OPTIMAL PLANNING AND OPERATION OF A WATER TRANSFER LINK

Ph.D. THESIS

by

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INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
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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 PLANNING AND OPERATION OF A WATER TRANSFER LINK** 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 July, 2005 to October, 2015 under the supervision of **Dr. D. K. Srivastava,** Professor, Department of Hydrology and **Dr. Sunita Devi,** Programmer, Department of WRD&M, 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.

(Mahendra Kumar Choudhary)

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

(Sunita Devi)
Supervisor

(D. K. Srivastava)
Supervisor

Dated: October ,2015

The Ph. D. Viva-Voce Examination of **Mr. Mahendra Kumar Choudhary**, Research Scholar has been held on ……………………

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ABSTRACT

The National Water Development agency (NWDA), Ministry of water Resources, Government of India has carried out studied on inter basin water transfer in India. It has identified 30 links for preparation of feasibility reports and has prepared feasibility reports of all the 30 links. This entails construction of large river linking projects, which warrants sound investigation, careful planning and huge expenditure. A faulty implementation of these projects may be more harmful than doing nothing at all. The studies for most of these rivers linking are at their initial stages. It is felt that the application of system analysis techniques will help in better planning for these Herculean tasks. The proposed Ken-Betwa link under the peninsular rivers development plan is considered for this study.

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. 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 integrated reservoir yield model (IRYM) and multi objective fuzzy linear programming, model (MOFLP) are applied to the Ken-Betwa water transfer link. The Ken-Betwa link project is located in the state of Madhya Pradesh and Uttar Pradesh in Central India. It is proposed to transfer 1020 MCM of water from proposed Daudhan reservoir in Ken basin to existing Barwa Sagar reservoir in Betwa basin. Only major and medium reservoir projects have been considered in the study. The contributions of the 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 20 years i.e., from 1980-81 to 1999-2000. Within year analysis has been made for 12 within-years time periods for the critical year. The water year in India starts in the month of June and ends in May. Annual reliabilities for the firm and secondary yields considered are 95.2 percent and 76.2 percent based on Weibull plotting position for a data series of 20 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 by medium variant population growth rate. As given in U.N. Publication 'World Population Prospects – 2004 revision'the medium variant population growth rate is applicable for India. 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 population. 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. On the basis of protein and calorie requirements for agricultural population and crop production the water demand to meet the minimum food requirements for agricultural population have been computed for each project.

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. The study is limited to the surface water resources only.

The fuzzy approach is applied using the multi objective fuzzy linear programming model (MOFLP) to obtain the solution of the problem to obtain some compromise solution in the purview of prevailing conflicting water issues, which exist everywhere these days. The two fuzzy objectives were the within year firm and secondary reservoir yields available from all the reservoirs in the system to meet various existing and future water needs in the system. Continuous hedging rule is used to define another set of rules for Daudhan reservoir operation.

Systems analysis techniques were successfully applied to solve the large scale Ken-Betwa Link water transfer problem in space and time. The model IRYM was used for planning and the model MOFLP was used for the operation of the Daudhan reservoir in Ken basin. Two cases of with and without water exports were considered. The outcome of the results have been analysed and put in Chapter 8 and Chapter 9.

(A) On the basis of the results following conclusions were drawn from planning model

(1) With export the total cropped intensity achieved for Betwa system is 73.1% of the target total cropped intensity. Without export the total cropped intensity of the reservoirs in Betwa basin varies from 100% to 2.2%.

(2) With export the total cropped intensity achieved at Daudhan reservoir is 9.93% of the target total cropped intensity, whereas without export it is 84.67%.

(3) The expected within year reservoir storage without export for Betwa system would vary between 55.21% and 25.98% of the reservoir storage capacity.

(4) The expected within year reservoir storage with export at Daudhan would vary between 3.98% and 0.004% of the reservoir storage capacity.

(5) The expected within year reservoir storage without export at Daudhan would vary between 48.97% and 8.8% of the reservoir storage capacity.

(B) On the basis of the results following conclusions were drawn from operation model

(1) With export the total cropped intensity achieved at Daudhan reservoir is 6.9% of the target total cropped intensity, whereas without export it is 85.13%.

(2) The expected within year reservoir storage with export at Daudhan would vary between 3.72% and 0.71% of the reservoir storage capacity.

(3) The expected within year reservoir storage without export at Daudhan would vary between 48.97% and 8.8% of the reservoir storage capacity.

(C) On the basis of the results following conclusions were drawn regarding Daudhan exporting reservoir

(1) The water export at Daudhan is expected to meet 95.63% of its proposed annual export target demand. Except for the month of July all the other seven months of for which the export is needed would meet their proposed water requirements. There would be a short fall of 31.81% in the month of July.

(2) Initial rule curve defining lower limits on the storages to be maintained for each within year periods during reservoir operation were derived.

(3) CHR is used to define another set of rules for Daudhan reservoir operation given by hedging trigger factors. These hedging trigger factors obtained for each month control releases to be made from reservoir.

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(MAHENDRA KUMAR CHOUDHARY)

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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;

A_i = culturable command area (CCA) of reservoir *i*;

B_i^f = Returns from annual firm energy for reservoir *i;*

B_i^s = Returns from annual secondary energy for reservoir *i;*

B_i^{fp} = gross return from annual firm energy generated by reservoir *i*;

B_{ir}^{cr} = gross return from unit weight of yield of crop *r* under reservoir *i*;

B_i^m = return from unit volume of municipal and industrial water released from reservoir *i;*

B_i^{sp2} = gross return from annual secondary energy generated by reservoir *i;*

Cr_r = calorie content of crop *r* per unit weight of yield produced;

C_f = conversion factor for computation of hydroelectric energy;

Ev^a = average annual evaporation volume loss rate per unit of active storage volume;

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

Ev_{ij} = annual evaporation volume loss from reservoir *i* in year *j*;

Ev_{it} = evaporation volume loss from reservoir *i* in period *t*;

E_i = annual firm energy generated by reservoir *i*;

$\overline{E_i}$ = annual secondary energy generated by reservoir *i;*

E_{it} = firm energy generated fron reservoir *i* in period *t*;

$\overline{E_{it}}$ = secondary energy generated fron reservoir *i* in period *t*;

ET = evapotranspiration;

ET_0 = reference crop evapotranspiration;

ET_c = crop evapotranspiration;

$ET_{c\ adj}$ = crop evapotranspiration under non standard condition;

e_s = saturated vapour pressure;

e_a	=	actual vapour pressure;
e_i	=	hydropower plant efficiency for reservoir *i;*
G	=	soil heat flux density;
Ha_{it}	=	productive storage head for reservoir *i* in period *t;*
h_{it}	=	number of hours for generation of energy for reservoir *i* in period *t;*
H_i	=	hydropower plant capacity for reservoir *i;*
I_{ij}	=	annual inflow at reservoir site *i* in year *j*;
K_c	=	crop coefficient;
m	=	set of contributing reservoirs upstream of reservoir *i*;
N	=	total number of years of river flows available;
n_f	=	number of failure years;
NPI	=	number of projects having irrigation component;
NPM	=	number of reservoir having municipal and industrial water supply component;
NC_t	=	number of crops in period *t;*
NPP	=	number of projects having power component;
Oy_i^{fp}	=	firm annual reservoir yield with reliability *p* for reservoir *i*;
Oy_{it}^{fp}	=	firm within-year reservoir yield with annual reliability *p* from reservoir *i* in period t;
Oy_i^{sp2}	=	incremental secondary annual reservoir yield with reliability *p2* for reservoir *i*;
Oy_{it}^{sp2}	=	incremental secondary within-year reservoir yield with annual reliability *p2* from reservoir i in period *t*;
Pr_r	=	protein content of crop *r* per unit weight of yield produced;
R_n	=	net radiation at the crop surface;
S_{j-1}^o	=	initial over-year storage at the beginning of year *j*;
S_j^o	=	final over-year storage at the end of year *j*;
S_N^o	=	final over-year storage at the end of the last year;
S_0^o	=	initial over-year storage at the beginning of starting year;

$S_{j,t-1}$ = initial storage at the beginning of period *t* inyear *j*;

S_{jt} = final storage at the end of period *t* in year *j*;

Sp_{ij} = excess release (spill) during year *j* from reservoir *i*;

Sp_{jt} = excess release (spill) during period *t* in year *j*;

S_{t-1}^{w} = storage at the beginning of the within-year period *t*;

S_{t}^{w} = storage at the end of the within-year period *t*;

$S_{i,cr}^{o}$ = initial over-year storage volume in the critical year for reservoir *i*;

T = air temperature at 2 m height;

TPR_i = total protein demand to be met by reservoir *i;*

TCR_i = total calorie demand to be met by reservoir *i*;

u_2 = wind speed measured at 2 m height;

Y_i^{o} = over-year storage capacity of reservoir *i*;

Y^{w} = within-year storage capacity of reservoir *i*;

Ya_i = total active storage capacity of reservoir *i*;

Z_{ir} = minimum area (in fraction of CCA) under each crop;

Z_i^{+} = best aspiration level of objective Z_i

Z_i^{-} = lowest acceptable level of objective Z_i

Z_i^{u} = highest aspiration level of objective Z_i

Z_i^{L} = lowest acceptable level of objective Z_i

θ_j^{p1} = factor to identify a successful or a failure year in case of a single firm yield model with complete failure year and its value be either 0 or 1;

D_j^{p1}. = factor to identify a successful or a failure year in case of a single firm yield model with partial failure year and its value will be in between 0 and 1;

θ_j^{p2} = factor to identify a successful or a failure year for incremental secondary yield in case of a multiple yield model and its value be either 0 or 1;

ρ_i^{p2} = fraction of total annual yield desired to be released in the failure years;

δ_k^f = fraction of firm reservoir yield coming as regenerated flow from upstream reservoir *k*;

δ_k^s = fraction of incremental secondary reservoir yield coming as regenerated flow from upstream reservoir *k;*

δ_k^{irr} = fraction of reservoir yield coming as regenerated flow from upstream reservoir *k* after utilization for irrigation purpose;

δ_k^{man} = fraction of reservoir yield coming as regenerated flow from upstream reservoir *k* after utilization for mandatory purpose;

β = exponent indicates the desired shape of membership function

β_{it} = ratio of the inflow in period t of the critical year of record to the total annual inflow of that year;

λ = membership function

ξ_{it} = percentage fraction of annual irrigation target for reservoir *i* in period *t;*

ξ'_{it} = percentage fraction of total target annual demand for reservoir *i* in period *t;*

α_{it} = hydropower plant factor for reservoir *i* in period *t;*

η_{it} = fraction of annual firm energy target for reservoir *i* in period *t;*

Φ_{ir} = fraction of CCA under crop *r* of reservoir *i*;

ψ_{ir} = yield of crop *r* per unit area of CCA under reservoir *i*;

Φ_{ir} = fraction of CCA under *crop r* of reservoir *i;*

Δ_{irt} = gross irrigation requirement (GIR) in depth by the crop *r* during period *t* of reservoir *i;*

μ_{it} = total mandatory release towards demands like municipal and industrial, environmental and ecological, and other downstream riparian rights during period *t* from reservoir *i;*

μ_i = Annual mandatory release from reservoir *i*;

μ_{kt} = total mandatory release during period *t* from upstream contributing reservoir *k;*

ϖ_i = maximum irrigation intensity allowed in reservoir *i* from management and soil erosion consideration; and

ψ_{ir}	=	yield of crop *r* per unit area of CCA under reservoir *i*.
Δ	=	slope vapour pressure curve;
γ'	=	psychrometric constant;
ζ_f	=	field application efficiency;
ζ_c	=	conveyance efficiency; and
$(e_s - e_a)$	=	saturated vapour pressure deficit.

SUBSCRIPTS AND SUPERSCRIPTS

f	=	firm reservoir yield indicator;
i	=	reservoir index;
j	=	year index;
k	=	index *k* refers to a contributing reservoir among the set of *m* contributing reservoirs at the upstream of reservoir *i*;
o	=	over-year storage indicator;
p	=	maximum possible reliability of annual reservoir yield;
p1	=	reliability less then *p* for a single annual reservoir yield;
p2	=	reliability less then *p* for a incremental secondary annual reservoir yield;
r	=	crop index;
s	=	incremental secondary reservoir yield indicator;
t	=	within-year time period index; and
w	=	within-year storage indicator.

ABBREVIATION

IBWT	Inter basin water transfer
KBLink	Ken – Betwa link
MP	Madhya Pradesh
NWDA	National water development agency
UP	Uttar Pradesh

UNITS

Ha	Hectare
Lakh	Hundred Thousand
MCM	Million cubic meters
mm	Millimeters
MW	Megawatts
Sqkm	Square Kilometer
TMC	Thousand million cubic feet

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

The constantly increasing population, water demands for various basic and developmental purposes has forced planners and engineers to contemplate and propose more comprehensive, complex and ambitious plans for water resources systems. The development, conservation and efficient use of water forms one of the main elements in the development planning. The water resources are limited considering the future demands. In India, the rainfall is mostly confined to the monsoon season and is unevenly distributed both in space and time even during the monsoon season. As a result, frequent droughts are experienced and nearly one third of the country is drought prone. In the monsoon, flood waters that otherwise run waste into the sea can be conserved in various storage reservoirs and can be utilized for beneficial purposes during non-monsoon periods. If the water availability and requirements of various river basins are assessed realistically, then planning can be done to transfer water from water surplus basins to basins that are deficit in water. Inter basin water transfers through inter-linking of rivers is viewed as an approach to correct the natural imbalance due to inequitable distribution of water resources.

1.2 BACKGROUND OF INTER BASIN WATER TRANSFER IN INDIA

Suggestions for a national water grid for transferring surplus water available in some regions to water-deficit areas have been made from time to time. The following section highlights the earlier proposals and attempts in India for interlinking of rivers.

1.2.1 National Water Grid By Late Dr. K. L. Rao

Central Water and Power Commission prepared a National Water Grid in 1972 to join river Ganga to river Cauvery by three different possible alignments. Dr. K. L. Rao studied one of the possible alignment for the Ganga-Cauvery link with some other links. The length of the Ganga-Cauvery link was 2640 kmto transfer the 1680 cubic meter of the flood water of the Ganga river. It was proposed to pump about 1400 cubic meter of water over a head of 549 m to transfer the water from river Ganga toPeninsular region and utilizing the remaining 280 cubic meter in the Ganga basin itself. Dr. K. L. Rao had also proposed a few additional links like (a) Link between Brahmaputra and Ganga river to transfer 1800 to 3000 cubic meterwater with a lift of 12 to 15 m, (b) Link to transfer 300 cubic meter of Mahanadi water to southwards, (c) Link from Narmada river to Western part of Rajasthan with a lift of 275 m and (d) Links from rivers of the Western Ghats towards east. The proposals examined by the Central Water Commission and they were found to be grossly under-estimated. It was also observed that the scheme would require about 5000 to 7000 MW power for lifting the water. It will also have no flood control benefits. Therefore, the proposal was not pursued as such.

1.2.2 Garland Canal By Captain Dastur

Proposal by Captain Dastur mainly consists of two canals, viz. (i) Himalayan canal with 4200 km length and 300 m widthcanalaligned along the southern slopes of the Himalayas running from the Ravi in the west to the Brahmaputra in the east and beyond. The Himalayan river water stored in 50 integrated lakes to be created by cutting the hill slopes of the Himalayas to the same level as the bed of the canal, and another 40 lakes beyond Brahmaputra will feed it. The proposal envisaged a storage capacity of 24.7 million ham to control and distribute 61.7 million ham of water, (ii) Central and Southern Garland Canal with 9300 km length and 300 m width.This Garland Canal was proposed to have about 200 integrated lakes having a storage capacity of 49.7 million ham to control and distribute 86.4 million ham. The Garland canals were proposed to be inter-connected at Delhi and Patna by 5 numbers of 3.7 m diameter pipelines for transfer of water. Captain Dastur estimated that all the surplus waters in the country will be utilized to irrigate219 million ham.

The proposal was examined by the experts from Central Water Commission, State Governments and Professors from IIT and University of Roorkee. They found that the proposal was economically prohibitive and technically unsound.

1.2.3 Establishment of National Water Development Agency (NWDA)

In 1980n the Ministry of Water Resources formulated a National Perspective Plan for Water Resources Development by transferring water from water surplus basins to water deficit basins by inter-linking of rivers. The Himalayan Rivers Development and Peninsular Rivers Development are the two main components of National Perspective Plan. In 1982 the National Water Development Agency (NWDA) was set up as a society to carry out detailed studies, survey and investigations and also to prepare feasibility reports of the links envisaged under the National Perspective Plan. After carrying out studies the NWDA identified 30 links all over the India for preparation of feasibility reports.

The studies for most of these river links are at their initial stages. It is felt that the application of system analysis techniques will help in better planning of these Herculean tasks. The proposed Ken-Betwa link under the peninsular rivers development plan is considered for this study.

The Ken basin from where water is proposed to be transferred to the Betwabasinis a sub-basin of the Yamuna basin. The Yamuna basin is a sub-basin of Ganga basin, andthe Ganga basin is a sub-basin of Ganga-Brahmaputra-Meghna system.

1.3 PROPOSED KEN-BETWA LINK PROJECT

The main purpose of the Ken-Betwa link project is to make available water to the water scarcity areas of Betwa river basin from the surplus waters ofKen river basin. NWDA carried out preliminary study of water balance of the river Ken upto Gangau dam site, which indicated that surplus waters are available in the Ken river basin. A preliminary feasibility study was carried out for diverting surplus waters of Ken river to water deficit areas of Betwa river basin. It was found in the study that the proposal is techno-economically viable. It was proposed to construct a dam across the river Ken in the upstream of the existing Gangau weir, to store and transfer the water through a link canal from river Ken to river Betwa. It was proposed to divert the 1020 MCM water from Ken river basin, after considering the demands of Ken basin and downstream commitments (viz. 1375 MCM for the state of Madhya Pradesh and 850 MCM for the state of Uttar Pradesh).

The proposed Ken-Betwa link project envisages the following works:

i. A dam near village Daudhanon Ken river at 2.5 km upstream of the existing Gangau weir with gross storage capacity of 2775 MCM.

ii. About 232 km long link canal including 2 km tunnel to transfer 1020 MCM of water from Ken river. After meeting en-route irrigation requirements 659 MCM will be released into Barwa sagar reservoir in Betwa river. to provide annual irrigation to 1.27 lakh ha (CCA 1.02 lakh ha) of drought prone areas of Betwa basin.

iii. Two power houses, with installed capacities of 3X20 MW at the foot of the dam and other 2X6 MW at the end of 2 km long tunnel.

iv. The existing outlet of Barwa Sagar shall be used to drop the link canal water into Betwa, through Barwa river.

v. Annual irrigation to an area of 47000 ha enroute of the Ken-Betwa link, where the level of irrigation is less than 30% of the Cultivable area.

vi. Annual irrigation to an area of 3.23 lakh ha (C.C.A. 2.41 lakh ha) as envisaged under "Ken Multi-purpose Project" which was earlier proposed by State Government of Madhya Pradesh.

vii. A provision of 11.75 MCM for drinking water supply to the villages and towns en-route of the link canal to meet the needs of about 3.3 lakh people.

1.4 PROBLEM IDENTIFICATION

For any inter basin water transfer project, the assessment of the water resources of the concerned basins are necessary to know the status of a basin as water surplus or water deficit in comparison to the basin's future water demands. The study proposes to assess the water resources potential of the concerned basins and to develop a methodology for planning and management of various aspects of water resources system related to inter basin water transfer. The improved yield model based on linear programming and fuzzy optimization linear programming model are proposed to be used. It is proposed to develop a screening model to screen interlinking alternative. When water demands at a reservoir are known, in case of shortage it is necessary to find out that, how much additional water is required to meet the water demands completely at different time periods. This additional water may be considered as an import requirement at that reservoir. But knowing only the import water requirement is not sufficient. The candidate reservoir/reservoirs that would supply this import water requirement (export) may not be capable of doing so after meeting their own water demands. This study proposes to develop a methodology to evaluate the import water requirement at a reservoir likely to face water shortage, the water exports that a reservoir can make after meeting its own water needsup to the maximum possible extent, and the effect of these imports and exports on the system as a whole in terms of meeting various water demands with different reliabilities.

An operation plan or release policy is a set of rules for determining the quantities of water to be stored and to be released or withdrawal from a reservoir or system of several reservoirs under various conditions. Typically, a regulation plan includes a set of quantitative criteria within which significant flexibility exists for operator judgment. The operating rules provide guidance to the water managers who make the actual release decisions. In modeling exercises, the reservoir system analysis model contains some mechanism for making release decisions within the framework of user specified operating rules and/or criteria function.

1.5 OBJECTIVES OF THE STUDY

The objectives of the present study for the optimal operation and planning of Ken Betwa water transfer link are stated as under:

1. To assess the water resources potential of the Ken and Betwa river basins, and of the catchment areas up to the proposed dam sites.
2. To apply the integrated reservoir yield model as an optimization model for planning to estimate the annual and within year yields (firm and secondary) at individual projects, at basin level and complete Ken-Betwa system.
3. To apply the model to the study area and evaluate the availability scenarios at the export points in the Ken Betwa water transfer link.
4. To evaluate the optimal cropping pattern at each reservoir site.
5. To formulate a multi-objective fuzzy linear programming, multi reservoir problem to obtain compromise solutions in the light of existing water scenarios.
6. To evaluate optimal operation policy for the water export reservoir using multi-objective fuzzy linear programming (MOFLP).

1.6 THE APPROACH AND METHODOLOGY

Water resources planning and management is broadly concerned with the accurateassessment, identification and development of different water resources systems. The carefulplanning for allocation of water resources to different developmental activities has becomeextremely important to meet the ever-increasing demand of water supply, hydropower, and irrigation etc. It emphasizes the need for planning and development of river basin water resources, which is a complex and difficult task, and creates numerous social, economical,environmental and engineering problems. Most of these difficulties are due to variable inflows and large number of possible alternatives. Optimal planning of a large-scale river basin as a unit of water resources system is having a high priority in the economic development of a region. This has resulted in an urgent need for accurate and efficient management of the water resources for its conservation and use. System engineering provides methodologies for studying and analyzing various aspects of a system and its response to various parameters by using optimization techniques. Often these aspects are very complex with different objectives, scopes, scales and timing considerations. In such cases there is usually no unique model for the solution of the problems.

1.6.1 Preliminary screening optimization model

For design of any system, an initial guess regarding the size of the system's design variables is required. These estimates can be obtained through the application of simple linear programming models. Yield model serves as an efficient preliminary screening model for reasonable reservoir designs with release reliabilities near targets. The objective function maybe to maximize annual yields, or return from the yields, or to minimize reservoir capacity.

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 Reservoir Yield Model is an implicit stochastic model and the modified and improved model represents the real life processes more faithfully than the deterministic model.

Study carried out by Dahe and Srivastava (2002) is a major achievement in this field. The purpose of their study was to achieve pre-specified reliabilities for energy generation and irrigation. They incorporated an allowable deficit in the annual irrigation target through a multi-yield model for a multi-reservoir system consisting of single-purpose and multipurpose reservoirs and applied it to eight reservoirs in Narmada river 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 simultaneously for each project and also satisfying the project specific demandsduring the successful years to the maximum possible extent.

Various virgin water year dependable flows at each at each reservoir site have been obtained from available discharge data at discharge sites and upstream utilizations. Details of import/export from identified projects 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 India's population is expected to stabilize at 2050 AD and therefore the estimate of future water demands will be more acceptable.

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.

In this study only the contribution of the major and medium projects have been considered individually for their contributions to the system. The minor irrigation projects are lumped and their contribution is evaluated accordingly.

1.6.2 Fuzzy linear optimization model

A model for planning multi-yields from a reservoir is developed using multi objective fuzzy linear programming (MOFLP) which is computationally simple and easy to execute to the real world situation of reservoir operation. Problem is formulated with two objective functions viz. maximization of release for annual irrigation and annual water supply, In case of irrigation project only the objective functions are maximization of annual firm release for irrigation and annual secondary release for irrigation, with several constraints of the system and is solved in an iterative manner. Linear membership functions are used to fuzzify the objective functions. Only objectives are taken to be fuzzy and all other parameters of the model are considered crisp in nature. MOFLP is used to obtain a compromise solution and corresponding optimal reservoir yields. The continuous hedging rule is used to define another set of rules for reservoir operation.

1.7 OUTCOMES OF THE STUDY

Systems analysis techniques were successfully applied to solve the large scale Ken-Betwa Link water transfer problem in space and time. The integrated reservoir yield model (IRYM) was used for planning and the multi objective fuzzy linear programming model (MOFLP) was used for the operation of the Daudhan reservoir in Ken basin. Two cases of with and without water exports were considered. The outcome of the results have been analysed and presented in Chapter 8 and Chapter 9.

(A) On the basis of the results following conclusions were drawn from planning model

(1) With export the total cropped intensity achieved for Betwa system is 73.1% of the target total cropped intensity. Without export the total cropped intensity of the reservoirs in Betwa basin varies from 100% to 2.2%.

(2) With export the total cropped intensity achieved at Daudhan reservoir is 9.93% of the target total cropped intensity, whereas without export it is 84.67%.

(3) The expected within year reservoir storage without export for Betwa system would vary between 55.21% and 25.98% of the reservoir storage capacity.

(4) The expected within year reservoir storage with export at Daudhan would vary between 3.98% and 0.004% of the reservoir storage capacity.

(5) The expected within year reservoir storage without export at Daudhan would vary between 48.97% and 8.8% of the reservoir storage capacity.

(B) On the basis of the results following conclusions were drawn from operation model

(1) With export the total cropped intensity achieved at Daudhan reservoir is 6.9% of the target total cropped intensity, whereas without export it is 85.13%.

(2) The expected within year reservoir storage with export at Daudhan would vary between 3.72% and 0.71% of the reservoir storage capacity.

(3) The expected within year reservoir storage without export at Daudhan would vary between 48.97% and 8.8% of the reservoir storage capacity.

(C) On the basis of the results following conclusions were drawn regarding Daudhan exporting reservoir

(1) The water export at Daudhan is expected to meet 95.63% of its proposed annual export target demand. Except for the month of July all the other seven months of for which the export is needed would meet their proposed water requirements. There would be a short fall of 31.81% in the month of July.

(2) Initial rule curve defining lower limits on the storages to be maintained for each within year periods during reservoir operation were derived.

(3) CHR is used to define another set of rules for Daudhan reservoir operation given by hedging trigger factors. These hedging trigger factors obtained for each month control

releases to be made from reservoir.

1.8 COMPOSITION OF THESIS

The Chapter wise scheme devised to report the research work is given below:

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 description of the Ken and Betwa basin, the river system, the configuration and basic information of reservoirs system and the water transfer proposal in the context of the present study.

Chapter 4

This chapter deals with the assessment of crop water requirement for the proposed crop planning in the study area so as to obtain the gross irrigation requirement (GIR) at each within year time period for the individual project. Basics of crop water requirement and the approach adopted for its assessment are described in brief.

Chapter 5

This chapter presents the basic concepts of yield model and its improvements in a chronological order and brief description of integrated reservoir yield model (IRYM) and its modelling.

Chapter 6

This chapter deals with the introduction of fuzzy logic and formulation and development of the multi objective fuzzy linear programming model (MOFLP) and hedging rules for reservoir operation.

Chapter 7

This chapter deals with the estimation of parameters connected with 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 8

This chapter provides the details of the computations and the procedures adopted to get the results and describes the detailed analysis of each aspects considered in this study using integrated reservoir yield model (IRYM).

Chapter 9

This chapter describes the detailed computation and analysis of each aspects considered in this study using multi objective fuzzy linear programming model (MOFLP) and hedging rules for reservoir operation.

Chapter 10

This is the concluding chapter which summarizes the conclusion inferred from analysis of results and findings of this study with reference to the modeling approach employed and its application to the Ken Betwa river basin system. Scope of further work based on this study is presented at the end of this chapter.

Chapter 10

SUMMARY AND CONCLUSIONS

A study was undertaken on large scale water transfers in space and time. The system under consideration was a trans-boundary river system in India consisting of the proposed Ken-Betwa water transfer link. 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 Chapters-8 and 9 of the model IRYM and for the model MOFLP, respectively.

10.1 SUMMARY

10.1.1 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 scares. 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.

The aim of the study was to apply systems analysis method to solve such problem. As said the study area is the proposed trans-boundary river system, i.e., Ken-Betwa water transfer link in India. 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.

10.1.2 The Modelling Approach

10.1.2.1 Basin water availability

Water transfers take place from a river basin with surplus waters to a water deficit basin. In planning water transfers, water balance of river basins are carried out at specified sites, generally at a point from where the water transfer is being proposed and for the river basin which needs water exports from water surplus river 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 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. The following steps are followed:

(a) First step is to estimate virgin flow at the specified site.

(b) 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.

(c) 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.

(d) Basically the procedure adopted is a lumped approach i.e.,

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.

10.1.2.2 Need of comprehensive river basin analysis for optimal water utilization

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:

(i) 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.

(ii) 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.

10.1.2.3 Use of optimization models

In the present study the following optimization models were applied:

(i) 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.

(ii) The fuzzy approach was also employed using the model MOFLP to obtain the solution of the problem to obtain some compromise solution in the purview of prevailing conflicting water issues, which exist everywhere these days. The two fuzzy objectives were the within year firm and secondary reservoir yields available from all the reservoirs in the system to meet various existing and future water needs in the system.

10.1.2.4 Approach for assessment and analysis of results

Analysis of the results obtained was carried out in detail. The assessment of the results followed the following guidelines.

(A) For the model IRYM:

(a) The crops, within year reservoir storages, firm yields and secondary yields were analysed with and without exports from the Ken basin as follows,

(i) The results of the crops involved are assessed and analysed 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 modelled total cropped intensities. The later criterion is also followed while analysing 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 analysed 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 analysed 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.

(b) At the export point Daudhan in Ken basin only the case of export was considered and analyzed

The analysis at the water export points are for the expected (i) within-year reservoir storages, (ii) within-year reservoir firm and secondary yields and (iii) within-year export values to be made available from the concerned reservoir. These yields would meet the water requirements for self and en-route irrigations.

(B) For the model MOFLP:

(i) The analysis at the water export points are for the expected (a) within-year reservoir storages, (b) within-year reservoir firm and secondary yields that would meet the water requirements other than the exports and

(ii) The within-year export values to be made available from the Daudhan reservoir in Ken basin to meet the export water requirements.

(iii) Compromise solutions at each reservoir are analyzed to achieve maximum degree of satisfaction levels for reservoir yields to meet various water needs.

(iv) Assessment is also made to derive reservoir operation policies for the exporting Daudhan reservoir in the following manner:

(a) Rule curve reservoir operation obtained from initial reservoir within year storages.

(b) CHR reservoir operation obtained from within year (i) initial reservoir inflow, (ii) storages, (iii) firm yields, (iv) secondary yields and (v) evaporations.

10.1.3 The Abstracts of the Results

The abstracts of the results obtained from the planning model with export for Ken-Betwa link in respect of the cropped areas are presented in the Tables 10.1.1 and 10.1.2. The abstracts of the results obtained from the model during operation with export at Daudhan in respect of the cropped areas are presented in the Tables 10.1.3 and 10.1.4. The outcomes of the results from the planning model and during operation at Daudhan in respect of the amount of water exports that would be available at the export point are given in the Table 10.1.5 and Table 10.1.6. The Table-10.1.7 gives the monthly water export targets achieved at Daudhan reservoir. The Table 10.1.8 gives the abstract of the compromise solutions obtained for Ken-Betwa link using operation model.

10.2 SUMMARY OF OUTCOMES DERIVED FROM THE STUDY

From the study the following conclusions are arrived at:

10.2.1 The Model IRYM

10.2.1.1 With export at Daudhan reservoir in Ken basin

(a) The cropped areas with export:

The following would be achieved in respect of the cropped areas at different levels in the entire system:

(i) At the Daudhan reservoir in Ken basin

(a) The total cropped intensity achieved is 0.149, out of which 0.113 for self and 0.036 for en-route irrigations.

(b) The crop Kharif vegetable and Rabi sunflower have the maximum total cropped intensity / average cropped intensity of 0.004 and most of the en-route kharif crops are having minimum total cropped intensity / average cropped intensity of 0.003.

(ii) In the Betwa basin

(a) Ten reservoirs have the highest intensity of irrigation with a value of 1.250 which equal to the proposed designed value. On the other hand the reservoir Parichha has the lowest intensity of irrigation with a value of 0.033 which does not meet the proposed designed value.

(b) The crop kharif paddy in Betwa basin has the highest total intensity of irrigation with a value of 2.729. Similarly, the crop kharif fodder has the lowest total intensity of irrigation with a value of 0.175.

(c) The crop Rabi wheat (local) in Betwa basin has the highest average intensity of irrigation with a value of 0.337. Similarly, the crop kharif fodder again has the lowest average intensity of irrigation with a value of 0.010.

(b) The within year storages, firm and secondary yields with export:

At the Daudhan reservoir with export the following was observed:

(i) The within year storages are expected to vary between the values of 109.644 in September to 0.011MCM in May and June.

(ii) The within year firm reservoir yields are expected to vary between the values of 31.831 in December to 0.109 MCM in July.

(iii) There would be no within-year secondary.

10.2.1.2 Without export at Daudhan reservoir in Ken basin

(a) The cropped areas without export:

At the Daudhan reservoir

(i) The total cropped intensity achieved at Daudhan reservoir is 1.277, out of which 1.139 for self and 0.138 for en-route irrigations.

(ii) The crop rabi wheat has a maximum total cropped intensity / average cropped intensity of 0.326 and most of the en-route kharif crops are having minimum total cropped intensity / average cropped intensity of 0.003.

(b) The within year storages, firm and secondary yields without export:

At the Daudhan reservoir without export the following was observed:

(i) The within year storages are expected to vary between the values of 1348.11 in October to 242.38 MCM in June.

(ii) The within year firm reservoir yields are expected to vary between the values of 300.901in June to 8.114 MCM in May. The months of July, August, October, December, January, February and April would have no yields.

(iii) The within year secondary reservoir yields are expected to vary between the values of 268.78 in February to 4.983 MCM in July. The months of September, November, March and May would have no yields.

10.2.1.3 The Water Export Point

The water export point at Daudhan reservoir in Ken basin would achieve the following towards meeting its respective water export target demand:

(1) The water export is expected to meet 95.63% of its proposed annualexport target demand. Expect for the month of July all the other seven months of for which the export is needed would meet their proposed water requirements. There would be a short fall of 31.81% in the month of July.

(2) 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.

10.2.2 The Model MOFLP

10.2.2.1 With export at Daudhan reservoir in Ken basin

From the study of MOFLP for the ken basin with export the following conclusions are arrived at:

(a) The cropped areas with export:

At Daudhan reservoir

(a) The total cropped intensity achieved is 0.104, out of which 0.066 for self and 0.038 for en-route irrigations.

(b) The crop Kharif pulses has a maximum total cropped intensity / average cropped intensity of 0.029 and most of the en-route kharif crops are having minimum total cropped intensity / average cropped intensity of 0.003.

(b) The within year storages, firm and secondary yields with export:

At the Daudhan reservoir with export the following was observed:

(i) The within year storages are expected to vary between the values of 102.344 in October and November to 19.665 MCM in August.

(ii) The within year firm reservoir yields are expected to vary between the values of 29.864 in June to 0.586 MCM in July. The months ofNovember, April and May would have no yields.

(iii) There would be no within-year secondary yields.

10.2.2.2 Without export at Daudhan reservoir in Ken basin

From the study of MOFLP for the Ken basin at Daudhan reservoir without export the following conclusions are arrived at:

(a) The cropped areas without export:

At the Daudhan reservoir

(i) The total cropped intensity achieved at Daudhan reservoir is 1.27, out of which 1.146 for self and 0.131 for en-route irrigations.

(ii) The crop rabi wheat has a maximum total cropped intensity / average cropped intensity of 0.3264 and most of the en-route kharif crops are having minimum total cropped intensity / average cropped intensity of 0.003.

(b) The within year storages, firm and secondary yields without export:

At the Daudhan reservoir without export the following was observed:

(i) The within year storages are expected to vary between the values of 1348.11 in October and November to 242.38 MCM in June.

(ii) The within year firm reservoir yields are expected to vary between the values of 349.72 in June to 5.07 MCM in April. The months of July, November, January and March would have no yields.

(iii) The within year secondary reservoir yields are expected to vary between the values of 253.77 in January to 4.98 MCM in July. The months of June, August, September, December, April and May would have no yields.

10.2.2.3 The Water Export Point

The behaviour of the water export point at Daudhan reservoir in Ken basin would be similar to as that of in case of IRYM, refer section 10.2.1.3.

10.2.3 Compromise Solutions from the Model MOFLP

10.2.3.1 Without export at Daudhan reservoir in Ken basin

For the Ken basin without export the following is achieved at the Daudhan reservoir in different multi-objective cases:

At the Daudhan reservoir

(A) Multi-objectives to (i) maximize annual releases for en-route water supply and (ii) maximize annual releases for self and en-route irrigations.

The best compromise solution would possibly supply optimally 1135.50 MCM as an annual firm yield (water supply) and 693.21 MCM as annual secondary yield (irrigation) with the degree of satisfaction equal to 0.62.

(B) Multi-objectives to (i) maximize annual firm releases for irrigation and (ii) maximize annual secondary releases for self and en-route irrigations.

The best compromise solution would possibly supply optimally 1349.35 MCM as an annual firm yield and 480.50 MCM as annual secondary yield with the degree of satisfaction equal to 0.43.

10.2.3.2 With export for Ken-Betwa link

The integrated Ken-Betwa link would achieve the best compromise solution with a degree of satisfaction of 0.35. This would possibly be able to meet 29.23% of its annual irrigation target which includes irrigations for self and en-route. The Daudhan reservoir would supply optimally 1306.18 MCM as an annual firm yield and 401.74 MCM as annual secondary yield.

10.2.4 Daudhan Reservoir Operation

10.2.4.1 Rule curve reservoir operation

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 Daudhan reservoir operation. These initial rule curve values can be further refined through reservoir simulation.

10.2.4.2 CHR reservoir operation

CHR is used to define another set of rules for Daudhan reservoir operation given by hedging trigger factors. These hedging trigger factors obtained for each month control releases to be made from reservoir. In case of exports, for both the IRYM and the MOFLP models these factors were same. But without exports these factors varied with the models.

10.3 CONCLUSION

10.3.1 The Model IRYM for Planning

At planning stage at the Daudhan reservoir in Ken basin the following were achieved during a normal water year during:

1. Total crop intensity with and without export

    (a) With export the total cropped intensity achieved is 0.149 which includes 4 crops from self-command and 8 crops from en-route command. This is 9.93% of the target total cropped intensity of 1.5.

    (b) Whereas without export the total cropped intensity achieved is 1.27 which includes 12 crops from self-command and 13 crops from en-route command. This is 84.67% of the target total cropped intensity.

2. Crop areas with and without export

   (a) With export the crops kharif vegetable and Rabi sunflower have the maximum total cropped intensity of 0.004 with the cropping areas of 408 Ha each. Most of the en-route kharif crops are having minimum total cropped intensity of 0.003 with the cropping areas of 141 Ha each.

   (b) Whereas without export the crop Rabi wheat has a maximum total cropped intensity of 0.326 with cropping area of 33252 Ha. Most of the en-route kharif crops are having minimum total cropped intensity of 0.003 with cropping areas of 141 Ha each.

3. Within year reservoir storages with and without export

   (a) With export the following is expected

      (i) The maximum within year storage of 109.644 MCM in the month of September, which is 3.98% of the live capacity of 2752.7 MCM.

      (ii) The minimum within year storage of 0.011 MCM in the months of May and June, which is 0.004% of the live capacity.

   (b) Without export the following is expected

      (i) The maximum within year storage of 1348.11 MCM in the month of October, which is 48.97% of the live capacity.

      (ii) The minimum within year storage of 242.381 MCM in the month of June, which is 8.80% of the live capacity.

4. Within year reservoir firm yields with and without export

   (a) With export the following is expected

      (i) The maximum within year firm yield of 31.83 MCM to meet the self and en-route irrigation demand in the month of December, which is 19.268% of the annual irrigation target demand of 1652.5 MCM.

      (ii) The minimum within year firm yield of 0.109 MCM to meet the self and en-route irrigation demand in the month of July, which is 0.0066% of the annual irrigation target demand.

   (b) Without export the following is expected

(i) The maximum within year firm yield of 300.90 MCM to meet the self and en-route irrigation demand in the month of June, which is 18.20% of the annual irrigation target demand.

(ii) The minimum within year firm yield of 8.114 MCM to meet the self and en-route irrigation demand in the month of May, which is 0.49% of the annual irrigation target demand.

5. Within year reservoir secondary yields with and without export

(a) With export the following is expected

(i) There are no within-year secondary yields that are likely to be available at the reservoir Daudhan.

(b) Without export the following is expected

(i) The maximum within year secondary yield of 268.78 MCM to meet the self and en-route irrigation demand in the month of February, which is 16.26% of the annual irrigation target demand.

(ii) The minimum within year firm yield of 4.983 MCM to meet the self and en-route irrigation demand in the month of July, which is 0.30% of the annual irrigation target demand.

10.3.2 The Model MOFLP during Operation

In operation at the Daudhan reservoir in Ken basin the following were achieved during a normal water year:

1. Total crop intensity with and without export

(a) With export the total cropped intensity achieved is 0.104 which includes 4 crops from self-command and 7 crops from en-route command. This is 6.93% of the target total cropped intensity of 1.5.

(b) Whereas without export the total cropped intensity achieved is 1.277 which includes 12 crops from self-command and 14 crops from en-route command. This is 85.13% of the target total cropped intensity.

2. Crop areas with and without export

(a) With export the crops Kharif pulses has the maximum total cropped intensity of 0.029 with the cropping areas of 2958 Ha. Most of the en-route kharif crops are having minimum total cropped intensity of 0.003 with the cropping areas of 141 Ha each.

(b) Whereas without export the crop Rabi wheat has a maximum total cropped intensity of 0.326 with cropping area of 33252 Ha. Most of the en-route kharif crops are having minimum total cropped intensity of 0.0037 with cropping areas of 174 Ha each.

3. Within year reservoir storages with and without export

   (a) With export the following is expected

      (i) The maximum within year storage of 102.344 MCM in the months of October and November, which is 3.72% of the live capacity of 2752.7 MCM.

      (ii) The minimum within year storage of 19.665 MCM in the month of August, which is 0.71% of the live capacity.

   (b) Without export the following is expected

      (i) The maximum within year storage of 1348.11 MCM in the month of October, which is 48.97% of the live capacity.

      (ii) The minimum within year storage of 242.381 MCM in the month of June, which is 8.80% of the live capacity.

4. Within year reservoir firm yields with and without export

   (a) With export the following is expected

      (i) The maximum within year firm yield of 29.864 MCM to meet the self and en-route irrigation demand in the month of June, which is 1.81% of the annual irrigation target demand of 1652.5 MCM.

      (ii) The minimum within year firm yield of 0.586 MCM to meet the self and en-route irrigation demand in the month of July, which is 0.03% of the annual irrigation target demand.

   (b) Without export the following is expected

(i) The maximum within year firm yield of 349.72 MCM to meet the self and en-route irrigation demand in the month of June, which is 21.16% of the annual irrigation target demand.

(ii) The minimum within year firm yield of 5.07 MCM to meet the self and en-route irrigation demand in the month of April, which is 0.3% of the annual irrigation target demand.

5. Within year reservoir secondary yields with and without export

(a) With export the following is expected

(i) There are no within-year secondary yields that are likely to be available.

(b) Without export the following is expected

(i) The maximum within year secondary yield of 253.77 MCM to meet the self and en-route irrigation demand in the month of January, which is 15.35% of the annual irrigation target demand.

(ii) The minimum within year firm yield of 4.983 MCM to meet the self and en-route irrigation demand in the month of July, which is 0.30% of the annual irrigation target demand.

10.3.3 The Daudhan Reservoir Operation Policies

For Daudhan the following reservoir operation policies were derived:

(i) Initial rule curve defining lower limits on the storages to be maintained for each within year periods during reservoir operation.

(ii) CHRs were used to define another set of rules for Daudhan reservoir operation given by within year hedging trigger factors. These hedging trigger factors obtained for each within year periods control releases to be made from reservoir.

10.4 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 basin.

2. Simulation being the more realistic is recommended for further screening for refining various aspects of the problem using the results of yield model

3. Since the Inter Basin Water Transfer involves issues like social, environmental issues. They can be studied.

4. Similar study using MOFLP can be done for other objectives such as hydro power generation, net benefits, crop production, labour requirement, optimal allocation of area for different crop etc.

5. Scope of present study was limited to only Daudhan reservoir in Ken basin which is the starting point of Ken-Betwa link and up to Parichha project in Betwa basin. As such a similar study needs to be carried out for the entire Ken-Betwa basin.

6. In this study analysis has been made for 12 within-years' time periods (Monthly) for the critical year. Similar study can be done by taking 36 within-years' time periods (Ten daily). This will depict a clear picture of temporal variation of water availability and also the better crop planning.

Table 10.1.1Abstract of total cropped intensity achieved at reservoirs at basin level with export at planning stage for Ken-Betwa link

Sl. No.	Basin Name	Reservoir Name	Total Cropped Intensity Achieved			
			Maximum	% Exceedance	Minimum	% Exceedance
1	Betwa	Kerwan, Kaliasote, Neemkheda, Kesari, Kethan, Koncha, Mola, Rajghat, Dukwan and Barwa Sagar	1.250	6	-	-
		Parichha	-	-	0.033	93

Note: The total cropped intensity achieved at DN, the only reservoir in Ken basin is 0.149.

Table 10.1.2Abstract of total cropped intensity achieved for crops at basin level with export at planning stage Ken-Betwa link

Sl. No.	Basin Name	Crop Name	Total Cropped Intensity Achieved				Average Cropped Intensity Achieved			
			Max.	% Excee-dance	Min.	% Excee-dance	Max.	% Excee-dance	Min	% Excee-dance
1	Ken	KKVG and KRSF	0.004	7	-	-	-	-	-	-
		EKJW, EKBJ, EKFD, EKMZ, EKPL and EKVG	-	-	0.003	92	-	-	-	-
		KKVG and KRSF	-	-	-	-	0.004	7	-	-
		EKJW, EKBJ, EKFD, EKMZ, EKPL and EKVG	-	-	-	-	-	-	0.003	92
2	Betwa	BKPD	2.729	7	-	-	-	-	-	-
		BKFD	-	-	0.175	92	-	-	-	-
		BRWL	-	-	-	-	0.337	7	-	-
		BKFD	-	-	-	-	-	-	0.011	92

Table-10.1.3 Abstract of total cropped intensity achieved at Daudhanreservoir in Ken basin with export during operation

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
1	Ken	1	Ken	1	Daudhan	0.104

Table 10.1.4Abstract of total cropped intensity achieved for crops at Daudhanreservoir in Ken basin with export during operation

Sl. No.	Basin Name	Crop Name	Total Cropped Intensity Achieved				Average Cropped Intensity Achieved			
			Max.	% Excee-dance	Min.	% Excee-dance	Max.	% Excee-dance	Min.	% Excee-dance
1	Ken	KKPL	0.029	8	-	-	-	-	-	-
		EKJW, EKFD, EKPL, EKVG	-	-	0.003	91	-	-	-	-
		KKPL	-	-	-	-	0.029	8	-	-
		EKJW, EKFD, EKPL, EKVG	-	-	-	-	-	-	0.003	91

Table-10.1.5 Abstract of total cropped intensity achieved at Daudhan reservoirin Ken basin without export at planning and during operation

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
1	Ken	1	Ken	1	Daudhan	1.2774

Table 10.1.6Abstract of total cropped intensity achieved for crops at Daudhan reservoir in Ken basin without export at planning and during operation

Sl. No.	Basin Name	Crop Name	Total Cropped Intensity Achieved				Average Cropped Intensity Achieved			
			Max.	% Excee-dance	Min.	% Excee-dance	Max.	% Excee-dance	Min.	% Excee-dance
1	Ken	KKPD	0.1632	4	-	-	-	-	-	-
		EKJW, EKBJ, EKFD, EKMZ, EKPL, EKVG	-	-	0.0037	96	-	-	-	-
		KKPD	-	-	-	-	0.1632	4	-	-
		EKJW, EKBJ, EKFD, EKMZ, EKPL, EKVG	-	-	-	-	-	-	0.0037	96

Table-10.1.7 Monthly water export targets achieved at Daudhan reservoir

Sl. No.	Month	Proposed Export Target in (MCM)	Target Amount Achieved	
			MCM	%
1	Jun	None	None	
2	Jul	140.00	95.47	68.19
3	Aug and Sep	185.00	185.00	100.00
4	Oct to Feb	102.00	102.00	100.00
5	Mar to May	None	None	
	Total	1020.00	975.47	95.63% Annually

Table 10.1.8 Abstract of compromise solution using operation model

Sl. No.	Basin	Reservoir	Step - 1 Firm Yield (MCM)		Step - 2 Secondary Yield (MCM)		Step - 3 Optimal compromise Yield in (MCM)		
			Max. Firm Yield	Min. Firm Yield**	Max. Secondary Yield	Min. Secondary Yield	Optimal Compromise Degree of Satisfaction (λ)	Optimal Firm Yield	Optimal Secondary Yield
1	Ken	(A) Daudhan (Water supply as Firm Yield)	1829.85	12.195	1121.70	0.00	0.62	1135.51	693.21
		(B) Daudhan*	1829.85	989.28	1121.70	0.00	0.43	1349.37	480.50
2	Betwa	Matatila (Maximum λ)	685.52	305.59	502.53	0.00	0.50	494.55	249.94
		Barwa sagar (Minimum λ)	7.47	4.56	6.02	0.00	0.39	5.70	2.35
3	Integrated Ken-Betwa link	Daudhan	1794.03	1048	1161	0.00	0.35	1306.18	401.74

*Irrigation water requirement to meet min.food requirements of agricultural population as a Firm Yield

**To meet min. food requirements of agriculture population

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Water transfers are a common component of many regional water systems and are being increasingly considered for meeting growing water demands and for managing the impacts of drought. Water transfer can take many forms and can serve a number of different purposes in the planning and operation of water resource systems. However, to be successful, water transfers must be carefully integrated with traditional water supply augmentation and demand management measures. This integration requires increased cooperation among different water use sectors and resolution of numerous technical and institutional issues, including impacts to third parties. Loucks (1992) discussed the role of water resources system models in planning. The major challenges faced by the water resources system planners and managers, the information they need to meet these challenges and the role analysts have in helping to provide this information, have been discussed. Lund and Israel (2003) identifies the many forms that water transfers can take, some of the benefits they can generate, and the difficulties and constraints, which must be overcome in their implementation.

Inter basin water transfer is not a new concept. Quite a number of inter basin water transfer have been implemented in the USA, Canada, Mexico, Sri Lanka, China and Russia.In India, the Western Yamuna Canal and the Agra Canal built in Mughal times are good examples of inter basin water transfer. The Kurnool Cudappa canal (1860-70) and Periyar Vaigai (1896) are also important examples of this concept. During the last century, and the present, the Rajasthan Canal, the Parambikulam-Aliyar, the Telugu Ganga and the Sardar Sarovar Projects have either been completed or are nearing completion.

Suggestions for inter basin water transfer in India to create a balance between surplus and deficit basins have been made from time to time since long; but two proposals put forward in the seventies viz.: (1) Garland Canal by Captain Dinshaw J. Dastur (1977) and (2) National Water Grid by Dr. K. L. Rao (1979) gained considerable attention. Both these proposals had been examined by the Central Water Commission (CWC) and expert academicians and found to be not worthwhile to be pursued further due to economic non-viability and other reasons.

The National Water Development Agency (NWDA) was set up in 1982 to carry out the detailed studiesand to prepare feasibility reports of the links under the National Perspective Plan. NWDA hasidentified 30 links for preparation of feasibility reports.

2.2 INTER BASIN WATER TRANSFER IN INDIA

Biswas (1983) stated that an attempt should be made to identify and assess secondary and tertiary benefits and costs, which are often neglected. Furthermore, in the feasibility studies environmental and social factor should also be considered along with engineering and economic factors. Abu-Zeid (1983) discussed the major water transfer projects in Egypt with its impact on agriculture, environment, siltation in the lake, downstream degradation of the Aswan Dam, effects of loss of silt on agriculture, fisheries, public health, land reclamation, canal system, etc.

Interregional Water Transfer (IWT) has been carried out since ancient times in Japan. Okamoto (1983) observed that, Japan being an island country the length of water transfer links is shorter in length and small in quantity than those of IWT projects in many other countries.According to Greer (1983) the most important fundamental lesson of the Texas Water Plan is the need for balanced planning of the proposed transfer scheme.Planning must be based on projected population, economic levels, and water needs at thirty, forty, or fifty years in the future for an undertaking of this magnitude.

In China the south-to-north water transfer is a gigantic project involving a human transformation of the environment (Dakang 1983). It will have a tremendous impact not only on the natural environment but also on the social environment and the productive activities of society as well.

Herrmann (1983) observed thatno rigorous modelling with validation by actual data has been done so far as the environmental impacts of large interregional water transfer.

Rao and Vijay (1991) made a study of Godavari-Cauvery river link. Jain (1993) made a study of the proposed Kalisindh-Chambal river link (India) by simulation technique. The objective was to verify whether the target water demands for the proposed reservoirs can be met with target reliabilities, and to know how far the project targets can be planned by simulation studies.

Lund (1993) examined the importance of the uncertainty of transfer completion is analytically under a decision theory framework and discussed some implications of uncertain transactions completion for water transfer policy. He commented that, seeking water transfers becomes more attractive to potential water purchasers if the probability of a successful transfer is increased, if more of the transfer costs for watertransfers are increased after a transfer has been approved, and if the costs of delaying implementation of alternative water supplies are small.

Israel and Lund (1995) focuses on recent experiences with water transfers, in California and offer a series of potential lessons for federal, state, and local managers for integrating water transfers in regional water resource systems.

Shao et al. (2003) reviewed the recent development in interbasin water transfer projects in China and also the feasibility study of transfer of water from south China to north China involving the Yellow River and Yangtze River. However, they observed that such projects are prone to problems and controversies, and may challenge the established basin management, policy making procedure and legal system which are taken for granted until such projects are put under consideration. The impacts of the project on the policy-making procedures, water law, natural environment as well as existing basin management method are also discussed.

India's scheme of interlinking its rivers to transfer water from 'water surplus' to 'water deficit' basins is fraught with substantive and serious impacts and implications. In order to appraise them appropriately, it is necessary to understand various aspects of interlinking such as its concept, technology and economics. Also, as there is majorcommonality of technology components such as dams and barrages for both interlinking of rivers and basin-wise water resources development for multipurpose benefits, it will be necessary to distinguish between the two. It is rational to consider the former as an additionality to the latter, so that impacts and implications of interlinking are correctly appraised (Prasad. 2003).

The methodology currently adopted for planning inter basin water transfer in India requires introduction of appropriate improvements for more realistic appraisal of the pertinent issues. Sharma and Sarma (2003) presented a critical study on basic approach to inter basin water transfer in India with special reference to the Brahmaputra basin. They discussed the technical, social and legal issues and point out some studies, application of modeling technique and engineering tools for in-depth scientific analysis as a precursor to water transfer.

Verma (2003) commented that before linking of rivers, there is a need to develop and manage land and water resources on watershed basis strictly following watershed development and management principles, in river basins. Development of watersheds in riverbasins before linking rivers will control floods, flow of silt and damage of lands and increase irrigated area, efficiency and life of the irrigation projects.

Ganguly (2003) discussed different issues related to inter basin water transfer. Which includes rehabilitation of the project affected peoples, reservoir sedimentation, water logging, submergence of minerals, archaeological monuments, rare species of flora and fauna Impact on environment, climate, society, wild life, aquatic life, ground water etc.

Rao (2003) discussed some of the issues related to inter basin water transfer, viz. political response,gigantism. performance of irrigation projects, river basin as unit for planning and management and political consensus; and suggests principles, strategy and the agenda for the Task Force, responsible for investigating and implementing the river linking projects.

Sarma and Srivastava (2003) presented a system analysis modeling approach for planning and operation of reservoirs, involved in inter basin water transfer projects and demonstrated the approach by applying it to the Parbati-Kalisindh-Chambal water transfer link involving five-reservoirs, proposed by National Water Development Agency (NWDA). India.

Singh and Gosain (2003) presented a study on the problems of transboundary watercourses. The study is divided into three sections. The first section surveys the basic philosophies behind the international water sharing laws and work done by the prominent international organizations in this arena. This is supplemented by a critical analysis of the Helsinki Convention (1992) and the UN Convention (1997). The second section provides an insight into the provisions of the Indian Constitution pertaining to the interstate river water disputes followed by a detailed analysis of the relevant Parliamentary legislations and the follow up measures including the enactment of Interstate Water Disputes Act, 1956 and the River Boards Act. 1956. The final section suggests ways and means to help resolve the conflicts pertaining to interstate rivers in India, which is consistent with the Indian Constitutional provisions as well as the philosophy and spirit of the international water sharing laws.

Due to huge volumes of water transfer involved, the inter basin water transfer projects planned in India will require large financial and other resources and will be among the biggest water resources development schemes ever undertaken in the world. In view of high stakes involved, it is important that a risk analysis of this scheme is carried out to identify the weak spots. Jain and Singh (2003) presented a preliminary qualitative risk analysis of the peninsular component of inter basin water transfer proposal. The analysis include: risk of insufficient water, risk due to natural hazards, environmental impacts of the proposed projects, risk due to law and order, risk due to social and political reasons and other issues.

Chander (2003) gave a framework for evaluating inter basin water transfer projects and suggested five criteria. He identified the database required for each of these criteria and suggested that the data be used in a simulation model to determine the impact of transfer for various hydrologic regimes. An interdisciplinary panel can then use these results to develop consensus regarding the size and route of the transfer.

Bhavanishankar and Raman (2003) gave an alternative proposal that should derive the same benefit as proposed linking of rivers in India, with least disturbance to ecology and environment.

Rao et al (2005) studied the inter basin water transfer in space and time with reference to monsoon rainfall runoff conditions prevalent in south India. The network problem is solved using linier programming and the utility is demonstrated with the help off tread off between two conflicting objectives i.e. maximising the storage in deficit reservoirs while minimising cost of transferring water through the links. Sarma (2007) applied LP and DP to the Parbati-Kalisindh-Chambal link in central India to find out the optimal yield for transfer in the link.

José Geraldo Pena de Andrade et al (2011) examine three select Brazilian experiences of transbasin water diversion between river basins, with a comparative review of other similar projects around the world.

2.3 WATER RESOURCES SYSTEM ANALYSIS

System analysis techniques have been used successfully in the management and operation of complex reservoir systems. The complexities of a multipurpose multiple reservoir system generally require release decisions to be made by an optimization or simulation model. The choice of methods depends on the characteristics of the system being considered, on the availability of data, and on the objectives and constraints specified. Most of the optimization models are based on some type of mathematical programming technique. In general, the available methods can be classified as follows (Yeh, 2003): linear programming; network flow; quadratic programming; dynamic programming; nonlinear programming; mixed integer linear programming; interior point method; and simulation.

Developments in the area of application of numerical methods have started since late forties. Dantzig did the break through by developing the simplex method for solving the linear programming in 1947 Works done by Kuhn and Tucker in 1951 on the necessary and sufficient conditions for optimal solution of nonlinear problems, and enunciation of principleof optimality by Bellman for solving the dynamic programming in 1957 are the landmarks inthe field of systems analysis. Numerous techniques for application of systems analysis in the field of water resources planning and management have been reported since the early work reported by Dorfman (1962). Hence, the literature available in this area is voluminous.

Reviews of the systems analysis techniques and their applications have been presented and published. Loucks and Falkson (1970) reviewed and compared three techniques, namely, DP, policy iteration and LP for the stochastic reservoir operation model incorporating first-order Markov chains. Stedinger et al. (1983) reviewed and compared LP based deterministic, implicitly stochastic and explicitly stochastic reservoir screening models. Yakowitz (1982) presented a review of application of dynamic programming to water resources systems. Stedinger (1984) compared the capacities and operating policies resultingfrom the original LDR model, LDR-based model of Loucks (1970), and simulation using the standard operation policies (SOP) and the minimum failure frequency policy. Loucks et al. (1985) reviewed some important short comings of management and policy models and argue for improved human-computer model interaction and communication, which can lead to more effective model use, which in turn should facilitate the exploration, analysis and synthesis of alternative designs, plans and policies by those directly involved in the planning, management, or policy making process. Yeh (1985) has provided a comprehensive state-of-the art review of theories and applications of systems analysis techniques of the reservoir problems. A set of conclusion and recommendations was also provided. Simonovic (1992) has provided a short review of reservoir management and operation models. Wurbs (1993) presented a comparison of models from a general overview perspective. Dandy et al. (1997) compared thenetwork linear programming, full optimization LP model,simulation and LP yield model for estimating the safe yield of the water supply system of Canberra which consisting of four reservoirs. Yeh (2003) reviewed the algorithms developed for optimizing the operations of water resources systems. The algorithms reviewed include linear programming, network flow, quadratic programming, dynamic programming, nonlinear programming, mixed integer linear programming, interior point method, and simulation. Labadie (2004) assess the state-of-the-art in optimization of reservoir system management and operations and consider future directions for additional research and application. Optimization methods designed to prevail over the high-dimensional dynamic, nonlinear, and stochastic characteristics of reservoir systems are scrutinized, as well as extensions into multiobjective optimization. A more detailed account of the methodologies and techniques is available in comprehensive texts andedited volumes (Maass et al., 1962; Hufschmidt and Fiering, 1966; Hall and Dracup. 1970; Ladson, 1970; James and Lee, 1971: 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; Killer and Lieberman, 1995; Wurbs. 1996; Biswas 1997; and ReVelle, 1999).

Application of the techniques to real life problems related to rivers in India is 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), Sarma (2004) Panigrahi (2006) Sethi (2007) and Thube (2007).

2.4 DETERMINISTIC MODELS

Deterministic model, which are governed by physical laws, do not explicitly consider uncertainty in hydrologic variables or model parameters. Loucks et al. (1981) reported that river basin models are more easily explained and understood if, at first, uncertainty is ignored. In deterministic models, the sequence of inflow entering into a reservoir system is explicitly specified in the model formulation. Hall et al. (1968) presented a monthly operation model of the Shasta reservoir for a period of low flows from 1928 to 1934. The objective was to maximize the total income from the sale of both water and power during the critical period. Harboe et al. (1970) proposed a two stage optimization procedures for Folsom reservoir and its power plant. The maximum annual firm energy production during a critical period of 12 years was determined for a given certain level of annual firm water supply from the reservoir.

Others use synthetically generated stream flow sequences that preserve selected statistically characteristics of the historical data. Hall et al. (1969) as well as Askew et al. (1971) 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. They showed that the generated records as a whole had significantly less severity than the historical records of the same length.

2.5 STOCHASTIC MODELS

Stochastic models, which are governed by the laws of uncertainty, 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 suitably by appropriate mathematical formulations. A time series of inputs are generated over the planning horizon. The model proposed by Young (1967) is noted as the earliest application of implicit stochastic optimization model using dynamic programming to a single reservoir operational problem.

In explicit stochastic models, either the Markov assumption or chance constraints are included as basic components to account for hydrological uncertainties (Lee et al. 1987). 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. A penalty for failure of the system is included in the objective function as a deficit cost. The authors described a discrete stochastic DP model and applied it to a two-reservoir problem around Lake Vyrnwy, Wales. The authors reported severe computational difficulties with this approach.

2.6 OPTIMIZATION TECHNIQUE

In system analysis**,** the main role of formal mathematical optimization models is to search through a large number of combinations of possible values for the decision variables to find the decision policy that maximizes or minimizes a defined objective function. Representing complex project objectives and performance criteria in the required format without unrealistic simplification, is a difficult aspect of modeling process that limits the application of optimization 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, objective function, constraint and availability of data (Yeh 1985).

2.6.1 Linear Programming Applications

Although there is a difficulty in formulating LP models due to non-linear functions of reservoir problems, still LP has been one of the most widely used techniques for solving these problems. The essential advantages of LP include the following (Mujumdar and Narulkar. 1993; Yeh, 1985: Yeh, 2003): it can accommodate relatively high dimensionality with comparative ease: universal optima are obtained; no initial policy is needed; and standard computer codes are readily available. LP models also include chance-constrained LP. stochastic LP. and stochastic programming with recourse. LP has been used extensively to optimize reservoir management and operation. For a nonlinear objective function, a Taylor series expansion can be used to perform linearization, and solutions are obtained by iteration. Dorfman (1962) initiated the application of LP technique in reservoir system planning problems. The early work on stochastic LP model reported in literature was by Marine (1962). He evaluated the value of flood control storage for hydroelectric and water supply purposes taking inflows as random variable and assuming it to be a Markov process. Thomas and Watermeyer (1962) extended Mamie's work applying the same technique for solvingstochastic reservoir operation problem. Loucks (1968) developed a stochastic LP model for a single reservoir. A first-order Markov chain described the net flows for each time period and transition probabilities of inflows were estimated from historical inflows. The stochastic model was applied to Fibger lakes within the Osevego river basin. He pointed out the dimensionality problem associated with this type of model in real situations, which can easily exceed several thousands of constraints.

ReVelle et al. (1969) initiated the application of chance-constrained LP to reservoir system optimization. He proposed the linear decision rules (LDR) that relate releases to storage and decision parameters. ReVelle and Kirby (1970) modified the original LDR to include evaporation losses using linearized storage-area curves and projected storage. They also used the objective of minimizing the probability of violating the minimum flow constraint. Loucks (1970) pointed out that the reservoir operation rules discussed by Young (1967) were fundamentally different than the original LDR. He proposed the 'linear release rule' relating the release to storage, inflow, and decision parameter, which resulted in less conservative results compared to the original LDR. Jores et al. (1971)

applied the original LDR, chance-constrained LP, synthetic streamflow generation and simulation in modeling the multiple source water supply system for Baltimore. The objective was to minimize the pumping costs of the backup supply. Nayak and Arora (1971) applied a modification of the original LDR. which replaced the usual initial storage with a net initial storage consisting of initial storage plus upstream reservoir releases scheduled for that period, to a multireservoir system of four reservoirs. Eisel (1972) developed a chance-constrained model based on LDR originally proposed by Bryant (1961). The resulting nonlinear separable convex programming problem was solved by the piece-wise linear approximation method of separable programming. Lot of works were reported based on LDR during seventies and early eighties, e.g., Eastman and ReVelle (1973); Lane (1973); Curry et al. (1973); Loucksand Dorfman (1975); ReVelle and Gundelach (1975); Gundelach and ReVelle (1975); Houck (1979); Jores et al. (1981); and Houck and Datta (1981). Stedinger (1984) compared the capacities and operating policies resulting from the original LDR model, Loucks (1970) LDR-based model, and simulation using the standard operation policies (SOP) and the minimum failure frequency policy. He found that the original LDR performed poorly when estimated capacities were compared to what was actually required during simulation. The capacities required by Loucks' LDR model were found to be more reasonable and roughly equal to those required with SOP. Similar results were obtained when operating policy performance was compared.

Cohon and Marks (1973) presented a case study of a river system in which development is to be planned according to national and regional objectives. A linear screening model for finding the best set of development alternatives was introduced and a brief discussion on methods for handling more than one objective in such models was presented. Benefit transformation curves were derived from a multiple objective linear programming model by Thampapillai and Siden (1979). These transformation curves were used to assess the relationship between objectives. The model consists of a weighted objective function, which can be parametized. Procedures were suggested to narrow the search for an efficient management strategy on the transformation curve. However, the validity of the transformation curve depends on how non commensurables are valued and so different methods of valuation were presented and used.

Hogan et al. (1981) discussed some important conceptual problems concerning the application of chance-constrained programming (CCP) to risky practical decision problems by comparing CCP to stochastic programming with recourse (SPR). Datta and Houck (1984) developed a real-time reservoir operation model based on a chance-constraint formulation assuming a particular form of linear decision rule. Simulation of actual operation using thismodel for a reservoir was carried out to demonstrate the feasibility and efficiency of this approach. Changchit and Terrell (1989) presented an application of chance-constrained goal programming methodology to a system of multipurpose reservoirs, and demonstrated the methodology by applying it to a three-reservoir system in Oklahoma. The model uses a time period of month.

Chaturvedi and Srivastava (1981) presented a sequential iterative modeling process where deterministic LP models and simulation are combined together to obtain alternative optimal planning, considering six major reservoirs for the Narmada river basin in India.

Tao and Lennox (1991) formulated a reservoir system operation problem by successive linear programming and applied it to the operation of the High Aswan Darn (HAD) in the Nile river basin. Afzal et al. (1992) developed a linear programming model to optimize the use of different quality water by alternative irrigation. The model described a method of allocating land and water to different crops wherever low rainfall, limited quantity, and different quality waters are the basic parameters governing the irrigation system. Mohan and Raipure (1992) developed a linear multi-objective programming model and used the constraint technique to derive the optimal releases for various purposes from a system of five reservoirs in India. Trade-off analysis between conflicting objectives of irrigation and hydropower was carried out. Crawley and Dandy (1993) used the linear programming technique for identification of optimum monthly operation policies for the Adelaide headwords 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. Mohan et al. (1998) presented a linear programming model for irrigation planning under stochastic inflows with reference to a tank irrigation system in South India. The model has been developed to determine optimal cropping pattern under different levels of dependable inflows. Suitable statistical distributions have been fitted for inflows into the reservoir for each month. This model maximizes net benefits and derives both optimal storages and releases for various inflow scenarios. The different rule curves derived from the model can be used for operation during normal water availability, water shortages and during the excess flow conditions.

The general formulation of integer linear programming (ILP) is identical to the LP formulation with the exception that decision variables are integers. If only some of thedecision variables are required to be integers and the others can be any real numbers, the formulation becomes mixed integer linear programming (MILP). Major and Lenton (1979) demonstrated the application of a system of three models in an integrated way for the planning of Rio Colorado basin in Argentina. A mixed integer linear programming screening model, for finding the most promising configurations, a simulation model to evaluate the hydrologic reliability of these configurations, and a sequencing model to schedule the configuration of projects in four time periods are presented. Helm et al. (1984) presented a procedure for the analysis of time phasing of reservoir system development based on the multiple reservoir stochastic model of Curry et al. (1973). The objective of the mixed integer continuous LP formulation was to select the reservoir sizing, timing, and to establish operating policies such that the total cost associated with the system of linked reservoirs is minimized.Duetotheresulting problemsize anditsgeneralstructure, Bender's decomposition was applied and the procedure is illustrated using a numerical example for three inter connected reservoirs. Malek-Mohammadi(1998)presented an integrated optimization model for planning irrigation systems considering surface reservoir capacity, ground water and spring withdrawal, delivery system capacities, land to be developed for irrigation, and cropping pattern. The system is optimized by means of a chance-constrained optimization model using mixed integer LP to maximize the net benefit associated with the development. The linear release rule proposed by Loucks (1970) was employed to determine the reservoir capacity. 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. The improvement achieved with the modified model is demonstrated using the same example as presented with the original model. Tuet al.(2003)develops a mixed integer linear programming (MILP) model that considers simultaneously both the traditional reservoir rulecurves and the hedging rules to manage and operate a multipurpose, multireservoir system.

Turgeon (1987) described a method for identifying the development scheme of a valley. The problem consists in selecting the sites on the river where reservoirs and hydroelectric power plants are to be built and then determining the type and size of the projected installations. The solution methodology used a parametric mixed integer linear programming employing the branch and bound algorithm. An LP parametric analysis is applied between the points where the MILP problem is solved. The techniques presented are used to study the development of a river in Northern Quebec.

Lele (1987) presented two algorithms that improve upon the sequent-peak procedure for reservoir capacity calculation. The first algorithm incorporates storage-dependent losses and the second extends the first algorithm to incorporate less than maximum reliability. Both the algorithms require a sequential iterative procedure for solution. The algorithms were found to give the same results as those obtained by using LP formulation.

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). They applied model to the Subernarekha River, having two reservoirs and two barrages in the mainstreamand three small command area reservoirs. They analyzed the sharing of water among the co-basin states. The main objective is to find the maximum annual benefits from hydropower and irrigation subject to various constraints on the system. Design constraints as per theTripartite Agreement(TPA) relating to the water shares among riparian states (i.e., Bihar, Orissa, and West Bengal) at individual dams and barrages are also considered. Vedula et al. (2005) developed deterministic linear programming model for optimal conjunctive use planning in multicrop irrigation in a canal command area to maximize the sum of annual relative yields of crops in a normal year. The model is applied to an existing reservoir command area in Chitradurga district, Karnataka State, India.

Khare et al. (2007) presented a simple economic-engineering optimization model to explore the potential of conjunctive use of surface and groundwater resources for proposed

Krishna (Nagarjunasagar)–Pennar (Somasila) canal, under peninsular rivers development as a part of India's ambitious river linking program using linear programming with various hydrological and management constraints, and to arrive at an optimal cropping pattern for optimal use of water resources for maximization of net benefits.

Moradi-Jalal et al. (2007) described an LP based optimization model for optimal multi-cropped irrigated areas associated with proper reservoir operation and irrigation scheduling to maximize annual benefits derived from crops and fruits over a planning horizon. The constraints sets are linked together appropriately by additional reservoir capacity constraints.

Mehmet et al (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.

2.6.1.1 Explicit stochastic LP

Explicit stochastic optimization is designed to operate directly on probabilistic descriptions of random stream flow processes rather than deterministic hydrologic sequences. This means that optimization is performed without the presumption of perfect foreknowledge of future events. In addition, optimal policies are determined without the need for inferring operating rules from results of the optimization.

The early work on stochastic LP model reported in literature was by Manne (1962). He evaluated the value of flood control storage for hydroelectric and water supply purposes taking inflows as random variable and assuming it to be a Markov process.

Loucks (1968) developed a stochastic LP model for a single reservoir. The stochastic model was applied to Fibger lakes within the Osevego river basin. He pointed out the dimensionality problem associated with this type of model in real situations, which can easily exceed several thousand of constraints.

Croley (1974) presented several heuristic procedures based on optimizing certain sub-problems such as time series realization of the stochastic inflows and a series of single stage problems with stochastic inflows.

Houck and Cohon (1978) also assumed a discrete Markov structure for the stream flows. They found a design and management policy for a multipurpose multiple-reservoir system by solving two LP problems sequentially in order to approximate a nonlinear formulation. The nonlinear program and the algorithm called SESLP (sequential explicitly stochastic linear programming) model are illustrated for a hypothetical two-site, dual-purpose planning problem. The major weaknesses of the model stated by them are huge data requirements and computational burden.

2.6.1.2 Chance-constrained LP

Another alternative to stochastic programming model, which reflects the probability conditions on constraints, is chance-constrained programming. These models are small; they define explicit operating policies, but their structure tends to lead to conservative estimates of design variables.

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

LeClerc and Marks (1973) applied the original LDR to a large-scale multiple reservoir system. They concluded that the original LDR is physically sound; the solution of the resulting LP when used in actual operations causes the water to be wasted; and the validity of LDR's is not yet verified.

Curry et al. (1973) extended the work of ReVelle et al. (1969). However they omitted the use of LDR's in the chance-constrained model. The advantages claimed are the ability to include the release quantities in the objectives function, and the inclusion of stochastic as opposed to deterministic demands. The development of a mathematical model for a system of linked system of multipurpose reservoirs with stochastic unregulated inflows was obtained as a straightforward generalization of the single reservoir model.

ReVelle and Gundelach (1975) proposed LDR 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, it also presented mathematical complexities.

Houck (1979) used multiple original LDR's conditioned on the previous period's streamflow to relax the feasible region of operating rules allowing improvement in reservoir operation. The method is limited by the amount of data needed to estimate the conditional cumulative distribution functions (CDF's) and the piecewise linearization of the CDF's for inclusion in LP. He found the multi-LDR's resulted in a larger but still manageable model.

Houck et al. (1980) extended the LDR model to include an objective of maximizing net economic efficiency benefits for multipurpose multiple reservoir systems, the extended LDR model has been shown to be well within the limits of computational feasibility for large reservoir systems.

Sethi et al. (2006) developed the deterministic linear programming (DLP) and chance-constrained linear programming (CCLP) models to allocate available land and water resources optimally on seasonal basis so as to maximize the net annual return from the study area, considering net irrigation water requirement of crops as stochastic variable.

2.6.1.3 Implicit Stochastic Reservoir Yield Model

Loucks et al. (1981) developed the yield model which is a implicitly stochastic LP model that incorporates several approximations to reduce the size of the constraint set needed to describe reservoir system operation and to capture the desired reliability target releases. A basic problem with the implicitly stochastic models is that many periods may need to be included in a model if an adequate distribution of unregulated natural stream flows is to result. This can be avoided in part by designing for the 'critical period' of record (Hall et al. 1969). Loucks et al. (1981) demonstrated that in several cases the yield model provides a reasonable estimate of the distribution of reservoir capacity requirements obtained with the sequent peak algorithm.

Palmer et al. (1982) developed simulation and LP models to determine the yield of the Potomac and Patuxent river basins when operated jointly with the Potomac river. The yield of each of the five reservoirs in the system was determined using simulation models. Simulation and linear programming models were developed to determine the yield of the reservoirsystem when operated jointly with the Potomac river. The models indicate that the yield, which results from the proper joint operation of the system, is significantly greater than the yield of the individual components of the system.

Lall and Miller (1988) presented an optimization model in the spirit of the yield model for selecting and sizing potential reservoirs on a river basin. Decomposing the problem into simulation and optimization components derived a compact, nonlinear formulation. Reservoir capacities are determined using a modified sequent peak algorithm to simulate monthly reservoir operation. Simulation is also employed to determine optimal sizes for hydropower generations at each site.

Lall (1995) developed a yield model for selecting between candidate 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 modelthe ground water subsystem. Example applications are presented with data from the Jordan river basin in Utah.

Sinha et al. (1999a) presented a nonlinear optimization model for selecting and sizing potential reservoir sites on river basins. The model improves the work 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. Sinha et al. (1999b) presented a yield model for selecting and sizing potential reservoirs and hydroplants on a river basin. A linked simulation-optimization framework is used for formulation. Sizing of reservoirs and hydroplants, and evaluation of objective function and constraints and their derivatives are done as a part of simulation.

Schwarz (2000) presented a multiobjective analysis to size reservoir and identify non-inferior system operating rules that mitigate the impacts of consumptive operations for the river Potomac.

Mariam (2000) adopted implicit stochastic yield model based on linear programming for planning optimal annual yield of proposed Morand reservoir in Narmada basin in India, and work out optimal allocations of land and water resources, using crop planning model, to develop cropping patterns for the annual reservoir yields that can be obtained from the reservoir for different degree of annual project dependability. He opined that the yield model provides a reasonably acceptable estimate of the annual reservoir yield for planning of the project.

Dahe and Srivastava (2000) have demonstrated the use of yield model for assessment of annual yield of Upper Narmada irrigation reservoir with specified reliability and the extent of availability of irrigation supply during failure years. Such an assessment can assist the planners to decide upon the irrigation policies regarding the area to be brought under irrigation with sustainable cropping pattern and to reduce the damages due to the likely shortages in supply during failure years.

Dahe (2001) has made an optimization approach employing the implicit stochastic yield model based on linear programming addresses issue of assessment and optimal utilization of annual yield for system of reservoirs. Basic yield model is extended to develop yield model for multi-reservoir system to achieve the desired annual reliabilities for irrigation and power generation and incorporate an allowable deficit in annual irrigation target. The study was carried out for 25 major irrigation reservoirs in Narmada basin in India for optimal planning of the river basin projects.

Dahe and Srivastava (2002) have extended the basic yield model and presented 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 and to incorporate an allowable deficit in annual irrigation target. They applied the yield model in eight reservoirs in the Narmada basin.

Panigrahi and Srivastava (2005) presented an integrated yield model (IYM) for river basin development to assess optimal annual yields from reservoirs based on pre-specified annual release reliabilities with site specific yield failure years and failure fraction factors and also simultaneously optimizing the cropping pattern at each site. The model was applied to Ong sub-basin of Mahanadi river basin in Odisha, India. Results showed that IYM closely reproduce the behavior of the system and results reasonably match with simulation. Panigrahi (2006) applied the improved IYM called the IRYM to 54 reservoirs in Mahanadi basin lying in Odisha state.

Thube (2007) improved the model to incorporate barrages and hydropower and applied to the transboundary Krishna river basin with 126 major and medium dams. Sethi (2008) applied the yield model to the Cauvery basin and examined the yield scenario within the framework of the Cauvery tribunal awards.

Srivastava D. K. And Awchi Taymoor A. (2009) applied models to provide useful strategy to evaluate the storage, water yield and the operational performance of the multipurpose Mula reservoir in India. Insufficient yield from the reservoir for the purpose of water supply and irrigation has led to the need for reevaluation.

2.6.1.4 FuzzyLinear Programming

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). Russell and Campbell (1996) proposed its application to find out reservoir operating rule by applying this to a single purpose hydroelectric project and concluded that although it is a promising approach but it suffers from the curse of dimensionality. It can supplement the conventional optimization techniques but cannot probably be a replacement. Shrestha et al. (1996) also used the fuzzy rule based modeling in reservoir operation. They constructed the model to derive operation rules for the Tenkiller Lake in Oklahoma. Fontane et al. (1997) have addressed the imprecise and no commensurable objectives for reservoir operation through fuzzy dynamic programming using an implicit stochastic approach.

Panigrahi and Mujumdar(2000) proposed a complete approach for long-term storage/transfer/distribution system management and developed fuzzy rule based model for the operation of a single purpose reservoir. The paper presented by Tilmant et al. (2002a) compares reservoir-operating policies obtained from fuzzy and nonfuzzy explicit stochastic dynamic programming. Despite major differences in the mathematical representation of operating objectives and/or constraints it was shown that both formulations yield similar measures of system performance. Faye et al. (2003) implemented an adaptation procedure of weighting parameters of the minimization criteria based on fuzzy logic. Fuzzy logic is shown to be very adequate when it comes to apprehend finely the stakes in presence in the long-term management.

Multi objective analysis in water resources has developed in explicit form largely through the work of Harvard Water Program (HWP). Much of the methodology and its research findings were published by Mass et al. (1962). Haimes and Hall (1974) developed a method for solving no commensurable multi objective functions, designated by surrogate worth tradeoff (SWT) method. Non-fuzzy multi objective approaches include Vedula and Rogers (1981) and SrinivasaRaju and Nagesh Kumar (1999). Yeh (1985) reviewed the various models used for optimal operation of reservoirs. Most of these models consider the uncertainty caused due to variability of inflows. However uncertainty caused because of imprecise objectives and goals is also a factor in developing operation policy of a reservoir.

To overcome some of the limitations in previous approaches, fuzzy based models were proposed. Shrestha et al. (1996) introduced a fuzzy-rule based model deriving the operation rules for a multi-purpose reservoir. Operation rules are generated on the basis of economic development criteria. Russell and Campbell (1996) proposed operating rules for a single purpose hydroelectric project, where both the inflows and selling prices of energy are uncertain. Anand Raj and Nagesh Kumar (1998 and 1999) proposed fuzzy based approach, RANFUW, for ranking multi criterion river basin planning alternatives using fuzzy numbers and weights.

Nagesh Kumar et al. (2001) developed optimal reservoir operation model using multi objective fuzzy linear programming (MOFLP) considering two objective functions viz. maximization of releases for irrigation and maximization hydro power produced for Hirakud reservoir to determine operation policies for different satisfaction level and various inflow scenarios.. They concluded that fuzzy linear programming is a simple and suitable tool for multi objective problem as compared to other method. Same conclusion was drawn by SrinivasRaju and Duckstein (2003) for the evalution of management strategy using MOFLP for irrigation planning considering three conflicting objectives viz. net benefits, agriculture productions and labour employment. SrinivasRaju K. and Duckstein L. (2003) also formulated MOFLP for two reservoir system of Jayakawadi irrigation project to perform sensitivity analysis for different dependable inflow. SrinivasRaju K. and Nagesh Kumar D. (2004) developed MOFLP for Sri Ram sagar project to study three conflicting objectives. They considered uncertainty in the inflow by stochastic programming.

Dubrovin T. et al. (2002) developed a fuzzy rule-based control model for multipurpose real-time reservoir operation for Paijannelake of Finland and compared the result with Sugeno method for fuzzy interface. Nazemi A.R. et al. (2002) modified fuzzy linear programming considering the stochastic properties of variables and applied for storage-yield problem of Saugatuck reservoir of Iran and compared with linear programming.A fuzzy rule based model for multi reservoir operation in long term was developed by Mohan and Prasad (2005). The performance of reservoir for irrigation, water supply and hydropower was evaluated with the developed model and compared with historical operation.Mehta R. and Jain S.K. (2005) developed fuzzy rule base model to study the sensitivity of reservoir operation with different number of categories of membership functions and shows that the performance of model improves with increasing number of categories of membership functions. Sahoo et al. (2006) developed the linear and fuzzy optimization models to optimize the economic returns, production and labour utilization for different cropping patterns

RamaniBai and Tamjis (2007) developed fuzzy logic model (FLM) on operation and control of hydro power dams in Malaysia. The results of their studies show that FLM can be used in number of applications and it is not sensitive to the real input data. Choudhari and Anand Raj (2009) suggested the irrigation planning with fuzzy linear programming for multi-reservoir, multipurpose system, SrinivasaRaju et al(2009) studied the multi-objective fuzzy and deterministic Goal programming to get the compromise solution of optimal irrigation planning while considering all the conflicting objectives together. Regulwar and Gurav (2010) proposed the irrigation planning model with fuzzy approach for Jayakwadi irrigation project Maharashtra, India by considering four different objectives together.

Dattatray, G. et al (2011) discussed the Multi Objective FuzzyLinear 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.

Mirajkar and Patel (2011) formulated a multi-objective fuzzy linear programming for crop planning in the right bank canal command area of Kakarapar weir in Gujarat, India. They developed linear programming model to maximize crop production and net benefits. They developed the linear membership functions and objectives were fuzzified for optimal allocation of areas of different crops in the command area.

2.6.1.5 Linear programming application in crop planning

The linear programming approach is capable of handling complex water resources problems, where a large number of decision variables and constraints are involved. Hence, it has been found to be suitable to apply in crop planning problems particularly.

Heady et al. (1973) employed linear programming models to obtain optimal water and land allocation and agricultural water needs for United States in 2000 A.D. The model included 223 production areas, 1891 land resources areas and 51 water supply regions.

Lakshminarayan and Rajagopalan (1977) used a linear programming model to determine the optimal cropping pattern and optimal release policy from canal and tube wells during various months in a year for maximizing the economic returns. Their model was applied to a situation in northern India. Sensitivity analysis was carried out on the tube well capacity, area available for irrigation, the operation cost for canals and tube wells, and values per pound of crops considered.

Matanga and Mariño (1979) developed a model for area-allocation, which is a linear optimization model to maximize gross margins from yields of crops under consideration subject to total water supply, maximum amount of water that could be delivered for irrigation purposes on any date of irrigation and irrigation labour. Sensitivity analysis was performed to study the effect of change in crop prices on the optimal results.

Chaturvedi and Chaube (1985) optimized Indo-Nepal region of the Ganga basin using LP model considering ground, surface water availabilities with the objective function to maximize the sum of irrigated areas.

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 yielded the cropping pattern and monthly schedule of reservoir releases and aquifer withdrawals that maximize the annual profit in irrigation district. Both the surface and ground water requirements of crops were considered.

Maya and Prasad (1989) presented a LP model for the optimization of net benefit and to find the optimal cropping pattern considering labour, animal power, resourse of farmers and fodder production.

Paudyal and Gupta (1990) used a multilevel optimization approach to solve a linear programming model developed to determine the optimal cropping pattern in various sub-areas of the basin, the optimal design capacities of irrigation facilities including both the surface and ground water resources and optimal water allocation policies for the conjunctive use.

Raman et al. (1992) in their paper deal with the development and application of an expert system for drought management. A linear programming model is used to generate optimal cropping patterns from past drought experiences and also from synthetic drought occurrences.

The problem of optimal allocation of a limited water supply, for irrigation of several crops in the same area, is addressed by El-Awar et al. (2001). Both intra-seasonal and inter-seasonal competition of water, among various crops, is considered. A linear programming mathematical model was developed to determine optimum water allocation.

Moradi-Jalal et al. (2007) described an LP based optimization model for optimal multi-cropped irrigated areas associated with proper reservoir operation and irrigation scheduling to maximize annual benefits derived from crops and fruits over a planning horizon. The constraints sets are linked together appropriately by additional reservoir capacity constraints.

2.6.1.6 Mixed Integer Linear programming

The analysis of river basin developments is viewed by Windsor and Chow (1972) as a multilevel optimization problem. In this particular study, mixed integer programming is coupled with historical, or stochastically generated, streamflow 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. Intangible water users, such as recreation and water quality control, are treated as optional constraints and their imputed values are obtained by a multiple solution technique. Part of the input to this model is provided by the irrigation sub model developed in a previous study.

Rose (1973) described an irrigation feasibility study carried out for a developing country. In essence the problem was to decide which major works to build and what crops to grow in order to make the most effective use of the natural and human resource available. The solution technique used was mixed integer programming.

Windsor (1975) 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.

Srinivasan et al. (1999) improved the mixed LP model developed by Moy et al. They presented a mixed-integer linear programming model for reservoir performance optimization. They improved the mixed-integer formulation of Moy et al. (1986) for reservoir performance optimization. They demonstrated the improvement achieved by the same example as presented in the original model.

Needham et al. (2000) reported a study addressing the questions related to flood-control operating procedures followed by the US Army Corps of Engineers, Rock Island District. An application of a mixed integer linear programming model is presented for a reservoir system analysis of three projects on the Iowa and Des Moines river. A strategy for evaluating the value of coordinated reservoir operations is developed in this study.

Wei and Hsu (2007) presented a real-time simulation-optimization operation procedure for determining the reservoir releases at each time step during a flood. The proposed procedure involves two models, i.e., a hydrological forecasting model and a reservoir operation model. In the reservoir operation model, they compared two flood-control operation strategies formulated as mixed-integer linear programming (MILP) problems for a multipurpose multireservoir system.

2.6.2 Dynamic Programming

Dynamic programming (DP), a method first introduced by Bellman (1957), has since been recognized as a powerful approach in the analysis of water resources system. DP has a wide variety of application in engineering and economic decision problem (Yakowitz 1982; Yeh 1985; Labadie 2004). The major attraction of DP is that it can handle non-convex, nonlinear, and discontinuous objective function without difficulty. In this method a complex multistage problem is decomposed into a series of simple problems that are solved recursively one at a time.

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).

The general approach to the solution of DP models, as related to reservoir operation has been summarized by Wurbs (1995). However, a major limitation in the use of DP is the well known ‘curse of dimensionality’ (Yakowitz 1982; Yeh 1985; Labadie 2004). The computational requirements of DP increase exponentially with each additional state variable and multiplicatively with each additional discrete class. As such, the usefulness of DP for multiple reservoir system analysis is limited by the huge demand that it can induce on computational resources. A way of alleviating the curse of dimensionality is by using Bellman’s concept of successive approximations which decomposes an original multi-state variable DP into a series of sub problems, each of one state variable, in such a manner that the sequence of sub problems converges to the solution of the original problem (Yeh 1985). Generally, the recursive optimization in DP is taken backwards in space or time. Alternatively, it is also possible to apply forward DP (Kottegoda 1980). Thus the problem formulation using DP is biased towards art rather than science. Yeh (1985) pointed out that there is no special reason for choosing either backward or forward formulation. As in the case of LP formulations, DP formulations have been applied both within a deterministic as well as stochastic framework as explained below.

2.6.3 Non Linear Programming (NLP)

In Non Linear programming of model the objective function and the constraints are characterized by nonlinear relationship. Although in real sense most of the water resources development problems are nonlinear in nature, use of non linear programming models to this field are limited. In these models the mathematics involved are complicated and it takes large computer time. Moreover, 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).

Lee and Waziruddin (1970) used NLP to maximize nonlinear objective of irrigation releases and storage in a hypothetical three-reservoir system in series subject to linear constraints. Gagnon et al. (1974) optimized the operation of a large hydroelectric system using Fletcher-Reeves gradient search method. Chu and Yeh (1978) proposed a gradient projection model for optimizing the hourly operation of a reservoir based hydropower system. Simonovic and Marino (1980) applied a gradient projection method with a two dimensional Fibonacci search to examine reliability related issues relevant for a single reservoir management problem. Roefs and Bodin (1970) presented formulations based on method of Dantzig-Wolfe decomposition, 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) discuss the limitations of deterministic optimization applied to reservoir operations. Deterministic feedback control (DFC) and stochastic dynamic programming are applied 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.

Morel-Seytoux (1999) presented a new approach for defining an optimal strategy of releases for deterministic reservoir operations in continuous time. The work is based on the marginal analysis theory of Massé (1946) and the stretched thread method. It is shown rigorously in this work that, in the general case, for a strategy to be optimal, the memory integrated future marginal value of the release must be constant. The generalization follows using the mathematical tools of constrained calculus of variations. The result is generalized to a system of several reservoirs and illustrated on a simplified description of the Seine river basin upstream of Paris, France.

Sinha et al. (1999a) presented a nonlinear optimization model for selecting and sizing potential reservoir sites on river basins. The model improves the work 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. The approach of evaluating derivatives by divided differences is replaced by automatic differentiation. The model is developed in the context of Par, Auranga, Ambica, and Purna river basins in India.

Devamane et al. (2006) formulated a detailed NLP model and applied to a multipurpose multireservoir system in the upper reaches of Krishna river basin in Karnataka, India. The system performances such as the irrigation deficit, frequency of irrigation deficit and power production are analyzed and compared with the results of an LP model.

Application of NLP have also been reported by Rosenthal (1981), Marino and Loaiciga (1985 a, 1985 b), Diaz and Fontane (1989), Guibert et al. (1990), and Wardlaw et al. (1997).

2.7 SIMULATION

It is a modeling technique that closely reproduces the behavior of a physical system. Optimization models determine the plan that should be adopted to satisfy specified decision criteria; while simulation model demonstrates what will happen if a specified plan is adopted. Optimization models can be used to screen the set of possible plans and to select a small number of them seen worthy of simulation (Jacoby and Loucks 1972).

Application of simulation in system analysis of water resources planning and management started in 1953 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).

There are several readily available, well documented, generalized 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).

According to Wurbs (1985), simulation with either deterministic or synthetically generated stochastic hydrologic inputs will likely continue to be the “work-horse” of reservoir system analysis. Wurbs (1995) introduced an excellent review discussing simulation models, which the author believes; 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 been used conjunctively with optimization models. The most effective strategy for analyzing multi reservoir operation problems will involve a combination of both optimization and simulation. Wurbs et al. (1985) reported that during the past twenty 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.

Wurbs and Karama (1995) presented a modeling approach using a generalized river/reservoir-system simulation model called RESSALT which applied 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.

Smith et al. (1997) considered a methodology to generate equitable and efficient operating policies on the U.S. Bureau of Reclamation's Klamath project. The issues such as endangered species protection, riparian rights, and irrigation related to the Klamath river, are taken into account with the aid of the STELLA II simulation language. The methodology focuses on generating alternatives towards achieving the best compromise solution.

Rangarajan et al. (1999) proposed a reliability programming model, which incorporates a four-step simulation algorithm to derive the loss function, which is a relationship between the reliability and its associated economic losses. The performance of the model was demonstrated through a case study.

Wurbs (2005) assessed the availability and reliability of water resources in Texas based on simulating river/reservoir system management and water allocation practices using sets of historical naturalized monthly stream flow sequences to represent basin hydrology.

2.8 COMBINED USE OF MODELS

2.8.1 Combination of LP and DP

To alleviate the dimensionality problem, which is more common in any water resources system optimization problem, decomposition methods have been suggested and used. One such decomposition, a variation of the Dantzig-Wolfe approach to large scale system optimization, leads to the adroit use of LP in conjunction with DP (Esogbue 1989). This can be done either by DP-LP technique or by LP-DP technique. In the first approach, DP is used to optimize the sub problems. These sub-optima are then combined to form a master problem that, in turn, is solved by LP. The alternative approach used a LP formulation to solve the sub problems where as the master problem is optimized by DP model.

Parikh (1966) used DP for optimizing individual reservoirs and LP for combining the reservoirs into an integrated optimization problem. The computational effort required in this approach was found to be substantial. Hall and Shephard (1967) employed a similar approach 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 sought to maximize the total monetary return from sale of water supply released by reservoirs and hydroelectric power generated through the plants. Other uses of water were considered as constraints.

Loucks and Falkson (1970) reviewed and compared three techniques namely DP, policy iteration, and LP for the stochastic reservoir operation model incorporating first-order Markov chains. The design parameters, i.e., reservoir capacity and the storage and release targets were assumed to be fixed. The algorithms were compared by applying them to a simplified numerical example. The information derived from each of the three model types yields identical polices. Dynamic programming models yield transient and steady state policies directly. Policy iteration methods take somewhat longer time for solution. Though linear programming takes greater amount of computational time, no computer programming or debugging is necessary since linear programming codes exist.

Windsor and Chow (1971) developed a multilevel optimization model for a farm irrigation system. Linear programming model was used for second level optimization for optimal land and water allocation. 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, at each field and each level of irrigation for linear programming model.

Trott and Yeh (1973) recognized that the reservoir operations problem must be addressed in the course of reservoir design. Becker and Yeh (1974), Becker et al. (1976) and Yeh et al. (1979) describe DP applications in which LP problems play an integral role. These studies are all directed toward finding operating policies for Central Valley Project in California.

Ponnambalam and Adams (1987) developed an Aggregation/decomposition models and stochastic dynamic programming (SDP) optimization was performed for 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 for the Parambikulam-Aliyar Project (PAP) to maximize the net benefits of agricultural production subject to the physical and institutional constraints of this canal-farm system.

Vedula and Nagesh Kumar (1996) used a stochastic dynamic programming (SDP) as a second module in an integrated module, consisted of two modules, 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. 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.

Goor (2011) presented a Stochastic Dual Dynamic Programming (SDDP) to solve multipurpose multireservoir operation problems in a stochastic environment. 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.

2.8.2 Combination of LP and Simulation

Jacoby and Loucks (1972)proposed the combined use of optimization and simulation models. This paper reports on an investigation of the use of analytical optimization models to screen a set of possible plans and to select a small number worthy of simulation analysis. Deterministic and stochastic LP screening models were developed and applied for the planning of Delware river basin system.

Major and Lenton (1979) demonstrated the application of system analysis techniques in an integrated way for the planning of Rio Colorado basin in Argentina. A system of three models was employed: a mixed integer linear programming screening model for finding the most promising configurations, a simulation model to evaluate the hydrologic reliability of these configurations, and a sequencing model to schedule the configuration of projects in four time periods.

Chaturvedi and Srivastava (1981) described a sequential iterative modeling process in which deterministic LP models were coupled with simulation to obtain optimal design alternatives considering six major reservoirs for the Narmada river basin in India. Two types of LP models were used. Simulation model continued screening on the basis of information obtained from LP models to find near optimal solutions.

2.9 SOME MORE APPLICATIONS OF SYSTEM ANALYSIS TECHNIQUE IN THE WATER RESOURCES SYSTEMS

In the recent past some new methodologies and techniques have come to be used in the analysis of complex water resources systems. They are 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.

Rose (1973) described an irrigation feasibility study carried out for a developing country. In essence the problem was to decide which major works to build and what crops to grow in order to make the most effective use of the natural and human resource available. The solution technique used was mixed integer programming.

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

Jamison (1979) advocated and discussed in relative detail a hierarchical structure in the planning, design and operation of water resource systems, with, possibly different model characteristics at each level of hierarchy, and interconnecting links between different levels.

Hashimoto et al. (1982) discussed three criteria for evaluating the possible performance of water resource systems. These measures describe how likely system is to fail (reliability), how quickly it recovers from failure (resiliency), and how severe the consequences of failure may be (vulnerability). These criteria can be used to assist in the evaluation and selection of alternative design and operating policies for a wide variety of water resource projects. They have illustrated the use of these criteria with the performance of a water supply reservoir.

Simonovic and Marino (1982) extended this approach for a system of multipurpose reservoirs. The reliability programming model is nonlinear and can be split into two models: search model and special linear programming model. A two-level solution algorithm is proposed. The procedure is illustrated using a portion of Red river system in Oklahoma and Texas, which is a system of three reservoirs.

Sampath (1986) presented a paper dealing with the national watershed development program in India for rainfed farming and stabilizing agricultural productivity through integrated approach of land, water, soil and human resource management.

Wurbs and Bergman (1990) presented 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.

Mohan and Rangacharya (1991) proposed 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.

Loucks (1992) discussed the role of water resource system models in planning. 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. He has reviewed some criteria for evaluating the success of any molding activity designed to help planners or managers to solve real life problems. The practice of modeling is said to be in transition, and the current research and computing technology are affecting this transition.

Srivastava and Patel (1992) used optimization (LP and DP)-simulation models for the 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.

Mohan and Arumugam (1994) presented 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.

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 the needs and opportunities in developing and implementing decision support system (DSS). The paper stressed 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.

Kumar et al. (1996) presented a simulation-optimization procedure for optimal operation of a multi-basin reservoir system. 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. The Box complex nonlinear programming algorithm is used for the optimization.

Simonovice and Bender (1996) present a collaborative planning-support system (CPSS) that interfaces available computer technologies with modeling and analysis tools in a user-friendly environment to enhance the communication between the proponent for resource development and affected or interested parties. CPSS does not provide solution but empowers participants by consensus. The CPSS module criteria and use of the concept is illustrated by an example from northern Manitoba, which focuses on fish habitat issues relating to a hydropower development project.

Wurbs (1996) presented a computer-based methodology for optimally sizing flood damage reduction system. The decision variables are the size of each structural component of the system, such as storage capacity for reservoirs and flow capacity for channel improvements, and the choice of which non-structural plan to implement in various regions of the floodplain. The decision criterion is to minimize total system cost, which is the sum of the discounted annual cost of implementing and maintaining each measure and the residual expected annual flood damages. A hydrologic and economic simulation model is combined with a search algorithm.

Loucks (1997) discussed the quantifying trends in system sustainability. The paper focuses on the measurement of the relative sustainability of renewable water resource systems. He stressed that being able to quantify the sustainability it can be included as one of the objectives in the management of water resource systems. The commonly used measures of reliability, resilience, and vulnerability based on subjective judgments concerning what is acceptable or unacceptable with respect to multiple system performance indicators, are combined into one index and used as a common measure of changes in relative system sustainability over time.

Arumugam and Mohan (1997) describe an integrated decision support system (DSS) that aids the operation of a tank (small-scale reservoir) irrigation system in south India.

Wurbs (1997) conducted 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. The key considerations involve sharing of limited supplies by numerous water quality constraints, return flows, hydrologic data compilation, and reliability assessment. 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.

Lohani and Loganathan (1997) discuss 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.

Jacobs and Vogel (1998) suggested a general approach using a graphical tool for allocating and permitting water withdrawals in a river basin. A mathematical programming methodology facilities optimal stream flow allocation while maintaining desired levels of in stream flow. The methodology is implemented using a spreadsheet optimization tool, Microsoft Excel Solver, and the solution is illustrated in a graphical format from so that non-technical individuals can easily understand the results. The methodology was applied to a hypothetical unregulated river basin.

Ravi Kumar and Venugopal (1998) presented a method for development of an operation model for a typical south Indian irrigation system. The first phase in the method is a simulation model for the command area of the reservoir, used to determine the expected demand sequences by simulating the command area with historical data. Second is a SDP model to obtain an optimal release policy. The simulation model is used to study the degree of failure associated with adoption of the optimal operating policy for different reservoir storages at the start of the crop seasons. The work relates to Krishnagiri Reservoir Project in southern India.

Vogel et al. (1999) performed experiments for the behavior of individual storage reservoirs across the United States; Storage-yield curves based on annual and monthly flow records are compared to show that the standardized net inflow and the coefficient of variation of net inflow C_v completely characterize the refill properties of storage reservoirs.

Loucks et al. (2000) presented a discussion on sustainable water resources management in an editorial. As defined in the Brundtland Commission's report "Our Common Future (WCED 1987), a development is sustainable if: it meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in future, while maintaining their ecological, environmental, and hydrological integrity (ASCE, 1998). They must be planned, designed, and managed in such a way that the life-support system at all biological levels remains functional and that the water and related land resources are not irreversibly degraded over time.

Lund (2000) derived and discussed theoretical hydropower operation rules for 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.

Jenkins and Lund (2000) presented 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) presented a series of computational procedures to estimate inflows into a multiple reservoir system where storage levels and gauged releases are available at regular intervals. The inflows are estimated by water budget computations.

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.

Murat Kilic · SuerAnac (2010) developed a multi-objective planning model and applied onthe 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

2.10 CROP WATER REQUIREMENT

Optimal use of water resources for irrigation purpose requires a proper understanding of crop water requirement. For this purpose, accurate estimation of crop evapotranspiration, denoted as ET_c is highly essential. ET_c can be calculated by knowing the reference crop evapotranspiration $\left(ET_0\right)$. Due to wide use of ET_0 data, several ET_0 estimation methods for different climatic variables have been developed over the last 50 years. ET_0 can be either measured using Lysimeter or estimated using climatological data. However, due to certain difficulties in measuring the ET_0 data, scientists and researchers have developed indirect methods of ET_0 estimation. These indirect ET_0 estimation methods based on climatological data, vary from empirical relationships to complex methods such as the Penman combination method (Penman 1948). These different ET_0 estimation methods can be grouped into empirical formulations based on temperature, radiation and pan evaporation, and combination theory.

Many studies have related pan evaporation with ET_0 (Christiansen 1968; Doorenbos and Pruitt 1977). The coefficient which converts the pan evaporation to evapotranspiration is a function of the kind of pan involved, pan environment and the climate. Christiansen and Hargreaves (1969) developed an equation for estimating reference crop evapotranspiration from United States Weather Bureau (USWB) 'Class' pan evaporation and several weather parameters. Doorenbos and Pruitt (1977) described a method for estimating ET_0 from pan evaporation data of the 'class A Pan', and 'Colorado Sunken Pan'. Thornthwaite (1948) assumed an exponential relationship between the mean monthly temperature and mean monthly consumptive use. Blaney and Criddle (1950) observed that the consumptive use of crops during growing season was closely correlated with mean monthly temperature and day light hours and developed a simplified formula for estimating consumptive use for the arid western regions of the United States.

Penman (1948) first derived the combination equation by combining components of energy balance and aerodynamics. Later many scientists modified the Penman equation by incorporating the stomatal resistance, and modifying the wind function and vapour pressure deficits (Penman 1963; Monteith 1965). Doorenbos and Pruitt (1975 and 1977) proposed a modified penman method for estimating ET_0. This equation is known as the FAO-24 Penman method. Monteith (1981) developed a combination method for estimating evapotranspiration, known as the Penman-Monteith method. To overcome shortcomings of previous FAO Penman method, Smith et al. (1996) developed the FAO Penman-Monteith method which provides values more consistent with actual crop water use data worldwide.

2.11 LATEST SOLUTION TECHNIQUES

In addition to the above mentioned techniques used in water resources system analysis, application of several modern techniques such as evolutionary algorithm (EA) is gaining momentum now a days. Evolutionary Algorithms, often referred to as evolutionary computing (EC) is only a small footpath to a more scientific universe so called as computational intelligence (CI) or artificial intelligence (AI) (Heitkoetter and Beasley 1995). Computational intelligence incorporates EA, 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 19th Century

(Charles Darwin and his theory of evolution).

In contrast to other search and optimization methods, ES can be used for both unconstrained and constrained (with linear and nonlinear constraints) optimization problems and for scalar as well as multi objective optimization. GA techniques are optimizers that used the ideas of evolution to optimize system configuration and operation. GA was first introduced to water resources system by East and Hall (1994).

GA was first introduced to water resources system by East and Hall (1994). They applied the GA technique for operating rule determination of a four-reservoir problem, which maximizes the benefits from power generation, irrigation and water supply subject to some physical constraints.

Later 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.

SrinivasaRaju and Nagesh Kumar (2004) applied Genetic Algorithms (GA) for irrigation planning. The GA technique is used to evolve efficient cropping pattern for maximizing benefits for an irrigation project in India. Results obtained by GA are compared with LP solution and found to be reasonably close. They opined that, GA is found to be an effective optimization tool for irrigation planning and the results obtained can be utilized for efficient planning of any irrigation system.

Ahmed and Sarma (2005) presented a GA model for finding the optimal operating policy of a multi-purpose reservoir, located on the river Pagladia, a major tributary of the river Brahmaputra. The operating policy derived from a synthetic monthly streamflow series of 100 years is compared with that of the SDP model on the basis of their performance in reservoir simulation. The simulated result shows that GA-derived policies are promising and competitive and can be effectively used for reservoir operation

Jothiprakash et al. (2006) developed an ANN model to generate the multisite streamflows and the results are compared with the classical multisite streamflow generation model developed by Hydrologic Engineering Centre named HEC-4. Both the models have been applied to the case study of Upper Krishna River Basin to evaluate their performances. They concluded that the streamflows predicted with simple ANN model are more satisfactory than the HEC-4 model in case of multisite streamflow generation.

Vasan and SrinivasaRaju (2007) presented the applicability of population based search optimization method, namely, Differential Evolution (DE) to a case study of Mahi Bajaj Sagar Project in Gujarat, India.

Garudkar, A.S. et al. (2011) developed an optimization model for the reservoir based on elitist GA approach considering the heterogeneity of the command area. They applied model to Waghad irrigation project in upper Godavari basin of Maharashtra, India..

2.12 SUMMARY

Amongst optimization techniques, a deterministic approach seems more promising. However, deterministic reservoir screening models based upon the historical mean monthly flows do not provide sufficient reservoir capacity to achieve reasonable system reliabilities. On the other hand, designing for the most critical flows of record results in large reservoir capacities and high system reliabilities. These are the findings of comparative study with evaluation by simulation carried out by Stedinger et al. (1983). Similar observations also put on record by Yeh (1985). If such a deterministic analysis is preferred for its simplicity and computational efficiency, the results usually need a refinement by subsequent simulation (Chaturvedi and Srivastava 1981).

On the other hand, 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).

An alternative to stochastic programming model is chance-constrained programming using linear decision rule (LDR), which received considerable attention after ReVelle et al. (1969) initiated its application to reservoir system optimization. However, 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.

In case of implicit stochastic optimization (ISO) method, although deterministic optimization methods can be directly applied, the main disadvantage of this approach is that optimal operational policies are unique to the assumed hydrologic time series. On the other hand when multiple regression analysis is applied to the optimization results for developing seasonal operating rules conditioned on observable information, the analysis may result in poor correlation that invalidate the operating rules and attempting to infer rules from other methods may require extensive trial and error process with little general applicability (Labadie 2004), whereas, explicit stochastic optimization (ESO) as applied to multi reservoir systems are more computationally challenging then ISO as recognized earlier by Roefs and Bodin (1970).

As regards dynamic programming (DP), although various modifications have been performed on the original DP formulation to mollify the curse of dimensionality of discrete dynamic programming, they fail to vanquish it completely.

Non linear programming algorithms generally considered powerful and robust 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) the generalized reduced gradient method (GRG) (Labadie 2004).

Hiew (1987) prepared a comprehensive comparative evaluation of 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 the most efficient among the various non linear programming algorithms. Grygier and Stedinger (1985) also concluded that SLP was the most efficient mathematical programming algorithms.

Real-world water resources problems are inherently multiobjective; therefore the imposition of a single-objective approach on such problems is overly restrictive and unrealistic (Cohon 1978). Multiobjective programming (MOP) gives set of non-inferior solutions. Mohan and Raipure (1992) and Cohon and Marks (1973) used the constraint technique to solve MOP model, due to its easy application in linear MOP problems.

Simulation is undoubtedly the most commonly used technique to assess the system yield as well as to assist in operation planning; it needs set of operating rules to assess the system yield accurately. Further it will not assess the maximum yield that can be achieved by developing the best possible set of operating rules for the system. This can only be achieved either by trial and error through repeated use of simulation or by optimization. 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.

2.13 SYSTEMANALYSISTECHNIQUESADOPTEDIN THIS STUDY

The objectives of the study are already discussed in Chapter 1. The present study is focused on the application of systems analysis to a water transfer link. The optimization of the system of reservoirs encompassing 16 reservoirs spanning in two river basins requires considerable computing effort.

Keeping in mind the review of literature on the various systems analysis techniques presented above and in the light of the proposed application of these techniques for comprehensive planning of a large river basin system where the basic issue is of optimal transfer of water resources from one basin to another and where the number of decision variables and constraints are more, the linear programming models seem to be more appropriate. For the nature and scope of the present study, 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 tractable. 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. For planning and operation of reservoirs multi objective fuzzy linear programming (MOFLP) model seem to be more appropriate, which is computationally simple and easy to implement to the real world situation of reservoir operation.

Chapter 3

THE STUDY AREA

3.1 INTRODUCTION

The present study for optimal planning and operation of a water transfer link is the KenBetwa link project which is located in the Central India in the state of Madhya Pradesh and Uttar Pradesh. Sonar, Bearma, Upper Ken and Lower Ken are the four sub basins of the Ken River. Upper Betwa, Dhasan, Birma, Jamni and Lower Betwa are the five sub basins of Betwa River.The study area Ken Betwa inter-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. The peninsular component of proposed inter basin water transfer links are shown in figure 3.1. (Source: NWDA)

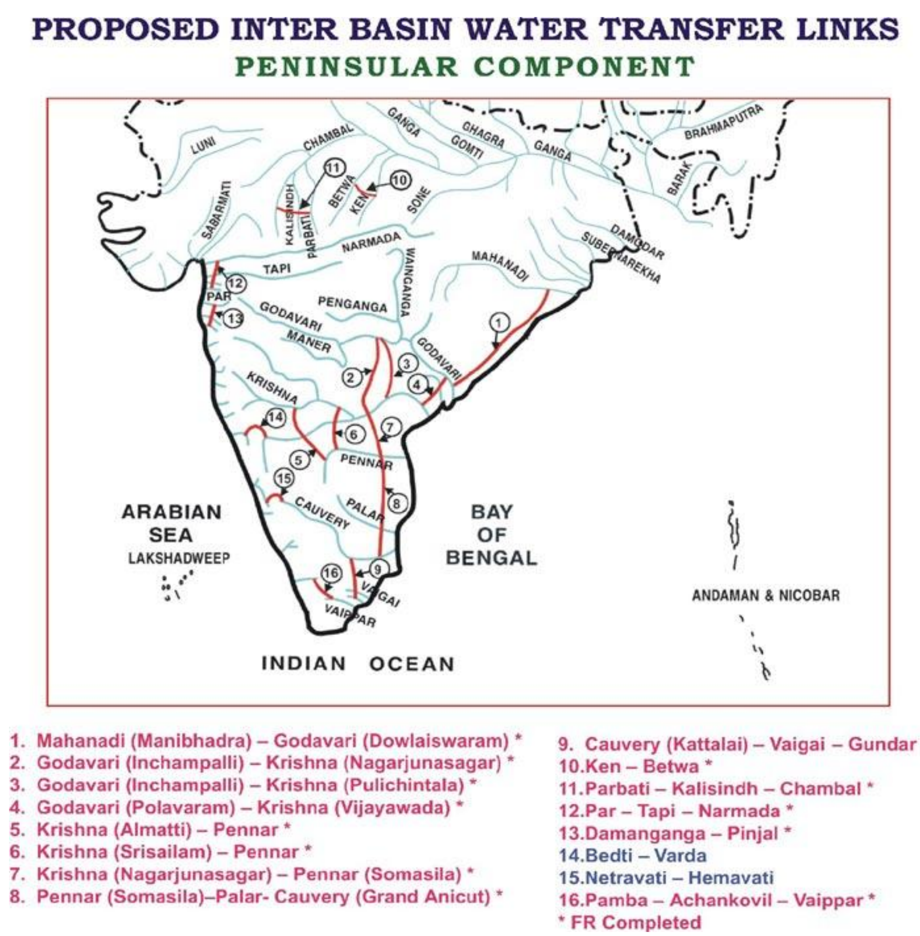


Fig. 3.1 Location showing Ken-Betwa link (Link No.10)

The Ken-Betwa link project envisages diversion of surplus waters of Ken basin to water deficit Betwa basin. This will be achieved by constructing a dam at Daudhan village in the Ken River and a link canal from the Daudhan dam to existing Barwa Sagar reservoir. The Barwa sagar reservoir is located in the upstream of Parichha weir in Betwa basin. It is proposed to construct Neemkheda, Richhan, Barari and Kesari projects in upper Betwa sub basin. An index map of the Ken-Betwa link with existing and proposed structures and the link canal is shown in figure 3.2. (Source: NWDA)The river network in Ken-Betwa system is presented in the maps (Source: Water Resources Department, Govt. of Madhya Pradesh) and line diagram in figure 3.3 to figure 3.6.

3.2 KEN RIVER BASIN

The Ken River originates from the village Ahirgawan in the Jabalpur district of Madhya Pradesh. It originates from the Kaimur hills at an elevation of about 550 m above mean sea level. The length of the river from its origin to its confluence with the river Yamuna is 427 km, out of which 68.38% (292 km) lies in Madhya Pradesh, 19.67% (84 km) lies in Uttar Pradesh and remaining 11.94% (51 km) forms the common boundary between the Madhya Pradesh and Uttar Pradesh. The riverKen joins the river Yamuna near Chilla village in Uttar Pradesh at an elevation of about 95 m above mean sea level.Ken river is the last tributary of the river Yamuna before the Yamuna river joins the Ganga river. The Ken river basin lies between 23°12'N to 25°54' N latitudes and 78°30'E to 80°36'E longitudes. The catchment area of the river is 28058 sqkm, out of which 87.22% (24472 sqkm) lies in the state of Madhya Pradesh and the remaining 12.78% (3586 sqkm) lies in the state of Uttar Pradesh.

The Ken basin covers Raisen, Narsingpur, Chhatarpur, Katani, Panna, Satna, Sagar and Damoh district of Madhya Pradesh and Banda and Hamirpur districts of Uttar Pradesh. It is bounded by Betwa basin in the west, Yamuna below Ken in the east, Vindhyan range in the south and free catchment of the Yamuna River in the north. Chandrawal, Kail, Urmil, Banne, Kutni, Mirshasan, Sonar, Bearma and Alona are the important tributaries of the river Ken. Sonar is the longest and largest tributary of Ken River which is 199 km long with a catchment area of 12621 sq. km and lies in Madhya Pradesh in the upstream of the proposed Daudhan dam site. The tributaries Shyamari, Mirhasan, Bearma and Alona joins Ken River in the upstream of the proposed Daudhan dam site. Tributary Banne joins Ken River between the proposed Daudhan dam site and the existing Bariarpur Pick up weiron which the Rangawan dam is constructed, while tributaries Chandrawal, Kail, Urmil and Kutni joins the Ken river in the downstream of Bariarpur Pick up weir.

3.2.1 Topography

The upper portion of Ken river is surrounded by a plateau which contains undulating amounts of shale, limestone and sandstone. Whereas the lower reaches of ken river is engrossed by recent alluvium upto the Daudhandam site. Stratigraphic studies have shown that the rock formations in the region mostly comprises of alluvial soil, Lameta beds, Deccan traps and Vindhyan system. The strata of Daudhan reservoir area proposedly located in the Panna and Chhatarpur districts of Madhya Pradesh comprises of Bundelkhand granite overlain by Bijawar group. The topography in the route of link canal is marked by features such as isolated hill tops, reserve forests, valleys, streams and rivers. Archean clorestised rocks predominantly define the geology of the formation whereas the reaches predominantly consist of Bundelkhand formations which is coarse grained.

3.2.2 Geology

Investigations into the dam site have shown the dam site to be composed of extremely hard, dense and compact quartz granite which is very stable as per the foundation grade point of view. Vindhyan Super Group overlain partly by flood plain alluvium. The reaches along the proposed canal alignment have shown the presence of Bundelkhand granite and rock of the Bijawar group.

3.2.3 Climate

Climatic variations in the area usually range from semi-arid to dry sub-humid with markedly high temperatures in summer season and mildly low temperatures in the winter season. The months from June to October witnesses the maximum rainfall about 90 percent of the annual rainfall. The temperature data have shown the maximum average temperature to be about 44.2^{o}C and the minimum average temperature to be 6.7^{o}C. Whereas the humidity data in the area (with five IMD stations) have shown the monthly mean maximum to be 95% in the monsoon and monthly mean minimum to be 9% in the summer season. The range of wind velocities in the area varies from a maximum of 16.1 km/hr at Sagar station to a minimum of 1 km/hr at Nowgong station. Cloud cover is observed to be maximum during the months of July or August whereas it is observed to be minimum during December. The monthly mean coefficients of sunshine usually falls in the range between 0.469 and 0.736.

3.2.4 Rainfall

21 rain gauge stations have been established in and around the Ken basin up to the Banda gauge and discharge site but the catchment up to the proposed Daudhan dam sites is mainly influenced by some 16 rain gauges. More than 90 percent of the total rainfall in the basin is during June to October (south-west monsoon). The lower part of basin receives an average annual rainfall between 90 cm and 100 cm whereas the upper part of basin receives about 120 cm of annual rainfall.

3.2.5 Soil type

The soil type is usually a mixture of red and black according to general specification. National Bureau of Soil Survey and Land Use Planning have broadly classified the soil in the basin into five categories as shown below-

1. Soil on hill and hill ridges, Entisols.
2. Plateau soils, Entisols, Inceptisols and Alfisols.
3. Pediment soils.
4. Soils of level alluvial plain and undulating flood plain, Inceptisols and Vertisols.
5. Soils of dissected flood plain.

The maximum area in the basin is covered by plateau soils which are yellowish brown to dark brown in colour and moderately eroded. Normal crop activity cannot be sustained by shallow soils. Kharif crops usually require deep soils. Soils of level alluvial plain and undulating flood plain are also present in the basin in major proportion. They are characterized by low organic matter, rich nutrient status and moderate erosion. They usually range from neutral to slightly alkaline. These soils make it possible to cultivate under dry and irrigated conditions.

3.2.6 Major Projects

Gangau Weir

Gangau masonry weir which is operating since 1915 is an old structure constructed on the Ken river in Chhatarpur district. The weir has a height of 19.2 m and a top width of 5.64 m.

The crest of the weir is 881 m long at a level of 232.4 m. The live storage capacity of the weir is 56.4 MCM. The structure has been designed for the highest flood discharge of 13677 cumec.

Bariarpur Pick Up Weir

This was built in the Panna district of Madhya Pradesh at Ajaigarh in 1906. The storage capacity of this weir is 12.6 MCM with a height and length of 8.23 m and 1636 m respectively. The command area of weir is 229360 ha in the districts of Banda (UP), Chitrakoot (UP) and Chhatarpur (MP).

Urmil Dam

This is an earthen dam constructed in Mahoba district at village Shamshera in Uttar Pradesh. The gross and live storage capacities of this dam are 116.6 MCM and 111.5 MCM respectively. This command area of the dam is about 6800 ha in the districts of Mahoba (UP) and Chhatarpur (MP), in addition to providing drinking water of 1.70 MCM.

Rangawan Dam

This is also an earthen dam constructed in Chhatarpur district of Madhya Pradesh over Banneriver in 1957. This dam has a height of 27.4 m, length of 2072 m with a live storage capacity of 155.24 MCM.

For this study area up to Daudhan reservoir is taken into consideration which is the starting point of the Ken-Betwa link canal. The above projects are situated downstream of Daudhan reservoir therefore not taken into consideration for this study. The location of the projects are shown in the line diagram of Ken basin (Figure3.4)

3.3 BETWA RIVER SYSTEM

The Betwa River originates near the village Barkherain the Raisen district of Madhya Pradesh at an elevation of about 576 m above mean sea level. It flows in the north-east direction in Madhya Pradesh and enters into the state of Uttar Pradesh near Bangawan village of Jhansi district. The length of the river from its origin to its confluence with the river Yamuna is 590 km, out of which 39.32%(232 km) lies in the state of Madhya Pradesh and the remaining 60.68%(358 km) lies in the state of Uttar Pradesh. The Betwa River joins the Yamuna river near Hamirpur in Uttar Pradesh at an elevation of about 106 m above mean sea level. The BetwaRiver is an interstate river between Madhya Pradesh and Uttar Pradesh. The river basin lies between 22°54'N to 26°00'N latitudes, and 77°10'E to 80°20'E longitudes. The catchment area of the Betwa basin is 44335 sqkm out of which 68.20%(30238 sqkm) lies in the state of Madhya Pradesh and the remaining 31.80%(14097 sqkm) lies in the state of Uttar Pradesh.

The Betwa basin covers the areas of Malwa plateu (Raisen, Bhopal and Vidisha district), Bundelkhand uplands (Tikamgarh, Sagar and Chhatarpur district) and the Vindhyan scrap lands(Guna and Shivpuri district) of Madhya Pradesh.It also covers the Bundelkhand regions (Jhansi, Hamirpur, Banda and Jalaun districts) of Uttar Pradesh.

The important tributaries of the river Betwa are Birma, Dhasan Jamini and Binaon the right bank and Kethan, Narain, Bah, Halali and Kaliasote on the left bank. The largest tributary of Betwa River is Halali which is 180.32 km long. The largest sub basin of Betwa is Upper Betwa sub basin which covers 38.4% (17025 sqkm) of the total area.

3.3.1 Topography

The upper reaches in the upper Betwa sub-basin above 500 m comprises of Vindhyan ranges running in the east-west direction whereas the middle and lower reaches consists of the Malwa plateau characterized by barren lands, cultivated lands and scrap lands. The lower Betwa sub-basin comprises of Shivpuri plateau at elevations of above 400m whereas the lower reaches are predominantly plain.

3.3.2 Geology

Pre-cambrian formations of Vindhyan sandstone covering an area of 3900 sqkm is seen at two widely apart localities- a linear ridge running north-west to south-east in the north whereas to the south of Bhopal ridges and hillocks around Lalamnagar, Vidisha and Raisen. Studies of geological strata have shown the presence of Laterite, Alluvium and Deccan traps with inter-trapped beds whereas the lower part is shown to contain sandstone conglomerate, quartzite and limestone. The formations of granite basement have been found to be overlain by coarse grained Bundelkhand gneiss.

3.3.3 Climate

The observation of temperature data in the basin have shown to go beyond 40^{o}C making summer season very hot whereas the winter is usually mild. Humidity studies in the basin have shown to range from an average monthly maximum of 83% in August to a minimum of 20.5%

in April. Upper reaches have shown to have higher wind velocities (varying between 6.6 km/hr and 18.9 km/hr) than the lower reaches (2.9 km/hr to 13 km/hr). The cloud cover is lower in the lower part of the basin compared to the upper part. The months of August and November witnesses the highest and lowest cloud covers.

3.3.4 Rainfall

25 rain gauges have been installed in and around the basin. The south-west monsoon period (June to October) provides more than 90% of the total rainfall to the basin. The annual precipitation in the upper part of basin is about 112.2 cm and 80-90 cm in the lower part of the basin.

3.3.5 Soil type

The upper Betwa basin is predominantly covered by deep black soil and medium black soil with small proportions of mixed red, black soil and skeletal soil. Black soil is most suitable for agriculture. Using good management practices these soils can be cultivated under both dry and wet conditions. Alluvial and plateau soils comprise the major proportion of soils in the Lower Betwa basin.

3.3.6 Major Projects

The major ongoing and existing projects in the Lower Betwa basin are Matatila dam, Rajghat dam, Parichha weir and Dukwan dam whereas there are two major projects in the upper Betwa basin namely Samrat Ashok Sagar (Halali) and Rajghat dam. The existing projects in the upper Betwa sub-basin are usually small or medium in size with the above two exceptions.

Rajghat dam

The Rajghat dam is situated on the border of Lalitpur district in Uttar Pradesh and Chanderi district in Madhya Pradesh over the main Betwariver and located at a distance of 22 km from Lalitpur. The Rajghat project comprises of a 562.50 m long and 43.80 m high masonry dam over Betwariver. The catchment area of the dam is 16317 sqkm out of which 15644 sqkm is in Madhya Pradesh and the remaining is in Uttar Pradesh. The maximum water level is 373.05 m whereas the full reservoir level is 371 m with a live storage of 1945 MCM.

The project in addition to having a power potential of 45 MW also irrigates 1.38 lakh ha land in Uttar Pradesh and 1.21 lakh ha land in Madhya Pradesh.

Matatila reservoir

This is located in the district of Lalitpur in Uttar Pradesh over the main Betwariver. It is a masonry dam with a length of 5.56 km. The top of dam has a reduced level of 310.90 m whereas the FRL and MWL are 308.46 m and 310.04 m. the estimated live storage capacity is 764.5 MCM. The project in addition to irrigating about 1.7 lakh hectare also has a power potential of 30 MW.

Samrat Ashok Sagar Project

It is a major irrigation project created over the Halali river which is a tributary of Betwariver. Halaliriver has an elevation of 487.68 m above mean sea level and merges with Betwa river near Vidisha. The command area of the project is on both sides of Halaliriver. The dam is situated in both Raisen and Vidisha districts of Madhya Pradesh. The entire submergence and catchment of the project is in MP itself. The command are of the project is about 37636 ha.

BarwaSagar

This is a medium project in the Lower Betwa sub-basin and located over the Barwanala in Jhansi district of UP near village Barwa. The proposed interlinking project from Ken to Betwa terminates in this reservoir. The reservoir has a catchment area of 180 sqkm. There is a proposal to enhance the capacity of reservoir from 475 ha m to 503.5 ha m.

Dukwan dam

Dukwan dam was constructed on Betwa river to enhance the irrigation capacity. It consists of an earth dam of 1800 m and masonry dam of 1172 m length. Full Reservoir Level is 275.55 and the maximum height of Dam is 8.22m.The catchment area and the submergence areas are 21342 sqkm. and 19.43 sqkm respectively. The gross storage capacity of reservoir is 57.80 MCM.

Parichha weir

Parichha weir is primarily an irrigation project constructed in 1906 and it is the last structure over Betwa River located near Jhansi city in Uttar Pradesh. The length of the weir is

1171.3m.One of the major tributary is Dhasan which joins with Betwa River in the downstream of Parichha weir.

Besides the above projects, four projects have been proposed in the upper Betwa sub-basin. These are Neemkheda, Richhan, Barari and Kesari. Out of these, Neemkheda dam and Barari barrage are to be constructed over the main Betwa River, whereas, Richhan and Kesari dam will be constructed over Richhan and Keotan tributary respectively. The other existing medium projects which are taken into consideration in the study are Kerwan, Kaliasote, Kethan, Koncha and Mola.The location of the projects are shown in the line diagram of Betwa basin (Figure.3.6). The salient features of projects in Betwa basin are presented in Table 3.1. The salient features of project in Ken basin (Daudhan reservoir) are presented in Annexure I. Monthly water utilization from the Daudhan reservoir including KB link demand are presented in Table 3.2. (Source NWDA)

Table 3.1 Salient features of Projects in Betwa basin

S.No.	Project	Catchment Area (sqkm)	CCA (Ha)	Intensity of Irrigation	Annual Irrigation (Ha)	Live Storage (MCM)
1	Kerwan	1306.2	4047	1.25	5058	322.27
2	Kaliasote	674.3	4588	1.25	5735	99.82
3	Nimkheda	1927.0	1053	1.25	1316	237.00
4	Richhan	36.6	1200	1.25	1500	5.70
5	Halali	1174.6	25090	1.50	37635	307.13
6	Barari	5333.0	32870	1.25	41087	37.00
7	Kesari	510.0	1840	1.25	2300	12.70
8	Kethan	1359.0	2526	1.25	3157	101.18
9	Kancha	2015.0	3765	1.25	4706	199.77
10	Mola	718.8	2400	1.25	3000	107.34
11	Rajghat	16317.0	173407	1.50	260110	1945.00
12	Matatila	20720.0	111289	1.50	166934	764.50
13	Dukwan	21841.6	3382	1.25	4227	57.80
14	Barwa Sagar	181.3	1660	1.25	2075	18.45
15	Parichha	26900.0	421540	1.50	632310	78.76

Table 3.2 Monthly water utilization from the Daudhan reservoir (NWDA Feasibility report of KB link 2005)

Sl.No.	Month	M.P. share	U.P. share	KB Link Demand	Total
1	Jun	76.18	124.73		200.91
2	Jul	50.81	129	140	319.81
3	Aug	101.54	129.04	185	415.58
4	Sep	132.55	69.49	185	387.04
5	Oct	123.64	13.77	102	239.41
6	Nov	152.35	32.88	102	287.23
7	Dec	174.67	88.62	102	365.29
8	Jan	218.39	115.78	102	436.17
9	Feb	192.52	101.61	102	396.13
10	Mar	152.35	20.73		173.08
11	Apr		11.2		11.2
12	May		13.15		13.15
Total		1375	850	1020	3245

Note: All values in MCM

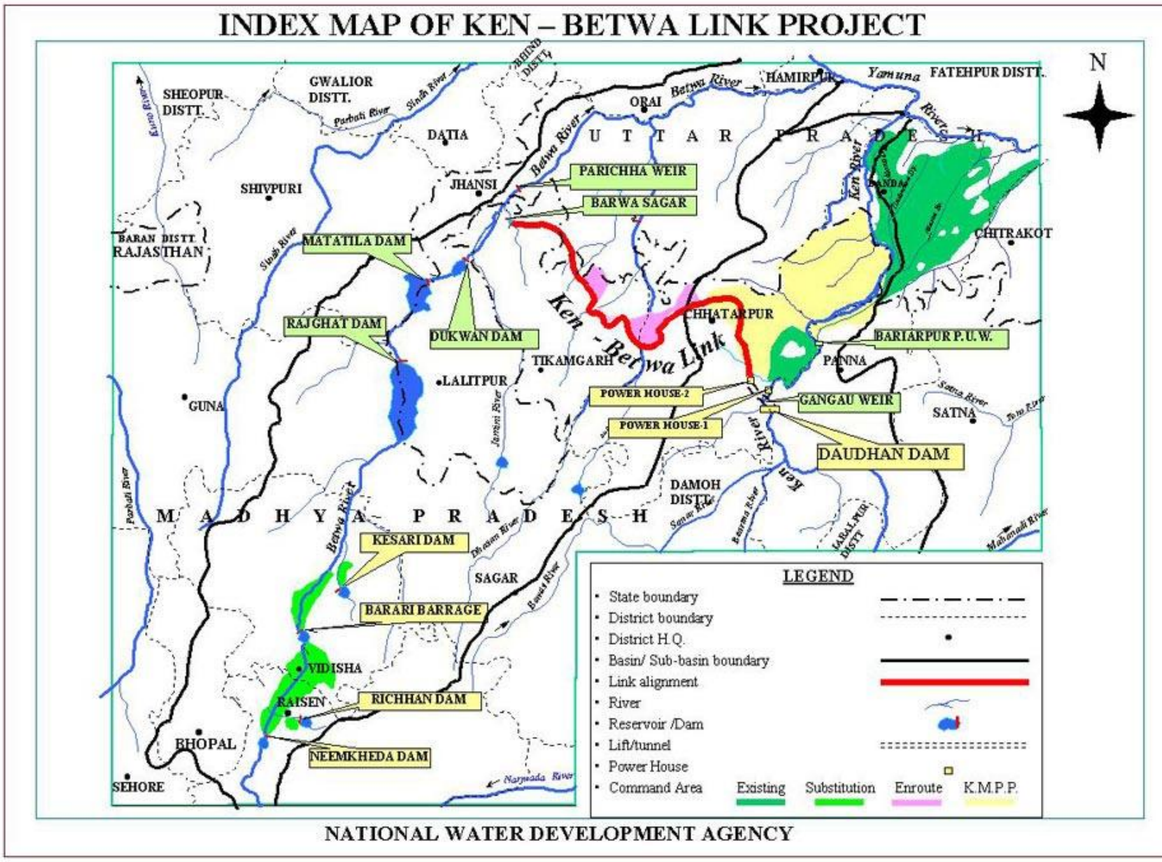


Fig. 3.2 Index map of Ken-Betwa link (Source NWDA)

KEN RIVER BASIN

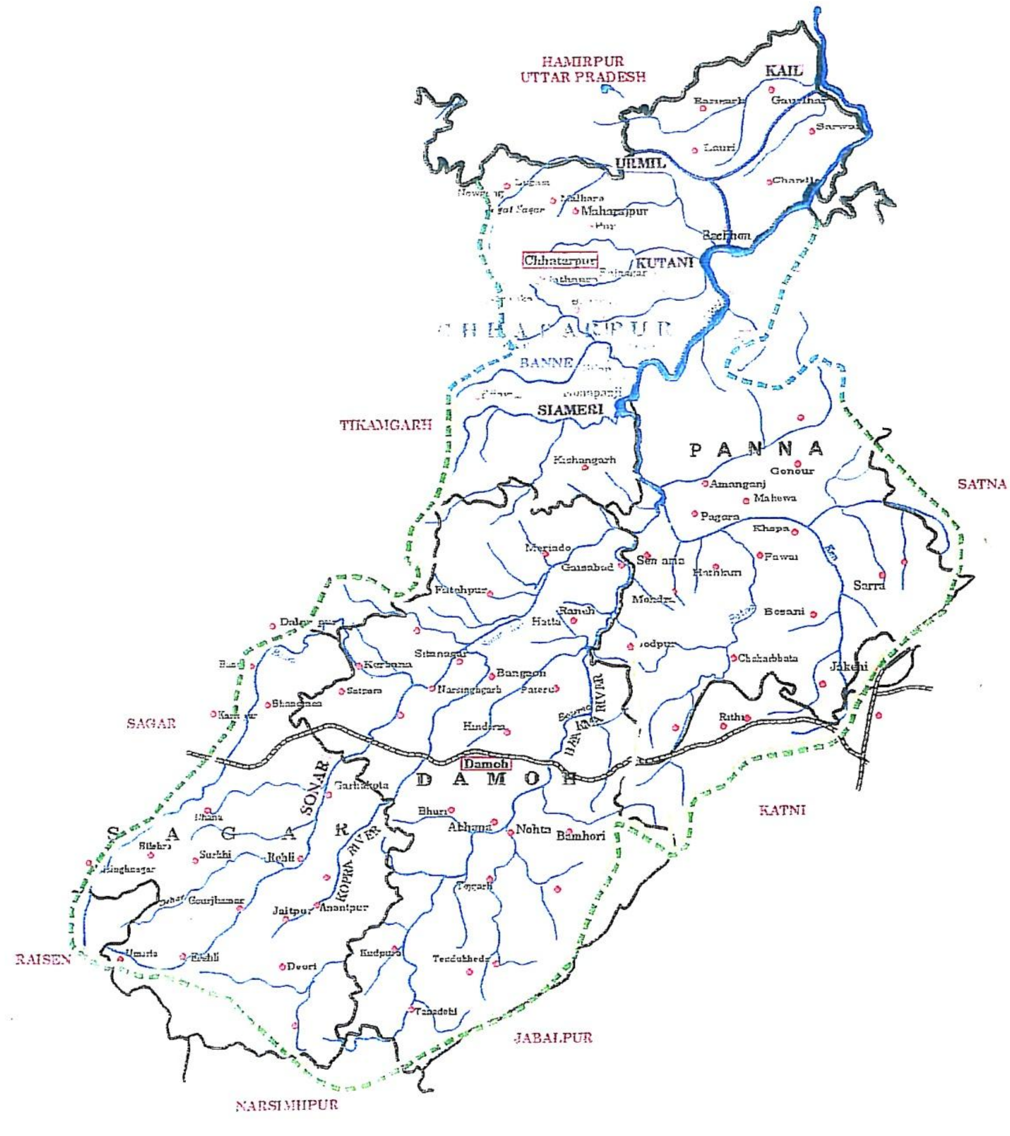


Fig. 3.3 Ken River Basin (Source WRD, Govt of MP)

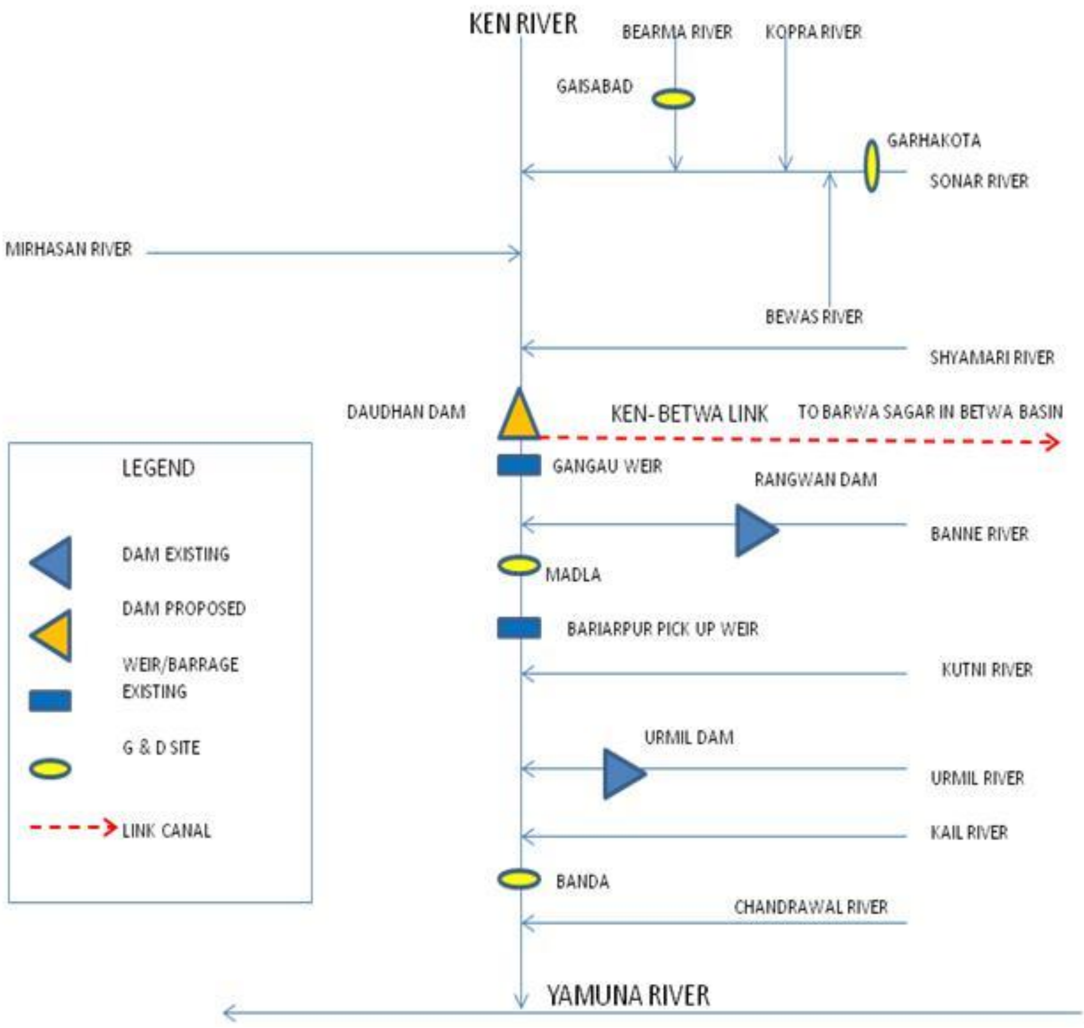


Fig. 3.4 Line Diagram of Ken River Basin System

Fig. 3.5 Betwa River Basin (Source WRD, Govt of MP)

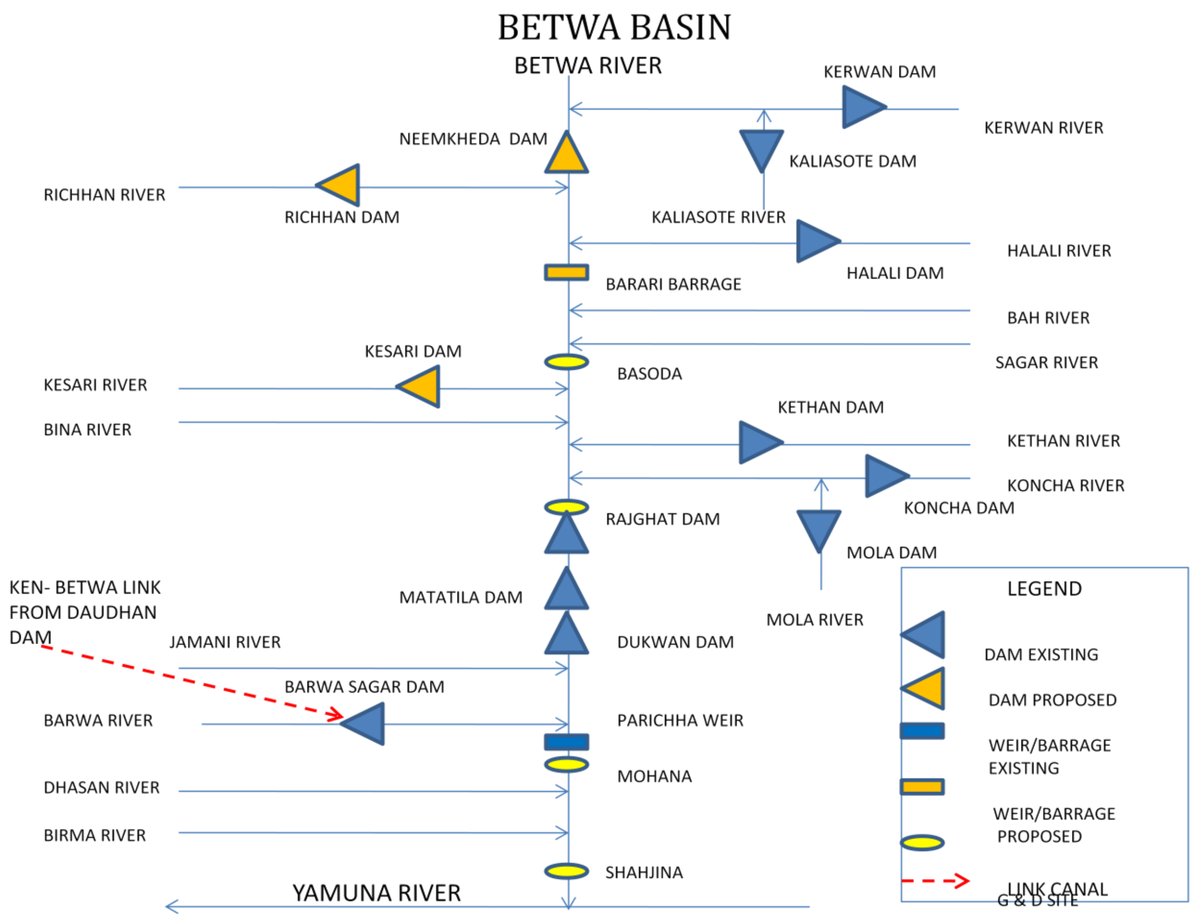


Fig. 3.6 Line Diagram of Betwa Basin

Chapter 4
CROP WATER REQUIREMENT

4.1 GENERAL

Crop water requirement (CWR) is the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place. This includes the losses due to evapotranspiration plus the losses during the application of irrigation water (unavoidable losses) and the quantity of water required for special operation such as land preparation, transplantation, leaching etc. Consumptive use (CU) is the loss due to evapotranspiration and the water that is used by the plant for its metabolic activities. Since the metabolic process is insignificant, the term consumptive use is generally taken equivalent to evapotranspiration (Michael, 2002).

4.2 EVAPOTRANSPIRATION

The combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET). Potential evapotranspiration (PET) is defined as the evapotranspiration from a large vegetation covered land surface with adequate moisture at all times. Evaporation and transpiration occur simultaneously and there is no easy way to distinguish these two processes. It can be defined as the amount of water lost from a cropped surface (normally expressed in units of water depth) per unit time. Evapotranspiration is one of the major components of the hydrologic cycle and its accurate estimation is of paramount importance for many studies such as hydrologic water balance, irrigation system design and management, crop yield simulation, and water resources planning and management. A common practice for estimating evapotranspiration (ET) from a well-watered agricultural crop is to first estimate reference crop evapotranspiration or reference evapotranspiration from a standard surface, denoted as ET_0 and then to apply an appropriate empirical crop coefficient, which accounts for difference between the standard surface evapotranspiration and crop evapotranspiration, denoted as ET_c. Crop evapotranspiration under standard conditions (ET_c) defined as the evapotranspiration from disease free, well-fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions (FAO, 1998). The crop evapotranspiration under non standard condition, denoted as $ET_{c\ adj}$ is calculated by adjusting the crop coefficient and / or using water stress coefficient, as the rate of evapotranspiration under non standard condition may reduce below ET_c. Allen et al. (1998) defined grass reference evapotranspiration $\left(ET_0\right)$ as "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1} and albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing and completely shading the ground and with adequate water".

4.2.1 Computation of ET_0

The reference crop evapotranspiration ET_0 can be either directly measured using lysimeter or water balance approach, or estimated indirectly using the climatological data. However, it is not always possible to measure ET_0 using lysimeter because it is a time consuming method and needs precisely and carefully planned experiments. The indirect ET_0 estimation methods based on climatological data vary from empirical relationships to complex methods based on physical processes such as the Penman combination method (Penman 1948). These different ET_0 estimation methods can be grouped into empirical formulations based on temperature, radiation and pan evaporation, and combination theory. The combination approach links evaporation dynamics with fluxes of net radiation and aerodynamic transport characteristics of natural surface. Based on the observations that biotic factors are not the only factor for latent heat transfer in plant, Monteith (1965) introduced a surface conductance term that accounts for the response of leaf stomata to its hydrologic environment. This modified form of the Penman equation is widely known as the Penman-Monteith evapotranspiration model. As per the opinion of different researchers, Penman-Monteith method ranked as best for all climatic conditions. The Penman-Monteith method can be taken as the standard for the comparison of other methods (FAO 1990). From the original Penman-Monteith equation and the equations of the aerodynamic and surface resistance, FAO has derived an equation to estimate ET_0 as per the recommendation of panel of experts, and the same known as FAO Penman-Monteith method (FAO 1998) is given below:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma' \frac{900}{T+273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma'\left(1 + 0.34u_2\right)} \tag{4.1}$$

where

ET_0	=	reference crop evapotranspiration	[mm day^{-1}];
R_n	=	net radiation at the crop surface	[MJ m^{-2} day^{-1}];
G	=	soil heat flux density	[MJ m^{-2} day^{-1}];
T	=	air temperature at 2 m height	[^{0}C];
u_2	=	wind speed measured at 2 m height	[m s^{-1}];
e_s	=	saturated vapour pressure	[kPa];
e_a	=	actual vapour pressure	[kPa];
Δ	=	slope vapour pressure curve	[kPa ^{0}C^{-1}];
γ'	=	psychometric constant	[kPa ^{0}C^{-1}]; and
$\left(e_s - e_a\right)$	=	saturated vapour pressure deficit	[kPa].

CropWat 4 window version 4.3 software uses FAO Penman-Monteith equation to calculate ET_0. CropWat is a computer program to calculate crop water requirements and irrigation requirements from climatic and crop data. Furthermore, this program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. However, in this study CropWat is used for estimation of reference crop evapotranspiration $\left(ET_0\right)$ and effective rainfall.

The entire command area is divided in to three parts Ken command, enroute command and Betwa command. Most of the Ken command area and Betwa command area are lying in the Chhatarpur and Vidisha district respectively. Therefore crop water requirements of Ken and Betwa command is calculated from the meteorological data of Chhatarpur and Vidisha respectively. Crop water requirements of enroute command is calculated from the data of Nowgaon meteorological stations which is in the enroute command. Using the meteorological data of these stations and with the help of CropWat 4 software, ET_0 values corresponding to each station has been calculated and presented in Tables 4.1 through 4.3 along with the respective meteorological data.

4.3 CROP COEFFICIENT

The crop coefficient $\left(K_c\right)$ is basically the ratio of crop evapotranspiration $\left(ET_c\right)$ to ET_0 and represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These characteristics are crop height, albedo (reflectance) of the crop-soil surface, canopy resistance and evaporation from soil, especially from exposed soil. Factors determining the crop coefficient are crop type, climate, soil evaporation and crop growth stages. Crop growth stage is divided into four stages such as initial, crop development, mid season and late season. The crop period, number of days in different stages and K_c values in each stage are taken from different literature (Allen et al. 1998, Doorenbos and Pruitt 1977, National Water Development Agency 1993, 2003, and Narsimulu 2002) and presented in Table 4.4 through 4.6.

4.4 IRRIGATION WATER REQUIREMENT

The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for pre sowing requirement, transplantation and percolation loss etc.

4.4.1 Net Irrigation Requirement (NIR)

Net irrigation requirement is the depth of irrigation water, exclusive of precipitation, carry over soil moisture, or ground water contribution or other gains in soil moisture that is required consumptively for crop production (Michael, 2002), i. e.,

$$NIR = \left\{ \begin{array}{l} \left(ET_c + Percolation\ losses + Pre\,showing\ and\ transplantation\ water\ requirement\right) \\ -Effective\ rainfall \end{array} \right\}$$

4.4.2 Effective Rainfall

Effective rainfall is that portion of total rainfall, which can be effectively used by a crop, i.e., rain which is stored in the crop root zone. Therefore, effective rainfall is less then the total rainfall due to interception, runoff and other losses etc. As per FAO methodology there are three methods for computation of effective rainfall such as:

1. Fixed percentage method
2. Dependable rainfall method and

3 By using the formula as given below:

Effective rainfall (ER) = 0.50 * Total rainfall (TR) - 5.00 where TR<50.00 mm/month, and

Effective rainfall (ER) = 0.70 * Total rainfall (TR) - 15.00 where TR>50.00 mm/month

In the present study the third method is used for computing the monthly effective rainfall with the help of CropWat 4 software packages and the results are presented in Table 4.7.

4.4.3 Field Irrigation Requirement (FIR)

It is the irrigation requirement, which includes the losses in the field, watercourses, and in field application, i. e.,

$$FIR = \frac{NIR}{\zeta_f} \tag{4.2}$$

where ζ_f = field application efficiency.

4.4.4 Gross Irrigation Requirement (GIR)

It is the field irrigation requirement plus the conveyance losses in canals, distributaries up to the field, i. e.,

$$GIR = \frac{FIR}{\zeta_c} \tag{4.3}$$

where ζ_c = conveyance efficiency.

For the purpose of the present study total efficiency ($\zeta_f * \zeta_c$) of 56% is considered.

In the feasibility report of National Water Development Agency (2005), 20 types of crops are proposed for the basin with each project having about 8 to 11 crops in kharif and rabi season. In this study crop coefficient approach for calculating the crop evapotranspiration (ET_c) has been adopted. By this approach, crop evapotranspiration is calculated by multiplying the ET_0 by K_c, i. e.,

$$ET_c = K_c * ET_0 \tag{4.4}$$

where ET_c = crop evapotranspiration [mm day^{-1}]; and

K_c = crop coefficient [dimensionless].

Specimen calculation for the gross irrigation requirement of three crops namely paddy, oilseed and sugarcane proposed to be grown in the area influenced by the Nowgoan, Chhatarpur and Vidisha climatological station respectively are presented in Tables 4.8 through 4.10.

Based on the calculation in accordance with the procedures stated in the foregoing sections, gross irrigation requirements of different crops are calculated to estimate the irrigation demand of the project. Seasonal, monthly and ten daily GIR and kt for Ken, enroute and Betwa command are presented in Table 4.11. The annual irrigation demand of Ken, en-route and in the four projects proposed in Betwa command are presented in Table 4.12 through 4.28 The annual irrigation demand as calculated in this study and that available in the feasibility report of National Water Development Agency (2005) is also presented for comparison.

Table 4.1 Climatological data and value of ETo at Chhatarpur

Altitude: 305 m (Above M.S.L.) Latitude: 24.34 Deg. (North) Longitude: 79.38 Deg. (East)

Sl.No	Month	Max Temp	Min. Temp	Humidity	Wind Speed	Sun Shine	Solar Rad.	ETo
		(deg.C)	(deg.C)	(%)	(Km/d)	(Hours)	(MJ/m2/d)	(mm/d)
1	Jan	24.5	11.6	45.5	165.6	8.5	15.9	3.55
2	Feb	27.4	13.9	36	170.4	9.1	18.7	4.58
3	Mar	32.7	18.5	24.5	179.2	9.4	21.6	6.17
4	Apr	37.3	23.3	20	216	9.5	23.6	8.03
5	May	40.7	27	23.5	242.4	9.3	24	9.15
6	Jun	36.9	25.7	51.5	264	5.6	18.5	6.96
7	Jul	29.7	22.9	86.5	252	2.6	13.9	3.41
8	Aug	28.4	22.4	86	247.2	2.8	13.7	3.26
9	Sep	29.3	21.7	78	230.4	4.6	15.3	3.85
10	Oct	30.5	19.2	52	170.4	7.1	16.8	4.55
11	Nov	27.7	15.5	38.5	160.8	8.2	15.9	4.05
12	Dec	25.4	12.9	42.5	156	8.7	15.3	3.46
	Average	30.9	19.6	48.7	204.5	7.1	17.8	5.09

Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients:

a = 0.25 b = 0.5

Table 4.2 Climatological data and value of ETo at Nowgoan

Altitude: 239 m (Above M.S.L.) Latitude: 25.07 Deg. (North) Longitude: 79.45 Deg. (East)

Sl.No	Month	Max. Temp	Min. Temp	Humidity	Wind Speed	Sun Shine	Solar Rad.	ETo
		(deg.C)	(deg.C)	(%)	(Km/d)	(Hours)	(MJ/m2/d)	(mm/d)
1	Jan	24.3	7.7	61.0	64.8	8.8	16.0	2.37
2	Feb	27.5	9.9	49.0	96.0	8.9	18.3	3.48
3	Mar	33.4	14.8	34.0	100.8	8.5	20.2	4.70
4	Apr	38.8	22.4	26.5	112.8	8.4	21.9	6.02
5	May	42.7	26.4	27.5	144.0	8.6	22.9	7.34
6	Jun	40.0	28.3	48.5	196.8	4.9	17.4	6.63
7	Jul	32.9	25.4	77.5	170.4	3.5	15.2	4.13
8	Aug	31.3	24.8	81.0	141.6	4.4	16.1	3.87
9	Sep	32.5	23.6	75.0	105.6	5.0	15.8	3.81
10	Oct	32.9	17.8	59.0	69.6	6.8	16.3	3.51
11	Nov	29.1	10.5	54.5	50.4	9.1	16.8	2.63
12	Dec	25.3	7.5	60.5	50.4	8.9	15.3	2.11
	Average	32.6	18.3	54.5	108.6	7.2	17.7	4.22

Note: Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients: a = 0.25 b = 0.5

Table 4.3 Climatological data and value of ETo at Vidisha

Altitude: 424 m (Above M.S.L.) Latitude: 23.53 Deg. (North) Longitude: 77.82 Deg. (East)

Sl.No	Month	Max. Temp	Min. Temp	Humidity	Wind Speed	Sun Shine	Solar Rad.	ETo
		(deg.C)	(deg.C)	(%)	(Km/d)	(Hours)	(MJ/m2/d)	(mm/d)
1	Jan	24.1	9.2	52.5	93.6	8.8	15.9	2.67
2	Feb	27.5	11.7	42.0	105.6	8.9	18.1	3.64
3	Mar	33.5	17.4	27.5	129.6	8.5	20.1	5.26
4	Apr	38.9	23.3	21.5	139.2	8.4	21.9	6.58
5	May	42.6	23.8	20.5	170.4	8.6	22.9	7.88
6	Jun	40.4	29.3	42.5	194.4	4.9	17.5	6.89
7	Jul	33.5	25.9	74.0	165.6	3.5	15.2	4.29
8	Aug	31.7	24.9	80.0	141.6	4.4	16.1	3.93
9	Sep	32.5	24.1	71.5	132.0	5.0	15.8	4.03
10	Oct	33.3	19.5	50.0	103.2	6.8	16.2	4.01
11	Nov	29.7	13.1	41.5	84.0	9.1	16.7	3.13
12	Dec	25.5	9.3	50.0	79.2	8.9	15.2	2.45
	Average	32.8	19.3	47.8	128.2	7.2	17.6	4.56

Note: Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients: a = 0.25 b = 0.5

Table 4.4 Crop period and Kc values of different crops (Ken command)

Sl. No.	Name of the crop	Crop period	No. of days	No. of days in different stages				Kc values for different stages			
				Initial	Development	Mid	Late	Kc-ini	Kc-dev.	Kc-mid	Kc-end
A	**KHARIF**										
1	Paddy	01/06 to 15/10	137	20	32	53	32	1.05	1.05 - 1.06	1.06	0.77
2	Maize	16/06 to 15/10	122	18	36	45	23	0.30	0.30 - 1.04	1.04	0.45
3	Pulses (K)	15/06 to 30/09	108	18	30	40	20	0.30	0.30 - 1.05	1.05	0.25
4	Groundnut	01/07 to 07/11	130	23	32	53	22	0.40	0.40 - 0.95	0.95	0.50
5	Vegetable	15/06 to 10/10	118	15	30	55	18	0.40	0.40 - 1.05	1.05	0.95
B	**RABI**										
1	Wheat (HYV)	01/11 to 15/03	135	20	30	60	25	0.70	0.70 - 1.13	1.13	0.40
2	Wheat	15/11 to 07/03	113	16	25	50	22	0.40	0.40 - 1.05	1.05	0.40
3	Gram	16/11 to 05/03	110	20	30	40	20	0.30	0.30 - 1.05	1.05	0.25
4	Oil Seeds	15/10 to 11/02	120	20	30	45	25	0.30	0.30 - 1.05	1.05	0.35
5	Sunflower	15/10 to 11/02	120	20	30	45	25	0.30	0.30 - 1.05	1.05	0.35
6	Barseem	15/10 to 11/02	120	20	30	45	25	0.30	0.30 - 1.05	1.05	0.35
7	Pulses (R)	01/12 to 02/03	92	15	22	35	20	0.30	0.30 - 1.05	1.05	0.25

Table 4.5 Crop period and Kc values of different crops (en-route command)

Sl. No.	Name of the crop	Crop period	No. of days	No. of days in different stages				Kc values for different stages			
				Initial	Development	Mid	Late	Kc-ini	Kc-dev.	Kc-mid	Kc-end
A	**KHARIF**										
1	Paddy	01/06 to 15/10	137	20	32	53	32	1.05	1.05 - 1.06	1.06	0.77
2	Jowar	16/06 to 15/10	122	18	36	45	23	0.30	0.30 - 1.00	1.00	0.50
3	Groundnut	01/07 to 07/11	130	23	32	53	22	0.40	0.40 - 0.95	0.95	0.55
4	Bajra	16/06 to 15/10	122	18	36	45	23	0.30	0.30 - 1.00	1.00	0.50
5	Fodder	01/07 to 15/10	107	16	32	39	20	0.30	0.30 - 1.00	1.00	0.25
6	Maize	16/06 to 15/10	122	18	36	45	23	0.30	0.30 - 1.05	1.05	0.55
7	Pulses (K)	15/06 to 30/09	108	18	30	40	20	0.30	0.30 - 1.05	1.05	0.25
8	Vegetable (K)	15/06 to 10/10	118	15	30	55	18	0.40	0.40 - 1.05	1.05	0.95
B	**RABI**										
1	Wheat	15/11 to 07/03	113	16	25	50	22	0.70	0.70 - 1.13	1.13	0.40
2	Fodder	15/11 to 14/02	92	14	28	33	17	0.30	0.30 - 1.00	1.00	0.25
3	Pulses (R)	01/12 to 02/03	92	15	22	35	20	0.30	0.30 - 1.05	1.05	0.25
4	Oil Seeds	15/10 to 11/02	120	20	30	45	25	0.30	0.30 - 1.05	1.05	0.35
5	Vegetable (R)	01/10 to 31/01	123	16	32	55	20	0.40	0.40 - 1.05	1.05	0.95
C	**PERENNIAL**										
1	Sugarcane	14/02 to 31/12	321	30	57	176	58	0.40	0.40 - 1.00	1.00	0.50

Table 4.6 Crop period and Kc values of different crops (Betwa command)

Sl. No.	Name of the crop	Crop period	No. of days	No. of days in different stages				Kc values for different stages			
				Initial	Development	Mid	Late	Kc-ini	Kc-dev.	Kc-mid	Kc-end
A	**KHARIF**										
1	Paddy	01/06 to 15/10	137	20	32	53	32	1.05	1.05 - 1.06	1.06	0.77
2	Maize	16/06 to 15/10	122	18	36	45	23	0.95	0.95 - 1.04	1.04	0.45
3	Jowar	16/06 to 15/10	122	18	36	45	23	0.30	0.30 - 1.00	1.00	0.50
4	Vegetable (K)	15/06 to 10/10	118	15	30	55	18	0.40	0.40 - 1.05	1.05	0.95
5	Pulses (K)	15/06 to 30/09	108	18	30	40	20	0.30	0.30 - 1.05	1.05	0.25
6	Groundnut (K)	01/07 to 07/11	130	23	32	53	22	0.40	0.40 - 0.95	0.95	0.55
7	Soyabeen	16/06 to 28/10	135	20	30	60	25	0.40	0.40 - 1.15	1.15	0.50
8	Fodder	01/07 to 15/10	107	16	32	39	20	0.30	0.30 - 1.00	1.00	0.25
B	**RABI**										
1	Wheat	15/11 to 07/03	113	16	25	50	22	0.70	0.70 - 1.13	1.13	0.40
2	Vegetable (R)	01/10 to 31/01	123	16	32	55	20	0.40	0.40 - 1.05	1.05	0.95
3	Gram	16/11 to 05/03	110	20	30	30	20	0.40	0.40 - 1.05	1.05	0.35
4	Oil Seeds	15/10 to 11/02	120	20	30	45	25	0.30	0.30 - 1.05	1.05	0.35
C	**PERENNIAL**										
1	Sugarcane	14/02 to 31/12	321	30	57	176	58	0.40	0.40 - 1.00	1.00	0.50

Table 4.7 Effective rainfall at Chhatarpur, Nowgoan and Vidisha

Month	Chhatarpur		Nowgoan		Vidisha	
	Total rainfall (mm/month)	Effective rainfall (mm/month)	Total rainfall (mm/month)	Effective rainfall (mm/month)	Total rainfall (mm/month)	Effective rainfall (mm/month)
Jan	49.47	19.74	23.00	6.50	29.60	9.80
Feb	16.54	3.27	16.50	3.25	12.80	1.40
Mar	9.81	0.00	8.40	0.00	9.60	0.00
Apr	4.48	0.00	2.30	0.00	4.20	0.00
May	9.34	0.00	6.80	0.00	8.30	0.00
Jun	130.62	76.43	90.40	48.28	145.40	86.78
Jul	380.86	251.60	341.60	224.12	462.60	308.82
Aug	412.02	273.41	341.00	223.70	418.50	277.95
Sep	191.57	119.10	168.80	103.16	228.10	144.67
Oct	32.22	11.11	29.40	9.70	63.90	29.73
Nov	59.76	26.83	10.00	0.00	4.00	0.00
Dec	61.55	28.09	5.70	0.00	6.90	0.00
Total (mm/year)	1358.24	809.581	1043.9	618.71	1393.9	859.15

Table 4.8 Specimen calculation for gross irrigation requirements (GIR) for paddy in enroute command at Nowgoan

Sl. No.	Starting Date/Month	No of Days	ETo in mm/day	ETo (mm)	Kc	ETc (mm)	Percolation losses	Other water requirements	Total water req.	Effective rainfall	NIR	GIR
1	1-Jun	10	6.63	66.3	1.05	69.62		15.00	84.62	16.09	68.52	122.36
2	11-Jun	10	6.63	66.3	1.05	69.62	60.96	75.00	205.58	16.09	189.48	338.36
3	21-Jun	10	6.63	66.3	1.0516	69.72	60.96		130.68	16.09	114.59	204.62
4	1-Jul	10	4.13	41.3	1.0547	43.56	60.96		104.52	72.30	32.22	57.54
5	11-Jul	10	4.13	41.3	1.0578	43.69	60.96		104.65	72.30	32.35	57.77
6	21-Jul	11	4.13	45.43	1.06	48.16	67.056		115.21	79.53	35.69	63.72
7	1-Aug	10	3.87	38.7	1.06	41.02	60.96		101.98	72.16	29.82	53.25
8	11-Aug	10	3.87	38.7	1.06	41.02	60.96		101.98	72.16	29.82	53.25
9	21-Aug	11	3.87	42.57	1.06	45.12	67.056		112.18	79.38	32.80	58.58
10	1-Sep	10	3.81	38.1	1.06	40.39	60.96		101.35	34.39	66.96	119.57
11	11-Sep	10	3.81	38.1	1.06	40.39	60.96		101.35	34.39	66.96	119.57
12	21-Sep	10	3.81	38.1	0.9513	36.24			36.24	34.39	1.86	3.31
13	1-Oct	10	3.51	35.1	0.8606	30.21			30.21	3.13	27.08	48.35
14	11-Oct	5	3.51	17.55	0.7926	13.91			13.91	1.56	12.35	22.05
	Total	137		613.85		632.65	621.79	90.00	1344.44	603.95	740.49	1322.30

Month wise net and gross irrigation requirement

	June	July	Aug	Sep	Oct	Total
NIR (mm)	372.59	100.26	92.44	135.77	39.42	740.49
GIR (mm)	665.34	179.03	165.08	242.45	70.40	1322.30
GIR (m)	0.665	0.179	0.165	0.242	0.070	1.32

Note:
a = Percolation loss at a rate of 6.096 mm per day
b = NIR is taken 56% of GIR
c = Presowing water requirement of 150 mm for 10% of the total calturable area
d = Water required for transplantation = 75 mm

Table 4.9 Specimen calculation for gross irrigation requirements (GIR) for oilseed in Ken command at Chhatarpur

Sl. No.	Starting date/month	No of Days	ETo in mm/day	ETo in mm	Kc	ETc	Other water requirements	Total water req.	Effective rainfall	NIR	GIR
1	15-Oct	6	4.55	27.3	0.3	8.19	50.00	58.19	2.15	56.04	93.40
2	21-Oct	11	4.55	50.05	0.3	15.015		15.02	3.94	11.07	18.45
3	1-Nov	10	4.05	40.5	0.375	15.1875		15.19	8.94	6.24	10.41
4	11-Nov	10	4.05	40.5	0.58	23.29		23.29	8.94	14.34	23.91
5	21-Nov	10	4.05	40.5	0.83	33.41		33.41	8.94	24.47	40.78
6	1-Dec	10	3.46	34.6	1.05	36.33		36.33	9.06	27.27	45.45
7	11-Dec	10	3.46	34.6	1.05	36.33		36.33	9.06	27.27	45.45
8	21-Dec	11	3.46	38.06	1.05	39.96		39.96	9.97	30.00	50.00
9	1-Jan	10	3.55	35.5	1.05	37.28		37.28	6.37	30.91	51.51
10	11-Jan	10	3.55	35.5	1.05	37.28		37.28	6.37	30.91	51.51
11	21-Jan	11	3.55	39.05	0.80	31.16		31.16	7.00	24.16	40.27
12	1-Feb	10	4.58	45.8	0.52	23.72		23.72	1.17	22.56	37.59
13	11-Feb	1	4.58	4.58	0.35	1.60		1.60	0.12	1.49	2.48
	Total	120		348.69		300.36		300.36	66.99	306.73	511.21

Monthwise net and gross irrigation requirement

	Oct	Nov	Dec	Jan	Feb	Total
NIR (mm)	67.11	45.06	84.54	85.98	24.04	306.73
GIR (mm)	111.85	75.09	140.90	143.29	40.07	511.21
GIR (m)	0.112	0.075	0.141	0.143	0.040	0.511

Note: a = NIR is taken 56% of GIR

b = Presowing water requirement = 50 mm

Table 4.10 Specimen calculation for gross irrigation requirements (GIR) for sugarcane in Betwa command at Vidisha

Sl. No	Starting Date/ Month	No of Days	ETo in mm/day	ETo (mm)	Kc	ETc (mm)	Other req.	Total water req.	Effective rainfall	NIR	GIR
1	14-Feb	7	3.73	26.11	0.40	10.44	75.00	85.44	0.35	85.09	151.95
2	21-Feb	8	3.73	29.84	0.40	11.94		11.94	0.40	11.54	20.60
3	1-Mar	10	5.31	53.1	0.40	21.24		21.24	0.00	21.24	37.93
4	11-Mar	10	5.31	53.1	0.43	22.46		22.46	0.00	22.46	37.44
5	21-Mar	11	5.31	58.41	0.51	31.37		31.37	0.00	31.37	52.28
6	1-Apr	10	6.57	65.7	0.62	41.26		41.26	0.00	41.26	68.77
7	11-Apr	10	6.57	65.7	0.73	47.24		47.24	0.00	47.24	78.73
8	21-Apr	10	6.57	65.7	0.83	53.22		53.22	0.00	53.22	88.70
9	1-May	10	7.79	77.9	0.94	70.19		70.19	0.00	70.19	116.98
10	11-May	10	7.79	77.9	1.00	71.67		71.67	0.00	71.67	119.45
11	21-May	11	7.79	85.69	1.00	78.83		78.83	0.00	78.83	131.39
12	1-Jun	10	6.79	67.9	1.00	62.47		62.47	28.93	33.54	55.90
13	11-Jun	10	6.79	67.9	1.00	62.47		62.47	28.93	33.54	55.90
14	21-Jun	10	6.79	67.9	1.00	62.47		62.47	28.93	33.54	55.90
15	1-Jul	10	4.28	42.8	1.00	39.38		39.38	99.62	0.00	0.00
16	11-Jul	10	4.28	42.8	1.00	39.38		39.38	99.62	0.00	0.00
17	21-Jul	11	4.28	47.08	1.00	43.31		43.31	109.58	0.00	0.00
18	1-Aug	10	3.95	39.5	1.00	36.34		36.34	89.66	0.00	0.00
19	11-Aug	10	3.95	39.5	1.00	36.34		36.34	89.66	0.00	0.00
20	21-Aug	11	3.95	43.45	1.00	39.97		39.97	98.63	0.00	0.00
21	1-Sep	10	4.04	40.4	1.00	37.17		37.17	48.22	0.00	0.00
22	11-Sep	10	4.04	40.4	1.00	37.17		37.17	48.22	0.00	0.00
23	21-Sep	10	4.04	40.4	1.00	37.17		37.17	48.22	0.00	0.00
24	1-Oct	10	4.09	40.9	1.00	37.63		37.63	9.59	28.04	46.73
25	11-Oct	10	4.09	40.9	1.00	37.63		37.63	9.59	28.04	46.73
26	21-Oct	11	4.09	44.99	1.00	41.39		41.39	10.55	30.84	51.40
27	1-Nov	10	3.26	32.6	0.97	29.27		29.27	0.00	29.27	48.79

Sl. No	Starting Date/ Month	No of Days	ETo in mm/day	ETo (mm)	Kc	ETc (mm)	Other req.	Total water req.	Effective rainfall	NIR	GIR
28	11-Nov	10	3.26	32.6	0.89	27.22		27.22	0.00	27.22	45.37
29	21-Nov	10	3.26	32.6	0.80	24.55		24.55	0.00	24.55	40.91
30	1-Dec	10	2.59	25.9	0.72	17.64		17.64	0.00	17.64	29.40
31	11-Dec	10	2.59	25.9	0.629	15.75		15.75	0.00	15.75	26.25
32	21-Dec	10	2.59	25.9	0.543	13.88		13.88	0.00	13.88	23.14
	Total	320		1515.57		1224.56	75.00	1299.56	848.70	849.95	1428.10
Month wise net and gross irrigation requirement											
Month	Feb	March	April	May	June	Jul	Aug	Sep	Oct	Nov	Dec
NIR (mm)	96.63	75.07	141.71	220.69	100.62	0.00	0.00	0.00	86.92	81.04	47.27
GIR (mm)	172.55	125.11	236.19	367.82	167.71	0.00	0.00	0.00	144.86	135	78.78
GIR (m)	0.173	0.125	0.236	0.368	0.168	0.000	0.000	0.000	0.145	0.135	0.079

Note: (a) NIR is taken 56% of GIR, (b) Presowing water requirement of 75 mm

Table 4.11 Monthly GIR and kt for Ken Betwa link project

Sl. No.	Month	Ken command		En-route command		Betwa command		Total	
		GIR (MCM)	kt	GIR (MCM)	kt	GIR (MCM)	kt	GIR (MCM)	kt
1	Jun	245.8	0.1796	89.8	0.3165	160.1	0.2346	495.7	0.2123
2	Jul	0.0	0.0000	4.3	0.0151	7.1	0.0104	11.4	0.0049
3	Aug	7.8	0.0057	10.3	0.0362	17.4	0.0255	35.4	0.0152
4	Sep	85.3	0.0623	29.9	0.1055	50.5	0.0740	165.7	0.0710
5	Oct	120.8	0.0883	19.3	0.0680	45.6	0.0668	185.7	0.0795
6	Nov	137.2	0.1002	31.9	0.1125	42.6	0.0624	211.7	0.0907
7	Dec	238.7	0.1744	22.2	0.0781	86.1	0.1261	347.0	0.1486
8	Jan	223.7	0.1634	26.2	0.0922	108.5	0.1590	358.3	0.1535
9	Feb	231.9	0.1694	31.8	0.1122	114.9	0.1684	378.7	0.1622
10	Mar	77.6	0.0567	6.7	0.0238	24.7	0.0362	109.0	0.0467
11	Apr	0.0	0.0000	4.4	0.0154	9.7	0.0142	14.1	0.0060
12	May	0.0	0.0000	7.0	0.0246	15.2	0.0223	22.2	0.0095
Total		1368.8	1	283.7	1	682.4	1	2334.9	1

Table 4.12 Annual irrigation demand in Ken command

Sl. No.	**Crop**	**Area in % of CCA**	**Area (ha)**	**GIR (m)**	**Water req. (MCM)**	**GIR (m) as per NWDA**	**Water req. (MCM) as per NWDA**
A	**KHARIF**						
1	Paddy	20	48238	0.630	303.90	0.649	313.06
2	Maize	8	19295	0.182	35.12	0.305	58.81
3	Pulses	15	36178	0.125	45.22	0.127	45.95
4	Oilseeds	12	28943	0.200	57.89	0.229	66.16
5	Vegetables	5	12059	0.063	7.60	0.305	36.76
	Subtotal	**60**	**144713**		**449.72**		**520.74**
B	**RABI**						
1	Wheat(HYV)	40	96475	0.560	540.26	0.610	588.11
2	Wheat(Local)	5	12059	0.440	53.06	0.457	55.13
3	Gram	8	19296	0.520	100.34	0.432	83.32
4	linseed	5	12059	0.511	61.62	0.330	39.82
5	Sunflower	5	12059	0.511	61.62	0.330	39.82
6	Barseem	3	7236	0.511	36.98	0.330	23.89
7	Masoor	8	19295	0.335	64.64	0.127	24.50
	Subtotal	**74**	**178479**		**918.52**		**854.60**
	Total	**134**	**323192**		**1368.24**		**1375.34**

Table 4.13 Annual irrigation demand in en-route command

Sl. No.	Crop	Area in % of CCA	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	32	15040	0.900	135.36	1.308	196.72
2	Jowar	2	940	0.089	0.84	0.123	1.16
3	Groundnut	4	1880	0.183	3.44	0.129	2.43
4	Bajra	2	940	0.089	0.84	0.123	1.16
5	Fodder	2	940	0.089	0.84	0.117	1.10
6	Maize	**2**	940	0.089	0.84	0.117	1.10
7	Pulses (K)	2	940	0.154	1.45	0.118	1.11
8	Vegetable (K)	2	940	0.095	0.89	0.189	1.78
	Sub total		**22560**		**144.49**		**206.55**
B	**RABI**						
1	Wheat	32	15040	0.577	86.78	0.393	59.11
2	Fodder	4	1880	0.264	4.96	0.318	5.98
3	Pulses (R)	4	1880	0.322	6.05	0.345	6.49
4	Oil Seeds	4	1880	0.334	6.28	0.29	5.45
5	Vegetable (R)	4	1880	0.429	8.07	0.317	5.96
6	**Sub total**		**22560**		**112.14**		**82.98**
C	**PERENNIAL**						
1	Sugarcane	4	1880	1.460	27.448	1.209	22.73
	Total	**100.00**	**47000.00**		**284.08**		**312.26**

Table 4.14 Annual irrigation demand in Betwa command (Kerwan project)

Sl. No.	Crop	Intensity of Irrigation (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	1011.8	0.89	7.20	1.284	10.39
2	Maize	2.5	101.2	0.074	0.06	0.082	0.07
3	Jowar	2.5	101.2	0.074	0.06	0.079	0.06
4	Vegetable (K)	2.5	101.2	0.081	0.07	0.149	0.12
5	Pulses (K)	6.25	252.9	0.141	0.29	0.075	0.15
6	Groundnut (K)	5	202.4	0.199	0.32	0.094	0.15
7	Soyabeen	2.5	101.2	0.217	0.18	0.066	0.05
8	Fodder	1.25	50.6	0.06	0.02	0.065	0.03
B	**RABI**						
1	Wheat	50	2023.5	0.5	8.09	0.395	6.39
2	Vegetable (R)	5	202.4	0.498	0.81	0.351	0.57
3	Gram	12.5	505.9	0.595	2.41	0.311	1.26
4	Oil Seeds	6.25	252.9	0.39	0.79	0.232	0.47
C	**PERENNIAL**						
1	Sugarcane	3.75	151.8	1.425	1.73	1.096	1.33
	Total		**5058.8**		**22.02**		**21.05**

Table 4.15 Annual irrigation demand in Betwa command (Kaliasote project)

Sl. No.	Crop	Intensity of Irrigation (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	1147.0	0.89	8.17	1.284	11.78
2	Maize	2.5	114.7	0.074	0.07	0.082	0.08
3	Jowar	2.5	114.7	0.074	0.07	0.079	0.07
4	Vegetable (K)	2.5	114.7	0.081	0.07	0.149	0.14
5	Pulses (K)	6.25	286.8	0.141	0.32	0.075	0.17
6	Groundnut (K)	5	229.4	0.199	0.37	0.094	0.17
7	Soyabeen	2.5	114.7	0.217	0.20	0.066	0.06
8	Fodder	1.25	57.4	0.06	0.03	0.065	0.03
B	**RABI**						
1	Wheat	50	2294.0	0.5	9.18	0.395	7.25
2	Vegetable (R)	5	229.4	0.498	0.91	0.351	0.64
3	Gram	12.5	573.5	0.595	2.73	0.311	1.43
4	Oil Seeds	6.25	286.8	0.39	0.89	0.232	0.53
C	**PERENNIAL**						
1	Sugarcane	3.75	172.1	1.425	1.96	1.096	1.51
	Total		**5735.0**		**24.97**		**23.86**

Table 4.16 Annual irrigation demand in Betwa command (**Neemkheda project**)

Sl. No.	Crop	Intensity of Irrigation (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	263.3	0.89	1.87	1.284	2.70
2	Maize	2.5	26.3	0.074	0.02	0.082	0.02
3	Jowar	2.5	26.3	0.074	0.02	0.079	0.02
4	Vegetable (K)	2.5	26.3	0.081	0.02	0.149	0.03
5	Pulses (K)	6.25	65.8	0.141	0.07	0.075	0.04
6	Groundnut (K)	5	52.7	0.199	0.08	0.094	0.04
7	Soyabeen	2.5	26.3	0.217	0.05	0.066	0.01
8	Fodder	1.25	13.2	0.06	0.01	0.065	0.01
B	**RABI**						
1	Wheat	50	526.5	0.5	2.11	0.395	1.66
2	Vegetable (R)	5	52.7	0.498	0.21	0.351	0.15
3	Gram	12.5	131.6	0.595	0.63	0.311	0.33
4	Oil Seeds	6.25	65.8	0.39	0.21	0.232	0.12
C	**PERENNIAL**						
1	Sugarcane	3.75	39.5	1.425	0.45	1.096	0.35
	Total	**125.00**	**1316.3**		**5.73**		**5.48**

Table 4.17 Annual irrigation demand in Betwa command (**Richhan project**)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (mcm)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	300.0	0.89	2.14	1.284	3.08
2	Maize	2.5	30.0	0.074	0.02	0.082	0.02
3	Jowar	2.5	30.0	0.074	0.02	0.079	0.02
4	Vegetable (K)	2.5	30.0	0.081	0.02	0.149	0.04
5	Pulses (K)	6.25	75.0	0.141	0.08	0.075	0.05
6	Groundnut (K)	5	60.0	0.199	0.10	0.094	0.05
7	Soyabeen	2.5	30.0	0.217	0.05	0.066	0.02
8	Fodder	1.25	15.0	0.06	0.01	0.065	0.01
B	**RABI**						
1	Wheat	50	600.0	0.5	2.40	0.395	1.90
2	Vegetable (R)	5	60.0	0.498	0.24	0.351	0.17
3	Gram	12.5	150.0	0.595	0.71	0.311	0.37
4	Oil Seeds	6.25	75.0	0.39	0.23	0.232	0.14
C	**PERENNIAL**						
1	Sugarcane	3.75	45.0	1.425	0.51	1.096	0.39
	Total	**125.00**	**1500.0**		**6.53**		**6.24**

Table 4.18 Annual irrigation demand in Betwa command (Halali project)

Sl. No.	Crop	Intensity of Irrigation (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	6272.5	0.89	44.66	1.284	64.43
2	Maize	2.5	627.3	0.074	0.37	0.082	0.41
3	Jowar	2.5	627.3	0.074	0.37	0.079	0.40
4	Vegetable (K)	2.5	627.3	0.081	0.41	0.149	0.75
5	Pulses (K)	6.25	1568.1	0.141	1.77	0.075	0.94
6	Groundnut (K)	5	1254.5	0.199	2.00	0.094	0.94
7	Soyabeen	2.5	627.3	0.217	1.09	0.066	0.33
8	Fodder	1.25	313.6	0.06	0.15	0.065	0.16
B	**RABI**						
1	Wheat	50	12545.0	0.5	50.18	0.395	39.64
2	Vegetable (R)	5	1254.5	0.498	5.00	0.351	3.52
3	Gram	12.5	3136.3	0.595	14.93	0.311	7.80
4	Oil Seeds	6.25	1568.1	0.39	4.89	0.232	2.91
C	**PERENNIAL**						
1	Sugarcane	3.75	940.9	1.425	10.73	1.096	8.25
	Total		**31362.5**		**136.54**		**130.49**

Table 4.19 Annual irrigation demand in Betwa command (**Barari project**)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	8217.5	0.89	58.51	1.284	84.41
2	Maize	2.5	821.8	0.074	0.49	0.082	0.54
3	Jowar	2.5	821.8	0.074	0.49	0.079	0.52
4	Vegetable (K)	2.5	821.8	0.081	0.53	0.149	0.98
5	Pulses (K)	6.25	2054.4	0.141	2.32	0.075	1.23
6	Groundnut (K)	5	1643.5	0.199	2.62	0.094	1.24
7	Soyabeen	2.5	821.8	0.217	1.43	0.066	0.43
8	Fodder	1.25	410.9	0.06	0.20	0.065	0.21
B	**RABI**						
1	Wheat	50	16435.0	0.5	65.74	0.395	51.93
2	Vegetable (R)	5	1643.5	0.498	6.55	0.351	4.61
3	Gram	12.5	4108.8	0.595	19.56	0.311	10.22
4	Oil Seeds	6.25	2054.4	0.39	6.41	0.232	3.81
C	**PERENNIAL**						
1	Sugarcane	3.75	1232.6	1.425	14.05	1.096	10.81
	Total	**125.00**	**41087.5**		**178.88**		**170.96**

Table 4.20 Annual irrigation demand in Betwa command (**Kesari project**)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	460.0	0.89	3.28	1.284	4.73
2	Maize	2.5	46.0	0.074	0.03	0.082	0.03
3	Jowar	2.5	46.0	0.074	0.03	0.079	0.03
4	Vegetable (K)	2.5	46.0	0.081	0.03	0.149	0.05
5	Pulses (K)	6.25	115.0	0.141	0.13	0.075	0.07
6	Groundnut (K)	5	92.0	0.199	0.15	0.094	0.07
7	Soyabeen	2.5	46.0	0.217	0.08	0.066	0.02
8	Fodder	1.25	23.0	0.06	0.01	0.065	0.01
B	**RABI**						
1	Wheat	50	920.0	0.5	3.68	0.395	2.91
2	Vegetable (R)	5	92.0	0.498	0.37	0.351	0.26
3	Gram	12.5	230.0	0.595	1.09	0.311	0.57
4	Oil Seeds	6.25	115.0	0.39	0.36	0.232	0.21
C	**PERENNIAL**						
1	Sugarcane	3.75	69.0	1.425	0.79	1.096	0.60
	Total	**125.00**	**2300.0**		**10.01**		**9.57**

Table 4.21 Annual irrigation demand in Betwa command (Kethan project)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	631.5	0.89	4.50	1.284	6.49
2	Maize	2.5	63.2	0.074	0.04	0.082	0.04
3	Jowar	2.5	63.2	0.074	0.04	0.079	0.04
4	Vegetable (K)	2.5	63.2	0.081	0.04	0.149	0.08
5	Pulses (K)	6.25	157.9	0.141	0.18	0.075	0.09
6	Groundnut (K)	5	126.3	0.199	0.20	0.094	0.09
7	Soyabeen	2.5	63.2	0.217	0.11	0.066	0.03
8	Fodder	1.25	31.6	0.06	0.02	0.065	0.02
B	**RABI**						
1	Wheat	50	1263.0	0.5	5.05	0.395	3.99
2	Vegetable (R)	5	126.3	0.498	0.50	0.351	0.35
3	Gram	12.5	315.8	0.595	1.50	0.311	0.79
4	Oil Seeds	6.25	157.9	0.39	0.49	0.232	0.29
C	**PERENNIAL**						
1	Sugarcane	3.75	94.7	1.425	1.08	1.096	0.83
	Total		**3157.5**		**13.75**		**13.14**

Table 4.22 Annual irrigation demand in Betwa command (Koncha project)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	941.3	0.89	6.70	1.284	9.67
2	Maize	2.5	94.1	0.074	0.06	0.082	0.06
3	Jowar	2.5	94.1	0.074	0.06	0.079	0.06
4	Vegetable (K)	2.5	94.1	0.081	0.06	0.149	0.11
5	Pulses (K)	6.25	235.3	0.141	0.27	0.075	0.14
6	Groundnut (K)	5	188.3	0.199	0.30	0.094	0.14
7	Soyabeen	2.5	94.1	0.217	0.16	0.066	0.05
8	Fodder	1.25	47.1	0.06	0.02	0.065	0.02
B	**RABI**						
1	Wheat	50	1882.5	0.5	7.53	0.395	5.95
2	Vegetable (R)	5	188.3	0.498	0.75	0.351	0.53
3	Gram	12.5	470.6	0.595	2.24	0.311	1.17
4	Oil Seeds	6.25	235.3	0.39	0.73	0.232	0.44
C	**PERENNIAL**						
1	Sugarcane	3.75	141.2	1.425	1.61	1.096	1.24
	Total		**4706.3**		**20.49**		**19.58**

Table 4.23 Annual irrigation demand in Betwa command (Mola project)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	600.0	0.89	4.27	1.284	6.16
2	Maize	2.5	60.0	0.074	0.04	0.082	0.04
3	Jowar	2.5	60.0	0.074	0.04	0.079	0.04
4	Vegetable (K)	2.5	60.0	0.081	0.04	0.149	0.07
5	Pulses (K)	6.25	150.0	0.141	0.17	0.075	0.09
6	Groundnut (K)	5	120.0	0.199	0.19	0.094	0.09
7	Soyabeen	2.5	60.0	0.217	0.10	0.066	0.03
8	Fodder	1.25	30.0	0.06	0.01	0.065	0.02
B	**RABI**						
1	Wheat	50	1200.0	0.5	4.80	0.395	3.79
2	Vegetable (R)	5	120.0	0.498	0.48	0.351	0.34
3	Gram	12.5	300.0	0.595	1.43	0.311	0.75
4	Oil Seeds	6.25	150.0	0.39	0.47	0.232	0.28
C	**PERENNIAL**						
1	Sugarcane	3.75	90.0	1.425	1.03	1.096	0.79
	Total		**3000.0**		**13.06**		**12.48**

Table 4.24 Annual irrigation demand in Betwa command (Rajghat project)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	43351.8	0.89	308.66	1.284	445.31
2	Maize	2.5	4335.2	0.074	2.57	0.082	2.84
3	Jowar	2.5	4335.2	0.074	2.57	0.079	2.74
4	Vegetable (K)	2.5	4335.2	0.081	2.81	0.149	5.17
5	Pulses (K)	6.25	10837.9	0.141	12.23	0.075	6.50
6	Groundnut (K)	5	8670.4	0.199	13.80	0.094	6.52
7	Soyabeen	2.5	4335.2	0.217	7.53	0.066	2.29
8	Fodder	1.25	2167.6	0.06	1.04	0.065	1.13
B	**RABI**						
1	Wheat	50	86703.5	0.5	346.81	0.395	273.98
2	Vegetable (R)	5	8670.4	0.498	34.54	0.351	24.35
3	Gram	12.5	21675.9	0.595	103.18	0.311	53.93
4	Oil Seeds	6.25	10837.9	0.39	33.81	0.232	20.12
C	**PERENNIAL**						
1	Sugarcane	3.75	6502.8	1.425	74.13	1.096	57.02
	Total		**216758.8**		**943.68**		**901.89**

Table 4.25 Annual irrigation demand in Betwa command (Matatila project)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	27820.8	0.89	198.08	1.284	285.77
2	Maize	2.5	2782.1	0.074	1.65	0.082	1.83
3	Jowar	2.5	2782.1	0.074	1.65	0.079	1.76
4	Vegetable (K)	2.5	2782.1	0.081	1.80	0.149	3.32
5	Pulses (K)	6.25	6955.2	0.141	7.85	0.075	4.17
6	Groundnut (K)	5	5564.2	0.199	8.86	0.094	4.18
7	Soyabeen	2.5	2782.1	0.217	4.83	0.066	1.47
8	Fodder	1.25	1391.0	0.06	0.67	0.065	0.72
B	**RABI**						
1	Wheat	50	55641.5	0.5	222.57	0.395	175.83
2	Vegetable (R)	5	5564.2	0.498	22.17	0.351	15.62
3	Gram	12.5	13910.4	0.595	66.21	0.311	34.61
4	Oil Seeds	6.25	6955.2	0.39	21.70	0.232	12.91
C	**PERENNIAL**						
1	Sugarcane	3.75	4173.1	1.425	47.57	1.096	36.59
	Total		**139103.8**		**605.60**		**578.78**

Table 4.26 Annual irrigation demand of Betwa command (Dukwan Project)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	845.5	0.89	6.02	1.284	8.68
2	Maize	2.5	84.6	0.074	0.05	0.082	0.06
3	Jowar	2.5	84.6	0.074	0.05	0.079	0.05
4	Vegetable (K)	2.5	84.6	0.081	0.05	0.149	0.10
5	Pulses (K)	6.25	211.4	0.141	0.24	0.075	0.13
6	Groundnut (K)	5	169.1	0.199	0.27	0.094	0.13
7	Soyabeen	2.5	84.6	0.217	0.15	0.066	0.04
8	Fodder	1.25	42.3	0.06	0.02	0.065	0.02
B	**RABI**						
1	Wheat	50	1691.0	0.5	6.76	0.395	5.34
2	Vegetable (R)	5	169.1	0.498	0.67	0.351	0.47
3	Gram	12.5	422.8	0.595	2.01	0.311	1.05
4	Oil Seeds	6.25	211.4	0.39	0.66	0.232	0.39
C	**PERENNIAL**						
1	Sugarcane	3.75	126.8	1.425	1.45	1.096	1.11
	Total		**4227.5**		**18.40**		**17.59**

Table 4.27 Annual irrigation demand in Betwa command (Barwa sagar project)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	415.0	0.89	2.95	1.284	4.26
2	Maize	2.5	41.5	0.074	0.02	0.082	0.03
3	Jowar	2.5	41.5	0.074	0.02	0.079	0.03
4	Vegetable (K)	2.5	41.5	0.081	0.03	0.149	0.05
5	Pulses (K)	6.25	103.8	0.141	0.12	0.075	0.06
6	Groundnut (K)	5	83.0	0.199	0.13	0.094	0.06
7	Soyabeen	2.5	41.5	0.217	0.07	0.066	0.02
8	Fodder	1.25	20.8	0.06	0.01	0.065	0.01
B	**RABI**						
1	Wheat	50	830.0	0.5	3.32	0.395	2.62
2	Vegetable (R)	5	83.0	0.498	0.33	0.351	0.23
3	Gram	12.5	207.5	0.595	0.99	0.311	0.52
4	Oil Seeds	6.25	103.8	0.39	0.32	0.232	0.19
C	**PERENNIAL**		0.0				
1	Sugarcane	3.75	62.3	1.425	0.71	1.096	0.55
	Total		**2075.0**		**9.03**		**8.63**

Table 4.28 Annual irrigation demand of Betwa command (Parichha project)

Sl. No.	Crop	Intensity of Area (%)	Area (ha)	GIR (m)	Water req. (MCM)	GIR (m) NWDA	Water req. (MCM) NWDA
A	**KHARIF**						
1	Paddy	25	105385.0	0.89	750.34	1.284	1082.51
2	Maize	2.5	10538.5	0.074	6.24	0.082	6.91
3	Jowar	2.5	10538.5	0.074	6.24	0.079	6.66
4	Vegetable (K)	2.5	10538.5	0.081	6.83	0.149	12.56
5	Pulses (K)	6.25	26346.3	0.141	29.72	0.075	15.81
6	Groundnut (K)	5	21077.0	0.199	33.55	0.094	15.85
7	Soyabeen	2.5	10538.5	0.217	18.29	0.066	5.56
8	Fodder	1.25	5269.3	0.06	2.53	0.065	2.74
B	**RABI**						
1	Wheat	50	210770.0	0.5	843.08	0.395	666.03
2	Vegetable (R)	5	21077.0	0.498	83.97	0.351	59.18
3	Gram	12.5	52692.5	0.595	250.82	0.311	131.10
4	Oil Seeds	6.25	26346.3	0.39	82.20	0.232	48.90
C	**PERENNIAL**						
1	Sugarcane	3.75	15807.8	1.425	180.21	1.096	138.60
	Total		**526925.0**		**2294.02**		**2192.43**

Chapter 5

INTEGRATED RESERVOIR YIELD MODEL AND ITS MODELING

5.1 A WATER RESOURCES SYSTEM AND ITS MODELING

A model attempts to capture essential features of a system and replicates its attributes. In the case of a large river basin especially, modeling of a water resources system is a cumbersome task. There may be two reasons behind this; firstly, there are large diversified different water uses throughout the basin and secondly, the water availability within the basin varies widely due to the uneven distribution of rainfalls. Other reasons being, extensive and intensive water uses, disparities in the water availability and water demands, demand based water planning with unknown required water supplies. Further, in the current scenario, the pressing water issues are (i) water disputes and tribunal awards in interstate trans-boundary rivers and (ii) real time operations of multi-reservoirs and managing water exports. In order to tackle all the above mentioned water issues for water analyses, there is a strong need of integrated river basin developments. A model for this purpose should be able to handle such large size problems and analyze them and provide answers to many intricate issues involved, for which otherwise the answers would remain untold.

Models have earlier been classified. Largely, a model can be a physical or mathematical in nature. Each of them has its merits and demerits. In the context of water resources system, the uses of mathematical models now have preference over others. Because some of them can handle large size problems; and for being fast, reliable and cost effective. These mathematical models have gathered momentum with the advent of fast computing devices.

In water resources systems applications, these models are commonly classified as deterministic models and stochastic models. A comparison between the two for river basin planning, establishes that the use of deterministic models (i) are unable to provide a complete representation of planning and management problems as they do not explicitly consider uncertainties in hydrologic variables or model parameters, (ii) are often found inadequate for preliminary plan formulation and evaluation, due to the non-prediction of the hydrologic process, that affect the performance of water resources systems, and (iii) the aforesaid limitations of deterministic models have resulted lately in the development and use of stochastic planning models.

The stochastic river basin planning models, that incorporate hydrologic variability and uncertainty and are structured for solution either by linear or dynamic programming techniques are of three types: (i) one which define a number of possible discrete stream flows and storage volumes and their probabilities, in each time interval and at each site; (ii) one which identify annual *firm* water yield, its within-year distributions, and its reliability; and (iii) one which have rules that express the unknown reservoir storage volume and release probability distributions as linear functions of the unknown unregulated stream flows, such models are called chance-constrained (Loucks et al. 1981).

The second one, out of the three above mentioned models, is an implicitly stochastic model. This model, although larger than the chance-constrained models, are much smaller than the stochastic design models. The implicitly stochastic models have resulted in relatively good estimates of both design and operating policy variables. Reservoir yield model comes under this category, considering its advantages in dealing with large size problems; it is selected for use in the present study for river basin water resources development.

5.1.1 The Screening-Simulation Models

5.1.1.1 Importance of screening-simulation models

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).

Chaturvedi and Srivastava (1981) made an attempt to study the problem of disputed height of the SSP reservoir in Narmada river basin with the help of screening-simulation modelling approach. The LP based complete reservoir yield model was used for the preliminary screening purposes to eliminate non optimal developmental strategies, and then followed by simulation model for further finer screening purposes. They concluded that the results of the preliminary screening model provide an initial starting base (the first question to be answered before one starts a simulation process) for simulation to follow next (also refer Srivastava, 1976). Srivastava and Patel(1992) showed the use of screening-simulation models for planning Karjan irrigation reservoir.

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. On the other hand, the optimization model is very approximate in nature.

There are three basic steps to be followed (the questions to be answered), essentially during making trial and error search process, for obtaining a better solution of the problem at hand in the simulation. First, from where to start making search (the initial base to start with, or the initial values of system's design variables to start with), second, how to proceed further and make useful searches (data sampling), and third, when and where to stop making searches (reaching compromise solution near to the likely expected optima, hopefully, the end of the simulation search process).

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 is well established. These models include (i) complete reservoir yield models and (ii) approximate reservoir yield models. 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).

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.

5.1.1.2 Importance of preliminary screening models

Mere simulation alone can't excel without prior screening by optimization (using preliminary screening using LP based reservoir yield models). The analyst is left nowhere, always guessing, and feels a never ending process. Short of time, not satisfied with exhausting exercises. Making compromises between various options of satisfactions (planning options), benefitting to one arising losses to others.

When even with a single reservoir with a few design variables, one faces this problem. What to say of an integrated reservoir systems' analysis through simulation, where there are several hundred plus 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; but at the end you are left at anywhere near to the likely guessing optimal, but always expecting hopefully. One should remember, that the simulation process is, as many types of problems so as many individual ways; thus every simulation is different.

So, in a large system, there ought to be a large number of system design variables. 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.

To say in simple terms that; the simulation can't excel without the prior use of optimization as a screening tool.

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 more useful in many ways. 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 and findings for many such intricate aspects can be derived from the enormous information available from the solutions of these models (Srivastava 2013).

Further, the expected findings and estimates from integrated systems optimization studies would be:

(a) Preliminary in nature and are only expected values in future which may be attained or achieved if all the projects are implemented and full development takes place in the system.

(b) Broad guidelines and provide a platform to a planning manager for a better understanding of the systems' behaviour of the river's water resources.

(c) Certainly serve useful purpose towards the rivers' water utilization up to a great extent.

(d) Just or tentative values obtained from a linear optimization model which needs refinements through the use of simulation modelling approach for accounting non-linearity in the system.

(e) Answers to many problems related to the water resources development in various river basins, and which were previously at times remained out of reach or were left unanswered. And which could not be directly derived or obtained otherwise by any other approach or means.

(f) Within the frame work of an overall plan for the basin/sub-basin within the provisions of tribunal award, water transfers, and all the water needs for the environmental purposes, M&I water supply, irrigation and in some cases hydropower etc.

(g) Enhancing 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 in more detail.

(h) Opening more desirable alternative long term perspective developmental options 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.

(i) Identifying and set priorities for promoting water resource development projects.

5.1.1.3 The issues in an integrated simulation study

The 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 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 analyzed, following project by project analysis and so on, under a broader scenario of developments.

This importance of simulation is described in a study by Wurbs (2005), through Texas water modelling system, where availability and reliability of water were assessed from 3,365 reservoirs based on simulating river/reservoir system management and water allocation practices. The water use was within the mandate of water management legislation enacted by Texas legislation in 1977, which was based on water rights and regulations prevalent/proposed in respect of the Texas river system. In the 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 were considered.

(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.

5.1.1.4 The water availability a major basic planning issue

Mostly people convey that, utilize water optimally. Usually and most often, it is meant to deliver sustainable solutions for a better life: rather directing or conveying towards the water consumption only, i.e., equal and judicial distribution, efficient and economic use, etc. etc? But forgetting and ignoring about knowing the 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 would be the water availability. Surly, a water plan should be supply based and not on demand. But, the water demand always prevails over supplies. Water availability from where and when and but then for whom, should be essentially established and ascertained first. Certainly, the screening-simulation models as discussed, above, have these capabilities to deliver and answer, and should be essentially recommended for all trans-boundary river basin water resources developments.

5.2 YIELDS FROM A RESERVOIR

Reservoir yield is a quantity of water that can be released by a reservoir for some specific use during a given time. A water planner is normally concerned and is interested in that, from a reservoir of a given size by its regulation of the historical stream flows, a maximum quantity of water is made available for use. This yield is called as *safe* or *firm yield*. If carefully modeled, this guaranteed firm yield derived; is in part dependent on the reservoir's active storage capacity, the within-year's distribution of reservoir inflows, and the reservoir operating policy. In literature, two types of reservoir yield models are available using linear programming (LP), i.e., the complete reservoir yield model and the approximate reservoir yield model (also termed as 'The Yield Model')

The complete reservoir yield models:

The complete reservoir yield models which are based on LP are being widely used, in this reservoir continuity equations are formulated or written for each within-year time periods. Here, the number of detailed equations written for the continuity and reservoir capacity constraints can become enormous for a large number of years and within-year periods are considered. This problem becomes enormous; with increase in number of reservoir sites being considered. The solutions from above reservoir storage models have shown that, to determine the required active storage capacity of a reservoir, it is only a relatively short sequence of flows within the total record of flows that generally play key role. This critical drought period is usually used in reservoir planning studies, to determine the firm yield of any particular reservoir or in a multi-reservoir system. As the severity of future droughts is unknown, many water planners accept the traditional practice of using the critical drought period for reservoir design and operation studies. This is on the assumption that, having observed such an event in the past, it is expected to experience similar drought conditions in the future (Hall and Dracup 1970).

The approximate yield (implicitly stochastic) models:

The approximate yield models which are based on LP developed were earlier by Loucks et al. (1981). These were later improved by Dahe and Srivastava (2002) and further by Panigrahi (2006). It is a general purpose, implicitly stochastic linear programming screening model. It incorporates several approximations, (i) to reduce the size of the constraint set needed to describe reservoir system operation and (ii) to capture the desired reliability of target releases considering the entire length of historical or synthetically generated unregulated inflow time series (Stedinger et al. 1983). This yield model consists of a set of constraints (i) at annual time steps to estimate the over-year reservoir capacity requirements and (ii) an additional set of constraints for within-year time periods based on a critical year to estimate the within-year reservoir capacity requirements (Dandy et al. 1997). These estimates meet the expected specified annual release reliability targets. Active reservoir storage capacity is simply the sum of these over-year and within-year storage capacities.

5.3 ANNUAL YIELDS AND THEIR RELIABILITY

Ensuring a reservoir yield with certainty from a reservoir is not usually possible. Apart from many other factors, it is mainly dependent on the long term inflows which are purely random in nature. Actually, the modeled annual reservoir yield with a magnitude equal to the lowest recorded annual inflow to the reservoir is not always 100% reliable. This is because; there is every possibility, that in future, there may be more extreme low flow year(s) than those occurred in the historic stream flow recorded. Under such conditions, it would be impossible to release the above said modeled reservoir yield by reservoir regulation. Hence, yield is always associated with a probability that it will be exceeded. In other words, associated with any historic yield is a probability that, that yield can be provided in any future year by a given size of reservoir with a particular operating policy. These probabilities are usually estimated from the unregulated historical flows. So, 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.

The Weibull plotting position method is usually used by water planners, to estimate the probability that any given stream flow will be exceeded. This involves the prediction of the mean number of random events that can occur in future. The probability associated with such a number is termed as *mean probability*. The mean probability of any particular stream flow being equaled or exceeded is based on the assumption that, any future flow has an equal probability of falling within any interval defined by a sequence of historical and/or synthetically generated stream flows. 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.

In the LP based approximate reservoir yield (implicitly stochastic) models, for a certain reservoir capacity, once an annual yield with the maximum possible annual reliability *p*, known as *firm annual reservoir yield* is defined; all other yields with reliability less than *p* are *incrementalsecondary annual reservoir yields*. The *total annual reservoir yield* is the summation of firm and incremental secondary annual yields. These yields hereafter in this study shall be referred to as *firm annual yield, incremental secondary annual yield (or alternately secondary annual yield) and total annual yield*. Firm annual yield with the maximum probability of exceedence *p* will be denoted as Oy^{fp}. Similarly; the *incremental secondary annual yield* with probability of exceedence *p1*, and the *secondary annual yield* with probability of exceedence *p2*, which are both less than *p*, are denoted by Oy^{sp2} and Oy^{sp2}, respectively.

5.4 THE COMPLETE RESERVOIR YIELD MODEL

The planning of a reservoir requires consideration of active storage volume for the reservoir, to fulfill the required release target to meet various water needs. The consideration of the reservoir capacity determination; to cater for inflows, spill and reservoir yield on annual basis may not serve our purpose totally. Because, a desired within-year distribution of annual yields always do not coincide with the within-the-year distribution of stream flows. This may cause reservoir to fail in meeting the within-the-year target demand during low flow periods, particularly in summer months. Though, the demands on annual basis may be satisfied. This thus, would require additional active reservoir storage capacity. Therefore, the introduction of within-year continuity constraint in the model can serve the purpose. This model is called the "*complete reservoir yield model*".

5.4.1 Determination of Various Firm Reservoir Yields

To deliver a safe or firm (i) annual yield Oy^{fp} with a maximum possible annual reliability p from active over year reservoir capacity Y^o, and (ii) within-year reservoir yields, Oy_t^{fp} that sum up to the annual yield Oy^{fp}; are individually considered in the estimation of the required active storage capacity. These can be determined by minimizing the reservoir capacities as follows:

Minimize Y^o for firm annual reservoir yield (5.1)

Minimize Y_a for within-year reservoir yields (5.2)

The objective function is subjected to the following constraints:

1. The reservoir continuity equation

<u>For firm annual yield</u>:-

$$S_{j-1}^o + I_j - Oy^{fp} - Sp_j = S_j^o \qquad \forall j \qquad (5.3)$$

where

S_{j-1}^o = initial over-year storage at the beginning of year *j*;

S_j^o = final over-year storage at the end of year *j*;

Sp_j = excess release (spill) during year *j;* and

I_j = annual inflow to reservoir during year *j*.

<u>For firm within-year yields</u>:-

$$S_{j,t-1} + I_{jt} - Oy_t^{fp} - Sp_{jt} = S_{jt} \qquad \forall jt \qquad (5.4)$$

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*; and

I_{jt} = annual inflow to reservoir in time *t* during year *j*.

2. The bounds on reservoir storage

For firm annual yield:-

$$S^o_{j-1} \le Y^o \qquad \forall j \qquad (5.5)$$

where Y^o = active over year reservoir capacity

For the year N (Chaturvedi and Srivastava, 1981),

(i) If $S^o_N = S^o_0$, the model is called continuous model

(ii) If $S^o_N \ne S^o_0$, the model is called discontinuous model

where

N	=	total number of years of river flows available
S^o_0	=	initial over-year storage at the beginning of year 1
S^o_N	=	initial over-year storage at the beginning of year N

For firm within-year yields:-

$$S_{j,t-1} \le Y_a \qquad (5.6)$$

where Y_a = total active storage capacity $\forall jt$

For the year N with a 12 within-year periods,

(i) If $S_{N,12} = S_{1,0}$, the model is called continuous model

(ii) If $S_{N,12} \ne S_{1,0}$, the model is called discontinuous model

The evaporation losses from the reservoir have been ignored here.

5.5 THE YIELD MODEL (THE APPROXIMATE RESERVOIR YIELD MODEL)

5.5.1 Single Reservoir Single Yield Model

As established by Loucks et al. (1981) that critical period of record determines the total reservoir storage requirements, it means that it may not be required to include every period of every year in a reservoir storage yield model as defined by equation 5.4 through 5.6. It also revealed that the over-year storage requirements are defined by the range of volumes at the beginning of each year *j*. The remaining storage requirement is the within-year storage capacity needed to get through the critical year. This critical year generally occurs at the end of a sequence of years having annual stream flows less than the annual reservoir yields. He found through simulation of a reservoir, that in a yield model, the reservoir storage capacity derived from solving above said equations is also obtainable from a model having (i) year to year over-year continuity constraints defining each year's initial storage volume (ii) plus a set of within-year continuity constraints for the critical year only. Such model would be capable of producing reasonably accurate results. This derived model is termed as the "*approximate reservoir yield model*".

As it is not possible to predict a bad or a worse water year in a true sense in actual practice, similarly, the results of a model run (the annual and within-year yields) would only identify later, whether the year under consideration was critical or not. It means that the same information is not possible to determine beforehand at the time of model application. Loucks et al. (1981) suggested that, better result could be obtained by defining, β_t, as some appropriate fraction of the total annual yield (outflow) to be the inflow in each period *t* within the critical year. A good choice for β_t is the ratio of inflow in period *t* of the driest year of record to the total inflow of that year. Thus, each β_t may represent the relative fraction of the critical year's inflow that is expected to occur in period *t*. Hence, $\sum_t \beta_t = 1$.

The number of constraint equations and the number of variables are reduced to a large extent in the latter case. The β_t's values based on the inflow distribution of the driest year flow record provides a reasonable estimate of the future storage requirements as does the complete yield model.

The various single reservoir single yield models earlier developed are described below:

(A) *Yield with maximum reliability* p*:*

To determine the safe or firm reservoir yield with maximum reliability p from a single reservoir yield model for a known reservoir capacity, the objective function can be written as follows:

$$\text{Maximize} \quad Oy^{fp} \tag{5.7}$$

The objective function is subjected to certain constraints. Two of them are discussed here and the others would be described later.

The following are the two reservoir continuity constraints:

(a) Over-year constraints

1. Over year storage continuity (equation 5.2), i.e.,

$$S_{j-1}^{o} + I_j - Oy^{fp} - Sp_j = S_j^{o} \qquad \forall j \qquad (5.8)$$

(b) Within-year constraints

1. Within-year storage continuity, i.e.,

The within-year continuity constraints for a single yield can be written as:

$$S_{t-1}^{w} + \beta_t Oy^{fp} - Oy_t^{fp} = S_t^{w} \qquad \forall t \qquad (5.9)$$

Where w = indicates within-year storage; S_{t-1}^{w} = storage at the beginning of the within-year period *t*; S_t^{w} = storage at the end of the within-year period *t*; and Oy_t^{fp} = firm within-year reservoir yield in period *t*.

Since summation of all β_t equal to one, these constraints ensure that $\sum_t Oy_t^{fp}$ equals the annual reservoir yield Oy^{fp}.

In the equation 5.9, the inflows and required releases are just in balance, so that the reservoir neither fills nor empties during the modelled critical year. This is similar to what would be expected in a critical year that generally occurs at the end of a draw-down period.

(B) <u>Yield with reliability p1 less than the maximum reliability p</u>:

This firm annual yield corresponds to a probability of exceedence *p1* (which has a probability less than p). The number of years of reservoir yield failure determines the estimated reliability of each reservoir yield. Once the desired reliability of a firm annual reservoir yield is assumed, one can select the appropriate number and the occurrence of failure years.

Incorporating a factor θ_j^{p1}, the over-year storage continuity constraints can be written by identifying a single firm annual reservoir yield, Oy^{fp1}, with an exceedence probability *p1* i.e.,

$$S_{j-1}^{o} + I_j - \theta_j^{p1} Oy^{fp1} - Sp_j = S_j^{o} \qquad \forall j \qquad (5.10)$$

where θ_j^{p1} = factor to identify a successful or a failure year in case of a single firm yield model with complete failure year and its value will be as follows:

$$\theta_j^{p1} = \begin{cases} 1 & \text{if the annual firm reservoir yield is to be provided in year } j \text{ (successful year)} \\ 0 & \text{if the annual firm reservoir yield is not to be provided in year } j \text{ (failure year)} \end{cases} \quad (5.11)$$

Now, in the objective function 5.7 and the within-year continuity equation 5.9, replace Oy^{fp} by Oy^{fp1}.

The required active storage volume capacity and the reservoir yield are dependent on each other. Therefore,

(a) In case, the magnitude of the reservoir yield is unknown, then (i) a trial and error procedure, such as simulation may ensure that any failure years selected is within the critical period (drought periods) of years for the associated reservoir yield, and (ii) select the years with the lowest flow within the critical period as the failure year, if only one trial failure year is being selected. This would ensure a wider range of applicable reservoir yield magnitudes.

(b) Select the failure year(s) from among those year(s), where (i) decrease in the required reservoir capacity would result for a desired reservoir yield, (ii) increase in the reservoir yield would result for a given reservoir capacity, and (iii) excess release (spill) would be made anyway, but no reduction in the required active storage capacity would result, then the reliability of the reservoir yield may be higher than intended.

(C) Allowable deficit in firm annual reservoir yield during failure years:

As per the model, it was shown earlier that a value of zero for θ_j^{p1} in equation 5.10 indicates that, the firm annual reservoir yield is not available in that particular year. In actual practice, such condition may not occur; and it may be possible to provide some reservoir yield during failure years in actual reservoir operation. This situation is desirable and can be considered, by allowing a partial failure or an *allowable deficit* in firm annual yield during failure years. This is possible by incorporated in the yield model another factor D_j^{p1} in place of the factor θ_j^{p1} in equation 5.10. Now the equation 5.10 is rewritten as follows:

$$S_{j-1}^{o} + I_j - D_j^{p1} Oy^{fp1} - Sp_j = S_j^{o} \qquad \forall j \qquad (5.12)$$

where D_j^{p1} = factor to identify a successful or a failure year in case of a single firm yield model with partial failure year, which indicates the extent of permissible failure or an allowable deficit

Where $D_j^{p1} = \begin{cases} (D_j^{p1}=1) & \text{if the annual firm reservoir yield is to be provided in year } j \text{ (successful year)} \\ (0<D_j^{p1}<1) & \text{if the annual firm reservoir yield is to be provided partially in year } j \text{ (failure year)} \end{cases}$

Now also, in the objective function 5.7 and the within-year continuity equation 5.9, replace Oy^{fp} by Oy^{fp1}.

For example, a value of D_j^{p1} = 0.8, indicates a 20% failure or deficit in providing firm annual yield. The value of D_j^{p1} is in part dependent on the consequences of failures and on ability to forecast when a failure may occur and to adjust the reservoir operating policy accordingly. This factor D_j^{p1} shall be called as *failure fraction*. This fraction can be effectively served as a control over the extent of failure or deficit in firm annual yield during failure years. A high value of D_j^{p1} could reduce the firm annual yield. However, it shall always be preferable beforehand to know the extent of failure than to face unexpected failures as in case when the value of D_j^{p1} is set to zero.

(D) Other model constraints:

The other model constraints are discussed below,

1. Over-year active storage volume capacity (equation 5.3), i.e,

$$S_{j-1}^{o} \le Y^{o} \qquad \forall j \qquad (5.13)$$

Where Y^o = over-year storage capacity of reservoir

2. Active reservoir storage capacity, i.e,

The within-year capacity Y^w is the maximum of all within-year storage volumes, i.e,

$$S_{t-1}^{w} \le Y^{w} \qquad \forall t \qquad (a)$$

Where Y^w = within-year storage capacity of reservoir;

The total active storage capacity is simply the sum of the over-year storage and within-year storage capacities, i.e.,

$$Y_a = Y^o + Y^w \qquad (b)$$

Combining equations (a) and (b),

$$Y^o + S^w_{t-1} \le Y_a \ \forall t \tag{5.14}$$

Where Ya =total active storage capacity of reservoir;

3. Proportioning of annual yield in within-year time periods t, i.e,

$$Oy^{fp}_t = \xi_t(Oy^{fp}) \qquad \text{Or} \qquad Oy^{fp1}_t = \xi_t(Oy^{fp1}) \qquad \forall t \tag{5.15}$$

Where ξ_t defines a predefined fraction of annual reservoir yield for the within-year yield in period t, and depends on the type of water use.

5.5.2 Single Reservoir Multiple Yield Model

The yield model discussed so far defines only single annual reservoir yield, i.e., firm or safe yield with a given reliabilities p and $p1$. An incremental secondary 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 yield can also be incorporated in the model. Let, Oy^{fp} and Oy^{sp2} represent these annual yields, respectively. No failure year is allowed in the firm annual yield where as failure years are allowed in case of secondary annual yield. The factor θ^{p2}_j shall be 1 for the selected successful years and zero for the remaining failure years.

5.5.2.1 Incorporation of evaporation losses

A model cannot directly identify storage volumes at the beginning of any period beforehand. Therefore, the evaporation losses are based on an expected storage volume in a given period. Thus,

The approximate expected storage volume = the initial active over year volume + the estimated

Average active within-year volume

$$= S^o_{j-1} + \frac{S^w_{t-1} + S^w_t}{2}$$

The storage area relationship and approximation of surface area per unit active storage volume is shown in Figure 5.1.

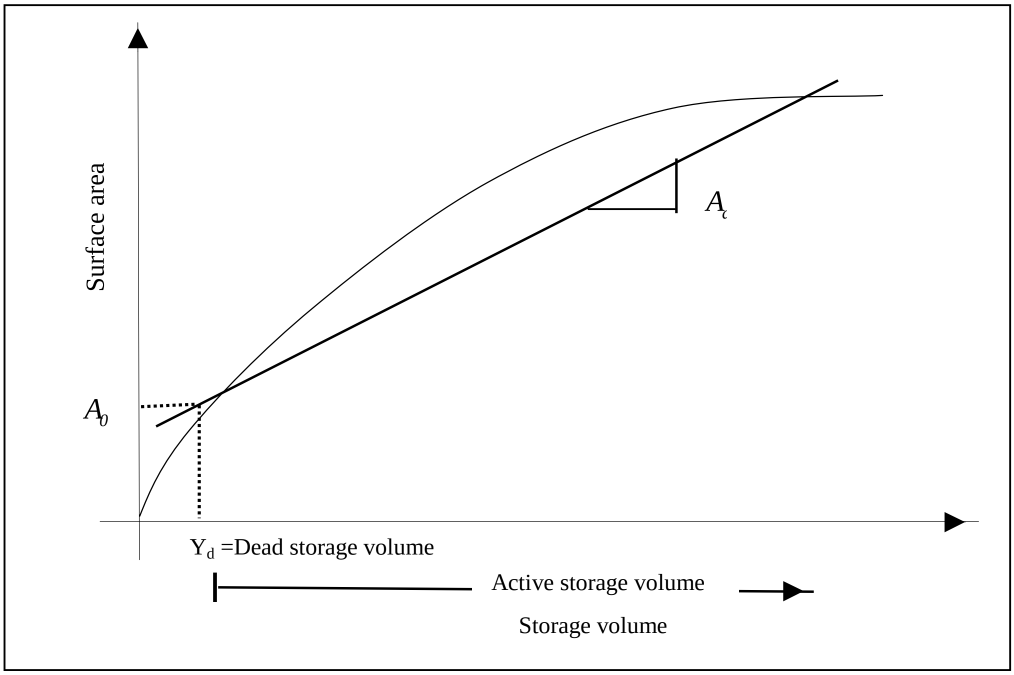


Figure 5.1 Storage area relationship and approximation of surface area per unit active storage volume

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

A_0 = water surface area at dead storage level.

Now the annual evaporation loss in year j equals

EV_j = Annual evaporation volume loss = average annual fixed loss from the dead storage + Sum of each within-year period's loss from active
Expected storage volume

$$\text{Or } EV_j = \sum_t \left[\gamma_t EV^0 + \left(S^o_{j-1} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t EV^a \right] \qquad \forall j \qquad (5.17)$$

Where

$EV^a = A_a \times$ Average annual depth of evaporation; and

$EV^0 = A_0 \times$ Average annual depth of evaporation.

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

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

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

Since, $\sum \gamma_t =$ equals 1, equation 5.17 becomes

$$EV_j = EV^0 + \left[S^o_{j-1} + \sum_t \left(\frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t \right] EV^a \qquad \forall j \qquad (5.18)$$

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

$$Ev_t = \gamma_t EV^0 + \left(S^o_{cr} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t EV^a \qquad \forall t \qquad (5.19)$$

Where

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

5.5.2.2 Mathematical statement of single reservoir multiple yield model

The multiple yield models for a single reservoir now can be written to derive two types of reservoir yields, i.e., the annual firm and secondary reservoir yields, of the desired reliabilities *p* and *p2,* respectivelyas follows:

The model objective function is:

Either Maximize $$\sum_t \left(Oy_t^{fp} + Oy_t^{sp2} \right) \qquad (5.20)$$

Or Minimize $$Y_a \qquad (5.21)$$

The objective function is subjected to the following constraints:

1. Equation for over-year storage continuity

$$S^o_{j-1} + I_j - Oy^{fp} - \theta^{p2}_j Oy^{sp2} - EV_j - Sp_j = S^o_j \qquad \forall j \qquad (5.22)$$

Where

$$\theta^{p2}_j = \begin{cases} 1 & \textit{in successful years} \\ 0 & \textit{in failure years} \end{cases}$$

2. Equation for over-year active storage volume capacity

$$S^o_{j-1} \le Y^o \qquad \forall j \qquad (5.23)$$

3. Equation for within-year storage continuity

$$S^w_{t-1} + \beta_t \left[(Oy^{fp} + Oy^{sp2}) + \sum_t Ev_t \right] - (Oy^{fp}_t + Oy^{sp2}_t) - Ev_t = S^w_t$$

$$\forall t \qquad (5.24)$$

4. Equation for definition of estimated annual evaporation losses

$$EV_j = EV^0 + \left[S^o_{j-1} + \sum_t \left(\frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t \right] EV^a \qquad \forall j \qquad (5.25)$$

5. Equation for definition of estimated evaporation losses in each period t of the critical year

$$Ev_t = \gamma_t EV^0 + \left(S^o_{cr} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t EV^a \qquad \forall t \qquad (5.26)$$

The initial over year storage volume in the critical year, i.e., S^o_{cr} is assumed to be zero.

6. Equation for total reservoir storage capacity

$$Y^o + S^w_{t-1} \le Y_a \qquad \forall t \qquad (5.27)$$

7. Equation for proportioning of annual yield in within-year time periods t

$$Oy^{fp}_t = \upsilon_t (Oy^{fp}) \quad \text{and} \quad Oy^{sp2}_t = \chi_t (Oy^{sp2}) \qquad \forall t \qquad (5.28)$$

Where υ_t and χ_t define a predefined fraction of annual reservoir yield for the above defined two within-year yields in period *t*. These fractions usually depend on the type of water use.

8. Equation for allowable deficit in the failure years

The secondary annual yield is made zero during the failure years by setting the value of factor θ_j^{p2} equal to zero. Sometimes production of a desired proportion of the total annual yield during failure years is required for many reasons, say to meet certain minimum water needs. This situation can be overcome by going for an allowable deficit in the failure years, a relation, i.e., firm annual reservoir yield equals failure fraction times the total annual reservoir yield is rearranged and represented in the following form, i.e.,

$$Oy^{fp} = \frac{\rho^{p2}}{1-\rho^{p2}} Oy^{sp2} \tag{5.29}$$

Where

ρ^{p2} = fraction of total annual yield desired to be released in the failure years.

5.5.3 Multiple Yield Model for Multi Reservoir System

Dahe (2001) and Dahe and Srivastava (2002) extended the single reservoir multiple yield model to multiple reservoir system comprising of single purpose and multipurpose reservoirs. The authors proposed two yields, each having the same reliability at all the reservoirs in the system, irrespective of a reservoir being single or multipurpose. Conceptually these two yields represent the following:

The water uses and the yields:

(1) A single purpose irrigation reservoir is normally a single yield problem, whereas, now it is represented by a two reservoir yield formulations. Thus, the annual irrigation target now is the sum of firm and secondary annual reservoir yields. This would serve two purposes for irrigation; i.e., the desired annual reliability by the firm yield and an allowable deficit criterion by the secondary yield.

(2) For a single purpose hydropower reservoir, the firm and the secondary reservoir yields serve for the firm and secondary annual energy generations, respectively.

(3) In the case of a multipurpose reservoir with two purposes, i.e., irrigation and hydropower, the above two provisions, (i) and (ii) still hold good. This with the assumption that, after energy production the release for power generation shall only be made available for irrigation, and

(4) For reservoirs having only irrigation use, an additional constraint was incorporated, by monitoring the allowable proportions of the firm and secondary annual reservoir yields.

The objective of the model was to maximize the returns from energy generation for known reservoir and hydro-plant capacities. The model was successfully applied to 8 reservoirs in the upper basin of Narmada river in India (Dahe and Srivastava, 2002). Dahe (2001) applied the model to all the 30 reservoirs in Narmada basin. For analysis 22 years flows were used in the study.

5.5.3.1 Limitations of the multiple yield model for multi reservoir system

The model worked well in its intended purpose of application applied to the upper basin of Narmada river. However, following paragraphs enunciate some of its limitations to handle some real world problems (Panigrahi and Srivastava 2005, Panigrahi 2006):

About the water uses:

(1) The model considered only two water uses, i.e., irrigation and hydropower. The municipal and industrial (M & I) water supply demand which has the highest priority and is mandatory was excluded. It was assumed that, the required quantities for the same could be met from the inflows, and so were deducted beforehand while applying the model, a practice which is often followed. With this assumption, (a) there is every possibility that, it may not be possible to meet the M & I demands during some critical within-year time periods during very lean periods, and (ii) in such case, it ignores the effect of reservoir operation on the releases required to be made for M & I from a reservoir.

(2) As there was no facility in the model to opt for releases made towards mandatory purposes. For this reason it became necessary to deduct the required mandatory water requirements from the modelled within-year reservoir yields (releases made) later. This

resulted in the remaining water available for other uses (i) fall short for which the released water (yield) was intended for, and (ii) may also sometimes become negative as well.

(3) The model considered only a common regeneration contribution factor, although it had two water uses.

About the failure fraction:

(4) The failure fraction monitors the extent of the firm annual yield available at all the reservoirs in the entire basin. The fraction is the ratio of the annual irrigation water requirements sufficient to cater the minimum annual food needs of the agricultural population during the failure years to the total annual irrigation water requirements for the cultivable command area. The values of these fractions vary from project to project. The assumption of a common value for the failure fraction within the entire river basin; is likely to result in under/over estimate of the reservoir yields by the model.

The underestimates of yields: For an underestimate of the total modelled annual reservoir yield, there is a possibility (a) that, the annual target release would have been otherwise met from a lower value of this fraction; and (b) this release, which may be less than the annual release target during successful years to help release more in the failure years.

The overestimates of yields: For an overestimate of the total modelled annual reservoir yield, there is a possibility that (a) either more release can be made available during failure years, or (b) a smaller capacity of the reservoir would have been sufficient to get the target demand while using an appropriate value of fraction that is suitable for the reservoir.

The value of failure fraction is based on the principle that, the project would at least be able to meet the minimum food needs of agricultural population during failure years. This assumption would be realized only under the context, that (i) the public distribution systems and the facilities available for supplying, managing and maintaining these agriculture food grain produce are well developed at all times and (ii) in actual practice it may not be always possible to adopt such a cropping pattern in Toto, considering agro-climatic conditions and food habits.

About the reservoir yields:

(5) From the modelled optimal within-year reservoir yields for field applications later, re-crop planning would be required. In the model for irrigation target constraint, the within-year water requirement distribution factors used are crop plan based as per the project reports. Therefore, these within-year yields resulting thereof are governed, by corresponding (a) distribution factors and (b) the actual water availability. Therefore, the modelled yields differ; from the actual needed field water requirements, hence is observed different from the suggested crop plan in project proposal. Adjustment between these two crop plans is extremely difficult, which is of course unavoidable.

(6) From the results of investigations on some projects, the multi yield model (Dahe and Srivastava 2002) reveals that, (i) it gives the desired proportions of firm and incremental secondary yields on annual basis only, and (ii) the within-year distribution of yields show that during some within-year time periods (a) their assigned proportionality is usually not followed and (b) even there is no firm yields found, means failing to deliver water in some critical water years.

(7) The values of percentage fractions, for irrigation and firm energy targets in within-year time periods differ greatly from each other. While, both these targets are to be met from the firm reservoir yield. These rigid constraints, therefore, for a multipurpose project, would cause model infeasible.

About the other factors:

(8) Consideration of a common set of failure years for the entire basin seems to be unrealistic, since the large basins normally have diverse hydrological conditions.

(9) The model study remained silent over solution strategies in regard the presence of barrages in the river basin.

5.5.4 Integrated Reservoir Yield Model

Panigrahi and Srivastava (2005) and Panigrahi (2006) overcame the limitations described in section 5.5.3.1 earlier and improved the yield model of Dahe and Srivastava (2002). The approach followed is discussed below:

About the water uses and reservoir yields:

(1) The model was capable of finding optimal yield from a multipurpose reservoir having mandatory release in addition to the irrigation and/or hydropower component. Therefore, for each project two types of annual yields, one the firm yield 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.

(2) A desired quantity towards mandatory water demands in each within-year time periods were intended to be released under all circumstances, which would be first fully met out of the within-year firm yields. Therefore, even during a failure year the maximum possible annual yield reliability *p* and simultaneously satisfying its within-year distribution were achieved.

(3) The releases made towards the municipal and industrial, environmental and ecological, and other downstream riparian rights were clubbed under the mandatory water demands.

(4) Firm power would be generated by the firm yield and secondary power by the secondary yield with the within-year distributions as that of irrigation, whereas, the irrigation demands would be met from both the yields.

About the crop plans:

(5) Major improvements were made by incorporating necessary constraints to assess crop plans at each reservoir in an integrated manner, thus optimal crop plans were derived simultaneously at the same time.

About the other factors:

(6) The hydrological diversity in a large river basin was considered, by selecting site specific failure years and allowable percentage yields during failure years at each reservoir.

(7) Separate regeneration contributions from different water uses are considered.

(8) An optimization-simulation approach was presented to deal with a system comprising both reservoirs and barrages.

The reservoir yield model, with the above described improvements, which had the capability to assess optimal yields and simultaneously optimizing the crop plans at each and every site in the river basin, was termed as the "I*ntegrated Reservoir Yield Model* (IRYM)".

The objective of the IRYM was to maximize the annual system yield, with an aim of simultaneously optimizing the cropping patterns at individual projects. Panigrahi and Srivastava (2005) applied the model to Ong Sub-basin of Mahanadi River in Orissa, India. Later, Panigrahi (2006) applied the model to the lower part of the Mahanadi river basin system lying in Orissa, which consisted of 24 major and 32 medium projects.

5.5.4.1 Limitations of the Integrated Reservoir Yield Model

The model improved by Panigrahi (2006) though did well in its application to the Mahanadi basin, India. However, the following paragraphs describe some of its limitations of the model to handle the some important planning issues.

About the reservoir yields:

(1) When the total in coming flow; consisting of the regenerations made from water uses at the projects upstream of the reservoir under consideration and its incoming catchment inflow,

(I) (a) is substantial but is less than its timely water demands and (b) is greater in comparison to the active storage of the reservoir; then model gives the annual firm yield (Oy^{fp}) and the annual secondary yield (Oy^{sp2}), either equal to zero or a very small quantity as compared to the total in coming flow to the reservoir, and

(II) (a) is greater than its timely water demands and (b) is greater in comparison to the active storage of the reservoir; then the model becomes infeasible, due to the constraints of within year continuity and water availability/requirement for certain time periods as within-year storage capacity is very small or even zero and also water requirement is less than the water available.

(2) The model gives smaller annual system yield, for a reservoir having inadequate live storage capacity,

(3) The firm and secondary reservoir yields are used for irrigation as well as for firm and secondary energy generation. Therefore, in case of a reservoir with small hydropower plant capacity, where irrigation is the main purpose, the water released for irrigation being large finds

the turbine capacity small. Under such circumstances, the model is likely to be infeasible. This is due the presence of the rigid power constraints, i.e., for firm energy generation, secondary energy generation, and plant capacity, and

(4) The releases towards mandatory water demands, i.e., municipal and industrial, environmental and ecological and other downstream riparian rights are clubbed together. As regeneration contribution factors as well as gross benefits differ for municipal and industrial water demands, this need to be considered separately.

The solution strategy:

(5) The IRYM (Panigrahi and Srivastava 2005, Panigrahi 2006) as well as the multiple yield model for multireservoir system (Dahe and Srivastava 2002) and the yield model (Loucks et al. 1981) had some major limitations. These models could not be applied to the system comprising of reservoirs and barrages simultaneously, because these models could not work in case of barrages. Hence, optimization-simulation model was recommended for a system with reservoirs and barrages (Panigrahi and Srivastava 2005, Panigrahi 2006).

Chapter 6

MULTI OBJECTIVE FUZZY LINEAR PROGRAMMING MODEL

6.1 INTRODUCTION

Multi objective analysis in water resources has developed in explicit form largely through the work of Harvard Water Program (HWP). Much of the methodology and its research findings were published by Mass et al. (1962). Haimes and Hall (1974) developed a method for solving noncommensurable multi objective functions, designated by surrogate worth trade-off (SWT) method. Non-fuzzy multi objective approaches include Vedula and Rogers (1981) and Srinivasa Raju and Nagesh Kumar (1999). Yeh (1985) reviewed the various models used for optimal operation of reservoirs. Most of these models consider the uncertainty caused due to variability of inflows. However uncertainty caused because of imprecise objectives and goals is also a factor in developing operation policy of a reservoir.

To overcome some of the limitations in previous approaches, fuzzy based models were proposed. Shrestha et al. (1996) introduced a fuzzy-rule based model deriving the operation rules for a multi-purpose reservoir. Operation rules are generated on the basis of economic development criteria. Russell and Campbell (1996) proposed operating rules for a single purpose hydroelectric project, where both the inflows and selling prices of energy are uncertain. Anand Raj and Nagesh Kumar (1998 and 1999) proposed fuzzy based approach, RANFUW, for ranking multi criterion river basin planning alternatives using fuzzy numbers and weights.

Nagesh Kumar et al. (2001) developed optimal reservoir operation model using multi objective fuzzy linear programming (MOFLP) considering two objective functions viz. maximization of releases for irrigation and maximization hydro power produced. They concluded that fuzzy linear programming is a simple and suitable tool for multi objective problem as compared to other method. Same conclusion was drawn by Srinivasa Raju and Duckstein (2003) for the evaluation of management strategy using MOFLP for irrigation planning considering three conflicting objectives viz. net benefits, agriculture productions and labour employment. A fuzzy rule based model for multi reservoir operation in long term was developed by Mohan and Prasad (2005). The performance of reservoir for irrigation, water supply and hydropower was evaluated with the developed model and compared with historical operation. Ramani Bai and Tamjis (2007) developed fuzzy logic model (FLM) on operation and control of hydropower dams in Malaysia. Choudhari and Anand Raj (2009) suggested the irrigation planning with fuzzy linear programming for multi-reservoir, multipurpose system, Srinivasa Raju et al. (2009) studied the multi-objective fuzzy and deterministic Goal programming to get the compromise solution of optimal irrigation planning while considering all the conflicting objectives together. Regulwar and Gurav(2010) proposed the irrigation planning model with fuzzy approach for Jayakwadi irrigation project Maharashtra, India by considering four different objectives together. Dattatray, G. et al (2011) discussed the Multi Objective Fuzzy Linear Programming (MOFLP) irrigation planning model formulated for deriving the optimal cropping pattern. Mirajkar and Patel (2011) formulated a multi-objective fuzzy linear programming (MOFLP) for crop planning in the command area.

In the present study, multi objective fuzzy liner programming (MOFLP) is used based on Zimmerman's (1978) vector maximization approach. Although his approach considers both objectives and constraints as fuzzy, whereas in the present study, only objectives are considered as fuzzy (Nagesh Kumar et al. 2001). As can be seen from the MOFLP formulation in the following sections, annual releases for irrigation and water supply are considered fuzzy (throughobjective functions) while releases were considered crisp. This approach gives only preliminary results and for detailed investigation other decision variables should also be considered as fuzzy variables. The previous studies on fuzzy model applications did not consider multiple reservoir yields and annual reliability of these releases. For this the application of basic implicit stochastic reservoir yield model of Loucks et al. (1981) is widely used. This model considers annual firm (water supply) and secondary (irrigation) releases of pre-specified annual reliabilities.

6.1.1 Fuzzy Logic

A real-world reservoir operation model can be very complex. It has to incorporate all the input imprecision's, while the output should fulfil all system requirements, such as meeting various demands without violating the physical constraints of the system. An appropriate tool to handle such imprecise elements is fuzzy logic. Fuzzy logic theory is a convenient way to map an input to an output space. There is numerous ways to handle an optimization problem. Among these, Fuzzy technique is “easy to understand and flexible”.

Salient features of fuzzy logic are It is conceptually easy to understand, It is flexible, It is tolerant of imprecise data, It can model nonlinear functions of arbitrary complexity, It can be built on top of the experience of experts who already understand the system, It can be blended with conventional control techniques and It is based on natural language (human communication).

6.1.2 Steps for Developing Fuzzy Logic Model

(1) Define the model objectives and criteria.

(2) Determine the input and output relationships and choose a minimum number of variables for input to the fuzzy logic model.

(3) Using the rule based structure of fuzzy logic, break the modelling problem down into a series of IF X AND Y THEN Z rules that define the desired system output response for given system input conditions. The number and complexity of rules depends on the number of input parameters that are to be processed and the number of fuzzy variables associated with each parameter.

(4) Create fuzzy logic membership functions that define the meaning (values) of input/output terms used in the rules.

(5) Create the necessary pre and post processing fuzzy logic.

(6) Test the system, evaluate the results, tune the rules and membership functions and retest until satisfactory results are obtained.

6.1.3 Fuzzy Reservoir Operation Model

In modelling of reservoir operation with fuzzy logic, the following distinct steps are

(i) Fuzzification of inputs, where the crisp inputs such as the inflow, reservoir storage and release are transformed into fuzzy variables. (ii) Formulation of the fuzzy rule set, based on the results obtained by an analytic method or using expert knowledge. (iii) Application of a fuzzy operator, to obtain one number representing the premise of each rule. (iv) Shaping of the consequence of the rule by implication.(v) Aggregation.(vi) Defuzzification of consequences.

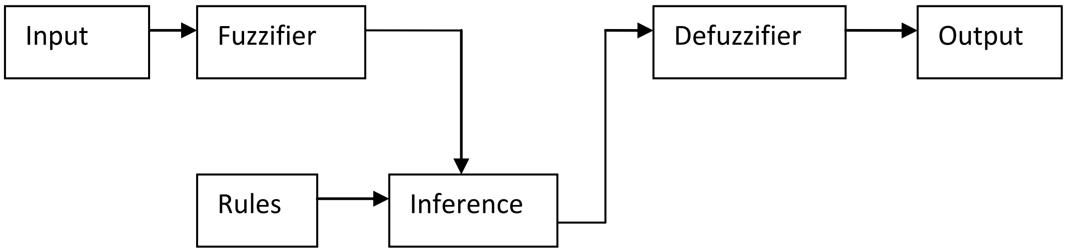


Fig: 6.1 Fuzzy logic basic elements

A fuzzy rule system is defined as the set of rules which consists of sets of input variables or premises $A_{i,k}$ in the form of fuzzy sets with membership function $\mu A_{(i,k)}$ and set of consequences $B_{i,k}$ also in the form of a fuzzy set.

If a_i is $A_{i,1}$ and a_2 is $A_{i,2}$ and…………… a_k is $A_{i,k}$ then $B_{i,k}$

In reservoir operation, every premise appears to play n equally important role. Therefore, among the usual logical operators "and", "or", "probor", only the "and" logical operator is used.

The system of mass balance equation and the physical or boundary conditions for reservoir operations also constitute rules. This is given as

$$S_{t-1} = S_t + I_t - R_t$$

With conditions $S_{t\min} < S_t < S_{t\max}$ and $R_{t\min} < R_t < R_{t\max}$ Where S_t , R_t and I_t are storage, release and inflow at time t respectively. S_{t-1} is the initial reservoir storage for the next event.

6.1.4 Fuzzification of the Inputs (Membership Function)

The first step in building a fuzzy inference system is to determine the degree to which the inputs belong to each of the appropriate fuzzy sets through the membership functions. Membership functions characterize the fuzziness in a fuzzy set – whether the elements in the set are discrete or continuous. It is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is referred as universe of discourse. If X is the universe of discourse and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs

$$A = \{x, \mu_A(x) | x \varepsilon X\}$$

Where $\mu_A(x)$ is called the membership function of x in A. The membership function maps each element of X to a membership value between 0 and 1. For reservoir operation modelling purposes, the membership functions required are those of inflow, storage, demand and release. When the standard deviation is not large it is appropriate to use a simple membership function consisting of only straight lines, such as a triangular or a trapezoidal membership function. The most commonly used membership function is triangular shape.

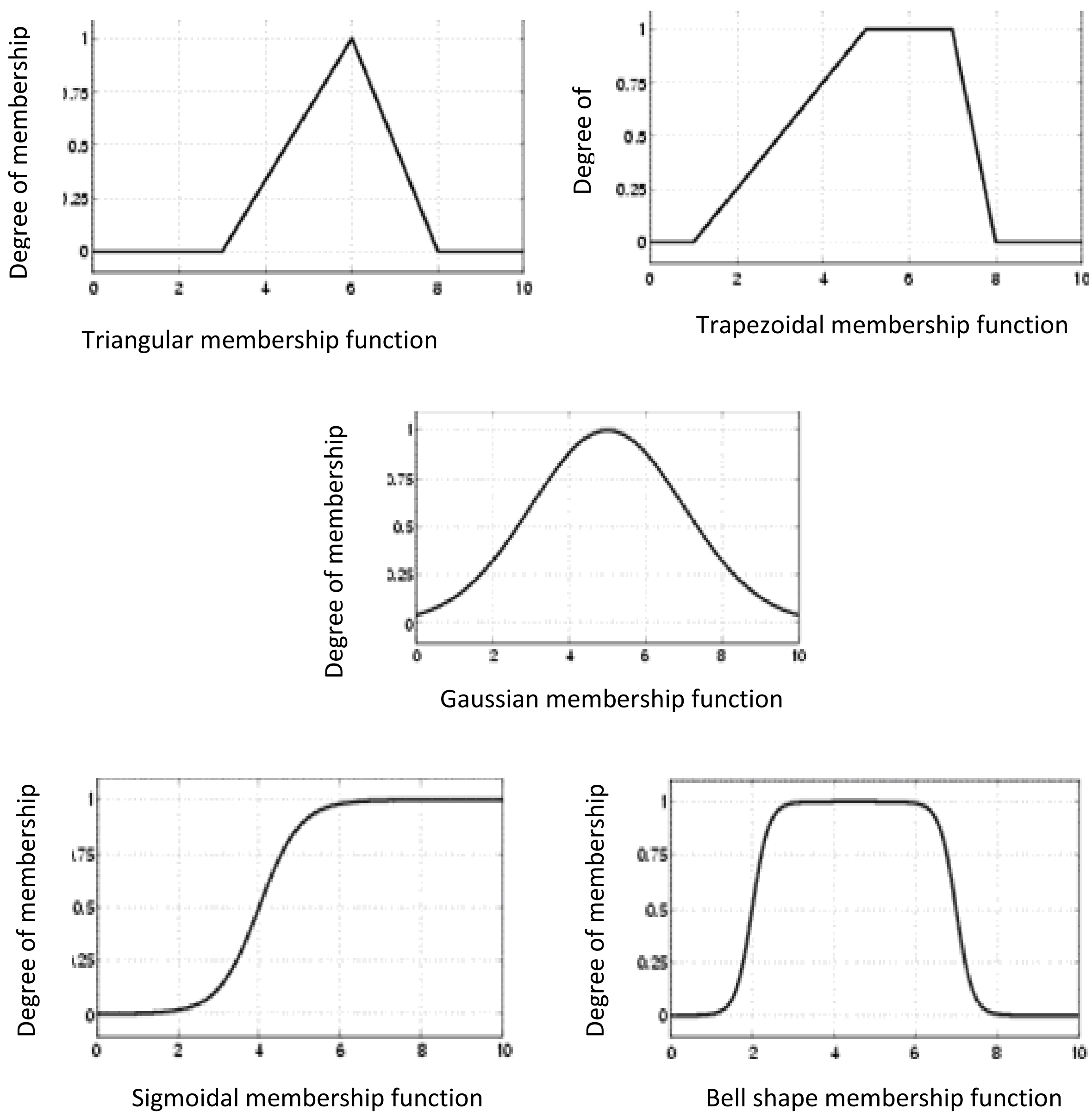


Fig: 6.2 Commonly used Membership functions

The equation describing the triangular membership function is given by

$$f(x; a, b, c) = \begin{cases} 0, & x \le a \\ (x - a) / (b - a), & a \le x \le b \\ (c - x) / (c - b), & b \le x \le c \\ 0 & c \le x \end{cases}$$

The parameters a and c locate the feet of the triangle and the parameter b locates the peak.

6.1.5 Fuzzy Rules

If – then rules are used to formulate the conditional statements that comprise fuzzy logic. A single fuzzy if-then rule assumes the form: “If x is A then y is B” where A and B are linguistic values defined by fuzzy sets on ranges X and Y respectively. The if-part of the rule “x is A” is called the antecedent or premise, while the then-part of the rule “y is B” is called the consequent or conclusion.

The premise is an interpretation that returns a number between 0 and 1, whereas the consequence is an assignment that assigns the entire fuzzy set B to the output variable y. Interpreting the fuzzy rule of the kind “if-then” involves distinct steps such as: first evaluating the premise and second, applying that result to the consequence (implication). In the case of binary or two valued logic, if the premise is true then the consequence is also true. But in a fuzzy statement involving a fuzzy rule, if the antecedent is true to some degree of membership, then the consequent is also true to that same degree.

6.1.6 Logical Operator

If the premise of a given rule has more than one part, then a fuzzy operator is applied to obtain one number that represents the result of the premise of that rule. The input to the fuzzy operator may be from two or more membership functions, but the output is a single truth value. It is superset of standard Boolean logic. In more general terms, the fuzzy intersection or conjunction (AND), fuzzy union or disjunction (OR), and fuzzy complement (NOT) are commonly used fuzzy operator. These functions are known as the classical operators as AND = min, OR = max, and NOT = additive compliment.

The fuzzy logic operators such as the AND or OR operators obey the classical two valued logic. The AND methods are supported for min (minimum) and Prod (Product) while the OR methods are supported for max (maximum) and the Probor (Probabilistic or method). The Probabilistic or method is calculated according to the equation

$$\text{Probor}(a,b) = a + b - ab$$

6.1.7 Implication

The fuzzy operator operates on the input fuzzy sets to provide a single value corresponding to the inputs in the premise. The next step is to apply these results on the output membership function to obtain a fuzzy set for the rule. This is done by the implication method. The input for the implication method is a single number resulting from the premise and the result of implication is a fuzzy set. Implication occurs for each rule by the AND method which truncates the output fuzzy set, or the prod method which scales the output fuzzy set. The truncation of the output fuzzy set is done at the higher of the two membership function values. In applying the implication to a set of rules, weightages may be attached to different rules to distinguish them from each other based on priorities.

6.1.8 Aggregation

Aggregation is the unification of the output of each rule by merely joining them. When the input value belongs to the intersection of the two membership functions, fuzzy rules corresponding to both the membership functions are invoked. Each of these rules, after implication, specifies one output fuzzy set. Aggregation occurs once for each variable. The input of the aggregation process is the list of truncated output function returned by the implication process of each rule. The output of the aggregation process is one fuzzy set for each output variable. The aggregation methods are given by: max (maximum), probor (probabilistic or) and sum (sum of each rule output)

6.1.9 Defuzzification

The conversion of a fuzzy set to single crisp value is called defuzzification. The result obtained from implication is in the form of a fuzzy set. For application this is defuzzified. The most common defuzzification method is the ‘centroid’ evaluation, which returns the centre of area under the curve. Other methods for defuzzification include ‘bisection’, which returns the bisection of the base of the output fuzzy set; ‘middle of maximum’, which returns the value of middle of maximum of the aggregation of the truncated output fuzzy subset; ‘largest of maximum’ which returns the value of largest of maximum of the aggregation of the truncated output fuzzy subsets; ‘smallest of maximum’, which returns the value of minimum of maximum of the aggregation of the truncated output fuzzy subsets.

6.2 ALGORITHM FOR MOFLP

To solve the MOFLP model, the following algorithm (for maximization problem) can be used:

Step 1: Solve the model as a multi-objective linear programming (MOLP) problem by taking one objective at a time and find for each objective (Z_i), respectively, the best Z_i^+ values (i.e., aspiration level of objective) and worst Z_i^- values (i.e., lowest acceptable level of objective) corresponding to the set of decision variables (X) of solutions.

Step 2: Define a linear membership function µi (x) for each objective as

$$\mu_i(X) = 0 \quad for\ Z_i \le Z_i^L \qquad \forall_i \tag{6.1}$$

$$\mu_i(X) = \left[\frac{Z_i - Z_i^L}{Z_i^U - Z_i^L}\right]^\beta \ for\ Z_i^L \le Z_i \le Z_i^U \qquad \forall_i \tag{6.2}$$

$$\mu_i(X) = 1 \ for\ Z_i \ge Z_i^U \tag{6.3}$$

Where Z_i^u = aspiration level of objective Z_i, Z_i^L = lowest acceptable level of objective Z_i, β = exponent indicates the desired shape of membership function. Assignment of value 1 to it gives rise to a linear membership function. The value of µi (x) reflects the degree of achievement. Value of µi (x) will be 1 for perfect achievement and 0 for no-achievement of a given strategy and some intermediate values otherwise. The model can be transformed into the following general optimization problem in matrix form:

Maximize µi (x)

Subject to: $AX \le B$

$X \ge 0$

where A = (mxn) matrix of known constants, B = (mx1) vector of constants and X = (nx1) vector of decision variables.

Step 3: An equivalent fuzzy LP (FLP) problem is then defined as follows:

Introducing a new variable λ, the MOFLP problem can be formulated as an equivalent LP problem.

Maximize λ

Subject to:

$$\mu_i(X) \ge \lambda \qquad \forall_i$$

$AX \leq B$

$0 \leq \lambda \leq 1$

$X \geq 0$

Step 4: Solve the LP problem formulated in step 3. The optimal solution to the above problem is an efficient compromise solution with respect to all the given objectives.

The methodology for fuzzy optimization as explained is applied to the case study, to determine the optimal reservoir yields.

6.3 FORMULATION OF MOLP MODEL

The MOLP model is developed for operation of the reservoir assuming stationary

inflows and average demands. Here the objective functions are considered as fuzzy and the constraints are considered as non-fuzzy (crisp).

Objective functions

The two objectives considered in the study of Daudhan reservoir in Ken basin are to maximise annual releases for water supply and to maximise annual releases for irrigation.

(1) Maximization of annual releases for water supply (i.e., Oy^{fp}) and

(2) Maximization of annual releases for irrigation (i.e., Oy^{sp2}), i.e.,

$$\text{Max. } Z_1 = Oy^{fp} \tag{6.4}$$

$$\text{Max. } Z_2 = Oy^{sp2} \tag{6.5}$$

Subject to set of constraints of IRYM model as presented in Chapter 5 from equation 5.29 to 5.92

The two objectives considered in the study of Daudhan reservoir in Ken basinand the projects in Betwa basin are to maximise annual firm releases and to maximise annual secondary releases.

(1) Maximization of annual firm releases for irrigation (i.e., Oy^{fp}) and

(2) Maximization of annual secondary releases for irrigation (i.e., Oy^{sp2}), i.e.,

$$\text{Max. } Z_1 = Oy^{fp} \tag{6.6}$$

$$\text{Max. } Z_2 = Oy^{sp2} \tag{6.7}$$

Subject to set of constraints of IRYM model as presented in Chapter 5 from equation 5.29 to 5.52

6.4 HEDGING RULES (HRs) FOR RESERVOIR OPERATION

Standard operation policy (SOP) is the one of the mode to evaluate the operational performance of a reservoir. In practical situation it is not a rule recommended for actual operation of a reservoir. Stedinger (1984) has presented the difficiencies of the rule that it neither provides a mechanism for rationing supplies when there is no sufficient water nor does it suggest a mechanism for releasing more water, when it is surplus. In other words, the SOP is very rigid. A realistic operating rule should suggest reductions in demand during periods of imminent drought even though the usual demand can be delivered from storage and current inflow. Such reductions would serve to avoid larger shortages in later periods. Bayazit and Ünal (1990) presented the effects of operating a water supply reservoir with a policy of hedging on various reservoir performance criteria. Theyhave reported the SOP as the most excellent in respect of reliability and resilience.It gives satisfactory results with regard to mean deficits. They have reported that the hedging improves the performance with respect to the mean deficit and vulnerability, if it is started with sufficient water in storage. Otherwise, it would decrease the risk of very large future deficits, although the average deficit and vulnerability will be increased. Shih and ReVelle (1994, 1995) have studiedthe continuous hedging rule (CHR) and discrete hedging rule (DHR) to operation of water supply during drought. No guideline is available to calculate the hedging trigger values in CHR. Tu et al. (2003) have studied a mixed integer linear programming model (MILP) to operate a multipurpose, multi-reservoir system.Theyconsider simultaneously both traditional reservoir rule curves and hedging rule curves. They have reported that guidelines are provided for reservoir releases by considering the HRs along with the rule curves. These studies on hedging rule show its effectiveness for public water demands and agriculture. One recent application of hedging rules was reported by Srivastava and Awchi (2009), they applied it for Mula reservoir operation in India. They presented that the application of the continues hedging rule for the operation of reservoir, using monthly hedging trigger values of Kp_t^{YM} which is obtained from the reservoir yield models, can give acceptable performance by showing decreased deficits particularly during the months of late non-monsoon season. The DHRs have very strong influence on reducung the number of reservoir empty conditions; and these can help to mitigate hazards during droughts and low flows.

6.4.1 The Hedging Rules (HRs)

The standard operating policy (SOP) is considered as classical operation policy for reservoir simulation as shown in Fig.6.3 (a). This is very rigid policy and does not allow rationing of water during actual or impending droughts. Hedging reduces the risk of large shortages at the cost of having more frequent small shortages. A hedging rule is therefore, economically optional if the loss and damage functions associated with the proposed water uses are convex in shortage quantities, i.e., when severe deficit causes proportionately more damages than that by mild deficits (Shih and ReVelle 1994).

6.4.2 Continuous hedging rules (CHR)

The CHR suggests that demand and subsequent release should be manipulated (rationed) to decline gradually as the reservoir contents and the projected inflow fall (Fig. 6.3 b). Shih and ReVelle (1994) suggested a model in which the demand was assumed to be same for the entire horizon of operations. The demand reduction/operation rule, shown in Fig. 6.3 b (line OA), uses a gradually declining draft (R_t^h), which is estimated by dividing (St-1+It) by the hedging trigger value (Kpt). In this case, the level of (St-1+It) at which the rationing starts and the portion of water demand to be met are determined at the same time by knowledge of Kpt assigned to each month t. Rationing is begun when (St-1+It) is less than the demand by Kpt times. Otherwise, full demand can be drafted from the reservoir. Obviously, when the trigger value is larger, the value of the maximum shortfall will be shorter. But more frequently rationing will be necessary. The trigger values may be arbitrarily set or can be decision variables in an optimization model.

6.4.3 Discrete hedging rules (DHR)

The DHR is more practical in the sense that the water managers do not usually have a continuous gradation of options, whereas rationing happens in discrete steps. For a specific month t in the DHR model (Fig. 3c), if (St-1+It) is greater than V1t, then the expected demand can be drafted from reservoir fully without recourse to rationing. If (St-1+It) is greater than V2t but less than V1t, then phase-1 rationing will be initiated for the coming month t, and demand will be reduced to only fraction $\alpha 1$ of the usual demand. If (St-1+It) is less than V2t but greater than V3t, phase -2 rationing will be initiated. That is, demand will be reduced to only $\alpha 2$ times the usual demand. In this model, it is assumed that minimum trigger volume will always be maintained in reservoir. The trigger-volumes depend on hydrology of inflows and water savings that result from various demand reduction measures. Shih and ReVelle (1995) tried to convert the CHR into the DHR. In fact, rationing was declared in discrete steps to find trigger volumes that transformed the CHR into the DHR as accurately as possible. They assumed a two-phase rationing in the DHR with $\alpha 1$ and $\alpha 2$ fractions, which are fractions of the actual demand to be delivered for phase-1 and phase-2, respectively. In this solution, V3t is known, but V1t and V2t are unknown. Their statement can be re-written as:

$$V1t = Kpt \,.\, Dt \,.\, \lambda \forall t \quad (6.8)$$

where Kpt is the monthly trigger value obtained using mathematical programming, Dt is demand and λ is phase-1 hedging trigger volume factor with its value 1.0 in Shih and ReVelle (1994).

The minimum storage volumes for each month, V3t, are known. These are defined as lower levels of allowable storage plus the inflows. In addition to this, the values of $\alpha 1$ and $\alpha 2$ should be known. To estimate V2t (Fig. 3c), they formulated a simple optimization problem of minimizing the geometric differences between the CHR and the DHR. The problem was to minimize Z= 0.5 (ax + by); and they obtained that:

$$V2t = \mu\, (\alpha 1 + \alpha 2)\, V1t \qquad \forall t \quad (6.9)$$

where $\mu = 0.5$ is the phase-2 hedging trigger volume factor in Shih and ReVelle (1994).

6.4.4 Application of continuous hedging rules

In the present study, it is tried to utilize the results of optimization models to estimate Kpt values related to CHR. These Kpt values are used later as an initial guess for the simulation work to find the set of monthly Kpt values which will provide the best reservoir operation performance.

For this, using the within year time period model results the Kpt values can be written for each month as:

$$Kpt = (\text{Initial reservoir storage} + \text{Inflow}) / (\text{Release} + \text{Evaporation}) \quad (6.10)$$

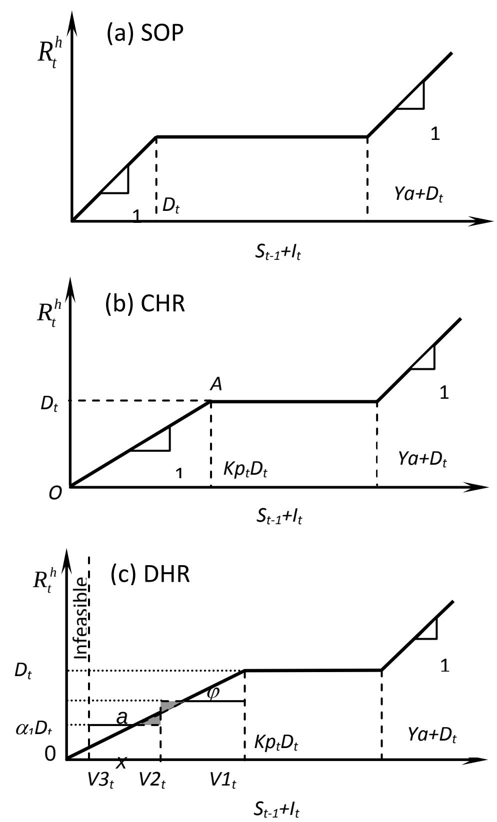


Fig. 6.3 Different reservoir operating policies

Chapter 7

ESTIMATION OF THE MODEL PARAMETERS

7.1 INTRODUCTION

For evaluation of a model, the estimation of relevant parameters is of utmost importance. The parameters involved in the model can be broadly divided in to four sets. The first one deals with the physical configuration of the system, mostly man made, depicting the arrangements made to harness the water resources represented through a physically constraining environment of catchment areas, reservoirs, hydropower plants, diversions, irrigation commands, networks of canals and water transfer links. The basic parameters involved in this case are the reservoir capacity, storage-area-evaporation relationship, spillway capacity, the command area characteristics, hydro plant capacity, configuration of the canal network, canal capacity and so on. The second set of parameters deals with the supply aspects impinging on the physical set up and dwelling on the estimation of water resources like surface flow, ground water flow, regenerated flow, imports and transfers received, upstream contributions. The third set of parameters is concerned with the demand aspects that draw from the physical resources. They are concerned with the targeted demand aspects like irrigation demand, domestic and industrial demands, hydropower demands, mandatory and environmental demands, export and transfer demands etc. The fourth set of parameters deal with the restrictions that have come with developments. They are subtle and are socio-politico-judicial in nature. The national boundary, the state boundary, tribunal orders in respect of the trans-boundary river systems, judicial interventions, constitutional provisions, submergence, rehabilitation, resettlement etc. constitute a constraining environment which has to be taken care of in order to make the model realistic. The classification of the parameters made here however are not to imply their not being inter dependent of each other but to facilitate better appreciation of the processes associated with systems analysis.

7.1.1 Collection, Compilation and Processing of Data

In any large water resource system, one of the foremost challenges lies in collection of data. In a country of near federal structure where water is a state subject, it is always difficult to get all the relevant data of basins. Nevertheless, all attempts have been made to source the data from authentic places. However, still in the face of non-availability of data, assumptions and approximations are made or data of some nearby locality with comparable characteristics are adopted. For the purpose of analysis in the present study, most of the basic data are taken from Central Water Commission, Water Resources Department Government of Madhya Pradesh, Water Resources Department Government of Uttar Pradesh, Preliminary water balance study reports of ken and Betwa river basins prepared by National Water Development Agency (NWDA), websites of NWDA, Government of Madhya Pradesh and Government of Uttar Pradesh.

7.2 ESTIMATION OF BASIC DATA AND PARAMETERS FOR PLANNING

7.2.1 Inflow Data

In absence of inflow data available at project sites, 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 gauge-discharge sites in the Ken and Betwa basin. For the study 20 years (1980-81 to 1999-2000) inflow data have been adopted being the common period. Inflow of Daudhan reservoir has been calculated from the inflow data of Banda gauging site. For Betwa basin inflow data of gauge-discharge site at Basoda, Rajghat and Mohana have been adopted. The virgin flow at any gauged site is calculated as (Wurbs 2005, Wurbs 1996):

$$\text{Virgin flow at gauged site} = \begin{pmatrix} \textit{Dischrge measured at gauged site} + \textit{utilization from upstream projects} + \\ \textit{evaporation losses at upstream projects} + \textit{storage effect at upstream projects} + \\ \textit{export from upstream projects if any} - \textit{regeneration from upstream projects} - \\ \textit{regeneration from import on the upstream if any} \end{pmatrix}$$

Then the virgin flow at any ungauged site can be computed on the basis of proportionate area as (Loucks 1981, Wurbs 1996):

$$\textit{Virgin flow at ungauged site} = \frac{\textit{catchment area at ungauged site}}{\textit{catchment area at gauged site}} \times \textit{Virgin flow at gauged site}$$

In absence of utilization data of projects for a certain period, average of available utilization data have been considered. Evaporation losses are considered as 20 percent of annual utilization from a project, if not available.

7.2.2 Upstream Abstractions in Minor Irrigation Projects

As follows from the preceding discussion, the utilizations of water in the upstream of the project head are essential in combination with evaporation loss, storage effect and export data. Referring to the upstream utilization of the projects, the data are available for the major and medium projects. Regarding minor irrigation projects, their locations and utilizations are also fairly known. Thus wherever data are available regarding utilizations, the time wise utilizations are deducted directly from the virgin inflow. However, the locations and utilizations of the minor projects in the upstream of projects are mostly not known in details. 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 medium project is arrived at.

Regeneration from irrigation is considered as 10 percent of the gross utilization for irrigation, 80 percent of municipal water supply of drawl and 97.5 percent of industrial use.

7.2.2.1 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 yield model 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).

7.2.2.2 Consideration of independent failure years instead of a common set of failure years

Background:

In reference to multisite problems, as stated by Loucks et al. (1981), "A special requirement, however, is that the failure year or years must be the same at all allocation sites throughout the basin. For basins having multiple gauge sites, the identification of failure years may be difficult, especially if the annual flows at different sites are not highly, and positively cross-correlated." In this connection, it is pertinent to reproduce below the inference drawn by Dahe (2001) from a study carried out on Narmada basin, India.

The reason for the requirement of same failure years throughout the basin seems to be embodied in the second sentence of above stated statement by Loucks et al. (1981), i.e., the difficulty in identification of failure years. However, if the difficulty in identifying the failure years can be overcome, it appears more appropriate to maintain the failure years as per the actual nature of flows at different sites. Another aspect that needs attention in this respect is that the number of failure years must be the same at all sites to maintain the same desired reliability throughout the basin.

Following points should be sufficient to provide a detailed account of the justification for maintaining the independent failure years at each site, instead of assuming identical (common set of failure years) failure years throughout the basin in a multiple reservoir system:

1. Assuming the same failure years at all the sites in a yield model may lead to an incorrect estimation of the reservoir yield at some or all reservoir sites and is thereby likely to affect the reservoir yield estimation for the system as a whole.

2. The LP deterministic models are widely used in practice based on monthly average flows or monthly flows of some predefined annual dependability. In case of use of these models for multiple reservoir systems, the following points are noteworthy:
   (i) When predefined annual flow dependability is 50 percent, the monthly average flows are used. However the corresponding annual flow is assumed to be the 50 percent water year dependable flow. Its dependability is not usually found out, and which is also not likely to be the same at all the reservoir sites.
   (ii) When monthly flows, e.g., with 75 percent annual dependability are considered, the 75 percent dependable water years are also not the same at each site.
3. The supremacy of simulation models in accurately predicting system behavior and their close representation of the actual system is undoubtedly well established. In a multiple reservoir situation the failure years are actually are not similar at different reservoir sites. A simulation model retains the original flow characteristics in the system, and the failure years if verified after the simulation will not be the same as per the assumed common set of failure years at all sites for a given reliability. Thus it seems more logical and in accordance with the actual behavior of the system, to retain the failure years as per their natural occurrences.
4. If it is possible to explicitly identify different failure years in a yield model, it shall have a close resemblance with a simulation results. The over-year continuity will then be more correctly maintained in a yield 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).

Hence it is felt that, “The failure years if possible should be explicitly determined in a yield model so that a multiple reservoir problem can be formulated without any restriction on maintaining the same failure years at all the sites throughout the basin.” This provides a better representation of the actual behavior of system and leads to a correct estimation of the system reservoir yield than in the case wherein the failure years are maintained same at all the sites.

Panigrahi (2006) modified multiple yield model for multireservoir system (Dahe 2001) as available in literature to suit the problem and applied to the system of 42 reservoirs in Mahanadi river basin in Odisha State, India, to find out the effect of considering independent failure years. Then the results so obtained were compared with the simulated result using two indices, namely; mean square error (MSE) and Nash-Sutcliffe model efficiency. It was concluded that adoption of site-specific failure years can produce better results in comparison to a common set of failure years at all the reservoirs in a large basin.

Therefore, independent failure years at each project are identified by applying Weibull's plotting position formula to the respective water year net inflow series and are considered in this study as 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 (Panigrahi 2006).

7.2.2.3 Selection of Criterion for Estimation of the Values of Parameter β_t

As described in section 5.5.1, the parameter β_t is required for the within-year continuity equation of the yield model. Within-year continuity equation estimates the within-year storage capacity required incase the distribution of within-year yields differs from the distribution of within-year inflows. In the yield model, the within-year continuity equation is written for the within-year time periods of one year only (the modeled critical year) to reduce the number of equations and thus the size of the model. Formulation of this equation is made with an assumption that the total inflow to the reservoir in a critical year is equal to the total yield that would be released from the reservoir in the said year. Logic behind adopting such an assumption is to keep the inflow and the required releases in balance, so that the reservoir neither fills nor empties during the modeled critical year. This is similar to what generally occurs at the end of a drawdown period (Loucks et al. 1981). Further, it is assumed that, the inflow in a within-year time period t of the modeled critical year is equal to β_t times the total storage lost from a reservoir in that year. So, in case of a critical year where there is no spill (as per assumption), this total storage loss occurs only from the yield to be released and the evaporation losses. The parameter β_t reflects the relative proportion of the critical year's inflow that is likely to occur in within-year period t.

Thus selection of criterion for estimation of the values of the parameter β_t is an important aspect of yield model as it has got the following implications:

1. If the distribution is acute, i.e., low inflows in periods of high demands; the within-year storage requirements are higher for a given reservoir capacity. This will lead to

a conservative reservoir design, or a low estimate of annual reservoir yield for a given capacity.

2. If the distribution closely follows the required proportion of yields, the within-year storage requirements shall be low.

The choice of these within-year flows (the values of parameter β_t) will primarily determine the reliability of the identified designs (Dahe 2001).

After carrying out studies with the values of parameter β_t derived from different criterion, Loucks et al. (1981) concluded that, use of β_t based on the driest year of record provides as reasonable estimate of the future storage requirements as does the complete and larger optimization model.

Simulation studies 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. Fortunately, this situation is not commonly encountered in practice, since demands for water generally increase during periods of low natural flows (Loucks et al. 1981).

Stedinger et al. (1983) compared the results of yield model with simulation for a hypothetical three-reservoir water supply system. They tried with β_t values based on: (i) average monthly flows; (ii) on the driest year of record and finally adopted the β_t values based on the average of within-year inflows in the driest and fifth driest years of record. They stated that, "A conservative choice is to select the within-year flows corresponding to the driest year of record. Modifications of the modeled within-year inflows or of the β_t 's, in the light of simulation experience, can provide system designs that more nearly meet desired release reliability targets in a cost efficient manner".

Dandy et al. (1997) conducted a study on methods for yield assessment of multiple reservoir systems. They evaluated the yield model with β_t values for the driest and the second driest year. They pointed out that though the second driest year following the driest year appeared to be the critical year from their previous results, the value of system annual reservoir yield that is closest to that obtained with full (complete) optimization model is given by the β_t

values of the driest year. Therefore, β_t 's based on inflows of the driest year of record have been considered in this study. The monthly β_t values for each reservoir are presented in table 7.25.

7.2.2.4 Allowable percentage yield during failure years

In India, irrigation projects are being planned to provide 75 percent dependable reservoir yield on an annual basis. Though 75 percent project dependability in terms of meeting the target annual demand is considered, the extent of yield failure during the failure years is not taken into account. As the significance (extent) of failure is not taken into account in counting a failure year, an occurrence of 95 percent deficit in the target annual demand gets an equal weightage to an occurrence of 5 percent deficit in the target annual demand. This seems inappropriate as a 5 percent deficit (95 percent availability) is very meager indicating low risk and can be treated as a successful year, whereas a 95 percent deficit (5 percent availability) can lead to a catastrophic failure having a long lasting effect.

When the extent of failure in annual reservoir yield (or allowable deficit in annual yield) during failure years is not taken into account in irrigation planning, the estimate of annual yield from a reservoir shall obviously be on the conservative side. This can help in justifying the feasibility of an irrigation project, but there is an associated risk 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. However, during planning if a provision for some proportion of the planned design annual reservoir yield to be made available during failure years can be defined, a 'risk aversion' as well as 'preparedness' against the yield failure for the agricultural activity can be incorporated. The obvious effect of this provision shall be to reduce the planned design annual yield from the reservoir. However, it is always better to know the extent of yield failure rather than to face unexpected severe failures.

In order to safeguard against an unacceptable risk of extreme shortages during critical years, additional reliability criteria need to be identified. These criteria are needed in order to minimize the risk associated with failures. Quantifying these criteria and incorporating them into planning models may result in improved designs and operating policies. Hence, it is felt that the irrigation planning criteria should include the provision for some proportion of design annual reservoir yield to be made available during the failure years. The design annual reservoir yield and a proportion of it to be made available from a reservoir during the failure years are referred by the nomenclature “annual reservoir yield” and “allowable percentage yield”.

Such a provision seems necessary to minimize the impact of severe failures during low flow years. For this some minimum assured annual irrigation supply is necessary to the farmer particularly after he has closed the option for unirrigated crops. Otherwise, it can cause the farmer considerable distress in terms of wasted inputs and labor on one hand and loss of an opportunity of more reliable unirrigated sustenance output on the other hand. Apart from this, the effect of such catastrophic failures gets carried over to subsequent years. The estimate of design annual reservoir yield without considering the allowable percentage yield shall always be on the conservative side as the extent of failure is not restricted. This can many a times lead to very severe failures during some of the failure years having low flows 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.

7.2.2.5 Criteria for deciding the percentage of annual yield to be made available during failure years

The incorporation of allowable percentage yield for failure years seems essential, yet assessment of its value needs consideration, as this will cause 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.

Dahe (2001) adopted same value of allowable percentage yield (derived from criterion of minimum food requirements of the agricultural population) for all the projects as considered in his study while Panigrahi (2006) considered different values of allowable percentage yield at each project satisfying the project specific demands as far as possible in successful years. It was felt more appropriate to consider different values of allowable percentage yield at each project satisfying the project specific demands as far as possible in successful years.

7.2.2.6 Reliability of different yields and water uses

Applying Weibull's plotting position formula, maximum possible reliability of the firm yield (*p*) considering the available 28 years inflow data (with no failure years) works out to be 97 percent. Similarly, allowing 7 failure years, the reliability of the secondary yield (*p2*) becomes 76 percent.

According to the National Water Policy the priorities of water use should be: (i) Drinking water, (ii) Irrigation, (iii) Hydropower, and (iv) Industrial and other uses. However, 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, against the specified target annual reliabilities for water supply, irrigation and hydropower generation (firm) of 100 percent, 75 percent and 90 percent, 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.

7.3 DEMAND PARAMETERS AND THEIR ESTIMATION

The demand parameters are the third set of parameters which are important from the model point of view. After the physical configurations provide the infrastructure for the model and after water resources has been estimated, it is time for estimation of demands to be made. In Indian context, which is more or less similar worldwide, the demands come from water use sectors like agriculture, drinking water and municipal uses, industrial uses, environmental uses. The demands connected with the infrastructure, like evaporation have already been discussed earlier. Agriculture remains the largest drawee and consumer of water resources in India unlike many developed countries where industry draws more water but agriculture remains the main consumer. In order to evaluate the demands, it is very important to know the populations likely to be dependent on the water resources of a particular area. Since, the population is a dynamic entity, it is also important to project population to a fixed planning horizon to estimate various demands associated with their direct and indirect consumption.

7.3.1 Planning Horizon

The planning horizon has been kept at 2050 AD as per the recommendation of the working group on inter basin transfer of water. There are two reasons for this. The first one is that during the period up to 2050 AD, we can expect considerable improvements in present technology of agricultural production, but radical breakthroughs (e.g., through genetic engineering, atomic fusion energy) for wide adoption in practice are improbable. Secondly, it is expected that the population to more or less stabilize by the year 2050AD. Furthermore extrapolating from the available data, it has been estimated that about 40% of the total population will live in urban areas.

7.3.2 Population and Domestic Water Needs

It is expected that population of India will hopefully stabilize by 2050 AD. Therefore the requirements of water for domestic use in the rural and urban areas and for live stock population of the basins have been calculated by projecting the rural, urban and live stock populations to 2050 AD. The per capita daily water requirement for the urban and rural population are taken as 135 litres and 70 litres respectively as per the norms prescribed by the Union Ministry of Urban Development, New Delhi in the 'Manual on Water supply and Treatment' (May 1999). The per capita daily water requirement for the livestock population has been assumed as 50 litres. The available district-wise census data for the year 2001 are used for human population forecasting. This population was projected for the year 2050 AD on the basis of medium variant growth rate as given in U.N. Publication 'World Population Prospects – 2004 revision'. The sub-basin population has been estimated on proportionate area basis from district population. The total projected human population has been divided into urban and rural as 66% and 34%, respectively, as considered by the NWDA. The formula used for population projection as

Provided in above referred U.N. publication is of the form

$$P_{t2} = P_{t1} * \exp\left[\frac{r}{100}(t_2 - t_1)\right]$$

Where, P_{t2} = Population at time t_2 and P_{t1} = Population at time t_1

r = population growth rate (%) between time t_2 and t_1

Population growth rate is the average exponential rate of growth of population over a given period. For India, the medium variant population growth rate as given in U.N. Publication 'World Population Prospects – 2004 revision' is presented in Table 7.1.

Population details of year 2001, projected population in year 2050 AD and the human water demand in year 2050 AD for different districts falling in the sub-basin are presented in Table 7.2. The total human population of 48,00,405 of the sub-basin in the year 2050 AD will need 198 MCM of water for domestic purposes.

The livestock population is calculated considering a growth rate of 1% as considered by NWDA. The live stock populations for the years 2004-2005 as provided in 'Tables of Agricultural Statistics of Madhya Pradesh 2004-2005' are used for live stock population forecasting in the year 2050 AD. The livestock population and water demand in the year 2050 AD is estimated as 34,41,819 and 63 MCM, respectively, as detailed in Table 7.3. The total domestic water needs of the urban, rural and livestock population works out to 261 MCM. Whole requirement for livestock and 50% of the water requirement for the rural population are proposed to be met from ground water resources. The ground water requirement works out to be 84 MCM. The whole requirement for urban population and 50% of the requirement for rural population are proposed to be met from surface water resources. The surface water requirement in this case works out to 177 MCM.

Table 7.1 Medium variant population growth rate (%) for India (World population prospects-2004 revision)

Period	2000-05	2005-10	2010-15	2015-20	2020-25	2025-30	2020-35	2035-40	2040-45	2045-50
Growth rate	1.55	1.4	1.26	1.11	0.93	0.75	0.61	0.53	0.43	0.32

Table 7.2 Projected human population and water requirement by the year 2050 AD

Sr.No.	District	Human population		Water demand in 2050 (MCM)		
		2001	2050	Urban	Rural	Total
1	Chattarpur	2,66,524	4,09,307	13.31	3.56	16.87
2	Damoh	10,23,720	15,72,149	51.13	13.66	64.79
3	Katni	2,25,095	3,45,683	11.24	3.00	14.25
4	Narsingpur	27,593	42,375	1.38	0.37	1.75
5	Panna	6,19,335	9,51,126	30.93	8.26	39.19
6	Raisen	35,462	54,459	1.77	0.47	2.24
7	Sagar	8,88,115	13,63,896	44.36	11.85	56.2
8	Satna	39,987	61,409	2.00	0.53	2.53
Daudhan Sub-basin		31,25,831	48,00,405	156.12	41.7	197.82

Table 7.3 Projected livestock population and water requirement by the year 2050 AD

Sr.No.	District	Livestock population		Water demand in 2050 (MCM)
		2001	2050	
1	Chattarpur	2,08,759	3,29,935	6.02
2	Damoh	5,83,137	9,21,624	16.82
3	Katni	1,26,961	2,00,657	3.66
4	Narsingpur	12,898	20,385	0.37
5	Panna	8,38,104	13,24,589	24.17
6	Raisen	20,474	32,358	0.59
7	Sagar	3,64,139	5,75,507	10.5
8	Satna	23,261	36,764	0.67
Daudhan Sub-basin		21,77,734	34,41,819	62.81

7.3.3 Agriculture Water Demand

Agriculture in India is the largest consumer of water in the world. It is therefore imperative that the water demands of the crops are found out and are superimposed on the system to get the best out of it. As regards to the crop demands, they have been calculated on the basis of the original crop plan adopted for the different projects by the project implementation authorities. Where the data are not available, particularly in the case of contemplated projects, the crop plan of nearby projects or those proposed by NWDA is adopted. Broadly in all the peninsular basins coming under the study areas of the thesis, the crops are produced in four categories like kharif, rabi, hot weather and perennial. Further, the irrigation intensities of different projects are different. While the same are available with respect of the existing projects, NWDA norms are followed in case of the proposed projects. Irrigation intensity is kept as 1.50 for major and 1.25 for medium projects.

7.3.4 Municipal and Drinking Water Demand

Total annual municipal water requirement for a project is calculated for the future scenario, i.e., to cater to the needs of the population projected for the year 2050. It is assumed that full requirement of urban population and 50 percent of rural population will be met from surface water sources and 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 liters and 70 liters, respectively and the same demand is distributed equally in all within-year time periods. For livestock population, requirement of 50 liters per capita is taken in the absence of standard norms.

7.4 ESTIMATION OF CROP WATER REQUIREMENT

For the purpose of this study, within-year time period wise (monthly) crop water requirements of each crop under each project are required. Since data in the required form was not available, it 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. The computation of crop water requirements are presented in Chapter 4.

7.4.1 Other Crop Related Data

Crop produce (yield), gross income (market price), protein and calorie contents of different crops as obtained from different reports (Agricultural statistics at a glance 2004, Ghei and Ghei 1973, Thapar 1981, and Panigrahi 2006) are taken in the calculations.

7.5 ESTIMATION OF NUTRITIONAL REQUIREMENT OF THE PROJECTED POPULATION

In a foreseeable future any development planning should take care of at least the minimum nutritional requirement of its population. Hence, nutritional requirement of the projected population of the study area has been computed by the following two approaches.

(i) As per the suggested standard nutritional (protein and calorie) requirement per capita per day for different age groups of male and female person by weighted average method.

(ii) As per the comprehensive per capita per day nutritional requirement.

Finally, the approach which gives higher nutritional requirement is accepted and the corresponding result is considered for further analysis.

(i) Nutritional requirements by weighted average method (per capita per day)

This approach may be considered as a summary or a macro approach for computing the weighted average nutritional requirement for a healthy person. The daily dietary allowances of protein and calorie for male and female in different age groups are obtained from Ghei and Ghei (1973) and Thapar (1981). The daily dietary allowances are shown in Table 7.4.

Table 7.4 Daily dietary allowances

Age group	Requirement of male		Requirement of female	
	Proteins (grams)	Calories (calorie units)	Proteins (grams)	Calories (calorie units)
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, 1981-2001 (Dahe 2001) and shown in Table 7.5 is used for the present analysis.

Table 7.5 Population projection in India in terms of age group and sex

Age group	Male (%)	Female (%)
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 protein and calorie for male and female are worked out separately by using the weighted average method. The male female ratio is used to obtain the weighted average of protein and calorie requirement on a per capita per day basis. The distribution between male and female in the study area of the census figures of 2001 on percentage basis is 52.11 percent and 47.89 percent, respectively. Using the above data, weighted average nutritional requirement for male and female person is computed first and then for the whole population is obtained. Details of such computations are given below along with Table 7.6.

Table 7.6 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)
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

Combined weighted average protein requirement per capita per day for the whole population shall be:

$$= \frac{(52.11 \times 63.78) + (47.89 \times 58.83)}{100}$$

$$= 61.409\, gms / day / person$$

Similarly, combined weighted average calorie requirement per capita per day for the whole population shall be:

$$= \frac{(52.11 \times 2524.90) + (47.89 \times 2003.17)}{100}$$

$$= 2275.04\ calorie\ units / day / person$$

(ii) Comprehensive per capita per day nutritional requirement

The protein and calorie content associated with the different crops has been considered as an index for the nutritious diet. Some crops which are popularly consumed in the study area are considered, two additional items, *viz*., milk and poultry/meat are also considered and the per capita per day nutritional requirement for an average person are determined. Details of each item, quantity required per capita per day, their nutritional contents, and computed values of nutritional contribution by each item for the stipulated quantity is given in Table 7.7.

Table 7.7 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	Paddy	75	3460	0.20	15.0	692.0
2	Wheat	121	3410	0.20	24.2	682.0
3	Other cereals	104	3490	0.05	5.2	174.5
4	Pulses	245	3480	0.05	12.25	174.0
5	Oil seeds	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

Nutritional requirement per capita per day to be met exclusively from crop produces comes to 82.40 grams (=102.90 - 7.5 - 13.0) of protein and 2215 (=2657.5 – 292.5 – 150.0) units of calorie.

Now, adopting the highest value from the above two approaches, annual protein and calorie requirement of the projected population for study area worked out to 1.4437 lakh ton and 33.81×10^{11} calorie unit, respectively.

7.6 EVAPORATION PARAMETERS

Average monthly evaporation depth for individual project is not available. But station wise and month wise details of evaporation are obtained from different reports (GOM 1999, NWDA reports). Evaporation of a reservoir is computed by multiplying pan evaporation data of a nearby station with pan coefficient considered as 0.7 in this study.

The average monthly evaporation data at all the reservoirs have been obtained from different NWDA reports. The evaporation volume loss due to dead storage (EV^0) has been obtained by the product of the average annual evaporation depth and the area at dead storage elevation for respective reservoirs. A linear fit for the storage-area data for each reservoir above the dead storage has been obtained from the storage area relationships. The evaporation volume loss rate (EV^a) is obtained by taking the product of the slope of the storage-area curve linearized above dead storage and the average annual evaporation depth at respective reservoirs. The parameter γ_t (the fraction of the annual evaporation volume loss that occurs in within-year period t) has been computed by taking the ratio of the monthly reservoir evaporation loss, wherever available. In case of non-availability of evaporation data, the ratio of the average monthly evaporation depth to the average annual evaporation depth at nearby reservoirs or observatory data has been utilised. The fraction of annual evaporation volume loss that occurs in a within-year time period *t* (monthly) denoted as γ_t is computed by taking the ratio of mean monthly depth of evaporation to the average annual depth of evaporation. This has been calculated for each of the reservoirs using the available evaporation data. The monthly γ_t value for each

Reservoir is presented in Table 7.26.

Table 7.8 Annual water requirement for Daudhan reservoir to meet the min. food requirements of Agriculture population (2011)

					Ken command		Enroute command	
Sl. No.	Crop	Crop produce required per capita per day	Yield of crop	GIR of crop	Crop area to meet min. food requirements	Water requirements of crop	Crop area to meet min. food requirements	Water requirements of crop
		(Quintal)	(Qtl / Ha)	(m)	(Ha)	(MCM)	(Ha)	(MCM)
1	Paddy	0.0015	10.32	0.63	29657.36	186.84	5783.80	36.44
2	Jowar	0.00075	8.95	0.09	17098.55	15.22	3334.57	2.97
3	Maize	0.00075	14.50	0.18	10553.93	19.21	2058.24	3.75
4	Groundnut	0.0006	9.61	0.18	12739.40	23.31	2484.45	4.55
5	Vegetables (K)	0.0025	100.00	0.06	5101.07	3.21	994.81	0.63
6	Wheat (HYV)	0.00095	25.10	0.56	7722.73	43.25	1506.09	8.43
7	Wheat (Local)	0.00095	16.73	0.44	11586.40	50.98	2259.59	9.94
8	Gram	0.0012	8.70	0.52	28143.82	146.35	5488.63	28.54
9	Pulses	0.0011	7.18	0.34	31260.02	104.72	6096.35	20.42
10	Vegetables(R)	0.0025	120.00	0.43	4250.89	18.24	829.01	3.56
	Total				158114.16	611.33	30835.54	119.22

Table 7.9 Aannual water requirement for Daudhan reservoir to meet the min. food requirements of Agriculture population in 2050

					Ken command		Enroute command	
Sl. No.	Crop	Crop produce required per capita per day	Yield of crop	GIR of crop	Crop area to meet min. food requirements	Water requirements of crop	Crop area to meet min. food requirements	Water requirements of crop
		(Quintal)	(Qtl / Ha)	(m)	(Ha)	(MCM)	(Ha)	(MCM)
1	Paddy	0.0015	10.32	0.63	39409.07	248.28	7685.59	48.42
2	Jowar	0.00075	8.95	0.09	22720.76	20.22	4431.02	3.94
3	Maize	0.00075	14.50	0.18	14024.19	25.52	2735.01	4.98
4	Groundnut	0.0006	9.61	0.18	16928.27	30.98	3301.36	6.04
5	Vegetables (K)	0.0025	100.00	0.06	6778.36	4.27	1321.92	0.83
6	Wheat (HYV)	0.00095	25.10	0.56	10262.06	57.47	2001.31	11.21
7	Wheat (Local)	0.00095	16.73	0.44	15396.16	67.74	3002.57	13.21
8	Gram	0.0012	8.70	0.52	37397.85	194.47	7293.36	37.93
9	Pulses	0.0011	7.18	0.34	41538.70	139.15	8100.91	27.14
10	Vegetables(R)	0.0025	120.00	0.43	5648.63	24.23	1101.60	4.73
	Total				210104.05	812.34	40974.65	158.42

Table 7.10 Annual water requirement for Kerwan to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	497.52	4.43	661.19	5.88
2	Jowar	286.84	0.21	381.20	0.28
3	Maize	177.05	0.13	235.29	0.17
4	Groundnut	213.71	0.43	284.02	0.57
5	Vegetables (K)	85.57	0.07	113.72	0.09
6	Wheat (Local)	388.74	1.94	516.62	2.58
7	Gram	472.13	2.81	627.45	3.73
8	Pulses	524.41	0.74	696.92	0.98
9	Vegetables(R)	71.31	0.36	94.77	0.47
	Total	2717.30	11.11	3611.19	14.77

Table 7.11 Annual water requirement for Kaliasote to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	564.00	5.02	749.58	6.67
2	Jowar	325.17	0.24	432.16	0.32
3	Maize	200.71	0.15	266.75	0.20
4	Groundnut	242.27	0.48	321.98	0.64
5	Vegetables (K)	97.01	0.08	128.93	0.10
6	Wheat (Local)	440.68	2.20	585.68	2.93
7	Gram	535.22	3.18	711.32	4.23
8	Pulses	594.48	0.84	790.08	1.11
9	Vegetables(R)	80.84	0.40	107.44	0.54
	Total	3080.36	12.60	4093.92	16.74

Table 7.12 Annual water requirement for Neemkheda to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	129.45	1.15	172.05	1.53
2	Jowar	74.63	0.06	99.19	0.07
3	Maize	46.07	0.03	61.23	0.05
4	Groundnut	55.60	0.11	73.90	0.15
5	Vegetables (K)	22.27	0.02	29.59	0.02
6	Wheat (Local)	101.14	0.51	134.43	0.67
7	Gram	122.84	0.73	163.27	0.97
8	Pulses	136.44	0.19	181.35	0.26
9	Vegetables(R)	18.55	0.09	24.66	0.12
	Total	707.00	2.89	939.67	3.84

Table 7.13 Annual water requirement for Richhan to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	147.54	1.31	196.03	1.74
2	Jowar	85.06	0.06	113.02	0.08
3	Maize	52.50	0.04	69.76	0.05
4	Groundnut	63.38	0.13	84.20	0.17
5	Vegetables (K)	25.38	0.02	33.72	0.03
6	Wheat (Local)	115.28	0.58	153.17	0.77
7	Gram	140.01	0.83	186.02	1.11
8	Pulses	155.51	0.22	206.62	0.29
9	Vegetables(R)	21.15	0.11	28.10	0.14
	Total	805.80	3.30	1070.64	4.38

Table 7.14 Annual water requirement for Halali to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	4626.96	41.18	6149.08	54.73
2	Jowar	2667.61	1.97	3545.17	2.62
3	Maize	1646.56	1.22	2188.23	1.62
4	Groundnut	1987.52	3.96	2641.35	5.26
5	Vegetables (K)	795.84	0.64	1057.64	0.86
6	Wheat (Local)	3615.28	18.08	4804.59	24.02
7	Gram	4390.82	26.13	5835.27	34.72
8	Pulses	4876.99	6.88	6481.37	9.14
9	Vegetables(R)	663.20	3.30	881.37	4.39
	Total	25270.78	103.35	33584.07	137.35

Table 7.15 Annual water requirement for Barari to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	4040.94	35.96	5370.22	47.79
2	Jowar	2329.75	1.72	3096.13	2.29
3	Maize	1438.02	1.06	1911.06	1.41
4	Groundnut	1735.80	3.45	2306.79	4.59
5	Vegetables (K)	695.04	0.56	923.68	0.75
6	Wheat (Local)	3157.39	15.79	4196.03	20.98
7	Gram	3834.72	22.82	5096.16	30.32
8	Pulses	4259.31	6.01	5660.42	7.98
9	Vegetables(R)	579.20	2.88	769.73	3.83
	Total	22070.17	90.26	29330.22	119.96

Table 7.16 Annual water requirement for Kesari to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	226.22	2.01	300.59	2.68
2	Jowar	130.42	0.10	173.30	0.13
3	Maize	80.50	0.06	106.97	0.08
4	Groundnut	97.17	0.19	129.12	0.26
5	Vegetables (K)	38.91	0.03	51.70	0.04
6	Wheat (Local)	176.75	0.88	234.87	1.17
7	Gram	214.67	1.28	285.25	1.70
8	Pulses	238.44	0.34	316.84	0.45
9	Vegetables(R)	32.42	0.16	43.09	0.21
	Total	1235.51	5.05	1641.74	6.71

Table 7.17 Annual water requirement for Kethan to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	310.52	2.76	412.69	3.67
2	Jowar	179.02	0.13	237.93	0.18
3	Maize	110.50	0.08	146.86	0.11
4	Groundnut	133.38	0.27	177.27	0.35
5	Vegetables (K)	53.41	0.04	70.98	0.06
6	Wheat (Local)	242.62	1.21	322.46	1.61
7	Gram	294.67	1.75	391.63	2.33
8	Pulses	327.30	0.46	435.00	0.61
9	Vegetables(R)	44.51	0.22	59.15	0.29
	Total	1695.92	6.94	2253.99	9.22

Table 7.18 Annual water requirement for Koncha to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	462.88	4.12	615.14	5.47
2	Jowar	266.87	0.20	354.65	0.26
3	Maize	164.72	0.12	218.91	0.16
4	Groundnut	198.83	0.40	264.24	0.53
5	Vegetables (K)	79.62	0.06	105.80	0.09
6	Wheat (Local)	361.67	1.81	480.64	2.40
7	Gram	439.26	2.61	583.75	3.47
8	Pulses	487.90	0.69	648.38	0.91
9	Vegetables(R)	66.35	0.33	88.17	0.44
	Total	2528.09	10.339	3359.68	13.741

Table 7.19 Annual water requirement for Mola to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	295.02	2.63	392.11	3.49
2	Jowar	170.09	0.13	226.07	0.17
3	Maize	104.99	0.08	139.54	0.10
4	Groundnut	126.73	0.25	168.43	0.34
5	Vegetables (K)	50.74	0.04	67.44	0.05
6	Wheat (Local)	230.52	1.15	306.38	1.53
7	Gram	279.97	1.67	372.10	2.21
8	Pulses	310.97	0.44	413.30	0.58
9	Vegetables(R)	42.29	0.21	56.20	0.28
	Total	1611.31	6.59	2141.56	8.76

Table 7.20 Annual water requirement for Rajghat to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	21318.07	189.73	28330.95	252.15
2	Jowar	12290.64	9.10	16333.82	12.09
3	Maize	7586.29	5.61	10081.91	7.46
4	Groundnut	9157.23	18.22	12169.63	24.22
5	Vegetables (K)	3666.71	2.97	4872.92	3.95
6	Wheat (Local)	16656.89	83.28	22136.41	110.68
7	Gram	20230.11	120.37	26885.09	159.97
8	Pulses	22470.08	31.68	29861.93	42.11
9	Vegetables(R)	3055.59	15.22	4060.77	20.22
	Total	116431.61	476.19	154733.44	632.83

Table 7.21 Annual water requirement for Matatila to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	13680.76	121.76	18181.24	161.81
2	Jowar	7887.46	5.84	10482.15	7.76
3	Maize	4868.46	3.60	6470.02	4.79
4	Groundnut	5876.61	11.69	7809.80	15.54
5	Vegetables (K)	2353.09	1.91	3127.17	2.53
6	Wheat (Local)	10689.48	53.45	14205.93	71.03
7	Gram	12982.57	77.25	17253.37	102.66
8	Pulses	14420.06	20.33	19163.74	27.02
9	Vegetables(R)	1960.91	9.77	2605.98	12.98
	Total	74719.39	305.59	99299.40	406.12

Table 7.22 Annual water requirement for Dukwan to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	415.77	3.70	552.54	4.92
2	Jowar	239.71	0.18	318.56	0.24
3	Maize	147.96	0.11	196.63	0.15
4	Groundnut	178.60	0.36	237.34	0.47
5	Vegetables (K)	71.51	0.06	95.04	0.08
6	Wheat (Local)	324.86	1.62	431.73	2.16
7	Gram	394.55	2.35	524.34	3.12
8	Pulses	438.24	0.62	582.40	0.82
9	Vegetables(R)	59.59	0.30	79.20	0.39
	Total	2270.79	9.29	3017.77	12.34

Table 7.23 Annual water requirement for Barwa sagar to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	204.09	1.82	271.20	2.41
2	Jowar	117.67	0.09	156.36	0.12
3	Maize	72.63	0.05	96.51	0.07
4	Groundnut	87.67	0.17	116.50	0.23
5	Vegetables (K)	35.10	0.03	46.65	0.04
6	Wheat (Local)	159.47	0.80	211.91	1.06
7	Gram	193.68	1.15	257.36	1.53
8	Pulses	215.12	0.30	285.86	0.40
9	Vegetables(R)	29.25	0.15	38.87	0.19
	Total	1114.68	4.56	1481.22	6.06

Table 7.24 Annual water requirement for Parichha to meet the min. food requirements of Agriculture population

		Year 2011		Year 2050	
Sl.No.	Crop	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)	Crop area to meet min. food requirements (Ha)	Water requirements of crop (MCM)
1	Paddy	51822.73	461.22	68870.51	612.95
2	Jowar	29877.69	22.11	39706.35	29.38
3	Maize	18441.74	13.65	24508.40	18.14
4	Groundnut	22260.59	44.30	29583.50	58.87
5	Vegetables (K)	8913.51	7.22	11845.73	9.60
6	Wheat (Local)	40491.74	202.46	53812.04	269.06
7	Gram	49177.99	292.61	65355.74	388.87
8	Pulses	54623.18	77.02	72592.21	102.36
9	Vegetables(R)	7427.92	36.99	9871.44	49.16
	Total	283037.09	1157.57	376145.92	1538.37

Table 7.25 Monthwise Bt value at different projects.

Sl. No.	Project	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
1	Daudhan	0.0598	0.1507	0.4512	0.1951	0.0416	0.0294	0.0165	0.0206	0.0173	0.0093	0.0020	0.0066	1
2	Kerwan	0.0417	0.1224	0.6310	0.0602	0.0313	0.0172	0.0162	0.0256	0.0319	0.0132	0.0086	0.0008	1
3	Kaliasote	0.0417	0.1224	0.6310	0.0602	0.0313	0.0172	0.0162	0.0256	0.0319	0.0132	0.0086	0.0008	1
4	Neemkheda	0.0417	0.1224	0.6310	0.0602	0.0313	0.0172	0.0162	0.0256	0.0319	0.0132	0.0086	0.0008	1
5	Richhan	0.0417	0.1224	0.6310	0.0602	0.0313	0.0172	0.0162	0.0256	0.0319	0.0132	0.0086	0.0008	1
6	Halali	0.0417	0.1224	0.6311	0.0602	0.0313	0.0172	0.0162	0.0256	0.0319	0.0132	0.0086	0.0008	1
7	Kesari	0.0417	0.1224	0.6311	0.0602	0.0313	0.0172	0.0162	0.0256	0.0319	0.0132	0.0086	0.0008	1
8	Barari	0.0417	0.1224	0.6310	0.0602	0.0313	0.0172	0.0162	0.0256	0.0319	0.0132	0.0086	0.0008	1
9	Kethan	0.0163	0.1233	0.6058	0.1112	0.0498	0.0161	0.0061	0.0250	0.0365	0.0084	0.0011	0.0004	1
10	Koncha	0.0163	0.1233	0.6061	0.1113	0.0498	0.0161	0.0061	0.0250	0.0365	0.0084	0.0011	0.0000	1
11	Mola	0.0163	0.1233	0.6061	0.1113	0.0498	0.0161	0.0061	0.0250	0.0365	0.0083	0.0011	0.0000	1
12	Rajghat	0.0163	0.1233	0.6061	0.1113	0.0498	0.0161	0.0061	0.0250	0.0365	0.0084	0.0011	0.0000	1
13	Matatila	0.0162	0.1227	0.6033	0.1108	0.0496	0.0160	0.0107	0.0249	0.0364	0.0083	0.0011	0.0000	1
14	Dukwan Barwa	0.0163	0.1233	0.6061	0.1113	0.0498	0.0161	0.0061	0.0250	0.0365	0.0084	0.0011	0.0000	1
15	Sagar	0.0162	0.1227	0.6033	0.1108	0.0495	0.0160	0.0107	0.0249	0.0364	0.0083	0.0012	0.0000	1
16	Parichha	0.0162	0.1227	0.6033	0.1108	0.0496	0.0160	0.0107	0.0249	0.0363	0.0083	0.0011	0.0000	1

Table 7.26 Monthwise Gamma value at different projects.

Sl.No.	Project	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
1	Daudhan	0.052	35.78	0.142	0.062	0.052	0.062	0.052	0.038	0.035	0.038	0.048	0.093	0.159
2	Kerwan	0.122	0.201	0.119	0.047	0.036	0.047	0.071	0.06	0.047	0.047	0.06	0.107	0.167
3	Kaliasote	0.122	0.1918	0.119	0.047	0.036	0.047	0.071	0.06	0.047	0.047	0.06	0.107	0.167
4	Neemkheda	0.19	0.1358	0.119	0.047	0.036	0.047	0.071	0.06	0.047	0.047	0.06	0.107	0.167
5	Richhan	0.076	0.191	0.119	0.047	0.036	0.047	0.071	0.06	0.047	0.047	0.06	0.107	0.167
6	Halali	0.174	0.135	0.119	0.047	0.036	0.047	0.071	0.06	0.047	0.047	0.06	0.107	0.167
7	Kesari	0.116	0.176	0.119	0.047	0.036	0.047	0.071	0.06	0.047	0.047	0.06	0.107	0.167
8	Barari	0.025	0.0254	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117
9	Kethan	0.116	0.16	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117
10	Koncha	0.116	0.1827	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117
11	Mola	0.116	0.1554	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117
12	Rajghat	0.08	0.747	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117
13	Matatila	0.09	0.8036	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117
14	Dukwan	0.122	0.201	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117
15	Barwa Sagar	0.03	1	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117
16	Parichha	0.09	0.8036	0.123	0.081	0.071	0.075	0.075	0.056	0.047	0.049	0.063	0.095	0.117

Chapter 8

COMPUTATION AND ANALYSIS OF IRYM RESULTS

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. The specific emphasis of the current study 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. A study was therefore undertaken for integrated river basin development for their water resources utilizations for large rivers in Indian. Therefore the aim of the study was to apply systems analysis method to solve such problem. The study area is Ken- Betwa link, 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-5. There are two river basins involved in this study in which water is to be exported from the reservoir Daudhan in the Ken basin to the Betwa basin.

In the study firstly the linear programming (LP) technique was employed as an optimization tool as described in Chapter-5. The model is based on the reservoir yield model approach, earlier used by various researchers, which is named as IRYM. 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-7. This chapter deals with the computations carried out for solving the problem at hand. The LINDO software was used for this purpose for the model runs. Only limited results obtained from various model runs are presented in this chapter.

The analysis is carried out in this chapter based on the above information. The analysis is described in this chapter in the manner; firstly, the analysis is carried out at each basin level for crops, with various sub-levels, aspects such as for each reservoir and for each crop, secondly, (a) for the within year reservoir storages the analysis is made at each basin level and (b) for the within year reservoir firm and secondary reservoir yields again the analysis is made at each basin level, and thirdly, the analysis is carried out for the water exporting point.

8.1 COMPUTATION OF LP PROBLEM

One of the objectives of the study is to apply IRYM in

8.1.1 Selection of Solver

The study is to assess the annual and within year yields (firm and secondary) at the major and medium 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 nonzero. The reason for using this solver over others is its relative ease of operation, ready availability and facility of sensitivity analysis.

8.1.2 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 (CRBA) has been improved and used as a pre processor to the solver to write the voluminous input matrix.

8.1.3 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-7 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 20 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 end 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-7.

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 95.2 percent (Weibull plotting position for 20 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 and 1.25 for all medium 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.

8.1.4 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 two alphabets denote name of the basin (Ken / Betwa); the third and fourth denotes name of the project; fifth and sixth alphabet denote name of the variable and last two numerals, i.e., at position seventhand eight represent annual or within-year time periods. However, in the case of crops, the fifth alphabet denotes the command area (Ken, Betwa or en-route), the sixth alphabet denotes the cropping season (Kharif / Rabi) and last two alphabets denote the crop name.

The notations used for the names of different projects along with the name of basin under which it comes and notations used for different crops are shown in separately in Table 8.1 and 8.2 respectively. 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.

8.1.5 Model Runs

The model runs were done for all the basins involved and at the export points of the Ken – Betwa link. 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.

8.1.5.1 Addressing infeasibility in the model runs

Wherever 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.

8.2 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. 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. The results of the various reservoir yields obtained from the IRYM are shown in Table 8.3 and also in Figure 8.1 to 8.17. The other results are compiled and are shown at proper places, as per the analysis carried out later in this chapter.

Table 8.1 Notations representing reservoirs

Sl. No.	Basin	Name of the project	Code
1	Ken	Ken	KNDN
2	Betwa	Kerwan	BTKR
3		Kaliasote	BTKL
4		Neemkheda	BTNK
5		Richhan	BTRN
6		Halali	BTHL
7		Barari	BTBR
8		Kesari	BTKS
9		Kethan	BTKN
10		Koncha	BTKO
11		Mola	BTML
12		Rajghat	BTRG
13		Matatila	BTMT
14		Dukwan	BTDK
15		Barwa Sagar	BTBS
16		Paricchha	BRPR

Table 8.2 Crop notations

Sl No	Command/Cropping Season	Name of the crop	Code
1	Ken Kharif crops	Paddy	KKPD
2		Maize	KKMZ
3		Pulses	KKPL
4		Oilseeds	KKOL
5		Vegetables	KKVG
6	Ken Rabi crops	Wheat(HYV)	KRWH
7		Wheat(Local)	KRWL
8		Gram	KRGR
9		linseed	KRLN
10		Sunflower	KRSF
11		Barseem	KRBR
12		Masoor	KRMS
1	En-route Kharif crops	Paddy	EKPD
2		Jowar	EKJW
3		Groundnut	EKGN
4		Bajra	EKBJ
5		Fodder	EKFD
6		Maize	EKMZ
7		Pulses (K)	EKPL
8		Vegetable (K)	EKVG
9	En-route Rabi crops	Wheat	ERWL
10		Fodder	ERFD
11		Pulses (R)	ERPL
12		Oil Seeds	EROL
13		Vegetable (R)	ERVG
14	En-route Perennial crop	Sugarcane	ERSC
1	Betwa Kharif crops	Paddy	BKPD
2		Maize	BKMZ
3		Jowar	BKJW
4		Vegetable (K)	BKVG
5		Pulses (K)	BKPL
6		Groundnut (K)	BKGN
7		Soyabeen	BKSB
8		Fodder	BKFD
9	Betwa Rabi crops	Wheat	BRWL
10		Vegetable (R)	BRVG
11		Gram	BRGM
12		Oil Seeds	BROL
13	Betwa Perennial crop	Sugarcane	BRSC

Table 8.3: Firm secondary and total yield for different projects in IRYM

Sl. No.	Name of the Project	Code	75% Annual Dependable Flow (MCM)	Single Project			Basin level Integration			System level integration		
				Total Yield (MCM)	Firm Yield (MCM)	Secondary Yield (MCM)	Total Yield (MCM)	Firm Yield (MCM)	Secondary Yield (MCM)	Total Yield (MCM)	Firm Yield (MCM)	Secondary Yield (MCM)
1	Daudhan	KNDN	5166.86	1829.85	708.15	1121.70	1829.85	708.15	1121.70	111.05	111.05	0.00
2	Kerwan	BTKR	49.66	27.07	8.79	18.27	27.06	8.79	18.27	27.08	14.74	12.34
3	Kaliasote	BTKL	25.64	30.69	18.37	12.32	30.69	15.95	14.74	30.69	21.60	9.09
4	Neemkheda	BTNK	93.3	7.04	2.29	4.75	1.26	0.00	1.26	1.26	0.00	1.26
5	Richhan	BTRN	1.25	1.76	0.57	1.19	1.76	0.57	1.19	1.76	0.57	1.19
6	Halali	BTHL	44.66	55.92	18.17	37.75	55.92	18.17	37.75	55.92	18.17	37.75
7	Barari	BTBR	202.76	46.59	19.01	27.58	50.33	50.33	0.00	50.33	50.33	0.00
8	Kesari	BTKS	18.88	12.31	4.00	8.31	12.31	4.00	8.31	12.31	9.75	2.56
9	Kethan	BTKN	45.27	16.9	16.90	0.00	16.90	15.67	1.23	16.9	16.90	0.00
10	Koncha	BTKO	57.76	25.19	16.94	8.24	25.18	8.18	17.00	25.18	8.18	17.00
11	Mola	BTML	26.61	16.06	10.20	5.85	16.06	5.22	10.84	15.22	5.22	10.00
12	Rajghat	BTRG	612.23	854.4	277.68	576.32	1147.38	839.12	308.26	1147.38	367.77	779.61
13	Matatila	BTMT	777.43	744.49	241.96	502.53	110.24	72.82	37.42	110.25	110.25	0.00
14	Dukwan	BTDK	819.49	22.62	15.21	7.40	0.00	0.00	0.00	0	0.00	0.00
15	Barwa sagar	BTBS	6.88	8.91	2.89	6.02	8.91	2.89	6.02	37.84	37.84	0.00
16	Parichha	BTPR	1009.31	120.72	39.23	81.48	121.04	38.50	82.54	95.54	12.34	83.20
Total			8957.99	3820.52	1400.36	2419.71	3454.89	1788.36	1666.53	1738.71	784.71	954.00

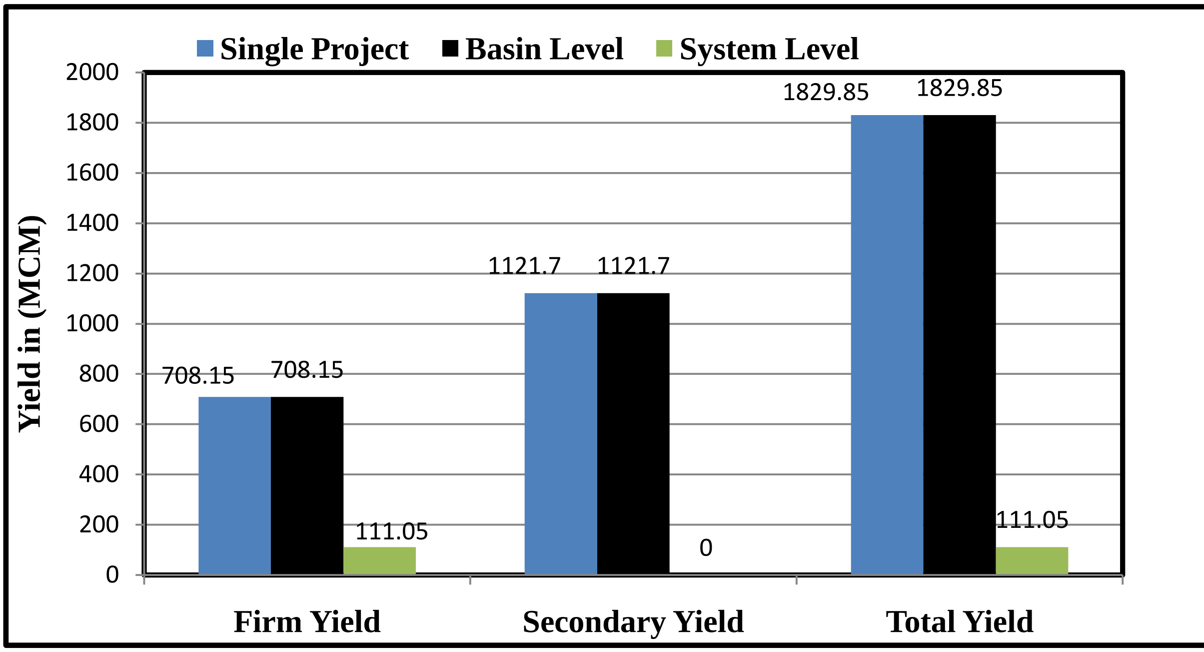


Fig. 8.1 Firm secondary and total yield for Daudhan project

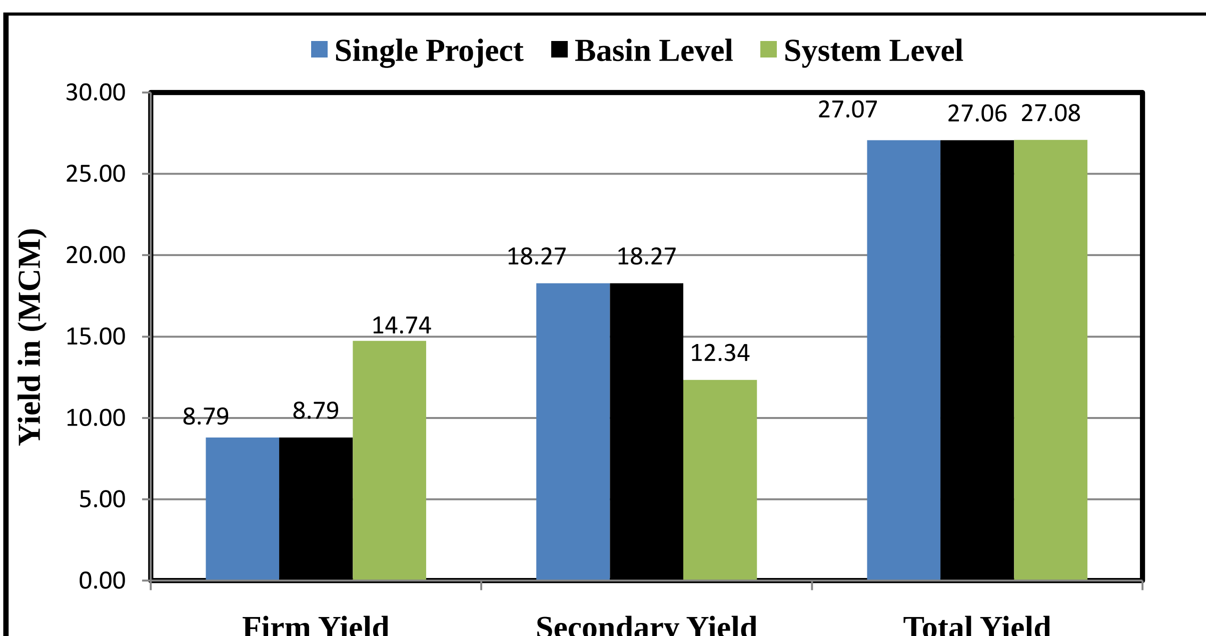


Fig. 8.2 Firm secondary and total yield for Kerwan project

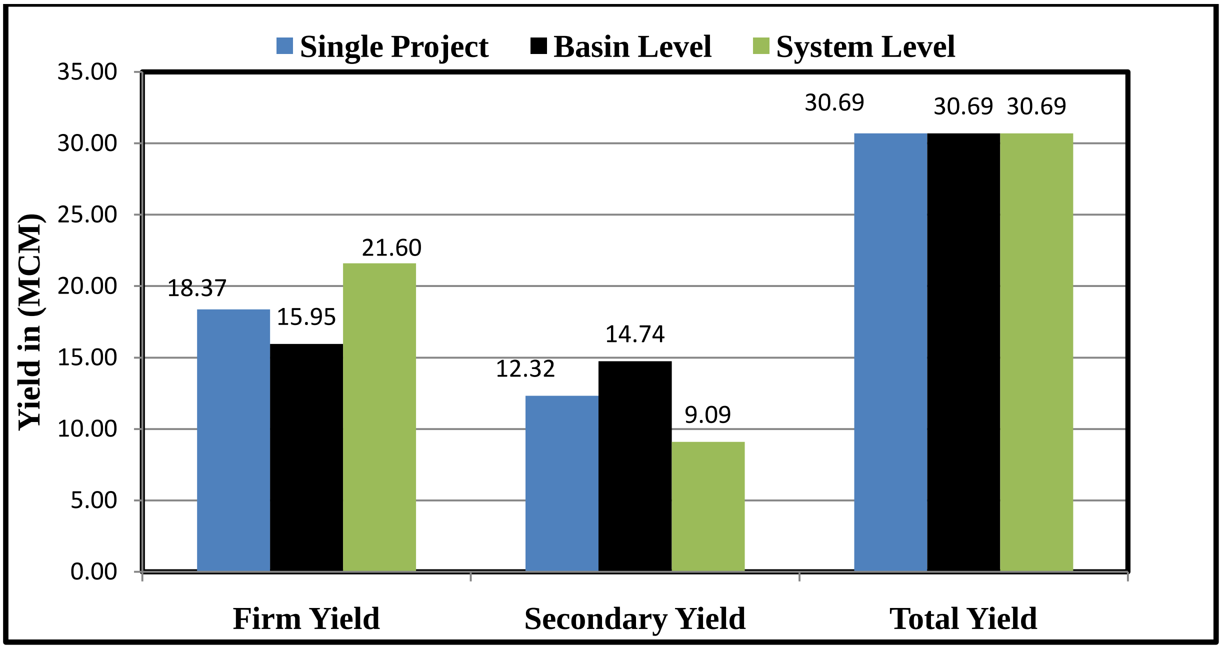


Fig. 8.3 Firm secondary and total yield for Kaliasote project

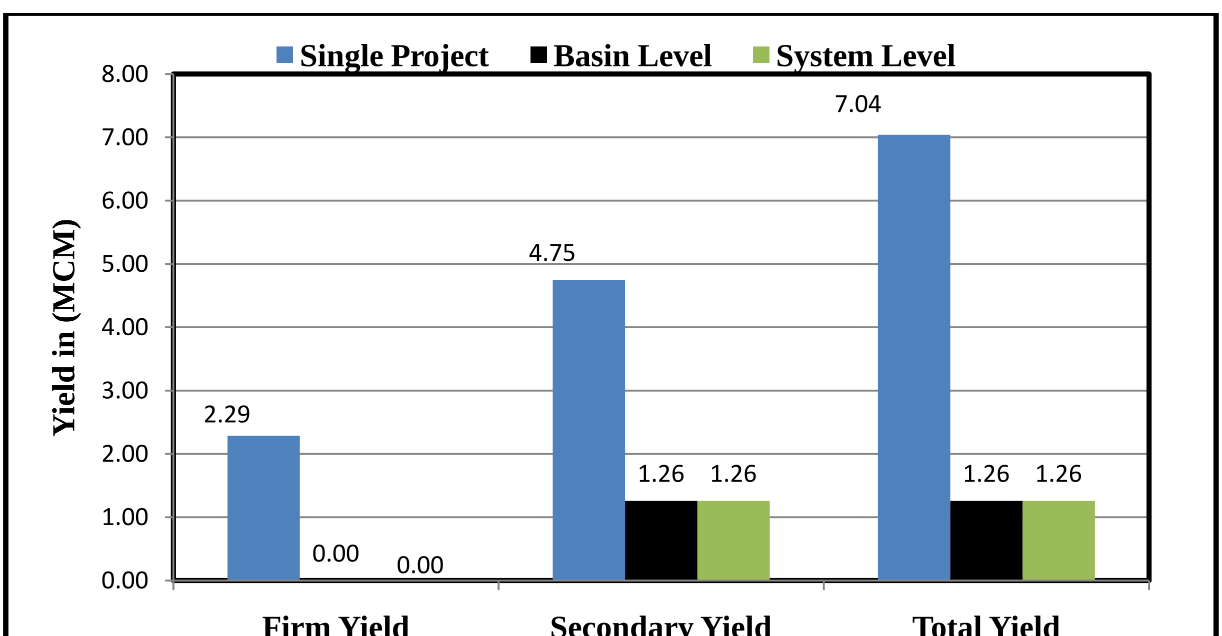


Fig. 8.4 Firm secondary and total yield for Neemkheda project

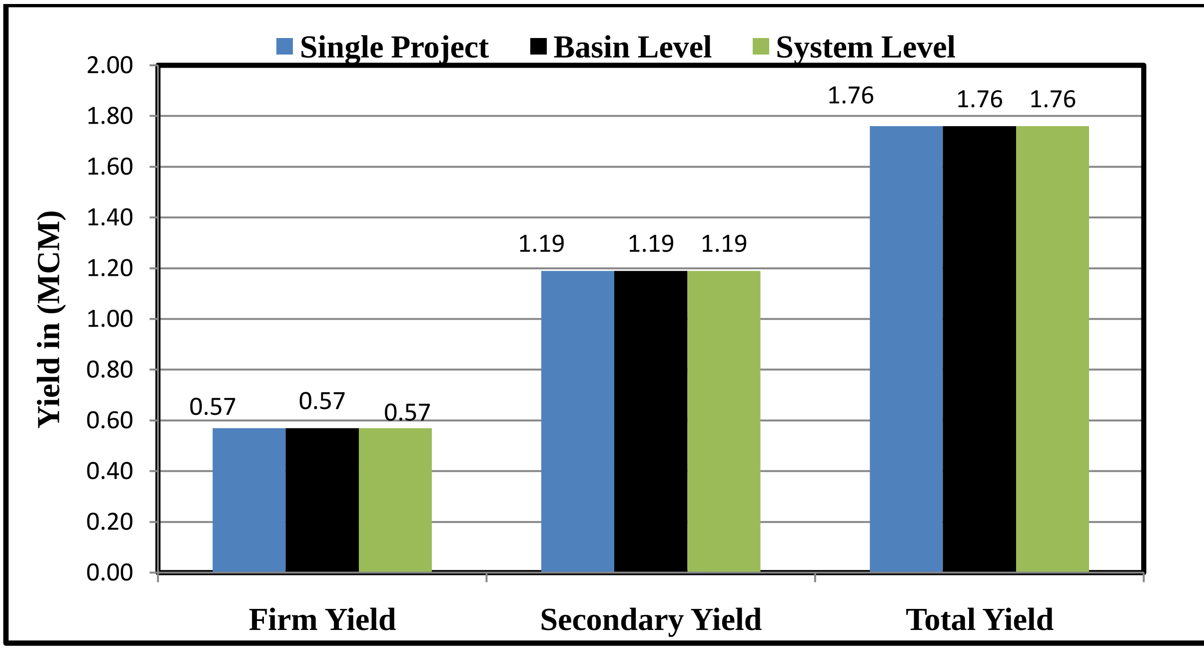


Fig. 8.5 Firm secondary and total yield for Richhan project

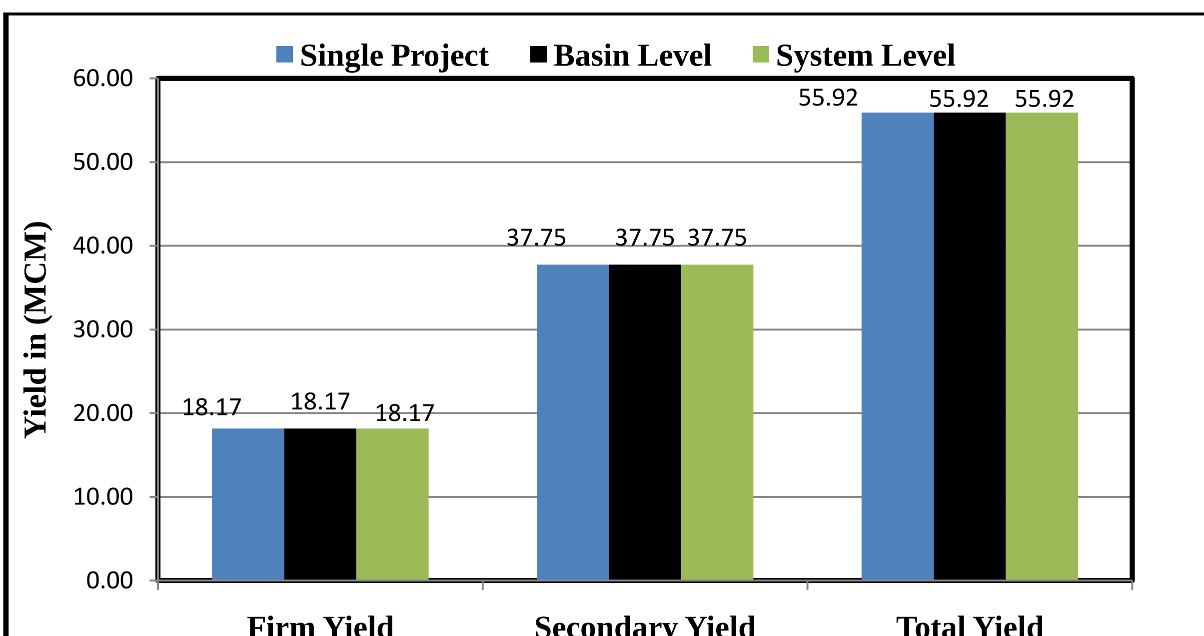


Fig. 8.6 Firm secondary and total yield for Halali project

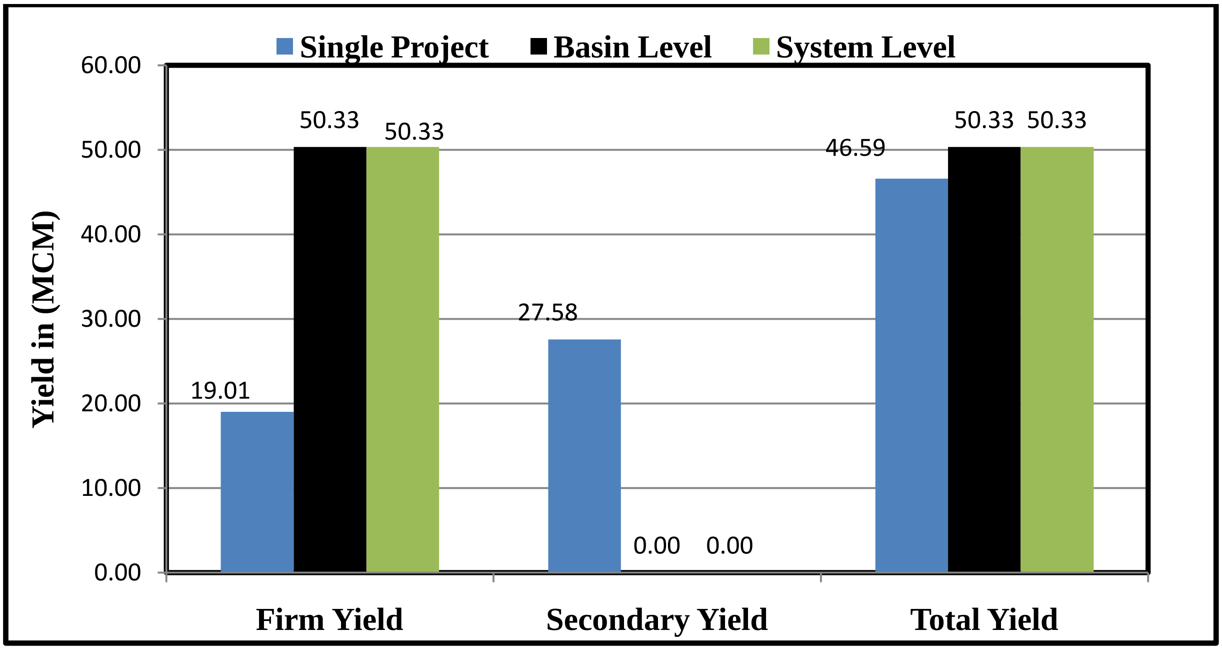


Fig. 8.7 Firm secondary and total yield for Barari project

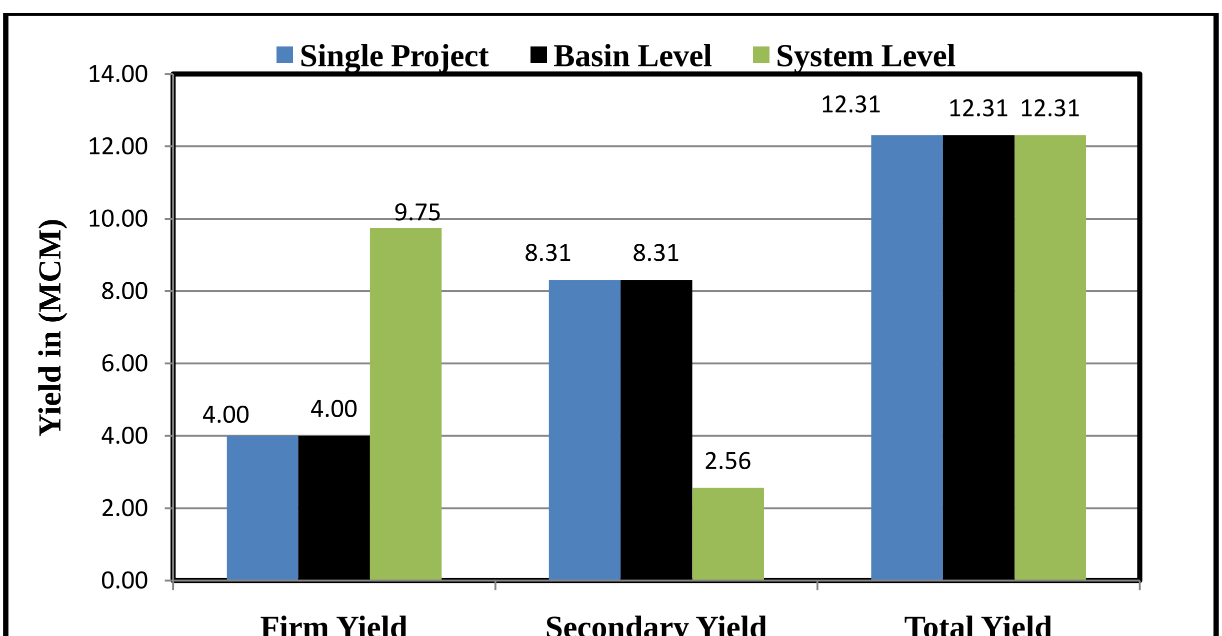


Fig. 8.8 Firm secondary and total yield for Kesari project

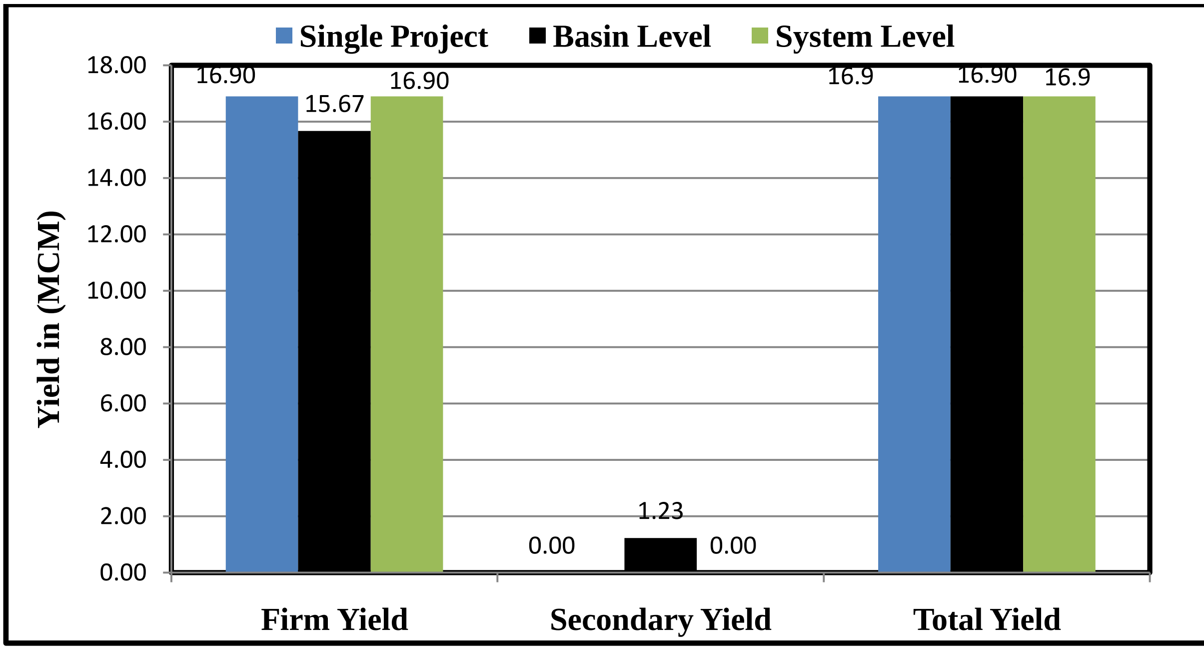


Fig. 8.9 Firm secondary and total yield for Kethan project

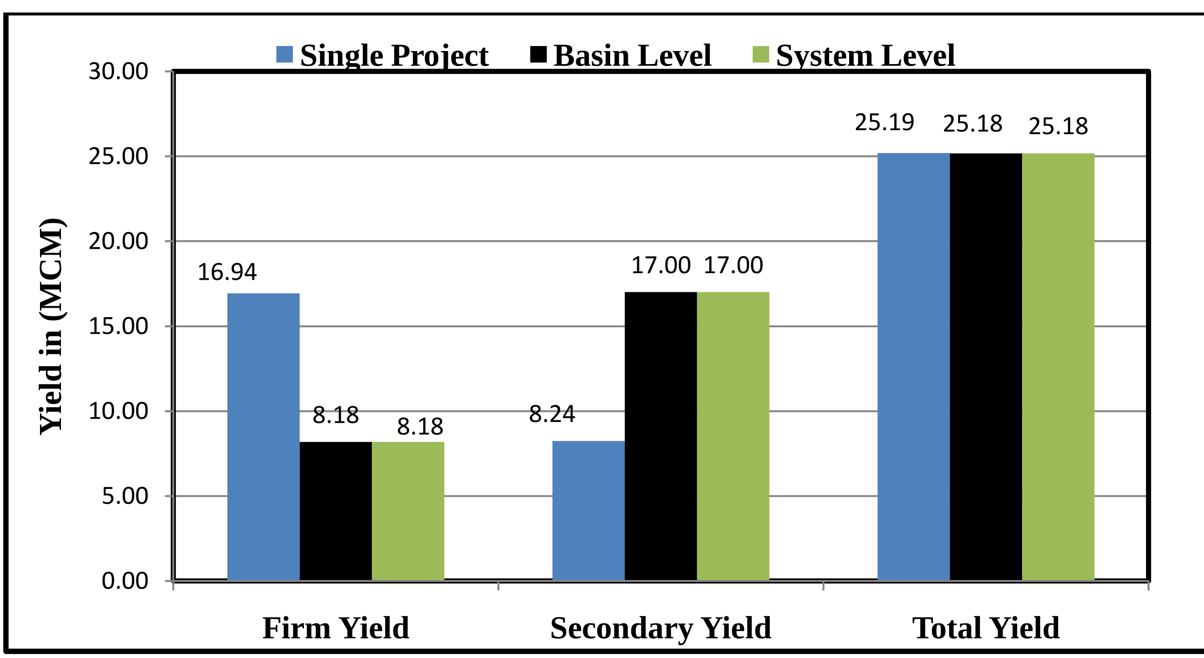


Fig. 8.10 Firm secondary and total yield for Koncha project

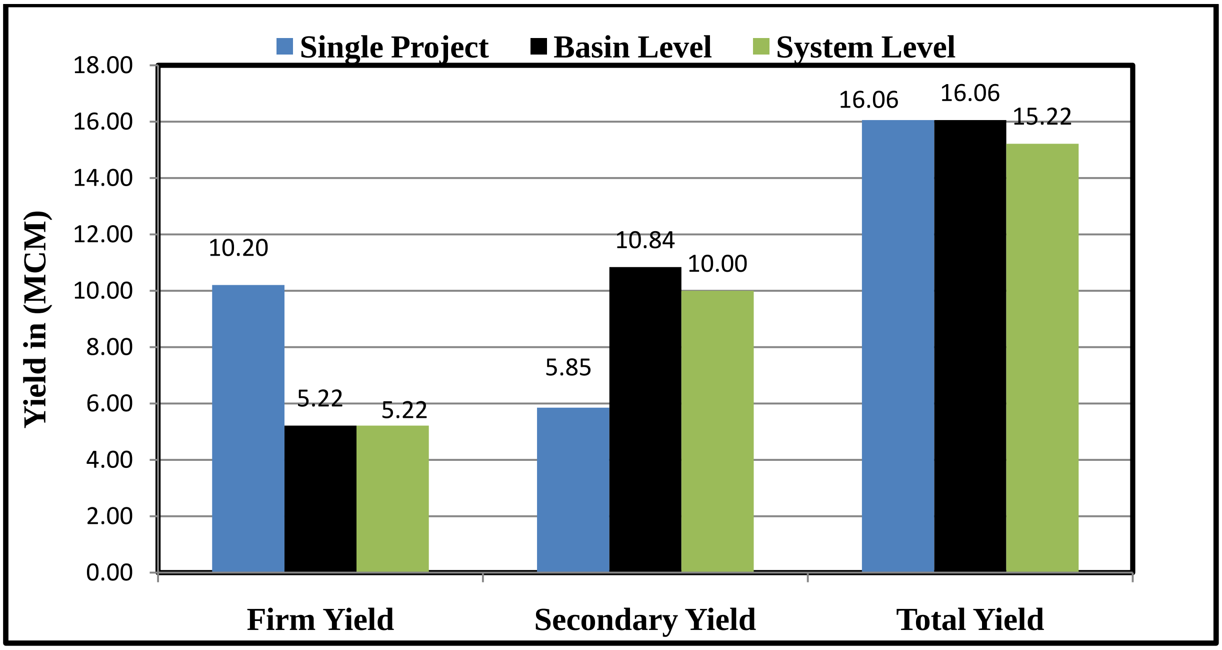


Fig. 8.11 Firm secondary and total yield for Mola project

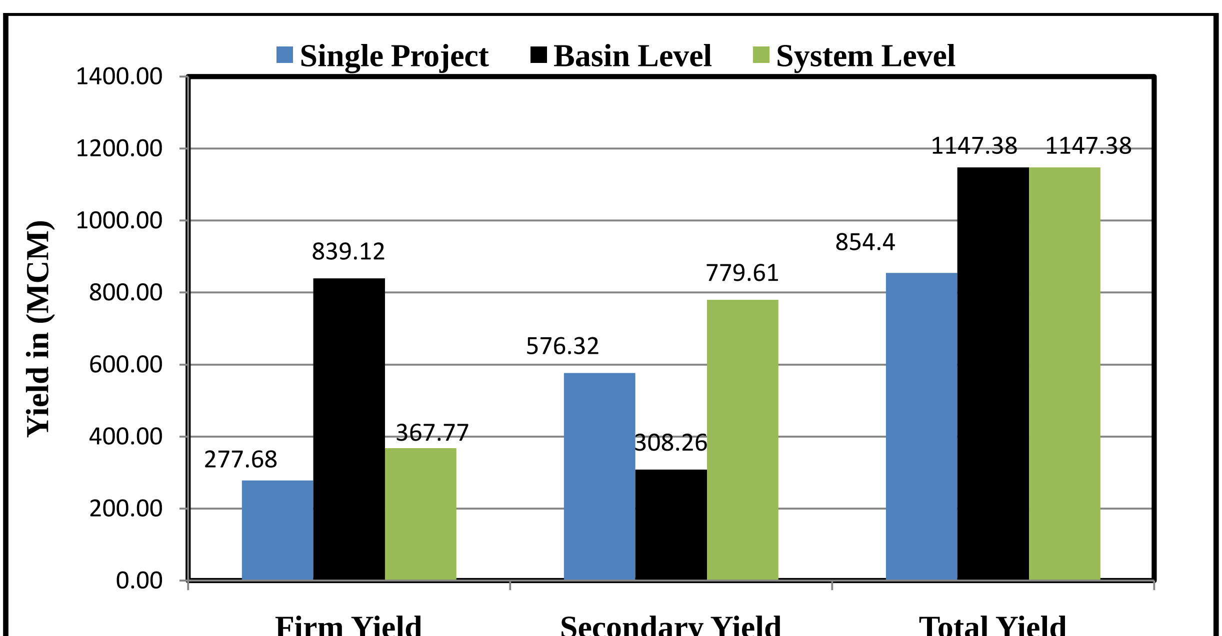


Fig. 8.12 Firm secondary and total yield for Rajghat project

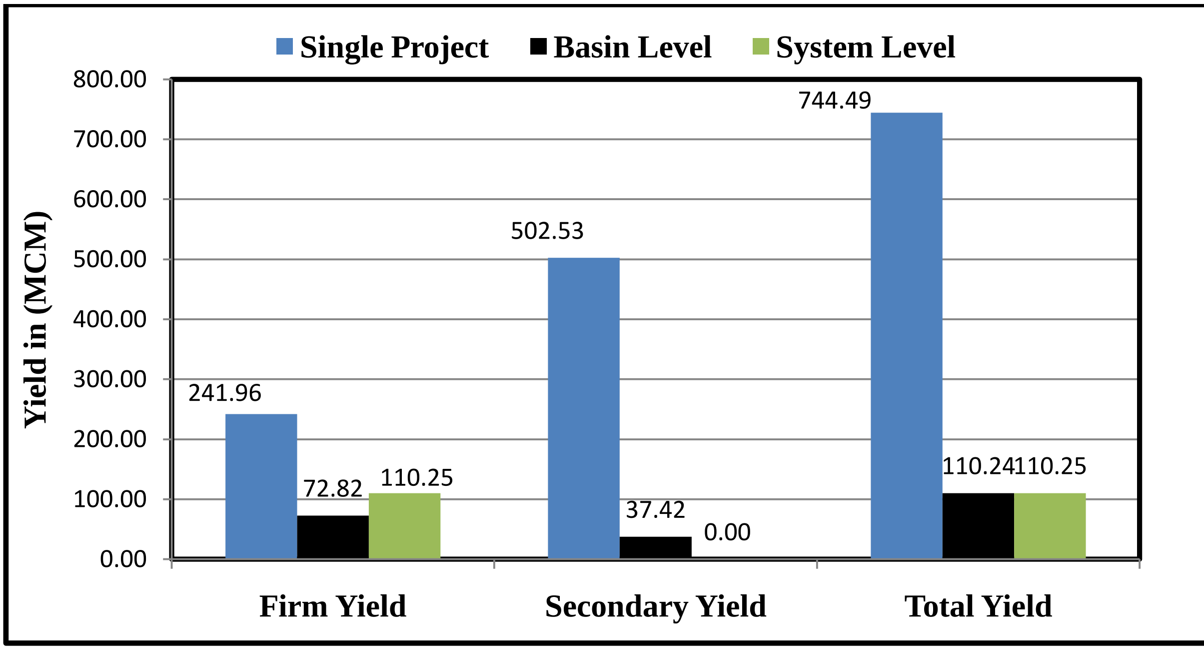


Fig. 8.13 Firm secondary and total yield for Matatila project

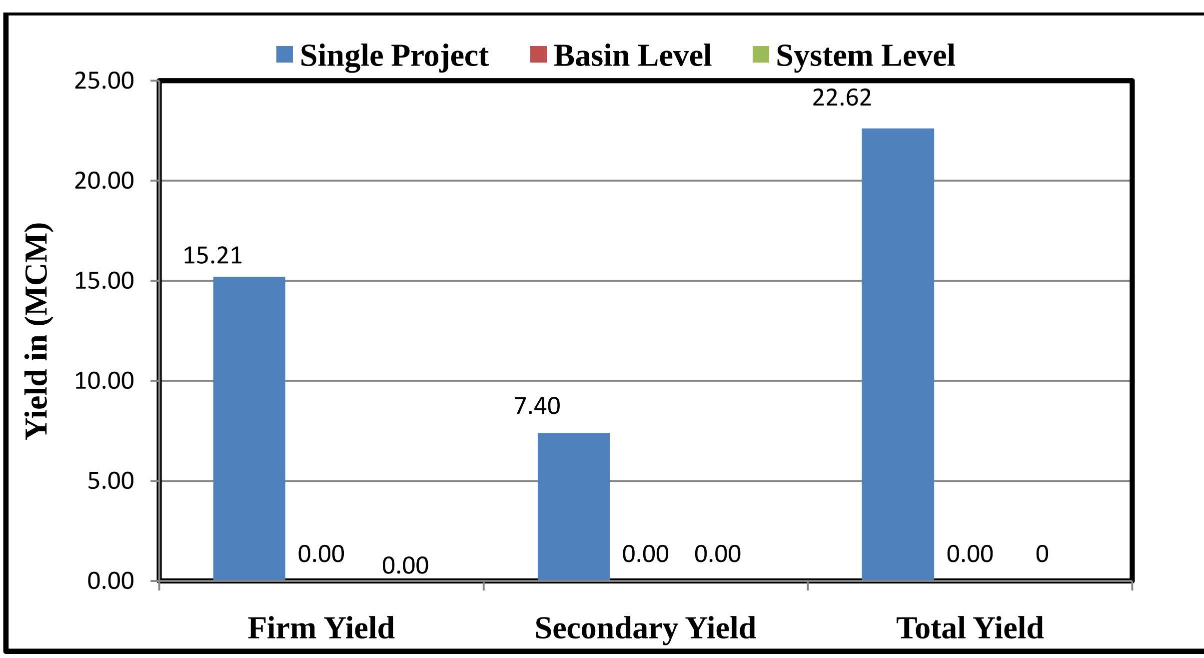


Fig. 8.14 Firm secondary and total yield for Dukwan project

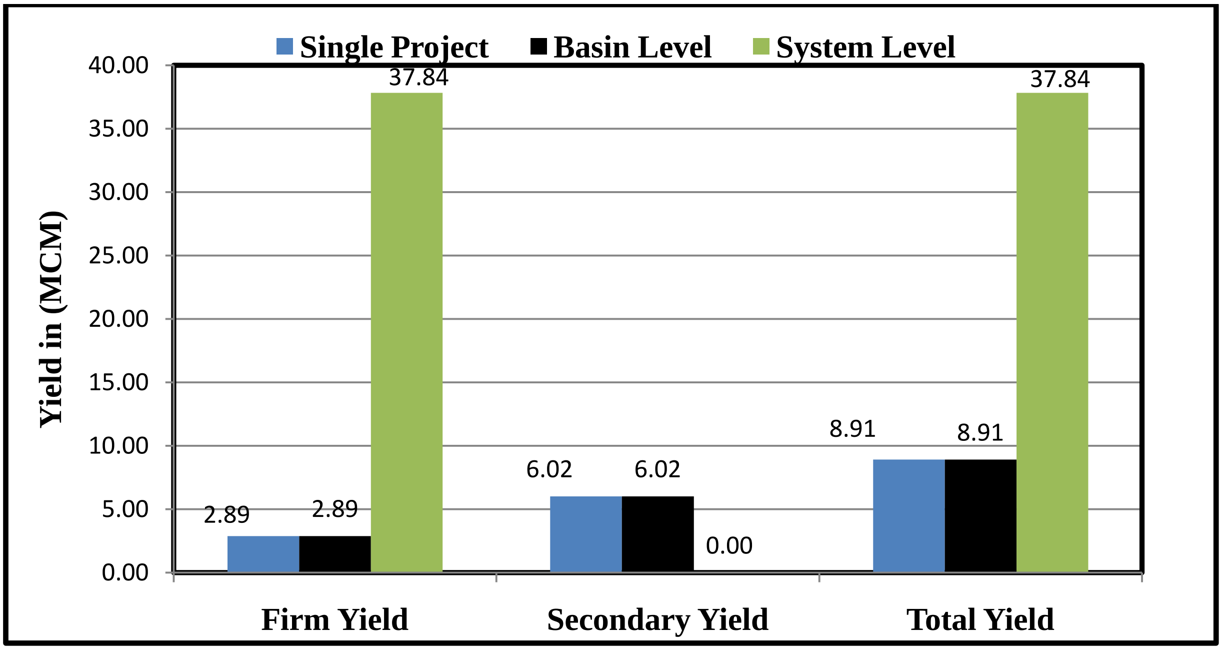


Fig. 8.15 Firm secondary and total yield for Barwa Sagar project

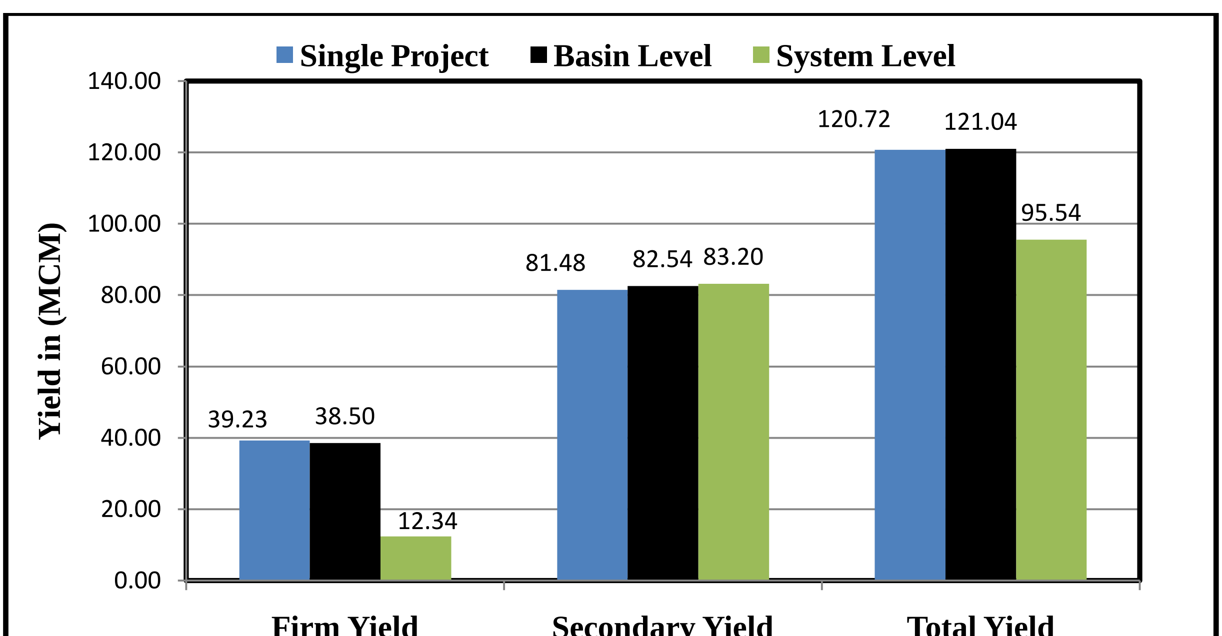


Fig. 8.16 Firm secondary and total yield for Parichha project

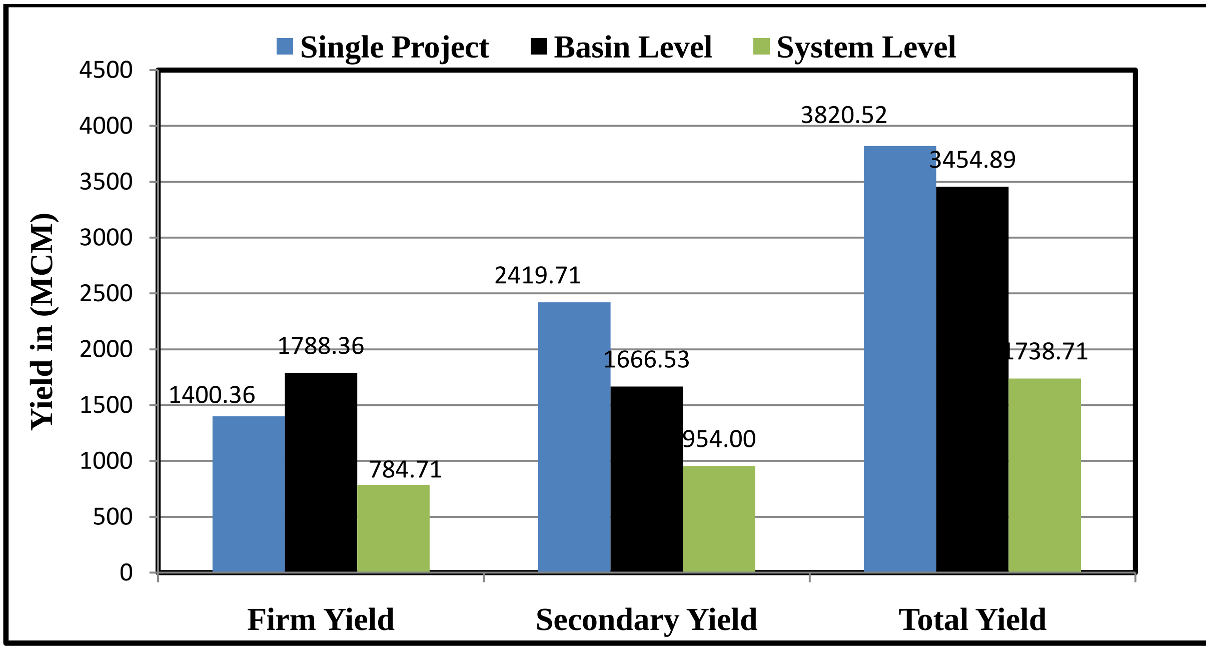


Fig. 8.17 Firm secondary and total yield for Integrated Ken-Betwa system

8.3 ANALYSIS OF IRYM RESULTS

The analysis is carried out in this chapter as follows: (i) for crops; the analysis is carried out at each basin level, with various sub-levels, for the aspects such as for each reservoir and for each crop, (ii) (a) for the within year reservoir storages; the analysis is made at each basin level and (b) similarly, for the within year reservoir firm and secondary reservoir yields; again the analysis is made at each basin level and (iii) lastly, the analysis is carried out for the water exporting point.

8.3.1 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 and at the crop levels for each of the basins. At the reservoir project level the assessment is based on the modelled total 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.

8.K.1 Analysis for Crops at Ken Basin Level

8.K.1.1 Crop intensities achieved at the reservoir levels in Ken basin.

(I) With Export

The total cropped intensity achieved at Daudhan reservoir in Ken basin is summarized in Table-8.K.1.1.It is found that a total cropped intensity of 0.149 is achieved with export, out of which 0.113 for self and 0.036 for en-route.

8.K.1.2 Crop intensities achieved for each crop in Ken

The total cropped intensity achieved and their percent exeedances for average cropped intensities for each crop at reservoir Daudhan in Ken basin with export are summarized in Table-8.K.1.2 and Figure- 8.K.1.2. It is found that with export at Daudhan for self irrigationthe crops kharif vegetable and rabi sunflower have a maximum total cropped intensity/average cropped intensity of 0.004 with the lowest percent exceedance of 7. On the other hand with export the crops en-route kharif jowar, en-route kharif bajara, en-route kharif fodder, en-route kharif maize, en-route kharif pulses and en-route kharif vegetable with a minimum total cropped intensity/average cropped intensity of 0.003 have the highest percent exceedance of 92.

(II) Without Export

8.K.1.3 Crop intensities achieved at the reservoir levels in Ken basin.

The total cropped intensity achieved at Daudhan reservoir in Ken basin without export is summarized in Table-8.K.1.3. It is found that a total cropped intensity of 1.277 is achieved without export, out of which 1.139 for self and 0.138 for en-route.

8.K.1.4 Crop intensities achieved for each crop in Ken

The total cropped intensity achieved and their percent exeedances for average cropped intensities for each crop at reservoir Daudhan in Ken basin without export are summarized in

Table-8.K.1.4. It is found that at Daudhan without export for self irrigation the crop rabi wheat has a maximum total cropped intensity / average cropped intensity of 0.326 with the lowest percent exceedance of 3. On the other hand the crops en-route kharif jowar, en-route kharif bajara, en-route kharif fodder, en-route kharif maize, en-route kharif pulses with a minimum total cropped intensity / average cropped intensity of 0.003 have the highest percent exceedance of 92.

8.B.1 Analysis for Crops at Betwa Basin Level

8.B.1.1 Crop intensities achieved at the reservoir levels in Betwa

The total cropped intensity achieved at each reservoir in Betwa basin is summarized in Table-8.B.1.1 and Figure-8.B.1.1, their percent exceedances are given in Table-8.B.1.1(a) and Figure-8.B.1.1(a). It is found that the reservoirs Kerwan, Kaliasote, Neemkheda, Kesari, Kethan, Koncha, Mola, Rajghat, Dukwan and Barwa Sagar with a cropped intensity of 1.250 have the lowest percent exceedance of 6 and the reservoir Parrichha with cropped intensity of 0.033 has the highest percent exceedance of 93.

8.B.1.2 Crop intensities achieved for each crop in Betwa

The total cropped intensity and their percentexeedances for average cropped intensities achieved for each crop in Betwa basin are summarized in Table-8.B.1.2.andFigure-8.B.1.2.It is found that in Betwa basin the crop kharif paddy has the maximum total cropped intensity of 2.729 and the crop kharif fodder with a minimum total cropped intensity of 0.175. The crop rabi wheat (local) with an average cropped intensity of 0.337 has the lowest percent exceedance of 7 and the crop kharif fodder with cropped intensity of 0.011 has the highest percent exceedance of 92.

8.3.2 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 policies beforehand. 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 states and (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 results by totalling the respective required values obtained for each reservoir:

The expected total within year storage available from all the reservoirs in the basin for finalizing broad tentative reservoir release schedule.

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.

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.

8.K.2 Analysis at Ken Basin Level

(I) With Export

In Ken basin the following is achieved during a normal water year:

(a) The expected total within-year storages that are likely to be available are presented in Table-8.K.2(a) and Figure-8.K.2(a). It is found that the expected maximum total within year storages of 109.646 MCM at the Daudhan reservoir would be available in the month of September. On the other hand the expected minimum total within year storages of 0.011 MCM at the reservoir would be available in the months of May and June.

(b) Similarly, the expected total within-year firm yields that are likely to be available from reservoir Daudhan are presented in Table-8.K.2(b)and Figure-8.K.2(b). It is found that the expected maximum total within year firm yield of 31.831 MCM at the Daudhan reservoir would be available in the month of December to meet the water requirements for self and en-route irrigations. On the other hand the expected minimum total within year firm yield of 0.109 MCM at the reservoir would be available in the month of July. The months of April, May and August would have no yields.

(c) There are no within-year secondary yields that are likely to be available at the reservoir Daudhan.

(d) The percent exceedances of the above maximum and the minimum values would be 92% and 7% for the within year storage, respectively. But for the within year firm yields the percent exceedances of the above maximum and the minimum values would be 69% and 7%, respectively.

(II) Without Export

In Ken basin the following is achieved during a normal water year without export:

(a) The expected total within-year storages that are likely to be available without export are presented in Table-8.K.2(c). It is found that the expected maximum total within year storages of 1348.110 MCM at the Daudhan reservoir would be available in the month of October without export. On the other hand the expected minimum total within year storages of 242.381 MCM at the reservoir would be available in the months of June without export.

(b) Similarly, the expected total within-year firm yields that are likely to be available from reservoir Daudhan are presented in Table-8.K.2(d). It is found that the expected maximum total within year firm yield of 300.901 MCM at the Daudhan reservoir without export would be available in the month of June to meet the water requirements for self and en-route irrigations. On the other hand the expected minimum total within year firm yield of 8.114MCM at the reservoir would be available in the month of May. The months of July, August, October, December to February and April would have no yields.

(c) Similarly, the expected total within-year secondary yields that are likely to be available from reservoir Daudhan are presented in Table-8.K.2(e). It is found that the expected maximum total within year secondary yield of 268.784 MCM at the Daudhan reservoir without export would be available in the month of February to meet the water requirements for self and en-route irrigations. On the other hand the expected minimum total within year secondary yield of 4.983 MCM at the reservoir would be available in the month of July. The months of September, November, March and May would have no yields.

The percent exceedances of the above maximum and the minimum values would be 92% and 7% for the within year storage, respectively. But for the within year firm yields the percent exceedances of the above maximum values would be 7%. But for the within year firm yields and secondary yields the percent exceedances of the above minimum values would be 38 and 57%, respectively.

8.B.2 Analysis at Betwa Basin Level

In Betwa basin the following is achieved during a normal water year:

(a) The expected total within-year storages that are likely to be available are presented in Table-8.B.2(a) and Figure-8.B.2(a). The expected maximum total within year storages of 2371.507 MCM from all the reservoirs would be available in the beginning of month of October. On the other hand the expected minimum total within year storages of 1116.070 MCM from all the reservoirs would be available in the beginning of month of July.

(b) Similarly, the expected total within year firm yields that are likely to be available in this basin are given in Table-8.B.2 (b) and Figure-8.B.2 (b). The expected maximum total within year firm yields of 211.783 MCM from all the reservoirs would be available in the month of February. On the other hand the expected minimum total within year firm yields of 2.811 MCM from all the reservoirs would be available in the month of August.

(c) Similarly, the expected total within year secondary yields that are likely to be available in this basin are shown in Table 8.B.2(c) and Figure 8.B.2(c). The expected maximum total within year secondary yields of 336.687 MCM from all the reservoirs would be available in the month of June. On the other hand the expected minimum total within year secondary yields of 12.962 MCM from all the reservoirs would be available in the month of July.

The percent exceedances of the above maximum and the minimum values would be 92% and 7%, respectively.

8.3.3 Analysis at the Daudhan Water Export Point in Ken Basin

(a) 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.

(b) 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.

8.K.3.1 About within year reservoir storages, firm yields and secondary yields at Daudhan

The expected within-year storages that are likely to be available at the water Export Point Daudhan (DN) in Ken basin were presented earlier in the Table-8.K.2(a) and Fig-8.K.2(a). Also the expected within-year reservoir firm yields that are likely to be available at the water Export Point for use other than what is required for export purposes (i.e., for mandatory water needs and irrigation) were presented Table-8.K.2(b) and Fig.-8.K.2(b). The expected within-year reservoir secondary yields were nil.

8.K.3.2 About within year exports at Daudhan

The expected within-year values that is possibly available as the water for export at the Export Point at Daudhan, out of which the exports could be made is presented in Table-8.K.3.1.and Figure 8.K.3.1.

As per the proposal of water export it is proposed to export annually 1020 MCM of water from Daudhan reservoir in the Ken basin to Barwa Sagar reservoir in the Betwa basin.

The proposed exported water would meet 312 MCM of irrigation demand en-route command, drinking water demand of the en-route command of 11.75 MCM, irrigation demand of 619 MCM for Betwa command and en-route transmission losses 37.25 MCM. As per the proposal water is to be exported in eight months, i.e., from July to February. From the study following conclusions are drawn towards meeting the water export target demand.

1. It is expected that the proposed export link would meet 975.63 MCM (95.65%) of its proposed annual export water target demand. Out of this exported annual amount of water; all the annual en-route drinking water demand of 11.75 MCM would be met, but only 926.63 MCM (94.97%) of the annual en-route and Betwa command irrigations would be met after taking into account the en-route transmission losses of 37.25 MCM.
2. The exported water is expected to meet only 95.47 MCM (68.19%) of its proposed monthly water export target demand in the month of July.Out of this exported amount of water in the month of July; all the en-route drinking water demand of 1.47 MCM in the month of July would be met, but only 89.35 MCM (93.59%) of the July's en-route and Betwa command irrigations would be met after taking into account the en-route transmission losses of 4.65 MCM.
3. On the other hand, it is expected that the link would meet all of its proposed monthly export water export target demands of 185.00 MCM in each of the months of August and September, and 102 MCM in each of the months from October to February.

Table- 8.K.1.1 Total cropped intensity achieved at each reservoir in Ken basin with export

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
1	Ken	1	Ken	1	Daudhan	0.149

Table- 8.K.1.2 Total cropped intensity and average cropped intensity achieved for each crop in Ken basin with export

Sl. No.	Crop Name	Total Cropped Intensity	% Exceedance	Average Cropped Intensity	Crop Name
1	KKPL	0.004	7	0.040	KKVG
2	KKVG	0.040	15	0.040	KRSF
3	KRSF	0.040	23	0.026	KRMS
4	KRMS	0.026	30	0.007	EKGN
5	EKJW	0.003	38	0.007	ERFD
6	EKGN	0.007	46	0.004	KKPL
7	EKBJ	0.003	53	0.003	EKJW
8	EKFD	0.003	61	0.003	EKBJ
9	EKMZ	0.003	69	0.003	EKFD
10	EKPL	0.003	76	0.003	EKMZ
11	EKVG	0.003	84	0.003	EKPL
12	ERFD	0.007	92	0.003	EKVG

Table- 8.K.1.3 Total cropped intensity achieved at each reservoir in Ken basin without export

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
1	Ken	1	Ken	1	Daudhan	1.277

Table- 8.K.1.4 Total cropped intensity and average cropped intensity achieved for each crop in Ken basin without export

Sl. No.	Crop Name	Total Cropped Intensity	% Exceedance	Average Cropped Intensity	Crop Name
1	KKPD	0.163	3	0.326	KRWH
2	KKMZ	0.065	7	0.163	KKPD
3	KKPL	0.122	11	0.122	KKPL
4	KKOL	0.097	14	0.097	KKOL
5	KKVG	0.04	18	0.065	KKMZ
6	KRWH	0.326	22	0.065	KRGR
7	KRWL	0.04	25	0.065	KRMS
8	KRGR	0.065	29	0.058	EKPD
9	KRLN	0.04	33	0.058	ERWL
10	KRSF	0.04	37	0.04	KKVG
11	KRBR	0.024	40	0.04	KRWL
12	KRMS	0.065	44	0.04	KRLN
13	EKPD	0.058	48	0.04	KRSF
14	EKJW	0.003	51	0.024	KRBR
15	EKGN	0.007	55	0.007	EKGN
16	EKBJ	0.003	59	0.007	ERFD
17	EKFD	0.003	62	0.007	ERPL
18	EKMZ	0.003	66	0.007	EROL
19	EKPL	0.003	70	0.007	ERVG
20	EKVG	0.003	74	0.007	ERSC
21	ERWL	0.058	77	0.003	EKJW
22	ERFD	0.007	81	0.003	EKBJ
23	ERPL	0.007	85	0.003	EKFD
24	EROL	0.007	88	0.003	EKMZ
25	ERVG	0.007	92	0.003	EKPL
26	ERSC	0.007	96	0.003	EKVG

Table- 8.B.1.1 Total cropped intensity achieved at each reservoir in Betwa basin with export

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
1	Betwa	1	Betwa	1	Kerwan	1.250
				2	Kaliasote	1.250
				3	Neemkheda	1.250
				4	Richhan	0.474
				5	Halali	0.554
				6	Barari	0.414
				7	Kesari	1.250
				8	Kethan	1.250
				9	Koncha	1.250
				10	Mola	1.250
				11	Rajghat	1.250
				12	Matatila	0.448
				13	Dukwan	1.250
				14	Barwa Sagar	1.250
				15	Parichha	0.033
						14.425

Table- 8.B.1.1(a) Total cropped intensity achieved and its percent exceedance at each reservoir in Betwa basin with export

Sl. No.	% Exceedance	Total Cropped Intensity	Reservoir Name
1	6	1.250	Kerwan
2	12	1.250	Kaliasote
3	18	1.250	Neemkheda
4	25	1.250	Richhan
5	31	1.250	Halali
6	37	1.250	Barari
7	43	1.250	Kesari
8	50	1.250	Kethan
9	56	1.250	Koncha
10	62	1.250	Mola
11	68	0.554	Rajghat
12	75	0.474	Matatila
13	81	0.448	Dukwan
14	87	0.414	Barwa Sagar
15	93	0.033	Parichha

Table- 8.B.1.2 Total cropped intensity and average cropped intensity achieved for each crop in Betwa basin with export

Sl. No.	Crop Name	Total Cropped Intensity	% Exceedance	Average Cropped Intensity	Crop Name
1	BKPD	2.729	7	0.337	BRWL
2	BKMZ	0.350	14	0.181	BKPD
3	BKJW	0.350	21	0.100	BRGM
4	BKVG	0.350	28	0.058	BKPL
5	BKPL	0.875	35	0.055	BROL
6	BKGN	0.700	42	0.046	BKGN
7	BKSB	0.350	50	0.046	BRVG
8	BKFD	0.175	57	0.030	BRSC
9	BRWL	5.067	64	0.023	BKMZ
10	BRVG	0.700	71	0.023	BKJW
11	BRGM	1.500	78	0.023	BKVG
12	BROL	0.828	85	0.023	BKSB
13	BRSC	0.450	92	0.011	BKFD

Table-8.K.2(a) Expected total within-year storages available in Ken basin in a normal water year with export

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	Jun	0.011	1	7	109.646
2	Jul	19.994	2	15	92.034
3	Aug	84.840	3	23	84.840
4	Sep	109.646	4	30	79.030
5	Oct	92.034	5	38	48.235
6	Nov	79.030	6	46	29.087
7	Dec	48.235	7	53	19.994
8	Jan	29.087	8	61	14.673
9	Feb	14.673	9	69	12.346
10	Mar	12.346	10	76	6.862
11	Apr	6.862	11	84	0.011
12	May	0.011	12	92	0.011

Table-8.K.2(b) Expected within-year firm yield in Ken basin with export

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	Jun	3.818	1	7	31.831
2	Jul	0.109	2	15	21.691
3	Aug	0.000	3	23	20.804
4	Sep	1.552	4	30	15.784
5	Oct	21.691	5	38	15.154
6	Nov	15.784	6	46	3.818
7	Dec	31.831	7	53	1.552
8	Jan	20.804	8	61	0.309
9	Feb	15.154	9	69	0.109
10	Mar	0.309	10		
11	Apr	0.000	11		
12	May	0.000	12		

Table-8.K.2(c) Expected total within-year storages available in Ken basin in a normal water year without export

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	Jun	242.381	1	8	1348.110
2	Jul	0.000	2	16	1165.864
3	Aug	277.522	3	25	1106.093
4	Sep	1106.093	4	33	1023.542
5	Oct	1348.110	5	41	786.515
6	Nov	1165.864	6	50	569.680
7	Dec	1023.542	7	58	330.152
8	Jan	786.515	8	66	277.522
9	Feb	569.680	9	75	257.201
10	Mar	330.152	10	83	248.092
11	Apr	257.201	11	91	242.381
12	May	248.092	12	-	-

Table-8.K.2(d) Expected within-year firm yield in Ken basin without export

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	Jun	300.901	1	7	300.901
2	Jul	0.000	2	15	193.589
3	Aug	0.000	3	23	120.097
4	Sep	120.097	4	30	85.447
5	Oct	0.000	5	38	8.114
6	Nov	193.589	6		
7	Dec	0.000	7		
8	Jan	0.000	8		
9	Feb	0.000	9		
10	Mar	85.447	10		
11	Apr	0.000	11		
12	May	8.114	12		

Table-8.K.2(e) Expected within-year secondary yield in Ken basin without export

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	Jun	48.823	1	7	268.784
2	Jul	4.983	2	15	264.408
3	Aug	19.556	3	23	256.298
4	Sep	0.000	4	30	253.768
5	Oct	256.298	5	38	48.823
6	Nov	0.000	6	45	19.556
7	Dec	264.408	7	51	5.074
8	Jan	253.768	8	57	4.983
9	Feb	268.784	9		
10	Mar	0.000	10		
11	Apr	5.074	11		
12	May	0.000	12		

Table-8.B.2(a) Expected total within-year storages available in Betwa basin in a normal water year with export

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	Jun	1570.286	1	7	2371.507
2	Jul	1116.070	2	15	2349.440
3	Aug	1308.056	3	23	2304.972
4	Sep	2349.440	4	30	2224.179
5	Oct	2371.507	5	38	2056.910
6	Nov	2304.972	6	46	1883.275
7	Dec	2224.179	7	53	1726.730
8	Jan	2056.910	8	61	1676.705
9	Feb	1883.275	9	69	1633.279
10	Mar	1726.730	10	76	1570.286
11	Apr	1676.705	11	84	1308.056
12	May	1633.279	12	92	1116.070

Table-8.B.2(b) Expected within-year firm yield in Betwa basin with export

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	Jun	177.700	1	7	211.783
2	Jul	9.937	2	15	177.700
3	Aug	2.811	3	23	170.921
4	Sep	50.047	4	30	56.659
5	Oct	28.543	5	38	50.047
6	Nov	15.587	6	46	28.543
7	Dec	170.921	7	53	15.587
8	Jan	56.659	8	61	9.937
9	Feb	211.783	9	69	7.322
10	Mar	6.898	10	76	6.898
11	Apr	7.322	11	84	4.452
12	May	4.452	12	92	2.811

Table-8.B.2(c) Expected within-year secondary yield in Betwa basin with export

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	Jun	336.687	1	7	336.687
2	Jul	12.962	2	15	177.573
3	Aug	53.366	3	23	122.066
4	Sep	113.970	4	30	113.970
5	Oct	122.066	5	38	93.030
6	Nov	93.030	6	46	53.366
7	Dec	22.898	7	53	45.284
8	Jan	177.573	8	61	33.906
9	Feb	22.798	9	69	22.898
10	Mar	45.284	10	76	22.798
11	Apr	17.063	11	84	17.063
12	May	33.906	12	92	12.962

Table-8.K.3.1 Monthly water export targets achieved at Daudhan reservoir with export

Sl. No.	Month	Proposed Export Target in (MCM)	Target Achieved	
			Target Amount (MCM)	% Target
1	Jun	-		-
2	Jul	140.00	95.47	68.19
3	Aug	185.00	185.00	100.00
4	Sep	185.00	185.00	100.00
5	Oct	102.00	102.00	100.00
6	Nov	102.00	102.00	100.00
7	Dec	102.00	102.00	100.00
8	Jan	102.00	102.00	100.00
9	Feb	102.00	102.00	100.00
10	Mar	-	-	-
11	Apr	-	-	-
12	May	-	-	-
	Total	1020.00	975.47	95.63% Annually

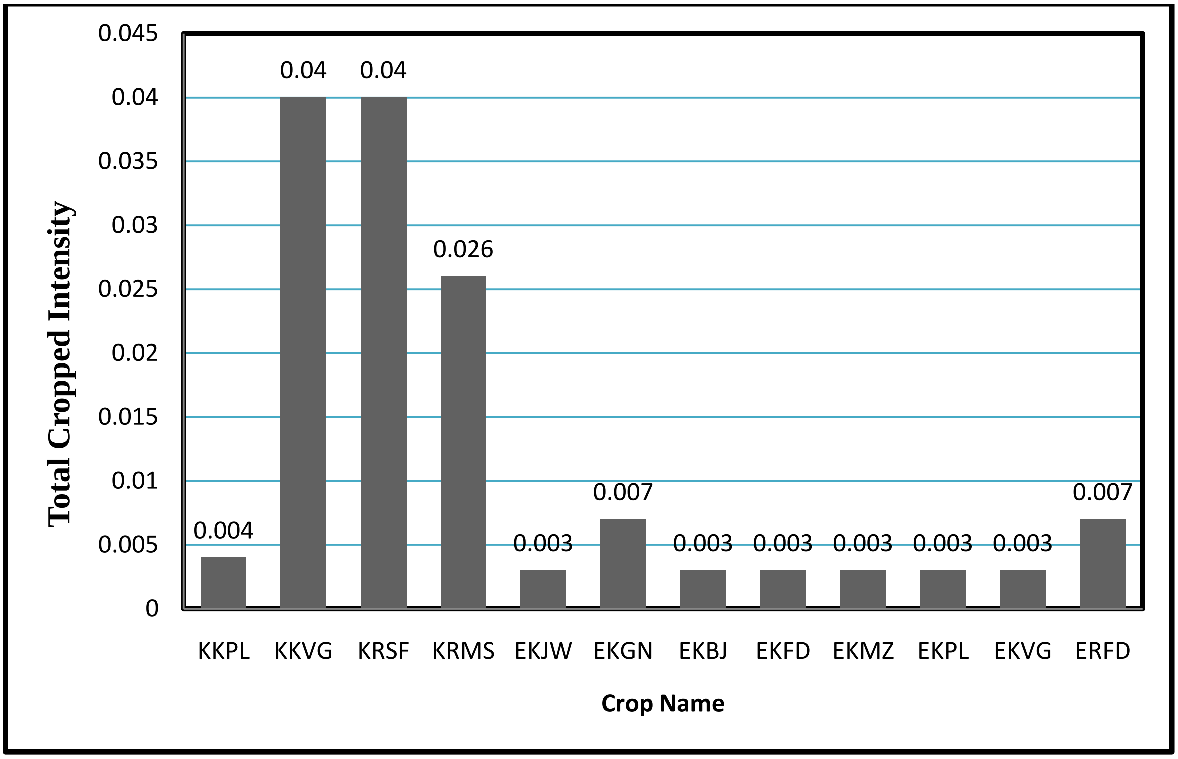


Fig- 8.K.1.2 Total cropped intensity and average cropped intensity achieved for each crop in Ken basin with export

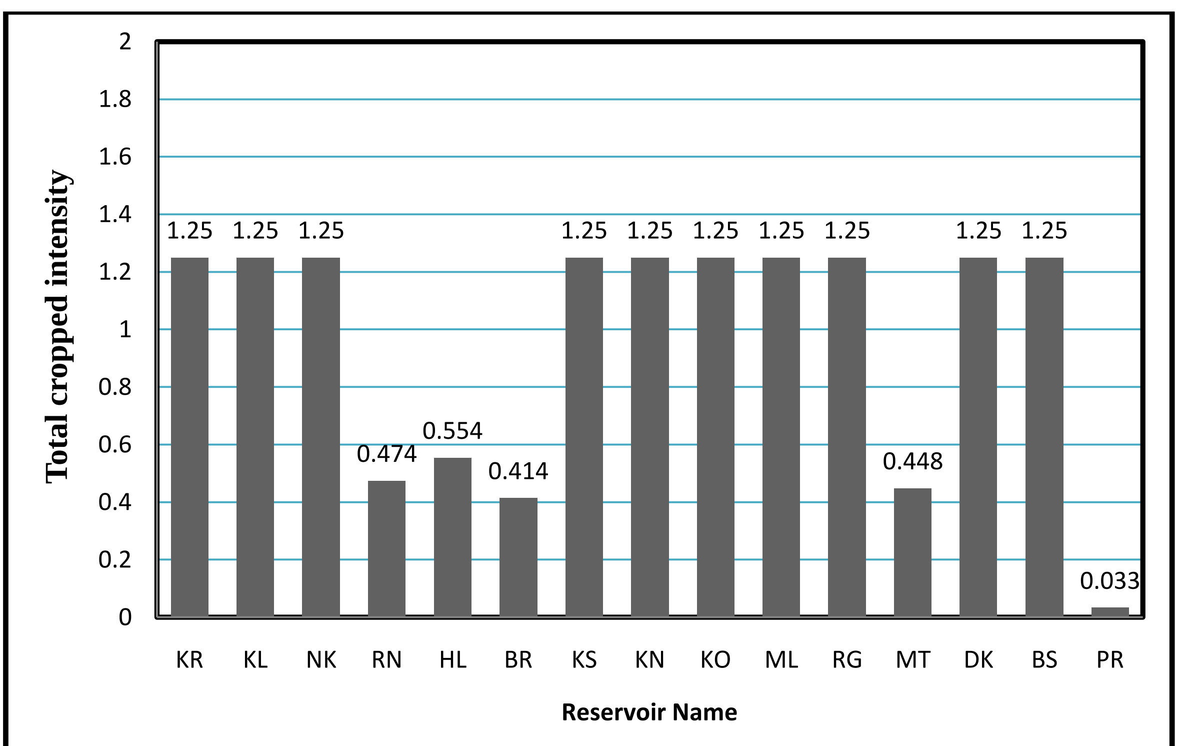


Fig.8.B.1.1 Total cropped intensity achieved at each reservoir in Betwa basin with export

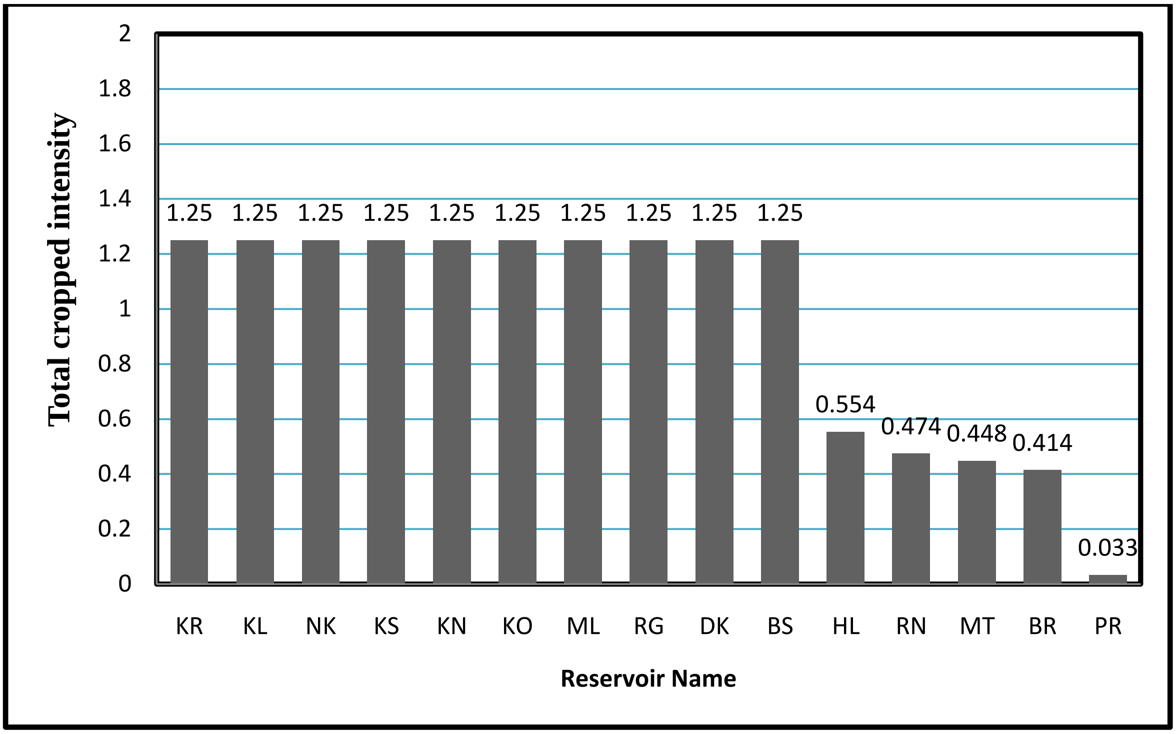


Fig.8.B.1.1(a) Total cropped intensity achieved and its percent exceedance at each reservoir in Betwa basin with export

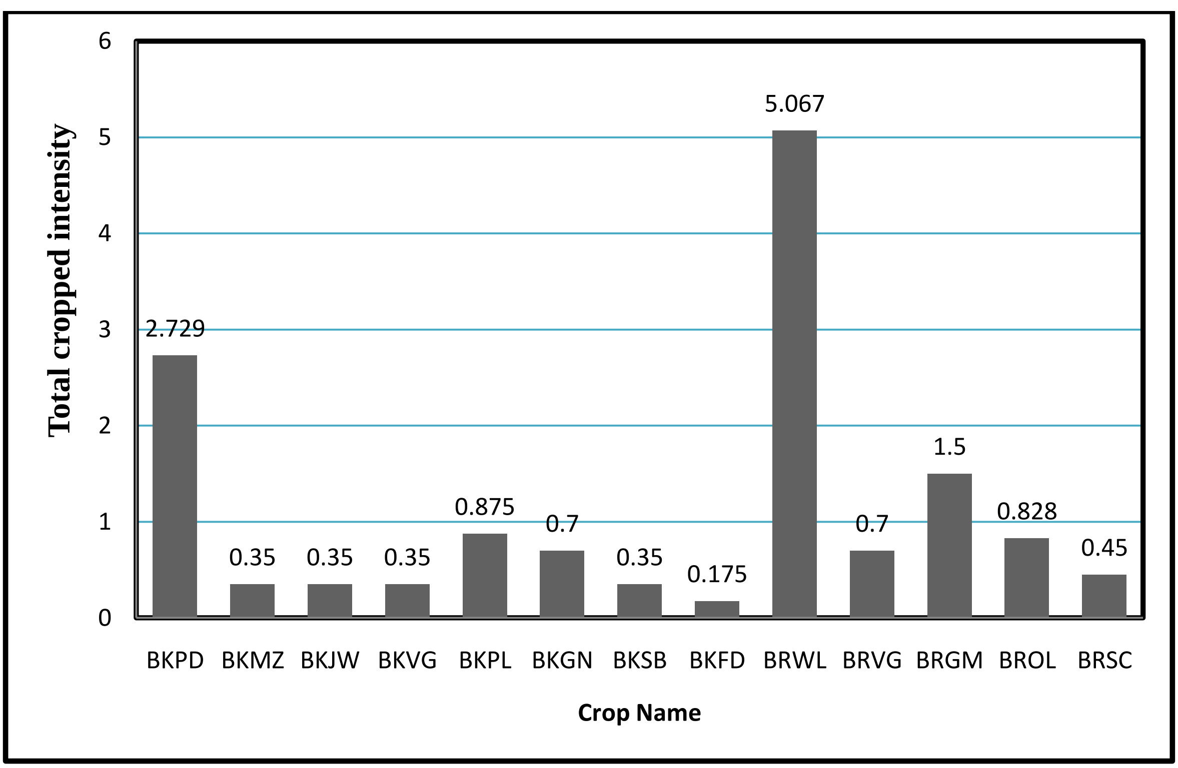


Fig.8.B.1.2 Total cropped intensity and average cropped intensity achieved for each crop in Betwa basin with export

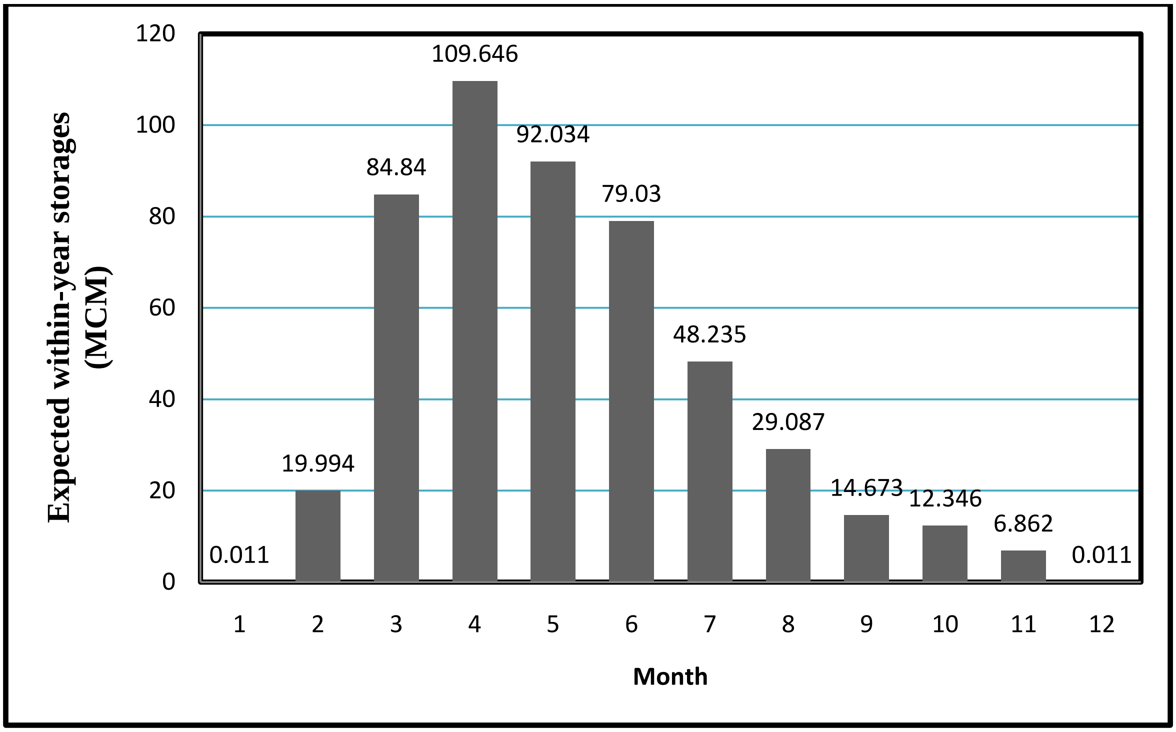


Fig.8.K.2(a) Expected total within-year storages available in Ken basin in a normal water year with export

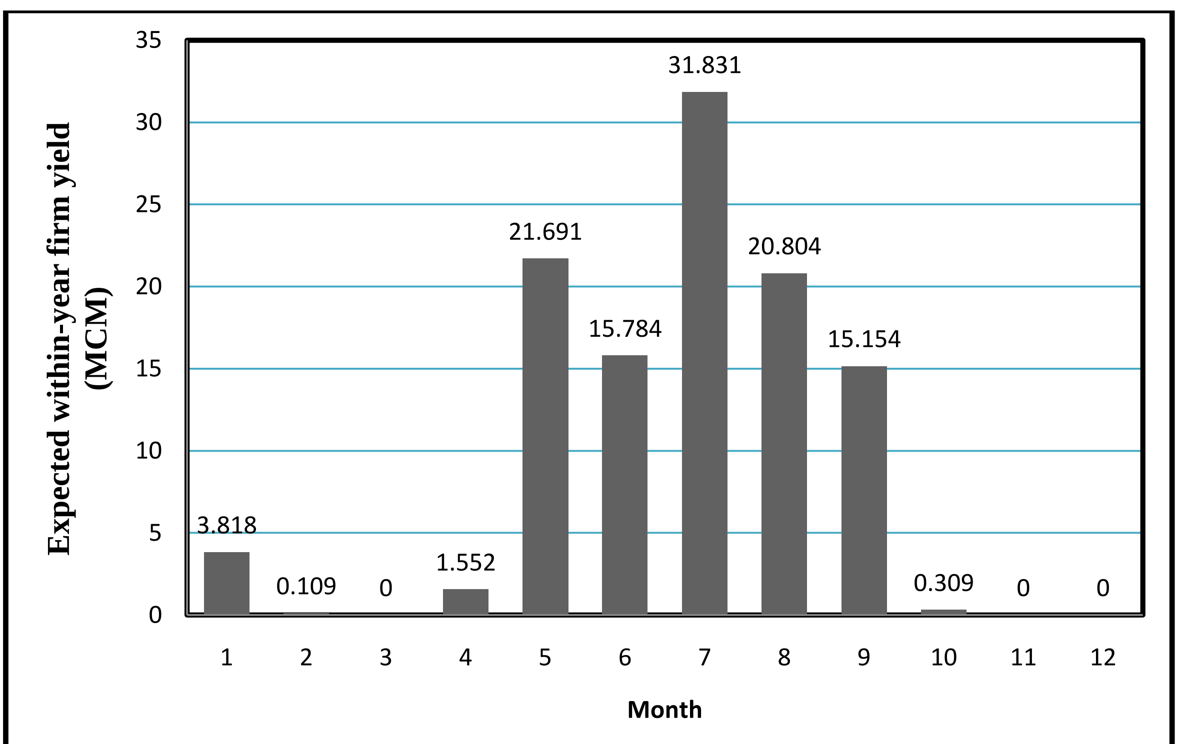


Fig.8.K.2(b) Expected within-year firm yield in Ken basin with export

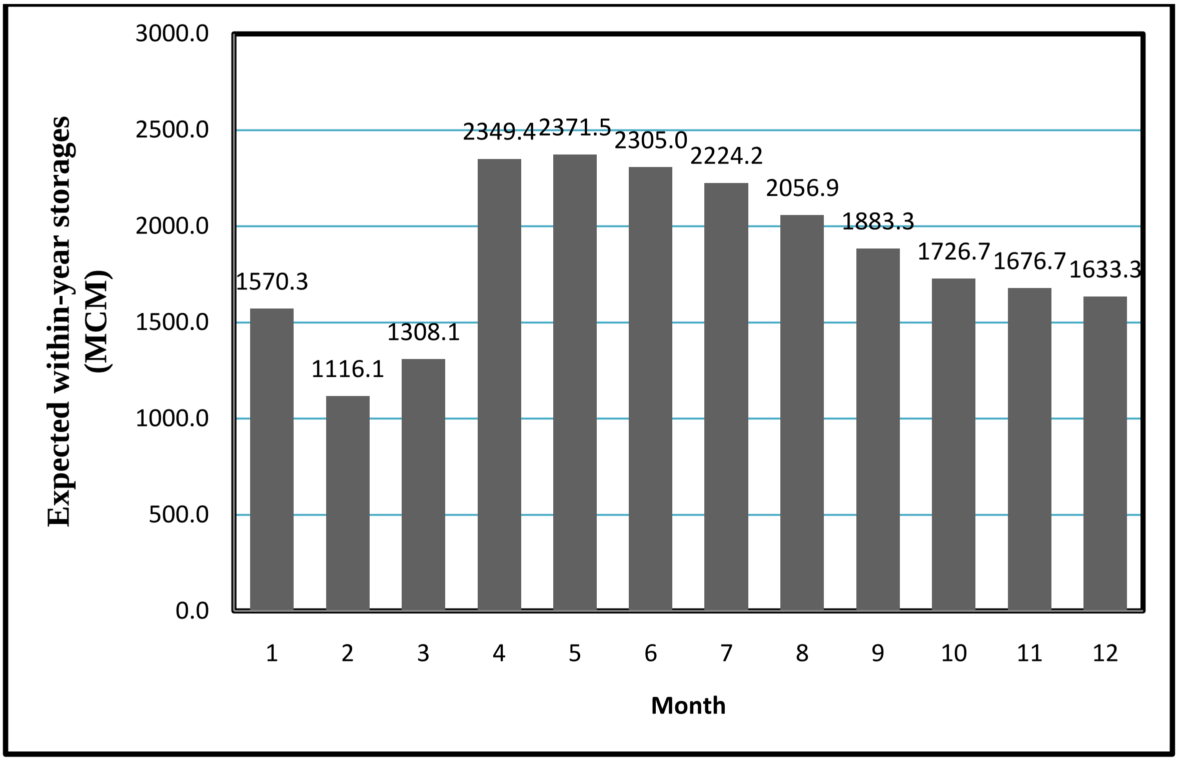


Fig.8.B.2(a) Expected total within-year storages available in Betwa basin in a normal water year with export

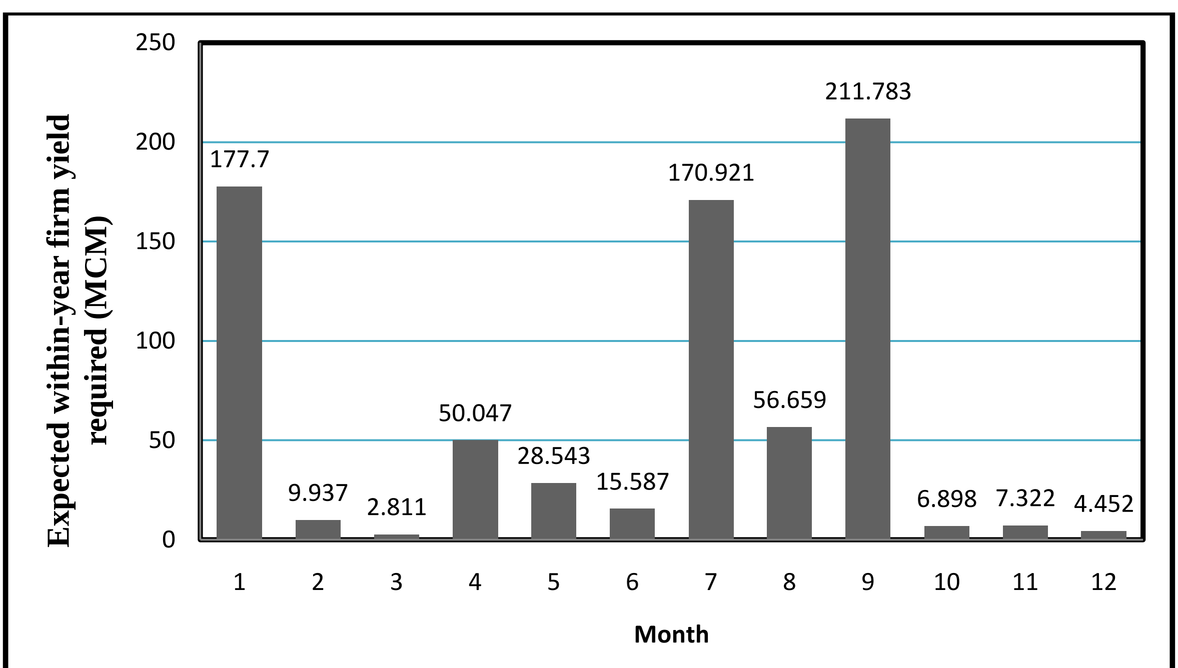


Fig.8.B.2(b) Expected within-year firm yield in Betwa basin with export

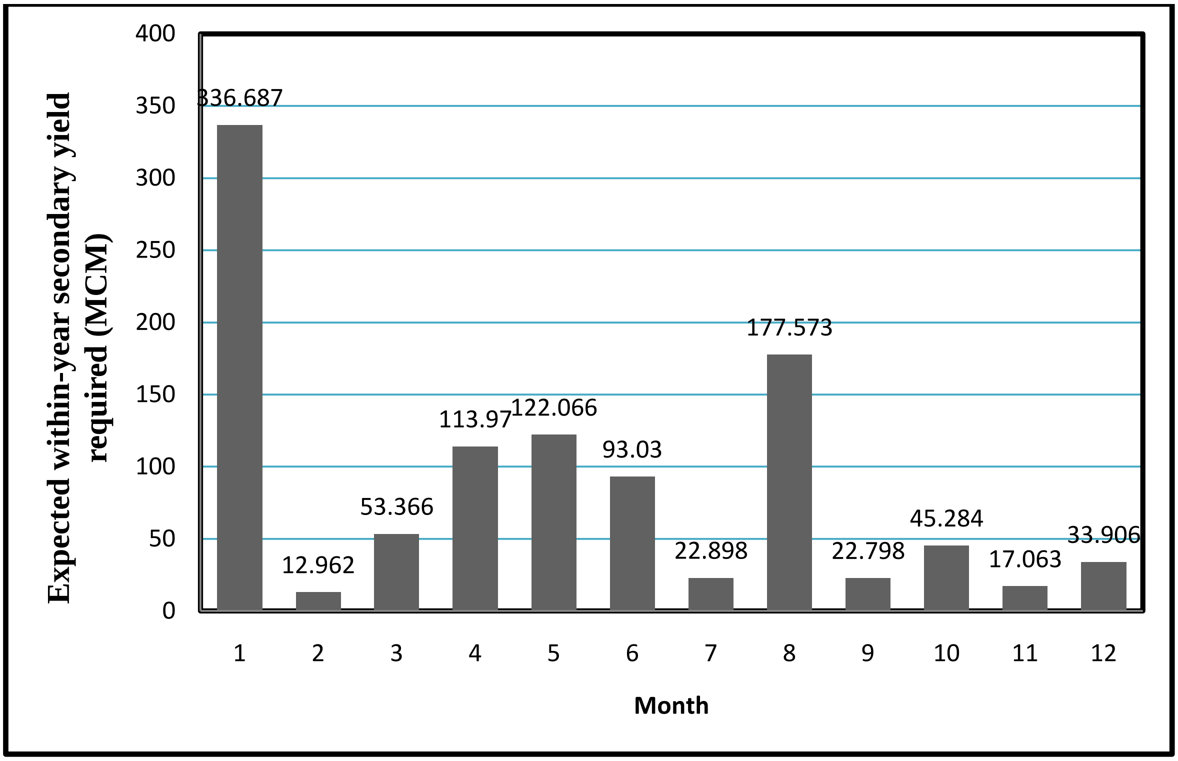


Fig.8.B.2(c) Expected within-year secondary yield in Betwa basin with export

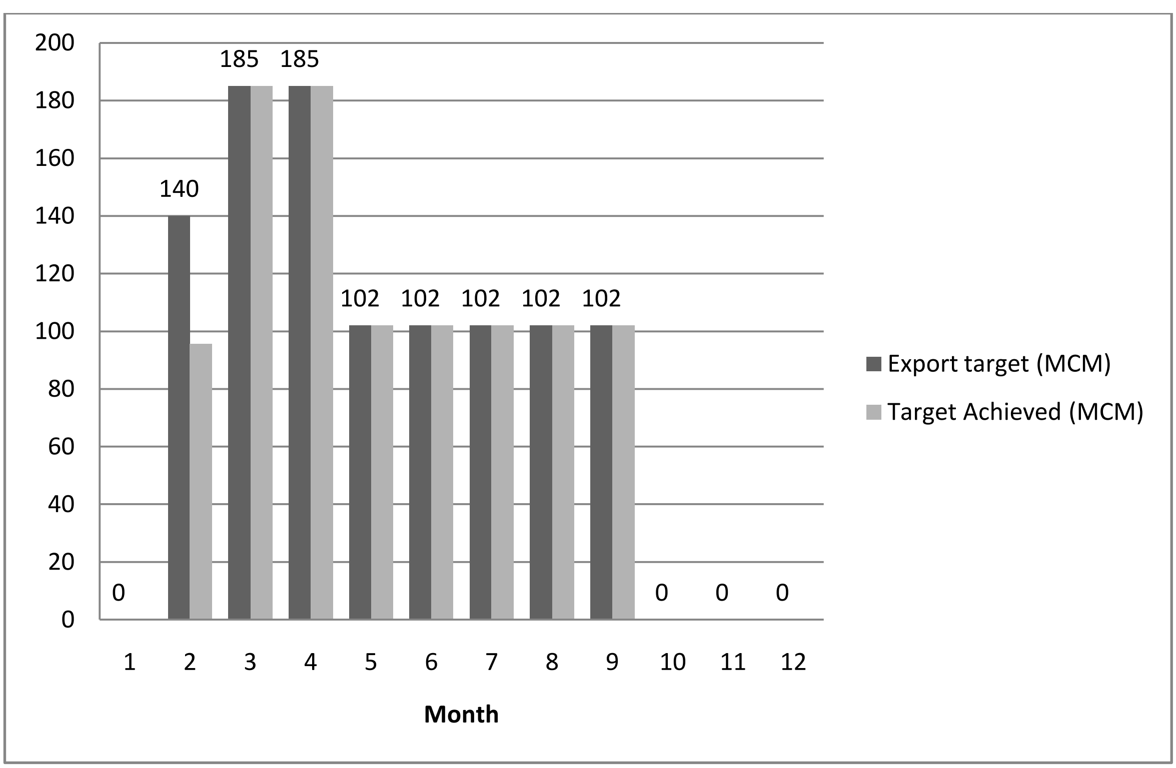


Fig.8.K.3.1 Monthly water export targets achieved at Daudhan reservoir with export

Chapter 9

COMPUTATION AND ANALYSIS OF MOFLP MODEL RESULTS

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 two river basins involved in this study in which water is to be exported from the reservoir Daudhan in the Ken basin to the Betwa basin.

Earlier the Chapter-5 discussed the application of the model IRYM for planning and analysing the Ken-Betwa water export link proposal and in the Chapter 8 the results obtained were analysed. Secondly, then to evaluate the optimal operation policy at the water export point Daudhan in the Ken basin the multi objective fuzzy linear programming (MOFLP) was employed as described earlier in the Chapter-6. The derivation of the various parameters to be used in the MOFLP model, the assessment of the water resources of these river basins is presented in the Chapter-7. This chapter deals with the computation of MOFLP and analyse the results.

The analysis is described in this chapter in the manner given below.

1. The analysis is carried out at Daudhan reservoir with and without export (a) for crops, (b) for the within year reservoir storages and (c) for the within year reservoir firm and secondary reservoir yields.
2. The analysis is carried out at each reservoir in Ken and Betwa basin to obtain compromise solutions for annual firm yield and annual secondary yield in the light of existing water scenarios.

9.1 COMPUTATION USING MOFLP MODEL

By adopting the MOFLP algorithm already explained in Chapter 6, the computations are done as follows:

Step-1: Using MOLP the best Z^+ and the worst Z^- values for both the objectives viz., Z_1 and Z_2 are determined by considering one objective at a time. For solution 20 years of annual inflows and 12 within year time periods (monthly) were considered. The annual inflow ranges from

3727.95 MCM to 13431.86 MCM. The value of EV^0 is 35.78 MCM. The water supply requirement for en-route of the link canal is 11.75 MCM, after considering transmission losses the water supply requirement is taken as 12.195 MCM. The annual release reliabilities for water supply and irrigation in the model considered were 100% and 75%, respectively. For the projects in Betwa basin the worst Z^- value is considered as minimum water requirements to meet the demand of agriculture population of the command are of project. The LINDO (2002) release 6.1 is used for the solution of MOLP model. The constraint method of multi objective analysis is used, i.e., when Z_1 is maximized, the corresponding value of Z_2 is considered to be the worst and is put as a constraint in the model and vice-versa. The worst values of the annual water supply objective (Z_1^-) and annual irrigation objective (Z_2^-) were taken as the export target for annual water supply from the project and annual irrigation target of the project. No other water export requirements for irrigation from the project were considered and were clubbed with the irrigation at the project for simplicity.

Step-2: Once the upper and lower limits of the objective functions are determined, the objective functions are Fuzzifier by considering a linear membership functions.

The formulation of MOFLP model for the planning problem is as follows:

Considering water supply as the objective 1 and irrigation as the objective 2, i.e. ,

$Z_1 = Oy^{fp}$ And $Z_2 = Oy^{fp2}$ we get

Maximize λ

Subject to:

$$\mu_1(X) \geq \lambda \text{ Or} \left[\frac{Oy^{fp} - Z_1^L}{Z_1^U - Z_1^L}\right]^{\beta} \geq \lambda \qquad \text{for } Z_1^L \leq Oy^{fp} \leq Z_1^U \qquad (9.1)$$

$$\mu_2(X) \geq \lambda \text{ Or} \left[\frac{Oy^{sp2} - Z_2^L}{Z_2^U - Z_2^L}\right]^{\beta} \geq \lambda \qquad \text{for } Z_2^L \leq Oy^{sp2} \leq Z_2^U \qquad (9.2)$$

$$0 \leq \lambda \leq 1 \qquad (9.3)$$

Where μ_1 and μ_2 are membership functions for water supply and irrigation, respectively. Z_1^U And Z_1^L, and Z_2^U and Z_2^L are the upper and lower bounds for annual water supply (firm yield) and irrigation (secondary yield), respectively.

Step-3: By incorporating the above information by substituting these values in the above equations (9.1) and (9.2) and fixing β = 1 for linear membership function yields the following MOFLP for Daudhan reservoir:

$$\mu_1(X) = 0 \qquad \text{For} \quad Oy^{fp} \le 12.195 \qquad (9.4)$$

$$\mu_1(X) = \left(\frac{Oy^{fp} - 12.195}{1829.85 - 12.195}\right) \ge \lambda \qquad \text{For} \quad 12.195 \le Oy^{fp} \le 1829.85 \qquad (9.5)$$

$$\mu_1(X) = 1 \qquad \text{For} \quad Oy^{fp} \ge 1829.85 \qquad (9.6)$$

$$\mu_2(X) = 0 \qquad \text{For} \quad Oy^{sp2} \le 0 \qquad (9.7)$$

$$\mu_2(X) = \left(\frac{Oy^{sp2} - 0}{1121.70 - 0}\right) \ge \lambda \qquad \text{For} \quad 0 \le Oy^{sp2} \le 1121.70 \qquad (9.8)$$

$$\mu_2(X) = 1 \qquad \text{For} \quad Oy^{sp2} \ge 1121.70 \qquad (9.9)$$

In this formulation, λ is the level of satisfaction derived by simultaneously optimizing the Fuzzifier objectives Z_1 and Z_2.

Step-4: Now finally the MOFLP to be solved is:

Maximize λ

Subject to:

$$0.000892\, Oy^{fp} - \lambda \ \ge 0.00671$$

$$12.195 \le Oy^{fp} \le 1829.85$$

$$0.000892\, Oy^{sp2} - \lambda \ \ge 0$$

$$0 \le Oy^{sp2} \le 1121.70$$

$$0 \le \lambda \le 1$$

And subject to set of constraints of IRYM model as presented in Chapter 5.

The solution of this LP model is obtained and the value of λ (maximum level of satisfaction) was found to be 0.618 for Z_1* equal to 1135.506 and Z_2*equal to 693.211, respectively. It may be possible to optimally supply 1135.506 mcm, (Z_1*) for water supply at 100% annual project reliability and 693.211 mcm (Z_2*) for irrigation at 75% annual project reliability. The results are shown in Table 9.1.

The solution of this LP model is also obtained considering worst value of Z_1 as water requirement to meet the minimum food for agricultural population as a firm yield. The value of λ (maximum level of satisfaction) was found to be 0.43 for Z_1* equal to 1349.35 and Z_2*equal to 480.58, respectively.

In Betwa basin the worst value of firm yield is considered as water requirement to meet the minimum food for agricultural population and worst value of secondary yield is taken as zero. In the four projects (Richhan, Halali, Barari and Parichha) the water requirement to meet the minimum food for agricultural population is higher than the upper bound of secondary yield. ($Z_2^U < Z_2^L$). For these four projects the worst value of firm yield is assumed as 10% of firm yield to calculate the membership function and satisfaction level. The results are shown in Table 9.2.

The MOFLP model is applied to the integrated Ken Betwa link and the results of annual firm, secondary and total yields are presented in Table 9.3.

Table: 9.1: Objective function values for different satisfaction levels for Daudhan

Sl. No.	Degree of satisfaction		Objective Value	
	$\mu_2(X)$	$\mu_2(X)$	Z_1 (Mcum)	Z_2 (Mcum)
1	0	0	12.195	0.000
2	0.1	0.1	193.961	112.170
3	0.2	0.2	375.726	224.340
4	0.3	0.3	557.492	336.510
5	0.4	0.4	739.257	448.680
6	0.5	0.5	921.023	560.850
7	0.6	0.6	1102.788	673.020
8	0.618	0.618	1135.506	693.211
9	0.7	0.7	1284.554	785.190
10	0.8	0.8	1466.319	897.360
11	0.9	0.9	1648.085	1009.530
12	1	1	1829.850	1121.700

Table 9.2: Optimal compromise degree of satisfaction and objective function values for different projects in MOFLP model

Sl. No.	Name of the Project	Step – 1 Firm Yield (MCM)		Step – 2 Secondary Yield (MCM)		Step – 3 Optimal compromise Yield in (MCM)		
		Max. Firm yield	Min. Firm Yield (To meet min. food requirements of agriculture population)	Max.Secondary Yield	Min.Secondary Yield	Optimal Compromise Degree of satisfaction (lemda)	Optimal Firm Yield	Optimal Secondary Yield
1	Daudhan	1829.85	989.28	1121.70	0.00	0.43	1349.37	480.50
2	Kerwan	27.07	11.11	18.27	0.00	0.47	18.55	8.52
3	Kaliasote	28.34	12.60	20.72	0.00	0.49	20.41	10.28
4	Neemkheda	7.04	2.89	4.75	0.00	0.47	4.82	2.22
5	Richhan	0.88	0.09*	1.06	0.00	0.82	0.74	0.98
6	Halali	51.67	5.17*	37.75	0.00	0.58	32.55	21.94
7	Barari	46.59	4.66*	31.45	0.00	0.57	28.62	17.97
8	Kesari	12.31	5.05	8.31	0.00	0.47	8.34	3.87
9	Kethan	16.90	6.94	11.41	0.00	0.47	11.47	5.42
10	Koncha	25.19	10.34	17.00	0.00	0.47	17.26	7.92
11	Mola	16.06	6.59	10.84	0.00	0.46	11.00	5.05
12	Rajghat	592.65	476.19	576.72	0.00	0.45	528.76	260.35
13	Matatila	685.52	305.59	502.53	0.00	0.50	494.55	249.94
14	Dukwan	22.62	9.92	15.27	0.00	0.47	15.50	7.12
15	Barwa sagar	7.47	4.56	6.02	0.00	0.39	5.70	2.35
16	Parichha	120.72	12.07*	81.49	0.00	0.57	74.16	46.56

Table 9.3: Optimal Yields in different projects using MOFLP model in Integrated Ken-Betwa link

Sl. No.	Name of the Project	Firm Yield (MCM)	Secondary Yield (MCM)	Total Yield (MCM)
1	Daudhan	99.79	11.26	111.05
2	Kerwan	27.07	0.00	27.07
3	Kaliasote	25.66	5.02	30.68
4	Neemkheda	1.26	0.00	1.26
5	Richhan	0.57	1.19	1.76
6	Halali	18.17	37.75	55.92
7	Barari	50.33	0.00	50.33
8	Kesari	12.31	0.00	12.31
9	Kethan	16.47	0.43	16.90
10	Koncha	15.28	9.90	25.18
11	Mola	16.06	0.00	16.06
12	Rajghat	870.30	277.09	1147.39
13	Matatila	57.96	52.29	110.25
14	Dukwan	0.00	0.00	0.00
15	Barwa sagar	0.00	0.00	0.00
16	Parichha	94.92	6.79	101.71
	Total	1306.15	401.72	1707.87

9.2 ANALYSIS OF MOFLP RESULTS

The analysis is described in this chapter in two ways as follows:

Firstly, it is done at the Daudhan reservoir with and without exports; (a) for crops, (b) for the within year reservoir storages and (c) for the within year reservoir firm and secondary reservoir yields. Secondly, it is done at each reservoir in Ken and Betwa basin for obtaining compromise solutions for annual firm yields and annual secondary yields in the light of existing water scenarios.

9.2.1 Analysis of Crops at 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 analyse for the crops grown in the basins in detail.

The results of the crops involved are assessed and analysed at the Daudhan reservoir at project level. At the reservoir project level the assessment is based on the modelled total cropped intensities. The later criterion is also followed while analysing 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.

9. K.1 Analysis for Crops at Ken with export.

9. K.1.1 Crop intensities achieved at the reservoir levels in Ken basin.

The total cropped intensity achieved at Daudhan reservoir in Ken basin is summarized in Table-9.K.1.1.It is found that a total cropped intensity of 0.104is achieved, out of which 0.066 for self and 0.038 for en-route.

9. K.1.2 Crop intensities achieved for each crop in Ken

The total cropped intensity achieved and their percentexceedance for average cropped intensities for each crop at reservoir Daudhan in Ken basin are summarized in Table-9.K.1.2 and Figure- 9.K.1.2. It is found that at Daudhan the crops kharif pulses have a maximum total cropped intensity / average cropped intensityof 0.029 with the lowest percent exceedance of 8**.** On the other hand the crops en-route kharif jowar, en-route kharif fodder, en-route kharif pulses and en-route kharif vegetable with a minimum total cropped intensity / average cropped intensity of 0.003 have the highest percent exceedance of 91.

9.2.2 Analysis of Storages, Firm Yield and Secondary Yields for Within Year Periods

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 Ken basin was therefore estimated from the model results.

The expected total within year storage available from all the reservoirs in the basin for finalizing broad tentative reservoir release schedule.

(i) 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.

(ii) 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 analysed 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 analysed 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.

9. K.2 Analysis at Ken with export

In Ken 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-9.K.2 (a) and Figure-9.K.2 (a). It is found that the expected maximum total within year storages of 102.344 MCM at the Daudhan reservoir would be available in the month of October and November. On the other hand the expected minimum total within year storages of 19.665 MCM at the reservoir would be available in the months of August. The months of July would have no within year storages.

(b) Similarly, the expected total within-year firm yields that are likely to be available from reservoir Daudhan are presented in Table-9.K.2 (b) and Figure-9.K.2 (b). It is found that the expected maximum total within year firm yield of 29.864 MCM at the Daudhan reservoir would be available in the month of June to meet the water requirements for self and en-route irrigation. On the other hand the expected minimum total within year firm yield of 0.586 MCM at the reservoir would be available in the month of July. The months of November, April and May would have no yields.

(c) There are no within-year secondary yields that are likely to be available at the reservoir Daudhan.

The percent exceedances of the above maximum and the minimum values would be 91% and 8% for the within year storage, respectively.But for the within year firm yields the percent exceedances of the above maximum and the minimum values would be 69% and 7%, respectively.

9. K.3 Analysis for Crops at Ken without export.

9. K.3.1 Crop intensities achieved at the reservoir levels in Ken basin.

The total cropped intensity achieved at Daudhan reservoir in Ken basin is summarized in Table-9.K.3.1. It is found that a total cropped intensity of 1.277 is achieved, out of which 1.146 for self and 0.131 for en-route.

9. K.3.2 Crop intensities achieved for each crop in Ken

The total cropped intensity achieved and their percentexceedance for average cropped intensities for each crop at reservoir Daudhan in Ken basin are summarized in Table-9.K.3.2 and Figures9.K.3.2 (a) and 9.K.3.2 (b). It is found that at Daudhan the crops Rabiwheat has a maximum total cropped intensity / average cropped intensityof 0.3264 with the lowest percent exceedance of 4**.** On the other hand the crops en-route kharif jowar, en-route kharif bajara, en-route kharif fodder, en-route kharif maize, en-route kharif pulsesanden-route kharif vegetable with a minimum total cropped intensity / average cropped intensity of 0.0037 have the highest percent exceedance of 96.

9.2.3 Analysis of Storages, Firm Yield and Secondary Yields for Within Year Periods

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 Ken basin was therefore estimated from the model results.

The expected total within year storage available from all the reservoirs in the basin for finalizing broad tentative reservoir release schedule.

(i) 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.

(ii) 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 analysed 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 analysed 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.

9. K.4 Analysis at Ken without export

In Ken basin the following is achievedduring a normal water year:

(i) The expected total within-year storages that are likely to be available are presented in Table-9.K.4 (a) and Figure-9.K.4 (a). It is found that the expected maximum total within year storages of 1348.11MCM at the Daudhan reservoir would be available in the month of October. On the other hand the expected minimum total within year storages of 242.38 MCM at the reservoir would be available in the months of June. The months of July would have no within year storages.

(ii) Similarly, the expected total within-year firm yields that are likely to be available from reservoir Daudhan are presented in Table-9.K.4 (b) and Figure-9.K.4 (b). It is found that the expected maximum total within year firm yield of 349.72 MCM at the Daudhan reservoir would be available in the month of June. On the other hand the expected minimum total within year firm yield of 5.07 MCM at the reservoir would be available in the month of April. The months of July, November, January and March would have no yields.

(iii) Similarly, the expected total within-year secondary yields that are likely to be available from reservoir Daudhan are presented in Table-9.K.4(c) and Figure-9.K.4(c). It is found that the expected maximum total within year secondary yield of 253.77 MCM at the Daudhan reservoir would be available in the month of January. On the other hand the expected minimum total within year secondary yield of 4.98 MCM at the reservoir would be available in the month of July. The months of June, August, September, December, April and May would have no yields.

The percent exceedances of the above maximum and the minimum values would be 94% and 7% for the within year storage, respectively.For the within year firm yields the percent exceedances of the above maximum and the minimum values would be 61% and 7%, respectively. For the within year secondary yields the percent exceedances of the above maximum and the minimum values would be 38% and 7%, respectively.

9.2.4 Analysis to Obtain Compromise Solutions

The results are assessed and analysed at all the reservoirs in Ken Betwa basin at project level and for integrated Ken Betwa link in the following manner.

(1) The percentage of annual irrigation target that the project would meet along with annual firm, secondary and total yield.

(2) The maximum annual secondary yield (irrigation), which would be possible to meet additional irrigation requirements at 75% annual project reliability.

(3) The maximum possible annual firm yield (water supply / irrigation).

(4) The best compromise solution possible for annual firm yield and annual secondary yield with the degree of satisfaction in the light of existing water scenarios.

The objective functions are considered as fuzzy and the constraints are considered as non-fuzzy (crisp) in the MOFLP model for operation of the reservoirs. To study the Daudhan reservoir the two objectives considered are to maximise annual releases for water supply and to maximise annual releases for irrigation. The study has been also carried out considering the two objectives as to maximise annual firm releases for irrigation and to maximise annual secondary releases for irrigation. Taking the worst value of firm yield as water requirement to meet the minimum food for agricultural population and worst value of secondary yield is taken as zero

The two objectives considered in the study of reservoirs in Betwa basin are to maximise annual firm releases and to maximise annual secondary releases. In Betwa basin the worst value of firm yield is considered as water requirement to meet the minimum food for agricultural population and worst value of secondary yield is taken as zero. In the four projects (Richhan, Halali, Barari and Parichha) the water requirement to meet the minimum food for agricultural population is higher than the upper bound of secondary yield in equation 8.2. ($Z_2^U < Z_2^L$). For these four projects the worst value of firm yield is assumed as 10% of firm yield to calculate the membership function and satisfaction level.

Daudhan Project

1. The Daudhan irrigation project would be able to meet optimally 1829.85 MCM of annual irrigation requirements which is 110.73% of its annual irrigation target. Out of this the annual firm and secondary yields would be 708.15 MCM and 1129.69 MCM, respectively.
2. In maximizing the annual secondary yield (irrigation), it would be possible to meet a total of 1121.70 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 708.15 MCM (which is higher than the value of12.195 MCM required to meet demand of drinking water (minimum firm yield) at 100%annual project reliability.
3. In maximizing the annual firm yield (water supply), it would be possible to supply 1829.85 MCM as firm yield annually. This could meet in future the irrigation water needs at 100%annual project reliability, but, there would be no additional water available as an annual secondary yield to meet the irrigation demand.
4. The best compromise solution would possibly supply optimally 1135.50 MCM(i.e., lying between 1829.85 MCM and 12.195 MCM) as an annual firm yield (water supply) and 693.21MCM (i.e., lying between 1121.70 MCM and 0.00 MCM) as annual secondary yield (irrigation) with the degree of satisfaction of 0.62 as presented in Figure 9.1.
5. In maximizing the annual secondary yield, it would be possible to meet a total of 1121.70 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 708.15 MCM

(which is lower than the value of 989.28 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.

6. In maximizing the annual firm yield, it would be possible to supply 1829.85 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population.But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

7. The best compromise solution would possibly supply optimally 1349.35 MCM(i.e., lying between 1829.85 MCM and 989.28 MCM) as an annual firm yield and 480.50 MCM(i.e., lying between 1121.70 MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.43 as presented in Figure 9.2.

Kerwan Project

1. The Kerwan irrigation project would be able to meet optimally 27.07 MCM of annual irrigation requirements which is 122.93% of its annual irrigation target. Out of this the annual firm and secondary yields would be 8.80 MCM and 18.27 MCM, respectively.

2. In maximizing the annual secondary yield, it would be possible to meet a total of 18.27 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 8.80 MCM (which is lower than the value of 11.11 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.

3. In maximizing the annual firm yield, it would be possible to supply 27.07 MCM as firm yield annually. This could meet in future the irrigation water needs at 100%annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population.But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

4. The best compromise solution would possibly supply optimally 18.55MCM(i.e., lying between 27.07 MCM and 11.11 MCM) as an annual firm yield and 8.52 MCM(i.e., lying between 18.27 MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.47 as presented in Figure 9.3.

Kaliasote Project

1. The Kaliasote irrigation project would be able to meet optimally 30.69 MCM of annual irrigation requirements which is 128.60% of its annual irrigation target. Out of this the annual firm and secondary yields would be 18.37 MCM and 12.32 MCM, respectively.
2. In maximizing the annual secondary yield, it would be possible to meet a total of 20.72 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 9.97 MCM (which is lower than the value of12.60 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.
3. In maximizing the annual firm yield, it would be possible to supply 28.34 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population. But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.
4. The best compromise solution would possibly supply optimally 20.41MCM (i.e., lying between 28.34 MCM and 12.60 MCM) as an annual firm yield and 10.23MCM (i.e., lying between 20.72MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.49 as presented in Figure 9.4.

Neemkheda Project

1. The Neemkheda irrigation project would be able to meet optimally 7.05 MCM of annual irrigation requirements which is 122.93% of its annual irrigation target. Out of this the annual firm and secondary yields would be 2.29 MCM and 4.75 MCM, respectively.
2. In maximizing the annual secondary yield, it would be possible to meet a total of 4.75 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 2.29 MCM (which is lower than the value of 2.89 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.

3. In maximizing the annual firm yield, it would be possible to supply 7.05 MCM as firm yield annually. This could meet in future the irrigation water needs at 100 %annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population.But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

4. The best compromise solution would possibly supply optimally 4.82MCM (i.e., lying between 7.05 MCM and 2.89 MCM) as an annual firm yield and 2.22MCM (i.e., lying between 4.75MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.47 as presented in Figure 9.5.

Richhan Project

1. The Richhan irrigation project would be able to meet optimally 1.76 MCM of annual irrigation requirements which is 26.95% of its annual irrigation target. Out of this the annual firm and secondary yields would be 0.57 MCM and 1.19 MCM, respectively.

2. It would not be possible to meet irrigation at 75% annual project reliability after meeting the irrigation demand of 3.29 MCM required to meet the minimum food requirement for agricultural population

3. Considering the worst value of firm yield as 10% of maximum firm yield i.e. 0.09 MCM, the best compromise solution would possibly supply optimally 0.74MCM (i.e., lying between 0.88 MCM and 0.09 MCM) as an annual firm yield and 0.98MCM (i.e., lying between 1.06MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.82 as presented in Figure 9.6.

Halali Project

1. The Halali irrigation project would be able to meet optimally 55.92 MCM of annual irrigation requirements which is 40.95% of its annual irrigation target. Out of this the annual firm and secondary yields would be 18.17 MCM and 37.74 MCM, respectively.

2. It would not be possible to meet irrigation at 75% annual project reliability after meeting the irrigation demand of 103.35 MCM required to meet the minimum food requirement for agricultural population

3. Considering the worst value of firm yield as 10% of maximum firm yield i.e. 5.16 MCM, the best compromise solution would possibly supply optimally 32.20MCM (i.e., lying between 51.67 MCM and 5.16 MCM) as an annual firm yield and 21.94MCM (i.e., lying between 37.75MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.58 as presented in Figure 9.7.

Barari Project

1. The Barari irrigation project would be able to meet optimally 46.59 MCM of annual irrigation requirements which is 26.05% of its annual irrigation target. Out of this the annual firm and secondary yields would be 19.01 MCM and 27.58 MCM, respectively.
2. It would not be possible to meet irrigation at 75% annual project reliability after meeting the irrigation demand of 90.26 MCM required to meet the minimum food requirement for agricultural population
3. Considering the worst value of firm yield as 10% of maximum firm yield i.e. 4.65 MCM, the best compromise solution would possibly supply optimally 28.62MCM (i.e., lying between 46.59 MCM and 4.65 MCM) as an annual firm yield and 17.97MCM (i.e., lying between 31.45MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.57 as presented in Figure 9.8.

Kesari

1. The Kesari irrigation project would be able to meet optimally 12.31 MCM of annual irrigation requirements which is 120.97% of its annual irrigation target. Out of this the annual firm and secondary yields would be 4.00 MCM and 8.31 MCM, respectively.
2. In maximizing the annual secondary yield, it would be possible to meet a total of 8.31 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 4.0 MCM (which is lower than the value of 5.05 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.
3. In maximizing the annual firm yield, it would be possible to supply 12.31 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for

agricultural population arising due to drastic increase in population.But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

4. The best compromise solution would possibly supply optimally 8.34 MCM (i.e., lying between 12.31 MCM and 5.05 MCM) as an annual firm yield and 3.87MCM (i.e., lying between 8.31MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.47 as presented in Figure 9.9.

Kethan

1. The Kethan irrigation project would be able to meet optimally 16.90 MCM of annual irrigation requirements which is 124.54% of its annual irrigation target. Out of this the annual firm and secondary yields would be 16.90 MCM and 0.00 MCM, respectively.
2. In maximizing the annual secondary yield, it would be possible to meet a total of 11.41 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 5.49 MCM (which is lower than the value of 6.94 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.
3. In maximizing the annual firm yield, it would be possible to supply 16.90 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population. But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.
4. The best compromise solution would possibly supply optimally 11.47 MCM (i.e., lying between 16.90 MCM and 6.94 MCM) as an annual firm yield and 5.42 MCM (i.e., lying between 11.41MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.47 as presented in Figure 9.10.

Koncha

1. The Koncha irrigation project would be able to meet optimally 25.19 MCM of annual irrigation requirements which is 122.94% of its annual irrigation target. Out

of this the annual firm and secondary yields would be 16.94 MCM and 8.24 MCM, respectively.

2. In maximizing the annual secondary yield, it would be possible to meet a total of 17.00MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 8.16 MCM (which is lower than the value of10.34 MCM required to meet the minimum food requirement for agricultural population) at 100% annual project reliability.

3. In maximizing the annual firm yield, it would be possible to supply 25.19 MCM as firm yield annually. This could meet in future the irrigation water needs at 100%annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population. But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

4. The best compromise solution would possibly supply optimally 17.26MCM (i.e., lying between 25.19 MCM and 10.34 MCM) as an annual firm yield and 7.92MCM (i.e., lying between 17.00MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.47as presented in Figure 9.11.

Mola

1. The Mola irrigation project would be able to meet optimally 16.06 MCM of annual irrigation requirements which is 122.97% of its annual irrigation target. Out of this the annual firm and secondary yields would be 10.20 MCM and 5.84 MCM, respectively.

2. In maximizing the annual secondary yield, it would be possible to meet a total of 10.84 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 5.21 MCM (which is lower than the value of 6.59 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.

3. In maximizing the annual firm yield, it would be possible to supply 16.06 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population. But, there

would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

4. The best compromise solution would possibly supply optimally 11.00MCM (i.e., lying between 16.06 MCM and 6.59 MCM) as an annual firm yield and 5.05MCM (i.e., lying between 10.84MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.47 as presented in Figure 9.12.

Rajghat

1. The Rajghat irrigation project would be able to meet optimally 854.40 MCM of annual irrigation requirements which is 90.54% of its annual irrigation target. Out of this the annual firm and secondary yields would be 277.68 MCM and 576.72 MCM, respectively.

2. In maximizing the annual secondary yield, it would be possible to meet a total of 576.72 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 277.68 MCM (which is lower than the value of 476.18 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.

3. In maximizing the annual firm yield, it would be possible to supply 592.65 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population. But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

4. The best compromise solution would possibly supply optimally 528.76 MCM (i.e., lying between 592.65 MCM and 476.18 MCM) as an annual firm yield and 260.35 MCM (i.e., lying between 576.72MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.45 as presented in Figure 9.13.

Matatila

1. The Matatila irrigation project would be able to meet optimally 744.49 MCM of annual irrigation requirements which is 122.93% of its annual irrigation target. Out of this the annual firm and secondary yields would be 241.96 MCM and 502.53 MCM, respectively.

2. In maximizing the annual secondary yield, it would be possible to meet a total of 502.53 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 241.96 MCM (which is lower than the value of 305.59 MCM required to meet the minimum food requirement for agricultural population) at 100% annual project reliability.
3. In maximizing the annual firm yield, it would be possible to supply 685.52 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population.But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.
4. The best compromise solution would possibly supply optimally 494.55 MCM (i.e., lying between 685.52 MCM and 305.59 MCM) as an annual firm yield and 249.94 MCM (i.e., lying between 502.53MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.50 as presented in Figure 9.14.

Dukwan

1. The Dukwan irrigation project would be able to meet optimally 22.62 MCM of annual irrigation requirements which is 125.67% of its annual irrigation target. Out of this the annual firm and secondary yields would be 15.22 MCM and 7.40 MCM, respectively.
2. In maximizing the annual secondary yield, it would be possible to meet a total of 15.27 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 7.35 MCM (which is lower than the value of 9.29 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.
3. In maximizing the annual firm yield, it would be possible to supply 22.67 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population.But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

4. The best compromise solution would possibly supply optimally 15.50MCM (i.e., lying between 22.62 MCM and 9.29 MCM) as an annual firm yield and 7.12 MCM (i.e., lying between 15.27MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.47 as presented in Figure 9.15.

Barwa Sagar

1. The Barwa Sagar irrigation project would be able to meet optimally 8.91 MCM of annual irrigation requirements which is 98.67% of its annual irrigation target. Out of this the annual firm and secondary yields would be 2.89 MCM and 6.02 MCM, respectively.
2. In maximizing the annual secondary yield, it would be possible to meet a total of 6.02 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 2.89 MCM (which is lower than the value of 4.65 MCM required to meet the minimum food requirement for agricultural population) at 100%annual project reliability.
3. In maximizing the annual firm yield, it would be possible to supply 7.47 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population.But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.
4. The best compromise solution would possibly supply optimally 5.70 MCM (i.e., lying between 7.47 MCM and 4.56 MCM) as an annual firm yield and 2.35 MCM (i.e., lying between 6.02MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.39 as presented in Figure 9.16.

Parichha Project

1. The Parichha irrigation project would be able to meet optimally 120.72 MCM of annual irrigation requirements which is 05.26% of its annual irrigation target. Out of this the annual firm and secondary yields would be 39.29 MCM and 81.48 MCM, respectively.

2. It would not be possible to meet irrigation at 75% annual project reliability after meeting the irrigation demand of 1155.57 MCM required to meet the minimum food requirement for agricultural population

3. Considering the worst value of firm yield as 10% of maximum firm yield i.e. 12.07 MCM, the best compromise solution would possibly supply optimally 74.16 MCM (i.e., lying between 120.72 MCM and 12.07 MCM) as an annual firm yield and 46.56 MCM (i.e., lying between 81.49MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.57 as presented in Figure 9.17.

Ken - Betwa Link

1. The complete Ken-Betwa link system would be able to meet optimally 1738.71 MCM of annual irrigation requirements which is 29.23% of its annual irrigation target. Out of this the annual firm and secondary yields would be 784.71 MCM and 954.00 MCM, respectively.

2. In maximizing the annual secondary yield, it would be possible to meet a total of 1161.00 MCM of additional irrigation requirements at 75% annual project reliability over and above after meeting the annual firm irrigation demand of 622.71 MCM (which is lower than the value of 1048.00 MCM required to meet the minimum food requirement for agricultural population) at 100% annual project reliability.

3. In maximizing the annual firm yield, it would be possible to supply 1794.03 MCM as firm yield annually. This could meet in future the irrigation water needs at 100% annual project reliability, required to meet the minimum food requirements for agricultural population arising due to drastic increase in population. But, there would be no additional water available as an annual secondary yield to meet any other food needs except the minimum food needs.

4. The best compromise solution would possibly supply optimally 1306.18 MCM (i.e., lying between 1794.03 MCM and 1408.00 MCM) as an annual firm yield and 401.74 MCM (i.e., lying between 1161.00MCM and 0.00 MCM) as annual secondary yield with the degree of satisfaction of 0.35 as presented in Figure 9.18.

9.2.5 Application of Continuous Hedging Rules

In the present study, it is tried to utilize the results of optimization model to estimate Kpt values related to CHR. These Kpt values are used later as an initial guess for the simulation work to find the set of monthly Kpt values which will provide the best reservoir operation performance.

The estimate of Kpt values can be written for each month as:

Kpt = (Initial reservoir storage + Inflow) / (Release + Evaporation) (9.1)

From the within year time period results from the models Kpt values are shown in Tables 9.4 to 9.7.

Table-9.K.1.1 Total cropped intensity achieved at each reservoir in Ken basin with export. (MOFLP)

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
1	Ken	1	Ken	1	Dauhan	0.104

Table- 9.K.1.2 Total cropped intensity and average cropped intensity achieved for each crop in Ken basin with export (MOFLP)

Sl. No.	Crop Name	Total Cropped Intensity	% Exceedance	AverageCropped Intensity	Crop Name
1	KKPD	0.007	8	0.029	KKPL
2	KKPL	0.029	16	0.014	ERWL
3	KRWH	0.011	25	0.012	KRWL
4	KRWL	0.012	33	0.011	KRWH
5	EKPD	0.005	41	0.007	ERFD
6	EKJW	0.003	50	0.007	KKPD
7	EKFD	0.003	58	0.005	EKPD
8	EKPL	0.003	66	0.003	EKJW
9	EKVG	0.003	75	0.003	EKFD
10	ERWL	0.014	83	0.003	EKPL
11	ERFD	0.007	91	0.003	EKVG

Table-9.K.2 (a) Expected total within-year storages available in Ken basinin a normal water year with export. (MOFLP)

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	Jun	26.096	1	8	102.344
2	Jul	0.000	2	16	102.344
3	Aug	19.665	3	25	93.869
4	Sep	83.464	4	33	83.464
5	Oct	102.344	5	41	80.305
6	Nov	102.344	6	50	63.876
7	Dec	93.869	7	58	45.804
8	Jan	80.305	8	66	38.936
9	Feb	63.876	9	75	33.235
10	Mar	45.804	10	83	26.096
11	Apr	38.936	11	91	19.665
12	May	33.235	12	-	-

Table-9.K.2 (b) Expected within-year firm yield in Ken basin with export. (MOFLP)

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	Jun	29.864	1	7	29.864
2	Jul	0.582	2	15	18.745
3	Aug	1.481	3	23	18.039
4	Sep	7.679	4	30	14.574
5	Oct	4.114	5	38	7.679
6	Nov	0.000	6	46	4.716
7	Dec	14.574	7	53	4.114
8	Jan	18.039	8	61	1.481
9	Feb	18.745	9	69	0.582
10	Mar	4.716	10	-	-
11	Apr	0.000	11	-	-
12	May	0.000	12	-	-

Table-9.K.3.1 Total cropped intensity achieved at Daudhan reservoir in Ken basin without export. (MOFLP)

Basin No.	Basin Name	Sub-Basin No.	Sub-Basin Name	Reservoir No.	Reservoir Name	Total Cropped Intensity
1	Ken	1	Ken	1	Daudhan	1.277

Table-9.K.3.2 Total cropped intensity and average cropped intensity achieved for each crop in Daudhan reservoir without export (MOFLP)

Sl.No.	Crop Name	Total Cropped Intensity	% Exceedance	Average Cropped intensity	Crop Name
1	KKPD	0.1632	4	0.3264	KRWH
2	KKMZ	0.0653	7	0.1632	KKPD
3	KKPL	0.1224	11	0.1224	KKPL
4	KKOL	0.0979	15	0.0979	KKOL
5	KKVG	0.0408	19	0.0653	KKMZ
6	KRWH	0.3264	22	0.0653	KRGR
7	KRWL	0.0408	26	0.0653	KRMS
8	KRGR	0.0653	30	0.0589	EKPD
9	KRLN	0.0408	33	0.0589	ERWL
10	KRSF	0.0408	37	0.0408	KKVG
11	KRBR	0.0245	41	0.0408	KRWL
12	KRMS	0.0653	44	0.0408	KRLN
13	EKPD	0.0589	48	0.0408	KRSF
14	EKJW	0.0037	52	0.0245	KRBR
15	EKGN	0.0074	56	0.0074	EKGN
16	EKBJ	0.0037	59	0.0074	ERFD
17	EKFD	0.0037	63	0.0074	ERPL
18	EKMZ	0.0037	67	0.0074	EROL
19	EKPL	0.0037	70	0.0074	ERVG
20	EKVG	0.0037	74	0.0074	ERSC
21	ERWL	0.0589	78	0.0037	EKJW
22	ERFD	0.0074	81	0.0037	EKBJ
23	ERPL	0.0074	85	0.0037	EKFD
24	EROL	0.0074	89	0.0037	EKMZ
25	ERVG	0.0074	93	0.0037	EKPL
26	ERSC	0.0074	96	0.0037	EKVG
	Total	1.2774		1.2774	

Table 9.K.4 (a) Expected total within-year storages available in Daudhan reservoir in a normal water year without export (MOFLP)

Sl.No.	Month	Expected Total Within-Year Reservoir Storages (MCM)	Sl.No.	% Exceedance of Expected Total Within-Year Reservoir Storages	Expected Total Within-Year Reservoir Storages (MCM)
1	Jun	242.38	1	7	1348.11
2	Jul	0	2	15	1165.86
3	Aug	277.52	3	23	1106.09
4	Sep	1106.09	4	30	1023.54
5	Oct	1348.11	5	38	786.51
6	Nov	1165.86	6	46	569.68
7	Dec	1023.54	7	53	330.15
8	Jan	786.51	8	61	277.52
9	Feb	569.68	9	69	257.2
10	Mar	330.15	10	76	248.09
11	Apr	257.2	11	84	242.38
12	May	248.09	12	92	0

Table 9.K.4(b) Expected within-year firm yield in Daudhan reservoir without export (MOFLP)

Sl.No.	Month	Expected Within-Year Firm Yield to meet Water Demands (MCM)	Sl.No.	% Exdeedance of Expected Firm Within-Year Reservoir Yield	Expected Within-Year Firm Yield (MCM)
1	Jun	349.72	1	7	349.72
2	Jul	0	2	15	264.41
3	Aug	19.55	3	23	256.3
4	Sep	120.09	4	30	120.09
5	Oct	256.3	5	38	112.93
6	Nov	0	6	46	19.55
7	Dec	264.41	7	53	8.11
8	Jan	0	8	61	5.07
9	Feb	112.93	9		
10	Mar	0	10		
11	Apr	5.07	11		
12	May	8.11	12		

Table 9.K.4 (c) Expected within-year secondary yield in Daudhan reservoir without export (MOFLP)

Sl.No.	Month	Expected Within-Year Secondary Yield to meet Water Demands (MCM)	Sl.No.	% Exceedance of Expected Secondary Within-Year Reservoir Yield	Expected Within-Year Secondary Yield (MCM)
1	Jun	0	1	7	253.77
2	Jul	4.98	2	15	193.59
3	Aug	0	3	23	155.85
4	Sep	0	4	30	85.45
5	Oct	0	5	38	4.98
6	Nov	193.59	6		
7	Dec	0	7		
8	Jan	253.77	8		
9	Feb	155.85	9		
10	Mar	85.45	10		
11	Apr	0	11		
12	May	0	12		

Table 9.4 Estimation of Kpt values from model IRYM without export

Month (1)	Initial storage (2)	Inflow (3)	Firm Release (4)	Secondary Release (5)	Evapo-ration (6)	Kp_t (7) = [(2)+(3)] / [(4)+(5) +(6)]	1/ Kp_t (8)
Jun	242.381	1355.551	300.901	48.824	5.972	4.492	0.22260
Jul	0	3414.738	0	4.984	2.679	445.64	0.00224
Aug	277.523	10227.58	0	19.556	3.725	451.221	0.00222
Sep	1106.093	4422.756	120.097	0	6.205	43.775	0.02284
Oct	1348.11	942.527	0	256.298	5.251	8.758	0.11418
Nov	1165.864	665.615	193.589	0	3.53	9.291	0.10763
Dec	1023.542	373.538	0	264.408	2.867	5.227	0.19131
Jan	786.515	466.209	0	253.769	2.705	4.884	0.20473
Feb	569.68	391.267	0	268.785	2.868	3.537	0.28269
Mar	330.153	211.42	85.448	0	4.757	6.004	0.16656
Apr	257.201	44.54	0	5.074	7.79	23.457	0.04263
May	248.093	149.591	8.115	0	10.583	21.27	0.04702

All volumes are in MCM.

Table 9.5 Estimation of Kp_t values from model MOFLP without export

Month (1)	Initial storage (2)	Inflow (3)	Firm Release (4)	Secondary Release (5)	Evapo-ration (6)	Kp_t (7) = [(2)+(3)] / [(4)+(5) +(6)]	1/ Kp_t (8)
Jun	242.381	1355.551	349.725	0	5.972	4.492	0.22260
Jul	0	3414.738	0	4.984	2.679	445.64	0.00224
Aug	277.523	10227.58	19.556	0	3.725	451.221	0.00222
Sep	1106.094	4422.756	120.097	0	6.205	43.775	0.02284
Oct	1348.112	942.527	256.298	0	5.251	8.758	0.11418
Nov	1165.866	665.615	0	193.589	3.53	9.291	0.10763
Dec	1023.544	373.538	264.408	0	2.867	5.227	0.19131
Jan	786.517	466.209	0	253.769	2.705	4.884	0.20473
Feb	569.682	391.267	112.931	155.853	2.868	3.537	0.28269
Mar	330.155	211.42	0	85.448	4.757	6.004	0.16656
Apr	257.344	44.54	5.074	0	7.79	23.468	0.04261
May	248.222	149.591	8.115	0	10.583	21.276	0.04700

All volumes are in MCM.

Table 9.6 Estimation of Kp_t values from model IRYM with export

Month (1)	Initial storage (2)	Inflow (3)	Firm Release (4)	Secondary Release (5)	Evapo-ration (6)	Kpt (7)=[(2)+(3)]/ [(4)+(5)+(6)] (7)	1/Kpt (8)
Jun	0.011	81.642	3.818	0	0.038	21.175	0.04722
Jul	19.994	205.662	0.109	0	0.035	1562.054	0.00064
Aug	84.84	615.984	0	0	0.165	4255.595	0.00023
Sep	109.646	266.373	1.552	0	0.377	194.979	0.00513
Oct	92.034	56.766	21.691	0	0.544	6.692	0.14943
Nov	79.03	40.088	15.784	0	0.394	7.363	0.13582
Dec	48.235	22.497	31.831	0	0.251	2.205	0.45356
Jan	29.087	28.079	20.804	0	0.181	2.724	0.36708
Feb	14.673	23.565	15.154	0	0.148	2.499	0.40018
Mar	12.346	12.733	0.309	0	0.182	51.113	0.01956
Apr	6.862	2.683	0	0	0.226	42.153	0.02372
May	0.011	9.01	0	0	0.16	56.324	0.01775

All volumes are in MCM.

Table 9.7 Estimation of Kp_t values from model MOFLP with export

Month (1)	Initial storage (2)	Inflow (3)	Firm Release (4)	Secondary Release (5)	Evapo-ration (6)	Kpt (7)=[(2)+(3)]/ [(4)+(5)+(6)] (7)	1/Kpt (8)
Jun	26.096	107.045	29.864	0	5.174	3.8	0.26316
Jul	0	269.654	0.582	0	2.261	94.851	0.01054
Aug	19.665	807.649	1.481	0	1.997	237.886	0.0042
Sep	83.464	349.255	7.679	0	2.53	42.386	0.02359
Oct	102.344	74.429	4.114	0	2.134	28.293	0.03534
Nov	102.344	52.562	0	0	1.556	99.525	0.01005
Dec	93.869	29.497	14.574	0	1.395	7.725	0.12944
Jan	80.305	36.815	18.039	0	1.505	5.993	0.16687
Feb	63.876	30.897	18.745	0	1.872	4.597	0.21754
Mar	45.804	16.695	4.716	0	3.54	7.57	0.1321
Apr	38.936	3.517	0	0	5.995	7.081	0.14122
May	33.235	11.813	0	0	8.138	5.535	0.18065

All volumes are in MCM.

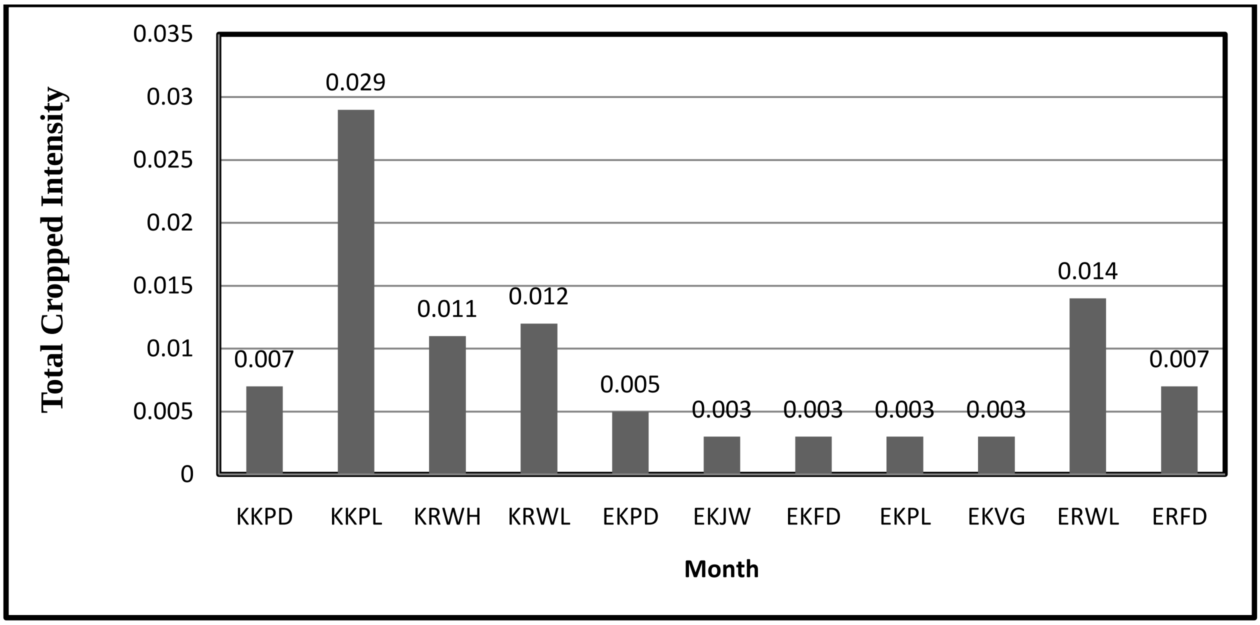


Fig.9.K.1.2 Total cropped intensity and average cropped intensity achieved for each crop in Daudhan reservoir with export

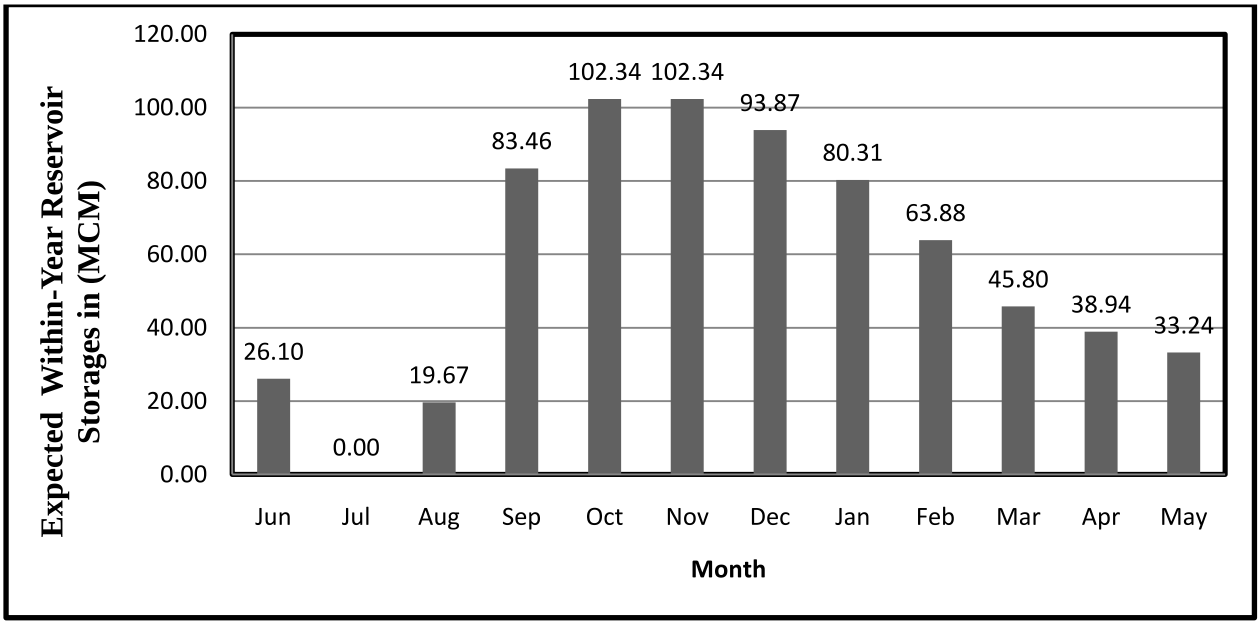


Fig. 9.K.2(a)Expected total within-year storagesavailable in Daudhan reservoir in a normal water year with export.

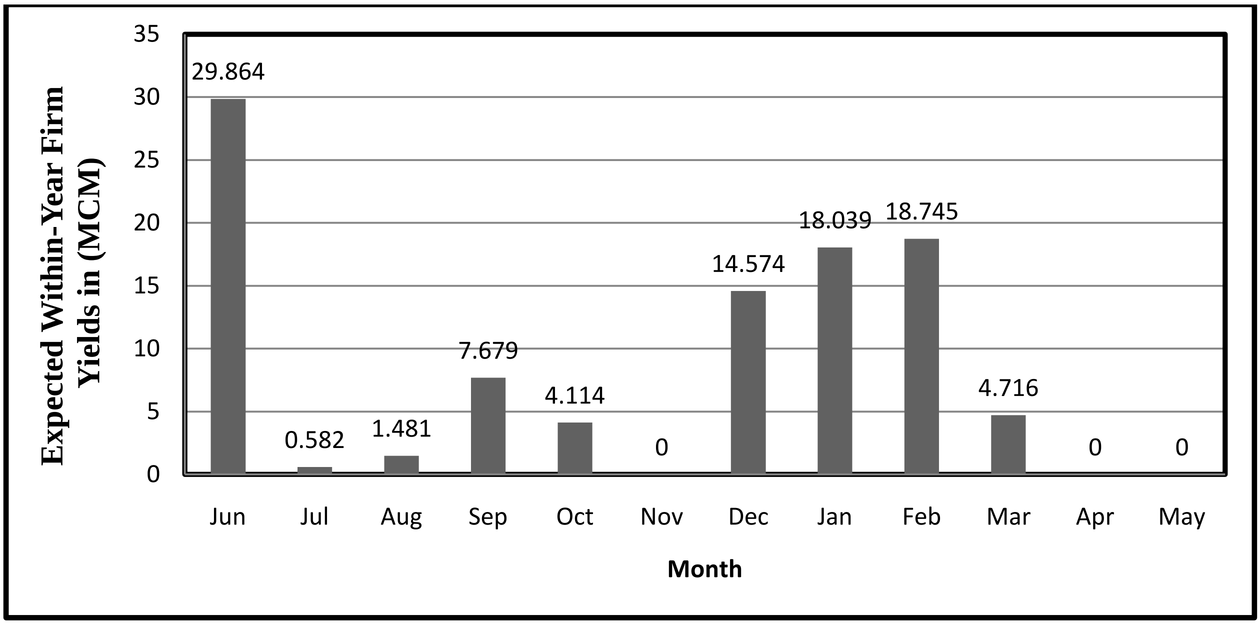


Fig.9.K.2(b) Expected within-year firm yields available in Daudhan reservoir in a normal water year with export.

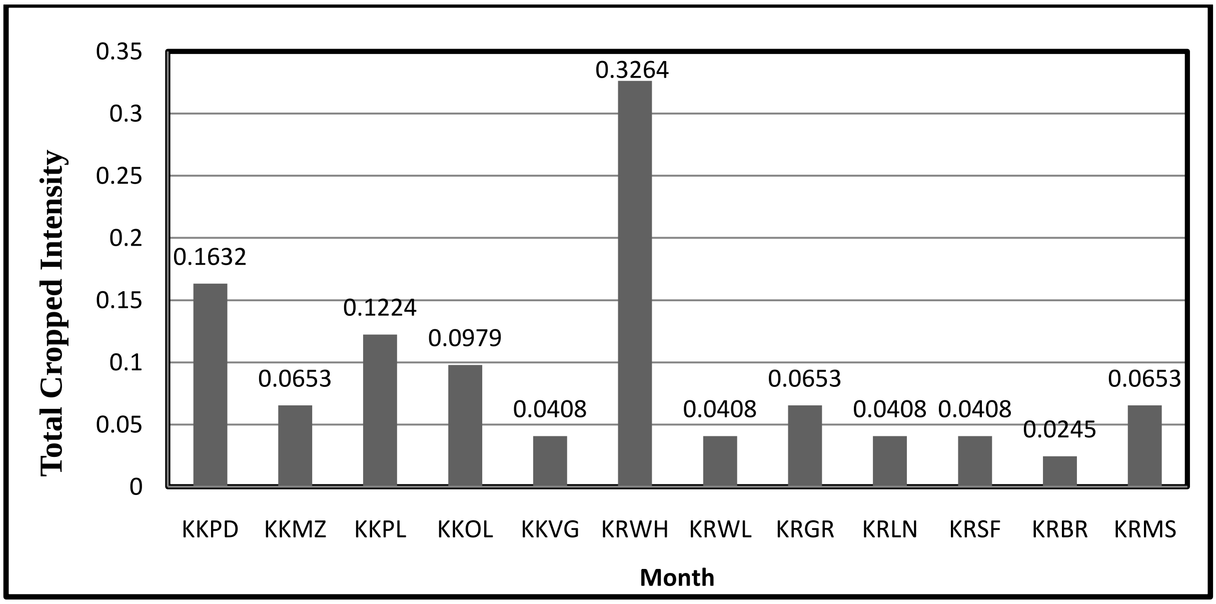


Fig. 9.K.3.2 (a) Total cropped intensity and average cropped intensity achieved for each crop in Daudhan reservoir for selfcommand without export

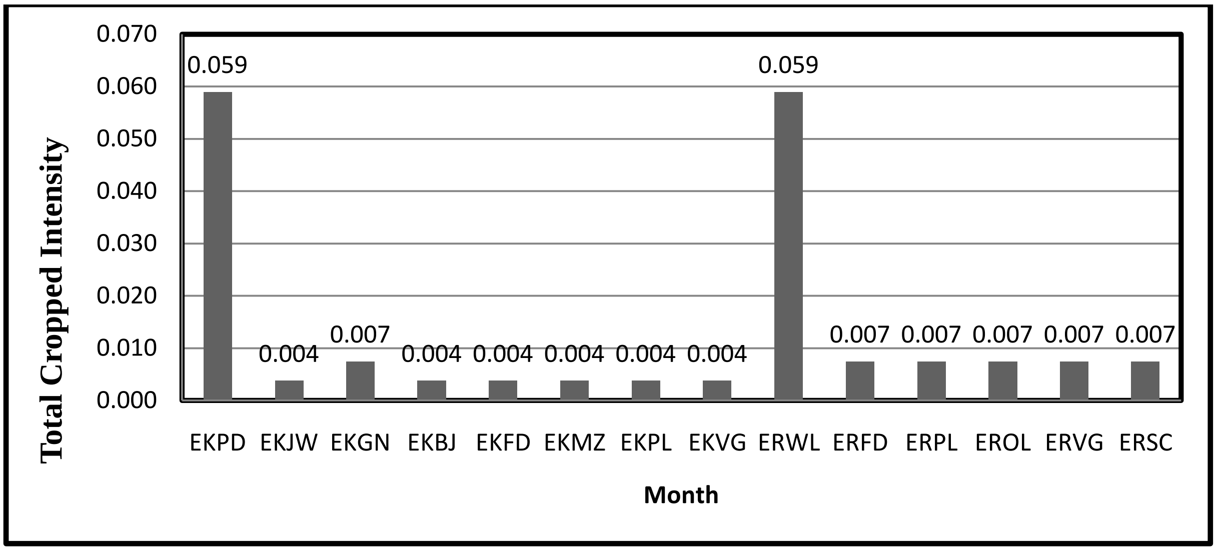


Fig. 9.K.3.2 (b) Total cropped intensity and average cropped intensity achieved for each crop in Daudhan reservoir for en-route command without export

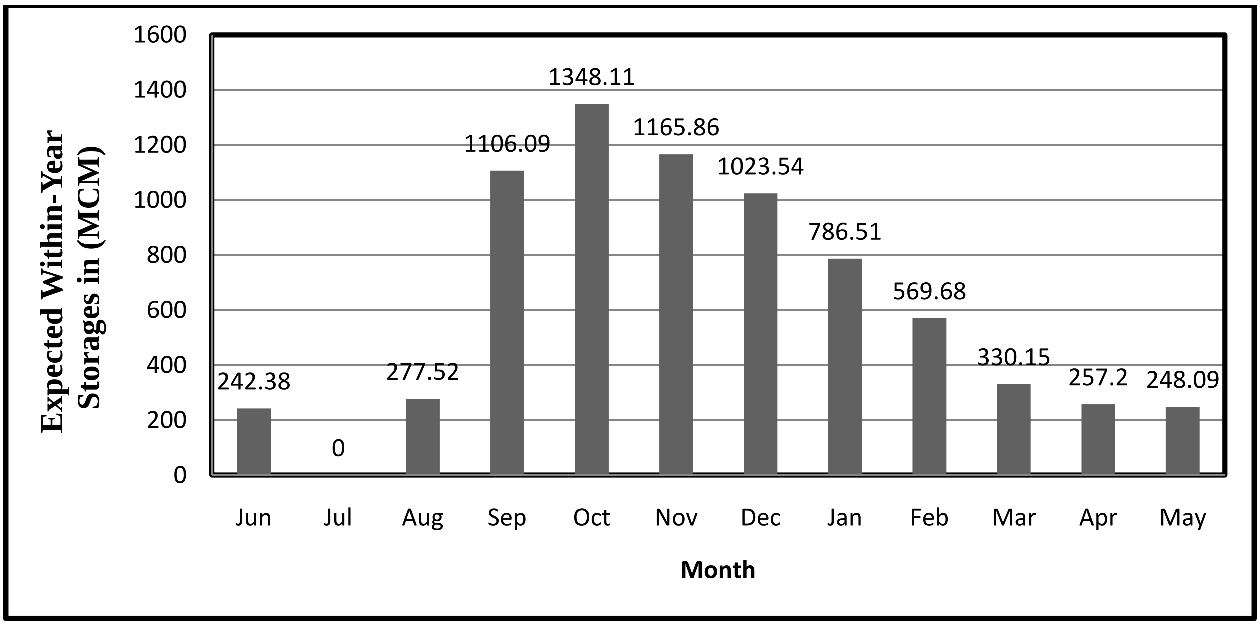


Fig.9.K.4 (a) Expected total within-year storages available in Daudhan reservoir in a normal water year without export

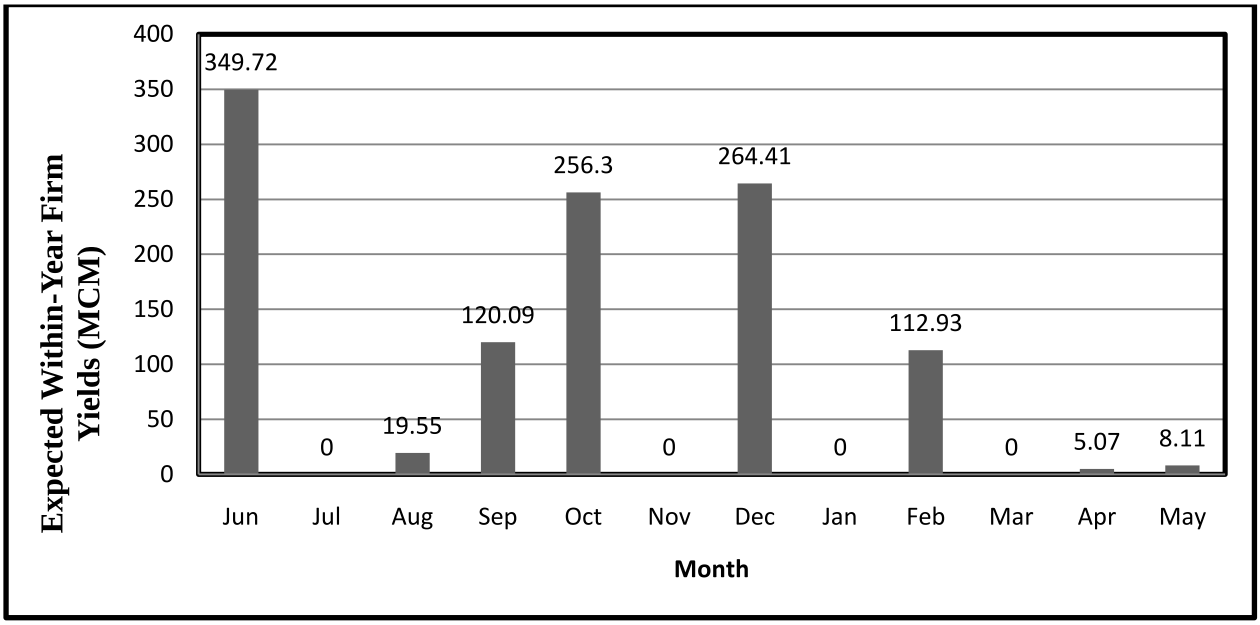


Fig.9.K.4 (b) Expected within-year firm yields available in Daudhan reservoir in a normal water year without export

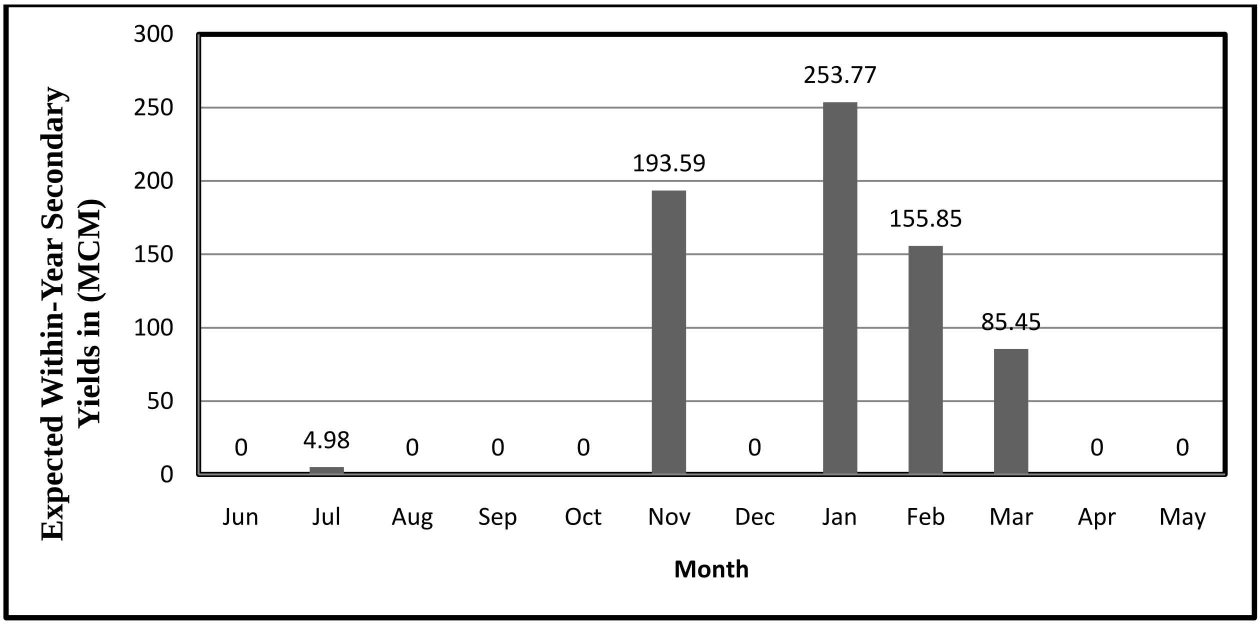


Fig.9.K.4 (c) Expected within-year secondary yields available in Daudhan reservoir in a normal water year without export

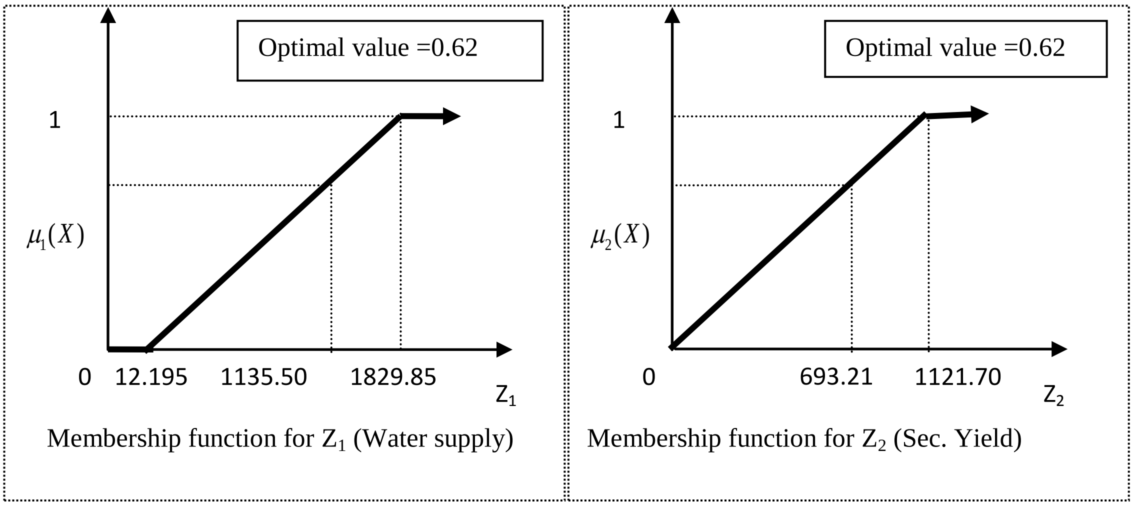


Fig.9.1 Membership function for Daudhan, water supply as a firm yield

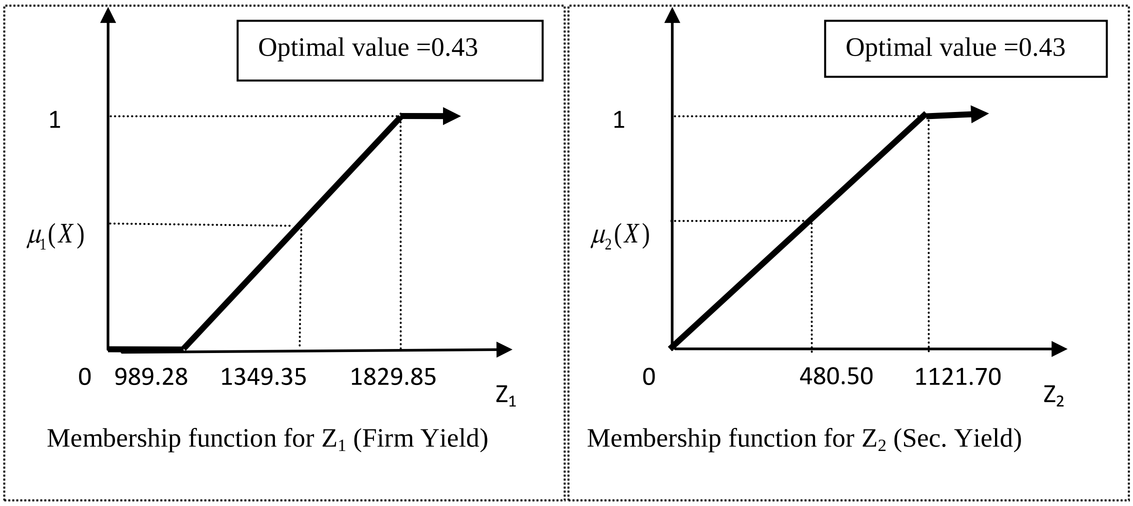


Fig.9.2 Membership function for Daudhan, to meet the irrigation demand for minimum food requirement for agricultural population as a firm yield.

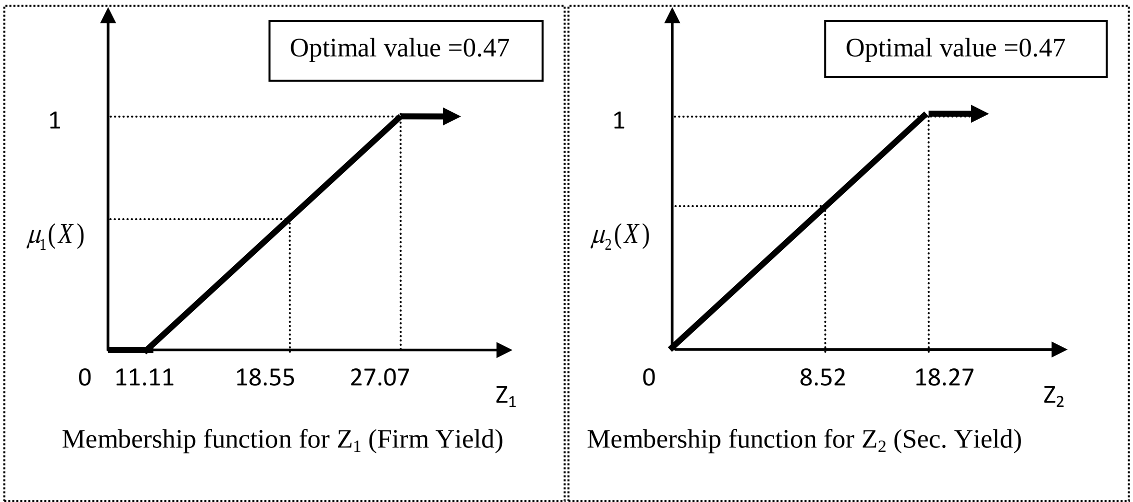


Fig.9.3 Membership function for Kerwan

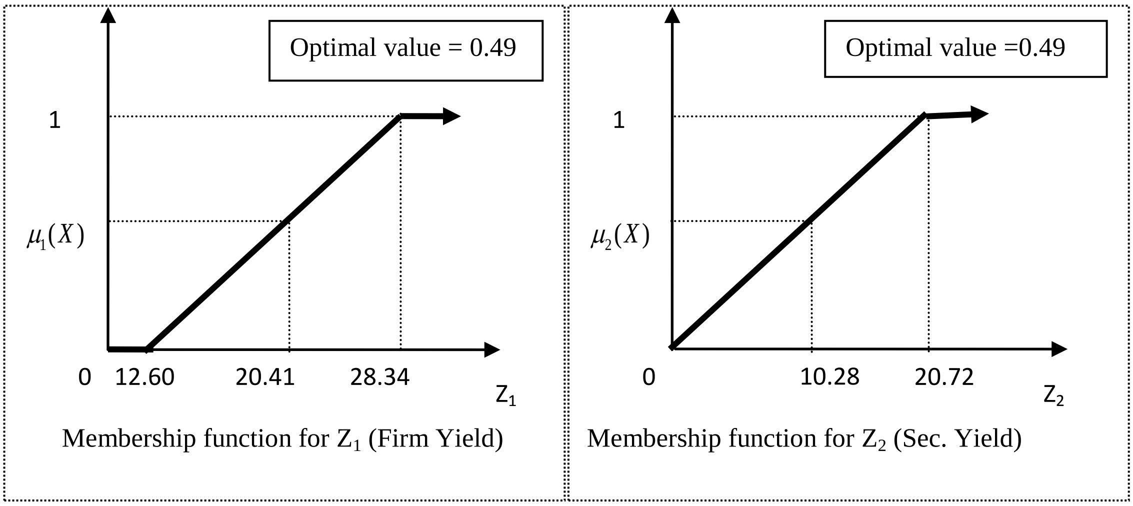


Fig.9.4 Membership function for Kaliasote

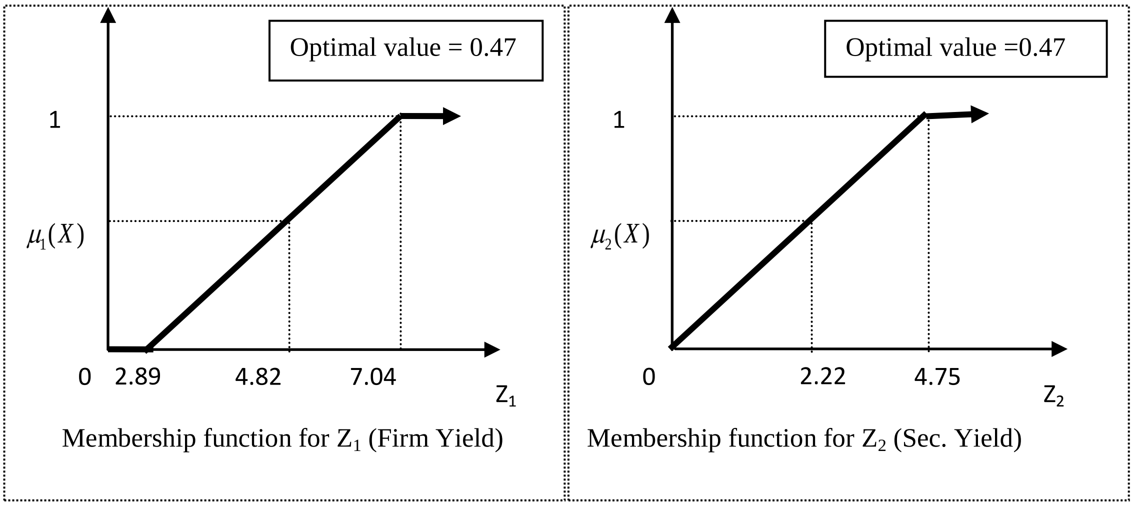


Fig.9.5 Membership function for Neemkheda

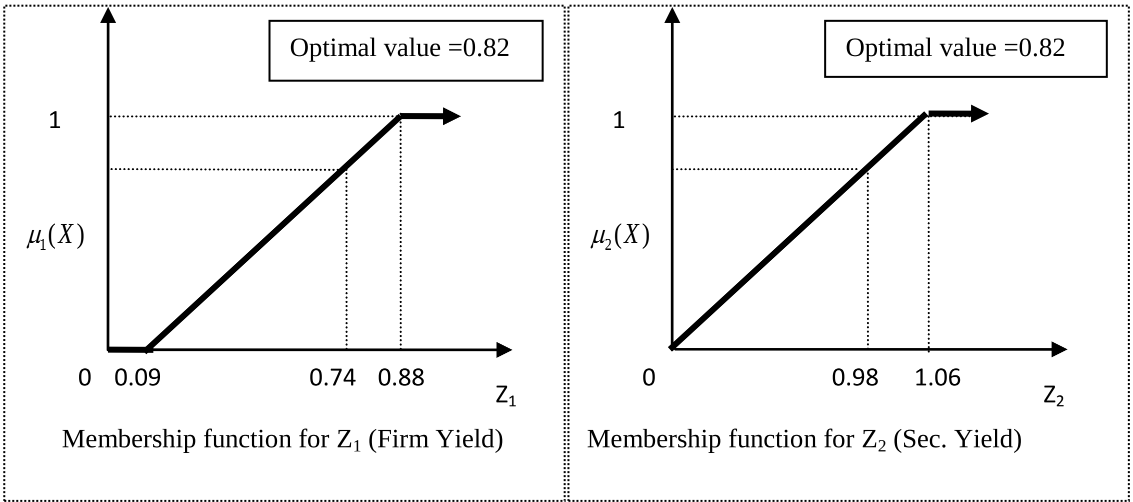


Fig.9.6 Membership function for Richhan

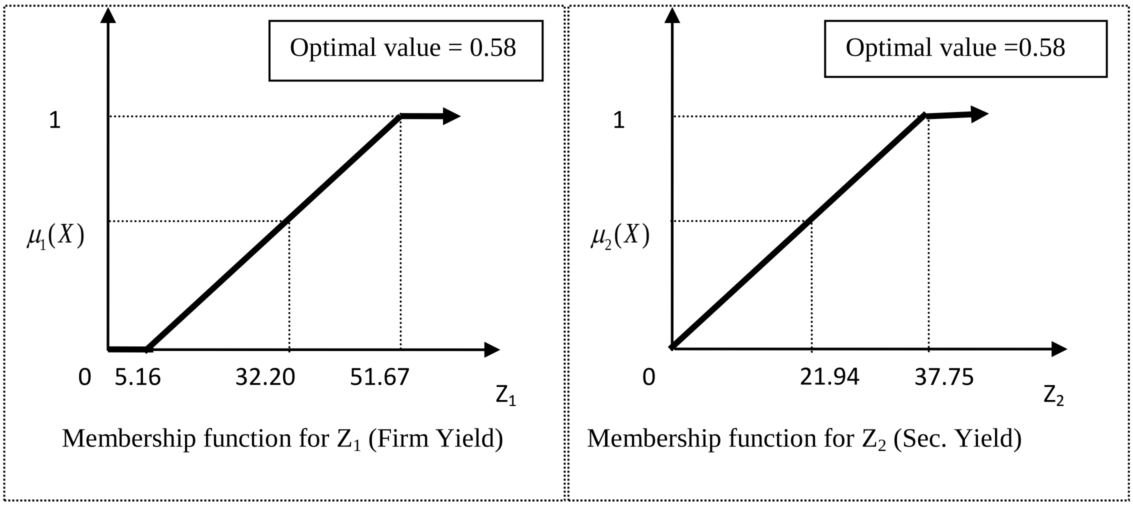


Fig.9.7 Membership function for Halali

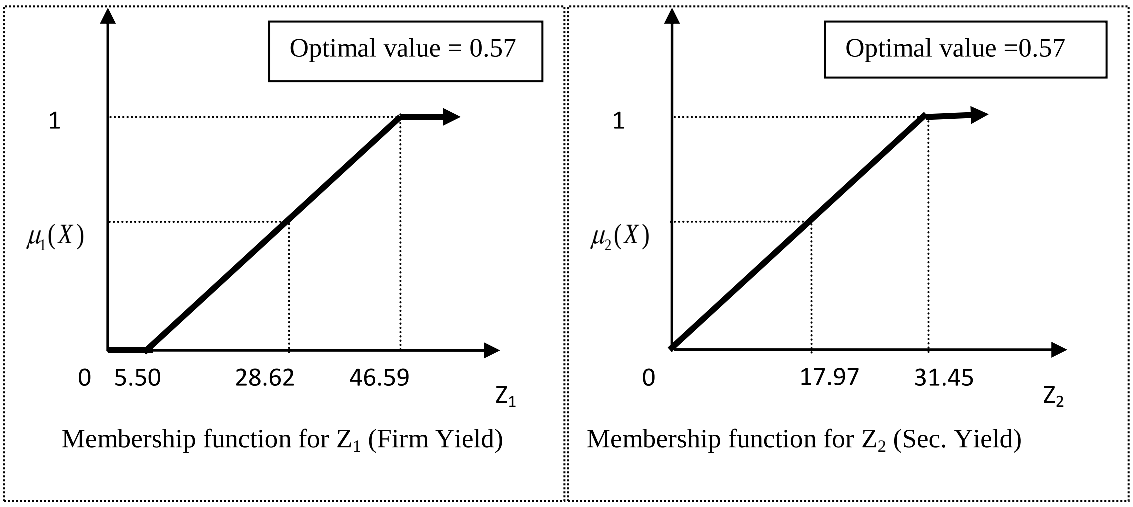


Fig.9.8 Membership function for Barari

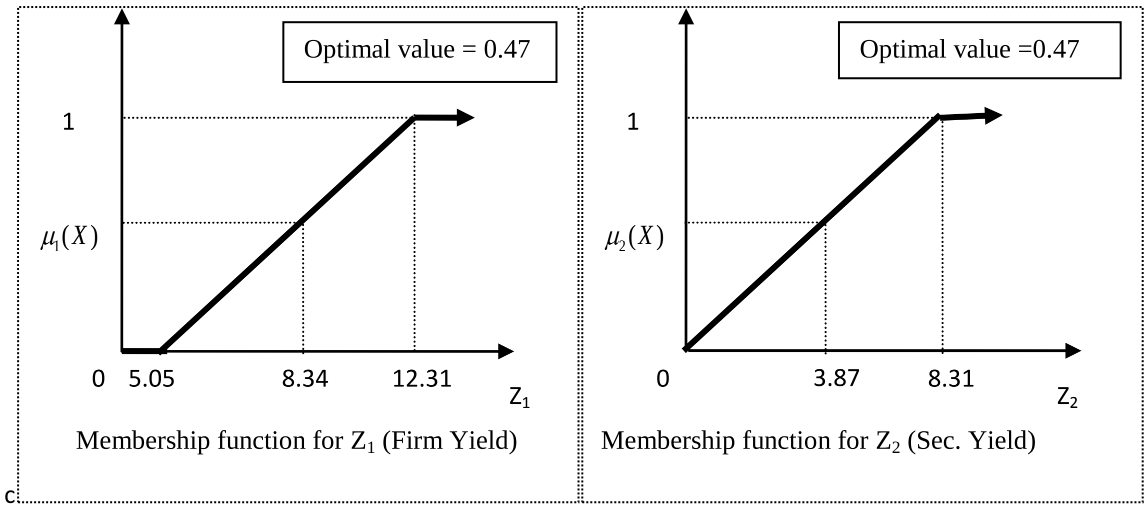


Fig.9.9 Membership function for Kesari

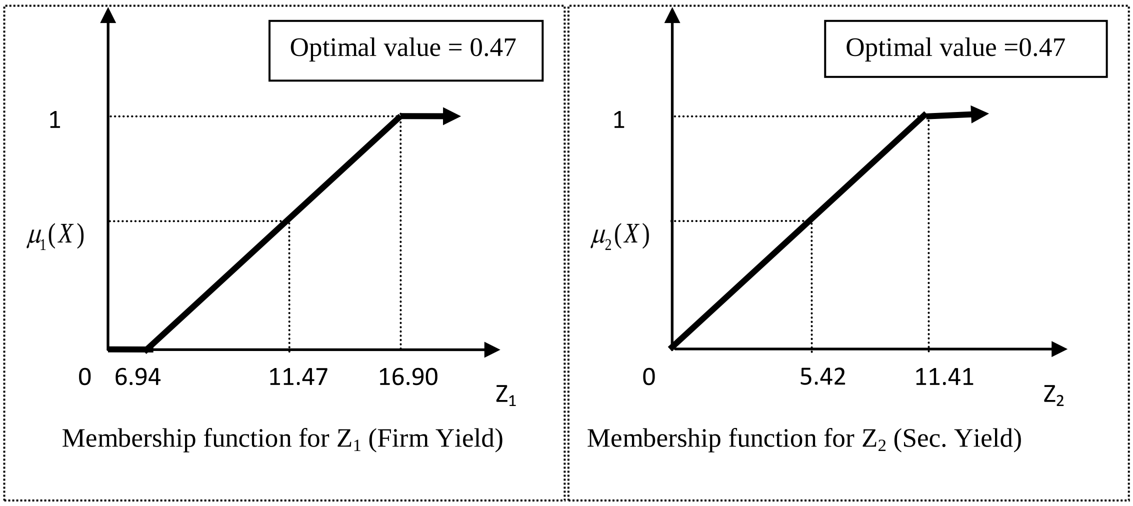


Fig.9.10 Membership function for Kethan

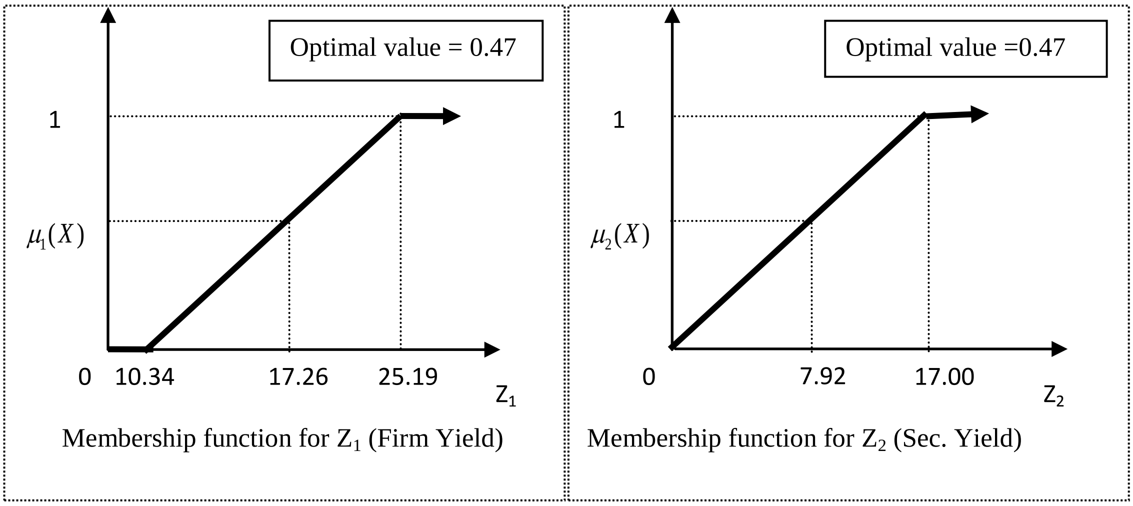


Fig.9.11 Membership function for Koncha

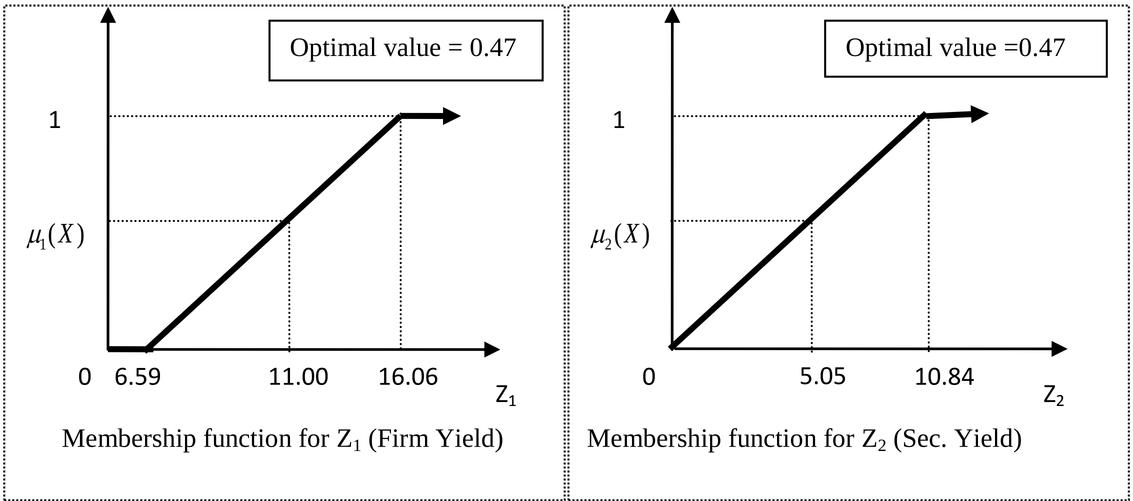


Fig.9.12 Membership function for Mola

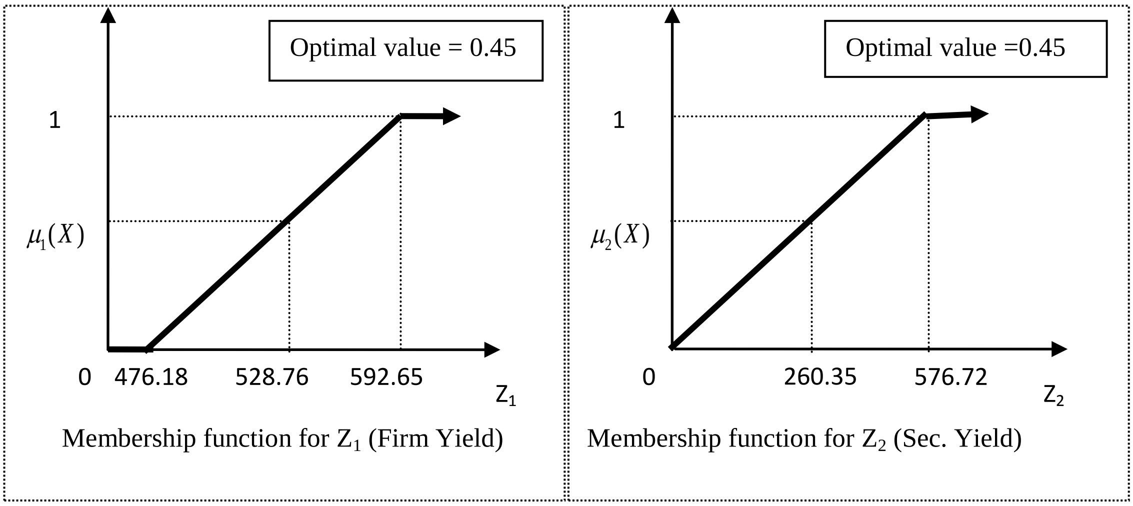


Fig.9.13 Membership function for Rajghat

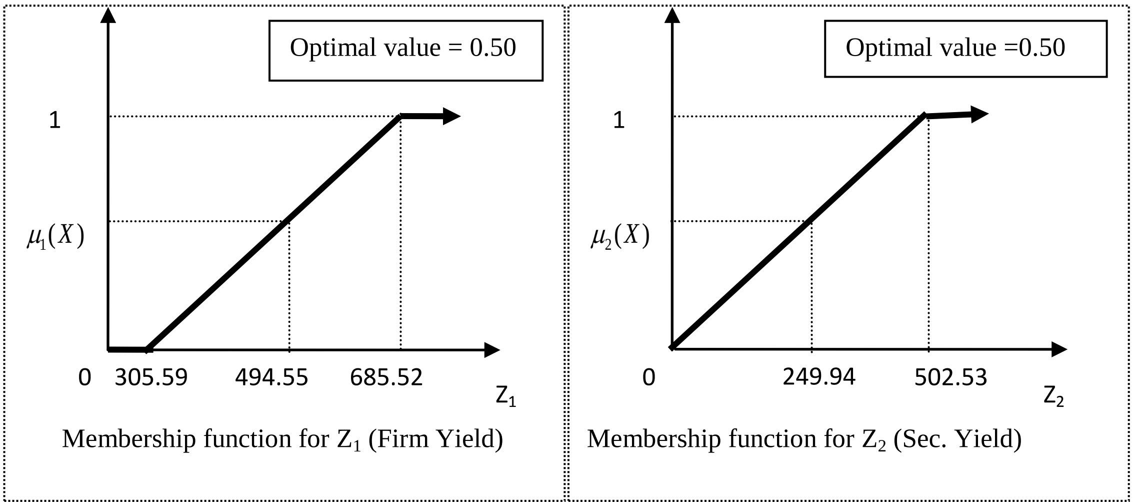


Fig.9.14 Membership function for Matatila

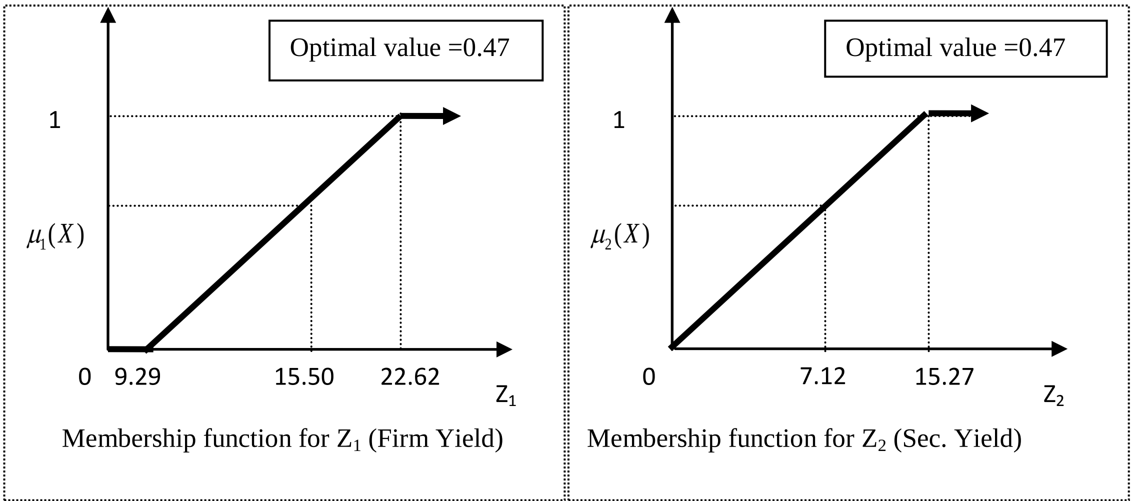
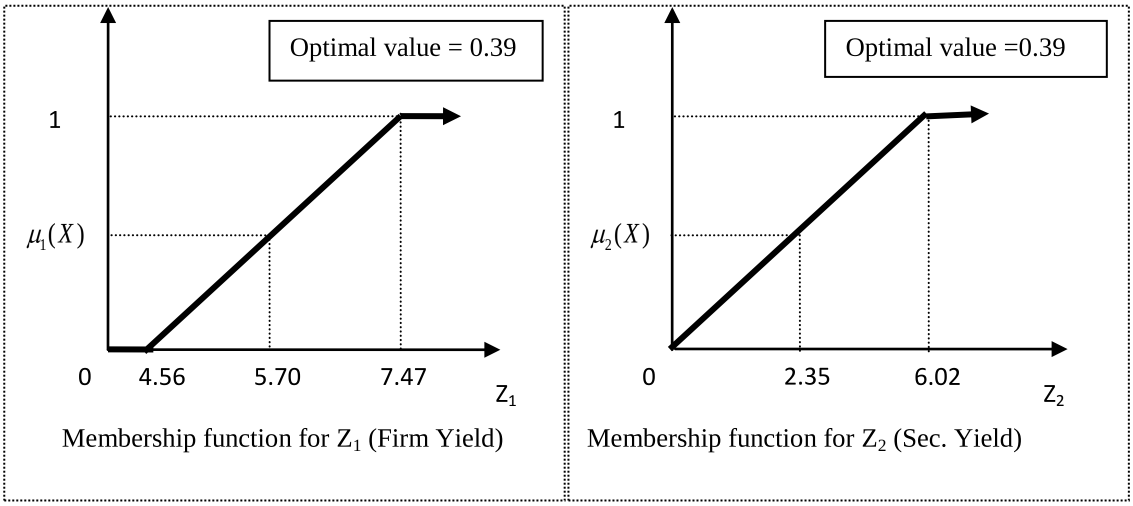
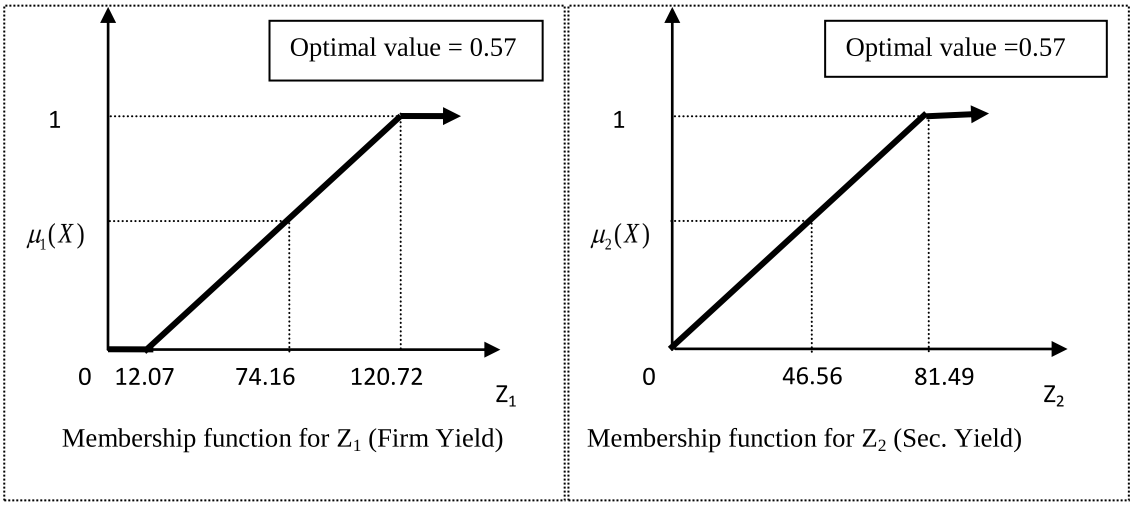


Fig.9.15 Membership function for Dukwan



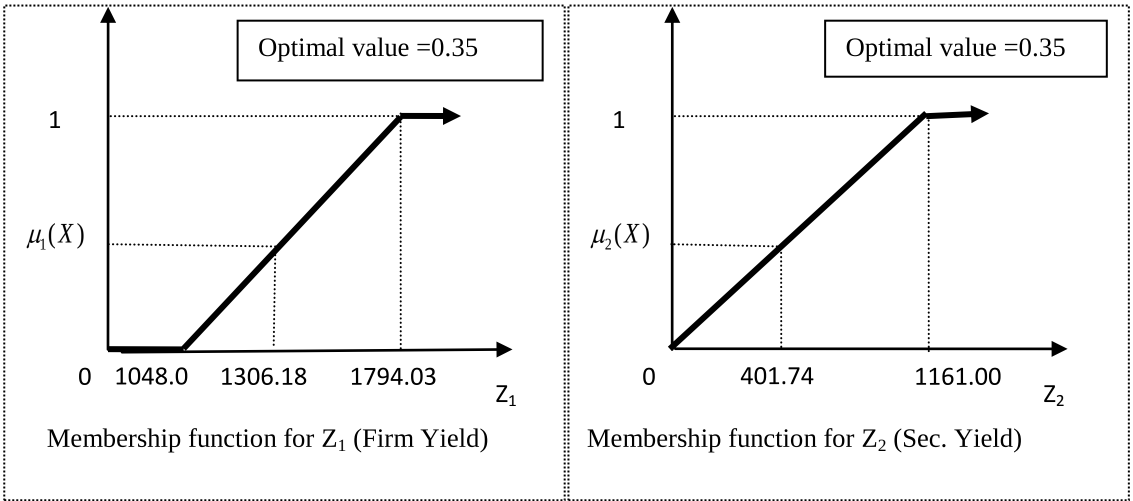
Membership function for Z_1 (Firm Yield)   Membership function for Z_2 (Sec. Yield)

Fig.9.16 Membership function for Barwa Sagar



Membership function for Z_1 (Firm Yield)   Membership function for Z_2 (Sec. Yield)

Fig.9.17 Membership function for Parichha



Membership function for Z_1 (Firm Yield)   Membership function for Z_2 (Sec. Yield)

Fig.9.18 Membership function for KB link System, to meet the irrigation demand for minimum food requirement for agricultural population as a firm yield.

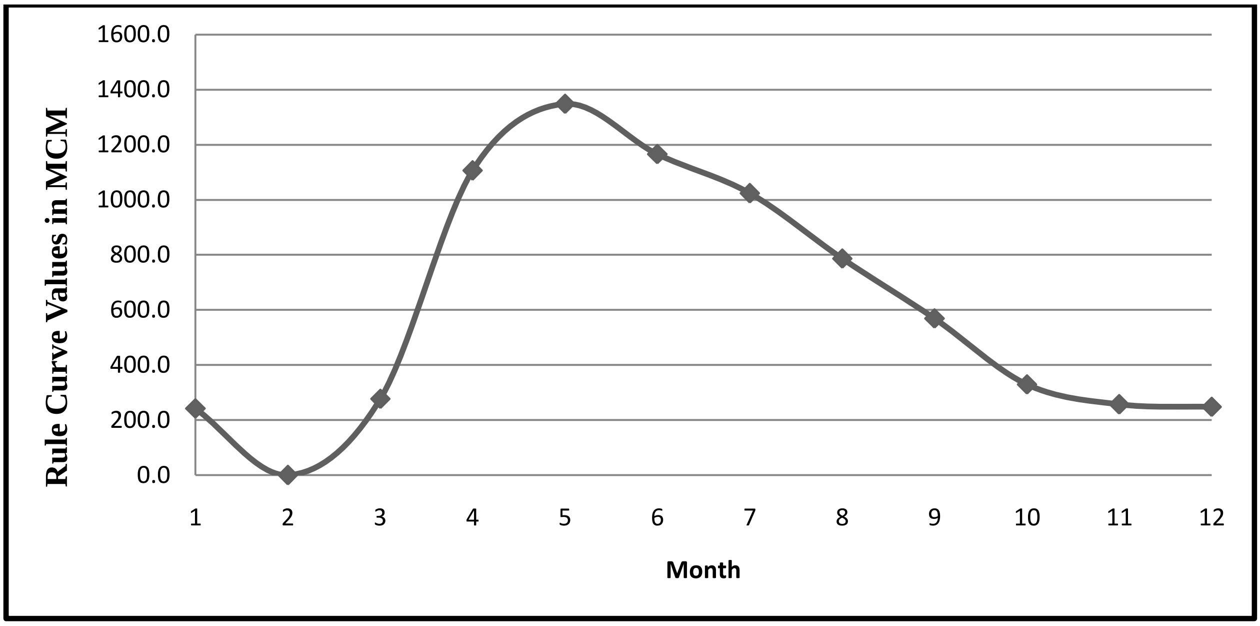


Fig. 9.19 Rule Curve from model IRYM and MOFLP without export for water year.

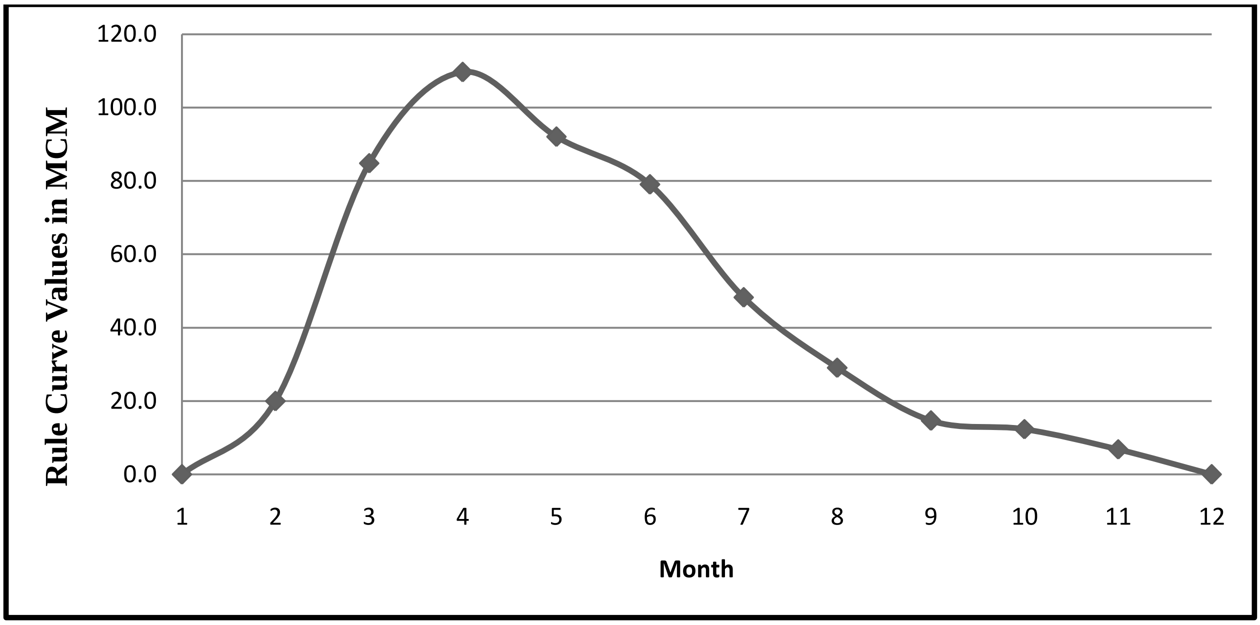


Fig. 9.20 Rule Curve from model IRYM with export for water year.

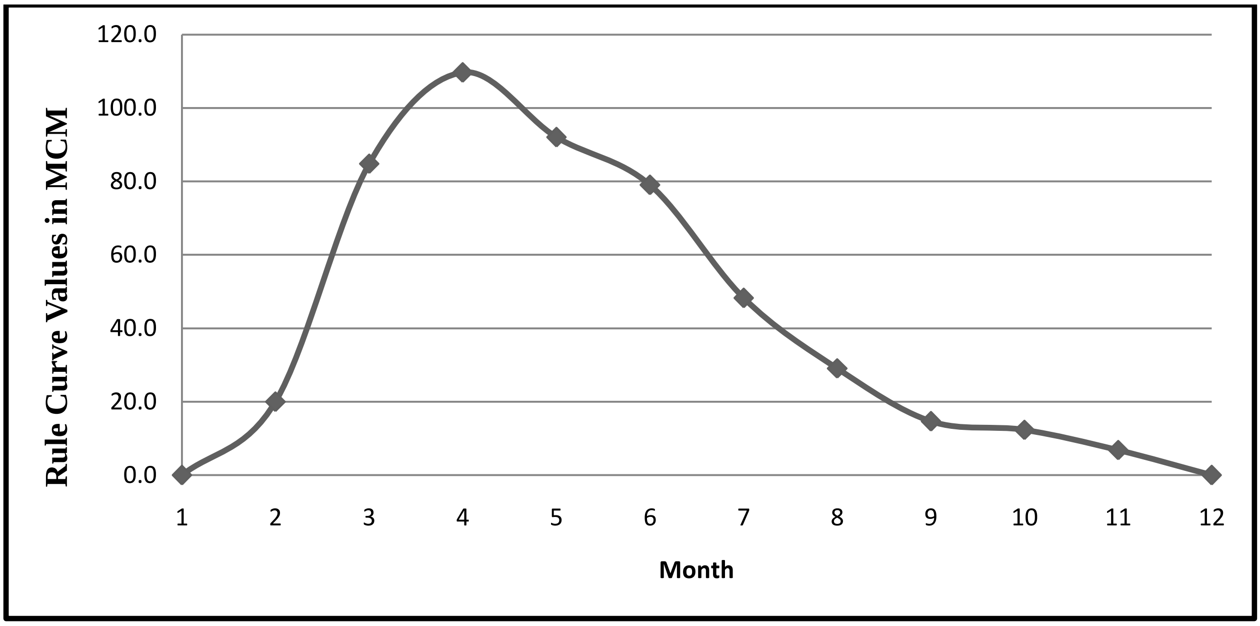


Fig. 9.21 Rule Curve from model MOFLP with export for water year.

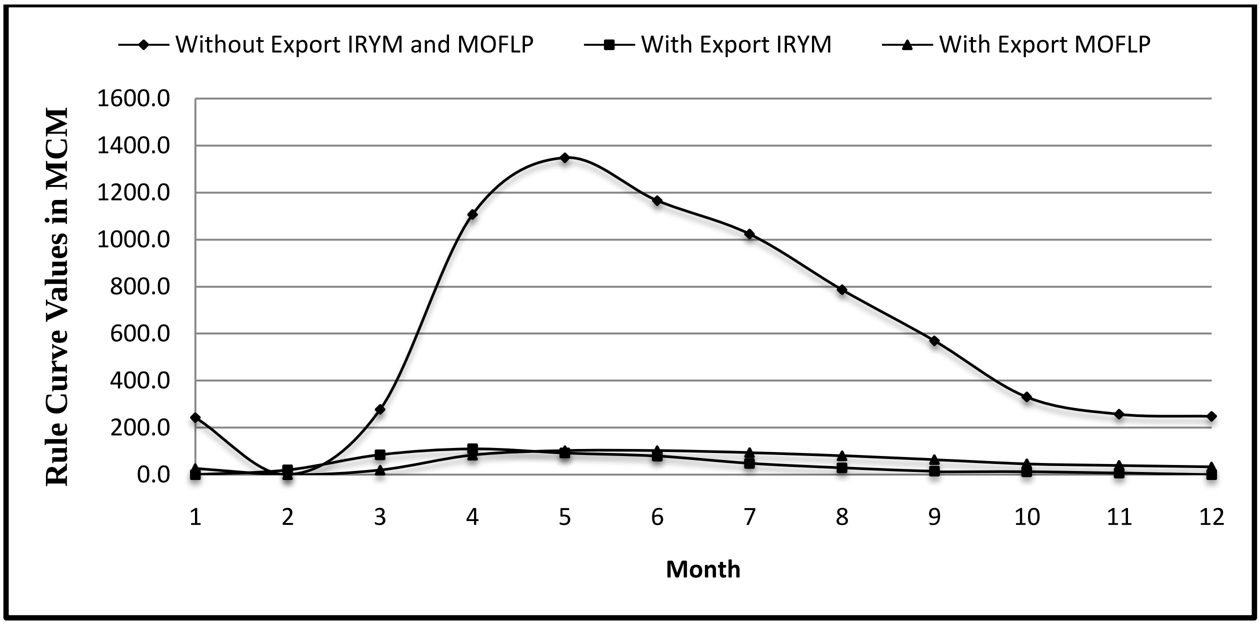


Fig. 9.22 Rule Curve from model IRYM and MOFLP with and without export for water year.