CROP AND IRRIGATION PLANNING
OF
KOSI IRRIGATION SYSTEM
NEPAL

A DISSERTATION

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

By

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CANDIDATE'S DECLARATION

I, hereby, certify that the work which is being presented in the dissertation entitled **"CROP AND IRRIGATION PLANNING OF KOSI IRRIGATION SYSTEM, NEPAL"** in the partial fulfillment of the requirement for the award of the Degree of Master of Technology, submitted in **Department of Hydrology** , Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from July 2007 to June 2008, under the supervision and guidance of **Dr. Ranvir Singh**, Professor, Department of Hydrology, Indian Institute of Technology, Roorkee.

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

Date: June……, 2008 **(Madan Mohan Jha)**

Place: Roorkee

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

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SYNOPSIS

Population increase in developing countries needs an increase in agricultural production to meet their increasing food and nutritional demand. The goal to meet these demands can be achieved through irrigated agriculture but rapid expansion of new irrigation schemes may not continue in the next decades due to many reasons e.g. scarce resource, economic and environmental conditions. Poor performance of irrigation system in these countries requires greater attention towards planning, management and development of resources of these systems. Efficient resource utilization is the central issue. Integrated or conjunctive use of surface and groundwater resources has now been recognized as a significant strategy for the optimum utilization of regional water resources. Integrated use is especially effective within the context of irrigation management. Systems approach and its framework, consisting of mathematical models, have long been used in analyzing complex water resources problems such as conjunctive use and irrigation planning. Conventionally, irrigation planning and management problems have been approached mainly from the economic and engineering feasibility point of view. But, there usually exist multiple considerations, which should be followed in irrigation development. For example, in Nepal, an updated working policy on irrigation development for the fulfillment of the country's basic needs of food and nutrition requirement has been in effect.

The following four strategies have been highlighted as significant:(1) the Government's contribution for feasible projects with less cost and higher internal rate of return, (2) availability of year round irrigation by integrated use of surface as well as ground water (3) extension of irrigation facilities to achieve targets for irrigated land area, and (4) the beneficiaries' participation in all phases of the projects. These considerations are based on a careful review of the past and present performance of irrigation projects. For developing countries, based on the United Nations Industrial Development Organization (UNIDO) guidelines, Goodman (1984) also indicated that the objectives of a water resources project may be expressed as the economic sector development, balanced regional development, engineering and economic feasibility, and financial viability. However, only in a few cases have multiple criteria or objectives been explicitly considered in irrigation planning. Generally, studies are based on surface water resources alone and do not deal with all the interrelated aspects of comprehensive round the year planning for the integrated use of surface and groundwater and considering with food and nutrient values. Therefore, The primary objective of the study is to allocate optimally the land and water resources for proposed cropping pattern. The specific objectives of the study are as follows; 1) To calculate Water Requirement by using most appropriate method 2) To devise a suitable cropping pattern for the study area.3) To find out optimal allocation of land and water resources in study area 4) Determining alternative irrigation development plans; 5) Selecting the most satisfactory development strategy considering multiple objectives by using Goal Programming.

The Kosi Irrigation System (KIS) in the far-eastern region of Nepal has been selected for the study. It is one of the typical surface irrigation systems in the country. The existing command area is about 11300 ha.

The present study outlines the principles of latest method used to estimate crop water requirement and optimization of land & water resources and discusses the application of these principles for profit maximization, food security, and nutritional requirement of population.

The study utilizes monthly discharge in canal of the system. Social, Agricultural, Hydro meteorological data are available from the project as well as different Government agencies. CROP WAT and LINDO Software will be used as analytic tool for crop water requirement and linear and goal programming for optimization.

The assessment of crop water requirement for various crops in different seasons is an important criterion in the selection of crops to be grown and it is one of the basic necessities in planning of an irrigation system. The comparative studies and many other research studies have confirmed the superior performance of the Penman-Monteith approach and correct estimates of gross irrigation requirement. By using Penman-Monteith method for estimating GIR would certainly reduce losses caused due to using overestimated values by other methods. Also cost of bigger size canal and canal structures may get reduced.

Linear programming and goal programming techniques were used to achieve these specific objectives of optimal allocation of resources of the irrigation system. Alternative plans for irrigation development are identified by analyzing trade-offs among the specified objectives of maximizing total net economic returns from agriculture (economic efficiency),nutritional requirement of the area (health) and total irrigated cropped area (balanced regional development) by using Goal programming.

An individual optimal solution for the four maximization problems are presented .It is seen that optimal solution of these plans is superior to existing one. Outputs of these plans are indicated different optimal plans. Thus trade off among them is done by using goal programming technique.

According to goal programming results, it is important to point out that the economic scenario may not satisfy the health and environment goals, but they end up to better numbers than the status quo. The planning model presented in this article is a versatile mathematical tool for generating and evaluating alternative irrigation development plans, mainly in a developing country, based on the conjunctive use of surface and groundwater. The multi-objective framework of the model provides more insight to the decision-making process than conventional use of optimization models. Trade-off possibilities identified between different objectives help the decision making agency in balancing different interests. It must, however, be stressed that the model results are initial guidelines. With the practical and satisfying estimates of the optimal levels of water resources development, more rigorous simulation models and economic analysis could be used to assess the detailed performance of the selected plans, designs and operation policies.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	DESCRIPTIONS
Cal.,cal	Calories
CCA	Cultivable Command Area
CWR	Crop Water Requirement
ET	Evapotranspiration
ET_o	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field capacity
FIR	Field Irrigation Requirement
GIR	Gross Irrigation Requirement
GW	Ground Water
Ha	Hectares
Ha-m	Hectare meter
Km	Kilometer
LP	Linear Programming
LINDO	Linear Interactive Discrete Optimizer
l/s	Liters per second
MCM	million cubic meters
NIR	Net Irrigation Requirement

LIST OF SYMBOLS

SYMBOL	DESCRIPTIONS
γ	Psychometric Constant
Δ	Slope Vapour Pressure Curve
Etc	Crop Evapotranspiration
e_a	Actual Vapour Pressure
e_s	Saturation Vapor Pressure
e_s-e_a	Saturation Vapour Pressure Deficit
G	Soil Heat Flux Density
K_c	Crop Coefficient
P	Rainfall
Pe	Effective rainfall
Rn	Net radiation
T	Air Temperature at 2 M Height
U2	Wind Speed at 2 M Height
η_a	Water Application Efficiency
η_c	Water Conveyance Efficiency

CHAPTER -1

INTRODUCTION

1.1 GENERAL

Population increase and the improvement of living standards brought about by development will result in a sharp increase in food demand during the next decades. FAO analysis (FAO, 2003) of 93 developing countries expects agricultural production to increase over the period 1998-2030 by 49 % in rain fed systems and by 81 % in irrigated systems. Therefore, much of the additional food production is expected to come from irrigated land, three quarters of which is located in developing countries. The irrigated area in developing countries in 1998 nearly doubled that of 1962. Huge investments worldwide are directed towards expanding the irrigated area. Building new physical systems rather than improving the performance of existing ones seems to have been the main concern of planners, practitioners, and decision makers in the past. There are many reasons to believe that such rapid rate of expansion will not continue in the next decades. Therefore, emphasis is now being placed on the need to improve the performance of existing systems.

Poor performance of irrigation systems in developing countries now requires that greater attention be given to increase water productivity. Water productivity is projected to increase through gains in crop yield and reductions in irrigation water. At the same time, the water input per unit irrigated area need to be reduced in response to water scarcity and environmental concerns. Significant improvement in agricultural productivity can be achieved through proper crop water planning which matches the crop water demand with available supply. In many

irrigation systems, especially the diversion types, water is usually the limiting and a highly variable factor for agricultural production during the dry season. In order to meet these demand, irrigation systems will have to utilize surface water in conjunction with ground water.
Conventional irrigation practices in most of the systems are designed to avoid crop stress in order to maximize yields. During the next few decades, as the inevitable expansion of irrigated lands for increased food production comes into conflict with accelerating economic competition for water and rising environmental concerns, these fundamental perceptions of irrigation management will probably be abandoned. The new operational rule that replaces it will be based on maximizing total benefits rather than yields (English, et al. 2002). This alternative approach, which might be referred to simply as 'optimization', is recognized by economists and a growing number of irrigation professionals as the most rational basis for irrigation management.

Irrigation planning and management problems have been approached mainly from the economic and engineering feasibility point of view. But, there usually exist multiple considerations, which should be followed in irrigation development. For example, in Nepal, an updated working policy on irrigation development for the fulfillment of the country's basic needs of food and nutrition requirement has been in effect (IP, 2003).The following four strategies have been highlighted as significant:(1) the Government's contribution for feasible projects with less cost and higher internal rate of return, (2) availability of year round irrigation by integrated use of surface as well as ground water (3) extension of irrigation facilities to achieve targets for irrigated land area, and (4) the beneficiaries' participation in all phases of the projects. These considerations are based on a careful review of the past and present performance of irrigation projects. For developing countries, based on the United Nations Industrial Development Organization (UNIDO) guidelines, Goodman (1984) also indicated that the objectives of a water resources project may be expressed as the economic sector development, balanced regional development, engineering and economic feasibility, and financial viability. However, only in a few cases have multiple criteria or objectives been explicitly considered in irrigation planning. Generally, studies are based on surface water resources alone and do not deal with all the interrelated aspects of comprehensive round the year planning for the integrated use of surface and groundwater and considering with food and calorific values.

The present study outlines the principles of latest method used to estimate crop water requirement, optimal allocation of land and water resources by using multi criteria decision for profit maximization, nutritional need, food security and national interest.

1.2. OBJECTIVES

The primary objective of the study is to allocate optimally the land and water resources for proposed cropping pattern. The specific objectives of the study are as follows:-

1) To calculate Water Requirement by using most appropriate method

2) To devise a suitable cropping pattern for the study area.

3) To find out optimal allocation of land and water resources in study area

4) Determining alternative irrigation development plans;

5) Selecting the most satisfactory development strategy considering multiple objectives by using Goal Programming.

1.3 METHODOLOGY

The study utilizes data made available by the Kosi Irrigation project office for monthly discharge in canal of the system. Social, Agricultural, Hydro meteorological data are available from the project as well as different government agencies. Related reports are consulted in preparation of dissertation report. CROPWAT and LINDO Software are used as analytic tool for crop water requirement and optimization respectively.

CHAPTER-2

REVIEW OF LITERATURES

2.1. GENERAL

The development of agriculture-based economy, which is prevalent in most of the under developed and developing countries, requires an integrated planning of its land and water resources to get the maximum economic returns. The immediate objective in both dry as well as irrigation farming should be to enhance the existing productivity levels to deal with the increasing level of population growth accounting for the uncertainties, inherent in climatic variables. The main input for increasing productivity in irrigated areas is to ensure timely supply of water to crops from the available surface water resources along with the proper utilization of groundwater potential. With a view to economizing on use of water and increasing the productivity of irrigated crops, conjunctive use of surface and groundwater should be permissible in all the command areas. It is necessary that the new techniques for economical use of water be used without any inhibitions. Water use for crop production is depending on the interaction of climatic parameters that determine crop evapotranspiration and water supply from rain. The compilation, processing and analysis of meteorological information for crop water use and crop production will therefore constitute a key element in developing strategies to optimize the use of water for crop production and to introduce effective water management practices. Review of literature is done firstly, on most appropriate method used for estimating crop water requirement and secondly, on operation research techniques (optimization techniques).

2.2 WATER REQUIREMENT

Estimates of evapotranspiration (ET) flux occurring from cropped land surfaces are essential in studies relating to hydrology, climate, and agricultural water management. The procedure for estimation of ET rates of agricultural crops is well established and involves as a first step, computation of reference crop evapotranspiration (ET0) using regularly recorded climatological data. ET0 is defined as "the rate at which water, if readily available, would be removed from soil and plant surfaces of a specific crop, arbitrarily called the reference crop" (Jensen et al. 1990).

A large number of more or less empirical methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. Relationships were often subject to rigorous local calibrations and proved to have limited global validity.

Owing to difficulties in direct measurement, several temperature-based, radiation-based, pan evaporation-based, and combination-type equations are commonly used to derive estimates of ET0. Innumerable worldwide studies have evaluated the performances of these methods under different climatological conditions (e.g., Clothier et al. 1982; Michalopoulou and Papaloannou 1991; Amatya et al. 1995; Ventura et al. 1999; Xu and Singh 2002).

Based on the available research results and recommendations of expert consultations in 1971 and 1972, four evapotranspiration methods were adopted in the FAO No-24 method to be used according the availability of climatic data, as indicated in Table1.1.

The FAO modified Penman was an adaption of the original Penman method and included a revised wind function, derived from lysimeter data of various locations worldwide.

The FAO radiation method was based on the Makkink method, developed originally for the humid conditions in the Netherlands. By introducing a correction coefficient for various wind and humidity conditions, its validity was extended to a wider range of climatic conditions.

Table 1.1 Climatic data required for the FAO evapotranspiration methods (after Doorenbos and Pruitt: FAO, 1977)

Method	Temperature	Humidity	Wind Speed	Sunshine	Evaporation
FAO Blaney Criddle	✱	O	O	O	
FAO Radiation	✱	O	O	✱	
FAO Penman	✱	✱	✱	✱	
Pan Evaporation		O	O	O	✱

✱: measured data essential   O : estimation required

The Blaney-Criddle method, introduced in the early 1950's in the arid western United States, found broad application in irrigation studies and was adapted as the FAO Blaney-Criddle method to a wider range of climatic conditions by introducing a correction factor, which can be determined from estimates on humidity, wind and sunshine conditions.

The evaporation pan method has been widely introduced in many agro-meteorological stations; the measured evaporation of water in a standardized container has been extensively used as an ETo parameter and is applied in many irrigation studies and in real-time irrigation scheduling. A pan factor is required, however, to correct the evaporation from a free water surface to the evapotranspiration of a green grass cover. The method has been consolidated in FAO No-24 by standardization of the pan factor for different climatic conditions and pan environments.

A key element in the procedures for determining crop water requirements (ETc) was the introduction of the crop coefficient standardized for the various crop growth stages. Crop coefficients for the various crop stages and a large number of crops were given with detailed calculation procedures, providing an easy and uniform method, which has become the accepted standard for crop water requirement calculations.

The large number of ETo estimation methods with various locally adapted or modified parameters has become confusing for the common user and practitioner. To evaluate the performance of the various estimation procedures under different climatological conditions, a major study was undertaken under the auspices of the Committee on Irrigation Water Requirements of the American Society of Civil Engineers (ASCE).

The ASCE study reported by Jensen et al. (1990) analyzed the performance of 20 different methods, using very detailed procedures to assess the validity of the methods compared to a set of carefully screened lysimeter data from 11 locations with variable climatic conditions. The study proved very revealing and showed the widely varying performance of the methods under different climatic conditions. Table 1.2 shows the performance of the 20 methods classified for humid and arid conditions.

In a parallel study commissioned by the European Community, a consortium of European research institutes evaluated the performance of various evapotranspiration methods using data from different lysimeter studies in Europe.

The studies confirm the overestimation of the Modified Penman introduced in FAO No-24, and the variable performance of the different methods depending on their adaption to local conditions.The comparative studies may be summarized as follows:

- The Penman methods require local calibration of the wind function to achieve satisfactory results.
- The Radiation methods show good results in humid climates where the aerodynamic term is relatively small, but performance is erratic and underestimates evapotranspiration in arid conditions.

Table 1.2. : Performance of various ETo methods (after Jensen et al., 1990),

LOCATIONS	HUMID			ARID		
Performance Indicator	Rank No.	Over Estimate [1]	Stand. Error [2]	Rank No.	Over-[1] Estimate	Stand. Error [2]
COMBINATION METHODS						
Penman-Monteith	1	+ 4%	0.32	1	- 1%	0.49
FAO-24 Penman (c=1)	14	+ 29%	0.93	6	+ 12%	0.69
FAO-24 Penman (corrected)	19	+ 35%	1.14	10	+ 18%	1.1
FAO -PPP-17 Penman	4	+ 16%	0.67	5	+ 6%	0.68
Penman (1963)	3	+ 14%	0.60	7	- 2%	0.70
Penman 1963, VPD #3	6	+ 20%	0.69	4	+ 6%	0.67
1972 Kimberley Penman	8	+ 18%	0.71	8	+ 6%	0.73
1982 Kimberley Penman	7	+ 10%	0.69	2	+ 3%	0.54
Businger-van Bavel	16	+ 32%	1.03	11	+ 11%	1.12
RADIATION METHODS						
Priestley Taylor	5	- 3%	0.68	19	- 27%	1.89
FAO-Radiation	11	+ 22%	0.79	3	+ 6%	0.62
TEMPERATURE METHODS						
Jensen-Haise	12	- 18%	0.84	12	- 12%	1.13
Hargreaves	10	+ 25%	0.79	13	- 9%	1.17
Turc	2	+ 5%	0.56	18	- 26%	1.88
SCS Blaney-Crddle	15	+ 17%	1.01	15	- 16%	1.29
FAO Blaney-Criddle	9	+ 16%	0.79	9	0%	0.76
Thornwaite	13	- 4%	0.86	20	- 37%	2.4
PAN EVAPORATION METHODS						
Class A Pan	20	+ 14%	1.29	17	+ 21%	1.54
Christiansen	18	- 10%	1.12	16	- 6%	1.41
FAO Class A	17	- 5%	1.09	14	+ 5%	1.25

[1]Over- or underestimation as percentage from 11 lysimeter data locations, corrected for reference type
[2] Weighted standard error of estimates, mm/day

•Temperature methods remain empirical and require local calibration in order to achieve satisfactory results. A possible exception is the Hargreaves method (Hargreaves and Samani, 1985) with has shown reasonable ETo results with a global validity.

•Pan evapotranspiration methods clearly reflect the shortcomings of predicting crop evapotranspiration from open water evaporation. The methods are susceptible to the micro-climatic conditions under which the pans are operating and their performance proves erratic.

•The excellent performance of the Penman-Monteith approach both in arid and humid climates is convincingly shown both in the ASCE study and the European study.

Similarly, studies carried out in India have identified the FAO-24 (Doorenbos and Pruitt 1977) Penman combination method to be the most accurate one (Subramaniam and Rao 1985; Mall and Gupta 2002). However, owing to the fact that the FAO-24 Penman method requires input data of humidity and wind speed that may not be available at all locations, efforts have been made to identify simpler methods for a few climate regimes of India (Mohan 1991). For instance, Mohan (1991) on the basis of comparisons with FAO-24 Penman ET0 estimates recommends the use of the FAO-24 radiation method in humid climates, the Hargreaves and Samani (1985) temperature-based equation in humid climates, and the FAO-24 Blaney–Criddle temperature-based equation in sub humid and semiarid climates of Tamil Nadu state, India. However, such findings may have limited relevance in view of the significant changes that have taken place in the past decade with regard to procedures for estimation of ET0. Following an improved understanding of the physics involved in crop evapotranspiration responses to vegetation characteristics, the Penman–Monteith (PM) method has been proposed as the best estimator of ET0 (Allen et al. 1994). The PM method is considered to be more "physically based" since it incorporates the effects of physiological and aerodynamic characteristics of the reference surface. Several worldwide studies have proved the superiority of the PM method across a wide range of climatic conditions (e.g., Jensen et al. 1990; Irmak et al. 2003; Itenfisu et al. 2003). Accordingly, the recent version of the FAO methodology for estimation of crop water requirements (Allen et al. 1998) (hereinafter referred to as FAO-56), recommends the sole use of the PM method for ET0 estimation in all climates. Interestingly, in a recent study carried out at a sub humid location in India, Kashyap and Panda (2001) found that FAO-56 PM estimates compared most favorably with ET0 values measured in a grass lysimeter and yielded average root mean square error (RMSE) of 0.08 mm/day. In contrast, the popular FAO-24 Penman method yielded an average RMSE of 0.76 mm/day. George et al. (2002) evaluated ET0 estimates by nine popular methods relative to the FAO-56 PM method at two humid locations in India. In view of such proven superiority of the FAO-56 PM method, it is imperative that this method be adopted by Indian sub continent practitioners as a standard in all analysis requiring computation of crop evapotranspiration. Use of the FAO-56 PM method will lead to the much required improvement in irrigation water-use efficiencies. The present study was taken up to evaluate the performances of present values of ET0 used relative to the values by FAO-56 PM method at the command area of Kosi Irrigation system.

The Penman-Monteith approach is used and window version of CROPWAT software is available for computation of crop evapotranspiration.

2.3 OPERATION RESEARCH TECHNIQUE

The previous section of this literature review has discussed the using of most appropriate method to calculate crop water requirement and to schedule irrigation according to a criteria of meeting crop need. Irrigation development planning was traditionally based on cropping pattern selection aiming at maximizing the revenue from irrigation activities. Due to a number of constraints and the desire to secure crop diversification, operational research techniques have been employed for finding optimal cropping patterns.

Operations Research or operational research (OR) is an interdisciplinary branch of mathematics which uses methods like mathematical modeling, statistics, and algorithms to arrive at optimal or good decisions in complex problems which are concerned with optimizing the maxima (profit, faster assembly line, greater crop yield, higher bandwidth, etc) or minima (cost, loss, lowering of risk, etc) of some objective function. The eventual intention behind using Operations Research is to elicit a best possible solution to a problem mathematically, which improves or optimizes the performance of the system.

Some of the primary tools used by operations researchers are statistics, optimization, queuing theory, game theory, graph theory, decision analysis, and simulation. Among these Optimization and Simulation are extensively used in water allocation problems.

2.3.1 Optimization

In mathematics, the term optimization, refers to the study of problems in which one seeks to minimize or maximize a real function by systematically choosing the values of real or integer variables from within an allowed set. In case of water resource allocation problems the input variable could be either deterministic or stochastic optimization. Stochastic optimization is useful for planning purposes, while deterministic optimization is available approach for real time reservoir operation.

The optimization packages are under development since1970, but are not commonly used and accepted by water policy makers. Now a day, several researchers have applied a number of simulation and optimization models to derive planning and operating strategies for land and water systems. In agriculture, where various crops are competing for a limited quantity of land and water resources, linear programming is one of the best tools for optimal allocation of land and water resources (Khepar and Chaturvedi, 1982; Kaushal et al., 1985; Panda et al.,1985; Paul et al.,2000). Most of the studies of optimization on irrigation water management adopt simplified or linear objective functions to maximize the net benefits while selecting an optimum-cropping pattern. Deterministic linear programming (DLP) is one of the best tools for optimum cropping pattern and irrigation programs for maximizing the economic return (Loucks et al., 1981; Khepar and Chaturvedi, 1982; Kaushal et al., 1985; and Sethi et al.,2002).Some of other literature available for optimization works is as follows :-

Maji and Heady (1978) formulated two chance-constrained linear programming (CCLP) models for inter-temporal allocation of irrigation water in the Mayurakshi Project in India. The models considered the stochastic nature of monthly inflows and the increased economic opportunity offered by the introduction of new high-yielding crop varieties. However, CCLP models had several limitations, since they did not account for alternatives with regard to the resources position and status of various system variables.

Sinha and Charyulu (1980) formulated LP model, considering the existing irrigation system of Gomati, Kalyani and Doab. The optimal cropping pattern was determined by allocating cultivated areas of various alternative crops with the maximize net benefit.

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

Kheper and Chaturvedi (1982) applied a linear programming formulation to make decisions on optimal cropping pattern and groundwater management alternatives in a canal irrigated area.

Various groundwater management alternatives in conjunction with optimum cropping pattern based on water production functions were compared.

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

Panda and Kheper (1985) also adopted techniques to maximize the net return from optimal irrigation planning. Both deterministic linear programming and chance-constrained linear programming were used.

Ranvir Singh et al. (1987) A multi-objective crop planning for Garufella watershed, Assam is done by comparing LP model with GP Model. Linear and Goal programming models for optimal utilization of irrigation water for the winter season have been developed in the model.

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

Paudyal and Das Gupta (1990) solved the complex problem of irrigation management in a large heterogeneous basin by using a multilevel optimization technique. The real problem consisted of determining the optimal cropping patterns in various sub areas of the basin, the optimal design capacities of irrigation facilities, including surface and groundwater resources, and the optimal water allocation policies for conjunctive use.

Onta et al.(1991) has developed a multi-objective linear programming based planning model for irrigation development, incorporating the integrated use of surface and groundwater 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.

Panda (1993) used LP and GP for optimal crop planning in Kansabahal Irrigation Project in Sundergarh District of Orissa.

Sinha (1997) used LP technique to optimally allocate multi-resource like land, water, human labour, seeds, manure and fertiulizers etc to maximize net benefit from the Badanala Irrigation project in Rayagada district of Orissa.

Gupta (1999) used linear programming and goal programming model for optimal crop planning in Barna Irrigation Project in MP.

Dahe (2001) utilized an optimization approach employing the implicit stochastic yield model based on linear programming for planning the optimal development of river basin with a case study of Narmada Basin.

Garnaik (2002) employed LP model for optimal use of land and water resources of Dejang Irrigation Project, Orissa for maximizing net benefit from the crops. He developed a cropping pattern that will give maximum net return from crops at full and nil (Rain fed) irrigation stage.

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

D. Latino Poulos et al (2005) used Goal programming for optimal allocation of land and water resources of Loudias river basin in Greece

. Janga Reddy and Nagesh Kumar (2006) used multi-objective differential evolution (MODE) approach for the simultaneous evolution of optimal cropping pattern and operation policies for a multi-crop irrigation reservoir system.

Janga Reddy and Nagesh Kumar (2007b) proposed an efficient multi-objective optimization algorithm namely MODE technique, by incorporating non-dominated sorting and Pareto-optimality principles into single objective differential evolution algorithm.

However, only in a few cases have multiple criteria or objectives been explicitly considered in irrigation planning. Generally, studies are based on surface water resources alone and do not deal with all the interrelated aspects of comprehensive round the year planning for the integrated use of surface and groundwater and considering with food and calorific values.

A summary of the existing literature on optimization concludes that this literature is somewhat limited in scope. Due to complications in water availability pattern and the need to incorporate various criteria, multi objective methods were proposed for this study. To handle the multiple criteria decision systems, in general, there are various tools available viz. the utility theory, the fuzzy programming, the vector maximum methods, the interactive methods, and the goal programming. The tool of goal optimization can deal with the uncertainties due to vagueness in various components of the management problem. The goal approach may provide a promising alternative to the existing management methods and allows incorporation of expert opinions. In this study an attempt has been made to optimally allocate land and water resources in a deterministic regime under a multi-crop environment for three complementary goals, viz. maximization of net annual return and maximization of protein and calorific value of population of command area, maximization of irrigated area. Linear programming and Goal programming models are used in the present study for optimization. These models were applied to Kosi Irrigation system of Nepal with a view to assist in decisions making.

CHAPTER- 3

STUDY AREA

3.1 GENERAL

The Kosi Irrigation System, situated in southern Nepal, as shown in Figure3.1, has been selected for the case study. The irrigation system has sarted in 1966 A.D. under **Mutual Benefit Agreement** between Government of Nepal and Government of India. The construction work of the system began in FY (1977/78) and completed in FY (1988/89) .This irrigation system has two components, namely; Pump Canal system and Distribution System. The two systems are fed by Western Kosi Main Canal (Indian) take off from barrage built across Kosi River within Nepal territory near the Indo-Nepal border. The main canal runs for 35.15 Km in head reach within Nepal territory before entering India. Of the two systems Distribution System is chosen for the study area. The Distribution Canal System irrigates gross command area of 14,125 hectares, but present cultivable command area (CCA) of it, is 11,300 hectares, which can be extended upto 13,500ha. Water from the distribution canal is delivered to the fields through 13 numbers of secondary canal 34 numbers of direct outlets. Highlighted part shown on the map is command area of the system.

3.2 LOCATION

The System is located in the North-Western section of the Kosi river basin between latitude $26^0 25'$ N and $26^0 34'$ N and longitude $86^0 30'$ E and $86^0 56'$ E .The entire irrigation system lies in Saptari district of Sagarmatha Zone of Nepal and covers 27 village development committees.

The command area of the Distribution system is bounded by the Western Kosi Main Canal (Indian) on north, Western Kosi flood Embankment on the east and Indo-Nepal border on the south and west. The Command area of the system, lying south of the Western Kosi Main Canal is fed by gravity flow through 13 secondary canals, off taking from its left side. The Distribution System has 195 number of water courses whose total length is 245.181 Km.

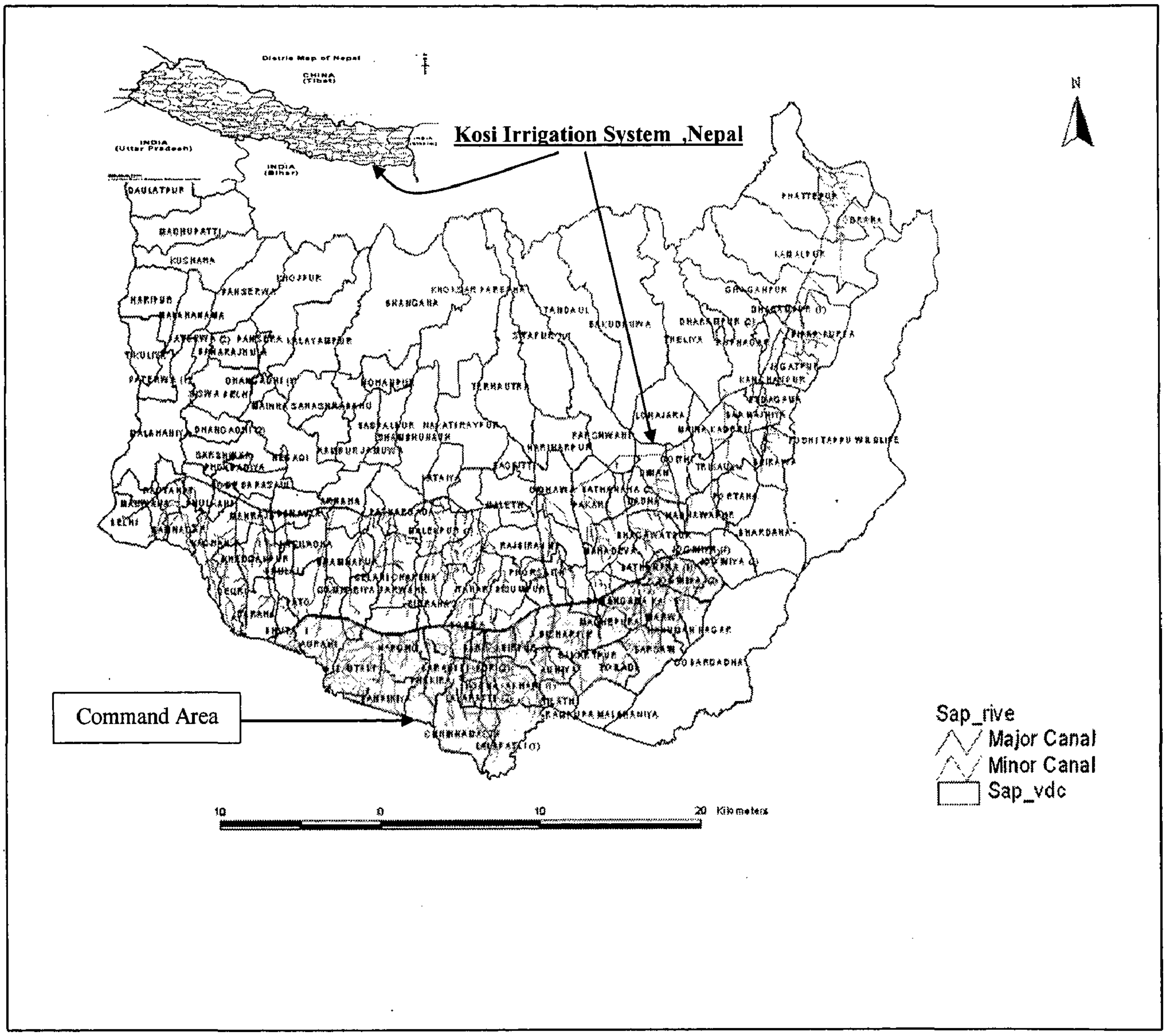

Fig. 3. 1 : map of command area

3.3 CLIMATE

The command area has a humid sub-tropical monsoon climate. The summer months are hot with temperature rises up to $40^{0}C$, while winters are cold with temperatures falling as low as $3^{0}C$. The temperature in the area remains high during the dry month of April, May and June. May being the hottest month. After mid July, temperature lowers down by the onset of monsoon.

3.4 RAINFALL

The area is located in a sub-tropical monsoon climate zone, which is characterized by two distinct seasons, dry and rainy. The dry season is from November through April, and the rainy (monsoon) season from May through October. The mean annual precipitation is around 1389 mm, of which about 95% occurs in the rainy season. The eighty percent of the annual rainfall occurs in the month of June to September. Climatic and hydrological datas of command area are presented in Table 3.1

3.5 TOPOGRAPHY

The System area is flat plain of terai lands having a general slope from north to south.The elevation of the command area of the Distribution System varies from 75 m at the head of the canal and 69 m at the tail of the canal. It slopes generally towards the south but there are many exceptions.

The eastern segment of the area intercepted between the Kosi embankment and Mahuli Dhar, is sloping towards the south west. The ground of the main canal has a steep slope of 1 in 600 for about one Kilometer; further south it becomes flat with ground level decreasing 4 m in 5 km.

Table 3.1: Climatic and rainfall of nearest station of Siraha

Month	Max Temp °c	Min Temp °c	Relative Humidity %	wind speed, (km/d)	Sun shine hr	Solar Radiation ($mj/m^2/d$)	Rainfall (mm)
January	22.5	8.5	81	86	8.3	14.9	26
February	25.3	10.2	77	104	9.2	18.2	8
March	30.7	14	71	121	9.6	21.6	20
April	34.7	20.3	60	147	10	24.2	29
May	34.4	23.7	67	147	9.3	24	74
June	33.6	25.2	78	130	6.7	20.2	237
July	32.3	25.3	84	121	6.2	19.3	331
August	32	24.8	87	104	5.9	18.3	363
September	31.4	23.9	89	95	6.2	17.3	211
October	31	21.6	78	86	7.8	17.3	80
November	28.7	14.1	81	78	8.9	16	9
December	24.3	9	91	78	8.8	14.7	1
							1389

(Sources: Depatment of Hydro-Meteorology Nepal, CLIMWAT)

3.6 HYDROLOGY

The source of Kosi Irrigation System (KIS) of Nepal is Kosi River. Kosi is the principal river in the project area .It starts in Tibet at elevation 5500 m and emerges out of the gorge at chatra in Nepal, where its catchments area is about 60,000 sqkm. A portion of the catchments is under glacier, which makes Kosi a perennial river. The most prominent feature in the catchments of Kosi is Mount Everest, the highest peak in the world. After flowing in Nepal and India for about 350 km, Kosi joins Ganga near Kursela in Bihar. Kosi has three main tributaries- Sun kosi, Arun and Tamur. Many other rain-fed tributaries join the river in terai and lower plains.

Prominent among the tributaries are Trijuga, sundari, Mahuli Dhar, khando, ghoydah Lukeshar, Kharag. Bihul, Mutni Dhar, Balan, Kajra Dhar, Siswari Dhar,. Amongst these khando and kharag are the two important tributaries passing through Project area.

Kosi brings in huge quantity of sediment which is deposited in terai plains, where the flat slope no longer provides sufficient velocity of flow to keep the sand and silt in suspension. Kosi is also known for its sudden spate of floods. A rise over 10 m, in 24 hours in the Kosi gorge upstream of chatra, is no surprise. The highest flood discharge of Kosi recorded in 1968 was 913,000 cusecs at Kosi barrage. Another high flood discharge of 850,000 cusecs was observed earlier in 1954. The normal flood discharge of Kosi during monsoon month is of order of 300,000 to 500,000 cusecs. The water sources for Distribution System and Pump Canal System is solely the Kosi barrage.

3.7 WATER ALLOCATION BY AGREEMENT

The water allocated for the Kosi canal system of Nepal, off taking from Western Koshi Main Canal (Indian), is at 720 cusecs; i.e. for the Pump Canal System 400 cusecs and for the Distribution System 320 cusecs. There is an agreement between Government of Nepal and the Government of India to supply 720 cusecs of water to Nepal portion perennially from Western Kosi Canal. As such low inflows in Kosi River are not likely to affect supplies to the Nepal portion.

3.8 GEOLOGY

The system area has the northern extension of the Indo-Gangetic plain and its geology is quite similar. The alluvial soils have been formed with the material transported and deposited in recent times by numerous rivers and streams. In most of the areas soils are derived from the old alluvium. The alluvium is confined to river courses and flanks subjected to periodic flooding. The plains are underlain by crystalline rock of autochthonous basement and nappe roots

3.9 GEOHYDROLOGY

Ground water is available at shallow depths in the command area and is generally potable. Depth of ground water varies from season to season. During rains it rises to within 2m of the ground surface and it is about 5m deep in April-May. In the southern part of the command area, which is composed of flat depression, near water logging conditions occur during rains. This is due to low topographic slopes and lack of proper drainage.

In view of abundance of ground water and relatively low incidence of rains during winters, it would be advantageous to exploit the ground water resources for conjuctive use with surface irrigation.

3.10 SOIL CHARACTERISTICS

The system command area mainly consists of active alluvial plains and recent alluvial plains "Lower Piedmont", the soils of which is very deep, sandy to fine loamy in texture and well drained to somewhat imperfectly or poorly drained.

The soils of the active alluvial plains are generally very deep, yellowish brown to grayish brown in color, dominantly coarse textured (loamy sand to loamy fine sand) lying on present river channels as well as low and high terraces. The soils have moderately high to high permeability and are very well drained. Due to the physiographic conditions, the soils are subject to occasional to severe flooding during rains.

The soils of the recent alluvial plains are very deep, dominantly sandy loam to clay loam in texture and moderately well drained to imperfectly drained lying on nearly level to undulating lands. The profile is wet for a small but significant part of time, usually because of a slowly permeable layer within or immediately beneath the solum. The water table is relatively high and an intermittently high water table (usually 3m to 5m deep) is met. The soils are young with less characteristics of profile development and are susceptible to erosion as well as deposition in major parts the area.

3.11 POPULATION

The system lies in Saptari district of Nepal. Population of the district with an area of 1363 square kilometer is 570,282 in 2001 of which 51% is male and 49% is female. The major part of the population lives in villages and earns its livelihood from agriculture and agro-based occupations. 95% population is based on agriculture. Population density is 418 per square kilometer and population growth rate 2.15%. Table 3.2 shows the population and area of Saptari district. Table 3.3 depicts population by age group and Table 3.4 shows estimated population of command area. The population of command area is estimated as 59,043 numbers in 2001.

Table 3.2: Population of Saptari District

Description	Population (no)	Remarks
Male	291409	51 %
Female	278873	49 %
Total	570282	100 %
Area	1363	Sqkm
Population density	418	per sq km
Population growth rate	2.15	percentage

Source: National Population Census 2001

Table 3.3: Population by age group

S N	Age group (Yr)	Male (%)	Female (%)
1	0 to 9	28	30
2	10 to 19	22	22
3	20 to 39	29	26
4	40 to 59	15	16
5	60 & above	6	6
6	Total	100	100

Source: National Population Census 2001

Population of the command area of Irrigation system in year 2032 is projected using relationship $P_{2032} = P_{2001}$ (1+r/100)^t . Here average growth rate is taken as 2.15 percent and value of t is taken as 31 years.Projected population of command area is calculated and presented as following Table 3.4.

Table 3.4: Projection of population of command area for 2032 AD

S N	System	Gross Command area (ha)	Population of 2001 (no)	Projected Population of 2032 (no)
1	Distribution system	14125	59043	114171

3.12 EXISTING CROPPING SYSTEM

There are three cropping seasons namely; Monsoon (Kharif), which starts from July/August and ends to October/November, winter (Rabi) from October/November to February/March and spring (Chaite) from Februaary/March to June /July. Major crops grown in the project area are paddy, wheat, maize, pulses, vegetable and oilseed. Because rice is the staple food of the local people, normal monsoon paddy is grown in almost all areas during the wet season. During the dry season, different crops are grown but early paddy and wheat are predominant. The different cropping patterns existing in the study area are Paddy (monsoon)-Wheat, Paddy-Mustard-Early

Paddy, Paddy-Vegetable/Pulses/Oilseed-Maize/Early paddy. The cropping intensity of the area is 166% quite low at presently. Due to problems such as low yield, limited market availability, difficulty in seed acquisition and post-harvest storage, local farmers are reluctant to grow wheat and maize. On the other hand, their keen interest to grow early paddy in addition to the Normal paddy is constrained by water management problem. Typical cropping calendar, including actual crop area coverage and yield during 2005/06 and 2006/07, are given below:

Table 3.5: Crop calendar and yield of area

S.No.	Crops	Cropping Season	Area (ha)	Yield (Kg/ha)
1	Paddy	15 July-15 Nov	11300	3300
2	Wheat	15 Nov-15 March	2500	2590
3	Oilseed	1Dec -15 March	400	700
4	Pulses	1Dec -15 March	400	660
5	Vegetable	1Dec-15 March	500	20000
6	Early Paddy	15 March- 30 July	3500	4000
5	Maize	15 March- 30 June	200	3000

Source: District Agricultural Development Office, Saptari 2007/08

CHAPTER 4

ESTIMATION OF VARIOUS INPUTS

4.1 INPUT DATA

Importance of reliable and realistic input data for the successful application of the water resources system models cannot be overemphasized. For the purpose of this study, various relevant study reports prepared by Government agencies, consultants and field observation are relied on as the basic sources of information. These studies are of a general nature, incorporating the regional or project-type characteristics (e.g. Source: Anuual Report of District Agricultural Development Office, Saptari, Project Report of Kosi Irrigation system, PDSP Manual etc). They contain the most up to date and representative information based on comprehensive analysis of available data in Nepal.

4.2 FOOD REQUIREMENT

Table 4.1 shows minimum food requirement by the population of command area on yearly basis. The food habit is verified at local basis. Main food of the area is rice and wheat. It is clearly from table that per capita requirement of rice is highest. This table represents general food habit of command area.

Minimum cropped area required to fulfill yearly food requirement of projected population of command area is estimated in Table 4.2. It is assumed that 70% of paddy requirement is fulfilled by monsoon paddy and remaining 30% of paddy requirement of projected population is covered by spring paddy. Table 4.3 shows protein and calorie content of different crops.

Table 4.1: Minimum food productions requirement by command area population

Name of crop	Crop Requirement in kg (per capita per year)	Minimum Production Requirement (ton / yr)
Paddy	100	11417
Wheat	30	3425
Maize	13	1484
Pulse	24	2740
Vegetables	70	7992
oilseed	25	2854

Source: Gopalan, et al. (1981)

Table 4.2 Annual minimum cropped area requirement of projected population

Name of crop	Yield (t/ha)	Requirement, t	area ha	Remarks
Monsoon Paddy	3.30	10390	3148	70% of total paddy
Spring Paddy	4.00	4453	1113	30% of total paddy
Wheat	2.59	3425	1322	
Maize	3.00	1484	495	
Oilseed	0.70	2854	4078	
Pulses(arhar)	0.66	2740	4152	

Table 4.3 protein and calorie content of different crops.

S. No.	Name of crop	Protein (gm/kg)	Calorie (cal/kg)
1	Paddy	73	3460
2	Wheat	121	3410
3	Maize	111	3420
4	Pulse	245	3480
5	Vegetables	40	800
6	Oil seed	220	5410

Source: Gopalan, et al. (1981)

4.2.1 Estimation of Protein and Calorie of different crops

Estimation of protein and calorie on unit area basis is done depending upon yield of different crops of command area and results are shown in Table 4.4. A multiplier 0.66 is applied to convert rice from paddy.

Table 4.4 protein and calorie available per unit area of study.

S.N.	Crop	Protein (gm/Kg)	Calorie (Cal/Kg)	Yield (kg/km2)	Protein (10^8g/km2)	Calorie (10^8Cal/km2)	multiplier for rice
		P.	C	Y	P*Y	C*Y	
1	Paddy	73	3460	330000	0.15899	7.5359	0.66
2	Wheat	121	3410	259000	0.31339	8.8319	
3	Oilseed	220	5410	70000	0.154	3.787	
4	Pulses (arhar)	245	3480	66000	0.1617	2.2968	
5	Vegetables	40	800	2000000	0.8	16	
6	Maize	111	3420	300000	0.333	10.26	
7	Paddy	73	3460	400000	0.19272	9.1344	0.66

4.2.2 Protein and Calorie requirement by 2032

The protein and calorie requirement is estimated on yearly basis presuming that yearly crop will meet the nutrient (protein and calorie) requirement.The protein and calorie requirement will vary according to age and sex. Table 4.5 indicating daily dietary allowances shows the average protein and calorie requirement as per group and sex. Table 4.6 indicates daily protein and calorie requirement for individuals. After estimation of protein and calorie requirement of male and female of the study area, the over all average per capita requirement of protein is estimated as 60.12 gm/cap/day and calorie requirement is estimated as 2194.96 cal/ cap/day as shown in Table 4.6.On annual basis protein and calorie requirement of projected population of 114171 is worked out **25.05 x10^8 gm** and **914.68 x 10^8** cal respectively.

Table 4.5: Protein and calorie requirement on sex and age basis

SN	Age group (Yr)	Male (%)	Female (%)	Male Requirement		Female Requirement	
				protein Gm	Calorie Cal unit	protein Gm	Calorie Cal unit
1	0 to 9	28	30	42	1500	42	1500
2	10 to 19	22	22	83.33	2600	73.33	2133
3	20 to 39	29	26	65	3000	60	2200
4	40 to 59	15	16	65	2800	60	2100
5	60 & above	6	6	65	2500	60	2000
6	Total	100	100				

Source: Gopalan, et al. (1981)

Table 4.6: show average protein and calorie requirement for individuals

SN	Male Requirement		Female Requirement		Combined Population Requirement	
	Weighted protein Gm	Weighted Calorie Cal unit	Weighted protein Gm	Weighted Calorie Cal unit	Weighted protein Gm	Weighted Calorie Cal unit
1	62.5926	2432	57.5326	1947.26	60.12	2194.96

4.3 NET RETURN

Net economic returns of different crops are shown in Table 4.7. Table depicts cost of input and output per hectare. All costs are in Nepalese Rupees. The cost of various items like seeds, fertilizer, labor etc are considered based on local market survey and annual report of District Agricultural Development Office (DADO), Saptari. Input requirement is obtained from DADO, Irrigation mannual and enquirying with local farmers. Net economic return per ha of different crops are estimated and presented in Table 4.7

Table 4.7: Net economical return from different crops

Particulars	Unit	MPaddy	S Paddy	Wheat	Maize	Oilseed	Pulses	Vegetabs
I.YIELD	(t/ha)	3.30	4.00	2.59	3.00	0.70	0.66	20
price	(NRs/t)	11000.00	9000.00	12000.00	12000.00	30000.00	28000.00	4500.00
value	(NRs/ha)	36300.00	36000.00	31080.00	36000.00	21000.00	18480.00	90000.00
BY PRODUCT	(t/ha)	1.25	1.25	1.00	0.60	0.40	0.50	
price	(NRs/ t)	1000.00	1000.00	1000.00	500.00	500.00	500.00	
value	(NRs/ha)	1250.00	1250.00	1000.00	300.00	200.00	250.00	
GROSS RETURN	(NRs/t)	37550.00	37250.00	32080.00	36300.00	21200.00	18730.00	90000.00
II.SEED	(Kg/ha)	30.00	30.00	110.00	25.00	9.00	40.00	1000
price	(NRs/Kg)	20.00	15.00	35.00	15.00	50.00	40.00	20.00
value	(NRs/ha)	600.00	450.00	3850.00	375.00	450.00	1600.00	20000.00
ORG	(t/ha)	0.60	0.60	0.50				1.00
price	(NRs/kg)	1500.00	1500.00	1500.00	1500.00	1500.00	1500.00	1500.00
value	(NRs)	900.00	900.00	750.00				1500.00
CHEMICALS								
UREA	(kg/ha)	80.00	80.00	90.00	60.00			90.00
price	(NRs/kg)	20.00	20.00	20.00	20.00	20.00	20.00	20.00
value	(NRs)	1600.00	1600.00	1800.00	1200.00			1800.00
DAP	(kg/ha)	40.00	40.00	40.00	30.00			30.00
price	(NRs/kg)	30.00	30.00	30.00	30.00	30.00	30.00	30.00
value	(NRs)	1200.00	1200.00	1200.00	900.00			900.00
MOP	(kg/ha)	40.00	40.00	40.00	30.00			
price	(NRs/kg)	15.00	15.00	15.00	15.00			
value	(NRs)	600.00	600.00	600.00	450.00			
PESTICIDES	(NRs/ha)	400.00	400.00	400.00	200.00			500.00
LABOUR	(md/ha)	175.00	175.00	110.00	123.00	60.00	66.00	200.00
price	(NRs/md)	120.00	120.00	120.00	120.00	120.00	120.00	120.00
value	(NRs/ha)	21000.00	21000.00	13200.00	14760.00	7200.00	7920.00	24000.00
ANIMAL LABOUR	(ad/ha)	44.00	44.00	40.00	25.00	23.00	19.00	30
price	(NRs/ad)	200.00	200.00	200.00	200.00	200.00	200.00	200.00
value	(NRs/ha)	8800.00	8800.00	8000.00	5000.00	4600.00	3800.00	6000.00
III.COST	(NRs/ha)	35100.00	34950.00	29800.00	22885.00	12250.00	13320.00	54700.00
IV.NET RETURN	(NRs/ha)	2450.00	2300.00	2280.00	13415.00	8950.00	5410.00	35300.00

4.4 SURFACE WATER AVAILABILITY

There is an agreement between Government of Nepal and the Government of India to supply 720 cusecs of water to Nepal portion perennially from Western Kosi Canal. Accordingly,The water allocation for the canal system of Nepal, off taking from Western Kosi Main Canal (Indian), is 720 cusecs; of which, the Pump Canal System and the Distribution System have utilized 400 cusecs and 320 cusecs respectively. As such low inflows in Kosi River are not likely to affect supplies to the Nepal portion.

For the estimation of total net available surface water in Kosi Irrigation system ,data of actual water available in past is considered and monthly water availability in the system is worked out. During 15th June to 15th of July the canal is closed for periodic maintenance. Table 4.8 indicates the monthly gross surface water availability of the system.

Table 4.8: Monthly surface water availability for Irrigation System

Month	Water available for utilization (ha-m)	Month	Water available for utilization
January	2332.8	July	1166
February	2332.8	August	2332.8
March	2332.8	September	2332.8
April	2332.8	October	2332.8
May	2332.8	November	2332.8
June	1166	December	2332.8

4.5 ESTIMATION OF GROUND WATER

Generally, in most of the irrigation projects, irrigation through surface water only leads to problem of water logging, alkalinity, salinity etc. Further tail farmers do not get sufficient surface water sometimes because of mismanagement in irrigation scheduling. To overcome these, ground water is also considered to be used for irrigation and to supplement canal water. So canal water is supplemented by using ground water in order to have conjunctive use of both surface and ground water to fulfill the crop water requirement particularly in non-monsoon period. Two methods used to get an estimatition of ground water potential of the area are as follows:

(I) Data Available from Different sources

The total available surface water potential (annual run-off) in the country is estimated to be 224 billion m^3. The estimated ground water potential in the Terai is 12 billion m^3 of which 5.8 to 9.6 billion m^3 could be extracted annually (estimated recharge) (Ministry of Water Resources, Nepal 1999). The ground water potential for the country is unclear but probably not much larger; the same figure of 12 million m^3 is quoted as referring to the country as a whole in Water and Energy Commission Secretariat (WECS), 1999. Current groundwater withdrawal is about 0.52 billion m^3 per year (WECS 1999) and for study area on an average ground water potential is taken as 8.775 billion m^3 per year, because command area lies in higher potential area of the country. Table 4.9 shows potential of ground water in command area.

Table 4.9 potential of ground water in command area

Component	Terai area	Command area
Area (Sq km)	34,019	141.25
Annual rechargeable water (ha-m)	877500	3643.46
Annual utilizeable water (ha-m)	52000	215.91
Annual balance water (ha-m)	825500	3427.55
Monthly / Max monthly availability (20% of total) (ha-m)		285.6 / 685.5

(2) Estimation by Ground Water Estimation Committee Norms

For estimation of ground water recharge, "Ground Water Estimation committee Norms, 1984"(GEC) are considered and 'rainfall infiltration method' is adopted. As this method is suitable in areas, where ground water level monitoring is not adequate in space and time.

The system command area mainly consists of active alluvial plains and recent alluvial plains "Lower Piedmont", the soils of which is very deep, sandy to fine loamy in texture and well drained to somewhat imperfectly or poorly drained. The soils of the active alluvial plains are generally very deep, yellowish brown to grayish brown in color, dominantly coarse textured (loamy sand to loamy fine sand) lying on present river channels as well as low and high terraces. The soils have moderately high to high permeability and are very well drained. The infiltration index is considered as 10 to 15%. The following consideration as per GEC, 1984 norms has been adopted for the area of study.

(a) Rainfall infiltration index is taken as 10%.

(b) 10% of total geographical area is not suitable for ground water recharge so net area contributing towards groundwater.

(c) Seepage factor as 30% during monsoon and non-monsoon.

(d) Total length of canal which is unlined is 364 km for distribution canal and main canal

(e) Average wetted perimeter of the canal section is considered as 4.6 meters.

(f) Canal runs for 215 days annually

(g) Recharge due to seepage from unlined canal is taken as 15 ha-m /million sqm of wetted area of canal.

(h) Only annual groundwater recharge is considered.

(i) Existing annual draft from ground water = 215.91 ha-m

Depending upon above mentioned criteria annual utilizable ground water of study area is worked out as follows:

(1) Annual ground water recharge during monsoon

= average annual monsoon rainfall x infiltration index x Net area suitable for recharge

= 1389*0.85*0.1*(14125)/1000 = 1667.668 ha-m

(2) Annual ground water recharge during non monsoon

= 1389*0.15*0.1*14125/1000 = 441.44 ha-m

(3) Return flow from Irrigation: Table4.10 indicates present irrigated area and gross irrigation requirement, which can be used to calculate return flow from irrigation.

Table4.10 Present cropped area and GIR

S.NO	Crops	Cropped Area (ha)	NIR (mm)	GIR (mm)
1	Monsoon Paddy	11300	75	179
2	Spring Paddy	3500	362	862
3	Wheat	2500	221	526
4	Maize	200	229	545
5	Oilseed	400	148	352
6	Pulses	400	199	474
7	Vegetables	500	109	260

(a) Return flow during monsoon = 11300*0.3*179/1000 = 606.81 ha-m

(b) Return flow during non monsoon = 0.3*(3500*862+2500*526+ 200*545+400*352 + 400 *474 +500*260)/1000 = 1470.42 ha-m

(4) Recharge due to canal seepage

canal length = 328 km average perimeter = 4.6 m

Canal seepage loss = (328*4.6*15)/1000 = 22.632 ha-m

(5) Recharge from water body

Total area of pond and tank in command area = 85 ha

Recharge by water body = 85*0.5 = 42.5ha-m

(6) Utilized water = 215.908

Annual ground water balance = (1)+(2)+(3)+(4)+(5)-(6) = 4035.562 ha-m

By comparing estimation of two methods, first method gives lower value of ground water potential which can be more safely used for analysis. So monthly draft is taken as 285 ha-m and maximum monthly potential can be taken 20% of total annual ground water potential (Ranvir singh, 1981) which can be 685.5 ha-m.

4.6 UNIT RATE OF WATER

The cost of surface water may be classified into two heads namely operation and maintenance cost and overhead cost of irrigation water.Total cost of surface water can be obtained by adding these two costs. Nepal government has allocated operation and maintenance cost for maintenance project at a rate of Nrs 700 per hectare command area per year. Overhead or fixed cost is not considered here for calculating total cost because fixed cost has already been recovered. Table 4.11 and Table4.12 show the unit cost of surface and ground water respectively.

Table: 4.11 Unit cost of Surface Water

Unit cost of Surface Water	
Annual O&M cost of project Nrs	700
Command Area ha	11300
Total Annual O&M Cost Nrs	7910000
Total water utilize, days	215
Total water utilize ha-m	7021.728
Unit cost of surface water, Nrs/ ha-m	1125.99
say	1126

(source Project office)

Table4.12: Unit cost of ground Water

Unit cost of ground Water	
Hourly cost, Nrs	73
Discharge, lps	15
Hourly amount of water, ha-m	0.0054
Unit cost of ground water, Nrs/ ha-m	13518.52
say	13519

(Source GW, Nepal)

From these calculations, unit rate of surface water and ground water are used as **Nrs1126 per ha-m** and **Nrs 13519 per ha-m** respectively.

4.7 WATER REQUIREMENT ESTIMATION

The assessment of crop water requirement for various crops in different seasons is an important factor in choice of crops and it is one of the basic necessities in planning of irrigation system. ETc is defined as the evapotranspiration from a disease-free, well fertilized crop, grown in large fields, under optimum soil water conditions to achieve maximum production under a given climatic region.

The water requirements of a given crop were derived through a crop coefficient that integrated the combined effects of crop transpiration and soil evaporation into a single crop coefficient, according to following relationship:

$ETcrop = Kc \times ETo$

Where: ETo is reference crop evapotranspiration, Kc is crop coefficient

Crop Coefficient

The crop coefficient (K_c) is the ratio of potential evapotranspiration for a given crop to the evapotranspiration of a reference crop. It represents an integration of effects of four primary characteristics that adjust the crop from reference grass namely crop height, albedo, canopy resistance and evaporation from soil, especially from exposed soil. The factors determining the crop coefficient are crop type, climate, crop growth stage and soil evaporation [Allen, 1998]. Crop coefficient of different crops are shown in appendix .

4.7.1 Description of the FAO Penman-Monteith method

The comparative studies and many other research studies have confirmed the superior performance of the Penman-Monteith approach. By introducing the aerodynamic and canopy resistance in the combination method, a better simulation of wind and turbulence effects and of the stomatal behavior of the crop canopy was achieved (Monteith, 1965). The earlier difficulties in the use of the method related to the estimation of the resistance values have largely overcome by progress in research and reliable estimates of the two parameters for a range of crops including the reference crops grass and alfalfa.

The FAO expert consultation reached unanimous agreement in recommending the Penman-Monteith approach as the best performing method to estimate evapotranspiration of a reference crop and adopted the estimates for bulk surface and aerodynamic resistance as elaborated by Allen et al. (1989) as standard values for the reference crop.

The adoption of fixed values for crop surface resistance and crop height required an adjustment of the concept of reference evapo transpiration which was redefined as follows:

Reference evapotranspiration is the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height (12 cm), a fixed crop surface resistance (70 s m^{-1}) and albedo (0.23), closely resembling the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with adequate water.

Thus defined, the Penman-Monteith equation used for 24-hour calculations of reference evapotranspiration and using daily or monthly mean data can be simplified as follows:

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{900}{T+273} U_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34 U_2)} \qquad (4.1)$$

where:

ET_0 : reference crop evapotranspiration [mm d^{-1}]

R_n : net radiation at the crop surface [MJ m^{-2} d^{-1}]

G : soil heat flux [MJ m^{-2} d^{-1}]

T : average air temperature [°C]

U_2 : wind speed measured at 2 m height [m s^{-1}]

(e_a-e_d) : vapour pressure deficit [kPa]

Δ : slope of the vapour pressure curve [kPa °C^{-1}]

γ : psychrometric constant [kPa °C^{-1}]

900 : conversion factor

The FAO Penman-Monteith equation can be adapted to hourly ETo calculations, of relevance in detailed research studies and for automatic weather stations, by replacing the conversion factor 900 in the equation by 37, equal to 900/24. Net radiation and soil heat flux are determined for hourly values by adjusted formulas for incoming radiation and heat flux. Comparison of hourly measured and calculated values and summations of hourly and 24-hour calculations showed good agreement (Allen et al., 1994b).

A key element in the development of the FAO Penman-Monteith equation is the assumption of the reference crop as a hypothetical crop with a fixed crop surface resistance value. Many studies on various crops have shown, however, that the crop resistance factor, which represents the stomatal behavior of the crop, is affected by climatic conditions. Solar radiation, air temperature, vapour pressure deficit, day length and wind have all been found to affect the crop resistance in different degrees and directions. The study commissioned by the European Community showed increasing crop resistance values for more southern latitudes and recommended a variable crop surface resistance factor.

However further studies undertaken by the FAO working group to evaluate this aspect (Itier, 1996; Jensen, 1994a) resulted as inconclusive and often contradictory. The original recommendation of the FAO expert panel for a universal crop is surface resistance of 70 sm^{-1} for a hypothetical grass crop is therefore maintained as a valid and standardized approximation.

4.7.2 Application of FAO Penman-Monteith with limited climatic data

The main reason to recommend the use of different ETo methods has been the limited availability of the full range of climatic data as, in particular, sunshine, humidity or wind data are often lacking.

To further standardize the use of the FAO Penman-Monteith method, additional studies undertaken to provide recommendations when limited meteorological data are available, as outlined below.

Wind data

Measured wind data are often lacking or prove unrepresentative for general crop conditions as the siting of the agro-meteorological station, the wind direction and the micro-climatic conditions of the station affect wind measurements. Daily wind speed values may show great variations on a day-to-day basis. Mean monthly values, however, show more consistent values with gradual changes over the year.

If no wind data are available, estimates can be made of average wind speed values for ETo calculations from global values on a monthly basis. Wind speed data from the nearest station can also be used for this purpose. The FAO CLIMWAT database (Smith: FAO, 1993) contains mean monthly data from more than 3200 stations and allows estimates on wind data for many locations worldwide.

In a further simplification, a worldwide average can be taken, based on CLIMWAT data, as: For windy conditions, wind speed can be approximated by an average value of 260 km day^{-1} or 3 m s^{-1} and, for low wind conditions; values of 90 km day^{-1} or 1 m s^{-1} can be taken.

$$U_2 = 2\ m\ s^{-1} \qquad (4.2)$$

Humidity data

The radiation method has been introduced in FAO No-24 to accommodate users in humid climates with measured data on temperature and radiation and with estimates for wind and humidity. Several studies (Allen, 1995) have shown that daily minimum temperature, which is more commonly available, allows reasonable estimates of the dew point temperature. Under more arid climates greater deviations may occur, with minimum temperature 1 to 3 degrees above dew point temperature when the weather station is surrounded by well-watered or irrigated vegetation, representing the reference condition. Actual vapour pressure (e_d) can be estimated (Tetens, 1930) from the minimum daily temperature (T_{min}) using the following relationship:

$$e_d = 0.611 \exp\left(\frac{17.27\, T_{min}}{T_{min} + 237.3}\right) \qquad (4.3)$$

ETo values determined according to the FAO Penman-Monteith method using humidity estimates from minimum temperatures and standardized wind values (2 m s^{-1}) were shown to improve ETo estimates over those made using a standard temperature formula (Allen, 1995).

Radiation data

Temperature methods such as the Blaney-Criddle, Turc, and the Hargreaves methods have proved to remain popular because of the lack of radiation data and the relatively easy calculation procedures.

Studies have been undertaken by the FAO working group to correlate radiation and sunshine duration with minimum and maximum temperature and with rainfall. Analogous to the relationship established in the Hargreaves method, radiation can be approximated (Allen, 1995) for inland stations from incoming extraterrestrial radiation (R_a) and the temperature deficit (T_{max}-T_{min}), using the following relationship:

$$R_s = 0.17 \frac{P}{P_o} (T_{\max} - T_{\min})^{0.5} R_a \qquad (4.4)$$

For higher elevations, a barometric correction (P/P_o) needs to be applied, where P_o is the baromeetric pressure at sea level. For coastal stations, a coefficient of 0.19 proved better, while for island stations a simple relationship could be established:

$$R_s = (-4 + 0.7\ R_a) \qquad (4.5)$$

The correlations proved to be weak on a global basis and better ETo estimates were obtained when using R_s data from the nearest station with comparable climatic conditions.

The FAO-Penman-Monteith equation is recommended as the standard method for estimating reference and crop evapotranspiration. The new method has been proved to have a global validity as a standardized reference for grass evapotranspiration and has found recognition both by the International Commission for Irrigation and Drainage and by the World Meteorological Organization.

Procedures have been established to estimate missing climatic data which allow the FAO Penman-Monteith method to be used under all conditions. This eliminates the use of any other method and will increase the transparency and consistency of reference and crop water requirement studies.

Calculation procedures for crop water management and applications for planning and management in irrigated and rain fed agriculture were further facilitated by the development of computerized procedures in CROPWAT, published as I&D No. 46 by Smith (1992). Results of ETo values of command area by using CROPWAT are shown in Table 4.13.

Table 4.13: Monthly values of ETo

Month	Max Temp oc	Min Temp oc	Humidity %	wind speed, (km/d)	Sun shine hr	Solar Radiation(mj/m^2/d)	Eto (mm/d)
January	22.5	8.5	81	86	8.3	14.9	2.2
February	25.3	10.2	77	104	9.2	18.2	3
March	30.7	14	71	121	9.6	21.6	4.3
April	34.7	20.3	60	147	10	24.2	5.7
May	34.4	23.7	67	147	9.3	24	5.8
June	33.6	25.2	78	130	6.7	20.2	4.8
July	32.3	25.3	84	121	6.2	19.3	4.4
August	32	24.8	87	104	5.9	18.3	4.1
September	31.4	23.9	89	95	6.2	17.3	3.7
October	31	21.6	78	86	7.8	17.3	3.6
November	28.7	14.1	81	78	8.9	16	2.9
December	24.3	9	91	78	8.8	14.7	2.2

4.7.3. Comparison of Reference Evapotranspiration values

The estimation of reference evaportranspiration for various crops in different seasons is an important criterion in the selection of crops to be grown and it is one of the basic needs in planning of an irrigation system. The comparative studies and many other research studies have confirmed the superior performance of the Penman-Monteith approach and correct estimates of reference evapotranspiration.Similraly, a comparison of Reference Evapotranspiration (ETo) values calculated on monthly average (mm/day) basis between Penmon monteith method and practiced modified Penmon method is shown in Table 4.14 and Figure 4.1. It confirms that ETo value reduces as low as 3.33 % in the month of December and as high as 25.85% in the month of August by estimating ETo values using Penmon-Monteith method as compared to existing ETo values using Modified Penmon method. Therefore, Penman-Monteith method for estimating ETo values would certainly reduce losses caused by overestimated values of other methods. Also cost of bigger size canal and canal structures would get reduced. Thus ETo values obtained from PM method are used to calculate irrigation requirement of different crops of the area for this study.

Table 4.14 comparison of reference ETo (mm/day)

Month	Penmen-Monteith method	Modified penman method	% decrease
January	2.2	2.44	-9.83
February	3	3.51	-14.52
March	4.3	5.18	-16.98
April	5.7	7.29	-21.81
May	5.8	7.8	-25.64
June	4.8	6.14	-21.82
July	4.4	5.77	-23.74
August	4.1	5.53	-25.85
September	3.7	4.59	-19.38
October	3.6	4.24	-15.09
November	2.9	3	-3.33
December	2.2	2.34	-5.98

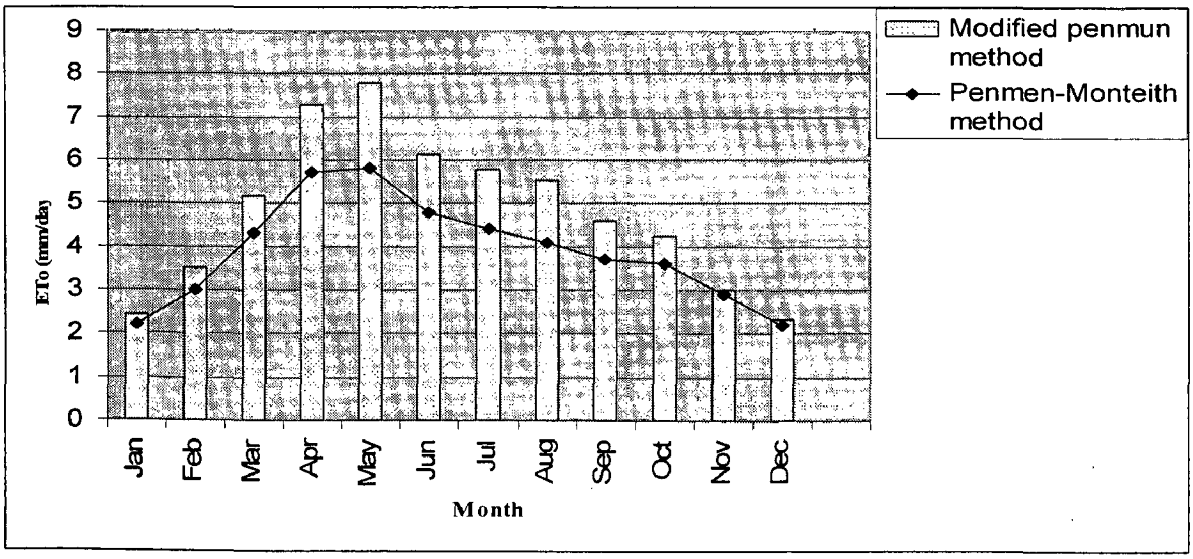

Fig.4.1 comparison of ETo values

4.7.4 Net Irrigation Requirement (NIR)

The net irrigation water requirement is the depth of irrigation water, exclusive of precipitation, carry-over soil moisture or ground water contribution or other gain in soil moisture that is required consumptively for crop production (Michael, 2002). It is the amount of irrigation water to bring soil moisture level in the effective root zone to field capacity. Neglecting carry over soil moisture or ground water contribution, NIR is computed as.

$$NIR = ETc - Pe$$

Where, ET_c = crop evapotranspiration in mm, Pe = effective rainfall in mm.

Effective Rainfall (Pe)

All the rainfall in a region is never completely utilized; a part of it may be lost by surface runoff, deep percolation or evaporation. The effective rainfall is that portion of the rain falling during the growing period of crops, which is available to meet the water requirement of crops. There are different methodologies available to estimate the effective rainfall based on the fixed percentage, dependable rain, and empirical formula and by the evapotranspiration / precipitation ratio method (USDA, 1969). The U.S. Department of Agriculture, Soil Conservation Service has developed tables relating the effective rainfall of the mean monthly rainfall and mean monthly consumptive use of the crops. Rainfall, Effective rainfall and ETo are shown in Table 4.14.

4.7.5 Field Irrigation Requirement (FIR)

It is the amount of water required to be applied to the field. This irrigation water requirement includes the losses due to seepage from the field distribution channels and deep percolation below crop root zone. It also includes runoff losses at the tail end of border and furrows in case of long fields (Michael, 2002). The losses in water application depend on the type of soil, grade (slope) of the field and method of irrigation. FIR is computed as:

FIR = NIR / η_a Where, η_a = water application efficiency.

Table 4.14: Monthly effective rainfall

Month	Eto (mm/d)	Rainfall (mm)	Effective Rainfall(mm)
January	2.2	26	25
February	3	8	8
March	4.3	20	19
April	5.7	29	28
May	5.8	74	65
June	4.8	237	147
July	4.4	331	158
August	4.1	363	161
September	3.7	211	140
October	3.6	80	70
November	2.9	9	9
December	2.2	1	1
Total	46.7	1389	831

N.B. Effective rainfall calculated using the USSCS formulas:

Effective R. = (125 - 0.2 * Total R.)* Total R. / 125 ...... (Total R. < 250 mm/month),

Effective R. = 0.1 * Total R. - 125 ... (Total R. > 250 mm/month).

4.7.6 Gross Irrigation Requirement (GIR)

GIR is the field irrigation requirement plus losses in the conveyance system due to seepage, evaporation, etc. This can be determined at outlet head or canal head depending upon the purpose of determination. It is the total amount of water applied through irrigation. GIR is computed as: GIR = FIR / η_c

Where, η_c = water conveyance efficiency of canal.

By using rainfall and climate data as mentioned above and CROPWAT software gross water requirement of different crops of command area are estimated. Field efficiency and conveyance efficiency are taken as 60 % and 70% respectively (Project report) .Table 4.15 shows the irrigation requirement of different crops of the area.

Table 4.15: Irrigation requirement of major crops of the area

		Kc	Eto (mm)	Etc (mm)	P(mm)	R eff (mm)	NIR (mm)	GIR (mm)
Paddy (m)	JulyII	1.10	66	72.6	331	158	0	0
	August	1.10	123	135.3	363	161	0	0
	September	1.10	111	122.1	211	140	0	0
	October	1.00	108	108	80	70	38	90
	NovemberI	0.95	43.5	41.33	4.5	4.5	36.83	88
Wheat	NovemberII	0.43	43.5	18.71	4.5	4.5	14.21	34
	December	0.85	66	56.1	1	1	55.1	131
	January	1.15	66	75.9	26	25	50.9	121
	February	1.03	90	92.7	8	8	84.7	202
	MarchI	0.40	64.5	25.8	20	19	6.8	16
Oilseeds	DecemberII	0.40	33	13.2	0.5	0.5	12.7	30
	January	0.63	66	41.58	26	25	16.58	39
	February	1.00	90	90	8	8	82	195
	MarchI	0.72	64.5	46.44	20	19	27.44	65
Pulses	December	0.45	66	29.7	1	1	28.7	68
	January	0.85	66	56.1	26	25	31.1	74
	February	1.05	90	94.5	8	8	86.5	206
	MarchI	0.96	64.5	61.92	20	19	42.92	102
Vegetable(winter)	November II	0.28	87	24.36	4.5	4.5	19.86	47
	December	0.34	66	22.44	1	1	21.44	51
	January	0.90	66	59.4	26	25	34.4	82
	FebruaryI	0.92	45	41.4	8	8	33.4	80
Maize 1	MarchII	0.45	64.5	29.03	10	9.5	19.53	46
	April	0.70	171	119.7	29	28	91.7	218
	May	1.05	174	182.7	74	65	117.7	280
	June	0.93	144	133.9	237	147	0	0
Paddy (E)	MarchII	1.10	64.5	70.95	10	9.5	61.45	146
	April	1.10	171	188.1	29	28	160.1	381
	May	1.18	174	205.3	74	65	140.3	334
	June	1.00	144	144	237	147	0	0
	JulyII	1.00	66	66	165.5	79	0	0

(Kc values are taken from Irrigation diary, Nepal 2006-07)

CHAPTER-5

MODEL FORMULATION

5.1 GENERAL

A model is representation of real world. Developing a model allows a comprehensive analysis because the process is a logical expression of complexities, unique characteristics, and possible uncertainties of the problem. Logical expression requires a mathematical formula in terms of equation, inequalities to represent the interrelationships among the system elements. The model must be capable of representing characteristics of problem, such as deterministic or stochastic nature, static or dynamic elements, input and output requirements and the measurement of objective criterion.

The model is the convenient vehicle which helps to analyze the complex reality in a concise and relatively simpler manner. A model clarifies the feasible decision alternatives, economic and non economic consequences of these alternatives and optimum alternative for the problem Continuous updating of model parameter is necessary because problem may change with time. After model formulation optimal values of decision variable are derived which optimize the given decision criterion (objective).

Mathematical models that were previously interpreted manually can now be analyzed on a computer, allowing the models to be operated rapidly. The study and use of the model though is of very old origin, but in the application of system analysis for water resources system is of recent origin. The true value of management science is realized when model solution is put to actual use.

The significant contribution of irrigation water to farmer's income and nutritional requirement, the need for sustainable and efficient water use, the regional constraints to water consumption, and the ensuring of the financial viability of water administration, are some of the reasons that make sustainable irrigation water management a complex but also a challenging issue. For this reason, there is a stressing need to formulate decision-making models in irrigation water management that recognize the multiplicity of objectives and goals and that seek for "optimal" solutions in a complex socio-economic and environmental system. Linear programming and Goal programming models are used in the present study to optimal allocation of resources in the command area of Kosi irrigation System, Nepal.

5.2 LINEAR PROGRAMMING

Linear programming (LP) is a mathematical modeling technique useful for allocation of 'scarce' or 'limited' resources such as labor, material, machine, time etc to several activities, such as product, services, project etc on the basis of given criterion of optimality. The criterion of optimality generally is either performance, return on investment, profit or cost etc. It is a remarkable tool whose application involves the general problem of allocating limited resources among competing activities in a best possible way. More precisely, this problem involves selecting the level of certain activities. The choice of activity levels then dictates how much of each resource will be consumed by each activity. Linear programming has found wide application in business and agriculture, as most managerial problems involve resource allocation. Linear programming involves the formulation and solution of a certain type of managerial problem by optimizing a linear objective function subject to linear constrains. The main advantages of linear programming are as follows:

1. Most of the times it is not possible to express field problems as equations, they may appear as inequalities. In such cases linear programming can be used to solve the problem.

2. It is often impossible to formulate as many equations as number of unknown, which is a necessary requirement for solution of simultaneous equations. In that case linear programming technique will help to solve the problem.

3. Solving simultaneous equations is very time consuming even if number of unknowns is equal to number of equations. Linear programming saves lot of time.

4. Linear programming can be used to solve the problem giving optimal solutions that algebraic and mathematical methods do not provide.

5.2.1 Requirements

A typical decision problem faced by management is the optimum allocation of scare resources. Resources may be money, manpower, materials, machine capacity, time, space, land, water or technology. Management's task is to achieve the best possible outcome with the given resources. The desired outcome may be measured in terms of profits, costs, effectiveness, sacrifice, time, space and welfare of the public. Expressed in a linear relationship among the system variables, it thus becomes the objective function of a linear programming model. The amount of available resources, also expressed as linear functions (equations or inequalities), represents constraints which define the feasibility area of optimization. Linear programming is used to identify the best combination of limited resources so as to optimize the objective.

5.2.2 General Structure of LP Model

The objective function:

A linear programming problem must have an explicit criterion to optimize. It is called the objective function. The objective function of each LP problem is expressed in terms of decision variables to optimize the criteria of optimality. The objective function may be one of either maximization or minimization of the criterion, but never both. For example, the objective of the programming may be maximization of profits, effectiveness, or utility or it can be minimization of costs, time or distance.

Limited Resources or Constraints or functional constraints:

If there is unlimited resources, efficient resources allocation would present no managerial problem. The restrictions normally are referred to as constraints. In order to apply linear, a decision problem must involve activities that require consumption of limited resources. The amount of limited resources is usually expressed as constraints of the problem.

Decision Variable and their relationship:

Linear programming is most effective for those problems that involve a large number of decision variables. These variables are usually interrelated in terms of utilization of resources, and require simultaneous solution. More over these activities or decision variable should be non negative.

5.2.3 Assumption of LP Model

Proportionality or Linearity

The primary requirement of linear programming is the linearity in the objective function and in the constraints. The word "linear" implies that relationships among the decision variables must be directly proportional. The contribution of each activity to the value of objective function is proportional to the level of activity. Similarly, the contribution of each activity to the left hand side of each functional constraint is proportional to the level of activity. Consequently, this assumption rules out any exponent other than 1 for any variables in terms of any function (whether the objective functions or the function on left hand side of as functional constraint) in a linear programming model. Although the proportionality rules out the exponents other than one, it does not prohibit cross product terms (terms involving the product of two or more variables).

Additivity:

Every function in a linear programming model (whether the objective functions or the function on the left hand side of functional constraints) is the sum of the individual contributions of the respective activities. In simple manner, it may be described as the primary requirement of linear programming is the linearity in the objective function and in the constraints.

Divisibility:

Decision variables in a Linear Programming model are allowed to have any values, including non integer values that satisfy the functional and non negativity constraints. Thus, these variables are not restricted to just integer values. Since each decision variable represents the level of some activity it is being assumed that the activities can be run at fractional levels. In other words, Linear Programming requires a complete divisibility of the resource utilized and the units of decision variables. Fractional values of the decision variables and resources must be permissible in obtaining an optimal solution. Resources and activities must be considered continuous within a relevant range.

Deterministic:

In Linear Programming, all model coefficients (e. g., unit profit contribution of each product, the amount of resource required per unit of product, and the amount of available resources) are assumed to be known with certainty. In other Words, Linear Programming implicitly assumes a decision problem in a static time period. In real World situation however, model coefficients are never deterministic. A number of techniques have been developed to handle Linear Programming problem with uncertain coefficients, such as sensitivity analysis, parametric linear programming and chance constrained programming.

5.2.4 Application Areas

Linear programming has been successfully applied to a wide spectrum of problem across many different fields. However, business and industry, agriculture, and military sectors have made the most extensive use of linear programming. In addition, many applications can be found in engineering and sciences, including branches of engineering like chemical, civil, architecture and economics, political science and forestry management and many more, the list of applications of linear programming is expected to grow especially in new areas of urban planning and development, ecology management, pollution control and population planning, Irrigation management etc.

5.2.5 Limitations

Any specification of values for the decision variables is called a solution and a solution for which all the constraint is satisfied is a feasible solution. An infeasible solution is the one where constraint is violated.

Linear programming does not give the solution of infeasible problems. For solving problem involving multiple conflicting objectives, using Linear Programming techniques, it is required to introduce another objective (other than objective function) as model constraints. The Linear Programming model is based on basic assumption that the optimal solution must satisfy all the system constraints. Moreover, it is assumed that all the constraints have equal importance. But in real world problems, this assumption is absurd. Because all the system constraints of any problem can not be satisfied. Moreover, all the constraints seldom have equal importance.

5.2.6 Linear promming Model

Linear programming is concerned with the optimization of a given objective subject to a number of environmental, social and / or system constraints. In real life linear programming model may be either of maximization or minimization type. The basic difference between the maximization and minimization models of linear programming is the direction of inequalities of the system constraints. The system constraints may be of (≤), (=) or (≥) type, decision variables may be non-negative or unrestricted in sign.

Maximize or Minimize $Z = C_1 X_1 + C_2 X_2 + \ldots + C_n Xn$

Subject to

$a_{11} X_1 + a_{12} X_2 + \ldots + a_{1n} Xn \leq \text{or} \geq \text{or} = b_1$

$a_{21} X_1 + a_{22} X_2 + \ldots + a_{2n} Xn \leq \text{or} \geq \text{or} = b_2$

$a_{31} X_1 + a_{32} X_2 + \ldots + a_{3n} Xn \leq \text{or} \geq \text{or} = b_3$

……………………………………………………………………………

……………………………………………………………………………

$A_{m1} X_1 + a_{m2} X_2 + \ldots + a_{mn} Xn \leq \text{or} \geq \text{or} = b_n$

$X_1, X_2, X_3, \ldots\ldots X_n \geq 0$

Where ,

C_j = Unit contribution rate or cost coefficient

a_{ij} = Technological coefficient or structural coefficient

b_i = Given resources (Right hand side value) or linear vector stipulation

X_j = Decision (or activity) variable

m = number of system constraints

n = number of decision variables

The preceding model can be formulated in a more general form as

Maximize or minimize $Z = \sum_{i=1}^{N} Cj * Xj$

subject to ,

$$\sum_{j=1}^{N} aijXj \quad \leq \text{ or} \geq \text{ or} = \quad b_i$$

$$Xj \geq 0$$

Where ,

$i = 1,2,, \ldots\ldots\ldots m$

$j = 1,2 , \ldots\ldots\ldots\ldots n$

5.2.7 Model Formulation

The following assumptions are made in the formulation of the model: (1) agricultural production is not large enough to affect the market prices of various crops; (2) all inputs, including water, required for optimal crop production are available; (3) water application, soil and land properties, and agricultural production are assumed to be uniform over the study area; (4) the economic unit values of inputs and outputs are assumed to be constant throughout the period of analysis.

From the planning perspective, the strategies mentioned by Ministry of Water Resources, Nepal (1988) may be specified as the operational objectives of maximization of net agricultural economic benefits, maximization of protein and calorific value and maximization of total irrigated cropped area, which govern the choice of a particular irrigation development plan. The first objective basically refers to the economic efficiency measure of the agriculture system and second and third objective is related to nutrition requirement while the fourth is concerned with balanced regional development, which relates to social equity for the generally uniform land holdings and socio-economic state of the farmers in the study area. The following multi-objective linear programming (LP) model is formulated:

The model formation requires selection of decision variables, objective function and system constraints.

The Decision Variables

The decision variables in the formulated Linear Programming model are

i) Optimal cropping areas Ai , i= 1,2...N

ii) Optimal water release Sj , Gj= 1,2...12

Objective function

In present study, for optimal allocation of land and water resources to different crops, following objective functions are formulated as per proposed cropping pattern under various constraints.

Objective1. Maximize the total net economic benefits from agriculture less the costs of production,

$$\text{Maximize } Z = \sum_{i=1}^{N} Ai * Ri - \sum_{i=1}^{12} Si * Cs - \sum_{i=1}^{12} Gi * Cg \qquad (5.1)$$

Where,

Ai= Area under i th crop activity in ha

R_i= Net return per hectare (excluding water charges) form ith crop activity in Rupees

N= Total number of crops

= 1,2,..............7

S_i= Optimal surface water releases

G_i= Optimal ground water release

C_s= Cost of unit volume of surface water

Cg= Cost of unit volume of ground water

Objective 2. Maximization of calorific value

$$\text{Maximize } Z=\sum_{i=1}^{N} Ai*Yi*Ci \qquad (5.2)$$

where ,

Y_i= Yield of i^{th} crop activity.

C_i= Calorie content of i^{th} crop activity.

Objective 3. Maximization of protein value

$$\text{Maximize } Z=\sum_{i=1}^{N} Ai*Yi*Pi \qquad (5.3)$$

Where,

Pi = Protien content of i^{th} crop activity.

Objective 4. Maximize the total irrigated cropped Area

$$\text{Maximize } Z=\sum_{i=1}^{N} Ai \qquad (5.4)$$

Constraints

The objectives are subject to various limitations like water (surface and groundwater) availability, minimum area for each crop, calorie requirements and protein requirement.

1. Crop water requirement:

if I_{it}, is the gross irrigation water requirement per unit area for crop type N *in month* t, The water utilization by any crop in any month should not be more than the surface and ground water available in that month .

The general constraint equation is ;

$$\sum_{i=1}^{N} I_{it} * Ai \le S_t + G_t \qquad (5.5)$$

Where,

I_{it} =Gross irrigation requirement in excess of effective rainfall for the i^{th} crop in t^{th} month.

N =Total number of crops which are grown in t^{th} month

A_i =Area allocation to i^{th} crop

S_t =Gross surface water released through canal head in t^{th} month.

G_t = Gross groundwater available in t^{th} month.

i =Number of crop activities

t = Number of months

2. Maximum area availability constraint :

Area under various crops during any month can not exceed the cultivable command area (CCA) of the study area . Hence total area under Kharif or monsoon crops can not exceed the CCA. Similarly, total area under Rabi (winter) crops and Spring crop should be less than CCA.

In this case the constraint equation is ;

$$\sum_{i=1}^{N} Aij \le TA \qquad (5.6)$$

Where,

TA = Total available land (CCA).

A_{ij} = Area allocated to the ith crop in j^{th} season.

3. Minimum Area Constraint:

In order to avoid excessive transportation of various food grains like pulses, cereals, oil seeds etc. and to fulfill the minimum requirement of the inhabitants of the study area as per their food habits and nutritional requirements, a minimum area for each crop is considered.

In this case the constraint equation is;

$$A_i \geq T_i \text{ (min)} \qquad (5.7)$$

Where,

T_i (min) = minimum area allocated to i th crop.

4. Surface Water availability Constraint:

The maximum surface water utilization by crops during any month can not exceed the net surface water available in that month for utilization or conveyance capacity of canal which ever is minimum.

The constraint equation is

$$S_t \leq Q_{st} \qquad (5.8)$$

Where,

S_t = Surface water requirement in month t.

Q_{st} = Surface water Available in month t .

5. Ground Water availability constraint:

Ground water withdrawal for irrigation in any month should not exceed the $(1/12)^{th}$ or 20% of utilizable balance annual ground water recharge.

The constraint equation may be given as;

$$G_t \leq Q_{gt} \tag{5.9}$$

Where,

G_t = Ground water requirement in t^{th} month.

Q_{gt} = Ground water Available in month t.

6. Protein requirement constraint

Protein requirement is imposed so as to satisfy the minimum protein requirement for the population in the study area in year 2032 AD.

The constraint equation is ;

$$\sum_{i=1}^{N} Ai * Yi * Pi \geq PR \tag{5.10}$$

Where,

Pi = Protein value of i^{th} crop.

PR = Total yearly protein requirement.

7. Calorie Requirements Constraint :

In order to satisfy the calorie requirement of the population of the study are during 2005 AD, this constraint is imposed as ;

$$\sum_{i=1}^{N} Ai * Yi * Ci \geq CR \tag{5.11}$$

Where,

Ci = Calorific value of i^{th} crop .

CR= Total yearly calorie requirement.

8. Non-negativity of the decision variables:

$A_i, G_t, S_t \geq 0$

5.2.8 Linear Programming Model for the study Area

The model formulated for the command area of Kosi irrigation system, Nepal is described below.

Objective Function

Objective1. Maximization of Net Return: -

Net return for each crop is estimated in Table 4.7. Similarly, unit rate of surface and ground water estimated earlier are Nrs 1126 and Nrs 13519 respectively. The objective function may be formulated as;

Maximize Z= 2.450 *A1 + 2.28 *A2 + 8.57 *A3 + 5.03 *A4 + 35.3 *A5 + 13.415* A6 + 2.300 *A7 - 1.126* S1 - 1.126 *S2 - 1.126* S3 - 1.126 *S4 - 1.126* S5 - 1.126* S6 - 1.126* S7 - 1.126* S8 - 1.126* S9 -1.126* S10 -1.126 *S11 - 1.126* S12 - 13.519* G1 - 13.519* G2 - 13.519* G3 - 13.519 *G4 - 13.519 *G5 - 13.519 *G6 - 13.519* G7 - 13.519* G8 - 13.519* G9 - 13.519* G10 - 13.519 *G11 - 13.519* G12

Objective2. Maximization of Calorific Value:-

Calorific value of each crop per unit area are estimated in chapter 4 and presented in Table 4.4. The objective function may be formulated as;

Maximize $Z= 7.535 * A_1+ 8.832 * A_2+3.787 * A_3+ 2.297 * A_4 + 16.000 * A_5 + 10.260* A_6+ 9.134 * A_7$

Objective 3. Maximization of Protein value :-

Protein content of each crop per unit area are estimated in chapter 4 and presented in Table 4.4. The objective function may be formulated as;

Maximize $Z= 0.159 * A_1 + 0.313* A_2 + 0.154 * A_3 + 0.162 * A_4 + 0.800 * A_5 + 0.333* A_6 + 0.193 * A_7$

Objective 4. Maximization of command Area:-

Total crop of all season is considered and the objective function may be formulated as;

Maximize $Z = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7$

Where,

A_1	Monsoon Paddy	A_2	Wheat,	A_3	Oilseed,
A_4	Pulses,	A_5	Vegetables,	A_6	Maize,
A_7	Spring Paddy				

S1 , S2, ... S12 are surface water released in each month from January to December. G1, G2, ... G_{12} are utilizable balance ground water recharge in each month from January to December. Here area is Sq km, Water supply in million cumecs.

Constraints

(1) **Water Availability Constraints**:

Monthly water requirement water for each crop is estimated in Table 4.15 and sum of water requirement of all crops on monthly basis must be less than monthly available sum of surface and ground water.

January	$0.121 * A_2 + 0.039 * A_3 + 0.074 * A_4 + 0.082 * A_5 \leq S1 + G1$
February	$0.202 * A_2 + 0.195 * A_3 + 0.206 * A_4 + 0.079 * A_5 \leq S2 + G2$
March	$0.016 * A_2 + 0.065 * A_3 + 0.102 * A_4 + 0.146 * A_7 \leq S3 + G3$
April	$0.218 * A_6 + 0.381 * A_7 \leq S4 + G4$
May	$0.280 * A_6 + 0.334 * A_7 \leq S5 + G5$
October:	$0.091 * A_1 \leq S10 + G10$
November:	$0.088 * A_1 + 0.034 * A_2 + 0.047 * A_5 \leq S11 + G11$
December:	$0.131 * A_2 + 0.030 * A_3 + 0.068 * A_4 + 0.051 * A_5 \leq S12 + G12.$

(2) **Land Availability Constraints**: Total cultivable command area of the system is 11300 ha so seasonal crop area must be less than total cultivable command area.

Summer $A_1 \leq 11300$

Winter $A_2 + A3 + A_4 + A_5 \leq 11300$

Spring $A_6 + A7 \leq 11300$

(3) **Minimum and maximum cropped area constraint**: Area under any crop should be more than minimum area which is needed for yearly food requirement of the projected population as per food habit and nutritional requirement. Due to unavailability of storage facilities for vegetables, cropped area for vegetable is allocated to maximum value. Minimum area required for each crop is presented in Table 4.1.

$A_1 \geq 31.48$

$A_2 \geq 13.22$

$A_3 \geq 40.78$

$A_4 \geq 41.52$

$A_5 \leq 4.00$

$A_6 \geq 4.95$

$A_7 \geq 11.13$

(4) Surface water availability constraints: Monthly Surface water should be less than monthly available surface water of the system as presented in Table 4.8.

January

$S_1 \leq 23.33$

February

$S_2 \leq 23.33$

March

$S_3 \leq 23.33$

April

$S_4 \leq 23.33$

May

$S_5 \leq 23.33$

June

$S_6 \leq 11.66$

July

$S_7 \leq 11.66$

August

$S_8 \leq 23.33$

September

$S_9 \leq 23.33$

October

$S_{10} \leq 23.33$

November

$S_{11} \leq 23.33$

December

$S_{12} \leq 23.33$

5) Ground water availability constraints: Monthly Ground water should be less than monthly available ground water of the area as presented in Table 4.9.

January

$G_1 \leq 6.85$

February

$G_2 \leq 6.85$

March

$G_3 \leq 6.85$

April

$G_4 \leq 6.85$

May

$G_5 \leq 6.85$

June

$G_6 \leq 6.85$

July

$G_7 \leq 6.85$

August

$G_8 \leq 6.85$

September

$G_9 \leq 6.85$

October

$G_{10} \leq 6.85$

November

$G_{11} \leq 6.85$

December

$G_{12} \leq 6.85$

(6) Calorie requirement constraint

$$7.535*A1 + 8.832*A2 + 3.787*A3 + 2.297*A4 + 16*A5 + 10.26*A6 + 9.134*A7 \geq 914.68$$

(7) Protein requirement constraint

$$0.159*A1 + 0.313*A2 + 0.154*A3 + 0.162*A4 + 0.8*A5 + 0.333*A6 + 0.193*A7 \geq 25.05$$

(8). Non-negativity of the decision variables:

$Ai, Gt, St \geq 0$

Using above objective functions and various system constraints, various linear programming optional plans are prepared and enlisted along with symbols. Table no 5.1 describe different individual maximization plan under different constraints.

Table 5.1 Different maximization plan

Constraints	Plan of Maximization of net economic return	Plan of Maximization of cropped Area	Plan of Maximization of Protein and calorific value
Seasonal area,Max cropped area, SW and GW	PLR_1	PLA_1	PLP_1
Seasonal area, Min max cropped area, SW and GW,	PLR_2	PLA_2	PLP_2
Seasonal area, Min max cropped area with SW only	PLR_3	PLA_3	PLP_3
Min max cropped area and SW & GW,	PLR_4	PLA_4	PLP_4

5.3 GOAL PROGRAMMING MODEL

5.3.1 General:

Linear programming models were formulated and solved to optimize an objective functi value (a single measure of effectiveness) under a set of constraints. However, optimization such a single objective function is not often representative of reality due to divergent a conflicting interests and objectives (economic as well as non-economic) of any business, serv or commercial organization. Consequently, there arises a need to attain a 'satisfactory' level achievement among and conflicting interests or goals of an organization or decision makers.

Multiple criteria decision-making (MCDM) is the method to solve decision problems t involve multiple and sometimes conflicting objectives. It is actually a way of looking at comp problems, by breaking them into more manageable pieces in order to present a coherent ove picture to the decision makers. MCDM is a substantially broader body of methodologies which Goal programming is a small subset.

5.3.2 Goal programming

Goal programming (GP) is an approach used for solving a multi-objective optimizat problem that balances trade-off in conflicting objectives. In other words, it is an approach deriving a best possible 'satisfactory' level of goal attainment. A problem is modeled into model in a manner similar to that of the LP model. However the GP model accommoda multiple and often conflicting in commensurable (dimension of goals and unit of measurem may not be same) goals in a particular priority order (hierarchy). A particular priority structur established by ranking and weighing various goals and their sub goals, in accordance with tl importance. A priority structure helps to deal with all goals (objective which cannot completely / or simultaneously achieved), in such a manner that more important goals are achieved first at the expense of less important goals.

Its general aim is to optimize several objective functions and at the same time to minimize the deviation for each of these objectives from the corresponding desired targets. It can be thought of as an extension or generalization of linear programming to handle multiple, normally conflicting objective measures. Each of these measures is given a goal or target value to be achieved. Unwanted deviations from this set of target values are then minimized in an achievement function. This can be a vector or a weighted sum dependent on the goal programming variant used. As satisfaction of the target is deemed to satisfy the decision maker(s), an underlying satisfying philosophy is assumed.

Goal programming was first used by Charnes, Cooper and Ferguson in 1955.The first engineering application of goal programming, due to Ignizio in 1962, was the design and placement of the antennas employed on the second stage of the Saturn V. This was used to launch the Apollo space capsule which landed the first men on the moon. In the context of agriculture; goal programming can be used in order to detect the best choice of crops, water consumption and farming practices in a given agricultural area. It is one of the oldest multi-criteria decision making techniques and perhaps the most frequently used one in agricultural planning.

The basic approach of goal programming is to establish a specific numeric goal for each of the objectives, formulate an objective function for each goal, and then seek a solution that minimizes the (weighted) sum of deviations of these objective functions from their respective goals. There are three possible types of goals:

1. A lower, one sided goal sets a lower limit that does not want to fall under (but exceeding the limit is fine).

2. An upper, one – sided goal sets an upper limit that we do not want to exceed (but falling under the limit is fine).

3. A two – sided goal sets a specific target that we do no want to miss on either side.

Goal programming, which is a special extension of linear programming, is capable of solving decision problems with a single goal or multiple goals. In Goal programming, instead of trying to maximize the objective criterion directly, as in linear programming, the deviations among Goals and what can be achieved within in the given set of constraints are to be minimized. In Goal Programming such type of variable is represented in two dimensions, positive and negative deviations from each sub goal or goal (where as in linear programming such variable is known as slack variable). Then the objective function becomes the minimization of these deviations based on the relative importance or priority assigned to them.

Professor Herbert A. Simon, an authority on decision theory, states that today's manager is not trying to optimize; instead he tries to "satisfice". An optimizer usually seeks the best possible outcome for a given objective, such as profit maximization in linear programming a satisfier, on the other hand, attempts to achieve a satisfactory level of multiple objectives. So according to professor Simon's theory, Goal Programming is an appropriate technique for modern decision analysis which gives best possible and satisfactory goal achievement.

5.3.3 Differences between LP and GP

Linear programming (LP) has two major limitations from its application point of view the first one is single objective function and the second one is same unit of measurement of various resources. However, in actual practice, the decision- maker not satisfies with single objective.

The solution of any LP problem is based on the cardinal value (the number that expresses exact amount such as 1, 2,3...) such as cost or profit, whereas GP allows ordinal ranking of goals in terms of their importance to the organization . Usually priority of a desired goal is assigned and then there priorities are ranked in an ordinal sequence. Whenever there are multiple incommensurable goals, LP incorporates only one of these goals in objective function and treats remaining goals as constraints. Since the optimal solution must satisfy all the constraints, this implies that the several goals within the constraint equation are of equal important and there goals have absolute priority over the goal incorporated into the objective function. However, in reality, such assumptions are absurd. It is quite possible that all constraints of the problem can not be satisfied. Such a problem is "Infeasible". Further, all constraints do not have equal importance. Such type of problems can be solved efficiently using goal programming technique.

5.3.4 Theory of Goal Programming

There are two-important features of objective function, firstly, it must be of minimization type and secondly, it consists of either a pair or a single deviational variable for each goal constraint.

Also the following three possibilities are open to an objective function in the Goal programming approach:

i. If over achievement is acceptable, positive deviation from the Goal (di^+) can be eliminated from the objective function.

ii. If under-achievement is acceptable, negative deviation (di^-) from the Goal can be eliminated from the objective function.

iii. If exact achievement of the Goal is desired, both negative (di^-) and positive (di^+) deviations must be present in the objective function.

The most important part of the Goal programming algorithm is its objective function which consists of the following three vectors:

a. Deviation variable

b. Ordinary priority factors, and

c. Weighted factors

a. Deviational Variable

The matrix used in Goal Programming is composed of two types of constraints. They can be Goal and Non Goal constraints. Each Goal constraints may be assigned a positive or a negative deviational variables or both. Anywhere along the line labeled, “Goal”, there is complete Goal attainment. If more than the desired Goal level is obtained, there is positive deviation from the goal (di^+). Under achievement (di^-) means the desired goal level was not attained and therefore, would be below this line. An optimal solution is obtained when the sum of non attainment of goals is minimized accordingly to priority structure established by the decision maker.

b. Priority ranking

Once the deviational variables have been determined, the next step is to assign the ordinal priority factors, i.e., the negative and / or positive deviations about the goal are ranked according to an ordinal priority ranking scale in order of preference of each goal level.

The goal programming solution will allow some lower priority goals to go unsatisfied in order that higher priority goals, which may conflict with lower priority, ones, achieve the targets. This ranking of deviational variables which appear in the objective function is the most important step in formulating a goal programming problem which consists of incompatible goals. Accordingly to this, the highest priority factor is assigned to deviational variables of most important goal. The lowest priority factor is assigned to deviational variable of least important goal. Thus, low order goals are considered only after higher order goals are achieved as desired. The priority factors have the relationship of Pj>>> Pj+1. The priority relationship indicates that if lower order goal is multiplied by 'n', however, larger "n" may be even then it can not be as important as the higher goal.

c. Weighted factors

One more step to be considered in the goal programming model formulation is the weighting of deviational variables at the same time priority levels. Deviational variables within same priority level can be ordered in an ordinal sequence based on their importance relative to each other. The higher weighting factor is assigned to more important deviational variables and the next lower to next lesser important and so. The deviational variables and ordinal priority factors are always present in each objective function whereas the weights need not be assigned but are useful when needed.

Based on the priority levels, the Goal programming can be classified as :

1. Preemptive Goal Programming.
2. Non-preemptive Goal Programming.

When there is a hierarchy of priority levels for the goals, means one or more of the goals clearly is far more important than the others, it falls under preemptive goal programming whereas when we deal with goals on the same priority level our approach is non-preemptive goal programming.

Goal programming can further categorized as

Lexicographic goal programming

The lexicographic method is based on the logic that in some decision making systems some goals seems to prevail. Pre-emptive weights are attached to the sets of goals, which are classified in different priorities. The procedure begins with comparing all the alternatives with respect to the higher priorities goals and continues with the next priority until only one alternative is left. In other words, the fulfillment of a set of goals that is situated at a certain priority is immeasurably preferable to the achievement of any other set placed at a lower priority. Because of this characteristic, there are no alternative optima if a higher priority could not be satisfied and excessive prioritization of goals can possibly lead to unrealistic models. So, the goals should be divided into a small number of pre-emptive priorities.

Weighted Goal Programming (WGP)

WGP considers all goals simultaneously within a composite objective function comprising the sum of all respective deviations of the goals from their aspiration levels. The deviations are then weighted according to the relative importance of each goal, wa. To avoid the possible bias effect of the solutions due to different measurement units of goals, percentage normalization takes place (i.e. the model minimizes the sum of the percentage deviations from the targets)

5.3.5 Application areas and limitations

In general a goal programming model performs three types of analysis: 1. It determines the input requirements to achieve a set of goals. 2. It determines the degree of attainment of defined goals with given resources. 3. It provides the optimum solution under the varying inputs and goal structures.

The most important advantage of goal programming is its great flexibility, which allows model simulation with numerous variations of constraints and goal priorities. Problem encountered in linear programming due to inequalities in the wrong direction, equality, variables unconstraint in sign etc., do not present any difficulty in goal programming. This is because we evaluate goals in terms of both under achievement and over achievement. Because of aforesaid characteristics and due to recent increase in interest in Goal programming, it can be applied to almost unlimited managerial and administrative decision areas. Beside these financial planning, marketing strategy planning, and decision analysis in public and nonprofit organizations are other application areas of goal programming.

Beside wide spectrum of applicability of goal programming, there are several complications that often emerge in goal programming problems. on positive right hand side values; Goal programming model seldom take negative right hand side values as it is based on simplex method which require nonnegative condition for variables, when we frame constraints.

The goal programming approach is not the ultimate solution for all managerial decision problems. It requires that the decision maker be capable of defining, quantify and ordering objectives. The model simply provides the best solution under the given constraints and priority structure of goals.

Goal programming technique relies heavily on decision maker's perception of the range of choice and feasibility, a set of goals may lead to an inferior solution. Thus whenever a goal programming solution yields zero deviations, the analyst should suspect that the set of goals has led to an inferior solution. Non inferiority in guaranteed only when strictly positive deviations are obtained.

5.3.6 Goal Programming Model

Goal programming is a linear mathematical model in which the optimum attainment of multiple goals is sought within the given decision environment. The decision environment determines the basic components of the model, namely the decision variables, constraints and the objective function.

Generalized form of goal programming models are;

Standard form	Vector form
Minimize $Z = d^- + d^+$	Minimize $Z = d^- + d^+$
Subject to	Subject to
$F(x) + d^- - d^+ = g_i$	or $CX + d^- - d^+ = g_i$
$\sum_{j=1}^{n} a_{ij} * X_j \leq bi$	or $Ax \leq B$
Where i= 1,2,3 ....n	
$Xj, d^-, d^+ \geq 0$	$Xj, d^-, d^+ \geq 0$

Where,

g_i = Goal level set by the decision maker

B = (m*1) column vector of right hand side constant

C = (1*n) Row vector of objective function coefficient

X = (n*1) column vector of real variables

A = (m*n) matrix of technological coefficients

d^- = deviational variable in negative direction

d^+ = deviational variable in positive direction

The expression $AX < B$ is the environmental or non-goal constraint and $CX + d^- - d^+ = g_i$ is the goal constraint. Here g_i is the goal desired which is expected from the objective function $f(x) = \sum_{j=1}^{n} C_j * X_j = CX$ to achieve as closely as possible subject to the constraint. Also, (d^-) denotes the amount by which the goal (g_i) is underachieved whereas (d^+) denotes the amount by which the goal (g_i) is overachieved by the objective function. Obviously goal (g_i) can not be simultaneously over achieved as well as underachieved. It will be either exactly achieved (in which case $d^- = d^+ = 0$), or over achieved (in which case $d^- = 0$, $d^+ > 0$) or under achieved (in which case $d^+ = 0$, $d^- > 0$). Hence, only those situations are acceptable in which at least one of the (d^-) and (d^+) is zero. In other words, $d^- * d^+ = 0$. It means that d^- and d^+ are complementary to each other. If d^- takes a non zero value, d^+ will be zero, and vice- versa. Since, at least one of the deviational variables will be zero. Moreover, if over achievement is acceptable, objective function should not contain positive deviation (d^+). Similarly, if underachievement of a certain goal is acceptable, negative deviation (d^-) can be eliminated from the objective function. In case, exact achievement of goal is desired, both (d^-) and (d^+) must be present in the objective function.

5.3.7 Model Formulation

Model is formulated as follows. There are two types of constraints i.e. goal constraint and non goal constraint.

Goal constraint

Let N_1 to N_4 and P_1 to P_4 are Negative and Positive deviation from different goals respectively.

1st Goal : Maximization of the total net economic benefits from agriculture less the costs of production.

$$\sum_{i=1}^{n} Ai * Ri - \sum_{i=1}^{12} Si * Cs - \sum_{i=1}^{12} Gi * Cg + N_1 - P_1 = \text{Total Net Return} \quad (5.12)$$

2nd Goal : Maximization of protein value

$$\sum_{i=1}^{n} Ai * Yi * Pi + N_2 - P_2 = \text{Total protein value} \quad (5.13)$$

3rd Goal : Maximization of calorific value

$$\sum_{i=1}^{n} Ai * Yi * Ci + N_3 - P_3 = \text{Total Calorific value} \quad (5.14)$$

4th Goal : Maximize the total irrigated cropped Area

$$\sum_{i=1}^{n} Ai + N_4 - P_4 = \text{Total area} \quad (5.15)$$

Where, A_i= Area under i th crop activity

R_i= Net return per hectare (excluding water charges) from i^{th} crop activity

n= Total number of crops = 1, 2,..............7

S_i= Optimal surface water releases

G_i= Optimal ground water release

Cs= Cost of unit volume of surface water

Y_i =Yield of i^{th} crop activity.

C_i= Calorie content of i^{th} crop activity.

P_i= Protien content of i^{th} crop activity.

C_g= Cost of unit volume of ground water

Non goal Constraints

1. Crop water requirement:

The water utilization by any crop in any month should not be more than the surface and ground water available in that month .

$$\sum_{i=1}^{n} I_{it} * Ai \leq S_t + G_t \qquad (5.16)$$

Where ,

I_{it} = Gross irrigation requirement in excess of effective rainfall for the i th crop in t th month in meter .

2. Maximum area availability constraint:

Area under various crops during any month can not exceed the cultivable command area (CCA) of the study area. Hence total area under monsoon crops can not exceed the CCA.
Similarly, total area under winter crops and spring crop should be less than CCA.

$$\sum_{i=1}^{n} Aij \leq AA \qquad (5.17)$$

Where ,

AA = Total available land (CCA)

A_{ij} = Area allocated to the i^{th} crop in j^{th} season.

3. Agricultural production requirement:

In order to avoid excessive transportation of various food grains like paddy, pulses, cereals, oil seeds etc. and to fulfill the minimum requirement of the inhabitants of the study area as per their food habits and nutritional requirements, a minimum area for each crop is considered and maximum area for vegetable crop due to limitation of storage

$$A_i \geq T_i \text{ (min)} \quad (5.18)$$

$$A_i \leq T_i \text{ (max)} \quad (5.19)$$

Where, T_i = area allocated to i th crop

4. Surface Water availability Constraint:

The maximum surface water utilization by crops during any month can not exceed the net surface water available in that month for utilization or conveyance capacity of canal which ever is minimum.

$$S_t \leq Q_{st} \quad (5.20)$$

Where,

S_t = Surface water requirement in t^{th} month

Q_{st} = Surface water Available in t^{th} month

5. Ground Water availability constraint:

Ground water withdrawal for irrigation in any month should not exceed the 20% of utilizable balance annual ground water recharge.

The constraint equation may be given as;

$Gt \leq Qgt$ (5.21)

Where,

Gt = Ground water requirement in t^{th} month

Qgt = Ground water Available in t^{th} month

6. Annual Ground Water availability: Groundwater pumping cannot exceed the annual ground water potential *(SY)*.

$$\sum_{i=1}^{12} Gi \leq SY \quad (5.22)$$

7. Non-negativity of the decision variables:

$S_t, G_t, A_i, AA \geq 0$ (5.23)

5.3.8 Method for multi-objective analysis

There are several schemes that could be applied in order to solve the above-formulated goal programming problem (e.g. Lexicographic, Minimax, Weighted, Extended, Interval).Among them, weighted goal programming (WGP) is selected for this study. To facilitate the implementation of the methodology, a computer software program called LINDO was used, which is designed as a good tool for Linear Multi objective and Goal programming problems .

5.3.9 Weighted Goal Programming (WGP)

WGP considers all goals simultaneously within a composite objective function comprising the sum of all respective deviations of the goals from their aspiration levels. The deviations are then weighted according to the relative importance of each goal, W_a. The model minimizes the sum of the percentage deviations from the targets. So, in the problem that is under consideration, the composite objective (achievement) function has the following form:

$$\text{Min} \quad W_1 * N_1 + W_2 * N_2 + W_3 * N_3 + W_4 * N_4 \quad (5.24)$$

Subject to

Eq (5.12) – Eq (5.23)

$n_j, p_j \geq 0$ (j = 1,2,...4)

Although decision makers' preference over each objective compared to another would give a better picture of the weight, they can be judged by assigning differential weights from both the government and farmers' viewpoints. For this reason, three different policy scenarios are examined by assigning a diverse set of weights in each case as shown in Table 5.2, Namely; a farmers' friendly (economic) scenario, health friendly and environmental welfare and finally, a

Table 5.2 Assignment of weight to different scenario

Goal	Economic scenario	Health friendly scenario	environmental scenario	Compromise scenario
W_1	0.5	0.15	0.1	0.25
W_2	0.2	0.3	0.2	0.25
W_3	0.2	0.3	0.2	0.25
W_4	0.1	0.25	0.5	0.25

compromising scenario are analyzed in order to infer the trade-offs between these, but also in order to estimate the abatement in each goal (deviation) that is necessary for a compromising solution. Gross return, Protein & calorific value and total irrigation water consumption are considered as the most important objectives in the economic, health and environmental scenario respectively, while equal weights are assigned to all objectives in the compromising one.

5.3.10 Goal programming (GP) model of study area

Following GP model under compromise scenario for an example is shown as follows

MIN 25 N1 +25 N2 +25 N3 +25 N4

Suject To

Goal constraints

Return) 2.450 A1 + 2.28 A2 + 8.57 A3 + 5.03 A4 + 35.3 A5 + 13.415 A6 + 2.300 A7 - 1.126 S1 - 1.126 S2 - 1.126 S3 - 1.126 S4 - 1.126 S5 - 1.126 S6 - 1.126 S7 - 1.126 S8 - 1.126 S9 -1.126 S10 -1.126 S11 - 1.126 S12 - 13.519 G1 - 13.519 G2 -13.519 G3 - 13.519 G4 - 13.519 G5 - 13.519 G6 - 13.519 G7 - 13.519 G8 - 13.519 G9 - 13.519 G10 - 13.519 G11 - 13.519 G12 +N1 - P1=2196

Protein) 0.159 A1+ 0.313 A2 + 0.154 A3 + 0.162 A4 + 0.8 A5 + 0.333 A6 + 0.193 A7 - P2 + N2 = 76

Calorie) 7.535 A1 + 8.832 A2 + 3.787 A3 + 2.297 A4 + 16 A5 + 10.26 A6 + 9.134 A7-P3 + N3 = 2504

Area) A1 + A2 + A3 + A4 + A5 + A6 + A7 -P4 + N4= 350

Non Goal constraints :

Water Availability constraints

JAN) 0.121 A2 + 0.039 A3 + 0.074 A4 + 0.082 A5 - S1 - G1 <= 0

FEB) 0.202 A2 + 0.195 A3 + 0.206 A4 + 0.079 A5 - S2 - G2 <= 0

MAR1) 0.039 A2 + 0.088 A3 + 0.125 A4 - 0.5 S3 - 0.5 G3 <= 0

MAR2) 0.046 A6 + 0.146 A7 - 0.5 S3 - 0.5 G3 <=0

APR) 0.218 A6 + 0.381 A7 - S4 - G4 <= 0

MAY) 0.280 A6 + 0.334 A7 - S5 - G5 <= 0

OCT) 0.091 A1 - S10 - G10 <= 0

NOV1) 0.088 A1 - 0.5 S11 - 0.5 G11 <= 0

NOV2) 0.034 A2 + 0.047 A5 - 0.5 S11 - 0.5 G11 <= 0

DEC) 0.131 A2 + 0.030 A3 + 0.068 A4 + 0.051 A5 - S12 - G12 <=0

Area (Min and Maximum) constraints

CROPM) A1 -AA <= 0

CROPW) A2 + A3 + A4 + A5 -AA <=0

CROPS) A6 + A7 -AA <= 0

CRW) A2 > 13.22

CRO) A3 > 40.78

CRP) A4 > 41.52

CRV) A5 < 4.00

CRM) A6 > 4.95

CRPS) A7 > 11.13

Surface water availability constraints

JS) S1 <= 23.33

FS) S2 <= 23.33

MS) S3 <= 23.33

AS) S4 <= 23.33

MYS) S5 <= 23.33

JUS) S6 <= 11.66

JLS) S7 <= 11.66

AUS) S8 <= 23.33

SS) S9 <= 23.33

ACS) S10 <= 23.33

NVS) S11 <= 23.33

DS) S12 <= 23.33

Ground water availability constraints

JG) G1 = 0

FG) G2 = 0

MG) G3 = 0

AG) G4 <= 6.85

MYG) G5 <= 6.85

JUG) G6 <= 6.85

JLG) G7 <= 6.85

AUG) G8 <= 6.85

SG) G9 <= 6.85

ACG) G10 <= 6.85

NVG) G11 <= 0

DG) G12 <=0

Total suface and ground water availability constraints

TG) G1 + G2 + G3 + G4 + G5 + G6 + G7 + G8 + G9 + G10 + G11 + G12 <= 34.27

TS) S1 + S3 + S4 + S5 + S6 + S7 + S8 + S9 + S10 + S11 + S12 <= 256.6

END

CHAPTER 6

RESULTS AND DISCUSSION

6.1 GENERAL

The main aim of present study is optimal allocation of land area and available water resources (surface water as well as ground water) to different crops cultivated in the command area of Kosi irrigation system, Nepal by using linear programming and goal programming techniques. Various optimal plans are prepared and comparison of each plan is done. Finally, the best plan is selected for optimal allocation of crop, land and water resources.

Accordingly models are formulated using linear programming techniques. Results of different plans are compared and optimal plan is selected. Similarly, various plans/scenarios are prepared and models are formulated using goal programming technique. Best plan is selected among different goal scenario. Lastly the optimal plan obtained by using linear programming technique and best plan obtained by using goal programming technique are compared and best one is selected as optimal crop plan for allocation of land and water resources.

Importance of reliable and realistic input data for the successful application of the water resources system models cannot be overemphasized. For the purpose of this study, various relevant study reports prepared by Government agencies and consultants are relied on as the basic sources of information. All the benefit and cost estimates were derived as the economic values in Nepalese Rupees (I US$ = 63 NRs) at the end of 2007. Details of various input data used are described in chapter 3 & 4.

6.2 L P MODEL APPLICATION AND RESULTS DISCUSSION

6.2.1 Individual optimal solutions

As the first step in modeling, the three objective functions were treated separately by solving the single objective LP problems using LINDO software. As discussed earlier Table 5.1 describe different individual plan under different constraints.

Maximization of net return

Individual optimal solutions for the maximization of net return problems are presented in Table 6.1, 6.2 and 6.3 as well as Figures 6.1, 6.2, 6.3 and 6.4. Table 6.1 and Figure 6.1 shows the maximum output of different maximization net return plan while Table 6.2 and Figure6.2 shows the irrigated cropped area under different maximization net return plan and Table 6.3 and Figure 6.3,6.4 shows water allocation (surface and ground water) under these plans. Comparing plane PLR1 and plan PLR4 which are giving first two maximum net returns, although plane PLR1 gives maximum return but it does not fulfill minimum food requirement because crops like wheat and pulse is absent in this plan. Secondly, calorific and protein value of plan PLR1 is less than plan PLR4. Thirdly, total cropped area of plan PLR1 is less than plan PLR4 but cropping intensity, which is ratio of cropped area to total area, is more in plan PLR1 as compared to plan PLR4 because total command area is increased from 11300 ha in plan PLR1 to 13255 ha in plan PLR4.

Table 6.1 Output of different maximization net return plan

Attributes	PLR1	PLR2	PLR3	PLR4	Existing
Total net return ($x10^5$ NRs)	2561.79	2152.19	1941.37	2244.32	675.12
Calorie($x10^8$ cal)	2434.12	2404.39	2153.39	2575.24	1517
Protein($x10^8$gm)	73.85	74.01	65.86	78.07	38
crop area($x10^2$ha)	333.78	331.64	307.17	357.4	188

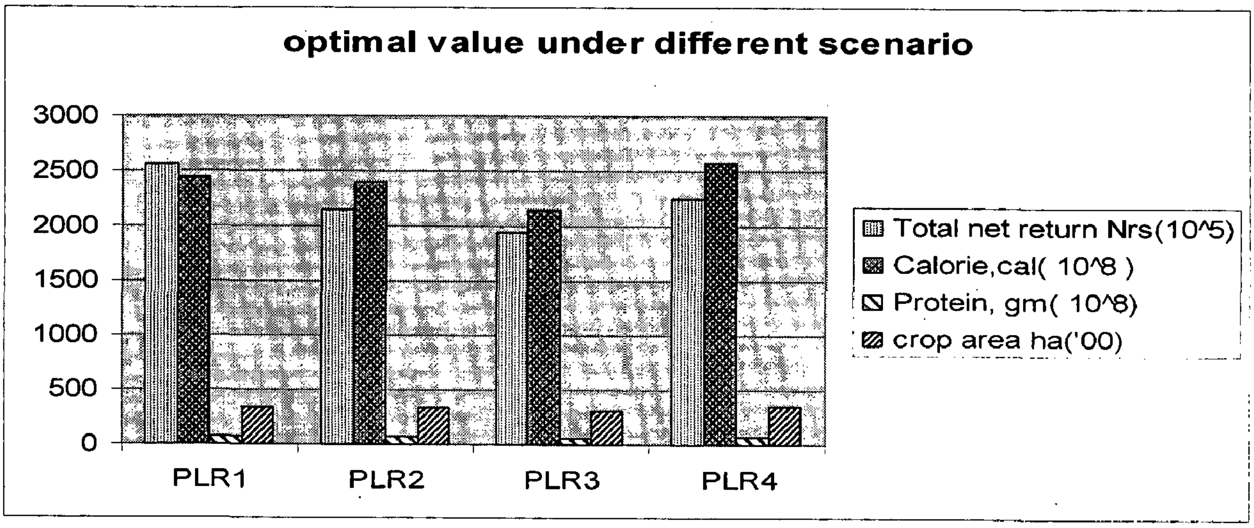

Fig.6.1 Maximum out put under different maximization of net return plan

Table 6.2 Irrigated crop area under different plan ('00 ha)

Crop	PLR1	PLR2	PLR3	PLR4	Existing
	Area	Area	Area	Area	
Paddy ha	113	113	113	132.556	113.00
Wheat	0	13.22	13.22	13.22	25.00
Oilseed	109	54.26	54.26	60.46	4.00
Pulse	0	41.52	41.52	41.52	4.00
Vegetable	4	4	4	4	4.00
Maize	107.78	94.51	70.04	94.51	2.00
Spring paddy	0	11.13	11.13	11.13	35.00
Total Area	333.78	331.64	307.17	357.396	188
CI(%)	295.38	293.48	271.83	269.61	166.37

Similarly, water allocation of 13265 ha-m in plan PLR1 is less than 14971 ha-m in plan PLR4. Also in plan PLR4 water use efficiency is highest 55% and 24% among the four compared plans. Thus plan PLR4 is selected as best among these four plans.

Table 6.3 water allocation (x 10^6 m3) under maximization net return plan

Month	PLR1		PLR2		PLR3		PLR4		Existing	
	S.W	G.W.	S.W	G.W.	S.W	G.W.	S.W	G.W.	S.W	G.W.
January	4.58	0	7.12	0	7.12	0	7.35	0	3.89	0.0
February	21.57	0	22.12	0	22.12	0	23.33	0	7.04	0.0
March	19.18	0	20.96	0	20.96	0	22.05	0	6.29	0.0
April	23.33	0.17	23.33	1.51	19.51	0	23.33	1.51	13.78	0.0
May	23.33	6.85	23.33	6.85	23.33	0	23.33	6.85	12.25	0.0
June	0	0	0	0	0	0	0	0	0.00	0.0
July	0	0	0	0	0	0	0	0	0.00	0.0
August	0	0	0	0	0	0	0	0	0.00	0.0
September	0	0	0	0	0	0	0	0	0.00	0.0
October	10.283	0	10.283	0	10.28	0	12.06	0	10.20	0.0
November	19.89	0	19.89	0	19.88	0	23.33	0	11.00	0.0
December	3.47	0	6.39	0	6.39	0	6.57	0	3.90	0.0
IWU	125.633	7.02	133.42	8.36	129.59	0	141.35	8.36	68.35	0.0
Utilize %	48.96	20.49	51.99	24.40	50.50	0	55.08	24.40	26.64	0.0
Total water use	132.65		141.78		129.59		149.71		68.35	

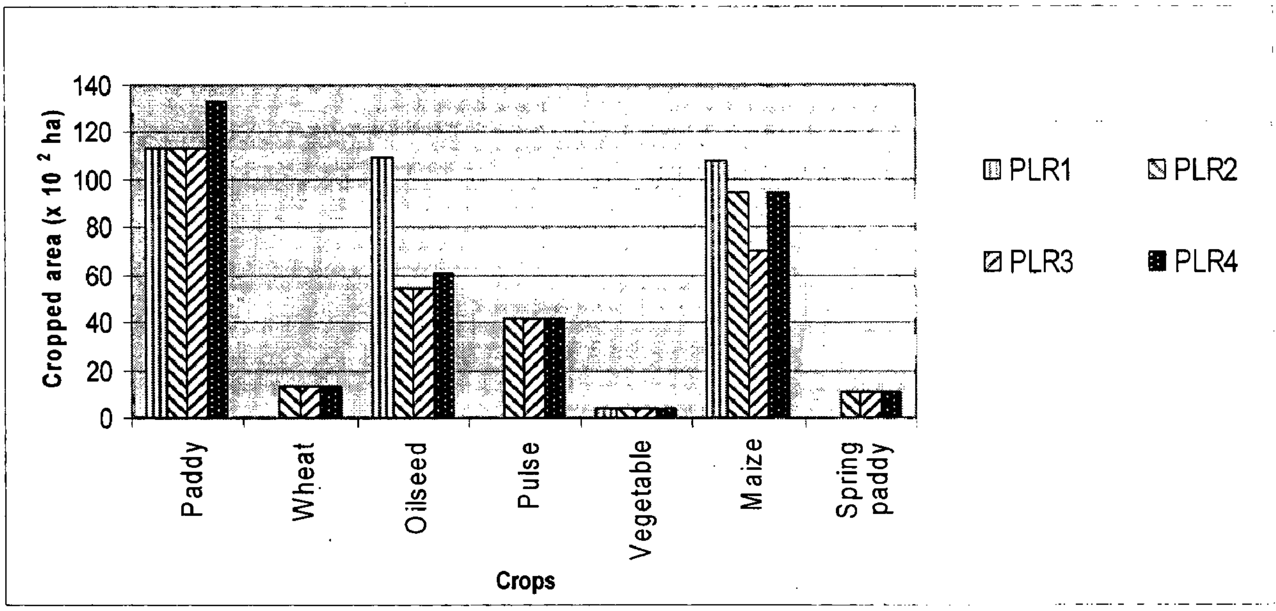

Fig. 6.2: cropped area under different maximization of net return plan

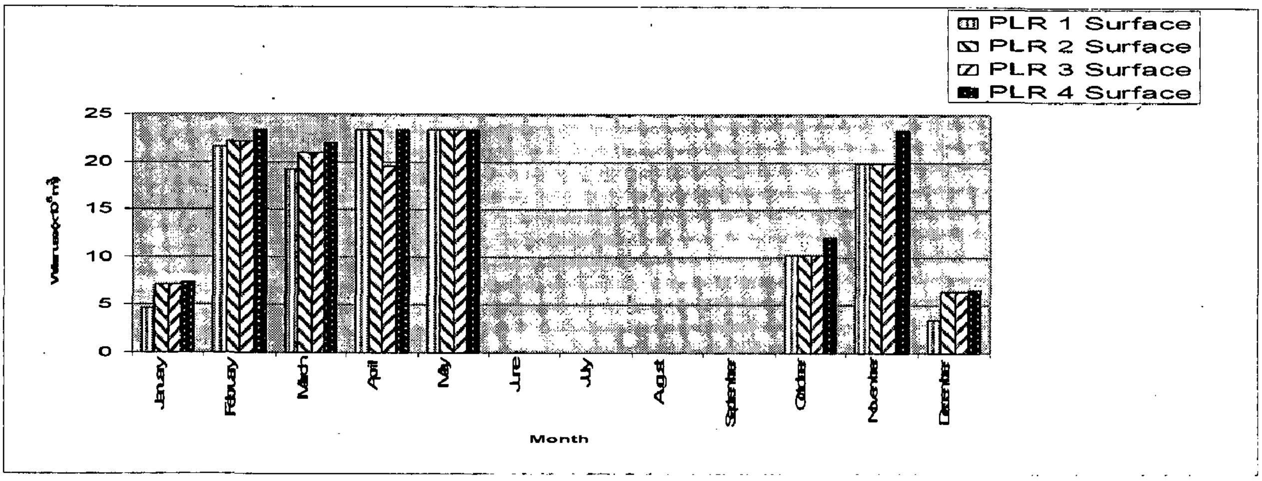

Fig. 6.3: surface water use under different maximization of net return plan

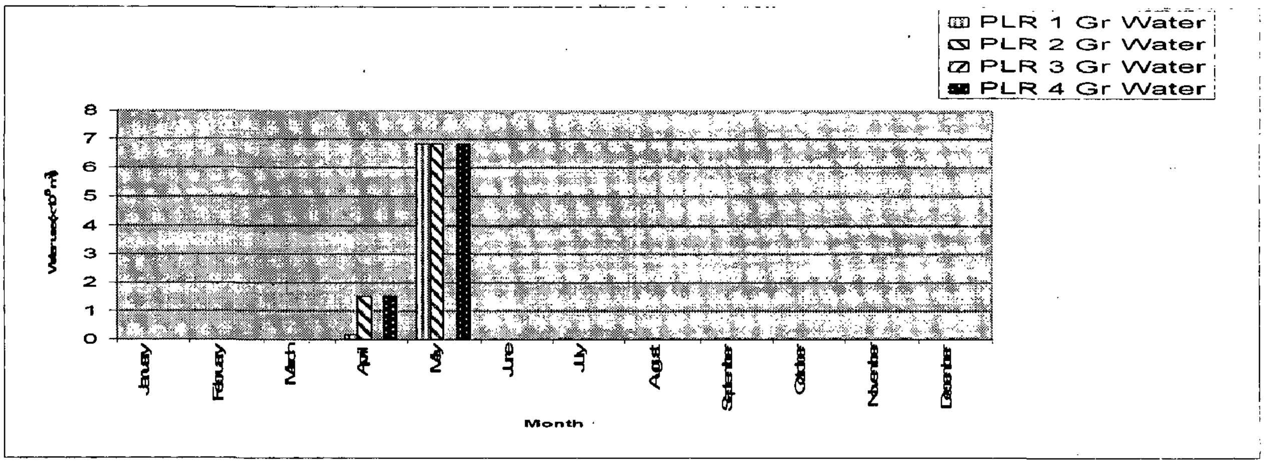

Fig. 6.4: ground water use under different maximization of net return plan

Maximization of Area

Table 6.4 and Figure 6.5 shows output under different maximization area plan while Table 6.5 and Figure 6.6 shows the irrigated crop area under different plan and Table 6.6 and Figure 6.7, 6.8 depict water allocation (surface as well as ground water) under different area plans. Plane PLA1 and plan PLA4 which gives first two maximum area is chosen for comparison , although plane PLA1 gives maximum calorific and protein value but it does not fulfill minimum food requirement of the area because pulse area is zero in plan PLA1.

Secondly, economic return Nrs 178.7 million of plan PLA1 is less than Nrs 219.6 million of plan PLA4. Thirdly, total cropped area of plan PLA1 is less than plan PLA4 but cropping intensity in plan PLA1 (295%) is more as compared to plan PLA4 (264%), because total command area is increased from 11300 ha in plan PLA1 to13255 ha in plan PLA4.

Table 6.4 output under different maximization area plan

Attributes	PLA1	PLA2	PLA3	PLA4	Existing
Total net return ($x10^5$ NRs)	1787.37	1982.41	1941.37	2196.49	675.12
Calorie ($x10^8$ cal)	2911.22	2404.39	2153.39	2504.01	1517
Protein ($x10^8$ gm)	88.88	74.01	65.86	75.8	38
cropped area ($x10^2$ ha)	333.78	331.64	307.17	350.45	188

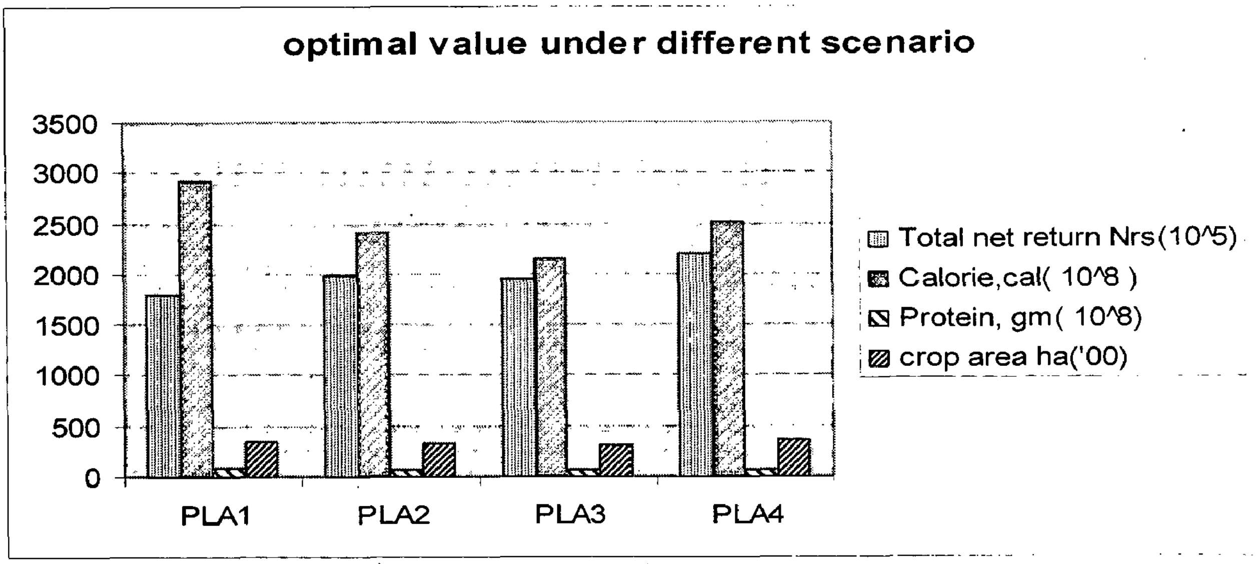

Fig. 6.5 Maximum out put under different maximization of area plan

Similarly, water allocation of 14134.3 ha-m in plan PLA1 is less than 14754 ha-m in plan PLA4. Surface water use efficiency (55.58%) of plan PLA4 is more than (47.01%) of plan PLA1. Thus plan PLA4 is selected as best plan among these four area plans.

Table 6.5 Irrigated crop area under different area plan ('00 ha)

Crop	PLA1	PLA2	PLA3	PLA4	Existing
	Area	Area	Area	Area	
Paddy	113	113	113	132.556	113.00
Wheat	94.57	13.22	13.22	13.22	25.00
Oilseed	14.43	54.26	54.26	60.46	4.00
Pulse	0	41.52	41.52	41.52	4.00
Vegetable	4	4	4	4	5.00
Maize	107.78	94.51	70.04	87.56	2.00
Spring paddy	0	11.13	11.13	11	35.00
Total Area	333.78	331.64	307.17	350.316	188
CI(%)	295.38	293.48	271.83	264.27	166.37

Table 6.6 water allocation (x 10^6 m^3) under different area plan

Month	PLA1		PLA2		PLA3		PLA4		Existing	
	S.W	G.W.	S.W	G.W.	S.W	G.W.	S.W	G.W.	S.W	G.W.
January	5.48	6.85	7.12	0	7.12	0	7.35	0	3.89	0.00
February	22.23	0	22.12	0	22.12	0	23.33	0	7.04	0.00
March	3.06	6.85	14.11	6.85	20.96	0	23.33	0	6.29	0.00
April	23.33	0.17	23.33	1.51	19.51	0	23.33	0	13.78	0.00
May	23.33	6.85	23.33	6.85	23.33	0	23.33	4.91	12.25	0.00
June	0	0	0	0	0	0	0	0	0.00	0.00
July	0	0	0	0	0	0	0	0	0.00	0.00
August	0	0	0	0	0	0	0	0	0.00	0.00
September	0	0	0	0	0	0	0	0	0.00	0.00
October	10.283	0	3.43	6.85	10.283	0	12.06	0	10.20	0.00
November	19.89	0	19.89	0	19.88	0	23.33	0	11.00	0.00
December	13.02	0	6.39	0	6.39	0	6.57	0	3.90	0.00
IWU	120.62	20.72	119.72	22.06	129.59	0	142.63	4.91	68.35	0
Utilize %	47.01	60.47	46.65	64.39	50.50	0	55.58	14.33	26.63	0
Total water use	141.343		141.78		129.593		147.54		68.35	

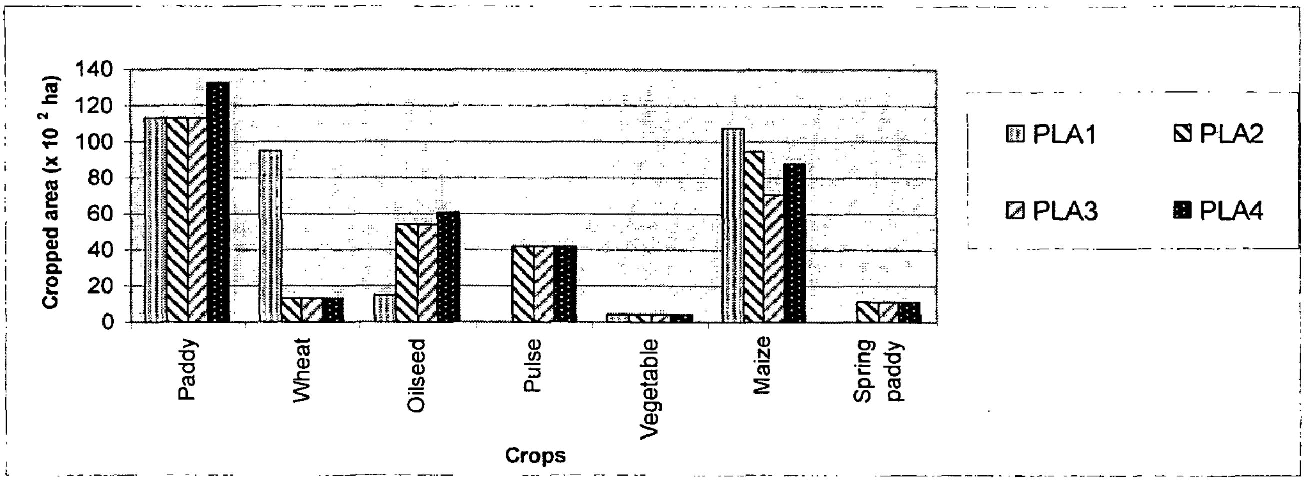

Fig. 6.6: cropped area under different maximization of area plan

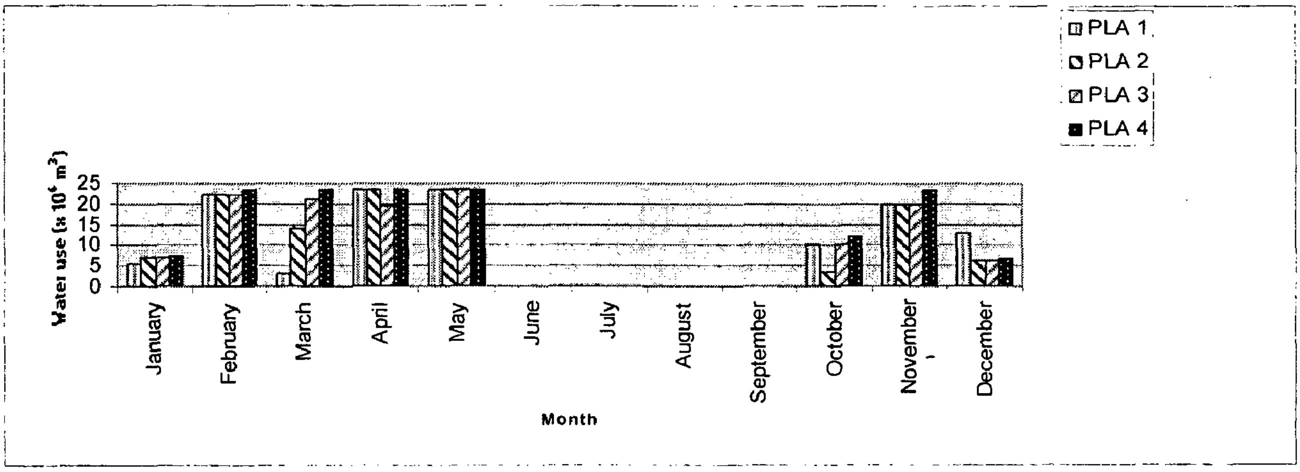

Fig. 6.7: surface water use under different maximization of area plan

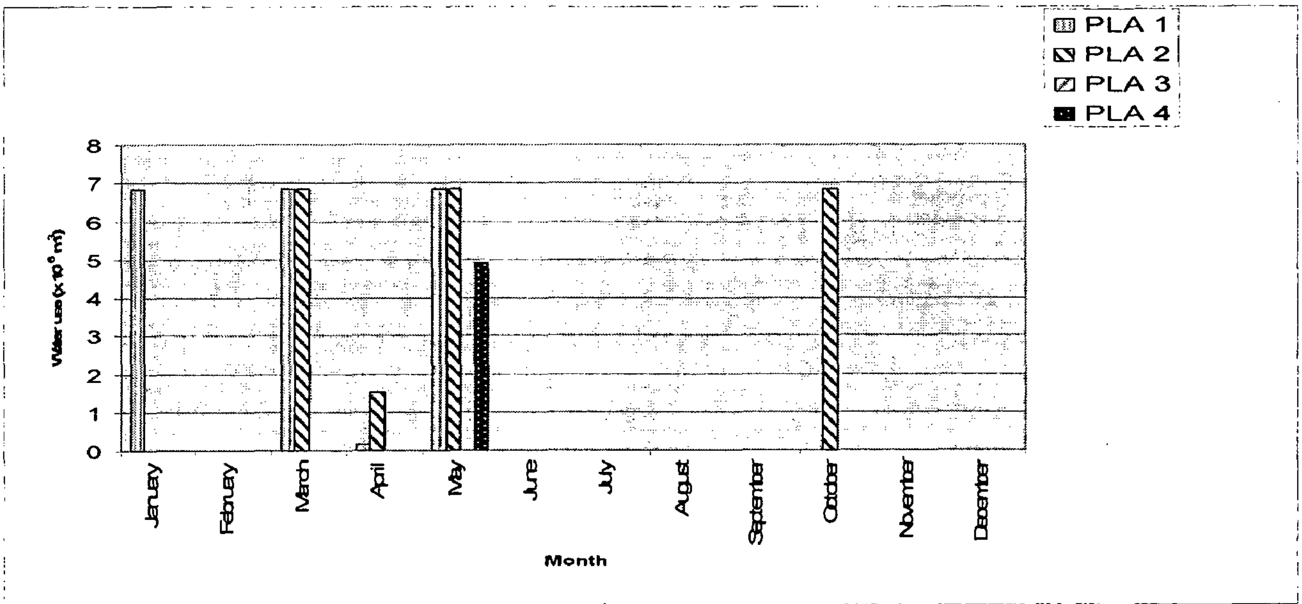

Fig. 6.8: ground water use under different maximization of area plan

Maximization of protein and calorific value

Maximization of protein value and calorific value are changed in same way under same constraints used. Therefore only protein maximization is considered here which gives maximum value of calorie under same plan.

Table 6.7 output under different maximization protein/calorific plans

Attributes	PLP1	PLP2	PLP3	PLP4	Existing
Total net return ($x10^5$ NRs)	1693.51	1744.95	1855.19	2067.25	675.12
Calorie ($x10^8$ cal)	2984.02	2472.4	2221.39	2575.24	1517
Protein($x10^8$gm)	91.18	76.15	68	78.67	38
crop area ($x10^2$ha)	333.78	331.64	307.17	349.77	188

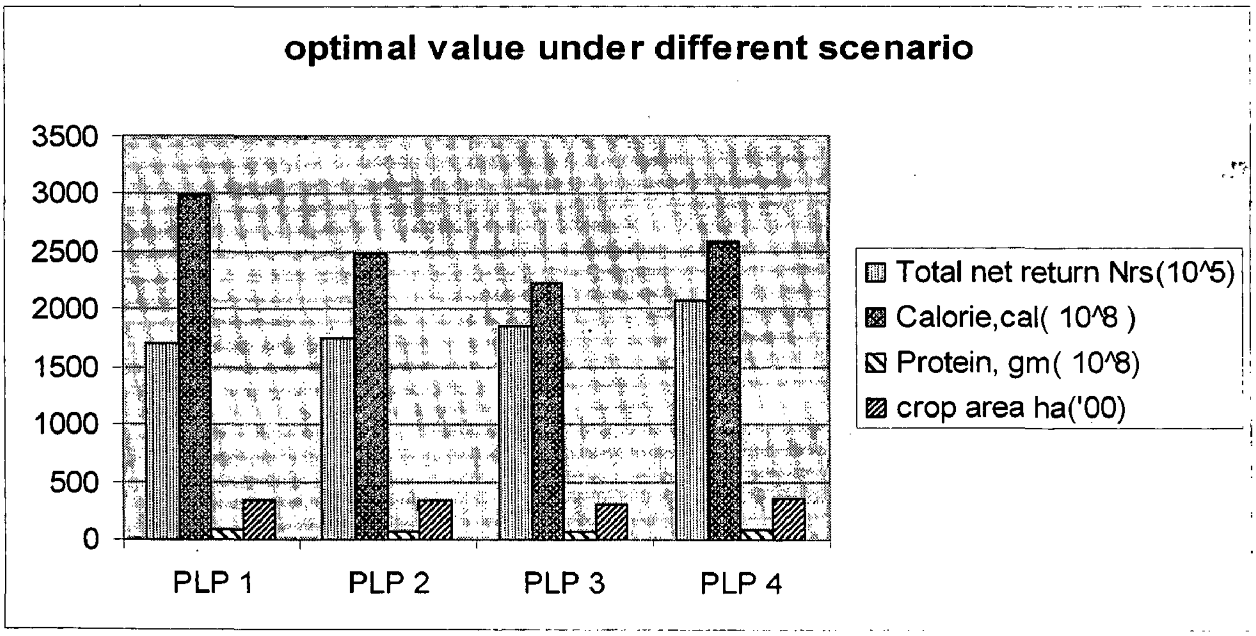

Fig. 6.9 out put under different maximization protein/calorific plan

Table 6.7 and Figure 6.9 show output under the maximization of protein/ calorific plan while Table 6.8 and Figure 6.10 show the irrigated cropped area under different plans and

Table 6.9 and Figure 6.11 & 6.12 show water allocation (surface as well as ground water) under different maximization protein/calorific plans. Plane PLP1 and plan PLP4 ,which give first two maximum protein and calorific value are chosen for comparison , although plane PLP1 gives maximum calorific and protein value but it does not fulfill minimum food requirement of the area because oilseed, pulses and spring paddy cropped areas are zero in plan PLP1. Secondly, economic return of Nrs 169.351 million of plan PLP1 is less than Nrs 206.725 million of plan PLP4. Thirdly, total cropped area 11300 ha of plan PLP1 is less than cropped area 13255 ha of plan PLP4, but cropping intensity is more in plan PLP1 as compared to plan PLP4 because total command area is increased. Similarly total water allocation 14399.3 ha-m in plan PLP1 is less than 15097 ha-m in plan PLP4. Thus plan PLP4 is selected as best among these four plans.

Table 6.8 Irrigated crop area under different protein/calorific plans ('00 ha)

Crop	PLP1	PLP2	PLP3	PLP4	Existing
	Area	Area	Area	Area	
Paddy	113	113	113	132.55	113.00
Wheat	109	26.7	26.7	32.22	25.00
Oilseed	0	40.78	40.78	40.78	4.00
Pulse	0	41.52	41.52	41.52	4.00
Vegetable	4	4	4	4	4.00
Maize	107.78	94.51	70.04	87.56	2.00
Spring paddy	0	11.13	11.13	11.13	35.00
Total Area	333.78	331.64	307.17	349.76	188
CI(%)	295.3805	293.4867	271.8319	263.8628	166.3717

Table 6.9 water allocation (x 10^6 m3) under different protein/calorific plan

Month	PLP1		PLP2		PLP3		PLP4		Existing	
	S.W	G.W.	S.W	G.W.	S.W	G.W.	S.W	G.W.	S.W	G.W.
January	6.67	6.85	2.86	5.36	8.22	0	8.89	0	3.89	0.00
February	22.23	0	22.21	0	22.21	0	23.33	0	7.04	0.00
March	3.06	6.85	12.79	6.85	19.64	0	23.33	0	6.29	0.00
April	23.33	0.17	23.33	1.51	19.51	0	23.33	0	13.78	0.00
May	23.33	6.85	23.33	6.85	23.33	0	23.33	4.9	12.25	0.00
June	0	0	0	0	0	0	0	0	0.00	0.00
July	0	0	0	0	0	0	0	0	0.00	0.00
August	0	0	0	0	0	0	0	0	0.00	0.00
September	0	0	0	0	0	0	0	0	0.00	0.00
October	10.28	0	3.43	6.85	10.28	0	12.06	0	10.20	0.00
November	19.89	0	13.03	6.85	19.88	0	23.33	0	11.00	0.00
December	14.48	0	7.75	0	7.74	0	8.47	0	3.90	0.00
IWU	123.27	20.72	108.73	34.27	130.81	0	146.07	4.9	68.35	0.00
Utilize %	48.04	60.48	42.37	100.02	50.98	0	56.92	14.30	26.64	0.00
Total water use	143.993				143		150.97		68.35	

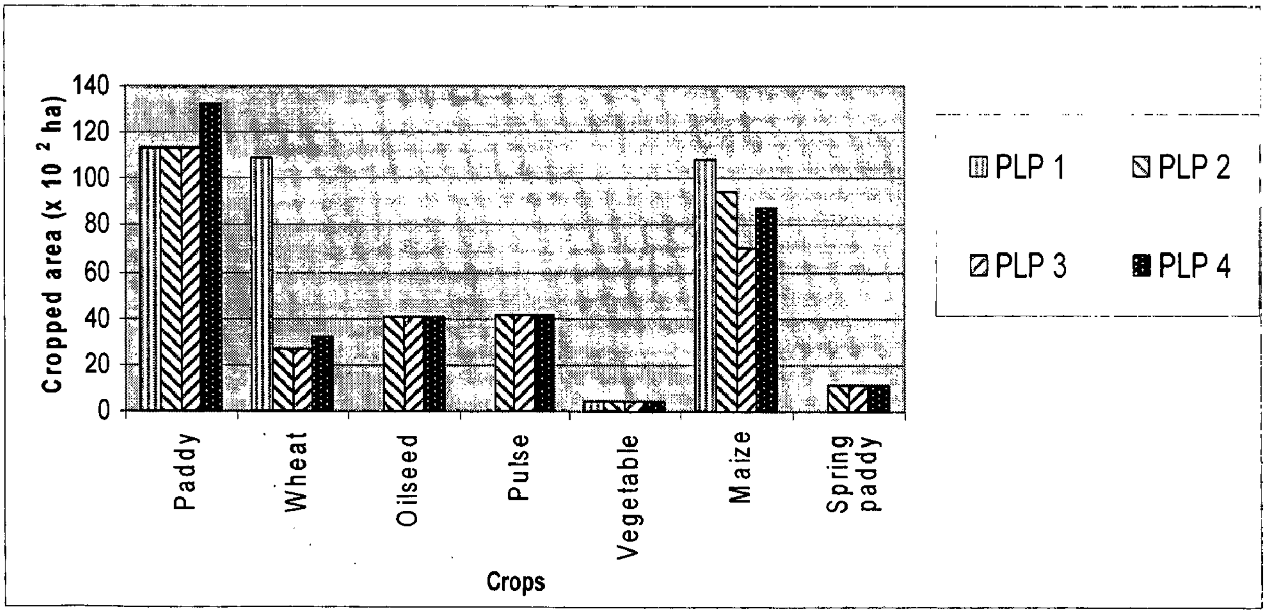

Fig. 6.10: cropped area under maximization protein/calorific plans

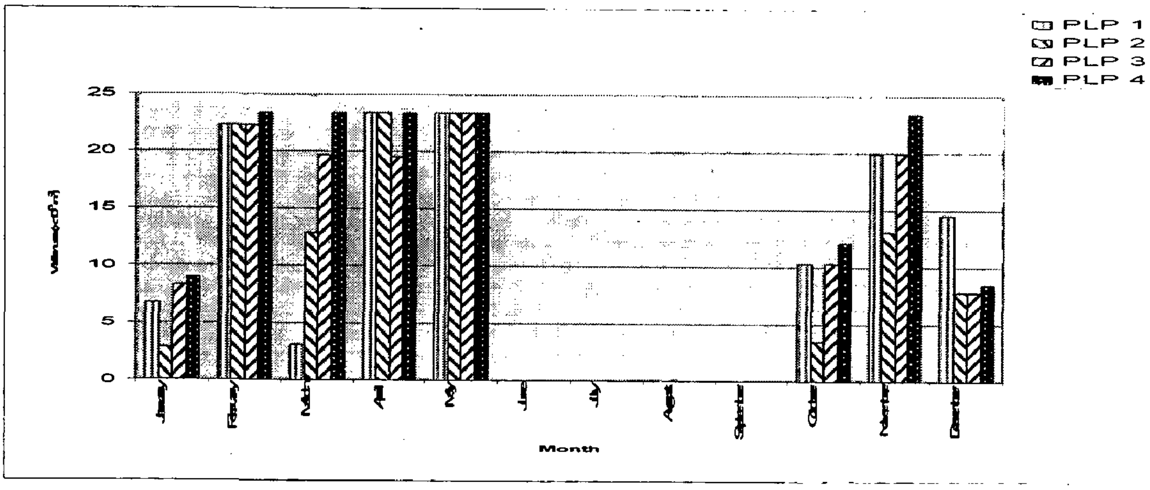

Fig. 6.11: surface water use under maximization protein/calorific plans

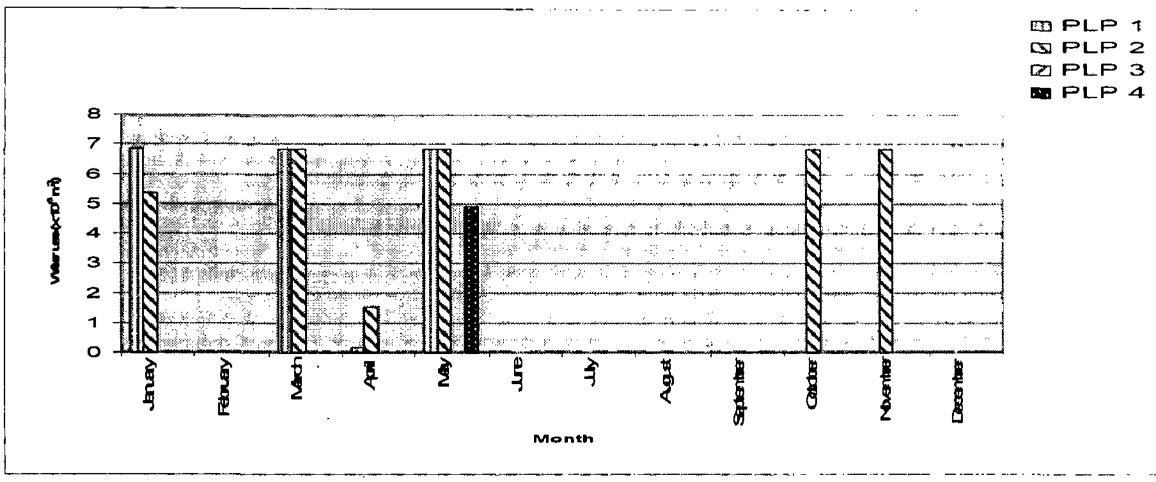

Fig. 6.12: ground water use under maximization protein/calorific plans

Now three best plans among different maximization plans are compared as shown in Table 6.10, 6.11 and 6.12. It is seen that total net return NRs 2244.32 x10^5 in plan PLR4 is highest. Total calorific values in PLR4 and PLP4 are same 2575.24 x 10^8 cal which is greater than PLA4 Plan. Total protein values are nearly same in plan PLR4 and PLP4 but greater than PLA4 plan.

Total Cropped area and cropping intensity of plan PLR4 are 35739 ha and 270% repectively, is highest as compared to 35031 ha and 264% of plan PLA4 as well as 34976 ha and 264% of plan PLA4. Maize production is highest in plane PLR4. Finally, total water allocation 14971 ha-m in plan PLR4 is less than 15097 ha-m in plan PLP4 and more than 14754 ha-m of plan PLA4 similarly, surface water use efficiencies in plan PLR4, plan PLA4 and plan PLP4 are 55%, 56% and 57% respectively and ground water use efficiency of 24% is highest in plan PLR4 as compare to 14 % of other two plans. Hence plan PLR4 is most suitable plan among the three plans.

Again comparing plan PLR4 with existing crop and water use of the system it is seen that net return in plan PLR4 is more than three times that of existing one. Total calorific value 2575.24 X 10^8 cal in plan PLR4 is nearly two times more than existing plan. Total protein value 78 X 10^8 g is more than two times of protein value of 38 X 10^8 g of existing one. Total cropped area and cropping intensity of plan PLR4 are 35739 ha and 270% is highest as compared to 18800 ha and 166 % of existing one, which are nearly two times more than that of existing one.

Table 6.10 comparison of output under three best plans

Attributes	PLR4	PLA4	PLP4	Existing
Total net return (x10^5 NRs)	2244.32	2196.49	2067.25	675.12
Calorie(x10^8 cal)	2575.24	2504.01	2575.24	1517
Protein(x10^8gm)	78.07	75.8	78.67	38
crop area (x10^2ha)	357.39	350.45	349.77	188

Paddy and vegetable cultivation are same for both the plans. Wheat and spring paddy areas are less in PLR4 plan as compared to existing one, but Maize and oilseed areas are many times more than existing one. 14971 ha-m water use in plan PLR4 is more than two times as compared to the present use of 6835 ha-m in.

Table 6. 11 comparison of Irrigated crop area under three best plans('00 ha)

Crop	PLR 4	PLA 4	PLP4	Existing
	Area	Area	Area	
Paddy	132.556	132.556	132.55	113.00
Wheat	13.22	13.22	32.22	25.00
Oilseed	60.46	60.46	40.78	4.00
Pulse	41.52	41.52	41.52	4.00
Vegetable	4	4	4	4.00
Maize	94.51	87.56	87.56	2.00
Spring paddy	11.13	11	11.13	35.00
Total Area	357.396	350.316	349.76	188
CI(%)	269.61	264.27	263.86	166.37

Table 6. 12 comparison of water allocation(x 106 m3) under three best plans

Month	PLR4		PLA 4		PLP 4		Existing	
	S.W	G.W.	S.W	G.W.	S.W	G.W.	S.W	G.W.
January	7.35	0	7.35	0	8.89	0	3.89	0.00
February	23.33	0	23.33	0	23.33	0	7.04	0.00
March	22.05	0	23.33	0	23.33	0	6.29	0.00
April	23.33	1.51	23.33	0	23.33	0	13.78	0.00
May	23.33	6.85	23.33	4.91	23.33	4.9	12.25	0.00
June	0	0	0	0	0	0	0.00	0.00
July	0	0	0	0	0	0	0.00	0.00
August	0	0	0	0	0	0	0.00	0.00
September	0	0	0	0	0	0	0.00	0.00
October	12.06	0	12.06	0	12.06	0	10.20	0.00
November	23.33	0	23.33	0	23.33	0	11.00	0.00
December	6.57	0	6.57	0	8.47	0	3.90	0.00
IWU	141.35	8.36	142.63	4.91	146.07	4.9	68.35	0.00
Utilize %	55.08	24.40	55.58	14.33	56.92	14.30	26.64	0.00
Total water use	149.71		147.54		150.97		68.35	

Water use efficiency in plan PLR4 is 55%, as compared to 26% of existing plan. Availability of water in the system is enough and its best utilization is more concerned. Thus

PLR4 is more efficient plan than existing one. Similarly, other individual maximization plans are superior to existing one. Now by comparing among the individual maximization plan, it is clearly seen that the three optimal solutions are in conflict with each other and a trade-off among them should be made by using weighted goal programming.

6.3 COMPARISON OF WGP RESULT

Individual optimal solutions for the four maximization problems are presented in Table 6.13. Output of these plans is conflicting among them. Thus trade off among them is done by using goal programming technique. Weights are allocated as per Table 5.2 and discussed in chapter 5.

Table 6.13: Optimal system variables under different scenario

Attributes	PLR1	PLP1/PLC1	PLA4
Total net return ($x10^5$ NRs)	2564	1694	2196
Calorie($x10^8$ cal)	74	91	76
Protein($x10^8$gm)	2434	2984.	2504
crop area($x10^2$ha)	334	334	350

Table 6.14 depicts the results of all the scenarios of weighted goal programming. More precisely, it displays the goal values, the deviation of attributes from goal and final values of each attributes to assess the results in a better way. It is clear from result that economic scenarios end up to highest value in terms of total net return and total cropped area but there is deviation of each attributes from its goals.

Again, environmental and compromise scenarios would have the most satisfactory solution with minimum deviation from the 'ideal point'. But all other attribute values are less than economic scenarios, but protein and calorific values are lowest among all. Similarly, health scenario has highest protein and calorific value but total net return is lowest among all.

Table 6.14: Optimal system variables under different scenario

Attributes	Economic scenario	Health scenario	Environmental scenario	compromise scenario
Total net return goal ($x10^5$ NRs)	2564	1694	2196	2196
Protein goal ($x10^8$ gm)	74	91	76	76
Calorie goal($x10^8$ cal)	2434	2984.	2504	2504
crop area goal ($x\ 10^2$ ha)	334	334	350	350
N1	319	0	0	0
N2	0	10	0	0
N3	0	315.47	0	0
N4	0	0	0	0
P1	0	324.20	0	0
P2	4.07	0	0	0
P3	141.25	0	4.69	0
P4	23.40	22.70	1.05	0.25
Total net return achieved ($x10^3$ NRs)	2245	2018.2	2196	2196
Protein ($x10^8$ gm)	78.07	81	76	76
Calorie ($x10^8$ cal)	2575.25	2668.53	2508.69	2504
crop area ($x\ 10^2$ ha)	357.39	356.7	351.05	350.25

Table 6.15 and Figure 6.13 shows sensitivity of cropped area with change in weight under different scenario. It is also clear that economic scenario maintained existing cropping pattern which has not possible earlier in PLR_1 plan (benefit maximization).

Table 6.16 shows water allocation under different scenario. Similarly, Figure 6.14 depicts sensitivity of optimal surface water use on monthly basis under different scenario and Figure 6.15 show sensitivity of optimal ground water use on monthly basis under different scenario. Environmental and compromise scenario allocate same total cropped area but less than economic one. Similarly, their total net returns are less than economic scenario. Health scenario has more calorific and protein value but less net return than economic scenario. This means that among the entire tested scenario, economic scenario would have the most satisfactory solution. In economic scenario, total cropped area and cropping intensity are 35739 ha and 269.62 % respectively.

Table 6.15 comparison of Irrigated crop area under different scenario('00 ha)

Crop	Economic Scenario	Health Scenario	Environmental Scenario	Compromise Scenario
Paddy ha	132.55	132.55	132.55	130.98
Wheat	13.22	32.22	13.22	13.22
Oilseed	60.46	40.78	58.75	58.41
Pulse	41.52	41.52	43.14	43.46
Vegetable	4	4	4	4
Maize	94.51	94.51	88.29	89.04
Spring paddy	11.13	11.13	11.13	11.13
Tatal Area	357.39	356.71	351.08	350.24
CI(%)	269.62	269.11	264.86	267.39

Table 6.16 comparison of water allocation(x 10^6 m3) under different scenario

Month	Economic Scenario		Health Scenario		Environmental Scenario		Compromise Scenario	
	Surface	Gr Water	Surface	Gr Water	Surface	Gr Water	Surface	Gr Water
January	7.36	0	23.33	0	7.41	0	7.42	0
February	23.33	0	23.33	0	23.33	0	23.33	0
March	22.05	0	20.07	0	22.16	0	22.17	0
April	23.33	1.51	17.99	6.85	23.33	0.16	23.33	1.51
May	23.33	6.85	23.33	6.85	23.33	5.11	23.33	6.85
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	12.06	0	12.06	0	12.06	0	11.92	0
November	23.33	0	23.33	0	23.33	0	23.33	0
December	6.57	0	23.33	0	6.63	0	6.64	0
IWU	141.36	8.36	166.77	13.7	141.58	5.27	141.47	8.36
Utilize %	55.08	24.40	64.99	39.98	55.17	15.38	55.13	24.40
Total water use	149.72		180.47		146.85		149.83	

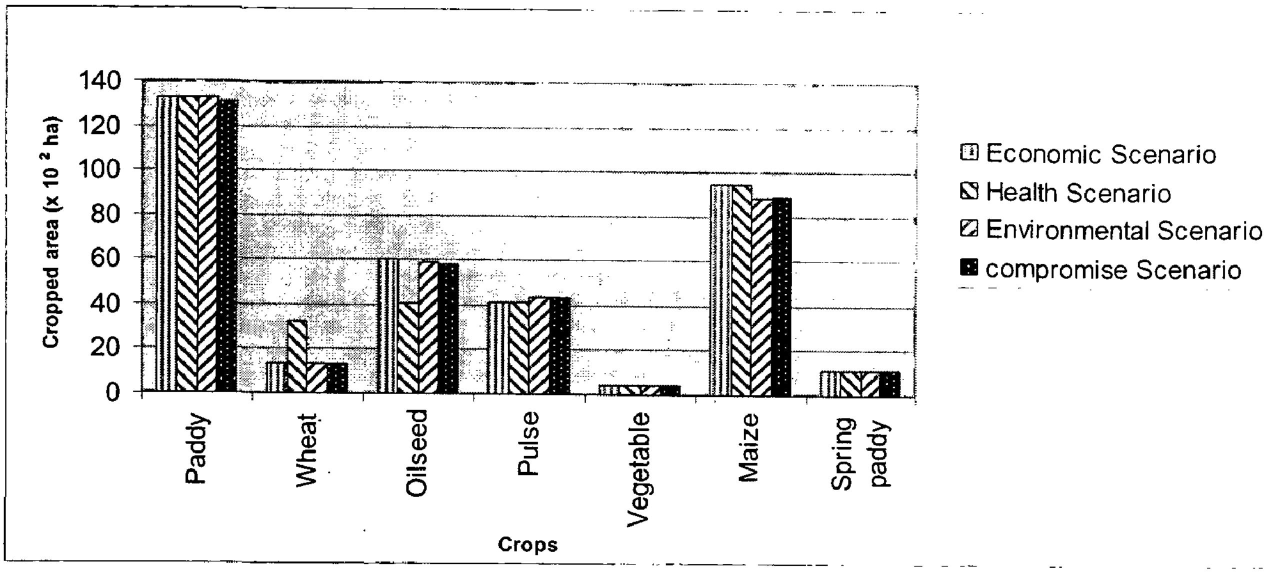

Fig. 6.13: sensitivity of cropped area under different scenario

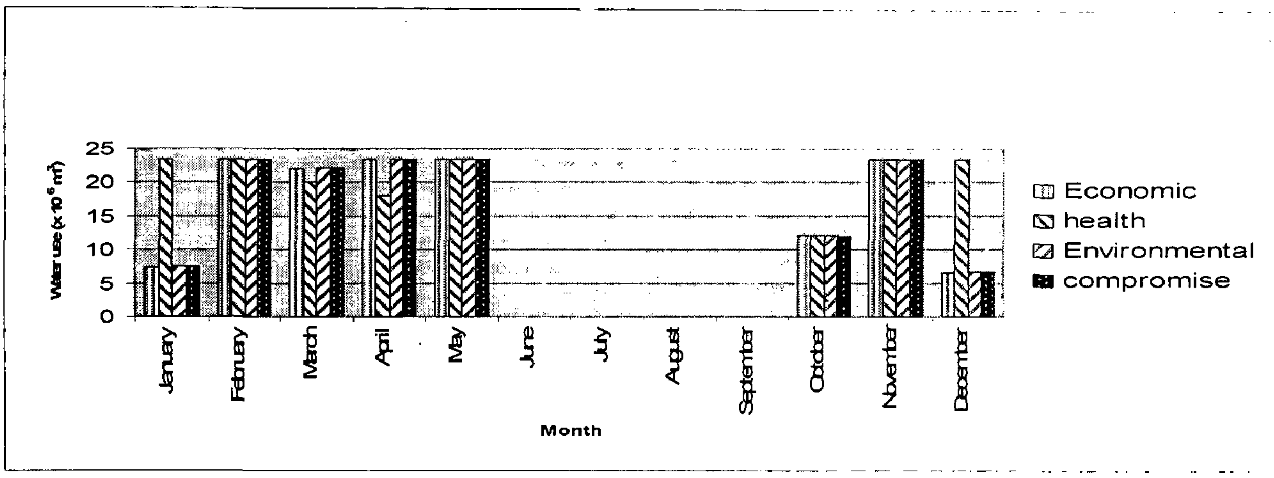

Fig. 6.14: Sensitivity of surface water use under different scenario

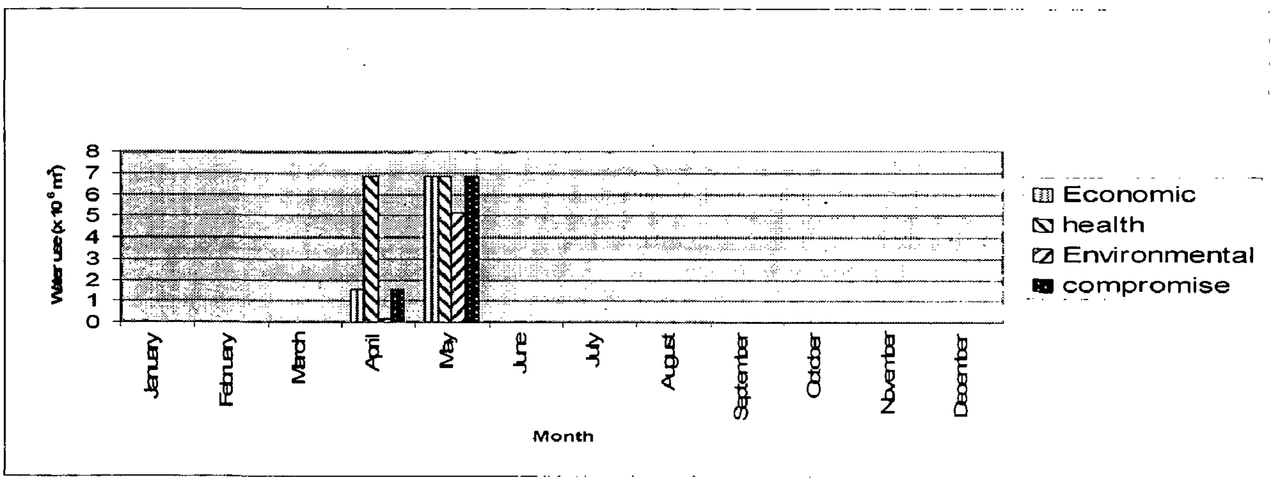

Fig. 6.15: Sensitivity of ground water use under different scenario

Calorific and protein values are also more than demand of the population of the area. Annual surface and ground water use efficiencies are 55% and 24% respectively. Therefore economic scenario is most suitable among all four scenarios.

Finally, attribute of most satisfactory economic scenario are compared with existing one. Table 6.17 compares different attributes of most satisfactory economic scenario with existing scenario. It is seen total net return in economic scenario is more than three times as compared to existing scenario. Similarly, values of other attributes in economic scenario are also higher than existing one. Figure 6.16 shows the comparison of cropped area under economic and existing scenario. Comparison with the existing cropped area indicates that the model seems to favor maize crop at the expense of spring paddy and wheat, due to water use efficieny considerations.

Table 6.17: comparison of different attributes under economic and existing scenario

Attributes	Economic scenario	Existing
Total net return ($x10^5$ NRs)	2245	675.12
Protein ($x10^8$ gm)	78.07	38
Calorie ($x10^8$ cal)	2575.25	1517
crop area (x 10^2 ha)	357.4	188

This significant difference in coverage of the main crops (e.g. spring paddy and wheat) raises two questions. The first is on the effectiveness (i.e. intensity of irrigation) of the existing as well as the proposed crop plans under prevalent conditions. The second question is on the practical viability of the model cropping plans. Both are satisfied at prevailing condition of area.

Now, monthly water allocation policies are presented in Figure 6.17. The figure highlights the relative importance and utilization of surface and groundwater in wet and dry seasons respectively. Groundwater allocation is required during spring season. Surface water allocation is increased significantly during the dry months (especially spring season) to cater for the increase in the cropped area under economic scenario.So economic scenario is most suitable and efficient.

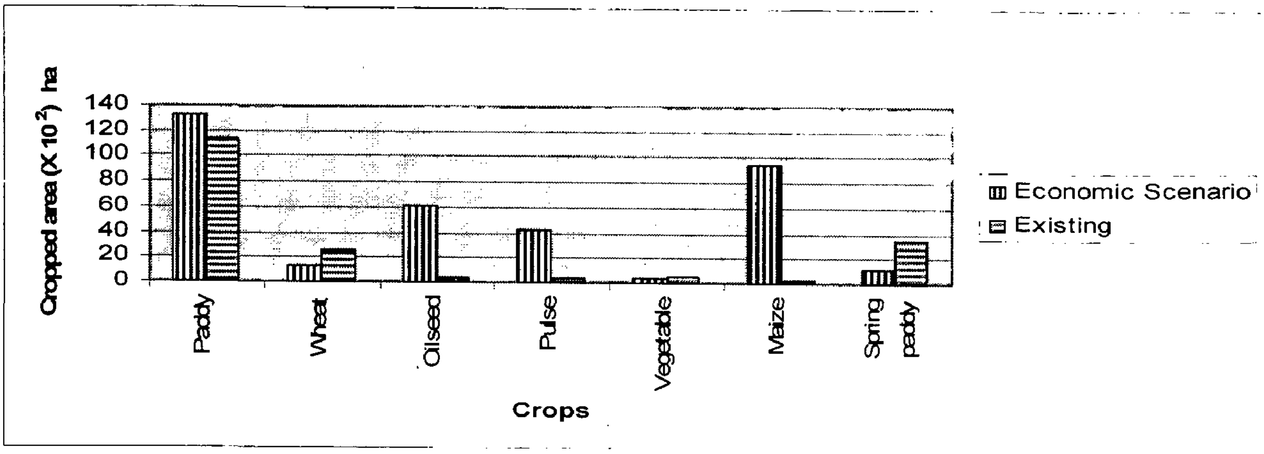

Fig. 6.16: comparison of cropped area under economic and existing scenario

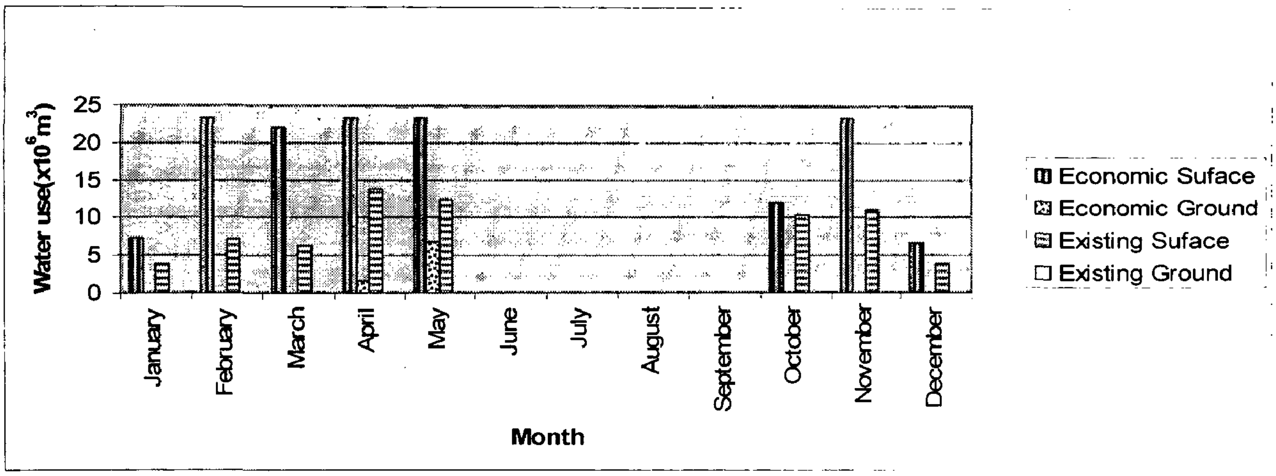

Fig. 6.17: comparison of water use under economic and existing scenario

6.4 COMPARISON OF LP AND GP MODELS

Table 6.18 summarizes the optimal values of the system variables obtained from the linear and goal planning model for various alternatives. In consonance with the objectives in individual maximization plan, the development areas decrease as relative preference shifts from net benefit maximization to cropped area maximization, maximization of protein and calorific value. The maximum monthly surface allocations which provide indicative system design capacities (canal capacity) are increased. Similarly, the annual surface water allocation is increased. All these figures provide good guidelines for appropriate levels of irrigation development.

Finally, It is seen from the result that best plan economic scenario of GP and best plan PLR4 of LP have similar attribute values. Under PLR4 and economic scenario (W_1=0.5, W_2=0.2, W_2=0.2, W_4=0.1), optimal alternative calls for irrigation development in an area of 35739 ha with a cropping intensity of 269.62 %. Total water use is 149.72 X10^6 m^3 and the corresponding annual surface and groundwater allocations are 141.36 x 10^6 and 8.36 X 10^6 m^3 respectively.

Table 6.18: comparison of different attributes under linear and goal plans

Attributes	Economic Scenario	Health Scenario	Environmental Scenario	Compromise Scenario	PLR4	PLA4	PLP4
Total net returnNRs (x10^5)	2245	2018.2	2196	2196	2244.3	2196.4	2067.2
Protein gm (x10^8)	78.07	81	76	76	78.07	75.8	78.67
Calorie cal (x10^8)	2575.25	2668.53	2508.69	2504	2575.2	2504.01	2575.2
cropped area ha (x 10^2)	357.39	356.7	351.05	350.25	357.39	350.45	349.7
CI (%)	269.62	269.11	264.86	267.39	269.61	264.27	263.86
Total water use cum (10^6)	149.72	180.47	146.85	149.83	149.71	147.54	150.97

CHAPTER-7

SUMMARY AND CONCLUSIONS

7.1 GENERAL:

In the present study an attempt has been made to develop an optimal crop and Irrigation plan in Kosi Irrigation System of Nepal by optimizing land and water resources from the point of view of maximization of net return, maximization of protein and calorific requirement as well as maximization of irrigated area. The System is located in the North-Western section of the Kosi river basin between latitude $26^0 25'$ N and $26^0 34'$ N and longitude $86^0 30'$ E and $86^0 56'$ E .The entire irrigation system lies in Saptari district of Sagarmatha Zone of Nepal and covers 27 village development committees. This irrigation system has two components namely; Pump Canal system and Distribution System. Of the two systems, Distribution system is chosen for study area. The Distribution Canal System of the Western Kosi Main Canal irrigates gross command area of 14,125 hectare. Cultivable command area of it, is 13,300 hectare. The system is characterized by adequate water supply and distribution facilities with less utilization of its resources due to lack of proper planning. The command area has a humid sub-tropical monsoon climate. The mean annual precipitation is around 1389 mm, of which about 95% occurs in the rainy season. The eighty percent of the annual rainfall occurs in the month of June to September. The water allocation for the canal system of Nepal, off taking from Western Kosi Main Canal (Indian), is at 720 cusecs; i.e. for the Pump Canal System 400 cusecs and for the Distribution System 320 cusecs. The major part of the population lives in villages and earns its livelihood from agriculture and agro-based occupations. 95% population is dependent on agriculture.

Population density is 418 per square kilometer and population growth rate is 2.15%. Population of the system's command area, is estimated as 114171 in 2032 of which 51% is male and 49% is female. Major crops grown in the project area are paddy, wheat, maize, vegetables and mustard. Because rice is the staple food of the local people, normal monsoon paddy is grown in almost all areas during the wet season. The requirements of protein and calorie requirement for projected population of study area are estimated to be 25.05x 10^8 gm /yr and 914.68 x10^8 cal/ yr respectively. The system is characterized by adequate water supply and distribution facilities with less utilization of its resources due to lack of proper planning.

Population increase needs an increase in agricultural production to meet their increasing food and nutritional demand. The goal to meet these demands can be achieved through irrigated agriculture, but rapid expansion of new irrigation schemes will not continue in the next decades due to many reasons e.g. scarce resource, economic and environmental conditions. Poor performance of irrigation systems require greater attention be given to planning, management and development of resources of these systems. Efficient resource utilization is the central issue.

Integrated or conjunctive use of surface and groundwater resources has now been recognized as a significant strategy for the optimum utilization of regional water resources. Integrated use is especially effective within the context of irrigation management. Systems approach and its framework, consisting of mathematical models, have long been used in analyzing complex water resources problems such as conjunctive use and irrigation planning.

A multi-objective model for irrigation development is presented with integrated use of surface and ground water resources. Alternative plans for irrigation development are identified by analyzing trade-offs among the specified objectives of maximizing total net economic returns from agriculture (economic efficiency),nutritional requirement of the area (health) and total irrigated cropped area (balanced regional development) by using Goal programming. More specifically, weighted goal programming technique is employed for compromising solution in terms of area and water allocation under different crops will come as close as possible to decision makers economic, health and environmental goals.

7.2 OBJECTIVE AND METHODOLOGY

The primary objective of the study is to allocate optimally the land and water resources for proposed cropping pattern of command area of Kosi Irrigation system. The specific objectives of the study are as follows,

1) To calculate Water Requirement by using most appropriate method.

2) To devise a suitable cropping pattern for the study area.

3) To find out optimal allocation of land and water resources in study area

4) Determining alternative irrigation development plans;

5) Selecting the most satisfactory development strategy considering multiple objectives by using Goal Programming

The study utilizes data made available by the project for monthly discharge in canal of the system. Social, Agricultural, Hydro meteorological data are available from the project as well as different government agencies. Related reports are consulted in preparation of dissertation report. CROP WAT and LINDO Software are used as analytic tool for crop water requirement and optimization respectively.

Linear programming and goal programming techniques were used to achieve these specific objectives of optimal allocation of resources of the irrigation system. In order to compare the two techniques same constraints were considered in both cases.

Linear programming is a class of mathematical programming models concerned with the efficient allocation of limited resources for known activities with the objective of meeting desired goal. The distinct characteristic of linear programming model is that the function representing the objective and constraints are linear. The present problem is a maximization problem subject to land availability, water availability surface and ground water, minimum area, maximum area, protein and calorific requirement constraints. Linear programming model for solving multi objective decision problem involved selected one objective at a time and other objective were considered (other than objective function) as model constraints. Linear Programming model is based on basic assumption that the optimal solution must satisfy all the system constraints. Moreover, it is assumed that all the constraints have equal importance. Linear programming does not give the solution of infeasible problems. For solving problem involving multiple conflicting objectives, goal programming is used with more satisfactory result.

In linear programming various optimal plans were studied by considering various combinations of constraints whereas in Goal programming there are several approaches that could be applied in order to solve the above-formulated goal programming problem (e.g. Lexicographic, Minimax, Weighted, Extended, and Interval). Among them, weighted goal programming (WGP) is selected for this study. WGP considers all goals simultaneously within a composite objective function comprising the sum of all respective deviations of the goals from their aspiration levels. The deviations are then weighted according to the relative importance of each goal. The model minimizes the sum of the percentage deviations from the targets.

7.3 RESULT AND DISCUSSION

The assessment of crop water requirement for various crops in different seasons is an important criterion in the selection of crops to be grown and it is one of the basic necessities in planning of an irrigation system. The comparative studies and many other research studies have confirmed the superior performance of the Penman-Monteith approach and correct estimates of reference evapotranspiration (ETo). By using Penman-Monteith method for estimating ETo would certainly reduce losses caused due to overestimated values used by other methods. Also, cost of bigger size canal and canal structures would get reduced.

Individual optimal solutions for the four maximization problems are presented in Tables 6.13. It is seen that optimal solution of these plans are superior to existing one. Plan PLR4 is most suitable plan among the LP plans.

However outputs of individual maximization plans are conflicting among them. Thus trade off among them is done by using goal programming technique. Weights are allocated as per Table 5.2 discussed in chapter 5. Table 6.14 depicts the results of all the scenarios of weighted goal programming. It is clear from the result that economic scenarios end up to be the highest optimal value in terms of total net return and total cropped area but there is deviation of each attributes from its goals.

Again, environmental and compromise scenarios would have the most satisfactory solution with minimum deviation from the 'ideal point'. But all other attribute values are less than economic scenarios, but protein and calorific values are lowest among all. Similarly, health scenario has highest protein and calorific value but total net return is lowest among all.

Figure. 6.13 shows sensitivity of cropped area with change in weight under different scenario. It is also clear that economic scenario maintained existing cropping pattern which has not possible earlier in PLR_1 plan (benefit maximization). Table 6.16 shows water allocation under different scenario. Environmental and compromise scenario allocate same total cropped area but less than economic one. Similarly, their total net returns are less than economic scenario. Health scenario has more calorific and protein value but less net return than economic scenario. This means that among the entire tested scenario, economic scenario would have the most satisfactory solution.

A comparision of linear and goal planning model is done. Table 6.18 summarizes the optimal values of the system variables obtained from the linear and goal planning model for various alternatives. It is seen from the result that best plan (economic scenario) of GP and best plan (PLR4) of LP have similar attribute values. These plans gives maximum net return of Nrs 2245 $x10^5$.Optimal alternative calls for irrigation development in an area of 35739 ha with a cropping intensity of 269.62 %. Total water use is 149.72 $X10^6$ m^3 and the corresponding annual surface and groundwater allocations are 141.36 x 10^6 and 8.36 X 10^6 m^3 respectively.Therefore economic scenario and PLR4 plan are most suitable among all plans.

Finally, comparision of attributes of most satisfactory economic scenario with existing one is done. It is seen that total net return in economic scenario is more than three times as compared to existing scenario. Similarly, values of other attributes in economic scenario are also higher than existing one. Figure 6.16 shows the comparison of cropped area under economic and existing scenario. Comparison with the existing cropped area indicates that the model seems to favor maize crop at the expense of spring paddy and wheat, due to water use efficieny considerations.This significant difference in coverage of the main crops (e.g. spring paddy and wheat) raises two questions. The first is on the effectiveness (i.e. intensity of irrigation) of the existing as well as the proposed crop plans under prevalent conditions. The second question is on the practical viability of the model cropping plans. Answers of both questions are satisfied at prevailing condition of the area.

Now, monthly water allocation policies are presented in Figure 6.17. The figure highlights the relative importance and utilization of surface and groundwater in wet and dry seasons respectively. Groundwater allocation is required during spring season. Surface water allocation is increased significantly during the dry months (especially spring season) to cater for the increase in the cropped area under economic scenario.Water use efficiency of the system is also increased. Thus it is concluded that PLR4 or economic scenarios are most suitable and efficient.

Summarizing the optimal values of the system attributes obtained from the planning model for various alternatives show that in consonance with the objectives in individual maximization plan, the development areas are decreased as relative preference shifts from net benefit maximization to cropped area maximization, maximization of protein and calorific value. The maximum monthly surface allocations which provide indicative system design capacities (canal capacity) are increased. Similarly, the annual surface water allocation is increased. All these figures provide good guidelines for appropriate levels of irrigation development.

7.4 CONCLUSIONS

This Study provides an analytical framework for incorporating environmental, health and economic concerns into irrigation water management. It makes use of the multi-criteria analysis in irrigated agriculture decision-making, aiming to depict the policy frontier between environmental and socioeconomic objectives and to underline some possible resolutions that will ameliorate the current situation. It also points out the indirect relationship between some competitive or complementary goals. The decision-maker can then interpret these results according to his intentions in order to choose the right measures aiming to come as close as possible to his most favourable final state.

According to goal programming results, it is important to point out that the economic scenario may not satisfy the health and environment goals, but they end up to better numbers than the status quo. The planning model presented in this article is a versatile mathematical tool for generating and evaluating alternative irrigation development plans, based on the conjunctive use of surface and groundwater. The multi-objective framework of the model provides more insight to the decision-making process than conventional use of optimization models. Trade-off possibilities identified between different objectives help the decision making agency in balancing different interests. It must, however, be stressed that the model results are initial guidelines. With the practical and satisfying estimates of the optimal levels of water resources development, more rigorous simulation models and economic analysis could be used to assess the detailed performance of the selected plans, designs and operation policies. Sensitivity analysis of the solution to changes in important input data can also be carried out to see the effect of uncertain parameters.

The developed Linear Programming and Goal Programming Models are found as effective tools for socio-economic development of the Kosi Irrigation System of Nepal and can be applied to any region with the variation in resource constraints.

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Appendix A

Crop Coefficient Used in Nepal

Crop Coefficients(Kc) for paddy Crops

Crop	Jan		Feb		March		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Approx. Duration (days)
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
Monsoon													1.10	1.10	1.10	1.10	0.95	0.95							90
Early							1.10	1.10	1.10	1.10	1.00	1.00													90
Late															1.10	1.10	1.10	1.10	0.95	0.95					90
Monsoon														1.10	1.10	1.10	1.10	1.05	0.95	0.95					105
Early						1.10	1.10	1.10	1.10	1.25	1.00	1.00	1.00												105
Late															1.10	1.10	1.10	1.10	1.05	0.95	0.95				105
Monsoon														1.10	1.10	1.10	1.10	1.05	1.05	0.95	0.95				120
Early														1.10	1.10	1.10	1.10	1.05	1.05	1.05	0.95	0.95			135
Late														1.10	1.10	1.10	1.10	1.05	1.05	1.05	1.05	0.95	0.95		150

Source Irrigation Diary 2007/2008 (After FAO-24)

Crop Coefficients(Kc) for Selected Crops

Crop	Jan		Feb		March		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Approx. Duration (days)
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
Maize 1					0.45	0.60	0.80	1.05	1.05	1.05	0.80														105
Maize 2							0.45	0.60	0.80	1.05	1.05	1.05	0.80												105
Pulses	0.50	0.75	0.95	1.05	1.05	0.96																		0.40	105
Oilseeds	0.46	0.82	1.00	1.00	0.72																			0.40	90
Wheat 1	1.15	1.15	1.15	0.90	0.40																	0.43	0.65	1.05	120
Wheat 2	1.05	1.15	1.15	1.15	0.90	0.40																	0.43	0.65	120
Vegetable (summer)													0.34	0.54	0.93	1.05	1.05	1.04	0.91						-
Vegetable (winter)	0.86	0.95	0.95	0.89																		0.28	0.34	0.54	-
Potatoes	1.01	1.13	1.13	1.08	0.94	0.77																0.42	0.55	0.79	130
Potatoes	0.79	1.01	1.13	1.13	1.08	0.94	0.77																0.42	0.55	130
Sugar-cane				0.45	0.60	0.80	1.05	1.05	1.05	1.05	1.05	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.1	1.05		0.95	0.95	-

Source Irrigation Diary 2007/2008 (After FAO-24)

APPENDIX –B1

LINEAR PROGRAMMING MODEL : MAXIMIZATION OF NET RETURN (LR1)

Max 2.450 A1 + 2.28 A2 + 8.57 A3 + 5.03 A4 + 35.3 A5 + 13.415 A6 + 2.300 A7 - 1.126 S1 - 1.126 S2 - 1.126 S3 - 1.126 S4 - 1.126 S5 - 1.126 S6 - 1.126 S7 - 1.126 S8 - 1.126 S9 -1.126 S10 -1.126 S11 - 1.126 S12 - 13.519 G1 - 13.519 G2 -13.519 G3 - 13.519 G4 - 13.519 G5 - 13.519 G6 - 13.519 G7 - 13.519 G8 - 13.519 G9 - 13.519 G10 - 13.519 G11 - 13.519 G12

ST

JAN) 0.121 A2 + 0.039 A3 + 0.074 A4 + 0.082 A5 - S1 - G1 <= 0

FEB) 0.202 A2 + 0.195 A3 + 0.206 A4 + 0.079 A5 - S2 - G2 <= 0

MAR1) 0.039 A2 + 0.088 A3 + 0.125 A4 - 0.5 S3 - 0.5 G3 <= 0

MAR2) 0.046 A6 + 0.146 A7 - 0.5 S3 - 0.5 G3 <=0

APR) 0.218 A6 + 0.381 A7 - S4 - G4 <= 0

MAY) 0.280 A6 + 0.334 A7 - S5 - G5 <= 0

OCT) 0.091 A1 - S10 - G10 <= 0

NOV1) 0.088 A1 - 0.5 S11 - 0.5 G11 <= 0

NOV2) 0.034 A2 + 0.047 A5 - 0.5 S11 - 0.5 G11 <= 0

DEC) 0.131 A2 + 0.030 A3 + 0.068 A4 + 0.051 A5 - S12 - G12 <=0

CROPM) A1<=113

CROPW) A2 + A3 + A4 + A5 <=113

CROPS) A6 + A7 <=113

CRV) A5 < 4.00

JS) S1 <= 23.33

FS) S2 <= 23.33

MS) S3 <= 23.33

AS) S4 <= 23.33

MYS) S5 <= 23.33

JUS) S6 <= 11.66

JLS) S7 <= 11.66

AUS) S8 <= 23.33

SS) S9 <= 23.33

ACS) S10 <= 23.33

NVS) S11 <= 23.33

DS) S12 <= 23.33

JG) G1 = 0

FG) G2 = 0

MG) G3 = 0

AG) G4 <= 6.85

MYG) G5 <= 6.85

JUG) G6 <= 6.85

JLG) G7 <= 6.85

AUG) G8 <= 6.85

SG) G9 <= 6.85

ACG) G10 <= 6.85

NVG) G11 <= 6.85

DG) G12 <=6.85

TG) G1 + G2 + G3 + G4 + G5 + G6 + G7 + G8 + G9 + G10 + G11 + G12 <= 34.27

TS) S1 + S3 + S4 + S5 + S6 + S7 + S8 + S9 + S10 + S11 + S12 <= 256.6

CAL) 7.535 A1 + 8.832 A2 + 3.787 A3 + 2.297 A4 + 16 A5 + 10.26 A6 + 9.134 A7-C =0

A) A1 + A2 + A3 + A4 + A5 + A6 + A7 - TA=0

P) 0.159 A1+ 0.313 A2 + 0.154 A3 + 0.162 A4 + 0.8 A5 + 0.333 A6 + 0.193 A7 - P = 0

END

APPENDIX –B2

RESULT OF LINEAR PROGRAMMING MODEL: MAXIMIZATION OF NET RETURN (LR1)

LP OPTIMUM FOUND AT STEP 15

OBJECTIVE FUNCTION VALUE

1) 2561.789

VARIABLE	VALUE	REDUCED COST
A1	113.000000	0.000000
A2	0.000000	6.393592
A3	109.000000	0.000000
A4	0.000000	3.717908
A5	4.000000	0.000000
A6	107.785713	0.000000
A7	0.000000	15.337399
S1	4.579000	0.000000
S2	21.570999	0.000000
S3	19.184000	0.000000
S4	23.330000	0.000000
S5	23.330000	0.000000
S6	0.000000	1.126000

S7	0.000000	1.126000
S8	0.000000	1.126000
S9	0.000000	1.126000
S10	10.283000	0.000000
S11	19.888000	0.000000
S12	3.474000	0.000000
G1	0.000000	12.393000
G2	0.000000	12.393000
G3	0.000000	12.393000
G4	0.167285	0.000000
G5	6.850000	0.000000
G6	0.000000	13.519000
G7	0.000000	13.519000
G8	0.000000	13.519000
G9	0.000000	13.519000
G10	0.000000	12.393000
G11	0.000000	12.393000
G12	0.000000	12.393000
C	2434.119385	0.000000
TA	333.785706	0.000000
P	73.845642	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
JAN)	0.000000	1.126000

FEB)	0.000000	1.126000
MAR1)	0.000000	2.252000
MAR2)	4.633857	0.000000
APR)	0.000000	13.519000
MAY)	0.000000	37.385208
OCT)	0.000000	1.126000
NOV1)	0.000000	2.252000
NOV2)	9.756000	0.000000
DEC)	0.000000	1.126000
CROPM)	0.000000	2.149358
CROPW)	0.000000	8.074560
CROPS)	5.214286	0.000000
CRV)	0.000000	26.986729
JS)	18.750999	0.000000
FS)	1.759001	0.000000
MS)	4.146000	0.000000
AS)	0.000000	12.393000
MYS)	0.000000	36.259209
JUS)	11.660000	0.000000
JLS)	11.660000	0.000000
AUS)	23.330000	0.000000
SS)	23.330000	0.000000
ACS)	13.047000	0.000000

NVS)	3.442000	0.000000
DS)	19.856001	0.000000
JG)	0.000000	0.000000
FG)	0.000000	0.000000
MG)	0.000000	0.000000
AG)	6.682715	0.000000
MYG)	0.000000	23.866207
JUG)	6.850000	0.000000
JLG)	6.850000	0.000000
AUG)	6.850000	0.000000
SG)	6.850000	0.000000
ACG)	6.850000	0.000000
NVG)	6.850000	0.000000
DG)	6.850000	0.000000
TG)	27.252714	0.000000
TS)	152.531998	0.000000
CAL)	0.000000	0.000000
A)	0.000000	0.000000
P)	0.000000	0.000000

NO. ITERATIONS= 15

APPENDIX –C1

GOAL PROGRAMMING MODEL : ECONOMIC SCENARIO

MIN 50 N1 +20 N2 +20 N3 +10 N4

ST

R) 2.450 A1 + 2.28 A2 + 8.57 A3 + 5.03 A4 + 35.3 A5 + 13.415 A6 + 2.300 A7

- 1.126 S1 - 1.126 S2 - 1.126 S3 - 1.126 S4 - 1.126 S5 - 1.126 S6 - 1.126 S7 - 1.126 S8 - 1.126 S9 -1.126 S10 -1.126 S11 - 1.126 S12

- 13.519 G1 - 13.519 G2 -13.519 G3 - 13.519 G4 - 13.519 G5 - 13.519 G6 - 13.519 G7 - 13.519 G8 - 13.519 G9 - 13.519 G10 - 13.519 G11 - 13.519 G12 +N1 - P1=2564

P) 0.159 A1+ 0.313 A2 + 0.154 A3 + 0.162 A4 + 0.8 A5 + 0.333 A6 + 0.193 A7 - P2 + N2 = 74

CAL) 7.535 A1 + 8.832 A2 + 3.787 A3 + 2.297 A4 + 16 A5 + 10.26 A6 + 9.134 A7-P3 + N3 = 2434

A) A1 + A2 + A3 + A4 + A5 + A6 + A7 -P4 + N4= 334

JAN) 0.121 A2 + 0.039 A3 + 0.074 A4 + 0.082 A5 - S1 - G1 <= 0

FEB) 0.202 A2 + 0.195 A3 + 0.206 A4 + 0.079 A5 - S2 - G2 <= 0

MAR1) 0.039 A2 + 0.088 A3 + 0.125 A4 - 0.5 S3 - 0.5 G3 <= 0

MAR2) 0.046 A6 + 0.146 A7 - 0.5 S3 - 0.5 G3 <=0

APR) 0.218 A6 + 0.381 A7 - S4 - G4 <= 0

MAY) 0.280 A6 + 0.334 A7 - S5 - G5 <= 0

OCT) 0.091 A1 - S10 - G10 <= 0

NOV1) 0.088 A1 - 0.5 S11 - 0.5 G11 <= 0

NOV2) 0.034 A2 + 0.047 A5 - 0.5 S11 - 0.5 G11 <= 0

DEC) 0.131 A2 + 0.030 A3 + 0.068 A4 + 0.051 A5 - S12 - G12 <=0

CROPM) A1 -AA <= 0

CROPW) A2 + A3 + A4 + A5 -AA <=0

CROPS) A6 + A7 -AA <= 0

CRW) A2 > 13.22

CRO) A3 > 40.78

CRP) A4 > 41.52

CRV) A5 < 4.00

CRM) A6 > 4.95

CRPS) A7 > 11.13

JS) S1 <= 23.33

FS) S2 <= 23.33

MS) S3 <= 23.33

AS) S4 <= 23.33

MYS) S5 <= 23.33

JUS) S6 <= 11.66

JLS) S7 <= 11.66

AUS) S8 <= 23.33

SS) S9 <= 23.33

ACS) S10 <= 23.33

NVS) S11 <= 23.33

DS) S12 <= 23.33

JG) G1 = 0

FG) G2 = 0

MG) G3 = 0

AG) G4 <= 6.85

MYG) G5 <= 6.85

JUG) G6 <= 6.85

JLG) G7 <= 6.85

AUG) G8 <= 6.85

SG) G9 <= 6.85

ACG) G10 <= 6.85

NVG) G11 <= 0

DG) G12 <=0

TG) G1 + G2 + G3 + G4 + G5 + G6 + G7 + G8 + G9 + G10 + G11 + G12 <= 34.27

TS) S1 + S3 + S4 + S5 + S6 + S7 + S8 + S9 + S10 + S11 + S12 <= 256.6

END

APPENDIX –C2

RESULTS OF GOAL PROGRAMMING MODEL : ECONOMIC SCENARIO

LP OPTIMUM FOUND AT STEP 35

OBJECTIVE FUNCTION VALUE

1) 15983.97

VARIABLE	VALUE	REDUCED COST
N1	319.679382	0.000000
N2	0.000000	20.000000
N3	0.000000	20.000000
N4	0.000000	10.000000
A1	132.556824	0.000000
A2	13.220000	0.000000
A3	60.463795	0.000000
A4	41.520000	0.000000
A5	4.000000	0.000000
A6	94.509216	0.000000
A7	11.130000	0.000000
S1	7.358188	0.000000
S2	23.330000	0.000000
S3	22.052788	0.000000
S4	23.330000	0.000000
S5	23.330000	0.000000
S6	0.000000	56.300003

S7	0.000000	56.300003
S8	0.000000	56.300003
S9	0.000000	56.300003
S10	12.062671	0.000000
S11	23.330000	0.000000
S12	6.573094	0.000000
G1	0.000000	619.650024
G2	0.000000	0.000000
G3	0.000000	619.650024
G4	1.513538	0.000000
G5	6.850000	0.000000
G6	0.000000	675.950012
G7	0.000000	675.950012
G8	0.000000	675.950012
G9	0.000000	675.950012
G10	0.000000	619.650024
G11	0.000000	9.036931
G12	0.000000	619.650024
P1	0.000000	50.000000
P2	4.071717	0.000000
P3	141.248444	0.000000
P4	23.399830	0.000000
AA	132.556824	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
R)	0.000000	-50.000000
P)	0.000000	0.000000
CAL)	0.000000	0.000000
A)	0.000000	0.000000
JAN)	0.000000	56.300003
FEB)	0.000000	2126.700195
MAR1)	0.000000	112.600006
MAR2)	5.053990	0.000000
APR)	0.000000	675.950012
MAY)	0.000000	1869.260376
OCT)	0.000000	56.300003
NOV1)	0.000000	1333.826172
NOV2)	11.027520	0.000000
DEC)	0.000000	56.300003
CROPM)	0.000000	0.000000
CROPW)	13.353023	0.000000
CROPS)	26.917604	0.000000
CRW)	0.000000	-334.172424
CRO)	19.683796	0.000000
CRP)	0.000000	-208.669815
CRV)	0.000000	1589.502808
CRM)	89.559212	0.000000

CRPS)	0.000000	-766.869934
JS)	15.971812	0.000000
FS)	0.000000	2070.400146
MS)	1.277212	0.000000
AS)	0.000000	619.650024
MYS)	0.000000	1812.960327
JUS)	11.660000	0.000000
JLS)	11.660000	0.000000
AUS)	23.330000	0.000000
SS)	23.330000	0.000000
ACS)	11.267330	0.000000
NVS)	0.000000	610.613098
DS)	16.756907	0.000000
JG)	0.000000	0.000000
FG)	0.000000	1450.750122
MG)	0.000000	0.000000
AG)	5.336462	0.000000
MYG)	0.000000	1193.310303
JUG)	6.850000	0.000000
JLG)	6.850000	0.000000
AUG)	6.850000	0.000000
SG)	6.850000	0.000000
ACG)	6.850000	0.000000

NVG)	0.000000	0.000000
DG)	0.000000	0.000000
TG)	25.906462	0.000000
TS)	138.563263	0.000000

NO. ITERATIONS= 35

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
N1	50.000000	INFINITY	49.999996
N2	20.000000	INFINITY	20.000000
N3	20.000000	INFINITY	20.000000
N4	10.000000	INFINITY	10.000000
A1	0.000000	107.467911	1.590499
A2	0.000000	INFINITY	334.172424
A3	0.000000	197.527237	3923.456055
A4	0.000000	INFINITY	208.669815
A5	0.000000	1589.502808	INFINITY
A6	0.000000	334.126892	INFINITY
A7	0.000000	INFINITY	766.869934
S1	0.000000	619.650024	56.300003
S2	0.000000	2070.400146	INFINITY

S3	0.000000	619.650024	56.300003
S4	0.000000	619.650024	INFINITY
S5	0.000000	1812.960327	INFINITY
S6	0.000000	INFINITY	56.300003
S7	0.000000	INFINITY	56.300003
S8	0.000000	INFINITY	56.300003
S9	0.000000	INFINITY	56.300003
S10	0.000000	619.650024	17.478012
S11	0.000000	610.613098	INFINITY
S12	0.000000	619.650024	56.300003
G1	0.000000	INFINITY	619.650024
G2	0.000000	INFINITY	INFINITY
G3	0.000000	INFINITY	619.650024
G4	0.000000	1532.692139	619.650024
G5	0.000000	1193.310303	INFINITY
G6	0.000000	INFINITY	675.950012
G7	0.000000	INFINITY	675.950012
G8	0.000000	INFINITY	675.950012
G9	0.000000	INFINITY	675.950012
G10	0.000000	INFINITY	619.650024
G11	0.000000	INFINITY	9.036917
G12	0.000000	INFINITY	619.650024
P1	0.000000	INFINITY	50.000000

P2	0.000000	675.898804	10.003139
P3	0.000000	14.262496	0.211081
P4	0.000000	107.467911	1.590499
AA	0.000000	107.467911	0.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
R	2564.000000	INFINITY	319.679382
P	74.000000	4.071717	INFINITY
CAL	2434.000000	141.248444	INFINITY
A	334.000000	23.399830	INFINITY
JAN	0.000000	7.358188	15.971812
FEB	0.000000	1.415093	3.838340
MAR1	0.000000	5.053990	0.638606
MAR2	0.000000	INFINITY	5.053990
APR	0.000000	1.513538	5.336462
MAY	0.000000	6.854171	1.943994
OCT	0.000000	12.062671	11.267330
NOV1	0.000000	10.895880	1.175066
NOV2	0.000000	INFINITY	11.027520
DEC	0.000000	6.573094	16.756907
CROPM	0.000000	13.353023	INFINITY
CROPW	0.000000	INFINITY	13.353023

CROPS	0.000000	INFINITY	26.917604
CRW	13.220000	19.001682	12.243452
CRO	40.779999	19.683796	INFINITY
CRP	41.520000	18.632719	41.520000
CRV	4.000000	10.055955	4.000000
CRM	4.950000	89.559212	INFINITY
CRPS	11.130000	19.937756	11.130000
JS	23.330000	INFINITY	15.971812
FS	23.330000	1.415093	3.838340
MS	23.330000	INFINITY	1.277212
AS	23.330000	1.513538	5.336462
MYS	23.330000	6.854171	1.943994
JUS	11.660000	INFINITY	11.660000
JLS	11.660000	INFINITY	11.660000
AUS	23.330000	INFINITY	23.330000
SS	23.330000	INFINITY	23.330000
ACS	23.330000	INFINITY	11.267330
NVS	23.330000	21.791759	2.350132
DS	23.330000	INFINITY	16.756907
JG	0.000000	0.000000	0.000000
FG	0.000000	1.415093	0.000000
MG	0.000000	0.000000	0.000000
AG	6.850000	INFINITY	5.336462

MYG	6.850000	6.854171	1.943994
JUG	6.850000	INFINITY	6.850000
JLG	6.850000	INFINITY	6.850000
AUG	6.850000	INFINITY	6.850000
SG	6.850000	INFINITY	6.850000
ACG	6.850000	INFINITY	6.850000
NVG	0.000000	INFINITY	0.000000
DG	0.000000	INFINITY	0.000000
TG	34.270000	INFINITY	25.906462
TS	256.600006	INFINITY	138.563263