RESERVOIR OPERATION PLANNING AND CROPPING PATTERN OPTIMIZATION FOR CHAMRAVATTOM REGULATOR-CUM-BRIDGE

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KERALA, INDIA

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PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree

Bachelor of Technology
In
Agricultural Engineering

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

Department of Land and Water Resources & Conservation Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR-679 573, MALAPPURAM

KERALA, INDIA

2008

DECLARATION

We here by declare that this project report entitled **"RESERVOIR OPERATION PLANNING AND CROPPING PATTERN OPTIMIZATION FOR CHAMRAVATTOM REGULATOR-CUM-BRIDGE"** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Tavanur,
Date: -01-2008

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(2003-02-20)

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(2003-02-09)

CERTIFICATE

Certified that this project report entitled **"RESERVOIR OPERATION PLANNING AND CROPPING PATTERN OPTIMIZATION FOR CHAMRAVATTOM REGULATOR-CUM-BRIDGE** " is a record of project work done independently by **Gulja S Nair, Neenu Peter and Prajitha M** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

Tavanur

Er. Rema K.P (Sel. gr)
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ACKNOWLEDGEMENT

We would like to express our deep sense of gratitude, utmost indebtedness and heartfelt thanks to **Er. Rema, K. P (Sel. gr)**, Asst. Professor, Department of Land and Water Resources and Conservation Engineering, K.C.A.E.T., for her valuable guidance, profound suggestions, constant backing, prolific encouragement and advice through out the project work.

We express our sincere gratitude to **Dr. M. Sivaswami**, Dean, K.C.AE.T, Tavanur for his support and co-operation during the course of the work.

We deep respect we express our heartfelt gratitude to **Dr. E. K. Mathew**, Head of the Department of LWRCE, K.C.A.E.T for their immense guidance during this work.

We express our heartfelt thanks to **Er. Sathyan, K. K**., and **Er. Renuka Kumari. J**, Asst. professor, Department of LWRCE, K.C.AE.T. for his constant encouragement and suggestions for carrying out this project work.

We sincerely acknowledge **Er. Vishnu, B,** Asst. Professor, Dept. of LWRCE for the co-operation offered in availing the facilities of the computer centre for our project work.

We are thankful to **Er. Sasikala**, Asst. Professor, Dept. of IDE for her support and encouragement during the course of our work.

With deep sense of gratitude, we acknowledge the help rendered by **Dr. Habeeburahman**, Head of KVK, Malappuram and **Er. Joby Bastian,** Asst. Prof., RARS, Kumarakom.

With extreme pleasure we extend our courteous gratitude and a high sense of loyalty to E**r. Sudheer**, **P**, Deputy Director, Aliyar sub division, Palakkad, for his assiduous interest, timely help and extremely valuable suggestions to carry out this work successfully.

With deep respect, we sincerely acknowledge **Mr. Surjith,** Asst. Engineer and **Mr. Thomas Mathew,** Asst. Executive Engineer, Project Office, Chamravattom, for providing the necessary information, related data and timely help rendered by them.

We would like to extend our sincere and cordial thanks **to Mr. Jayanthakumar, Mr. Krishnakumar, N. C., Mr. Vijayan, P.V., Mr. Jose Varghese**, Asst. Directors of Ponnani, Perumpadappu, Tirur and Thalappilly blocks respectively for providing us with the relevant data on cropping pattern.

We offer our hearty thanks to **Er. Cibinraj** for his sincere and timely help in getting the necessary information for the study.

We express our heartfelt thanks to the library staff for their help extended towards us in collecting the literature for this work.

We are grateful to Miss. Lekshmi, computer centre staff for her kind co-operation and help.

We express our deep sense of gratitude to our loving parents and our dear classmates for their stable support and inspiration through out our study.

Above all we bow our head before the God Almighty whose blessings empowered us to complete this work successfully.

Gulja S Nair

Neenu Peter

Prajitha M

Dedicated To Our Loving Parents

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SYMBOLS AND ABBREVIATIONS

Agril.	-	Agricultural
Apr	-	April
ASCE	-	American Society of Civil Engineers
Asst.	-	Assistant
Aug	-	August
B/C	-	Benefit Cost ratio
cm	-	centimeter(s)
CWRDM	-	Centre for Water Resources Development and Management
Dec	-	December
Dept.	-	Department
Engg.	-	Engineering
ET	-	Evapotranspiration
ET_0	-	Reference Evapotranspiration
ETo*	-	Corrected Evapo-transpiration
et al.	-	and others
etc.	-	Etcetera
FAO	-	Food and Agricultural Organization
Feb	-	February
Fig.	-	Figure
FRL	-	Full Reservoir Level
g/cm^3	-	gram per cubic centimeter(s)
ha	-	hectare
IDE	-	Irrigation and Drainage Engineering
i.e.	-	that is
Jan	-	January
J.	-	Journal

Jul	-	July
Jun	-	June
KAU	-	Kerala Agricultural University
K.C.A.E.T	-	Kelappaji College of Agricultural Engineering and Technology
km	-	Kilometre(s)
LP	-	Linear Programming
LWRCE	-	Land and Water Resources & Conservation Engineering
m	-	metre(s)
M	-	Million
Mar	-	March
Mha-m	-	Million hectare metre(s)
Mkm^3	-	Million cubic kiloMetres
Mm^3	-	Million cubic metre
mm/day	-	millimetre(s) per day
m^3/sec	-	cubic metre(s) per second
MSL	-	Mean sea level
NABARD	-	National Bank for Agricultural and Rural Development
Nos.	-	Numbers
Nov	-	November
Oct	-	October
RCB	-	Regulator-cum-bridge
Res.	-	Research
RH	-	Relative Humidity
R.L	-	Reduced Level
Rs.	-	Rupees
SDP	-	Stochastic dynamic programming
Sep	-	September
Sl. No.	-	Serial number
sq. km	-	square kilometer(s)
Vol.	-	Volume
˚ C	-	Degree Celsius
˚	-	degree

‘	-	minute
/	-	per
%	-	per cent
@	-	at the rate of
&	-	and
ρ	-	Density

INTRODUCTION

1. INTRODUCTION

Water appears to be so common that it is difficult to understand the fact that it is available only in limited quantity. It is a very scarce commodity which one cannot afford to waste. We have to constantly remind ourselves that it is water which makes the earth so green and full of life, and also different from any other known planet in the universe. Hence we have to make it sure that we do not fritter away a single drop of this immeasurable wealth, and use it for the best developmental purposes, for sustaining human life and culture.

Due to rapid growth of population and increased demand of water for power generation, agriculture, industry, domestic uses and several other purposes, water has become a critical factor in many areas both in quantity and quality. Considering the earth as a whole, availability of water is practically constant whereas population is on an increasing trend. Out of the world's total available water, 1400 Mkm^3, about 95% is contained in oceans as saline water and 4% is in form of snow and ice. Thus, the fresh and unfrozen water is only 1% of total availability, out of which 99% is ground water and only 1% is present as surface water in lakes, rivers, soil and atmosphere.

The total quantum of water available on annual basis may be enough to meet all our demands; however it is not available in required quantities. This calls for scientific, long term, equitable and efficient utilization of available water at the local, state, regional, national and sometimes even at international levels, both in time and space.

Agricultural sector has been playing a major role in the development of our country. Water is vital for agriculture. The basic source of water in India is precipitation in the form of rainfall and snowfall. Water is confined as (i) soil moisture (ii) stored water in surface storage like reservoirs, tanks, ponds, streams etc. (iii) ground water in sub surface (iv) sea water and (v) waste water like sewage, effluent etc. The country's average annual rainfall is about 119.4 cm which amounts to 400 Mha-m. Out of this, 70 Mha-m is lost to atmosphere, 215 Mha-m soaks into the ground and remaining 115 Mha-m flows as surface runoff. But by the addition of 20 Mha-m by rivers from catchments lying outside the country and 45 Mha-m by the regenerated flow from ground water, the total annual surface flow in the country has been estimated to be 180 Mha-m.

Out of this 180 Mha-m, 15 Mha-m is stored in various reservoirs and tanks and 15 Mha-m is utilized through diversion works and direct pumping. The remaining 150 Mha-m goes to sea and to some adjoining countries. On full development, the use of water through diversion works or direct pumping is expected to increase to 45 Mha-m, the balance 105 Mha-m even then continue to flow to sea and neighbouring countries.

Agro-climatically Kerala state, situated on the southwest corner of India, is a humid region. Receiving about 300 cm of average annual rainfall and with 40 minor rivers and 4 medium rivers, chain of back water bodies, tanks, ponds, springs and wells Kerala is often considered as the land of water. Still the state experiences severe shortage of water for domestic, irrigation and hydro power generation during the summer months. The rivers hardly contain any water during six months in a year. Compared to national average, Kerala receives 2.78 times more rainfall, but due to steep sloping and undulating topography rain water is not much retained on land. At the same time, unit land of Kerala has to support 3.6 times more population when compared to national level scenario. Hence for self-sufficiency unit land of Kerala has to produce 3.6 times drinking water, food, biomass and associated water requirement compared to national average. Proper management of water resources of Kerala would certainly make the situation more comfortable than today.

Bharathapuzha river, the second longest river of the state takes its origin at an elevation of + 1964 m above M.S.L. from Anamalai hills and flows through the districts of Coimbatore, Palakkad, Malappuram and Thrissur and joins the Arabian sea near the Ponnani town, where it is known as Ponnanipuzha. Its four main tributaries are

(1). Gayatripuzha

(2). Kannadi river or Chitturpuzha or Amaravathy

(3). Kalpathypuzha and

(4). Thuthapuzha.

The length of the river is 209 km with a catchment area of 6186 sq. km. The catchment area is spread over 11 taluks from the Western Ghats to the Arabian Sea. About 2/3 rd of the drainage area of the basin i.e., 4400 sq. km. lies in Kerala State and the balance in Tamil Nadu.

Bharathapuzha basin is bounded by Tirur, Chaliyar, and the Bhavani basins on the north and the Kecheri river basin on the south. This basin contains 1, 25,700 ha of wet lands, 46,050 ha garden lands and 35.400 ha waste lands.

Out of the waste lands about 4300 ha can be converted as wet lands and 25,500 ha can be converted as garden lands if adequate irrigation facilities are provided. Thus the total area of wet lands will be 1, 30,000 ha and that of garden lands will be 74,300 ha. At present 10 major irrigation projects are existing on various tributaries of the river in addition to a number of minor and lift irrigation schemes. Even with all these schemes only a portion of wet lands can be irrigated now. This basin is one of the few basins in the State where there is a large extent of lands suitable for cultivation of paddy. There is also scope for new major and minor schemes in this basin. As the schemes described above are able to irrigate only a portion of area in the basin, additional schemes have to be implemented.

Reservoirs are the most important elements of complex water resources development system. They are used for spatial and temporal redistribution of water in quantity and quality and for enhancing the ability of water to generate hydro power. The most important characteristic of reservoir is its potential to cater to multi purpose demand.

The National water policy (1987) suggested that the water resources development projects should be planned and developed as far as possible as multi- objective projects with drinking water supply as top priority followed by irrigation, hydro power etc.

The multi purpose concept in reservoir system is a sound one and its use is increasing day by day due to the following reasons.

(i) Multipurpose projects make the maximum use of a river valley in a unified and a co-ordinated manner.

(ii)In many cases, a mono- purpose reservoir project proves uneconomical and hence, the multipurpose concept has been found necessary in order to provide the much needed economic justification.

In a multi purpose project, the water management would require optimum use of water for various needs at different times. The need for an integrated and comprehensive planning of limited water resources for maximum economic benefits emphasizes the importance of system analysis. Optimization techniques and use of fast digital computers have made it possible to use the system analysis for solving the problems related to resource planning.

The second important demand after drinking needs to be met from a reservoir is irrigation. Irrigation consumes a huge quantity of water and quite naturally the major allocation from a reservoir system goes for irrigation. Hence, our aim should be to increase the effectiveness of every drop of water used for irrigation in terms of economy. There lies the importance of crop wise and season wise allocation of the area in the command. Here also, the system analysis techniques play a vital role in optimizing the area allocation for different crops considering various socio-economic constraints.

Bharathapuzha has many structures along its course among which the most important projects are Malampuzha dam, Walayar dam, Pothundi dam, Mangalam Dam, Meenkara dam, Chulliyar dam, Kanjirapuzha dam and Chittur dam. Another major project which has just been completed is the Regulator cum bridge at Thrithala. The bridge connects the two villages- Pallipuram and Thrithala. The main objective of the regulator is drinking water supply. The water supply projects towards Thrissur district has already started. The shutter height of the regulator is 5m and it can store a huge quantity of water. Also the new bridge reduces the distance from Thrissur to Kozhikode by 11km. This project is the largest in Bharathapuzha in the last many decades.

The proposed project at Chamravattom across Bharathapuzha envisages the construction of a Regulator–cum–bridge across Bharathapuzha at a place locally known as Chamravattom.

The project has been proposed with the following objectives:

- To evolve sufficient storage for irrigating a gross command area of 9659 ha.
- To stabilize the Irrigation potential of the command area, that is presently irrigated by nine lift irrigation schemes in the area.
- To solve the drinking water problems in the area by increasing the water table level in the nearby wells in Tirur, Ponnani and the surrounding 14 grama panchayats.

- To control effectively the intrusion of saline water towards the upstream side of the regulator.
- The river when bridged will be an important link connecting Ponnani and Tirur thereby reducing the distance between Cochin and Kozhikode by 20 km.
- Recurring damages of river bank now being experienced can be prevented as the upstream side is proposed to be protected by flood banks.
- To rebuild the environmental conditions of the existing area.

The proposed project being a multi-purpose one, the main objectives include the determination of optimum water storage for meeting drinking and irrigation purposes, preventing the saline water intrusion etc. Hence the shutter height becomes a critical deciding factor for which the reservoir operation plan to be formulated properly.

The concept of system analysis is to focus on the system under consideration as a whole, instead of each of its individual components, in order to improve the planning, design or operation of the entire system. It is a logical and systematic approach wherein assumptions, objectives and criteria are enumerated. The technique can help the decision maker to arrive at a better decision through the developed frame work for analyzing the problem. Thus for optimizing the cropping pattern, the best suitable technique is system analysis. System analysis has been used in all the phases of water resources development say basin/regional planning, project planning, design of project components, operation and maintenance of the project. The conflicts arising between various competing uses and the need for systematic planning including allocation of water for different purposes necessitate the system as a whole. The procedures and techniques used to analyze the system under consideration as a whole, instead of each component separately; so as to improve the performance of the system is called system analysis.

There are different classes of models generally used in system analysis. Among these, mathematical programming has considerable application in water resources planning for finding the minimum or maximum of a function of several variables under a prescribed set of constraints. The most widely used mathematical model is Linear Programming Model because of the easy availability of its software packages. The limitation of Linear Programming Model is the use of only linear objective functions and constraint relationship in terms of decision variables.

From the above discussions, it can be inferred that any proposed multi objective

storage reservoir with irrigation component should undergo analysis in terms of optimum water allocation and most efficient cropping pattern for the command area. For the economic and beneficial implementation of a multipurpose reservoir, the preparation of reservoir working table which ultimately decides the maximum storage level that is expected is of great concern. The optimization of the cropping pattern of the command area can be done by linear programming technique. With this idea, a study has been carried out for the proposed regulator cum bridge at Chamravattom in Malappuram district of Kerala .
The specific objectives of the study are:

1. To prepare the reservoir working schedule for the economic and beneficial functioning of the regulator cum bridge.
2. To maximize the net benefit of the crops in the command area.
3. To maximize the area under cultivation using the available water.
4. To minimize the cost of production of the crops.
5. To evaluate the benefit-cost ratio.
6. Model sensitivity analysis.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The general practice in developing countries had been to access the availability of water for one or two programmes of water resource development and then to sanction and implement the scheme. With the growing demand of water due to increase in population and economic development, it has been found that adhoc releases of water for various users at different times have resulted in confusion. It is, therefore, advisable to have total water planning in a region for allocating water to different sectors for future also. The total and utilizable surface and ground water resources of the region are determined and requirement of water for different uses found out. More often than not total requirements would exceed the availability. In such circumstances water has to be allocated to different sectors after prioritization and optimization. There is no fixed universal mathematical principle by which priorities can be set up in a particular location. The priority to which water should be given would depend upon the local conditions like climate, soil, habits of the people, status of development of agriculture and industries, recreational and tourist requirements etc.

A reservoir is created with the purpose of impounding part of the runoff from the catchment upstream by the construction of a dam across a river or stream. Storage is done during the period when the flow is in excess of demand and released during the lean period so as to maintain constant water supply for drinking, irrigation and other uses including power generation.

Reservoirs can be classified on the basis of the purpose served by them:

1. Storage reservoirs

Storage or conservation reservoirs store surplus water during excess flow so as to maintain continuous supply for domestic needs, power generation, industrial purpose etc, during the period of lean supply in the river but when demand is keen.

2. Flood control reservoirs

These reservoirs hold back the excess water, beyond the safe carrying capacity of the river downstream temporarily during flood and releases later when flood exceeds. They are of two types,

i) Retarding reservoirs

Retarding reservoirs are those at which gates are provided at the outlet to regulate the releases but the discharge capacity of the outlet and spillway is so fixed that it is not in excess of the flood carrying capacity of the reservoir channel downstream.

ii)Detention reservoirs

Detention reservoirs are those which have a gated outlet so as to provide a greater flexibility in the operation of reservoirs.

3. Distribution reservoirs

Distribution reservoirs are usually of limited storage capacity used primarily to cater to fluctuations in demand which occur over short period of several hours to several days. They also serve as local storage to take care of emergency in the event of break in main supply line or failure of the pumping plant.

4. Multipurpose reservoirs

These are also termed as multiuse reservoir. In this reservoir, the storage and release of water are for a combination of two or more purposes such as public water supply, irrigation, hydel power generation, flood control, navigation, recreation, fisheries etc.

5. Balancing reservoirs

It is a reservoir, usually of limited capacity, located downstream of the main reservoir to store excess water let down from the upstream side. It provides flexibility of operation, distribution and permit regular supply to cater to fluctuations in the requirement.

2.1 Reservoir Planning

Planning is an integral part of water resources development and management. Whether or not particular plans or programs are eventually implemented, planning process itself forces us to think what we are or should be doing to address a particular set of problems or needs. It should lead to a better understanding of what will happen if we do or do not act, if we decide to do something, which of the many possible actions is likely to be the best. Such planning requires information. Models are an increasingly important source of information, but such information is never complete. Hence is never a substitute for the judgment of experienced planners and managers.

The hydrologic aspects of reservoir planning mainly deals with

1. Water availability in the river on which the dam is proposed to be constructed

2. Determination of storage capacity to serve the target pattern of demand and
3. Operation of the reservoir with the given target pattern.

Van Horn (1971) developed a simulation model for numerical abstraction of a system under study. A sequence of mathematical statements described the design and operating characteristics of the components of the system being modeled. Such a sequence of statements adjusted to coincide with the characteristics of a basin and combined with a series of historical or generated stream flow at various gauging stations, provide a means of simulating the operations of that system in order to protect and analyze its performance.

Bhaskar and Whitlatch (1980) analysed a single multipurpose reservoir using a backward looking dynamic programme algorithm to obtain optimal releases. Monthly policies were derived by regressing the optimal set of releases on the input and state variables. Linear and non-linear policies were developed, verified and compared through simulation.

Mohan and Keskar (1991) studied the goal programming approach for multi-purpose reservoir operation and applied it to the Bhadra reservoir system. Irrigation and hydropower were taken a dual purposes. The objective of the model was to satisfy sequentially a series of operating criteria. Two goal programming models, one with the objective function as minimizing the deviation from storage targets and other with the objective function as minimizing the deviation from release targets were formulated and applied to the reservoir system under studies. The result proved that the model with release target is preferred over the model with storage targets for determining the operational policies for the multi-purpose reservoir system.

Mohan and Raipure (1992) developed a linear multi objective programming model. The constraint technique was used to derive the optimal releases of various purposes from a large scale multi-reservoir system consisting of five reservoirs in India. Maximization of irrigation releases and hydropower production have been considered as the twin objectives in the model, subjected to constraints on physical limitations, environmental restrictions and storage continuity. The trade-off analysis between the conflicting objectives of irrigation and hydro power was also carried out and transformation curve was plotted. The optimal point on this curve gives the best combination of the twin objectives considered in the model.

Abbas *et al*. (1994) presented a mixed integer linear optimization model for river basin development for irrigation. It was a chance constraint optimization model that considered the interaction between design and operation parameters. The model was capable of integrating all decision variables in the design phase, then accounting directly for any inter dependency between design variables. Solution of the model provided optimal extend of land development for irrigation, cropping pattern, reservoir and canal capacities as well as necessary decision rule operational parameters. Also, solution of model revealed the importance of direct inclusion of the reservoir cost in the model in comparison to only minimizing reservoir capacity under an assumed demand distribution.

Hajilal *et al*. (1995) studied dynamic programming model for 14 seasons for deciding optimal reservoir operations for irrigation management and applied this to a Paithab reservoir of Jaikawadi Irrigation project (Maharashtra). The problem of real time operation for optimizing the crop yield in the command area is considered to occur at two distinct stages, i.e the planning stage and real time management stage. It was concluded that for irrigation management the prediction of inflows close to actual ones in water shortage years is of utmost importance as real time release policies can only then be framed accurately for optimal use of limited water. In high flow seasons there is no much control over the inflows as most of the inflows will be lost in the form of spills.

Vedula and Kumar (1996) developed an integrated model based on seasonal inputs of reservoir inflow and rainfall in the irrigated area to determine the optimal reservoir release policies and irrigation allocations to multiple crops. The model was conceptually, made up of two modules. Module 1 was an intra-seasonal allocation model to maximize the sum of relative yields of all crops for a given state of the system using LP. The module considered reservoir storage continuity, soil moisture balance and crop root growth with time. Module 2 was a seasonal allocation model to derive the steady state reservoir operating policy using Stochastic Dynamic Programming (SDP). Reservoir storage, seasonal inflow and seasonal rainfall were the state variables in the SDP. The objective in SDP was to maximize the excepted sum of relative yield of all crops in a year. The results of module 1 and the transition probabilities of seasonal inflow and rainfall form the input to module 2. The use of seasonal inputs coupled with LP-SDP solutions strategy in the present formulation facilitates in relaxing the limitations of an earlier study while effecting additional improvements. The model was applied to an existing reservoir in Karnataka state.

Onta *et al*. (1991) conducted a study on a multi objective linear programming model for irrigation development incorporating the integrated use of surface and ground water resources. Evaluation of the objectives by Compromise programming was carried out to indicate the optimal scale of development, cropping plans, system design capacities and water allocation planning. These related studies need to be extended to incorporate the reliability of resources to consider the uncertainty in the natural phenomena.

Ravikumar and Venugopal (1999) conducted a study on optimal reservoir operation under cropping pattern uncertainty and an innovative three-dimensional stochastic dynamic programming model was formulated to arrive at minimum initial storage that can meet the demand at specified reliability for each cropping season. The applicability of the model to a typical Southern Indian irrigation system, Krishnagiri reservoir, was demonstrated and the potential utility of the model was discussed in the study.

Leena (2001) conducted a study on the Simulation of reservoir system. The main objectives of the study were:

- To develop a simulation model for monthly operation of reservoir with multiple objectives using historic inflow data
- To evolve a reservoir management policy for Peechi reservoir system with a view to optimize the water supply to Thrissur town, kole lands and to serve the facilities of fisheries and recreation.

The model aimed to minimize the deviation of the release from target for each demand. The model was formulated with appropriate priorities according to the needs of the region. The program was written in Visual Basic-6.0 and the result gave the monthly release and deficits of different demands. The model has an advantage that even non-technical decision makers can comprehend the results obtained from this.

2.2 Crop water Requirements

The estimation of water requirement of crops is one of the basic needs of crop planning on a farm and for the planning of any irrigation project. Water requirement may be defined as the quantity of water required by a crop or any pattern of crops in a given period of time for its normal growth under field conditions at a place (Michael *et al*. 1977). Water requirement includes the losses due to evapotranspiration plus the losses during the application of irrigation water and the quantity of water required for special operations such as land preparation, transplanting, leaching etc.

The original Penman equation (1948) predicted the loss of water by evaporation from an open surface. The Penman equation takes into account the direct prediction of ET crop by the use of appropriate reflection coefficient for incoming solar radiations, the effect of plant resistance to transpiration and by inclusion of appropriate wind function.

This approach has not been used now and a slightly modified method suggested the effect of climate on crop water requirements. The only variation with the original Penman method (1948) is that this involves a revised wind function term and an additional correction factor for day and night time weather conditions, not representative of climates for which wind function was determined.

A number of methods are used for estimating ET_0. Estimate values vary widely due to lack of standardization of the reference. Evaporation measured by lysimeters of various grasses and/or alfalfas has been used as a standard for estimating equations. Different versions of Penman combination equations have been proposed. The Research Centre for the European Community and the ASCE committee on irrigation requirements have evaluated various equations for estimating ET_0. Due to its simplicity and accuracy of estimate the Hargreaves *et al*. equation (1985) is recommended for general use. ET_0 is used in irrigation planning, design and scheduling and for other water adequacy studies. George H. Hargreaves, in his study-“Defining and using Reference evapotranspiration” concluded that:

- Procedure for calculation of reference evapotranspiration (ET_0) should be standardized.
- Perennial rye grass or Alta fescue grass is proposed as the standard reference crop.
- A Penman combination equation is recommended as reference for calibrating or evaluating other methods for computing ET_0.
- Kc needs to be standardized for each crop.

Palaskar *et al*.(1985) in Maharashtra compared the pan evaporation and Modified Penman methods for the estimation of crop water requirements. For all the parameters on an average, the ratio of the estimate by Pan Evaporation method to the estimate by Modified Penman method was 0.9.

Gan *et al*. (1991) studied the Sensitivity of Reservoir sizing to evaporation estimates. Net reservoir evaporation is defined as open water evaporation less original evapotranspiration from reservoir site. The rates were estimated on a monthly basis by the method of Morton using climatological data that included average annual precipitation, air temperature, dew point temperature and sunshine ratio. Study provided information on the order of magnitude of net reservoir evaporation that may be expected on a monthly basis, which will aid in practical design.

2.3 System Analysis

The application of system engineering techniques to water resources management problems appears to have a good potential since it is possible to consider the complex issues in totality with system approach. This technique deals not only with engineering aspects of water resources planning and management, but also covers the multi disciplinary areas considering other relevant factors such as physical, social, economical, political and other characteristics of specific problems for which the techniques are to be applied.

Though the System analysis is often used synonymously with operation research, it has much broader connotation. The term was originally used for mathematical analysis of systems of equation. Operations research was derived from procedure for solving complex scheduling problems during World war II. Today, system analysis implies a systematic solution procedure involving complex equations and interdisciplinary trade-offs. Operations research usually connotes linear and dynamic programming technique, but it can also be interpreted to mean system analysis.

In general, crop planning procedure involves selection of crop activities from a number of feasible alternatives so as to satisfy the objectives of the planner under the limiting conditions of available land and water resources, social requirements and other physical and technological constraints in the planning environment. Thus the optimal allocation of water for irrigation depends not only on the effective use of water but also on other inputs like fertilizers, labour etc. While obtaining the solution for optimal cropping pattern for a particular region, factors like soils, topography, climate, agro biology and socio economy are also to be considered.

Maji (1977) applied linear programming model in optimal allocation of land, water and other farm resources in the command area of the Mayurakshi project in West Bengal. The objective of the study was to evolve an optimal cropping pattern. For this purpose, the monthly gross irrigation requirement of each crop was integrated with monthly reservoir operations. The result indicated that the overall intensity of cropping in the command area could be increased from the existing level of 105% to 150%. They also suggested that agricultural operations in the command area would be more efficient if the existing emphasis on kharif season irrigation is shifted to Rabi season irrigation.

Arlen D. Feldmen (1992) studied about system analysis application at the Hydrologic Engineering Centre (HEC). HEC has been actively applying system analysis techniques since its inception in 1964. HEC's basic system analysis method has been the simulation of watershed and river basin processes. System analysis at HEC has been an approach to problem solving as much as the technical methods.

Numan *et al*. (1992) demonstrated the utility of optimal control theory for the deterministic operation of very large multi reservoir- Mahaveli system. The system includes 19 reservoirs and 35 release links. The model was designed to minimize a hydro electric energy shortage objective and satisfy pre-specified irrigation demand constraints. Two alternative approaches were explored. The first one involved monthly application of the optimal control algorithm to find an optimal policy for the next year based on current storage and forecasted inflows and demands. The second alternative was an implicit stochastic approach, in which linear operating rules were derived using deterministic optimal control and historical data. Both the alternatives gave reasonable and comparable results. The implicit stochastic optimization alternative had a great advantage regarding computer time and storage requirements.

Verma and Srivastava (2000) presented the application of weighted goal programming methodology to a system of multi purpose reservoirs for optimal monthly operation policy. The weighted goal programming model was developed and applied to the Mahanadi reservoir project complex comprising of six multi- purpose reservoirs.

2.4 Optimization of cropping pattern

Dudley (1971) had dealt with the intermediate problem of deciding the area of a single crop to be planted at the beginning of an irrigation season by a single decision maker with full control on operation of the reservoir. They had treated the inflows into the reservoir and crop water demand as stochastic variables. Their result indicated that the best acreage to be planted is an approximate linear function of the initial stage in the reservoir.

Anderson and Maass (1973) developed a digital model to approximate the critical operating decision variables of an irrigation system for both short and long run problems. In the short run, model yields solution for the best way of water allocation for irrigation under water shortage condition. The advantage of this model is its simple format of decision output which enable farmers and operators of irrigation systems to make decision on their own regarding the effects on cropping pattern, crop production and farm income on different water supply restrictions and different rules for delivering water. In case of long run problem, the model aids in comparing alternative programs or design for the development of new supplies of irrigation water and new distribution system.

Sowell *et al*. (1976) conducted studies on agricultural water demand in North Carolina. The objectives of the study were

- Determination of total water requirement for a given level of agricultural activity.
- Optimum level of agricultural activity or a given level of water available in a specified area.
- Economic feasible irrigation water requirements for each crop grown in the area.

Michael *et al* (1978) reported that for a given set of crops that may be grown under the specified agro climatic restrictions, an efficient crop planning must recognize the following often conflicting goals.

- Optimal use of fixed as well as variable resources in production.
- Increasing employment opportunity and income for the agricultural labour.
- Attainment of national objectives of self sufficiency in food production.

Shortcomings in any one of the above mentioned goals will lead either to undesirable socio economic consequences or a failure of cropping pattern into reality.

Vedula and Rogers (1981) developed a deterministic model for a four reservoir system on a monthly basis using LP technique. This model was applied to Cauvery river basin in South India with the aim of finding optimum cropping patterns subject to land, water and downstream release constraints. In this model, they considered two objectives namely, maximizing net economic benefits and maximizing irrigated crop area. They have analyzed the resulting trade-offs in the context of multi objective planning. In addition to crop area, the other decision variables are storage at the beginning of each month and monthly downstream releases of each reservoir. Constraints have also been laid on limits of individual crops to be grown. Representative values of crop yields were used for calculating the net benefits of the crops from the study regions.

A study was undertaken by Acharya and Gupta (1983) to investigate the benefits achieved through implementation of a medium irrigation project on river Som in Rajasthan and to suggest an optimal cropping pattern using LP model. The model was developed for three distinct cropping seasons and solved using simplex algorithm. The result showed that only 14.7, 19.0 and 22.0 percent area can be put under cultivation in kharif, rabi and summer seasons respectively. It also revealed that more than 70 % of water resource remained unutilized as capital. This was the major constraint which restricted the utilization of other valuable resources in the command area.

Gomathi *et al*. (1990) conducted a study for the irrigation project planning of the regulator-cum-bridge at Thrithala in Kerala. The planning included suggestion of a suitable cropping pattern for the command area. They considered several patterns randomly. The irrigation requirements and thus the demand on reservoir were computed and the capacity of the reservoir to supply the demand was checked by preparing reservoir working tables for a number of consecutive years. Those proposals which satisfied the 75% of demand were taken to be compatible. Ultimately the benefit cost analysis was performed to select the most viable one.

Raman *et al*. (1992) conducted a study for crop planning during droughts for the Bhadra reservoir project, a multi purpose river valley project for irrigation and hydropower in Karnataka. A linear programming model was used to generate optimal cropping patterns from past drought experiences as also from synthetic drought occurrences.

A linear programming model was developed by Paul and Raman (1992) for obtaining an optimal cropping pattern from among the different alternatives for any command area by the conjunctive use of surface and ground water, for getting maximum net returns from the command area as well as for maximizing the area of cultivation. The study revealed that when the traditional cropping pattern was changed, the entire command area could be cultivated with the same available water and an increased net benefit could be obtained. It also revealed that when the objective was to maximize the area, a total of 19 Mm^3 of water was left unused for irrigation purpose. This quantity was 28 Mm^3 when the model was run for maximizing the net benefit. Since this surplus water was found during the summer months, this could be utilized for domestic and downstream releases.

Balasubramaniam *et al.* (1996) established a linear programming analysis in a tank irrigation system for near real representation and optimal allocation of area of Aralikottai tank system in Tamil Nadu. The actual conditions were simulated at each sluice command level whereas the best operational policy was attempted for the entire system as a whole. The analysis was conducted separately for a drought year (1988) and a surplus year (1990) with the available five year data from 1988 to 1992. The major conclusions indicated that the late transplantation of the rice crop and excess water application during the period of water availability (leading to water stress during the last stages of crop maturity) were the causes of the meager benefits in a drought year. Also in a surplus year the excessive water application over the entire cropping season resulted in under utilization of land resources and moderate benefits. The existing status of irrigation could be improved to the maximum benefit from the tank command area based on the quantification done.

Juan *et al.* (1996) developed a model to determine optimal irrigation strategies for a single season. This has been achieved by using a simple relation between yield and amount of irrigation water which takes into account the effect of uniformity of water application. The main objective of the model was to provide a procedure by which farmers can evaluate and compare alternative assumptions on excepted water regimes for the following year in order to optimize crop rotations, crop production and farm income and to obtain the optimum use of irrigation works, farm lands and other resources. This requires data that are readily available to the farmer.

Mainuddin *et al.*(1997) formulated a monthly irrigation planning model for determining optimal cropping pattern and ground water abstraction requirement in an existing ground water development project. Two objectives, maximization of net economic benefits and maximization of net irrigated area aspired to by both the irrigation authority and individual farmers in the Sukhothan Ground Water Development Project in Thailand were considered. To account the uncertainty in water resources availability, the model was solved for three levels of reliability of rainfall and ground water resources (80, 50, and 20 percent). The effects of deficit irrigation on the net benefit and cropping intensity as well as on the yield of crop were also assessed by considering three levels (no deficit, 25 % deficit and 50 % deficit) of water application to the crop. To select best alternative plan, a multi -objective analysis was carried out using the Analysis Hierarchy process considering the performance of the decision makers, including farmers and irrigation project managers.

Bindhu (2000) formulated a monthly irrigation planning model for determining the optimal cropping pattern in an existing lift irrigation scheme at Tavanur in Malappuram district of Kerala. The study dealt with linear programming technique for obtaining an optimal cropping pattern from various alternatives for a command area by the conjunctive use of surface and ground water. Three conditions were considered in model formulation. In order to make the best use of available water resources and to get the maximum benefits and to put maximum area under cultivation, different trials were conducted with different crop combinations subjected to the constraints identified using the model. By using the developed model for area and benefit maximization, the decision makers can recommend a better cropping pattern to the farmers in advance, which satisfy both objectives to the desired level. The model was found very flexible to alter the constraints or to add more constraints according to the decision of policy makers from time to time based on socio-economic considerations.

Saritha (2001) formulated the optimal water use and cropping pattern for Thrithala regulator cum bridge at Thrithala in Palakkad district of Kerala. The objective of the Linear Programming Technique was to optimize water allocation from the reservoir for different purposes. The problem was formulated as a monthly operational model and operating horizon was taken as 12 months .The water requirement for each of the purposes was taken as the target to be achieved by the model. With irrigation allocation from this model, another Linear Programming Model was used to obtain an optimal cropping pattern for the command area of the project with the objectives of maximizing net profit from the command area for the year and maximizing the net area put under cultivation in a year. The LP model was solved using Excel Solver software package. The result showed that the optimal cropping pattern with net benefit maximization objective gave a net benefit of 773 lakhs, which was 80 % higher than that proposed by Irrigation department. The area that can be irrigated was doubled. The study summarizes that optimal operational policy, even for a small water resources project increases its economic viability to a great extent and make the project more socially acceptable.

Jisha *et al*. (2003) conducted a study on optimal cropping pattern for Pothundy canal irrigation project in Palakkad. LP model was developed for obtaining optimal allocation of total area available in a month as cultivable command area. It included area allocation for profit maximization, cost minimization and for maximization of area per year. The model was solved using What’s best 4.0 software package and optimal cropping patterns for three models were obtained. The data obtained were analyzed and B/C ratio was plotted. The sensitivity analysis was also done.

Srinivasa *et al.* (2005) studied the optimal irrigation planning strategies for the Nagarjuna Sagar Right Canal command in the semiarid region of South India. The specific objective of the study was to allocate the available land and water resources in a multicrop and multiseason environment and to obtain irrigation weeks requiring irrigation of a fixed depth of 40 mm. The problem was solved in four stages. First, weekly crop water requirements were calculated from the evapotranspiration model by the Penman-Monteith method. Second, seasonal crop water production functions were developed using the single-crop intra-seasonal allocation model for each crop in all seasons. Third, allocations of area and water were made at seasonal and inter-seasonal levels by deterministic dynamic programming, maximizing the net annual benefit from the project. And fourth, once optimal seasonal allocations have been attained, irrigation scheduling was performed by running a single-crop allocation model. Optimal cropping pattern and irrigation water allocations were then made with full and deficit irrigation strategies for various levels of probability of exceedance of the expected annual water available. The results revealed that the optimization approach can significantly improve the annual net benefit with a deficit irrigation strategy under water scarcity.

To account for the alarming water scarcity, conservation structures are very important. These conservation structures serve multiple objectives. There exist a large number of demands for water among which irrigation forms a major one. Water should be supplied in required quantities during the critical stages of crop growth so as to get maximum benefit. The water that is stored in the conservation structures can be effectively utilized when allocated based on a better cropping pattern instead of the traditional pattern. There comes the relevance of cropping pattern optimization.

MATERIALS AND **METHODS**

3. MATERIALS AND METHODS

The materials used and the methodology adopted for the study are described in this chapter.

3.1 Project details

3.1.1 Location

The Bharathapuzha locally known as Ponnanipuzha joins the Arabian Sea at Ponnani. Thirunavaya, the historically important place for the only Brahma temple in South India and the Mamanga festival is situated on the right bank of this proposed RCB. The project is about 6 km upstream of the confluence point of the river and sea. The latitude and longitude of the site are 10º 51' North and 75º 57’ East. The project site is in the Ponnani and Tirur taluks of Malappuram district.

3.1.2 Salient Features of Regulator-Cum-Bridge

1. Location	:	Chamravattom
Taluk	:	Ponnani and Tirur
District	:	Malappuram
State	:	Kerala
2. Width of the river at RCB site	:	1000m
3. Length of the RCB	:	978m
4. Number of shutters	:	70 Nos.
5. Size of shutters	:	12 x 4 m
6. R.L of the river bed	:	+1.5 m
7. Proposed FRL of reservoir	:	+6.00 m
8. Storage capacity	:	24.49 Mm^3
9. Water spread area	:	868 ha
10. Maximum flood discharge	:	8496 m^3/sec
11. Mean annual rainfall	:	2721 mm
12. Width of roadway	:	7.5 m
13. R.L of roadway	:	+9.35 m
14. B/C Ratio	:	@5% =5.9
		@10% =2.90

3.1.3 Command area

The area benefited falls in Ponnani and Tirur taluks in Malappuram district and Thalapilly taluk in Thrissur district. An ayacut of 9659 ha in Ponnani and Tirur taluks of Malappuram district is very well benefited by proper irrigation and drinking water supplies. The bridge will be an important link between Ponnani and Tirur town reducing 20 km distance between Cochin and Kozhikode.

3.1.4 River System and basin characteristics

The Bharathapuzha basin is bounded by Tirur, Chaliyar, and Bhavani basins on the north and Kecheri river basin on the south. At present nine major irrigation projects are existing on various tributaries of the river in addition to a number of minor and lift irrigation schemes. This basin is one of the few basins in Kerala where there is a large extend of lands suitable for cultivation of paddy. There is also good scope for new major and minor irrigation schemes in this basin. The basin map Bharathapuzha River is as shown in Fig. 1

3.1.5 Topographic Features

As far as the catchment area is concerned, the average altitude varies from 1964 m in the east to 1m in the west. The gross catchment area is 6186 sq.km. The project area falls in the low land and sea board. The long and narrow stretch of sandy sea board is low and is in several parts liable to be flooded during the monsoon inundation. Topography of the area of the reservoir is fairly even without many undulations. No canal system is envisaged in the project as the ayacut area is to be fed by the already existing lift irrigation systems. The command area is quite suitable for irrigated agriculture.

3.1.6 Major soil types

Most part of the basin consists of low laterite table lands fringed, on the seaward side by a narrow belt of recent alluvial formation except for a thin line of arenaceous soil on the very source of the sea. The soil of the basin mainly belongs to the Hard Ferruginous series composed of a mixture of clay and river sand in varying proportions. The soil is classified as sandy loam .It is observed that it is suitable for paddy cultivation. The project site and the command are made up of recent deposits. The recent depositions consist of alluvial, marine and lacustrine deposits.

The soil are broadly classified as

1. Moderately deep to very deep well drained yellowish red to dark red gravelly clay soils.
2. Very deep, imperfectly drained alluvial soils, brownish in colour.
3. Very deep brownish grey to dark greyish brown coastal alluvial soils.

The pH of the soil varies from 5.5 to 6.2. The soil is generally deficient in all major nutrients.

3.1.7 Climate

The south west monsoon (starting from June and extending up to the middle of October) and the north east monsoon (starting from the middle of October and extending up to November) are prevalent in the catchments and ayacut area of the project. At an average, the south west monsoon provides 65% and north east monsoon 30% of the annual precipitation. The remaining 5% occurs as the non seasonal showers. As the temperature of the area rarely exceeds 35 ºC, neither an extreme hot nor cold is felt in the locality. The area receives sufficiently heavy down pours averaging to about 2800mm. High humidity rate is experienced in the area.

3.1.8 Crop

Paddy is the main crop cultivated in the area. Coconut, areca nut, banana, tapioca and pepper come in the subsequent positions.

3.1.9 Population

The area is well inhabitated particularly along the coastal regions. The intensity of population in Ponnani and Tirur taluks is 1070 per sq.km. Kozhikode city is the nearest municipal corporation and Ponnani town is the nearest municipality.

3.1.10 Irrigation Potential

The gross command area as per the present proposed cropping pattern according to the Irrigation Department is 4344 ha.

3.2 Collection of Data

The various data required including the details of the project location, evaporation, rainfall, stage levels at Kuttipuram and Thrithala, survey details of the site, water demand etc were collected.

Meteorological data

The rainfall, evaporation, sunshine hours, wind speed, relative humidity, maximum and minimum temperature data for 18 years starting from 1987 to 2004 were collected from the Regional Agricultural Research Station, Pattambi. The data are provided in Appendix 1.

River inflow data

The river flow stage levels for Kuttipuram and Thrithala were collected for the same period from the Irrigation Department. The collected data are appended in Appendix 2.

Drinking water demand

The drinking water requirement data was provided by Kerala Water Authority. It is given in Appendix 3.

RCB details

The details about the RCB, command area map, site survey to find water spread area, the design maps and the cropping pattern proposed by the Irrigation department were collected from the Project office at Chamravattom. The details of the cropping pattern obtained were based on the survey conducted in 1983. The cropping pattern proposed by the Irrigation Department is given in Appendix 4.

Existing area under cultivation

The data was updated by contacting the Agricultural Officers of the four blocks- Ponnani, Tirur, Perumpadappu and Thalappilly, which come under the command area of the project. The present cropping pattern and the details of cost and benefit of each crop were also collected as given in Appendix 5.

Visit

For understanding the functions of a Regulator-Cum-Bridge, a visit was made to the RCB at Thrithala, which has been commissioned shortly. The visit was very useful as the structure is of the same type as the proposed RCB at Chamravattom. A visit was also done to the proposed project site at Chamravattom. The site for the proposed RCB is given in plate 1. The canal for lift irrigation scheme is shown in plate 2 and the picture of the existing crops near the banks of the proposed RCB site is given in plate 3.

Plate 1: Picture of the site of the proposed RCB

Plate 2:Existing lift irrigation canal near the site

Plate 3:Crops near the site of the proposed RCB

3.3 Reservoir Operation Plan

The reservoir operation plan is based on the obtained details about rainfall, evaporation, stage level, and water demand. The working table was prepared using 18 years data. The optimal shutter height was decided based on these working tables. The tables for a water storage depth of 4, 5 and 6 m were prepared.

The proposed project is being funded by NABARD. The prepared reservoir working tables were submitted by the Irrigation department for the approval of financial assistance from NABARD. The tables are reported in the newly revised project report of the RCB that is available at the project office at Chamravattom.

The working table was prepared for every year starting from 1987 January till December 2004. It was assumed that on January 1, the reservoir is at full storage level. Then based on the inflow in to the reservoir and the demand, the water that will be remaining for the next day was calculated. Instead of finding water use for each day, a month is divided in to three segments each with ten days. Jan-01 means the first 10 days of January and so on.

River inflow on each day = Stage level at Kuttipuram – Stage level at Thrithala.

The surface area corresponding to various storage levels were determined by using the survey details of the site. Evaporation in depth was converted to volume terms.

Net total of available water = Initial storage + Inflow - Evaporation loss

Now the demand on the reservoir including the drinking water and the irrigation requirement were subtracted from the obtained net total availability of water. Then the deficit was determined if any. The remaining volume of water was taken as the initial storage of the next ten days. This was done for the whole year. The same procedure was repeated for 4, 5 and 6 meters for a period of 18 years from 1987 to 2004.

3.4 Irrigation Requirement.

Irrigation requirement of the command area was obtained by estimating the crop water requirement and then deducting the effective rainfall from that. Crop water requirement for different crops were computed using Modified Penman method. Effective rainfall was taken as 75 % of the 75% chance rainfall. Effective rainfall may be defined as the portion of the rainfall which is useful directly or indirectly for crop production at the site where it falls. 75% chance rainfall is that rainfall which is certain to occur with a probability of 0.75. The 75 % chance rainfall was calculated using Weibull formula, given as

$P = m/(N+1)$

Where, P is the Probability of occurrence of a rainfall of specified magnitude (in this case 75 %).

m is the order number

N is the number of years.

The calculations are tabulated in Appendix 6.

The gross irrigation requirement for each month is worked out taking the gross irrigation efficiency as 57%.

The equation for reference crop evapotranspiration is given by

$ETo^* = W.Rn + (1-W). f(u) .(ea-ed)$

in which,

ETo* = Reference crop ET in mm/day (not adjusted)

ea = Saturation vapour pressure in mbar at the mean air temperature in ˚C.

Ed = Mean actual vapour pressure of air in mbar

= ea * RHmean/100, in which RH = Relative humidity.

f(u) = Wind related function

(1-W) = Temperature and elevation related weighing factor for the effect of wind and humidity.

W = A temperature and elevation related weighing factor for the effect of radiation.

Rn = Net radiation

= Rns-Rnl

Rns = Net incoming short wave solar radiation

$= Ra^* (1-\alpha)^*(0.25+0.50n/N)$

in which,

Ra = Extra terrestrial radiation expressed in mm/day.

n/N = Ratio between actual and possible hours of bright sunshine.

α = Reflection coefficient

Rnl = Net long wave radiation

= f(t).f(ed)..f(n/N)

in which,

f(t) = Correction factor for temperature

f(ed) = Correction factor for vapour pressure

f(n/N) = Correction factor for ratio of actual and maximum bright sunshine hours

To determine, the unadjusted reference crop ETo* is adjusted for day and night time weather conditions.

The calculation of ETo is given in Appendix 7.

The relation between the crop ETo and reference crop ET (ETc) is given by crop coefficient (Kc). Crop coefficient varies with the type of crops, stages of growth and the existing climatic conditions. Procedure for selecting appropriate Kc values is given in FAO publications “Crop water requirement “. With its help, the Kc values for various crops were estimated. Kc values for mixed crops were determined on the basis of the ground cover produced by the canopy of the main crop. The crop coefficient values for various crops are given in Table 1.

Now,

Crop Evapotranspiration ETc = Kc * ETo

in which,

Kc = Crop coefficient and

ETo = Adjusted evapotranspiration

The detailed calculations of the crop water requirement for different months are attached in Appendix 8.

Table 1 Crop Coefficient (Kc) for different crops

Crops	Crop Coefficient
Paddy	1.1
Coconut	0.75
Coconut + Pepper + Arecanut	0.75
Pepper + Arecanut	0.70
Coconut + Banana + Vegetables	0.75
Banana	0.87
Vegetables	0.95

3.5 Demand on Reservoir.

The multi-objectives of the reservoir system are:

i. Drinking water demand

ii. Irrigation demand
iii. Downstream release
iv. Industrial demand
v. Prevention of saline water intrusion

The drinking water requirement of the command area to be met from the reservoir is taken as 4.5 Mm^3 per month as per the Kerala Water Authority. The minimum downstream flow is assumed to be 0.7 Mm^3. A portion of the water requirement of the industries which is expected to flourish in the near future will also be met. The demand is assumed as 12 Mm^3 per month for the development of optimization model.

One of the major concerns of the project is the prevention of salt water intrusion during summer seasons. Ghyben-Herzberg relation for hydrostatic equilibrium between fresh and saline water is given by

$$Z = \rho_f * h_f / (\rho_s - \rho_f)$$

Where,

Z = depth of fresh water-saline water interface from MSL.

h_f = difference between water table level and MSL.

ρ_f = density of fresh water

ρ_s = density of saline water

For typical sea water conditions, ρ_s = 1.025 g/cm^3 and ρ_f = 1.000 g/cm^3 .So the equation becomes

$$Z = 40.\, h_f ,$$

i.e., for hydrostatic equilibrium, one meter depth of water table from MSL requires a depth of 40 metres between MSL and fresh water–saline water interface.

3.6 Water available in the reservoir for irrigation

The water available for irrigation is calculated by deducting the demands on the reservoir from the net water available.

Water available for irrigation = Net available water – (Drinking water demand + Irrigation demand + Downstream release + Industrial demand + Demand for prevention of saline water intrusion.). The monthly available water in the reservoir was calculated given in

Appendix 9.

3.7 MODEL DEVELOPMENT

An irrigation planning and operation model involves the development of methods for estimating which crops should be grown within an irrigation area and the area to be cultivated under each crop. The model provides a systematic means of estimating the farm income and expense budget and also helps to optimize the resource allocation. The mathematical model involves identification of the decision variables, the constraints and the objective function, which is to be maximized or minimized.

Assumptions made in formulating the problem.

Only principal crops such as three rice crops, coconut, pepper, arecanut, banana and vegetables are considered.

1. All inputs other than water, namely seeds, fertilizers, weedicides and pesticides of desired quality are available in adequate quantities.
2. Gross irrigation efficiency is taken as 57 %.

The model has been formulated on a seasonal basis as Kharif, Rabi and Summer. Three conditions arise in each season:

A. Maximization of net economic profit.

B. Maximization of area.

C. Minimization of cost of production.

The variables used in the model are:

Z is the net benefit from the command area to be maximized

X_j is the area under j^{th} crop

Q_k is the total available surface water in k^{th} season.

P_j is the net return from j^{th} crop per hectrae.

Q_{kj} is the quantity of water required for irrigating j^{th} crop in k^{th} season.

A is the total area available for cultivation and

n is the number of crops considered in a particular season.

C_j is the cost of production of jth crop

The area constraints are taken randomly based on the present area under cultivation.

Part I, Part II and Part III represent Kharif, Rabi and Summer seasons respectively.

3.7.1 Condition A : Maximization of net economic profit

Objective function is

$$\text{Max } Z = \sum_{j=1}^{n} P_j * X_j$$

3.7.2 Condition B : Maximization of area.

Objective function is

$$\text{Max } A = \sum_{j=1}^{n} X_j$$

3.7.3 Condition C : Minimization of cost of production

Objective function is

$$\text{Min } Z = \sum_{j=1}^{n} C_j * X_j$$

The following constraints and boundary conditions were considered for all the above cases.

Constraints

The optimization is subjected to the following constraints:

1. The total water available for irrigation in k^{th} season.
2. The total area available for cultivation in any season is 18,560 ha.
3. These constraints can be expressed as :

$$\sum_{j=1}^{n} X_j * Q_{kj} \leq Q_k$$

Boundary conditions

1. Lower and upper bounds are given for any particular crop as desired by the decision makers.

2. Lower and upper bounds given for the total area under cultivation in each season.

Table 2 Cost of production and Net profit from each crop

Crops	Cost of production(Rs/ha)	Profit (Rs/ ha)
Paddy	20000	1800
Coconut	8500	32300
Coconut + Pepper + Arecanut	69000	95800
Pepper + Arecanut	60500	63500
Coconut + Banana + Vegetables	153500	117300
Banana	125000	75000
Vegetables	20000	10000

Let the areas allotted for different crops in ha denoted as:

Paddy nursery	- X1
Paddy puddling	- X2
Paddy main field	- X3
Coconut	- X4
Coconut + Pepper + Arecanut	- X5
Pepper + Arecanut	- X6
Coconut + Banana + Vegetables	- X7
Banana	- X8
Vegetables	- X9

Table 3 Various cases of area constraints for part I and part III were as follows:

Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
X1 = 0.1X3	X1 = 0.1X3	X1 = 0.1X3	X1 = 0.1X3	X1 = 0.1X3	X1 = 0.1X3
X2 = 0	X2 = 0	X2 = 0	X2=0	X2 = 0	X2 = 0
X3 ≥ 1200	X3 ≥ 1200	X3 ≥ 1200	No lower limit	X3 ≥ 1200	X3 ≥ 1200
X4 ≥ 200	X4 ≥ 200	X4 ≥ 200	X4 ≥ 200	X4 ≥ 200	X4 ≥ 200
X5 ≥ 140	X5 ≥ 140	X5 ≥ 140	X5 ≥ 140	X5 ≥ 140	X5 ≥ 140
X6 ≥ 10	X6 ≥ 10	X6 ≥ 10	X6 ≥ 10	X6 ≥ 10	X6 ≥ 10
X7 ≥ 50	X7 ≥ 50	X7 ≥ 50	X7 ≥ 50	X7 ≥ 50	X7 ≥ 50
X8 ≥ 50	X8 ≥ 50	X8 ≥ 50	X8 ≥ 50	X8 ≥ 50	X8 ≥ 50
X9 ≥ 100	X9 ≥ 100	No lower limit	X9 ≥ 100	X9 ≥ 100	X9 ≥ 100
X3 ≤ 3641	X3 ≤ 3641	X3 ≤ 3641	X3 ≤ 3641	X3 ≤ 3641	X3 ≤ 3641
X5 ≤ 6120	X5 ≤ 6120	X5 ≤ 6120	X5 ≤ 6120	X5 ≤ 6120	X5 ≤ 6120
X6 ≤ 100	X6 ≤ 100	X6 ≤ 100	X6 ≤ 100	X6 ≤ 100	X6 ≤ 100
X7 ≤ 600	X7 ≤ 600	X7 ≤ 600	X7 ≤ 600	X7 ≤ 600	No upper limit
X8 ≤ 1200	No upper limit	X8 ≤ 1200	X8 ≤ 1200	X8 ≤ 1200	X8 ≤ 1200
X9 ≤ 250	X9 ≤ 250	X9 ≤ 250	X9 ≤ 250	No upper limit	X9 ≤ 250
			X4 ≤ 1500		

The area constraints are the same for part II also except the third constraint. The third constraint was taken as X3 ≥ 2745.

The model was run with the above values and the results obtained were analyzed.

3.8 Analysis by LPP

The analysis was conducted using a software package called 'LINDO'- Linear, INteractive and Discrete Optimizer. LINDO is a convenient but powerful tool for solving linear, integer and quadratic programming problems. These problems occur in areas of business, industry, research and government.

In order to make the best use of all the available water resource and to get the maximum benefit different trials were done with different crop combinations and constraints. The net profit from each crop is given in Table 2. The area constraints for the six cases are shown in Table 3.

The benefit-cost (B/C) ratio for all the cases are calculated as

B/C ratio = (Net benefit from the given crops)/ (total cost of production of the crops).

Sensitivity analysis was also done to determine the variation in net profit with fluctuations in the market price. It indicates the changes in the model output resulting from the changes in the model component, the input or the parameters. It also shows the rate of change in one factor with respect to change in another factor.

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

This chapter describes the salient findings of the study conducted for the proposed regulator-cum-bridge at Chamravattom, regarding the optimum storage level, optimization of cropping pattern for the command area and also towards the prevention of saline water intrusion during summer season.

4.1 River discharge at the site

Along the course of Bharathapuzha River, the site for the proposed regulator-cum-bridge comes after the RCB at Thrithala. When the stage levels were recorded (1987-2004), the RCB at Thrithala was not in an operating condition. Thus the stage level measured at Kuttipuram included the flow at Thrithala also. So in order to get the actual flow reaching the proposed RCB at Chamravattom, the stage level at Thrithala was deducted from that at Kuttipuram. The assumption was that if the Thrithala RCB is in working condition, then the flow coming at the Thrithala RCB will be stored fully.

Table 4 River Flow data at the site

Month	**Mean river inflow (Mm^3)**
Jan	58.52
Feb	31.12
Mar	20.83
Apr	24.49
May	80.19
Jun	305.53
Jul	365.84
Aug	393.23
Sep	185.29
Oct	285.6
Nov	122.58
Dec	91.43

River flow records obtained for a period of 18 years are given in Appendix 9.The monthly river flow data are given in Table 4. The mean of monthly river discharge reveals that maximum flow occurs during the month of August, followed by July and June. Minimum flow occurs during March, followed by April and February. The mean monthly maximum flow is 393.23 Mm^3 and the mean minimum flow is 20.83 Mm^3. About 90% of the river flow occurs during June to

December.

A graph was prepared to show the mean monthly river flow at the site and is given in Fig 4

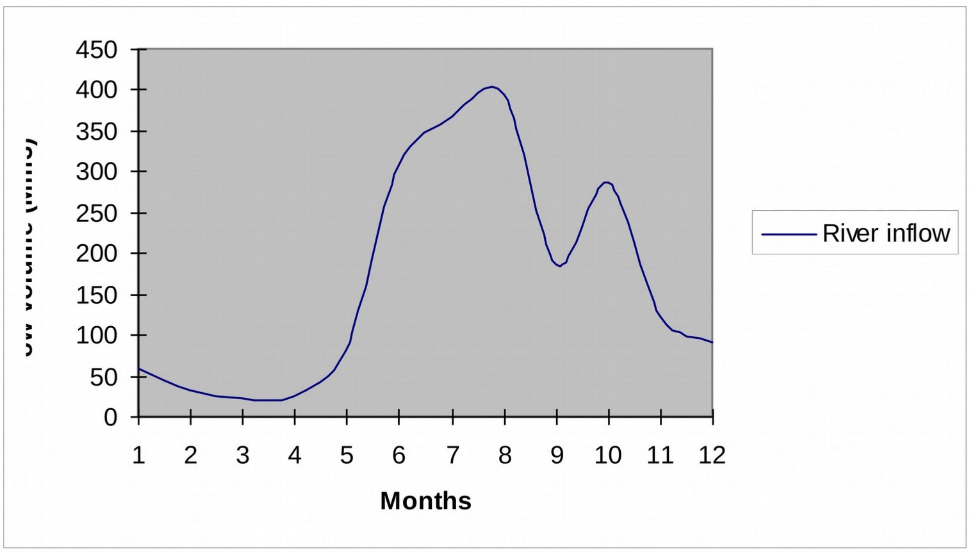

Fig.2 Mean monthly river flow.

The stage data has its importance in flood warning and flood protection works. Reliable long-term stage data corresponding to peak floods can be analyzed statistically to estimate the design peak river stages for use in the design of hydraulic structures like bridges.

4.2 Reservoir operation plan

The reservoir operation plan was prepared for each year starting from 1987 to 2004. The data was worked out on the basis of calendar year. It was found that there is not much difference in the results when taken as water year and calendar year. Usually the Irrigation Department follows the calendar year.

Since the regulator site lies at the mouth of an estuary, a large storage structure cannot be constructed. A small structure of storage height ranging from four to six metres is the only option. Thus the working plan was prepared for storage heights of 4 m, 5 m and 6 m. By analyzing the working schedule of 18 years, it was found that there was deficit during the months of February- May and November-December. The optimum storage level which gives minimum deficit should be selected. Therefore a shutter height of +4.0 m was decided, provided a dead storage of +2.00 m (storage level is 6 m). The reservoir working plan for a storage levels of 4,5 and 6 m and for the year 2003 is given in Table 5 and the remaining working tables are appended in Appendix10.

4.3 Saline water intrusion

The main concern of the proposed RCB was the prevention of the saline water intrusion of the area. As per the research study conducted by the CWRDM, the coastal areas of Malappuram are facing threat of saline water intrusion, especially in the Ponnani area. The Irrigation Department has suggested the erection of steel piles beneath the structure.

According to the Ghyben-Herzberg relation, for hydrostatic equilibrium, one meter depth of water table from MSL requires a depth of 40 metres between MSL and fresh water–saline water interface. As per the geological study at the regulator site, hard rock formations are explored at depths of about 18 m to 40 m. For preventing the intrusion of saline water, a dead storage level of 1.5m is provided at the upstream side in all seasons. The storage volume corresponding to this is 10.17 Mm^3.

4.4 Water available in the reservoir for irrigation.

The water available for irrigation during the three seasons are calculated and given in Table 6. The calculation is made by taking the monthly average of 18 years. The Kharif season includes four months- June, July, August and September. October, November and December comes under Rabi season. Summer season includes January to May.

Table 6 Water Availability in Mm^3 for each season

Season	Water Availability (Mm^3)
Kharif	827.15
Rabi	364.45
Summer	191.52

4.5 Irrigation requirement

Table 7 shows reference crop evapotranspiration (ET_0) for different months and Table 8 shows the season wise irrigation requirement of different crops.

Table 7 Reference crop Evapotranspiration (ET_0) for different months

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET_0 (mm/day)	4.9	5.0	5.5	5.2	5.1	3.7	3.2	3.8	4.1	4.3	3.2	3.8

The highest ET_0 of 5.5 mm/day was found for the month of March.

Table 8 Season wise water requirement of crops (m^3/ha)

Crops	Kharif	Rabi	Summer
Paddy nursery	1508.25	509	2641
Paddy puddling	0.07	0.04	0.07
Paddy main field	2800.49	7062.69	10306.95
Coconut	510	1288.5	5019.75
Coconut + Pepper + Arecanut	970.5	2036.8	7737.5
Pepper + Arecanut	786	1716.1	6572.75
Coconut + Banana + Vegetables	0	1295.8	5086.4
Banana	687.60	1545.06	5951.55
Vegetables	0	0	3916.81

4.6 Optimization of cropping pattern

Monthly optimal water releases for irrigation given by the reservoir as shown in Table3.3.were used for obtaining optimum cropping pattern for the command area of the project. The different approaches used to arrive at the optimal cropping pattern were:

i. To obtain the maximum seasonal net return from the command area.
ii. To minimize the cost of production in the command area.
iii. To obtain the maximum area of cultivation in each season.
iv. To obtain the benefit-cost ratio for each case.
v. To do the sensitivity analysis.

For each of the three seasons, six trials were conducted with different constraints set as described in Table 3.The solution to the linear programming model was obtained using the software package-Lindo.

4.6.1 Optimal cropping pattern for kharif season.

All the six cases in Table 3 were tried with the model to get the optimal allocation of area, profit maximization and cost minimization for each crop under the command area. The details are given in Table 9 to Table 14. The trials were conducted with an irrigation efficiency of 57%.

Table 9 Cropping pattern for Case I of Part 1

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120	2.36	364.1	2.2	120	1.64
X3	1200		3641		1200	
X4	9240		6649		200	
X5	6120		6120		140	
X6	100		100		10	
X7	600		600		50	
X8	1200		1200		50	
X9	100		250		100	
Total	Rs.1054638000		18560 ha		Rs. 51890000	

Table 10 Cropping pattern for Case II of Part 1

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120	1.78	364.1	1.79	120	1.64
X3	1200		3641		1200	
X4	200		200		200	
X5	6120		6120		140	
X6	10		100		10	
X7	600		50		50	
X8	10330		8349		50	
X9	100		100		100	
Total	Rs. 1441681000		18560 ha		Rs. 51890000	

Table 11 Cropping pattern for Case III of Part 1

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120		364.1		120	
X3	1200		3641		1200	
X4	9340		6899		200	
X5	6120	2.36	6120	2.96	140	1.65
X6	100		100		10	
X7	600		600		50	
X8	1200		1200		50	
X9	0		0		0	
Total	Rs. 1056868000		18560 ha		Rs. 49890000	

Table 12 Cropping pattern for Case IV of Part 1

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	364.1		364.1		0	
X3	3641		3641		0	
X4	1500		1500		200	
X5	6120	2.1	6120	2.1	140	2.1
X6	100		100		10	
X7	600		600		50	
X8	1200		1200		50	
X9	250		250		100	
Total	Rs. 810529800		13411 ha		Rs. 27890000	

Table 13 Cropping pattern for Case V of Part 1

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120	2.36	364.1	2.3	120	1.64
X3	1200		3641		1200	
X4	9240		7349		200	
X5	6120		6120		140	
X6	100		100		10	
X7	600		50		50	
X8	1200		1200		50	
X9	100		100		100	
Total	RS. 1054638000		18560 ha		Rs. 51890000	

Table 14 Cropping pattern for Case VI of Part 1

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120	1.76	364.1	2.49	120	1.64
X3	1200		3641		1200	
X4	200		8349		200	
X5	140		6120		140	
X6	10		100		10	
X7	16860		50		50	
X8	50		50		50	
X9	100		250		100	
Total	Rs. 2005095000		18560		Rs. 51890000	

For profit maximization, the cropping pattern described under case III was found to give better net profit compared with other cases (Fig. 6). Higher area allocation for coconut resulted in better net benefit. Since coconut is a perennial crop, effort is required only during the initial stages and maintenance required is minimal when compared to other crops like paddy.

In case of area maximization, the maximum area with a better B/C ratio was also for case III and maximum area allocation was given to coconut. The main constraint for this objective is the availability of water.

To minimize the cost of production, the optimal solution was obtained for case IV. Here no area was allocated to paddy. The cost of cultivation for paddy is very high compared to coconut, but the return is very low. Therefore maximum area should be given to coconut. But the solution suggests total cultivation to an area of only 550 ha.

4.6.2Optimal cropping pattern for Rabi season

All the six cases in Table 3 were tried to get the optimal results of the three objectives.

The details are given in Table 15 to Table 20. The irrigation efficiency was taken as 57%.

Table 15 Cropping pattern for Case I of Part II

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
			364.1			
X1	274.5		3641		274.5	
X3	2745		6799		2745	
X4	1184.96		6120		200	
X5	6120	2.01	100	2.22	140	1.44
X6	100		600		10	
X7	600		1200		50	
X8	1200		100		50	
X9	250				100	
Total	Rs.798741100		18560 ha		Rs. 82790000	

Table 16 Cropping pattern for Case II of Part II

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	274.5	1.6	364.1	1.8	274.5	1.44
X3	2745		3641		2745	
X4	200		200		200	
X5	140		6120		140	
X6	10		100		10	
X7	600		600		50	
X8	10004.6		7799		50	
X9	250		100		100	
Total	Rs.848672800		18560 ha		Rs. 82790000	

Table 17 Cropping pattern for Case III of Part II

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	274.5	2.08	364.1	2.21	274.5	1.43
X3	2745		3641		2745	
X4	1184.95		6649		200	
X5	6120		6120		140	
X6	100		100		10	
X7	600		600		50	
X8	1200		1200		50	
X9	250		250		0	
Total	Rs.798741100		18560 ha		Rs. 86790000	

Table 18 Cropping pattern for Case IV of Part II

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	268.79		364.1		0	
X3	2687.9		3641		0	
X4	1500		1500		200	
X5	6120	2.09	6120	2.07	140	2.12
X6	100		100		10	
X7	600		600		50	
X8	1200		1200		50	
X9	250		250		100	
Total	Rs.808814300		13411ha		Rs. 27890000	

Table 19 Cropping pattern for Case V of Part II

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	274.5		364.1		274.5	
X3	2745		3641		2745	
X4	200		6799		200	
X5	140	1.6	6120	2.22	140	1.44
X6	10		100		10	
X7	600		600		50	
X8	10004.6		1200		50	
X9	250		100		100	
Total	Rs.848670000		18560 ha		Rs. 82790000	

Table 20 Cropping pattern for Case VI of Part II

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	274.5	1.75	364.1	2.28	274.5	1.49
X3	2745		3641		2745	
X4	200		7199		200	
X5	140		6120		140	
X6	10		100		10	
X7	12469.5		50		50	
X8	50		1200		50	
X9	250		250		100	
Total	Rs.1494366000		18560 ha		Rs. 82790000	

For the profit maximization objective, case IV gives the maximum profit (Fig 7). The maximum area was allocated to mixed cropping of coconut, arecanut and pepper.

In case of area maximization, maximum area with a better B/C ratio was obtained for case VI. The maximum area allocation was given to coconut.

For the third objective, the optimal solution was obtained for case IV. The solution yielded no area for paddy. As the beneficiary area includes kole lands, paddy cultivation cannot be fully avoided in this area .So a minimum area must be allocated to it.

The proposed project will stabilize the yield of second crop when there is a failure of North-east monsoon

4.6.3 Optimal cropping pattern for Summer season

The six cases in Table 3 were tried for the three objectives with an irrigation efficiency of 57%. The calculations are given in Table 21 to Table 26.

Table 21 Cropping pattern for Case I of Part III

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120	2.36	364.1	2.21	120	1.64
X3	1200		3641		1200	
X4	9240		6649		200	
X5	6120		6120		140	
X6	100		100		10	
X7	600		600		50	
X8	1200		1200		50	
X9	100		250		100	
Total	Rs.1054638000		18560 ha		Rs. 51890000	

Table 22 Cropping pattern for Case II of Part III

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120	1.79	364.1	1.8	120	1.64
X3	1200		3641		1200	
X4	200		200		200	
X5	6120		6120		140	
X6	10		100		10	
X7	600		50		50	
X8	10330		8349		50	
X9	100		100		100	
Total	Rs.1441681000		18560 ha		Rs. 51890000	

Table 23 Cropping pattern for Case III of Part III

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120		364.1		120	
X3	1200		3641		1200	
X4	9340	2.37	6899	2.23	200	
X5	6120		6120		140	1.65
X6	100		100		10	
X7	600		600		50	
X8	1200		1200		50	
X9	0		0		0	
Total	Rs.1056860000		18560 ha		Rs. 49890000	

Table 24 Cropping pattern for Case IV of Part III

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	364.1		364.1		0	
X3	3641		3641		0	
X4	1500		1500		1500	
X5	6120	2.07	6120	2.07	140	2.88
X6	100		100		10	
X7	600		600		50	
X8	1200		1200		50	
X9	250		250		100	
Total	Rs.810529000		13411 ha		Rs38940000	

Table 25 Cropping pattern for Case V of Part III

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120		364.1		120	
X3	1200		3641		1200	
X4	9240		6799		200	
X5	6120	2.36	6120	2.22	140	1.64
X6	100		100		10	
X7	600		600		50	
X8	1200		1200 100		50	
X9	100				100	
Total	Rs.1054638000		18560 ha		Rs. 51890000	

Table 26 Cropping pattern for Case VI of Part III

Crops	With maximum profit		With maximum area under cultivation		With minimum cost of production	
	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio	Area (ha)	B/C Ratio
X1	120		364.1		120	
X3	1200		3641		1200	
X4	200		200		200	
X5	140	1.76	6120	1.88	140	1.64
X6	10		100		10	
X7	16860		7049		50	
X8	50		1200 250		50	
X9	100				100	
Total	Rs.2005095000		18560 ha		Rs. 51890000	

For the first objective, the maximum net profit was obtained for case III (Fig.8) and the higher area allocation was given to coconut.

For area minimization also case III was found to be a better one with a BC ratio of 2.23 and maximum area allocation was given to coconut.

For cost minimization, the optimal case was IV. There was no area allocation for paddy. But the solution gives a total cultivation area of only 18560 ha.

4.6.4 Analysis of Benefit-Cost ratio

The B/C ratio for all the six cases each for profit maximization, area maximization and minimization of total cost of production was calculated separately.

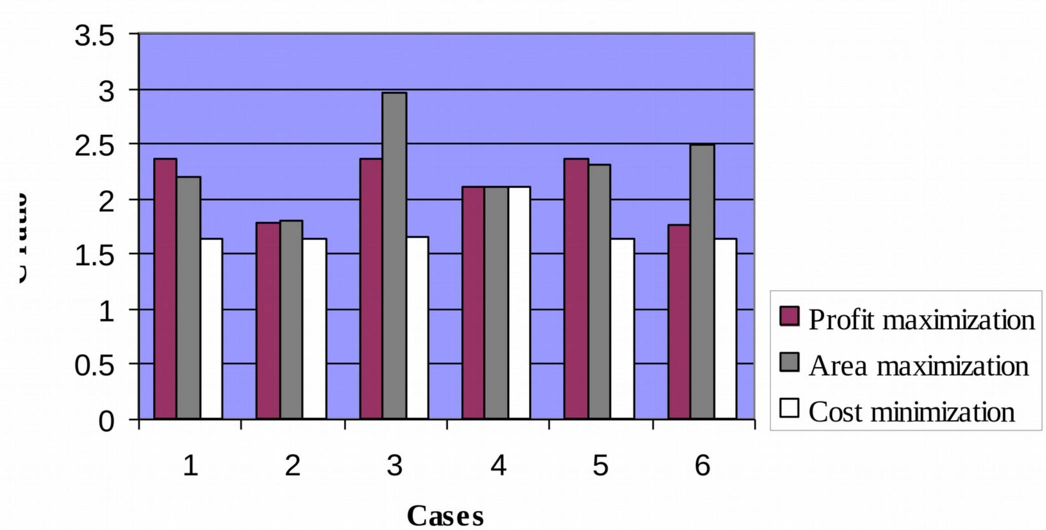

Fig. 3 Variation of B/C under different optimizations-Kharif season

Among the different optimizations, for the kharif season the highest B/C ratio obtained was 2.96 (Fig. 3) It was obtained for case III of area maximization. For profit maximization, cases I, III and V have the same B/C ratio. Among these three, the case III which gives maximum profit was considered optimal. Case IV gave the optimum solution while considering the cost minimization objective.

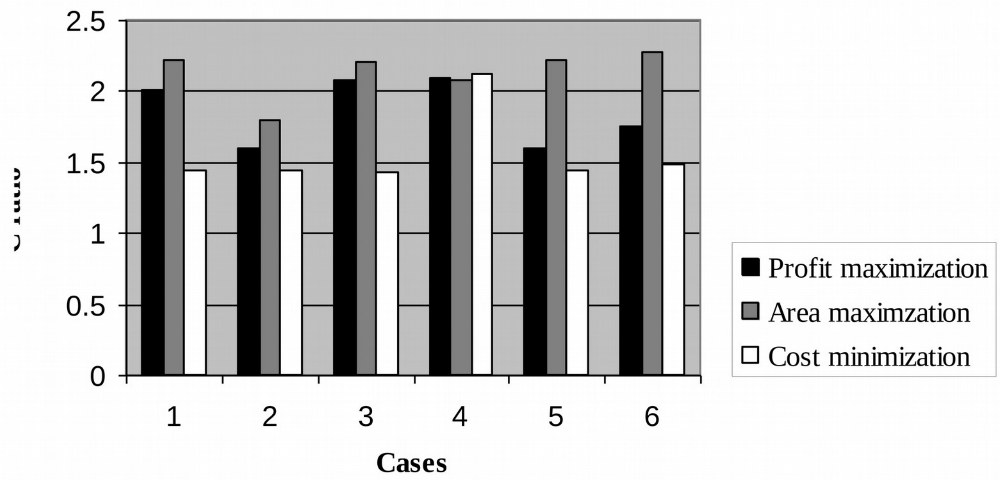

Fig. 4 Variation of B/C under different optimizations- Rabi season

The B/C ratio of 2.28 was found as the highest one for case VI of area maximization objective of the Rabi season (Fig. 4) among all optimization objectives. The highest B/C ratio was obtained for case IV for the objective to maximize profit. When considering the cost minimization case only, case IV again gave the optimal solution.

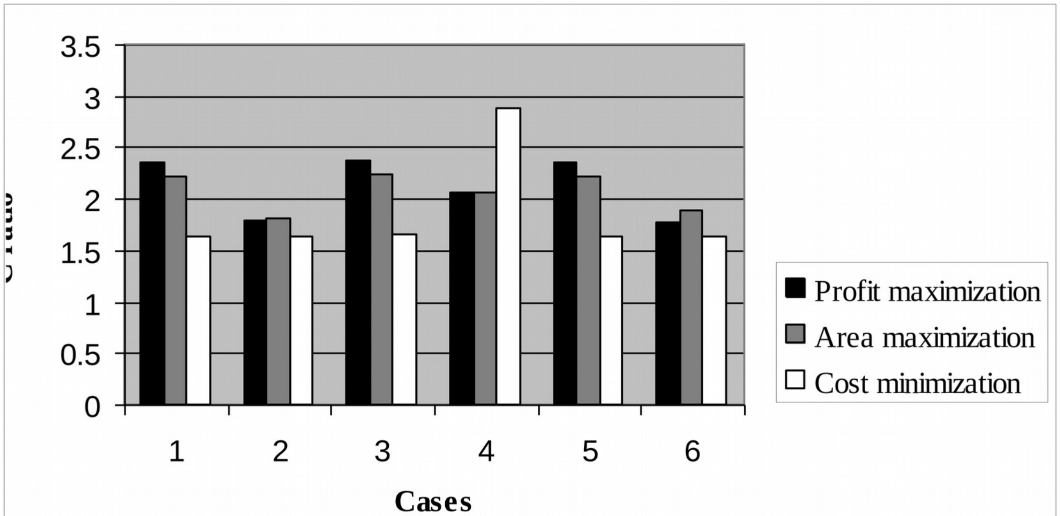

Fig .5 Variation of B/C under different optimizations-Summer season

It was observed that for summer season the highest B/C ratio was 2.28 for the minimum cost of production (Fig.5), when considering different optimizations. The B/C ratio was found highest for case III while considering the profit maximization objective only. When the aim was area maximization, the B/C ratio was found highest for case III again.

Among the three seasons, the best B/C ratio of 2.96 was found during the Kharif season. It was obtained for case III with the area maximization objective.

4.6.5. Sensitivity Analysis

Sensitivity analysis was carried out to study the effect of changes in the returns from each crop on the optimal solution. The LINDO model gives the allowable increase or decrease for the objective coefficient of each variable, that is the amount by which that objective coefficient can be increased or decreased without causing a change in the basis (the set of non-zero variables). Sensitivity analysis was conducted for case I of profit maximization objective for the three seasons. The allowable increase and decrease for the objective coefficients are given in Table 27.

Table 27 Sensitivity analysis of the model

Variable	Current coefficient	Objective coefficient ranges for Kharif & Summer		Objective coefficient ranges for Rabi	
		Allowable increase	Allowable decrease	Allowable increase	Allowable decrease
X3	1800	30500	Infinity	176522.8	Infinity
X4	32300	31200	22300	15377.73	31973.96
X5	95800	Infinity	63500	Infinity	44741
X6	63500	Infinity	31200	Infinity	20480.96
X7	117300	Infinity	85000	Infinity	84817
X8	75000	Infinity	42700	Infinity	36268.58
X9	10000	22300	Infinity	Infinity	10000

It is obvious that the area allocation obtained as per the model is optimal. The sensitivity analysis shows that even if the profit values change over a wide range, then also the area allocated for each crop remains unchanged. In all the three cases, it is observed that the least range of profit is for coconut. Here the most sensitive parameter is the profit of coconut.

Four trials were conducted by taking the profit values in the range obtained by the sensitivity analysis. The analysis was done for optimal cases of the profit maximization objective for the three seasons. The returns considered for the four trials are shown in table 28.

Table 28: Net returns from each crop under different trials

Trial 1	Trial 2	Trial 3	Trial 4
1800	2000	1600	1950
32300	32500	32000	32800
95800	99000	94700	94900
63500	64700	61200	62000
117300	119000	115000	117550
75000	76500	74750	74650
10000	10500	9550	10500

The area allocation obtained for all trials for a particular season was observed as same. The results obtained are given in table 29.

Crops	Kharif & Summer				Rabi			
	Trial 1	Trail 2	Trial 3	Trail 4	Trial 1	Trail 2	Trial 3	Trail 4
X3	1200	1200	1200	1200	2745	2745	2745	2745
X4	9240	9240	9240	9240	1184.96	1184.96	1184.96	1184.96
X5	6120	6120	6120	6120	6120	6120	6120	6120
X6	100	100	100	100	100	100	100	100
X7	600	600	600	600	600	600	600	600
X8	1200	1200	1200	1200	1200	1200	1200	1200
X9	100	100	100	100	250	250	250	250
Net benefit (M Rs.)	1056.8	1081.5	1058.2	1055.7	808.8	832.3	799.1	804.2

Tabe 29 : Cropping pattern obtained for various trials

While conducting the four trials, it was observed that the area allocation remained the same for a particular season. The net benefits obtained at each trial found to change a little, but there was no significant difference from the optimized benefit.

4.6.6.Optimal cropping pattern Vs the cropping pattern proposed by Irrigation Department

A comparative study conducted on the cropping pattern by the Irrigation Department and that obtained using the optimization model revealed that the total area under cultivation benefited by the project increased four times. By implementing the project, the beneficiary areas can be made productive throughout the year. As saline water intrusion can be prevented during the summer season, the possibility of cultivation of a second crop in the kole lands is assured. Thus food security and thereby the social and economic status of the people are fully ensured.

SUMMARY AND CONCLUSION

5. SUMMARY AND CONCLUSION

Water resources projects involving reservoirs are very expensive and interlinked with many social issues. Hence they must be subjected to thorough analysis to see that each drop of water impounded is utilized in the best possible manner and in a socially acceptable way. The construction and operation of a reservoir is justified only when it produces maximum net benefit. Keeping this idea in mind, a study has been conducted for the proposed regulator-cum-bridge at Chamravattom in Malappuram district of Kerala with the specific objectives of preparing the Reservoir Working Schedule and determining the optimum cropping pattern for the command area.

The project selected is a multi-purpose one including the objectives of drinking water demand, irrigation demand, downstream flow demand, industrial demands and the prevention of saline water intrusion. The storage height for the RCB was determined by preparing reservoir working schedule for different heights. The storage height which gave the least deficit was fixed. Linear programming technique was used to optimize the cropping pattern of the command area. The problem was formulated as a monthly operational model. This is done for the three seasons- Kharif, Rabi and Summer. The mathematical model was formulated with all the known quantities on the right hand side of the constraint equations. The LP model was solved using LINDO software package.

The model was used to obtain an optimal cropping pattern for the command area of the project with the objectives of maximizing the net profit from the command area for different seasons, maximizing the net area put under cultivation in each season and minimizing the cost of production. Maximizing the net profit from the command area consisted of maximization of the net returns from the command area in economic terms with the available water and area bounds for different crops. The objective of area maximization was to maximize the area which can be put under cultivation with the same available water and the same constraints. Minimizing the cost of production in the command area involved minimization of the cost with the available water and area constraints. Six sets of constraints were considered. The cropping pattern which gave maximum net profit in the case of net profit maximization, the cropping pattern which gave net maximum area under area maximization and the cropping pattern which gave minimum cost under cost minimization, were selected.

The following conclusions can be drawn from the study.

1. Analysis of river flow data of 18 years at the site reveals that monthly mean maximum flow of 393.23 Mm^3 occurs in the month of August and monthly mean minimum flow of 20.83 Mm^3 during March. About 90% of the river flow occurs during June to December. The estimation of river flow data is important in flood warning, flood protection works and design of the structure.

2. Based on the river inflow data the reservoir working schedule was prepared for 18 years starting from 1987 to 2004 for the storage heights of 4, 5 and 6 meters. The storage height was fixed as 6 meters as it gave the least deficit. The prepared working schedule has been included in the revised project report submitted by the Irrigation Department to NABARD for the funding of the proposed RCB.

3. A study was conducted on the saline water intrusion which is a major concern of the area. According to the Ghyben-Herzberg relation, for hydrostatic equilibrium one meter depth of water table from MSL requires a depth of 40 metres between MSL and fresh water–saline water interface. As per the geological study at the regulator site, hard rock formations are explored at depths of about 18 m to 40 m. For preventing the intrusion of saline water, a dead storage level of 1.5m is provided at the upstream side in all seasons.

4. The evapotranspiration rates for different months were calculated using Modified Penman method. The highest ET of 5.5 mm/day was found for the month of March.

5. The crop water requirements of the crops for different seasons were determined by considering 75% chance rainfall.

6. Optimal cropping pattern with net benefit maximization gave a net benefit of Rs 106 crores for Kharif and Summer seasons and Rs 80 crores for Rabi season.

7. Optimal cropping pattern with area maximization objective gave a total annual irrigated area of 18560 ha in all the three seasons.

8. Among the different optimizations, for the kharif season the highest B/C ratio of 2.96 was obtained for area maximization. The B/C ratio of 2.28 was found as the highest one for area maximization case of the Rabi season. It was observed that for summer season the highest B/C ratio was 2.28 for the minimum cost of production.

9. Sensitivity analysis shows that even if the profit values change over a wide range, then also the area allocated for each crop remains unchanged. The analysis indicates that the most sensitive parameter is the profit of coconut.

10. The total area benefited by the project as obtained by the model study is four times the area proposed by the Irrigation Department. Cultivation is possible in the water stressed periods also, especially in the kole lands.

11. The study summarizes that optimal operational policies, even for small water resource projects, increase the economical viability to a great extent and make the project more socially acceptable. Hence, all reservoirs must be planned based on optimal operational policies incorporating maximum number of objectives to improve their utility value and better social acceptance.

The construction work of the proposed RCB is at the commencing stage. NABARD has granded the loan and the work is to be initiated in the near future. The Irrigation Department will monitor the timely progress of the construction works. This being a dream project of the local people of the area, the optimal water use and cropping pattern determination forms an important aspect of the proposed project.

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RESERVOIR OPERATION PLANNING AND CROPPING PATTERN OPTIMIZATION FOR CHAMRAVATTOM REGULATOR-CUM-BRIDGE

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ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree of

Bachelor of Technology
In
Agricultural Engineering

Faculty of Agricultural Engineering and Technology
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2008

ABSTRACT

Water scarcity is an alarming problem that we face now-a-days. Even though we have abundant sources of water, good quality water is not available when most needed. There comes the relevance of water conservation structures. Allocation of water in case of multi purpose projects among various competing needs such as drinking water, irrigation, industrial demands, downstream release, pisciculture etc. is a matter of great concern. Hence reservoirs must be subjected to thorough analysis to see that each drop of water impounded is utilized in the best possible manner .So a study was undertaken for the proposed Regulator-Cum-Bridge at Chamravattom in Malappuram district with the specific objectives of determining the optimum storage height and cropping pattern optimization for the command area.

The storage height was optimized by considering the inflow and demands on the reservoir for 18 years data. The height was decided as six meters as it gave least deficit when compared to four and five. The optimal cropping pattern was suggested by using Linear Programming Model. Three objectives were considered- maximization of profit, maximization of area under cultivation and minimization of production cost. The model was developed on a seasonal basis for Kharif, Rabi and Summer and solved using LINDO software. The optimal solution was determined by analyzing the B/C ratio under different cases for a particular season. Sensitivity analysis was also performed to find whether the solutions obtained are optimal. The total area benefited by the project as obtained by the model study was four times the area proposed by the Irrigation Department. The study summarizes that optimal operational policies, even for small water resource projects, increase the economical viability to a great extent and make the project more socially acceptable.