Total water needs).

The amount of the water balance will determine the surplus or the deficit in the basin at that specified site.

(2) The National Water Policy of Ministry of Water resources, Government of India has emphasized that the water resources available to the country should be brought within the category of utilizable resources to maximum possible extent. As per this policy, the following is achieved:

(1) The resource planning in the case of water has been carried out for a hydrological unit, such as at each sub-basin level and then at the basin as a whole. To achieve this, all the major individual developmental reservoir projects formulated by the states and considered within the frame work of such an overall plan for a basin or sub-basin were analyzed, so that the best possible combination of options of water use was made available.

(2) Comprehensive analysis was carried out taking into account not only the needs of the environmental water needs; M&I water supply, irrigation etc. After taking into account the requirements of the areas/basins due consideration was given for water to be made available to water short areas by transfer from other areas including transfers from one river to another, based on a national perspective.

(3) In the present study the linear programming (LP) technique was employed as an optimization, the reason being its applicability to handle large size optimization problems for their solution. The model is based on the reservoir yield model approach, earlier used by various researchers, which is being presented in a generalized form now. The model considers over the year and within the year reservoir storages separately, and provides as well the within the year firm and secondary reservoir releases. The firm reservoir release also takes care of the minimum food requirements of the people in the concerned region, especially the farmers. The release of water towards meeting of the downstream environmental

is made mandatory. The project dependability (reliability) is pre-assigned by defining project's success and failure in terms of successful and failure years. In this study the water-year project dependability taken is 75%. A provision of export and import of water is also being made in the model.

(4) Analysis of the results obtained was carried out in detail. The assessment of the results followed the following guidelines.

(i) The results of the crops involved are assessed and analyzed at the reservoir project levels, at the sub-basin levels and at the crop levels for each of the basins. At the reservoir project level the assessment is based on the modeled total cropped intensities. At the sub-basin level this is done on the basis of the modeled average cropped intensities. The later criterion is also followed while analyzing at the cropped level. At places the expected probability of exceedance of some of the items are presented for the maximum and the minimum values achieved.

(ii) The results for the within-year reservoir storages are assessed and analyzed at the basin level. The reservoir storages considered for this purpose are the expected total reservoir storage available in the entire basin system for each of the within-year periods.

(iii) The results for the within-year reservoir firm and secondary yields are again assessed and analyzed at the basin level. The criteria used were same as that in case of the within-year reservoir storages. Therefore the reservoir firm and secondary yields considered for this purpose are the expected total yields available in the entire basin system for each of the within-year periods.

(iv) The analysis at the water export points are for the expected (a) within-year reservoir storages, (b) within-year reservoir firm and secondary yields and (c) within-year export values to be made available from the concerned reservoir.

8.1.3 The Assessment of Results

The abstracts of the model results in respect of the cropped areas in the Tables from 8.1.3.1 to 8.1.3.3, and for the outcomes of the results at the various export points are given in the Tables from 8.1.3.4 to 8.1.3.5

8.2 CONCLUSIONS

From the study the following conclusions are arrived at:

8.2.1 The Cropped Areas

The following would be achieved in respect of the cropped areas at different levels in the entire system:

(i) The reservoir **Lower Bhabani** in the sub-basin of **Bhabani** and in the basin of **Cauvery** has the highest intensity of irrigation with a value of **2.3**. Similarly, the reservoir **Pimpalgaon Joge** in the sub-basin of **Upper Bhima** in the basin **of Krishna** has the lowest intensity of irrigation with a value of **0.003**.

(ii) The sub-basin **Lower Krishna** in the basin of **Krishna** has the highest average intensity of irrigation with a value of **0.208**. Similarly, the sub-basin **Upper Bhima** in the basin **Krishna** has the lowest average intensity of irrigation with a value of **0.053.**

(iii) The crop **Cotton** in the in the basin **Pennar** has the highest average intensity of irrigation with a value of **0.35**. Similarly, the crop **Safflower** in the in the basin **Krishna** has the lowest average intensity of irrigation with a value of **0.022**.

8.2.2 The Basin Storage and Yield

(iv) The basin **Godavari** has the highest value of the total within year storage in the month of **November**. Similarly, the basin **Krishna** has the lowest value of the total within year storage in the month of **July**.

(v) The basin **Mahanadi** has the highest value of the total within year firm yield in the month of **July**. Similarly, the basin **Cauvery**has the lowest value of the total within year firm yield in the month of **December.**

(vi) The basin **Godavari** has the highest value of the total within year secondary yield in the month of **July**. Similarly, the basin **Mahanadi** has the lowest value of the total within year secondary yield in the month of **November.**

8.2.3 The Water Export Points

(a) The various water export points would achieve the following towards meeting their respective water export target demands:

(1) Water export point-1 at the project Manibhadra is expected to meet 100% of its proposed annualexport target demand.

(2) Water export point-2 & 3 at the project Inchampalli is expected to meet 6.7% of its proposed export target demand.

(3) Water export point-4 at the project Polavaram is expected to meet 41.53% of its proposed export target demand.

(4) Water export point-5 at the project Almatti is expected to meet 100% of its proposed export target demand.

(5) Water export point-6 at the project Srisailam is expected to meet 16.9% of its proposed export target demand.

(6) Water export point-7 at the project Nagarjunasagara is expected to meet 25.69 % of its proposed export target demand.

(7) Water export point-8 at the project Somasila is expected to meet 94.59% of its proposed export target demand.

(8) Water export point-9 at the project Kattalai is expected to meet 100% of its proposed export target demand.

(b) The various water export basins would achieve the following towards meeting their respective water export target demands:

(1) Mahanadi basin comprising the water export point-1 at the project Manibhadra is expected to meet 100% of its proposed annualexport target demand.

(2) Godavari basin comprising the water export point-2, 3&4at the projects Inchampalli and Polavaram is expected to meet 13.8% of its proposed export target demand.

(3) Krishna basin comprising of water export points 5, 6& 7 at the projects Almatti, Srisailam and Nagarjunasagara is expected to meet 100% of its proposed export target demand.

(4) Pennar basin comprising water export point-8 at the project Somasila is expected to meet 94.59% of its proposed export target demand.

(5) Cauvery basin comprising water export point-9 at the project Kattalai is expected to meet 100% of its proposed export target demand.

8.3 THE MAJOR CONTRIBUTIONS FROM THE PRESENT STUDY

8.3.1 The Problem at Hand and Need of the Systems Analysis Study

Systems studies are needed for the optimal evaluation of water utilizations and water export potentials of various interstate trans-boundary rivers in space and time under the constraints put by rivers' water disputes tribunal awards.

Advantages and use of linear programming (LP) based preliminary screening optimization models for planning and management of large complex water resources systems is already well established and acknowledged (Loucks et al., 1981; Chaturvedi and Srivastava, 1981; and Srivastava 1976). The number of system constraints and variables become very high, when a large number of single-purpose and multi-purpose reservoirs are present in the system. Therefore, one faces a very difficult task of modelling and solving the large integrated system for its solution. This cause basically restricted many in attempting such problems. Simulation should always follow the preliminary screening optimization models for further refinement for solution near to optimal (Wurbs 2005).

The working group on inter-linking of rivers recommends the application of systems analysis approach on the issues involving water utilizations and transfer of waters. This of course is a herculean and tedious task requiring a lot of expertise in the field of systems analysis.

8.3.1.1 The water availability a major basic planning issue

One should utilise water optimally. It mandates delivery of sustainable solutions for a better life. Rather than directing or conveying towards the water consumption through equal and judicious distribution, efficient and economic use is prioritized. This results in non-achievement of sustainable solutions towards a better water availability in respect of space and time.

Therefore, the major issue, in an integrated screening-simulation model study and analysis or otherwise, for arriving at better and reliable model solutions, most importantly is the water availability. It's the question of the supply vs. demand and, not the demand vs. Supply. Surly a Plan should be supply based and not on demand. But, the water demand always prevails over supplies.

The task at hand is huge and enormous; is multi-disciplinary, multi-objective, and multi-stakeholders; is very data extensive, and must be available in useful and uniform format. The most important of all is a good and reliable estimation of the water availabilities at two levels in space and time within the system, i.e., firstly, as the river inflows available at every project site as inputs, and secondly, as the expected modelled multi-yields available from every reservoir as outputs for water use by its stakeholders.

8.3.1.2 Importance of the systems analysis approach

The screening-simulation models:

In the present study, the comprehensive generalized reservoir yield model (GRYM) for preliminary screening purpose is employed. The importance of the screening- simulation is explained below:

The comprehensive preliminary screening models: Systems analysis for integrated trans-boundary river basin water resources developments with multi-reservoir system, using linear programming (LP) optimization based approximate reservoir yield model is a new methodology. There are a large number of well known problems related to the expected behavioural aspects of integrated multi-reservoir system in a river basin. Out of the large information available from the solutions of these optimization models, up to a large extent, detailed in-depth answers for many such untold aspects can be derived (Srivastava 2013).

The versatile simulation model: System analysis using simulation model for river basin water resources development consisting of multi-reservoirs is very effective, efficient and more realistic, is non-linear and truly represents the system's behaviour of the system being analyzed. It provides a large number of important information regarding physical behaviour of the system being analysed.

Simulation is essentially a trial and error search process, for obtaining a better solution of the problem at hand in the simulation. For the simulation the first question to be answered is, from where to start making search (the initial base to start with, or the initial values of system's design variables to start with).

Mere simulation alone can't excel without prior screening by optimization (using preliminary screening using LP based reservoir yield models). In simulation, there are several hundred plus system design variables present to be sampled. It's purely a trial and error process of making searches (non-systematic search). It doesn't ever guarantee you an optimal answer. Thus, the optimization model mainly provides a starting base (the answer to the first question, i.e., gives beforehand the initial guess for values of various system design variables; so a relief to the analyst) for the simulation process to start. This is most essentially mandatory and important (Chaturvedi and Srivastava 1981, Srivastava 1976, Srivastava and Patel 1992).

Therefore, preliminary screening of infeasible and non-optimal developmental alternative plans, through optimization models, provide a great help to the simulation process in all the above three aspects (basic steps) of difficulties faced. Thereby, preliminary screening models give a lot of impetus to simulation's success.

8.3.2 Present Studies' Contributions and Outcomes

Systems analysis for integrated trans-boundary river basin water resources developments with multi-reservoir system, using linear programming (LP) optimization based approximate reservoir yield model is a new methodology. There are a large number of well known problems related to the expected behavioural aspects of integrated multi-reservoir system in a river basin. Detailed in-depth answers for many such intricate aspects can be derived from the enormous information available from the solutions of these models (Srivastava 2013).

The research work in this present thesis on integrated systems optimization studies, using GRYM, contribute in achieving and providing optimally the answers to the following intricate behavioural aspects of the peninsular trans-boundary river system in India consisting of five major river basins, in respect of the large scale water transfers through nine Water Transfer Links in space and time:

(i) Detailed analysis of the expected multi-yields (firm and secondary) with their within-year distributions from each reservoir;

(ii) Detailed analysis of the expected cropping statistics (i.e., at each reservoir level, sub-basin/sub-basin levels and spatially, about (a) various cropping intensities and (b) various food produce, etc.) within the river system;

(iii) Detailed expected multi-reservoir operation policies i.e., for each reservoir during the within-year time periods

(iv) The expected statistics of the reservoir performance in terms of each reservoir's (a) either full condition (i.e., the month during the monsoon, if it spills or fills) or partial full condition (i.e., at the end of the monsoon, if it does not spill) and (b) empty condition during the non-monsoon, if any; and

(v) The expected quanta of the within-year time distributions of the water shares from each reservoir amongst the concerned specified multi-reservoirs involved in various disputed trans-boundary inter-basin river waters for allocating and diverting/exporting them among their respective riparian co-basin states.

Further, the expected findings estimates from integrated systems optimization studies would be:

(a) To provide a broad guidelines and platform to a planning manager for a better understanding of the systems' behaviour of the river's water resources.

(b) To find answers to many questions hitherto unanswered related to the water resources development in various river basins due to lack of approach or means.

(c) To make an overall plan for development of water resources in the basin/sub-basin within the provisions of tribunal award, water transfers, and all the water needs.

(d) Enhance the knowledge about the properties of the system's behavior in terms of the expected extents of the water availability and its utilization with respect to space and time.

(e) Open more desirable alternative long term perspective developmental alternatives for comprehensive planning, which is certainly going to encourage, boost and assist in better developmental prospects for increased utilization of the water resources potential in the river basin, leading towards water resources sustainability in the future in the region.

(f) Identify and set priorities for promoting water resource development projects.

8.4 OTHER IMPORTANT ISSUES IN AN INTEGRATED STUDY

The other major issues, in an integrated simulation study and analysis (valid also for the screening models as well) for arriving at better and reliable model solutions would be; firstly and most importantly the water availability and, secondly its utilisation are as follows:

(i) One major problem would be of common period river flows at various project sites (on a same river or among different rivers)

(ii) The analysis should be carried out at three different development scenarios (a) the existing, (b) the ongoing, and (c) the future.

(iii) All the project sites (reservoirs) involved need to be studied and analysed, following project by project analysis and so on, under a broader scenario of developments.

(iv) In the prior screening by LP optimization model before simulation, consideration is required, to study various dependable water-year flow conditions; i.e., normal flow (the 75%), average flow (the 50%), surplus flow or a wet condition (say, the 10%) and low flow or dry condition (the 90% or 100%). This is very essential, for the simulation to succeed, which would provide the range of various system variables involved, for preparing the samples for various trials during the simulation, before some compromise developmental solution is arrived. This of course would certainly need a considerable computational time and effort.

(v) The systems analysis work using screening-simulation models for optimal sustainable trans-boundary river basin water resources development is very huge, manifold, time consuming, exhausting, cumbersome, and a herculean task; requiring excessive prior data processing and analysis, and then the required modeling

(vi) The optimization model is very approximate in nature.

8.5 ASSUMPTIONS AND CONSIDERATIONS

In addition to the general assumptions of hydrometeorologic similarity among some of the nearby segments of the system and applicability of linear programming (LP), the following assumptions have been made:

(i) Location of most the minor irrigation projects are known. But that of very small schemes like those of ponds, tanks and few rain fed channels are not known. The scale of study is so large (197 major projects) that even the contributions of medium projects have not been considered individually for brevity and have been lumped alongwith the minor irrigation projects for evaluation of their contributions.

(ii) Data on crop water requirement, that are available for respective sub-basins, are assumed to be same for all the projects situated in that sub-basin.

(iii) Unless otherwise available at individual sites, the meteorological parameters like monthly evaporation data etc. of a sub-basin are also applicable for the all the sites of that sub-basin.

(iv) The return flows from surface irrigation are considered uniformly at 10%.

(v) An important assumption in the adopted methodology is that the flows, as analyzed in the study, are independent and, therefore, do not possess internal dependence. The same has also been reiterated by Loucks et al. (1981)

8.6 SCOPE FOR FURTHER STUDIES

1. Scope of the study was limited to only surface water resources of river basin. A study needs to be carried out for conjunctive use of surface water and ground water for the entire basins.

2. Only major projects have been taken in the study. However, the scope can be widened to include medium projects as well. Although this will make the problem even larger and more complex, veracity of applicability of the model can be put to further test.
3. Simulation being the more realistic is recommended for further refining various aspects of the problem using the results of yield model.
4. Since the Inter Basin Water Transfers involves social, environmental, displacement and rehabilitation issues, further studies can be undertaken on these aspects.
5. Multi objective analyses can be carried out to present feasible alternatives to decision makers.

Table 8.1.3.1 Abstract of total cropped intensity achieved at reservoirs at basin level

Sl. No.	**Basin Name**	**Sub-Basin Name**	**Reservoir Name**	**Total Cropped Intensity Achieved**			
				Maximum	**% Exceedance**	**Minimum**	**% Exceedance**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
1	M	U	DH, SN, PR, LT and KL	1.500	26%	-	-
		S	KH, DK, KN and SG				
		J	JD				
		D	MD and KU				
		L	MB				
		S	TN	-	-	0.023	98%
2	G	H	DN	1.414	1	-	-
		U	JW	-	-	0.242	98
3	K	L	PD	1.998	2	-	-
		B	PJ	-	-	0.003	97
4	C	B	LB	2.300	7	-	-
		U	HE	-	-	0.647	92
5	P	D	SS	1.000	-	1.000	-

Table 8.1.3.2 Abstract of total cropped intensity achieved at sub-basins at basin level

Sl. No.	Basin Name	Sub-Basin Name	Total Cropped Intensity Achieved				Average Cropped Intensity Achieved			
			Maximum	% Exceedance	Minimum	% Exceedance	Maximum	% Exceedance	Minimum	% Exceedance
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	M	T	13.275	9	-	-	-	-	-	-
		H	-	-	1.028	90	-	-	-	-
		D	-	-	-	-	0.190	9	-	-
		S	-	-	-	-	-	-	0.065	90
2	G	H	33.243	10	-	-	-	-	-	-
		N	-	-	1.000	90	-	-	-	-
		J	-	-	-	-	0.152	10	-	-
		R	-	-	-	-	-	-	0.0824	90
3	K	U	9.081	10	-	-	-	-	-	-
		V	-	-	1.599	90	-	-	-	-
		L	-	-	-	-	0.208	10	-	-
		B	-	-	-	-	-	-	0.053	90
4	C	U	5.608	20	-	-	-	-	-	-
		I	-	-	1.600	80	-	-	-	-
		U	-	-	-	-	0.104	20	-	-
		I	-	-	-	-	-	-	0.084	80

Table 8.1.3.3 Abstract of total cropped intensity achieved for crops at basin level

Sl. No.	Basin Name	Crop Name	Total Cropped Intensity Achieved				Average Cropped Intensity Achieved			
			Maximum	% Exceedance	Minimum	% Exceedance	Maximum	% Exceedance	Minimum	% Exceedance
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	M	MPDK	13.094	3	-	-	-	-	-	-
		MILK	-	-	0.100	96	-	-	-	-
		MPDK	-	-	-	-	0.267	3	-	-
		SUGP	-	-	-	-	-	-	3	96
2	G	PADK	14.100	3	-	-	-	-	-	-
		CHLR	-	-	0.080	96	-	-	-	-
		PADK	-	-	-	-	0.243	3	-	-
		FODK	-	-	-	-	-	-	0.037	96
3	K	JOWK	4.613	3	-	-	-	-	-	-
		SUNK	-	-	0.028	96	-	-	-	-
		JOWK	-	-	-	-	0.121	3	-	-
		SAFR	-	-	-	-	-	-	0.022	96
4	C	PADK	3.331	5	-	-	-	-	-	-
		JOWS	-	-	0.150	95	-	-	-	-
		COTS	-	-	-	-	0.350	5	-	-
		TOBK	-	-	-	-	-	-	0.040	95
5	P	PADK	0.19	11	-	-	0.19	11	-	-
		PADK	-	-	0.04	89	0.04	89	0.04	89

Table 8.1.3.4 : Linkwise annual target and achievement

Link No	Export point	Expected % of achievement
(1)	(2)	(3)
1	Manibhadra	100.00
2	Inchampalli	6.70
3	Inchampalli	
4	Polavaram	41.53
5	Almatti	100.00
6	Srisailam	16.90
7	Nagarjunasagara	25.69
8	Somasila	94.59
9	Kattalai	100.00

Table 8.1.3.5 : Basin wise annual target and achievement

Link No	Exporting Basin	Expected % of achievement
(1)	(2)	(3)
1	Mahnadi	100.00
2	Godavari	13.80
3	Krishna	100.00
4	Pennar	94.59
5	Cauvery	100.00

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(I) Numbering of the States under Consideration, in General and involved in Exports and Imports of Water

(A) The s^{th} State under Consideration in General

SN_s = the number of the s^{th} state under consideration in general;

$BN_{s,b}$ = the number of the b^{th} sub-basin of the s^{th} state under consideration in general; and

$RN_{s,b,i}$ = the number of the r^{th} reservoir in the b^{th} sub-basin of the s^{th} state under consideration in general.

(B) The s^{th} Exporting State under Consideration

(i) Used in the water share equation

ESN_s = the number of the s^{th} exporting state under consideration;

$EBN_{s,p}$ = the number of the p^{th} sub-basin of the s^{th} exporting state under consideration

$ERN_{s,p,q}$ = the number of the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration.

ISN_{nis} = the number of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration;

$IBN_{nis,d}$ = the number of the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration; and

$IRN_{nis,d,c}$ = the number of the c^{th} reservoir in the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration.

(ii) Used in the water availability equation

For the s^{th} exporting state under consideration which is exporting state water to the nis^{th} state, the nomenclature used for numbering the nis^{th} state and for numbering their respective sub-basins and reservoirs are defined here, i.e.,

ISN_{nis} = the number of the nis^{th} state, to which the water is being exported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} exporting state under consideration;

$IBN_{nis,d}$ = the number of the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} exporting state under consideration; and

$IRN_{nis,d,c}$ = the number of the c^{th} reservoir in the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} exporting state under consideration.

(C) The s^{th} Importing State under Consideration

NES_{isn} = the number of the isn^{th} state from which water is being imported by the v^{th} reservoir in the u^{th} sub-basin of the s^{th} importing state under consideration;

$NEB_{isn,z}$ = the number of the z^{th} sub-basin of the isn^{th} state from which water is being imported by the v^{th} reservoir in the u^{th} sub-basin of the s^{th} importing state under consideration; and

$NER_{isn,z,k}$ = the number of the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state from which water is being imported by the v^{th} reservoir in the u^{th} sub-basin of the s^{th} importing state under consideration.

(ii) Used in the water availability equation

For the s^{th} importing state under consideration which is importing water from the isn^{th} state, the nomenclature used for numbering the isn^{th} state and for numbering their respective sub-basins and reservoirs are defined here, i.e.,

NES_{isn} = the number of the isn^{th} state from which water is being imported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} importing state under consideration;

$NEB_{isn,z}$ = the number of the z^{th} sub-basin of the isn^{th} state from which water is being imported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} importing state under consideration; and

$NER_{isn,z,k}$ = the number of the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state from which water is being imported by the i^{th} reservoir in the b^{th} sub-basin of the s^{th} importing state under consideration.

(C_2)-b

NIS_s = the number of the s^{th} importing state under consideration;

$NIB_{s,u}$ = the number of the u^{th} sub-basin of the s^{th} importing state under consideration; and

$NIR_{s,u,v}$ = the number of the v^{th} reservoir in the u^{th} sub-basin of the s^{th} importing state under consideration.

(D) Total Number of States in General, and the Statesinvolved in Exports and Imports of Water under Consideration

(D_1) Total Number of States in General under Consideration

$TNBS_s$ = the total number of sub-basins of the s^{th} state under consideration; and

$TNRS_{s,b}$ = the total number of reservoirs in the b^{th} sub-basin of the s^{th} state under consideration.

(D_2) Total Number of States to which Water is being exported by the s^{th} State under Consideration

TNS = the total number of states exporting water;

$NTEB_s$ = the total number of sub-basins of the s^{th} exportingstate under consideration;

$NTER_{s,p}$ = the total number of reservoirs in the p^{th} sub-basin of the s^{th} exporting state under consideration;

TIS_s = the total number of states, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration;

$NTIB^{nis}$ = the total number of sub-basins of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration; and

$NTIR^{nis,d}$ = the total number of reservoirs in the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the q^{th} reservoir in the p^{th} sub-basin of the s^{th} exporting state under consideration.

(D_3) Total Number of States which are Importing Water from the isn^{th} State

$IBTN_s$ = the total number of sub-basins of the s^{th} importingstate under consideration;

$IRTN_{s,u}$ = the total number of reservoirs in the u^{th} sub-basin of the s^{th} importing state under consideration;

TES_s = the total number of states, importing water from the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state;

$EBTN^{sin}$ = the total number of sub-basins of the s^{th} importingstate under consideration, importing water from the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state; and

$ERTN^{sin,z}$ = the total number of reservoirs in the u^{th} sub-basin of the s^{th} importing state under consideration, importing water from the k^{th} reservoir in the z^{th} sub-basin of the isn^{th} state.

(II) <u>The Numbering of the Upstream States, contributing regenerated flows (return flows) from irrigation etc. to the downstream state under consideration</u>

$NTUS_s$ = the total number of upstream states, contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

$NTUB_{s,l}$ = the total number of sub-basin in the l^{th} upstream state, contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

$NTUR_{s,l,y}$ = the total number of reservoirs in the y^{th} sub-basin of the l^{th} upstream state, contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

USN_l = the number of the l^{th} upstream state,contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

$UBN_{l,y}$ = the number of the y^{th} sub-basin of the l^{th} upstream state,contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

$URN_{l,y,x}$ = the number of the x^{th} reservoir in the y^{th} sub-basin of the l^{th} upstream state,contributing regenerated flows (return flows) from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration;

$ISNU_{nis}$ = the number of the nis^{th} state, to which the water is being exported by the x^{th} reservoir in the y^{th} sub-basin of the l^{th} upstream state (the l^{th} state is also contributing regenerated flows from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration);

$IBNU_{nis,d}$ = the number of the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the x^{th} reservoir in the y^{th} sub-basin of the l^{th} upstream state (the l^{th} state is also contributing regenerated flows from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration); and

$IRNU_{nis,d,c}$ = the number of the c^{th} reservoir in the d^{th} sub-basin of the nis^{th} state, to which the water is being exported by the x^{th} reservoir in the y^{th} sub-basin of the l^{th} upstream state (the l^{th} state is also contributing regenerated flows from irrigation etc. to the i^{th} reservoir in the b^{th} sub-basin of the s^{th} downstream state under consideration).