OPTIMAL DEVELOPMENT OF WATER RESOURCES OF RUSHIKULYA RIVER BASIN (ORISSA)

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
HYDROLOGY

By

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JUNE, 2008

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled **"OPTIMAL DEVELOPMENT OF WATER RESOURCES OF RUSHIKULYA RIVER BASIN (ORISSA)"** in partial fulfilment of the requirements for the award of the degree of Master of Technology in Hydrology, submitted in the **Department of Hydrology**, **Indian Institute of Technology, Roorkee**, is an authentic record of my own work carried out during the period from July 2007 to June 2008 under the supervision and guidance of **Dr. D. K. Srivastava**, Professor, Department of Hydrology, Indian Institute of Technology, Roorkee.

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

Roorkee

Date 30.06.2008

30.6.08

GOKULA CHANDRA PADHI

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

30.6.08

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ACKNOWLEDGEMENT

I offer my heartfelt gratitude and sincere thanks to my esteemed guide Dr.D.K.Srivastava, Professor, Department of Hydrology, Indian Institute of Technology, Roorkee, for his excellent guidance, constant encouragement, valuable instruction and keen interest throughout the preparation of this dissertation. I feel gifted to be his student.

I am also highly thankful and immensely grateful to Dr.B.S.Mathur, Professor, Dr.D.C.Singhal, Professor, Dr.N.K.Goel, Professor, Dr.H.Joshi, Professor, Dr.M.Perumal, Associate Professor, and Dr.D.S.Arya, Assistant Professor, Department of Hydrology, Indian Institute of Technology, Roorkee for their advice and useful cooperation during the preparation of this dissertation.

I would like to acknowledge the help and support extended by Mr.P.C.Choudhury, Trainee Officer, Mr.A.Kar, Trainee Officer, Mr.M.M.Mishra, Trainee Officer, Mr.H.Mohanty, Research Scholar, Mr.C.S.Padhi, Research Scholar, Mr.R.M.Das, Research Scholar, Mr.B.Sethi, Ex Research Scholar and Mr P.K.Parhi, Ex Research Scholar during the preparation of this dissertation.

I express my humble thanks to all my friends and colleagues and to all those directly and indirectly encouraged me and put a helping hand in every step of this study.

I am deeply indebted to Government of Orissa, Department of Water Resources, Bhubaneswar, for sponsoring me to this course.

I would like to express my highest appreciation for the inspiration, strong moral and emotional support extended by my wife Jyotsna, son Anish and daughter Asmita during my endeavour to complete this dissertation work.

I shall remain obliged to the almighty for being with me during all the difficult times in my life.

30.6.08

GOKULA CHANDRA PADHI

SYNOPSIS

Water has always played an important role in providing livelihood, hygiene and environmental securities since the dawn of civilization. The demand pattern is changing rapidly with increase in population, urbanization and rapid industrialization. Keeping in view the constraints of water availability and the variety of its uses, water allocation issues need to be addressed in a wise manner.

Rushikulya river basin having a catchment area of 8963 sq.km is an important river basin of Orissa state. In this work entitled "Optimal development of water resources of Rushikulya river basin (Orissa)", an attempt has been made to study the optimal benefits with an optimal cropping pattern and to study the design parameters of irrigation projects in this basin.

Future population projection of the basin by the planning horizon 2051AD has been done considering the growth rate from the year 1961 to 2001. Water demand for various purposes has been estimated. Domestic use has been estimated on the basis of water consumption per capita and coverage rates, taking into account difference in social strata. Industrial water demand that has been estimated by Government of Orissa on the basis of water demand per industrial employee depending on the type of industry is adopted. Irrigation demand has been estimated using standard FAO method. Surface water potential has been estimated using flow duration curve and ground water potential as estimated by Government of Orissa has been adopted in this study.

To develop an optimal cropping pattern for the basin, both Linear programming (LP) and Goal programming (GP) techniques have been used. In LP model, five plans have been developed with the objective of maximization of net benefits while meeting minimum food, protein and calorie requirements of the basin and in GP model, four plans have been developed giving priority to three main goal constraints i.e. maximization of net return, protein and calorie requirements and minimum food requirements. Comparison among different LP and GP plans has been made and the best plan out of above has been recommended for the basin.

Yield model has been developed to estimate the yield based on specific reliability of targets as well as the extent of supply assured during the failure years in case of existing reservoirs and to estimate the minimum active storage capacity subject to minimum required extent release in case of proposed reservoirs. 75% reliability for irrigation and 100% reliability for water supply have been adopted in this study. Single reservoir multiple yield model with twelve time within periods have been developed for all the ten reservoirs in the basin.

In this study for computation of ET_O (Reference Evapo-transpiration), the software package CROPWAT window version 4.3 (FAO-1992) has been used. Software package Auto CAD has been used for calculation of influence factor of the rain gauge stations of the basin and Software package LINDO has been used for solving LP and GP models.

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LIST OF ABBREVIATIONS/NOTATIONS

ABBREVIATIONS/NOTATIONS	DESCRIPTIONS
cal :	Calories
CCA :	Cutivable Command Area
CA:	Catchment area
FAO :	Food and Agricultural Organization
Ha :	Hectares
Ham :	Hectare meter
Kg:	kilogram
Sq.km/Km^2:	square kilometer
Lakh kcl/yr:	lakh kilo calories per year
LINDO:	Linear Interactive Discrete Optimizer
MCM:	Million Cubic Meter
MGD:	Million gallon day
Rs/Ha:	Rupees per Hectare
Qnt/Ha:	Quintal per Hectares

CHAPTER-1

INTRODUCTION

1.1 GENERAL

Water is the most precious gift of nature. No flora or fauna is possible without water in this universe. It is a natural resource, which is finite, cannot be created and has no substitute. The main reason why mankind has shown a preference to settle near rivers was the assured supply of water. Even today, a considerable portion of world population lives in areas adjacent to water bodies.

Although there is abundance of water on the surface of earth, only 3% of total water resources are fresh water and rest 97% is contained in the seas and oceans as saline water. Out of the total fresh water, 75% occurs as polar ice and glaciers, 24% remains in sub soil. Only 1% of fresh water accounts for water in lakes and rivers. Hence fresh water resources are really very scarce and scarcity is further aggravated by extreme variation in distribution of resources, both in space and time.

The increase in population and consequent rise in demand of water for irrigation, hydropower generation, domestic and industrial use and maintenance of ecological health has caused a lot of concern among water resources experts. This has attracted the attention of decision-makers, planners and water resources experts for an integrated and comprehensive planning of water resources which includes careful planning for allocation of water resources for various purposes such as domestic, industrial, hydropower generation, irrigation and environmental requirements etc.

The water resources allocation decisions are multi-objective in nature, which involve economic, social and environmental dimensions and values. Hence the water resources allocation process aims at optimal use of land and water resources so as to have the maximum net return from the cultivable command area by meeting all requirements of water.

In a given agro-climatic region, cropping pattern is to be decided in such a manner that it optimizes the return from the available resources particularly irrigation water. Planned use of surface and ground water is one management technique, which is developed to obtain the maximum benefit from available water resources. Because of the hydraulic interaction between the two sources, the extent to which efficiency is attained is proportional to the degree of integrated planning.

The term optimal clearly refers to an orderly process by which the decision variables are solved in such a way so as to maximize the degree of achievements of the given objectives. Various techniques are available to optimize the given objective. But the linear optimization technique is best suited for water resources planning and allocation processes, as it can efficiently and effectively allocate scarce resources to achieve clearly stated organizational objectives, when there exist large number of constraints and definable relationship among the decision variables. The technique of linear optimization is known as linear programming. It has been successfully applied to a wide range of problems like business, industry, agriculture and military sectors etc. It has also become more suitable for practical use, primarily because of development of computer technology.

1.2 RIVER BASIN PLANNING

The planning process for a river basin can be described as an orderly procedure to obtain an optimum development of the water and related land resources. River basin planning concentrates the planning effort in the natural hydrological unit, the river basin. It offers a framework for bringing out integration in planning consistence with overall economic, social and environmental policies of the country.

The main objectives of river basin planning are:

- To prepare a long-term perspective plan for the development of the basin's water resources.
- To develop a comprehensive and integrated approach to the development of water and other natural resources using water, with due regard to constraints imposed by configuration of water availability.
- To review the management of existing water resources project and incorporate necessary changes so as to make the projects sustainable.
- To identify and set priorities for promoting water resources development projects.

1.3 OBJECTIVES OF THIS STUDY

The main objectives of this study are:

- To allocate surface and ground water resources of the Rushikulya basin to domestic, industrial, irrigation, hydropower generation and environmental purposes, so as to have the optimum net return taking care of the anticipated population growth by the year 2051 AD.
- To optimally allocate the land and water resources to maximize net return from the existing cropping pattern while meeting the minimum food, protein and calorie requirement of the basin population by the year 2051 AD.
- To examine the performance of the existing projects and to suggest the necessary changes, both technical and administrative, to be incorporated, to make the project sustainable.
- To optimize future water resource projects.

1.4 STEPS INVOLVED IN STUDY

Following step-wise approach has been drawn to meet the above mentioned objectives.

(i) The human, livestock and poultry population projections has been made up to the year 2051AD using the existing trend of growth from the available census data.

(ii) Domestic, industrial, irrigation, hydropower and environmental requirements of water for the basin have been estimated taking into account the projected population by the year 2051 AD.

(iii) Annual and monthly availability of surface water has been computed considering 75% dependable yield of generated runoff data at various gauge discharge sites of the basin.

(iv) An optimal allocation plan has been developed using optimization technique to maximize the net benefit with a change in cropping pattern meeting other requirements of water in the study area.

(v) Stochastic river basin planning model has been developed to estimate the annual yield of the existing reservoirs and to minimize the size of the proposed reservoirs in the basin by the year 2051 AD.

1.5 METHODOLOGY

The present study utilizes following methodology to achieve the objectives.

FAO-56 Penman-Monteith method has been used to determine reference crop evapo-transpiration, while calculating the gross irrigation requirement (GIR). Thiessen polygon has been drawn to calculate the weighted average monthly rainfall of the basin. 75% dependable yield of basin has been calculated using Flow Duration Curve.

LP and GP model has been used for optimal crop planning. In case of LP all constraints are having equal importance. In case of GP a hierarchy of importance among goals or constraints will be considered so that the low order goals will be considered only after the higher order goals are satisfied.

Yield model has been used to arrive at yield estimates based on specific reliabilities of targets as well as the extent of supply assured during the failure years in case of existing reservoir projects and to minimize the active reservoir storage capacities of the proposed reservoirs.

Software package LINDO has been used for solving LP and GP models and Software package Auto CAD has been used for calculation of influence factor of the rain gauge stations of the basin.

1.6 DATA USED IN THE PRESENT STUDY

The data used in this study have been collected from various offices such as data bank of Engineer-in-chief, Water Resources Department, Orissa, Agricultural Department, Orissa, Basin planning report of Rushikulya basin, Orissa etc. Some data have been collected from different books, journals etc.

For the precipitation of the basin, data of 23 rain gauge stations have been considered. The rainfall data of all the 23 stations from the year 1961 to1999 have been collected from Water Resources Department, Orissa for this study.

The runoff data of 28 sites covering the whole basin has been considered (source: Water Resources Department, Orissa) for estimating annual and monthly 75% dependable yield of the basin.

The data for the availability of ground water resources in the basin area has been taken from Ground water survey and investigation Directorate.

The cropping pattern, yield of crop and other crop related data for the basin has been collected from the Agricultural Department, Orissa.

CHAPTER-2

REVIEW OF LITERATURE

2.1 OPERATION RESEARCH TECHNIQUES

The operation research techniques are used to get the best result or the best return from any operation or any allocation process particularly when water resources allocation problems are dealt with. The popular operation research techniques include optimization method, simulation, network flow theory, game theory etc. Among these, optimization and simulation are extensively used in water resources allocation problems.

During world war-II, U.S Air Force sought more effective procedure of allocating limited resources in the best possible manner. Since the techniques were aimed at getting the best result from military operation, these techniques were known as Operation Research techniques.

2.2 OPTIMIZATION

Optimization is the science of choosing the best among a number of possible solutions. The term optimum solution essentially refers to the best from the solution of the mathematical model under all assumptions and constraints whether explicitly stated or implicitly included in the formulation. Dentzig and Thapa (1997) defined optimization theory as "that branch of mathematics dealing with techniques for maximizing or minimizing an objective function subject to linear, non-linear and integer constraints on the variables".

The availability of resources is always limited. Hence in optimization problems these scarcities of resources are expressed with the help of constraints. These constraints restrict the range over which the decision variables can change and thus effect the optimal solution.

2.3 CLASSIFICATION OF OPTIMIZATION TECHNIQUES

The optimization techniques can be classified as Linear Programming (LP), Non-linear Programming (NLP), Goal Programming (GP) and Dynamic Programming (DP) etc. These classifications are useful from computational point of view and have been developed solely for the efficient solution of a particular class of problems.

In case of water resources allocation problems, the input variables could be either deterministic or stochastic. Depending on this the techniques can be classified as deterministic optimization or stochastic optimization. According to Yeh and Becker (1982), stochastic optimization is useful for planning purposes, while deterministic optimization is a viable approach for real time reservoir operation.

Although optimization encompasses a very wide range of subjects, keeping in view the current status of the application of optimization techniques in water resources it is broadly classified as LP, NLP and DP only.

2.3.1 Linear programming

The optimization problems in which objective functions and constraints are linear functions of decision variables and decision variables are non-negative in nature are termed as linear programming. The linear programming approach is a mathematical technique concerned with maximization or minimization of a linear objective function of many variables subject to linear equality or inequality constraints.

An optimization problem can be classified as an LP problem if it meets following conditions:

(i) The decision variables are nonnegative, i.e. positive or zero.

(ii) The objective function is described by a linear function of the decision variables.

(iii) The operating rule governing the process, commonly known as constraints are expressed as a set of linear equations or in-equations.

A typical LP model with 'm' constraints and 'n' variables can be represented in standard form as:

Minimize (or maximize): $Z = c_1 x_1 + c_2 x_2 + \ldots\ldots\ldots\ldots + c_n x_n$ (2.1)

Subject to:

$$a_{11}x_1 + a_{12}x_2 + \ldots\ldots\ldots\ldots + a_{1n}x_n = b_1$$

$$a_{21}x_1 + a_{22}x_2 + \ldots\ldots\ldots\ldots + a_{2n}x_n = b_2$$

$$\begin{array}{cccc} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{array} \quad (2.2)$$

$$a_{m1}x_1 + a_{m2}x_2 + \ldots\ldots\ldots\ldots + a_{mn}x_n = b_m$$

$$x_i >= 0,\ i = 1,2,3\ldots\ldots\ldots\ldots\ n. \quad (2.3)$$

$$b_i >= 0,\ i = 1,2,3\ldots\ldots\ldots\ldots\ m. \quad (2.4)$$

Where, Z represents the objective function; x_i's are the decision variables and c_i's are the cost (or benefit) coefficients representing the cost (or benefit) incurred by increasing the x_i decision variable by one unit. The a_{ij} coefficients are called technological coefficients and quantify the amount of a particular resource 'i' required per unit of the activity 'j'.

The linear programming models are capable of handling varied and complex water resources problems as they can consider a large number of decision variables along with an equally large number of constraints which may be in the form of equalities or inequalities. Hence linear programming model is extensively used during last four decades for handling water resources system as it is perhaps the best known and one of the most widely used technique of management science.

2.3.2 Goal programming

In linear programming, we assume that all constraints have equal importance in solving the problems. However this assumption is not realistic as all constraints may not have equal importance. Such problems can be solved efficiently using GP. Charnes and Cooper (1961), as a tool to resolve infeasible linear programming problems first introduced the concept of GP.

GP is a linear mathematical model in which the optimum attainment of multiple goals is sought within the given decision environment. It is a special extension of linear programming, which is capable of solving decision problems with a single goal or multiple goals. Here goals set by management are often achievable at the expense of other goals. In such cases a hierarchy of importance among these conflicting goals is established so that low order goals are considered only after the higher order goals are satisfied.

In GP the objective function is composed of either a pair or a single deviational variable for each goal constraint. If more then the desired goal level is achieved, there is a positive deviation (d^+) from the goal and if less then the desired goal level is achieved, it is a negative deviation (d^-) from goal. The exact achievement of a goal requires both negative and positive deviation to be represented in the objective function to achieve the ordinal solution. An optimal solution of non-attainment of goals is minimized according to the priority structure established. To achieve the goals according to their importance, GP provides a means by which the negative or positive deviations about the goals may be ranked according to preference of each goal level.

A GP problem in standard format is:

Minimize $Z = d^- + d^+$ (2.4)

Subject to $BX + d^- - d^+ = h$ (2.5)

$AX \leq b$ (2.6)

$X, d^-, d^+ \geq 0$

Where, B is a (1x n) row vector of objective function coefficient, X is an (n x1) column vector of real variables, b is an (m x 1) column vector of right hand side constant, A is an (m x n) matrix of technological coefficients, d^+, d^- are deviational variables in positive and negative directions, and h is the goal level set by decision maker.

2.3.3 Non-linear programming

An optimization problem in which either the objective function and/or one or more constraints are non-linear functions of decision variables is termed as a NLP problem.

The NLP models are suitable for treating non-convex, non-linear and discontinuous objectives and constraint functions with ease. Therefore these models have certain important advantages for the analysis of water resources system. The necessary and sufficient condition for the optimal solution of programming problems laid foundation for a great deal of research in Non-linear Programming. A NLP model may be constrained as well as un-constrained. Among NLP models, DP has been extensively used.

2.3.4 Dynamic programming

The DP model is a mathematical technique formulated largely by Richard Bellman in 1953 AD to improve the computational efficiency of certain optimization problems. The basic idea of this technique is to decompose the problem, which are conceptually more manageable. So far as water resources allocation is considered the DP model is found to be extremely useful to optimally allocate the water resources.

Many problems in water resources involve a sequence of decisions from one period to the next period and known as sequential decision problems. Such problems can be decomposed into a series of smaller and easily solvable problems that can be conveniently solved by DP. The DP approach is mostly used when the objective function is non-linear type and it involves allocation type problems such as

(i) Allocating water to different purposes from one source.

(ii) Allocating budget to different purposes.

An important feature of DP is its non-linearity and constraints can be readily accommodated. In fact, constraints serve to reduce the region to be covered in computations and are helpful in that sense. Following steps are followed in DP:

(i) The problem is decomposed in to sub-problems called stages and each sub-problem is optimized over its alternatives only, so that it is never necessary to enumerate all combinations in advance.

(ii) An optimization is applied to each sub-problem and all non-optimal combinations are systematically discarded.

(iii) The sub-problems are linked together in a specified way so that it is never possible to optimize over infeasible combinations.

The DP is essentially an enumerative technique suited specially to multi stage decision problems. Some of its advantages are as follows:

(i) The DP formulation is same for linear as well as non-linear problems. Thus no extra effort is required for non-linear problems.

(ii) The incorporation of constraints is easy as compared to LP and NLP problems. Here constraints limit the feasible region and lead to reduction in the computational time.

(iii) The stochastic nature of problems can be easily considered in the DP formulation.

The major disadvantages of DP are that a generalized program is difficult to write using it, where as standard computer programs are widely available for LP.

2.4 YIELD MODEL

Broadly, three types of stochastic river basin planning models, that incorporate hydrologic variability and uncertainty and are structured for solution either by linear or dynamic programming techniques, are: (i) models that define a number of possible discrete stream flows and storage volumes and their probabilities, in each time interval and at each site; (ii) models that identify an annual firm water yield, its within-year distributions, and its reliability; and (iii) chance-constrained models which have rules that express the unknown reservoir storage volume and release probability distributions as linear functions of the unknown unregulated stream flows (Loucks et al. 1981). Out of these three models, the second one is implicitly stochastic model. Implicit stochastic models, although larger than chance-constrained models, are much smaller than the stochastic design models. They have resulted in relatively good estimates of both design and operating policy variables. 'Reservoir Yield' model comes under this category and considering its advantages in dealing with large-scale problems it has been selected for use in the present study.

2.5 APPLICATION OF OPTIMIZATION TECHNIQUES

Application of optimization techniques i.e. LP, GP, DP and NLP etc. to water resources management varies from relatively simple problems of straightforward allocation of resources to complex situation of operation and management. Generalized computer packages like APEX-IV, LINDO are available for solving LP problems.

ReVelle (1969) developed a stochastic model that determines the optimal size and operating policy of a multipurpose reservoir. He used chance-constrained optimization model to design the size of the reservoir and also developed an operating policy for the reservoir.

Loucks and Dorfaman (1975) evaluated and compared various LD rules used in chance- constrained models for estimating optimum reservoir capacities. He also applied the model to minimize the size of the reservoirs.

Singh (1981) worked out a plan involving land and water resources (surface and ground water) and their future development for individual river basin and also for India as a whole. Multi-level and multi-period analysis was done using linear programming techniques to optimize land, water, and fertilizer resources for each of 20 river basins individually and Indian sub-continent as a whole.

Loucks (1981) developed the yield model which is a general purpose 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.

Agrawal and Agrawal (1982) applied LP technique in combination with water budgeting to optimize agricultural production, yield per unit area from total irrigation water actually applied through canals in Hissar, Haryana.

Singh (1990) employed modified simplex method of LP to optimize land, water and fertilizer resources of Narmada Basin under four phases of development.

Vedula and Mohan (1990) developed a real time operational methodology for the Bhadra reservoir in the state of Karnatak (India).

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

Edirisisinghe (2000) used optimization model as the main tool that recognizes the randomness of stream flow for capacity determination of hydro reservoirs. He studied the complex interaction among various system reliabilities (hydropower, flood, irrigation etc.).

Dahe and Srivastava (2002) utilized an optimization approach employing the implicit stochastic yield model based on linear programming for planning the optimal development of a river basin with a case study of Narmada basin.

Jena (2004) used LP, DP and NLP techniques for optimal utilization of water of Harbhangi irrigation project in Orissa. He applied LP for reservoir yield optimization. Further, considering the non-linearity of the hydropower related problems, he applied DP and NLP for optimal planning of hydropower power schemes with multi-plants and/or multi-units.

Parhi (2005) used LP and GP models for optimal crop planning of Brahmani basin (Orissa).

Panigrahy and Srivastava (2006) developed an implicit stochastic optimization model named as integrated reservoir yield model based on linear programming for planning the optimal development of a river basin with a case study of transboundary Mahanadi river basin lying in Orissa state.

CHAPTER-3

DESCRIPTION OF THE STUDY AREA

3.1 RUSHIKULYA RIVER BASIN

The River Rushikulya is one of the medium sized east flowing rivers of Orissa state. The river originates at an elevation of 1000m near village Matabarhi in the district of Kandhamala. The basin lies between latitude 19^0- 07′ north to 20^0- 19′ north and longitude 84^0-01′ east to 85^0-06′ east. The catchment area of the basin is 8963 sq.km and it lies entirely in the state of Orissa. It covers 5.76% of total geographical area of the state. The catchment of Rushikulya is leaf shaped. The river travels a total length of 175km and joins with the Bay of Bengal near Chatrapur in Ganjam district. The basin is situated in between Mahanadi basin on the left and Vansadhara basin on the right. The entire basin consists of flat plains and valleys with isolated hills. The coastal plains of the basin contain fertile irrigated lands. The basin is continuously slopping towards the main valley and hence no drainage congestion is felt. There are in all 8 numbers of tributaries of the River Rushikulya. The prominent tributaries of Rushikulya are Padma, Joro, Badanadi, Boringanalla, Baghua, Dhanei, Ghodahada. The index map of Rushikulya Basin is shown in Fig. 3.1.The schematic diagram of the basin is shown in Fig. 3.2. The basin map is shown in Fig. 3.3.

3.2 GEOLOGICAL FEATURE

The geological features in and around the basin comprises of khondolite and charcolite groups of rock formation. The western part of the basin is made of hard rock while the eastern part is composed of alluvial formation and sandy zones.

3.3 CLIMATE

The climate of the entire basin is of tropical monsoon type. There are four well-defined seasons i.e. summer (March to May), monsoon (June to September), post monsoon

(October to November) and winter (December to February). Thunderstorms are quite frequent during monsoon. The average maximum and minimum temperature varies from 45^0C to 27^0C during summer and minimum temperature varies from 9.6^0C to 15.3^0C during winter. The relative humidity varies from 88% to 93% during July to September. Mean wind velocity at Gopalpur is 13.83km/hr and that of Kandhamal is 2.486km/hr. The coastal part of the basin lies in the track of cyclone storm that originates in the Bay of Bengal during the month of April to November.

3.4 RAINFALL

Rain is the only mode of precipitation in the basin. The basin receives 82% of its total annual rainfall from southwest monsoon which is active from June to October. The weighted average annual rainfall of the basin is 1285 mm.

3.5 SOILS

The soil in general of the Rushikulya is very good for agriculture. The soil of the basin has been divided into three numbers of soil groups. One group represents coastal sandy soil and coastal alluvial soil, second group represents red sandy soil and red loamy soil and the last group representing laterite soil.

3.6 FOOD AND AGRICULTURE

Paddy is the main crop grown in the basin. Other crops that are grown in the basin are pulses, groundnut, ragi, vegetables, oilseed, sugarcane etc. 23% of the basin population is either cultivators or agricultural labour and more than 64% of the population is depending on agriculture. The total cultivable area of the basin is 370000 Ha which is 41% geographical area. In Rushikulya basin most of the irrigation projects are from diversion schemes and provide kharif irrigation only.

3.7 SURFACE WATER DEVELOPMENT

3.7.1 Existing project

3.7.1.1 Major project

The century old Rushikulya irrigation project which commands to an area of 61790Ha is the only major irrigation project of Rushikulya basin. It is an integrated project consisting of (i) a reservoir across Boringnallah near Bhanjanagar (ii) a reservoir on a small nallah near Sorada (iii) a weir across river Padma to divert water of Padma to Sorada reservoir (iv) an anicut across Badanadi at Sorisamuli to divert Badanadi water to Bhanjanagar reservoir (v) a diversion weir across Badanadi near Madhabarida to divert Badanadi water to Janivilli anicut (vi) an anicut near Janivilli across Rushikulya to feed Rushikulya canal for irrigation and drinking water supply to Berhampur town.

3.7.1.2 Medium project

Nine numbers of medium irrigation projects presently exist in this basin. Details of above projects are given in Fig. 3.4.

3.7.1.3 Minor project

In Rushikulya basin 1153 numbers of minor irrigation projects are existing which commands to an area of 78555Ha during Kharif season only.

3.7.2 Proposed project

3.7.2.1 Major project

Because of the terrain and non-availability of suitable site, no more major irrigation project is feasible in this basin.

3.7.2.2 Medium project

In Rushikulya basin 8 numbers of future potential medium projects (including one on-going) have been identified. The details of the projects are given in Fig. 3.4.

3.7.2.3 Minor project

The water studies of minor irrigation project have not done in details.

3.8 GROUND WATER DEVELOPMENT

Ground water has been used for domestic, industrial, irrigation use etc. As per the assessment made by the Ground water survey and investigation Directorate, the total ground water potential in Rushikulya basin has been estimated to be 114759 Ham. Present utilization of ground water by all sectors is 22012 Ham which is 19.18% of the ground water potential. Balance ground water resources available for irrigation are 89402 Ham.

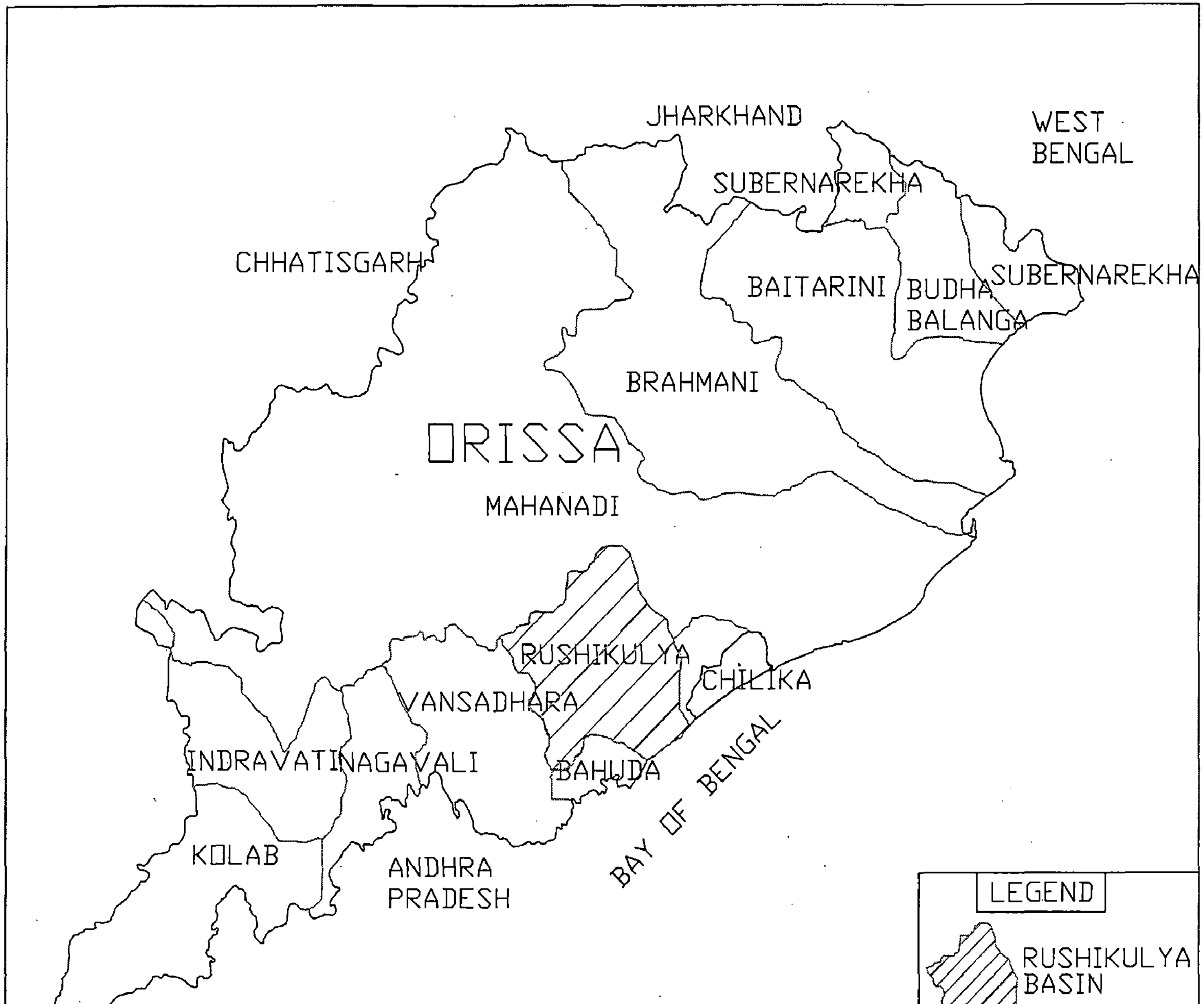


FIGURE 3.1 INDEX MAP OF RUSHIKULYA RIVER BASIN

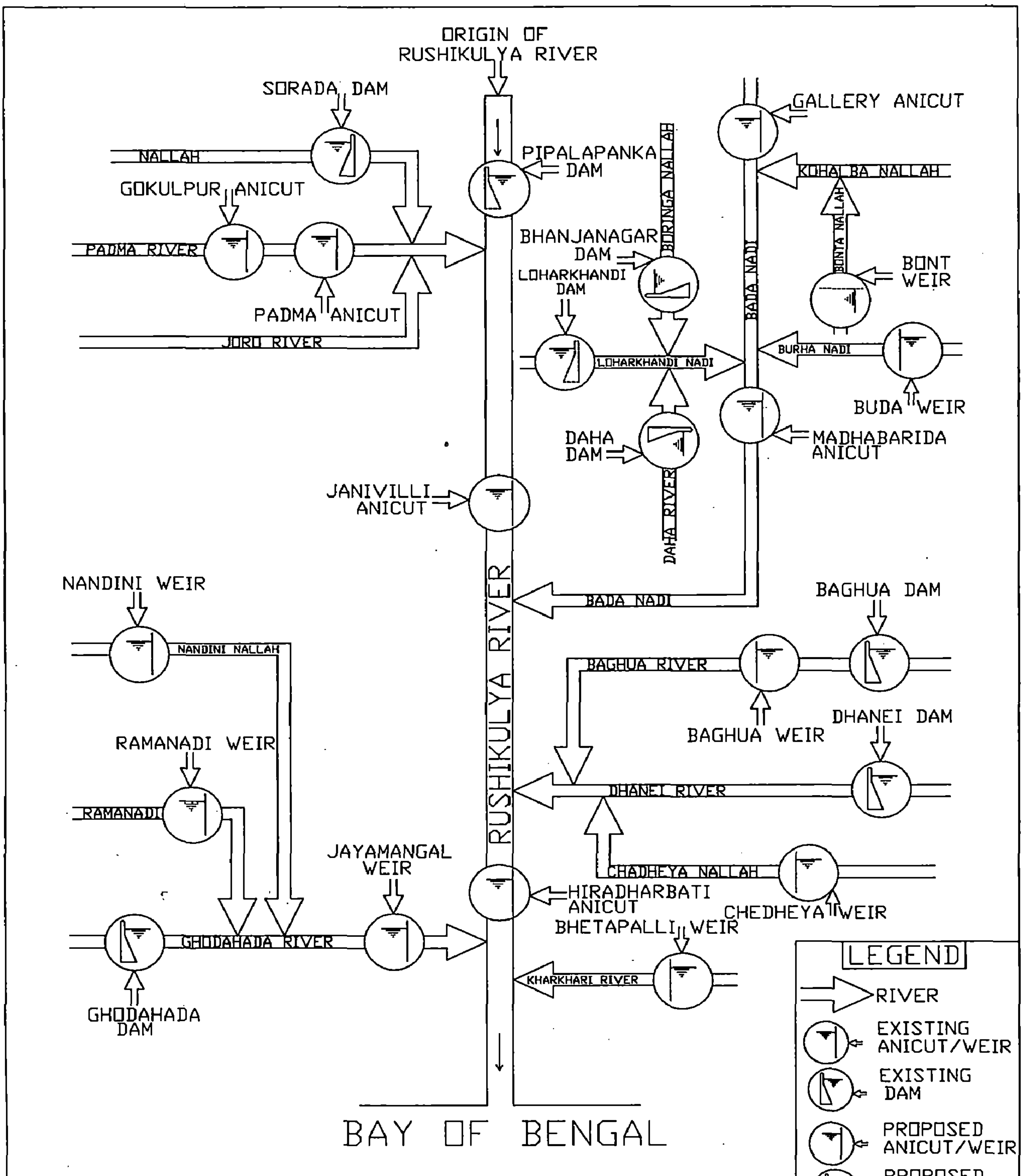


FIGURE 3.2 SCHEMATIC DIAGRAM OF RUSHIKULYA BASIN

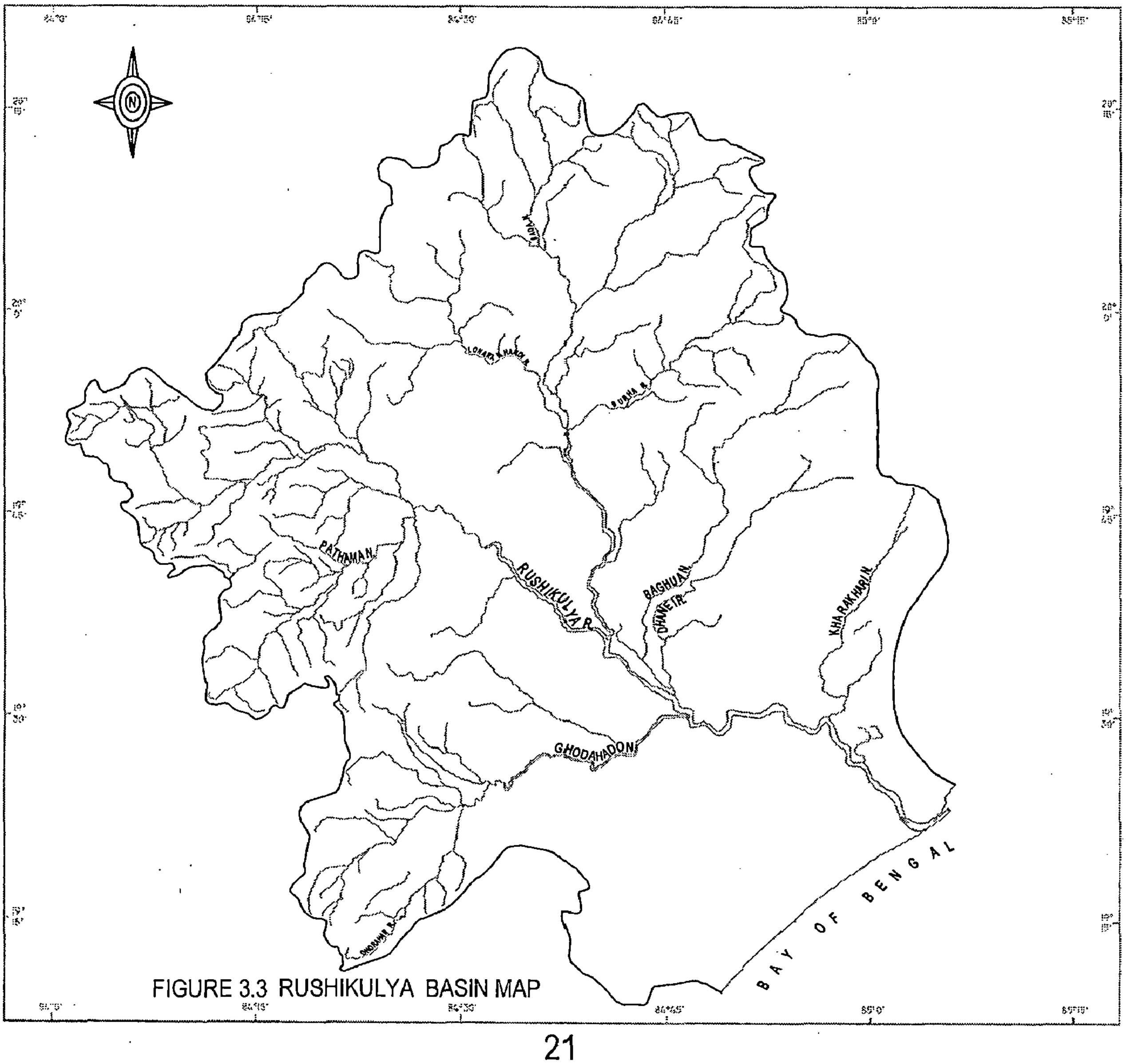
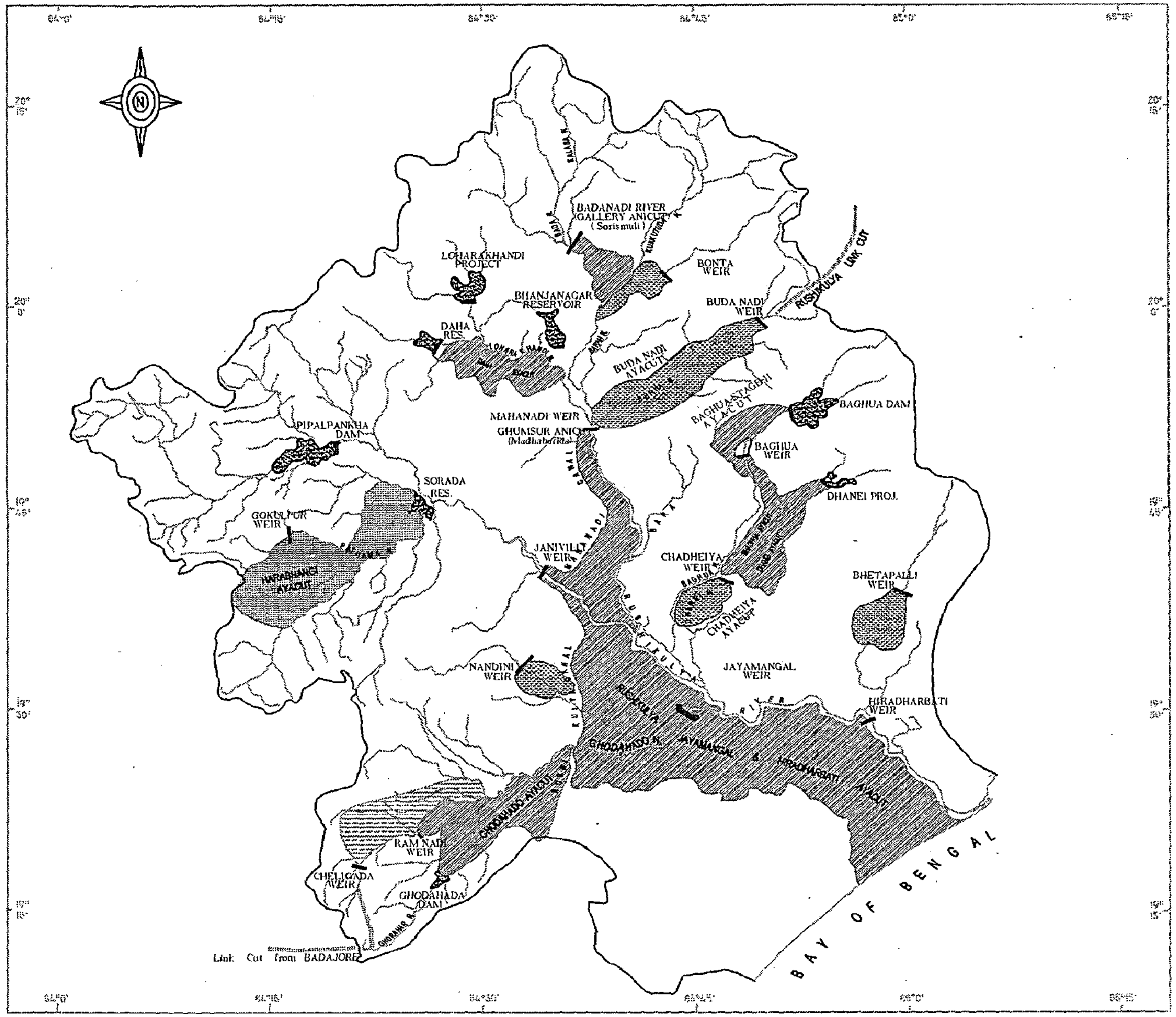


FIGURE 3.3 RUSHIKULYA BASIN MAP



SL. No	NAME OF PROJECT	CA IN Sq.km.	CCA IN Ha	REMARK
COMPLETED PROJECTS				
1.	RUSHIKULYA SYSTEM		61790	INTEGRATED SYSTEM
2.	GHODAHADO DAM	142	6560	
3.	DAHA DAM	168	6580	
4.	DHANEI DAM	123	4625	
5.	RAMA NADI WEIR	198	990	
6.	JAYAMANGALA WEIR	945	7350	
8.	HIRA DHARABATI WEIR	403	6270	
8.	BHAGHUA WEIR	229	3240	
9	BHAGHUA DAM	171	7700	
10	HARABHANGI DAM	504	9150	IMPORT FROM VANSADHARA
ONGOING PROJECTS				
1	CHELIGADA DAM	173.5	3510	IMPORT FROM VANSADHARA
PROPOSED PROJECTS				
1.	PIPALPANKHA DAM	512	NIL	INDUSTRIAL WATER SUPPLY
2.	LOHARKHANDI DAM	196	146	INDUSTRIAL WATER SUPPLY
3.	CHADHEIYA WEIR	30	600	
4.	NANDINI WEIR	136	1600	
5.	BUDANADI WEIR	294	3700	
6.	BONT WEIR	105	1800	
7.	BHETAPALLI WEIR	204	3900	

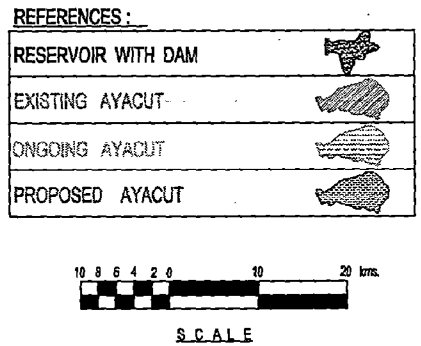


FIGURE 3.4 IRRIGATION PROJECTS (MAJOR & MEDIUM) IN RUSHIKULYA BASIN

CHAPTER-4

ESTIMATION OF WATER DEMAND

4.1 GENERAL

For planning the allocation of water resources for various purposes, it is very much essential to asses the present as well as future demand of water for various segments such as domestic, industrial, irrigation, hydropower generation and environmental requirements etc. As humans are the largest consumers of the water, it is essential to predict the human population to estimate the future requirement of water. For this purpose, the population projection has been made corresponding to year 2051 AD by which time the population is likely to stabilize. At the same time, population of livestock and poultry has also been projected corresponding to the year 2051AD.

4.2 PROJECTED POPULATION OF THE BASIN

4.2.1 Projected human population

The human population of the basin from the year 1961 AD to 2001AD has been furnished in Table 4.1.

Table 4.1 Present human population of the basin

Year	Rural Population	Urban Population	Total Population	Annual growth rate
1961	1335182	133136	1468318	
1971	1583590	232639	1816229	2.15%
1981	1793825	330327	2124152	1.58%
1991	2123760	413748	2537508	1.79%
2001	2378229	564672	2942901	1.49%

Source: Spiral study report (2001) of Rushikulya basin.

The future population projection has been made considering the growth rate from the year 1961 to 2001 and extending a trend line up to the year 2045 AD such that the growth rate of population for the year 2045 onwards is zero.

The projected population of the basin up to 2051AD has been shown in table 4.2

Table 4.2 Present and projected population of the basin

Year	Growth Rate in (%)	Total population	Urban %	Urban population	Rural population
2001	1.49	2942901	19.2	564672	2378229
2011	1.18	3302660	22.3	735456	2567204
2021	0.83	3587249	24.7	887316	2699933
2031	0.5	3770702	26.4	994827	2775875
2041	0.17	3835296	27	1035646	2799650
2051/45	0.0	3868021	26.8	1035646	2832375

4.2.2 Projected livestock and poultry population

The livestock and poultry population of the basin as per 1995 census is 2013047 & 1358939 respectively. Assuming 1% annual growth rate, livestock and poultry population of the basin has been projected by the year 2051AD.

4.3 ESTIMATION OF DOMESTIC DEMAND

Domestic water requirement includes the assessment of water needed for human, poultry and live stock population. The domestic water demand has been shown in Table 4.3

Table 4.3 Domestic Water Demand (in MCM)

Year	Rural Population	Rural Demand	Urban Population	Urban Demand	Livestock Population	Livestock Demand	Poultry Population	Poultry Demand	Total Demand
2001	2378229	60.76	564672	41.22	2136890	31.20	1442541	3.69	136.87
2011	2567204	65.59	735456	53.69	2360456	34.46	1593463	4.07	157.81
2021	2699933	68.98	887316	64.77	2607412	38.07	1760174	4.50	176.32
2031	2775875	70.92	994827	72.62	2880205	42.05	1944328	4.97	190.56
2041	2799650	71.53	1035646	75.60	3181538	46.45	2147797	5.49	199.07
2051	2832375	72.37	1035646	75.60	3514397	51.31	2372449	6.06	205.34

Note: Urban, Rural, Livestock and Poultry water demand has been taken as 200, 70, 40 and 7 liters/capita/day as per the Government of India norms.

4.4 INDUSTRIAL WATER DEMAND

Water is required by the industries for the production of goods and services. As industrial growth and development depends on each other, care should be taken at planning stage to allocate water in proper quantity for the growth and development of industry. Table 4.4 shows the future industrial water demand of the basin.

Table 4.4 Industrial water demand of basin

Year	Water Demand in MCM	Year	Water Demand in MCM
2001	48.6	2031	91
2011	59	2041	95.5
2021	77.9	2051	96.4

Source: Spiral study report (2001) of Rushikulya basin

4.5 IRRIGATION WATER REQUIREMENT

The term crop water requirement implies the total amount of water required by crop to meet the losses through evaporation and transpiration occurring simultaneously known as crop evapo-transpiration.

The crop evapo-transpiration (ET_C) = $ET_O * K_C$ (4.1)

Where, ET_O = Reference crop evapo transpiration , K_C = Crop co-efficient

4.5.1 Reference crop evapo-transpiration

The reference evapo-transpiration is the rate of evapo- transpiration from a hypothetical grass with an assumed height of 0.12m, actively growing under well-watered condition and completely shading the ground. Various methods have been developed over the last 50 years to estimate reference evapo-transpiration from different climatic condition. In this study for computation of ET_o, FAO-56 Penman-Monteith method (FAO-1998) has been used as the earlier modified Penman was found to overestimate ET_o even by up to 20%

for low evaporative conditions. The FAO Penman-Monteith equation (FAO-1998) used for calculation of daily reference evapo-transpiration can be written as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900 u_2 (e_s - e_a)}{T + 273}}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (4.2)$$

Where, ET_O =Reference Evapo-transpiration

Rn =Net radiation at the crop surface [$MJm^{-2}day^{-1}$]

G= Soil heat flux density [$MJm^{-2}day^{-1}$]

T=Mean daily air temperature at 2 meter height [^0C]

u_2=Wind speed at 2 meter height [$m\ s^{-1}$]

e_s=Saturation vapour presser[kPa]

e_a=Actual vapour presser [kPa]

Δ=Slope vapour presser curve [kPa $^0C^{-1}$]

γ= Psychometric constant [kPa $^0C^{-1}$]

In this study for computation of ET_O, the software package CROPWAT window version 4.3 (FAO-1992) along with the hydrometeorological data of Dhaugaon hydrometry station (Shown in annexure 4.1) which lies inside the basin has been used. The computed data of ET_O is presented in table 4.5.

Table 4.5 ET_O for different months of the basin

Month	ET_O(mm/month)	Month	ET_O (mm/month)
Jan	84.7	July	108.57
Feb	104.47	Aug	99.08
Mar	136.97	Sept	101.14
April	158.67	Oct	107.81
May	174.44	Nov	86.93
June	126.13	Dec	81.1

4.5.2 Crop coefficient

The crop coefficient K_C is basically the ratio of the crop evapo-transpiration ET_C to the reference evapo-transpiration ET_O. It represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. Factors determining the crop co-efficient are crop type, climate, soil evaporation and crop growth stage. The crop growth stage is divided into four stages such as

(i) Initial stage, i.e. from germination to 10% ground cover.

(ii) Crop development stage, i.e. from 10% ground cover to 80 % ground cover.

(iii) Mid-season stage, i.e. from attainment of 80% ground cover to time of shor maturity.

(iv) Late season stage, i.e. from mid season to harvest.

The value of K_C has been determined as per FAO Irrigation and Drainage (Reference: FAO-24 and FAO-56). The Table 4.6 shows the K_C values of different crops.

Table 4.6 K_C values of different crops of Rushikulya basin

Name of crop	Crop Period	Total days	Days of different stages				Kc values of different stages			
			Initial	Develop	Mid	Late	Kc ini	Kc dev.	Kc mid	Kc enc
Paddy(K)	Jul15-Nov30	135	30	30	45	30	1.05	1.04	1.02	0.88
Pulses(K)	Jul20-Oct31	100	20	30	30	20	0.4	0.66	0.92	0.63
Sesame(K)	Jul1-Oct20	110	20	30	40	20	0.35	0.64	0.92	0.59
Vegetables(K)	Jul1-Nov30	150	20	30	60	40	0.5	0.76	1.02	0.77
Ragi(R)	Dec15-Mar15	90	15	25	35	15	0.3	0.57	0.84	0.57
Pulses(R)	Dec1-Mar15	105	20	30	35	20	0.4	0.66	0.92	0.64
Groundnut(R)	Dec15-Mar15	90	15	25	35	15	0.4	0.71	1.02	0.75
Vegetables(R)	Dec1-Mar15	105	20	30	40	15	0.6	0.74	0.88	0.76
Sugarcane	Feb10-Dec31	320	30	50	180	60	0.40	0.71	1.02	0.77

Source: FAO-24 and FAO-56.

4.5.3 Average and effective monthly rainfall

The average monthly rainfall of 23 rain gauge stations have been taken and weighted monthly rainfall of the whole basin has been computed after drawing thiessen polygon and computation of influence factor of each rain gauge station. The effective rainfall is that portion of rainfall falling during the growing period of crops, which is available to meet the water requirement of crops. The average monthly rainfall and thiessen polygon along with influence factor of rain gauge stations have been furnished in annexure 4.2 and 4.3 respectively.

The effective rainfall can be obtained by using following relationship. (Source: FAO-IWM)

(i) $Re = 0.8\,P - 25$ when $P > 75$mm and (ii) $Re = 0.6\,P - 10$ when $P < 75$mm.

Where, P =Weighted Monthly Rainfall in mm and Re = Effective Monthly Rainfall in mm.

4.5.4 Net irrigation requirement (NIR)

The net irrigation water requirement is the holding capacity of soil at root zone depth to store available moisture for plant's growth. Hence, net irrigation requirement is computed using following formula.

$$\mathbf{NIR = ET_C - Re} \qquad (4.3)$$

Where, ETc = Crop evapo-transpiration in mm and Re = Effective Rainfall in mm.

4.5.5 Gross irrigation requirement (GIR)

It is the irrigation requirement, which includes the losses in the field watercourses and the conveyance losses in the canals, distributaries up to the field. Hence the gross irrigation requirement (GIR) can be written as

$$\mathbf{GIR = NIR/ (n_c * n_f)} \qquad (4.4)$$

Where, n_c = Conveyance efficiency of channel, and

n_f = Field efficiency .

In the present case n_c and n_f has been taken as 0.80 and 0.70 respectively. Table 4.7 shows the gross irrigation requirement for different crops.

Table 4.7 Irrigation water requirements

Crop	Month	K_c	ET_o mm/day	ET_c mm/month	P mm/month	R_e mm/month	NIR mm	GIR mm
Paddy(K)	June			200	172	113	87	156
	July	1.05	3.5	215	244	171	44	80
	Aug	1.04	3.2	220	263	186	35	62
	Sept	1.03	3.37	224	217	149	75	134
	Oct	1.02	3.48	227	151	96	131	234
	Nov	0.88	2.9	196	52	21	175	312
Pulses(K)	July	0.4	3.5	14	244	171	0	0
	Aug	0.57	3.2	55	263	186	0	0
	Sept	0.83	3.37	84	217	149	0	0
	Oct,	0.73	3.48	76	151	96	0	0
Sesame(K)	July	0.45	3.5	47	244	171	0	0
	Aug	0.73	3.2	70	263	186	0	0
	Sept	0.92	3.37	93	217	149	0	0
	Oct	0.59	3.48	41	151	96	0	0
Vegetables(K)	July	0.59	3.5	62	244	171	0	0
	Aug	0.84	3.2	81	263	186	0	0
	Sept	1.02	3.37	103	217	149	0	0
	Oct	0.93	3.48	97	151	96	2	3
	Nov	0.77	2.9	67	52	21	45	81
Ragi(R)	Dec	0.3	2.62	12	5	0	12	21
	Jan	0.62	2.73	51	12	0	51	90
	Feb	0.84	3.73	94	22	3	91	163
	Mar	0.57	4.42	38	29	7	31	55
Pulses(R)	Dec	0.49	2.62	38	5	0	38	68
	Jan	0.75	2.73	61	12	0	61	110
	Feb	0.88	3.73	98	22	3	95	169
	Mar	0.64	4.42	42	29	7	35	62
Groundnut(R)	Dec	0.4	2.62	16	5	0	16	28
	Jan	0.76	2.73	63	12	0	63	112
	Feb	1.02	3.73	115	22	3	112	198
	Mar	0.75	4.42	50	29	7	43	76
Vegetables(R)	Dec	0.65	2.62	51	5	0	51	91
	Jan	0.79	2.73	65	12	0	65	116
	Feb	0.88	3.73	99	22	3	96	171
	Mar	0.76	4.42	50	29	7	43	77
Sugarcane	Feb	0.4	3.73	30	22	3	27	47
	Mar	0.61	4.42	80	29	7	73	131
	Apr	0.71	5.29	113	43	16	97	173
	May	1.02	5.63	173	74	34	139	247
	June	1.02	4.2	129	172	113	16	29
	July	1.02	3.5	107	244	171	0	0
	Aug	1.02	3.2	98	263	186	0	0
	Sept	1.02	3.37	103	217	149	0	0
	Oct	1.02	3.48	107	151	96	11	19
	Nov	0.77	2.9	67	52	21	46	82
	Dec	0.77	2.62	61	5	0	61	108

4.6 HYDRO-POWER WATER REQUIREMENT

Hydropower water requirement includes assessment of water needs for hydropower generation as well as evaporation loss from reservoir. The topography of the basin is almost flat and in the absence of sufficient head, there is no suitable site for setting up Hydro Electric Project. Hence Hydro Power Consideration has not been taken into account in this study.

4.7 ENVIRONMENTAL WATER REQUIREMENT

The environmental water requirement includes the minimum flow required to maintain the water quality, river regime and river eco-system. As a common practice environmental water requirement is taken as 1% of the gross water requirement of the system.

4.8 TOTAL WATER REQUIREMENT

The total water requirement of the basin under study has been shown in Table 4.8 which includes both present and future requirement. Irrigation demand has been calculated based on minimum food requirements for the population of different decade and adult equivalent of 88% of total population of the basin.

Table 4.8 Total water requirements of basin in MCM

Year	Domestic Demand	Industrial Demand	Irrigation Demand	Environmental Demand	Total Demand
2001	136.87	48.6	2815	30	3031
2011	157.81	59	3159	34	3410
2021	176.32	77.9	3431	37	3723
2031	190.56	91	3607	39	3927
2041	199.07	95.5	3669	40	4003
2051	205.34	96.4	3700	40	4042

4.9 FUTURE CROPPING PATTERN

It has been planned by the Water Resources Department, Orissa, to achieve th CCA of 370000 ha within the basin area by the year 2051 AD. Accordingly a future- cropping pattern has been anticipated as per the food habit of basin population assuming tha the existing cropping trend will continue. Table 4.9 shows the future-cropping pattern as pe the present food habit of basin population.

Table 4.9 Future cropping patterns as per food habit of basin population

Season	Crop Type	Crop Area (in Ha)
Kharif	Paddy	281200
	Pulses	37000
	Sesame	25900
	Vegetables	18500
Rabi	Ragi	11100
	Pulses	262700
	Groundnut	44400
	Vegetables	44400
Perennial	Sugarcane	7400

4.10 FOOD PRODUCTION REQUIREMENT

By the year 2051 the population of the basin will be 3868021 and the CCA will b 370000 ha. Accordingly the minimum production requirement to fulfill the basic food need of the population of basin has been calculated. MPR has been calculated based on 88% adul equivalent of total population by 2051.This has to be taken care of while planning optima cropping pattern.

Table 4.10 shows minimum production requirement (MPR) by the year 2051 AD.

Table 4.10 Minimum food productions requirement by 2051

Crop name	Crop Requirement in kg per cap/year	Crop Requirement in gm per cap/day	MPR in million Ton/year
Paddy	222.89	611	0.759
Ragi	2.64	7	0.009
Pulses	24	66	0.082
Oilseeds	45	123	0.153
Vegetable	70	192	0.238
Sugarcane	109.5	400	0.373

Source: Source: Spiral study report (2001) of Rushikulya Basin

4.11 PROTEIN AND CALORIE CONTENT OF CROPS

Table 4.11 shows the protein and calorie content of different crops.

Table 4.11 Protein and calorie content of different crops

Name of Crop	Protein (gm/kg)	Calorie (cal/kg)
Paddy	75	3460
Ragi	104	3490
Maize	111	3420
Pulses	223	3350
Groundnut	315	5610
Sesame	220	5410
Vegetables	40	800
Sugarcane	-	400

4.12 PROTEIN AND CALORIE REQUIREMENT BY 2051

Protein and calorie requirement of the study area has been computed 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. This approach may be considered as a broad 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 4.12.

Table 4.12 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 (Panigrahy 2006) and shown in table 4.13 is used for the present analysis.

Table 4.13 Population of different age group of male and female

Age group	Male %	Female %
0 to 9 years	21.42	21.44
10 to 19 years	20.23	20.2
20 to 39 years	33.16	32.51
40 to 59 years	17.69	18.48
Above 60 years	7.5	7.37
Total	100	100

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 basin of the census figures of the year 2001 on percentages basis is 50.1 percent and 49.9 percent respectively. Using the above data, weighted average nutritional requirements 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 4.14

Table 4.14 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

= (50.1x63.78+49.9x58.83)/100 = 61 gms /day/person

Similarly combined weighted average calorie requirement per capita per day for the whole population shall be

= (50.1x2524.90+49.9x2003.17)/100 = 2265 calorie units /day/person

Now adopting the above values, annual protein and calorie requirement of basin by 2051AD has been computed and shown in Table 4.15

Table 4.15 Protein and calorie requirement by the year 2051 AD

Population	Minimum protein Requirement (lakh kg/yr)	Minimum Calorie Requirement (lakh kcl/yr).
3868021	861.2149	31977.8966

4.13 CROP YIELD AND NET BENEFIT AT NIL AND FULL IRRIGATION STAGE

The crop yield and net benefit at nil and full nil irrigation stage has been shown in Table 4.16 and Table 4.17

Table 4.16 Crop yield and net benefit from crops at no irrigation stage

Name of Crop	Cost of inputs other then water (Rs/Ha)					Yield qnt/ha	Rate Rs/qnt	Return Rs/ha	Net Benefit Rs/ha
	Seed	Fertilizer	Pesticides	Labour	Total				
1	2	3	4	5	6=2+3+4+5	7	8	9=7*8	10=9-6
Pulses-K	600	1000	400	1482	3482	6.5	3000	19500	16018
Sesame-K	600	1000	400	2223	4223	6	2300	13800	9577

Table 4.17 Crop yield and net benefit from crops at full irrigation stage

Name of Crop	Cost of inputs other then water (Rs/Ha)					Yield qnt/ha	Rate Rs/qnt	Return Rs/ha	Net Benefit Rs/ha
	Seed	Fertilizer	Pesticides	Labour	Total				
1	2	3	4	5	6=2+3+4+5	7	8	9=7*8	10=9-6
Paddy-K	750	3000	250	8645	12645	32	740	23680	11035
Vegetables-K	500	8000	1500	7410	17410	81.65	600	48990	31580
Ragi-R	124	1482	494	1853	3953	10.6	600	6360	2407
Pulses-R	600	1000	400	1482	3482	4.5	3000	13500	10018
Groundnut-R	3000	1000	400	6175	10575	20	2000	40000	29425
Vegetable-R	500	8000	1500	7410	17410	80	600	48000	30590
Sugarcane	10000	8000	2000	9880	29880	740	94	69560	39680

Source:Agricultural statistics of Ganjam district, Orissa.

CHAPTER –5

ASSESSMENT OF AVAILABILITY OF WATER RESOURCES

5.1 GENERAL

The appraisal of water resources availability is a basic requirement in planning optimal water resources development of any river basin. This includes assessment of:

(i) Sources of water,

(ii) Quantity of water,

(iii) Quality of water, and

(iv) Dependability of water.

The sources of water may be both surface and ground water. Hence it is very much essential to assess its quantity, quality and dependability.

5.2 ASSESSMENT OF SURFACE WATER

From the available run-off data at various gauge discharge sites of Rushikulya basin, the 75% dependable yield has been calculated using Flow Duration Curves. It has been assessed by Govt. of Orissa that 680MCM of water will be imported from the neighboring river basin Vansadhara & Mahanadi by year 2051.It has been assumed that whole urban & industrial demand and 50% of rural demand is to be met from surface water. Accordingly surface water available for irrigation purpose has been calculated as 3630 MCM. Table 5.1 shows the data involved in the calculation process of Flow Duration Curve. A typical Flow Duration Curve for calculating 75% dependable yield of basin has been shown in Figure 5.1.

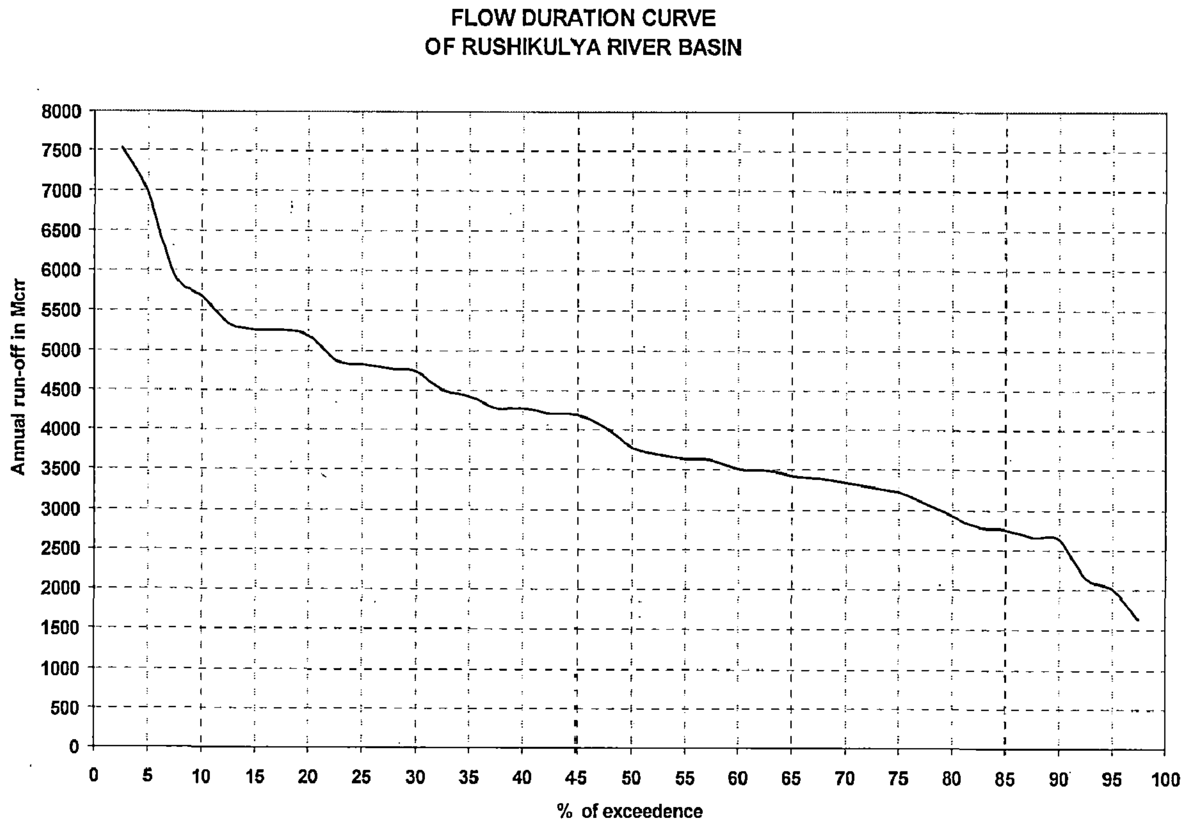
Table 5.1 75% Dependable yield of basin

Run-off in MCM

Sl.no	Year	Run-off	Run-off in Descending order	% of exceedence
1	1961	3504	7537	2.5
2	1962	5251	6944	5
3	1963	5174	5915	7.5
4	1964	4863	5679	10
5	1965	2746	5334	12.5
6	1966	3075	5253	15
7	1967	3621	5251	17.5
8	1968	5679	5174	20
9	1969	4729	4863	22.5
10	1970	4183	4825	25
11	1971	4762	4762	27.5
12	1972	3629	4729	30
13	1973	4409	4502	32.5
14	1974	3485	4409	35
15	1975	3330	4276	37.5
16	1976	3393	4276	40
17	1977	3227	4199	42.5
18	1978	4502	4183	45
19	1979	2651	4027	47.5
20	1980	3771	3771	50
21	1981	3275	3682	52.5
22	1982	2628	3629	55
23	1983	5253	3621	57.5
24	1984	1624	3504	60
25	1985	4276	3485	62.5
26	1986	3412	3412	65
27	1987	2004	3393	67.5
28	1988	4027	3330	70
29	1989	4199	3275	72.5
30	1990	7537	**3227**	**75**
31	1991	5915	3075	77.5
32	1992	4825	2919	80
33	1993	2785	2785	82.5
34	1994	5334	2746	85
35	1995	6944	2651	87.5
36	1996	2138	2628	90
37	1997	4276	2138	92.5
38	1998	3682	2004	95
39	1999	2919	1624	97.5
	Average	4027		

Hence 75% Dependable yield of the basin is **3227** MCM

Fig 5.1 A typical Flow Duration Curve Showing 75% dependable yield



5.3 ASSESSMENT OF GROUND WATER AVAILABILITY

Ground water is an important source of water and its development is crucial especially in areas where surface water resources are scare. In many areas ground water is the only dependable water source for drinking as well as irrigation.

The appraisal of ground water is much more complicated than that of surface water as ground water is not confined to any channel or exposed to vision for direct measurement. The basic information needed for assessing the ground water availability are (i) type of aquifers (ii) location of aquifers (iii) thickness of aquifers (iv) hydraulic conductivity and storage co-efficient of aquifers (v) annual recharge etc. These are obtained from water level observations in wells, surface geological mappings, test drilling and pumping test data.

Table 5.2 shows the availability of ground water resources in the basin area.

Table 5.2 Ground water potential of rushikulya basin

Sl. No	Name of District	Name of Block	%Age of block area inside the basin to total block area	Ground water resources assessed in Ham	Utilisable resource for domestic & industrial use in Ham	Utilisable resource for irrigation use in Ham	Annual draft for irrigation use in Ham	Balance resources for irrigation use as of 1999 in Ham
1	2	3	4	5	6	7	14	15
1	Gajapati	Mohana	22.28	1138.51	61.05	1077.46	60.16	1017.3
		R.Udayagiri	15.96	652.44	20.75	631.69	44.69	587
2	Nayagarh	Dasapalla	17.93	2846.39	47.34	2799.05	59.89	2739.16
		Odogaon	17.88	2381.79	77.24	2304.55	183.09	2121.46
		Nuagaon	19.54	529.92	46.51	483.41	83.24	400.17
3	Kondhamal	Chakapada	18.47	492.23	21.06	471.17	56.7	414.47
		G.Udayagiri	26.73	574.96	28.33	546.63	42.23	504.4
		Raikia	62.74	2440.59	110.42	2330.17	203.91	2126.26
		Kotgarh	0.85	43.18	1.28	41.9	1.18	40.72
		Daringibadi	43.84	3853.97	141.6	3712.37	89.87	3622.5
4	Khurda	Banapur	12.23	1315.46	75.7	1239.76	16.63	1223.13
5	Ganjam	Rangailunda	100	5605	398	5207	829	4378
		Kukudakhandi	100	6050	391	5659	385	5274
		Chikiti	34.21	1532.27	100.92	1431.35	380.07	1051.28
		Patrapur	2.07	108.47	8.24	100.23	11.61	88.62
		Hinjilicut	100	4891	447	4444	1423	3021
		Sheragarh	100	3023	376	2647	675	1972
		Digapahandi	74.05	5247.92	365.07	4882.85	618.32	4264.53
		Sanakhemundi	100	5218	479	4739	855	3884
		Aska	100	4270	526	3744	1386	2358
		Bhanjanagar	99.11	9303.46	453.92	8849.54	775.04	8074.5
		Beloguntha	100	3919	366	3553	628	2925
		Buguda	100	4630	390	4240	513	3727
		Chatrapur	100	5081	442	4639	880	3759
		Dharakote	100	3992	327	3665	618	3047
		Ganjam	45.91	1335.52	132.68	1202.84	505.47	697.37
		Jagannathprasad	94.15	7192.12	365.3	6826.82	773.91	6052.91
		Kabisuryanagar	100	3116	378	2738	572	2166
		Khallikote	31.81	1391.69	146.33	1245.36	286.93	958.43
		Kodala	92.11	3614.4	378.57	3235.83	441.21	2794.62
		Polasara	100	4670	449	4221	615	3606
		Purushottampur	100	6063	486	5577	1818	3759
		Sorada	100	8236	451	7785	1038	6747
			Total	114759	8488	106271	16869	89402

Source: Spiral study report (2001) of Rushikulya basin

5.3.1 Monthly availability of ground water

The monthly availability of ground water has been estimated taking the capacity of pumping plant into consideration, assuming 10 hours of working per day to pump out 1/12th of total annual utilizable water. If the pump is operated all the 24 hours of the day, 20 % of the annual ground water could be pumped out in one month. This concept also takes care of over utilization of ground water. The monthly ground water availability of the Rushikulya basin has been calculated as 21254 Ham.

5.4 UNIT COST OF WATER IN STUDY AREA

As per Government of Orissa, water resources department, the unit cost of water is as follows.

(i) For drinking purposes @ Rs 1000/Ham (Both surface & ground water)

(ii) For irrigation purposes@ Rs 2700/Ham.(surface water) and @ Rs 3500/Ham (ground water).

(iii) For industrial purposes.

(a) From river @ Rs 4400/Ham

(b) From reservoir @ Rs 5600/Ham

(c) From ground water @ Rs 7000/Ham

CHAPTER-6

OPTIMIZATION OF CROPPING PATTERN USING LP MODEL

6.1 GENERAL

A model is a simplified representation of reality. An optimization model helps to get the optimal solution out of several alternatives. To meet the growing demand of food, agricultural production is to be increased by increasing the production per unit area by optimal use of land and water resources. At the same time, the availability of water to meet hydropower, domestic, industrial and environmental requirements are to be kept under consideration. For this LP model has been used to identify the best combination of limited resources so as to optimize the objective.

6.2 OBJECTIVE FUNCTION

The objective of the present LP model is to maximize net benefit from the crops. Hence, it can be written as:

Max Z = Max [(Return from Khariff +Return from Rabi+ Return from Sugarcane)-(Cost of watering from surface source+ Cost of watering from ground source)]

$$= Max\left[\sum_{j=1}^{NCR}\{B_{jk}Y_{jk} - C_{jk}\}A_{jk} + \sum_{j=1}^{NCR}\{B_{jr}Y_{jr} - C_{jr}\}A_{jr} + \{B_S Y_S - C_S\}A_S\right] - \left[\sum_{m=1}^{NOM}\{C_S S_m\} + \sum_{m=1}^{NOM}\{C_g G_m\}\right] \tag{6.1}$$

Where,

NCR=Number of feasible crops in any period.

B_{jk}=Monetary return from jth crop in Rs per qtl during Kharif.

Y_{jk}= Yield from jth crop in qtl per km^2 during Kharif.

C_{jk}= Cost of inputs other then water for jth crop in Rs per km^2 during Kharif.

A_{jk}= Area of jth crop km^2 during Kharif.

B_{jr}, Y_{jr}, C_{jr} and A_{jr} are corresponding values during Rabi.

B_s, Y_s, C_s and A_s are corresponding values for sugarcane.

C_s and C_g are cost of surface and ground water respectively (in Rs/MCM).

S_m and G_m are surface and ground water resources in m^{th} period (in MCM).

NOM=Total number of period in a year (12 months.)

6.3 CONSTRAINTS

The above objective function is to be optimized with the following constraints

(i) Land availability constraint

The area under various crops during any period cannot exceed the cultivable command area of the study area. It can be written as:

$$\sum_{j=1}^{NCR} A_{jm} \leq A \tag{6.2}$$

Where, A_{jm} = Area of j^{th} crop (in km^2) in m^{th} period.

A = Cultivable command area (in km^2) of the study area.

(ii) Irrigation water requirement constraint

The water requirement for various crops in each month cannot exceed surface and ground water resources. If I_{jm} is the gross irrigation requirement (in meter) of j^{th} crop during m^{th} period. It can be written as:

$$\sum_{m=1}^{NOM} \sum_{j=1}^{NCR} A_j I_{jm} \leq S_m + G_m \tag{6.3}$$

(iii) Surface water availability constraint

The gross annual surface water release cannot exceed total surface water available annually. It can be written as:

$$\sum_{m=1}^{NOM} S_m \leq \text{Gross availability of surface water} \qquad (6.4)$$

(iv) Ground water availability constraint

Total ground water withdrawal annually cannot exceed annual utilizable ground water. It an be written as:

$$\sum_{m=1}^{NOM} G_m \leq \text{Annual utilizable ground water} \qquad (6.5)$$

And monthly ground water withdrawal cannot exceed 20% annual utilizable ground water. It is based on the assumption that excessive withdrawal of ground water may cause mining. It can be written as:

$$\sum_{m=1}^{NOM} G_m \leq 20\% \text{ of annual available ground water} \qquad (6.6)$$

(v) Total water availability constraint

Total water allocated for all purposes cannot exceed the gross availability of water from surface and ground sources. It can be written as:

$$\sum_{m=1}^{NOM} S_m + \sum_{m=1}^{NOM} G_m \leq \text{Total water available} \qquad (6.7)$$

(vi) Protein requirement constraint

In order to satisfy the protein requirement of the population of the study area the protein value of all the crops produced should exceed the protein requirement. It can be written as:

$$\sum_{j=1}^{NCR} A_j Y_j P_j \geq P_r \qquad (6.8)$$

Where, A_j = Area of j^{th} crop (in km^2)

Y_j = Yield of j^{th} crop (qtl / km^2)

P_j = Protein value of j^{th} crop (kg / qtl)

Pr = Protein requirement of the study area (in kg).

(vii) Calorie requirement of constraint

In order to satisfy the calorie requirement of the study area, the calorific value of all crops produced cannot be less then the calorie requirement of study area. It can be written

as: $$\sum_{j=1}^{NCR} A_j Y_j C_j \geq C_r \qquad (6.9)$$

Where, C_j = Calorie value of j^{th} crop (kcal / qtl)

Cr =Total calorie requirement of study area (in kcal).

(viii) Minimum crop area constraint

In order to satisfy basic food needs of the population of the study area, minimum area of some crops may be imposed.

It can written as:

$$A_j \geq A_{min.j} \qquad (6.10)$$

Where, $A_{min.j}$ = Minmum area of j^{th} crop (in km^2).

(ix) Maximum crop area constraint

In order to avoid excessive production of certain crops over minimum production requirements, maximum crop area constraints may be imposed. It can be written as:

$$A_j \leq A_{max.j} \qquad (6.11)$$

Where, $A_{max.j}$ =Maximum area of j^{th} crop in km^2.

(x) Canal capacity constraint- Assuming that the canal is capable of carrying only 20% of gross irrigation water requirement of crops, the canal capacity constraint can be written

as:

$$S_m \leq 20\% \text{ of gross irrigation requirement of crops} \qquad (6.12)$$

6.4 NOTATIONS

In this model attempt has been made to maximize benefit while meeting food, protein and calorie requirement. In this model the decision variables are A_j, S_k and G_k.

For A_j i.e. area under j^{th} crop the following notations has been used.

A1 = Area of Paddy in km^2 during Kharif.

A2 = Area of Pulses in km^2 during Kharif.

A3 = Area of Sesame in km^2 during Kharif

A4 = Area of Vegetables in km^2 during Kharif

A5 = Area of Ragi in km^2 during Rabi

A6 = Area of Pulses in km^2 during Rabi

A7 = Area of Groundnut in km^2 during Rabi

A8= Area of Vegetables in km^2 during Rabi

A9 = Area of Sugarcane in km^2.

For S_k i.e. optimal surface water release the following notations are used for 12 months in the model.

S1, S2, S3, S4, S4, S5, S6, S7, S8, S9, S10, S11, S12 are releases of surface water in MCM during the months of January, February, March, April, May, June, July, August, September, October, November, December respectively.

For G_k i.e. optimal ground water withdrawal the following notations are used for 12 months in the model.

G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, G12 are releases of ground water in MCM during the months of January, February, March, April, May, June, July, August, September, October, November and December respectively.

6.5 LP MODEL

In this study five LP models have been developed. The models are as follows:

6.5.1 LP-1 (Maximizing benefit meeting food, protein and calorie requirement)

OBJECTIVE FUNCTION

Net benefit values, (B_jY_j-C_j) for each crop has been calculated and shown in Table 4.16 and 4.17. C_s and C_g values have been taken as Rs 2.7 and Rs 3.5 (in Lakhs) per MCM respectively. Hence objective function of this model becomes

MAX[11.035A1+16.018A2+9.577A3+31.580A4+2.407A5+10.018A6+29.425A7+30.590A8+39.680A9-2.7S1-2.7S2-2.7S3-2.7S4-2.7S5-2.7S6-2.7S7-2.7S8-2.7S9-2.7S10-2.7S11-2.7S12-3.5G1-3.5G2-3.5G3-3.5G4-3.5G5-3.5G6-3.5G7-3.5G8-3.5G9-3.5G10-3.5G11-3.5G12].

CONSTRAINTS

(i). Land availability constraint: Total cultivable areas available during Kharif and Rabi in the study area are 3700 and 3700 km^2 respectively. So total area allocated for different crops in a particular season should be less then or equal to the cultural command area (CCA). Hence the land availability constraints are:

A1+A2+A3+A4 +A9 $\leq$3700

A5+A6+A7+A8+A9$\leq$3700

(ii). Irrigation water requirement constraint: The gross irrigation water requirement of crops has been shown in Table 4.7. Monthly crop water requirements should not exceed the maximum available water from both surface and ground water sources. The constraints for use of both surface and ground water are as follows:

0.09A5+0.11A6+0.112A7+0.116A8-S1-G1$\leq$0

0.163A5+0.169A6+0.198A7+0.171A8+0.047A9 -S2-G2$\leq$0

$0.055A5+0.062A6+0.076A7+0.077A8+0.131A9-S3-G3\leq 0$

$0.173A9 -S4-G4\leq 0$

$0.247A9 -S5-G5\leq 0$

$0.156A1+0.029A9 -S6-G6\leq 0$

$0.08A1-S7-G7\leq 0$

$0.062 A1-S8-G8\leq 0$

$0.134A1-S9-G9\leq 0$

$0.234 A1+0.003A4+0.019A9-S10-G10\leq 0$

$0.312A1+0.081A4+0.082A9-S11-G11\leq 0$

$0.021A5+0.068A6+0.028A7+0.091A8+0.108A9-S12-G12\leq 0$

(iii). Surface water availability constraints-. Total surface water available for irrigation use is 3630 MCM as calculated in 5.2. This can be written as:

$S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12 \leq 3630$

(iv). Ground water availability constraint- Maximum utilizable ground water available in the basin is 1062.71 MCM/year as per table 5.2. So the ground water availability constraint is as follows:

$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G1+G12 \leq 1062.71$

(v). Monthly ground water availability constraint-Assuming that the monthly ground water withdrawal cannot exceed 20% of the annual utilizable ground water, the monthly ground water constraint can be written as follows:

$G1 \leq 212.54$

$G2 \leq 212.54$

$G3 \leq 212.54$

$G4 \leq 212.54$

$G5 \leq 212.54$

$G6 \leq 212.54$

$G7 \leq 212.54$

$G8 \leq 212.54$

$G9 \leq 212.54$

$G10 \leq 212.54$

$G11 \leq 212.54$

$G12 \leq 212.54$

(vi). Protein requirement constraint-The protein requirement of the population of the study area should be satisfied by the crops produced in the study area. This can be written as follows:

$$0.24A1+0.145A2+0.152A3+0.327A4+0.110A5+0.100A6+0.630A7+0.320A8 \geq 861.2149$$

(vii). Calorie requirement constraint – The crops produced should satisfy total calorie requirement for the population of the study area. This can be written as:

$$11.07A1+2.18A2+3.4A3+6.53A4+3.70A5+1.51A6+11.22A7+6.40A8+29.60A9 \geq 31977.896$$

(viii). Minimum crop area constraint- In order to satisfy basic food needs of the basin population, the minimum area of some crops has to be imposed. This can be written as:

$32A1 \geq 75869$

$10.6A5 \geq 899$

$6.5A2 + 4.5A6 \geq 8169$

$6A3+20A7 \geq 15317$

$81.65A4+80A8 \geq 23827$

$740A9 \geq 37272$

(ix). Canal capacity constraint- Assuming that the canal is capable of carrying only 20% of gross irrigation requirement of crops, the canal capacity constraint can be written as follows:

$S1 \leq 740$

$S2 \leq 740$

$S3 \leq 740$

$S4 \leq 740$

$S5 \leq 740$

$S6 \leq 740$

$S7 \leq 740$

$S8 \leq 740$

$S9 \leq 740$

$S10 \leq 740$

$S11 \leq 740$

$S12 \leq 740$

6.5.2 LP-2 (Maximizing benefit meeting food requirements)

OBJECTIVE FUNCTION

Net benefit values, (B_jY_j-C_j) for each crop has been calculated and shown in Table 4.16 and 4.17. C_s and C_g values have been taken as Rs 2.7 and Rs 3.5 (in Lakhs) per MCM respectively. Hence objective function of this model becomes

MAX[11.035A1+16.018A2+9.577A3+31.580A4+2.407A5+10.018A6+29.425A7+30.590A8+39.680A9-2.7S1-2.7S2-2.7S3-2.7S4-2.7S5-2.7S6-2.7S7-2.7S8-2.7S9-2.7S10-2.7S11-2.7S12-3.5G1-3.5G2-3.5G3-3.5G4-3.5G5-3.5G6-3.5G7-3.5G8-3.5G9-3.5G10-3.5G11-3.5G12].

CONSTRAINTS

(i). Land availability constraint- Total cultivable areas available during Kharif and Rabi in the study area are 3700and 3700km^2 respectively. So total area allocated for different crops in a particular season should be less then or equal to the cultural command area (CCA). Hence the land availability constraints are:

$$A1+A2+A3+A4+A9 \leq 3700$$

$$A5+A6+A7+A8+A9 \leq 3700$$

(ii). Irrigation water requirement constraint-The gross irrigation water requirement of crops has been shown in Table 4.7. Monthly crop water requirements should not exceed the maximum available water from both surface and ground water sources. The constraints for use of both surface and ground water are as follows:

$$0.09A5+0.11A6+0.112A7+0.116A8-S1-G1 \leq 0$$

$$0.163A5+0.169A6+0.198A7+0.171A8+0.047A9-S2-G2 \leq 0$$

$$0.055A5+0.062A6+0.076A7+0.077A8+0.131A9-S3-G3 \leq 0$$

$$0.173A9-S4-G4 \leq 0$$

$$0.247A9-S5-G5 \leq 0$$

$$0.156A1+0.029A9-S6-G6 \leq 0$$

$$0.08A1-S7-G7 \leq 0$$

$$0.062\,A1-S8-G8 \leq 0$$

$$0.134A1-S9-G9 \leq 0$$

$$0.234\,A1+0.003A4+0.019A9-S10-G10 \leq 0$$

$$0.312A1+0.081A4+0.082A9-S11-G11 \leq 0$$

$$0.021A5+0.068A6+0.028A7+0.091A8+0.108A9-S12-G12 \leq 0$$

(iii). Surface water availability constraints-. Total surface water available for irrigation use is 3630 MCM as calculated in 5.2. This can be written as:

$$S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12 \leq 3630$$

(iv). Ground water availability constraint- Maximum utilizable ground water available in the basin is 1062.71 MCM/year as per table 5.2. So the ground water availability constraint is as follows:

$$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G1+G12 \leq 1062.71$$

(v). Monthly ground water availability constraint-Assuming that the monthly ground water withdrawal cannot exceed 20% of the annual utilizable ground water, the monthly ground water constraint can be written as follows:

$G1 \leq 212.54$

$G2 \leq 212.54$

$G3 \leq 212.54$

$G4 \leq 212.54$

$G5 \leq 212.54$

$G6 \leq 212.54$

$G7 \leq 212.54$

$G8 \leq 212.54$

$G9 \leq 212.54$

$G10 \leq 212.54$

$G11 \leq 212.54$

$G12 \leq 212.54$

(vi). Minimum crop area constraint- In order to satisfy basic food needs of the basin population, the minimum area of some crops has to be imposed. This can be written as:

$32A1 \geq 75869$

$10.6A5 \geq 899$

$6.5A2 + 4.5\ A6 \geq 8169$

$6A3+20A7 \geq 15317$

$81.65A4+80A8 \geq 23827$

$740A9 \geq 37272$

(vii). Canal capacity constraint- Assuming that the canal is capable of carrying only 20% of gross irrigation requirement of crops, the canal capacity constraint can be written as follows:

$S1 \leq 740$

$S2 \leq 740$

$S3 \leq 740$

$S4 \leq 740$

$S5 \leq 740$

$S6 \leq 740$

$S7 \leq 740$

$S8 \leq 740$

$S9 \leq 740$

$S10 \leq 740$

$S11 \leq 740$

$S12 \leq 740$

6.5.3 LP-3 (Maximizing benefit meeting food requirement with maximum allowance of 50% excess production over MPR).

This plan is based on assumption that excess production over MPR may lead to wastage of some perishable items, which needs cold storage.

OBJECTIVE FUNCTION

Net benefit values, $(B_jY_j\text{-}C_j)$ for each crop has been calculated and shown in Table 4.16 and 4.17. C_s and C_g values have been taken as Rs 2.7 and Rs 3.5 (in Lakhs) per MCM respectively. Hence objective function of this model becomes

MAX[11.035A1+16.018A2+9.577A3+31.580A4+2.407A5+10.018A6+29.425A7+30.590A8+39.680A9-2.7S1-2.7S2-2.7S3-2.7S4-2.7S5-2.7S6-2.7S7-2.7S8-2.7S9-2.7S10-

2.7S11-2.7S12-3.5G1-3.5G2-3.5G3-3.5G4-3.5G5-3.5G6-3.5G7-3.5G8-3.5G9-3.5G10-3.5G11-3.5G12].

CONSTRAINTS

(i). Land availability constraint- Total cultivable areas available during Kharif and Rabi in the study area are 3700 and 3700 km^2 respectively. So total area allocated for different crops in a particular season should be less then or equal to the cultural command area (CCA). Hence the land availability constraints are:

$A1+A2+A3+A4+A9 \leq 3700$

$A5+A6+A7+A8+A9 \leq 3700$

(ii). Irrigation water requirement constraint-The gross irrigation water requirement of crops has been shown in Table 4.7. Monthly crop water requirements should not exceed the maximum available water from both surface and ground water sources. The constraints for use of both surface and ground water are as follows:

$0.09A5+0.11A6+0.112A7+0.116A8-S1-G1 \leq 0$

$0.163A5+0.169A6+0.198A7+0.171A8+0.047A9-S2-G2 \leq 0$

$0.055A5+0.062A6+0.076A7+0.077A8+0.131A9-S3-G3 \leq 0$

$0.173A9-S4-G4 \leq 0$

$0.247A9-S5-G5 \leq 0$

$0.156A1+0.029A9-S6-G6 \leq 0$

$0.08A1-S7-G7 \leq 0$

$0.062A1-S8-G8 \leq 0$

$0.134A1-S9-G9 \leq 0$

$0.234A1+0.003A4+0.019A9-S10-G10 \leq 0$

$0.312A1+0.081A4+0.082A9-S11-G11 \leq 0$

$0.021A5+0.068A6+0.028A7+0.091A8+0.108A9-S12-G12 \leq 0$

(iii). Surface water availability constraints-. Total surface water available for irrigation use is 3630 MCM/year as calculated in 5.2. This can be written as:

$$S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12 \leq 3630$$

(iv). Ground water availability constraint- Maximum utilizable ground water available in the basin is 1062.71 MCM/year as per table 5.2. So the ground water availability constraint is as follows:

$$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G1+G12 \leq 1062.71$$

(v). Monthly ground water availability constraint-Assuming that the monthly ground water withdrawal cannot exceed 20% of the annual utilizable ground water, the monthly ground water constraint can be written as follows:

$$G1 \leq 212.54$$

$$G2 \leq 212.54$$

$$G3 \leq 212.54$$

$$G4 \leq 212.54$$

$$G5 \leq 212.54$$

$$G6 \leq 212.54$$

$$G7 \leq 212.54$$

$$G8 \leq 212.54$$

$$G9 \leq 212.54$$

$$G10 \leq 212.54$$

$$G11 \leq 212.54$$

$$G12 \leq 212.54$$

(vi). Minimum crop area constraint- In order to satisfy basic food needs of the basin population, the minimum area of some crops has to be imposed. This can be written as:

$32A1 \geq 75869$

$10.6A5 \geq 899$

$6.5A2 + 4.5\ A6 \geq 8169$

$6A3 + 20A7 \geq 15317$

$81.65A4 + 80A8 \geq 23827$

$740A9 \geq 37272$

(vii) Maximum crop area constraint- Assuming that it may be difficult to store very huge amount of food grains, maximum area constraint has been imposed such that maximum area of crops will not exceed 50% of the crop area that satisfies the minimum food requirement. This can be written as:

$32A1 \leq 113803$

$10.6A5 \leq 1348$

$6.5A2 + 4.5\ A6 \leq 12254$

$6A3 + 20A7 \leq 22976$

$81.65A4 + 80A8 \leq 35741$

$740A13 \leq 55908$

(viii). Canal capacity constraint- Assuming that the canal is capable of carrying only 20% of gross irrigation requirement of crops, the canal capacity constraint can be written as follows:

$S1 \leq 740$

$S2 \leq 740$

$S3 \leq 740$

$S4 \leq 740$

$S5 \leq 740$

$S6 \leq 740$

$S7 \leq 740$

$S8 \leq 740$

$S9 \leq 740$

$S10 \leq 740$

$S11 \leq 740$

$S12 \leq 740$

6.5.4 LP-4 (Maximizing benefit allowing 20% deviation over existing cropping pattern).

This plan is based on the assumption that a change can only be introduced gradually. A 20% deviation over existing cropping pattern allows gradual introduction of modified cropping pattern.

OBJECTIVE FUNCTION

Net benefit values, (B_jY_j-C_j) for each crop has been calculated and shown in Table 4.16 and 4.17. C_s and C_g values have been taken as Rs 2.7 and Rs 3.5 (in Lakhs) per MCM respectively. Hence objective function of this model becomes

MAX[11.035A1+16.018A2+9.577A3+31.580A4+2.407A5+10.018A6+29.425A7+30.590A8+39.680A9-2.7S1-2.7S2-2.7S3-2.7S4-2.7S5-2.7S6-2.7S7-2.7S8-2.7S9-2.7S10-2.7S11-2.7S12-3.5G1-3.5G2-3.5G3-3.5G4-3.5G5-3.5G6-3.5G7-3.5G8-3.5G9-3.5G10-3.5G11-3.5G12].

CONSTRAINTS

(i). Land availability constraint- Total cultivable areas available during Kharif and Rabi in the study area are 3700and 3700km^2 respectively. So total area allocated for different crops in a particular season should be less then or equal to the cultural command area (CCA). Hence the land availability constraints are:

$$A1+A2+A3+A4+A9 \leq 3700$$

$$A5+A6+A7+A8+A9 \leq 3700$$

(ii). Irrigation water requirement constraint-The gross irrigation water requirement of crops has been shown in Table 4.7. Monthly crop water requirements should not exceed the maximum available water from both surface and ground water sources. The constraints for use of both surface and ground water are as follows:

$$0.09A5+0.11A6+0.112A7+0.116A8-S1-G1 \leq 0$$

$$0.163A5+0.169A6+0.198A7+0.171A8+0.047A9-S2-G2 \leq 0$$

$$0.055A5+0.062A6+0.076A7+0.077A8+0.131A9-S3-G3 \leq 0$$

$$0.173A9-S4-G4 \leq 0$$

$$0.247A9-S5-G5 \leq 0$$

$$0.156A1+0.029A9-S6-G6 \leq 0$$

$$0.08A1-S7-G7 \leq 0$$

$$0.062A1-S8-G8 \leq 0$$

$$0.134A1-S9-G9 \leq 0$$

$$0.234A1+0.003A4+0.019A9-S10-G10 \leq 0$$

$$0.312A1+0.081A4+0.082A9-S11-G11 \leq 0$$

$$0.021A5+0.068A6+0.028A7+0.091A8+0.108A9-S12-G12 \leq 0$$

(iii). Surface water availability constraints-. Total surface water available for irrigation use is 3630 MCM as calculated in 5.2. This can be written as:

$$S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12 \leq 3630$$

(iv). Ground water availability constraint- Maximum utilizable ground water available in the basin is 1062.71 MCM/year as per table 5.2. So the ground water availability constraint is as follows:

$$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G1+G12 \leq 1062.71$$

(v). Monthly ground water availability constraint-Assuming that the monthly ground water withdrawal cannot exceed 20% of the annual utilizable ground water, the monthly ground water constraint can be written as follows:

$$G1 \leq 212.54$$

$$G2 \leq 212.54$$

$$G3 \leq 212.54$$

$$G4 \leq 212.54$$

$$G5 \leq 212.54$$

$$G6 \leq 212.54$$

$$G7 \leq 212.54$$

$$G8 \leq 212.54$$

$$G9 \leq 212.54$$

$$G10 \leq 212.54$$

$$G11 \leq 212.54$$

$$G12 \leq 212.54$$

(vi). Cropping pattern with 20%deviation from existing pattern constraint: The existing cropping pattern has been shown in Table 4.9. Allowing 20% deviation over the existing cropping pattern, the constraints can be written as:

$$A1 \leq 3374.40$$

$$A1 \geq 2249.60$$

$$A2 \leq 444.00$$

$A2 \geq 296.00$

$A3 \leq 310.80$

$A3 \geq 207.20$

$A4 \leq 222.00$

$A4 \geq 148.00$

$A5 \leq 133.20$

$A5 \geq 88.80$

$A6 \leq 3152.40$

$A6 \geq 2101.60$

$A7 \leq 532.80$

$A7 \geq 355.20$

$A8 \leq 532.80$

$A8 \geq 355.20$

$A9 \leq 88.80$

$A9 \geq 59.20$

(vii). Canal capacity constraint- Assuming that the canal is capable of carrying only 20% of gross irrigation requirement of crops, the canal capacity constraint can be written as follows:

$S1 \leq 740$

$S2 \leq 740$

$S3 \leq 740$

$S4 \leq 740$

$S5 \leq 740$

$S6 \leq 740$

$S7 \leq 740$

$S8 \leq 740$

$S9 \leq 740$

$S10 \leq 740$

$S11 \leq 740$

$S12 \leq 740$

6.5.5 LP-5 (Existing cropping pattern)

If the existing trend of cropping pattern continues, the cropping pattern by the year 2051AD will be as per table 4.9.

A1=2812

A2=370

A3=259

A4=185

A5=111

A6=2627

A7=444

A8=444

A9=74

6.6 OPTIMIZATION RESULT AND DISCUSSION

For the purpose of getting optimum result, software package LINDO has been used. The optimal results for the above plans using linear programming technique have been determined and compared.

6.6.1 Comparison of net return

Fig. 6.1 shows the graphical comparison of benefits of different plans.

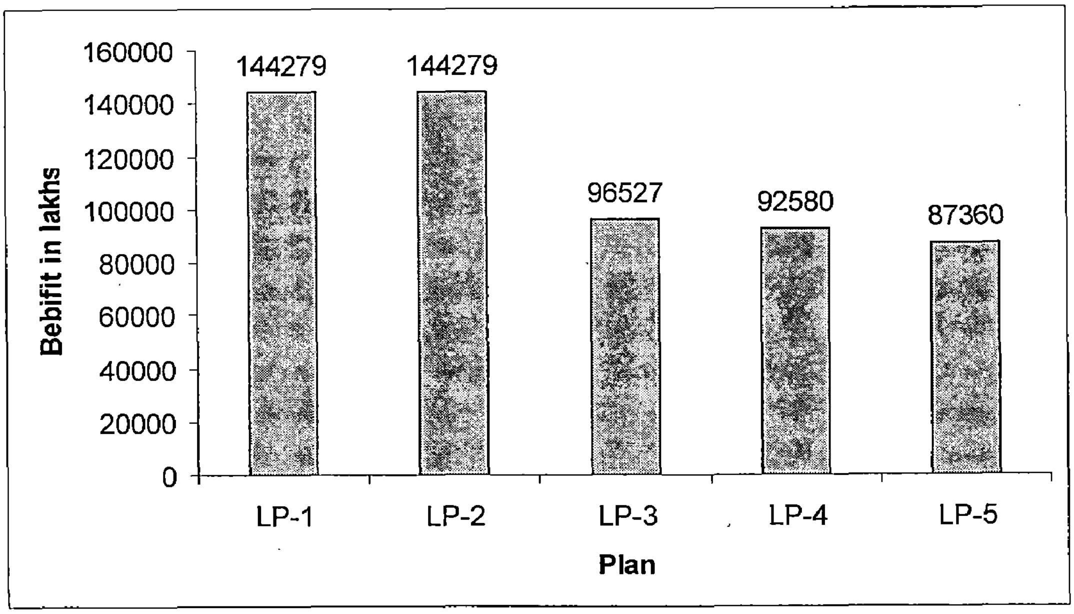


Fig. 6.1 Graphical comparison of benefits of different plans

6.6.2 Comparison of crop areas under different plans

Table 6.1 shows areas of crops under different plans and Fig. 6.2 shows the graphical comparison of crop areas under LP-1 and LP-5.

Table 6.1 Areas of crops under different plans

	Crop Area in Sq.km				
Crop	LP-1	LP-2	LP-3	LP-4	LP-5
Paddy(K)	2371	2371	2781	2599	2812
Pulses(K)	1257	1257	843	444	370
Sesame(K)	0	0	0	311	259
Vegetables(K)	22	22	0	222	185
Ragi(R)	85	85	127	89	111
Pulses(R)	0	0	1505	2457	2627
Groundnut(R)	766	766	1149	533	444
Vegetables(R)	2799	2799	447	533	444
Sugarcane	50	50	76	89	74
Total	7350	7350	6927	7275	7326

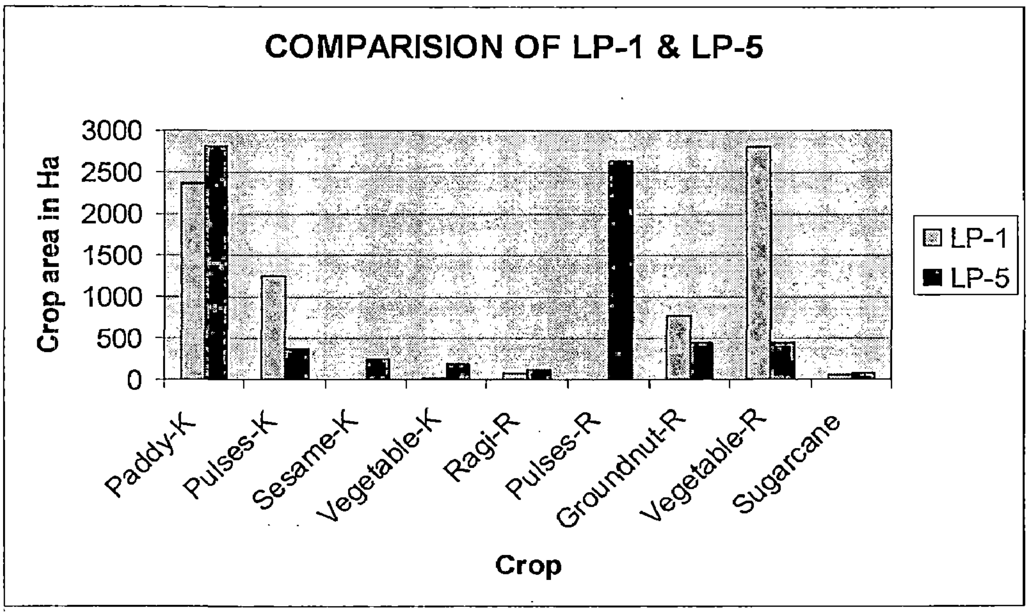


Fig. 6.2 Graphical comparison of areas under crops of Plan-1 and Plan-5

6.6.3 Comparison of water requirements for different plans

Table 6.2 and Table 6.3 shows the comparison of surface water and ground water requirements and Fig. 6.3 shows the graphical comparison of total water requirement for different plans.

Table 6.2 Comparison of surface water requirement for different plans

Water requirement (in MCM)	LP-1	LP-2	LP-3	LP-4	LP-5
S1	418	418	145	187	378
S2	435	435	372	633	631
S3	527	397	284	325	533
S4	9	9	13	15	0
S5	12	12	19	22	0
S6	371	371	436	408	228
S7	209	339	495	295	501
S8	147	147	172	0	174
S9	318	318	373	136	164
S10	343	343	440	610	447
S11	533	533	661	740	740
S12	307	307	221	259	44

Table 6.3 Comparison of ground water requirement for different plans

Water requirement (in MCM)	LP-1	LP-2	LP-3	LP-4	LP-5
G1	0	0	213	213	22
G2	213	213	213	0	0
G3	83	213	213	213	0
G4	0	0	0	0	13
G5	0	0	0	0	18
G6	0	0	0	0	213
G7	213	83	0	168	0
G8	0	0	0	161	0
G9	0	0	0	213	213
G10	213	213	213	0	213
G11	213	213	213	96	158
G12	0	0	0	0	213

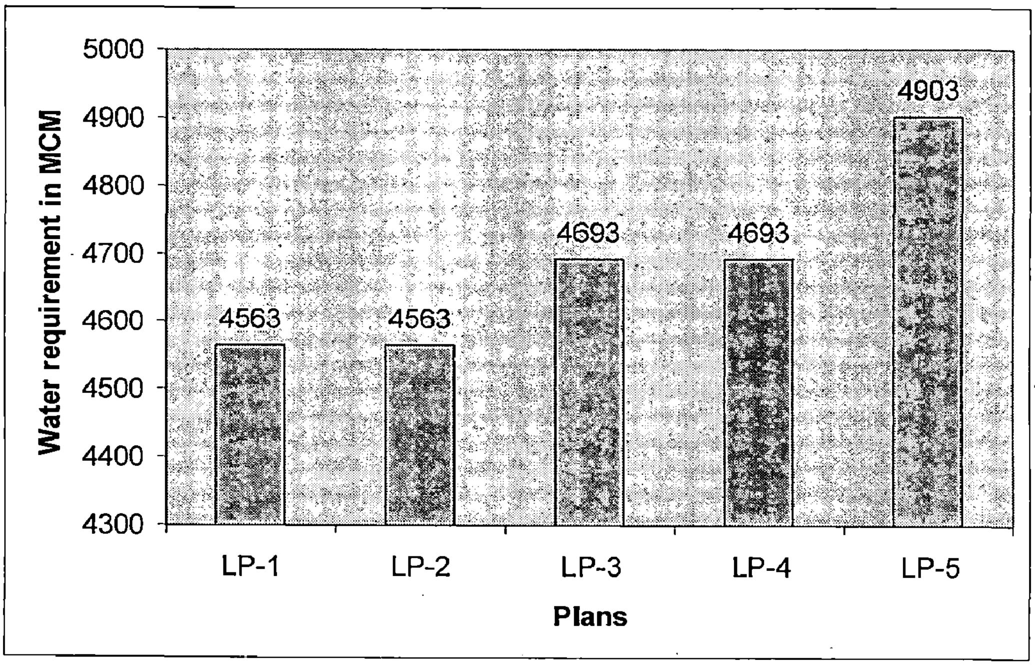


Fig. 6.2 Graphical comparison of total water requirement under various Plans

6.7 DISCUSSION

From the results, it is clear that the LP-1 and LP-2 gives optimum and identical result in all respect. LP-1 gives maximum benefit, consumes least amount of water, covers large area of crops and simultaneously meets the protein, calorie and basic food needs of the basin population. Hence LP-1 is recommended for Rushikulya basin. As farmers are usually habituated with the existing cropping patterns, they may not accept the suggested cropping pattern immediately. Hence the farmers should be educated about the benefit of the suggested cropping pattern before introducing it. Once they see the benefit, they will start accepting it. In view of the above it is suggested that the proposed cropping pattern may be introduced gradually. The order of introduction may be from LP-5 to LP-1.

CHAPTER-7

OPTIMIZATION OF CROPPING PATTERN USING GP MODEL

7.1 GENERAL

Goal Programming (GP) is a linear mathematical model in which the optimum attainment of multiple goals is sought within the given decision environment. It is a special extension of LP, which is capable of solving decision problems with a single or multiple goals. Here goals set by management are often achievable at the expense of other goals. In such cases a hierarchy of importance among these conflicting goals is established so that low order goals are considered only after the higher order goals are satisfied.

Here two types of constraints are considered. These are goal and non-goal constraints. Each goal constraint may be assigned a positive or negative deviational variable or both. If over achievement is acceptable, positive deviation from the goal can be eliminated from objective function. Similarly if under achievement is acceptable, negative deviation can be eliminated.

7.2 GOAL CONSTRAINTS

The main goal constraints are:

- Maximization of net return.
- Self-sufficiency in Protein and Calorie requirements.
- Self-sufficiency in food requirements.

7.2.1 Net return constraint

The equation for net return constraint with both side deviational variables can be expressed as:

$$\sum_{J=1}^{NCR} N_J * A_J + d_1^- - d_1^+ = \text{Net return} \qquad (7.1)$$

Where, N_J = Net return from J^{th} crop (in Rs/ km^2).

A_J = Area of J^{th} crop (in km^2).

d_1^- = Under achievement of net return.

d_1^+ = Over achievement of net return.

NCR =Number of feasible crops in any period

7.2.2 Protein and calorie requirement constraint

The equation for protein and calorie requirement constraint with both side deviational variables can be expressed as:

(i) $\sum_{J=1}^{NCR} A_J*Y_J*P_J + d_2^- - d_2^+$ = Target for protein requirement (7.2)

(ii) $\sum_{J=1}^{NCR} A_J*Y_J*C_J + d_3^- - d_3^+$ = Target for calorie requirement (7.3)

Where, Y_J = Yield from J^{th} crop (in qtl/km^2).

d_2^- = Under achievement of target for protein requirement.

d_2^+ = Over achievement of target for protein requirement.

d_3^- = Under achievement of target for calorie requirement.

d_3^+ = Over achievement of target for calorie requirement

P_J and C_J are protein and calorie value of J^{th} crop in kg/qtl and cal/qtl respectively.

7.2.3 Minimum production requirement constraint

The equation for minimum production requirement constraint with both side deviational variables can be expressed as:

$A_J*Y_J + d_{am}^- - d_{am}^+ = Q_{J\,min}$ (7.4)

Where, d_{am}^- = Under achievement of target for minimum production requirement.

d_{am}^+ = Over achievement of target for minimum production requirement.

$Q_{J\,min}$ = Minimum production requirement of J^{th} crop (in qtl).

7.3 NON-GOAL CONSTRAINTS

The non-goal constraints are

- Cultivable area constraint
- Irrigation water requirement constraint
- Surface water availability constraint
- Ground water availability constraint
- Canal capacity constraint

(i) Cultivable area constraint

The area under various crops during any period cannot exceed the cultivable command area of the study area. It can be written as:

$$\sum_{j=1}^{NCR} A_{jm} \leq A \qquad (7.5)$$

Where, A_{jm} =Area of j^{th} crop in m^{th} period (in km^2).

A = Cultivable command area of the study area (in km^2).

(ii) Irrigation water requirement constraint

The water requirement for various crops in each month cannot exceed surface and ground water availability. If I_{jm} is the gross irrigation requirement of j^{th} crop during m^{th} period, it can be written as:

$$\sum_{m=1}^{NOM} \sum_{j=1}^{NCR} A_j I_{jm} \leq S_m + G_m \qquad (7.6)$$

Where, S_m and G_m are surface and ground water availability in m^{th} period (in MCM).

(iii) Surface water availability constraint

The gross annual surface water release should not exceed total availability of surface water annually. It can be written as:

$$\sum_{m=1}^{NOM} S_m \leq \text{Gross availability of surface water} \qquad (7.7)$$

(iv) Ground water availability constraint

Total ground water withdrawal annually should not exceed annual utilizable ground water. It can be written as:

$$\sum_{m=1}^{NOM} G_m \leq \text{Annul utilizable ground water} \qquad (7.8)$$

Further monthly ground water withdrawal cannot exceed 20% annual utilizable ground water. It can be written as:

$$\sum_{m=1}^{NOM} G_m \leq 20\% \text{ of annual available ground water} \qquad (7.9)$$

(v) Canal capacity constraint

This constraint has been imposed assuming that the canal is capable of carrying only 20% of gross irrigation water requirement of crops. This assumption makes the canal construction economical.

It can be written as:

$S_m \leq$ 20% of gross irrigation requirement of crops. (7.10)

7.4 GP MODEL

In this study, three major goal constraints are considered. Priorities to goals have been assigned as P1, P2 and P3 etc. i.e. from highest (P1) to lowest (P3). Here four GP models have been developed.

7.4.1 GP MODEL-1 (GP-1)

In GP1, highest priority (P1) has been assigned to maximization of net return, second priority (P2) has been assigned to the fulfillment of calorie and protein requirements of basin population and third priority (P3) has been assigned to the fulfillment of minimum food requirements. Between the protein and calorie requirements more weight-age has been assigned to calorific value as compared to protein value in the ratio (2:1). In (P3) category, weight-age from highest to lowest is Paddy, Vegetables, Oilseed, Pulses, Sugarcane and Ragi. Here the net return has been considered as the maximum value above which over achievement is not possible. Hence over achievement (d_1^+) has not been included.

Model objective function

The objective is to minimize the under achievement from the target value. Using the same notations as used in LP model, the objective function can be written as:

$$\text{Min } Z = P1d_1^- + P2d_2^- + 2P2d_3^- + 6P3d_4^- + 5P3d_5^- + 4P3d_6^- + 3P3d_7^- + 2P3d_8^- + P3d_9^-$$

Constraints

(i) Net return constraint

11.035A1+16.018A2+9.577A3+31.580A4+2.407A5+10.018A6+29.425A7+30.590 A8+39.680A9-2.7S1-2.7S2-2.7S3-2.7S4-2.7S5-2.7S6-2.7S7-2.7S8-2.7S9-2.7S10-2.7S11-2.7S12-3.5G1-3.5G2-3.5G3-3.5G4-3.5G5-3.5G6-3.5G7-3.5G8-3.5G9-3.5G10-3.5G11-3.5G12+d_1^-=144279

(ii) Protein requirement constraint

0.24A1+0.145A2+0.152A3+0.327A4+0.110 A5+0.100 A6+0.630A7+0.320A8 +d_2^--d_2^+=861.2149

(iii) Calorie requirement constraint

11.07A1+2.18A2+3.4A3+6.53A4+3.70A5+1.51A6+11.22A7+6.40A8+29.60A9+d_3^--d_3^+=31977.8966

(iv) Minimum production requirement constraint

32A1 +d_4^--d_4^+= 75869

81.65A4+80A8+d_5^--d_5^+=23827

6A3+20A7+d_6^--d_6^+=15317

$6.5A2 + 4.5A6 + d_7^- - d_7^+ = 8169$

$740A9 + d_8^- - d_8^+ = 37272$

$10.6A5 + d_9^- - d_9^+ = 899$

(v) Cultivable area constraint

$A1+A2+A3+A4+A9 \leq 3700$

$A5+A6+A7+A8+A9 \leq 3700$

(vi) Irrigation water requirement constraint

$0.09A5+0.11A6+0.112A7+0.116A8-S1-G1 \leq 0$

$0.163A5+0.169A6+0.198A7+0.171A8+0.047A9-S2-G2 \leq 0$

$0.055A5+0.062A6+0.076A7+0.077A8+0.131A9-S3-G3 \leq 0$

$0.173A9-S4-G4 \leq 0$

$0.247A9-S5-G5 \leq 0$

$0.156A1+0.029A9-S6-G6 \leq 0$

$0.08A1-S7-G7 \leq 0$

$0.062A1-S8-G8 \leq 0$

$0.134A1-S9-G9 \leq 0$

$0.234A1+0.003A4+0.019A9-S10-G10 \leq 0$

$0.312A1+0.081A4+0.082A9-S11-G11 \leq 0$

$0.021A5+0.068A6+0.028A7+0.091A8+0.108A9-S12-G12 \leq 0$

(vii) Surface water availability constraint

$S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12 \leq 3630$

(viii) Ground water availability constraint

$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G1+G12 \leq 1062.71$

$G1 \leq 212.54$

$G2 \leq 212.54$

$G3 \leq 212.54$

$G4 \leq 212.54$

$G5 \leq 212.54$

$G6 \leq 212.54$

$G7 \leq 212.54$

$G8 \leq 212.54$

$G9 \leq 212.54$

$G10 \leq 212.54$

$G11 \leq 212.54$

$G12 \leq 212.54$

(ix) Canal capacity constraint

$S1 \leq 740$

$S2 \leq 740$

$S3 \leq 740$

$S4 \leq 740$

$S5 \leq 740$

$S6 \leq 740$

$S7 \leq 740$

$S8 \leq 740$

$S9 \leq 740$

$S10 \leq 740$

$S11 \leq 740$

$S12 \leq 740$

7.4.2 GP MODEL-2 (GP-2)

In GP2, highest priority (P1) has been assigned to the fulfillment of calorie and protein requirements of basin population, second priority (P2) has been assigned to the maximization of net return and third priority (P3) has been assigned to fulfillment of minimum food requirements.

Model objective function

The objective function in the GP model-2 will be

$$\text{Min } Z = P1d_2^- + 2P1d_3^- + P2d_1^- + 6P3d_4^- + 5P3d_5^- + 4P3d_6^- + 3P3d_7^- + 2P3d_8^- + P3d_9^-$$

Constraints

(i) Net return constraint

$$11.035A1+16.018A2+9.577A3+31.580A4+2.407A5+10.018A6+29.425A7+30.590A8+39.680A9-2.7S1-2.7S2-2.7S3-2.7S4-2.7S5-2.7S6-2.7S7-2.7S8-2.7S9-2.7S10-2.7S11-2.7S12-3.5G1-3.5G2-3.5G3-3.5G4-3.5G5-3.5G6-3.5G7-3.5G8-3.5G9-3.5G10-3.5G11-3.5G12+d_1^-=144279$$

(ii) Protein requirement constraint

$$0.24A1+0.145A2+0.152A3+0.327A4+0.110A5+0.100A6+0.630A7+0.320A8+d_2^- - d_2^+=861.2149$$

(iii) Calorie requirement constraint

$$11.07A1+2.18A2+3.4A3+6.53A4+3.70A5+1.51A6+11.22A7+6.40A8+29.60A9+d_3^- - d_3^+=31977.8966$$

(iv) Minimum production requirement constraint

$$32A1+d_4^- - d_4^+= 75869$$

$$81.65A4+80A8+d_5^- - d_5^+=23827$$

$$6A3+20A7+d_6^- - d_6^+=15317$$

$$6.5A2+4.5A6+d_7^- - d_7^+= 8169$$

$740A9+d_8^- - d_8^+ = 37272$

$10.6A5+d_9^- - d_9^+ = 899$

(v) Cultivable area constraint

$A1+A2+A3+A4+A9 \leq 3700$

$A5+A6+A7+A8+A9 \leq 3700$

(vi) Irrigation water requirement constraint

$0.09A5+0.11A6+0.112A7+0.116A8-S1-G1 \leq 0$

$0.163A5+0.169A6+0.198A7+0.171A8+0.047A9-S2-G2 \leq 0$

$0.055A5+0.062A6+0.076A7+0.077A8+0.131A9-S3-G3 \leq 0$

$0.173A9-S4-G4 \leq 0$

$0.247A9-S5-G5 \leq 0$

$0.156A1+0.029A9-S6-G6 \leq 0$

$0.08A1-S7-G7 \leq 0$

$0.062A1-S8-G8 \leq 0$

$0.134A1-S9-G9 \leq 0$

$0.234A1+0.003A4+0.019A9-S10-G10 \leq 0$

$0.312A1+0.081A4+0.082A9-S11-G11 \leq 0$

$0.021A5+0.068A6+0.028A7+0.091A8+0.108A9-S12-G12 \leq 0$

(vii) Surface water availability constraint

$S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12 \leq 3630$

(viii) Ground water availability constraint

$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G1+G12 \leq 1062.71$

$G1 \leq 212.54$

$G2 \leq 212.54$

$G3 \leq 212.54$

$G4 \leq 212.54$

$G5 \leq 212.54$

$G6 \leq 212.54$

$G7 \leq 212.54$

$G8 \leq 212.54$

$G9 \leq 212.54$

$G10 \leq 212.54$

$G11 \leq 212.54$

$G12 \leq 212.54$

(ix) Canal capacity constraint

$S1 \leq 740$

$S2 \leq 740$

$S3 \leq 740$

$S4 \leq 740$

$S5 \leq 740$

$S6 \leq 740$

$S7 \leq 740$

$S8 \leq 740$

$S9 \leq 740$

$S10 \leq 740$

$S11 \leq 740$

$S12 \leq 740$

7.4.3 GP MODEL-3 (GP-3)

In GP3, highest priority (P1) has been assigned to the fulfillment of minimum food requirements, second priority (P2) has been assigned to the maximization of net return and third priority (P3) has been assigned to the fulfillment of calorie and protein requirements of basin population.

Model objective function

Min $Z = 6P1d_4^- + 5P1d_5^- + 4P1d_6^- + 3P1d_7^- + 2P1d_8^- + P1d_9^- + P2d_1^- + P3d_2^- + 2P3d_3^-$

Constraints

(i) Net return constraint

$11.035A1+16.018A2+9.577A3+31.580A4+2.407A5+10.018A6+29.425A7+30.590A8+39.680A9-2.7S1-2.7S2-2.7S3-2.7S4-2.7S5-2.7S6-2.7S7-2.7S8-2.7S9-2.7S10-2.7S11-2.7S12-3.5G1-3.5G2-3.5G3-3.5G4-3.5G5-3.5G6-3.5G7-3.5G8-3.5G9-3.5G10-3.5G11-3.5G12+d_1^-=144279$

(ii) Protein requirement constraint

$0.24A1+0.145A2+0.152A3+0.327A4+0.110\ A5+0.100\ A6+0.630A7+0.320A8 +d_2^- - d_2^+=861.2149$

(iii) Calorie requirement constraint

$11.07A1+2.18A2+3.4A3+6.53A4+3.70A5+1.51A6+11.22A7+6.40A8+29.60A9+d_3^- -d_3^+=31977.8966$

(iv) Minimum production requirement constraint

$32A1 +d_4^- -d_4^+= 75869$

$81.65A4+80A8+d_5^- -d_5^+=23827$

$6A3+20A7+d_6^- -d_6^+=15317$

$6.5A2 +4.5\ A6+d_7^- -d_7^+= 8169$

$740A9+d_8^- -d_8^+=37272$

$10.6A5+d_9^- -d_9^+=899$

(v) Cultivable area constraint

$A1+A2+A3+A4+A9 \leq 3700$

$A5+A6+A7+A8+A9 \leq 3700$

(vi) Irrigation water requirement constraint

$0.09A5+0.11A6+0.112A7+0.116A8-S1-G1 \leq 0$

$0.163A5+0.169A6+0.198A7+0.171A8+0.047A9-S2-G2 \leq 0$

$0.055A5+0.062A6+0.076A7+0.077A8+0.131A9-S3-G3 \leq 0$

$0.173A9-S4-G4 \leq 0$

$0.247A9-S5-G5 \leq 0$

$0.156A1+0.029A9-S6-G6 \leq 0$

$0.08A1-S7-G7 \leq 0$

$0.062A1-S8-G8 \leq 0$

$0.134A1-S9-G9 \leq 0$

$0.234A1+0.003A4+0.019A9-S10-G10 \leq 0$

$0.312A1+0.081A4+0.082A9-S11-G11 \leq 0$

$0.021A5+0.068A6+0.028A7+0.091A8+0.108A9-S12-G12 \leq 0$

(vii) Surface water availability constraint

$S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12 \leq 3630$

(viii) Ground water availability constraint

$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G1+G12 \leq 1062.71$

$G1 \leq 212.54$

$G2 \leq 212.54$

$G3 \leq 212.54$

$G4 \leq 212.54$

$G5 \leq 212.54$

$G6 \leq 212.54$

$G7 \leq 212.54$

$G8 \leq 212.54$

$G9 \leq 212.54$

$G10 \leq 212.54$

$G11 \leq 212.54$

$G12 \leq 212.54$

(ix) Canal capacity constraint

$S1 \leq 740$

$S2 \leq 740$

$S3 \leq 740$

$S4 \leq 740$

$S5 \leq 740$

$S6 \leq 740$

$S7 \leq 740$

$S8 \leq 740$

$S9 \leq 740$

$S10 \leq 740$

$S11 \leq 740$

$S12 \leq 740$

7.4.4 GP MODEL-4 (GP-4)

From the results of GP-1, GP-2 and GP-3 it has been found that, as there was not scarcity of resources, these models were giving identical results. Hence GP-4 has been developed limiting the maximum availability of water from surface and ground sources to 600 MCM and 200MCM respectively. This has been done to observe the effect of the scarcity of water in achieving goals. In GP4, highest priority (P1) has been assigned to maximization of net return, second priority (P2) has been assigned to the fulfillment of calorie and protein requirements of basin population and third priority (P3) has been assigned to the fulfillment of minimum food requirements.

Model objective function

$$\text{Min } Z = P1d_1^- + P2d_2^- + 2P2d_3^- + 6P3d_4^- + 5P3d_5^- + 4P3d_6^- + 3P3d_7^- + 2P3d_8^- + P3d_9^-$$

Constraints

(i) Net return constraint

$$11.035A1+16.018A2+9.577A3+31.580A4+2.407A5+10.018A6+29.425A7+30.590A8+39.680A9-2.7S1-2.7S2-2.7S3-2.7S4-2.7S5-2.7S6-2.7S7-2.7S8-2.7S9-2.7S10-2.7S11-2.7S12-3.5G1-3.5G2-3.5G3-3.5G4-3.5G5-3.5G6-3.5G7-3.5G8-3.5G9-3.5G10-3.5G11-3.5G12+d_1^-=144279$$

(ii) Protein requirement constraint

$$0.24A1+0.145A2+0.152A3+0.327A4+0.110A5+0.100A6+0.630A7+0.320A8+d_2^- - d_2^+=861.2149$$

(iii) Calorie requirement constraint

$$11.07A1+2.18A2+3.4A3+6.53A4+3.70A5+1.51A6+11.22A7+6.40A8+29.60A9+d_3^- - d_3^+=31977.8966$$

(iv) Minimum production requirement constraint

$$32A1+d_4^- - d_4^+ = 75869$$

$$81.65A4+80A8+d_5^- - d_5^+=23827$$

$$6A3+20A7+d_6^- - d_6^+=15317$$

$$6.5A2+4.5A6+d_7^- - d_7^+= 8169$$

$$740A9+d_8^- - d_8^+=37272$$

$$10.6A5+d_9^- - d_9^+=899$$

(v) Cultivable area constraint

$$A1+A2+A3+A4+A9 \leq 3700$$

$A5+A6+A7+A8+A9 \leq 3700$

(vi) Irrigation water requirement constraint

$0.09A5+0.11A6+0.112A7+0.116A8-S1-G1 \leq 0$

$0.163A5+0.169A6+0.198A7+0.171A8+0.047A9-S2-G2 \leq 0$

$0.055A5+0.062A6+0.076A7+0.077A8+0.131A9-S3-G3 \leq 0$

$0.173A9-S4-G4 \leq 0$

$0.247A9-S5-G5 \leq 0$

$0.156A1+0.029A9-S6-G6 \leq 0$

$0.08A1-S7-G7 \leq 0$

$0.062A1-S8-G8 \leq 0$

$0.134A1-S9-G9 \leq 0$

$0.234A1+0.003A4+0.019A9-S10-G10 \leq 0$

$0.312A1+0.081A4+0.082A9-S11-G11 \leq 0$

$0.021A5+0.068A6+0.028A7+0.091A8+0.108A9-S12-G12 \leq 0$

(vii) Surface water availability constraint

$S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12 \leq 600$

(viii) Ground water availability constraint

$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G1+G12 \leq 200$

$G1 \leq 40$

$G2 \leq 40$

$G3 \leq 40$

$G4 \leq 40$

$G5 \leq 40$

$G6 \leq 40$

$G7 \leq 40$

$G8 \leq 40$

$G9 \leq 40$

$G10 \leq 40$

$G11 \leq 40$

$G12 \leq 40$

(ix) Canal capacity constraint

$S1 \leq 120$

$S2 \leq 120$

$S3 \leq 120$

$S4 \leq 120$

$S5 \leq 120$

$S6 \leq 740$

$S7 \leq 120$

$S8 \leq 120$

$S9 \leq 120$

$S10 \leq 120$

$S11 \leq 120$

$S12 \leq 120$

7.5 GP RESULT

Software package LINDO has been used to get the GP results. The abstract of GP results has been shown in Table 7.1. From Table 7.1, it is clear that GP-1, GP-2 and GP-3 models give identical results. This is due to the fact that all the requirements i.e. maximization of net benefit as obtained in LP (LP-1), fulfillment of protein and calorie requirements and fulfillment of minimum food requirements of basin population can be achieved simultaneously. The GP-1, GP-2 and GP-3 results also show that there is sufficient over achievement of protein, calorie and minimum food production requirements. The result of GP-4 shows that due to scarcity of water resources, there is considerable under achievement of net benefit from crops. However there is over achievement of minimum protein requirements as well as minimum Vegetables, Pulses, and sugarcane requirements.

7.6 COMPARISON OF LP AND GP RESULTS AND DISCUSSION

A comparison has been made between the best LP and GP plans. Among LP plans, (LP-1) and among GP Plans, GP-1 gives the best and identical result. As there is no scarcity of resources, it is possible to achieve all three objectives simultaneously i.e. optimum net return, protein, calorie and minimum food requirements.

Hence LP-1 is recommended for Rushikulya basin. The order of introduction may be from LP-5 to LP-1.

Table 7.1 Optimal allocation of land and water resources under various GP plans

Item	GP-1	GP-2	GP-3	GP-4
Paddy(K) Area in km^2	2371	2371	2371	0
Pulses(K) Area in km^2	1257	1257	1257	1725
Sesame(K) Area in km^2	0	0	0	0
Vegetables(K) Area in km^2	22	22	22	1911
Ragi(R) Area in km^2	85	85	85	0
Pulses(R) Area in km^2	0	0	0	0
Groundnut(R) Area in km^2	766	766	766	0
Vegetables(R) Area in km^2	2799	2799	2799	908
Sugarcane Area in km^2	50	50	50	64
Total water utilized in MCM	4563	4563	4563	710
Total calorie achieved (kg/yr)	$25462*10^5$	$25462*10^5$	$25462*10^5$	0
Total Protein achieved (kg/yr)	$1285*10^5$	$1285*10^5$	$1285*10^5$	$304*10^5$
Net Return (in Lakhs)	144279	144279	144279	116275

CHAPTER-8

YIELD MODEL

8.1 GENERAL

It is an alternative modeling approach for reservoir planning and operation. It emphasizes the yield that can be achieved and their reliabilities with a given stream flow sequence. Yields refer to flows having a relatively high reliability or probability of being equaled or exceeded in future periods. This model can be used to estimate the storage capacities required to deliver various yields with greater probabilities.

8.2 THE CONCEPT OF YIELD MODEL

The yield model developed by Loucks et al. (1981) was subsequently improved by Dahe and Srivastava (2002) and Panigrahy and Srivastava (2006). It is a general purpose, implicitly stochastic linear programming screening 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 of target releases considering the entire length of historical or synthetically generated unregulated inflow time series (Stedinger et al. 1983).

The yield model estimates over-year and within-year reservoir capacity requirements separately to meet the specified release reliability targets. Without the introduction of within-year continuity constraint in the model, there is every possibility that the reservoir may fail to meet the target demand during low flow periods particularly in summer months, even though the demand on annual basis is well satisfied.

8.3 RELIABILITY OF ANNUAL YIELDS

Associated with any historic inflow, there is a probability associated with the yield that 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.

Various methods are employed to estimate the probability that any given stream flow will be exceeded. The commonly employed method is the Seibel plotting position method, which 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. Having an estimate of the mean probability of a given unregulated stream flow makes it possible to define the mean probability of any particular reservoir yield.

For a certain reservoir capacity, once a yield with the maximum possible reliability, *p,* known as *firm annual reservoir yield* is defined, all other yields with reliability less than *p* are *incremental secondary annual reservoir yields*. Summation of firm and incremental secondary annual yields is the *total annual reservoir yield.* These yields hereafter in this study shall be referred to as *firm annual yield, secondary annual yield and total annual yield.* Firm annual yield with probability of exceedence *p* will be denoted as Oy^{fp}. Similarly, secondary annual yield with probability of exceedence *p2*, which is less than *p* is denoted by Oy^{sp2}.

8.4 THE COMPLETE YIELD MODEL

The active over-year reservoir capacity Y^o required to deliver a safe or firm annual yield Oy^{fp}, when the same firm yield differs from the annual inflows in year j I_j to the reservoir, can be determined by minimizing Y^o required to satisfy the basic constraints such as water balance equation and reservoir capacity limitations. Ignoring the evaporation losses the model can be formulated as follows:

Minimize Y^o (8.1)

Subject to

$$S_{j-1}^o + I_j - Oy^{fp} - Sp_j = S_j^o \qquad \forall_j \qquad (8.2)$$

$$S_{j-1}^o \leq Y^o \qquad \forall_j \qquad (8.3)$$

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; and Sp_j =excess release (spill) during year ,for the year N , S_N^o = S_0^o, where 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; and N = total number of years of river flows available.

The model presented above considers the variables namely the active storage volume, inflows, spill and reservoir yield on annual basis. However, a desired within-year distribution of annual yields that does not coincide with distribution of stream flows (within-the-year) may require additional active reservoir storage capacity. As such, within-year reservoir yields, Oy_t^{fp}, that sum up to the firm annual yield Oy^{fp} may also be considered in the estimation of the required active storage capacity.

Both the storage capacity requirements can be obtained by minimizing the total active storage capacity Y_a subject to the continuity and capacity constraints for every within-year period of each year. This model is defined by equations 4.4 through 4.6 for each period t in each year j and is called the "*complete yield model*", i.e.,

Minimize Y_a (8.4)

Subject to

$$S_{j,t-1} + I_{jt} - Oy_t^{fp} - Sp_{jt} = S_{jt} \qquad \forall_{jt} \qquad (8.5)$$

$$S_{j,t-1} \leq Y_a \qquad \forall_{jt} \qquad (8.6)$$

where $S_{j,t-1}$ = initial storage at the beginning of period t in year 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; and Oy_t^{fp} = reservoir yield during period t.

In equation 8.5 if t is the last period in year j, then the next period is $t = 1$ in the year $j + 1$. Further, the final storage of last time period of year j equals to the initial storage of the first time period of year $j + 1$ and in case of the last year of record, the final storage of the end time period equals to the initial storage of the first time period of the starting year.

Since the reservoir storage requirements are determined from critical period of record, this suggests that it may not be necessary to include every period of every year in a reservoir storage yield model such that defined by equation 8.4 through 8.6. It has been shown by Loucks et al. (1981) that the range of volumes at the beginning of each year j defines the over-year storage requirements. 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.

8.5 THE APPROXIMATE YIELD MODEL

As discussed in the foregoing section, the model which reduces the size drastically by considering over-year continuity constraint for each year along with an additional set of within-year continuity constraint for the critical period only and capable of producing reasonably accurate results is termed as approximate yield model.

Identification of the critical year and its within-year distribution of inflows is an important as well as a sensitive aspect in particular reference to the within-year continuity constraints and formulation of the approximate yield model. The critical year depends in part on the values of the annual and within-year yields, and it is not possible to identify the same beforehand at the time of model application. In view of the aforesaid difficulties, an approach suggested by Loucks et al. (1981), i.e., by letting some appropriate fraction, β_t, of the total annual yield (outflow) to be the inflow in each period t within the critical year generally gives better result. Hence, $\sum_t \beta_t = 1$. 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. Each β_t thus reflects the relative proportion of the critical year's inflow that is likely to occur in period t.

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

$$S_{t-1}^{w} + \beta_t Oy^{fp} - Oy_t^{fp} = S_t^{w} \qquad \forall_t \qquad (8.7)$$

where w = superscript to indicate 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 equals to one, these constraints ensure that $\sum_t Oy_t^{fp}$ equals the annual reservoir yield Oy^{fp}.

In the equation 8.7, the inflows and required releases are just in balance, so that the reservoir neither fills nor empties during the modeled critical year. This is similar to what would be expected in a critical year that generally occurs at the end of a drawdown period. The within-year capacity Y^{w} is the maximum of all within-year storage volumes, i.e.,

$$S_{t-1}^{w} \le Y^{w} \qquad \forall_t \qquad (8.8)$$

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

$$Y_a = Y^o + Y^w \qquad (8.9)$$

Combining equation 8.8 and 8.9,

$$Y^o + S_{t-1}^w \leq Y_a \qquad \forall_t \qquad (8.10)$$

The complete yield model defined by equation 8.4 through 8.6 can be compared with the approximate yield model defined by equation 8.4, 8.2, 8.3, 8.7, and 8.10. By this, for a hydrologic record of n years, each having t periods, the number of constraint equations is reduced from $2nt$ to $2(n + t)$. Similarly, the number of variables is reduced from $2nt + t + 2$ to $2n + 2t + 3$.

The approximate yield model hereafter in this study shall be referred to as the "*The Yield Model*".

8.6 FORMULATION OF THE YIELD MODEL

8.6.1 Single Reservoir Single Yield Model

8.6.1.1 Firm reservoir yield with maximum reliability (p)

The single reservoir yield model to determine the safe or firm reservoir yield with maximum reliability for a known reservoir capacity can be written as:

Maximize $\quad Oy^{fp} \qquad (8.11)$

Subject to the following constraints:

1. Over year storage continuity (equation 8.2), i.e.,

$$S_{j-1}^o + I_j - Oy^{fp} - Sp_j = S_j^o \qquad \forall_j \qquad (8.12)$$

2. Over-year active storage volume capacity (equation 8.3), i.e.,

$$S_{j-1}^o \leq Y^o \qquad \forall_j \qquad (8.13)$$

3. Within-year storage continuity (equation 8.7), i.e.,

$$S_{t-1}^{w} + \beta_t Oy^{fp} - Oy_t^{fp} = S_t^{w} \qquad \forall_t \qquad (8.14)$$

4. Active reservoir storage capacity (equation 8.10), i.e.,

$$Y^{o} + S_{t-1}^{w} \leq Y_a \qquad \forall_t \qquad (8.15)$$

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

$$Oy_t^{fp} = \xi_t (Oy^{fp}) \qquad \forall_t \qquad (8.16)$$

where ξ_t defines a predefined fraction of annual reservoir yield for the within-year yield in period *t*.

8.6.1.2 Firm reservoir yield with reliability (*p1*) less than the maximum reliability (*p*)

The yield model can be used to find out reservoir yields having reliability less than the maximum estimated probability of exceedence *p*. This also can be called as firm annual yield, although not as firm as the yield corresponding to maximum estimated probability of exceedence *p*. These are treated as firm so far as the reliability of the purpose for which it is to be used. In these cases a reservoir yield failure is permitted. Reliability of these firm yields are denoted by *p1*. The number of years of reservoir yield failure determines the estimated reliability of each reservoir yield. An annual reservoir yield that fails in n_f years has an estimated probability $[(n - n_f) / (n + 1)]$ of being equaled or exceeded in any future year. Once the desired reliability of a firm annual reservoir yield is known, the problem is to select the appropriate number and the occurrence of failure years (n_f).

The over-year storage continuity constraints can now be written in a form appropriate for identifying a single firm annual reservoir yield with an exceedence probability *p1* less than the maximum reliability *p* by incorporating a factor θ_j^{p1}, i. e.,

$$S_{j-1}^{o} + I_j - \theta_j^{p1} Oy^{fp1} - Sp_j = S_j^{o} \qquad \forall_j \qquad (8.17)$$

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:

$$\theta_j^{pl} = \begin{cases} 1 & \text{if the annual firm reservoir yield is to be provided in year } j \text{ (successful year)} \\ 0 & \text{if the annual firm reservoir yield is not to be provided in year } j \text{ (failure year)} \end{cases} \quad (8.18)$$

While writing equation 8.17, the failure year(s) should be selected from among those year(s) in which permitting a failure decreases the required reservoir capacity for a desired reservoir yield, or increases the reservoir yield for a given reservoir capacity. If a failure is selected in which excess release (spill) would be made anyway, no reduction in the required active storage capacity will result, and the reliability of the reservoir yield may be higher than intended.

The failure years, if any, must be selected from within the critical drought periods for the desired reservoir yield. The critical years that determine the required active storage volume capacity may be dependent on the reservoir yield itself. When the magnitude of the reservoir yield is unknown, some trial and error procedures (e.g. simulation) may be necessary to ensure that failure years are within the critical period of the years for the associated reservoir yield. To ensure a wider range of applicable reservoir yield magnitudes, the years having the lowest flow within the critical period should be selected as the failure year if only one failure year is selected.

8.6.1.3 Incorporation of allowable deficit in firm annual reservoir yield during failure years

The value of θ_j^{pl} in equation 8.17, when set to zero indicates that the firm annual reservoir yield is not being provided in that particular year. It means a year can either be treated as successful year or there shall be a complete failure. As such during a failure year, there is no provision to account for reservoir yield less than the firm annual yield, even though it may be possible to provide some reservoir yield depending upon the flows during failure years in actual reservoir operation. But, such complete yield failure is not at all desirable. If a partial failure or an *allowable deficit* in firm annual yield during failure years is to be incorporated in the yield model, the factor θ_j^{pl} in equation 8.17 can be replaced by another factor D_j^{pl}. Accordingly, equation 8.17 is rewritten as follows:

$$S_{j-1}^{o} + I_j - D_j^{pl} Oy^{fpl} - Sp_j = S_j^{o} \qquad \forall_j \qquad (8.19)$$

where D_j^{pl} .= 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 as follows:

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

The value of D_j^{pl} when greater than zero and less than one, indicates the extent of permissible failure or an allowable deficit, i.e., $(1 - D_j^{pl})$ in firm annual yield during a failure year. For example, a value of D_j^{pl} = 0.8, indicates a 20% failure or deficit in firm annual yield. The value of D_j^{pl} 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^{pl} shall be called as *failure fraction.* It can be effectively used to exercise a control over the extent of failure or deficit in firm annual yield during failure years. This factor may affect the firm annual yield depending upon the flows during the critical period. A high value of D_j^{pl} is likely to reduce the firm annual yield. However, it shall always be preferable to know the extent of failure than to face unexpected failures as in case when the value of D_j^{pl} is set to zero.

8.6.2 Single Reservoir Multiple Yield Model

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

Thus the over-year storage continuity constraint (equation 8.17) can now be written as:

$$S_{j-1}^{o} + I_j - Oy^{fp} - \theta_j^{p2} Oy^{sp2} - Sp_j = S_j^{o} \qquad \forall_j \qquad (8.20)$$

Where $\theta_j^{p2} = \begin{cases} 1 & \text{in successful years} \\ 0 & \text{in failure years} \end{cases}$

In equation 8.20, for the year N, $S_N = S_0$

Where N = total number of years of river flows available

In multiple yield problems, the factor θ_j^{p2} for incremental secondary reservoir yields are zero in failure years; otherwise, the firm yield is essentially increased by $\theta_j^{p2} Oy^{sp2}$.

8.6.2.1 Incorporation of evaporation losses

Since the approximate yield model discussed in the foregoing sections does not directly identify the exact storage volumes at the beginning of each period in each year, evaporation losses must be based on an expected storage volume in each period and year. The approximate expected storage volume in any period t in year j can be defined as the initial over year volume S^o_{j-1}, plus the estimated average within-year volume $[(S^w_{t-1} + S^w_t)/2]$. The annual evaporation volume loss Ev_j in each year j can be based on these estimated average storage volumes. The storage area relationship and approximation of surface area per unit active storage volume is shown in Figure 8.1.

Considering the average annual depth of evaporation; $Ev^a = A_a \times$ Average annual depth of evaporation; and $Ev^0 = A_0 \times$ Average annual depth of evaporation.

Where 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; A_a = water surface area per unit active storage volume above dead storage level; and A_0 = water surface area at dead storage level.

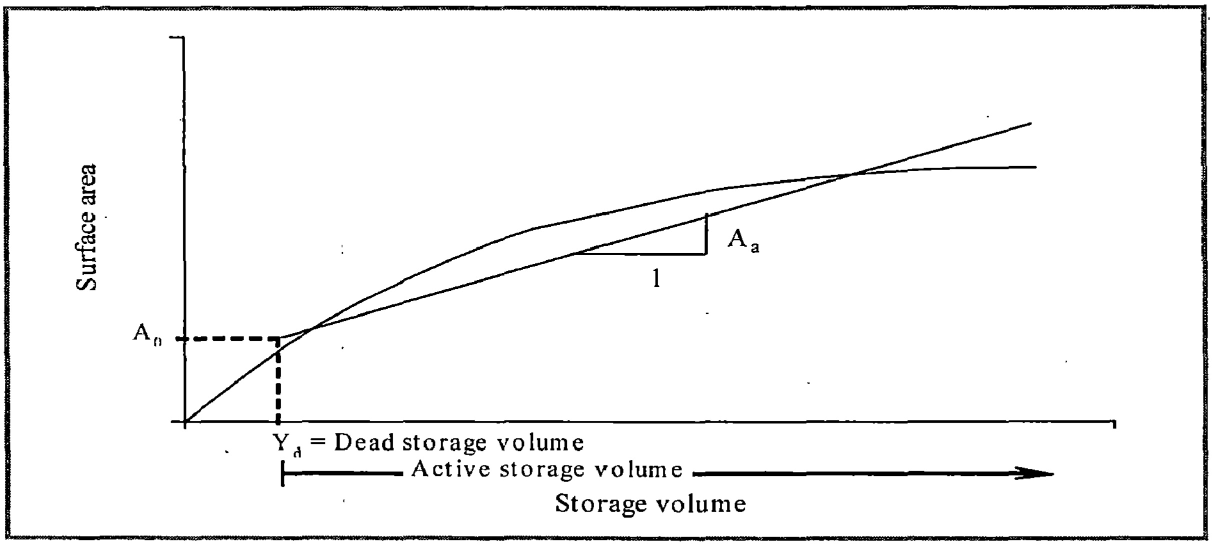


Figure 8.1 Storage area relationship and approximation of surface area per unit active storage volume

The evaporation loss will be approximately equal to the average annual fixed loss Ev^0 from the dead storage, plus the sum of each period's volume loss per unit of active storage volume times the expected storage volume in the period. Let γ_t be the fraction of the annual evaporation loss that occurs in period *t*. Then the annual evaporation loss in year *j* equals

$$Ev_j = \sum_t \left[\gamma_t Ev^0 + \left(S^o_{j-1} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t Ev^a \right] \qquad \forall_j \qquad (8.21)$$

Since the sum of all fractions γ_t equals 1, equation 5.21 can be simplified to

$$Ev_j = Ev^0 + \left[S^o_{j-1} + \sum_t \left(\frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t \right] Ev^a \qquad \forall_j \qquad (8.22)$$

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

$$Ev_t = \gamma_t Ev^0 + \left(S^o_{cr} + \frac{S^w_{t-1} + S^w_t}{2} \right) \gamma_t Ev^a \qquad \forall_t \qquad (8.23)$$

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

8.6.2.2 Mathematical statement of single reservoir multiple yield model

The single reservoir multiple yield model now can be written to derive two types of reservoir yields of the desired reliabilities by incorporating constraints to take into account the evaporation losses. This can be applied either to determine the optimal yield for a known reservoir capacity by maximizing the sum of firm and incremental secondary within-year reservoir yields or to obtain the required capacity for desired yields by minimizing the active reservoir capacity.

Objective function:

Maximize $$\sum_t \left(Oy^{fp}_t + Oy^{sp2}_t \right) \qquad (8.24)$$

Where Oy_t^{fp} =firm reservoir yield with reliability p in time t; and Oy_t^{sp2} = incremental secondary reservoir yield with reliability $p2$ in time t.

Or

Minimize $\quad Y_a$ (8.25)

Subject to the following constraints:

1. Over-year storage continuity

$$S_{j-1}^o + I_j - Oy^{fp} - \theta_j^{p2} Oy^{sp2} - Ev_j - Sp_j = S_j^o \qquad \forall_j \qquad (8.26)$$

Where Oy^{fp} = annual firm reservoir yield, Oy^{sp2} = annual secondary reservoir yield, and

$$\theta_j^{p2} = \begin{cases} 1 & \text{in successful years} \\ 0 & \text{in failure years} \end{cases}$$

2. Over-year active storage volume capacity

$$S_{j-1}^o \le Y^o \qquad \forall_j \qquad (8.27)$$

3. Within-year storage continuity

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

$$\forall_t \qquad (8.28)$$

4. Definition of estimated annual evaporation losses

$$Ev_j = Ev^0 + \left[S_{j-1}^o + \sum_t \left(\frac{S_{t-1}^w + S_t^w}{2} \right) \gamma_t \right] Ev^a \qquad \forall_j \qquad (8.29)$$

5. Definition of estimated evaporation losses in each period t of the critical year

$$Ev_t = \gamma_t Ev^0 + \left(S_{cr}^o + \frac{S_{t-1}^w + S_t^w}{2} \right) \gamma_t Ev^a \qquad \forall_t \qquad (8.30)$$

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

6. Total reservoir storage capacity

$$Y^{o} + S^{w}_{t-1} \leq Y_{a} \qquad \forall_{t} \qquad (8.31)$$

The equations 8.24 to 8.31 present the single reservoir multiple yield models, which can incorporate annual firm and incremental secondary reservoir yields and the evaporation losses. A within-year distribution of annual reservoir yields can be specified in this model by writing additional constraints.

8.6.2.3 Proportion of total annual yield in failure years in single reservoir multiple yield model

The model presented in the preceding section did not consider an allowable deficit criterion as the incremental secondary annual yield is made zero during the failure years by setting the value of factor θ_{j}^{p2} equal to zero. Thus, while maximizing annual yield, the model in the above stated form may not produce desired proportion of the total annual yield during failure years. To over come this other additional constraint is applied. So, in order to obtain the identical results as that of in the single yield model with allowable deficit in the failure years, a relation, i.e., firm annual reservoir yield equals failure fraction times the total annual reservoir yield is represented in the following form, i.e.,

$$Oy^{fp} = \frac{\rho_{i}^{p2}}{1-\rho_{i}^{p2}} Oy^{sp2} \qquad (8.32)$$

where ρ_{i}^{p2}= fraction of total annual yield desired to be released in the failure years from reservoir i.

With the above additional constraint, for known reservoir capacity the single reservoir multiple yield model will provide optimal annual yield with allowable percentage yield (or fraction of total annual yield, ρ_{i}^{p2}) during failure years, equal to the annual yield that a single reservoir single yield model would have given.

In case of a multiple yield formulation, the total annual reservoir yield is considered to be the sum of firm and incremental secondary reservoir yields. It can incorporate an allowable deficit criterion while maintaining the desired reliability of the annual reservoir yield. This could be achieved by not allowing incremental secondary annual yield during the failure years by assigning the value of $\theta_j^{p2} = 0$ in equation 8.26 and restricting the proportion of the firm annual yield to failure fraction$\left(\rho_i^{p2}\right)$times the sum of firm and incremental secondary annual yields. Further, the reliability of the annual yields in both the single and multiple yield formulation is maintained same as the values of annual yields during equal number of successful and failure years are identical. In case of multi yield formulation, the total annual yield will be maximum when the allowable percentage yield during failure years is set to zero and reaches to a minimum value if no deficit in failure years is allowed.

8.7 Application of Yield Model to present study area

The scope of the present study is limited only to major and medium reservoir projects due to non availability of required data and detailed plan proposal for the irrigation potential proposed to be created through minor irrigation projects. As per the Government of Orissa (2001), Rushikulya river basin envisages 10 numbers of reservoir projects. Out of these 7 reservoirs only exists and the rest will be implemented in different phases within the planning horizon. Details of these projects are given in table 8.1.

All the above mentioned projects are on various tributaries of Rushikulya river except one existing (Harabhangi dam project) and one ongoing (Cheligada dam project) are on tributaries of nearby river basin(Vansadhara river basin). All the reservoirs are having irrigation component except Pipalapanka and Loharkhandi reservoirs which are exclusively meant for industrial water supply. Sorada, Bhanjanagar and Cheligada Reservoirs have municipal water supply component in addition to irrigation component. The Sorada reservoir has no independent aycut of its own and functions as a storage reservoir and it provides irrigation to Rushikulya system as well as drinking water supply to Berhampur municipality. The Bhanjanagar reservoir provides irrigation to Rushikulya system as well as drinking water supply to Berhampur municipality in addition to its own aycut. All the 8 reservoirs inside the Rushikulya river basin are in parallel.

Table 8.1 Reservoirs details

Reservoir	CA in sq.km	CCA in Ha	Kharif in Ha	Rabi in Ha	Dead storage capacity in Ham	Gross storage capacity in Ham	Live storage capacity in Ham	Status	Purpose
Daha	168	6580	6580	1345	605	2800	2195	Existing	Irrigation
Dhanei	123	4625	4625	1420	220	1533	1313	Existing	Irrigation
Baghua	171	7700	6305	2464	650	3750	3100	Existing	Irrigation
Ghodahada	142	8560	7758	1000	388	3440	3052	Existing	Irrigation
Bhanjanagar	64	1342	1342	0	0	5766	5766	Existing	Irrigation and water supply
Sorada	43	-	-	-	0	4975	4975	Existing	Storage reservoir
Pipalapanka	512	-	-	-	397	14695	14298	Proposed	Industrial water supply
Loharkhandi	196	-	-	-	44	4759	4715	Proposed	Industrial water supply
Harabhangi	504	9150	9150	6820	5500	14125	8625	Existing	Irrigation
Cheligada	173.5	3610	3610	270	875	5201	4326	Ongoing	Irrigation and water supply

8.7.1 Estimation of input data

In case of a complex and large water resources system, it is difficult to get all the relevant data. Hence, in the absence of any data some reasonable and logical assumptions are made. For the purpose of analysis in the present study ,most of the basic data are taken from Department of Water Resources(DOWR), Orissa and other required data are suitable assumed/or derived.

8.7.2 Inflow series

Monthly observed inflow data at different reservoir sites has been used in this study except data generated by DOWR, Orissa through HYMOS software package has been used in case of proposed reservoirs.

8.7.3 Evaporation parameters

Average monthly evaporation depth for individual project is not available. As such, it is assumed that uniform meteorological conditions prevail upon in this basin, one single data set that is available has been considered for the present study. Average annual fixed evaporation volume loss due to dead storage (Ev^{o}) is obtained by multiplying the average annual evaporation depth by the water spread area at dead storage elevation of a reservoir. A linear fit for the storage-area data for each reservoir above dead storage level is obtained. Slope of the aforesaid line is the water surface area per unit active storage volume above dead storage level and denoted as A_a. Now, the average annual evaporation volume loss rate per unit active storage volume (Ev^a) is obtained by multiplying the average annual depth evaporation with A_a. The equation of regression line of storage-area relationships, Dead storage area (A_o) and the values of coefficients Ev^o,A_a, and Ev^a of all the reservoirs are given in table 8.2.

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. Above derived γ_t values has been adopted for all the reservoirs. The mean monthly depth of evaporation and values of parameter γ_t for the basin is given in table 8.3.

Table 8.2 Evaporation parameters for different reservoirs

Name of reservoirs	Equation of regression line	A_o in Ha	Ev^o In Ham	A_a	Ev^a Ham/ Unit storage
Daha	A = 0.1057*S + 188.06	252	377	0.1057	0.158
Dhanei	A = 0.2086*S + 79.326	125	187	0.2086	0.31
Baghua	A = 0.1379*S + 261.92	352	526	0.1379	0.206
Ghodahada	A = 0.0747*S + 150.25	179	268	0.0747	0.112
Bhanjanagar	A = 0.1465*S + 114.06	114	171	0.1465	0.22
Sorada	A = 0.2075*S + 137.45	137	206	0.2075	0.31
Pipalapanka	A = 0.0649*S + 206.99	233	348	0.0649	0.097
Loharkhandi	A = 0.1689*S + 92.1	100	149	0.1689	0.253
Harabhangi	A = 0.0666*S + 274.88	548	738	0.0666	0.0897
Cheligada	A = 0.0943*S + 92.654	175	262	0.0943	0.141

Table 8.3 Mean monthly depth of evaporation and value of parameter γ_t

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Evaporation in mm	93.9	123.8	155.3	188.9	227.8	141.4	118.3	98	96.3	91.9	81.6	79.9
γ_t	0.063	0.083	0.104	0.126	0.152	0.094	0.079	0.065	0.064	0.061	0.054	0.053

8.7.4 Irrigation demand

There is no uniform cropping pattern which is being adopted through out the entire irrigation projects. It varies from project to project. Crop planning proposed by Government of Orissa has been taken as such for the propose of this study, since that might have been proposed keeping in mind the long existing practices and food habits of local inhabitants. Details of crop planning with their respective area coverage of each project are given in table 8.4.

For the purpose of this study monthly crop water requirement of each crop under each project is required. Basing upon the calculation in accordance with the procedures stated in chapter-4, gross irrigation requirement of different crops are calculated to estimate the irrigation demand at each project. Table 8.5 depicts the month wise irrigation demand of all the existing and proposed projects with in the study area.

Table 8.4 Cropping pattern as proposed by Government of Orissa

Name of project	Name of crop	Area(Ha)	Name of project	Name of crop	Area(Ha)	Name of project	Name of crop	A
Daha irrigation project			**Ghodahada irrigation project**			**Cheligada dam project**		
	Kharif	**6580**		**Kharif**	**7758**		**Kharif**	**3[illegible]**
	Mid. Paddy	4525		Early paddy	1279		Early paddy	7[illegible]
	Raggi	633		Mid Paddy	3156		Mid Paddy	1[illegible]
	Maize	633		Late Paddy	2693		Late Paddy	2[illegible]
	Vegetables	789		Ragi	250		Ragi	4[illegible]
	Rabi	**1345**		Vegetables	370		Vegetables	1[illegible]
	Pulses	685		**Rabi**	**920**		**Rabi**	**2[illegible]**
	Groundnut	300		Pulses	140		Pulses	1[illegible]
	Sesame	180		Groundnut	540		Groundnut	1[illegible]
	Vegetables	180		Vegetables	230			
				Sugarcane	10			
Dhanei irrigation project			**Baghua irrigation project**			**Harabhangi irrigation project**		
	Kharif	**4625**		**Kharif**	**6305**		**Kharif**	**91**
	Early paddy	1754		Early paddy	1540		Early Paddy	2[illegible]
	Mid Paddy	2520		Mid Paddy	2070		Mid Paddy	31
	Raggi	237		Raggi	1001		Late Paddy	1[illegible]
	Maize	114		Maize	1540		Raggi	4[illegible]
	Rabi	**1420**		**Rabi**	**2464**		Groundnut	7[illegible]
	Paddy	220		Paddy	770		Maize	1[illegible]
	Ragi	200		Pulses	385		**Rabi**	**6[illegible]**
	Pulses	120		Groundnut	385		Paddy	11
	Groundnut	350		Sesame	385		Pulses	7[illegible]
	Sesame	398		Wheat	385		Groundnut	1[illegible]
	Sunflower	17		Sugarcane	154		Vegetable up	10
	Vegetables	115					Vegetable low	10
							Potato	30
							Mustard	53
							Sugarcane	36
Bhanjanagar dam project	**Kharif**	**1342**						
	paddy	982						
	Ragi	52						
	Maize	15						
	pulses	41						
	groundnut	5						
	vegetables	162						
	sugarcane	84						

Table 8.5 Monthly gross irrigation water requirement from reservoirs (in Ham)

Reservoir	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Daha	153	217	186	0	0	521	603	72	632	1036	1530	95	5045
Dhanei	249	304	276	100	0	591	907	123	478	806	554	151	4539
Baghua	603	598	600	377	39	501	772	104	403	678	503	411	5589
Ghodahada	102	173	151	2	2	1443	1946	916	1166	1113	1387	60	8460
Bhanjanagar	0	4	11	14	20	149	223	51	130	251	334	9	1197
Harabhangi	1041	1061	1047	982	301	2251	1847	891	1104	1650	877	767	13820
Cheligada	28	50	38	0	0	323	486	140	309	435	386	17	2211

8.7.5 Water supply demand

As per the Government of Orissa (2001), one cumec of drinking water supply to Berhampur Municipality has to be met from Cheligada dam project. Similarly provision of 60 MGD and 35 MGD industrial water supply has been kept from Pipalapanka and Loharkhandi dam project respectively. Both Sorada and Bhanjanagar reservoirs are simultaneously supplying 960 Ham of water annually to Berhampur municipality. Hence for the present study the above amount with efficiency of 30% has been distributed among the both reservoirs in proportion to their reservoir capacities i.e. water supply share of Sorada and Bhanjanagar reservoirs are 46% and 54% respectively.

The water supply demand to be met from different reservoirs in this basin by the planning horizon 2051AD is given in table 8.6.

8.6 Monthly water supply requirement from reservoirs (in Ham)

Reservoir	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Sorada	126	114	126	122	126	122	126	126	122	126	122	126	1482
Bhanjanagar	146	132	146	141	146	141	146	146	141	146	141	146	1718
Pipalapanka	837	756	837	810	837	810	837	837	810	837	810	837	9855
Loharkhandi	488	441	488	473	488	473	488	488	473	488	473	488	5749
Cheligada	268	242	268	259	268	259	268	268	259	268	259	268	268

8.7.6 Estimation of the coefficient "percentage fraction of target annual irrigation demand in a within time period t"

Percentage fraction of target annual irrigation demand in a time period t is defined as the ratio between the irrigation demand in period t and annual irrigation demand. The value of this coefficient is denoted by ξ_t. For monthly time periods it is computed from the monthly and annual irrigation demand at each project for the proposed crop plan. The values of percentage fraction so calculated for each project are given in table 8.7

Table 8.7 Percentage fraction of target annual irrigation demand in a within time period t

Reservoir	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Daha	0.030	0.043	0.037	0.000	0.000	0.103	0.119	0.014	0.125	0.205	0.303	0.019
Dhanei	0.055	0.067	0.061	0.022	0.000	0.130	0.200	0.027	0.105	0.178	0.122	0.033
Baghua	0.108	0.107	0.107	0.068	0.007	0.090	0.138	0.019	0.072	0.121	0.090	0.073
Ghodahada	0.012	0.020	0.018	0.000	0.000	0.171	0.230	0.108	0.138	0.132	0.164	0.007
Bhanjanagar	0.000	0.003	0.009	0.012	0.017	0.125	0.186	0.043	0.109	0.210	0.279	0.008
Harabhangi	0.075	0.077	0.076	0.071	0.022	0.163	0.134	0.064	0.080	0.119	0.063	0.056
Cheligada	0.012	0.022	0.017	0.000	0.000	0.146	0.220	0.063	0.140	0.197	0.174	0.008

8.7.7 Estimation of the coefficient "percentage fraction of target annual total demand in a within time period t"

For proportioning the annual yield in within year time periods, a coefficient namely percentage fraction of target annual total demand in a within time period t denoted as ξ_t' is used. For the monthly time periods it is defined as the ratio between the monthly and annual water demands for all purposes. The value of this coefficient is computed after clubbing all the water demands that are to be met from a reservoir. Values of ξ_t' for each project are given in table 8.8

Table 8.8 percentage fraction of target annual total demand in a within time period t

Reservoir	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Daha	0.030	0.043	0.037	0.000	0.000	0.103	0.119	0.014	0.125	0.205	0.303	0.019
Dhanei	0.055	0.067	0.061	0.022	0.000	0.130	0.200	0.027	0.105	0.178	0.122	0.033
Baghua	0.108	0.107	0.107	0.068	0.007	0.090	0.138	0.019	0.072	0.121	0.090	0.073
Ghodahada	0.012	0.020	0.018	0.000	0.000	0.171	0.230	0.108	0.138	0.132	0.164	0.007
Sorada	0.085	0.077	0.085	0.082	0.085	0.082	0.085	0.085	0.082	0.085	0.082	0.085
Bhanjanagar	0.050	0.047	0.054	0.053	0.057	0.100	0.126	0.068	0.093	0.136	0.163	0.053
Pipalapanka	0.085	0.077	0.085	0.082	0.085	0.082	0.085	0.085	0.082	0.085	0.082	0.085
Loharkhandi	0.085	0.077	0.085	0.082	0.085	0.082	0.085	0.085	0.082	0.085	0.082	0.085
Harabhangi	0.075	0.077	0.076	0.071	0.022	0.163	0.134	0.064	0.080	0.119	0.063	0.056
Cheligada	0.055	0.054	0.057	0.048	0.050	0.108	0.140	0.076	0.106	0.131	0.120	0.053

8.7.8 Identification of failure years for individual project

When the annual reservoir yield with reliability (*p*1 or *p*2) less than the maximum possible reliability (*p*) is to be estimated, failure is allowed in meeting the target annual demand in some years in accordance with the desired reliability, *p1* or *p*2. 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,

3. Making trial 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. In the present study, failure years have been identified on Visual inspection of the historical annual flow data.

8.7.9 Estimation of parameter β_t

As described in section 8.5, the parameter is required for the within-year continuity equation of the yield model. The within-year continuity equation is written for the within-year time period 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 reservoir in a critical year is equal to the total yield that would be released from the reservoir in the said year. 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. The parameter β_t reflects the relative proportion of the critical year's inflow that is likely to occur in period t. Hence the value of parameter β_t should be so chosen that the reservoir yield will be closest to that obtained with complete optimization model. In the present study parameter β_t based on 75% dependable flow year has been adopted for reservoirs with irrigation component and β_t based on inflow of the driest year has been adopted for reservoirs having only water supply component. The value of parameter β_t adopted in respect of each reservoirs are given in table 8.9

Table 8.9 Value of parameter β_t

Reservoir	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Daha	0.032	0.032	0.032	0.013	0.002	0.010	0.056	0.273	0.291	0.177	0.050	0.033
Dhanei	0.006	0.027	0.000	0.000	0.018	0.038	0.180	0.276	0.251	0.200	0.005	0.000
Baghua	0.002	0.007	0.015	0.027	0.016	0.201	0.088	0.276	0.254	0.096	0.015	0.003
Ghodahada	0.000	0.000	0.000	0.009	0.001	0.006	0.043	0.175	0.389	0.356	0.022	0.000
Sorada	0.000	0.000	0.000	0.022	0.000	0.000	0.333	0.170	0.031	0.048	0.108	0.290
Bhanjanagar	0.000	0.000	0.000	0.000	0.048	0.024	0.130	0.214	0.240	0.292	0.040	0.012
Pipalapanka	0.013	0.034	0.015	0.074	0.033	0.151	0.288	0.207	0.125	0.054	0.004	0.001
Loharkhandi	0.015	0.001	0.010	0.053	0.034	0.135	0.130	0.179	0.111	0.103	0.200	0.028
Harabhangi	0.005	0.002	0.001	0.007	0.008	0.105	0.203	0.275	0.250	0.058	0.074	0.012
Cheligada	0.005	0.016	0.022	0.033	0.060	0.101	0.072	0.077	0.079	0.217	0.256	0.062

8.8 Result and Analysis

Single reservoir multi-yield model has been run with twelve time within-year period for all the 10 reservoirs in the basin and the reservoir wise findings are as follows.

i) Daha reservoir project:

Results of optimization shows that annual yield of this reservoir is 4640 Ham against the target annual demand of 5045 Ham i.e. the annual yield is 8 % less than the target annual demand when the model is run for 21 years of observed inflow data considering 4 failure years i.e. with a reliability of yield as 77 % . Annual yield likely to be made available during the failure years would be 2605 Ham. This means 52 % of the target annual demand or 56 % of the annual yield in successful years can be made available during a failure year. The reservoir does not require any over year storage reservoir capacity. This may be attributed to the large annual inflows the reservoir is receiving. The result shows that 95 numbers of times the reservoir is getting filled up during the analysis period and the average annual spills is 47 % of annual average inflow. Single reservoir multi-yield model for twelve time within-year periods of Daha reservoir has been furnished in annexure 8.1.

ii) Ghodahada reservoir project:

Results of optimization shows that annual yield of this reservoir is 2799 Ham against the target annual demand of 8460 Ham i.e. the annual yield is 67 % less than the target annual demand when the model is run for 20 years of observed inflow data considering 4 failure years i.e. with a reliability of yield as 76 % . Annual yield likely to be made available during the failure years would be 1400 Ham. This means 17 % of the target annual demand or 50 % of the annual yield in successful years can be made available during a failure year. The reservoir requires 1256 Ham over year storage capacity i.e. 41 % of live storage capacity. The result shows that 70 numbers of times the reservoir is getting filled up during the analysis period and the average annual spills is 44 % of annual average inflow.

iii) Dhanei reservoir project:

Results of optimization shows that annual yield of this reservoir is 2731 Ham against the target annual demand of 4539 Ham i.e. the annual yield is 40 % less than the target annual demand when the model is run for 18 years of observed inflow data considering 3 failure years i.e. with a reliability of yield as 79 % . Annual yield likely to be made available during the failure years would be 1885 Ham. This means 42 % of the target annual demand or 69 % of the annual yield in successful years can be made available during a failure year. The reservoir does not require any over year storage reservoir capacity. This may be attributed to the large annual inflows the reservoir is receiving. The result shows that 100 numbers of times the reservoir is getting filled up during the analysis period and the average annual spills is 49 % of annual average inflow.

iv) Baghua reservoir project:

Results of optimization shows that annual yield of this reservoir is 4806 Ham against the target annual demand of 5589 Ham i.e. the annual yield is 14 % less than the target annual demand when the model is run for 39 years of generated inflow data considering 9 failure years i.e. with a reliability of yield as 75 % . Annual yield likely to be made available during the failure years would be 1346 Ham. This means 24 % of the target annual demand or 28 % of the annual yield in successful years can be made available during a failure year. The reservoir requires 322 Ham over year storage capacity i.e. 10 % of live storage capacity. The result shows that 92 numbers of times the reservoir is getting filled up during the analysis period and the average annual spills is 37 % of annual average inflow.

v) Pipalapanka reservoir project:

Results of optimization shows that the required reservoir capacity to meet the target annual demand of 9855 Ham is 6611 Ham when the model is run for 39 years of generated inflow data considering zero failure years i.e. with a reliability of yield as 97.5 % . The reservoir requires 2058 Ham over year storage. The result shows that 95 numbers of times the reservoir is getting filled up during the analysis period and the average annual spills is 55 % of annual average inflow. Single reservoir multi-yield model for twelve time within-year periods of Pipalapanka reservoir has been furnished in annexure 8.2.

vi) Loharkhandi reservoir project:

Results of optimization shows that the required reservoir capacity to meet the target annual demand of 5749 Ham is 5444 Ham when the model is run for 39 years of generated inflow data considering zero failure years i.e. with a reliability of yield as 97.5 % . The reservoir requires 3234 Ham over year storage. The result shows that 85 numbers of times the reservoir is getting filled up during the analysis period and the average annual spills is 44 % of annual average inflow.

vii) Cheligada Dam Project:

Results of optimization shows that the required reservoir capacity to meet the target annual demand of 5326 Ham is 4872 Ham when the model is run for 25 years of observed inflow data considering zero failure years i.e. with a reliability of yield as 95 % in case of water supply and five failure years i.e. with a reliability of yield as 77 % in case of irrigation. The reservoir requires 3467 Ham over year storage. The result shows that 76 numbers of times the reservoir is getting filled up during the analysis period and the average annual spills is 38 % of annual average inflow.

viii) Harabhangi reservoir project:

Results of optimization shows that annual yield of this reservoir is 17785 Ham against the target annual demand of 13820 Ham i.e. the annual yield is 29 % more than the target annual demand when the model is run for 42 years of observed inflow data considering 9 failure years i.e. with a reliability of yield as 77 % . Annual yield likely to be made available during the failure years would be 7114 Ham. This means 51 % of the target annual demand or 40 % of the annual yield in successful years can be made available during a failure year. The reservoir does not require any over year storage reservoir capacity. This may be attributed to the large annual inflows the reservoir is receiving. The result shows that 100 numbers of times the reservoir is getting filled up during the analysis period and the average annual spills is 39 % of annual average inflow.

ix) Bhanjanagar Dam Project:

Results of optimization shows that annual yield of this reservoir is 5022 Ham against the target annual demand of 2915 Ham when the model is run for 20 years of observed inflow data considering zero failure years i.e. with a reliability of yield as 95 % in case of water supply and four failure years i.e. with a reliability of yield as 76 % in case of irrigation. Annual yield likely to be made available during the failure years would be 2511 Ham. This means balance annual yield of 2105 Ham and balance firm yield of 793 Ham can be used to feed Rushikulya system.

x) Sorada Dam Project:

Results of optimization shows that annual yield of this reservoir is 2547 Ham against the target annual demand of 1482 Ham when the model is run for 20 years of observed inflow data considering zero failure years i.e. with a reliability of yield as 95 % in case of water supply and four failure years i.e. with a reliability of yield as 76 % in case of irrigation. Annual yield likely to be made available during the failure years would be zero Ham. Hence the reservoir has shortfall of 100 % to meet the firm water supply demand during failure years. In order to meet above firm yield, annual yield of this reservoir has been reduced to 1792 Ham. This means balance annual yield of 310 Ham is only available to feed Rushikulya system.

Since the firm yield of Bhanjanagar reservoir is in excess of the target demand and the firm yield of Sorada reservoir is in shortfall of the target demand, hence two more trials has been done. In 2nd trial, the water supply share of Bhanjanagar reservoir is 80% and that of Sorada reservoir is 20% and in 3rd trial it is 90% and 10% respectively.

The result of optimization shows that the balance annual yield available to feed the Rushikulya system is 3018 Ham in 2nd trial and 2918 Ham in 3rd trial as against 2417 Ham in 1st trial. Hence the optimal share of water supply of Bhanjanagar reservoir is 80% and that of Sorada reservoir is 20%.

CHAPTER-9

CONCLUSION

The conclusion drawn from the study on "optimal development of water resources of Rushikulya river basin (Orissa)" is stated on the findings of the work done below.

1). Optimal cropping pattern has been developed for the basin using LP and GP techniques which gives maximum net return to the farmers while meeting the protein, calorie and minimum food requirements of the basin population by the planning horizon i.e. 2051 AD. The developed cropping pattern also requires minimum quantity of water. Five LP models and four GP models has been developed and comparison among the best LP and GP model has been made. The LP-1 model gives maximum net return of Rs 144279 lakh and consumes 4563 MCM of water against the existing cropping pattern which gives maximum net return of Rs 87360 lakh and consumes 4903 MCM of water. Hence cropping pattern corresponding to LP-1 model has been recommended for the basin.

Sensitivity analysis at different dependability levels may be carried out to assess the possible optimum cropping pattern. Also constraint for area of soil suitable for different crops may be imposed on the LP model and studies on the above may be carried out.

2). Yield model has been developed to study the performance of all the ten reservoir projects in the basin. Out of 7 numbers existing reservoir projects, six numbers are in shortfall of meeting the target demand with maximum shortfall of 67% and minimum shortfall of 8% and one is 29% excess of meeting the target demand. The ongoing project requires 4872 Ham live storage capacity to meet the target demand as against the proposed capacity of 4326 Ham. Similarly the two proposed reservoirs require 5444 Ham and 6611 Ham live storage capacity as against the proposed capacity of 4715 Ham and 14298 Ham respectively to meet the target demand. Pipalapanka reservoir gives annual yield of 14773 Ham with the proposed live storage capacity of 14298 Ham against the target demand of 9855 Ham. Hence economic analysis may be carried out to use the balance water of Pipalapanka reservoir in Rushikulya system instead of going for reduction of proposed reservoir capacity. The excess yield of Harabhangi irrigation project may be utilized to increase the rabi potential. From the optimization result, it is observed that if Bhanjanagar reservoir meets 80% and Sorada reservoir meets 20% of water supply demand of Berhampur town, than balance water available to feed Rushikulya irrigation system will be maximum.

The yield model has also been run for two time within-year periods. The result shows that the annual yield is reduced when the model runs with twelve time within-year periods. Hence it is observed that annual yield reduces when the duration of within-year period became smaller. In case of Daha reservoir project, annual yield is 5759 Ham for two time within-year periods and 4640 Ham for twelve time within-year periods.

Further study may be carried out taking weekly or ten-daily within-year time periods which would be appropriate since most of the crops generally require water on weekly basis.

Integrated yield model for the whole basin may be developed taking into account all the diversion as well as reservoir projects jointly and conjunctively using both surface and ground water potential of the basin.

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Annexure-4.1

Hydro meteorological data of Dhaugaon hydrometry station

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Maximum Temperature(°c)	29.5	33.2	35.8	38.6	40.4	36.6	33.9	31.9	33.1	31.8	30.5	29.8
Mean Minimum Temperature (°c)	16.1	19.1	23.2	25.4	27.5	27.4	26.8	26.2	25.9	24.5	19.8	15.9
Air Humidity(%)	87.8	88.5	89.1	80.7	80.6	80.5	86.6	88.8	89.7	89.5	87.2	84.7
Mean wind Speed (km/day)	40.5	49.3	55.2	62	66.9	35.8	26.4	22.8	22.1	29.5	29.5	29.4
Mean daily sun-Shine (hour)	7.2	8.4	8.1	8.4	8.3	5.1	3.5	3.1	4.2	6.4	7	7.7
Monthly Pan Evaporation (mm)	93.9	123.8	155.3	188.9	227.8	141.4	118.3	98	96.3	91.9	81.6	79.9

Annexture: 4.2

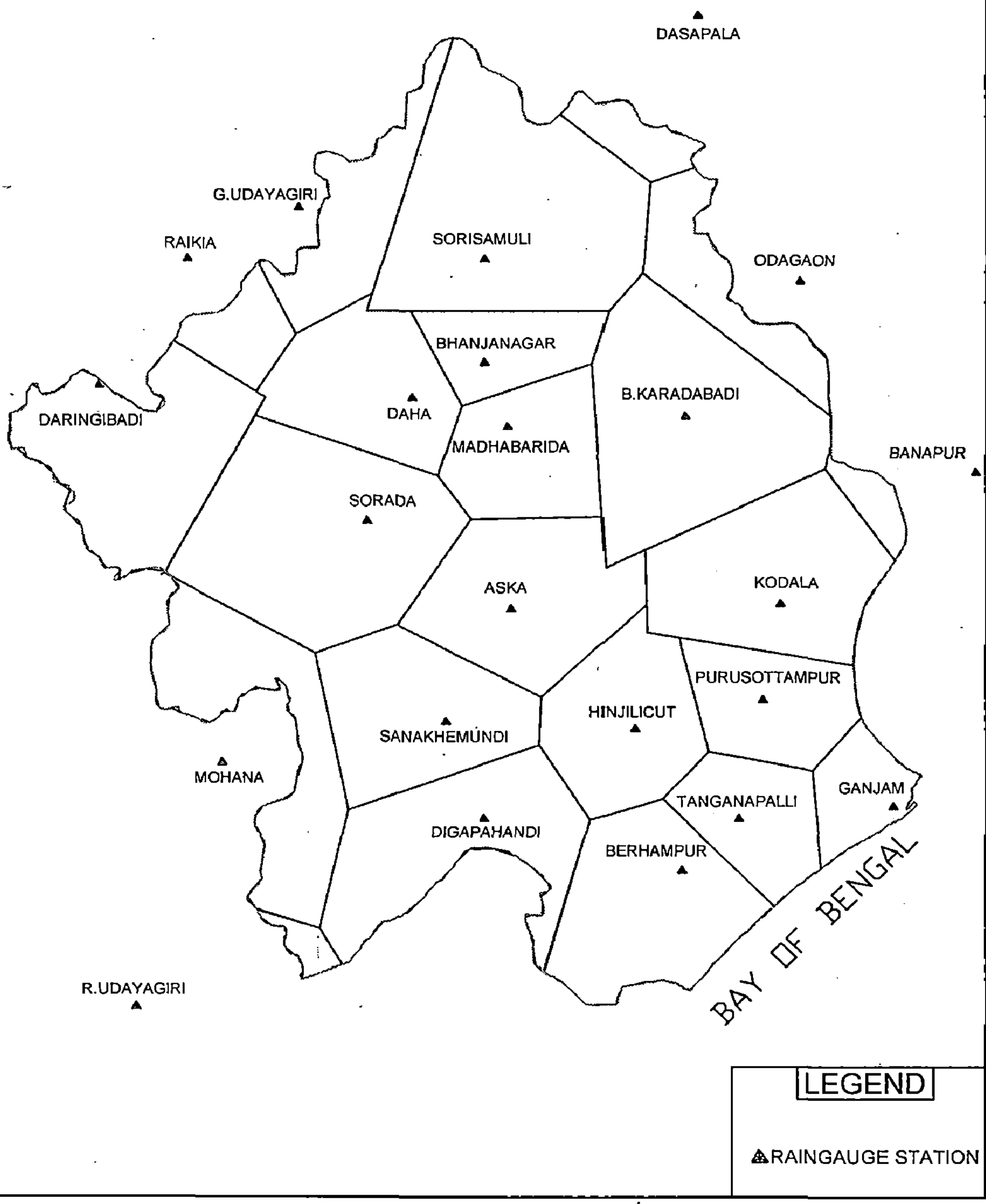
Rushikulya River Basin

Rainfall in mm

Sl.no	Raingauge Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Influence factor
1	Berhampur	11	19	15	21	50	143	203	240	227	180	69	5	1185	0.0566
2	R.Udaygiri	9	21	39	64	117	208	271	266	220	152	59	7	1433	0.0043
3	Dasapalla	14	14	35	38	54	186	319	315	217	110	22	4	1328	0.0116
4	Odogaon	8	21	25	42	60	131	215	242	143	110	34	5	1035	0.0245
5	Banapur	5	20	21	17	58	202	274	287	287	219	48	5	1442	0.0073
6	G.udaygiri	16	28	42	56	99	187	278	293	244	144	48	6	1442	0.0331
7	Daringbadi	15	19	23	62	96	192	292	303	224	126	48	9	1408	0.0639
8	Raikia	13	23	27	42	95	195	271	308	196	105	39	4	1319	0.0147
9	Sorada	10	20	30	45	79	149	228	221	205	122	44	3	1156	0.0876
10	Sorisamuli	16	21	34	58	53	198	307	293	235	122	50	5	1391	0.0970
11	Madhabarida	10	29	32	47	69	162	270	318	272	144	41	3	1398	0.0376
12	B.Koradabadi	10	25	24	37	69	184	251	285	231	140	38	4	1301	0.0823
13	Bhanjanagar	17	34	36	41	84	201	276	295	214	154	44	2	1397	0.0245
14	Kodala	10	24	21	30	58	184	252	271	246	183	62	5	1344	0.0634
15	Aska	8	18	33	38	81	173	213	224	205	153	45	2	1194	0.0566
16	Purusottampur	8	26	27	26	63	174	260	281	229	189	66	4	1352	0.0333
17	Hinjilicut	9	21	25	25	63	168	217	261	193	180	61	6	1229	0.0450
18	Sanakhemundi	24	20	35	52	80	164	221	255	197	131	44	10	1233	0.0523
19	Digapahandi	11	20	23	42	74	140	191	216	196	185	72	3	1173	0.0581
20	Ganjam	12	16	17	19	66	135	171	194	162	183	66	6	1047	0.0179
21	Mohana	12	30	54	71	124	191	219	257	215	151	54	3	1380	0.0543
22	Tanganapalli	12	12	14	11	36	127	201	205	184	198	49	2	1051	0.0293
23	Daha	17	27	29	57	93	185	260	278	220	166	78	7	1418	0.0447
	Weighted Average Rainfall (P)	**12**	**22**	**29**	**43**	**74**	**172**	**244**	**263**	**217**	**151**	**52**	**5**	**1285**	
	Effective Rainfall (Re)	**0**	**3**	**7**	**16**	**34**	**113**	**171**	**186**	**149**	**96**	**21**	**0**	**796**	

ANNEXURE . 4.3

THIESSEN POLYGON OF RUSHIKULYA RIVER BASIN



RAINGAUGE STATION	INFLUENCE FACTOR
ASKA	0.0224
BANAPUR	0.0029
BERHAMPUR	0.0224
BHANJANAGAR	0.0097
B.KORADABADI	0.0326
DAHA	0.0177
DARINGBADI	0.0253
DASPALLA	0.0046
DIGAPAHANDI	0.023
GANJAM	0.0071
G.UDAYGIRI	0.0131
HINJIILICUT	0.0178
KODALA	0.0251
MADHABARIDA	0.0149
MOHANA	0.0215
ODAGAON	0.0097
PURUSOTTAMPUR	0.0132
RAIKIA	0.0058
R.UDAYGIRI	0.0017
SANAKHEMUNDI	0.0207
SORISAMULI	0.0384
SORADA	0.0347
TANGANAPALLI	0.0116
TOTAL	1

ANNEXURE -8.1

! YIELD MODEL OF DAHA IRRIGATION PROJECT

MAX OFY+OSY
SUBJECT TO

! OVER YEAR CONTINUITY EQUATION

1) SO1+EVO1+SP1+OFY-SO0=3967
2) SO2+EVO2+SP2+OFY-SO1=3114
3) SO3+EVO3+SP3+OFY+OSY-SO2=11866
4) SO4+EVO4+SP4+OFY+OSY-SO3=7332
5) SO5+EVO5+SP5+OFY+OSY-SO4=19076
6) SO6+EVO6+SP6+OFY+OSY-SO5=10204
7) SO7+EVO7+SP7+OFY+OSY-SO6=15674
8) SO8+EVO8+SP8+OFY-SO7=5224
9) SO9+EVO9+SP9+OFY+OSY-SO8=6824
10) SO10+EVO10+SP10+OFY+OSY-SO9=14142
11) SO11+EVO11+SP11+OFY+OSY-SO10=8309
12) SO12+EVO12+SP12+OFY+OSY-SO11=5768
13) SO13+EVO13+SP13+OFY+OSY-SO12=11543
14) SO14+EVO14+SP14+OFY+OSY-SO13=5815
15) SO15+EVO15+SP15+OFY-SO14=4919
16) SO16+EVO16+SP16+OFY+OSY-SO15=10363
17) SO17+EVO17+SP17+OFY+OSY-SO16=6800
18) SO18+EVO18+SP18+OFY+OSY-SO17=12112
19) SO19+EVO19+SP19+OFY+OSY-SO18=6636
20) SO20+EVO20+SP20+OFY+OSY-SO19=9838
21) SO0+EVO21+SP21+OFY+OSY-SO20=10344

! OVER YEAR STORAGE BOUND EQUATION

22) SO0-YO<=0
23) SO1-YO<=0
24) SO2-YO<=0
25) SO3-YO<=0
26) SO4-YO<=0
27) SO5-YO<=0
28) SO6-YO<=0
29) SO7-YO<=0
30) SO8-YO<=0
31) SO9-YO<=0
32) SO10-YO<=0
33) SO11-YO<=0
34) SO12-YO<=0
35) SO13-YO<=0
36) SO14-YO<=0
37) SO15-YO<=0
38) SO16-YO<=0
39) SO17-YO<=0
40) SO18-YO<=0
41) SO19-YO<=0
42) SO20-YO<=0

! WITHIN YEAR CONTINUITY EQUATION

43) SW1-SW0-0.032OFY-0.032OSY+0.968EVW1-0.032EVW2-0.032EVW3-0.032EVW4-0.032EVW5-0.032EVW6-0.032EVW7-0.032EVW8-0.032EVW9-0.032EVW10-0.032EVW11-0.032EVW12+WFY1+WSY1=0
44) SW2-SW1-0.032OFY-0.032OSY-0.032EVW1+0.968EVW2-0.032EVW3-0.032EVW4-0.032EVW5-0.032EVW6-0.032EVW7-0.032EVW8-0.032EVW9-0.032EVW10-0.032EVW11-0.032EVW12+WFY2+WSY2=0
45) SW3-SW2-0.032OFY-0.032OSY-0.032EVW1-0.032EVW2+0.968EVW3-0.032EVW4-0.032EVW5-0.032EVW6-0.032EVW7-0.032EVW8-0.032EVW9-0.032EVW10-0.032EVW11-0.032EVW12+WFY3+WSY3=0
46) SW4-SW3-0.013OFY-0.013OSY-0.013EVW1-0.013EVW2-0.013EVW3+0.987EVW4-0.013EVW5-0.013EVW6-0.013EVW7-0.013EVW8-0.013EVW9-0.013EVW10-0.013EVW11-0.013EVW12+WFY4+WSY4=0
47) SW5-SW4-0.002OFY-0.002OSY-0.002EVW1-0.002EVW2-0.002EVW3-0.002EVW4+0.998EVW5-0.002EVW6-0.002EVW7-0.002EVW8-0.002EVW9-0.002EVW10-0.002EVW11-0.002EVW12+WFY5+WSY5=0
48) SW6-SW5-0.01OFY-0.01OSY-0.01EVW1-0.01EVW2-0.01EVW3-0.01EVW4-0.01EVW5+0.99EVW6-0.01EVW7-0.01EVW8-0.01EVW9-0.01EVW10-0.01EVW11-0.01EVW12+WFY6+WSY6=0
49) SW7-SW6-0.056OFY-0.056OSY-0.056EVW1-0.056EVW2-0.056EVW3-0.056EVW4-0.056EVW5-0.056EVW6+0.944EVW7-0.056EVW8-0.056EVW9-0.056EVW10-0.056EVW11-0.056EVW12+WFY7+WSY7=0
50) SW8-SW7-0.273OFY-0.273OSY-0.273EVW1-0.273EVW2-0.273EVW3-0.273EVW4-0.273EVW5-0.273EVW6-0.273EVW7+0.727EVW8-0.273EVW9-0.273EVW10-0.273EVW11-0.273EVW12+WFY8+WSY8=0
51) SW9-SW8-0.291OFY-0.291OSY-0.291EVW1-0.291EVW2-0.291EVW3-0.291EVW4-0.291EVW5-0.291EVW6-0.291EVW7-0.291EVW8+0.709EVW9-0.291EVW10-0.291EVW11-0.291EVW12+WFY9+WSY9=0
52) SW10-SW9-0.177OFY-0.177OSY-0.177EVW1-0.177EVW2-0.177EVW3-0.177EVW4-0.177EVW5-0.177EVW6-0.177EVW7-0.177EVW8-0.177EVW9+0.823EVW10-0.177EVW11-0.177EVW12+WFY10+WSY10=0
53) SW11-SW10-0.05OFY-0.05OSY-0.05EVW1-0.05EVW2-0.05EVW3-0.05EVW4-0.05EVW5-0.05EVW6-0.05EVW7-0.05EVW8-0.05EVW9-0.05EVW10+0.95EVW11-0.05EVW12+WFY11+WSY11=0
!54) SW0-SW11-0.033OFY-0.033OSY-0.033EVW1-0.033EVW2-0.033EVW3-0.033EVW4-0.033EVW5-0.033EVW6-0.033EVW7-0.033EVW8-0.033EVW9-0.033EVW10-0.033EVW11+0.967EVW12+WFY12+WSY12=0

! OVER YEAR EVAPORATION EQUATION

55) EVO1-0.158 SO0-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
56) EVO2-0.158 SO1-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.0009SW10-0.009SW11-0.009SW0=377
57) EVO3-0.158 SO2-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
58) EVO4-0.158 SO3-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
59) EVO5-0.158 SO4-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
60) EVO6-0.158 SO5-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377

61) EVO7-0.158 SO6-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
62) EVO8-0.158 SO7-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
63) EVO9-0.158 SO8-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
64) EVO10-0.158 SO9-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
65) EVO11-0.158 SO10-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
66) EVO12-0.158 SO11-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
67) EVO13-0.158 SO12-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
68) EVO14-0.158 SO13-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
69) EVO15-0.158 SO14-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
70) EVO16-0.158 SO15-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
71) EVO17-0.158 SO16-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
72) EVO18-0.158 SO17-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
73) EVO19-0.158 SO18-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
74) EVO20-0.158 SO19-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377
75) EVO21-0.158 SO20-0.012SW1-0.015SW2-0.018SW3-0.022SW4-0.02SW5-0.014SW6-0.011SW7-0.01SW8-0.01SW9-0.009SW10-0.009SW11-0.009SW0=377

! WITHIN YEAR EVAPORATION EQUATION

76) EVW1-.005 SW0-.005 SW1=24
77) EVW2-.007 SW1-.007 SW2=31
78) EVW3-.008 SW2-.008 SW3=39
79) EVW4-.01 SW3-.01 SW4=48
80) EVW5-.012 SW4-.012 SW5=57
81) EVW6-.007 SW5-.007 SW6=36
82) EVW7-.006 SW6-.006 SW7=30
83) EVW8-.005 SW7-.005 SW8=25
84) EVW9-.005 SW8-.005 SW9=24
85) EVW10-.005 SW9-.005 SW10=23
86) EVW11-.004 SW10-.004 SW11=21
87) EVW12-.004 SW11-.004 SW0=20

! WITHIN YEAR STORAGE BOUND EQUATION

88) YO+SW0<=2195
89) YO+SW1<=2195
90) YO+SW2<=2195
91) YO+SW3<=2195
92) YO+SW4<=2195

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93) YO+SW5<=2195
94) YO+SW6<=2195
95) YO+SW7<=2195
96) YO+SW8<=2195
97) YO+SW9<=2195
98) YO+SW10<=2195
99) YO+SW11<=2195
! WITHIN YEAR PROPORTION YIELD EQUATION
100) WFY1+WSY1-0.03 OFY-0.03 OSY=0
101) WFY2+WSY2-0.043 OFY-0.043 OSY=0
102) WFY3+WSY3-0.037 OFY-0.037 OSY=0
103) WFY4+WSY4=0
104) WFY5+WSY5=0
105) WFY6+WSY6-0.103 OFY-0.103 OSY=0
106) WFY7+WSY7-0.119 OFY-0.119 OSY=0
107) WFY8+WSY8-0.014 OFY-0.014 OSY=0
108) WFY9+WSY9-0.125 OFY-0.125 OSY=0
109) WFY10+WSY10-0.205 OFY-0.205 OSY=0
110) WFY11+WSY11-0.303 OFY-0.303 OSY=0
!111) WFY12+WSY12-0.019 OFY-0.019 OSY=0
! FIRM YIELD CONSTRAINT
112) -
OFY+WFY1+WFY2+WFY3+WFY4+WFY5+WFY6+WFY7+WFY8+WFY9+WFY10+W
FY11+WFY12=0
! SECONDAR Y YIELD CONSTRAINT
113) -
OSY+WSY1+WSY2+WSY3+WSY4+WSY5+WSY6+WSY7+WSY8+WSY9+WSY10+W
SY11+WSY12=0
! FAILURE FRACTION
114)0.44OFY-0.56OSY >=0
END
```

ANNEXURE-8.2

!YIELD MODEL OF PIPALAPANKA DAM PROJECT
MIN YA
SUBJECT TO
!OVER YEAR CONTINUITY EQUATION
1) SO1+EVO1+SP1+OFY+OSY-SO0=18424
2) SO2+EVO2+SP2+OFY+OSY-SO1=28697
3) SO3+EVO3+SP3+OFY+OSY-SO2=28439
4) SO4+EVO4+SP4+OFY+OSY-SO3=28739
5) SO5+EVO5+SP5+OFY+OSY-SO4=17254
6) SO6+EVO6+SP6+OFY+OSY-SO5=22895
7) SO7+EVO7+SP7+OFY+OSY-SO6=25510
8) SO8+EVO8+SP8+OFY+OSY-SO7=34231
9) SO9+EVO9+SP9+OFY+OSY-SO8=28421
10) SO10+EVO10+SP10+OFY+OSY-SO9=24746
11) SO11+EVO11+SP11+OFY+OSY-SO10=25233
12) SO12+EVO12+SP12+OFY+OSY-SO11=11700
13) SO13+EVO13+SP13+OFY+OSY-SO12=30791
14) SO14+EVO14+SP14+OFY+OSY-SO13=20390
15) SO15+EVO15+SP15+OFY+OSY-SO14=16554
16) SO16+EVO16+SP16+OFY+OSY-SO15=21784
17) SO17+EVO17+SP17+OFY+OSY-SO16=24147
18) SO18+EVO18+SP18+OFY+OSY-SO17=21719
19) SO19+EVO19+SP19+OFY+OSY-SO18=17095
20) SO20+EVO20+SP20+OFY+OSY-SO19=24249
21) SO21+EVO21+SP21+OFY+OSY-SO20=16747
22) SO22+EVO22+SP22+OFY+OSY-SO21=15106
23) SO23+EVO23+SP23+OFY+OSY-SO22=30554
24) SO24+EVO24+SP24+OFY+OSY-SO23=8543
25) SO25+EVO25+SP25+OFY+OSY-SO24=23041
26) SO26+EVO26+SP26+OFY+OSY-SO25=16816
27) SO27+EVO27+SP27+OFY+OSY-SO26=12688
28) SO28+EVO28+SP28+OFY+OSY-SO27=24039
29) SO29+EVO29+SP29+OFY+OSY-SO28=16984
30) SO30+EVO30+SP30+OFY+OSY-SO29=48417
31) SO31+EVO31+SP31+OFY+OSY-SO30=41061
32) SO32+EVO32+SP32+OFY+OSY-SO31=33179
33) SO33+EVO33+SP33+OFY+OSY-SO32=12816
34) SO34+EVO34+SP34+OFY+OSY-SO33=27181
35) SO35+EVO35+SP35+OFY+OSY-SO34=36222
36) SO36+EVO36+SP36+OFY+OSY-SO35=9663
37) SO37+EVO37+SP37+OFY+OSY-SO36=21923
38) SO38+EVO38+SP38+OFY+OSY-SO37=24586
39) SO0+EVO39+SP39+OFY+OSY-SO38=15483
!OVER YEAR STORAGE BOUND EQUATION
40) SO0-YO<=0
41) SO1-YO<=0
42) SO2-YO<=0

43) SO3-YO<=0
44) SO4-YO<=0
45) SO5-YO<=0
46) SO6-YO<=0
47) SO7-YO<=0
48) SO8-YO<=0
49) SO9-YO<=0
50) SO10-YO<=0
51) SO11-YO<=0
52) SO12-YO<=0
53) SO13-YO<=0
54) SO14-YO<=0
55) SO15-YO<=0
56) SO16-YO<=0
57) SO17-YO<=0
58) SO18-YO<=0
59) SO19-YO<=0
60) SO20-YO<=0
61) SO21-YO<=0
62) SO22-YO<=0
63) SO23-YO<=0
64) SO24-YO<=0
65) SO25-YO<=0
66) SO26-YO<=0
67) SO27-YO<=0
68) SO28-YO<=0
69) SO29-YO<=0
70) SO30-YO<=0
71) SO31-YO<=0
72) SO32-YO<=0
73) SO33-YO<=0
74) SO34-YO<=0
75) SO35-YO<=0
76) SO36-YO<=0
77) SO37-YO<=0
78) SO38-YO<=0

!WITHIN YEAR CONTINUITY EQUATION

79) SW1-SW0-0.013OFY-0.013OSY+0.987EVW1-0.013EVW2-0.013EVW3-0.013EVW4-0.013EVW5-0.013EVW6-0.013EVW7-0.013EVW8-0.013EVW9-0.013EVW10-0.013EVW11-0.013EVW12+WFY1+WSY1=0
80) SW2-SW1-0.034OFY-0.034OSY-0.034EVW1+0.966EVW2-0.034EVW3-0.034EVW4-0.034EVW5-0.034EVW6-0.034EVW7-0.034EVW8-0.034EVW9-0.034EVW10-0.034EVW11-0.034EVW12+WFY2+WSY2=0
81) SW3-SW2-0.015OFY-0.015OSY-0.015EVW1-0.015EVW2+0.985EVW3-0.015EVW4-0.015EVW5-0.015EVW6-0.015EVW7-0.015EVW8-0.015EVW9-0.015EVW10-0.015EVW11-0.015EVW12+WFY3+WSY3=0
82) SW4-SW3-0.074OFY-0.074OSY-0.074EVW1-0.074EVW2-0.074EVW3+0.926EVW4-0.074EVW5-0.074EVW6-0.074EVW7-0.074EVW8-0.074EVW9-0.074EVW10-0.074EVW11-0.074EVW12+WFY4+WSY4=0

83) SW5-SW4-0.033OFY-0.033OSY-0.033EVW1-0.033EVW2-0.033EVW3-0.033EVW4+0.967EVW5-0.033EVW6-0.033EVW7-0.033EVW8-0.033EVW9-0.033EVW10-0.033EVW11-0.033EVW12+WFY5+WSY5=0
84) SW6-SW5-0.151OFY-0.151OSY-0.151EVW1-0.151EVW2-0.151EVW3-0.151EVW4-0.151EVW5+0.849EVW6-0.151EVW7-0.151EVW8-0.151EVW9-0.151EVW10-0.151EVW11-0.151EVW12+WFY6+WSY6=0
85) SW7-SW6-0.288OFY-0.288OSY-0.288EVW1-0.288EVW2-0.288EVW3-0.288EVW4-0.288EVW5-0.288EVW6+0.712EVW7-0.288EVW8-0.288EVW9-0.288EVW10-0.288EVW11-0.288EVW12+WFY7+WSY7=0
86) SW8-SW7-0.207OFY-0.207OSY-0.207EVW1-0.207EVW2-0.207EVW3-0.207EVW4-0.207EVW5-0.207EVW6-0.207EVW7+0.793EVW8-0.207EVW9-0.207EVW10-0.207EVW11-0.207EVW12+WFY8+WSY8=0
87) SW9-SW8-0.125OFY-0.125OSY-0.125EVW1-0.125EVW2-0.125EVW3-0.125EVW4-0.125EVW5-0.125EVW6-0.125EVW7-0.125EVW8+0.875EVW9-0.125EVW10-0.125EVW11-0.125EVW12+WFY9+WSY9=0
88) SW10-SW9-0.054OFY-0.054OSY-0.054EVW1-0.054EVW2-0.054EVW3-0.054EVW4-0.054EVW5-0.054EVW6-0.054EVW7-0.054EVW8-0.054EVW9+0.946EVW10-0.054EVW11-0.054EVW12+WFY10+WSY10=0
89) SW11-SW10-0.004OFY-0.004OSY-0.004EVW1-0.004EVW2-0.004EVW3-0.004EVW4-0.004EVW5-0.004EVW6-0.004EVW7-0.004EVW8-0.004EVW9-0.004EVW10+0.996EVW11-0.004EVW12+WFY11+WSY11=0
!90) SW0-SW11-0.001OFY-0.001OSY-0.001EVW1-0.001EVW2-0.001EVW3-0.001EVW4-0.001EVW5-0.001EVW6-0.001EVW7-0.001EVW8-0.001EVW9-0.001EVW10-0.001EVW11+0.999EVW12+WFY12+WSY12=0

!OVER YEAR EVAPORATION EQUATION

91) EVO1-0.097 SO0-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
92) EVO2-0.097 SO1-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
93) EVO3-0.097 SO2-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
94) EVO4-0.097 SO3-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
95) EVO5-0.097 SO4-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
96) EVO6-0.097 SO5-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
97) EVO7-0.097 SO6-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
98) EVO8-0.097 SO7-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
99) EVO9-0.097 SO8-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
100) EVO10-0.097 SO9-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
101) EVO11-0.097 SO10-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
102) EVO12-0.097 SO11-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348

103) EVO13-0.097 SO12-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
104) EVO14-0.097 SO13-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
105) EVO15-0.097 SO14-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
106) EVO16-0.097 SO15-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
107) EVO17-0.097 SO16-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
108) EVO18-0.097 SO17-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
109) EVO19-0.097 SO18-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
110) EVO20-0.097 SO19-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
111) EVO21-0.097 SO20-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
112) EVO22-0.097 SO21-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
113) EVO23-0.097 SO22-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
114) EVO24-0.097 SO23-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
115) EVO25-0.097 SO24-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
116) EVO26-0.097 SO25-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
117) EVO27-0.097 SO26-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
118) EVO28-0.097 SO27-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
119) EVO29-0.097 SO28-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
120) EVO30-0.097 SO29-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
121) EVO31-0.097 SO30-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
122) EVO32-0.097 SO31-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
123) EVO33-0.097 SO32-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
124) EVO34-0.097 SO33-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
125) EVO35-0.097 SO34-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
126) EVO36-0.097 SO35-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348

127) EVO37-0.097 SO36-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
128) EVO38-0.097 SO37-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348
129) EVO39-0.097 SO38-0.007SW1-0.009SW2-0.011SW3-0.014SW4-0.012SW5-0.008SW6-0.007SW7-0.006SW8-0.006SW9-0.006SW10-0.005SW11-0.006SW0=348

!WITHIN YEAR EVAPORATION EQUATION

130) EVW1-.003 SW0-.003 SW1=22
131) EVW2-.004 SW1-.004 SW2=29
132) EVW3-.005 SW2-.005 SW3=36
133) EVW4-.006 SW3-.006 SW4=44
134) EVW5-.007 SW4-.007 SW5=53
135) EVW6-.005 SW5-.005 SW6=33
136) EVW7-.004 SW6-.004 SW7=28
137) EVW8-.003 SW7-.003 SW8=23
138) EVW9-.003 SW8-.003 SW9=22
139) EVW10-.003 SW9-.003 SW10=21
140) EVW11-.003 SW10-.003 SW11=19
141) EVW12-.003 SW11-.003 SW0=19

!WITHIN YEAR STORAGE BOUND EQUATION

142) YO+SW0-YA<=0
143) YO+SW1-YA<=0
144) YO+SW2-YA<=0
145) YO+SW3-YA<=0
146) YO+SW4-YA<=0
147) YO+SW5-YA<=0
148) YO+SW6-YA<=0
150) YO+SW7-YA<=0
151) YO+SW8-YA<=0
152) YO+SW9-YA<=0
153) YO+SW10-YA<=0
154) YO+SW11-YA<=0

!WITHIN YEAR PROPORTION YIELD EQUATION

155) WFY1+WSY1-0.085 OFY-0.085 OSY=0
156) WFY2+WSY2-0.077 OFY-0.077 OSY=0
157) WFY3+WSY3-0.085 OFY-0.085 OSY=0
158) WFY4+WSY4-0.082 OFY-0.082 OSY=0
159) WFY5+WSY5-0.085 OFY-0.085 OSY=0
160) WFY6+WSY6-0.082 OFY-0.082 OSY=0
161) WFY7+WSY7-0.085 OFY-0.085 OSY=0
162) WFY8+WSY8-0.085 OFY-0.085 OSY=0
163) WFY9+WSY9-0.082 OFY-0.082 OSY=0
164) WFY10+WSY10-0.085 OFY-0.085 OSY=0
165) WFY11+WSY11-0.082 OFY-0.082 OSY=0
!166) WFY12+WSY12-0.085 OFY-0.085 OSY=0

!FIRM YIELD CONSTRAINT

167) -
OFY+WFY1+WFY2+WFY3+WFY4+WFY5+WFY6+WFY7+WFY8+WFY9+WFY10+WFY11+WFY12=0

!SECONDARY YIELD CONSTRAINT

168) -
OSY+WSY1+WSY2+WSY3+WSY4+WSY5+WSY6+WSY7+WSY8+WSY9+WSY10+WSY11+WSY12=0

!TARGET DEMAND CONSTRAINT

169) OFY+OSY>=9855
170) WFY1+WSY1>=837
171) WFY2+WSY2>=756
172) WFY3+WSY3>=837
173) WFY4+WSY4>=810
174) WFY5+WSY5>=837
175) WFY6+WSY6>=810
176) WFY7+WSY7>=837
177) WFY8+WSY8>=837
178) WFY9+WSY9>=810
179) WFY10+WSY10>=837
180) WFY11+WSY11>=810
181) WFY12+WSY12>=837
END